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HELICOPTER ENGINEERING

PART THREE

QUALIFICATION ASSURANCE

HEADQUARTERS, U.S. ARMY MATERIEL COMMAND

APRIL 1972



HEADQUARTERS
UNITED STATES ARMY MATERIEL COMMAND
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ENGINEERING DESIGN HANDBOOK
HELICOPTER ENGINEERING, PART THREE
QUALIFICATION ASSURANCE

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FOREWORD

The *Helicopter Engineering Handbook* forms a part of the Engineering Design Handbook Series which presents engineering data for the design and construction of Army equipment.

This volume, AMCP 706-203, *Qualification Assurance*, is Part Three of a three-part Engineering Design Handbook titled *Helicopter Engineering*. Along with AMCP 706-201, *Preliminary Design*, and AMCP 706-202, *Detail Design*, this part is intended to set forth explicit design standards for Army helicopters, to establish qualification requirements, and to provide technical guidance to helicopter designers in both the industry and within the Army.

The first volume of the handbook, AMCP 706-201, discusses the characteristics and subsystems which must be considered during preliminary design of a helicopter. Additionally, possible design problems encountered during helicopter design are discussed and possible solutions suggested.

AMCP 706-202 deals with the evolution of the vehicle from an approved preliminary design configuration. As a result of this phase, the design must provide sufficient detail to permit construction and qualification of the helicopter in compliance with the approved detail specification and other requirements. Design requirements for all vehicle subsystems also are included in AMCP 706-202.

This volume, AMCP 706-203, defines the requirements for airworthiness qualification of the helicopter and for demonstration of contract compliance, and also describes the test procedures accomplished by the Army. The volume is divided into 11 chapters, and is organized as described in Chapter 1, the introduction to the volume.

PREFACE

This volume, AMCP 706-203, *Qualification Assurance*, is the final section of a three-part engineering handbook, *Helicopter Engineering*, in the Engineering Design Handbook series. It was prepared by Forge Aerospace, Inc., Washington, D.C., under subcontract to the Engineering Handbook Office, Duke University, Durham, N. C.

The Engineering Design Handbooks fall into two basic categories, those approved for release and sale, and those classified for security reasons. The Army Materiel Command policy is to release these Engineering Design Handbooks to other DOD activities and their contractors, and other Government agencies in accordance with current Army Regulation 70-31, dated 9 September 1966. It will be noted that the majority of these Handbooks can be obtained from the National Technical Information Service (NTIS). Procedures for acquiring these Handbooks follow:

a. Activities within AMC, DOD agencies, and Government agencies other than DOD having need for the Handbooks should direct their request on an official form to:

Commanding Officer
Letterkenny Army Depot
ATTN: AMXLE-ATD
Chambersburg, Pennsylvania 17201

b. Contractors and universities must forward their requests to:

National Technical Information Service
Department of Commerce
Springfield, Virginia 22151

(Requests for classified documents must be sent, with appropriate "Need-to-Know" justification, to Letterkenny Army Depot.)

Users of the handbook are encouraged to contact USAAVSCOM, St. Louis, Mo., Flight Standards and Qualification Division (AMSAV-EFI), with their recommendations and comments concerning the handbook. Comments should be specific and include recommended text changes and supporting rationale. DA Form 2028, Recommended Changes to Publications (available through normal publications supply channels) may be used for this purpose. A copy of the comments should be sent to the Commanding General, AMC, ATTN: AMCRD-TV, Washington, DC 20315.

Revisions to the handbook will be made on an as-required basis and will be distributed on a normal basis through the Letterkenny Army Depot.



CHAPTER 1

INTRODUCTION

AMCP 706-201, *Helicopter Engineering, Part One, Preliminary Design*, is the first volume of the *Helicopter Handbook Series* and discusses the preliminary design phase and contract definition procedures, including the roles and applications of weight and performance estimation; flying quality predictions; and system safety, reliability, and maintainability considerations. At the conclusion of the preliminary definition period, a helicopter configuration will have been selected and its general characteristics and capabilities defined in procurement specifications. Data required during contract definition, in response to a Request for Proposal (RFP) or a Request for Quotation (RFQ), have been defined in Chapter 14 of AMCP 706-201.

The same disciplines and procedures continue in greater detail throughout design and qualification. AMCP 706-202, *Helicopter Engineering, Part Two, Detail Design*, the second volume, describes the follow-on detail (or engineering development) phase in terms of design requirements, criteria, and procedures for the total system and its subsystems. The system and subsystems are re-examined, refined, and defined as the design and optimization process continues. The specification requirements and qualification plans are translated into hardware layouts, with appropriate investigations, analyses, and exploratory testing. Detail drawings, re-analyses, and qualification testing follow.

This volume, AMCP 706-203, includes the requirements and procedures for substantiation of the airworthiness of the vehicle through proof of compliance with contractual design requirements and performance guarantees.

Airworthiness, as defined in AMCR 70-33, is "a demonstrated capability of an aircraft, or aircraft subsystem or component to function satisfactorily when used within the prescribed limits".

It is the intent of this volume to delineate the responsibilities of both the procuring activity and the contractor in the planning and execution of the airworthiness qualification program for a new model helicopter. The helicopter systems to which such a program is applicable may be completely new, or may be the result of major modification of a previously qualified system.

For simplicity, the internal workings of the Government are not discussed. Governmental responsibilities are always related to only the procuring activity.

Although dependent ultimately upon specific tests and demonstrations of the complete helicopter system, airworthiness qualification is a continuing process which begins with the initiation of system development. Included are design reviews, during both the initial subsystem definition phase and the final detail design of assemblies and installations. The construction and inspection of a full-scale mock-up by experts is a specialized design review. Conducted as early in the program as possible, the mock-up review permits evaluation of the relationship and interaction between all required subsystems in a manner which is impossible when using only two-dimensional layouts and drawings.

During the design and initial fabrication phase, prior to the availability of components or complete systems for test, analyses are performed to substantiate subsystem configurations and performance. Also during this period detailed plans are prepared for the testing of components, subsystems, and the complete helicopter as required to verify compliance with applicable design and performance requirements. The preparation of these analyses and plans by the contractor and their review and approval by the procuring activity are significant elements of the airworthiness qualification program.

Qualification of a new model helicopter includes qualification of components, of subsystems, and finally of the complete helicopter system. Each of these efforts is described in the chapters which follow. Also included is a discussion of Governmental testing, which is conducted to confirm that system performance complies with contract requirements. This testing includes that required to obtain the data necessary for verifying safe helicopter operation for follow-on Governmental testing and for the preparation of operational and service manuals for the system. Following completion of the helicopter qualification and preparation by the procuring activity of the Airworthiness Qualification Substantiation Report, Governmental testing continues, in the form of Service Tests, to insure operational suitability

and to determine to what degree the helicopter meets the characteristics stated in the requirement document. However, discussion of these efforts beyond airworthiness qualification is not within the scope of this handbook.

Throughout this volume, the mandatory qualification requirements have been identified with the contractual language which makes use of the imperative word "*shall*". To assist in the use of this document in the planning of a qualification program, the word "*shall*" has been italicized in the statement of each such requirement.

Since the qualification requirements for individual

programs may vary from the level of detail described in this volume, the procuring activity will specify in its Request for Proposal the extent to which these requirements are applicable to the qualification of a given helicopter. Deviations from this handbook not specifically included in the RFP will be considered when adequately substantiated in the contractor's response to the RFP. This handbook will not be incorporated in a contract by reference in whole or in part. However, the handbook may be furnished to contractors as a basis for establishing contract requirements to be included in the Airworthiness Qualification Specification (Chapter 2).

CHAPTER 2

AIRWORTHINESS QUALIFICATION PROGRAM REQUIREMENTS

2-1 INTRODUCTION

The Coordinated Test Program (CTP) is the primary development planning document used to describe the formal, comprehensive program for testing. The CTP is required by AR 70-10 for all research and development projects entering engineering development. The CTP for helicopters normally is prepared by the Army Project Manager, and has the following objectives:

1. To serve as a management tool to insure that the necessary elements of a test program are addressed
2. To insure that adequate coordination is effected among the agencies which require test data
3. To insure that adequate testing is planned for arriving at type classification and a production decision
4. To provide justification for the number of prototypes to be used during testing.

The CTP also must provide the justification for combining tests, for conducting them concurrently, or for eliminating them in an effort to avoid duplicate and unnecessary testing.

Helicopters and allied equipment are developed under a specific analytical process to substantiate that they are airworthy. The total of all elements in this analytical process is the Airworthiness Qualification Program (AQP). The program is described fully in the CTP and is an element of the Request for Proposal (RFP) or Request for Quotation (RFQ). The AQP provides general guidance on engineering analyses, formal inspections, design reviews, safety assessments, contractor demonstrations, and all contractor and Governmental qualification tests essential to defining and implementing the procurement of any major Army air item and/or its allied equipment. This general information then will provide the basis for the Airworthiness Qualification Specification (AQS), which is written by the contractor. Inherent in the AQS is the dissemination of data necessary to demonstrate proof of compliance with the system description or detail specification.

The AQS is designed to insure that the necessary information is obtained to permit the issuance of the Safety-of-Flight Releases and/or Interim Statements of Airworthiness Qualification required during engineering development. It also permits the issuance of a Statement of Airworthiness Qualification, and Army publication of an Airworthiness Qualification Substantiation Report, upon the completion of the program. Lastly, the AQS will adhere to the policies, objectives, definitions, and procedures specified in:

1. AR 70-10, *Test and Evaluation During Research and Development of Materiel*
2. AMCR 70-32, *Aeronautical Design Standards (ADS) for U.S. Army Aircraft Systems and Subsystems*
3. AMCR 70-33, *Airworthiness Qualification of U.S. Army Aircraft Systems and Subsystems*.

The types of tests which comprise the CTP, as well as the test agency, test hardware, and test objectives for a complete helicopter system and allied equipment, are summarized in Tables 2-1 and 2-2. These tests normally should be conducted in the sequence shown in the tables, especially where test results are required prior to further testing and in those situations where extreme climatic conditions will be encountered. Concurrent and integrated test phasing will be used when justified by fund and time limitations.

2-2 AIRWORTHINESS QUALIFICATION SPECIFICATION (AQS)

2-2.1 GENERAL

As noted in the previous paragraph, the contractor's airworthiness qualification test plan is the key element in the overall coordinated plan for development of new helicopters.

For each helicopter system subject to qualification or requalification because of major modifications, a qualification specification will be prepared to establish

those engineering tests or analyses which are essential to the airworthiness substantiation of the system. This work is divided into those tests to be performed under an engineering development contract, or any other appropriate procurement action such as a product improvement contract.

2-2.2 AIRWORTHINESS QUALIFICATION SPECIFICATION REQUIREMENTS

The Airworthiness Qualification Specification will be prepared by the prime system contractor in response

TABLE 2-1. SUMMARY OF CTP TEST REQUIREMENTS—HELICOPTER SYSTEM

TYPE TEST	TEST AGENCY	TEST HARDWARE	TEST OBJECTIVE
CONTRACTOR'S AIRWORTHINESS QUALIFICATION TESTS (AQT)	CONTRACTOR	MODELS MDCK-UPS COMPONENTS SUBSYSTEMS ALLIED EQUIPMENT PROTOTYPE SYSTEM	DEVELOPMENT PROVE OUT ASSEMBLIES, COMPONENTS, AND THE TOTAL HELICOPTER QUALIFICATION DETERMINE DESIGN LIMITS AND FLIGHT ENVELOPE DEMONSTRATION OF ADEQUACY OF HELICOPTER TO FUNCTION SAFELY WITHIN FLIGHT ENVELOPE
ARMY PRELIMINARY EVALUATIONS (APE)	MATERIEL DEVELOPER (AVSCOM)	PROTOTYPE SYSTEM	VERIFICATION OF FLIGHT ENVELOPE AND PRELIMINARY CONTRACT COMPLIANCE PROVIDE QUANTITATIVE AND QUALITATIVE FLIGHT TEST DATA DETECTION OF DEFICIENCIES AND EVALUATION OF CORRECTIONS PROVIDE PRELIMINARY OPERATIONAL USE DATA
AIRWORTHINESS AND FLIGHT CHARACTERISTICS	MATERIEL DEVELOPER (AVSCOM)	PROTOTYPE SYSTEM	FINAL VERIFICATION OF FLIGHT ENVELOPE AND CONTRACT COMPLIANCE ACHIEVEMENT OF APPLICABLE MILITARY SPECIFICATIONS DETAILED STABILITY, PERFORMANCE, AND HANDLING CHARACTERISTICS OPERATIONAL CHARACTERISTICS FOR TECHNICAL MANUALS ADEQUACY OF THE SYSTEM, SUBSYSTEMS, AND ALLIED EQUIPMENT UNDER EXTREME TEMPERATURE CONDITIONS
ENDURANCE	CONTRACTOR	PROTOTYPE SYSTEM	DETERMINATION OF ENDURANCE AND RELIABILITY OF BASIC DESIGN DETERMINATION OF ADEQUACY OF DESIGN CHANGES TO CORRECT DEFICIENCIES REVEALED DURING PRIOR TESTS.
OPERATIONAL SERVICE TESTS (OST)	INDEPENDENT TEST AGENCY (TECOM/TEST BOARD(S))	PROTOTYPE SYSTEM	DETERMINATION OF THE DEGREE TO WHICH THE SYSTEM MEETS THE CHARACTERISTICS OF THE REQUIREMENTS DOCUMENT DETERMINATION OF INSPECTION CYCLES DEVELOPMENT OF OPERATING AND MAINTENANCE COSTS DETERMINATION OF COMPONENT SERVICE LIFE AND QUICK CHANGE KITS REFINEMENT OF MANPOWER, EQUIPMENT, SKILLS, AND TRAINING REQUIREMENTS

TABLE 2-2. SUMMARY OF CTP TEST REQUIREMENTS—ALLIED EQUIPMENT

TYPE TEST	TEST OBJECTIVES	RELATION TO SYSTEM TEST
ENGINEERING DESIGN TESTS (EDT)	DETERMINATION OF THE INHERENT STRUCTURAL, MECHANICAL, ELECTRICAL, AND PHYSICAL PROPERTIES DETERMINATION OF HUMAN AND SAFETY IMPLICATIONS	CONTRACTOR DEVELOPMENT AND AIRWORTHINESS QUALIFICATION TESTS
CONTRACTOR DEMONSTRATION (CD)	DEMONSTRATION OF PERFORMANCE AGAINST CONTRACT SPECIFICATIONS DETERMINATION OF HUMAN PERFORMANCE REQUIREMENTS	CONTRACTOR DEVELOPMENT AND AIRWORTHINESS QUALIFICATION TESTS
RESEARCH AND DEVELOPMENT ACCEPTANCE TESTS (RDAT)	DETERMINATION THAT SPECIFICATIONS OF DEVELOPMENT CONTRACT HAVE BEEN FULFILLED SERVES AS BASIS FOR ACCEPTANCE OR REJECTION PROTOTYPES	ARMY PRELIMINARY EVALUATIONS
ENGINEERING TESTS (ET)	DETERMINATION OF TECHNICAL PERFORMANCE, RELIABILITY, MAINTAINABILITY, ENDURANCE, AND SAFETY CHARACTERISTICS OF THE ITEM AND ITS MAINTENANCE PACKAGE DETERMINATION OF HUMAN FACTOR IMPLICATIONS OF DESIGN AND MATERIALS	AIRWORTHINESS AND FLIGHT CHARACTERISTIC TEST
OPERATIONAL SERVICE TESTS (OST)	DETERMINATION OF THE MILITARY WORTH OF THE ITEM DETERMINATION OF THE DEGREE THAT THE ITEM MEETS THE CHARACTERISTICS OF THE REQUIREMENTS DOCUMENT	OPERATIONAL SERVICE TEST

to the requirements established by the procuring activity in the RFP. Elements of the AQS include:

1. System Safety
2. Design Review and Release of Drawings
3. Mock-ups
4. Procurement and Process Specifications
5. Component Tests
6. System Surveys
7. Formal Contractor Demonstrations.

These elements are described in the paragraphs which follow.

2-2.2.1 System Safety

As part of the Airworthiness Qualification Specification, the contractor will establish the means by which the results of the System Safety Program (SSP) are to be applied in the airworthiness qualification of the system. The provisions and requirements of the System Safety Program Plan (SSPP) are stated in par. 3-2. This program produces data and information leading to assurances that the optimum degree of hazard elimination or control has been attained in the design of the system. The contractor will include two areas which ultimately combine to form the basis for the System Safety portion of airworthiness qualification: (1) interim/final safety statements and (2) system specification compliance. In addition, the contractor will insure that all components tests, system surveys, and formal demonstrations are planned and conducted in close coordination with the System Safety Program. Hazard analysis will be an integral and essential factor in all such tests and demonstrations to insure that these activities are conducted with minimum risk.

2-2.2.2 Design Reviews and Release of Drawings

Design reviews will be conducted on an as-required basis. This portion of the AQS will outline the contractor's procedures for conducting such reviews. Specific requirements are not presented in this volume because each contractor usually has his own review procedures and drawing approval process. It is not considered feasible to try to standardize these areas. Participation in the design reviews does not limit or restrict other elements of the procuring activity from the responsibility of insuring that the drawings conform to the requirements of MIL-D-1000 through normal contract channels.

Design review of detailed drawings is required for each subsystem. Basic reasons for the inclusion of these

reviews in the qualification program of helicopters are delineated as follows:

1. To insure that there are no obvious conflicts with design criteria
2. To insure that there are no obvious design pitfalls in disciplines such as safety, reliability, and maintainability.
3. To maintain a positive record of the configuration which is being proposed for analysis and testing
4. To establish a basis for updating and identifying parts which pass or fail the qualification tests
5. To provide a foundation for an audit trail of all airworthiness substantiating actions.

2-2.2.3 Mock-ups

The specifications for the mock-ups required by the RFP will be included in the AQS. See Chapter 5 for a detailed discussion of mock-ups.

2-2.2.4 Procurement and Process Specifications

In order for the procuring activity to maintain cognizance over the detail configurations for which airworthiness substantiation is desired, review of certain pertinent drawings and approval of procurement specifications of contractor-furnished equipment (CFE) components are essential. To insure adequate structural integrity, material and process specifications also must be subjected to the approval of the procuring activity.

This section of the AQS should list those procurement and process specifications which must be subjected to approval by the procuring activity.

Typical examples of the key procurement and process specifications (drawings defined in MIL-D-1000) to be submitted are:

1. Specification control
2. Source control
3. Interface control
4. Installation control
5. Installation
6. Control.

Specification control drawings or source control drawings which constitute contractor procurement specifications should be included automatically in the AQS. Details of procurement and process specification requirements are described in Chapter 6.

2-2.2.5 Component Tests

The objectives of component testing are to make a preliminary determination whether the reliability requirements for component life will be met by the hardware under test and to insure adequate integrity for use in higher level assemblies in ground and flight tests. This section of the AQS will define complete test requirements.

2-2.2.5.1 Prequalification Bench Tests

Prequalification bench tests are not classified as "must-pass" tests. The primary objective of prequalification testing is to uncover any defect or design deficiency and to detect any fatigue-critical component or part. In addition, the program will be used for the incorporation and evaluation of "fixes" and, in general, to refine the component or subsystem design. The prequalification test time and severity will be specified and funded as part of the contract.

2-2.2.5.2 Qualification Tests

The objective of the qualification tests is to demonstrate formally that the prequalification testing has detected any defects or fatigue-limited parts in the component or subsystem. Establishment of initial time between overhauls (TBO) will be made by the procuring activity at the completion of the testing outlined in par. 2-2.2.5.1 and revised periodically depending on service or additional bench test experience. The length and severity of the qualification tests will be specified by the procuring activity and funded as part of the contract.

2-2.2.5.3 Tiedown Tests

The total propulsion system—including all gearboxes, engine(s), shafting, rotor systems, brakes, clutches, accessories, and controls—will be installed on the ground test vehicles and subjected to qualification testing in accordance with a test procedure approved by the procuring activity. The first test period will be the preliminary flight approval test (PFAT) and must be completed satisfactorily before first flight. The procuring activity will determine satisfactory completion of the test. Retesting may be required, depending on the nature and severity of the failures.

2-2.2.5.4 Reliability Bench Tests

Additional bench testing will be required by the procuring activity to enhance the prequalification status of selected components or subsystems. The test schedule should be similar to that used in par. 2-2.2.5.1, utilizing

as much of the original hardware as possible. Duration of the test will be determined by the procuring activity.

2-2.2.5.5 Component and Subsystem Inspections

As a minimum, formal military qualification tests of components and subsystems will include:

1. Engines
2. Main transmissions
3. Main rotor and tail rotor subsystems, including hub and blades
4. Propeller and propeller gearboxes
5. Tail rotor gearboxes
6. Intermediate gearboxes
7. Flight controls
8. Fuel systems
9. Landing gear
10. Electrical.

These tests will be followed by a disassembly inspection accomplished in the presence of representatives of the contractor, the procuring activity, and the Army Commodity Commands, if applicable. The inspections will be performed to determine if the components and subsystems have successfully passed the qualification tests defined in the AQS.

The inspection of mechanical and hydromechanical components is divided into two phases. The first involves inspection of all parts immediately after disassembly; the second inspection involves a review of the results of the initial inspection. Data should be made available to the inspection team for both phases.

All mechanical and hydromechanical components and assemblies will be subjected to a complete analytical disassembly and inspection. Inspection techniques may include, but not be limited to: (1) visual, (2) dimensional, (3) magnetic particle, (4) fluorescent penetrant, (5) X-ray, and (6) ultrasonic.

Photographic coverage of all items of significance is required during inspections for later utilization in the qualification test report.

2-2.2.5.6 Electrical and Electronic Components

In general, less sophisticated inspections will be conducted on electrical and electronic components at the end of component testing than those specified for mechanical and hydromechanical components in the previous paragraphs. Appropriate inspection reports will be prepared. A description of component test requirements is given in Chapter 7.

2-2.2.6 System Surveys

System surveys include all tests designed to determine system characteristics and demonstrate satisfactory system operation within the normal flight envelope as well as to determine conformance with airframe unit design requirements. In determining system characteristics, account will be taken of the influence of all subsystems, fixed and movable, and expected operating environments. The requirements of par. 2-2.2.7 also will apply to the system surveys specified here.

System surveys should include, but not be limited to:

1. **Flight Load Survey.** Flight loads will be obtained throughout the flight envelope for all critical components. Sufficient data will be obtained to allow a preliminary estimate of fatigue lives and to determine if resonant frequencies of critical components are tuned to the frequencies of the primary exciting forces (see par. 8-2).

2. **Engine Vibratory Survey.** Flight and ground vibratory surveys will be conducted to verify that engine vibrations do not exceed the allowable vibratory limit specified in the engine model specification (see par. 8-3).

3. **Propulsion System Temperature Survey.** Flight and ground temperature surveys will be conducted to verify that the engine(s), engine accessories, engine fluids, airframe structure, transmission system, gearboxes, heat exchangers, etc., do not exceed their allowable temperature limits (see par. 8-4).

4. **Engine Air Induction System Survey.** Flight and ground engine inlet surveys will be conducted to verify proper inlet pressure recovery and distortion patterns (see par. 8-5).

5. **Engine Exhaust Survey.** Flight and ground engine exhaust subsystem surveys will be conducted to evaluate operation and performance (pressure survey) and ejector cooling performance, if applicable (see par. 8-6).

6. **Total System Vibratory Survey.** These tests are required to demonstrate compliance with vibratory comfort requirements and to demonstrate that the helicopter is free from excessive vibrations, or roughness affecting its structural integrity or its capability to perform its mission. Vibratory measurement instrumentation will be installed at the required locations. Quantitative data should be collected during unaccelerated and accelerated flight over the full range of the flight envelope and of allowable rotor speeds (see par. 8-7).

7. **Crew Environmental Survey.** A survey should be performed to demonstrate compliance with crew environmental requirements under all specified operating conditions and modes (see par. 8-8).

8. **Infrared (IR) Radiation and Countermeasure System Survey.** An IR radiation and countermeasure system survey should be performed, if applicable, to demonstrate that the IR signature has been reduced to acceptable levels. The survey will include documentation of all trade-offs made in minimizing the signature (see par. 8-9.2).

9. **Radar Reflectivity Survey.** A survey should be performed to demonstrate that the radar reflectivity is minimal and absorption is maximum. The survey will include a detailed report of techniques to minimize radar reflectivity (see par. 8-9.3).

10. **Lightning Protection Survey.** A survey will be performed to establish a high degree of confidence that the helicopter system can survive a lightning strike. As a minimum, the survey will demonstrate that the fuel system meets Federal Aviation Administration AC 20-53. Further, the bonding concepts of MIL-B-5087 should be demonstrated as capable of surviving lightning strikes (see par. 8-9.4).

11. **Acoustical Survey.** An acoustical survey will be performed, if applicable, to demonstrate that the acoustical signature meets the appropriate requirements. This survey will be performed under all specified operating conditions and modes (see par. 8-9.6).

2-2.2.7 Formal Contractor Demonstrations

This portion of the airworthiness qualification specification will contain the specific Army requirements for the formal demonstration of the helicopter to show its capability to comply with requirements of the helicopter detail specification.

The purpose of the formal contractor demonstrations is:

1. To demonstrate that the helicopter can be operated safely by Army pilots during the procuring activity's test program to limits consistent with the contract design limits without excessive malfunctions, failures, or other unsatisfactory conditions

2. To demonstrate those specification requirements which will not be substantiated during the procuring activity test program. These contractor demonstrations are usually "pass-fail" tests of a specific design requirement.

3. To obtain quantitative information on safe flight limits for operation by Army pilots

4. To verify that the helicopter has completed contractor tests and is ready for delivery to the procuring activity for Governmental test.

2-2.2.7.1 Demonstration Sites

The demonstration normally is conducted at the contractor's flight test facility; other flight test facilities may be used with prior Governmental approval. Tests involving the carrying and release of guided missiles, explosives, and armament should be performed at a location specified by the procuring activity.

2-2.2.7.2 Helicopter Configuration for Demonstrations

Helicopters used for the performance of formal demonstrations should be identical, within production tolerances, to helicopters which are to be delivered or have been delivered for Governmental tests or operational use. For those demonstrations in which engine power is a critical parameter, calibrated engines will be utilized.

2-2.2.7.3 Contractor Pilot Approval

For formal demonstrations, all contractor test pilots will be approved, by name, by the procuring activity. Contractors should instruct demonstration pilots thoroughly concerning the design, aerodynamic and structural features, and/or other unusual characteristics of the demonstration helicopters.

2-2.2.7.4 Helicopter Flight Approval

Demonstration helicopters should not be operated by contractor pilots without a Safety-of-Flight Release issued by the procuring activity.

2-2.2.7.5 Test Conference

Prior to the development of detail test plans for the formal demonstration program, one or more test planning conferences should be held between the contractor and the procuring activity to insure that the requirements of the formal demonstration programs are understood and to expedite the conduct of the program by resolving any questions or ambiguities that may exist. Additional test conferences may be held as required.

2-2.2.7.6 Specific Demonstration Requirements

Demonstration requirements will be developed during contract definitions, and generally will include the following:

1. Structural Demonstration. Structural demonstration should consist of quantitative flight test mea-

surements of all combinations of gross weight, configuration, center of gravity (CG), altitude, airspeed, load factor, and control motions required to demonstrate compliance with the helicopter detail specification structural requirements (see par. 9-2).

2. Engine/Airframe Compatibility Test. Both ground and flight tests of engine/airframe compatibility are conducted to verify engine, engine control, drive train, and rotor subsystem dynamic matching, (torsional stability) characteristics (see par. 9-3.2).

3. Lubrication Subsystem Demonstration. A lubrication subsystem demonstration is conducted to determine if the engine oil system(s) and transmission oil system(s) operate satisfactorily, maintain the required oil pressure, and are free from excessive oil discharge at the breathers; and to demonstrate the adequacy of the oil cooling and bypass system. The oil cooling test may be conducted during the engine temperature survey (see par. 9-3.4.1).

4. Fuel Subsystem Demonstration. A fuel subsystem demonstration is conducted to determine the capacity of the fuel tank(s) of the helicopter and amount of unusable fuel, fuel vent system adequacy, the operational characteristics of the fuel supply system under various boost pump failure conditions, the temperature safety limits of fuel system equipment, and the fuel system operational capabilities under actual service conditions. In addition, the satisfactory operation of the fuel supply under extreme operating conditions should be demonstrated (see par. 9-3.4.2).

5. Dynamic Instability Demonstration. The contractor will demonstrate that the helicopter is free of mechanical instability at all operating conditions, at the entire range of gross weights, and throughout the extreme temperature range (see par. 9-4).

6. Flying Quality Demonstration. The flying quality demonstration will consist of quantitative flight test measurements demonstrating compliance with the requirements of the handling quality specification. This compliance will be demonstrated throughout the final flight envelope in both powered and autorotative flight, and should include demonstration of a height-velocity curve (see par. 9-5.3).

7. Electrical Demonstration. The contractor will demonstrate the performance of the complete electrical system. The demonstration, consisting of ground and flight tests, will be adequate to determine the capability of the system to perform the functions required by the applicable specifications (see par. 9-6).

8. Avionic Demonstration. The contractor will demonstrate the performance of the complete avionic installation. The demonstration, consisting of ground

and flight tests, should verify the capability of the system to perform the functions dictated by the applicable specifications (see par. 9-7).

9. **Electromagnetic Compatibility (EMC) Demonstration.** The contractor will demonstrate that the various subsystems function properly in any possible electromagnetic environment that can be generated by operation of onboard equipment. The contractor also will demonstrate that no single subsystem operates as a possible source of electromagnetic energy that can cause other onboard equipment to malfunction (see par. 9-7.6).

10. **Hydraulic Subsystem Demonstration.** The contractor will demonstrate the performance of the complete hydraulic subsystem. The demonstration, consisting of ground and flight tests, should be sufficient to determine the capability of the subsystem to perform adequately the functions required by the applicable specifications (see par. 9-8.2).

11. **Furnishing and Equipment Demonstration.** All specified equipment, actually installed in, or specifically required for, the demonstration helicopter will be demonstrated satisfactorily on the ground and/or in flight, as applicable (see par. 9-10).

12. **Armament Demonstration.** The contractor will demonstrate the performance of the complete armament system. The demonstration, consisting of ground and flight tests, will be adequate to determine the capability of the system to perform the functions required by the applicable specifications. Sufficient tests will be performed to prove the structural integrity and functional performance of all armament subsystems (see par. 9-12).

13. **External Store Demonstration.** The contractor should define and demonstrate an external store separation envelope for all external stores required to be carried by the helicopter. Separation envelopes will be demonstrated for both powered and autorotative flight (see par. 9-13).

2-2.3 TEST SEQUENCING

This handbook does not attempt to regulate the sequence of either the analyses or tests essential to airworthiness qualification of a new model helicopter. The scheduling of these activities is largely a function of the extent to which the helicopter design includes new or novel features, the availability of equipment, economic considerations, and delivery constraints.

An airworthiness qualification program includes tests conducted by both the contractor and the procuring activity. With the exception of Army Preliminary

Evaluations (APE), the testing performed by the procuring activity follows the contractor's qualification and demonstration program. In fact, service testing, as the name implies, includes tests performed with operational helicopters. Therefore, this test phase normally will continue past the publication of the Airworthiness Qualification Substantiation Report (AQRS) by the procuring activity.

In the preparation of the AQS, the contractor should propose a schedule which will result in a logical sequence of the required analysis and test efforts in order to minimize the risks involved in the qualification program. During formal contract negotiations, the impact of economic constraints and designated dates for completion of qualification on this schedule can be addressed.

A qualification program subject to minimum risk would require that all components be well developed prior to commencement of subsystem testing, that subsystems be qualified individually prior to total helicopter system testing, and that all operational conditions for the helicopter be carefully tested on the ground prior to first flight. Also, each of the test phases would be preceded by sufficient analyses to assure that design requirements have been met, and that successful completion of subsequent tests is probable. Such a program will be unreasonably long, particularly if the manufacture and assembly of production helicopters are not undertaken concurrent with the qualification program.

Although subject to change in accordance with the RFP for a given model helicopter, certain minimum test precedence requirements will normally apply. A preliminary flight approval test (PFAT) of the power and propulsion system should have been completed on the ground (par. 2-2.2.5.3) prior to first flight of the new model helicopter. This test, using either a tied-down helicopter or a simulated vehicle containing all required subsystems, will include a minimum of 50 hr, with 150 hr preferred. Also, the structural static test program (par. 9-2) should have demonstrated the adequacy of the airframe for design limit loads. Included in this requirement is landing gear drop testing which, as a minimum, will have demonstrated a normal landing at design limit touchdown speed. Further, sufficient component fatigue test data should be available to assure that the service life of fatigue-critical components is adequate for initial flight testing (minimum of 200 hr under conservatively assumed loadings).

Prior to initiation of the ground tiedown test, main transmissions, other gearboxes, and principal components of the drive system should have completed a minimum of 200 hr of bench testing. The major portion

of this testing must have been at maximum rated torque and speed, but pertinent transient conditions also should have been tested.

Demonstration requirements for individual subsystems, as defined by pertinent Military Specifications, in several cases include the stipulation that an analysis of system capability and performance be submitted for approval, together with appropriate subsystem drawings and descriptions, prior to test initiation. Although apparently a sequence requirement, such stipulations normally will not affect qualification schedules. The analyses required are performed routinely in the design of the subsystem and must, therefore, be completed well in advance of subsystem testing.

The RFP for a specific model helicopter will indicate the number of helicopters to be assigned to test and qualification programs. Should these guidelines not include specific assignments—such as structural, flying qualities and performance, avionics, and armament—the contractor will include utilization of the assigned helicopter in the proposed schedule. In addition to minimum risk to the qualification program, overall program cost—in both dollars and calendar time—must be considered in the preparation of such a proposal.

2-2.4 TEST COORDINATION

A test coordination system will be established and executed by the procuring activity. This system will be responsive to all informational requirements dictated by the CTP. Sufficient manpower for onsite test coordination will be provided by the procuring activity. Proposed operating procedures for this coordination are described in the paragraphs which follow.

2-2.4.1 Test Coordinator

The duties and responsibilities of the test coordinator are:

1. To maintain liaison with the contractor to determine start and completion dates and duration of each test. He will keep this information current by means of log books, schedules, and milestone displays.
2. To develop a procedure for rapid and timely witness/observer notification of tests, cancellations, and/or rescheduling.
3. To design and distribute test witnessing forms.
4. To provide witnesses/observers with written data and information, such as plant procedures, detailed test procedures, and forms on which to record test data and observations.

5. To brief each witness/observer on the status of the test, including preceding and subsequent tests. The reasons for past failures and retesting requirements should be included, if applicable. Interfaces with other equipment tests also should be described.

6. To forward completed witness reports and comments to the procuring activity. He will take further action on reports and provide additional information as required.

7. To insure that the witness signs off the contractor's test report in accordance with MIL-STD-831.

The test coordinator will outline the status of the test(s) to be conducted, recent changes in the test plans (if any), an orientation on the facilities to be used, and pertinent safety considerations including special equipment, protective clothing to be used, communication channels, and any necessary restrictions.

8. To perform as the test witness when an authorized witness has not been appointed or is absent.

2-2.4.2 Test Witness

The witness is responsible for reviewing the plans of test(s) contract requirements (system specifications, etc.), and for familiarizing himself with all aspects of the test(s) to be witnessed. As the Government's representative, he is responsible for verifying the contractor's test report, which is prepared in accordance with MIL-STD-831. As early as possible, he will inform the test coordinator of his special requirements in the areas which follow (if applicable):

1. Specific documentation and data (e.g., plans, reports, drawings) which he will use in his witnessing activities
2. Special briefings unique to his areas of interest
3. Portion of the test he desires to witness.

The test witness will review and countersign the test report prepared by the contractor. This constitutes verification of the scope and details of the test, and that the test was conducted with or without deviations from the Government-approved test plans. It does not necessarily indicate concurrence in the conclusions presented. The witness/observer provides his evaluation of the test to the test coordinator and discusses with him any requirements for special witnessing reports.

The test witness/observer will turn in to the test coordinator any test documentation and equipment or clothing issued to him for the conduct of the test. Test witnessing reports will be submitted as required.

To insure an effective test witnessing program, the following statement should be included in the appropriate segments of the contract:

"Before conducting any required test, the local representative of the procuring activity (test coordinator) will be notified by the contractor in sufficient time in order that he or his representative may witness the test to certify and approve the results and observations obtained during the test. If the test is such that interpretation of the behavior of the article under test is likely to require engineering knowledge and experience, the test coordinator will be so notified in advance".

2-2.4.3 Cognizant Service Plant Activity

The Cognizant Service Plant Activity (CSPA) is an on-site representative of the procuring activity responsible for contract administration and quality control, and will monitor the efforts of the contractor to the full extent of the CSPA's capability. Because it is impractical for the CSPA to assemble engineering talent equal to the technical expertise available throughout the AMC Commodity Commands, it will be necessary for the activity to rely heavily on the Commodity Commands for assistance.

2-2.4.4 Test Witnessing Procedures

The test coordinator will be responsible for insuring that a qualified Army witness, generally from outside the CSPA, is present during the important phases of a test program. For tests which are considered a significant part of the qualification program, the test witness(es) generally will be provided by the procuring activity. In these instances, the CSPA will furnish a test observer to inform the contractor of any objections the test witness(es) voices about the test setup and/or procedures. Members of the CSPA will serve as test witnesses when the Flight Standards and Qualification Division of AVSCOM fails to provide a witness and the test coordinator is unavailable.

2-2.5 AIRWORTHINESS QUALIFICATION SUBSTANTIATION REPORT

An AQSR will be prepared and published by the procuring activity upon successful completion of the airworthiness qualification program. This report will contain, but not be limited to, the following:

1. A summary of the qualification program, including helicopters involved, hours flown, ground tests accomplished, the start and end dates of tests, basis for qualification, and number and type of rounds fired if armament subsystems are qualified for use on the helicopter system.

2. A discussion of the degree of compliance with the system description on a paragraph-by-paragraph basis with emphasis on performance guarantees.

3. A discussion of the degree of compliance with specification design criteria which may not be included in the helicopter detail specification.

4. A description of the operating instructions and flight limitations. This will include documentation of all flight envelope limitations, mandatory retirement lives of fatigue-critical components, and cautions and warnings to be included in the Operator's Manual and other appropriate training and service manuals. Technical justification for all such instructions or limitations will be included.

5. An index of all data used in qualification approval, including all contractor reports, specifications, drawings, and Governmental test reports.

An adequate file will be maintained by the procuring activity for retention of the complete qualification program. Copies of pertinent documents will be furnished to the cognizant engineering project office within USAAVSCOM, the Project Manager, and the Defense Documentation Center, as appropriate.



CHAPTER 3

SYSTEM SAFETY

3-1 INTRODUCTION

System safety is defined as "the optimum degree of hazard elimination and/or control within the constraints of operational effectiveness, time, and cost attained through the specific application of management, scientific, and engineering principles throughout all phases of a system life cycle".

A System Safety Program (SSP) is a formal approach to the elimination of hazards through engineering design and analysis, management, and supervisory control of conditions and practices. The SSP encompasses the accomplishment of system safety management, research, and engineering tasks, and is an essential element of the airworthiness qualification of the system.

The normal helicopter engineering process is illustrated in Fig. 3-1. Milestones or checkpoints for system safety within the engineering process must be established at the outset of a helicopter development program. Typical milestone tasks delineated in MIL-STD-882 are shown in Fig. 3-1 opposite the equivalent tasks in the helicopter engineering process. (These milestones are only considered typical and not necessarily complete in number.) The system activity starts early in the preliminary design stage of helicopter design and continues throughout the entire process. The safety system process described subsequently is applied in an iterative manner as the program progresses.

System safety requirements throughout the entire helicopter life cycle are beyond the scope of this handbook. Only the periods from contract definition through the airworthiness qualification are included. Toward this end, appropriate portions of MIL-STD-882 *shall* apply to all Army airworthiness qualification programs.

3-1.1 OBJECTIVES

The ultimate objective of a System Safety Program is to maintain the highest level of operational mission effectiveness through the conservation of human and materiel resources by the early identification, evaluation,

and correction of system hazards. This objective is obtained by insuring that:

1. Safe features consistent with mission requirements are designed into the system from the beginning of the design process
2. Hazards associated with each system, each subsystem, and allied equipment are identified, evaluated, and eliminated or controlled to an acceptable level
3. Control is established over hazards that cannot be eliminated by design selection to protect personnel, equipment, and property
4. Minimum risk is involved in the acceptance and use of new materials and new production and testing techniques
5. Retrofit actions required to correct hazardous conditions are minimized through the timely application of safety criteria from the preliminary design through qualification phases of a system
6. Retrofit actions taken to improve performance, maintainability, reliability, or other functions are considered from the standpoint of safety with respect to interfacing subsystems or allied equipment
7. The historical safety data generated by similar system programs and operational experience are used to preclude the incorporation of previously identified hazards into the new system.

3-1.2 SYSTEM SAFETY PROCESS

The system safety process is shown graphically in Fig. 3-2, and described subsequently. This process shows a logical approach to attaining the system safety objectives specified in par. 3-1.1. The process is repeated as necessary in an iterative fashion at every level of complexity in the design of a system until the requisite assurance of the system hazard level is attained. The SSPP *shall* reflect how the contractor plans to apply this process in the conduct of his System Safety Program.

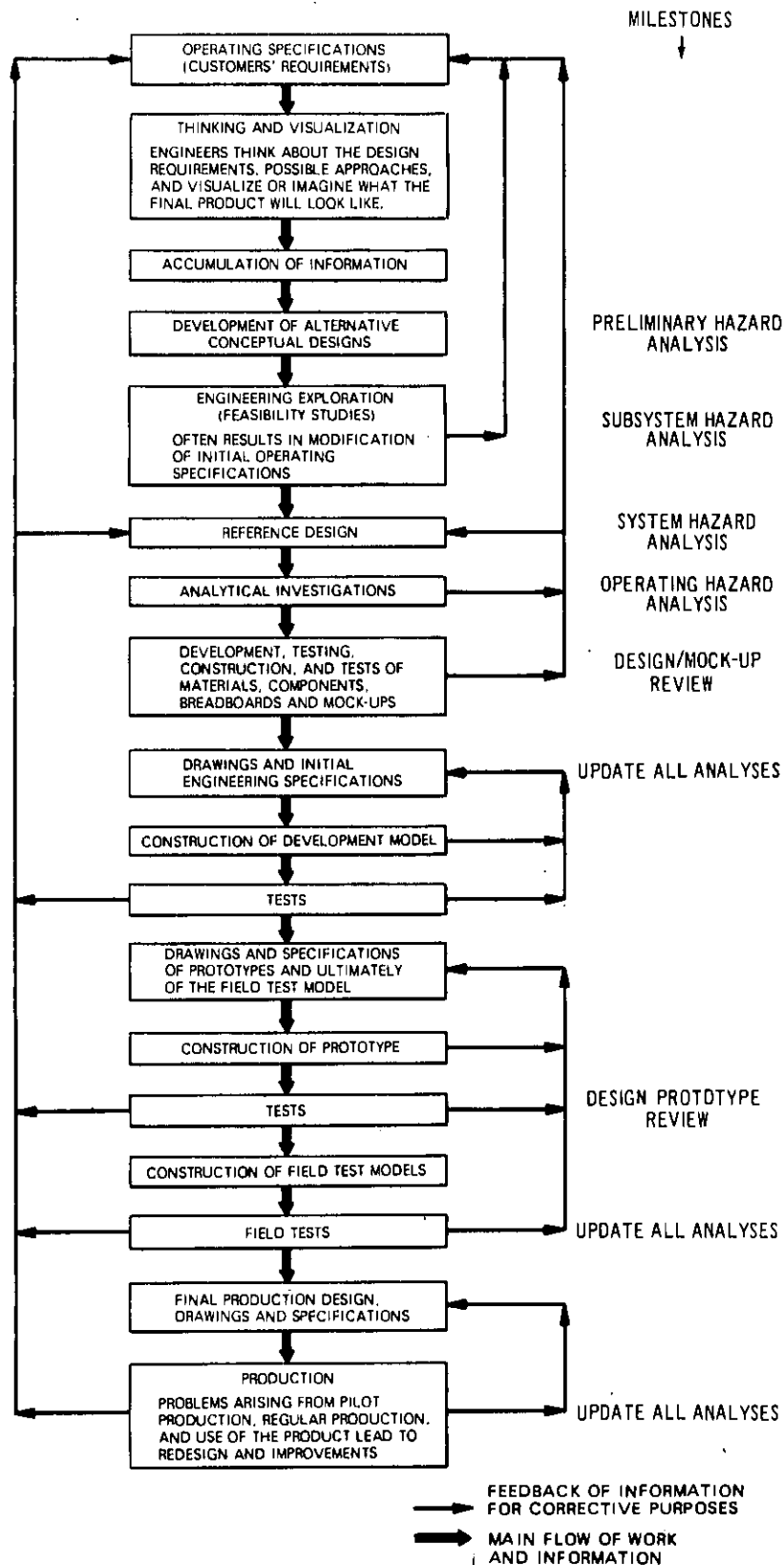


Fig. 3-1. System Safety Milestones in Engineering Development

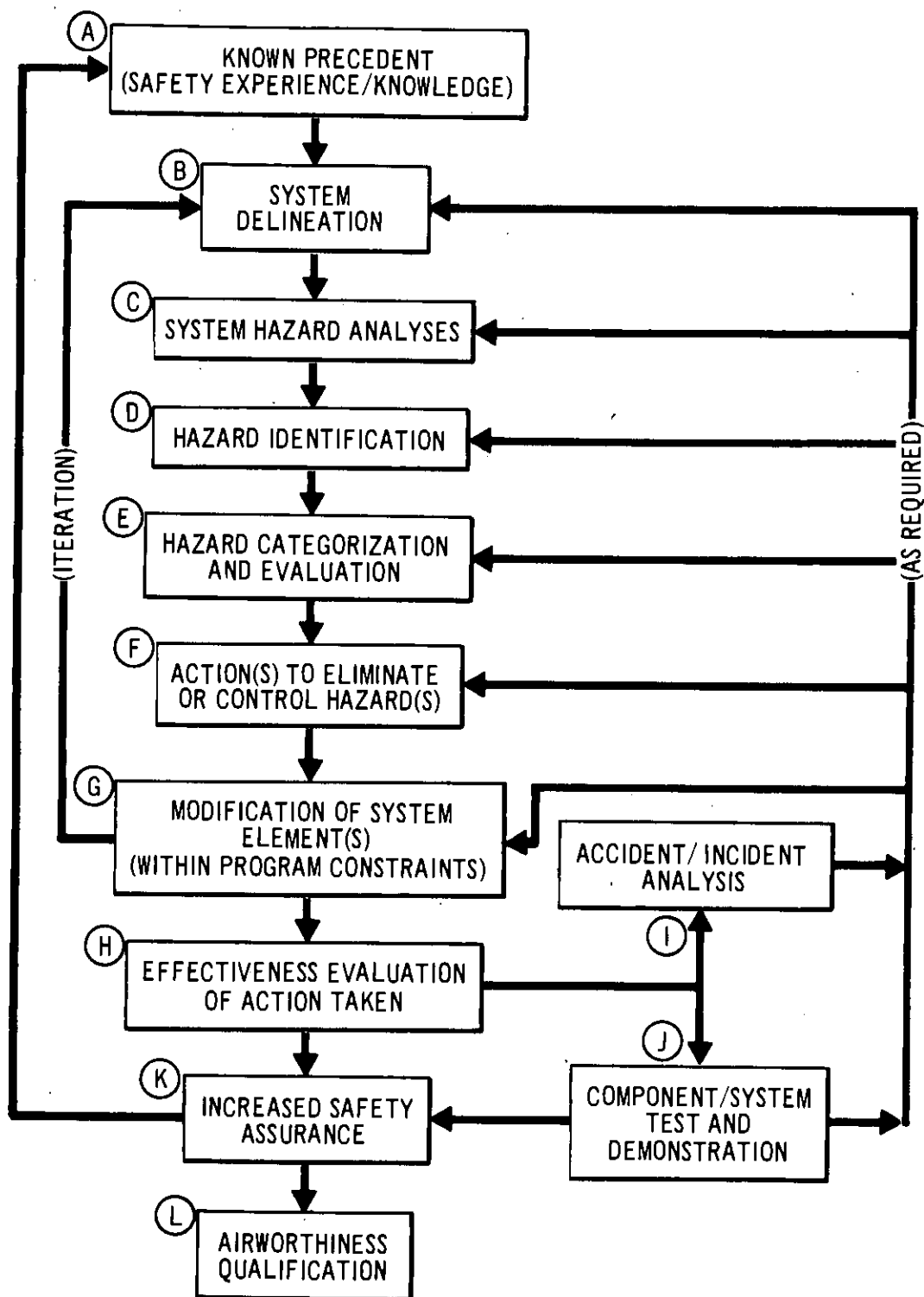


Fig. 3-2. System Safety Process

3-1.2.1 Known Precedent (Block A, Fig. 3-2)

From the beginning, a System Safety Program must be based on the experience and knowledge gained from previous operations in correcting design features which have resulted in the accidental loss or damage to materiel or injuries or death to personnel. Those design features which have not shown unacceptable hazards also are identified. It is essential that the designers of future helicopters benefit from all previous experience which affects safe operation.

3-1.2.2 System Delineation (Block B)

The boundaries of the system under consideration and its constituent elements are defined clearly as early as possible and revised as required during the system life cycle. Such delineation establishes the limits for succeeding steps in the process and reduces complex systems to manageable parts. Any entity can be labeled a "system" provided it is accurately defined.

3-1.2.3 System Hazard Analyses (Block C)

The heart of the system safety process is the analysis of a system and its elements in a comprehensive and methodical manner. Beginning with preliminary hazard analyses of design concepts and continuing through an integrated hazard analysis of the complete system, this analytical process distinguishes system safety from other separate, but closely interfacing, disciplines. The contractor will select the methodology and techniques for hazard analysis best suited for the particular system element under consideration and for the applicable level of detail in design.

3-1.2.4 Hazard Identification (Block D)

Using the systematic hazard analyses, the designer/engineer identifies those features of a system which potentially may cause damage, loss, or injury. Such identification assists the designer in his initial efforts by calling attention to undesirable features which either can be eliminated or controlled efficiently early in the design process. As design progresses, additional hazards are identified throughout the system safety process.

3-1.2.5 Hazard Categorization and Evaluation (Block E)

It is impractical to eliminate all hazards identified in a system. The appropriate action to be taken as a result of hazard identification depends on the nature and degree of severity of the hazard. Categorization of haz-

ards according to criteria specified by the procuring activity serves to guide corrective action based upon degree of severity. Evaluation of identified hazards requires relating a hazard to its impact on mission effectiveness, system performance, and program success. This categorization and evaluation are essential parts of the decision-making process as to appropriate corrective action.

3-1.2.6 Action(s) to Eliminate or Control Hazard(s) (Block F)

The system safety process produces no useful result until some action is taken to eliminate or control identified hazards. The effect of alternative courses of action in the design process and trade studies to eliminate or control identified hazards should be considered. Thus, management is presented with a tool by which decisions can be made in the light of other program constraints.

3-1.2.7 Modification of System Element(s) (Block G)

Any action taken in Block F necessarily will result in the modification of some element or elements of the helicopter system. As a result, the delineation of the system (Block B) must be revised accordingly. The system safety process then is repeated as required until such time as no unacceptable additional hazards are generated by the system modification. This step insures that a new hazard is not inadvertently introduced into the system while another hazard is eliminated.

3-1.2.8 Effectiveness Evaluation of Action Taken (Block H)

Actions taken to correct hazards as a result of the system safety process are evaluated for their effectiveness in accomplishing the system safety objective. A satisfactory evaluation results in increased assurance in the level of safety of the system (Block K).

3-1.2.9 Accident/Incident Analysis (Block I)

The occurrence of an accident or incident, of course, leads to an unsatisfactory evaluation. The analysis of such accident or incident experience should reveal any deficiencies in the conduct of the system safety program and direct corrective action to the appropriate step in the process.

3-1.2.10 Component/System Test and Demonstration (Block J)

Analytical techniques alone will not be sufficient to adequately identify system hazards. This inadequacy is determined in Block H. Tests and demonstrations normally conducted as a part of a helicopter development program are planned and conducted to reveal and correct such inadequacies. In addition, these tests and demonstrations serve to verify the results of the system safety process and contribute to the assurance desired. Should system testing reveal additional problems, corrective action is applied at the appropriate step in the process.

3-1.2.11 Increased Safety Assurance (Block K)

The assurance that the objectives of system safety are being met is cumulatively increased as the program progresses and contributes increased knowledge for subsequent cycles of the process (Block A).

3-1.2.12 Airworthiness Qualification (Block L)

Ultimately, the system safety process results in data and information which serve as an essential element of airworthiness qualification. Methods and procedures to be followed are prescribed in the Airworthiness Qualification Specification.

3-1.3 ANALYTICAL METHODOLOGY

Hazard analysis is the heart of the system safety process. The primary emphasis in analysis is on inductive thought. Deductive reasoning also is employed but to a lesser degree.

The ultimate purpose of hazard analysis is to aid management in reaching the determination that the objectives discussed in par. 3-1.1 have been achieved within the constraints of the particular helicopter development program. In addition these analyses form a baseline which can be evaluated objectively by someone other than a system safety analyst to measure the effective influence of subsequent design changes.

There are several types of widely used analyses for system safety. Selection of analytical methodology or techniques to be used in a given program is the responsibility of the contractor and depends upon the level of detail required by program phases, requirements for quantitative or qualitative results, and the particular capabilities developed by the contractor.

Analytical techniques *shall* be described fully in the System Safety Program Plan (SSPP).

3-1.4 KNOWLEDGE OF HAZARDS

The system safety analyst must have a thorough knowledge of not only helicopter engineering but also of hazardous conditions.

For example, major helicopter configurations—such as the type of rotor (e.g., hinged or rigid), the method for directional control, and the projected approach for overcoming gyroscopic precession—have inherent safety implications. The trade-offs utilized to reach a decision regarding these configurations must include system safety considerations. In addition, hazards are more likely to be present at interfaces between subsystems than within a single subsystem. Some examples of possible interrelationships which could lead to hazards are the height of the main rotor above the ground and the location of the pilot relative to the rotor path.

The system safety analyst also must be aware of those conditions which have been proven by past experience to be hazardous for helicopters. And the consideration of hazards must not be limited to those conditions involving only hardware. The interactions of the helicopter with personnel who operate and maintain it, and between personnel and the environment in which the helicopter is utilized, provide potentially hazardous conditions which must be considered during design.

3-1.5 CLASSIFICATION OF HAZARDS

Since it is impossible to eliminate and/or control all possible hazards, they are usually ranked in degree of severity (i.e., consequence in operation of the helicopter). Four hazard levels ranging from negligible to catastrophic are defined and established in MIL-STD-882. These are listed in Table 3-1. However, this is not the only acceptable way to classify hazards. Besides the consequence of the hazards, the probability and resources required to eliminate and/or control them must be considered before the procuring activity can authorize expenditure of resources to resolve the hazards. The contractor *shall* develop a procedure to categorize hazards which is compatible with the program requirements. One possible range of values for the three parameters—consequence, probability, and required resources—is listed in Tables 3-1, 3-2, and 3-3.

Table 3-1 is an example of how the four hazard levels of MIL-STD-882 could be interpreted specifically for the helicopter of interest. In this case, each hazard level is interpreted in terms of system objectives, functional

capability, and personnel safety. All possible hazards in the helicopter could be graded for severity against these four levels, and one of the four code letters in Table 3-1 assigned to each hazard.

Table 3-2 provides a range of probabilities for any given hazard occurrence. The same code letter procedure could be used.

Table 3-3 involves an intermediate conversion of various resources (e.g., policy, procedures, manpower) into a dollar equivalence before a code letter can be selected.

Once three code letters have been assigned to each possible hazard, they are combined to form one index of significance. The Hazard Totem Pole of Table 3-4 is one way to list these code combinations in order of importance or significance.

3-1.6 RESOLUTION OF HAZARDS

MIL-STD-882 discusses the methods of resolving hazards. The first, and most desirable method, is to eliminate an identified hazard by selection of a design in which the hazard does not appear. If elimination of a hazard is impossible or uneconomical, the next step is to make the system tolerant of the hazard.

Three ways of making a design tolerant of identified hazards are stipulated in MIL-STD-882 in a descending order of desirability. The first alternative is to reduce the significance of a hazard through the use of appropriate safety devices. Ideally, such devices should not require human intervention but should operate automatically if the specified hazardous condition arises.

The next choice is to place warning devices in the system to make known to the crew the existence of a hazardous condition. These devices would require human intervention to respond to the warning produced. Audio or visual indicators are commonly used in this respect, but there is a limit on the number of such devices that can be effectively employed in a system design. Such features must be coordinated closely with the human factors engineering function.

The final, and least desirable, choice is to prepare, disseminate, and enforce special operating procedures regarding an identified hazardous condition. However, these procedures are a weak link in the achievement of system safety because of the inability to verify communication of the procedure to the person who must operate in accordance with such procedures.

3-1.7 SUBSTANTIATION OF HAZARD RESOLUTION

Once each possible hazard has been analyzed for its

significance and the resolution of the hazard is determined, there is need for assurance that proper corrective action has been taken. This can be accomplished by inspections, additional analyses, and design reviews.

A particular type of design review which is effective for system safety is the mock-up review (see par. 5-3). The helicopter mock-up also can become an excellent method of identifying additional potential hazards. Additionally, the mock-up brings the subsystems together at an early stage, before interface problems become too expensive to change.

3-2 SYSTEM SAFETY PROGRAM PLAN (SSPP)

3-2.1 GENERAL

The detailed controlling document of the System Safety Program is the System Safety Program Plan (SSPP). This plan *shall* constitute a detailed description of the contractor's approach to system safety and relates the methods to be employed to satisfy the requirements of a Request for Proposal (RFP) or a Request for Quotation (RFQ).

The purpose of the SSPP is to provide a basis of understanding between the contractor and the procuring activity as to how the system safety program will be incorporated into the development effort. It must contain the necessary details for determining adequacy and measurability; a definition of the safety effort to be made; an outline of the management structure through which the plan will be enforced; and an identification of the milestones by which it can be monitored. The plan *shall* define the safety analysis techniques to be employed, the degree of design review participation, and the safety data reporting system. Past accident experience serves as an important safety design consideration and the method of utilization of these data must be discussed in the SSPP. Furthermore, the safety interface between contractors and subcontractors, including Government-furnished equipment (GFE) suppliers, such as engine manufacturers, must be defined.

Only the requirements for the portion of the SSPP needed to support the system acquisition program from contract definition through completion of airworthiness qualification are included in the paragraphs which follow.

3-2.2 SAFETY ANALYSIS AND HAZARD EVALUATION PROCEDURES

There are several safety analysis and hazard evaluation techniques which may be used, depending on the

TABLE 3-1. HAZARD SEVERITY FOR HELICOPTERS

CODE	MIL-STD-882 HAZARD LEVEL	EFFECT ON SYSTEM OBJECTIVES	EFFECT ON FUNCTIONAL CAPABILITY	EFFECT ON PERSONNEL SAFETY
A	CATASTROPHIC	AIRLIFT RENDERED IMPOSSIBLE-- MISSION IS LOST	NO PORTION OF THE HELI- COPTER CAN BE SALVAGED FOR USE ELSEWHERE --TOTAL LOSS	PERSONNEL SUFFER DEATH OR MULTIPLE INJURIES BY FACTORS IN CODE B
B	CRITICAL	AIRLIFT IMPAIRED SERIOUSLY-- MISSION ACCOMPLISHED ONLY BY AUXILIARY METHODS	TWO OR MORE MAJOR SUB- SYSTEMS OF HELICOPTER ARE DAMAGED-- THIS CON- DITION REQUIRES DEPOT-LEVEL MAINTENANCE	PERSONNEL INJURED EITHER: (1) OPERATING THE HELI- COPTER, (2) MAIN- TAINING THE HELICOPTER, (3) BEING AIR- LIFTED BY HELICOPTER, OR (4) BEING IN VICINITY OF THE HELICOPTER
C	MARGINAL	AIRLIFT IS POSSIBLE BY UTILIZING AVAILABLE REDUNDANT OPERATIONAL OPTIONS	NO MORE THAN ONE COMPO- NENT OR SUB- SYSTEM DAMAGED. THIS CONDITION IS EITHER REPAIRABLE OR REPLACEABLE WITHIN ONE HOUR ON SITE	PERSONNEL- INJURING FACTORS IN CODE B CAN BE CONTROLLED BY EITHER AUTO- MATIC DEVICES, WARNING DE- VICES, OR SPECIAL OPERATING PROCEDURES
D	NEGLIGIBLE	NO MEASUR- ABLE EFFECT ON AIRLIFT MISSION	NO APPARENT DAMAGE TO HELICOPTER	NO INJURY TO PERSONNEL

requirements of the technical data package and the Airworthiness Qualification Plan (AQP) generated for the helicopter system. Selection of the best technique will permit efficient use of existing data and relate the safety analysis to the other engineering disciplines. The depth of documentation also is dependent upon the complexity of the system and the requirements of the AQP. A necessary criterion for depth and adequacy of the technique employed is traceability, i.e., cause to

effect or effect to cause. Analysis techniques to be considered in the SSPP may include, but are not limited to, those discussed in pars. 3-2.2.1 through 3-2.2.3.

3-2.2.1 System/Subsystem Hazard Analysis

Hazard analysis is a qualitative technique used primarily to assess the operational safety level of the helicopter system/subsystem. Its product is a hazard

TABLE 3-2. HAZARD PROBABILITY FOR HELICOPTERS

CODE	DESCRIPTION OF SITUATION
J	HAZARD OF INTEREST WILL OCCUR WITHIN 10 CUMULATIVE HOURS OF OPERATION
K	HAZARD OF INTEREST WILL OCCUR WITHIN 100 CUMULATIVE HOURS (4 CUMULATIVE DAYS) OF OPERATION
L	HAZARD OF INTEREST WILL OCCUR WITHIN 1000 CUMULATIVE HOURS (41 CUMULATIVE DAYS) OF OPERATION
M	HAZARD OF INTEREST WILL OCCUR WITHIN 10,000 CUMULATIVE HOURS (14 CUMULATIVE MONTHS) OF OPERATION

TABLE 3-3. HAZARD ELIMINATION/CONTROL RESOURCES

CODE	CALCULATED DOLLAR EQUIVALENCE*
P	LESS THAN \$1000 REQUIRED TO ELIMINATE/CONTROL THIS HAZARD
Q	\$1000 - 10,000 REQUIRED TO ELIMINATE/CONTROL THIS HAZARD
R	\$10,000 - 100,000 REQUIRED TO ELIMINATE/CONTROL THIS HAZARD
S	OVER \$100,000 REQUIRED TO ELIMINATE/CONTROL THIS HAZARD

*CALCULATED DOLLAR VALUE OF ALL RESOURCES (REVISION OF POLICY, PROCEDURES, MANPOWER, DOLLARS, TECHNOLOGY, FACILITIES, MATERIALS, AND SCHEDULE) REQUIRED TO EITHER ELIMINATE OR CONTROL THE HAZARD OF INTEREST.

analysis summary which documents the following:

1. A brief description of the function being analyzed
2. The hazard involved classified to the appropriate level as specified in MIL-STD-882
3. A statement concerning the hazard effects
4. A recommended corrective action
5. A remarks column noting the status and/or accomplishment of the corrective actions.

The hazard analysis is based on an operational sequence chart in which specific tasks are defined and their interrelationships shown. This analysis also can be effective when used to assess the safety posture and

to document corrective actions for operations that are planned divergencies from the normal operational mode. This technique requires the safety analyst to be familiar with the detailed functional systems of the helicopter.

3-2.2.2 Fault Tree Analysis

The purpose of fault tree analysis is to establish the probability of occurrence of the hazard. Fault tree analysis is primarily quantitative and utilizes detailed component failure probabilities to calculate overall probability of the undesired event (Refs. 1, 2, and 3). However, it also can be used qualitatively to identify the conditions which may need further accident prevention work. In this application as a safety tool, the decision as to whether remedial action is required is based upon a comparison of the output probabilities to the safety level deemed acceptable. The fault tree analysis is a statistical hazard-oriented model. At the apex of the tree, the undesired event is identified. Working from this apex a net of all events which contribute to the hazardous condition is constructed. Each event that may cause such a condition is assigned to a failure rate and an "Undetected Fault Time", which is the duration of the time a fault condition exists undetected in a system. Failure rate need not be a constant value but varies with the activity being performed or the stress levels encountered. For example, an engine is subject to more failures at maximum power than at idle.

A situation where one or more events will result in a specific fault is represented on the Fault Tree as an "OR-gate". When all input events must take place simultaneously before the output event will occur, this is represented on the Fault Tree as an "AND-gate".

3-2.2.3 Failure Mode and Hazardous Effect Analysis (FMHEA)

The purpose of FMHEA is to avoid costly modifications. This is accomplished by detecting design and operational deficiencies in early design and testing phases, which assures a high level of safety before the initiation of quantity production. An additional objective is the determination of the critical failure modes which have a serious effect on the successful completion of a mission and on the safety of the crew. The analysis consists of an independent critical review of the system, coupled with a systematic examination of all conceivable failures, and an evaluation of the effects of these failures on the mission capability of the system.

The system is described in a functional block diagram showing the critical functions which constitute the system. A "critical function" is one that must be

TABLE 3-4. HAZARD TOTEM POLE

HAZARD SIGNIFICANCE RANKING ¹	CODE COMBINATION ²			NUMBER OF HELICOPTER HAZARDS
	HAZARD SEVERITY	HAZARD PROBABILITY	HAZARD RESOURCES	
1	A	J	P	3
2	A	J	Q	NONE
3	A	K	P	1
4	B	J	P	16
5	A	J	R	7
6	A	K	Q	NONE
7	A	L	P	4
8	B	J	Q	22
64	D	M	S	2

¹ Because there are 4 codes for each of the 3 hazard parameters, the hazard totem pole must contain 64 code combinations, i.e., 4x4x4. The ordering or ranking of the code combinations in this example is such that the first combination (AJP) is the most significant and code combination DMS is least significant to helicopter design management. This ordering can be varied depending on the criteria one sets for relative significance among hazard severity, probability, and resources. In the ordering illustrated, all three parameters were equally weighted but preference was given first to severity, then probability, and finally resources. Both *weighting* and *preference* of codes should be established prior to preparing a hazard totem pole.

² The codes being combined are those from Tables 3-1, 3-2, and 3-3.

performed if the system is to operate. In this diagram, the blocks are connected to each other by lines which represent the "inputs" and "outputs" of each function. A failure is now defined as a break in an output line. If each output line is in turn systematically cut, either alone or in critical combination with other failures, all possible functional failures in the system will be covered. Each critical function is reviewed for failure probability based upon two questions. The first is, how can this assumed functional failure actually occur, i.e., what pieces of hardware would have to fail first to result in this functional failure? It is not necessary for the analyst to identify all possible hardware failures; if he can only identify one or two, he can establish some probability of system failure. Secondly, how can this failure mode be removed, i.e., must this be designed this way?

3-2.3 SAFETY TESTS

Safety tests *shall* be integrated into appropriate test plans. Partial verification of safety characteristics or procedures may be demonstrated by laboratory tests, functional mock-ups, or model simulation, when approved by the procuring activity. The detailed test plans for all tests *shall* be reviewed to insure that:

1. Safety is demonstrated adequately.

2. The testing will be carried out in a safe manner.
3. All additional hazards introduced by testing procedures, instrumentation, test hardware, etc., are properly identified and minimized.

3-2.4 DATA

Safety data requirements during the development phase will be incorporated into those from other phases of the system life cycle and specified in the *Contract Data Requirements List* (DD Form 1423). System safety data acquisition and acceptance will be in accordance with MIL-STD-882.

REFERENCES

1. J. Feutz and J. Tracy, *Fault Tree for Safety*, D6-5713, The Boeing Co. January 1966.
2. J. Feutz and T. A. Waldeck, *The Application of Fault Tree Analysis to Dynamic Systems*, The Boeing Co., presented at the System Safety Symposium, Seattle, Wash., June 1965.
3. J. B. Peller, *Fault Tree Analysis as a Tool for System Safety Engineering*, Report X5-1002/319, North American Aviation/Autonetics, Anaheim, California, January 1965.

CHAPTER 4

DATA AND DOCUMENTATION PROCEDURES AND REQUIREMENTS

4-1 INTRODUCTION

This chapter discusses the data and documentation requirements, from the beginning of engineering development until all necessary elements and characteristics of the configuration and helicopter system have been defined, investigated, and qualified for production. The data discussed subsequently are intended to be a composite list of data which could be made available to the Government by the contractor. The data requirements for a specific program should be tailored within this list. Subsequent chapters discuss the need, use, and required content of specific items of data.

DD Form 1423 is the only contractual instrument for the purchase of data and documentation. Therefore, data needs will be converted from those listed herein into the items on the authorized data list, TD-3, and then entered on DD Form 1423. The need for each item must have thorough justification for its needs. Data may be informative only, or for review, approval, or other action. When drawings are required, the appropriate sections of MIL-D-1000 will apply. The *DOD Index of Data Item Descriptions*, TD-3, provides usage guidelines and references for submittal of data.

The contractor *shall* provide the procuring activity (to the extent specified by DD Form 1423) with various types of data—such as test plans, test reports, technical analyses, specifications, drawings, and other reports—during the helicopter system development. These data serve several functions, including configuration control and documentation of design and test data. Data are provided at strategic milestones during the qualification program, consistent with the information system of the procuring activity. An “audit trail” is established so that each milestone of system development may be monitored throughout the development process. Data inputs should be sufficient to allow the procuring activity to assess achievement of design requirements and to determine problem areas requiring modification.

4-2 APPLICABLE DOCUMENTS

Government specifications, standards, and aeronautical standard drawings applicable to Army helicopter developments will be in accordance with those cited in USAAVSCOM Pamphlet No. 70-1, the approved *List of Military Specifications, Standards, and Aeronautical Standard Drawings*. The documents governing requirements in this handbook will be those issues in effect at the time of formal solicitation of proposals.

The contractor will use the specifications and standards in the order of precedence established by MIL-STD-143. This Standard prescribes the criteria which govern and control the selection of material and parts when such selection criteria have not been specified. Such documents, when listed in USAAVSCOM Pamphlet No. 70-1, may be used without further approval. However, in some applications, selection of a specification or standard in this order of precedence may result in “overdesign”, with unnecessarily increased costs or a degradation of performance of the total system. In these cases, a new or improved specification or standard, or a manufacturer's specification, is required. If, in the opinion of the contractor, the optimum specification or standard for a specific application is not listed, an alternate should be submitted to the procuring activity for the required approval, before use.

Justification for using the alternate specification or standard, with supporting evidence of its suitability, will be submitted with a request for approval. Contractors should submit such requests for approval when use of the specification or standard is being contemplated in order to avoid potential delays in the qualification progress.

Contractor documents *shall* not be changed without prior consent of the approving authority. Approval of contractor documents is given on an individual contract basis; it is the contractor's responsibility to request and obtain approval for continued use of such documents.

In addition, satisfactory operation of equipment procured under any specification or standard is the responsibility of the contractor. The use of such specifications or standards, whether listed or approved by the procuring activity, is not an automatic acceptance of the finished product or its acceptability for the total helicopter system. Acceptance or proof of compliance *shall* be accomplished in accordance with the procedures of the approved AQS.

Copies of Government Specifications, Standards, and aeronautical standard drawings referenced in this handbook may be obtained by the procedure specified in USAVSCOM Pamphlet No. 70-1.

4-3 DATA REQUIREMENTS

Data and documentation *shall* be submitted in accordance with the requirements of DD Form 1423. Potential data requirements are summarized in Table 4-1 (page 4-16).

4-4 PROGRAM PLANS

The helicopter test and demonstration plans include:

1. Airworthiness Qualification Specification, pars. 2-1 and 2-2
2. Electromagnetic Compatibility Control Plan, par. 9-11
3. System Safety Program Plan, par. 3-2
4. Reliability Plan, par. 10-1.1
5. Maintainability Plan, par. 10-2.2
6. Human Factors Engineering Plan, MIL-H-46855
7. Weight and Balance Control and Management Program Plan, to meet the requirements of MIL-W-25140.

The contractor *shall* maintain and periodically update the preceding plans to reflect changes or expansions and to reflect configuration changes of the helicopter system and its subsystems. Revised and additional pages *shall* be furnished as required by the contract data package.

4-5 DESIGN REVIEWS

Design reviews provide technical program control throughout the design phase. They allow for timely application of experience gained on previous programs, and result in savings of both time and money when

changes are introduced before fabrication has progressed to a significant stage.

A design review of the schematic drawings for each subsystem is required to insure that the conceptual design meets the specification requirements and that unsafe conditions or unreasonable maintainability features are not inherent in the subsystem designs.

Design reviews will be conducted by the procuring activity as required so as to adhere to the contractor's schedule.

4-5.1 DESIGN DRAWING REVIEWS

A design review of detail drawings for each subsystem is required to:

1. Insure that there are no obvious conflicts with design criteria
2. Insure that there are no obvious design deficiencies in disciplines such as system safety, maintainability, and reliability
3. Maintain a positive record of the configuration which is being recommended for analysis and test
4. Establish a basis for updating and identifying components which fail the qualification tests
5. Provide a foundation of documentation for an audit trail of all airworthiness substantiating action.

Procuring activity participation in design review does not relieve the contractor from the responsibility of insuring that the drawings conform to the requirements of MIL-D-1000, before their final acceptance.

4-5.2 DATA FOR DESIGN REVIEWS

The contractor *shall* prepare, assemble, and provide appropriate data packages for the design reviews scheduled in the AQS. The packages will define areas to be reviewed and will include an agenda coordinated with the procuring activity prior to the review. Data *shall* be provided from which the procuring activity may assess the compliance of the design with the contractual requirements, the adequacy of the design, and the progress made in the configuration definition and qualification program defined by the AQS. In addition, a summary *shall* include the status and results of analyses and tests; and system safety, reliability, and maintainability programs, and conclusions drawn; status of procurement and process specifications; schematics and drawings (Consolidated Drawing List, par. 4-7.15); and current predictions compared with contractual weight and mission performance. Problem areas and remedial action must be highlighted, and supporting detail data made available.

4-6 MOCK-UPS

Mock-ups meeting the requirements of Chapter 5 *shall* be provided. Also, the mock-up photographs required by par. 5-3 *shall* be provided.

The contractor *shall* furnish reference material, office facilities, and administrative assistance to facilitate conduct of the Mock-up Review. Mock-up data and inspection checkoff lists *shall* be provided, in accordance with par. 5-3.

4-7 ENGINEERING DATA

Since the data which follow are not always required, and the extent to which they are required is mentioned in DD Form 1423, no use is made of the imperative verb "*shall*" as in other sections of the handbook.

4-7.1 AERODYNAMIC AND FLUTTER INVESTIGATION PROGRAM REPORT

A report will be submitted showing the planned aerodynamic and flutter investigation program and schedule. This report, amplifying the overall program and schedule of the AQS, will outline the purpose and scope of each proposed investigation; indicate the test facilities to be employed, and test dates and occupancy time required; describe the scale and type of models to be constructed and tested; and present the ranges of test variables to be investigated. The requirements of MIL-A-8870 will apply to wind tunnel flutter model investigations.

Where use of Governmental facilities is planned, the contractor will make preliminary contact with the facility to determine feasibility and desirability of conducting the proposed investigations and to obtain tentative confirmation of availability. If the tests are to be conducted in a privately operated facility, a detailed description of tests to be conducted plus specific test objectives will be submitted. Following approval of the report, a formal request detailing the specific test programs will be made to the test facility.

When aerodynamic and flutter models are required, the model design will be suitable for carrying out the investigation program, including scale ratio and strength and installation features, and for utilization in the maximum practical number of suitable alternate Governmental and private test facilities. Approval of the model design by the operator of the test facilities to be utilized is required prior to model construction. Model drawings should be made available to the pro-

curing activity on request. For dynamic and free-flight model investigations, weight, inertia, and other pertinent design information must be furnished for simulation of full-scale conditions in the construction testing of the model.

Data from aerodynamic and flutter investigations will be kept current by prompt submittal of pertinent reports which include:

1. Interim Letter Reports. These will be submitted immediately following completion of each facility occupancy; they will cover items such as tests conducted, scope, contractor's observations of the tests including any difficulties encountered, significant results, and any conclusions or recommendations based on inspection of the available preliminary test results.

2. Aerodynamic Test Data Reports. These will present the basic aerodynamic data and test results obtained from the investigations conducted in contractor-furnished and private test facilities. Aerodynamic test data obtained from Governmental facilities will be provided by the facility. The reports should identify the configurations tested, any differences from the configuration tested and reported on previously, and from the current helicopter configuration. Graphic presentation is desired with reference (if possible) to axes consistent with the stability and control and estimated flying quality report required in par. 4-7.2.3. Tabulated detailed data are not desired unless specifically requested.

3. Flutter Model Test Report. A report of the flutter model investigation conducted in accordance with MIL-A-8870 will be submitted.

4. Flutter Analysis Reports. Preliminary and final (if required) flutter and divergence analysis reports will be submitted. These reports will be prepared in accordance with MIL-A-8870 and will compare the flutter and divergence limit speeds for the rotor blades and for the fixed lifting and control surfaces of the helicopter with the requirements of MIL-S-8698. Subject to the approval of the procuring activity, freedom from flutter or divergence may be substantiated analytically, with no flutter testing required.

4-7.2 AERODYNAMIC STABILITY AND CONTROL REPORTS

4-7.2.1 Digital and Analog Computer Program Report

If the helicopter response characteristics are to be simulated analytically on digital and/or analog computers, a report will be submitted outlining the program and providing for later revisions. Results ob-

tained from the computer will be submitted, preferably in graphic form.

4-7.2.2 Flight Simulator Program Report

If a piloted simulator to assist the development is planned, a report will be submitted outlining the program and providing for later revisions. Results obtained from the simulation studies should be submitted by Interim Letter Reports similar to those required in par. 4-7.1(1).

4-7.2.3 Aerodynamic Stability and Control and Flying Quality Reports

An initial report containing complete information on the aerodynamic stability and control characteristics and resultant flying qualities will be submitted. This report should be updated with revised pages to reflect the development progress of the helicopter design, particularly the latest and most applicable results of the contractor's analytical and investigative programs and any major configuration changes. The report will contain all the data necessary to define the aerodynamic configuration and its control system characteristics, together with relevant data on center of gravity (CG), weight, and moment and product of inertia. In a separate section of the report, all aerodynamic data necessary to define the stability and control characteristics throughout the design envelope will be submitted with documentation references, including inputs such as aeroelasticity, power (thrust), exhaust wake effects, external stores, and ground effect, as applicable. Where applicable data exist, the stability and control parameters will be converted into flying quality characteristics, including the effects of automatic stabilization and control devices, and must be compared with the requirements in Chapter 6 of AMCP 706-201 and in the detail specification. The methods and procedures used for this conversion should be illustrated. Where applicable, available flight test results will be presented to substantiate the data.

In addition, a complete and updated report reflecting the initial flight configuration and data outlined previously will be submitted. This report will detail compliance with the requirements in Chapter 6 of AMCP 706-201 and in the detail specification.

A complete description of the helicopter to be delivered to the procuring activity for stability and control tests will be furnished. The descriptive data will be sufficient to describe the design configuration and detail characteristics affecting the helicopter flying qualities. External details such as aerodynamic surfaces, lift, drag, and flow control devices, and external stores may

be shown on three-view drawings or other sketches. The data will include details of the control systems (including feel and power systems) such as the type of controls, aerodynamic and mass balances, gearing and boost ratios, trim and feel devices, mechanical advantage changes, capacities and operating pressures for boosted systems, description of artificial stability devices, and recommended gain and follow-on settings.

4-7.3 CHARACTERISTIC AND PERFORMANCE DATA

4-7.3.1 Basic Aerodynamic Data

The contractor will submit all basic aerodynamic data used in the calculation of the helicopter performance; the geometric characteristic data defining the helicopter configuration, and the documents and/or references showing the derivation of these data (drawings, analyses, substantiating calculations, tests). If the basis is wind tunnel or flight test data, the procedures followed in adjusting these data for differences in configuration, Reynolds number, surface conditions, and regimes must be explained. Revision pages will be submitted to reflect significant changes. The types of data which follow will be included, as applicable:

1. Drag analysis itemized by helicopter components such as rotor hubs, fuselage, wing, stabilizing surfaces, and landing gear to derive a parasite drag coefficient.
2. Sectional lift, drag, and moment coefficients as functions of angle of attack and airspeed for each new section. If standard NASA/NACA airfoils are used, these data may be referenced. Wing efficiency factor "e" as a function of wing lift coefficient will be reported.
3. Incremental drag coefficients for drag devices; each required external stores, tank, pod, etc.; or combinations of these, as appropriate, for the helicopter configuration and loading capabilities.
4. Nondimensional hover and forward flight performance curves (thrust and torque coefficients, and, for forward flight, advance ratio).
5. Rotor blade stall and compressibility limits.
6. Ground effects at appropriate wheel heights.
7. Net thrust, power available, and fuel flow variations versus appropriate altitudes, temperatures (standard, tropical, and hot days in accordance with MIL-STD-210), and speeds. Data also are required for both rated engine power and partial thrust/power operations, with all losses (filtering, induction system, nozzles, bleeds, accessory drives and power extractions,

transmission losses, efficiencies, etc.) and tail rotor powers indicated.

8. Complete aerodynamic description of main rotor(s) and antitorque rotor including parameters such as radius, number of blades, chords, effective solidity ratio, twist, taper, hinge offsets, airfoil and tip geometry, and hovering tip speed; wing and control surface areas and geometry; wetted area of components and the helicopter; overlap and projected disk area for tandems.

4-7.3.2 Substantiation of Performance Data Report

This report will be submitted, along with a copy of the current General Arrangement Drawing (see par. 4-7.9.1) to substantiate the performance shown on each issue of the Standard Aircraft Characteristics Charts described in par. 4-7.3.3. The aerodynamic data of par. 4-7.3.1 will be included, using the format and general content in accordance with applicable requirements of MIL-C-5011. Revisions to the previous report will be submitted whenever changes in helicopter configuration, engine(s), or basic aerodynamic data result in significant performance changes.

4-7.3.3 Standard Aircraft Characteristics (SAC) Charts

The First, Second, and Third SAC Charts will be prepared in accordance with MIL-C-5011. The First Chart will be submitted based on the aerodynamic data required in par. 4-7.3.1 and as accepted by the procuring activity. The Second and Third Charts, reflecting current performance status; will be submitted—based on Government flight tests, contractor flight tests, or calculations—in the order of preference available at the time these charts are requested by the cognizant procuring activity.

4-7.4 WEIGHT AND BALANCE DATA

The contractor must establish a system of weight control and reporting in accordance with MIL-W-25140 and the proposed Weight Control Plan (par. 10-1 of AMCP 706-201) approved by the procuring activity. Data to be submitted during the development include:

1. Weight and Balance Control and Management Program Plan. This report provides data on intent, approach, and methods to be used to insure minimal weight and balance variations within constraints of specification design requirements, program cost, and schedule.

2. Estimated weight and balance report, when specifically requested by the procuring activity

3. Weight and balance status reports

4. Calculated weight report

5. Sample Charts A and E in AN 01-1B-40

6. Actual weight reports and appendices. Prior to releasing the helicopter for flight, the Cognizant Service Plant Activity (CSPA) will insure that it has been weighed to determine actual weight and CG. The contractor will insure that loadings employed for initial flights do not jeopardize safety of flight from a strength or flying quality standpoint, and that more critical loadings for subsequent flights are approached gradually. Weight and balance data for test helicopters will have been submitted and accepted prior to conducting demonstrations

7. Approved Charts A and E and revisions in AN 01-1B-40

8. Post design weight analysis report, when specifically requested by the procuring activity. This report will be submitted not later than six months after delivery of the first helicopter, and will contain the following information:

- a. A brief discussion of the weight design philosophy, the procedures and methods for implementing weight control objectives, and the organizational structure of the weight group
- b. Graphic plots of the predicted and guaranteed empty weight, and the primary mission gross weight versus time
- c. Tabulations of the original group weights, and subsequent changes through major change points, as shown on Item 8b, to the final weights
- d. Brief description or identification of the major changes for each weight group in Item 8c.

4-7.5 STRUCTURAL DESIGN, ANALYSIS, AND TEST DATA

These data and reports should be submitted in accordance with the requirements of Chapters 2 and 8 and pars. 4-7.9 and 4-7.13.

4-7.6 HUMAN FACTORS ENGINEERING DATA

Reports will be submitted in accordance with MIL-H-46855, and the appendix thereto, as implemented by

the contractor's approved Human Factors Engineering Plan (par. 4-4(6)). Included are:

1. Human factors engineering (HFE) test plan
2. HFE progress report
3. Operator task load analysis
4. Operator/maintainer position planning data
5. Work and crew station layouts
6. Internal and external noise survey data
7. Final HFE report (see par. 4-7.13 for human factors engineering verification plans and reports)
8. Aircrew station vision report.

4-7.7 SYSTEM SAFETY DATA

The data to be submitted include:

1. Hazard analyses, in accordance with MIL-STD-882 and the approved System Safety Program Plan (par.3-2.2)
2. System safety specifications for the system and each contract end-item (par. 3-2.4).

4-7.8 RELIABILITY AND MAINTAINABILITY DATA

Contractor data requirements will include:

1. Reliability and maintainability reports, in accordance with MIL-STD-1304 and MIL-STD-470, including analyses and summaries to show quantitative interrelationships and trade-offs between reliability and maintainability (pars. 10-1.1 and 10-2.1). (See par. 4-7.13(17) for reliability test plans and reports.)
2. Maintenance engineering analyses, in accordance with TM 38-703-3 (par. 10-2.1.3).
3. Logistic support reports, in accordance with the Maintainability Plan (par. 4-4(5)), covering areas such as development and implementation of the maintenance philosophy, handbooks, maintenance trainers and training, provisioning, and GFE.

4-7.9 SUBSYSTEM DESIGN APPROVAL DATA

These data—including drawings, schematics, and associated substantiating analyses, calculations, and detailed information for airframe and propulsion, and drive systems and equipment subsystems—will be submitted to the procuring activity for review during the detail design phase. The drawings should be the layouts or first drawings normally prepared by the contractor, which show the required information. Legibility of the drawings must be such that all lines are distinct and

appear in their entirety, and that all numbers, lettering, and other characters are clear. Where applicable, the drawings will include all references to specifications required for materials, processes, etc. Drawings required by pars. 4-7.9.3 to 4-7.9.7 will show the major structural design features including all important fitting attachments, carry-through structures, joints, splices, load-carrying doors, cutouts and other discontinuities, typical sections through load-carrying members, materials employed and heat treatment, types of riveting, types of welding, and other methods of attachment of important parts. The contractor must indicate clearly on all required drawings any authorized or requested deviations from detail or other applicable design specification requirements in order to facilitate Governmental review. The attention of the reviewer should be drawn to such deviations by clear markings on the drawing in colored crayon or other suitable means (par. 4-2). All drawings will be submitted as promptly as practical and will not be delayed until complete follow-on assembly, installation, or engineering drawings have been prepared (par. 4-8.1.3). The drawings and associated data listed subsequently will be submitted.

4-7.9.1 General Arrangement Drawings

These drawings will include the applicable information specified in Appendix A of this chapter.

4-7.9.2 Inboard Profile Drawings

These drawings, consisting of side elevation and plan views, and including the necessary cross sections, should show to a practical degree major structure; engine drive system and gearboxes; equipment; armament; useful load items; normal entrances, emergency exits, and escape hatches; and location of crew, passengers, and their equipment. Each item will be labeled plainly. The elevation view may be on one sheet and the plan view on another. The outlines of the main structure will be in dashed lines and the system installations in full lines. The information shown must be in agreement with the weight and balance data required in par. 4-7.4(2). The reference lines for horizontal and vertical arms used in the weight and balance data will be shown.

4-7.9.3 Rotor(s) and Propeller(s) Drawings

Drawings of non-GFE rotor(s) and propeller(s) will include: a plan view showing centerlines of all main members; general distribution of the main structural material together with typical cross sections in the chordwise direction including sections through the

spar; typical joints between spar and ribs; typical view of the hub; and views of dampers, restrainers, and typical attachment fittings.

4-7.9.4 Stabilizing/Control Surface Drawings

These drawings will include plan views of the surfaces and control surfaces showing centerlines of all members; tab installations; general distribution of main structural material and typical cross sections in the chordwise direction, including sections through the main beams; typical joints between beams and ribs or bulkheads; method of skin reinforcement; structural arrangement around major discontinuities; typical views of fuselage attachment; and, where folding is required, essential features of the hinge and fold mechanism.

4-7.9.5 Wing (Compound Helicopters) Drawings

These drawings will show the typical information outlined for stabilizing surfaces, including applicable views of landing gear, engine mount, jacking and/or hoisting sling attachment fittings and carry-through, and locations of equipment installed in the wing.

4-7.9.6 Body Drawings

These drawings will include a plan and elevation view of the fuselage structure showing centerlines of all main members; general distribution of main structural material with typical cross sections of stringers, bulkheads, and frames; and typical views of rotor pylons, masts, stabilizing surfaces, booms, landing gear, engine mount, and jacking and/or hoisting sling attachment fittings and carry-through structures, and installation and assembly of fixed and movable sections of cockpit or cabin enclosures, including all operating and emergency controls. The drawings must be in sufficient detail to show the method and materials employed in reinforcing and mounting transparent components and hinges, tracks, rollers, guides, lift assemblies, and other components of movable section mechanisms; the method of latching movable sections in open, closed, and intermediate positions; and the method of emergency operating of jettisoning movable sections. If power operation is used, the drawing should be accompanied by calculations indicating the power and time required for both normal and emergency actuation under critical loading conditions.

4-7.9.7 Hull Drawings

These drawings will include design load waterline, total displacement, location of CG and a table of off-sets; calculations for total volume of the hull, and calculations to determine the required bulkhead locations and heights, including data to show the margin against upsetting (turnover angle) under the worst condition, including flooded and unflooded compartments; curves representing the variation in draft, trim, and center of buoyancy for a range of horizontal CG values between the recommended helicopter forward and aft limits, and gross weights, with successive pairs of adjacent compartments flooded; and a sketch (to scale) showing the location of each watertight bulkhead, waterline obtained with successive pairs of compartments flooded (at normal load and corresponding CG), and location at each hatch and enclosure, using the bow and keel as the datum line for dimensions. (Note: These data may be obtained by appropriate tank testing of a scale displacement model of suitable size, in which case a detailed description including photographs of the equipment should be included.)

4-7.9.8 Landing Gear (Wheel-type)

The contractor will submit:

1. A general arrangement drawing of the landing gear, showing the side view elevation relationship of landing gear to fuselage structure, and to the most forward and most aft CG locations. Information required in Appendix A of this chapter—pars. 2, 3, 7, 8a, 8d, 9b, 9c, 10d, and 10k—must be shown, as applicable.

2. Three-view drawing(s) of the main and auxiliary gear showing principal members. If the gear is retractable, it will be shown in the fully extended and retracted positions, and the most critical clearance dimensions of the wheel well between structural members and other equipment will be identified. The principal members of the gear will include outlines of the shock strut, drag brace, tension strut, torque arms, jack-points, towing and tiedown fittings, wheels (and brackets if used), retraction and extension linkages, actuators, shrink linkages, steering and/or shimmy damper, uplocks, and downlocks. Wheel and tire toe-in and/or camber angles in relation to the axle or strut will be indicated. Outline of door linkages will be shown in relation to gear linkages and functions. Type of material and heat treatment information should be listed or indicated for all principal members of the gear.

3. Nose steering, towing, and turnover angle drawing, consisting of a plan view showing the tread and wheelbase of landing gear and distance between dual

wheels; maximum nose steering angle and corresponding minimum turning radius about the main gear; maximum auxiliary gear swivel angle for towing using tow-bar and minimum turning radius about the main gear; and turnover angle with the most critical CG location.

4. Tiedown arrangement drawing, consisting of a plan view showing the complete tiedown configuration; attachments to helicopter gear; fuselage, wing, and tail fittings; and angles extending to ground tiedown points.

5. Helicopter jacking drawing, showing location of jacks and helicopter jackpoints including all fuselage and/or wing points, and wheel axle and/or strut points.

6. Landing gear design report, including the information and calculations specified in Chapter 12 of AMCP 706-202.

7. Landing gear specification or specification control drawings, as applicable, for the:

- a. Nose or tail wheel
- b. Nose or tail wheel tire
- c. Nose shock strut
- d. Nose gear steering and shimmy damper
- e. Solid tail and/or bumper wheel
- f. Bumper wheel tire
- g. Main wheel and brake assembly
- h. Main wheel tire
- i. Main wheel shock strut
- j. Antiskid brake control system
- k. Main and nose gear actuators
- l. Ski installations and/or emergency flotation gear
- m. Rotor brake
- n. Steering and damper.

4-7.9.9 Landing Gear (Skid-type)

The contractor will submit drawings, a landing gear design report, and landing gear specification or specification control drawings similar to those cited in par. 4-7.9.8 and as applicable to components of the skid gear configuration, including ground handling wheels.

4-7.9.10 Landing Gear (Float-type)

Drawings and data required should include:

1. General arrangement drawing of the landing gear, showing the side and front view elevation relationships of the floats and the center of buoyancy in static attitude to the most forward, most aft, and most lateral CG locations. Water clearances of critical helicopter structure, stores, and propeller to float clearance will be shown.

2. Float line drawings and sketch similar to those specified for the hull (par. 4-7.9.7).

3. Buoyancy calculations and curves similar to those specified for the hull (par. 4-7.9.7).

4-7.9.11 Landing Gear (Ski-type and Bear Paws)

Drawings, a landing gear design report, and landing gear specification or specification control drawings, similar to those cited in par. 4-7.9.8 as applicable to components of the ski gear configuration, will be submitted.

4-7.9.12 Engine (Main and APU), Transmission, and Drives

Data submittal requirements will include:

1. Propulsion system schematic drawings showing a functional arrangement of the location and identification of all pertinent components of the systems and elements: lubrication, fuel, air induction, cooling, power transmission, auxiliary power, engine inlet anti-icing filtering or particle separator, accessory drives, firewalls, infrared radiation suppression, exhaust, controls, and smoke abatement. For turbine engines, in accordance with MIL-D-17984, a report of the calculation of duct losses will be submitted with the induction system schematic drawing. An analysis of the propulsion system cooling and exhaust systems will be provided, showing temperature and pressure design limits for fuselage and components, required airflow, and heat units (BTU), and will be submitted with schematic drawings of these systems.

2. Propulsion system installation drawings, excluding fuel and oil tanks, detailing the location, mounting, vibratory isolation, and access for inspection and maintenance of all systems and elements: engine, auxiliary power plant, fuel, lubrication, air induction, cooling, starting, propulsion controls, engine inlet anti-icing, filtering or particle separator, accessory drives, infrared radiation suppression, power transmission, and smoke abatement. For power transmission systems, including gearboxes, drawings also will include lubrication system, bearings, and gearing; typical views of transmission housing including mounting provisions; typical cross sections and details of clutch mechanism, free-wheeling devices, rotor brake, shaftings and shaft supports, and torque-limiting devices.

3. A separate and complete list of all contractor-furnished components used in each applicable system will be submitted. This list need not include fuel and oil tanks, lines and fittings, and instrumentation. Components will be handled under a surveillance system as follows. A schematic diagram will be submitted for

approval with a design report. After approval, representatives of the procuring activity, the CSPA, and the contractor will survey the system and classify each component as either "surveillance" (complex modified and/or developmental units) or "nonsurveillance" (other modified or off-the-shelf items). Surveillance items will require full transmittal of all design data documents for release by the cognizant review activity prior to contractor procurement action. Surveillance items to be approved will be accompanied by detail assembly drawings showing installation and mounting provisions, internal design details, materials, and performance characteristics. Nonsurveillance items will require the same data as surveillance items but will not be submitted for release. Instead, the contractor should maintain a file of the data on nonsurveillance items subject to the procuring activity of CSPA inspection at any time. In event of disagreement as to surveillance category, the procuring activity's decision will be final.

4. Design data and installation details of internal and external fuel tanks, lubricating oil tanks, and respective system piping will be submitted with a complete list of all piping and fittings (including tank fittings) for the fuel and lubricating oil systems. Nonstandard parts will be marked and itemized separately.

5. A complete performance and functional performance and functional analysis report will be submitted including all pertinent data, i.e., flow rates, pressure, frictional loads, and power consumption, and torque requirements for all applicable propulsion systems.

4-7.9.13 Flight Controls and Stability Augmentation Systems

The contractor will submit drawings, engineering data, and calculations for the flight control system in accordance with MIL-F-18372. Also to be submitted are drawings which include an engineering layout showing location of system components, range of movement of controls and control surfaces, diagrams, and engineering data for the system as appropriate, and in accordance with MIL-C-18244.

4-7.9.14 Electrical Loads

Data requirements will include:

1. AC and DC electrical load analyses in accordance with MIL-E-7016. Letters of transmittal will comment on the adequacy of the power supply. These analyses are:

- a. Preliminary load analysis, which will form the basis for selecting power generation

equipment and for design of generation and distribution system

- b. Intermediate load analyses incorporating significant load or power source changes subsequent to the submittal of the preliminary load analysis
- c. Final corrected load analysis, which will be marked "Final Corrected" and will include all changes incorporated in the complete helicopter. If no changes have been made to data previously submitted, a new cover sheet will be submitted which states this. The values entered in this analysis will be measured values.

2. Wiring diagrams in accordance with the requirements of MIL-W-5088. These diagrams will include sufficient equipment internal circuitry to allow for understanding the system function. A brief description of any system or equipment not having readily recognizable operating functions will be included with the following diagrams:

- a. Preliminary wiring diagrams, consisting of both elementary, single-line functional diagrams and schematic functional diagrams of the power distribution and lighting systems
- b. Master wiring diagrams, consisting of installation schematic wiring diagrams giving information of interconnection of components. This will include identification of wires, connectors, junction points, terminal blocks, and equipment.

3. General arrangement drawings of the electrical equipment installation showing the location of all major items of electrical equipment

4. Exterior light installation drawings showing location and visibility characteristics. Any deviations from the requirements of MIL-L-6730 must be indicated.

5. Nonstandard electrical equipment specifications and substantiating data in accordance with MIL-E-7080.

4-7.9.15 Hydraulics and Pneumatics

The contractor will submit engineering data, drawings, and calculations in accordance with MIL-H-5440 and MIL-P-5518, respectively, for hydraulic and pneumatic subsystems.

4-7.9.16 Avionics

Contractors will submit:

1. General arrangement drawings of avionic

equipment installations showing the location of all major items of electronic equipment, the exterior arrangement of electronic controls for crew members including console and control panels, and the location of exterior equipment. Drawings or photographs of the console mount and control panels will show clearly the location of each control panel in relation to other control panels in each compartment. Each control panel will be identified using Military Standard nomenclature where applicable.

2. Antenna system drawings, model data, and specification and engineering reports, in accordance with MIL-A-7772

3. Radome engineering data, defining the radome and its characteristics, including overall transmissibility curves, boresight shaft characteristics, radar tracking noise, effects of equipment located in or affixed to the radome, and changes to electrical characteristics resulting from radome heating.

4. CFE avionic design data, in accordance with MIL-D-18300, when CFE electronic equipment or systems, or modification of GF AE, are required.

4-7.9.17 Instrumentation and Navigational Equipment

The contractor will submit:

1. Arrangement drawings of instruments and navigational equipment described in MIL-I-18373. These drawings will include all supports, panels, or mounts; all electrical connectors; all pitot and static connection fittings; all fluid connection fittings; and all interfaces such as hose, tubing, and wiring necessary for proper installation and operation. Sketches will be furnished showing the location of external airframe stores in relation to pitot or static sensors whose operation or removal may cause a change in air mass measurement indication.

2. A block diagram showing all components and functionally identified circuits of the entire instrumentation system. This block diagram will identify, by Governmental nomenclature, each component of the system, and will include the functional relationships and purposes of the components.

3. CFE design data in accordance with MIL-D-18300, when CFE instruments and navigational equipment or systems, or modification of GFE, are required.

4-7.9.18 Crew Stations, Furnishings, and Equipment

4-7.9.18.1 Seats

The contractor will furnish drawings of all seat assemblies and installations for crew, passengers, and troops, and litters for medical evacuees. If applicable, these drawings must show range of adjustment and include all safety belt, shoulder harness, or other restraint installations and controls; parachute provision takeup mechanisms/devices; tracks; catapults/rockets motors, rails, operating gear, stabilizing and personnel parachutes; limb restraint systems; and other components/subassemblies required for ejectable seats by MIL-S-18471. The sequence of emergency escape operations using the ejectable seats must be indicated.

4-7.9.18.2 Survival Systems

Contractor requirements will include:

1. Escape mechanism drawings (other than for ejectable seats) showing installation and indicating sequence of emergency escape operations, including stowed and mechanically ejected life raft installations

2. Drawings and data for fire detector, suppression, and prevention systems installation including hand, engine, and auxiliary power unit fire extinguishers

3. Drawings for oxygen system installation in accordance with MIL-I-8683 or MIL-I-19326, as applicable, showing (in phantom) any adjacent armor, miscellaneous crew equipment, and fluid systems such as fuel, oil, or hydraulic

4. Drawings and data for carbon monoxide detection, in accordance with MIL-STD-800.

4-7.9.18.3 Environmental Control System

Drawings and data which follow will be furnished:

1. Heating and ventilating system installation drawings and data in accordance with MIL-H-18325

2. Thermal insulation installation drawings

3. Cabin pressurization installation for pressurized helicopters, in accordance with MIL-E-18927, including heating, cooling, and ventilating provisions

4. Engineering data for air-conditioning and pressurization systems which cover the helicopter profile should include an air supply for cooling and demonstrate that moisture does not condense within electronic components. In addition, the means used for eliminating entrapped moisture should be indicated.

5. Installation drawings and data of acoustical in-

sulation in accordance with MIL-S-6144 and MIL-A-8806

6. Anti-icing and/or deicing, defogging, and defrosting installation data as follows: wing and empennage anti-icing system (in accordance with MIL-D-8804 for pneumatic boot systems and with MIL-T-18607 for thermal anti-icing systems), all transparencies requiring protection in accordance with MIL-T-5842 (with MIL-I-18259 for fluid systems), and systems for protection of periscope lenses, fuel vents, radomes, antennas, and stores

7. Analytical report of the anti-icing of engine air induction and related equipment showing compliance with the detail specification. The report will contain a description of the operation of the inlet anti-icing system.

8. Drawings of the windshield and other transparent components of wiper, washing, degreasing, and air blast system installations, as applicable

9. Drawings, test reports, specification control drawings, and other engineering data applicable to nonstandard parts in environmental control systems.

4-7.9.18.4 Equipment

Drawing and data requirements will include:

1. Constant speed drive system detail specification based on the requirements of MIL-T-7101, system and installation drawings, and substantiating calculations showing adequacy of the system to fulfill its operating requirements

2. Rescue hoist installation drawings

3. Cargo hoisting and handling installation drawings

4. Drawings of photographic equipment installations showing camera combinations and components and mounting arrangements including relationships of cameras, helicopter structure, and camera windows. A system wiring diagram will be included.

5. Engineering data for external tanks (CFE), in accordance with MIL-T-18847; installation drawings; detail specification for the tank(s); load and stress analysis report, in accordance with MIL-S-8698 or MIL-A-8860, as applicable; and procedures and time for installation or removal of the tank(s) and removal and replacement of functional components of the tank(s)

6. Drawings of the aerial refueling system (as tanker and/or receiver); 1/40 scale drawings showing tanker with drogue trailed and the areas of rotor downwash and engine exhaust wake, and receiver, with probe extended, if retractable; a report covering air refueling capability data such as aerial refueling en-

velope of altitude versus true airspeed, fuel transfer rate versus pressure at the reception coupling or receiver nozzle; and tanker package and component description, with design data and installation details such as hose reels and mechanization, procedure, and time to install.

4-7.9.19 Armor and Armament

Drawings and data will be furnished according to the list which follows:

1. Functional diagrams showing all items of the entire armament system. These diagrams will identify, by Governmental nomenclature, each item of the system, and will include the functional relationships and purposes of the items. The interconnection to systems such as hydraulic, pneumatic, and electrical will be shown.

2. Equipment installation and arrangement drawings showing the location of all major items of armament equipment for which provision has been made, and the location of exterior equipment. Drawings of the console mount and control panels will show the location of each control panel in relation to all other control panels in each compartment.

3. Helicopter armament characteristic report

4. CFE armament design data in accordance with MIL-D-18300, when CFE armament equipments or systems, or modification of GFE, are required

5. Installation drawings showing (in phantom) extent, shape, thickness, and type of armor equipment, and structure in the vicinity; and installation and removal features for removable armor and other features in compliance with the requirements of MIL-I-8675. Ballistic capability of the armor in terms of caliber, velocity, and obliquity must be indicated.

6. Survivability analysis report in accordance with par. 14-2 of AMCP 706-202

7. Splash-spall protection analysis report in accordance with par. 14-2 of AMCP 706-202.

4-7.9.20 Miscellaneous

Drawings and data will be furnished as listed subsequently:

1. A list of all cartridge-actuated devices used in any system, such as canopy jettisoning, hoist cable guillotine, flight refueling hose guillotine, and emergency escape door actuation. The list should show clearly the type, quantity, and system in which the devices are used.

2. Engineering data for each mechanical, hydraulic, and pneumatic nonstandard part. These parts,

which do not conform to any approved standard in Groups I and II of MIL-STD-143, or to a contractor standard which has been approved previously by the procuring activity for continued use, include: bearings, bolts, cable connecting fittings, power transmission chains, loop clamps, eyelets, fasteners, quick release fasteners, grommets, hinges, hose connecting fittings, hydraulic and pneumatic tube connecting fittings, thread inserts, keys, lubrication fittings, nuts, pins, quick release pins, spring pins, collar-locked headed pins, preformed packings and gaskets, pulleys, retaining rings, rivets, blind rivets, screws, springs, studs, turnbuckles, universal joints, and washers. These data will include:

- a. The reasons an approved standard part cannot be used to perform the functions required by the application or design problem
- b. The specific materials from which the part is manufactured
- c. The specific platings, coatings, or surface treatments, if applicable, should be completely described.
- d. Values for the physical and mechanical properties, or the performance requirements specified for the part
- e. A drawing of the part, with the dimensions necessary to completely define the geometrical limits of the part.

(For the test specification describing test methods and procedures to be used to determine if a product conforms to the specified requirements, see par. 4-7.13.)

3. A finish specification, in accordance with MIL-F-7179, and a three-view drawing, in accordance with both MIL-I-18464 and MIL-C-18263. Paragraph numbers of the specification will correspond with those in MIL-F-7179. This specification and forwarding letter will indicate all desired deviations from MIL-F-7179 and other applicable specifications.

4. Special material part lists including:

- a. Structural adhesive bonding list, composed of sandwich construction and, if not obvious from the titles, a brief description of the parts and their locations. Information will be included identifying the specific adhesives and adherents used, including the facing and core materials of sandwich construction.
- b. List of lubricants and any supplemental data submitted in accordance with MIL-STD-838.

5. Report of material and processes development and evaluation, consisting of a summary technical description of materials and processes research, develop-

ment, and evaluation work which has been conducted or planned under the development contract. If a component containing a radioactive element requiring a license from the Atomic Energy Commission is used in the helicopter, the procuring activity must be notified of the need for a license as soon as the design has been sufficiently defined.

6. Procurement and process specifications, consisting of subsystem, end-item, part, assembly, material, process, and purchase specifications (Chapter 6). All contractor-prepared specifications for subsystems and equipment to be furnished by the contractor as required by the applicable helicopter detail specification should be included. The specification will be in accordance with MIL-STD-490 unless otherwise specified. Specification revision pages will be in accordance with applicable requirements of MIL-STD-490.

7. An interchangeability and replaceability list in accordance with MIL-I-8500.

8. Nomenclature and nameplate data in accordance with MIL-N-18307. Referenced in that specification is MIL-STD-196 which defines the type designation system used for electrical and electronic equipment. It is also referenced in MIL-STD-875 which defines the type of designation system used for aeronautical and aeronautical support items. Type designations for photographic items are discussed in MIL-STD-155. Item identification data submittals, discussed in FED-STD-5B, will be in accordance with MIL-N-18307.

4-7.10 PHOTOGRAPHS

Photographs measuring 8 in. by 10 in. will be required, and should show the complete helicopter and the maximum amount of detail in at least six positions: forward, rear, port, starboard, three-quarters front, and three-quarters rear with wheel, skid, ski, and/or float landing gear.

4-7.11 CONTRACT DETAIL SPECIFICATION REVISION PAGES

Revised pages for the detail specification should be submitted in accordance with MIL-STD-490.

4-7.12 HELICOPTER INVENTORY RECORD

An inventory record will be furnished in accordance with MIL-R-9441.

4-7.13 TEST PLANS AND QUALIFICATION TEST REPORTS

Component and equipment qualification test plans and procedures will be submitted in accordance with the requirements of Chapters 2 and 7, and as implemented specifically in the AQS for the developmental program. These plans and procedures will be designed to demonstrate compliance of the components and equipment with (1) all applicable design (including environmental and service life) and procurement specifications or specification control drawings, and (2) reliability and maintainability factors reflected in the reliability and maintainability program reporting required in pars. 4-4 (4), 4-4 (5), and 4-7.8. After approval of these test plans and procedures and the consummation of the testing, qualification test reports verifying compliance with applicable requirements will be submitted. Plans and reports will be submitted for components and equipment (representative of production hardware) listed subsequently, and also for appropriate subsystems, when formal demonstration and reports of total subsystem compliance are not specifically required in par. 4-7.14.

The components and equipment include:

1. Structural, including dynamic, components, in accordance with MIL-S-8698 (par. 4-7.5)
2. Surface controls, in accordance with MIL-F-18372
3. Rotor braking devices, in accordance with approved specification or specification control drawings (par. 4-7.9.8(7))
4. Landing gear components, in accordance with the approved specification or specification control drawings required in par. 4-7.9.8(7), 4-7.9.9, and 4-7.9.11; including wheels, consisting of a complete stress analysis for all fatigue and static loads on all major components of the test wheel or wheel and brake assembly. This analysis may be accomplished by either analytical or test strain data. The analysis will be governed by the requirements defined in MIL-A-8868.
5. Engines (main and APU), transmissions, and drives, in accordance with the approved specification or specification control drawings required in par. 4-7.9.12(3)
6. Fuel system, in accordance with MIL-F-38363 and MIL-G-7940
7. Oil dilution system, in accordance with MIL-O-19838
8. Fuel tanks, in accordance with MIL-T-5578 for

self-sealing tanks; MIL-T-18847 for external auxiliary tanks; and MIL-T-27422 for crash-resistant tanks

9. Oil tanks, in accordance with MIL-T-5578 for self-sealing tanks.

10. Electrical subsystem components, in accordance with the contractor's test plans approved by the procuring activity

11. Avionic subsystem components as follows:

- a. CFE electronic equipment, in accordance with MIL-I-8700 and MIL-T-5422; AV-2000, Section 4, for reliability; AR 70-10 for maintainability; MIL-T-23103 for thermal design; and MIL-I-6181 for radio interference
- b. Engineering approval tests, in accordance with MIL-I-8700. Bonding resistance tests are specified in Item 17.

12. Instrument and navigation subsystem components as follows:

- a. GFE instruments, in accordance with the applicable Military Specifications for the items included
- b. CFE instruments, in accordance with the approved test plans
- c. All instruments installed in accordance with MIL-I-18373
- d. Integral instrument lighting, in accordance with MIL-L-25467 (red lighting) or MIL-L-27160 (white lighting); post or eyebrow lighting on instrument panels, in accordance with MIL-L-5057

13. Seats, automated crew escape systems, and associated crew furnishings as follows:

- a. Fixed seats and manual egress (crash and inflight); structural and functional tests, in accordance with the approved test plans
- b. Automated escape systems, in accordance with MIL-A-23121, MIL-S-18471, MIL-A-9426, and MIL-STD-810, as applicable.

14. Survival subsystem components and equipment as follows:

- a. Escape mechanisms (other than ejectable seats) including stowed and mechanically ejected life raft installations, in accordance with the approved test plans
- b. Fire detector, suppression, and prevention systems, including hand, engine, and auxiliary power unit fire extinguishers, in accordance with approved test plans and MIL-E-22285 and MIL-F-7872, as applicable

- c. Oxygen system, in accordance with MIL-I-8683 or MIL-I-19326, as applicable
- 15. Environmental control subsystem components and equipment as follows:
 - a. Heating and ventilating, in accordance with MIL-H-18325
 - b. Cabin pressurization, in accordance with MIL-E-18927
 - c. Anti-icing, defogging, and defrosting, in accordance with MIL-T-18607 for thermal and MIL-D-8804 for pneumatic heat systems, and with MIL-I-18259 for fluid systems
 - d. Wiper, washing, degreasing, and air blast rain removal, in accordance with approved test plans
- 16. Components and equipment, in accordance with approved test plans as follows:
 - a. Cargo hoisting and handling, including doors and ramps
 - b. Rescue hoist
 - c. Constant speed drive
 - d. Photographic
 - e. Aerial refueling
 - f. CFE external fuel tanks
 - g. Armament
 - h. Armor ballistic tests, in accordance with Chapter 7
 - i. Cartridge-actuated devices
 - j. Nonstandard parts
- 17. Additional reporting requirements, including
 - a. Human engineering design verification, in accordance with MIL-H-46855 (par. 4-7.6)
 - b. Reliability, in accordance with MIL-STD-1304 and MIL-STD-470 (par. 4-7.8)
 - c. Watertightness, in accordance with MIL-W-6729, for the helicopter; and with MIL-H-8661, for hulls and main and auxiliary floats
 - d. Exhaust system endurance, in accordance with par. 8-6.3.3
 - e. Bonding and lightning protection, as follows:
 - (1) A report of the bonding resistance measurements required by MIL-B-5087. This report should show the measurement results which indicate compliance with MIL-B-5087, and will attempt to justify cases failing to comply. A new report will be submitted whenever new measurements are required by a change in design or construction methods which materially affects bonding. Minor bonding changes may be measured and a

revision or addendum to, the original report supplied.

- (2) A report describing the details of lightning protection analysis and design, including the results of the lightning protection tests required by MIL-B-5087. This report will include a plan view and profile and detail drawings. A new report must be submitted whenever a major change in the lightning protection system results in the need for additional lightning protection tests. Minor changes not requiring retesting may be covered by a revision of, or addendum to, the original report.
- f. Hydraulic and pneumatic subsystem and component tests, in accordance with MIL-H-5440, MIL-P-5518, MIL-T-5522, and MIL-H-8775, as applicable.

4-7.14 FORMAL DEMONSTRATION PLANS AND REPORTS

Formal demonstration ground and flight test plans, surveys, and procedures, including instrumentation and in accordance with the requirements in Chapter 9, must be submitted for approval by the procuring activity. These plans and procedures should be designed to meet the objectives of the subsystem and overall helicopter tests specified in Chapters 7 and 9, including inputs to the overall reliability and maintainability reports. Following approval of these plans and procedures, test progress reports and final reports verifying compliance with the applicable subsystem and total helicopter design requirements will be submitted. Plans and reports are required for the subsystems and the total helicopter in the areas which follow, representative of the production hardware:

- 1. Instrumentation
- 2. Mechanical instability
- 3. Aerodynamics
- 4. Structural
- 5. Propulsion and power system
- 6. Avionics
- 7. Electrical
- 8. Instruments
- 9. Electromagnetic compatibility
- 10. Armament
- 11. External stores
- 12. Fuel system
- 13. Hydraulics and pneumatics

14. Lubrication
15. Furnishings and equipment
16. Ground support equipment
17. Engine starting
18. Total system surveys
19. Maintainability.

4-7.15 ENGINEERING MANUFACTURING DRAWINGS AND CONSOLIDATED DRAWING LIST

4-7.15.1 Preparation of Drawings

Drawings and referenced documents will be prepared with complete descriptions of the equipment articles to be delivered under the contract, excluding Government-furnished components. The term "equipment articles" includes all contractor-furnished, design-engineered, material articles; the contract end-items, contractor-furnished components, and parts; contractor-furnished support equipment, and spares and repair parts. Drawings and associated data will be prepared in accordance with MIL-D-1000 and MIL-STD-100, and will contain information sufficient for the intended use categories of MIL-D-1000 specified in the AQS. Applicable drawings prepared previously for other applications but meeting these requirements will not be redrawn. Drawings will be prepared and/or revised to reflect Class I design changes (as defined in MIL-STD-480 and MIL-STD-481) CSPA-designated Class II design changes in sufficient time to permit delivery of microfilm copies at least 30 days prior to delivery of the first equipment article affected by the change. They will be revised to reflect all other Class II changes (1) when a maximum of five such changes per drawing is reached, or (2) within 30 days following delivery of the last article in the production block to which the drawings apply, whichever occurs first.

4-7.15.2 Consolidated Drawing List

A complete, consolidated list of engineering drawings will be developed and maintained by the contractor as the detail design progresses. This list must be complete in order to define the current configuration in depth, and to provide an audit trail of the helicopter system. Revisions to the list will reflect periodic additions or revised drawings resulting from design reviews or testing in the sequential airworthiness qualification steps. The current list, periodically revised as agreed upon by the contractor and the CSPA, will be furnished to the CSPA and at all design reviews. In final form the

list will serve as a base for configuration management of subsequent production helicopters.

4-7.16 SUMMARY OF DATA AND DOCUMENTATION

The contractor will submit a complete list in report form of the estimated dates for submittal of design data required in par. 4-3. This report will consist of the titles and submittal dates of all design data and titles of other applicable data previously submitted. This list will reference contractor letters by which data have been submitted and the letters by which data have been accepted, and will show estimated submittal dates for data not yet submitted. The summary should list each paragraph in the applicable AQS, and should reference the transmittal letters accompanying data submitted under that paragraph.

4-8 REPORTS AND DATA

Reports will be prepared in accordance with MIL-STD-831, except as specified herein. A Table of Contents should be provided when necessary to facilitate ready use. The source of all engineering data used in the reports will be referenced, and configurations will be defined clearly to provide the desired audit trail. Reports and data will be typewritten and in accordance with MIL-D-5480; nonreproducible copies will be in accordance with Type I Class 1 and reproducible copies in accordance with Type I Class 2. Nonreproducible drawings will be in accordance with MIL-D-5480, Type II Class 1.

Classified data and drawings will contain the proper security classification on each page of reports, specifications, photographs, etc., and on each drawing in accordance with the existing security regulations.

4-8.1 DATA SUBMITTAL, INSPECTION, AND ACTION

Quantities, distribution, and submittal dates of required data and documentation will be as specified in Table 4-1 and in DD Form 1423. Where data and documentation are generated by the contractor as the result of the suggestions of the Helicopter Engineering Handbook Series, and where no specific requirements are prescribed for submittal to the procuring activity, the contractor should retain copies in his files for information and review by the procuring activity during design reviews or other milestone points which may be desired.

TABLE 4-1. DATA AND DOCUMENTATION REQUIREMENTS

PARAGRAPH	TITLE OF DATA	ACTION	KIND OF COPIES	TYPE OF REPORT	SUBMITTAL DATE
4-4	PROGRAM PLANS				
4-4(1)	AIRWORTHINESS QUALIFICATION SPEC.	APPROVAL	NONREPRODUCIBLE	RECURRING	INITIAL PLANS NOT LATER THAN 30 DAYS AFTER NOTIFICATION OF CONTRACT AWARD, UPDATING PERIODICALLY TO REFLECT CHANGES. EXPANDED DETAILS AND STEPS, AS GENERATED FROM DETAILED PROGRAM PLANNING, DETAILED DESIGN OF SYSTEMS AND SUBSYSTEMS, AND GOVERNMENT TEST PLAN INPUTS.
4-4(2)	ELECTROMAGNETIC COMPATIBILITY CONTROL PLAN	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-4(3)	SYSTEM SAFETY PROGRAM PLAN	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-4(4)	RELIABILITY PLAN	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-4(5)	MAINTAINABILITY PLAN	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-4(6)	HUMAN FACTORS ENGINEERING PLAN	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-6	DESIGN REVIEWS	REVIEW	NONREPRODUCIBLE	NONRECURRING	NOT LATER THAN SCHEDULED DATE FOR THE PARTICULAR REVIEW.
4-6.1	DESIGN DRAWING REVIEWS	REVIEW	NONREPRODUCIBLE	NONRECURRING	
4-6	HELICOPTER MOCK-UP	APPROVAL	NONREPRODUCIBLE	NONRECURRING	MOCK-UPS NOT LATER THAN SCHEDULED BY CAGS, AND RETAINED AT CONTRACTOR'S PLANT FOR MOCK-UP BOARD ACTION. PHOTOS NOT LATER THAN 15 DAYS AFTER MOCK-UP INSPECTION.
4-6	HELICOPTER MOCK-UP PHOTOGRAPHS	REVIEW	PRINTS	NONRECURRING	
4-6	MOCK-UP REFERENCE DATA	REVIEW	NONREPRODUCIBLE	NONRECURRING	NOT LATER THAN DATE OF MOCK-UP.
4-7	ENGINEERING DATA				
4-7.1	AERODYNAMIC AND FLUTTER INVESTIGATION PROGRAM REPORT	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.1	PROPOSED PROGRAMS FOR INVESTIGATIONS AT GOVERNMENT FACILITIES	APPROVAL	NONREPRODUCIBLE	NONRECURRING	90 DAYS AFTER CONTRACT AWARD BUT 60 DAYS BEFORE START OF TEST.
4-7.1	PROPOSED PROGRAMS FOR INVESTIGATIONS AT OTHER PRIVATELY OPERATED FACILITIES	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.1	AERODYNAMIC AND FLUTTER MODEL DRAWINGS AND DATA	ACCEPTANCE	NONREPRODUCIBLE	NONRECURRING	90 DAYS PRIOR TO START OF TEST
4-7.1	AERODYNAMIC AND FLUTTER INVESTIGATION REPORTS				
4-7.1(1)	INTERIM LETTER REPORTS	REVIEW	NONREPRODUCIBLE	RECURRING	DURING TEST AND/OR UPON COMPLETION OF A SIGNIFICANT PHASE OF TEST.
4-7.1(2)	AERODYNAMIC TEST DATA REPORTS	REVIEW	NONREPRODUCIBLE	RECURRING	
4-7.1(3)	FLUTTER MODEL TEST REPORT	REVIEW	NONREPRODUCIBLE	NONRECURRING	90 DAYS AFTER COMPLETION OF INVESTIGATIONS.
4-7.1(4)	FLUTTER ANALYSIS REPORT(S)	APPROVAL	NONREPRODUCIBLE	NONRECURRING	120 DAYS PRIOR TO START OF GROUND TEST
4-7.2	AERODYNAMIC STABILITY AND CONTROL REPORTS	ACCEPTANCE	NONREPRODUCIBLE	RECURRING	60 DAYS PRIOR TO INITIATION OF PROGRAM
4-7.2.1	DIGITAL AND ANALOG COMPUTER PROGRAM REPORT	ACCEPTANCE	NONREPRODUCIBLE	RECURRING	60 DAYS PRIOR TO INITIATION OF PROGRAM
4-7.2.2	FLIGHT SIMULATOR PROGRAM REPORT	ACCEPTANCE	NONREPRODUCIBLE	RECURRING	60 DAYS PRIOR TO INITIATION OF PROGRAM
4-7.2.3	AERODYNAMIC STABILITY AND CONTROL AND FLYING QUALITY REPORTS				INITIAL REPORT 180 DAYS AFTER AWARD OF CONTRACTOR.
4-7.2.3	INITIAL REPORT	REVIEW	NONREPRODUCIBLE	NONRECURRING	120 DAYS PRIOR TO FIRST FLIGHT
4-7.2.3	UPDATED REPORT	REVIEW	NONREPRODUCIBLE	RECURRING	QUARTERLY
4-7.2.3	DESCRIPTIVE DATA REQUIRED WITH STABILITY AND CONTROL TEST ROTORCRAFT	REVIEW	NONREPRODUCIBLE	RECURRING	120 DAYS PRIOR TO FIRST FLIGHT
4-7.3	CHARACTERISTIC AND PERFORMANCE DATA				
4-7.3.1	BASIC AERODYNAMIC DATA	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.3.2	SUBSTANTIATION OF PERFORMANCE DATA REPORT	APPROVAL	NONREPRODUCIBLE	RECURRING	NOT LATER THAN 120 DAYS AFTER AWARD OF CONTRACT FOR INITIAL DATA. REVISIONS QUARTERLY.
4-7.3.3	STANDARD AIRCRAFT CHARACTERISTICS CHARTS	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.4	WEIGHT AND BALANCE DATA				
4-7.4(1)	WEIGHT AND BALANCE CONTROL AND MANAGEMENT PROGRAM PLAN	APPROVAL	NONREPRODUCIBLE	NONRECURRING	PRIOR TO SIGNING CONTRACT.
4-7.4(2)	ESTIMATED WEIGHT AND BALANCE REPORT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	30 DAYS AFTER CONTRACT
4-7.4(3)	WEIGHT AND BALANCE STATUS REPORTS	APPROVAL	NONREPRODUCIBLE	RECURRING	AT LEAST BI-MONTHLY
4-7.4(4)	CALCULATED WEIGHT REPORT	APPROVAL	NONREPRODUCIBLE	RECURRING	AS REQUIRED BY CONTRACT DATA REQS LIST
4-7.4(5)	SAMPLE CHARTS A AND E FOR HANDBOOK AN 01-1B-40	APPROVAL	REPRODUCIBLE	RECURRING	30 DAYS PRIOR TO FIRST FLIGHT
4-7.4(6)	ACTUAL WEIGHT REPORTS AND APPENDICES	APPROVAL	REPRODUCIBLE	RECURRING	30 DAYS PRIOR TO FIRST FLIGHT
4-7.4(7)	APPROVED CHARTS A AND E AND REVISIONS	APPROVAL	REPRODUCIBLE	RECURRING	WITH OPERATOR'S HANDBOOK
4-7.4(8)	POST DESIGN WEIGHT ANALYSIS REPORT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	45 DAYS AFTER DELIVERY OF FIRST AIRCRAFT FOR FLIGHT TEST
4-7.6	HUMAN FACTORS ENGINEERING DATA				
4-7.6(1)	HUMAN FACTORS ENGINEERING (HFE) TEST PLAN	APPROVAL	NONREPRODUCIBLE	NONRECURRING	30 DAYS AFTER AWARD OF CONTRACT
4-7.6(2)	HUMAN FACTORS ENGINEERING PROGRESS REPORT	ACCEPTANCE	NONREPRODUCIBLE	NONRECURRING	QUARTERLY
4-7.6(3)	OPERATOR TASK LOAD ANALYSIS	APPROVAL	NONREPRODUCIBLE	RECURRING	90 DAYS AFTER CONTRACT
4-7.6(4)	OPERATOR/MAINTAINER POSITION PLANNING DATA	APPROVAL	NONREPRODUCIBLE	NONRECURRING	30 DAYS AFTER TASK LOAD ANALYSIS
4-7.6(5)	WORK AND CREW STATION LAYOUTS	APPROVAL	REPRODUCIBLE	RECURRING	UPON COMPLETION OF PRELIMINARY DESIGN
4-7.6(6)	INTERNAL AND EXTERNAL NOISE SURVEY DATA	APPROVAL	NONREPRODUCIBLE	NONRECURRING	IN ACCORDANCE WITH TEST SCHEDULE SUBMITTED BY CONTRACTOR
4-7.6(7)	FINAL HUMAN FACTORS ENGINEERING REPORT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	PRIOR TO COMPLETION OF CONTRACT
4-7.6(8)	AIRCRAFT STATION VISION REPORT	REVIEW	NONREPRODUCIBLE	NONRECURRING	PRIOR TO COMPLETION OF CONTRACT
4-7.7	SYSTEM SAFETY DATA				
4-7.7(1)	HAZARD ANALYSES	REVIEW	NONREPRODUCIBLE	RECURRING	CONTINUOUS UPDATE
4-7.7(2)	SYSTEM SAFETY SPECIFICATIONS	APPROVAL	REPRODUCIBLE	RECURRING	

TABLE 4-1. DATA AND DOCUMENTATION REQUIREMENTS (Cont.)

PARAGRAPH	TITLE OF DATA	ACTION	KIND OF COPIES	TYPE OF REPORT	SUBMITTAL DATE
4-7.8	RELIABILITY AND MAINTAINABILITY DATA				
4-7.8(1)	RELIABILITY AND MAINTAINABILITY REPORTS	REVIEW	NONREPRODUCIBLE	RECURRING	90 DAYS OF CONTRACT AWARD
4-7.8(2)	MAINTENANCE ENGINEERING ANALYSES	REVIEW	NONREPRODUCIBLE	RECURRING	90 DAYS OF CONTRACT AWARD
4-7.8(3)	LOGISTIC SUPPORT REPORTS	REVIEW	NONREPRODUCIBLE	RECURRING	90 DAYS OF CONTRACT AWARD
4-7.9	SUBSYSTEM DESIGN APPROVAL DATA				
4-7.9.1	GENERAL ARRANGEMENT DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.2	INBOARD PROFILE DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.3	ROTOR(S) AND PROPELLER(S) DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.4	STABILIZING/CONTROL SURFACES DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.5	WING (COMPOUND ROTORCRAFT) DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.6	BODY DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.7	HULL DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.8	LANDING GEAR (WHEEL-TYPE)				
4-7.9.8(1)-(5)	DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.8(6)	LANDING GEAR DESIGN REPORT	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.8(7)	LANDING GEAR SPECIFICATION OR SPECIFICATION CONTROL DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.9	LANDING GEAR (SKID-TYPE)				
4-7.9.9	DRAWINGS				
4-7.9.9	LANDING GEAR DESIGN REPORT	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.9	LANDING GEAR SPECIFICATION OR SPECIFICATION CONTROL DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.10	LANDING GEAR (FLOAT-TYPE)				
4-7.9.10(1)-(2)	DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.10(3)	BUOYANCY CALCULATIONS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.11	LANDING GEAR (SKI-TYPE AND BEAR PAWS)				
4-7.9.11	DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.11	LANDING GEAR DESIGN REPORT	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.11	LANDING GEAR SPECIFICATION OR SPECIFICATION CONTROL DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.12	ENGINE (MAIN AND APU) TRANS. AND DR.				
4-7.9.12(1)-(2)	DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	GENERAL ARRANGEMENT DRAWINGS ARE REQUIRED FOR PROPOSAL EVALUATION. DETAILED DRAWING, SPECIFICATIONS, AND DATA ARE REQUIRED PRIOR TO GOVERNMENT WITNESS OF TESTS. DESIGN ANALYSIS AND REPORTS ARE REQUIRED PRIOR TO FIRST FLIGHT.
4-7.9.12(3)	LIST OF CONTRACTOR-FURNISHED COMPONENTS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.12(4)	DESIGN DATA - TANKS AND PIPING	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.12(5)	PERFORMANCE AND FUNCTIONAL ANALYSIS REPORT	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.13	FLIGHT CONTROLS AND AUTOMATIC CONTROL AND STABILIZATION				
4-7.9.13	DRAWINGS AND DATA - FLIGHT CONTROL SYSTEM	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.13	DRAWINGS AND DATA - AUTOMATIC CONTROL AND STABILIZATION SYSTEM	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.14	ELECTRICAL EQUIPMENT				
4-7.9.14(1)	AC AND DC ELECTRICAL LOAD ANALYSIS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.14(2)	WIRING DIAGRAMS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.14(3)	ELECTRICAL EQUIPMENT INSTALLATION DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.14(4)	EXTERIOR LIGHT INSTALLATION DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.14(5)	NONSTANDARD ELECTRICAL EQUIPMENT SPECIFICATIONS AND SUBSTANTIATING DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.15	HYDRAULIC AND PNEUMATIC ENGINEERING DATA, DRAWINGS, AND CALCULATIONS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.16	AVIONICS				
4-7.9.16(1)	EQUIPMENT INSTALLATION GENERAL ARRANGEMENT DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.16(2)	ANTENNA SYSTEM DRAWINGS, DATA, SPECIFICATION AND ENGINEERING REPORTS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.16(3)	RADOME ENGINEERING DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.16(4)	CFE AVIONIC DESIGN DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.17	INSTRUMENTATION AND NAVIGATIONAL EQUIPMENT				
4-7.9.17(1)	INSTRUMENTS AND NAVIGATIONAL EQUIPMENT ARRANGEMENT DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.17(2)	BLOCK DIAGRAM	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.17(3)	CFE DESIGN DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18	CREW STATIONS, FURNISHINGS, AND EQUIPMENT				
4-7.9.18.1	SEAT(S) DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.2	SURVIVAL SYSTEM				
4-7.9.18.2(1)	ESCAPE MECHANISM DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	

TABLE 4-1. DATA AND DOCUMENTATION REQUIREMENTS (Cont.)

PARAGRAPH	TITLE OF DATA	ACTION	KIND OF COPIES	TYPE OF REPORT	SUBMITTAL DATE
4-7.9.18.2(2)	FIRE DETECTOR, SUPPRESSION, AND PREVENTION SYSTEM INSTALLATION DRAWINGS AND DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.2(3)	OXYGEN SYSTEM INSTALLATION DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.2(4)	CARBON MONOXIDE PROTECTION DRAWINGS AND DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.3(1)	ENVIRONMENTAL CONTROL SYSTEM				
4-7.9.18.3(2)	HEATING AND VENTILATION SYSTEM INSTALLATION DRAWINGS AND DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.3(2)	THERMAL INSULATION INSTALLATION DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.3(3)	CABIN PRESSURIZATION INSTALLATION DRAWINGS AND DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.3(4)	ENGINEERING DATA FOR AIR-CONDITIONING AND PRESSURIZATION SYSTEMS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.3(5)	ACOUSTICAL INSULATION INSTALLATION DRAWINGS AND DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.3(6)	ANTI-ICING, DEFOGGING, DEFROSTING INSTALLATION DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.3(7)	ANTI-ICING OF ENGINE INLET AND RELATED EQUIPMENT ANALYSIS REPORT	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.3(8)	WIPER, WASHING, DEGREASING AND AIR BLAST AND RAIN REMOVAL SYSTEM INSTALLATION DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.3(9)	DRAWINGS, TEST REPORTS, SPECIFICATION CONTROL DRAWINGS AND OTHER ENGINEERING DATA FOR ECS NONSTANDARD PARTS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.4	EQUIPMENT				
4-7.9.18.4(1)	CONSTANT SPEED DRIVE SYSTEM DETAIL SPECIFICATION; SYSTEM AND INSTALLATION DRAWINGS; AND SUBSTANTIATING CALCULATIONS	APPROVAL	REPRODUCIBLE	RECURRING	GENERAL ARRANGEMENT DRAWINGS ARE REQUIRED FOR PROPOSAL EVALUATION. DETAILED DRAWING, SPECIFICATIONS, AND DATA ARE REQUIRED PRIOR TO GOVERNMENT WITNESS OF TESTS. DESIGN ANALYSIS AND REPORTS ARE REQUIRED PRIOR TO FIRST FLIGHT.
4-7.9.18.4(2)	RESCUE HOIST INSTALLATION DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.4(3)	CARGO HOISTING AND HANDLING INSTALLATION DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.4(4)	PHOTOGRAPHIC EQUIPMENT INSTALLATION DRAWINGS AND SYSTEM WIRING DIAGRAM	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.4(5)	EXTERNAL FUEL TANKS (CFE) ENGINEERING DATA, INSTALLATION DRAWINGS, AND DETAIL SPECIFICATION	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.18.4(6)	AIR REFUELING SYSTEM DRAWINGS AND DATA	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.19	ARMOR AND ARMAMENT				
4-7.9.19(1)	FUNCTIONAL DIAGRAMS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.19(2)	EQUIPMENT INSTALLATION AND ARRANGEMENT DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.19(3)	HELICOPTER ARMAMENT CHARACTERISTIC REPORT	REVIEW	NONREPRODUCIBLE	RECURRING	
4-7.9.19(4)	CFE ARMAMENT DESIGN DATA	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.9.19(5)	ARMOR INSTALLATION DRAWINGS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.19(6)	SURVIVABILITY ANALYSIS REPORT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.9.19(7)	SPLASH SPALL PROTECTION ANALYSIS REPORT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.9.20	MISCELLANEOUS				
4-7.9.20(1)	LIST OF CARTRIDGE-ACTUATED DEVICES	REVIEW	NONREPRODUCIBLE	NONRECURRING	
4-7.9.20(2)	ENGINEERING DATA FOR NONSTANDARD PARTS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.20(3)	FINISH SPECIFICATION	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.20(4)	SPECIAL MATERIAL PART LIST	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.20(5)	MATERIAL AND PROCESS DEVELOPMENT AND EVALUATION REPORT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.9.20(6)	PROCUREMENT AND PROCESS SPECIFICATIONS	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.20(7)	INTERCHANGEABILITY AND REPLACEABILITY LIST	APPROVAL	REPRODUCIBLE	RECURRING	
4-7.9.20(8)	NOMENCLATURE AND NAMEPLATE DATA	REVIEW	REPRODUCIBLE	RECURRING	
4-7.10	PHOTOGRAPHS	REVIEW	NONREPRODUCIBLE	NONRECURRING	AS REQUIRED
4-7.11	CONTRACT DETAIL SPECIFICATION REVISION PAGES	APPROVAL	NONREPRODUCIBLE	NONRECURRING	90 DAYS PRIOR TO COMPLETION OF CONTRACT NEGOTIATION.
4-7.12	HELICOPTER INVENTORY RECORD	ACCEPTANCE	REPRODUCIBLE	RECURRING	ACCEPTANCE OF EACH PRODUCTION AIRCRAFT

TABLE 4-1. DATA AND DOCUMENTATION REQUIREMENTS (Cont.)

PARAGRAPH	TITLE OF DATA	ACTION	KIND OF COPIES	TYPE OF REPORT	SUBMITTAL DATE
4-7.13	TEST PLANS AND QUALIFICATION TEST REPORTS				
4-7.13(1)	STRUCTURAL	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(2)	SURFACE CONTROLS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(3)	ROTOR BRAKING DEVICE	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(4)	LANDING GEAR COMPONENTS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(4)	WHEEL STRESS DATA	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(5)	ENGINE TRANSMISSIONS AND DRIVES	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(6)	FUEL SYSTEM	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(7)	OIL DILUTION SYSTEM	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(8)	FUEL TANKS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(9)	OIL TANKS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(10)	ELECTRICAL SUBSYSTEM COMPONENTS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(11)	AVIONIC SUBSYSTEM COMPONENTS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(12)	INSTRUMENT AND NAVIGATION SUBSYSTEM COMPONENTS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(13)	SEATS, AUTOMATED AIRCREW ESCAPE SYSTEMS, AND ASSOCIATED CREW FURNISHINGS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(14)	SURVIVAL SUBSYSTEM COMPONENTS AND EQUIPMENT	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(14)	ESCAPE MECHANISM	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(14)	FIRE DETECTOR, SUPPRESSION, AND PREVENTION SYSTEMS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(14)	OXYGEN SYSTEM	APPROVAL	NONREPRODUCIBLE	RECURRING	TEST PLANS MUST BE SUBMITTED AND APPROVED AT LEAST 30 DAYS PRIOR TO START OF TEST. QUALIFICATION REPORTS MUST BE APPROVED PRIOR TO COMPLETE QUALIFICATION AND/OR CONTRACT COMPLETION.
4-7.13(15)	ENVIRONMENTAL CONTROL SUBSYSTEM COMPONENTS AND EQUIPMENT	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(15)	HEATING AND VENTILATING	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(15)	CABIN PRESSURIZATION	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(15)	ANTI-ICING, DEFOGGING, AND DEFROSTING	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(15)	WIPER, WASHING, DEGREASING, AND AIR BLAST RAIN REMOVAL	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	MISCELLANEOUS COMPONENTS AND EQUIP.	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	CARGO HOISTING AND HANDLING	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	RESCUE HOIST	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	CONSTANT SPEED DRIVE	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	PHOTOGRAPHIC	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	AERIAL REFUELING	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	CPE EXTERNAL FUEL TANKS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	ARMAMENT	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	ARMOR BALLISTIC TESTS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	CARTRIDGE-ACTUATED DEVICES AND CARTRIDGES	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(16)	NONSTANDARD PARTS				
4-7.13(17)	HUMAN ENGINEERING DESIGN VERIFICATION	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(17)	RELIABILITY	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(17)	WATERTIGHTNESS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(17)	EXHAUST SYSTEM ENDURANCE PLANS AND REPORTS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(17)	BONDING AND LIGHTNING PROTECTION	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.13(17)	HYDRAULIC AND PNEUMATIC SUBSYSTEMS COMPONENTS	APPROVAL	NONREPRODUCIBLE	RECURRING	
4-7.14	FORMAL DEMONSTRATION				
4-7.14(1)	INSTRUMENTATION REPORT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(2)	MECHANICAL INSTABILITY	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(3)	AERODYNAMICS	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(4)	STRUCTURAL	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(5)	PROPULSION AND POWER SYSTEM	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(6)	AVIONICS	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(7)	ELECTRICAL	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(8)	INSTRUMENTS	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(9)	ELECTROMAGNETIC COMPATIBILITY	APPROVAL	NONREPRODUCIBLE	NONRECURRING	TEST PLANS, SURVEYS, PROCEDURES, AND INSTRUMENTATION MUST BE SUBMITTED AND APPROVED 30 DAYS PRIOR TO START OF TEST.
4-7.14(10)	ARMAMENT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(11)	EXTERNAL STORES	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(12)	FUEL SYSTEM	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(13)	HYDRAULICS AND PNEUMATICS	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(14)	LUBRICATION	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(15)	FURNISHINGS AND EQUIPMENT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(16)	GROUND SUPPORT EQUIPMENT	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(17)	ENGINE STARTING	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(18)	TOTAL SYSTEM SURVEYS	APPROVAL	NONREPRODUCIBLE	NONRECURRING	
4-7.14(19)	MAINTAINABILITY	ACCEPTANCE	REPRODUCIBLE	RECURRING	
4-7.15	ENGINEERING MANUFACTURING DRAWINGS AND CONSOLIDATED DRAWING LIST	ACCEPTANCE	REPRODUCIBLE	RECURRING	INITIAL SUBMITTAL 30 DAYS PRIOR TO FIRST ARTICLE DEMONSTRATION. REVISIONS FOR EACH APPROVED CLASS I ECP'S AND FOR 5 CLASS II ECP'S FOR EACH DRAWING.
4-7.16	SUMMARY OF DATA AND DOCUMENTATION	ACCEPTANCE	REPRODUCIBLE	RECURRING	PRIOR CONTRACT COMPLETION

Maintaining the planned helicopter development schedule and delivery dates for Governmental tests in accordance with the AQS in order to insure timely completion of the development program, is one of the contractor's responsibilities. Therefore, the contractor must make every effort to expedite submittal of data and documentation for review, acceptance, and release, and to proceed with the follow-on development and submittal schedule in anticipation of prompt review and approval actions by the procuring activity. The contractor must allow reasonable and commensurate time for adequate Governmental review of submitted data and for the potential impact of revision generated by withheld releases or acceptances.

The procedure which follows may be employed to accomplish expeditious release of drawings and data—when it is considered necessary by the Cognizant Service Plant Activity (CSPA) and the contractor, —and is subject to approval by the procuring activity.

Drawings and substantiating data should be submitted to the CSPA for provisional release; copies should be sent concurrently to the procuring activity for review and release. These drawings and data may be considered finally released or accepted 30 days after the date of the CSPA endorsement, or such longer interval as may be mutually agreed upon, unless otherwise advised by the reviewing activity within that period. The words "For Approval Within --- Days", or similar legend, should be prominently displayed in the transmittal letter accompanying the drawings and data in accordance with this paragraph. The contractor may issue limited purchase orders for long lead-time items as well as drawings for shop fabrication upon provisional release by the CSPA of such drawings.

4-8.1.1 Submittal

Data and documentation should be submitted to the procuring activity via the CSPA in the quantities specified in DD Form 1423. All letters forwarding such material, and other correspondence relative to such material when submitted previously, also will be furnished in triplicate to the CSPA. Unrelated subject matter, to be reviewed by the Government, will be submitted under separate forwarding letters for ease and promptness in distribution, review, action, and filing by the reviewing activities. Consultation with the CSPA on detail arrangements is encouraged. Shipments of data and documents will be made at the contractor's expense.

4-8.1.2 Inspection

The CSPA will examine all data submittals for completeness, and for compliance with the applicable specifications and contractual requirements. Data not conforming to applicable requirements will be returned to the contractor for revision, prior to submittal to the procuring activity designated in DD Form 1423 and prior to release for manufacture. All CSPA comments will be endorsed on the contractor's forwarding letter.

4-8.1.3 Actions

Action taken on engineering design, analysis, drawings, and test data and documentation will be by release, approval, acceptance, or review (information only) as designated and summarized in Table 4-1. Engineering data submitted for review (information only) need not be acknowledged; however, the action activity may notify the contractor of any design features which would not be satisfactory for future production helicopter. Actions will be designated for Army review and approval activities on the applicable DD Form 1423 furnished with the RFP. Such actions may be redelegated to the CSPA, or otherwise revised or redelegated for particular cases. Such revisions will be indicated in the specified data and documentation requirements, as tailored in the applicable AQS and DD Form 1423.

The CSPA will review the Summary of Data and Documentation required in par. 4-7 for agreement with the records of his office, and comment accordingly when forwarding the summaries and revisions thereof.

After the acceptance of approved drawings, the CSPA will release all drawings necessary for manufacture which do not conflict with or change the accepted configuration. The intent of this requirement is that, once the basic line configuration of the design has been approved, the manufacturing drawings will be developed and released expeditiously.

In the release, approval, or acceptance of data and documentation, the contractor assumes responsibility for accuracy or completeness of details, or for any deviations from applicable detail or design specification requirements. Also, such release, approval, or acceptance *shall* not be construed as approval or acceptance of non-Governmental specifications or standards referenced therein. All authorized deviations, or requests for deviations, from the contract detail specification and other applicable specifications must be brought to the attention of the procuring activity by the contractor or by the CSPA in his forwarding endorsement requesting approval for new deviations, in accordance with the procedure in par. 4-2.

In releasing manufacturing drawings for fabrication of parts, the CSPA does not assume responsibility for the accuracy, completeness of detail, or proper form, fit, and functioning of contractor-constructed parts or assemblies. The responsibility for satisfactory construction and functioning of parts, subsystems, and the total helicopter system, and satisfactory weight, performance, and flying qualities, etc., in accordance with the governing contract documents, will rest entirely with the contractor.

4-8.2 REVISION OF DATA AND DOCUMENTATION

Data and documentation requiring revision and resubmittal for release, approval, or acceptance must have all corrections marked so that they may be identified and found readily. Data and documentation—once released, approved, or accepted—will not be changed without written authorization by the reviewing activity and, when so authorized, will be furnished to all addressees on the original distribution list.

4-9 MODIFICATION OF REQUIREMENTS

For programs involving minor or major modifications of a previously qualified helicopter, time, funding, and common sense considerations indicate the desirability of tailoring these requirements to suit the needs of the particular case. Such action, or guidance for such action, normally would be initiated by the procuring activity in its RFP but also could be initiated by the contractor in either his response to a RFP or his submittal of an unsolicited proposal.

Such tailoring should insure that all necessary procedures, investigations, analyses, tests, demonstrations, and associated data and documentation are accomplished and furnished. This information must be sufficient to provide documented proof of compliance of a configuration with its objectives and to assure savings in manpower, time, and funds afforded by omission of duplicate requirements. Deviations from the AQS are subject to procuring activity concurrence regarding applicability of prior data, and approval of the revised AQS.

Where applicable helicopter engineering data exist—and such data are acceptable to the Army and have been furnished in accordance with the requirements specified in Table 4-1—the contractor will submit only revised title pages. These pages will note the applicability, revisions, or additions, and the revised or additional pages and appendices necessary to reflect the differences between the prototype and a production design. Procuring activity concurrence with such applicability, and the extent of data and documentation coverage, would in such cases be reflected in its approval of the proposed AQS (par. 4-2).

APPENDIX A

GENERAL ARRANGEMENT DRAWINGS

The general arrangement drawings required in par 4-7.9.1 will consist of fully dimensional front elevation, side elevation, and plan views of the helicopter, accurately portraying the external configuration including stores, lights, surfaces, antennas, and other visible features. The scale of the drawings will be 1/20th unless otherwise specified in the applicable AQS. The drawings will show at least the following information, as applicable.

1. Reference lines for establishing horizontal and vertical distances. The vertical reference line may be the centerline of the fuselage, the hull deck line, etc. The horizontal reference line may be the rotor thrust line, leading edge root chord, fuselage station zero, firewall, or other convenient reference perpendicular to the vertical reference.

2. Main and auxiliary landing gear ground contact component (wheels and tires, skis, amphibious gears, skid gears, ground handling wheels, as applicable) in solid lines for the normal, three-point static attitude at design gross weight condition; the outlines of the landing gear strut, position of doors and fairings for retractable gears; tail bumpers; tail rotor guards; and scuff plates for skid gear. The ground contact components also will be shown in dotted lines in fully retracted position, and in the no-load position (fully extended/skis trailing) and the fully deflated/flat tire positions as necessary to establish the ground lines noted in Item 3b which follows:

3. Ground lines as follows:

a. With static deflections of shock absorbers, tires, or skid

(1) Normal three-point/skid attitude

(2) Maximum tail down

(3) Vertical reference line level. Identify angles to ground lines 3a(1) and 3a(2), and 3b.

b. With critical combination of no-load and fully deflated shock absorbers and/or tires, or fully deflected skids to establish minimum propeller or tilted rotor ground clearances or 8d

4. Dimensions and data, as applicable, and suitably tabulated for clarity, where necessary as follows:

a. Overall helicopter length, height, and span for:

(1) Level and static positions (on wheels, skis, skids, and amphibious gear)

(2) Folded (rotors, propellers, tails, wings, or blades removed if removable)

(3) Height over fuselage and tail in static position, and overall height in hoisting attitude (top of sling to lowest point gear extended)

b. Main and tail rotor(s) and propeller(s):

(1) Diameter

(2) Distance between centerlines at hubs

(3) Overlap

(4) Effective disk area

(5) Total blade area

(6) Location and angle of thrust line relative to reference lines

5. Wing(s), and stabilizing and tail surfaces

a. Span

b. Chords, including location, length, and incidence of all construction chords

c. Dihedral, from horizontal to leading edge of chord plane

d. Sweep back, of leading edge or constant percentage chord line

e. Designation of airfoil section

f. Horizontal and vertical distances from reference lines to the leading edge mean aerodynamic chord, and the length and incidence of the mean aerodynamic chord

g. Horizontal distance from reference line to elevator and rudder hinge lines

h. Stabilizer incidence

i. Angle between zero lift axis of wing and propeller axis

- j. Angle between level landing ground line and ground lines corresponding to 50%, 75%, and 90% $C_{L_{max}}$ of wings
 - k. Areas
6. Miscellaneous surfaces, such as ailerons, spoilers, flaps, slats, speed brakes, and tabs
- a. Type
 - b. Spanwise location and span
 - c. Chord
 - d. Hinge axis location
 - e. Angular movement
 - f. Areas
7. Landing gear, including ground handling wheels
- a. Tread
 - b. Wheelbase and location of axle of main wheels horizontal reference line (static position)
 - c. Tire sizes
 - d. Flat tire rolling radii
 - e. Skid length
 - f. Tail bumper location
8. Clearances
- a. Static ground line to:
 - (1) Rotor(s) tip(s) in static drooped, and zero and fully coned positions
 - (2) Tail bumper and tail rotor guards
 - (3) Propeller tips
 - b. Minimum critical tip clearance of the rotor(s) and propeller(s) from the fuselage, tail boom, or other parts of the helicopter
 - c. Clearances between disks on multirotor/propeller helicopter
 - d. Minimum critical propeller or tilted rotor tip clearances attainable by no load, static, or fully deflated shock absorbers and/or tires and fully deflected skids, including flat tires on main or auxiliary gear. Ground line to which measured *shall* be identified or defined.
9. Center of Gravity
- a. Horizontal and vertical distances from reference lines of Item 1 to normal gross weight CG
 - b. Side elevation angle between a line joining the CG with the point of contact of main wheels and a normal to the static three-point attitude ground line of Item 3a(1) for nose wheels, or the vertical reference line level ground line of Item 3a(3) for tail wheels
 - c. Front elevation angle between a line joining the CG with the point of contact of main wheels, or skid tubes, and a normal to the horizontal ground line
10. For float and hull helicopters, the following additional data:
- a. Gross displacement of hull, each main float, and each auxiliary float (in pounds of sea water at 64 lb/ft³)
 - b. Maximum draft and corresponding weight empty, normal gross weight, and maximum overload gross weight
 - c. Load waterline for design gross weight
 - d. Ground line with helicopter on amphibious gear, static deflections, and minimum draft required for amphibious gear extension
 - e. Length, beam, and height of hull, main floats, and auxiliary floats
 - f. Angle between vertical reference line and the following: hull or float deck, thrust line, forward keel at main step, after keel at main step, and load waterline
 - g. Vertical distance from reference line to load waterline at main step
 - h. Distance from bow to each step of hull and floats and depth of each step
 - i. Location of center of buoyancy for design gross weight condition and height from center of buoyancy to CG
 - j. Clearance of auxiliary float above load waterline and propeller clearance above waterline or float
 - k. Applicable data (Item 7) for wheeled portion of amphibious gear.



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CHAPTER 5

MOCK-UPS

5-1 INTRODUCTION

At an early stage in the development cycle, a full-scale helicopter mock-up should be fabricated by the contractor to function as a design tool in determining the optimum helicopter configuration. This mock-up should provide a full-size representation of the physical arrangement in sufficient detail to permit demonstrating compatibility of the handling, maintaining, loading, and operating requirements of the helicopter and its equipment. Particular regard must be given to crew and passenger stations, cargo and weapon provisions, equipment arrangement, and propulsion system installations. Visibility for the flight crew, lighting, effective clearances, and personnel safety also must be considered. Individual subsidiary mock-ups may be required for specific areas such as special landing gear, flight control systems, engine compartments, and crew stations. Approval of the mock-up will enable the contractor to continue with the design of the actual helicopter with reasonable assurance that the general arrangement and the equipment installations will be satisfactory.

The full-scale mock-up may be used to assist in packaging and in arrangement trade-off studies for selected components. Such a mock-up offers a three-dimensional presentation for other engineering disciplines—such as maintainability, reliability, producibility, and system safety—to evaluate and plan subsequent test demonstrations. The mock-up should be used as a design tool to establish effective arrangements or to resolve subsystem interface problems as they affect form, fit, and function.

The use of production materials in the construction of the full-scale mock-up is not required. The full-scale structure can be fabricated from inexpensive materials such as plywood, plastic, or foamcore; and should represent the external aerodynamic configuration as well as the internal space considerations.

When required by appropriate procurement action, the mock-up *shall* represent accurately the size and location of structural members in areas which affect

vision and critical clearances. Major subsystem components, wiring, cables, tubing, piping, and structural members *shall* be mocked up (where relevant) to show the accessibility of inspection and maintenance. The items mocked up need not be of actual material or weight (unless otherwise specified); however, they *shall* be of actual size and shape to depict mounting points and limits of all control movements. The strength of the mock-up structure *shall* be sufficient to support all mock-up equipment and the weight of inspection personnel, and *shall* accommodate any loading or unloading demonstrations or trials required in par. 5-2 or which might be appropriate during development of the configuration.

The strength of the mock-up structure also *shall* be sufficient to enable personnel to perform simulated maintenance tasks with appropriate tools and test equipment. All items not readily identifiable *shall* be marked clearly with the appropriate designation and descriptive name. Items subject to relocation such as fire extinguishers, map cases, or first aid kits *shall* not be permanently installed but *shall* be attached to the structure in a manner which will permit evaluation of alternate sites. Items having both an installed and stowed location *shall* be placed in the installed position. The stowage provision for items such as removable copilot/observer flight controls, weapon sights, ground handling wheels, protective covers, and removable seats also *shall* be mocked up. Provisions for maintenance, lubrication, and other servicing of equipment and airframe elements such as the propulsion and avionic subsystems, gearboxes, and fuel system *shall* be mocked up and their access openings identified.

Items of Government-furnished equipment—such as arctic clothing, protective helmets, and standard tool kits—which are required for mock-ups and are not available at the contractor's facility should be requisitioned from the procuring activity in sufficient time so that they may be on site at least 60 days prior to the date of official mock-up inspection.

5-2 MOCK-UP DEMONSTRATION REQUIREMENTS

The internal and external shape and size of the helicopter mock-up shall duplicate the dimensions of the engineering design in order to permit the assessment of general configuration suitability for the loading and unloading of crew, troops, cargo, weapons, ammunition, and fuel; for the performance of crew functions; and for post-crash escape. The maintainability features of the helicopter with respect to component accessibility, adequacy of builtin work platforms, and ground crew requirements to perform scheduled and unscheduled maintenance also *shall* be demonstrated.

Other design features which *shall* be demonstrated on the mock-up include the accessibility to doors, cargo compartment, and fueling locations. The operation of doors, windows, hatches, emergency exits, controls, and functional equipment such as retractable landing gear or retractable steps also *shall* be demonstrated.

The mock-up *shall* be configured to allow the actual installation of any equipment which will alter its exterior shape or size. Flexibly mounted equipment—hoists, external auxiliary fuel stores, weapon racks, or battlefield illumination devices—*shall* be capable of traversing their full range of movement.

In areas where there is mechanical motion of components, the helicopter skins may be replaced locally with see-through panels to facilitate observation and demonstration of systems.

The mock-up *shall* incorporate all the steps, ladders, handholds, access hatches, and work platforms defined in the helicopter design. Environmental devices, such as windshield wipers and deicer boots, which may affect the external configuration of the helicopter also *shall* be part of the mock-up.

The external markings for the helicopter *shall* be shown, including the insignia, the size and location of special equipment items, and instructions such as "BATTERY", "NO STEP", and "NO HAND HOLD". The location of fuel filler necks and single-point fueling attachments *shall* be shown in relation to personnel requirements and to permit evaluation of required operations such as removal of filler caps or the insertion of the pressure-fueling probe.

5-2.1 FUSELAGE

The fuselage mock-up *shall* include the crew stations, passenger and/or cargo compartments, and equipment compartments. All doors, hatches, windows, escape areas, access ways, hand grips, steps, tie-

down provisions, and jacking provisions *shall* be mocked up. The fuselage mock-up may be used to determine routing of items such as cables and lines. Access points for maintenance and repair of helicopter equipment *shall* be included in the mock-up.

The size and location of escape hatches and emergency provisions for both crew and passengers *shall* be mocked up. All escape hatches and emergency provisions must be operational, including removable panels. Photographs and motion films of a simulated emergency evacuation should be provided for a slow-speed evaluation of potential hazards to the occupants from controls, equipment, or structure. The mock-up should be flexible enough to allow subsequent installations or simulations of equipment for evaluation in the helicopter.

5-2.1.1 Flight Crew Stations

Cockpit(s) *shall* be completely mocked up and *shall* include flight controls, propulsion controls, controls for retractable landing gear, electrical consoles and controls, armament equipment and electronic controls, instruments and navigation equipment, oxygen subsystem, normal and emergency controls for canopy and/or door actuation (including jettisoning), and cockpit furnishings and equipment, including mirrors, microphones, headphones, etc. All furnishings and equipment *shall* duplicate the production articles as closely as possible in size, shape, and location. Actual safety belts, shoulder harnesses, parachutes, emergency kits, life rafts, seat pads, and back pads *shall* be installed, when applicable. Seats *shall* be of exact size and shape and, if applicable, crew seats *shall* be capable of adjustment. The crew design eye position, seat reference point, and measurement techniques related to vision, controls, and displacements *shall* be identified in accordance with MIL-STD-850, MIL-STD-1333, and MS 33575. All flight controls *shall* be operable through their normal envelope, although they need not operate their respective rotors or surfaces. Control friction devices *shall* be mocked up, and stops *shall* be installed to limit all control movements to those anticipated for the actual helicopter. The neutral positions of the cyclic control *shall* be simulated. Control locks, when applicable, and means for adjusting the directional control and brake pedals shall be included in the mock-up. Cockpit canopies (including framing), hatches, windows, etc., *shall* be mocked up in sufficient detail that the overall field of view from the cockpit is depicted accurately. Use of mirrors for viewing external cargo *shall* be demonstrated, if applicable. Provisions *shall* be made for not less than three persons to stand outside

the mock-up on each side of the cockpit by use of removable platforms and walkways.

To the extent possible, transparencies provided within the mock-up should be within the optical quality limits established for the helicopter. Radii of curvature, thickness of panels, and framing widths for windshields and other transparencies in the cockpit *shall* simulate those of the actual helicopter. Adverse weather and/or night vision aids *shall* be mocked up. Individual paper, cardboard, plastic, or metal dials representing all required instruments *shall* be mocked up. The individual dials and panels as a whole *shall* be capable of easy relocation. Extra panels, with dials that can be relocated easily also should be provided apart from the mock-up.

Unless otherwise specified, the size, clearance, reach distance, etc., of any crew station *shall* be demonstrated to accommodate for each dimension, the 5th to 95th percentiles of U.S. Army aviators, as defined in Ref. 1. Allowances *shall* be made for increased size and bulk due to flight clothing, body armor, helmets, gloves, etc., as well as for any restrictions in range or force of movement due to clothing, equipment, or maneuver of the helicopter. Unless required by the detail specification or system descriptions, the use of parachutes by crew members need not be considered.

The mock-up demonstration *shall* be patterned after Appendix 2 of MIL-M-8650. The crew compartment mock-up(s) should permit a realistic evaluation of typical crew visual tasks, including identification and monitoring of controls and displays, out-the-window viewing, normal compartment ingress/egress, onboard equipment controls and servicing, and emergency escape. All furnishings and equipment essential to performing these tasks *shall* be available in the mock-up for demonstration purposes.

5-2.1.2 Other Crew Stations, and Passenger and Cargo Compartments

The seating arrangement in the passenger compartment *shall* be completely mocked up, using actual seats and belts when they are available. This section of the mock-up should be used to demonstrate the adequacy of compartment size, headroom, aisle width, and other physical characteristics. When the helicopter is to be used for assault, the troop loading/unloading sequence and timing should be demonstrated. Rearrangement of compartment doors and/or seating arrangement for minimum loading/unloading times may result, as well as elimination of hazards such as a step edge which may

trip an entrant or an obstacle which may catch loose clothing or equipment.

The interior of the passenger compartment *shall* simulate as closely as possible the configuration of the actual helicopter. Items of interest include interior lighting, lighting controls, and intercommunication stations (with headsets), microphones, and controls. Passenger compartment doors, windows, and emergency exits *shall* be included in the mock-up.

By removing the seats, the passenger compartment of some helicopters may be converted to a cargo hold. If this is the case, the compartment tiedown accommodations *shall* duplicate those on the helicopter to establish compatibility with standardized loading and unloading procedures. Also, the adequacy of the doors and compartment to receive/discharge cargo efficiently will be demonstrated at the mock-up by conducting actual loading/unloading sequences.

The mock-up *shall* permit evaluation of several important environmental constraints upon aft compartment design features. These include night operation; constraints of winter clothing and personal field gear as they reduce personnel agility, mobility, and dexterity; and, to the extent practicable, the degrading effects of an abnormal helicopter position on cargo/personnel loading and unloading.

Other special operational work stations (e.g., weapon operator, communication operator, winch operator, observer, medical attendant, litter, and/or internal cargo compartments including associated support equipment) *shall* be demonstrated by means of the full-scale mock-up(s).

In the case of multipurpose helicopters, a significant feature to be demonstrated is the ability of the typical ground crew to effect the conversion, e.g., from a gunship to a medical evacuation configuration. For this reason a full-fuselage mock-up is more economical than several partial mock-ups.

5-2.1.3 Propulsion and Power System Mock-up

The propulsion and power system mock-up *shall* include the engine(s), Auxiliary Power Unit APU(s), engine compartment components, transmissions, gearboxes, drive shafts, couplings, rotor brakes, and the starting, cooling, lubrication, and fuel subsystems. The contractor *shall* prepare an inspection checklist of this system utilizing Appendix 3 of MIL-M-8650 as a guide.

The propulsion and power system mock-up will be fabricated in sufficient detail to perform all required maintenance and servicing functions. The system com-

ponents may be made of wood or may be a prototype representation of the production propulsion system.

The engine compartment or nacelle group *shall* be completely mocked up including propellers (if applicable), engine mounts, engine cowl(s), baffles, air intakes, alternate doors, built-in work platforms, firewalls, shrouds, and maintenance and servicing access doors.

Accessories such as particle separators (if specified) *shall* be mocked up to determine component arrangement and effects on the external configuration or compartments. All inlet ducting *shall* be mocked up to allow evaluation of susceptibility to foreign object damage (FOD); the exhaust system mock-up *shall* permit evaluation of infrared protection devices.

The lubrication system *shall* be mocked up to include dummy tanks, filler units, oil coolers, oil reservoirs, piping, valves, fittings, drains, and disconnects.

The fuel system *shall* be mocked up, including dummy tanks (with auxiliary tanks, internal and/or external), filler units, piping, important valves, fittings, drains, disconnects, dummy aerial refueling probe, and fuel dump outlet, as appropriate.

The APU *shall* be completely mocked up and *shall* be comparable in detail with the propulsion system installation.

5-2.1.4 Electrical/Electronic System Mock-up

All items of the electrical power system *shall* be mocked up, including control panels, generators and/or alternators, batteries, voltage regulators, transformers, and inverters. Cooling and/or lubricating systems for electrical power components *shall* be completely mocked up, including ducts, piping, tanks, and valves.

Electrical distribution and control equipment *shall* be mocked up. This *shall* include wiring, cabling, connectors, junction and terminal panels, relays, contactors, switches, circuit breakers, fuses, and meters. Critical wire runs (power feeders, electrically unprotected wires, and congested area wires) *shall* be mocked up, as well as representative wiring to illustrate installation techniques and hardware.

All items of electronic equipment, including communication and navigation systems, *shall* be mocked up, including panels and console structure, antennas, masts, and lead-ins. Cabling need be simulated only in the vicinity of the terminating equipment.

5-2.1.5 Hydraulic and Pneumatic System Mock-ups

All major items of the hydraulic and pneumatic systems *shall* be mocked up, including main and emergency pumps, reservoirs, accumulators, filters, controls, and sufficient piping to show clearances.

5-2.1.6 Armament and Armor Mock-ups

The armament installation *shall* be completely mocked up including fixed and movable weapons and accessories; turrets; rockets, guided missiles, and accessories; fire control subsystems; internal or external stores as applicable (including racks, supports, shackles, sway bracing, ejectors, etc.); dummy armor plate and bullet-resistant glass; and hoisting provisions, as applicable. The fixed and movable weapons, turrets, and fire control equipment *shall* permit the full range of movement. Particular attention should be given to showing all armament installations in such detail that clearances (both ground and structural) and physical arrangement can be readily checked. The arrangement *shall* be such that loading and unloading of gun ammunition and removal and installation of guns may be demonstrated. Missile-launching mechanisms *shall* be completely mocked up and capable of movement through the normal operating travel.

If armor protection is specified, the mock-up *shall* include the armor protection of the engine(s), APU(s), controls, wiring, and liquid-carrying lines, as well as flight crew stations.

5-2.2 ROTOR HUBS AND BLADES

If rotor hub and blade mock-ups are required, they *shall* permit demonstration of adequate structural clearances for all mechanical motions and that limits of movements established by stops are suitable for the design. The mock-up also *shall* portray the location of hydraulic reservoirs, sight gages, lubrication fittings, and other features, thus permitting the maintainability of the overall rotor assembly to be evaluated. An individual rotor blade section should be available during the mock-up review of the hub and root blade assembly.

It is impractical to construct a full-diameter mock-up of the main rotor(s) because the strength required of a mock-up hub to support the weight of the full-scale rotor would prohibit the use of conventional mock-up materials and complicate construction. Therefore, a completely detailed, full-size mock-up of the hub with representative blade-root sections attached will suffice

for most requirements except blade folding. However, scale models may be used.

For those helicopters for which blade folding is required, the mock-up *shall* demonstrate compatibility of rotor and hub components during the complex geometric manipulations generally associated with the folding.

Blade folding may be manual or may be powered by any of the available secondary power systems. The folding operation, security of locks, and functioning of the "SAFE-UNSAFE" indicator *shall* be demonstrated with an operable mock-up which duplicates the exact motions of the blades. Actual components *shall* be used in the powered system, if possible.

For a rotor designed for manual blade folding, the mock-up need not be made in the detail required for the powered folding rotor. However, the blade locking provisions *shall* be accurately detailed to allow for the evaluation of the folding procedures and provisions for the fail-safe security of the locks.

The mock-up of the hub and rotor blades *shall* include all provisions for controlling the rotor; i.e., the swashplate, control rods, and pitch horn connections to the blades. The available range of motions *shall* simulate those actually used on the helicopter.

Gearboxes with appropriate shafting are used to transmit mechanical power to the tail rotor. Such gearboxes, along with their associated couplings and drive shafts, sometimes are subjected to frequent inspection or maintenance. The adequacy of the design for visual inspection and maintenance accessibility *shall* be shown in the tail group mock-up. Oil-level sight gages and appropriate access doors *shall* be configured for verification of accessibility and inspection. The arrangement of control bell cranks and tubes may suggest clear, nonstructural panels for visibility of operation in the mock-up. The tail rotor *shall* be mocked up completely, including full-length blades.

Helicopters which have tail booms and tail rotors usually have some type of ground contact device at the extreme end of the tail group. This may be a part of the primary landing gear and shock absorption system or simply a guard to prevent inadvertent contact of the structure or antitorque rotor with the ground. If the member is a part of the basic landing gear system, it *shall* be part of the actual mock-up, in accordance with the considerations of par. 5-2.3. If it is a simple guard to protect against structural ground strikes, it may be exhibited on the mock-up without regard to the materials. The primary concerns here are to allow evaluation of the possible obstructions to personnel and tail rotor protection, plus the suitability of the retraction system kinematics, if applicable.

Any movable aerodynamic control surfaces within the tail group *shall* be mocked up to demonstrate their normal movements.

5-2.3 LANDING GEAR

Landing gear mock-ups may not always be essential. If they are required, they *shall* conform to the requirements of this paragraph. The mock-up of a fixed landing gear—including brakes, swiveling features, and accessories such as floats, bear paws, etc.—*shall* permit evaluation of accessibility to the helicopter for personnel and cargo loading/unloading and the effect of the gear on the maintainability of the helicopter.

Retractable landing gear mock-ups *shall* demonstrate the operation of the retraction mechanism, fairing doors, and the positive lock provisions. The kinematics of the retraction linkages *shall* be operative in order to allow evaluation of possible interferences with doors, hatches, or special exterior equipment while in any of the intermediate landing gear positions during the retraction or extension cycle. The mock-up *shall* include a representation of all equipment in the wheel well in order to determine possible interferences and environmental problems. The flexure of the lines and hoses for landing gear retraction, brakes, and drive power *shall* be demonstrated in the mock-up. The addition of transparent panels to the mock-up structure will aid in determining the suitability of the wheels-stowed configuration and assist in determining possible design faults.

An alternate means of supporting the mock-up at the static gross weight of ground position should be employed for helicopters incorporating retractable landing gear. The size and shape of shock absorption devices are important in the evaluation of landing gear clearance and operation. However, simulation of the landing gear spring rate or load deflection characteristics is not warranted or desired because of the disparity of loads and weights which would be imposed on the mock-up structure.

5-2.4 LIGHTING MOCK-UP

A full-scale mock-up of the interior and exterior lighting *shall* be constructed. The lighting mock-up inspection should be conducted as soon as possible after approval of the helicopter mock-up. The full-scale mock-up *shall* be employed for exterior lighting inspection and may be employed for crew stations (except for the cockpit), passenger stations, cargo compartments, and equipment compartments. An actual helicopter cockpit or cockpit section *shall* be provided, when

practical, for inspection of cockpit lighting. If an actual cockpit or cockpit section cannot be employed for the cockpit lighting mock-up, the cockpit may be simulated. The framing, windows, windshields, bulkheads, and other cockpit sections which are visible to the pilot and/or copilot *shall* duplicate those of the production helicopter. Soft metals, plastics, and wood suitably coated to represent the production article may be used. The contractor *shall* develop an interior/exterior lighting system mock-up checklist utilizing Appendix 9 of MIL-M-8650 as a guide. Particular attention will be paid to the electrical power provided to insure that the power available to the mock-up does not exceed that of an actual helicopter.

5-2.4.1 Interior Lighting

Complete interior lighting, with glare shields, *shall* be mocked up. Provisions *shall* be made for viewing the mock-up in a completely darkened room or by simulating complete darkness in the mock-up itself. Either a darkened room or red goggles *shall* be provided for at least a 30-min dark adaptation. Passage from the cockpit lighting mock-up to any other lighting mock-up station or compartment in the helicopter *shall* not require readapting observers to darkness. The mock-up *shall* be illuminated with all instrument lights operative and *shall* be provided with equipment identical to that to be installed in the operational helicopter. In the case of instruments and console controls, the equipment to be installed or similar equipment (not paste-ups) *shall* be used. Where controls for energizing indicator lights cannot be actuated in the mock-up, the indicator lights *shall* be energized by switches external to the mock-up or by internal switches not normally employed for the mock-up inspection. Adjustable dimming *shall* be provided for all lights to allow the light intensity to be varied for the evaluation of night operations and the effects of glare. A simulated rotor disk *shall* be provided to permit representative reflections to be evaluated.

Provision *shall* be made for inspection of the actual helicopter cockpit or cockpit section in daylight (bright sunlight) to determine adequacy of warning lights, caution lights, etc.

5-2.4.2 Exterior Lighting

The location of exterior lighting *shall* be included in the mock-up. Provision *shall* be made by the contractor for viewing the exterior lighting mock-up in a reasonably darkened area. Provisions *shall* be made for viewing the effects of external lighting on cockpit interiors (glare, etc.). Navigation lights, formation lights, land-

ing and taxi lights, anticollision beacons, and high-intensity strobe lights *shall* be demonstrated for visibility, light intensity, and flash frequency at the required azimuths and elevation angles. Structural interferences with lighting patterns may be determined, and corrective measures taken, either by relocating the light or moving the obstructing appendage on the airframe.

5-3 MOCK-UP REVIEW AND APPROVAL

The contractor *shall* present the mock-up to the procuring activity in a suitable demonstration facility. He *shall* furnish reference material, office facilities, and clerical assistance to the Mock-up Review Board. Included *shall* be provision for maintenance of Mock-up Change Status.

The contractor *shall* provide a data package to the procuring activity at least two weeks prior to the review. These data *shall* consist of, but not be limited to, the following:

1. Development history, purpose, and mission of the helicopter system as it may be related to the appropriate mock-up inspections
2. Recommended checklists prescribed by the procuring activity, e.g., the sample baseline checklist for seats and furnishings shown in Table 5-1
3. Appropriate crew/passenger compartment layout drawings and helicopter subsystem and hardware drawings, photographs, and illustrations
4. Description of features requiring demonstrations of the compatibility of the helicopter with military personnel, and with assigned missions
5. External vision plot, illustrating the field of vision around the helicopter from the crew's normal eye position, per the Aitoff's Equal Area projection vision plots defined in MIL-STD-850
6. Photometric data, as appropriate, prior to the lighting mock-up inspection.

Copies of the detail specification, preliminary drawings, and other material considered necessary or requested by the Board chairman should be made available to the inspection team.

The procuring activity will prepare a mock-up review plan which will identify the Mock-up Review Board members and other evaluators, the planned duration of the mock-up review, the checklist to be used by the evaluators, and other pertinent data.

Specific evaluation procedures to be employed by the Mock-up Review Board will be established prior to an official mock-up demonstration. Such procedures will include definition of any objective scoring techniques and necessary tools or devices such as stop watches,

TABLE 5-1. SAMPLE BASELINE CHECKLIST FOR SEATS AND FURNISHINGS

CREW SEATS	1. IS THE VERTICAL AND FORE AND AFT ADJUSTMENT ACCOMPLISHED SEPARATELY (VERSUS INTEGRATED OPERATION)? 2. IN WHAT INCREMENTS CAN THE ADJUSTMENT BE MADE? 3. WHERE IS THE ADJUSTMENT CONTROL LOCATED? 4. IS THE LOCATION SATISFACTORY? 5. IS THE SEAT DESIGNED FOR THE PROPER EQUIPMENT? 6. IS THE SEAT EQUIPPED WITH A CORRECTLY MOUNTED INERTIAL REEL WITH A "STALOCK" FEATURE? 7. IS THERE AN INDICATOR OR REFERENCE POINT PROVIDED SO THAT THE CREW CAN DETERMINE THE CORRECT EYE LEVEL?
PASSENGER ACCOMMODATIONS	1. ARE THE PASSENGER SEATS PROVIDED APPROPRIATE TO THE PASSENGERS TO BE CARRIED? 2. IS ADJUSTMENT PROVIDED FOR THE SEATS? 3. ARE SATISFACTORY SAFETY BELTS PROVIDED? 4. ARE SHOULDER HARNESS AND INERTIAL REELS PROVIDED? 5. ARE SEATS DESIGNED FOR THE APPROPRIATE MISSION EQUIPMENT? 6. IF LITTERS ARE PROVIDED, CHECK TO SEE THAT THE FOLLOWING ARE SATISFACTORY: a. VERTICAL DISTANCE BETWEEN LITTERS b. HEIGHT OF TOPMOST LITTER ABOVE AN IN-FLIGHT STABLE SURFACE c. AISLE SPACE BETWEEN LITTERS

motion picture photographs, special lighting, and evaluation check sheets. The evaluation procedures will be based on an operational sequence analysis or other task analyses performed earlier during contractor system definition studies (see MIL-H-46855).

The mock-up inspection team will convene at the contractor's plant for inspection of the mock-up on the date established by the procuring activity.

Standardized design and mission suitability checklists will be used by the Mock-up Review Board to augment and/or provide guidelines for the evaluation of the mock-up. The inspection team should have sufficient time to review the mock-up, take measurements, review necessary criteria documents, and prepare comments prior to the critique.

Mock-up review team members will observe personnel in the 5th to the 95th percentiles who are wearing Army flight clothing, Arctic clothing, and survival equipment, and are performing mission functions, including ingress and egress, under night lighting conditions. Measurements will be made of seat, panel, control, and other spatial relationships within the

crew/passenger compartment to determine specification compliance.

An evaluation of the alternate uses of certain areas of the fuselage for various operational functions may be desirable, e.g., the operation of weapons from the doors or elsewhere through blisters or cutouts in the passenger compartment. The size of the hatches, particularly for the crew, may be influenced strongly by the access routes to the hatches within the crew compartment. Internal equipment obstruction will be evaluated together with the possibility of using the console, instrument panel, and seat bottoms or seat backs as steps to facilitate rapid egress from the compartment. Evaluation of the mock-up will identify any changes needed to assure that the emergency escape paths are not compromised by external fuselage projections such as pitot heads or antennas which might injure the personnel or impede their exit from the helicopter.

Each evaluator will provide the mock-up review chairman with copies of the completed checklists and with appropriate documentation of specification compliance. The specifications, standards, and other docu-

ments referenced in the helicopter detail specification will be the criteria upon which judgments of contractual compliance are made. Design areas which do not comply with the detail specification or system description and other problem areas will be documented as either deficiencies or shortcomings per AR 310-25, on the form prescribed by the procuring activity. If it is practical, recommended design solutions to mock-up problem areas should be incorporated into the mock-up during the inspection.

After completion of the mock-up inspection, the procuring activity will submit a status report to the contractor. Mock-up approval will be granted upon the contractor's compliance with the required changes and/or approved deviations, as specified by the procuring activity. The contractor *shall* provide photographs of the approved mock-up.

5-4 MOCK-UP DISPOSITION

Mock-ups *shall* be retained by the contractor until the actual helicopter has been finally accepted. Final

disposition of the mock-ups *shall* be specified by the procuring activity. Permanent changes *shall* not be made to the approved mock-up unless specifically authorized by the procuring activity; removal of articles intended for installation in the actual helicopter may be authorized by the procuring activity after approval of the mock-up.

5-5 OTHER SUBSYSTEM MOCK-UPS

Functional subsystem mock-ups may be required to substantiate the design. Such mock-ups and their requirements are discussed individually in Chapter 8.

REFERENCE

1. Robert W. White, Natick Laboratories Report, No. EP-150, Headquarters, Quartermaster Research and Engineering Center, Environmental Protection Research Center, Natick, Mass., June 1961.

CHAPTER 6

PROCUREMENT AND PROCESS SPECIFICATIONS

6-1 INTRODUCTION

End-item specification preparation and coordination *shall* be in accordance with MIL-STD-490.

6-1.1 GENERAL

Procurement and process specifications are designed to assure manufacturing and fabrication repeatability within defined parameters regardless of the selected source. Therefore, these documents serve as a means of providing structural reliability and safety of the helicopter throughout its useful life.

Material and processing variables that affect the long-term performance of hardware are presented in this chapter. Where adequate existing specifications are available, they are referenced; when they are not available, the considerations necessary for their preparation are discussed. New specifications or standards *shall* be developed in accordance with USAAVSCOM Pamphlet No. 70-1 and MIL-STD-143. These documents *shall* define the specific manufacturing and fabrication processes and methods of control required to demonstrate proof of compliance.

6-1.2 MAKE-OR-BUY PLAN—PROCUREMENT

The contractor *shall* develop a make-or-buy plan and submit it to the procuring activity for approval prior to the release of any procurement documents. This plan *shall* include all of the details necessary to insure the delivery of a complete system of hardware. MIL-STD-885 may be used as a guide in preparing the plan.

6-1.3 END-ITEM COMPONENT SPECIFICATIONS

The contractor *shall* provide End-item Component Specifications to establish the requirements for performance, design, test, and qualification of end-item equipment. The end-item specification *shall* cite all applicable documents, establish the performance requirements, detail the quality assurance provisions, and establish the delivery and acceptance provisions.

6-1.4 PURCHASE SPECIFICATIONS

The contractors shall provide a purchase specification for each class of material employed and shall define the performance requirements and acceptance tests.

Because contract provisions take precedence over any specification provisions, cognizance of the contract provisions must always be present when selecting a specification. Purchase specifications are divided into two groups. MIL-STD-143, which provides a guide to the selection of specifications, describes Group I as Standards and Specifications listed individually in the *DOD Index of Specifications and Standards*. These are Federal and Military Standards and Specifications, Air Force - Navy Standards, and Air Force - Navy Design Standards. Group II includes industry standards and specifications. All helicopter specifications fall under Group I unless specifically approved by the procuring activity. ANA Bulletin No. 147 provides a list of Aerospace Material Specification (AMS) numbers that can be used without prior approval in the absence of Military Specifications.

Purchase of tools and parts *shall* be in accordance with a detailed layout drawing relating each dimensionally to the overall tool system and permitting configuration control of subsequent engineering changes.

A process specification may be required along with the purchase specification to define items such as parts, castings, and forgings that are partially or fully processed by the supplier. These items are detailed in the paragraphs which follow.

6-1.5 PROCESS SPECIFICATIONS

The contractor *shall* prepare a detailed description of the manufacturing or assembly process and methods of control of manufacturing variables in the form of a titled, numbered, and dated process specification. Regardless of whether the specification governs a supplier

or an in-house operation, the objective of the specification is to define parameters within which the subcontractor can demonstrate contract compliance. The specification and purchase order will be accompanied by a production drawing, bill of materials (BOM), parts list (PL), and a detailed work sheet. In many cases an existing process specification can be referenced, e.g., MIL-A-9067. In the paragraphs which follow, specific kinds of processes will be discussed, and in each case existing process specifications will be cited. In the event that a process specification does not exist or is inadequate for a required process, it is the responsibility of the contractor to generate the process specification and obtain the approval of the procuring activity before contracting for procurement or employing the process in-house.

6-1.6 QUALITY ASSURANCE PROGRAM

The quality assurance program *shall* be conducted in accordance with MIL-Q-9858. The program must assure adequate quality throughout all areas of contract performance such as manufacturing, processing, assembly, inspection, test, packaging, and shipping. All supplies and services under the contract, whether manufactured or performed within the contractor's plant or at any other location, must be controlled by the requirements of MIL-Q-9858 in order to assure conformance to contractual requirements. The program will provide for the prevention and ready detection of discrepancies and for timely and positive corrective action.

For each specification, the contractor will provide a system of inspection, controls, and tests so that the material, the process, the part, or the end-item will be qualified to the satisfaction of the contractor and the procuring activity. The contractor *shall* establish and maintain a system of calibration for all test equipment in accordance with MIL-C-45662. Test reports and records include the following information:

1. Identification of the program and Governmental agency
2. Supplier of the material and contract data
3. Material specification or purchase specification number
4. Identification of the material
5. Type and dimensions of the specimen
6. Position of the specimen
7. Environmental conditions
8. Individual test method data
9. Additional data required by the specification

10. Test apparatus, including data of last calibration

11. Test results, including action indicated.

Records *shall* be available for the duration of the contract, or as specified by the procuring activity.

In the subsequent paragraphs, quality control aspects of specific materials and processes are detailed, and numerous guiding specifications cited. Military Specifications of particular help in inspection, controls, and tests are MIL-STD-109, MIL-I-6870, MIL-D-1000, MIL-I-45208, MIL-C-45662, MIL-STD-105, and MIL-STD-414.

6-2 FERROUS MATERIALS

6-2.1 GENERAL

The types of ferrous materials most commonly used in helicopter development are carbon and alloy steels, corrosion-resistant steel, and maraging steel. Application and selection of these materials are discussed in AMCP 706-202. The purchase and manufacturing controls of the selected material are discussed in the subsequent paragraphs.

6-2.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test ferrous materials in accordance with Federal Test Method Standard No. 151 as required in the purchase specification. The tests are listed in Table 6-1. If the material has been certified by the supplier, it *shall* be verified in accordance with the contractor's approved quality assurance plan.

6-3 NONFERROUS METALLIC MATERIALS

6-3.1 GENERAL

The types of nonferrous metallic materials most commonly used in helicopters are aluminum alloys, magnesium alloys, titanium and titanium alloys, copper and copper alloys, and nickel and nickel alloys. The use of aluminum and magnesium requires special controls for detecting and controlling corrosion. Special packaging, handling, and storage requirements may be required in order to maintain acceptable material.

TABLE 6-1. METALS, TEST METHODS OF FEDERAL TEST METHOD STANDARD NO. 151

METHOD	TEST	METHOD	TEST
DEFINITIONS OF TERMS.		MAGNETIC TEST FOR LOCAL COATING THICKNESS	ASTM A 219
ELECTROMAGNETIC TESTING	ASTM E 268	CHEMICAL DROPPING TEST FOR LOCAL COATING THICKNESS	ASTM A 219
LIQUID PENETRANT INSPECTION	ASTM E 270	ELECTRICAL:	
MAGNETIC PARTICLE INSPECTION	ASTM E 269	RESISTIVITY TEST OF ELECTRICAL CONDUCTOR MATERIAL	ASTM B 193
MECHANICAL TESTING	ASTM E 6	HEAT TREAT RESPONSE:	
METALLOGRAPHY	ASTM E 7	END-QUENCH HARDENABILITY TEST	ASTM A 255
MICROSCOPY	ASTM E 175	CORROSION:	
RADIOGRAPHY	ASTM E 52	SALT SPRAY TEST	ASTM B 117
COMPOSITION:		SYNTHETIC SEA-WATER SPRAY TEST	812
CHEMICAL ANALYSIS	111	INTERGRANULAR-CORROSION TEST FOR CORROSION-RESISTANT AUSTENITIC STEELS	ASTM A 393
SPECTROCHEMICAL ANALYSIS	112	INTERGRANULAR-CORROSION TEST FOR ALUMINUM ALLOYS	822
MECHANICAL PROPERTIES:		STRESS-CORROSION TEST FOR ALUMINUM ALLOY PLATE, EXTRUSIONS, AND FORGINGS (BY ALTERNATE IMMERSION)	823
TENSION TEST	ASTM E 8	MERCURIOS NITRATE TEST FOR COPPER ALLOYS	ASTM B 154
CHARPY IMPACT TEST	ASTM E 23	RADIOGRAPHIC:	
COLD-BENDING TEST	ASTM E 290	RECOMMENDED PRACTICE FOR RADIOGRAPHIC TESTING	ASTM E 94
HARDNESS CONVERSION TABLE FOR STEEL	ASTM E 140	CONTROLLING QUALITY OF RADIOGRAPHIC TESTING	ASTM E 142
BRINELL HARDNESS TEST	ASTM E 10	MAGNETIC:	
ROCKWELL HARDNESS TEST	ASTM E 18	DRY POWDER MAGNETIC PARTICLE INSPECTION	ASTM E 109
DIAMOND PYRAMID HARDNESS TEST	ASTM E 92	WET MAGNETIC PARTICLE INSPECTION	ASTM E 138
STRENGTH OF BRAZED JOINTS	AWS C3.2	LIQUID PENETRANT:	
METHOD & DEFINITIONS FOR MECHANICAL TESTING OF STEEL PRODUCTS	ASTM A 370	LIQUID PENETRANT INSPECTION	ASTM E 165
METALLOGRAPHIC:		ULTRASONIC:	
AUSTENITE GRAIN SIZE IN STEEL	ASTM E 112	ULTRASONIC TESTING BY THE RESONANCE METHOD	ASTM E 113
GRAIN SIZE IN WROUGHT COPPER	ASTM E 112	ULTRASONIC TESTING BY THE REFLECTION METHOD	ASTM E 114
MACRO-ETCH TEST FOR STEEL	ASTM A 317	ULTRASONIC CONTACT INSPECTION OF WELDMENTS	ASTM E 164
LEAK TESTING:		ULTRASONIC INSPECTION OF LONGITUDINAL AND SPIRAL WELDS OF WELDED PIPE AND TUBING	ASTM E 273
LEAK TESTING (HELIUM MASS SPECTROMETER)	441	INCLUSION CONTENT:	
LEAK TESTING (PRESSURIZED GAS)	442	DETERMINING INCLUSION CONTENT OF STEEL	ASTM E 45
LEAK TESTING (VACUUM)	443	PREMIUM AIRCRAFT QUALITY STEEL	
COATINGS		CLEANLINESS MAGNETIC PARTICLE INSPECTION PROCEDURE	AMS 2300
WEIGHT AND COMPOSITION OF COATING ON LONG TERNE SHEETS	ASTM A 309	AIRCRAFT QUALITY STEEL CLEANLINESS, MAGNETIC PARTICLE INSPECTION PROCEDURE	AMS 2301
WEIGHT OF ZINC COATING	ASTM A 90		
WEIGHT OF COATING ON HOT DIP TIN PLATE AND ELECTROLYTIC TIN PLATE	513		
WEIGHT AND COMPOSITION OF COATING ON SHORT TERNE PLATE (FOR MANUFACTURING PURPOSES AND FOR ROOFING)	514		
ELECTRONIC TEST FOR LOCAL COATING THICKNESS	520		
MICROSCOPIC TEST FOR LOCAL COATING THICKNESS	ASTM A 219		

6-3.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test nonferrous metallic materials in accordance with FTMS No. 151 as required in the purchase specification. The tests are listed in Table 6-1. If the material has been certified by the supplier, it *shall* be verified in accordance with the contractor's approved quality assurance plan.

6-4 NONMETALLIC MATERIALS

6-4.1 GENERAL

The most common types of nonmetallic materials utilized in the helicopter include glass and other ceramic materials, thermoplastic and thermosetting materials, natural and synthetic elastomers, and fluoroplastics. The design uses are discussed in Chapter 16 of AMCP 706-202. The procurement, inspection, and process controls of these materials will depend upon

their design application. As a result, the contractor may be required to develop special manufacturing processes in order to meet the design requirements.

6-4.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test nonmetallic materials as required in the purchase specification. Tests will be in accordance with FTMS No. 406 and No. 601, where applicable. The tests for FTMS No. 406 are listed in Table 6-2. If the material has been certified by the supplier, it *shall* be verified in accordance with the contractor's approved quality assurance plan with the approval of the procuring activity.

6-4.2.1 Plastics

Plastic materials *shall* be tested in accordance with the applicable methods specified in FTMS No. 406. The number and frequency of tests *shall* be determined by the contractor.

6-4.2.2 Elastomers

Elastomers *shall* be tested in accordance with the applicable methods specified in FTMS No. 601. The number and frequency of tests *shall* be determined by the contractor with the approval of the procuring activity.

6-4.2.3 Glass and Other Ceramic Materials

Glass and other ceramic materials *shall* be tested in accordance with the requirements of the purchase specification. The number and frequency of tests *shall* be determined by the contractor with the approval of the procuring activity.

6-4.3 PROCESS SPECIFICATIONS

The contractor *shall* provide detailed process specifications which, whenever possible, *shall* conform to the applicable Military Specifications.

6-5 COMPOSITES

6-5.1 GENERAL

It is convenient to group composite materials as laminates, filament-wound structures, honeycomb and sandwich structures, armor materials, and advanced composites. Design applications of these materials are described in Chapter 16 of AMCP 706-202.

The properties of a composite material, the manner of forming, and the use requirements of an item fabricated of composite materials are used to determine the type of analysis or test that will most effectively provide quality assurance concerning the acceptance of raw material, of processing during manufacturing, and acceptability of the item. The inspection procedures and the actual tests applied may cover a wide range—from physical tests to mechanical and chemical tests—depending on the application involved. The process controls and verification procedures *shall* be developed by the contractor and approved by the procuring activity. The test methods of FTMS No. 175 are listed in Table 6-4. Test methods for plastics are given in Table 6-2 and taken from FTMS No.-406. Additional tests for composites, taken from MIL-STD-401, are given in Table 6-3. Tests for metallic components and processes, which are listed in Table 6-1, are taken from FTMS No. 151. The reader is referred to these tables for identification of the specific tests referred to in the discussion which follows.

6-5.2 RECEIVING INSPECTION AND TEST

The contractor will inspect and test materials entering into the fabrication of composite materials in accordance with the test procedures applicable to the class of materials involved. Test procedures will be those detailed in the applicable Military Specification or in one of the ASTM tests. Applicable tests are given in the paragraphs which follow. If these are not adequate, tests suggested by the supplier and approved by the procuring activity will be employed. The sampling procedures *shall* conform to MIL-STD-105 and MIL-STD-414.

6-5.2.1 Laminates

Laminated material is widely used in electrical applications such as instrument panels, printed circuits, and parts of instruments. In these applications electrical factors such as bulk resistance, dielectric constant, loss tangent, and moisture permeability become important tests. Resistance to weathering may be important in some applications. In these cases, it is necessary to determine the effect of sunlight, atmospheric contaminants, industrial dusts, and fungus and bacterial attack.

Laminates also are used for structural members such as rotor blades, fuel cells, and helicopter skin. For these applications, mechanical property tests such as tensile strength, shear strength, fatigue life, and environmental (resistance to moisture, temperature, and salt spray, etc.) tests are of primary importance.

Laminates fabricated in-house *shall* be controlled by the procedure detailed in Chapters 16 and 18 of AMCP 706-202. The laminate usually is made from fabrics pre-impregnated with resin. Tests of such pre-impregnated fabrics *shall* include determination of the resin content, volatiles, gel time, "B" stage, shelf life, and cure. These properties are discussed in Chapter 16 of AMCP 706-202. The most effective evaluation, however, is to prepare test bars and determine the mechanical properties, including tensile strength, flexural strength, and interlaminar shear. Lay-up procedures and the time-temperature-pressure relations in cure and post-cure must be monitored carefully. Finally, for examination of the completed laminate part, visual and dimensional inspection will be supplemented with ultrasonic examination to detect voids or debonded areas. Test tabs laid up and cured along with the work piece are evaluated to verify mechanical properties and, when justified by the number of parts made, a part can be cut up and the pieces tested.

Important characteristics of flexible laminates are wear-resistance and resistance to oils, solvents, dust,

TABLE 6-2. TEST METHODS FOR PLASTICS AND BONDED STRUCTURES

TITLE OF METHOD	FED. SPEC. METHOD NO.	ASTM METHOD NO.	TITLE OF METHOD	FED. SPEC. METHOD NO.	ASTM METHOD NO.
ABRASION WEAR (LOSS IN WEIGHT)	1091		IZOD IMPACT STRENGTH	1071	D256 METHOD A
ACCELERATED SERVICE TESTS (TEMPERATURE AND HUMIDITY EXTREMES)	6011		LIGHT DIFFUSION	3031	
ACCELERATED WEATHERING TEST: CARBON ARC WITHOUT FILTERS (ALTERNATE NAVY TEST)	6022		LINEAR THERMAL EXPANSION (FUSEO-QUARTZ TUBE METHOD)	2031	D696
ACCELERATED WEATHERING TEST: SOAKING, FREEZING, DRYING, ULTRA-VIOLET CYCLE (ALTERNATE NAVY TEST)	6023		MACHINABILITY	5041	
ACCELERATED WEATHERING TEST (SUNLAMP-FOG TYPE)	6021		MAR RESISTANCE	1093	O673
ACETONE EXTRACTION TEST (FOR DEGREE OF CURE OF PHENOLICS)	7021	D494	MODIFIED SALT-SPRAY TEST (ALTERNATE NAVY TEST)	6072	
ARC RESISTANCE	4011	D495	OPTICAL UNIFORMITY AND DISTORTION	3041	D637
BEARING STRENGTH	1051		POROSITY	5021	
BLOCKING	1131	D884	POWER FACTOR AND DIELECTRIC CONSTANT	4021	D150
BONDING STRENGTH	1111	D229	PUNCHING QUALITY	5031	D617
BRITTLENESS TEMPERATURE BY IMPACT	2051	D746	RESIN IN ORGANIC-FILLED PLASTICS	7061	
CHEMICAL RESISTANCE	7011	D543	ROCKWELL INDENTATION	1081	
COLORFASTNESS TO LIGHT	6031	D620	HARDNESS TEST		
COMPRESSIVE PROPERTIES OF RIGID PLASTICS	1021	D695	SALT-SPRAY TEST	6071	
COMPRESSIVE STRENGTH OF ELECTRICAL INSULATING MATERIALS	1022	D649	SHATTERPROOFNESS	1073	
CONSTANT-STRAIN FLEXURAL FATIGUE STRENGTH	1061		SHATTERPROOFNESS (GAGE WINDOWS)	1075	
CONSTANT-STRESS FLEXURAL FATIGUE STRENGTH	1062		SHEAR STRENGTH (DOUBLE SHEAR)	1041	
CRAZING RESISTANCE UNDER STRESS	3053		SHOCKPROOFNESS	1072	
DEFORMATION UNDER LOAD	1101	D621	SHDR-TIME STABILITY TO ELEVATED TEMPERATURES OF PLASTICS CONTAINING CHLDRINE	7051	
DELAMINATION	6041		SPECIFIC GRAVITY BY DISPLACEMENT OF WATER	5011	
DIELECTRIC STRENGTH	4031	D149	SPECIFIC GRAVITY FROM WEIGHT AND VOLUME MEASUREMENTS	5012	
DRYING TEST (FOR WEIGHT LOSS)	7041		SURFACE ABRASION (SCRATCHING)	1092	
ELECTRICAL RESISTANCE (INSULATION, VOLUME, SURFACE)	4041	D257	SURFACE STABILITY, OPTICAL	3051	
ELECTROSTATIC CHARGE	4051		TEAR RESISTANCE OF FILM AND SHEETING	1121	D1004
FALLING BALL IMPACT TEST	1074		TENSILE PROPERTIES OF PLASTICS	1011	D638
FLAME RESISTANCE	2023		TENSILE PROPERTIES OF THIN SHEETS AND FILMS	1013	D882
FLAMMABILITY OF PLASTICS 0.050 in. AND UNDER IN THICKNESS	2022	D568	TENSILE STRENGTH OF MOLDED ELECTRICAL INSULATING MATERIALS	1012	D651
FLAMMABILITY OF PLASTICS OVER 0.050 in. IN THICKNESS	2021	D635	TENSILE-TIME-FRACTURE AND CREEP	1063	
FLEXURAL PROPERTIES OF PLASTICS	1031	D790	THERMAL EXPANSION TEST (STRIP METHOD)	2032	
FLOW-TEMPERATURE TEST FOR THERMOPLASTIC MOLDING MATERIALS	2041	D569	VISIBLE LIGHT TRANSMISSION AND HAZE	3021	D672
HEAT DISTORTION TEMPERATURE	2011	D648	VISIBLE LIGHT TRANSMISSION AND HAZE (INTEGRATING SPHERE METHOD)	3022	D1003 METHOD A
HOT OIL BATH TEST	6061		VOLATILE LOSS	6081	D1203
INDEX OF REFRACTION	3011	D542	WARPAGE	6051	
INTERNAL STRESS IN TRANSPARENT PLASTICS	3052		WATER ABSORPTION TEST (FOR WEIGHT AND DIMENSIONAL CHANGES)	7031	D570
			WATER VAPOR PERMEABILITY	7032	D697

and abrasion, as well as damping characteristics. Laminates of this type are subjected to peel, tear, tensile, and elongation tests; solvent stress crack tests; and evaluations for abrasion resistance and fatigue.

6-5.2.2 Filament-wound Structures

Frequently, the resin for filament winding is applied during the winding process. It is important to maintain control over volatiles, percentage of curing agent, gel time, "B" stage, and cure. The glass filament, or

tow, *shall* be tested prior to receipt; the most critical aspect here is control of tension, lay-up pattern, and relative humidity. Suitably configured test pieces formed during the lay-up *shall* be subjected to mechanical and physical tests in accordance with the contractor's test plan.

The finished product usually is subjected to ultrasonic and radiographic inspection, and then functionally tested to loads one-third greater than the peak operational loads. Items such as rotor blades *shall* be subjected to vibratory and fatigue tests. Such tests are

properly part of end-item specifications rather than part of procurement and process specification.

6-5.2.3 Honeycomb and Sandwich Structures

Any procurement and process specifications must take into account the need for verification and/or control of all the component parts of honeycomb and sandwich structures, and the relation of these parts to each other. A significant factor is the geometric configuration of the sandwich.

The tests applied to the materials used in honeycomb and sandwich structures *shall* be the same as those applied to the class of materials involved. Control of the structure involves careful monitoring of the several stages of manufacture, with test specimens being formed at the same time that the assembly is being laid up. These tests *shall* include, but not be limited to, the following:

1. Tensile Shear. The sandwich is pulled with parallel shear stresses on the opposite faces.
2. Flatwise Tensile. The sandwich is pulled normal to the faces.

3. Tensile. The sandwich is pulled in longitudinal tensile stress.

4. Compressive Strength. The sandwich is crushed normal to the faces.

5. Edgewise Compression. The sandwich is crushed parallel to the faces.

6. Flexural Strength. The sandwich is stressed on a bridging span.

These tests are listed in Table 6-2; MIL-C-8073 lists additional tests.

Other important parameters include the fillet or bond between the face material and the honeycomb, adhesion to the face material, and integrity of the honeycomb, inserts, fillers, and other sandwich materials. In addition to the mechanical tests, the structural specimens may be subjected to thermal, electrical, or other physical tests—depending on the intended use of the part. Finished parts are examined visually, and are inspected using ultrasonics, radiography, and other nondestructive testing techniques, with special emphasis on detecting delamination and areas with poor fillets.

TABLE 6-3. TEST METHODS FOR CORE MATERIALS AND SANDWICH STRUCTURES

ASTM METHOD	TITLE
C 177	METHOD OF TEST FOR THE THERMAL CONDUCTIVITY OF MATERIALS - GUARDED HOT PLATE
C 236	METHOD OF TEST FOR THE THERMAL CONDUCTIVITY AND TRANSMITTANCE
C 271	METHOD OF TEST FOR THE DENSITY OF CORE MATERIALS
C 272	METHOD OF TEST FOR THE WATER ABSORPTION OF CORE MATERIALS
C 273	SHEAR TEST IN FLATWISE PLANE
C 297	METHOD OF TEST - TENSION - FLATWISE PLANE
C 363	METHOD OF TEST - DELAMINATION STRENGTH
C 364	METHOD OF TEST - EDGEWISE COMPRESSION
C 365	METHOD OF TEST - FLATWISE COMPRESSION
C 393	METHOD OF TEST - FLEXURE TEST
C 394	METHOD OF TEST - SHEAR FATIGUE
D 1781	METHOD OF TEST - CLIMBING DRUM PEEL TEST

6-5.2.4 Armor Materials

Verification of the properties of the materials comprising the armor sample is accomplished by tests applicable to the class of material employed. For example, in the case of carbide plates dispersed in nylon, it is important to determine the number and distribution of the plates and their frangibility. The number and distribution may be determined using radiography, and frangibility by using a drop hammer impact test. Hardness *shall* be verified on a hardness tester. The nylon *shall* be tested for its usual fabric properties, but also *shall* be subjected to high strain-rate impact. The test specimens of armor first are evaluated in high strain-rate impact and then on actual firing range, using the type of projectile against which the armor is designed to be effective. A detailed discussion of armor materials is contained in Chapter 16 of AMCP 706-202.

6-5.2.5 Advanced Composites

Advanced composites may be evaluated by the same mechanical and physical tests employed for other reinforced composites, generally using test specimens produced during manufacture of the parts. The parts are subjected to dimensional, ultrasonic, radiographic, and other nondestructive tests prior to functional tests.

6-5.2.6 Special Requirements

Helicopters are subjected to environmental and operational conditions which are particularly severe for some composite materials. Rain and dust are especially severe on radomes, leading edges, and rotor blades. Protection against rain and dust is often provided by an elastomeric coating, usually polyurethane, which is sprayed, brushed, or taped. However, as operating speeds and temperatures increase, polyurethane fails to withstand the increased impact and shear stresses. An alternative protective device is a thin metal strip adhesively bonded.

Flammability and flame propagation tests are referenced in Table 6-2. Test specimens are exposed to flames of controlled dimensions and temperature in atmospherically controlled chambers. The times of char, flame, and rate of flame or combustion propagation are measured. Nonflammable and self-extinguishing material *shall* be required.

6-6 ADHESIVES

6-6.1 GENERAL

Since there is no adequate method of classifying adhesives functionally (although it is often useful to talk about "high-temperature" or "metal-bonding" adhesives), they commonly are classified by the chemical composition of the binder employed. On this basis, any adhesive may be classified as one of six chemical types:

1. Natural. Vegetable- and animal-based materials and some inorganics. Examples: casein, starch, bone glue, or sodium silicate.

2. Ceramic. Primarily used with metals, must be fired at high temperatures, usually brittle. Example: "sauereisen".

3. Elastomeric. Flexible cements used for rubber, plastic, films, metal foil, paper, and cloth. High peel strength. Examples: natural rubber, neoprene, or butadiene-styrene.

4. Thermoplastic. Primarily used with porous materials such as wood, paper, cloth, and leather. Temperature-sensitive, resistant to moisture and organic solvents. Examples: polyvinylacetate or cellulose acetate.

5. Thermosetting. Powerful bonding agents used for all bonding applications. Have high shear but often low impact strength. Examples: phenolic-epoxy, melamine, or cyanoacrylates.

6. Alloy. Blended adhesives containing binders from two or more different chemical groups. Special formulations have high shear, high impact strength, high resistance to special environmental conditions. Example: phenolic-polyvinyls, epoxy-silicone, or polyester-nitrile.

6-6.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test adhesives in conformance with FTMS No. 175. These tests are listed in Table 6-4. If this is not sufficient, tests suggested by the supplier and acceptable to the procuring activity will be employed. The sampling procedures *shall* conform to MIL-STD-105.

The shelf-life of adhesives is highly variable from one type to another and normally prescribed methods of storage *shall* be specified by the manufacturer. The accepted period for retest is "half-life" of the material. If found to be acceptable on retest, the material may be used for a period of time not exceeding twice the shelf-

life specified by the manufacturer. Further test methods are found in Part 16 of the ASTM Standards.

The most frequently employed tests are:

1. *Climbing Drum Peel Test For Adhesives*, ASTM D1781. The peel strength for many adhesives is less than 5 lb/in. but may approach 100 lb/in. for certain elastomeric and alloy adhesives.

2. *Impact Strength of Adhesives*, ASTM D950. The impact strength of adhesives depends largely on their flexibility and the rigidity of the adherends. For most adhesives the value is less than 2 ft-lb/in.² but may be as much as 50 ft-lb/in.² for alloy adhesives.

3. *Shear Strength Properties of Adhesives by Tension Loading*, ASTM D1002. Good shear strengths are about 2000 psi, but particular adhesives may exhibit shear strengths of 7000 psi.

4. *Tensile Properties of Adhesive Bonds*, ASTM D897. Tensile strengths of most adhesives are below 500 psi, but special adhesives may have tensile strengths of 15000 psi.

5. *Shear Strength Properties of Adhesives by Flexural Loading*, ASTM D1184. The flexural strength, a measure of shear and cleavage strength, *shall* fall between the tensile and shear strengths.

The tests listed in Table 6-4 are by no means all-inclusive. Other tests have been devised to evaluate particular properties for specific applications. The specific test depends on the materials to be bonded, the use requirements of the bonded part, and the environmental and functional loads to which the bond may be exposed. A bond requiring high thermal conductivity *shall* be tested thermally and one requiring permeability to ultra high-frequency electromagnetic waves *shall* be tested by electronic means.

The load characteristics of the five types of mechanical tests listed are illustrated in Fig. 6-1. In each test, the dimensions and configuration of the specimen must be defined closely in order to provide a known area of adhesive bond (known width of bond in the case of the peel test); a standardized adherend is employed. The tests must be made with equipment that can provide a controlled rate of loading. The load at failure must be determined and, preferably, the strain (percentage elongation or deformation) and strain rate should be measured.

Mechanical properties may be evaluated as a function of environmental conditions. In the course of system and subsystem qualification acceptance, those systems containing adhesive bonds may be subjected to the conditions of MIL-E-5272.

In addition to the evaluation of incoming materials, the tests of Table 6-4, and particularly the five previously listed, are used to provide process control in the bonding step. For this purpose, the part may be designed to provide a flange or other area of excess material that can be cut into specimens. Alternatively, specimens, called control tabs, may be laid up and cured along with the work piece. Testing of these control tabs provides a measure of the effectiveness of the process employed on a piece-to-piece, step-by-step basis. No quality assurance program *shall* be considered without conducting some destructive testing as described in Fig. 6-1. Ideally, the test specimen should be a precise copy of the assembly it represents. However, properly chosen standard test specimens will be satisfactory. If practical, the test should subject the specimen to the anticipated service environment, under the anticipated service load, and measure the time to failure. However, the procedure employed must yield results that have a strong correlation with results obtained in full-scale tests.

After bonding has been completed and the part removed from the fixture, the part is inspected as a purchased part. All parts *shall* be inspected visually. In addition, the part may be subjected to tapping, ultrasonic tests, button tensile tests, and proof loading.

In the case of proof loading, the part is subjected to the same type of stress—such as tension, compression, shear, or peel—as that anticipated in service; stress also should be greater than the service load, but less than the design failure load of the assembly.

Sealing compounds do not have a load-bearing function, and are subjected to somewhat different tests. Sealants are tested in accordance with MIL-S-7124 and MIL-S-7502, as appropriate. These tests also are fully described in FTMS No. 175.

6-6.3 PROCESS SPECIFICATIONS

The contractor *shall* provide detailed process specifications which conform to MIL-A-9067. Wherever possible, these *shall* conform to the applicable Military Specifications.

Cleaning and surface preparation are of primary importance in obtaining a satisfactory adhesive bond. For this reason, a process specification is required to detail the complete processes and treatments for preparing the metal faying surfaces prior to their bonding.

**TABLE 6-4. ALPHABETICAL INDEX OF TEST METHODS OF FEDERAL TEST METHOD
STANDARD NO. 175**

TITLE	PART I FEDERAL	PART II ASTM
ADHESIVES FOR BRAKE LINING AND OTHER FRICTION MATERIAL		D1205
AMYLACEOUS MATTER IN ADHESIVES		D1488
APPLIED WEIGHT PER UNIT AREA OF DRIED ADHESIVE SOLIDS		D898
APPLIED WEIGHT PER UNIT AREA OF LIQUID ADHESIVE		D899
ASH CONTENT OF ADHESIVES	4032	
BLOCKING POINT OF POTENTIALLY ADHESIVE LAYERS		D1146
BRUSHING PROPERTIES OF ADHESIVES	3021	
CLEAVAGE STRENGTH OF METAL-TO-METAL ADHESIVES		D1062
CLEAVAGE STRENGTH OF METAL-TO-METAL ADHESIVE BONDS		D1062
COPPER CORROSION BY ADHESIVES	4031	
CLIMBING DRUM PEEL TEST FOR ADHESIVES		D1781
CONDUCTING CREEP TESTS FOR METAL-TO-METAL ADHESIVES, RECOMMENDED PRACTICE FOR		D1780
CONSISTENCY OF ADHESIVES		D1084
DELAMINATION	2021	
DENSITY OF ADHESIVE IN FLUID FORM		D1875
DETERMINING THE EFFECT OF MOISTURE AND TEMPERATURE ON ADHESIVE BONDS		D1151
EFFECT OF MOISTURE AND TEMPERATURE ON ADHESIVE BONDS		D1151
FATIGUE STRENGTH OF ADHESIVES	1061	
FILLER CONTENT OF PHENOL, RESORCINOL, AND MELAMINE ADHESIVES		D1579
FLEXIBILITY OF ADHESIVES	1081	
GRIT OR LUMPS (OR UNDISSOLVED MATTER) IN ADHESIVES	4041	
HYDROGEN ION CONCENTRATION OF DRY ADHESIVE FILMS		D1583
IMPACT STRENGTH OF ADHESIVES		D950
IMPACT STRENGTH OF ADHESIVE BONDS		D950
IMPACT VALUE OF ADHESIVES		D950
NONVOLATILE CONTENT OF AQUEOUS ADHESIVES		D1489
ODOR TEST FOR ADHESIVES	4051	
PEEL OR STRIPPING STRENGTH OF ADHESIVE BONDS		D903
PEEL OR STRIPPING STRENGTH OF ADHESIVES		D903
PEEL STRENGTH OF ADHESIVES (CLIMBING DRUM APPARATUS)		D1781
PEEL RESISTANCE OF ADHESIVES (T-PEEL TEST)		D1876
pH OF ADHESIVES AND BONDED ASSEMBLIES		D1583
RESISTANCE OF ADHESIVE BONDS TO CHEMICAL REAGENTS		D896
RESISTANCE OF ADHESIVE BONDS TO WATER (WET STRENGTH)		D1151
RESISTANCE OF ADHESIVES FOR WOOD TO CYCLIC LABORATORY AGING CONDITIONS		D1183
RESISTANCE OF ADHESIVES TO CYCLIC LABORATORY AGING CONDITIONS		D1183
RUBBER CEMENTS		D816
SHEAR STRENGTH PROPERTIES OF ADHESIVES BY COMPRESSION LOADING		D905
SHEAR STRENGTH PROPERTIES OF ADHESIVES BY FLEXURAL LOADING		D1184
SHEAR STRENGTH PROPERTIES OF ADHESIVES BY TENSION LOADING		D1002
SHEAR STRENGTH PROPERTIES OF ADHESIVES DETERMINED WITH SINGLE LAP CONSTRUCTION BY TENSION LOADING		D1002
SHEAR STRENGTH PROPERTIES OF ADHESIVES IN PLYWOOD-TYPE CONSTRUCTION BY TENSION LOADING		D906
STRENGTH PROPERTIES OF ADHESIVES IN SHEAR BY TENSION LOADING (METAL-TO-METAL)		D1002
TENSILE PROPERTIES OF ADHESIVES		D897
TENSILE PROPERTIES OF ADHESIVE BONDS		D897
TENSILE PROPERTIES OF ADHESIVES FOR RUBBERLIKE MATERIALS		D816
TOTAL SOLIDS CONTENT	PROCEDURE A USE	D553
	PROCEDURE B USE	D1489
VISCOSITY AND TOTAL SOLIDS CONTENT OF RUBBER CEMENTS		D553

6-7 PAINTS AND FINISHES

6-7.1 GENERAL

Paints and finishes are materials and processes used for protection of metal parts, as well as for the application of the required color and markings of the complete helicopter. Included are processes such as anodizing of aluminum parts and plating of steel parts. Application of finishes *shall* be in accordance with the contractor's finish specification for the specific model helicopter.

The first, and often most critical, step in the process is the cleaning of the surfaces to be finished. Regardless of the surface, the materials must be free of unwanted residue such as grease, dust, and corrosion. The processing must be monitored constantly, analyzed, and

maintained at the proper compositions and conditions. Each step, if not controlled, can contaminate the next bath or work area. The use of deionized rinse water, thorough rinse, and complete drying with clean air are among the more critical stages in any of the processes. Other quality control problems in the finishing operations are:

1. Inadequate masking of the areas not to be affected by the finishing step
2. Use of the wrong masking material
3. Improper mixing of coating material
4. Improper control of application
5. Improper control of the drying step
6. Contamination before the next operation.

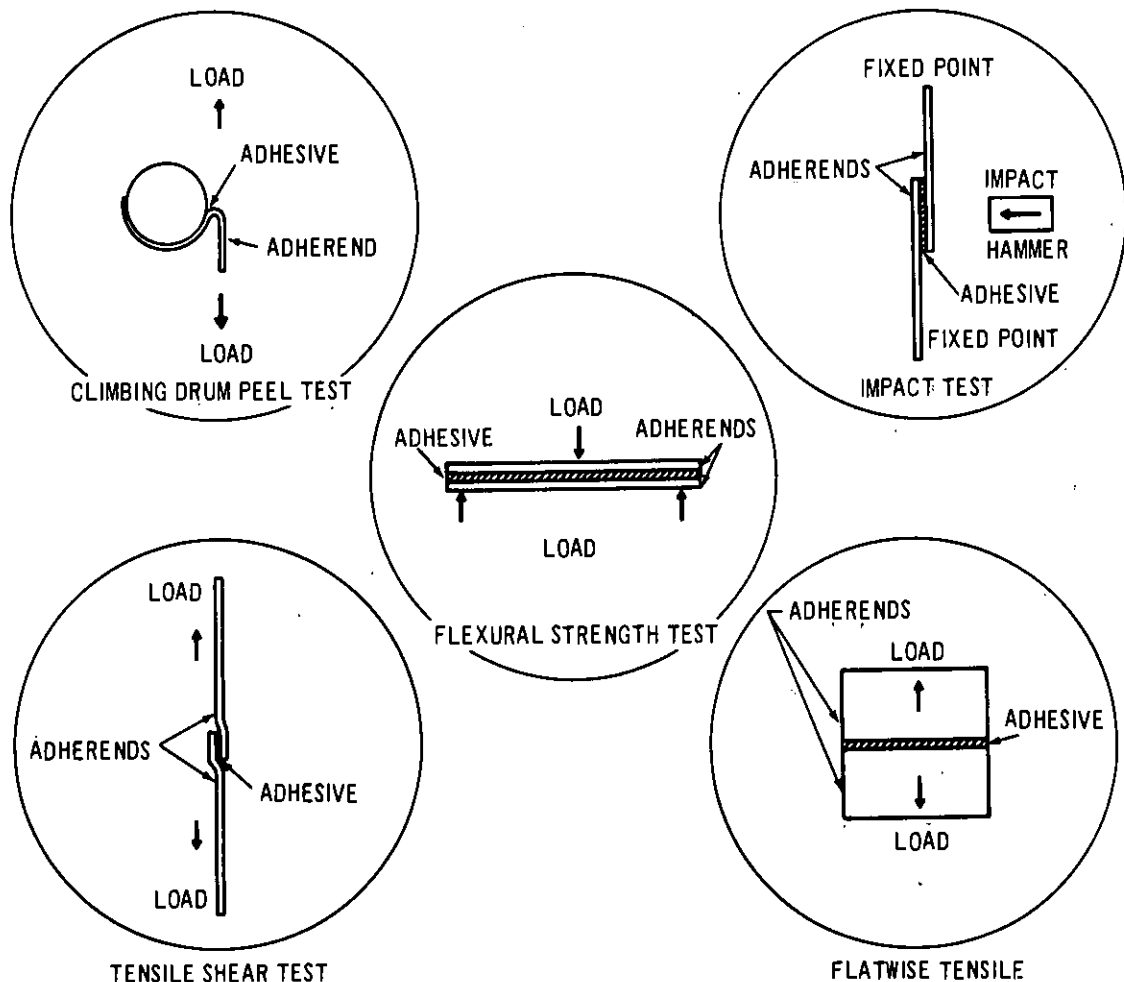


Fig. 6-1. The Load Characteristics of Five Types of Destructive Tests for Adhesives

6-7.2 RECEIVING INSPECTION AND TEST

The contractor must inspect and test materials entering into the finishing program in accordance with the test procedure applicable to the class of materials involved. Test procedures *shall* be those detailed in the applicable Military Specifications or in one of the ASTM tests. Some of these are included in a summary of the more frequently used FTMS No. 141 tests given in Table 6-5. If the tests described are not adequate, tests suggested by the supplier and approved by the procuring activity *shall* be used. The sampling procedure shall conform to MIL-STD-105 and MIL-STD-414.

6-7.3 PROCESS SPECIFICATIONS

The contractor *shall* provide detailed process specifications. Wherever possible, these *shall* conform to the applicable Military Specification.

The parts being processed must be inspected visually at several stages, and the test tabs processed along with the part *shall* be subjected to tests such as flexibility, impact flexibility, salt spray corrosion, and accelerated

weathering. Nondestructive tests applied to the work piece include adhesion and strippability, hardness, and dry film thickness using a magnetic gage. In the case of metal coatings, one or more of the tests listed in Table 6-1 may be used. Metal test tabs must be sectioned to determine coating thickness and continuity. The tabs *shall* be examined for blister, peel, and pitting; and subjected to the bend test.

6-8 LUBRICANTS, GREASES, AND HYDRAULIC FLUIDS

6-8.1 GENERAL

Appropriate lubricants and greases are required during the assembly of mechanical components of the helicopter as well as for the servicing of aircraft used in the contractor's ground and flight tests. Hydraulic fluids are used in the primary hydraulic system of the helicopter as well as in applications such as hydraulic dampers, landing gear, shock absorbers, and brakes. The lubricant used in each application *shall* be in accordance with the contractor's component and final assembly drawings.

6-8.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test lubricants, greases, and hydraulic fluids in accordance with the test procedures in the applicable Military Specifications. Representative methods of FTMS No. 791 are listed in Table 6-6. The test methods for most of the lubricating and hydraulic fluid materials covered by Military Specifications are detailed in the applicable specification. Additional methods, given in the ASTM Standards, Part 17, are tests for physical and chemical properties, functional service, and engine performance. Those listed in Table 6-6 are more frequently used for receiving and acceptance of lubricating materials and hydraulic fluids. Many of the other tests are used to qualify products for conformance to one of the specifications dealing with an end-use requirement. Of the tests listed in Table 6-6, the flash and fire points and pour point readily identify deviations from specifications. The viscosity, viscosity index, and low-temperature stability further verify the materials, and are indicative of the suitability of the lubricant to perform a particular lubricating job under specific environmental and operating conditions. Important tests for hydraulic fluids are shear stability and particulate contamination. Color, dirt content, neutralization number, and oxidation resistance are all indicative of the functional per-

TABLE 6-5. SELECTED TEST METHODS OF
FEDERAL TEST METHOD STANDARD NO.

141

TEST	141 NO.	ASTM NO.
ABRASION RESISTANCE (TABOR)	6112	
ACCELERATED WEATHERING	6151	D-822
ADHESION AND STRIPABILITY	6317	
DRY FILM THICKNESS (MAGNETIC TYPE GAGE)	6181	D-1186
EXPOSURE TESTS	6160	
GLOSS, SPECULAR	6101	D-523
HUMIDITY	6071	D-2247
FLEXIBILITY - COLD CRACKING	6223	
- % ELONGATION	6222	
HIDING POWER	4122	
IMPACT FLEXIBILITY	6226	
KNIFE TEST	6304	
RUSTING RESISTANCE	6451	D-610
RING AND BALL SOFTENING	4495	E-28
SALT SPRAY (FOG) TEST	6061	B-117
SPRAYING PROPERTIES	4331	
STORAGE STABILITY	3022	
VEHICLE SOLIDS	4051	
VISCOSITY	4287	
VOLATILE AND NONVOLATILE	4041	
VOLUME PERCENT PIGMENT	4312	

formance and contamination of lubricants, and readily indicate degradation under use or in storage. They also alert the user of potential hazards to equipment. If the tests outlined previously are not adequate, tests suggested by the supplier and approved by the procuring activity *shall* be used. The sampling procedure *shall* conform to MIL-STD-105 and MIL-STD-414. For additional information on hydraulic fluids, refer to AMCP 706-123.

6-9 CASTINGS, FORGINGS, AND EXTRUSIONS

6-9.1 GENERAL

Castings, forgings, and extrusions constitute a significant portion of the empty weight of a helicopter. These components are used in a number of critically loaded areas: gears and shafts, hubs, landing gear, and major load-bearing beams. Other applications include control levers and links, gearbox housings, structural fittings, and frames. The parts produced range from the

smallest parts of instruments to large forgings for rotor hubs. The materials employed in these processes include cast iron, steels, high-performance alloys, copper, magnesium, aluminum, titanium, and zinc. Sand, investment, centrifugal, permanent mold, and die castings are the common methods used to produce castings.

6-9.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test materials entering into the in-house production of castings, forgings, and extrusions, and *shall* inspect and test castings, forgings, and extrusions in accordance with the test procedures applicable to the class or grade of part involved.

Some of the test methods are listed in Table 6-1. Further tests are found in the ASTM Standards. If the tests listed are not adequate, those suggested by the supplier and approved by the procuring activity *shall* be used. The sampling procedure *shall* conform to MIL-STD-105 and MIL-STD-414. Laboratories and personnel required to conduct certain of the tests listed in Table 6-1 must be certified. Certification require-

TABLE 6-6. SELECTED TEST METHODS OF FEDERAL TEST METHOD STANDARD NO. 791

TEST	791B METHOD	ASTM METHOD
ASTM COLOR OF PETROLEUM PRODUCTS	102	D1500
CONTAMINATION, PARTICULATE, IN HYDRAULIC FLUIDS	3009	
COPPER CORROSION BY PETROLEUM PRODUCTS (COPPER STRIP TEST)	5325	D130
DENSITY AND SPECIFIC GRAVITY OF LIQUIDS BY LIPKIN BICAPILLARY PYCNOMETER	402	D941
DIRT CONTENT OF GREASE	3005	
EVAPORATION LOSS OF LUBRICATING GREASES AND OILS (HIGH TEMPERATURE)	350	
FLASH AND FIRE POINTS BY CLEVELAND OPEN CUP	1103	992
LOW TEMPERATURE STABILITY	3458	
ANALYSIS OF LUBRICATING GREASE	5412	D128
NEUTRALIZATION NUMBER	5106	D664
OXIDATION RESISTANCE	5308	
POUR POINT	201	D97
SHEAR STABILITY (SONIC OSCILLATION)	3471	
VISCOSITY OF TRANSPARENT AND OPAQUE LIQUIDS (KINEMATIC AND DYNAMIC VISCOSITIES)	305	D445
CALCULATING VISCOSITY INDEX	9111	D2270
WEAR LIFE OF DRY, SOLID FILM LUBRICANTS	3807	
OSCILLATION TEST OF GREASE IN HELICOPTER BEARINGS	6516	

ments are contained in MIL-STD-410, MIL-I-6866, MIL-I-6868, and MIL-I-6870.

6-9.2.1 Castings

The inspection and test of castings are governed by MIL-C-6021. They are classified as follows:

1. Class I. Any casting whose failure will cause significant danger to operating personnel or would result in a significant operational penalty. This includes loss of major components, loss of control, unintentional release or inability to release armament stores, or failure of weapon installation components. Class I castings *shall* be further classified as:

- a. IA. A Class I casting, the single failure of which would result in the loss of the craft.
- b. IB. All other Class I castings.

2. Class II. All other castings:

- a. IIA. Castings having less than 200% margin of safety
- b. IIB. Castings having greater than 200% margin of safety, or for which no stress analysis is required.

The contractor *shall* determine the class and make the necessary callouts on the drawings and specifications, and supporting documents.

These classes are not applicable to hydraulic or pneumatic system components or other castings requiring hydrostatic proof testing, which must satisfy the requirements of MIL-H-8775.

Castings *shall* be 100% visually inspected for inadequate fillets, recesses, sharp corners, cracks, cleanliness, surface defects, shrink, stress raisers, and tool marks. In addition, the castings *shall* be 100% inspected by magnetic particle or by penetrant dye, except that Class IIB castings may be sampled per MIL-STD-105.

During processing, the castings *shall* be subjected to the appropriate inspection after each operation such as heat treat, machining, grinding, and plating. They are reinspected prior to assembly.

Radiographic examination pertaining to classes consists of:

- 1. Class IA: 100%
- 2. IB: Per MIL-C-6021
- 3. IIA: MIL-C-6021
- 4. IIB: Not required.

The procuring activity may introduce additional standards into the line and may request one section of a part for test. The maximum acceptable defects by radiographic examination are given in Table 6-7.

In addition to the nondestructive tests in Table 6-7, it is necessary to perform the following tests and/or inspections:

1. Chemical Analysis. The sample is taken from drillings or millings, or tension test bars from the casting.

2. Tensile Tests. In the case of castings weighing 500 lb or more, the test coupons will be attached to the casting or machined from an extension of the casting. Separate bars may be cast when (a) the extra length on a permanent mold casting is not practical; (b) there are less than 10 castings or 500 lb in the lot,¹ and (c) specimens of the required dimensions cannot be machined from the casting. Tensile specimens will be taken from midway between the inside and outside diameter of the portion of the casting remaining after finish machining.

3. Hardness. Method ASTM E10 (Brinell) or Method ASTM E18 (Rockwell) of FTMS No. 151 *shall* be used, depending on the alloy.

4. Dimensional. Allowable tolerance will be shown on the first item detail layout drawings.

6-9.2.2 Forgings

The procuring activity may require forging die qualification inspection. The forging stock will be of such size and dimensions that the work accomplished in forming to finished shape will result in approximately uniform grain throughout. The forging operation must produce an internal grain flow pattern such that the direction of flow in highly stressed areas will be essentially parallel to the principal stresses. The grain pattern will be essentially free from reentrant and sharply folded lines. Tensile specimens are to be taken from the midsection with the axis of the test specimen perpendicular to both the radius of the forging and the axis of the forging. The tensile yield and ultimate strength will be determined on a minimum of two specimens. Ultrasonic testing, magnetic particle, and/or fluorescent penetrant inspection may be required. Determination of hardness is mandatory, and grain flow and radiography may be required. Minimum required tests of steel forgings are listed in Table 6-8.

¹ A lot is defined as all castings of a specific design of one alloy produced by the same process at one facility and submitted for inspection at one time.

TABLE 6-7. ACCEPTANCE REQUIREMENTS FOR CASTINGS, MIL-C-6021

DEFECT	RADIOGRAPHIC REFERENCE	MAXIMUM PERMISSIBLE RADIOGRAPH PER ASTM E71			
		GRADE A OR CLASS I A HIGH STRESS AREAS	GRADE B OR CLASS I A LOW STRESS AREAS, CLASS I B HIGH STRESS AREAS	GRADE C OR CLASS I B LOW STRESS AREAS, CLASS II A HIGH STRESS AREAS	GRADE D OR CLASS I LOW STRESS AREAS
GAS AND BLOWHOLES	A	NONE	1	2	3
SAND SPOTS AND INCLUSIONS	B	NONE	1	2	3
INTERNAL SHRINKAGE	C	NONE	1	2	3
HOT TEARS	D	NONE	NONE	NONE	NONE
CRACKS	E	NONE	NONE	DWG.TOL.	DWG.TOL.
UNFUSED CHAPLETS	F	NONE	NONE	1	2
INTERNAL CHILLS	G	NONE	NONE	NONE	1

DEFECT	RADIOGRAPHIC REFERENCE	MAXIMUM PERMISSIBLE RADIOGRAPH PER NAVAER 00-15PC-504 OR ASTM E98			
		GRADE A OR CLASS I A HIGH STRESS AREAS	GRADE B OR CLASS I A LOW STRESS AREAS, CLASS I B HIGH STRESS AREAS	GRADE C OR CLASS I B LOW STRESS AREAS, CLASS II A HIGH STRESS AREAS	GRADE D OR CLASS I LOW STRESS AREAS
GAS HOLES	1.1	NONE	2	4	6
GAS POROSITY (ROUND)	1.21	NONE	1	2	5
GAS POROSITY (ELONGATED)	1.22	NONE	1	3	5
SHRINKAGE CAVITY	2.1	NONE	1	3	4
SHRINKAGE POROSITY OR SPONGE	2.2	NONE	1	3	5
FOREIGN MATERIAL (LESS DENSE MATERIAL)	3.11	NONE	1	3	5
FOREIGN MATERIAL (MORE DENSE MATERIAL)	3.12	NONE	NONE	1	2
SEGREGATION	3.2	NONE	NONE	1	1
HOT CRACKS	4.1	NONE	NONE	NONE	NONE
COLD CRACKS	4.2	NONE	DWG.TOL.	DWG.TOL.	DWG.TOL.
COLD SHUTS	4.3	NONE	DWG.TOL.	DWG.TOL.	DWG.TOL.
SURFACE IRREGULARITIES	5.1	NONE	DWG.TOL.	DWG.TOL.	DWG.TOL.
MISRUNS	5.2	NONE	DWG.TOL.	DWG.TOL.	DWG.TOL.
CORE SHIFT	5.3	NONE	DWG.TOL.	DWG.TOL.	DWG.TOL.

DEFECT	RADIOGRAPHIC REFERENCE	MAXIMUM PERMISSIBLE RADIOGRAPH PER NAVAER 00-15PC-504 OR ASTM E 98			
		GRADE A OR CLASS I A HIGH STRESS AREAS	GRADE B OR CLASS I A LOW STRESS AREAS, CLASS I B HIGH STRESS AREAS	GRADE C OR CLASS I B LOW STRESS AREAS, CLASS II A HIGH STRESS AREAS	GRADE D OR CLASS II A LOW STRESS AREAS
GAS HOLES	1.1	NONE	1	2	3
GAS POROSITY (ROUND)	1.2	NONE	NONE	1	2
SHRINKAGE CAVITY	2.1	NONE	NONE	1	2
MICRO-SHRINKAGE	2.3	1	2	3	6
FOREIGN MATERIAL (LESS DENSE MATERIAL)	3.11	1	2	3	5
FOREIGN MATERIAL (MORE DENSE MATERIAL)	3.12	1	1	2	2
HOT CRACKS	4.1	NONE	NONE	NONE	NONE
COLD CRACKS	4.2	NONE	DWG.TOL.	DWG.TOL.	DWG.TOL.
COLD SHUTS	4.3	DWG.TOL.	DWG.TOL.	DWG.TOL.	DWG.TOL.
SURFACE IRREGULARITIES	5.1	DWG.TOL.	DWG.TOL.	DWG.TOL.	DWG.TOL.
MISRUNS	5.2	DWG.TOL.	DWG.TOL.	DWG.TOL.	DWG.TOL.

NOTES:

- (1) WHEN TWO OR MORE TYPES OF DEFECTS ARE PRESENT TO AN EXTENT EQUAL TO OR NOT SIGNIFICANTLY BETTER THAN THE ACCEPTANCE STANDARDS FOR RESPECTIVE DEFECTS, THE PARTS SHALL BE REJECTED.
- (2) WHEN TWO OR MORE TYPES OF DEFECTS ARE PRESENT AND THE PREDOMINATING DEFECT IS NOT SIGNIFICANTLY BETTER THAN THE ACCEPTANCE STANDARD, THE PART SHALL BE CONSIDERED BORDERLINE.
- (3) BORDERLINE CASTINGS WILL BE CONSIDERED ACCEPTABLE UPON REVIEW BY COMPETENT ENGINEERING PERSONNEL AND GOVERNMENT QUALITY CONTROL.
- (4) GAS HOLES OR SAND SPOTS AND INCLUSIONS ALLOWED BY THIS TABLE SHALL BE CAUSE FOR REJECTION WHEN CLOSER THAN TWICE THEIR MAXIMUM DIMENSION TO AN EDGE OR EXTREMITY OF A CASTING.
- (5) DWG.TOL. IS DEFINED AS MINIMUM THICKNESS OF MATERIAL AFTER DEFECT IS REMOVED BY MACHINING.

6-9.2.3 Extrusions

Extrusions are subjected to essentially the same tests as forgings. A first article detail layout and inspection *shall* be required.

The detail layout *shall* illustrate the billet to be extruded, the die, and the extruded product. The layout must include the grain flow lines; the required contour and cross section; and the grain structure, hardness, and tensile strength in the longitudinal, lateral, and transverse directions, as well as the location of the test specimens. First article inspection will be used to verify the contour and dimensions. The test specimens *shall* be used to verify the grain structure, flow lines, hardness, and tensile strength in the longitudinal, lateral, and transverse directions.

6-10 SHEET METAL FORMING

6-10.1 GENERAL

Accepted forming practices utilized in the fabrication of helicopters include hydroforming, stretch press forming, drop hammer forming, and explosive forming. In each of these techniques the material is stretched or compacted, which results in varying thicknesses. Methods and techniques for controlling these thickness variations are required in order to assure repeatability of the qualified design. These are discussed in the subsequent paragraphs.

6-10.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test materials used in the fabrication of sheet metal products in accordance with the test procedure applicable to the class of materials involved. Test procedures will be those de-

tailed in the applicable specification or in one of the ASTM tests. If the tests described are not adequate, tests suggested by the supplier and approved by the procuring activity *shall* be employed. The sampling procedures *shall* conform to MIL-STD-105 and MIL-STD-414.

6-10.3 PROCESS SPECIFICATIONS

The contractor *shall* provide detailed process specifications, defining materials, machines, ideas, inspection stages, and tests. The procuring activity may require a first article detail layout of certain parts.

Inspection and test requirements for parts formed by hydroforming, stretch press forming, drop hammer forming, or explosive forming are identical. The procedures and tests used are dependent on the size, configuration, and material of the part rather than on the process used. Most inspection of sheet metal parts is visual in order to discover defects and to make a dimensional check of the formed part. Machine forming operations require examination of the parts on a preplanned sampling basis (MIL-STD-105). This examination includes verification of the weight and dimensions, suitable tensile tests, and penetrant dye and/or magnetic penetrant inspection to detect cracks. Metallurgical examination of grain structure may be required to investigate unsatisfactory test results. A very useful test for materials subjected to drawing is the Erichsen test, which determines the deep-drawing qualities of sheet metal. Blanks of metal are placed in the small press and sealed with a holder so that a certain amount of inward flow is allowed under the action of the punch. Experienced operators are able to judge average grain size of the sample by the roughness of the formed dome. The roughness or surface texture of the formed part can be estimated or measured. The type of fracture is indicative of the structure and directional properties of the metal. Thickness of the stretched and drawn material is determined by using suitable micrometers.

TABLE 6-8. STEEL FORGING TEST REQUIREMENTS BY GRADE

TEST	GRADE		
	A	B	C
TENSILE	X	X	
HARDNESS	X	X	X
MAGNETIC PARTICLE OR PENETRANT DYE	X		X
GRAIN FLOW	X		
CHEMICAL ANALYSIS	X		X

6-11 MACHINING OPERATIONS

6-11.1 GENERAL

The machining operation normally is the last process preceding final inspection, followed by finishing, painting, assembly, and shipping. For this reason, all possible quality defects will be cumulative to this point. Defects and rejects in this area, as well as other areas,

will be documented and parts dispositioned in accordance with approved procedures.

6-11.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test materials entering into the machining operations in accordance with the test procedures applicable to the class of materials involved. The test procedures *shall* be those detailed in the applicable Military Specification, an approved non-Governmental specification, or one of the ASTM tests. Applicable tests have been listed in Table 6-1 of par. 6-2.2, which presents the metal test methods of FTMS No. 151. The sampling procedure *shall* conform to MIL-STD-105 and MIL-STD-414. No material is to be issued for machine operations without a record of receiving inspection and test.

6-11.3 PROCESS SPECIFICATIONS

Machining process specifications may relate to the use of the machine, use of the material, or special instructions for a particular part. The specifications also *shall* define the inspection requirements.

The first step in inspection and test is examination of a part to verify that the operation performed is the one scheduled, in the correct sequence, and in conformance to the drawing, specifications, and shop instructions. Further verification of compliance with the drawing is then determined by test.

Inspection of machining operations is concerned with dimensions, particularly where close tolerances are involved. Very precise instruments are required and the measurements must be made under "standard conditions".

An increasing number of machines are being designed to handle optical profile projection and automatic inspection functions. Special tools often are required to serve as masters to verify large parts or complex assemblies. These are discussed in par. 6-15.

In addition to these dimensional inspections, any or all of the tests referred to in the preceding paragraphs may be employed in the several stages of processing. This is particularly true of hardness tests after heat treating.

6-12 JOINING OPERATIONS

6-12.1 GENERAL

The joining systems discussed herein are welding, brazing, soldering, riveting, and swaging. The equip-

ment as well as personnel involved in the process may require certification in order to meet specified requirements. The system for controlling these operations is discussed in the paragraphs which follow.

6-12.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test materials entering into the fabrication of joined parts in accordance with the test procedures applicable to the class of materials involved. Test procedures *shall* be those detailed in the applicable Military Specification, one of the approved non-Governmental specifications, or an ASTM test.

Verification of the materials to be joined and of the materials employed in joining is to be accomplished by means of one or more of the test methods listed in Table 6-1.

The materials to be employed for joining operations often are tested by actually welding, brazing, or soldering samples; observing the performance of the materials; and destructively testing the specimens. The procedures for qualifying the materials *shall* be the same as those for qualifying the parts.

6-12.2.1 Welding

The welding procedure *shall* be qualified in accordance with the requirements of MIL-STD-248. The operator *shall* be certified to the requirements of MIL-T-5021.

The initial weld inspection is visual. Some of the defects readily detected visually are porous welds, poor penetration, warping, undercutting, distortion, cracked welds, poor appearance, poor fusion, spatter, and magnetic flow. Any of these may be cause for rejection of a part. A series of gages provides a means of checking the size and contour of beads and fillets.

Other nondestructive tests used for inspection purposes are:

1. Magnetic Particle Test. Detects surface or near surface cracks, porosity, or other discontinuities.
2. Penetrant Dye Test. Detects surface flaws, cracks or cold shuts, partial weld or lap, pits, and porosity.
3. Ultrasonic Inspection. Detects deep-seated flaws, cracks, voids, and porosities.
4. Radiographic Inspection. Detects deep-seated flaws, cracks, voids, and porosities even in thick, complex specimens.

Destructive tests employed are tensile test, bend test, Charpy impact, chemical analysis, metallography, and hardness.

6-12.2.2 Brazing

Brazing *shall* be performed in accordance with MIL-B-7883. There are two grades of brazed joints:

1. Grade A. Joints for critical fittings and structural applications, the single failure of which would cause danger to personnel, loss of major components, or loss of control.

2. Grade B. Joints for noncritical fittings and noncritical structural applications.

Both A and B grades are examined for porosity. One pinhole which has a diameter no greater than 0.015 in. per linear inch; fine porosity not exceeding 50% of the braze fillet width and not more than one per linear inch; and linear surface porosity not exceeding 3/16 in. or one per linear inch are permitted. Also, the braze must be free of blisters and residual flux. The joint should be examined for excess braze material, unmelted brazing alloy, and penetration; i.e., the brazing alloy must appear on all edges of the joint.

Grade A joints must not have more than 20% of the faying surface unbrazed for aluminum or 15% for all other metals. No single unbrazed area is to exceed 20% of the overlap area. Grade A joints are to be subjected to radiographic examination.

Ultrasonic examination and penetrant dye inspection also may be useful in the evaluation of brazed joints, and the destructive tests may be applied as determined by the requirements of the application.

6-12.2.3 Soldering

Soldering *shall* be accomplished in accordance with MIL-S-45743. The visual methods of inspection for solder joint are similar to those for brazed joints. Because of the requirements for electrical continuity or for complete sealing against fluids normally applicable to soldered joints, no porosity is tolerated. The surfaces must be completely wet and the bead or fillet smooth. Dirty solder surfaces or dirty faying surfaces must not be tolerated.

Nondestructive tests normally are not used for solder joints, but the destructive tests and proof testing of cables and conduits are often required on a sampling basis.

6-12.2.4 Riveting

The inspection of riveted joints is primarily visual with particular attention directed to the set and flare of

the rivet; contact between the faying surfaces; absence of cracks or strain lines; buckling or warp; and presence of primer, adhesive, or sealer where required. Attention also is directed to detecting any separation due to misalignment or failure to deburr the holes before riveting. The riveted joint *shall* be checked dimensionally for conformance to the riveting pattern.

The primary nondestructive test is radiographic, which detects cracks and distortions that may be present in heavier assemblies not easily inspected visually. Penetrant dye may reveal cold working cracks that are not readily visible, and vibration may reveal areas of seams that have not been set with adequate compression.

Riveted specimens or sections from riveted parts may be subjected to tensile testing to verify strength requirements.

6-12.2.5 Swaged Joints and Cables

The inspection of swaged joints is primarily visual with particular attention directed to the set of the swaging cleat or joint, absence of cracks or strain lines, and the presence of proper flare. The primary nondestructive test is radiographic, which may detect cracks and distortions that are present in heavier assemblies. Penetrant dye may reveal surface stress and cold working cracks that are not readily visible. A hardness profile near large, swaged joints may be required. Swaged parts and cables may be subjected to proof testing to verify load-bearing capacity.

If the tests described are not adequate, tests suggested by the manufacturer and approved by the procuring activity *shall* be employed. The sampling procedure *shall* conform to MIL-STD-105 and MIL-STD-414.

6-13 HEAT TREATMENT

6-13.1 GENERAL

Heat treat equipment and operations must be demonstrated to be capable of producing the combinations of mechanical properties in the various metals defined by appropriate material specifications and design drawings.

6-13.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test materials entering into the heat treating processes, and *shall* inspect and test parts that have been heat treated in accordance

with the procedures applicable to the class of materials involved. Test procedures *shall* be those detailed in the applicable Military Specification, or in one of the ASTM tests. Some of these test methods are listed in a summary of FTMS No. 151 in Table 6-1. If the tests described are not adequate, tests suggested by the supplier and approved by the procuring activity *shall* be employed. The sampling procedures *shall* conform to MIL-STD-105 and MIL-STD-414.

6-13.3 PROCESS SPECIFICATIONS

The contractor *shall* provide detailed process specifications which *shall* conform to the requirements of Chapter 18 of AMCP 706-202, wherever possible.

The requirements for temperature uniformity in the heat treatment of all engineering metals are much the same and will be illustrated by the requirements for steel. The design and the capacity of the heating equipment must be such that the temperature at any point in the working zone does not exceed the maximum of the respective range specified for the process and does not vary more than 25°F (15°F for tempering or aging) from the desired heat treating temperature after the charge has been brought up to temperature. Representative heat treat temperatures for various metals are shown in Table 6-9.

6-13.3.1 Steels

Heat treatment of steels *shall* be performed in accordance with the requirements of MIL-H-6875. The suitability of the equipment and processes selected *shall* be confirmed by tests on materials heat treated by the

contractor. Processed specimens *shall* be examined for surface contamination, and tested for mechanical properties. The microstructure *shall* be examined metallurgically, although routine quality control may utilize only hardness tests.

6-13.3.2 Aluminum Alloys

Heat treatment of aluminum alloys *shall* be accomplished in accordance with MIL-H-6088. All parts for any charge for which the specified mechanical properties are not obtained *shall* be rejected. When eutectic melting or high-temperature oxidation occur, the lot *shall* be rejected.

When a lot is rejected, the equipment and procedure must be requalified. Parts in which eutectic melting, high-temperature oxidation, or diffusion through the cladding are found may not be reprocessed. Other rejected parts with a thickness of less than 0.25 in. may be reprocessed once; parts thicker than 0.25 in. may be reprocessed twice.

6-13.3.3 Copper Alloys

Heat treatment of copper alloys *shall* be performed in accordance with MIL-H-7199.

Acceptance of the heat treating process and related equipment for production use *shall* be determined by the results of tensile and grain size tests made on production material. A minimum of two samples *shall* be selected from each of the types of material in a batch (plate, bar, formed parts, etc.) and tested according to ASTM E8 and ASTM E112 of FTMS No. 151. The samples *shall* meet the grain size, tensile strength, yield strength, and elongation requirements for the applica-

TABLE 6-9. REPRESENTATIVE HEAT TREAT TEMPERATURES
TEMPERATURE IN °F FOR:

METAL	SOLUTION H T ANNEALING FURNACE COOL	NORMALIZE AIR COOL	HARDEN QUENCH	TEMPER QUENCH	STRESS RELIEF AIR COOL
STEEL - 4140	1525 - 1575	1600 - 1700	1525 - 1600	1075	1600 - 1700
TITANIUM 4AL-3MO-1V	1620 - 1700		900 - 975		900 - 1100
COPPER - BE ALLOY NO.175	1700		900		
ALUMINUM 2024	900 - 930		370 - 380		
MAGNESIUM AZ91C	775 - 790		400 - 425		

ble alloy and temper designation as shown in the material specification. Failure to meet requirements indicates improper heat treatment; the lots represented by the tests *shall* be rejected, and no further material processed until the equipment and procedure have been requalified. Reprocessing of overheated material is not permitted, although other materials may be reprocessed.

6-13.3.4 Titanium

Heat treatment of titanium and titanium alloys *shall* be accomplished in accordance with MIL-H-81200.

The suitability of equipment and the heat treating process for titanium *shall* be determined by the resulting mechanical properties, microstructure, and contamination level of hydrogen, oxygen, and nitrogen. A minimum of nine tensile, nine Charpy impact, and nine bend tests *shall* be made each month on specimens from a production load. The tensile yield, ultimate tensile, and Charpy impact strengths, and the elongation and reduction in area must not be less than those specified in the procurement specifications. There *shall* be no evidence of metal separation or cracking in the bend test. When tests indicate improper heat treatment, all material processed in, and subsequent to, the batch tested *shall* be rejected, and the equipment and the process requalified. Rejected materials may be reprocessed by beginning with annealing or solution heat treat in an acceptable furnace.

6-14 PEENING

6-14.1 GENERAL

Shot-peening frequently is used to improve the fatigue characteristics of helicopter components. The peening process is used for local hardening, and surface and subsurface stressing.

Materials and processes employed in shot-peening *shall* be performed in accordance with the requirements of MIL-S-13165.

6-14.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test materials entering into the peening operations in accordance with the test procedure detailed in the applicable Military Specification, an approved non-Governmental specification, or in one of the ASTM tests. The sampling procedure *shall* conform to MIL-STD-105 and MIL-STD-414.

6-14.3 PROCESS SPECIFICATIONS

The contractor *shall* provide detailed process specifications to govern the peening processes to be employed. There *shall* be separate specifications for each type of peening: cleaning, stress relief, prestressing, and forming. Material, equipment, and operator safeguards *shall* be defined clearly. The specifications must provide for material uniformity, for equipment, and for operator certification, and *shall* contain the peening safeguards outlined in Chapter 18 of AMCP 706-202.

The composition and particle size of shot and glass beads *shall* be verified by chemical analysis and screening. For cleaning operations, visual inspection usually is adequate. For stress relief, randomly selected parts may be sectioned and examined metallurgically and a hardness, or microhardness, profile determined. For larger parts, a hardness profile may be run on the area processed on each part. In prestressing for fatigue resistance and for hardening, and in forming by shot-peening, it is customary to use test strips of the same composition and temper as the metal being worked. The test strips should be subjected to the same peening operations as the metal being worked; i.e., the same shot, air pressure, angle of incidence, number of passes, and time of application. The test strips then should be tested mechanically (e.g., tensile, fatigue, and bending); should be tested for surface hardening; and then should be sectioned to determine metallurgically the depth of working. Contour-formed parts should be checked optically, by templates or against mold masters. The magnetic particle, penetrant dye, or radiographic tests may be applicable, depending on the part being worked.

6-15 TOOL CONTROL

6-15.1 GENERAL

One of the critical functions in assuring repeatability in the manufacturing and assembly cycle is tool control. The tools utilized in the manufacturing and fabrication cycle must have the capacity to reproduce each detail, subassembly, and assembly in accordance with the accepted design configuration. As engineering design changes are proposed, it is essential that they be reviewed for impact on applicable tooling. These changes also must be monitored for impact on subcontractors. The subsequent paragraphs discuss the system and procedures essential in controlling tools for the complete system manufacturing cycle.

6-15.2 RECEIVING INSPECTION AND TEST

The contractor *shall* inspect and test materials entering into the fabrication of tools in accordance with the test procedures applicable to the class of materials involved. The sampling procedures *shall* conform to MIL-STD-105 and MIL-STD-414. Purchased parts and tools *shall* be inspected for compliance to the detail layout drawing.

6-15.3 PROCESS SPECIFICATIONS

The contractor *shall* provide a detailed process specification covering the fabrication of tools to be employed in the manufacture and assembly of the helicopter. The contractor also *shall* provide detailed process instructions for the use of the tools in production, for recheck and/or recalibration, and for inspection of the parts produced by the tool.

6-15.4 INSPECTION, QUALITY CONTROL, AND CONFIGURATION CONTROL

Control of design, tooling, production, and qualification is accomplished by configuration management. Elements of identification are contract end-item

specification numbers, serial numbers, drawing and part numbers, and change and code identification numbers. Elements of change are drawing change notices. Recording and verification are achieved by engineering release and change incorporation records. Physical configuration control is achieved by means of continuous inspection at all stations, by periodic audit and recalibration of all tools, and by programmed reference to master tools, dies, or templates.

The evolution of master tooling is illustrated in Fig. 6-2. Master tool control normally is the only practical method of coordinating tooling and insuring interchangeability. The accuracy and ease with which mating assemblies fit or are individually interchangeable are dependent on the control of size, shape, and matching condition at attachment points. The subcontracting of assemblies and detail parts makes control of each assembly more critical. The concept of master tooling employs a parent or master tool which establishes and maintains all critical points, planes, and surfaces; and is used in making manufacturing, assembly, and inspection tools.

The contractor *shall* prepare a program of inspection and tool verification to be employed in the manufacture of the contract end-item. This program then becomes part of a comprehensive configuration control plan.

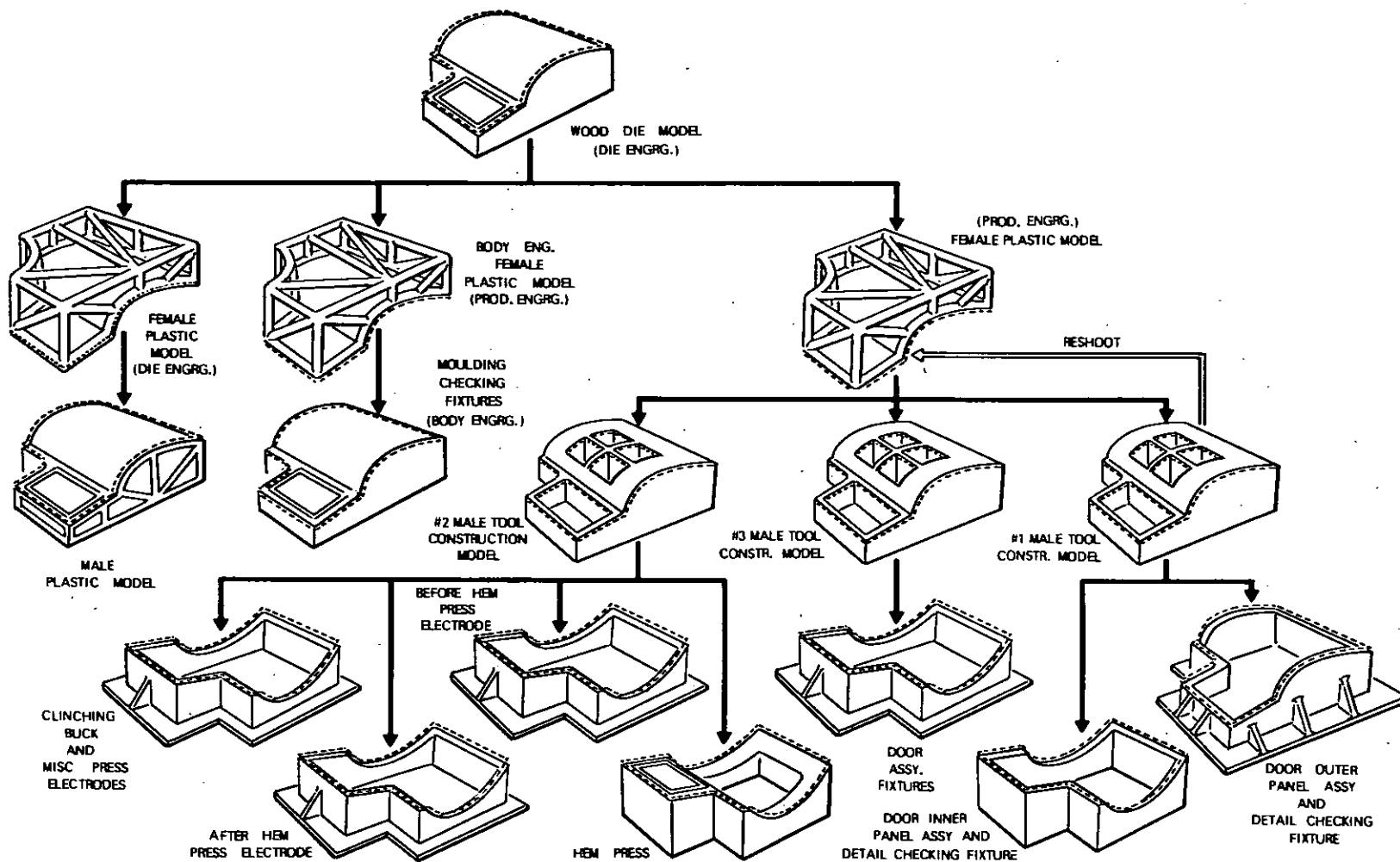


Fig. 6-2. Master Tooling Coordination



CHAPTER 7

COMPONENT TESTS AND QUALIFICATION

7-1 INTRODUCTION

Many individual components used in helicopter subsystems must be qualified separately in addition to being qualified in the subsystem installation. As with the helicopter system, component qualification involves demonstration of compliance with specific design requirements. The methods of qualification and types of testing vary greatly since the requirements differ significantly among subsystems and among components. For those components directly affecting safety of flight—such as the engine, transmission, rotor and drive shafting—qualification essentially must be completed prior to the first flight of the helicopter or sufficient testing *shall* have been conducted to justify limited flight testing. Although qualification of helicopter engines is beyond the scope of this handbook, transmission and drive shafting qualification is discussed.

Because of the diversity of components within a helicopter, and the great variety of applicable qualification requirements, this chapter cannot provide detailed information on component qualifications. However, the types of components included in a night VFR helicopter and the types of tests which *shall* be performed in each category of component are identified. Also, reference is made to all applicable specifications wherever possible.

In several cases, where applicable specifications do not provide sufficient information for the preparation of an appropriate plan or the conduct of an adequate program, additional information is presented. This is particularly true of transmission and drive system components. Experience has indicated the need for a significant amount of testing prior to formal qualification. Although not outlined by the applicable design or test specifications, this prequalification testing is required to assure satisfactory performance and to verify the suitability of the component for helicopter installation.

Although prequalification testing is not required for other types of components, failure to obtain early assurance that the design complies with qualification requirements can have serious impact on program cost

and schedule commitments because procurement of production quantities often cannot be withheld pending completion of component qualification. In these cases, sufficient testing to identify deficiencies in design or operational requirements can avoid extensive and costly rework.

7-2 QUALIFICATION REQUIREMENTS

Component qualification testing consists of four basic types: (1) functional; (2) structural; (3) endurance; and (4) environmental.

7-2.1 FUNCTIONAL TESTS

Qualification of helicopter components includes the demonstration of specified functional or operational characteristics. In the case of components furnished by the contractor, the operational design performance requirements *shall* be specified in the contract end-item or procurement specification prepared by the contractor and approved by the procuring activity. Examples of some operational requirements for several types of components are:

1. Fuel or Hydraulic Pumps. Flow rate and pressure at design input speed and torque
2. Avionic Components. Signal strength and frequency at design input voltage
3. Instruments. Accuracy of indication over design range, using calibrated source.

7-2.2 STRUCTURAL TESTS

Numerous components cannot be qualified for installation on a helicopter until demonstration of their structural integrity has been achieved. Included are items such as castings which form a part of the primary structure, armor components, fuel and oil tanks, and transparent areas (i.e., windshields and canopies). For critical dynamic components, determination of service life based on fatigue loads is the basis for qualification. In the case of fuel, oil, and hydraulic system compo-

nents, proof pressure and burst pressure tests are an important qualification requirement.

The airframe static test portion of the structural demonstration (par. 9-2.4) includes the tests of transparent areas since they cannot be tested realistically independent of their support structure. Many other components also are tested during the airframe static test but some, such as engine mounts and control system components, also are subjected to separate fatigue tests.

7-2.3 ENDURANCE TESTS

In the case of components subject to wear and/or deterioration, qualification *shall* include an appropriate endurance test. For example, MIL-F-8615 prescribes an endurance test for fuel system components equivalent to at least 1200 hr of aircraft operation. These tests must cover the design envelope of altitude and temperature under the most severe operating conditions. When operation in the helicopter may be expected to include a dry or nonlubricated condition, a portion of the endurance test *shall* be performed with the component running dry. After completion of the endurance test the component *shall* demonstrate an acceptable level of operation.

Hydraulic system components may be subjected to repeated cycles of pressure variation, i.e., impulse testing, in order to demonstrate their endurance capabilities.

7-2.4 ENVIRONMENTAL TESTS

Qualification of some components *shall* include environmental test conditions representative of actual operations. Procurement specifications for the various types of components identify the environmental tests to which each type *shall* be subjected. The method of performing the test also may be included directly, or by reference to specifications and/or standards, such as MIL-STD-810, MIL-E-5272, or MIL-T-5422. To the maximum extent possible, combined environments should be employed and the equipment should be operating during the test.

7-3 QUALIFICATION PROCEDURES

7-3.1 TEST SPECIMENS

Each component to be tested *shall* be of the production design configuration and *shall* be subjected to quality assurance inspections to insure that it meets design and acceptance criteria. The use of a component

in the qualification test which is not identical to the proposed production components *shall* be approved by the procuring activity.

In some cases, preproduction tests will be required. The component configuration *shall* be recorded including all deviation from the proposed production configuration, whether in terms of material, process, or dimensions. If it is acceptable to the procuring activity, significant changes may be incorporated into component design during the qualification test program as deficiencies are discovered. In these cases, the component configuration used for each of the test specimens in each portion of the qualification test *shall* be recorded. Once a final configuration is obtained, a rerun of some of the tests may be required by the procuring activity.

If it is necessary to remove or replace any hardware on the test specimens during any of the tests, the reason for removal *shall* be recorded, along with an accurate determination of the amount and type of testing that the replaced item had undergone. If the item replaced was a normal maintenance or overhaul item which was not expected to last the life of the test component, then the qualification *shall* proceed as planned. On the other hand, if the item replaced was one that normally should not fail in service, then the design of the item *shall* be reviewed and an analysis made to determine if redesign and retesting will be necessary. When retesting is necessary to qualify a redesigned item, then the amount of testing *shall* be dependent on the reasons for the original failure. If a complete retest is to be conducted using the same basic test component upon which the failure occurred, the chances for failure of some other item in the component undergoing qualification testing are increased and this *shall* be taken into account if other component part failures are encountered.

The number of specimens of each component to be used in the qualification program *shall* be in accordance with the appropriate general specification (e.g., MIL-F-8615, MIL-E-5400), or *shall* be as proposed by the contractor and approved by the procuring activity. Normally one specimen of each component is used for qualification testing. But, in some cases, additional components and tests may be required in order to obtain statistical data, or to cover all necessary test conditions. For example, crashworthy fuel system components or armor components are tested to destruction; therefore, the number of specimens is at least equal to the number of performance test conditions. Also, fatigue tests to determine service lives of dynamic components require sufficient samples to define endurance limits.

7-3.2 TEST PLANS

Qualification test plans *shall* be prepared for the components requiring qualification testing. These test plans *shall* state in specific terms the component design parameters which will be monitored during the test, the number of specimens to be tested, the tests which will be conducted on each specimen, the duration and severity of each test, the procedure for accomplishing each test including a test setup description, and identification of the success or failure criteria, as appropriate. When environmental tests (vibration, humidity, sand and dust, etc.) are a part of the qualification procedure, a functional test of the component *shall* be required both before and after the environmental tests to determine if there has been any significant degradation in operation. This functional test *shall* be the same as the quality assurance test given to each production component.

7-3.3 QUALIFICATION BY SIMILARITY

7-3.3.1 Previously Qualified Contractor-furnished Equipment (CFE)

In some cases, it is possible to use on a new model helicopter systems or components which have been used on a previously qualified helicopter. These systems or components may be used in their off-the-shelf configuration, or with some minor modifications to make them compatible with the new model.

If an off-the-shelf component (including the Qualified Products List (QPL)) is used on the new helicopter, and the design requirements are the same as, or less severe than, those for the previous installation, then the component *shall* be considered qualified and no new tests will be necessary. On the other hand, if the design requirements and/or operating conditions are more severe, requalification of the component *shall* be performed. However, this requalification *shall* encompass only those tests necessary to show that the component will perform adequately under the new requirements.

For components which require minor changes of configuration with no change in operational requirements, the necessity for requalification depends on the nature and extent of the modification. Changes such as the relocation of an electrical connector, substitution of a noncritical bearing, or alteration of a part on a hydraulic component probably require no retest. Alterations such as the mounting method of a vibration-sensitive component, elimination of dust shields, or changes

in the circuitry of an electronic component require requalification of the component. The type and amount of retesting necessary depends upon the specific modification.

Components which have both minor design changes and changes in operational requirements follow the same general rules with regard to qualification. If the design changes are noncritical and the new operational requirements are less severe, no requalification is required. Since each case is different, no definite requirements can be stated herein for the amount of requalification necessary. The contractor *shall* propose a requalification test program, subject to approval by the procuring activity.

7-3.3.2 Previously Qualified Government-furnished Equipment (GFE)

Government-furnished equipment (GFE) will have been qualified by the manufacturer for its intended function prior to delivery to the Government. Minor alterations in the configuration of GFE components may be required for use in a new model helicopter. The operating environment also may be different from that for which the equipment was qualified originally. Therefore, partial or complete requalification may be required. Modifications to GFE *shall* not be made, however, without approval of the procuring activity.

The requirements for requalification of modified GFE components generally are the same as those for contractor-furnished equipment (CFE). An exception may occur where it is not possible to obtain detailed reports of the previous qualification, and there is some question about how the modification will affect operation of the component during environmental tests. In this case, it may be necessary to perform a complete requalification test to determine the effects of any modifications or changes in operating environments. The contractor shall propose a requalification test program, to be approved by the procuring activity.

7-4 QUALIFICATION TESTS

7-4.1 TYPES OF COMPONENTS

Many components must be qualified formally prior to installation in a helicopter. The qualification requirements for each type of component are generally similar.

The types of components to be considered, with examples of each, are shown in Table 7-1.

7-4.2 TYPES OF TESTS

Qualification of any component requires demonstration of compliance with the design and operational criteria pertinent to its installation and use in the helicopter. The categories of tests required for such qualification are discussed in par. 7-2. Within each category, the type, or types, of test performed varies with the type of component.

7-4.2.1 Functional Tests

Table 7-2 shows the types of functional tests required for example components of the types shown in Table 7-1.

This listing is not complete; only a few examples are given. Functional test requirements for other components are stated in general specifications for the type of component being considered—e.g., MIL-F-8615 for fuel system components, MIL-H-8775 for hydraulic system components, and MIL-E-5400 for avionic components — or may be defined by the contractor, based upon the subsystem design criteria.

TABLE 7-1. EXAMPLE COMPONENTS REQUIRING QUALIFICATION

COMPONENT TYPES	EXAMPLE COMPONENTS
1. STRUCTURAL (INCLUDING DYNAMIC COMPONENTS)	ROTOR BLADES DRIVE SHAFTS CASTINGS (CLASS A) WINDSHIELD ARMOR FUEL CELLS CREW SEATS
2. ELECTROMECHANICAL	GENERATOR OR ALTERNATOR FUEL BOOST PUMP TRIM ACTUATOR (CONTROL SYSTEM) OIL COOLER FAN POWER TURBINE GOVERNOR BEEP ACTUATOR
3. HYDROMECHANICAL	LANDING GEAR OLEO STRUT FLIGHT CONTROL ACTUATOR ROTOR BRAKE LANDING GEAR RETRACTION CYLINDER
4. MECHANICAL	ROTOR HUBS TRANSMISSIONS AND GEARBOXES FUEL SHUTOFF VALVE (DIRECT) OVERRUNNING CLUTCH
5. INSTRUMENT	FUEL QUANTITY INDICATOR ENGINE INSTRUMENTS: TEMPERATURE TORQUEMETER ATTITUDE INDICATOR
6. ELECTRICAL	VOLTAGE REGULATOR ANTI-ICING/DEICING ELEMENT
7. AVIONICS	RADIO* INTERCOM* FIRE CONTROL COMPUTER*

*PRESENTATION OF QUALIFICATION TEST PLANS FOR ANY OF THESE COMPONENTS IS BEYOND THE SCOPE OF THIS HANDBOOK

TABLE 7-2. EXAMPLE FUNCTIONAL TESTS

EXAMPLE COMPONENT	PERFORMANCE FUNCTIONAL TEST
WINDSHIELD	OPTICAL DISTORTION WITHIN ACCEPTABLE LIMITS.
GENERATOR	REQUIRED VOLTAGE AND CURRENT OUTPUT AND ACCEPTABLE TEMPERATURE RISE, WITH RATED INPUT SHAFT SPEED AND TORQUE.
ROTOR BRAKE	REQUIRED ENERGY ABSORPTION FROM RATED SPEED, WITH RATED SUPPLY PRESSURE.
FUEL SHUTOFF VALVE	RATED FLOW WITH ACCEPTABLE PRESSURE DROP OPEN, OPERATING TORQUE WITHIN ALLOWABLE TOLERANCE, AND LEAKAGE AT RATED SUPPLY PRESSURE WITHIN TOLERANCE WHEN CLOSED.
ENGINE TORQUEMETER	ACCURACY WITHIN REQUIRED LIMITS, WITH CALIBRATED SIGNALS

In most cases, functional testing for qualification must be repeated after endurance tests and environmental tests in order to demonstrate that these tests have not adversely affected the operational capacity of the component. In some cases, endurance testing constitutes functional testing for extended periods of time.

The functional testing of components should be conducted under conditions which duplicate service conditions as closely as possible. Test parameters such as electrical power (both voltage and current), hydraulic or pneumatic power (pressure and flow rate), and mechanical power (rotational speed and torque) *shall* be monitored.

7-4.2.2 Structural Tests

Almost all component qualifications include demonstration of structural integrity, either by analysis or testing. In some cases, the requirement is to assure adequacy of the mounting provisions, as with a generator or alternator, or with instrument or avionic components. In the case of structural components, the demonstration of adequate structural integrity is the principal qualification requirement. For such components, the criteria may be static strength, fatigue strength, deflection, or a combination of all of these.

7-4.2.2.1 Component Static Load Tests

Static load tests may be conducted to limit loads, ultimate loads, or failing loads, according to MIL-T-8679. A failing load test is advantageous when the location, type, or other details of the failure, or when knowledge of the growth potential of the component, is desired. Since a test to limit loads is inherent in the

other loading conditions, it usually is not specified for qualification unless it is important that the test specimen not be destroyed or unless a check for yielding is all that is desired. The static load test of many components is conducted in conjunction with the static test of the airframe, which is discussed in par. 9-2.

Testing of components not discussed in par. 9-2 *shall* be conducted as follows (for all components listed, the critical load condition(s) *shall* be determined; subsequent testing must include the critical load condition(s)):

1. Rotor Blades. The main and tail rotor blades (if applicable), or portions of the large main blade, *shall* be tested for flapwise and chordwise buckling or bending. Spar, nose cap, trailing edge, and box section components should be tested individually in order that the strength properties and methods of failure may be determined.

2. Rotor System Dynamic Components. Although fatigue is more critical to these components, static load tests furnish useful information on strength properties and load distribution. Examples of dynamic components are pitch links and arms, swashplates, drive link, fixed link, rotor hub, mast, and the pitch housing.

3. Control System Components. The basic test for the flight control components—including collective, cyclic, antitorque, and elevator (if applicable) controls—is the proof load and operations test which demonstrates that the systems will not deflect excessively, bind, or otherwise interfere with each other, with other components, or with the airframe, while operated throughout the full range of travel and under design limit loads. Both the pilot's and copilot's controls *shall*

be loaded and the applied loads *shall* be reacted at the blades and control surfaces. The controls *shall* be cycled through their full range of travel with the limit loads applied, and the number of times cycled *shall* be kept to a minimum because of the danger of low cycle fatigue. Hydraulic systems *shall* be fully operative during the test to simulate actual operating conditions. Additional tests *shall* be conducted as described in par. 9-2.2.

4. Actuators. Rotor and control system actuating cylinders *shall* be subjected to proof pressure tests for leaks, loosening of components, and permanent deformation. In addition, limit and ultimate column loads, tension loads, and compression loads *shall* be applied to the actuating cylinder at the output, while hydraulic pressure is applied to the actuating cylinder at the output, and inlet ports. Column load tests are accomplished with the cylinders in the most critical position. The actuators *shall* be inspected for static and dynamic leakage after the limit load tests. A burst pressure test also *shall* be performed.

5. Transmission and Gearbox Housings. For some designs, the transmission top case is the principal support for the main rotor mast; the case also may be subject to loads from dynamic components such as swashplate supports or idler link. Static testing of gearbox housings *shall* include ultimate load for critical nonflight (e.g., crash) conditions and failing load for the critical flight condition.

6. Castings. Class 1A castings *shall* be static tested to failure for critical loading conditions for which a casting factor less than 1.33 is shown. Due to the unreliability of castings and the inherent scatter of casting test results, three casting specimens *shall* be tested (usually the least acceptable ones) and a minimum casting factor of 1.25 *shall* be demonstrated at the ultimate load. Calculated margins of safety for Class 1A castings *shall* not be less than 0.33 for limit and ultimate calculations using minimum guaranteed properties from MIL-HDBK-5. The primary purpose of classifying castings is to establish inspection and testing requirements. MIL-C-6021 does not specify static tests for all castings. Castings used as nonstructural connections in fuel systems *shall* be subjected to pressure proof tests.

7. Crashworthy Fluid Systems. Breakaway valves and couplings *shall* be tested statically and dynamically in all applicable breakaway modes (i.e., tension, compression, shear, and bending). Crashworthy fuel cells *shall* be tested in accordance with MIL-T-27422. All other components of crashworthy systems *shall* be subjected to static and dynamic load tests. Ref. 1 describes

typical test procedures for crashworthy fluid system components.

8. Armor. Ballistic evaluations must be conducted on lightweight armor materials for use as windshield, canopy utility components, passive armor, structural armor, etc. Lightweight armor provides resistance to:

- a. Penetration by projectiles
- b. Penetration by fragments.

Resistance to penetration by projectiles is the most prevalent evaluation required for minimum weight armor. The ballistic limit method is employed for this purpose. The protection ballistic limit V_{50} is defined as the striking velocity of a projectile at which the probability of a complete penetration is 50%. The ballistic limit is defined as the average of six fair impact velocities comprising the three lowest velocities resulting in complete penetration and the three highest velocities resulting in partial penetration. A maximum spread of 150 fps *shall* be permitted between the lowest and the highest velocities employed in determining the V_{50} ballistic limit. Partial and complete penetrations are judged on the basis of results shown in Fig. 7-1.

A double set of velocity screens should be used, and the velocity measurements checked against each other. Whenever these measurements do not agree within 10 fps, the round will be disregarded. The average of the two velocities should be used in ballistic limit determinations.

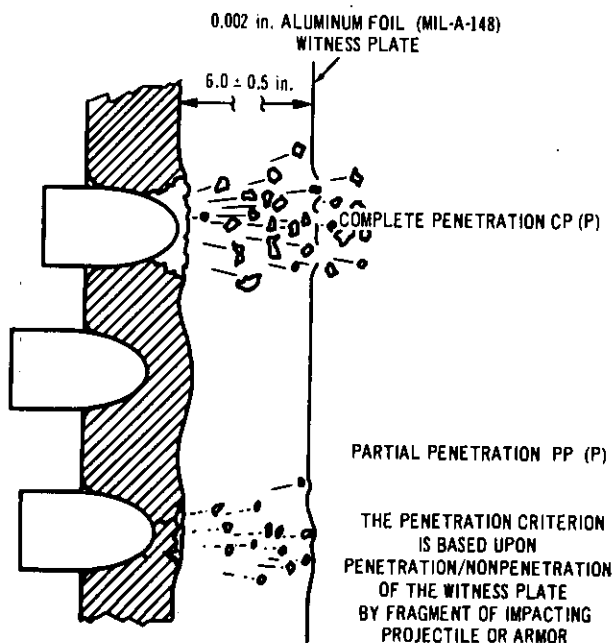


Fig. 7-1. Protection Criterion

TABLE 7-3. ARMOR MATERIAL SPECIFICATION

NUMBER	TITLE
MIL-S-12560	ARMOR, PLATE, WROUGHT, HOMOGENEOUS COMBAT-VEHICLE TYPE NO. 1/4 TO 6 in., INCLUSIVE
MIL-S-46100	STEEL ARMOR PLATE, WROUGHT HIGH HARDNESS
MIL-S-11356	STEEL ARMOR, CAST, HOMOGENEOUS, COMBAT-VEHICLE TYPE NO. 1/4 TO 12 in., INCLUSIVE
MIL-S-46099	STEEL ARMOR PLATE, ROLL BONDED, DUAL HARDNESS
MIL-A-46063	ALUMINUM ALLOY ARMOR PLATE, HEAT TREATABLE, WELDABLE
MIL-A-46118	ALUMINUM ALLOY ARMOR, 2219, ROLLED PLATE AND DIE FORGED SHAPES
MIL-A-46027	ALUMINUM ALLOY ARMOR PLATE, WELDABLE, 5083 AND 5456
MIL-T-46077	TITANIUM ALLOY ARMOR PLATE, WELDABLE
MIL-G-5485	ARMOR LAMINATED, FLAT, BULLET-RESISTANT
MIL-A-46108	ARMOR, TRANSPARENT LAMINATED, GLASS-FACED, PLASTIC COMPOSITE
MIL-A-46103	ARMOR, LIGHTWEIGHT, CERAMIC-FACED COMPOSITE, PROCEDURE REQUIREMENTS

A summary of material specifications which include armor acceptance testing is provided in Table 7-3.

In the case of fragment simulator projectiles (MIL-P-46593), hardness of the projectiles is a critical factor. These projectiles are required to be held at a hardness level between 29 and 31 Rockwell C. All projectiles should be inspected, if possible, after impact with a target to determine the effect of the impact on the projectile and whether the projectiles are performing consistently.

In a ballistic limit determination, it is necessary to change propellant weight on successive rounds to obtain a 25 to 50 fps difference in velocity. The propellant charge should be decreased by this amount after obtaining a complete penetration, and increased by this amount after a partial penetration. Once a change from complete to partial, or partial to complete, penetration has been confirmed, the propellant weight change can be reduced to provide a smaller difference in velocity between rounds. The velocity difference between complete and partial penetrations should be no greater than 25 fps.

With most armor targets, there is a zone of mixed results within which both complete and partial penetrations will be obtained over some range of velocity.

When the zone of mixed results is greater than 50 fps, it is desirable to base the V_{50} PBL on five complete and five partial penetrations within a spread of 125-150 fps to improve the accuracy of the evaluation. If the zone of mixed results is 300 fps or more, as it may be for some heterogeneous armor arrangements, complete penetrations can occur at velocities of 150 fps or more below the V_{50} PBL. Ballistic limits or merit rating comparisons in such cases may be misleading. It is better in these cases to select the velocity at which protection is desired and fire sufficient rounds (preferably 20) at that velocity and determine the percentage of rounds defeated.

The testing of personnel armor is affected by most of the same factors that influence other lightweight armor tests. Presently, the standard test for personnel armor employs the caliber .22 fragment-simulating projectile. Due to the poor flight characteristics of this projectile, the distance of the test panel from the weapon *shall* be in accordance with MIL-STD-662, which requires 12.5 ft. The ballistic limit for personnel armor is based on the average of the velocities for 10 fair impacts consisting of the five lowest velocities giving complete penetration and the five highest velocities giving partial pene-

tration. The velocity spread for the 10 rounds used *shall* not be greater than 125 fps. If a greater velocity spread is obtained, seven complete and seven partial penetrations are used in the calculations.

7-4.2.2.2 Component Fatigue Tests

A large number of helicopter components are fatigue-critical. This means that their structural adequacy is based on a stated service life when subjected to repeated cycles of alternating loads, rather than on a positive margin of safety under critical static loads. Qualification of a fatigue-critical component requires determination of its service life, either finite or infinite, or demonstration of acceptable fail-safe characteristics.

Determination of the service lives of fatigue-critical components is discussed in Chapter 4 of AMCP 706-201.

Fatigue testing *shall* be performed on all critical, primary, structural load-carrying components. The required testing *shall* be sufficiently extensive to provide data adequate for service life determination or to demonstrate acceptable fail-safe characteristics. Components to be tested include:

1. Main Rotor System. In the main rotor system, the components are obtained from the critical areas, the number of which is dependent on the rotor configuration. Critical area components include the hub-to-mast attachment, actuators, swash plates hub-to-blade root attachment, centrifugal tension-torsion strap (if applicable), and a basic blade section. Additional areas of testing in the main rotor blade may be required, due to concentrated mass areas such as a tip weight or antinode weights which provide rapid changes in section properties with resultant local stress concentrations. Each area of the main rotor system *shall* be considered thoroughly in the design stages to include the critical areas in the test program.

2. Antitorque Rotor System (if applicable). This system is similar to the main rotor system and the components selected for fatigue testing should be based on the identified critical areas. Fatigue testing *shall* be conducted on the hub, blade root end, tension-torsion reaction system, and basic blade sections.

3. Main Rotor Control System. Fatigue testing of the control system components forward of the boost system (if installed) usually is not required, since such a system isolates the oscillatory loads which originate in the rotor system. Fatigue testing *shall* be performed on all components from the control system boosters up to and including the main rotor pitch control arm. In the absence of a control boost system, all control sys-

tem components subject to critical fatigue loading *shall* be fatigue tested.

4. Antitorque Rotor Control System. This system is similar to the main rotor control system; fatigue testing *shall* be performed on all components from the booster system to the pitch control arm, or on all components subject to critical fatigue loading.

5. Power Drive Systems. Fatigue testing of the power train drive system components *shall* be accomplished and should include the main rotor mast, transmission input shaft, antitorque rotor drive shaft, miscellaneous power takeoff shafts (if critical), and gear flanges.

6. Transmission and Gearbox Housings (if applicable). Fatigue testing of the basic transmission case or other critical gearbox housings *shall* be accomplished, including the local transmission or gearbox housing support structure.

7. Engine Mount. Any portions of the engine mounting system, including airframe-mounted attachments determined to be fatigue-critical during the flight load survey, *shall* be fatigue tested.

8. Other Components. Fatigue tests *shall* be conducted on any other structural components for which fatigue loads are found to be critical. Attachments and mountings—such as for horizontal and vertical stabilizers, landing gear, and armament—should be investigated during the flight load survey to determine the need for additional fatigue tests. Particular attention must be given to identifying analytically the mountings located in the vicinity of antinodes of the fundamental fuselage modes. Locations of such mountings then *shall* be confirmed by vibration test.

7-4.2.2.2.1 Fatigue Test Requirements

The laboratory fatigue test of helicopter components can be accomplished in various ways. The methods used most often are spectrum and S-N testing (i.e., testing which results in curves of stress versus number of cycles to failure). In spectrum fatigue testing, inflight loading conditions are reproduced as closely as possible. The relative magnitude and distribution of the test loads *shall* be based on measured flight loads. In view of the fact that the flight load survey may not have been completed when the fatigue test program is initiated, the first tests may be started with loading conditions based on computed loads or the flight loads measured on prototype hardware.

The test parts *shall* be instrumented with strain gage locations identical to those used in flight test. Strain gages are not required if the test loads applied to the component(s) can be verified with acceptable accuracy

by other means. Oscillatory loads *shall* be applied to each specimen in increments of the measured flight loads; the load distribution *shall* be representative of all flight conditions. In some cases, it may be necessary to superimpose gust loads on the fatigue loading spectrum.

The preferred method of fatigue testing is the S-N technique, since service lives can be determined from S-N data for any load condition. The procedures for S-N testing are well documented and therefore are not repeated herein. However, variables which significantly influence the test results—number of specimens, methods of applying loads, data scatter limits, etc.—must be approved by the procuring activity. As a minimum, the requirements of MIL-T-8679 *shall* apply.

Since spectrum testing involves reproducing in the laboratory load amplitude and frequency distributions directly proportional (equal to or greater than) to those encountered in flight, it may be considered a more exact basis for the initial determination of service life. However, it is not possible to determine whether alteration of mission profiles or of the frequency of alternate missions, or any other significant change in the helicopter flight spectrum, has an effect upon component service lives without retesting in accordance with the altered spectrum. Spectrum testing, therefore, *shall* be employed only when specifically approved by the procuring activity.

7-4.2.2.2.2 Test Specimens

Fatigue test specimens *shall* be of production configuration and quality. The number of specimens to be tested *shall* be proposed by the contractor and approved by the procuring activity.

7-4.2.2.2.3 Frequency of Loading

Comparison of available fatigue test data with the effect of loading frequency on metallic materials indicates that tests conducted within a frequency range factor of 10 give similar results. Test load frequency of application, therefore, *shall* be kept within a factor of 10 of the normal operating frequency of application.

For the main rotor, normal operating frequency (one per rev) is dependent on the rotor rpm, and usually ranges from 4 to 8 Hz. The tail rotor operating frequency (also one per rev) usually is in the range from 15 to 30 Hz.

Special care should be exercised in selecting load application frequencies for laminated and bonded structures to insure that there is no excessive buildup of temperature leading to premature bond line failures.

7-4.2.2.2.4 Verification of Test Fixtures

Each fatigue test setup has unique features based on the design characteristics of the helicopter. Rotor system components, for example, may be subjected to four loads (centrifugal force, flapwise and chordwise bending, and torsion) simultaneously. Loadings *shall* be verified by analysis and by the use of strain gages installed on the component as appropriate. Force and moment distributions *shall* be verified during testing and compared with design and flight distributions.

Most critical areas are located at joints or transitions. Strain gages, however, should be located in relatively uniform sections. Installations adjacent to joints and/or rapid changes of section *shall* be avoided, since these local stress concentrations will influence the strain gage output and result in improper readout.

Use of experimental stress analysis techniques such as stress coat, photo stress, and plastic models should be encouraged. These techniques are not used for detailed analysis but to determine rapidly the critical areas and approximate strain magnitudes. The loading of these critical areas then can be checked with appropriately located strain gages on both the flight test hardware and laboratory components.

Load cells and integral test equipment *shall* be calibrated to comply with MIL-Q-9858 and MIL-C-45662. Strain gages *shall* be calibrated to known external forces and moments.

7-4.2.2.2.5 Use of Tested Parts

Any parts subjected to structural static tests above design limit load or parts that have been subjected to fatigue testing *shall* not be used on any flight articles. Obsolete parts or parts that have been subjected to static or fatigue testing *shall* be:

1. Intentionally damaged and disposed of as scrap
2. Prominently identified as not for flight use.

Components such as transmissions, gearboxes, and blade sections may be used as training aids. Additional sections of fatigue-tested blades may be used to develop repair procedures for damaged blade sections.

7-4.2.3 Endurance Tests

Many types of components *shall* be subjected to endurance tests—particularly electromechanical, hydromechanical, and mechanical components.

Endurance tests are required to demonstrate that wear resulting from normal use will not result in unacceptable performance degradation during a reasonable period of helicopter operation. For this reason, formal

qualification of components of new design is not commenced until an extensive prequalification test program has been completed satisfactorily.

Prequalification tests include investigation of abnormal operating conditions: overspeed, overtorque, and overpressure. Failure or excessive wear of shafts, bearings, seals, gears, impellers, armatures, and similar items during these tests usually will be cause for design improvements and further testing.

Endurance testing of transmissions and gearboxes, both as components and as parts of the power transmission system, *shall* be in accordance with MIL-T-5955 and MIL-T-8679. Qualification of the drive system is described in par. 9-3.3. Endurance test requirements for rotor systems (both main and antitorque) also are given in MIL-T-8679. Endurance test requirements for some other components are given in MIL-C-5503, MIL-S-7780, MIL-M-8609, MIL-F-8615, MIL-C-8838, MIL-G-21480, MIL-P-26366, and MIL-S-26547.

7-4.2.4 Environmental Tests

Environmental testing *shall* be performed to demonstrate that components will function satisfactorily in the design operational environments or after exposure to these environments.

Since a duplication of actual environmental conditions is not practical, standard laboratory procedures have been established for simulation of critical environments for test purposes. Existing test methods may be modified or new ones written when required. The test procedure to be followed must be clear and detailed, and must specify methods and conditions which are attainable in the laboratory, so that results can be duplicated.

7-4.2.4.1 Laboratory Environmental Simulation

Laboratory environmental tests are conducted under simulated single or combined environmental conditions.

Single-environment testing is the exposure of the component to each of the required environmental conditions one at a time. The decision to conduct a single environmental test must be based on the conclusion that the selected environment does not interact with other environments; that the interaction is small enough to be neglected; or that the test furnishes a reliable prediction of component performance in the range of interaction that will occur in service. This method permits isolation of the cause of failure and also makes it relatively simple to attain and control the

environment. Since the interaction of two environmental elements cannot be checked directly, the sequence of tests must be carefully chosen. To obtain as much data as possible from a single component, the tests *shall* be run in order of increasing damage potential. Suggested test sequences are given in MIL-STD-810, MIL-E-5272, MIL-T-5422, and MIL-F-8615.

Combined-environment testing is the simulation of two or more environments simultaneously, e.g., shock and extreme temperature, or vibration and dust. Two advantages of combined testing are the savings in the time required for the test program and a better correlation of test data to actual service data. Disadvantages include the difficulty of establishing cause of failures, and the increase in test equipment cost.

An important consideration in environmental test planning is whether the component under test should be operating during the test. In general, if the laboratory environment involved in the test is an operating service environment, the component *shall* be operating. If the laboratory environment represents a storage or transportation condition, then operation of the component is not required.

The subsequent paragraphs describe various environments and the laboratory methods which *shall* be employed.

7-4.2.4.1.1 Shock

A shock test is conducted to demonstrate that components will withstand the dynamic shock environment to which they may be subjected during handling, transportation, or service use.

The equipment generally used in performing a shock test is a free-fall machine with a guided drop carriage and an impact base which controls the deceleration of the drop carriage. The machine can be one of a number of commercially available units, or it can be constructed per the detail drawings given in MIL-STD-202. Alternative methods, for application of the required acceleration, that are acceptable for some components include pulse inputs to an electrodynamic shaker and vertical acceleration tests, e.g., Hyge Tester.

The shock pulse wave shape *shall* be either the sawtooth pulse or the half-sine pulse specified in MIL-STD-202 and MIL-STD-810. The procuring activity *shall* approve the shock test plan.

7-4.2.4.1.2 Vibration

The vibratory test is used to determine the effects of vibration on the physical and operational characteristics of components. The vibratory frequencies, magnitudes, and wave shapes are specified in Method 514 of MIL-STD-810.

Vibration testing can be accomplished in many ways, some of which are mechanical eccentric displacements, rotating eccentric masses, servo-controlled hydraulic actuators, and electrodynamic shakers. Each has advantages and disadvantages. The eccentric masses provide an inexpensive and simple approach to obtaining high sinusoidal forces, but there is no provision for keeping force or displacement constant during frequency sweeps. With the closed-loop, servo-hydraulic actuators, large forces and amplitudes are possible and can be controlled during sweeps. However, the cost is increased significantly and the frequency is limited to a maximum of about 400 Hz. Electrodynamic shakers which have high force capabilities with high frequencies are available, but the displacement amplitudes are limited and the cost for the larger shakers and control systems is quite high.

The vibratory levels required by MIL-STD-810 *shall* be applied to each of three mutually perpendicular axes of the test component. Test procedures *shall* be as specified by MIL-STD-810, unless otherwise required by the procuring activity. The test component should be operated before and after each of the vibratory periods to note any degradation of performance.

7-4.2.4.1.3 Sand and Dust

The sand and dust test is used to determine the ability of the test component to resist the effects of a sand- and dust-laden atmosphere. This test simulates the effect of sharp-edged sand and dust particles on the performance of mechanical and electrical apparatus, and is applicable to all mechanical, electrical, electronic, electrochemical, and electromechanical devices which may be exposed to a dry, dust-laden service atmosphere. Not included in this test method are the conditions which may cause erosion of items such as rotor blades.

The chamber used for the sand and dust test must control dust concentration and the velocity, temperature, and humidity of the circulating air. MIL-E-5272 provides acceptable design standards for this type of chamber. The sand and dust size and chemical characteristics, as well as the dust concentrations, air temperatures and humidities, and test times are detailed in MIL-STD-202 and MIL-STD-810.

In conducting the test, the component is placed in the environmental chamber and subjected to the test conditions stated in Method 110 of MIL-STD-202 or Method 510 of MIL-STD-810. Measurements and/or operational checks *shall* be taken before testing begins and at the conclusion of tests to indicate the effect of the environment on the test component.

7-4.2.4.1.4 Salt Spray

The salt spray (salt fog) test is conducted to determine the resistance of equipment or components to the effects of a salt atmosphere. This test is intended only as an indicator to give relative results, i.e., to determine uniformity of protective coatings of different lots of the same product, once some standard has been established. There are several important limitations of this test:

1. Withstanding this test successfully does not guarantee that the test item will prove satisfactory under all corrosive conditions.
2. The salt fog used in the test (MIL-STD-810) does not duplicate the effects of a marine atmosphere.
3. It is doubtful that a direct relationship exists between salt fog corrosion and corrosion due to other media.
4. This test generally is unreliable for comparing the corrosion resistance of different materials or coatings or for predicting their comparative service life.

The test procedure is detailed in Method 101C of MIL-STD-202 or Method 509 of MIL-STD-810. In both cases, the procedure involves subjecting the component to a finely atomized spray of sodium chloride solution of a definite concentration and specific gravity. The chamber is maintained at an elevated temperature and the test is run continuously for a minimum of 48 hr.

7-4.2.4.1.5 Extreme Temperature

High- and low-temperature tests are conducted to determine the resistance of components to the maximum or minimum temperature conditions anticipated during storage or service. Differential expansion or contraction of mating parts causing binding, permanent set or loss of resiliency of packings and gaskets, and loss or congealing of lubricants are only a few of the difficulties which may be encountered at extreme temperatures.

Test chambers for high-temperature tests can be convective or radiant heated. The low-temperature chamber can be cooled by normal refrigeration or by dry ice if the required temperature is not too low, the test duration too long, or the test specimen too large.

Test procedures *shall* follow the requirements of MIL-STD-810 and Methods 501 and 502 for the high- and low-temperature tests, respectively.

7-4.2.4.1.6 Rain

Rain tests are conducted to determine the efficiency of protective covers or cases. The test is applicable to

all items which may be exposed to rain under service conditions. This test method excludes conditions where rain-induced erosion might occur on items such as rotor blades.

The test is conducted in a chamber having provisions for producing falling rain of a specific drop size and intensity. Also required are provisions for a horizontal wind with a minimum velocity of 40 mph.

The test *shall* be conducted according to Method 506 of MIL-STD-810, except that the rainfall rates and drop size may be changed according to the climatic extremes given in MIL-STD-210.

7-4.2.4.1.7 Humidity

This test is performed to evaluate the influence of a warm, highly humid atmosphere (tropical) on materials used in the test components. However, the test also is applicable for components designed for operation in other than tropical regions.

It is conducted in a chamber incorporating temperature and humidity controls for obtaining temperatures of 160°F minimum and up to 95% relative humidity. Testing *shall* be conducted according to Method 507 of MIL-STD-810 or Method 103B of MIL-STD-202.

7-4.2.4.2 Altitude

Altitude tests are conducted to demonstrate satisfactory operation over the altitude range anticipated in service. Therefore, the component must be in operation during the test.

The altitude test should be conducted in accordance with Method 500 of MIL-STD-810. However, the maximum altitude *shall* be 30,000 ft for helicopter components.

7-4.2.4.3 Other Environments

Additional environments for which certain types of components must be qualified are sunshine, thermal shock, fungus, fuel oil, corrosion, erosion immersion, explosion, and icing. Icing tests may be required to demonstrate either continuous operation in such an environment, or to demonstrate the start of operation following storage under icing conditions. Procedures for these tests are given in MIL-STD-202, MIL-STD-810, MIL-E-5272, MIL-T-5422, or MIL-F-8615. The applicable military or procurement specifications also may dictate special environmental test requirements to be conducted.

7-5 TRANSMISSION AND DRIVE SYSTEM COMPONENTS

Qualification of transmission and drive system components is accomplished in two stages: prequalification and qualification. This paragraph details the prequalification and qualification bench tests for these components in particular because they are the principal ones for which the airframe contractor is responsible. The final system qualification is conducted during the transmission and drive system demonstration (par. 9-3.3).

7-5.1 TRANSMISSION AND GEARBOX BENCH TESTS

Flight power and loading parameters are simulated in test transmissions by means of regenerative loop arrangements, which require only a fraction of normal input horsepower, or by an open loop system, which requires a full input power and a full power load absorber. The system is driven at normal operating speed by an electric motor, hydraulic motor (or motors), or other suitable prime mover.

In a regenerative loop test stand, the installation may consist of the test transmission, a dummy transmission, appropriate connecting gearboxes, and shafting and couplings to link like power input shafts, main rotor shafts, and power takeoff shafts into a continuous loop. Torque is applied to the loops by one of a number of methods, of which the following are examples:

1. Through the shaft couplings during installation
2. By rotating a stationary ring gear in the dummy gearbox
3. By rotating the entire dummy gearbox, or commercial reduction gearbox
4. By hydraulic pressure displacing helical gearing in the axial direction
5. By hydraulic cylinder and cam arrangement twisting a connecting shaft.

The last four methods permit change of torque while the rig is in operation. In addition, thrust loads and moments representative of flight are applied to the main rotor shaft of the test transmission.

Intermediate and tail rotor transmissions generally are integrated in a common rig with a single loop. The principle is the same as previously described, utilizing test and dummy gearboxes.

A transmission-mounted lubrication pump *shall* be mounted on the transmission for all tests required by

MIL-T-5955 and MIL-T-8679. This is necessary because the compatibility of the transmission-mounted lubrication pump and the transmission must be established early enough in the program to preclude interference with the flight program.

Transmission prequalification testing should include determination of major modes of failure, and demonstrating that the failure/malfunctions are noncatastrophic and fail-safe, and can be detected by the inspection and detection techniques. Prequalification testing also verifies design criteria by insuring proper lubrication, gear meshing, etc., prior to formal qualification.

The preceding objectives can be accomplished by an overstress bench test on the initial transmission, at take off rating or slightly above. A portion of the test *shall* be conducted at lower power levels to check lubrication and vibration. Based on experience, the operation of the gearbox at powers of more than 120% of the maximum operating conditions can produce results that are not meaningful.

A gearbox containing two primary drive systems—such as the rotor and propeller drive trains found on some compound helicopter—*shall* be subjected to accelerated or overstress testing in each operational mode. Each test phase *shall* include operation at or above the maximum rated power for each drive system, with the time distributed in proportion to the anticipated proportion of service operation in each flight mode. However, a conservative approach should be applied, i.e., more test time should be applied to each drive train than is anticipated for service operation.

The use of several test gearboxes to account for variables in interfaces, strength, manufacturing tolerances, etc., is desirable and will aid greatly in uncovering major problem areas. The prequalification testing of four or more transmission units is preferable; testing of two units *shall* be mandatory.

While much attention has been given to bench testing as a transmission development tool, tiedown or flight test programs also are essential to examining the interface problems between engines, transmissions, rotors, controls, and airframe system. Many vibratory, cooling, lubrication, and operational problems cannot be solved until that phase of the qualification program is begun.

A minimum of two test gearboxes *shall* be subjected to the prequalification tests described in the paragraphs which follow.

A 200-hr overstress prequalification test *shall* include 75% of the test time at maximum takeoff power or greater, 15% at 110% of maximum takeoff

power¹ or greater, and the remaining 10% at normal cruise power. Speeds *shall* be varied from 90% to 110% of normal operating speed. All other required time, such as for cooling tests, *shall* not be credited toward the total 200 hr. The test objectives are to determine the modes of failure, detectability of failures, and extent of fail-safe features. In addition, the program *shall* be used for the incorporation and evaluation of fixes and in general to “debug” the transmission. The requirement is not to “pass” this test but to evaluate the design and compare its performance with the design requirements.

Upon completion of the initial 200-hr overstress prequalification test, which may be interrupted by major malfunctions, another 200-hr overstress bench test *shall* be conducted on a second gearbox which incorporates all modifications suggested by the initial test. The fabrication of fixes and improved items *shall* be initiated while the first test program is in progress, with the power schedule for the second gearbox test the same as for the initial test.

A 200-hr official qualification bench test *shall* be conducted in accordance with the contractor's test plan, approved by the procuring activity. The objective of this test is to verify that the prequalification testing has eliminated all of the weaknesses in the transmission. Successful completion of this test will establish a configuration baseline suitable to commit to production. All components in this test transmission *shall* be considered as having zero time. This does not necessarily mean that they have to be new parts; however, any parts which fail during this test *shall* be subjected to rerun during a penalty test. The length of this penalty test *shall* be determined by the procuring activity, based on the nature and severity of the failure. It may be as high as 200 hr.

7-5.2 CLUTCHES

As components of the power train, overrunning clutches *shall* be tested with either the engine or the drive system(s). In either system, the test requirements *shall* represent service conditions as closely as possible. Therefore, the dynamic response of the test system(s) also must be representative of the flight system(s).

The flight modes of loading of a clutch are difficult to reproduce within a bench test stand due to problems of matching dynamic characteristics and load buildup. Generally, the first multiple loading modes approach-

1. The power levels indicated for the bench tests refer to transmission ratings. These ratings are *not necessarily the same* as the engine ratings for the helicopter.

ing the service spectrum are those imposed on the clutches as a result of compliance with MIL-T-8679. This specification defines the ground testing of components peculiar to helicopters and includes engagement/disengagement operation (see par. 9-3.3.6). The tests outlined are those needed to substantiate or qualify the drive system. Details of the clutch qualification program, including bench, ground test vehicle, and flight testing, *shall* be proposed by the contractor and approved by the procuring activity.

As a minimum, the test program *shall* demonstrate that the clutch is capable of 200 engagements without adjustment and 2400 engagements without replacement. An endurance test also *shall* be conducted. The objective is to demonstrate a potential mean time between removals (MTBR) of at least 1200 hr based on the root mean cubic torque for the design mission.

The contractor test program *shall* include procedures/techniques for measuring progressive wear, after acceptable wear patterns have been defined. The measurements and patterns, plus wear limits developed by the vendor, *shall* provide a basis for evaluating probable clutch life.

The substantiation of the clutch test program *shall* consist of the summation of all tests performed. Each bench and ground test *shall* contribute an evaluation of the operational characteristics at certain modes of loading. However, only the inspection of the components from flight vehicles at progressive time periods *shall* provide final substantiation of the overrunning clutch(es).

7-5.3 BRAKES

Operation of the power train braking systems must be demonstrated during a vehicle tiedown or in an integrated dynamic facility test. Preceding these tests, detailed analysis and braking tests *shall* be accomplished through energy simulation techniques by the brake vendor or by the contractor. The initial data from these programs *shall* provide the limitations to be applied to operation on the first flight vehicles.

The qualification program proposed by the contractor and approved by the procuring activity *shall* contain the conclusions of a detailed analysis of the energy absorption/thermal characteristics of the brake and energy simulation tests which will demonstrate the characteristics of the brake system. Energy simulation tests *shall* be conducted in a test facility which duplicates the mass moment of inertia of the vehicle dynamic system that is to be stopped by the brake.

The energy simulation test program *shall* include a period during which the brake *shall* be applied 10 times

at an interval representing the minimum interval between applications projected for the vehicle. Local temperatures *shall* be measured to determine the effect of temperature buildup and to demonstrate adequately that temperatures will not exceed contractor-established limits within critical zones. The data *shall* further demonstrate that the application rate will not produce structurally damaging loads in any of the components of the dynamic systems.

The operating procedure for the simulated load testing of the brake requires that the rotating surface of the brake assembly *shall* be brought to the maximum brake application speed. Then the brake *shall* be applied to bring the system to a complete stop. This procedure *shall* be continued until the cyclic life of the brake assembly has been satisfactorily demonstrated. At periodic intervals, the wear pattern and amount of progressive wear *shall* be measured. At the completion of the test, the brake *shall* be disassembled for a detailed inspection for mechanical wear.

An analysis *shall* be submitted which substantiates that the location of the brake disk with relation to the transmission does not produce a dynamically unstable system. The analysis *shall* show that no critical vibratory mode exists within $\pm 10\%$ of an operating speed over the operating speed range of the power train.

The requirement for system demonstration appears within the vehicle ground endurance test of MIL-T-8679 (see par. 9-3.3). However, the effect that faulty operation will have on the endurance program suggests that a brake system functional test precede the endurance program. This test is to demonstrate that interlocks, indicators, and safety devices are adequate to preclude inadvertent pilot operation of the brake under ground or flight conditions. The functional test also should demonstrate that any system failure is fail-safe. As a minimum, the endurance test *shall* be adequate to demonstrate that the brake system is capable of accomplishing 400 stops under conditions specified in the helicopter model specification without the replacement of any part being required. A minimum of 400 stops is required by the Army in lieu of 300 required by MIL-T-8679.

The brake assembly installed on the ground test vehicle (GTV) also *shall* be used for a functional and reliability evaluation on a continuing basis throughout the ground run testing. Initial tests *shall* include temperature measurements at critical points in the system to aid in establishing normal operation limitations. During initial running of the ground test vehicle, a satisfactory technique *shall* be developed for making brake engagements compatible with the propulsion system. Brake engagements *shall* be made at an appropriate rotor

speed to bring the rotor to rest with the engine at either ground idle or shutdown.

Sufficient operational cycles *shall* be accumulated to develop wear patterns and to extrapolate expected wear life of brake components. Applied force *shall* be of sufficient level to produce operational verification that system pressure limit devices are operating.

The initial evaluation on the GTV *shall* serve as the basis for a preliminary operating procedure. Verification of the utilization procedures *shall* require pilot demonstration on an operational vehicle, including evaluation of caution placards for visibility of location and significance of content.

7-5.4 SHAFTING, COUPLINGS, AND BEARINGS

Shafting, couplings, and bearings are those components external to the main transmission(s) and other gearboxes which constitute the mechanical interconnect between the power train subsystems. These components are subject to diverse dynamic loading and, therefore, *shall* be adequately analyzed and tested prior to incorporation on a vehicle. These components *shall* be verified operationally in conjunction with the drive train during the vehicle ground endurance test.

MIL-T-5955 serves as the basis for qualification of the components, whereas MIL-T-8679 requires assurance that components comply with demonstration requirements. Adequate testing and analyses *shall* be conducted to demonstrate that there are no Category III (critical) or Category IV (catastrophic) hazard levels present which will affect the safety of the helicopter system. Such levels are defined by MIL-STD-882 (see Chapter 3).

7-5.4.1 Shafting and Couplings

Short shafts usually are supported by couplings only, and long shafts by a combination of couplings and rolling element bearings in bearing mount assemblies. Within the bearing assembly, the mount will be the primary element influencing the dynamics of the system. Therefore, shafting and couplings are mutually inclusive mechanically, and any analysis or system simulation of loads or dynamic behavior also *shall* consider the shaft and mating couplings as integral systems.

MIL-T-5955 provides that, prior to qualification testing, the contractor *shall* submit empirical or analytical data to show that excessive vibration will not occur within the shafting system. Vibration is defined as excessive when the dynamically induced load pro-

duces cycles structurally damaging to the drive system or associated support structure. The analysis also *shall* establish that there are no whirling critical speeds within 10% of any operational speed, and that shafts operating above the first critical speed will not experience damaging loads or damage-inducing excursions when passing through the $\pm 10\%$ band about the critical speed. If shaft dampers are incorporated into a shafting system, it *shall* be demonstrated that loss of damping will not induce catastrophic failure in the drive system.

Unless manufacturing tolerances are shown to be adequate for maintaining satisfactory balance, all rotating parts of the drive system *shall* be subjected to balancing by a dynamic balance machine which *shall* measure the magnitude of the unbalance and the angular position where correction is to be applied.

The criteria used to determine satisfactory balance are generally a function of a contractor's engineering experience. In general, the criterion for a smooth system is if the bearing displacement from an unbalanced load does not exceed 0.001 in. peak-to-peak at 1000 rpm and 0.0001 in. peak-to-peak at 10,000 rpm.

Unbalance of the rotating parts of the drive system is created by the following:

1. Dissymmetry
2. Nonhomogeneous material
3. Distortion at operating speeds
4. Eccentricity
5. Misalignment of bearings
6. Thermal gradients
7. Hydraulic or aerodynamic unbalance.

Shafting unbalance will result in a reduction of bearing and coupling life as well as a detrimental load input into the vehicle structure. Thus balancing is a critical consideration from the design phase through design substantiation. The contractor *shall* include the balancing method to be employed, the rotational speed for balancing, and the particular point in the manufacturing cycle at which the balancing procedure is to be accomplished. If balancing is to be performed by a supplier, then the contractor *shall* evaluate carefully the supplier's understanding of and capability for such work.

Excess shaft misalignment can result in excessive coupling wear or failure and may induce shaft failure; therefore, the contractor *shall* establish the misalignment limits at each shaft interface. Since couplings generally are supplier-furnished, the contractor *shall* require data which demonstrate the required life under the spectrum of misalignment and predicted loads.

Where data are not available, the contractor *shall* consider the requirement of a bench test program for simulation of operating conditions. In addition to coupling tests, a "closed-loop" regenerative stand can be used to verify bearing life and balance criteria.

MIL-T-8679 further requires that a mechanical instability rev-up test be performed to demonstrate the freedom from mechanical instability of the vehicle, including the shafting and coupling installation (see par. 9-3.3.7). Sufficient monitoring and local measurements to substantiate safe operation under all conditions *shall* be required.

The procedures for the vehicle vibratory test *shall* be described in the mechanical instability rev-up test plans submitted to the procuring activity. This report *shall* contain a description of the procedures for measuring and identifying the frequency modes of the shafting. Consideration *shall* be given to identification of axial modes of shafts suspended between axially soft couplings. The results of the test *shall* be reported in the mechanical instability test report.

The measurement of the dynamic characteristics of the shafting *shall* contain sufficient information to verify the balance procedure. Measurements *shall* be obtained horizontally and vertically in a radial plane at representative bearing and end supports. These vibratory levels will provide a measure of suitability of balance.

There is no simple relationship between unbalance and vibratory level since factors such as the proximity of resonant frequencies, tolerance, and fits also influence the composite vibratory level. Therefore, in place vibratory amplitude measurements will not directly indicate an absolute standard for permissible vibratory levels. However, the first rotational speed vibratory component will provide an indication of the state of unbalance.

Fig. 7-2 presents a composite of ratings of acceptable vibratory levels. The figure shows a family of curves which describes the bearing motion, as subjective judgments. However, those levels lying in the region above "unsatisfactory" will produce some form of accelerated mechanical wear. Qualification of the shafting includes satisfactory completion of the transmission and drive system demonstration (par. 9-3.3.7).

7-5.4.2 Bearings

This discussion is restricted to the bearings supporting the interconnect shafts of the drive train. Since bearings are subcontracted for by the prime contractor, the bearing life ratings are based on tests performed by the subcontractor. The term "life" can be defined basi-

cally as that period of operation limited by fatigue phenomena. The evaluation of the adequacy of the fatigue life *shall* be based on the capability of the individual bearings to exceed the contractor-specified operational time in 90% of the cases.

Neither MIL-T-5955 nor MIL-T-8679 provides any specific requirements for the shafting bearings. However, they are included and are subjected to the requirements of the specifications as components of the drive train.

Bearing selection *shall* be substantiated analytically for the required life by industry-accepted methods or by a technique which has been demonstrated as producing realistic life predictions. The contractor *shall* prepare and submit to the bearing supplier detail specifications which define specific criteria to be used for acceptance of the bearings. If the bearings are to be incorporated into an assembly by a supplier, then the supplier acceptance procedures *shall* be approved by the contractor.

7-5.5 ACCESSORIES

The requirements discussed within these paragraphs apply only to those accessories installed on or driven by the transmission(s). Typical of these accessories are cooling fan drives, lubrication pumps, generators/alternators, hydraulic/pneumatic pumps, and tachometer generators.

The primary specifications covering the transmission and drive system (MIL-T-5955 and MIL-T-8679) do not detail requirements for the transmission-mounted accessories. However, par. 3.7.1.1.6 of MIL-T-8679 states that either actual accessories or suitable loading devices *shall* be installed on all accessory drives and operated at normal loading conditions during transmission tests. Thus these specifications primarily are concerned with the effect of accessory loads on the transmission drives. Specific requirements for many accessories are given in individual specifications (e.g., MIL-P-7858, MIL-P-19692, MIL-G-21480, and MIL-G-5413). In the absence of appropriate specifications, the contractor *shall* submit proposed specifications for approval by the procuring activity.

The contractor *shall* prepare a procurement specification which defines the qualification and quality assurance requirements with which the accessories must comply. The specification *shall* reflect the extremes of operational and environmental conditions to insure adequate, trouble-free service operation and *shall* establish a bench test load spectrum which is representative of operation on the vehicle. The spectrum may be synthetic, but it must include the characteristics of the

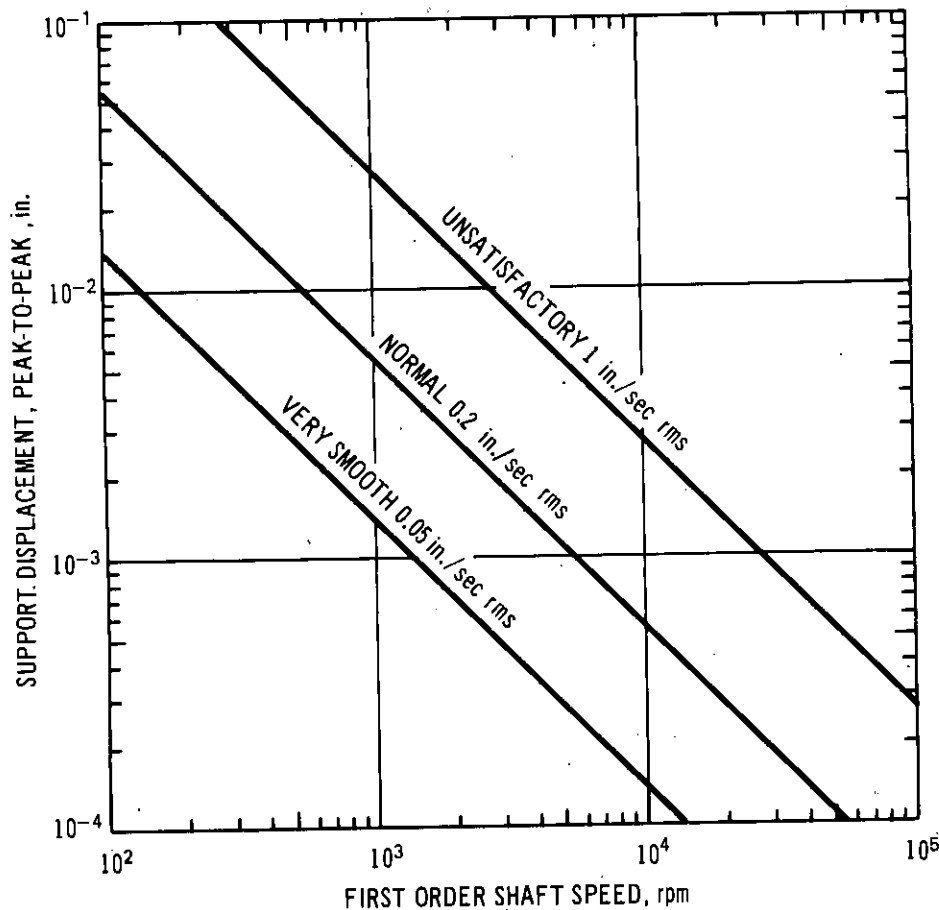


Fig. 7-2. Vibratory Tolerance Criteria

real vehicle system. This is particularly significant for transient loads, which *shall* have the proper rise time, amplitude, and wave shape. The number of transient cycles required *shall* be defined by the contractor for each system. In addition, the bench test *shall* substantiate structural integrity during a continuous duty over-speed condition.

The accessories *shall* be capable of operating under the environmental conditions to which the transmission will be subjected, as defined by MIL-T-5955.

The contractor *shall* provide an analysis of the vibratory characteristics of each accessory installation which establishes that there *shall* be no resonant condition in the accessory installation over the operating speed and accessory load range of the transmission system. For the case of no-load on an accessory system (system failure), there *shall* be no detrimental vibratory excitation of the accessory or transmission for continuous duty operation at any speed within the operating speed range. The analysis *shall* include data to substantiate that the maximum rate of acceleration or deceleration

of the power train will not subject the accessories or the transmission to structurally damaging loads.

The accessory supplier *shall* submit to the contractor a test plan detailing the procedures for qualifying the accessory. The contractor *shall* review and approve the plan prior to initiation of the accessory qualification program. Previous qualification of an accessory is acceptable, provided that the previous requirements were the same as, or more severe than, the requirements of the new installation. A change in accessory supplier is a cause for requalification of the accessory.

The supplier must notify the contractor of the test schedule, and it will be the responsibility of the contractor to notify the procuring activity, and to monitor the qualification program.

The contractor also *shall* approve the procedures for teardown inspection, which must be included in the test plan. After completion of the qualification tests, the components *shall* be completely disassembled and inspected visually, dimensionally, and by magnetic and/or fluorescent particle techniques to ascertain the mechanical condition of the components. The

qualification of electrical components *shall* be determined by measurements which will identify electrical/magnetic breakdown. All the tests specified in the test plan *shall* be completed without failure, excessive wear, or other damage to any parts of the accessory. Accessory qualification *shall* be achieved prior to initiation of the 150-hr tiedown tests of MIL-T-8679.

7-6 DOCUMENTATION

Documentation requirements for the qualification of helicopter components begin with the definition of design requirements. Overall system requirements are contained in the helicopter detail specification. Subsystem and component specifications *shall* be prepared by the contractor, as appropriate, and approved by the procuring activity. The design requirements stated by these specifications *shall* be compatible with the system requirements, and with such additional detail in terms of performance, structural integrity, reliability, and environmental capability as will assure the compliance of the helicopter with all mission and design requirements.

Each component specification also *shall* include demonstration or qualification test requirements. This is particularly important for those specifications which will be used for procurement. It *shall* be clearly stated which demonstrations *shall* be the responsibility of the subcontractor or component supplier and which *shall* be conducted by the contractor.

Prior to initiation of formal qualification tests, a test plan *shall* be prepared by the subcontractor or contractor and approved by the contractor or by the procuring activity. The test plan *shall* describe the procedure for the conduct of each test; the test setup, including all subsidiary test equipment required to supply power, apply loads, control test conditions, etc.; the in-

strumentation and data recording equipment; and all required pre- and post-test inspections. The test plan also *shall* specify the number of specimens to be tested and the proposed test schedule.

Notification by the contractor or the procuring activity, as appropriate, of approval of the test plan should include identification of official witnesses for any part of the proposed testing.

Upon completion of qualification testing of a component, a detailed test report *shall* be prepared and submitted to the procuring activity for approval. This report *shall* include the results of any prequalification testing, particularly design changes which may have been made to correct deficiencies found during this testing. The specimen(s) tested *shall* be described in detail, including appropriate bills of materials or part lists. For those components of the transmission and drive subsystem for which qualification testing is completed in phases, a detailed report *shall* be submitted upon completion of the bench test phase and an addendum submitted upon completion of the helicopter tiedown test phase.

For those fatigue-critical components for which qualification consists of demonstration of an acceptable service life, the test report may only present the fatigue test results in the form of an S-N curve. In accordance with the procedures discussed in Chapter 4 of AMCP 706-201, service lives *shall* be determined based on these test results, the helicopter maneuver spectrum, and the flight load survey data.

REFERENCE

1. S. Harry Robertson, *Development of a Crash-resistant Flammable Fluids System for the UH-1A Helicopter*, TR 68-82; USAAVLABS, January 1969.

CHAPTER 8

HELICOPTER SURVEYS

8-0 LIST OF SYMBOLS

- A = area, ft²
 a = radius of a small sphere, ft
 b = number of blades, dimensionless
 L = length of a cylinder, ft
 MGT = measured gas temperature, °C
 N_g = gas generator speed, rpm
 N_p = power turbine speed, rpm
 P_{∞} = free stream total pressure, (absolute), psi
 $\bar{P}_{t1}$ = mean total pressure (absolute) at engine inlet face, psi
 P_{t1} = local total pressure (absolute) at engine inlet face, psi
 V_{cr} = cruise airspeed, kt
 V_{DL} = design limit airspeed, kt
 V_H = maximum level flight speed at the basic design gross weight, using intermediate power or as may be limited by blade stall or compressibility, kt
 V_{NE} = airspeed not to be exceeded, kt
 V_T = true airspeed kt
 θ = ratio of ambient temperature °R to sea level standard temperature °R, dimensionless
 λ = wave length, cm

8-1 INTRODUCTION

Verification of the adequacy of the helicopter to perform its assigned mission requires testing which includes all anticipated operating conditions. This testing can be divided into two categories: surveys and demonstrations.

Surveys, discussed in this chapter, are tests of actual hardware, components, subsystems, or systems. Surveys gather information about the equipment under test over a wide range of conditions. Test data can be accumulated within and/or beyond the hardware design limiting conditions.

A survey is primarily not a go/no-go test although a few demonstration points may be obtained during a

survey to reduce the cost of testing. For example, an engine vibration survey may be conducted over a wide range of flight conditions measuring vibration at many points in the power plant area. Several specific locations for a few flight conditions may be required for the demonstration of not-to-exceed vibration levels. These data could be obtained during the routine conduct of the survey. Surveys provide information concerning one or both of the following conditions:

1. Actual Conditions. Preliminary design or prototype hardware is evaluated to determine the relationship between design requirements or goals and the actual hardware. The widest range of parameters possible is usually tested, including test points outside of the design limits.

2. Interrelationship Conditions. Components and subsystems first are bench tested; then a system survey is made after the components and subsystems are assembled into a system. A survey can be conducted to determine the interrelationship characteristics between components and/or subsystems for parameters such as temperature, airflow, vibration, etc. Since these parameters are difficult, if not impossible, to predict to the required accuracy throughout the entire operating envelope, the component and subsystem bench tests may not have been conducted under conditions sufficiently representative of their operational environment. Although emphasis has been placed on accumulation of general test data, this should not be construed to mean that survey data cannot be used to show proof-of-compliance with individual specification requirements. In fact, in the interest of financial and schedule economy, this may be advisable. If a specification data point is attained and properly witnessed during a survey test, it may be permissible to use this information to substantiate qualification.

8-2 FLIGHT LOAD SURVEY

8-2.1 GENERAL

A flight load survey is conducted to obtain data

which can be correlated with design loads or stresses for each flight condition in the maneuver spectrum defined for the helicopter. Accordingly, a comprehensive flight load survey *shall* be accomplished to determine the component stress levels (mean plus oscillatory) resulting from each condition in the operational maneuver spectrum and over the operational range of gross weight, airspeed, CG, and altitude. Data from the survey *shall* be used in fatigue life calculations.

8-2.2 FLIGHT LOAD SURVEY PLAN

The contractor *shall* prepare a flight load survey plan which will:

1. Set forth, in accordance with the detail specification, the tentative flight envelope for the helicopter, as defined by the relationship of gross weight to V_{DL} (design limit airspeed) and CG
2. Define ground and flight conditions to be examined
3. Define instrumentation for the tests
4. Define data analysis methods and reporting criteria.

The flight load survey *shall* encompass all normal operating limits anticipated for the helicopter, including engine and transmission limits, maximum gross weight, rotor speed, operating altitudes, V_{DL} , and CG limits, as well as any other applicable limits such as load factor, blade stall, or vibration level.

Flight conditions applicable to all types of assigned missions such as internal and external cargo operations and armed configurations *shall* be included. The order in which the maneuvers are performed should be logical and allow the data to be recorded in the least possible time. A spectrum showing examples of flight maneuvers is presented in Table 8-1.

8-2.3 TEST REQUIREMENTS

The pilot techniques and the description of any special maneuvers which pertain to specific mission requirements *shall* be approved by the procuring activity.

The in-ground effect (IGE) maneuvers should be flown in normal wind conditions. Although calm winds are not required, wind velocities above 15 kt are unacceptable. Hovering turns should be executed at a turn rate of approximately 30 deg/sec. Control reversals in hovering flight should have an amplitude of approximately ± 1 in. at a frequency of 1.0 to 2.0 Hz.

Level flight and dive conditions should be stabilized

at each airspeed using the power required for each condition of rotor rpm, pressure altitude, CG, etc.

Accelerations along the flight path are started from IGE hover. Power is applied rapidly, and constant altitude maintained. Normal rotor rpm transients are permitted to occur. As soon as practical, the rotor speed is stabilized at the desired value. The acceleration is terminated at $0.8 V_H$ (V_H = maximum level flight speed at intermediate power).

The deceleration is initiated at $0.8 V_H$, using the power required for this airspeed. A rapid cyclic flare is executed and the power is reduced. Normal rotor rpm transients are permitted to occur. As soon as practical the rotor rpm is stabilized at the desired value. The airspeed is permitted to decrease at constant altitude until a hover condition is attained.

Normal turns are entered from the desired trim airspeed and power. The turn is initiated at a roll rate determined to be appropriate for the vehicle being tested and aft cyclic is applied, with fixed collective position, until a normal CG load factor of approximately 1.4-1.5 g's is attained. A visual "g" meter *shall* be used to aid the pilot. The rollout of the turn should be executed in the same manner as the rollin. Gunnery or other special mission turns should be executed using a technique and peak load factor acceptable to the procuring activity.

Symmetrical pullups and pushovers are entered from the required airspeed and power. The cyclic control is applied at the rate necessary to obtain load factors of 1.4 to 1.5 g's for pullups and 0.5 to 0.6 g's for the pushovers.

Transition to autorotation is entered at the desired trim airspeed and power. Simultaneously, collective pitch is reduced and the throttle rolled off at a normal rate. Both cyclic and directional control throttle are applied to obtain the flight path necessary to achieve stabilized descent at the airspeed for minimum rate of descent. Transition from autorotation to powered flight is the reverse of this technique.

Control reversals at high forward airspeed are accomplished by moving the appropriate control at a frequency of 1.0 to 2.0 Hz. The magnitude of the control inputs should be appropriate for the trim airspeed. In general, the amplitude should be limited to the value which will not change the airspeed or the helicopter attitude.

Landing maneuvers should be executed from the trim approach airspeed and rate of descent using techniques appropriate to the specific helicopter and landing gear configuration.

8-2.4 INSTRUMENTATION AND DATA ANALYSIS

The dynamic components to be strain-gaged and the location of these gages *shall* be specified in the test plan. In addition to the strain-gaged components, other performance parameters—such as airspeed, altitude, load factor, rotor rpm, engine power, vibration accelerations, and control positions—*shall* be measured so that acceleration, load, or stress data can be correlated with the maneuver or operating condition which produced them. The discussion which follows will deal only with the strain-gaged dynamic components since the other flight parameters are not used directly in the determi-

nation of the component service life.

Each sensor and strain-gage assembly utilized for the flight load survey should be calibrated individually to insure accuracy of the recorded data over the expected range.

Fatigue-critical components, known or potential, *shall* be strain-gaged. As a minimum, the main rotor blades, rotor hub assembly, controls, tail rotor and/or propeller (if applicable), and directional controls *shall* be strain-gaged. Additional components may be strain-gaged when a helicopter incorporates new or unique design concepts. Sometimes, kinematic relationships are used to determine the loads in a noninstrumented component. For example, only one component in a

TABLE 8-1. TYPICAL HELICOPTER MANEUVER SPECTRUM

SE SINGLE ENGINE TE TWIN ENGINE		DENSITY ALTITUDE (ft x 10 ⁻³)			COMPOSITE
		0 TO 4	4 TO 8	8 TO 12	
		% TIME			
MANEUVER		40.0	50.0	10.0	
1.	LOITER AS	18.55	17.76	17.51	18.05
2.	LEVEL FLIGHT 0.6 V _{NE}	1.53	2.88	2.71	2.32
3.	LEVEL FLIGHT 0.7 V _{NE}	1.94	1.93	1.78	1.92
4.	CRUISE 0.8 V _{NE}	10.68	6.01	4.02	7.68
5.	CRUISE 0.9 V _{NE}	29.42	17.71	12.23	21.85
6.	HIGH-SPEED V _{NE}	7.24	23.07	31.11	17.54
7.	IGE HOVER	3.24	**	**	**
8.	OGE HOVER	0.21			
9.	FLAT PITCH	2.92			
10.	NORMAL START	2.59			
11.	NORMAL SHUTDOWN	1.29			
12.	IGE TURNS	0.26			
13.	IGE CONTROL REVERSALS	0.07			
14.	IGE SIDEWARD FLIGHT	0.10			
15.	IGE REARWARD FLIGHT	0.03			
16.	VTO TO 40 ft AND ACCEL.	0.18			
17.	NORMAL TAKEOFF AND ACCEL.	0.37			
18.	SLIDE TAKEOFF AND ACCEL.	0.09			
19.	TE SLIDE ON LANDING	0.11			
20.	TE APPROACH AND LANDING	0.48			
21.	SE APPROACH AND LANDING	0.01			
22.	SE APRCH. WITH TE RCVY. IGE	0.01			
23.	TE CLIMB	4.36			
24.	SE CLIMB	0.04			
25.	ACCEL. CLIMB AS TO CRUISE	1.62			
26.	OGE TURNS	2.19			
27.	OGE CONTROL REVERSALS	0.06			
28.	CYCLIC PULL-UPS	0.03			
29.	DECEL. TO DESCENT AS	2.02			
30.	TE DESCENT	4.84			
31.	SE DESCENT	0.05			
32.	TE TO SE TRANSITION IN CLIMB	0.01			
33.	TE TO SE TRANSITION IN CRUISE	0.01			
34.	SE TO TE TRANSITION	0.01			
35.	SLING LOAD LIFTOFF	0.02			
36.	SLING LOAD LANDING	0.02			
37.	MIN. PWR. APRCH. - PWR. RCVY. IGE	0.50			
38.	FIRE SUPPRESSION PUSH-OVER	0.17			
39.	FIRE SUPPRESSION DIVE	1.21			
40.	FIRE SUPPRESSION PULL-UP	0.86			
41.	FIRE SUPPRESSION HIGH "g" TURNS	0.66			
TOTAL 100%		←-----→			100%

* THIS COLUMN IS THE COMPOSITE SPECTRUM TO BE USED IN LIFE DETERMINATION.

** THE VALUES OF No. 7 THROUGH No. 41 ARE IDENTICAL TO THOSE LISTED FOR 0 TO 4000 ft.

series of control linkages need be instrumented; the loads in the other linkages are calculated from their geometric relationships.

In general, the location of the strain gages on a particular component is the responsibility of the fatigue analyst. Two sources of information are available upon which to base this judgment. In the case of components utilizing new geometry, material, or manufacturing techniques, a logical evaluation of the critically stressed area should be made to determine the location and distribution of the strain gages. Tools available to assist in this determination are holography, photoelastic techniques, and analysis procedures. In the case of components similar to previous designs, data compiled from fatigue testing of these components plus service experience can be used to determine proper locations for, and distributions of, strain gages. When differences in components exist, no matter how subtle, these differences should be given adequate consideration since the mechanism of fatigue can be affected drastically.

The loads or stresses in all critical dynamic components occurring during the flight conditions discussed in par. 8-2.3 must be recorded in order to permit a comprehensive analysis. For maneuvers other than level flight, the record should be initiated during an initial stabilized condition, continued throughout the maneuver, and discontinued after a stabilized flight condition is once again attained. For example, if a right turn is executed from stabilized level flight, the record would be started before initiation of the turn. Recording would continue until the right turn has been completed and the helicopter has returned to straight and level flight. In the case of stabilized flight conditions such as hover and level flight, the record should cover enough revolutions of the rotor to permit any possible harmonic phenomena with respect to rotor natural frequencies to be identified.

The data recorded during the flight load survey will be reduced in accordance with the appropriate Read Option from Table 8-2. These options are described subsequently. From the results of this survey and supporting fatigue analysis and tests, the contractor *shall* define the critical component service lives, using the methods described in Chapter 4 of AMCP 706-201.

The term "Read Option" means the criterion to be employed in determining which cycle or cycles of data should be read within each record and in what manner. Table 8-2 lists the read options which may be used during data analysis.

Read Option No. 1, the most important of the options, is applicable to all data which originate from a load or stress transducer—such as a bending bridge on a rotor blade, an axial load gage on a control tube, or

a stress bridge on a honeycomb panel. The record is scanned and the maximum value of oscillatory loads ($\pm$, or single amplitude) read, together with the corresponding mean value. The magnitude of the mean and oscillatory load thus obtained then are assumed to have occurred throughout the entire maneuver for whatever number of cycles were recorded during that maneuver.

The magnitude of load, together with the number of cycles recorded during the maneuver, are the data used in the computation of fatigue damage at the critical location on the component. Since the peak load is assumed to have occurred throughout the maneuver, the fatigue damage computed for the component will be greater than if each cycle had been treated individually. (Most maneuver loads build up and decay gradually.) Thus, the analysis should yield conservative values of fatigue damage.

In certain cases, however, it may be necessary to treat each cycle within a record on an individual basis. For instance, when an abnormally high load occurs (much larger than any other cycle in the record) as a result of aerodynamically induced transients, accelerations, or a similar phenomenon, the record should be read cycle by cycle. For example, one cycle from a bending bridge on a rotor blade may be several times larger than the next cycle in the same record. This could result from a blade natural frequency being excited by an unusually large wind gust. Obviously, it would be unrealistic to consider this high load to have acted throughout the maneuver. Thus, each cycle

TABLE 8-2. READ OPTION TERMS

OPTION No.	DESCRIPTION
1	READ THE MAXIMUM OSCILLATORY AND CORRESPONDING MEAN LOAD RECORDED IN DATA RECORD REGARDLESS OF LOCATION WITHIN THE RECORD.
2	READ THE MAXIMUM POSITIVE OR NEGATIVE MEAN VALUE AND CORRESPONDING OSCILLATORY VALUE RECORDED IN THE RECORD.
3	READ BOTH MEAN AND OSCILLATORY VALUE APPLICABLE TO EACH DATA RECORD.
4	READ THE MEAN VALUE APPLICABLE TO THE DATA RECORD.

within the maneuver should be evaluated individually for possible fatigue damage.

Read Option No. 2 is applicable to parameters which are used to describe the maneuver being flown. Pertinent parameters include items such as accelerations, control positions, pressures, and flow rates. The largest positive or negative mean value and corresponding oscillatory load cycle would be read within each record.

Read Option No. 3 is applicable to airspeed, altitude, and rotor rpm. The mean and oscillatory values for each record are read while the recording is being made.

Read Option No. 4 is used primarily to read parameters when very little variation in magnitude occurs with respect to time. Examples of such parameters are outside air temperature, engine inlet temperature, and exhaust temperature.

8-2.5 DOCUMENTATION

A report of the results of the survey *shall* be prepared. All operating conditions, on the ground and in flight, will be summarized and survey data *shall* be presented. Performance of the subsystems will be reviewed, and any configuration changes made as a result of the survey *shall* be discussed. Any helicopter operating limitations resulting from inability of the subsystems to meet stated requirements throughout the required range of environmental and performance parameters *shall* be identified. Recommendations for changes to the subsystem configuration and additional testing *shall* be included.

8-3 ENGINE VIBRATION SURVEY

8-3.1 GENERAL

An engine vibration survey *shall* be conducted to determine the engine vibration environment in the helicopter. To establish that no significant vibration problems exist, experience with similar installations, analyses, and engineering judgment should be applied.

8-3.2 ENGINE VIBRATION SURVEY PLAN

8-3.2.1 Airframe Manufacturer Requirements

The airframe manufacturer *shall* prepare an engine installation vibration test plan which will include, but not be limited to, the following:

1. A list of primary parameters to be recorded—such as amplitude, frequency, acceleration, torque, force, stress, and displacement measurements—as well

as other pertinent system parameters including rotor speed, airspeed, altitude, outside air temperature, gross weight, and helicopter CG location.

2. Tests to be conducted:

- a. Ground tests in accordance with par. 8-3.3.1
- b. Flight tests in accordance with par. 8-3.3.2

3. Instrumentation requirements

4. Pertinent data analyses and documentation requirements

5. Allowable vibration limits:

- a. Steady state
- b. Transient

6. Engine torque and rpm stability, response to power demand, and load sharing if applicable.

8-3.2.2 Engine Manufacturer Coordination

The engine manufacturer will establish the location and direction of vibration sensors. The sensor locations will be common to both the engine test cell and the aircraft installation test measurements.

The engine manufacturer will define acceptable installation vibration limits by amplitude and applicable frequency for each sensor location. The engine manufacturer will describe the sensors, data acquisition system, and data analysis methods which may be used.

8-3.3 TEST REQUIREMENTS

8-3.3.1 Ground Tests

Ground tests *shall* be conducted to record data for the most critical engine vibration conditions. These conditions include:

1. Idle rpm
2. Slow sweep from idle rpm to maximum power-on rotor speed at low collective pitch
3. Continuous operation at rotor speed specified for engine warmup, if applicable
4. Steady-state operation at any rotor speed of Item 2 at which the engine responds significantly and at which the helicopter can be operated continuously.

8-3.3.2 Flight Tests

Flight tests of the engine installation(s) *shall* cover those extremes of the flight envelope which induce the highest vibrations.

Prior to acquisition of the engine vibratory data, an analytical evaluation of the unbalance of all rotors and the drive shafting, and of the track of the lifting rotor(s) *shall* be made. The maximum acceptable unbalance or

out-of-track condition *shall* be included in defining the determining engine vibration levels.

The discussion which follows relates a sample procedure which may be used to evaluate the vibratory environment.

For a clean helicopter, the flights presented on Table 8-1 for the range of helicopter configurations illustrated in Fig. 8-1 may be conducted. This flight spectrum is derived from analysis, experience, and mission profile. The flight conditions or maneuvers which typically produce the highest vibrations, and constitute 20% of the flight spectrum, are noted in Table 8-1.

The full spectrum may be flown with a typical mission loading at the gross weight/CG configuration. Data should be acquired at the normal rotor speeds. The data from all sensors for each of the configurations should then be evaluated statistically to determine the critical gross weight and CG combination; a complete flight spectrum should be completed at this gross weight and CG combination if different from the first loading configuration.

Special intake or exhaust duct configurations or other kits which significantly change the engine vibratory characteristics should be evaluated in those regimes, which, based upon the baseline data and calculation estimates, will produce the highest vibrations.

8-3.4 INSTRUMENTATION AND DATA ANALYSIS

Instrumentation requirements for the engine vibratory survey include:

1. Sensors (acceleration, velocity, and displacement)
2. Signal conditioning equipment
3. Recording equipment
4. Data acquisition system frequency range, dynamic range, overall accuracy, and calibration methods and procedures for Items 1 through 3.

The airframe manufacturer *shall* specify in the test plan data analysis procedures which will be used to compare the measured data with the allowable vibration limits.

The final data presentation specified in the test plan *shall* be in a form which provides direct comparison with the installation vibration limits. For example, the allowable vibration limits will be specified by the engine manufacturer in terms of:

1. Engine displacements (rigid body motion, and torsional and bending modes)
2. Overall vibration (peak, rms, average)

3. Narrow-band and wide-band analyses (discrete frequency)

4. Specified combinations of Items 1 through 3.

The test plan *shall* include details such as filter characteristics, sweep rates, sampling rates, and the total number of samples per data point, as applicable.

The procedure for vibratory evaluation of the engine/airframe which follows is acceptable unless the procuring activity directs otherwise or approves deviations. The flow of data is shown in Fig. 8-2.

1. The engine manufacturer will determine the effective engine masses, inertias, and stiffnesses and their required distribution, and *shall* conduct an analysis to obtain the engine's natural frequencies and bending modes of the engine.

2. The engine manufacturer should conduct a free-free vibratory test of the engine to obtain the frequency response characteristics, natural frequencies, and mode shapes. These results will be compared with the analysis in Item 1, and a determination will be made of the modifications of parameters required to achieve reasonable agreement between calculated and measured values.

3. The airframe manufacturer *shall* conduct a frequency analysis of the engine installation, taking into account the significant fuselage contributions, to determine the fundamental rigid and flexible body natural frequencies in the plane(s) of predominant rotor excitations.

4. The airframe manufacturer *shall* tabulate and identify the inherent airframe excitation sources and their variations with rotor speed. The excitation frequencies *shall* be identified at idle, maximum placard power-on rotor speed, and minimum placard power-on rotor speed.

5. The engine manufacturer will review the results from Items 3 and 4, and will identify potential problem areas in accordance with par. 8-3.3.

6. The airframe manufacturer *shall* draft a test plan in accordance with par. 8-3.2.

7. The engine manufacturer will review the test plan and either approve the plan or recommend modifications to the procuring activity.

8. The procuring activity will approve the test plan or request a modification.

9. The airframe manufacturer *shall* conduct the testing defined in the test plan. The airframe manufacturer *shall* write a final report which will be submitted in accordance with par. 8-3.5.

10. The engine manufacturer will review the final

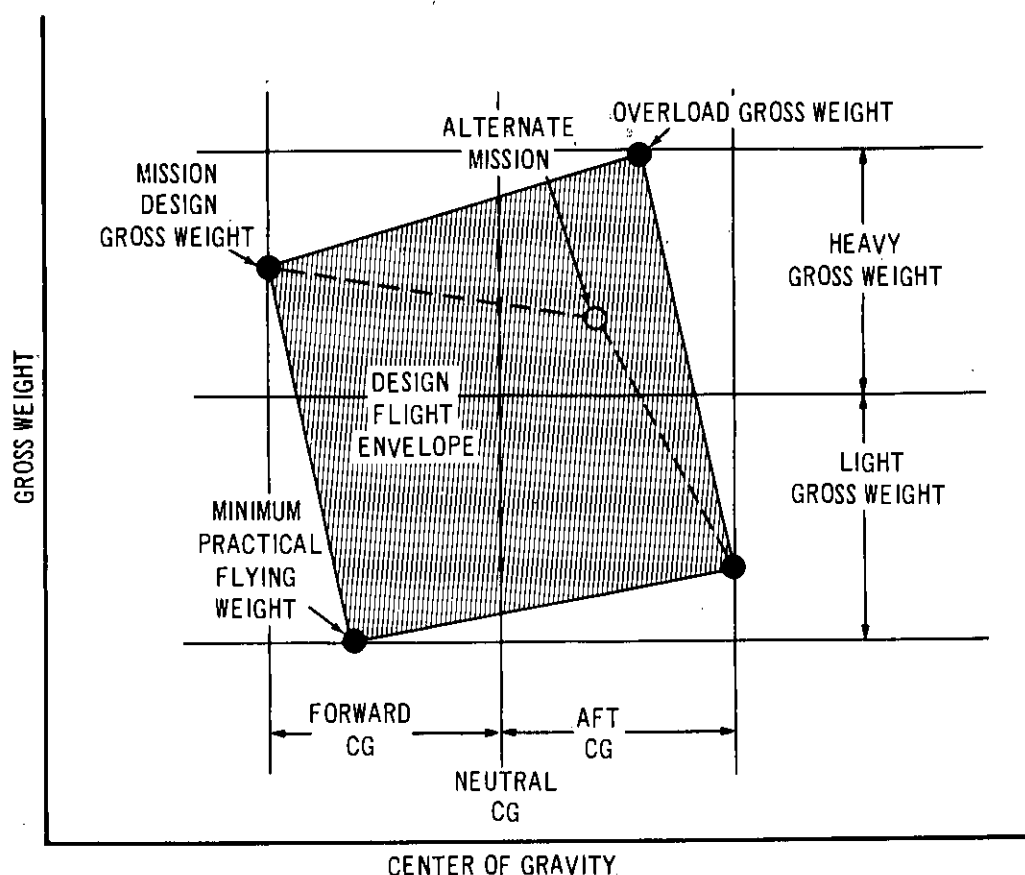


Fig. 8-1. Helicopter Configurations

report and recommend either approval of the report or modification of the installation.

11. The procuring activity will approve the report or request modification of the installation.

12. The airframe manufacturer will conduct any required modification and retesting, and submit additional data as an addendum to the final report.

8-3.5 DOCUMENTATION

A final report *shall* be published by the airframe manufacturer, and submitted to the procuring activity and the engine manufacturer. The engine manufacturer should write a critique of the report to be supplied to the procuring activity and to the airframe manufacturer. Final evaluation and directives for corrective action *shall* be made by the procuring activity.

The final report *shall* document the ground and flight programs, and *shall* include, but not be limited

to, description of test vehicle and engine installation, test equipment and procedures, flight log, test data, test results, conclusions, and recommendations.

Specifically, the final report *shall* define the engine rigid body and flexible body modes for the installation and compare these with the helicopter excitation sources.

The test results *shall* define the selection method of the critical helicopter gross weight/CG configuration and *shall* show the relationship of the measured data to the applicable criteria. If some data exceed the specified limits, the frequency of occurrence of the exceedance *shall* be specified based on the flight spectrum distribution (Table 8-1). The test results *shall* describe the predominant frequencies of response; *shall* show engine mode shapes at these predominant frequencies; and *shall* present time histories; overall, octave band, or discrete frequency analyses; and mode shape plots for the cruise flight condition and for the condition or conditions producing the highest vibratory levels.

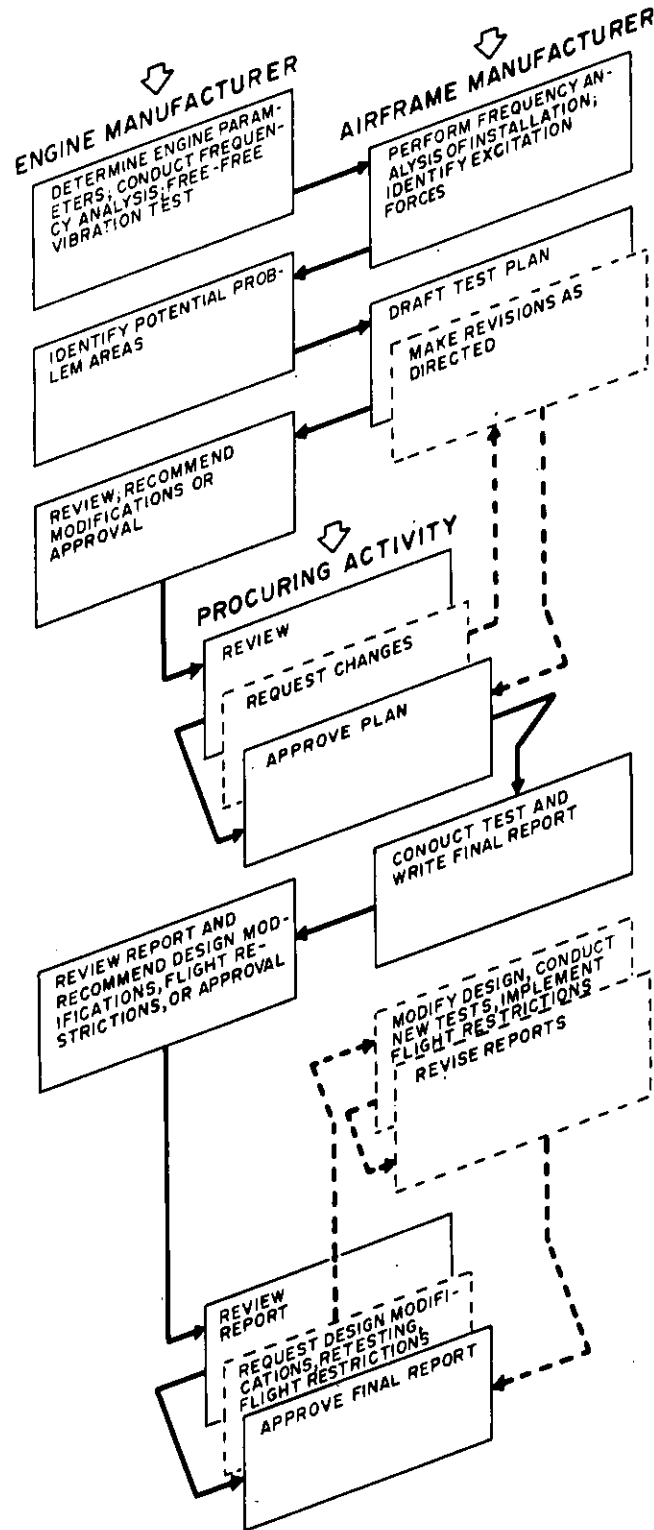


Fig. 8-2. Data Flow for Engine/Airframe Vibration Evaluation

8-4 PROPULSION SYSTEM TEMPERATURE SURVEY

8-4.1 GENERAL

The propulsion system temperature survey is conducted to determine that the propulsion system installation provides satisfactory cooling. Included in the propulsion system temperature survey *shall* be the determination of:

1. Engine, transmission, and gearbox oil inlet and outlet temperatures
2. Temperatures of major engine components
3. Temperatures of airframe mounted accessories such as gearboxes, transmissions, APU's, and generators
4. Critical temperatures of engine compartment structure
5. Heat exchanger inlet and outlet temperatures for both the hot and cold fluids.

8-4.2 PROPULSION SYSTEM TEMPERATURE SURVEY PLAN

An analysis *shall* be performed to substantiate proper propulsion system compartment and component cooling, and *shall* be presented to the procuring activity prior to the start of testing. Sample testing transfer and cooling airflow calculations *shall* be included for the installation. The analysis *shall* include, but not be limited to, the following analytical data:

1. Pressure drop versus airflow for cooling air ducts, engine air induction system, and engine compartment
2. Heat exchanger performance curves (i.e., effectiveness versus cooling airflow and hot fluid flow)
3. Component, accessory, and fluid temperature trends for the ground and flight conditions which result in the most critical cooling
4. Pressure recovery curves for the engine and heat exchanger air induction systems
5. Heat rejection rates for engine, transmissions, and gearboxes
6. Engine case surface temperature distributions
7. Ejector or cooling fan performance curves.

The propulsion system temperature survey plan *shall* include (1) a definition of ground and flight test requirements, (2) the instrumentation requirements, and (3) the data analysis and documentation requirements.

8-4.3 TEST REQUIREMENTS

Tests *shall* be conducted to investigate adverse conditions with regard to the cooling characteristics of the aircraft structure and of the helicopter and engine-mounted components, consistent with the mission. Critical cooling—such as that associated with the use of auxiliary power units, heavy gross weight operation, inflight refueling, engine or component malfunction, and cooling airflow null points—*shall* be investigated as applicable. Operation of special features in the cooling system—such as suckin doors, blowout doors or panels, controllable air inlets, and cooling air ejectors—*shall* be demonstrated. The test requirements outlined herein will provide general guidance from which detail test plans may be formulated based upon mission requirements and the helicopter systems involved.

8-4.3.1 Ground Tests

Ground cooling tests *shall* be conducted at ambient temperatures corrected as specified in par. 8-4.4 with the helicopter positioned with the left side, right side, nose, and tail to the wind, with true wind velocities not exceeding 10 kt. For multiengine installations, the test engine *shall* be on the downwind side of the fuselage. Helicopter configuration *shall* be with accessory and blowin doors positioned as normally prescribed for ground operation. The engine *shall* be run at the listed engine powers until 5 min after temperatures stabilize or to the power time limitations of the helicopter. Any engine operation limitations *shall* be noted. Temperature stabilization is attained when the temperature increase or decrease is less than 2°F/min. Data *shall* be recorded at 30-sec intervals for all tests and *shall* be recorded for 15 min following engine shutdown. The following conditions *shall* be tested:

1. Ground idle power
2. Flight idle power (if applicable)
3. 40% maximum continuous power
4. 80% maximum continuous power
5. Maximum continuous power
6. Intermediate power (30-min rating)
7. Maximum power (10-min rating)
8. Ground idle power
9. Shutdown.

8-4.3.2 Flight Tests

A takeoff and climb to the service ceiling altitude (or maximum allowable altitude within existing design

limitations) *shall* be conducted using maximum power and best rate of climb airspeed. Data *shall* be recorded at 1000-ft intervals if practical. This test *shall* be repeated using intermediate power.

The level flight runs listed subsequently *shall* be conducted at selected altitude intervals up to service ceiling. Each run *shall* be for the time necessary to obtain approximate structural temperature stabilization or for the maximum time within applicable limitations, whichever is shorter. Data *shall* be recorded at 30-sec intervals and 5 min after temperature stabilization (if possible), except where continuous recordings are necessary. The level flight runs to be conducted are:

1. Hover out-of-ground effect (OGE)
2. Hover in-ground effect (IGE)
3. Flight at minimum power required speed
4. Maximum continuous power
5. Intermediate power
6. Maximum power.

8-4.4 INSTRUMENTATION AND DATA ANALYSIS

The detailed instrumentation requirements must be determined for each helicopter on an individual basis. Generally, thermocouples are employed as temperature-sensing devices because of simplicity, cost, and required data accuracy. Other temperature-sensing methods such as thermistors and temperature-sensitive paint are highly inaccurate in determining temperatures and may be used only to add confidence that overheating does not exist, e.g., in an area washed by the exhaust gas or on relatively hot areas of the engine installation.

A general list of the required temperature data follows:

1. Critical engine component temperatures determined by the engine manufacturers
2. Exhaust gas temperature (minimum of four thermocouples)
3. Ambient temperature
4. Accessory temperatures
5. Generator temperatures
6. Critical structural temperatures determined by the contractor and procuring activity
7. Engine compartment air inlet and outlet temperatures
8. Engine and gearbox oil inlet and outlet temperatures
9. Compressor inlet temperature
10. Heat exchanger inlet and outlet temperatures.

To evaluate properly that adequate cooling is obtained, other parameters require measurement. These include:

1. Pressure altitude
2. Airspeed
3. Time
4. Engine rpm (both gas generator and power turbine) and torque
5. Wind velocity and direction relative to the helicopter
6. Engine compartment airflow rate.

For all test conditions, temperature data *shall* be corrected to hot atmospheric conditions on a one-to-one basis. Hot atmospheric air temperatures are 22°F warmer than the temperatures in Table III of MIL-STD-210. Applicable cooling data *shall* be presented for the flight conditions tested for all individually cooled accessories along with the manufacturer's specified cooling requirements. Temperature limits *shall* be those specified in the applicable helicopter design specifications or those established with Army approval by the engine or component manufacturer.

8-4.5 DOCUMENTATION

A report of the results of the survey *shall* be prepared. All operating conditions, on the ground and in flight, *shall* be summarized and survey data *shall* be presented. Performance of the subsystems *shall* be reviewed, and any configuration changes made as a result of the survey *shall* be discussed. Any helicopter operating limitations resulting from inability of the subsystems to meet stated requirements throughout the required range of environmental and performance parameters *shall* be identified. Recommendations for changes to the subsystem configuration and additional testing may be included.

8-5 ENGINE AIR INDUCTION SYSTEM SURVEY

8-5.1 GENERAL

The engine air induction system survey is conducted to determine the engine airflow conditions and to relate these quantities to free stream conditions. Particular requirements are for detailed measurements of air temperature and total and static pressures at the engine inlet, from which mean pressures and pressure variations across the engine inlet face can be established.

The air pressure and temperature at the engine inlet have a direct bearing on the power output and fuel consumption of the installed engine. Gradients which exceed the allowable limits defined by the engine manufacturer have an adverse effect on operation of the engine and may cause compressor stall or surge. In demonstrating compliance with the prescribed engine inlet operating limits, emphasis *shall* be placed on instrumentation requirements, test procedures, analysis techniques, and the determination of overall performance effects.

8-5.2 ENGINE AIR INDUCTION SYSTEM SURVEY PLAN

The engine air induction system plan *shall* define ground and flight test programs which will investigate conditions to be expected throughout the operating envelope. Because of the many combinations of gross weight (power required), flight speed, maneuver, altitude, and ambient temperature, it is desirable to perform this survey in conjunction with other flight tests to reduce the number of flights needed for the survey.

Special consideration *shall* be given to evaluating all features associated with the induction system and the possible operating combinations that might occur during normal operation or following the failure of a system. Such systems may include an inlet sand and dust separator with a secondary scavenge system, an inlet screen, or an inlet barrier filter with a bypass system. Operations *shall* be considered with and without screens, with and without secondary scavenge air, and with bypass closed and open. Each system may have a restricted operating regime, perhaps at takeoff, hover, and landing; however, it is important that all operating anomalies be uncovered. In a configuration where hot anti-icing air is discharged into the induction system, additional data *shall* be obtained. This hot airstream may have an adverse effect on the compressor due to temperature gradients and local separation in the duct.

8-5.3 TEST REQUIREMENTS

8-5.3.1 Ground Tests

Ground tests, both crosswind and tailwind, *shall* include the following requirements:

1. Ballast helicopter to prevent liftoff.
2. Run a power sweep, from ground idle to 80% maximum continuous power, to maximum continuous power, and to maximum power.
3. Run up each engine, in turn, for multiengine helicopters.

8-5.3.2 Flight Tests

For acceptable results, all flights should be performed in smooth air, and at least two data records should be taken at each condition. The flight condition *shall* be steady to provide representative records. In addition to recording inlet pressures and temperatures, it will be necessary to record basic flight and engine data, including pressure altitude, flight speed, outside air temperature (OAT), gas generator speed, engine measured gas temperature, engine torque, and rotor speed.

Flight test requirements are:

1. Hover (both IGE and OGE):
 - a. Establish hover flight both in and out of ground effect at the highest possible power (high gross weight).
 - b. Establish hover with each engine, in turn, at maximum power for multiengine helicopters; the remaining engine(s) provide only the additional power required to maintain the stable condition.
 - c. Establish hover with all engines at equal power for multiengine helicopters.
 - d. Establish rearward level flight with all engines at equal power.
2. Level flight speed sweep:
 - a. Operate at flight speeds between minimum power speed and V_H , with emphasis on normal operating speeds and speeds critical to the proposed helicopter usage.
 - b. Use matched and mismatched powers for multiengine helicopter, to provide a power spectrum at each flight speed.
3. Climb. Ballast helicopter to normal gross weight and perform intermediate power climb.
4. Sideward flight and sideslips:
 - a. Establish level flight speed at a steady state yaw angle.
 - b. Establish sideward flight using ground features or a pace vehicle as a speed reference.

A single flight will not suffice for the complete air induction survey program because testing must be performed at several gross weights.

8-5.3.3 Effect on Engine Performance

Induction system losses *shall* be included when using the engine specification to calculate power available and engine fuel flows. These effects vary with flight condition, ambient condition, and power setting, and usually are governed by a limiting engine parameter

such as engine measured gas temperature, gas generator speed, or fuel flow. However, it is common practice to develop a representative overall power loss and/or fuel flow increase for general application in determining performance, thus simplifying flight manual preparation and pilot use.

8-5.4 INSTRUMENTATION AND DATA ANALYSIS

The instrumentation required for the inlet survey is prescribed in MIL-T-25920. In some cases, the installation may dictate the need for instrumentation additional to the minimum required in the specification. In others, the engine manufacturer may define special instrumentation requirements for that particular engine installation. In addition, the engine manufacturer may supply special instrumentation peculiar to his design, or provide an instrumented engine inlet section. Fig. 8-3 shows a typical inlet instrumentation arrangement.

Total pressure probes are installed as rakes. A minimum of four such rakes *shall* be installed in accordance with MIL-T-25920. For convenience, the probes are located on centers of equal annular area in the engine inlet, to provide for simple averaging of measured pressures, so that the arithmetic mean of the pressures reflects the true mean (Fig. 8-3).

Static pressure in the duct may be measured using a stream static probe on each rake and/or flush wall statics in the same plane as the rakes. When instrumentation locations are defined in the applicable engine model specifications, the same locations *shall* apply to the helicopter installation (MIL-T-25920).

Total and static pressures may be recorded on magnetic tape or an oscillograph recorder via an instrument such as a "scannivalve". The scannivalve cycles, selects each pressure probe in turn, and applies it to a pressure transducer which is referenced to the helicopter static system. The static system reference should be a known reference pressure source. For most pressure recordings, it will be advantageous to record the reference pressure at the beginning and the end of each data cycle for ease of identification. Inlet pressure instrumentation *shall* have a flat frequency response from 5 to 100 Hz (MIL-T-25920). The complete system *shall* be calibrated against known pressures applied to each probe.

At least two inlet temperature probes *shall* be used (MIL-T-25920). They *shall* be located in, or close to, the plane of the pressure probes, and their recovery factor must be known.

Installations where hot gas ingestion from the engine or other sources is suspected will dictate the use of additional probes.

The inlet total temperature probes should be balanced against a free stream probe of known recovery factor in the same bridge circuit; in this way, a more direct reading of temperature increase is obtained. Probes exposed to solar heating or other radiation should be shielded (Fig. 8-3). The cockpit outside air temperature (OAT) gage should not be used as the datum for inlet temperature measurement because it will not provide the required accuracy. Generally, inlet total temperature increase may be expected to be small (0-2°F) for ducted inlets. For plenum chamber inlets, the temperature increase will be larger because inlet air may be heated by components within the engine compartment.

Pressure recovery is defined as the mean total pressure (absolute) $\bar{P}_{t1}$ at the engine inlet face divided by the absolute free stream total pressure (absolute) P_{t0} . The pressure recovery of the air induction system $\bar{P}_{t1}/P_{t0}$ may exceed unity at low forward speed due to the influence of the rotor's downwash component. Pressure recovery may be plotted against TAS for the inlet variations in each operating mode. A typical plot of test results is shown in Fig. 8-4.

The method used to show compliance with pressure distortion limits dictated by the engine manufacturer will depend upon the definition provided in the engine specification. It may vary from a simple statement of percent pressure variation about the mean pressure, to a complex evaluation of the period and amplitude of the pressure variation around the engine inlet face. Regardless of the definition used, a convenient method of showing pressure distortion is to plot isobars over the inlet annulus, mapping lines of constant $P_{t1}/\bar{P}_{t1}$. From these plots, peaks and troughs are easily identified relative to the mean pressure level in the duct. Such a plot is shown in Fig. 8-5.

The typical plot shown in Fig. 8-5 illustrates regions of minimum and maximum pressure of a current engine inlet. In this case the low pressure area in the lower portion of the map is caused by a sand and dust separator upstream in the air induction duct.

Inlet temperature usually is greater than free stream static temperature due to converting kinetic energy to heat and to the heat added by other sources inherent in the design.

Although inlet temperature distortion limits usually are not identified in the engine specification, it is recommended that a distortion of 10°F be reported to the procuring activity. Among sources of additional heat to be considered are ingestion of exhaust gases from main engines, auxiliary power units, and guns.

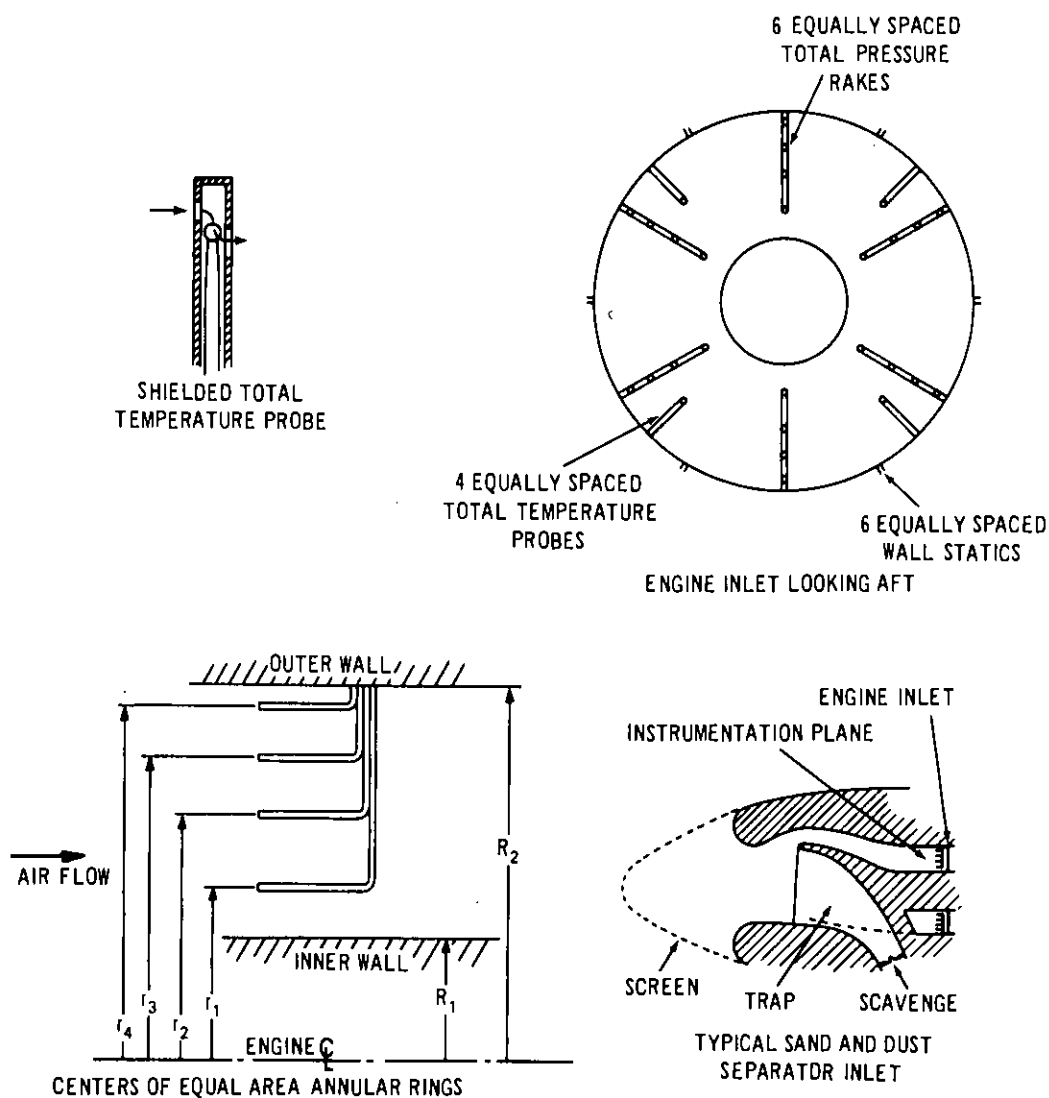


Fig. 8-3. Test Instrumentation

8-5.5 DOCUMENTATION

The engine air induction survey report *shall* include a description of the test, equipment, and data reduction methods, together with a summary of the results. The report *shall* include comparisons with applicable specification values supplied by the engine manufacturer, test instrumentation, summary of test points, curves of inlet recovery versus flight speed and condition, curves of power and fuel flow effects under various conditions, and pressure distortion plot (where distortion is not a problem, only sample extreme conditions need be addressed).

Raw test data and data reduction sheets need not be included in the report unless specifically required. An example of test points is shown in Fig. 8-6.

8-6 ENGINE EXHAUST SYSTEM SURVEY

8-6.1 GENERAL

The engine exhaust survey is conducted to verify the design of the exhaust system.

8-6.2 ENGINE EXHAUST SYSTEM SURVEY PLAN

The contractor's engine exhaust system survey plan *shall* include:

1. A definition of the ground and flight conditions to be investigated
2. A definition of instrumentation and data analysis requirements. Further, engine exhaust system analyses *shall* be submitted to the procuring activity prior to the start of testing, in accordance with Chapter 8 of AMCP 706-201. These analyses *shall* present the engineering work conducted to substantiate the design of the exhaust system. Calculations *shall* be presented to include turbine exit pressures, exhaust gas flow, installed ejector performance curves, installed horsepower losses, and pertinent heat transfer analyses for

the standard tailpipe or the infrared radiation suppressors and surrounding structure (see par. 8-9.2).

8-6.3 TEST REQUIREMENTS

All auxiliary systems which extract air from the engine, the inlet duct, or the engine compartment *shall* be operated normally during the tests. The tests specified herein *shall* be conducted with the production scheduling of variable geometry of inlet and exhaust, if applicable, and the production exhaust duct configuration, except where specifically noted otherwise. For helicopters employing an infrared radiation suppressor which is not part of the standard configuration, tests *shall* be conducted for both the standard configuration and the suppressor installation. The effect of the infrared radiation suppressor will be compared with the baseline configuration.

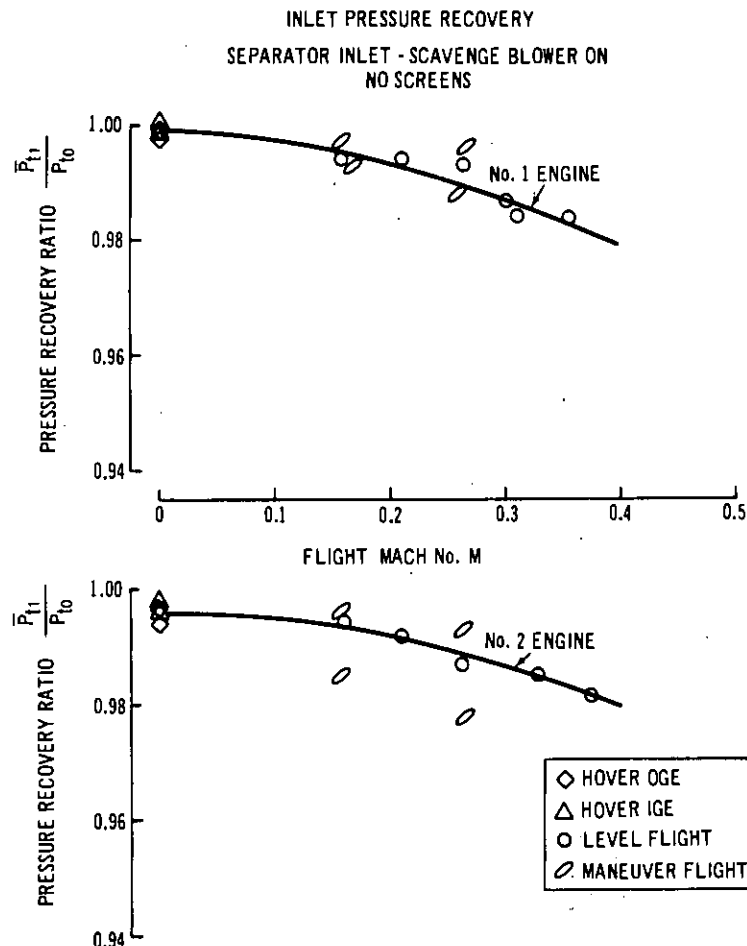


Fig. 8-4. Inlet Recovery vs Flight Speed

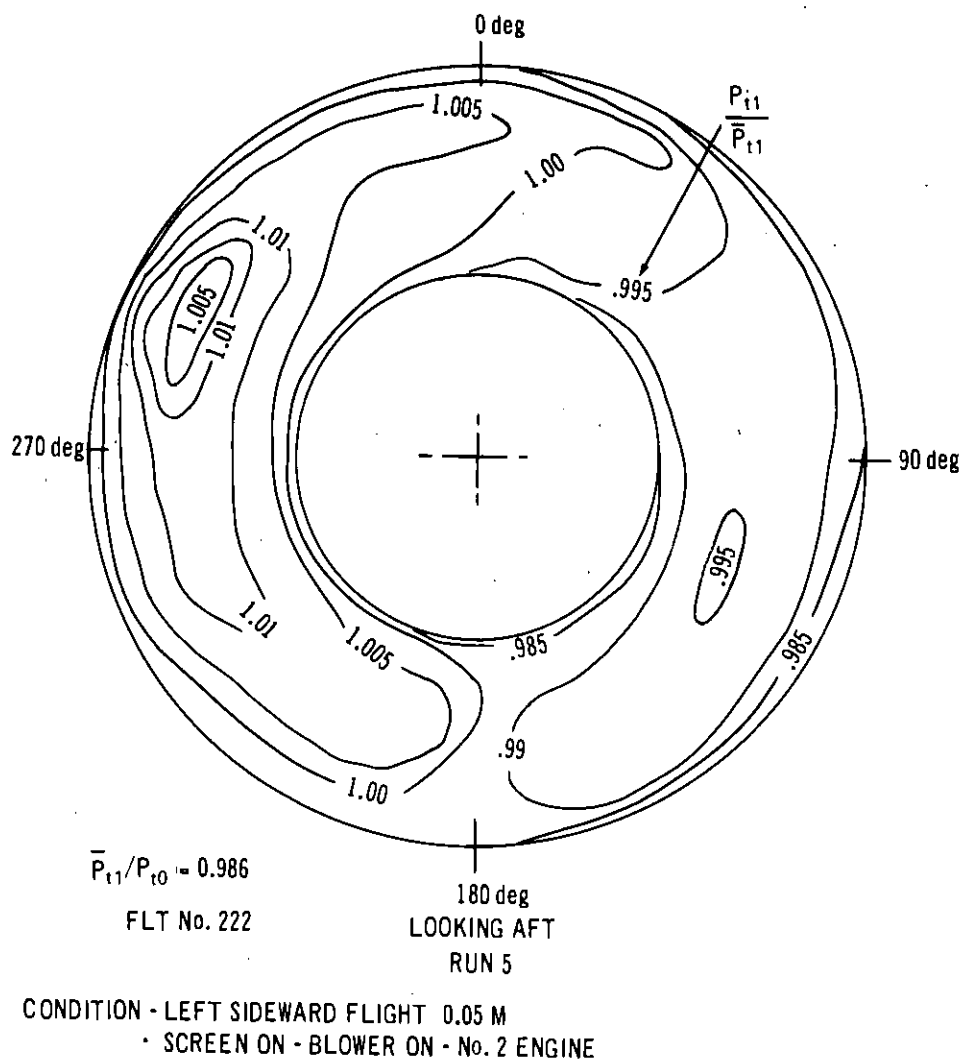


Fig. 8-5. Pressure Distortion Plot

8-6.3.1 Ground Tests

The engine *shall* be operated on the ground at the power settings which follow under static and taxi conditions:

1. Ground idle
2. Flight idle
3. 40% maximum continuous power
4. 80% maximum continuous power
5. Maximum continuous power
6. Intermediate power
7. Maximum power.

8-6.3.2 Flight Tests

The engine *shall* be operated over the power range from flight idle (autorotation) to maximum power in flight, and test altitudes *shall* be varied from sea level to maximum service ceiling. The test conditions *shall* be conducted with the power settings listed in par. 8-6.3.1, and also *shall* include maximum and minimum flight speeds, and all areas of the flight envelope where exhaust duct performance is significant for helicopter performance.

8-6.3.3 Exhaust System Endurance Test

In addition to the preceding test requirement, endurance tests *shall* be conducted on the production tail-

pipe. The endurance test schedule *shall* consist of 20 cycles of operation as follows:

1. 10 min, ground idle
2. 5 min, maximum power
3. 30 min, intermediate power
4. 60 min, 60% maximum continuous power
5. 60 min, 90% maximum continuous power
6. 60 min, maximum continuous power
7. 5 min, maximum power
8. 10 min, 60% maximum continuous power
9. 30 min, intermediate power
10. 3 hr, maximum continuous power.

Equivalent flight tests may be substituted for this 150-hr tiedown test if approved by the procuring activity.

8-6.4 INSTRUMENTATION AND DATA ANALYSIS

Data acquisition and reduction systems, calibration techniques, location and installation of instrumentation, general test procedures, and other pertinent information

influencing the validity of the test data *shall* be presented in the detail test plan.

The following data *shall* be measured:

1. Pressure altitude
2. Airspeed
3. Time
4. Engine rpm (both gas generator and power turbine) and torque
5. OAT
6. Engine inlet temperature
7. Engine inlet pressure
8. Exhaust pressure (static and total)
9. Exhaust temperature
10. Bleed airflow, temperature, and pressure
11. Fuselage temperatures affected by exhaust gas heating.

A minimum of four pressure probes each *shall* be installed for the measurement of the static and total exhaust pressure and the engine inlet pressures.

Exhaust duct coefficients *shall* be determined and compared with the engine manufacturer's reference ducts. Secondary and tertiary airflow, as applicable,

INLET PRESSURE SURVEY (WITH SCREENS)
FLIGHT No. 3 A/C TAB 23 NOMINAL G.W. 20000 lb

RUN NO.	CONDITION	IAS	PRESSURE OR PRESSURE ALTITUDE	% TORQUE		PRESSURE RECOVERY		$V_T/\sqrt{\theta}$ kt	SYMBOL	
				NO. 1	NO. 2	NO. 1	NO. 2		BLOWER ON	BLOWER OFF
5	POWER CHECK (GR) 94% N_g	0	14.696 psia	62		0.995		0	◇	
6	" " 94% N_g	0	"	62		0.995		0		□
7	" " 98% N_g	0	"	77		0.994		0	◇	
8	" " 98% N_g	0	"	77		0.994		0		□
9	" " 100% N_g	0	"	85		0.994		0	◇	
10	" " 100.8% N_g	0	"	85		0.994		0		□
11	" " 94% N_g	0	"		58		0.994	0	◇	

IAS - INDICATED AIRSPEED

GR - GROUND RUN

N_g - GAS GENERATOR SPEED

Fig. 8-6. Example Summary of Test Points

shall be determined. Included in this test will be the measurement of turbine outlet pressure, exhaust gas temperature, tailpipe surface temperatures, exhaust duct outlet pressure, exhaust gas flow, ejector inlet pressure and airflow, and the structural temperatures affected by the exhaust wake. If infrared radiation suppression devices are incorporated, the power losses created by the installation compared to the standard tailpipe *shall* be determined, in addition to the effects on engine compartment cooling and exhaust gas temperature (EGT). Data furnished *shall* show the following:

1. Flight speed
2. Angle of attack and yaw
3. Altitude and ambient pressure
4. Ambient temperature
5. Compressor air bleed and power extraction
6. Power setting
7. Installed power and specific fuel consumption of the helicopter.

8-6.5 DOCUMENTATION

A report of the results of the survey *shall* be prepared. All operating conditions, on the ground and in flight, *shall* be summarized and survey data *shall* be presented. Performance of the subsystems *shall* be reviewed, and any configuration changes made as a result of the survey *shall* be discussed. Any helicopter operating limitations resulting from inability of the subsystems to meet stated requirements throughout the required range of environmental and performance parameters *shall* be identified. Recommendations for changes to the subsystem configuration and additional testing *shall* be included.

8-7 TOTAL SYSTEM VIBRATORY SURVEY

8-7.1 GENERAL

Both ground and flight vibratory survey requirements are covered in the paragraphs which follow. The ground vibratory tests are required to confirm mode shapes and natural frequencies of major structural items and installed subsystems and components of the helicopter. These frequencies will have been predicted by analysis, and appropriate changes will have been made in the design configuration so that natural frequencies do not coincide with the helicopter excitation

frequencies in the normal operating range of rotor speeds.

The flight vibratory survey is required to determine whether vibratory levels at crew and personnel stations are within acceptable levels and also to investigate vibratory levels occurring at principal equipment locations. Unless otherwise specified by the procuring activity, the vibratory requirements of MIL-H-8501 *shall* apply.

8-7.2 GROUND VIBRATION TESTS

8-7.2.1 Airframe Vibration

The principal modes of motion of the airframe *shall* be investigated to confirm the mode shapes and to determine natural frequencies relative to the anticipated excitation frequencies during normal operation. For these tests, which *shall* be performed at both minimum and maximum gross weight, the main rotor blades *shall* be replaced by equivalent concentrated rigid weights. The helicopter *shall* be suspended so that its vertical natural frequency is less than one-half normal main rotor operating speed. Excitation *shall* be applied along each axis (vertical, longitudinal, and lateral) one at a time, at each main rotor hub operating at realistic phase and frequency.

Accelerometers are used to record the response to the applied excitation. For vertical excitation, the accelerometers (eight or more) are arranged along the fuselage centerline to record vertical accelerations. Should the configuration include external stores, accelerometers *shall* be installed at the forward and aft ends of each store. Vertical, lateral, longitudinal, and torsional accelerations should be recorded at appropriate locations, e.g., pylons, seats, controls, ramps, doors. Additional accelerometers *shall* be installed on the wing and empennage. In a typical test, the excitation source, whether electromagnetic or mechanical, is swept automatically at a slow rate over the range from just above the natural frequency of the suspended helicopter to at least 50 Hz. During such a sweep, mobility (motion/force) or impedance (force/motion) is plotted automatically for one accelerometer taking the ratio of signals output from the tracking filter. Simultaneously, all signals are being recorded on magnetic tape, unfiltered. Thus, the test can be stopped to play back the other accelerometers; however, such playback usually awaits a convenient break in the test.

The mode shape information gathered during such a test varies, depending on the objective. In some cases, all accelerometers are recorded on a direct writing oscillograph at frequencies of interest, including natural

and rotor excitation frequencies. Mode shape diagrams are made by using one acceleration vector as a phase reference and locating all others simultaneously. In many cases, only a sketch of a local motion is made, such as the coupled motion of a rocket pod and the store boom. Frequently, such a sketch suggests the nature of a problem and its solution as effectively as does a measured mode shape.

Most vibratory testing to date has covered the range below 50 Hz, with most of the interest in the 3- to 30-Hz range. Conducting routine tests above 50 Hz should be avoided because of the complexity of the response caused by banging and chucking of components such as drive shafts, bell cranks, and control tubes. Oscillograph recordings of these responses are difficult or impossible to interpret; however, magnetic tape and appropriate filters produce usable information.

For those helicopters for which mechanical instability, or ground resonance, may be critical (i.e., lowest main rotor inplane natural frequency equal to or less than normal operating rotor speed), additional vibratory testing *shall* be performed to determine the effective hub mass and damping as well as hub natural frequency. For these tests, the helicopter *shall* rest unrestrained upon its landing gear on a surface which is equivalent to, or closely simulates the type of surface from which the helicopter is intended to operate when equipped with that type of landing gear. Should the helicopter be intended for normal use with alternate landing gear configurations, the testing *shall* be repeated with each different configuration. For any landing gear utilizing pneumatic tires or floats, the tire or float pressure *shall* be that intended for normal use.

This investigation of effective hub frequency, mass, and damping *shall* include the rational estimation of the variations, if any, of these parameters throughout the range of temperatures between the temperature extremes specified in the helicopter detail specification. Should it appear that the value of any of these parameters will be more critical with respect to mechanical instability at some temperatures other than those at which the testing was performed, the procuring activity may require repetition of these tests at the more critical temperature(s).

8-7.2.2 Rotor System Vibration

Nonrotating natural frequencies, both in and out of the plane of rotation (chordwise and flapwise), *shall* be determined for all rotor blades. Where applicable, the rotor blades *shall* be mounted in the hub which *shall* be so suspended that the vertical natural frequency of

the suspended rotor system *shall* be less than one-half the calculated value of the lowest natural frequency being investigated. For these tests, the excitation may be applied either to the hub or to a point on the blade appropriate to the mode under investigation. Plots of the computed coupled natural frequencies versus operating speed *shall* be prepared. Typical plots are shown in Fig. 8-7.

8-7.3 FLIGHT TESTS

An inflight vibratory survey of the helicopter *shall* be conducted. The vibration levels at all crew and passenger stations *shall* be measured in order to demonstrate compliance with the applicable requirements. Vertical and horizontal (both lateral and longitudinal) vibration levels *shall* be obtained. The location of the accelerometers *shall* be selected carefully to give a realistic representation of what the cabin occupants feel. This should be accomplished by placing triaxial accelerometers on the seats and on the instrument panel and center console. Longitudinal and lateral vibrations at the top of the cyclic control column, normal vibrations at the end of the collective control, longitudinal vibrations at the rudder pedals, and vertical vibrations at the crew station heel troughs also *shall* be obtained during this survey. Passenger seat vibratory levels *shall* be obtained at forward, mid, and aft passenger compartment locations as a minimum. The vibration measured at the crew station and pilot's seat should be analyzed harmonically and shown on a common time-line with other vibrations.

MIL-H-8501 states that the vibration level at the pilot, crew, passenger, and litter stations for frequencies below 32 Hz *shall* not exceed ± 0.15 g for steady flight speeds from 30 kt rearward up to V_{cr} or ± 0.20 g for speeds above V_{cr} (cruise speed) and frequencies below 36 Hz. Generally, this requirement represents the limiting vibratory comfort levels. Often the b harmonic of the main rotor (b = number of blades) produces most of the airframe vibrations and, for most helicopters, this frequency is below 32 Hz.

Helicopter crew and passengers usually are sensitive to the frequency vibrations. In fact, vibration levels considerably below those permitted by MIL-H-8501 have been found to be both annoying and distracting. The excitations in this range usually are either out-of-track or out-of-balance main rotor blades.

In maneuvering flight—slow or rapid linear acceleration or deceleration from any speed to any other speed within the design flight envelope—MIL-H-8501 requires that the vibration levels below 44 Hz *shall* not

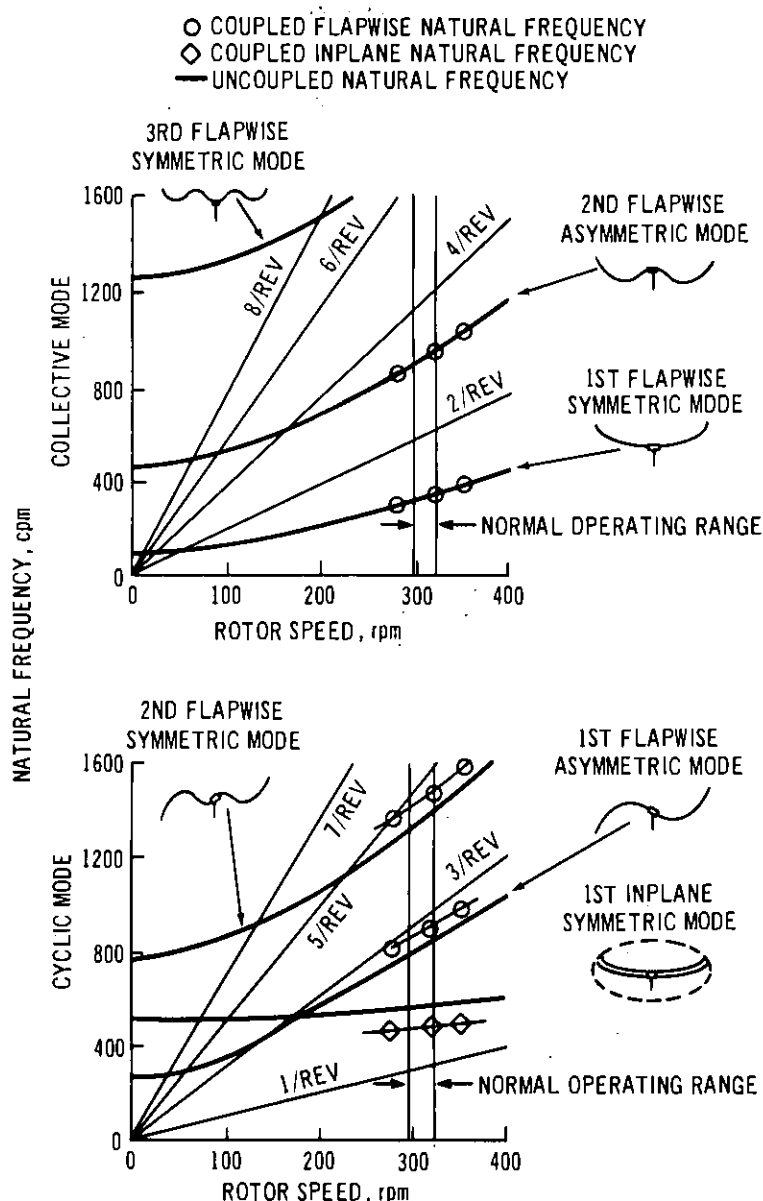


Fig. 8-7. Typical Plots of Rotor Natural Frequency vs Operating Speed

exceed ± 0.3 g at pilot, crew, passenger, or litter stations.

Generally, it is assumed that the levels specified in MIL-H-8501 pertain to the vibrations at discrete frequencies, obtained by harmonic analysis. For complex vibrations, consisting of the superposition of many frequencies, higher frequencies often are obscured by lower ones; e.g., a ± 0.35 g vibration at 30 Hz is hardly detectable when superimposed on a ± 0.15 g vibration at 10 Hz. When not combined with this lower frequency, the 30-Hz vibration is quite noticeable.

For frequencies in the 32- to 150-Hz range, human tolerance to acceleration is significantly higher than in the 2- to 32-Hz range, and the cabin limits are related to amplitude rather than "g" level. Applicable limits are given by MIL-H-8501.

While high-frequency main rotor harmonics (usually above the sixth or seventh) will fall within the frequency range to which these limits apply, the predominant sources of vibration usually will be the tail rotor harmonics, drive system shaft unbalance, and engine unbalance.

Frequencies above 150 Hz are seldom, if ever, felt in the cabin area unless a high-frequency source is attached to the cabin floor or roof. Human response to these frequencies is greatly attenuated, except when the vibrations are manifested as sound.

Vibration levels are a function of gross weight, CG, rotor speed, airspeed, maneuvering loads, and loading conditions. The load (internal or external) sometimes introduces its own natural frequency and may affect cabin vibrations noticeably. Although the ideal situation is to eliminate vibrations under all conditions, a more practical approach is to require that vibratory levels meet the specification at two typical mission conditions.

During the vibratory surveys, the sensitivity to main and tail rotor out-of-balance and out-of-track conditions *shall* be investigated; procedures should be established to balance and track these rotors.

The vibratory survey on a new helicopter also *shall* include the fuselage outside the cabin area. This is already necessary for engine-airframe compatibility (par. 9-3.2) but is also required for environmental information for radios, weapons, external stores, etc. Sufficient pickups *shall* be used along the fuselage, wings and empennage, and transmission or main rotor mounting. These vibratory levels must be evaluated to assure not only that they do not affect the capability of the helicopter to perform its mission, but also that they do not affect structural integrity. To this extent, the flight vibratory survey must be coordinated with the flight load survey (par. 8-2).

Areas of high vibration level should be subjected to strain gage measurements, fatigue testing, and fatigue analysis to assure structural integrity. Special attention should be paid to equipment and components which are cantilever-mounted.

8-7.4 INSTRUMENTATION

Accelerometers are suitable transducers over a wide frequency range (0-1000 Hz or more) when recording on magnetic tape; however, velocity pickups are more suitable for recording over a wide frequency range when recording with an oscillograph. If an accelerometer is used with an oscillograph, the trace sensitivity which produces a reasonable high-frequency output on the paper results in a low-frequency output which is unreadable.

8-7.5 DOCUMENTATION

A report of the results of the survey *shall* be prepared. All operating conditions, on the ground and in

flight, *shall* be summarized and survey data *shall* be presented. Performance of the subsystems *shall* be reviewed, and any configuration changes made as a result of the survey *shall* be discussed. Any helicopter operating limitations resulting from inability of the subsystems to meet stated requirements throughout the required range of environmental and performance parameters *shall* be identified. Recommendations for changes to the subsystem configuration and additional testing *shall* be included.

8-8 CREW ENVIRONMENTAL SURVEY

8-8.1 GENERAL

The crew environmental survey is conducted to verify that the crew station environmental control system (ECS) is adequate to control the cabin environment and also to assure minimum human performance degradation within the operating environment and mission flight profile of the helicopter. This generally will be demonstrated by climatic hangar, ground, and flight tests, as appropriate. The suitability of the crew station environment must be verified under the extremes of the projected mission environment.

Aircrew environmental test criteria described subsequently have been established as the maximum acceptable environmental limits before serious crew performance decrements are likely to occur.

8-8.2 CREW ENVIRONMENTAL SURVEY PLAN

Economic considerations require the development of test plans, schedules, and operations which simultaneously test as many environmental control system operations as practical. In this regard, environmental tests frequently can be conducted concurrently with other surveys. Coordinated test operations are required during the climatic laboratory evaluation, where sea level ECS operational characteristics are established. Operational flight characteristics are established at the respective cold and tropic or desert test sites where near-design climatic conditions exist.

8-8.3 TEST REQUIREMENTS

Experience has shown that aircrews generally are unable to estimate accurately the thermal stress to which they are being subjected (Ref. 1), and therefore are unlikely to provide consistently valid assessments of the crew station ECS. Therefore tests *shall* be struc-

tured to give quantitative results whenever possible. Environmental parameters for crew stations are:

1. Crew station surface and ambient temperature distribution
2. Airflow velocity, particularly at each crew and passenger station
3. Air supply toxicity and contamination
4. Emergency smoke removal
5. Temperature and airflow measurements relative to defogging and deicing of crew station windshield and window areas
6. Wet Bulb Temperature, °F
7. Solar radiation black globe temperature, °F
8. Dry Bulb Temperature, °F.

Items 6, 7, and 8 will be used to determine Wet Bulb Globe Temperature (WBGT), which is the heat stress index preferred by the Army. The Wet Bulb Temperature is measured using only ambient convection for evaporation and the Dry Bulb Temperature is measured with a shaded thermometer. The Solar Radiation Black Globe thermometer measures the temperature at the center of a 6-in. diameter copper sphere whose exterior surface has been painted flat black. Detailed procedures and equipment requirements are defined in TB MED Bulletin No. 175 (Ref. 2).

8-8.3.1 Ground Tests

Compliance with the ECS requirements *shall* be established during flight test operations. Certain ground tests not normally conducted at the Climatic Hangar at Eglin Air Force Base, Florida, also *shall* be performed.

Tests to determine compartment contamination levels *shall* be performed during ground operation with all engines operating and the helicopter stationed in a wind heading most likely to ingest contaminants into the cabin air supply. Compartment contamination *shall* not exceed the limits specified in Ref. 3 and MIL-STD-800.

8-8.3.2 Flight Tests

Test operations *shall* be conducted to evaluate the controllability and the capacity of each environmental control system throughout the flight spectrum. Specifically, airflow velocity conditions at cruise altitudes *shall* be established. Temperature control response characteristics *shall* be determined by manually resetting the temperature control adjustment above and below the design setting. Helicopters equipped with combustion heaters *shall* be tested at flight and atmospheric conditions which require intermittent or low output

heating operations. Fail-safe characteristics of the environmental control systems *shall* be demonstrated by simulating failures of the power source supplied to the temperature or airflow controls. Heating, cooling, and ventilation system capacity *shall* be verified by operating the helicopter at the most critical design speed and altitude.

Heating system flight tests *shall* be conducted at night to eliminate solar effects, with minimum electrical and personnel loads within the compartment. Air-conditioning and ventilation (cooling) tests should be conducted in conditions as close as possible to the outside design curve on Fig. 8-8, with solar radiation and simulated maximum personnel and electrical heat loads.

Contamination characteristics of the compartment air supply *shall* be established during fueling and fuel jettison operations and weapon firing. Air samples should be collected with the ECS in normal operation.

Tests *shall* be conducted to demonstrate satisfactory flight procedures for smoke removal. Test personnel and crews should be equipped with suitable masks during this program.

8-8.3.3 Climatic Hangar Tests

Climatic hangar tests of the helicopter crew compartment are conducted to determine performance compliance of each environmental system. Normal and extreme temperature ranges are evaluated at static sea level conditions. Climatic conditions, including varying humidity levels, can be simulated at a temperature range of from -65° to 160°F. Heavy and/or freezing rain can be simulated at the required temperature conditions for evaluating transparent area anti-icing, defrosting, defogging, and rain removal systems. The operating capability of all ECS equipment can be demonstrated in the Eglin hangar at the required 160°F limit, including solar radiation effects. Air-conditioning and ventilation system tests and compartment airflow, temperature, and contamination surveys can be performed at design atmospheric conditions. Heating, ventilation, compartment temperature distribution, and anti-icing/deicing conditions of related transparent areas can be established at varying low-temperature conditions in this facility. (See pars. 8-9.7 and 11-4 for a detailed discussion of this subject.)

8-8.4 INSTRUMENTATION AND DATA ANALYSIS

The test helicopter *shall* be instrumented and equipped with data acquisition systems that will with-

stand flight test environments. Measurements *shall* be recorded automatically to define transient and steady-state conditions for comparison with human performance standards. Crew compartments *shall* be instrumented to measure ambient air temperature gradients from foot to head levels. Simultaneously, ambient air temperature external to the crew station *shall* be measured for a base line data comparison. Similarly, wall, floor, and ceiling surface temperatures *shall* be determined, including air outlets and exposed ducting. Air-flow velocity patterns *shall* be measured within the compartment, and at the head, chest, and leg locations of the crew stations. The WBGT parameters should be measured at each crew station at approximately chest level. Temperatures of interior and exterior surfaces of transparent areas *shall* be measured to determine the heat flux for anti-icing evaluations.

Crew station ambient temperature measurements used to compute the WBGT Index can be taken conveniently with thermistors. These should be positioned midway between the cabin roof and floor, as close as possible to the crew member without interfering with movement or vision. Shielded thermocouples which mask extraneous temperature effects are necessary where temperature measurements for surfaces or air-flow determinations are required. Surface temperatures are exceptionally difficult to establish; therefore, the recommended thermocouple installation techniques described in Ref. 4 should be used.

Temperatures of interior and exterior surfaces of transparent areas should be determined from calibrated thermocouple installations which will describe the heat flux for anti-icing evaluations. The laboratory calibration should be at conditions of surface velocities and cabin airflow conditions that will be experienced in flight. Hot-wire anemometers or velometers should be used to establish airflow velocity. Positions of the instruments or probes which indicate maximum velocity readings determine flow direction.

Cleanliness and toxicity levels of the air supplied to the occupied compartments are determined by approved and established laboratory analysis methods specified in Ref. 3. Evacuated containers are used to collect the samples. Colorimetric detection devices enable a quick visual determination of dangerous carbon monoxide concentrations within an area. In addition, continuous gas monitors of laboratory quality may be used to sample and record various air toxicity levels, if they are reliably read during flight within the accuracy required by the reference cited previously.

The following measurements *shall* be recorded during all ECS and ventilation system tests:

1. Ground ambient Dry Bulb Temperature, °F
2. Ground ambient Wet Bulb Temperature (ambient airflow), °F
3. Ground ambient Globe Temperature, °F
4. Outside air temperature (inflight), °F
5. Dry Bulb Temperature, pilot/copilot station at chest level, °F
6. Wet Bulb Temperature, pilot/copilot station at chest level, °F
7. Globe Temperature, pilot/copilot station at chest level, °F
8. Air velocity, pilot/copilot station (foot level), fpm
9. Air velocity, pilot/copilot station (chest level), fpm
10. Air velocity, pilot/copilot station (head level), fpm
11. Temperatures of any surfaces in the crew station which feel hot to the touch from causes other than solar radiation, °F
12. Internal and external surface temperatures of the windshield measured at the top, middle, and bottom of the transparent area at centerline of pilot and copilot (deicing and defogging tests only), °F
13. Air velocity at each cooling or ventilation air discharge, fpm
14. Passenger compartment Dry Bulb Temperature, °F*
15. Passenger compartment Wet Bulb Temperature, °F*
16. Passenger compartment Globe Temperature, °F*.

(*Note: These measurements *shall* be taken at 10-ft intervals, at head height, along the helicopter centerline.)

8-8.5 DOCUMENTATION

A report of the results of the survey *shall* be prepared. All operating conditions, on the ground and in flight, *shall* be summarized and survey data *shall* be presented. Performance of the subsystem *shall* be reviewed, and any configuration changes made as a result of the survey *shall* be discussed. Any helicopter operating limitations resulting from inability of the subsystems to meet stated requirements throughout the required range of environmental and performance parameters *shall* be identified. Recommendations for

changes to the subsystem configuration and additional testing *shall* be included.

8-9 HELICOPTER SYSTEM SURVEYS

8-9.1 GENERAL

Helicopter system surveys will be conducted to verify those additional characteristics of the helicopter system necessary for its achieving optimum mission effectiveness. Included are factors pertinent to the operational environment, both natural and combat-induced; i.e., radar reflectivity, infrared radiation suppression, lightning protection, icing protection, acoustical noise (both internal and external), and climatic conditions.

8-9.2 INFRARED (IR) RADIATION AND COUNTERMEASURE SYSTEM SURVEY

8-9.2.1 Passive IR Countermeasure Tests

8-9.2.1.1 Airframe/IR Suppressor Compatibility Tests

Prior to installation testing of an IR suppressor unit, certain analyses must be performed to verify good design practices and flight safety. The analyses required include:

1. Calculations to verify structural integrity of the installation
2. Vibratory analysis to verify that no resonant conditions exist for the suppressor installation
3. Heat transfer calculations to verify adequate cooling airflow and an estimate of pertinent surface temperatures. The cooling fan calibration data obtained from the component tests of Chapter 7 are required to determine cooling airflows at various conditions.
4. Calculations of estimated horsepower losses for the IR suppressor installation.

Compatibility tests with the IR suppressor installed on the rotorcraft *shall* be accomplished prior to the IR signature measurements. However, this testing *shall* be limited to obtaining a Safety-of-Flight Release and determining performance degradation. Complete qualification testing will follow the IR signature testing. Since the signature testing may indicate that the suppressor is not acceptable, qualification testing prior to this test is not justified. Prior to any airframe compatibility tests, the component qualification tests (required in Chapter 7) of the IR suppressor unit and the cooling air fan *shall* have been completed. These qualification

tests *shall* include endurance tests, hot and cold flow testing, pressure drop testing, and the applicable environmental tests required by MIL-STD-810.

8-9.2.1.1.1 Ground Tests

The following ground tests *shall* be performed to demonstrate IR suppressor compatibility:

1. With the helicopter tied down, perform a series of gas generator rpm (N_g) accelerations and decelerations over the operating range of the engine (30 min).
2. Perform a ground run using power variations from ground idle to maximum power (30 min).
3. Perform a ground run at maximum continuous power (30 min).
4. Perform a ground run at maximum continuous power with the cooling fan shut off, i.e., no cooling to the IR suppressor (30 min).

At the completion of this testing, the IR suppressor installation should be inspected for cracks in welds, structural failure, overheating, etc.

8-9.2.1.1.2 Flight Tests

The flight tests described are those required for the IR suppressor whether it is a kit configuration or a part of the basic aircraft. Load data acquisition, and performance and handling qualities data acquisition are therefore included. The exact structure of the test programs *shall* be developed and submitted by the contractor for approval by the procuring activity.

The following flight tests *shall* be conducted:

1. Hover IGE at maximum continuous power until temperatures stabilize.
2. Maintain level flight at maximum continuous power (airspeed determined by the procuring activity) at three pressure altitudes (to be determined by the procuring activity) until temperatures stabilize. Repeat with intermediate and maximum power conditions until temperatures stabilize or power condition time limit is reached.
3. Allow temperatures to stabilize in flight at sea level and perform climb at maximum continuous power to service ceiling.
4. Perform speed/power polar. The test *shall* be run to determine the maximum airspeed attainable in level flight at several power settings throughout the engine power range (vary gross weight and altitude).
5. Perform the following additional maneuvers to quantitatively verify helicopter stability and controllability:
 - a. Maximum g turns
 - b. Climb at maximum rate

- c. Rearward flight
- d. Level flight at V_H
- e. Left and right sideslips
- f. Induced disturbance to verify dynamic stability.

8-9.2.1.1.3 Instrumentation and Data Analysis

The following instrumentation requirements are applicable to the testing conducted to verify Safety-of-Flight and provide data to determine helicopter performance degradation:

1. The IR suppressor *shall* be instrumented with a minimum of 10 thermocouples to measure interior and exterior surface temperatures which are affected by the exhaust gas. The contractor *shall* determine the thermocouple locations subject to approval by the procuring activity.
2. Thermocouples *shall* be installed to measure temperatures at the critical tailpipe fairing and fuselage locations which are affected by exhaust gas heating.
3. A minimum of 10 static pressure probes *shall* be equally spaced radially at the exhaust inlet of the IR suppressor. Measurements *shall* be taken to indicate the turbine back pressure created by the IR suppressor installation.
4. Static pressure probes *shall* be installed to measure the static pressure rise across the cooling fan and to determine proper operation for the helicopter installation. These data can be compared with the laboratory bench tests in order to determine the amount of cooling air delivered by the fan.
5. Temperature probes *shall* be installed in the suppressor plenum chamber or suppressor inlet to measure the coolant air temperature.
6. The engine compartment *shall* be instrumented with thermocouples in accordance with par. 8-4.4, in order to measure specified engine and structural temperatures.
7. If the IR suppressor cooling air inlet and a heat exchanger cooling air inlet are combined, then temperature probes *shall* be provided to measure the hot fluid inlet and outlet temperatures of the heat exchanger. These data are required to verify that the IR suppressor does not deprive the heat exchanger of cooling air.
8. Accelerometers *shall* be installed to measure vertical, lateral, fore, and aft accelerations at all suppressor attachment locations and all other critical locations. The locations *shall* be determined by the contractor and approved by the procuring activity.
9. Strain gages *shall* be installed to measure loads

at all engine and/or fuselage attachment locations for the IR suppressor.

10. Suitable recording devices *shall* be provided to record the cockpit control panel readout parameters: (1) measured gas temperature (MGT), (2) torque, (3) gas generator rpm (N_g), (4) power turbine rpm (N_p), (5) outside ambient temperature (OAT), and (6) ambient pressure.

11. Instrumentation such as accelerometers, transducers, and gyro's *shall* be installed to measure control stick positions, angles, rates, and accelerations in roll, yaw, and pitch. See par. 9-5.3 for detailed instrumentation requirements.

A compatibility test report *shall* include the following:

1. Plots of the temperature time histories for the various ground and flight conditions performed
2. Plot of torque versus true airspeed and a plot of SHP versus true airspeed
3. SHP losses created by the IR suppressor installation
4. Coolant fan SHP requirements
5. Weight and CG changes due to IR suppressor installation
6. Analysis of vibratory data and a comparison with frequencies of other helicopter systems to verify that no resonant conditions exist
7. Any backup data required to aid in verifying structural integrity
8. Coolant airflows as a function of helicopter operating condition (i.e., exhaust pressure, airspeed, OAT, ambient pressure)
9. Graphical presentation of the control position (longitudinal, lateral, pedal, and collective) versus true airspeed for all level, rearward, and sideward flight conditions
10. Graphical presentation of the angle of pitch and roll and control positions versus sideslip angle (for the sideslip conditions)
11. Graphical presentation of the angle, rate, and acceleration in pitch, roll, and yaw, and control positions versus time following the disturbance.

8-9.2.1.2 IR Signature Survey

Three test modes are required to determine the IR signature of a helicopter and the subsequent effectiveness of a countermeasure device against an IR missile threat: (1) ground operation, (2) hovering operation, and (3) a fly-by.

Spectral data *shall* be taken at all test conditions with a spectrometer. In addition, thermovision imaging *shall* be conducted during the ground and hovering tests as a means of determining all primary and secondary "heat" sources. Current analytical methods utilize the spectral data obtained during the ground/hovering tests to derive the helicopter acquisition range for a particular IR missile. Fly-by testing is conducted with missile simulators as a means of verifying the predictions.

8-9.2.1.2.1 Ground and Hovering Conditions

The spectral data *shall* be measured at 15-deg increments while the helicopter is rotated through 360 deg on the ground. The distance between the helicopter and the spectrometer *shall* be determined by the test facility, with consideration given to obtaining the best possible resolution.

To measure the spectral data at varying aspect angles, altitudes, and slant ranges, hover readings are required at a series of altitude and slant ranges:

1. Slant range, 200 ft; altitude, 20 ft
2. Slant range, 280 ft; altitude, 200 ft
3. Slant range, 600 ft; altitude, 60 ft
4. Slant range, 2000 ft; altitude, 200 ft
5. Slant range, 6000 ft; altitude, 600 ft.

It is desirable to measure the data in 15-deg increments. However, since this poses difficulties for the pilot, the helicopter *shall* be rotated through 360 deg in 2-5 min. This procedure will be repeated at least two times to insure that sufficient data have been obtained.

In addition to obtaining spectral data, thermovision imaging of the helicopter *shall* be obtained.

8-9.2.1.2.2 Fly-by Test Condition

The fly-by testing *shall* be conducted employing a missile simulator which measures radiometric data. A flight grid *shall* be determined based on the capabilities of the test facility and the size of the helicopter.

The purpose of measuring the radiometric data is to determine the acquisition and lock-on ranges of the pertinent missile seeker and to verify the analytical method employed in determining the acquisition ranges from the spectral data taken during the ground and hovering modes.

Spectral data measurements permit the evaluation of the helicopter against any missile threat. The radiometric measurements taken with missile simulators currently being used only permit evaluation of the threat due to a missile operating in the specified wave length of the REDEYE missile. An example of the flight grid is presented in Fig. 8-9.

The helicopter is flown in both directions along a number of parallel vectors. One vector is directly over the missile simulator, while the others are offset, to obtain a polar plot of aspect angles (the lock-on for each vector flown results in a different reading). The altitude and slant range are determined by the test facility.

IR signature testing for helicopters currently is being evaluated against ground-to-air missile protection only. If air-to-air missile protection is required, the pertinent data would have to be measured by a chase aircraft.

8-9.2.1.2.3 Instrumentation and Data Analysis

During the spectral measurements, separate spectral atmospheric attenuation measurements *shall* be taken to verify the particular atmospheric models to be employed. The test will be performed with a minimum of direct solar illumination. That is, for ground and hovering conditions, the data *shall* be measured with the instrumentation facing away from the sun and a sweep *shall* be made of the background periodically during the test to measure background radiation and subtract it from the basic data.

To evaluate fully the spectral and radiometric data, the following parameters *shall* be measured:

1. Engine parameters: MGT, N_g , N_p
2. Ambient temperature
3. Ambient pressure
4. Ambient humidity
5. Tailpipe or IR suppressor surface temperatures
6. Pertinent fuselage temperatures affected by exhaust or secondary IR sources such as heat exchanger locations.

The engine power setting for all tests *shall* be maximum continuous power. This condition *shall* be used due to the time required to complete each test (i.e., if maximum power were utilized, engine limitations may be exceeded for certain tests). The procuring activity may, however, request spectral data at maximum MGT conditions. It is extremely important that, for all testing (suppressed and unsuppressed or the effectiveness testing of two IR suppressors), the MGT be held constant since this parameter determines the IR signature level.

The instrumentation available to measure spectral and radiometric data may vary at different test facilities. However, the following types of instrumentation are required:

1. Spectrometer covering the IR region of interest with an adjustable field of view sufficient to focus on the entire helicopter

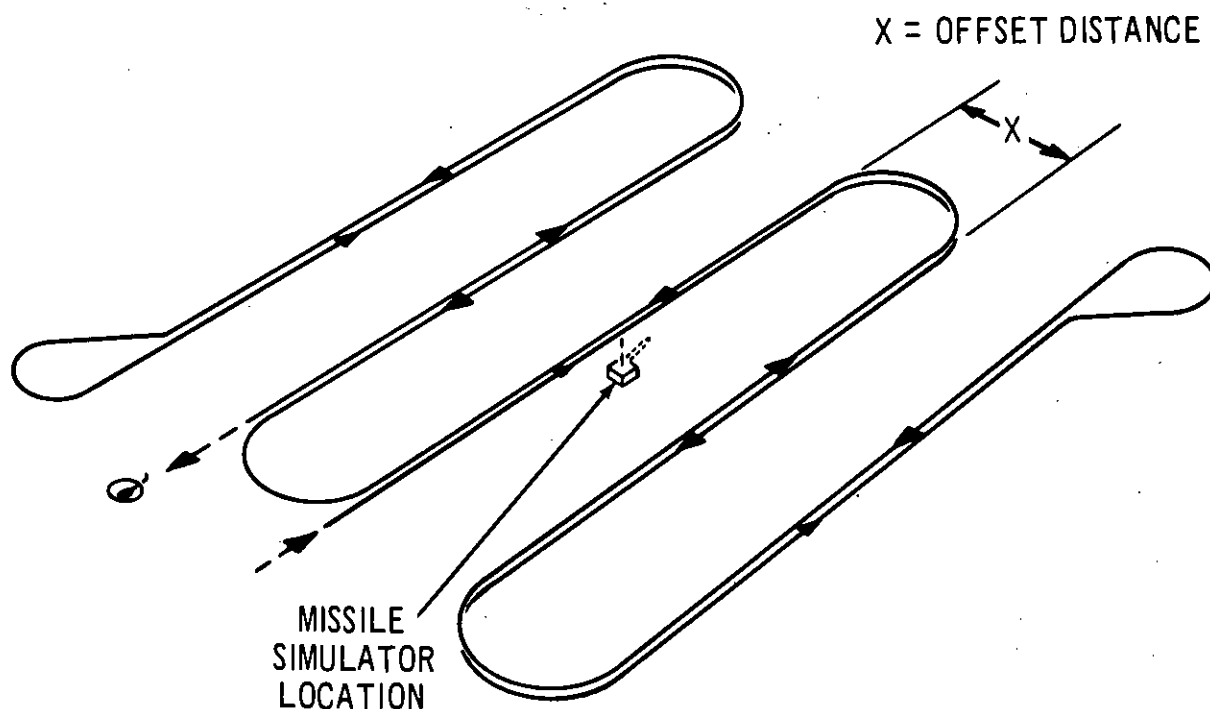


Fig. 8-9. Grid for Typical Helicopter Fly-by of Missile Simulator

2. Thermovision camera
3. Missile seekers to perform as radiometers

4. A test setup which contains all the necessary calibration, recording, and support equipment. This includes instruments to measure humidity, temperature, and pressure; radar to track the helicopter position; and an oscilloscope which provides a visual indication of the spectral and radiometric patterns.

All measurement equipment *shall* be calibrated prior to and after each test segment.

The measured spectral data taken *shall* be compiled and the background data subtracted in order to obtain the absolute signature data. Then, the spectral data *shall* be analyzed by computer techniques to determine the acquisition ranges of the missiles. All parameters must be corrected to apply to the same atmospheric and helicopter conditions (i.e., same temperature, humidity, and MGT). The acquisition ranges obtained from the fly-by tests will be compared with those obtained by use of computer techniques.

The following data will be submitted in the final report:

1. Spectral radiant intensity versus wavelength plots for the various azimuths, aspect angles, and slant

ranges. The ambient conditions *shall* be specified on each plot.

2. The parameters—azimuth, spectral radiant intensity, ambient temperature, MGT, N_s , N_p , and engine torque—*shall* be presented in tabular form for the conditions mentioned in Item 1.

3. Integrated radiant intensity plot for the unsuppressed and suppressed helicopter. Specify range and aspect angle, and ambient conditions on the plot.

4. Radiometric missile radiant intensity polar plot.

5. Acquisition range envelopes for two specified signal-to-noise ratios computed for missile spectral bands with the radiometric fly-by data acquisition ranges superimposed for comparison of computer method accuracy. Specify ambient conditions, MGT, altitude, signal-to-noise ratio, and vehicle velocity and superimpose the inner and outer kinematic launch boundaries on the polar plots.

6. Thermovision gray scale images as a function of azimuth, aspect angle, and slant range.

7. Polar plots of suppression effectiveness for missile spectral bands.

8. Spectral plots of atmospheric attenuation for all conditions tested.

8-9.2.1.3 Qualification Tests

The testing required in par. 8-9.2.1.1 and this paragraph comprises the qualification of an IR suppressor. At the completion of these tests, the feasibility of the use of an IR suppressor and its installation can be evaluated properly. When two or more IR suppressors are being evaluated, the optimum suppressor can be determined by a trade-off analysis which considers IR signature reduction and horsepower losses.

At the successful completion of the airframe compatibility and IR signature survey, the installed IR suppressor configuration *shall* be subjected to the Engine Exhaust Survey requirements in par. 8-4. As a minimum, the following tests also *shall* be conducted:

1. Endurance test to verify its compatibility with the service requirements
2. Sand and dust test
3. Rerun of certain airframe/IR suppressor compatibility tests, as a result of any engineering changes resulting from previous tests.

8-9.2.2 Active IR Countermeasure System

The qualification of active IR countermeasure system components is the responsibility of the U.S. Army Missile Command. Therefore, the only testing to be accomplished under the auspices of the U.S. Army Aviation Systems Command involves installed flare dispenser/airframe interface compatibility. The IR signature survey described in par. 8-9.2.1.2 is, however, applicable to an active IR countermeasure system since the helicopter baseline IR signature determines the design parameters for the flares. Flight testing *shall* be conducted to determine the following items for the flare installation:

1. Performance
2. Stability and control
3. Vibrational and structural criteria
4. Jettison envelope.

8-9.2.2.1 Flight Test Conditions

As a minimum, the following individual flight tests *shall* be conducted:

1. Perform speed/power polar. This test *shall* be conducted at a minimum of two gross weights at altitudes varying from sea level to helicopter service ceiling. The maximum airspeed attainable in level flight at several power settings throughout the engine power range *shall* be determined.

2. Perform the following maneuvers to verify helicopter controllability and stability:

- a. Level flight of Item 1
- b. Maximum "g" turns
- c. Climb at maximum rate
- d. Rearward flight
- e. Level flight at V_H
- f. Left and right sideslips
- g. Induced disturbance to verify dynamic stability.

8-9.2.2.2 Instrumentation and Data Analysis

The helicopter *shall* be instrumented with accelerometers located at the flare dispenser attachments and other critical locations determined by the contractor and the procuring activity which will verify that no resonant vibrational conditions exist. Strain gages also *shall* be installed at the attachment locations to measure the structural loading. The vibrational and structural data *shall* be measured for all flight conditions.

Other instrumentation requirements include equipment such as transducers, onboard recorders, and all necessary instrumentation required to measure and record stick positions (longitudinal, lateral, collective, and pedal), true airspeed, angle of pitch and roll, sideslip angle, and angle rate, and acceleration in pitch, roll, and yaw directions.

The specific data requirements for each test to verify control and stability are:

1. Measure airspeed, control stick positions, and time for all test conditions.
2. Measure angle of pitch, roll, and sideslip for maximum "g" turns and sideslip conditions.
3. Measure angle, rate, and acceleration of pitch, roll, and yaw for the dynamic stability condition.

The following data *shall* be included with the flight test program:

1. Graphical presentation of the control position (longitudinal, lateral, pedal, and collective) versus true airspeed for all level, rearward, and sideward flight conditions
2. Graphical presentation of the angle of pitch and roll and control positions versus sideslip angle (for the sideslip conditions)
3. Graphical presentation of the angle, rate, and acceleration in pitch, roll, and yaw, and in the control position versus time following the disturbance.

8-9.2.3 Documentation

Two reports *shall* be submitted to the procuring activity, one on airframe/IR suppressor compatibility and other installed testing, and the second on the sur-

vey and IR suppressor effectiveness. The required contents of the latter report are discussed in par. 8-9. 2.1.2.3. These separate reports are required since, normally, the contractor performs the installation tests and an independent agency conducts the IR signature survey and evaluation. Also, in many cases the contractor does not have a need-to-know for the IR missile threat data. The IR signature survey and analyses report will be classified.

8-9.3 RADAR REFLECTIVITY SURVEY

The radar reflectivity survey will determine the radar cross section of the helicopter and aid in the definition of techniques to minimize radar reflectivity.

The radar cross section measured in square units is defined as 4π times the ratio of the power per unit solid angle scattered back toward the transmitter to the power per unit area striking the target. For large complex structures and short wave lengths, the values vary rapidly with aspect angle. The effective areas of several important configurations are listed in Table 8-3.

The frequency range of the searching radar must be taken into consideration. At the present time, radar techniques exist from the 100-MHz range (UHF) to more than 36,000 MHz and include the laser (visible coherent light). In general, the conventional radar range lies between UHF and super HF. Table 8-4 correlates the nomenclature with the frequency.

Radar illuminates the helicopter much as a point source of light does. If a helicopter is illuminated by a point source of light in the absence of other light, only

TABLE 8-4. SIGNIFICANT RADAR FREQUENCY NOMENCLATURE

LETTER DESIGNATION	FREQUENCY, GHz	WAVELENGTH, cm
P	0.225 - 0.39	133.3 - 76.9
L	1.12 - 1.70	26.7 - 17.7
LS	1.70 - 2.60	17.7 - 11.5
S	2.60 - 3.95	11.5 - 7.6
C	3.95 - 5.85	7.6 - 5.15
XN	5.4 - 8.2	5.6 - 3.65
XB	7.05 - 10.0	4.25 - 3.0
X	8.2 - 12.4	3.65 - 2.42
K	12.4 - 36.0	2.42 - 0.834

the highlights are seen by the observer. This, to a large degree, is true of a scanning radar. If, then, a shiny sphere were to be illuminated by a point source of light in the absence of other light, only one point of light would strike the observer's eye. The same is true for a coherent radar. In theory, a sphere would be the ideal configuration for minimum reflectivity.

By contrast, for an ideal maximum reflectivity object, a right-angled metallic box would reflect best. This is not exactly true for a known narrow-band situation. A paraboloid of revolution, with its primary axes aimed directly at the source, will throw the maximum amount of energy back to the source. This is true of light and of electromagnetic energy of any frequency. However, the major and minor axes are critical, and one set of dimensions satisfies only one frequency. A corner reflector has a broader bandwidth and is a more common device in evaluations of radar reflectivity.

The geometry and the material from which the helicopter is constructed determine the target size presented to a given radar (i.e., of a given frequency, antenna beam width, pulse width, repetition rate, and receiver sensitivity). The helicopter will present a target of a different size when scanned from different aspect angles. For example, most helicopters will present a much smaller target when viewed from the front than when viewed from the side. This is a function of the area and the shape exposed to the incident electromagnetic waves and the aspect angle viewed, as well as the scanning radar frequency, radar type, polarization, and other radar characteristics.

The helicopter differs from a fixed-wing aircraft as a radar target primarily because of the presence of large rotating mechanism(s). The main rotor(s) of a helicopter present a constantly varying view to the radar. In this process, the rotor can act as a variable geometry

TABLE 8-3. TARGET ECHOING AREA

REFLECTOR	CROSS SECTION
TUNED $\lambda/2$ DIPOLE	$0.22 \lambda^2$
SMALL SPHERE WITH RADIUS = a , WHERE a/λ IS LESS THAN 0.15	$9\pi a^2 (2\pi a/\lambda)^4$
LARGE SPHERE WITH RADIUS = a , WHERE $a/\lambda > 1$	πa^2
CORNER REFLECTOR WITH ONE EDGE = a (MAXIMUM)	$4\pi a^4/(3\lambda^2)$
FLAT PLATE WITH AREA = A (NORMAL INCIDENCE)	$4\pi A^2/\lambda^2$
CYLINDER WITH RADIUS a , LENGTH = L (NORMAL INCIDENCE)	$2\pi L^2 a/\lambda$
SMALL METAL FIGHTER AIRCRAFT	200 ft ²
LARGE AIRPLANE (DC-8 TYPE)	800 ft ²

* λ -WAVELENGTH

radar reflector which covers a wide frequency spectrum.

The changing dimensions of a rotor system, as a result of control system inputs, vary the physical geometry and, therefore, alter the electrical resonances of the conductive parts. In some cases, reinforcement of radar signals will result, and in others, cancellation. The radar thus sees a target which appears alternately larger and smaller. This is one form of scintillation. Also, there are Doppler effects due to differences in velocity along the length of the rotors. These affect the radar reflections detected by Doppler radar.

Helicopters are made up of angles, dipoles, stubs, and dispersion configurations with many resonant frequencies. Dimensionally, they are extremely complex and from a practical standpoint, cannot be analyzed theoretically.

8-9.3.1 Radar Reflectivity Survey Plan

The contractor's radar reflectivity survey plan *shall* define:

1. Ground and flight test conditions to be investigated
2. Instrumentation and data analysis requirements.

8-9.3.2 Scale Model Techniques

In order to determine the radar reflectivity of a helicopter design, model studies must be conducted. This technique is satisfactory when the model itself is large and the radar frequency low. Model techniques have been used in the infrared frequency range with some success. Consideration should be given to utilizing coherent light techniques as the state of the art advances.

The scaling technique has long been used for antenna pattern range work and is considered to be valid within the measurement technique constraints. An example of this technique is the use of a 1/20 scale model. Equivalent reduction of the wavelength requires multiplication of the radar frequency by 20. Because so much of the radar spectrum is in the frequency range of 10 MHz and above, the required frequency multiplication raises problems of suitable equipment.

This technique is mentioned as a means of roughly predicting results for a full-size helicopter. As new high-frequency techniques become available in the millimeter wave and coherent light region, these should be utilized for frequency scaling.

However, the modeling method produces gross results, at best, and in certain cases will produce misleading information. The ultimate test results can be obtained only from a full-scale model.

8-9.3.3 Test Requirements

The radar spectrum is wide, and a test which covers the full spectrum, using spherical coordinates and including cross-polarization requirements, is economically unsound because of its complexity. If the helicopter is to be used only for training or rear support, testing should be minimal. Forward area tactical, night-day helicopters *shall* undergo careful scrutiny, although even this must be limited. Test considerations are:

1. What is the helicopter utilization?
2. Where is the area of operation?
3. Will it encounter enemy radar?
4. What type of enemy radar will it encounter?
5. What is the mission profile?

From these considerations, the contractor and the Army can develop a test plan. The test plan *shall* include the following:

1. Radar frequencies to be used
2. Type of electrical test (spherical coordinates; vertical-horizontal polarization, cross-polarization tests, inflight or tower tests)
3. Type of flight tests (hovering or forward flight cloverleaf)
4. Maximum acceptable reflectivity
5. Reflectivity standard.

The three commonly accepted comparison standards are the sphere, the corner reflector, and flat plate. Whenever possible, the sphere will be used as a standard for several reasons. Both the corner reflector and flat plate are frequency-sensitive. Alignment of both the plate and the corner reflector is critical, and the reflectivity will vary with the geometrical layout. One of the disadvantages of a flat plate reflector is the precision to which it must be constructed. Also, the plate presents a handling problem because, in order to minimize error, each edge must taper to a knife edge. Therefore, the recommended method of testing is to utilize the sphere.

Standard spheres are available for several frequency ranges. Usually, the sphere is suspended in air beneath a device which enables the sphere to be scanned without extraneous interference. Nylon monofilament is suggested as a suspension medium.

8-9.3.4 Instrumentation and Data Analysis

Because of minor imperfections inherent in the sphere, it must be calibrated a number of times both prior to and after the helicopter tests. A minimum of five determinations (a better sample is 10) of radar

reflection coefficients of a given sphere *shall* be made. The variables which can occur during the testing are:

1. Radar transmitter output
2. Radar receiver sensitivity
3. Geometrical variations of the sphere
4. Attenuation characteristics of the atmosphere
5. Ambient electromagnetic interference.

After the characteristics of the sphere are determined, the characteristics of the helicopter must be obtained. The ideal actuation would be to suspend the helicopter with a noninterfering device, but this is impractical. However, because most helicopters have good hovering characteristics, the best flight test procedure is to hover the helicopter in a level attitude and rotate it slowly while a reflectivity curve is plotted from the ground radar receiver. Safe autorotation altitude must be maintained in case of engine failure during the test. This altitude, to a large degree, dictates the distance between the radar and the helicopter. For a hovering altitude of h ft, the distance between the radar and the helicopter should be $10h$ ft. For instance, if safe autorotation hover height is 500 ft, the distance between the radar and the helicopter should be 5000 ft. In this case, the tangent of the angle included is small, and a horizontal spherical cut is made. Conical cuts of the bottom hemisphere can be made all the way to -90 deg in this manner.

One of the problems which must be resolved in this process is determination of the relative helicopter heading from the radar under these conditions. A crude, but effective, method is to plot the output of the receiver on a linear chart while an observer is keying a 10- or 15-deg marker from an airborne transmitter. A more sophisticated method is to couple, by telemetry, the compass heading of the helicopter to the ground station and to slave a polar plotter to the telemetry data. This will result in an analog synchronized signal with little additional data reduction required.

Of prime importance is the monitoring of the variables in the ground station radar transmitter and receiver. These include changes to the output power and to receiver sensitivity, and atmospheric attenuation, which varies with changes in humidity. As with any other type of calibration, it is extremely important to minimize variables.

If the helicopter cannot hover, then the multilegged cloverleaf must be used. The height-versus-distance formula *shall* be maintained, but the cloverleaf *shall* be flown over a fixed landmark in level flight. A 36-legged cloverleaf will result in a plot of reflectivity every 10 deg. This is a discrete angular plot and cannot be con-

strued to mean an analog plot, because of the extreme sharpness of the lobes. However, it will provide an overall picture of the test helicopter reflectivity.

Another method may be employed, but practical experience has shown less consistent results than those achieved with the prior two patterns. The third flight pattern consists of making two small-diameter, 360-deg turns (diameter must be less than 1/10th of the radar distance) in each direction while flying as close to "wings level" as practicable. The radar return is then averaged and plotted as an analog. The three flight patterns are shown in Fig. 8-10.

After the flight tests are completed, the calibration tests utilizing the sphere *shall* be repeated, and all test parameters and variables again considered carefully.

All plots *shall* be reduced to decibels, which then can be referenced directly to the sphere as a ratio of decibel-to-decibel. A reflection coefficient, which has no dimensions, may be obtained.

8-9.3.5 Documentation

A report of the results of the survey *shall* be prepared. All operating conditions, on the ground and in flight, *shall* be summarized and survey data *shall* be presented. Performance of the subsystems *shall* be reviewed, and any configuration changes made as a result of the survey *shall* be discussed. Any helicopter operating limitations resulting from inability of the subsystems to meet stated requirements throughout the required range of environmental and performance parameters *shall* be identified. Recommendations for changes to the subsystem configuration and additional testing *shall* be included.

8-9.4 LIGHTNING PROTECTION SURVEY

The lightning protection survey is conducted to assess the helicopter susceptibility to lightning strikes, and to define techniques and procedures to minimize system vulnerability. Lightning problems on helicopters are expected to increase because of the greater use of plastics and conductive composite materials which are more vulnerable than metals to lightning damage, and because helicopters are being flown more often in instrument weather. Experience in aircraft operation during recent years has initiated intensive lightning survey work. As a result, test equipment and commercial laboratory facilities for making lightning protection surveys are now available. As a minimum, helicopter fuel systems and rotor blades must be checked with artificial lightning discharge currents to assure that neither can be damaged to the extent that comple-

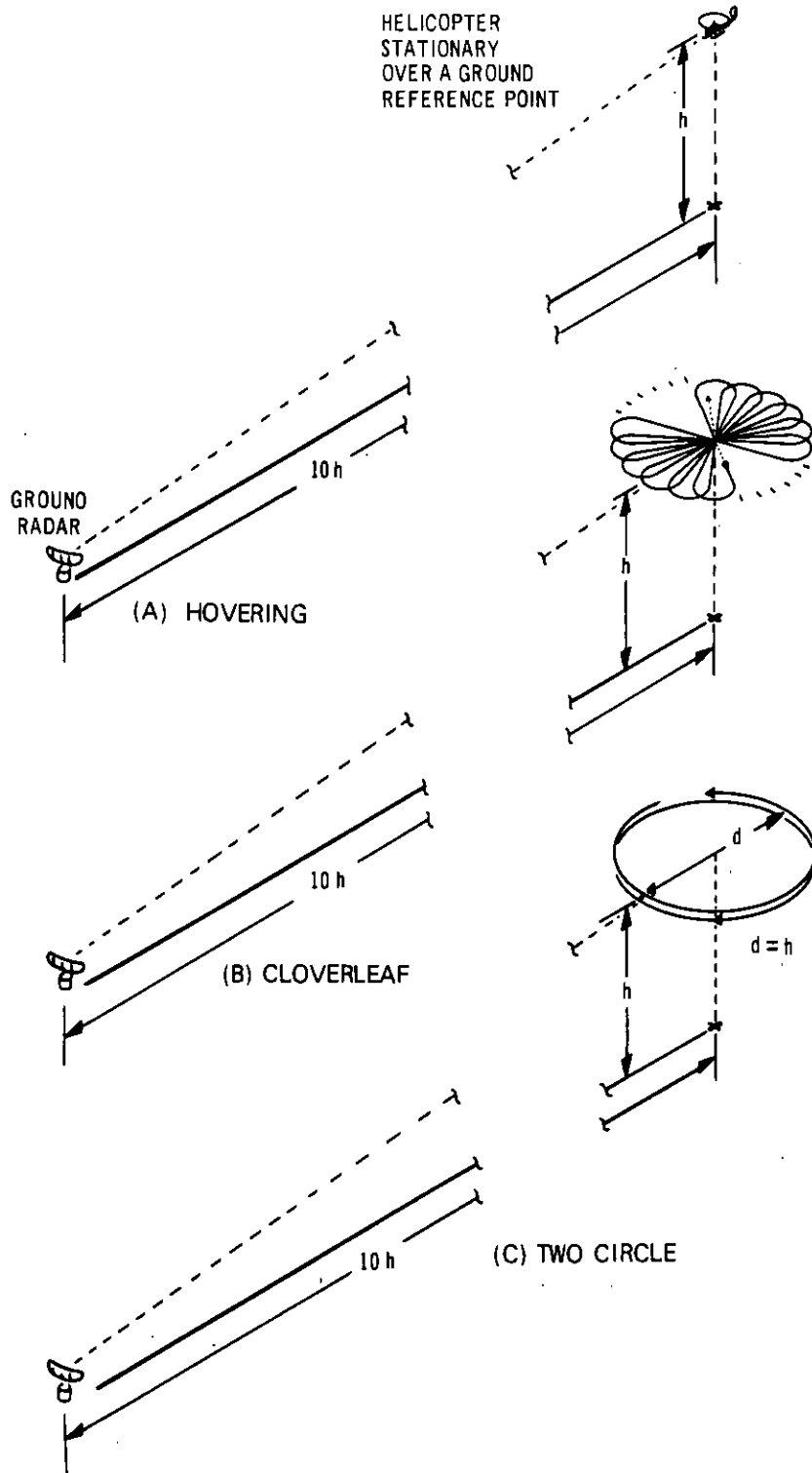


Fig. 8-10. Flight Test Demonstration Methods

tion of the mission will be prevented. Additional areas are outlined in the lightning checklist defined subsequently.

The effects of lightning include pitting, melting, and puncture of generally limited extent in metal skins; moderate size holes in dielectric composite materials; slightly greater areas of damage in conductive composite materials; and explosive effects where arcs are permitted to develop for any substantial distances inside structures of either metal or plastic as discussed in the following paragraphs.

8-9.4.1 Lightning Protection Survey Plan

The contractor's lightning protection survey plan *shall* define as a minimum:

1. The test conditions to be investigated
2. The items to be included on the lightning protection survey checklist.

8-9.4.2 Lightning Laboratory Tests

Laboratory discharges have demonstrated nearly total destruction of some Fiberglas blade designs, indicating the need for at least minimum artificial lightning discharge tests of all helicopter blade designs.

In particular—where metallic components such as control rods, rain erosion coatings, and trailing edge tabs are used—internal arcs which can produce explosive effects may develop. Other areas of concern include metallic conductive paths and metal-to-metal joints such as bearings, where lightning arcs can produce a variety of effects from total welding of small ball bearings in the races to pit marks on larger bearings, with subsequent fatigue or corrosion-induced failure. Equally important is the helicopter fuel system in which explosions can develop with relatively small energies. A complete evaluation includes review of items such as fuel filler caps, fuel tank access doors (plastic and metal), fuel pumps, fuel drain valves, and fuel quantity probes. All lightning-induced sparking within a tank area must be suppressed. Particular care must be taken with systems using JP-4 fuel since it is flammable near 32°F (0°C), the temperature at which most lightning strikes occur.

An additional problem is that of electromagnetic pulse coupling into the helicopter electrical and electronic circuits. Failures of several basic types can result, including:

1. Direct explosive damage of components or systems from lightning strikes strongly coupled into the interior of the vehicle
2. Damage to components, particularly semicon-

ductor devices which are particularly vulnerable to low-energy, high-voltage-induced surges

3. Lightning electromagnetic pulse-triggered discharges in the electrical power circuits which result in power failure arcs. These effects can be produced by either electrical or magnetic fields from nearby lightning discharges or by lightning discharges contacting remote sections of the helicopter, and also through conductively coupled surges into the vehicle interior from lightning current passage through the exterior skin.

To simulate these effects, at least two artificial lightning generators are required. These include:

1. High-voltage impulse generators to produce long arc discharges which can puncture dielectrics, induce electrical streamering off unshielded electrical components, and demonstrate the paths by which the natural lightning discharge will pass through the vehicle. These generators are of the Marx type, in which a bank of capacitors is charged in parallel and discharged in a series by spark-gap switching.
2. High-current artificial lightning discharges which simulate the magnetic force effects, blast effects, high-current sparking of joints, and lightning stroke shock waves. These generators essentially are parallel or series-parallel capacitor banks without switching.

Complete lightning test facilities include additional equipment such as:

1. Slow-wave current generators with higher energies but intermediate currents and time durations which simulate the effects of intercloud or intracloud natural lightning discharges in the melting of lightning conductors, and generation of gas pressures in enclosed sections through vaporization of plastic resins or small metallic conductors. The gas pressures can be amplified by the presence of liquids. These generators consist of large parallel capacitor banks.
2. Long-duration, low-current generators for reproducing the metal-erosion effects of the continuing components in the natural lightning discharge which may exist for periods of up to a second. They are primarily responsible for the metal erosion which occurs on the trailing edge sections of blades or aft portions of the helicopter. These generators consist of a bank of batteries or a DC generator. A more detailed outline of current components and effects is shown in Table 8-5.

Because of the complexity of the natural lightning current components on various portions of the helicopter, the general approach has been to utilize a single,

severe, high-current test wave which reproduces most of these effects as defined in MIL-B-5087. Although it is not specifically stated, MIL-B-5087 also implies the need for high-voltage long arc discharge testing in requiring that the components or vehicle be tested with discharges approaching from all normal directions or lightning stroke approaches. Thus, the requirements of MIL-B-5087 can be approximated by using a high-voltage generator for producing long arc discharges and determining the lightning stroke penetration path through the vehicle, and a high-current impulse generator to reproduce most of the damage effects. The exact requirements of current rise time and waveform require more elaborate lightning generation facilities which generally are available only in major laboratories.

Because of the expense of setting up complete artificial lightning discharge facilities, simple, low-energy facilities can be used at least for development and routine quality assurance testing, which, while not meeting MIL-B-5087 wave form requirements, can provide full, 200,000-A currents. However, the use of these facilities does not replace the need for full qualification tests.

Basic tests *shall* include, as a minimum:

1. High-voltage tests to determine stroke contact points and paths through the component
2. High-current tests to determine possible resultant damage
3. Tests of electrical surges induced in critical wiring circuits
4. Simple bonding tests to check for possible precipitation static radio interference generation from lightning protection hardware
5. Artificial lightning discharge tests of the full-scale helicopter.

Illustrative examples of each are given subsequently.

For checking dielectric components, two test sequences generally are used. Initial high-voltage tests are made to determine the contact points and paths through the dielectrics. High-current discharges are used after the path has been identified to determine what damage would be produced. The test discharges can be produced as a single multiple discharge; however, the severe damage which could occur tends to obscure the basic damage mechanisms, thus reducing the value of the testing. For this reason high-voltage and high-current tests are generally recommended.

An example of high-voltage impulse testing of dielectric or composite structures is illustrated in Fig. 8-11.

Tests of plastic helicopter blades (both chord and span) *shall* be conducted to demonstrate the ability to withstand natural lightning discharges. Such tests

should be made after humidity cycling of the blades because trapped water vapor can produce explosive effects inside the blades. Full-size production or pre-production blades *shall* be tested to assure that the blades being tested *shall* duplicate as closely as possible the blades going into service. Slight changes in component designs to facilitate production can result either in greatly reduced hazards or in characteristics which create greater danger when exposed to lightning discharge currents.

A typical test for all common helicopter fuel tank components is illustrated in Fig. 8-12. The test arrangement consists of high-energy artificial lightning current bank of capacitors which is connected through low inductance connections and a simple paddle switch to the test object; a simulated fuel tank in which the components are mounted to permit instrumentation and cameras and for recording of possible sparking; and suitable measurement equipment to verify that the currents being used meet the requirements MIL-B-5087.

The usual procedure is to mount the component being tested into the test chamber wall, to set-up cameras (with at least an f4.7 lens and using 3000 ASA speed film) for photographing possible sparking, and to install oscilloscopes for surge voltage measurement on the inside of the test chamber. Then, artificial lightning discharges are fired to the external fuel tank components, and the interior of the tank is monitored for any possible sparking of components. If sparking occurs, the component has failed the test. In general, fuels are not used in the testing of special components except where sparking would not be observable from the camera position. In this case, stoichiometric fuel mixtures are contained in a clear plastic bag near the component inside the test chamber to assist in verification of possible sparking by ignition of the fuel. Actual production prototype components are used for these tests.

Tests for lightning electromagnetic surge penetration also use the shielded chamber with the components mounted on the exterior wall. In this case, both cameras and oscilloscopes are used inside the chamber to measure possible voltage pulse coupling. Considerable caution must be taken in making these tests because poorly designed components may produce voltages sufficiently high to damage oscilloscopes. The components are mounted to the test chamber and the normal wiring is installed with load terminations the same as those used in the helicopter. Actual wiring lengths *shall* be used to assure that pulse reflection effects will be duplicated properly in the tests. The discharges are fired to the components and, after verification that the voltages do not exceed safe levels (by use of neon bulbs, for example), the oscilloscope probes are attached directly

TABLE 8-5. LIGHTNING CURRENT COMPONENTS AND EFFECTS

EFFECTS	HIGH VOLTAGE	FAST ELECTRIC FIELD CHANGE	HIGH CURRENT	FAST MAGNETIC FIELD CHANGE	INTERMEDIATE CURRENT	LONG DURATION CURRENT
DIELECTRIC PUNCTURE	X	X				
ELECTRICAL SURGES	X	X	X	X		
MAGNETIC FORCES			X			
SPARKING OF JOINTS			X			
SHOCK WAVES			X	X		
SLOW RISING PRESSURES					X	
METAL PUNCTURE					X	
METAL EROSION						X

to the component wiring to measure voltage penetration.

One important associated problem of lightning protection development is the precipitation static interference which may be produced by the protective hardware. Electrically floating metal parts can charge through frictional contact with atmospheric particles and then spark over and produce severe UHF/VHF radio interference. Measurements of electrical continuity *shall* be made with an ohmmeter to assure that all metal parts are connected electrically to the airframe or blade. This should be determined after blade vibration and weathering tests have been performed. Through flexure or erosion, these tests could produce cracks in metal foil or conducting paint, which in turn, could produce electromagnetic interference.

Although much can be accomplished with preliminary tests of components in the simulated helicopter fuel tank skin, the complexity suggests that tests are more effective if performed on a full-size vehicle.

8-9.4.3 Lightning Checklist

A checklist of major items which *shall* be reviewed for lightning tests includes the following:

1. Rotor blades (see MIL-B-5087):
 - a. Metal
 - b. Metal and nonmetal combinations
 - c. All-plastic
2. Fuel system components mounted in the outer skin (see MIL-C-38373):
 - a. Fuel filler caps
 - b. Fuel access doors
 - c. Fuel quantity probes
 - d. Fuel vents
 - e. Fuel jettison tubes
 - f. Fuel pumps
 - g. Plastic fuel tank wall sections
 - h. Wiring attached to Items 2a through 2g
3. Personnel safety, i.e., shielding from induced shocks (see MIL-B-5087)
4. Navigation and collision lights

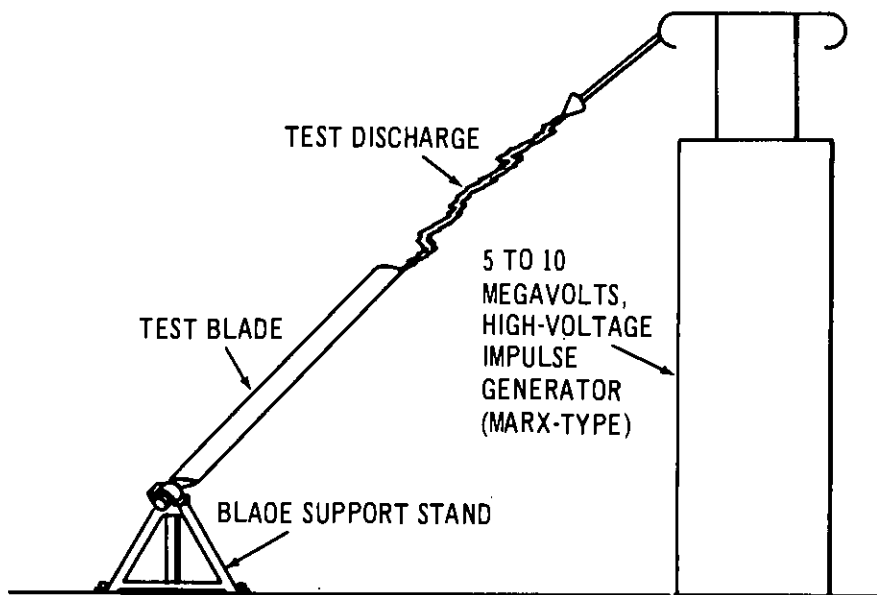


Fig. 8-11. High-voltage Long-arc Test Arrangement

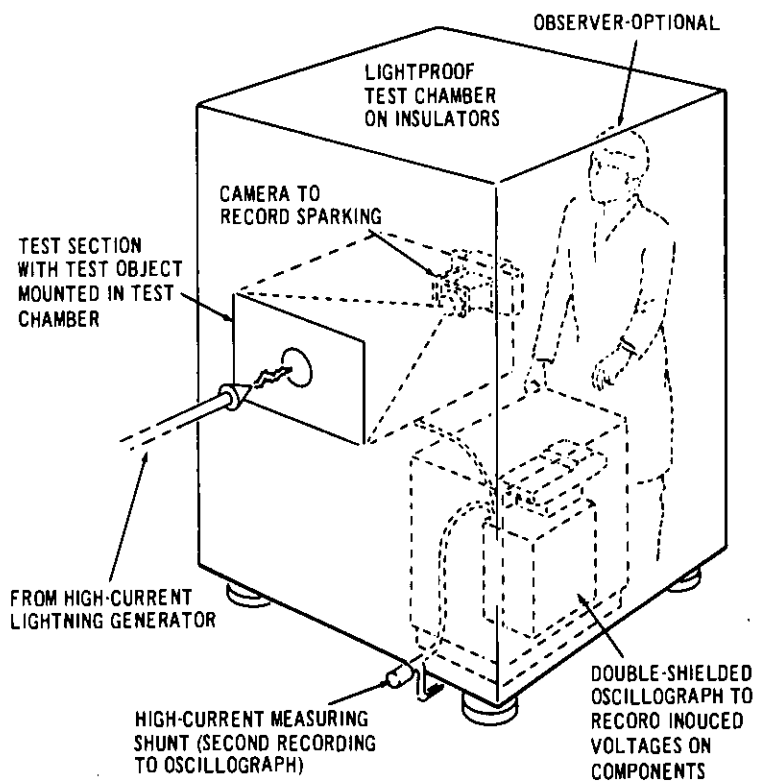


Fig. 8-12. Component Sparking and Induced Voltage Test Arrangement

5. Antennas (see MIL-A-9094)
6. Wiring, if connected to flight critical circuitry (see MIL-E-6051)
7. Active discharger heads and sensors
8. External stores and pods.

8-9.4.4 Documentation

A report of the results of the survey *shall* be prepared. All operating conditions, on the ground and in flight, *shall* be summarized and survey data *shall* be presented. Performance of the subsystems *shall* be reviewed, and any configuration changes made as a result of the survey *shall* be discussed. Any helicopter operating limitations resulting from inability of the subsystems to meet stated requirements throughout the required range of environmental and performance parameters *shall* be identified. Recommendations for changes to the subsystem configuration and additional testing *shall* be included.

8-9.5 ICING SURVEY

The ice protection survey is conducted to verify the operating capability of the helicopter in conditions conducive to ice formation. Certain helicopter systems and components need special equipment to protect against the effects of ice formation. Other systems may not require special protection, but the operating capability of the total helicopter in icing conditions *shall* nonetheless be verified. Possible effects of ice formation are decreased controllability, power loss, engine flameout, reduced visibility, engine damage, and decreased effectiveness of auxiliary systems that depend on airflow as a heat transfer medium. Other effects of excessive ice accumulation include decreased lift capability and increased drag characteristics.

8-9.5.1 Icing Survey Plan

The contractor's icing survey plan *shall* define:

1. Actual and simulated test conditions to be investigated
2. Instrumentation and data analysis requirements.

8-9.5.2 Test Requirements

The icing tests *shall* determine:

1. Increase in power required to maintain given flight conditions as a function of accreted ice thickness
2. Capability of the engine air induction system to

maintain airflow for full engine power capability and insure that ice ingestion will not occur

3. Capability of the windshield system to maintain visibility requirements
4. Helicopter controllability
5. Heat transfer system performance of the anti-icing or deicing system
6. Possibilities of structural damage when ice is shed
7. Vibration levels during deice system cycling
8. Proper operation of all ice protection system equipment and controls.

Ice protection systems *shall* be subjected to the test operations which follow to establish verification of design and performance:

1. Icing tunnel tests
2. Clear, dry air flight tests
3. Simulated icing flight tests
4. Natural icing flight tests.

Previous helicopter icing tests have shown that selection of the test site and the prediction of consistent natural icing conditions present major difficulties. Often, these difficulties lead to a costly and lengthy test program. Simulated icing flight tests are extremely difficult to establish because of the dependence on ambient conditions (temperature, wind velocity and gust factor) which affect liquid water content and droplet size. In addition, no simulated environment has produced conditions that can subject a medium-to-heavy helicopter to icing conditions in a single complete test.

Clear, dry air testing of ice protection systems demonstrates that proper airflows and air temperature are attained, and verifies the structural integrity and proper design of the component or system (i.e., no leakage, or thermal or pressure damage). Also, the effect on the system/component of a nonicing condition is demonstrated (e.g., higher structural surface temperatures result under such conditions). This dry air testing also demonstrates system flight safety and other effects such as power loss and drag while operating in a nonicing atmospheric condition. Laboratory or simulated icing conditions verify proper system functioning in icing conditions. Tunnel testing of the anti-icing/deicing system components provides the most closely controlled icing tests. It also provides an opportunity to reduce results to significant engineering terms (liquid water content, droplet size, surface temperature, altitude, and airspeed).

8-9.5.2.1 Icing Tunnel Tests

Icing tunnel tests allow evaluation of systems under icing conditions and permit optimization of the design prior to flight. Icing conditions can be simulated in the tunnel at the desired flight or ground operating condition. During these tests, power density, hot airflow, hot air temperature requirements, bleed air requirements, and anti-icing fluid requirements for ice protection of various aerodynamic shapes such as airfoils, air induction systems, and windshields *shall* be established.

In general, full-scale model sections of the surfaces being investigated *shall* be tested to establish maximum ice impingement limits and accretion rates. These characteristics *shall* be established at the most severe attitudes anticipated in the mission profile. Subsequent tests on models incorporating ice protection systems will permit establishment of the power or heat flux density levels necessary to protect the surface. The use of development models allows independent control of heat flux or power distribution for selected surface areas. Final designs *shall* be tested to verify operational and control characteristics.

Test conditions on helicopter engine air induction systems *shall* reflect the downwash characteristics and effects obtainable with the particular helicopter configuration. Tests on components (in the laboratory or in flight) *shall* be conducted over the full spectrum of icing condition parameters (particularly temperature and liquid water content) to insure that engine performance requirements are met, that downwash impingement does not introduce special problems, and that no hot spots exist which could cause system failure. Cold spots which may permit ice accretions, which then can detach and cause engine damage, also *shall* be evaluated.

Generally, an acceptance test duration of 30 min with full performance compliance *shall* be required at each condition. To minimize the possibility of damage, preliminary, short-duration tests usually will be conducted to perform visual checkout prior to the acceptance test.

Heat transfer characteristics of the windshield or canopy can be established at simulated flight conditions. Complete systems can be evaluated, and windshield wiping, washing, and defogging operations can be developed or demonstrated in the icing tunnel. Tests *shall* be conducted to demonstrate that visibility requirements across the airspeed and icing spectrum are met. In addition, tunnel tests *shall* identify hot spots which can result from airflow stagnation and cause system failure. In general, 30 min of compliance testing

at the conditions defined in MIL-T-5842 *shall* be necessary for acceptance.

8-9.5.2.2 Clear, Dry Air Flight Tests

Functional, safety, and performance characteristics of each ice protection system in the helicopter *shall* be demonstrated. Therefore, test procedures *shall* consider maximum operational capability of each system, and its controls and protective devices. Flight evaluation tests *shall* be conducted throughout the full range of power, altitude, and speed conditions expected during the mission profile to determine the adequacy of the ice protection system. Testing techniques *shall* be developed to evaluate the effect of each ice protection system on helicopter performance during cruise, loiter, and maneuvers.

The effects of operating hot air systems (on both power consumed and on conditions of protected surface) *shall* be determined, particularly at the descent or low engine power settings, and at altitude.

Data on electrothermal ice protection systems *shall* be obtained during sea level hover and high-speed conditions, inasmuch as electrical power availability is not significantly varied by altitude operation. These data then can be compared with dry air tunnel data.

Distribution and control of ice protection systems using a freezing point depressant liquid *shall* be established. Fluid coverage of protected areas or chalked surfaces *shall* be determined using dyes to permit photographic recording. Although design flow rates of the system can be verified, adequate performance *shall* be established in actual icing tests.

Helicopter flying qualities and handling characteristics *shall* be evaluated at various flight conditions for inflated and deflated pneumatic boot systems (if used). Particular emphasis *shall* be placed on landing approaches to assure that safety of flight is not impaired.

Effects on helicopter performance and handling characteristics of icing of unprotected areas can be evaluated by simulating ice shapes and weights on these surfaces. Flutter and stall characteristics, particularly during landing approaches or climb operations, *shall* be evaluated, as well as drag effects for mission range determinations. The results of this testing *shall* be used to aid in identifying the need for adding ice protection.

8-9.5.2.3 Simulated Icing Flight Tests

Simulated icing flight test operations are used as an expedient. The U.S. Air Force's converted water-tanker aircraft are capable of generating cloud formations from a tail boom spray rig. The technique can be used to subject the total helicopter or selected portions to inflight icing conditions. Cloud characteristics can

be controlled and varied in progressive stages, as required. The accreted ice formations and the water droplet sizes developed by the tanker aircraft do not duplicate those created by natural environments. However, this technique may be considered for tests to obtain pilot observations on visibility, control, and icing buildup during hover and low-speed maneuvers.

In the case of rotor blades, tests *shall* be conducted throughout the ice condition spectrum to insure correct operation, determine cycling time, determine impingement surface limits, and detect ice thickness. An optimum system will insure that:

1. No runback and refreezing of melted ice occurs
2. The deiced accretion will not cause structural damage or loss of performance when shed
3. Any cycling time requirements as a function of ice accretion are established
4. Ice buildup and shedding do not introduce unacceptable levels of vibration.

With the rotor blade deice system turned off, the increased power required to maintain given flight conditions versus accreted ice thickness also *shall* be determined. This can be demonstrated by hovering in an artificial snow cloud created by a snowmaking machine.

Table 8-6 is a partial listing of available icing test facilities which can be used for simulation testing. Test area size and conditions are shown.

8-9.5.2.4 Natural Icing Flight Tests

Flight tests *shall* be conducted in natural atmospheric snow. Wet snow is the most critical type; while dry, powdery snow usually is handled by the conventional anti- and/or deicing protection systems. Of primary importance for wet snow tests are engine air induction systems. Particle separators, especially, have a tendency to accumulate snow, which may break loose and pass through the engine in large pieces.

Initially, short periods of flight *shall* be conducted into icing clouds to obtain data on ice protection systems, power loss, and flying qualities. Flight time in icing conditions *shall* be increased progressively to obtain full performance data. Extreme care *shall* be exercised to insure that excessive ice that would constitute an unacceptable hazard is not allowed to accumulate on the helicopter during testing.

8-9.5.3 Instrumentation and Data Analysis

Test instrumentation can be placed in three categories for the icing survey:

1. Photographic recording

2. Icing condition recording
3. System performance and power recording.

Each subsystem under test *shall* be equipped with instrumentation to establish qualification test compliance and allow extrapolation of test data for comparison with icing criteria. Test data may be recorded automatically; on magnetic tape, oscillographs, and photo panels; or manually.

8-9.5.3.1 Photographic Recording

Photographic recording of ice protection surfaces is used extensively during test operation. Both movie and still cameras and/or closed circuit television are in common use.

For helicopter testing, cameras may be positioned for fuselage and engine inlet and air induction system monitoring, and rotor hub-mounted for rotor blade monitoring.

8-9.5.3.2 Recording of Icing Conditions

Special instrumentation is necessary to measure atmospheric water vapor content and droplet size. Instrumentation scheduled for flight test *shall* be calibrated and used in the same manner as in the icing tunnel test. A variety of instruments has been developed for such purposes. The most widely used has been the rotating multicylinder device. Others are fixed cylinders, sooted slides, capillary collectors, and rotating-disk meters, in addition to high-speed photographic methods. Standard ice detection devices and airfoil shapes also *shall* be calibrated to determine the atmospheric parameters.

The minimum data to be collected for the helicopter or subsystem under test are:

1. Liquid water content, g/m³
2. Droplet size, microns
3. Icing rate, in./hr
4. Temperature, °F.

8-9.5.3.3 System Performance and Power Recording

Instrumentation suitable for flight operation *shall* be used to measure the energy supplied to ice protection systems. Electrical energy can be determined using voltage and current measurements. Liquid flow measurements can be obtained using turbine-powered flowmeters, rotometers, or volume-time measurements with a calibrated tank arrangement. The preferred method of determining hot airflow rates is to use static pressure and temperature measurements of the airflow at calibrated sections of the installed pneumatic duct

TABLE 8-6. ICING PROTECTION SYSTEM TEST FACILITIES

ICING TUNNELS AND ENGINE ICING CHAMBERS

NASA LEWIS RESEARCH CENTER CLEVELAND, OHIO	SIZE: 6 ft X 9 ft SPEED: 0 TO 240 kt TEMPERATURE: DOWN TO -20° F LIQUID WATER CONTENT: 0 TO 2.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 10 TO 30
NAVAL AIR PROPULSION TEST CENTER TRENTON, NEW JERSEY	SIZE: 23 ft X 23 ft TWO ENGINE TEST CHAMBERS (SEA LEVEL) SPEED: 0 TO MACH 0.9 TEMPERATURE: -23° TO -4° F LIQUID WATER CONTENT: 1.0 TO 2.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 15 TO 25
NAVAL AIR PROPULSION TEST CENTER TRENTON, NEW JERSEY	SIZE: 17 ft DIAMETER ONE ENGINE TEST CHAMBER (ALTITUDE) SPEED: 0 TO MACH 2.4 TEMPERATURE: -23° TO -4° F LIQUID WATER CONTENT: 1.0 TO 2.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 15 TO 25
NAVAL AIR PROPULSION TEST CENTER TRENTON, NEW JERSEY	SIZE: 14.5 ft DIAMETER TWO ENGINE TEST CHAMBERS (ALTITUDE) SPEED: 0 TO MACH 2.4 TEMPERATURE: -23° TO -4° F LIQUID WATER CONTENT: 1.0 TO 2.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 15 TO 25
NAVAL AIR PROPULSION TEST CENTER (AED) PHILADELPHIA, PENNSYLVANIA	SIZE: 2 ft DIAMETER SPEED: 70 TO 75 MPH TEMPERATURE: DOWN TO -22° F LIQUID WATER CONTENT: 0.1 TO 3.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 15 TO 50
LOCKHEED CALIFORNIA BURBANK, CALIFORNIA	SIZE: 2.5 ft X 4.0 ft SPEED: 50 TO 185 kt TEMPERATURE: DOWN TO -5° F LIQUID WATER CONTENT: 0.7 TO 4.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 7 TO 35
LOCKHEED CALIFORNIA BURBANK, CALIFORNIA	SIZE: 2.5 ft X 2.5 ft SPEED: 50 TO 210 kt TEMPERATURE: DOWN TO -2° F LIQUID WATER CONTENT: 0.7 TO 4.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 7 TO 35
THE BOEING COMPANY SEATTLE, WASHINGTON	SIZE: 15 in X 20 in SPEED: 0 TO 200 kt TEMPERATURE: -150° TO -30° F LIQUID WATER CONTENT: DOWN TO 5.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 15 TO 25

ICING TUNNELS AND ENGINE ICING CHAMBERS (CON'T)

NATIONAL RESEARCH COUNCIL OF CANADA OTTAWA, CANADA	SIZE: 1 ft X 1 ft SPEED: 0 TO 0.9 MACH TEMPERATURE: DOWN TO -40° F LIQUID WATER CONTENT: 0 TO 3.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 15 TO 60
NATIONAL RESEARCH COUNCIL OF CANADA OTTAWA, CANADA	SIZE: 4.5 ft X 4.5 ft SPEED: 0 TO 200 MPH TEMPERATURE: DOWN TO -13° F LIQUID WATER CONTENT: 0 TO 3.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 15 TO 60
NATIONAL RESEARCH COUNCIL OF CANADA OTTAWA, CANADA	SIZE: 5 in X 8 in. SPEED: 0 TO 500 MPH TEMPERATURE: DOWN TO -13° F LIQUID WATER CONTENT: 0 TO 3.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 30 TO 60

NATURAL ICING HELICOPTER SPRAY RIG

NATIONAL RESEARCH COUNCIL OF CANADA OTTAWA, CANADA	SIZE: 55 ft X 10 ft HELICOPTERS TO 55 ft DIAMETER SPEED: HOVER TEMPERATURE: LOCAL AMBIENT LIQUID WATER CONTENT: 0 TO 0.9 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 30 TO 60

TANKER AIRCRAFT

WRIGHT- PATTERSON AIR FORCE BASE DAYTON, OHIO	AIRCRAFT MODEL: C-130 SPEED: UP TO 150 kt TEMPERATURE: AMBIENT LIQUID WATER CONTENT: 0.1 TO 1.1 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 80 TO 100
WRIGHT- PATTERSON AIR FORCE BASE DAYTON, OHIO	AIRCRAFT MODEL: KC-135 SPEED: UP TO 500 kt TEMPERATURE: AMBIENT LIQUID WATER CONTENT: 0.1 TO 1.1 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 80 TO 100

CLIMATIC HANGAR AND ICING SPRAY RIG

EGLIN AIR FORCE BASE FLORIDA	SIZE: 30 ft X 30 ft SPEED: 0 TEMPERATURE: -30° TO 0° F LIQUID WATER CONTENT: 0.5 TO 2.0 (GRAMS/CUBIC METER) DROPLET SIZE (MICRONS): 15 TO 90

system. The use of calibrated venturis and orifices is undesirable because of their effects on system pressure loss and flow rate.

System outputs are gaged by the temperature or fluid flow patterns generated on the protective surface area. Depressant system flow patterns and distribution can be recorded photographically using dyed fluids and/or chalked surfaces. Measurement of surface temperature distribution may require a number of thermocouples with a suitable recording system. Thermocouple installation methods specified in Section 3 of Ref. 4 will be followed whenever possible.

The minimum instrumentation to be provided for the powered subsystems includes:

1. Electrothermal Systems:
 - a. Input power (voltage and current)
 - b. Cyclic rate (if cyclic system installed)
 - c. Element "on-time" and "off-time"
 - d. System or component temperature (thermocouples and/or temperature-sensitive paint).
2. Fluid Systems:
 - a. Flow rate
 - b. Flow pressure
 - c. Flow time
 - d. Flow dispersion pattern (utilizing colored fluids, chalked surfaces, or fluid-sensitive paint).
3. Hot Pneumatic Systems:
 - a. Flow rates
 - b. Input temperature
 - c. Pressure drop
 - d. Pitot probes
 - e. Anti-iced surface temperatures (thermocouples and/or temperature-sensitive paint)
 - f. Cyclic or "on-time"
4. Pneumatic Boot Systems:
 - a. Boot pressure
 - b. Cyclic time.

The instrumentation method used for the icing survey *shall* be compatible with the data acquisition system specified for the test helicopter, whether it consists of a photo panel, an onboard digital data acquisition console, or radio telemetry-ground station data acquisition and "on-time" data reduction.

Test data obtained during flight operations *shall* be extrapolated to the design requirements to verify compliance with the ice protection objectives. System operating parameters developed from icing tunnel and dry air flight tests *shall* be used. Analytical techniques can

be developed from the icing accretion and/or thermal balance.

8-9.5.4 Documentation

A report of the results of the survey *shall* be prepared. All operating conditions, on the ground and in flight, *shall* be summarized and survey data *shall* be presented. Performance of the subsystems *shall* be reviewed, and any configuration changes made as a result of the survey *shall* be discussed. Any helicopter operating limitations resulting from inability of the subsystems to meet stated requirements throughout the required range of environmental and performance parameters *shall* be identified. Recommendations for changes to the subsystem configuration and additional testing *shall* be included.

8-9.6 ACOUSTICAL NOISE SURVEY (INTERNAL AND EXTERNAL)

The acoustical noise survey is conducted to provide data which will assist in establishing an accurate definition of the helicopter internal and external acoustical fields. These data are used to substantiate that specification requirements have been adequately met. Helicopter configurations and flight conditions which give the "worst case" measurements are covered.

8-9.6.1 Acoustical Noise Survey Plan

The contractor's acoustical noise survey plan *shall* define:

1. External and internal noise conditions to be investigated
2. Instrumentation and noise measurement requirements
3. Test schedule
4. Data analysis requirements.

8-9.6.2 Test Requirements

There are two types of noise measurements: prognostic and diagnostic. Prognostic measurements determine the acoustical environment with respect to established criteria such as annoyance, distraction, speech interference, hearing damage, and external detectability. Diagnostic measurements locate and determine the characteristics of individual noise sources; they also assist in deciding the means for and amount of noise reduction required, and in determining when the desired reduction has been attained.

This paragraph will discuss only the prognostic measurements, which are of two types, internal and external. Although the equipment used for both types

of measurements is similar, the instrument configurations are quite different.

8-9.6.2.1 Internal Noise

The internal noise survey is conducted to obtain data which can be used for determining compliance with an established limit on the amount of noise permitted within the helicopter. The limit may be based on hearing, speech communication requirements, effects of crew performance, and/or comfort level as stated in the detail specification (see par. 3.1.6 of MIL-A-8806).

8-9.6.2.1.1 Helicopter Operational Modes

As both intensity and duration of noise contribute to the noise exposure, it is necessary to determine the noise intensity for all operational modes of the helicopter. The sound levels for each mode, used in conjunction with the time spent in each mode, enable the noise exposure to be calculated for a given mission profile. This is then compared with the limiting exposure permitted.

There are four categories of operational modes, each with several conditions:

1. Flight Condition:
 - a. Hover
 - b. Maximum performance takeoff and climb
 - c. Cruise
 - d. Normal letdown to landing
 - e. Maneuvers
2. Helicopter Configuration:
 - a. Front and rear doors on
 - (1) Window vents fully open (if applicable)
 - (2) Window vents fully closed (if applicable)
 - b. Rear doors off
 - c. All doors off
3. Weapons:
 - a. Inactive
 - b. Active (only with Items 2a, 2b, 2c, as applicable)
4. Noise Control Means:
 - a. Absent
 - b. Installed.

These modes combine to require 110 measurement conditions. In any specific measurement task the combinations should be scanned to determine which are the important ones, so that the measurement task can be reduced to acceptable dimensions. These data will then serve as a guide for concentrating measurements on the significant modes of operation.

8-9.6.2.1.2 Instrumentation

The test equipment complement should permit both delayed (tape-recorded) and real-time (onsite) measurement of the noise. The minimum equipment and the performance requirements should be:

1. An instrumentation-quality microphone which is designed for measurements in a diffuse sound field without use of incidence corrections or accessories. When a precision sound level meter (SLM) with free-field microphone is used, a quality random incidence corrector microphone is required.

2. Calibration equipment for SLM to assure ± 0.2 dB accuracy

3. Octave band analyzer (OBA) filter set, in accordance with ANSI Standard S1.11-1966, octave, half octave, and third octave band filter sets

4. Battery-operated tape recorder, with a 0.5 hr minimum recording time; frequency range of from 20 to 11,000 Hz within ± 2 dB; signal-to-noise ratio of at least 40 dB; and single audio/signal track

5. Environmental instruments, including hygrometer and thermometer

6. Means for determining helicopter altitude, velocity, power settings, and positions of controls at time of measurement

7. Signal cabling that will not generate spurious signals caused by vibration and electrical fields.

8-9.6.2.1.3 Noise Measurement

The noise measurement procedure described in the paragraphs that follow illustrate a proven and acceptable means of acquiring the needed noise data. It is recognized that current industry-wide emphasis on noise research will bring about continuing improvements in procedures and equipment. These more efficient procedures, if available, should be included in the contractor test plans for approval by the procuring activity.

A representative microphone location *shall* be established in the empty passenger compartment (MD) with all doors on, window vents closed, and no weapon firing. An extension cable on the SLM microphone should be used, and the microphone should be fastened to a long wand. In this way the area may be probed rapidly without undue acoustical interference from the body of the observer. The slow A-scale of the SLM should be used, the microphone kept at expected passenger ear level, and the readings noted on a plan of the passenger area. For precise measurements, representative points should be selected in those areas for which the long-time average levels differ by more than 3 dB

from average levels in adjacent areas. A rough-level contour map of the area will aid in this, and can be prepared from the survey measurements.

In the pilot area, the measurement point *shall* be at ear with the latest approved American Standards Association (ASA).

The extension cable to the SLM should be used for all microphone positions. The plane of the microphone diaphragm should be horizontal, and the microphone suspended to minimize pickup of vibration. A convenient suspension uses weak individual rubber bands, so that the weight of the microphone and cord stretches the rubber bands to at least 2 in. An alternative is to use the long wand, held loosely by an observer whose body serves as the vibration isolator.

The SLM, the tape recorder, and octave band analyzer (OBA) should be vibration-isolated. The amount of isolation depends on the sensitivity of the individual instruments. A simple test for excessive vibration effects is to replace the microphone with a shielded capacitor having the same electrostatic capacitance as that of the condenser microphone capsule used in the SLM. Any residual output indication is then due to internal noise, electrical and magnetic pickup; the internal noise is known from laboratory evaluation and verification of instrument performance. The overall signal-to-noise ratio, with all noise sources active, should be greater than 40 dB.

Upon establishing the test configuration and microphone locations, a tape recording of the noise is made for analysis in the laboratory where the signals can be repeated as often as necessary.

The tape recorder should be operated without undue excursions beyond its normal operating range. The recordings, which must be made for all measurements, must contain information from which the absolute values of the levels can be recovered. The most widely used scheme for doing this involves the SLM, which provides the input to the tape recorder. It is a characteristic of the output from the SLM that the magnitude of the signal delivered depends only on reading the meter for steady signals, and not on its attenuator setting. The acoustical calibrator is applied to the SLM microphone, and the SLM (on wideband) is adjusted to read the calibration value (suitably corrected for barometric pressure). With the SLM output connected to the tape recorder, and knowing the calibration of the tape recorder level control, that control should be set so that overload on the SLM and tape recorder will occur concurrently. Data for this should have been developed already by laboratory tests on the SLM and tape recorder. After 10 sec of calibration tone have been recorded, the calibrator must be removed. Appropriate

data such as that pertaining to the date, time, environment, calibration tone, and setting of controls on SLM and tape recorder should be transferred verbally into the voice data microphone before calibration tone recording. If settings of any of the tape recorder controls are changed during the taping, it will be necessary to repeat the calibration tone recording procedure.

In recording the noise on tape, the widest possible SLM response, often denoted as "linear", should be used. For steady noise, a minimum recording time of 10 sec will suffice; for unsteady noise, a recording that will encompass the extremes of noise level experienced and provide data on the time durations of each significant noise event should be made.

8-9.6.2.1.4 *Weapon Noise Measurement*

Measurements of weapon noise can be performed with a SLM equipped with peak-detector modifications and instrumentation-quality recorder. An unmodified SLM is not designed to handle the fast rise times and high peaks of impulse noise. In addition, a normal audio tape recorder will not measure impulse noise successfully. The recording of impulse noise can most easily be recorded by FM recording with a minimum bandwidth of 0-40 kHz.

It is important to note that weapon firing is highly nonlinear. Therefore, on-the-ground and inflight noise measurements with weapon firing must be evaluated empirically for each situation. The peak sound pressure level (SPL) and duration of the noise required to correlate with the hearing hazard can be measured best by using an oscilloscope and photographically recording the pressure versus time history of the weapon firing.

8-9.6.2.1.5 *Intelligibility Tests*

The intelligibility of the helicopter communication system *shall* be tested using phonetically balanced (PB) word lists, American National Standards Institute Method S3.2-1960, or Modified Rhyme Test (MRT) word lists. The more precise PB lists are preferred, but they also require considerable training prior to actual tests, while the MRT lists require little prior training. When the helicopter radio system is being tested, the lists will be put on magnetic tape and the modulation of the RF signal will be adjusted to 70%. The level of the RF signal fed to the antenna will be the minimum specified for the radio being used. The helicopter intercom system will be tested in a similar manner except that the word lists will be read on the helicopter instead of played back from a tape recorder so that the headset microphone also is evaluated. If it is operationally feasible, the copilot and two passengers will act as subjects and conduct the intelligibility test in round-robin fashion.

ion. Flight conditions will include normal cruise, and also the "worst case" noise condition found during the internal noise measurements. Ordinarily the "worst case" condition will be weapon firing, unless the firing is of very short duration.

8-9.6.2.2 External Noise

The external noise survey will determine the external sound pressure levels produced by helicopters in various flight conditions. The data collected will be used to determine peak noise levels, and spectral content and sound directivity, and will be sufficient to allow estimation of the probability of aural detection of the helicopter.

A subsidiary purpose of this survey is to assess the hearing damage risk experienced by a ground crew working in the helicopter external noise field. The test program *shall* be planned with both detectability and hearing damage risk in mind.

Because detectability depends on more than acoustical factors, the survey results should be regarded as applicable only to the particular situation. The initial surveys should be regarded as preliminary findings.

8-9.6.2.2.1 Helicopter Operational Modes

The intensity, spectral content, and direction of sound mediations, and, to some extent, the direction of noise depend upon the operational mode. There are at the least nine combinations of operational modes necessary for the external detectability noise survey:

1. Flight Condition:
 - a. Hover
 - b. Cruise
 - c. Dash
2. Altitude:
 - a. Minimum terrain clearance
 - b. Medium altitude
 - c. Maximum normal operating altitude.

For ground crew noise exposure measurements, only the hover and letdown modes are of interest. This condition ordinarily persists for a somewhat longer period of time than takeoff. For the hearing damage risk assessment, the duration of the noise exposure is an important parameter. Because these measurements are relatively easy to make, the discussion primarily will deal with the detectability measurement.

8-9.6.2.2.2 Instrumentation

The three types of equipment needed in the survey are used for (1) noise data acquisition and analysis, (2) meteorological data, and (3) electronic tracking, location, communication, and guidance of the helicopter.

The test site is an important consideration in the noise data acquisition system. Effects of terrain and weather will have a profound effect on detectability. Thus an early decision must be made concerning use of idealized or real-life data. In the idealized site, a perfectly reflective plane surface with a stable, windless atmosphere is desired, e.g., a calm day over a large inland lake. Presumably, the results then can be used to predict the noise fields in a variety of nonideal situations. However, the conceptual framework does not now exist for making predictions, such as for the fluctuating sound field received through a turbulent, unstable atmosphere over rolling jungle terrain. Therefore, it is recommended that the surveys use sites that simulate those of real-life interest in terrain, ground cover, and weather.

The penalty is that the results apply to only one situation. Therefore, the equipment complement for the initial measurements of acoustical and meteorological parameters should be capable of acquiring detailed information. This will permit eventual selection of the important parameters that can satisfactorily characterize a given situation. Present experience indicates that these parameters, taken along the acoustical path, are:

1. Noise source strength and radiation
2. Temperature and wind velocity gradients
3. Relative humidity
4. Scale and intensity of turbulence
5. Terrain geography
6. Character and density of ground cover
7. Location of listening instrument.

The acoustical system will use microphones, amplifiers, calibration equipment (pistonphones), seven-channel tape recorder, multichannel time code generator. The system will be based on a straight-line array of equally spaced, outdoor-type condenser microphones. The number of microphones and their spacing should provide reasonable assurance that sideline noise characteristics are adequately described and any unusual terrain or ground feature is taken into account. There is little evidence that the effects of surface air turbulence are minimized if the source elevation is greater than 15 deg above the observer. To include effects that cause fluctuations in received level, it is recommended that a penultimate microphone subtend crowns, elevation angle of 15 deg as the helicopter, at maximum altitude condition, passes over the center of, and at right angles to, the microphone array.

If the microphones are in open terrain, they should be located 4.92 ft (1.5 m) above the ground. Nearby obstacles should have only a small effect, and no major

transverse dimension of an obstacle should be greater than one wavelength of the lowest frequency of interest. Such obstacles should be greater than five wavelengths from the microphone. This means that a compact obstacle should subtend a solid angle of no more than 0.002 steradian at the microphone.

It is desired that the earth surface at the test sight be uniform with a low sound-absorbing ground cover. Dusty earth does not fulfill this condition, nor does grass over 6 in. high, or dense, leafy shrubbery. Hard-packed earth usually is acceptable, as is asphalt or concrete paving.

If the microphones are located in a jungle, their sites should be similar to those for detectors that might be placed specifically for listening. The microphones should be soft-suspended to reduce vibration-induced output. It is best to avoid leafy tree crowns, where the local ambient noise from leaf rustle may become excessive in even a light breeze. It may be necessary to mount the microphones above the crowns, to simulate what might be done by someone seeking to detect helicopter.

Pistonphones or other suitable means of calibration should be used to set levels for the whole system. When the microphone positions do not permit rapid calibration in place, the calibration should be checked daily. Results should be suspected whenever a sudden shift in system sensitivity occurs. Once a pistonphone calibration has been obtained, an insert voltage calibration using a microvolter should be employed for rapidly monitoring the electronics.

Since the noise signature of the moving helicopter varies with distance from the field microphone position on the ground, all the data must be taped for later analysis under laboratory conditions. A convenient center for the field gear is a van or recording module that can be airlifted. This should have humidity control for the inside air and preferably full air conditioning. For flyover recording, the extraneous contributors to ambient noise may have to be shut down during the critical data acquisition stage. If electrical power is supplied by a motor generator set, the motor generator must not raise the ambient noise in any octave band when in operation.

There must be preamplifiers and line amplifiers at the microphones to deliver the proper signal level through hard wire lines to the van. Monitoring and voltage insertion facilities will be needed at the microphone ends of the lines.

The recording system must be able to handle the frequency range of from 20.0 to 11,200 Hz, within ± 2 dB. FM recording probably will be necessary. The signal-to-noise ratio should be at least 40 dB, and may require prefiltering of the signal into two or three

bands, providing preemphasis, and recording the conditioned signals. The Dolby noise-reducing device used in sound recording may be useful, if modified for the expected spectrum.

The output of a time-code generator should be added on an edge band of the tape. The generator will be tied in with the tracking and locating devices, so that, at each instant of time on the tape, the helicopter position and velocity are known.

Meteorological conditions should be determined along the whole acoustical path. If the terrain is relatively flat, with minimum ground cover, it is sufficient to make measurements at one point only. This will ordinarily be near the recording van, using a meteorological tower at least 130 ft (40 m) high. Instruments will be placed at various levels for reading and recording temperature (on strip chart recorders), vector air velocity, relative humidity, precipitation, barometer pressure, and turbulence scale and intensity. It is expected that turbulence will be especially intense in the region up to about 33 ft (10 m) above the ground.

The time variation of the meteorological variables probably will be slow. Therefore, standard strip chart recorders should be sufficient. Event markers will indicate the flyover instant on the charts.

The third equipment group will indicate the position of the helicopter, and correlate it with the tape recording of the time code and the noise signal. Ground-based radar and communications equipment will furnish the chief inputs. The use of a time-code generator to connect all events has already been noted.

8-9.6.2.2.3 Noise Measurement

The helicopter should be flown at right angles to and over the center of the line array of microphones for all flight conditions and altitudes. Some flights may also be scheduled over one end (or even beyond the end) of the array, if terrain features or ground cover create a new situation. Because of the direction of noise from the rotors, the pilot should keep the pitch angle as constant as possible.

Due to the effects of meteorological conditions; it is not expected that results will be duplicated. Hence some real-time means of rapidly indicating steadiness of the results is needed. This can be supplied by bridging an A-weighted SLM across the ground zero microphone. The readings at the closest point of approach provide a rough indication of uniformity. As noted earlier, the number of flights for one speed condition and altitude should roughly equal the extreme range of the A-weighted readings, in dB. Such data, plus communications and other information, can be placed ver-

bally on a lower performance tape recorder, together with the time code.

The need for constant suspicion of delicate field instrumentation cannot be overemphasized. Pistonphone calibration of the whole system should be carried out whenever possible, and insert voltage checks should be made before and after each run. If the weather is rough, condenser microphones may develop wind noise, low internal resistance, or bad frequency response from moisture, cables may fray, especially at connectors, and flexing cables may generate noise.

The initial measurements will provide data for selecting the more meaningful measurements which eventually will be used, as with the internal noise survey.

8-9.6.3 Data Analysis

When the data are to be used to assess detectability by the ear of an observer, the helicopter signal often exists in a background of continuous ambient noise. In this situation the ear detects the helicopter with respect to the periodicity of the signal and to critical bands of noise. In frequency ranges important for ear detection, these bands average close to third-octave (10th-decade) bands; thus the taped data should be examined with a third-octave analyzer.

When electronic detection schemes are used, attention often is focused on periodic components of the signal. The blade passage rates of the rotors, tail propeller, and turbine engine compressor provide such components. Hence the taped data also must be subjected to narrow-band analysis. An integration time sufficient to reduce the fluctuation of readings to within acceptable limits established by the total system accuracy *shall* be used.

The helicopter acoustical signal contains characteristic components, of which blade slap is perhaps the most prominent. Until pattern recognition devices have been perfected, detection by a trained ear remains necessary. Narrow-band analysis is as close as the state of the art permits for objective approaches.

At large distances the received signal will exhibit large fluctuations especially at higher frequencies. If a lull in the ambient noise occurs along with a signal maximum, then the probability of detection is increased greatly momentarily. Although it is difficult to quantify this effect, the implication is that some measure of the rate and extent of the fluctuations should be presented for each third-octave band, along with the mean value of the sound pressure level. The fluctuations are principally a function of turbulence and refraction in the transmitting medium, and are characteristic only of the particular test situation. Nevertheless,

to understand and quantify the problem, a large number of well-documented and coordinated acoustical and meteorological measurements are required.

Because of the mass of data that must be reduced, an automated and computerized system should be employed. However, the components and requirements for a hybrid system that can be utilized include:

1. A time code receiver to control the tape playback machine, enabling quick shuttling to any preselected time. The measurement log book should list the interesting events.
2. Post-equalizers to complement pre-equalizers that may have been used in the recording. These will not be necessary if the Dolby noise control system is employed.
3. A bank of standard parallel third-octave filters, covering the range from 12.5 to 16,000 Hz
4. An analog-to-digital converter, multiplexed to the outputs of the filters
5. Digital rms presentation of at least 50 dB dynamic range
6. Adjustable integration times covering the range from below the pulse integration time of the ear (about 100 msec) to above the period of fluctuations due to atmospheric effects (about 32 sec). The times should be independently adjustable for each analysis band.
7. An incremental tape recorder, to store data for possible final format processing, including spectra versus time.
8. Analog digital processing and outputting (print-out and graphic) of A-, B-, and C-scale sound levels; accepted measures of annoyance as perceived noise, decibels (PNdB), effective perceived noise, decibels (EPNdB), and Zwicker and Stevens loudness.

8-9.6.4 Documentation

A report of the results of the survey *shall* be prepared. All operating conditions, on the ground and in flight, *shall* be summarized and survey data *shall* be presented. Performance of the system *shall* be reviewed, and any configuration changes made as a result of the survey *shall* be discussed. Any helicopter operating limitations resulting from inability of the subsystems to meet stated requirements throughout the required range of environmental and performance parameters *shall* be identified. Recommendations for changes to the subsystem configuration and additional testing *shall* be included.

8-9.7 CLIMATIC LABORATORY SURVEY

As part of the qualification test cycle, the entire helicopter *shall* be tested in a laboratory under controlled conditions which include environmental elements such as temperature, shock, vibration, icing, sand and dust, and salt spray (see Chapter 7 for component testing under these conditions). This is necessary to insure that the systems, subsystems, and components can function satisfactorily throughout the range of climatic extremes, and that there are no undesirable interactions.

The climatic laboratory survey is an essential step in evaluating the effect of climatic conditions on:

1. Airframe and dynamic system operation and strength
2. Engine operation and performance
3. The operating characteristics of:
 - a. Transmissions
 - b. Avionic and control systems
 - c. Auxiliary power units (APU's)
 - d. Fuel, electrical, and hydraulic systems
 - e. Heating, ventilating, and air conditioning
 - f. Windshield, engine, and rotor blade anti-icing
 - g. Maintenance procedures
 - h. The handling and firing of external stores and weapons (if required)
4. Pilot capabilities.

There is no climatic laboratory available which can reproduce accurately all environmental extremes to which the helicopter may be exposed in service. Therefore, the climatic laboratory test *shall* be followed by testing under actual climatic conditions during the Contractor Airworthiness Qualification Tests and/or by the Category II test activities (see par. 11-4).

8-9.7.1 Climatic Laboratory

The primary Governmental test facility located at Eglin Air Force Base is an insulated hangar 250 ft wide and 200 ft deep, with a maximum height of 70 ft in the center sloping to 35 ft at the sides (Fig. 8-13). The temperature range is from +165° to -65°F, with a maximum cooling rate of 60°F in 24 hr. The relative humidity control is from 10% to 95% ($\pm 5\%$). An airflow rate of 650 lb/sec at -65°F is available with accurate control. A spray frame is located in the center of the chamber for creating icing conditions. Icing of engines is accomplished by using portable icing equipment altered for each requirement. Snow-making equipment can produce approximately 700 ft³/hr.

Rain, from a light mist to 15 in./hr, can be produced by an overhead spray system.

The testing periods for the Climatic Laboratory Main Chamber are set up according to predetermined time-temperature dates and are published as regular and special test cycles. Four test periods per year are scheduled, and the laboratory is held for one week at each of the following temperatures: +165°, +125°, +70°, 0°, -25°, and -45°F. This is usually followed by two weeks at -65°F. The remainder of the quarter is available for installation and removal of the helicopter. Since other helicopters and/or equipment may be tested concurrently, the normal procedure is to change the laboratory temperature on the predetermined date regardless of whether or not an individual contractor has completed all his required testing. Pretest planning reviews are conducted including the Climatic Laboratory personnel, the test activity, and the contractor—particularly to resolve the interfaces among tiedown restraints, removal of exhaust from the Main Chamber, power, fuel, oil, instrumentation, data handling, and support equipment.

Either the Department of Defense or the procuring activity must make the request to use the Climatic Laboratory; no action can be taken on requests received directly from the contractor.

The request for testing *shall* contain the following information:

1. Description of the helicopter, including dimensions and weight
2. Any safety hazards associated with handling or operating the helicopter
3. Radio frequencies associated with the helicopter equipment which might require authorization
4. Description of the test procedures
5. Total floor area (square feet) to be occupied by the test, this is divided into:
 - a. Area occupied by helicopter
 - b. Area occupied by support equipment
 - c. Area adjacent to helicopter for physical work operations of test personnel
6. List of military and civilian personnel who will be present to conduct test
7. Date helicopter will arrive at Climatic Laboratory
8. Priority of test (DOD)
9. Security classification of helicopter(s) test program, and test results
10. Support required, including:
 - a. Fuel, oil, and lubricants
 - b. Ground support equipment

- c. Instrumentation design and fabrication
- d. Installation of exhaust ducts
- e. Required spray rigs
- f. Chemical laboratory services
- g. Still and motion picture coverage
- h. Cold weather clothing
- i. Electrical power services
- j. Machine and instrument shop services
- k. Storage space
- l. Office space and equipment.

8-9.7.2 Climatic Laboratory Tests

In the qualification testing of a new helicopter design, testing in the Climatic Laboratory should be extensive enough to evaluate both the operation of the helicopter and special support equipment, and comprehensive maintenance procedures, including major component removals. Currently, there is no Military Specification which defines requirements for climatic testing of the total helicopter. Therefore, the tests *shall* be designed to duplicate actual operational conditions as closely as possible.

The helicopter *shall* be restrained at the transmissions and landing gear attachments in a tiedown system capable of absorbing the rotor thrust at the maximum helicopter operating power.

The primary and redundant tiedown rig is designed by the airframe manufacturer and approved by U.S. Army Aviation Systems Test Activity (USAASTA) and U.S. Air Force Armament Development and Test Center (ADTC). The support structures normally are designed and fabricated by ADTC and consist of appropriate crosspit members and frame boxes of steel "I" beams anchored and weighted to the chamber floor. Extreme care must be exercised by the prime airframe manufacturer to assure that the restraining system does not place the helicopter in a ground resonance condition. The prime airframe manufacturer is responsible for the adequacy of the ground restraint.

Exhaust gases from the auxiliary power units and cabin heaters *shall* be vented outside the Climatic Laboratory to minimize the effect of helicopter operation on the laboratory ambient temperature. Electrical load banks are required to develop maximum generating capacity from the electrical system.

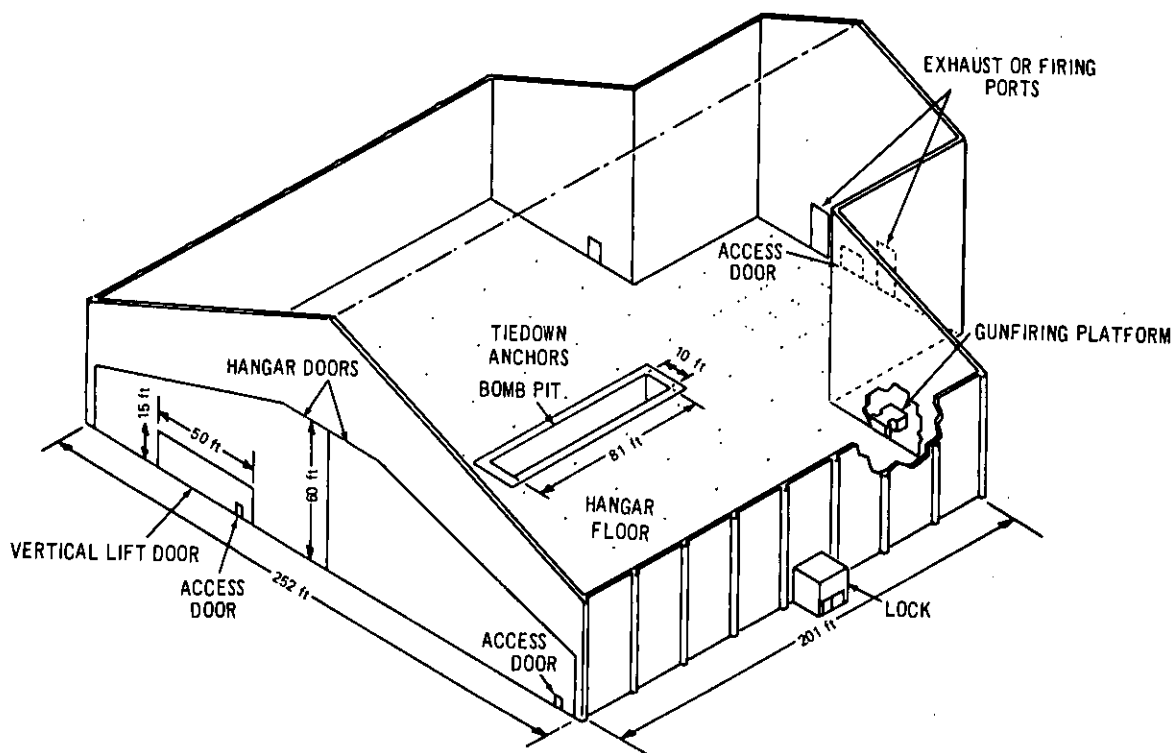


Fig. 8-13. Climatic Laboratory, Main Hangar, Eglin AFB, Florida

A typical test sequence should involve "soak" (usually 48 hr) at the programmed ambient temperature followed by standard preflight maintenance and inspection procedures. Prior to startup of the helicopter main power units, the operation of the APU's and the equipment which can be operated on auxiliary power should be checked.

Following engine start, a predetermined test sequence *shall* be followed to simulate, by varying power levels, control movements and systems operation, the helicopter takeoff, climb, cruise, descent, and landing. The tiedown test requirements of MIL-T-8679 provide a guide to this type of simulated mission profile.

Inspections are performed on the airframe, engines, rotor blades, actuators, lines, and connectors for evidence of cracks and leakage of oil, fuel, or hydraulic fluid. All controls, latches, and mechanisms are operated to insure proper functioning and provide a basis for evaluating the protective coverings. The hydraulic and electrical subsystems, and starting characteristics are determined using the APU when applicable. Special attention is given to the problem areas arising from battery starts. All systems are operated in a sequence consistent with the existing operating procedures. During rotor operation, a simulated mission consisting of climb, cruise, maneuver, and descent is performed. Emphasis is placed on operation of the rotors, transmission, engine, flight controls, weapon, and heating-ventilation systems. Tests are repeated as often as possible at each temperature to define problems encountered and to determine if these problems could be corrected by improved maintenance techniques or quality control, or will necessitate a design change.

8-9.7.2.1 Test Requirements

During the environmental tests, a simulation of the actual operating conditions encountered during operational flight should be conducted. However, due to the complex interaction of loads, temperature, and vibration with the total system, actual conditions can be approached only by simulation on individual components.

While the effect of ambient temperature on the helicopter can be evaluated under actual conditions of vibration, load transfer, and temperature gradient within the system, certain limitations should be recognized. These are:

1. Tiedown restraints on the helicopter which may modify load and vibration paths from those normally present in flight
2. Changes in flow and recirculation patterns around the helicopter due to operation at high engine/rotor powers while in ground effect (a condition not

normally encountered under actual operational conditions)

3. Modification of the environment within the Climatic Laboratory when operating a large helicopter (40,000 lb GW and above) due to the high downwash velocities and high heat generation when operating at high power.

8-9.7.2.2 Instrumentation and Data Analysis

Sensitive instrumentation, consisting primarily of temperature and pressure sensors, should be installed in the helicopter in accordance with the requirements in MIL-I-5289 and the USAASTA *Flight Test Instrumentation Specification for Climatic Laboratory Test*. Critical parameters are monitored visually and recorded photographically and on magnetic tape during the testing.

Sufficient instrumentation should be installed so that problems can be isolated to specific subsystems or components. This necessitates, as a minimum, instrumentation both upstream and downstream of each major component in each helicopter. The instrumentation provides quantitative information on the performance of the system or subsystem that may be used as a basis for recommendations for specific design changes.

The data acquisition system for the climatic test is installed partly in the helicopter (sensors) and partly in a heated test control booth (signal conditioning and recording equipment). A cable harness from the helicopter to the test control booth is used to convey data and system control signals; the record system should be controlled by the pilot in the helicopter. An intercommunication system, separate from the helicopter system, is used to transmit data from the helicopter to the control booth and laboratory control room.

Data parameters to be recorded will vary according to the particular helicopter. A typical data package should include:

1. Pressures and Temperatures:
 - a. Engine and Transmissions. Oil pressure to bearing, pumps, filters, etc. Air pressure in combustor, engine discharge, and anti-icing systems. Fuel pressures at engine manifold, filters, and auxiliary power units. Temperatures at same locations as pressures plus heat exchangers and engine components
 - b. Hydraulic Systems. Flight control and utility system at pumps, filters, stability system actuators, engine starters, control actuators, etc.
 - c. Component and air temperature of electrical

power generating systems, electrical and avionic components and compartments

d. Ambient air temperatures at crew stations and in main cabin

2. Positions. Engine fuel control actuators; engine condition levers; and actuators and valves in the fuel, hydraulic, and flight control systems. Rotor blade control and damping parameters

3. Loads and Vibrations. Loads in rotor shafts, blades, actuators, and dynamic system components. Engine-mount loads and vibrations. Crew station and cabin vibrations.

4. Miscellaneous. Rotor and engine speeds, electrical system voltage, frequencies and current, test chamber ambient temperature, performance (e.g., fuel flow), and rotor or engine torque.

The recording systems used may consist of any combination of:

1. Climatic Laboratory Data System. A high-speed, low-signal level digital data system used for recording low-frequency response parameters. On-site computer processing produces identified, time-correlated tabulations in engineering units on magnetic tape

2. Oscillograph or Magnetic Tape. Used for medium- to high-frequency response parameters.

3. Photo Recorders. For position, speed, pressure, and temperature data

4. Temperature Recording Systems.

Since the data acquisition system essentially is an airborne system, laboratory standard accuracies will not be attained. Assuming selection of optimum recording system for specific parameters, normal accuracies of airborne systems are:

1. Temperatures $\pm 2^\circ$

2. Pressures $\pm 5\%$ full scale

3. Electrical power $\pm 3-5\%$; full-scale frequency $\pm 1\%$

4. Rotor speed $\pm 3.25\%$ (frequency recorded with frequency reference)

5. Engine speed $\pm 1\%$

6. Positions $\pm 3-5\%$ full-scale

7. Loads (strain gaged) $\pm 3-5\%$ full-scale

8. Vibration $\pm 8\%$ full-scale.

For a large data package involving complex processing, the analog-to-digital computer, which is compatible with the magnetic tape system, is the most versatile, accurate, and efficient system.

A detailed log of daily operations *shall* be made to correlate the test runs and results. This should include:

1. Climatic Laboratory temperature

2. Run number, time, and duration

3. Component and system changes

4. Helicopter oil, fuel, and air pressures during servicing operations

5. Helicopter battery voltage

6. Auxiliary power unit and engine start times.

Processed data *shall* be shown generally as time histories for the entire test period under laboratory conditions or for specific runs or portions of the run, such as engine start and system operation. The attained values are compared with predicted or predetermined safe values for compliance or satisfactory performance. Since test time is limited, a "quick look" data-scanning procedure *shall* be used to identify potential deficiencies.

Since the Climatic Laboratory test time at a given temperature is limited, it will not be possible to correct major deficiencies on site. Those deficiencies involving minor system rework or component changes may be corrected when working on an expedited basis. Normally, however, if the deficiency cannot be corrected in less than three days, the test program will proceed, provided a "work around" or change to the test plan can be made to negate the effect of the deficiency. The contractor *shall* institute design changes to correct the deficiency and then test the component and/or subsystem in an environment-controlled test facility.

Once the laboratory test has shown that the deficiency has been corrected, the design changes should be incorporated in a test helicopter for a repeat test in the Climatic Laboratory; if this is not possible, a facility possessing the natural climatic conditions should be selected. The repeat testing *shall* be conducted to show that all deficiencies have been corrected prior to the Category II climatic tests.

8-9.7.3 Documentation

A test report *shall* be written at the conclusion of the test. This report includes qualitative and quantitative data, recommendations for improvements and/or design changes, and graphical data. Typical results are shown in Figs. 8-14 through 8-26.

REFERENCES

1. S. Moreland and J. A. Barnes, *Exploratory Study of Pilot Performance During High Ambient Temperatures/Humidity*, TM 6-70, U.S. Army Human Engineering Laboratories,

Aberdeen Proving Ground, Maryland, March 1970.

2. TB MED Bulletin No. 175, *The Etiology, Prevention, Diagnosis, and Treatment of Averse Effects of Heat.*

3. U.S. Air Force Specification Bulletin No. 526, *Contaminants, Cabin Air, Maximum Allowable Concentration of.*
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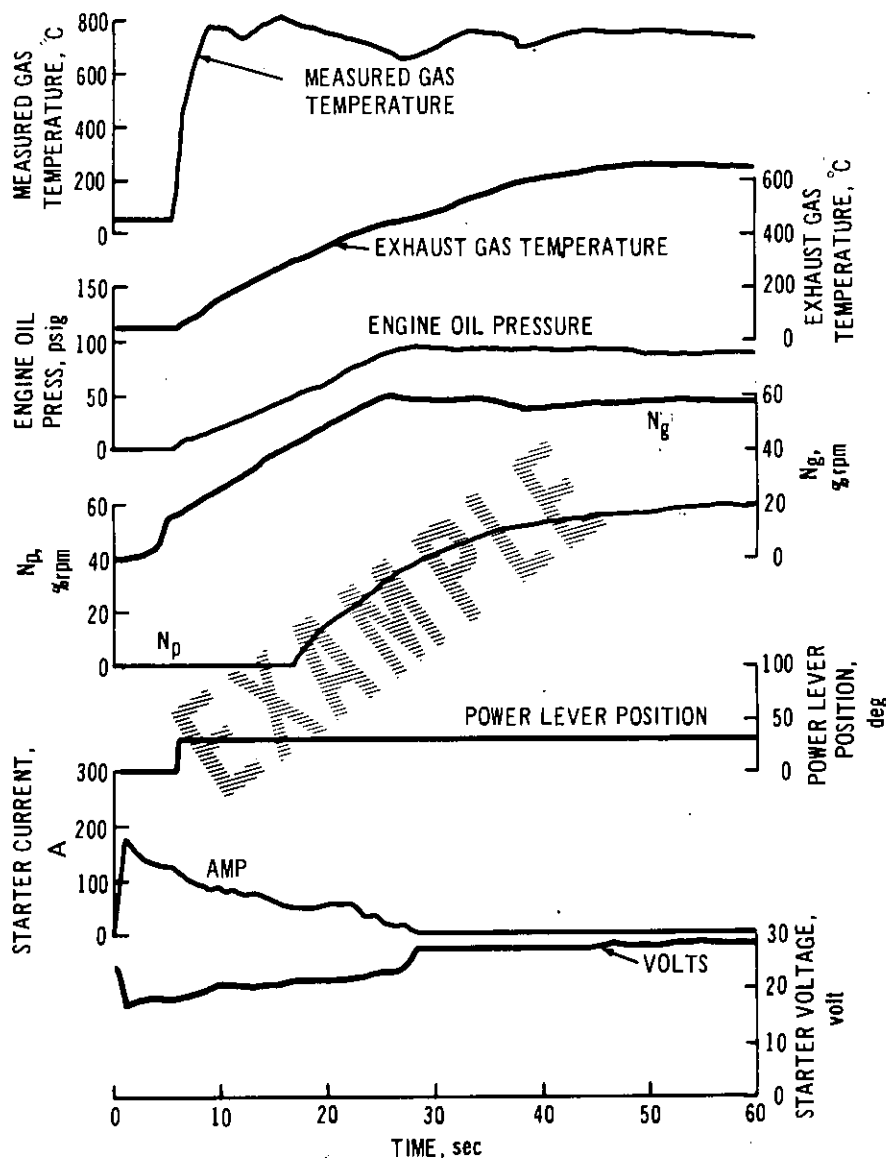
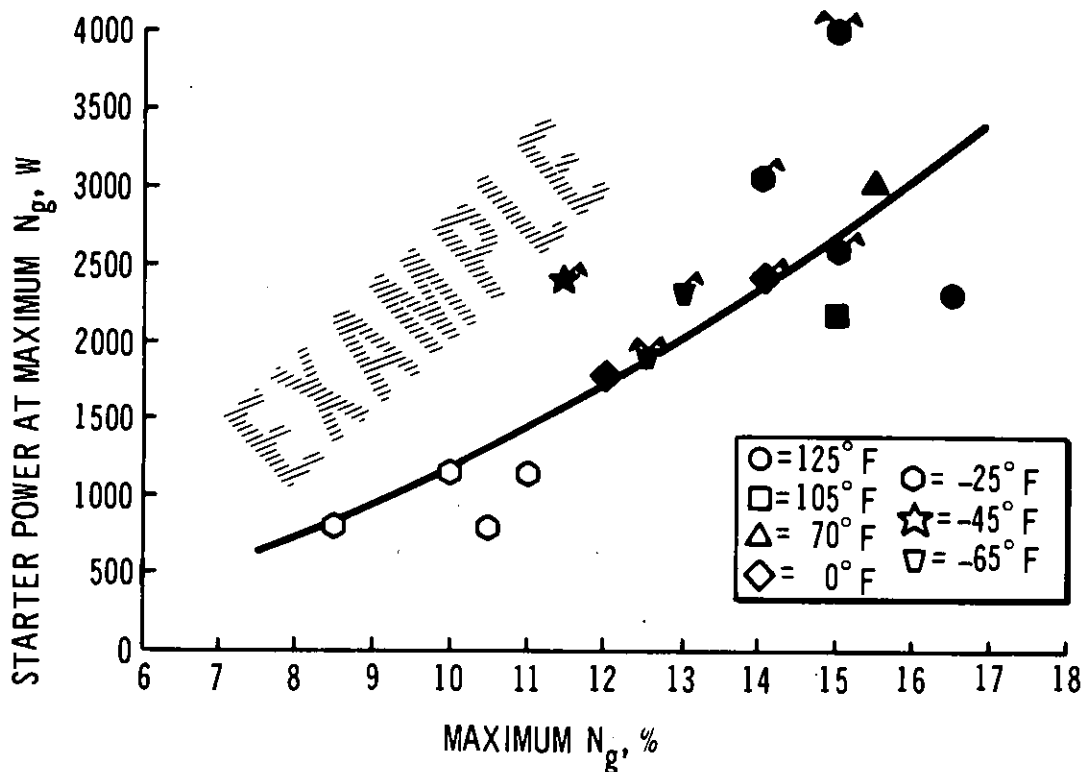


Fig. 8-14. Engine-starting Characteristics



- NOTES: 1. SHADED SYMBOLS INDICATE SUCCESSFUL STARTS, OPEN SYMBOLS INDICATE NO START.
2. SINGLE-FLAGGED SYMBOLS INDICATE 70° F BATTERY USED. DOUBLE-FLAGGED SYMBOLS INDICATE APU USED, AND NO FLAG INDICATES AMBIENT-SOAKED BATTERY USED.

Fig. 8-15. Starter Performance

Fig. 8-16. Engine and Transmission Oil Systems During Starts

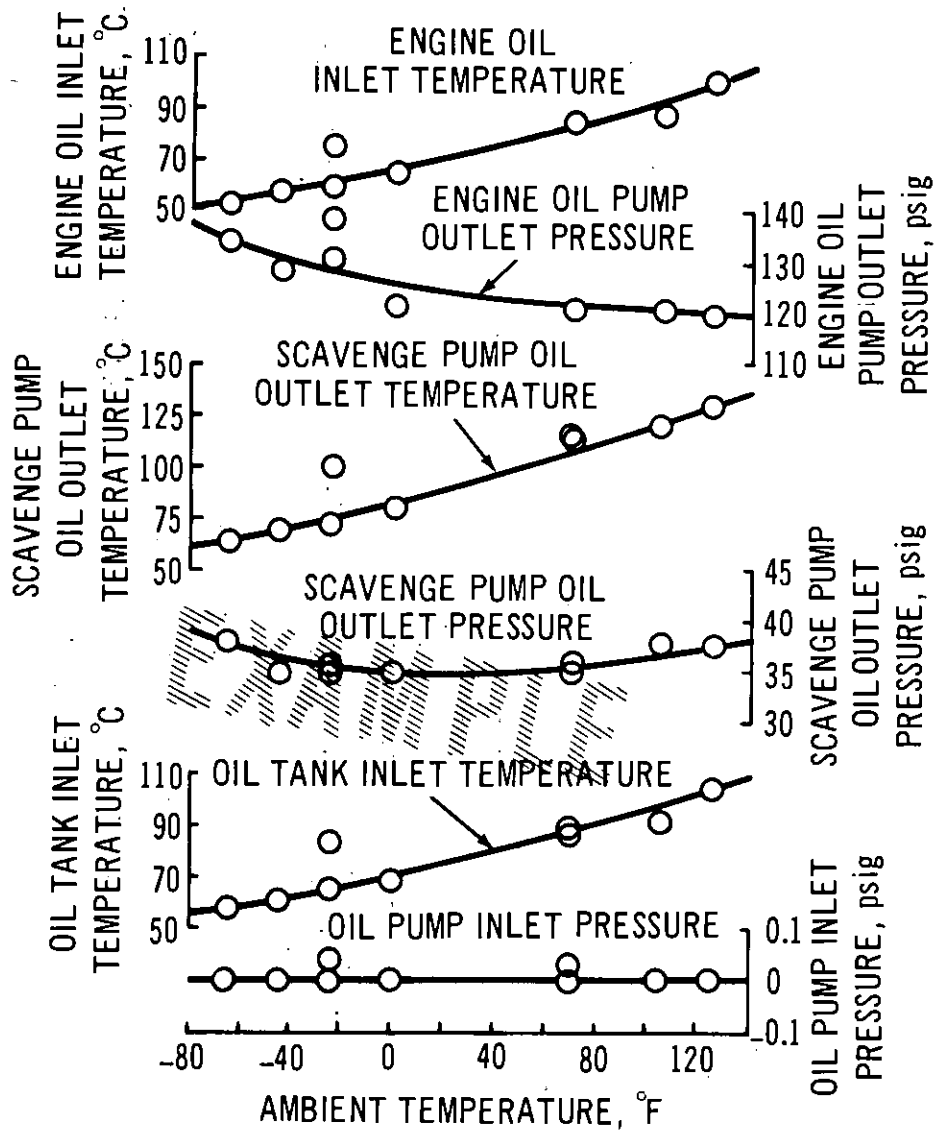
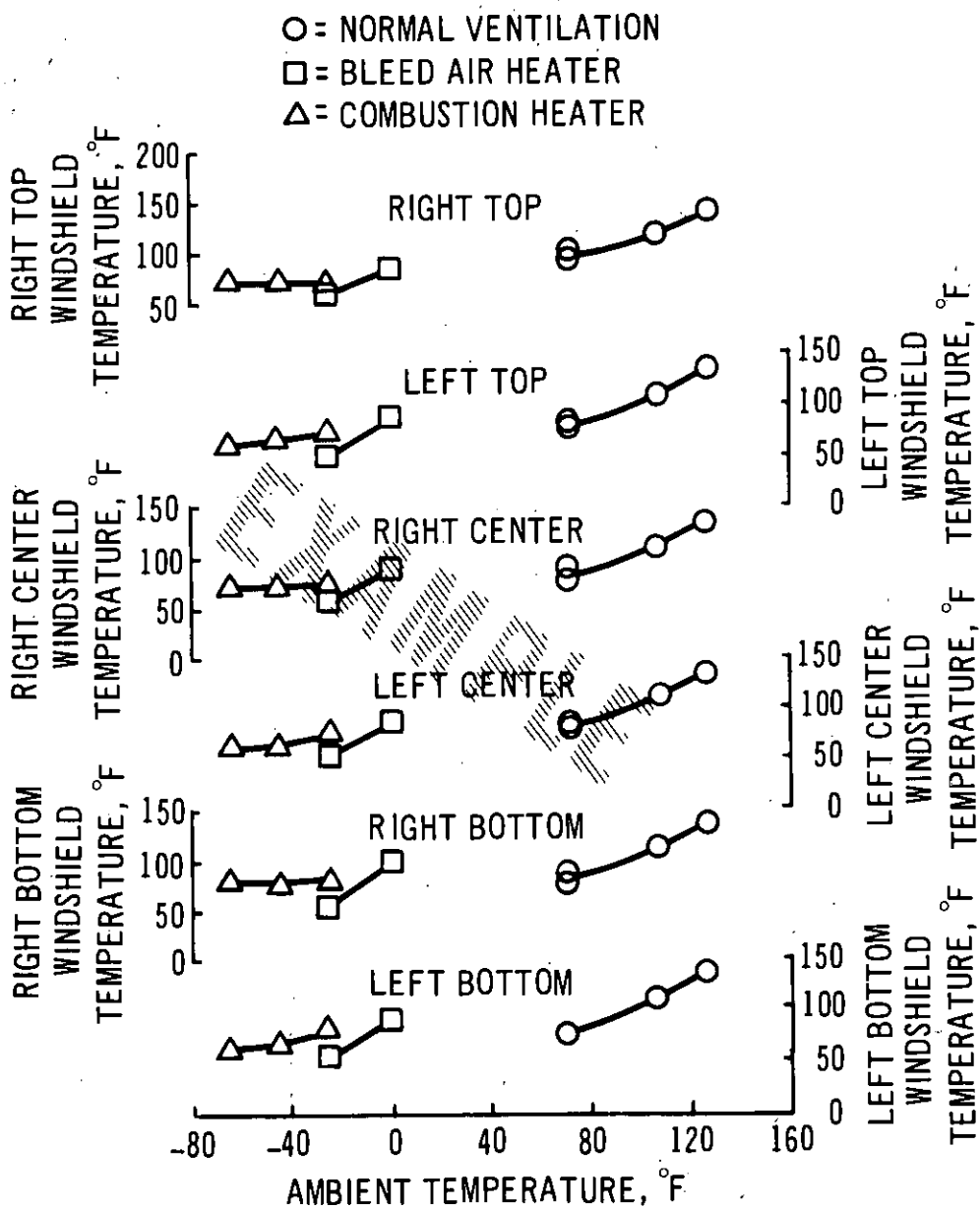
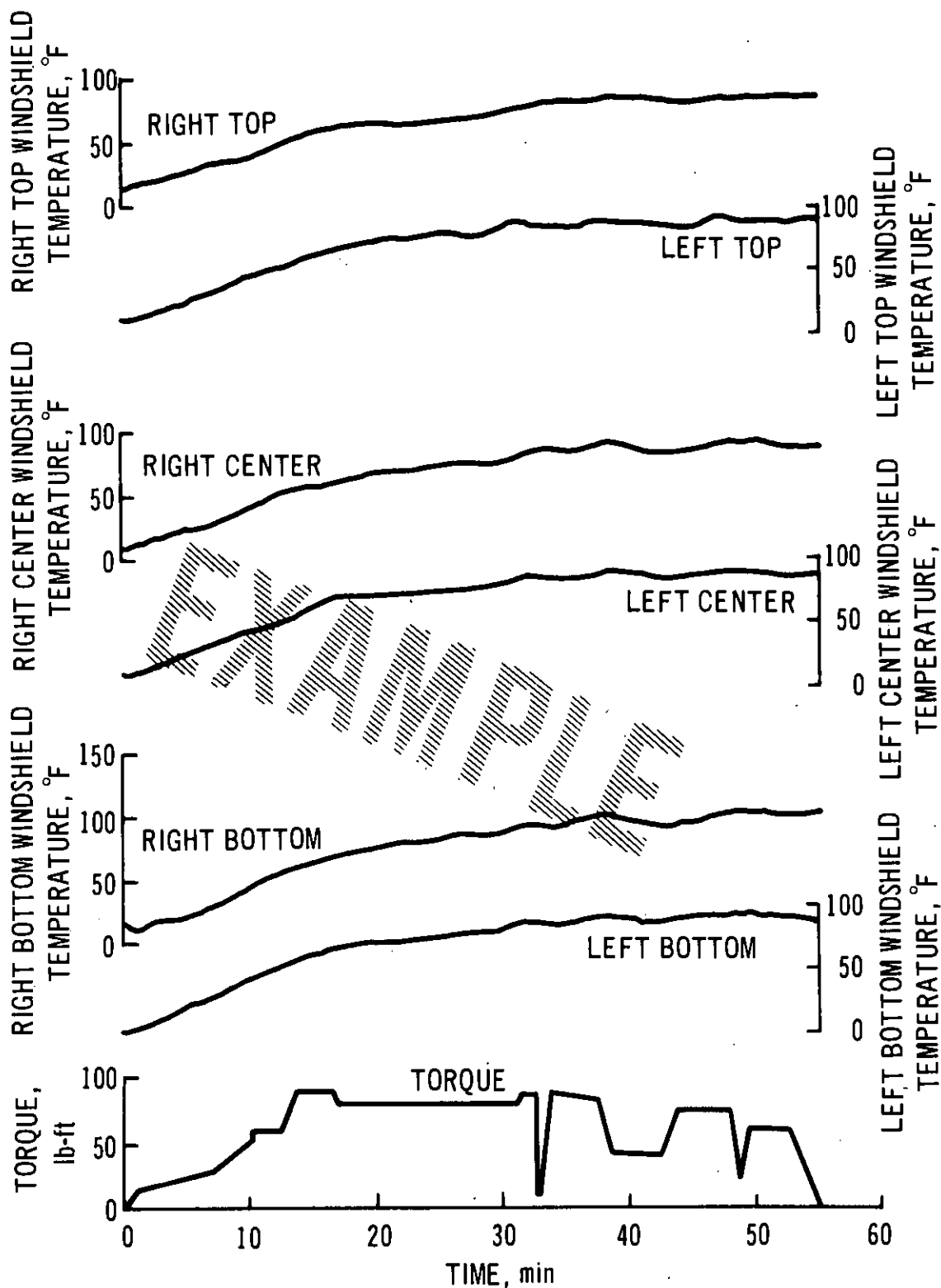


Fig. 8-17. Summary, Engine Oil Temperature and Pressure



NOTE: ALL TEMPERATURES RECORDED AT ½-in. OFFSET.

Fig. 8-18. Summary, Windshield Defog Temperature



NOTE: ALL TEMPERATURES RECORDED AT ½-in. OFFSET.

Fig. 8-19. Windshield Defog Temperature Survey

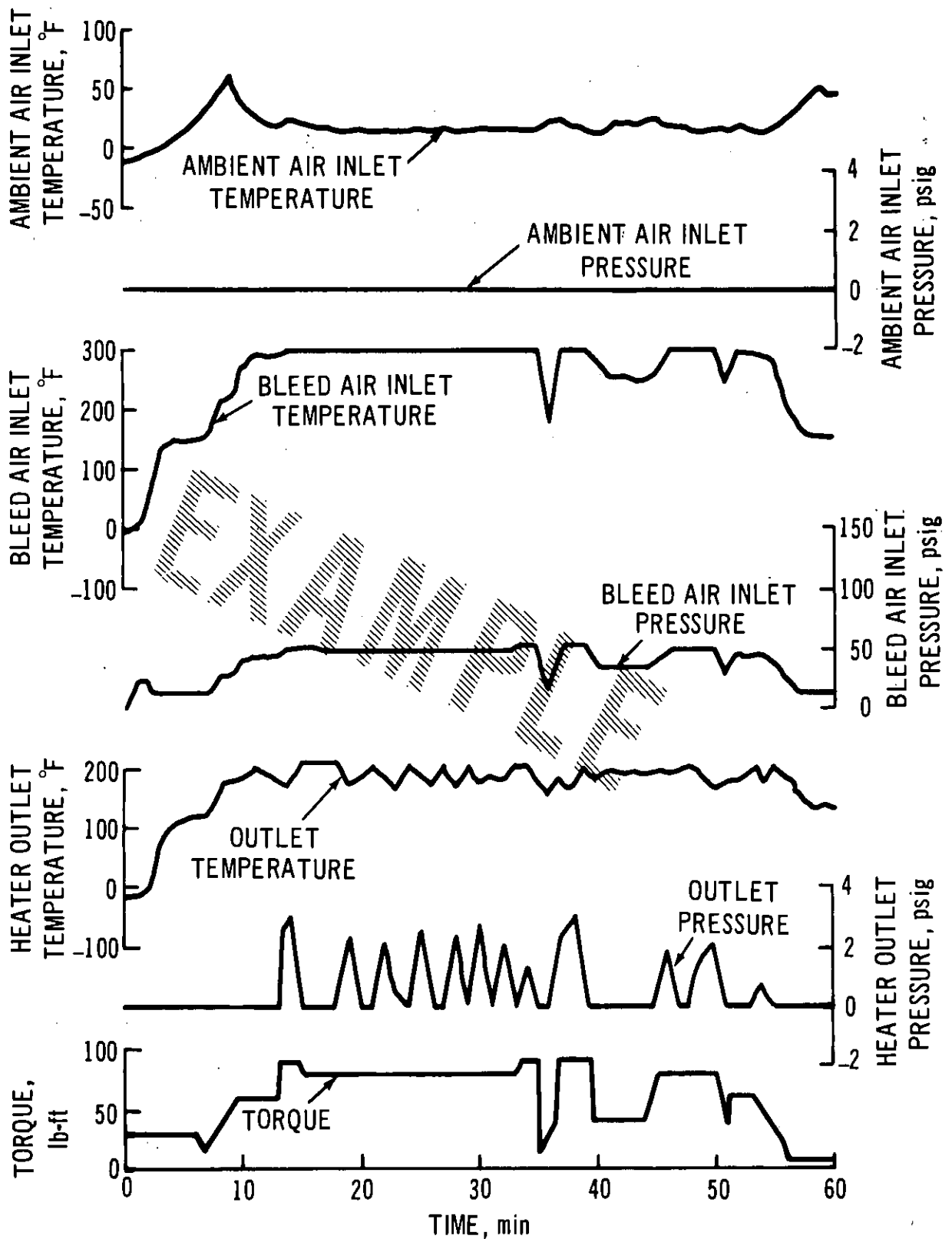


Fig. 8-20. Heater System Temperature and Pressure Survey

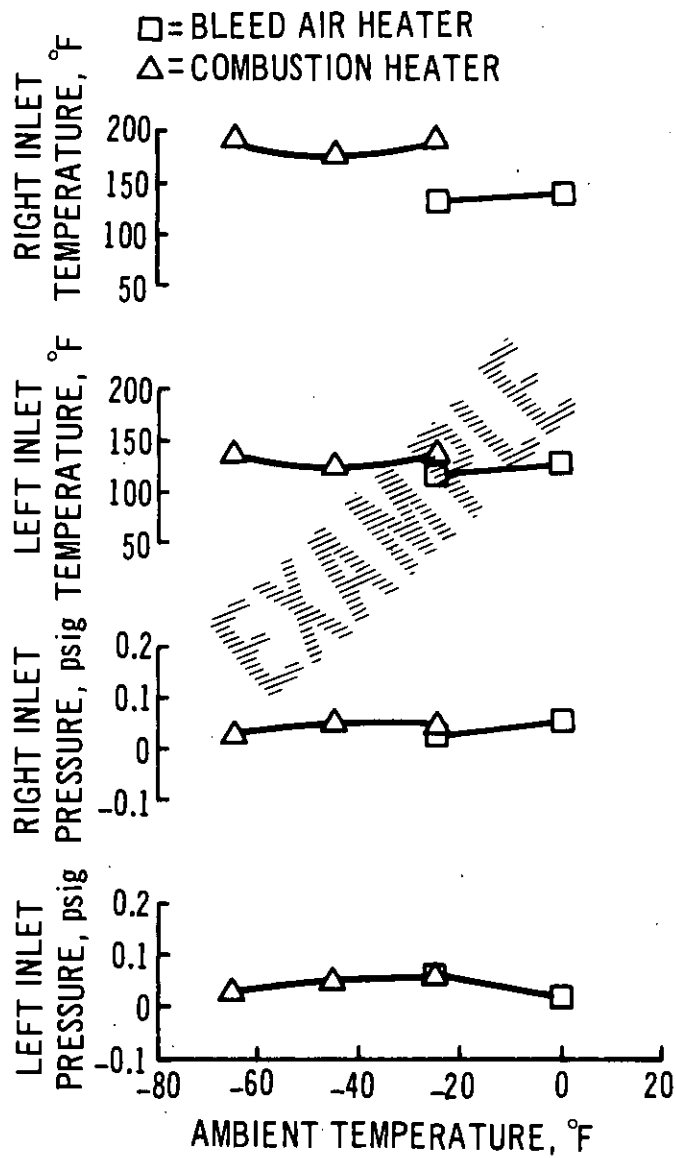


Fig. 8-21. Summary, Cockpit Inlet Temperature and Pressure

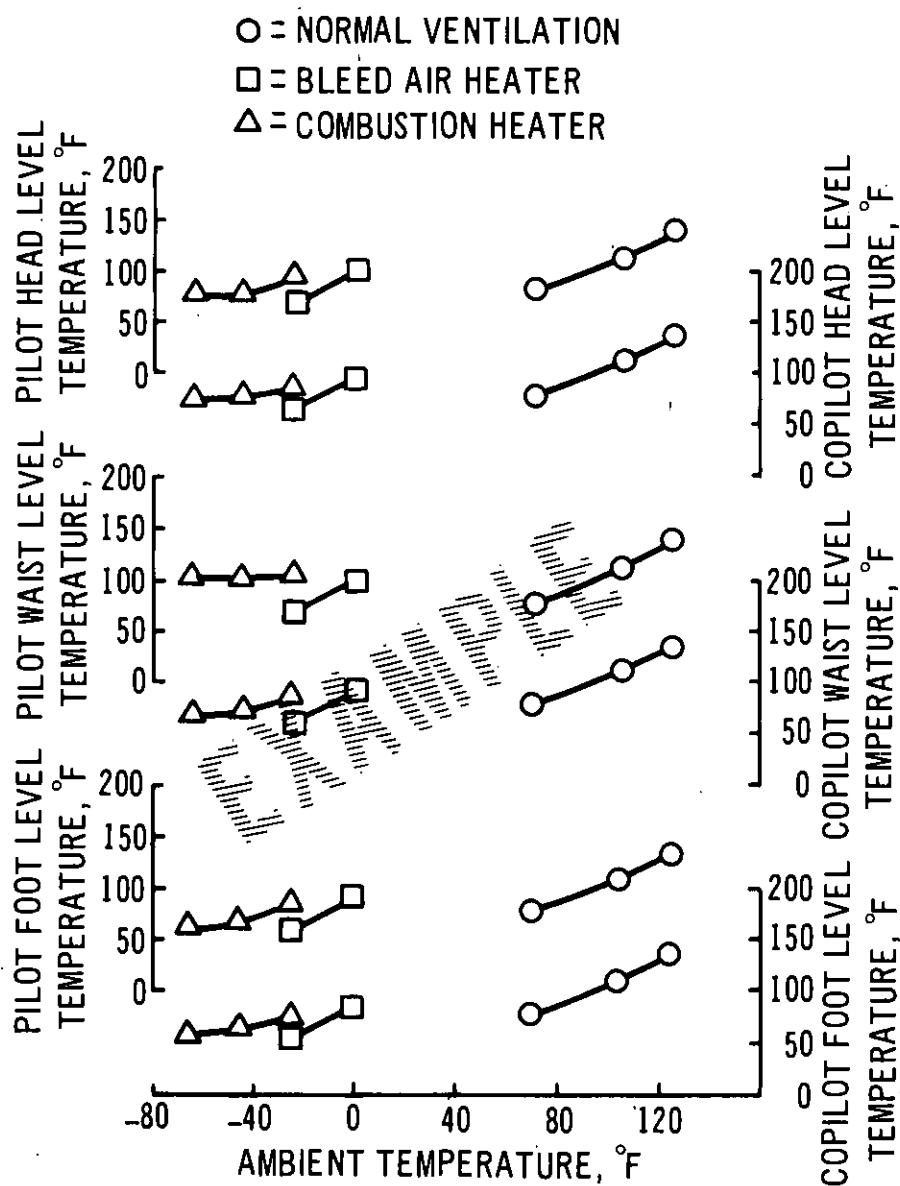


Fig. 8-22. Summary, Cockpit Temperature

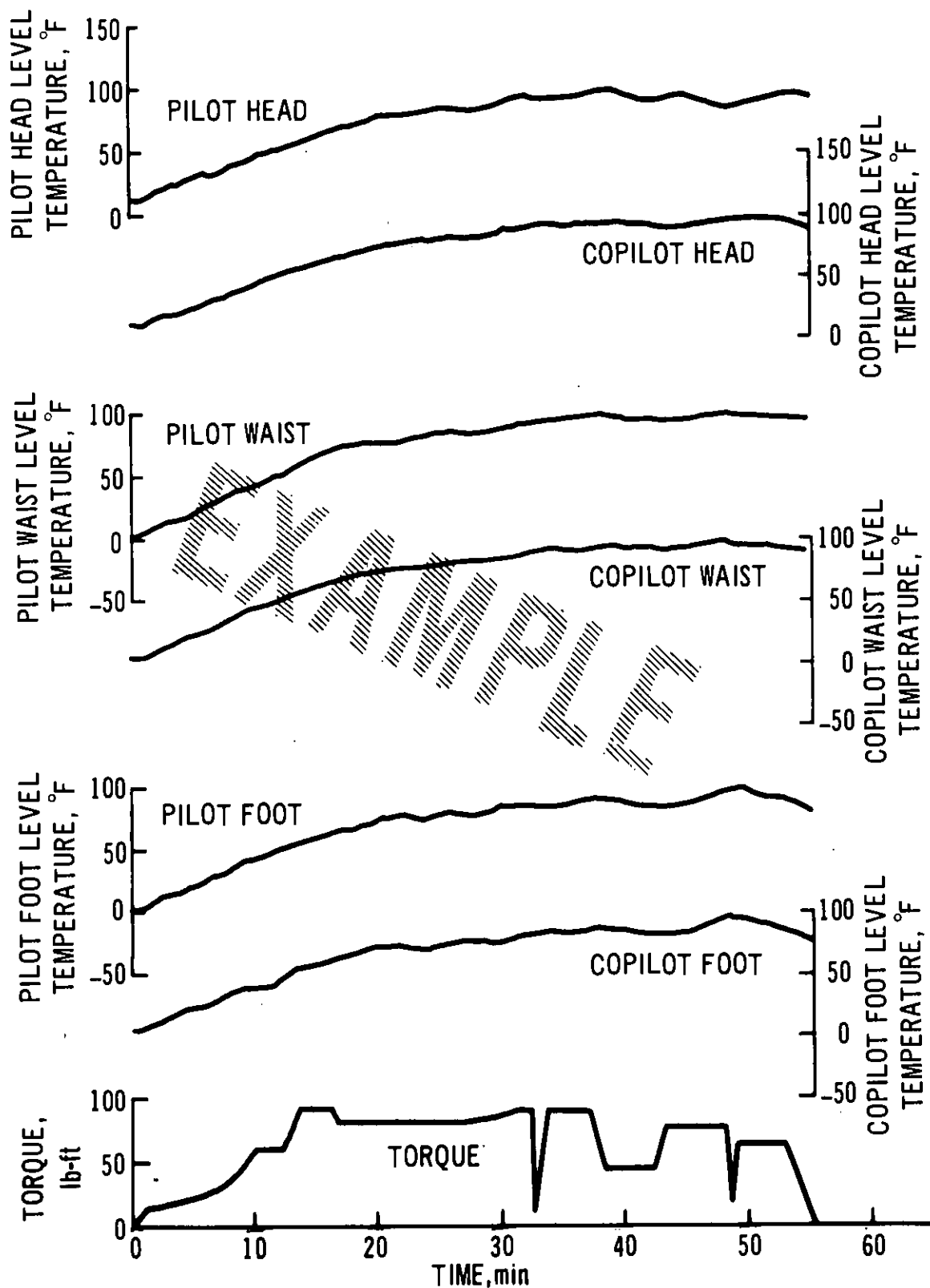


Fig. 8-23. Cockpit Temperature Survey, Bleed Air Heater

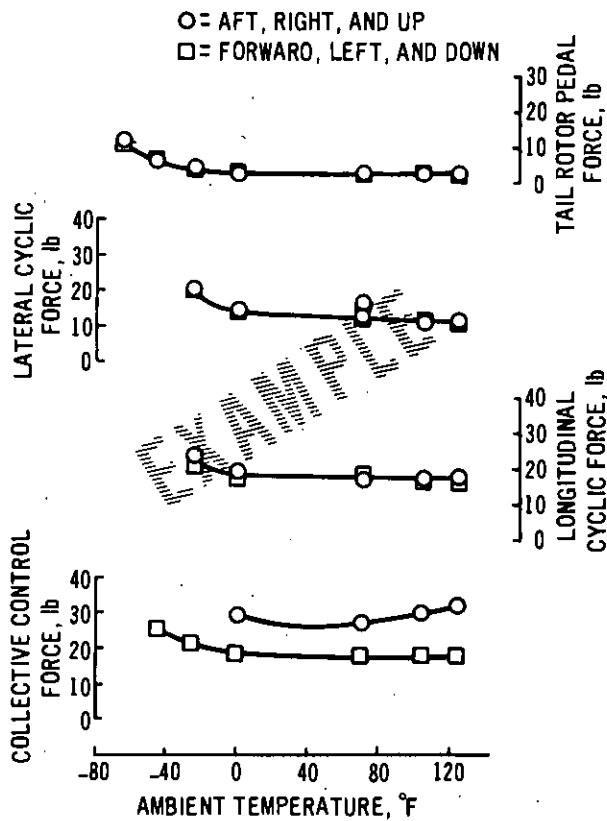


**Fig. 8-24. Summary, Control Breakout Force:
Rotors Stationary, Friction Off**

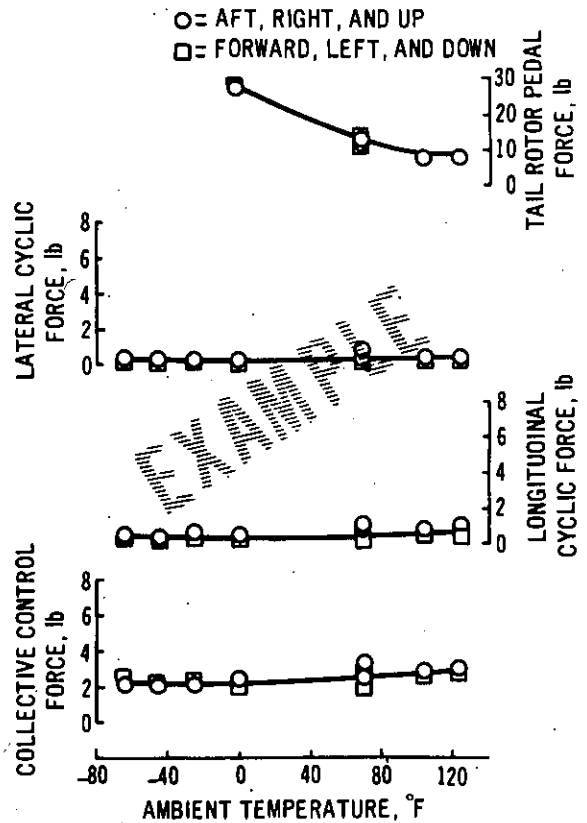


**Fig. 8-25. Summary, Control Breakout Force:
Rotors Turning, Hydraulic Boost On, Friction and
Force Trim Off**

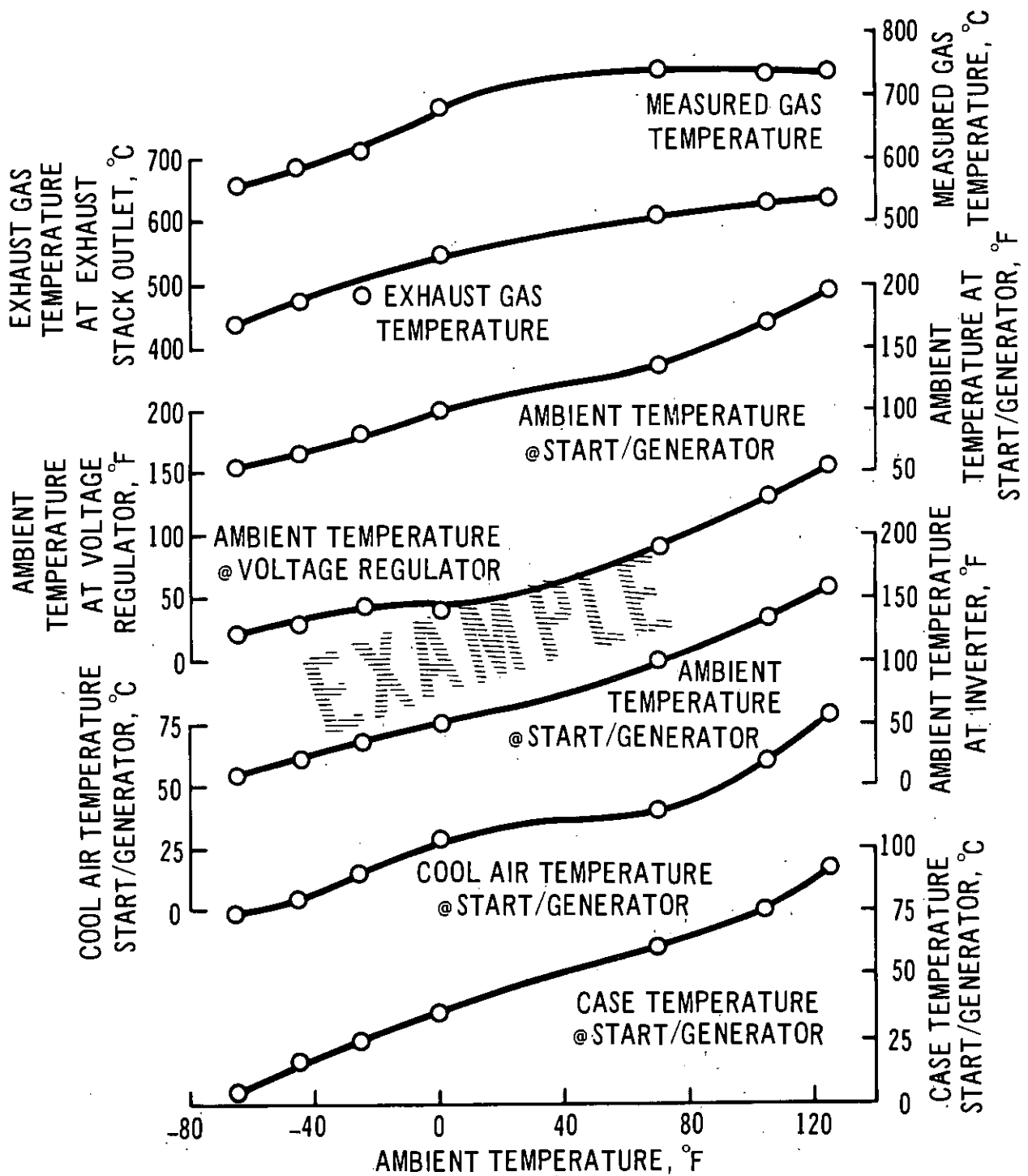


Fig. 8-26. Summary, Engine Temperature Survey

CHAPTER 9

HELICOPTER SYSTEM DEMONSTRATIONS

9-0 LIST OF SYMBOLS

A	= rotor disk area, ft ²	$(R/D)_{TL}$	= test tapeline rate of descent, fpm
A_n	= projected area of the n -th part, ft ²	SHP_{STD}	= standard shaft horsepower
A_{masked}	= projected area of the masked part, ft ²	SHP_t	= test shaft horsepower
A_v	= vulnerable area, ft ²	T	= bearing temperature, °F
A_{vi}	= vulnerable area of the i -th part, ft ²	T_{St}	= test ambient temperature, °R
$A_{v\ masked}$	= vulnerable area of masked part, ft ²	T_{STD}	= standard ambient temperature, °R
$A_{v\ masking}$	= vulnerable area of the masking part, ft ²	t	= time, sec
A_{vt}	= vulnerable area of the target, ft ²	V_{DL}	= design limit speed, kt
C	= lumped constant = f (bearing installation)	V_H	= maximum level flight speed, kt
C_p	= power coefficient, dimensionless	V_{MA}	= maximum airspeed for stabilized autorotation, kt
C_T	= thrust coefficient, dimensionless	V_{maxRC}	= airspeed for maximum rate of climb, kt
d	= vertical component of mass travel after gear contact, in.	V_T	= true airspeed, kt
h	= free drop height, in.	W	= effective weight on gear (main, nose, or tail) as determined by design criteria for the test load condition, lb
H_i	= indicated height, ft	W_{STD}	= standard test weight, lb
H_{TL}	= tapeline altitude, ft	W_e	= effective weight to be used in the drop test, lb
I_{xx}	= rolling mass moment of inertia of helicopter, slug-ft ²	W_t	= test weight, lb
I_{yy}	= pitching mass moment of inertia of helicopter, slug-ft ²	β	= sideslip angle, deg
K_P	= power factor, dimensionless	μ	= advance ratio, dimensionless
K_W	= weight factor, dimensionless	ρ_t	= test air density, slug/ft ³
L	= ratio of the assumed rotor lift to the helicopter weight, dimensionless	ϕ	= bank angle, deg
N	= bearing speed, rpm	ΩR	= rotor tip speed, fps
N_p	= power turbine speed, rpm	ζ	= damping ratio, dimensionless
n	= helicopter CG load factor, dimensionless	ω	= frequency, rad/sec
n_j	= drop test fixture load factor, dimensionless	ω_n	= natural frequency, rad/sec
n_L	= limit load factor, g		
n_z	= normal load factor, g		
p	= probability of attaining a hit		
p_{masked}	= probability of damage to the masked part when it is hit through a masking part		
$p_{masking}$	= probability of damage to the masking part when it is hit		
p_n	= probability of damage per hit on the n -th part		
$(R/C)_i$	= indicated rate of climb, fpm		
$(R/C)_t$	= test rate of climb, fpm		
$(R/C)_{TL}$	= test tapeline rate of climb, fpm		
$(R/D)_i$	= indicated rate of descent, fpm		

9-1 INTRODUCTION

Airworthiness qualification of a new model helicopter is dependent upon demonstration of compliance with the requirements of the contract and the detail specification. Since many requirements are applicable to individual subsystems of the helicopter, it is appropriate that the adequacy of the major subsystems be demonstrated individually. Each of the required demonstrations is described in this chapter.

Although the qualification program consists of separate demonstrations, it is not intended that separate testing be conducted. Conduct of the required demon-

strations *shall* be in accordance with the approved AQS. This document, prepared in accordance with the guidelines provided by the procuring activity in the RFP, *shall* indicate the utilization of test helicopters in the demonstration program (see par. 2-2.3). Specific helicopters often are assigned to individual demonstrations, particularly when testing must be performed at different test sites. Also the instrumentation requirements for certain demonstrations are so extensive as to preclude concurrent conduct of other tests. The structural flight demonstration is the obvious example of such a consideration.

Each demonstration consists of both ground and flight tests. Although it is not required that all tests be performed on the same helicopter, the program normally can be performed most efficiently in that manner, since the test instrumentation required need be installed in only one test vehicle. However, substantial portions of the propulsion and power system demonstration *shall* be conducted on a vehicle specifically assigned to ground test. Owing to the duration and severity of the survey and demonstration testing to be performed on the ground test vehicle, it will not be qualified for flight. Conduct of survey tests (Chapter 8) on this vehicle probably will require instrumentation both necessary to, and sufficient for, the ground test portion of several subsystem demonstrations. The vehicle upon which such tests are performed *shall* be as indicated in the AQS.

9-2 STRUCTURAL INTEGRITY DEMONSTRATION

9-2.1 GENERAL

The discussion which follows details the demonstration procedures and test requirements necessary to prove the structural integrity of the helicopter, and to insure that the airframe design is structurally adequate for the required design loads and that the landing gear is capable of meeting the design standard.

9-2.2 STATIC TEST PROGRAM

The static test program *shall* be developed and conducted in accordance with par. 3.2 of MIL-T-8679.

The static test program requires demonstration of compliance with prescribed structural design criteria such as no failure at ultimate loads and no yielding at limit loads. In addition, the following vital information is obtained:

1. Verification that load paths and stresses are as predicted

2. Identification of poor structural design details to alleviate and prevent (where possible) future structural maintenance difficulties.

9-2.2.1 Test Requirements

The static test article *shall* be a complete airframe and *shall* duplicate the structure of the flight article in all but two cases. These exceptions are:

1. The omission of items of fixed equipment and their support structure is permissible, provided that this does not significantly affect the load and stress distributions, and the strength or deflection, or both, of the static test article. Items which would fall into this category include furnishings, electrical and hydraulic systems, avionics, and wheels and/or brakes.

2. The use of substitute parts and/or test fixtures is permitted, provided that they reproduce the effects of the parts from the standpoint of strength, stiffness, mass characteristics, and load transmittal. However, the structural integrity of the parts for which substitutes are made *shall* be demonstrated by separate tests. Items which fall into this category include rotor systems, power plants and accessories, and transmission systems.

In order to demonstrate the adequacy of the airframe structure, the static test article *shall*:

1. Support limit loads without detrimental or permanent deformation. At any load up to limit loads, the deformation *shall* not interfere with safe operation of the helicopter.

2. Support ultimate loads without failure for at least 3 sec. However, where proof of strength is shown by dynamic tests simulating actual load conditions, the 3-sec limit does not apply.

Where structural flexibility is such that any rate of load application likely to occur in the operating conditions might produce transient stresses appreciably higher than those corresponding to static loads, the effects of the rate of application *shall* be considered in the static test program at any load up to limit load.

An instrumented test article *shall* be incrementally loaded from no load to the maximum required load in increments not to exceed 10% of the design limit load or 6.7% of the maximum required load. To insure the detection of structural failures, the helicopter structure *shall* be inspected after each test load incremental application. The test setup *shall* simulate the most critical design loads on the wing, empennage, rotor, fuselage

(including transparent areas), and landing gear resulting from all critical flight and ground-handling conditions. Thermal environmental effects *shall* be simulated along with load application where operational environments impose significant effects. The thermal environmental effects may be simulated by the application of the operational thermal gradient (utilizing heating or cooling), or by increasing sufficiently the applied loading to the affected structure in order to account for reduction in allowable strength of materials due to temperature.

The sequence in applying the loading conditions *shall* be selected so that structural damage occurring in one condition *shall* not affect the results obtained in the others. After each failure condition, the airframe structure *shall* be inspected and repaired as required to permit further testing. If repairs and reinforcements are incorporated in the test article to satisfy airframe strength and/or rigidity requirements, they *shall* be representative of those which will be incorporated in the flight article. Additional structural substantiation tests on the reinforced structure *shall* be conducted as deemed necessary by the procuring activity.

For helicopters whose configurations differ markedly from those for which past experience is available, the static test program *shall* be expanded to include any new or unusual design features and test conditions.

In addition to substantiating static strength, the static test vehicle also *shall* be used to substantiate fail-safe capability. Where fail-safe design is provided by the use of redundant attachments and/or members, a percentage of redundancy *shall* be agreed upon by the procuring activity. The structure *shall* be tested to the critical fail-safe loading condition by removing members or attachments to simulate failure and increasing the load levels. The term "fail-safe", as applied to a helicopter or its members, means that the structure remaining—or a portion of the original structure—can sustain a percentage of its design load without catastrophic failure or excessive structural deformation following the initiation of any fracture or crack.

In each static test required, all parts which are critical to the pertinent design condition *shall* be tested and loaded simultaneously, if practicable. To achieve this end, aerodynamic ground, thrust, control inertia, and other loadings *shall* be simulated. The locations of the loading fixtures *shall* be selected to provide the best fit for the overall desired shear, moment, and torsional distributions. Hard points and other natural load points can be selected in order to preclude overloading of any local structure.

Balanced helicopter loads *shall* be applied for each of the conditions. The tests *shall* be carried to limit, ultimate, and failing loads; the failure conditions *shall* be applied to the static test article after the completion of all ultimate tests. The following are examples of test conditions which *shall* be tested:

1. Fuselage. Test the fuselage forebody, midbody, and aftbody for critical downbending, upbending, sidebending, torsional, and shear conditions. Test the aftbody to failure for the most critical bending and/or torsional and/or shear condition.

2. Wing and Carry-through Structure. Test to ultimate loads for critical downbending, upbending, chordwise bending, and torsional conditions. Test landing condition (vertical impact) to failure.

3. Horizontal Tail and Carry-through Structure. Test upbending and unsymmetrical downbending conditions to ultimate. Test to downbending condition failure.

4. Vertical Tail, Tail Landing Gear, and Carry-through Structure. Test critical towing and pushing and side load flight and ground conditions to ultimate loads. Test landing condition (vertical impact) to failure.

5. Main Landing Gear and Carry-through Structure. Test to ultimate loads for critical unsymmetrical landing. Turning, skidding oscillation, and towing conditions will be investigated for wheel gears.

6. Nose Landing Gear and Carry-through Structure. Test critical unsymmetrical landing condition, and critical ground-towing condition to ultimate loads.

7. Control System. Test to failure the critical cyclic pitch control, collective pitch control, and tail rotor control conditions.

8. Engine Mounts and Carry-through Structure. Test longitudinal crash and critical nonflight condition to ultimate loads and/or crash loads. Test to failing loads for the most critical design condition.

9. Transmission and Main Rotor Mounts, and Carry-through Structure. Test to ultimate loads for longitudinal crash, vertical crash, and side crash conditions. In addition, test the most critical design condition to failing loads.

10. Tail Rotor Support and Carry-through Structure. Test to ultimate loads the critical upload, download, and sideload conditions and maximum thrust condition.

11. Seats and Carry-through Structure. Conduct failure tests on each typical seat and carry-through structure for the critical condition.

12. Cockpit Enclosure. Test the critical unsymmet-

rical flight condition to ultimate loads and the most critical of the unsymmetrical or symmetrical flight conditions to failure.

13. **External Store Structure.** Test to ultimate loads for the critical condition on the basic structure and attachment fittings for external armament or fuel tanks. The loads *shall* be applied to the mounting structure.

14. **Hoisting Sling and Rescue Hoist Installation.** Test to failure loads for critical condition.

15. **Doors, Fairings, and Removable Sections.** Conduct ultimate flight load tests for critical flight conditions for those items not previously tested.

16. **Fittings.** Test to failure for critical condition where the ultimate strength has not been demonstrated by other tests.

17. **Main Ribs, Bulkheads, and Frames.** Test to failure for the critical conditions where ability to withstand ultimate load has not been demonstrated by other tests.

18. **Gun Recoil and Blast Tests.** Conduct recoil firing and blast tests which will adequately prove the structural integrity of the helicopter for the critical limit loads resulting from the firing of guns, rockets, ATO units, etc., mounted on the fuselage and/or wing.

The majority of the critical loads and reactions to the helicopter structure from flight and ground-handling conditions are generated by the pilot, rotor, power plant, transmission, external stores, landing gear, etc. In the static test program these loadings may be applied through representative substitute parts and/or test fixtures.

Where substitute parts are used, the final configuration attachments or mountings *shall* be used to introduce their respective loads into the fuselage structure. The substitute parts must duplicate the stiffness characteristics of the final configuration parts.

The application of the test loads for the substantiation of the structural integrity of the static test article *shall* be such that the magnitude, distribution, and sequencing of the loads duplicate the specified load distribution as closely as practicable. The equipment used to apply and to measure the magnitude of the test loads should be as approved by the procuring activity.

Fuselage loads can be applied by using hydraulic jacks through loading frames located at specific fuselage stations. The loading frames should be designed to distribute the load to the fuselage so that local deformations or failures do not occur because of the method of load application.

Wing loads can be applied by using hydraulic jacks through loading frames located at specific wing stations. These loading frames should extend chordwise along the upper and lower wing surfaces, contacting the front and rear beams through felt-faced pads, or the equivalent. The frames are connected by bolts located forward of the front beam and aft of the rear beam. Similar loading frame installations should be used on the vertical and horizontal stabilizers, if required.

Main and nose or tail landing gear loads (for wheel gears) can be applied by using hydraulic jacks through loading fittings attached to the axles. These fittings should provide the capability for applying the simulated landing gear loads experienced during the various design conditions.

The static test program does not demonstrate fully the structural adequacy of the helicopter for the design flight envelope. The structural demonstration and the flight load survey (see pars. 9-2 and 8-2) also are required in order to prove the structural integrity of the helicopter by (1) a flight demonstration of critical design conditions, and (2) a comprehensive measurement of flight loads for comparison of actual loads with those assumed in design and used for laboratory testing.

9-2.2.2 Instrumentation and Data Analysis

The instrumentation must be capable of measuring the magnitude of the concentrated loads applied through the various loading components. A typical load-measuring device is a load cell, or load transducer, located between the loading jack and the component load station. The load cells *shall* be calibrated against known loads.

Prior to the start of testing, axial and shear strain gages *shall* be installed on the wing, fuselage, rotor system horizontal and vertical stabilizers, and landing gear. The number and location of these gages *shall* be sufficient to determine that load paths and stresses are as predicted. The static test strain and load instrumentation *shall* be located in the same manner as the flight load and structural demonstration instrumentation. Deflection gages *shall* be located on the exterior surfaces of the test article for measurement of structural deflections. The strain gage and deflection gage *shall* be monitored during the application of the test loadings to detect the rapid buildup of stresses or deflections prior to possible catastrophic results. Deflection and strain measurements *shall* be obtained at a sufficient number of load increments below limit or maximum design landing load to establish the rate of deflection, strain, and permanent set. If a change in rate occurs, the subsequent increments *shall* be sufficiently small to de-

termine if this change is linear or curvilinear. Deflection and strain measurements may be discontinued after design ultimate load has been reached, unless the purpose of the test is to determine the maximum practical strength (growth potential) of the structural component being tested.

Individual loading apparatus applying each test load *shall* be monitored. The applied load and strain gage and deflection data *shall* be recorded at each increment.

The transparent areas of the helicopter, such as the windshield canopy or pilot enclosure, which are subjected primarily to pressure loadings require special consideration. The proper application of the magnitude and distribution of these pressures is required for the substantiation of the structural integrity of these areas. Two means of achieving this are a pressure bag system which conforms to the shape of the area to be tested, or a tension pad-whiffle tree arrangement. Uniform pressures can be applied over the entire area and peak pressures can be applied at critical locations.

The information which follows *shall* be recorded for each static test condition demonstrated:

1. Shear and Moment Distributions. The applied shear and bending and torsional moment distributions versus station *shall* be plotted together with desired distributions. These data *shall* be provided for each component, such as fuselage, wing, and stabilizers
2. Individual Jack Loads
3. Strain Gage Readings and Corresponding Stress Levels at Each Increment
4. Deflection at Each Increment.

All instruments used to obtain test data *shall* be calibrated in compliance with MIL-Q-9858 and MIL-C-45662.

In the event of equipment malfunction, safety devices *shall* be provided to preclude overloading the test article. These safety devices may be electrical, hydraulic, and/or mechanical. The electrical system normally consists of solenoid valves in the circuit between the jack ports and the servo-valve. Electrical power is interrupted when the differential signal driving the servo-valve exceeds a preset limit. This results in "locking up" the hydraulic jack at the load level existing at the time of valve closure. The servo loops should be connected electrically so that all loading jacks lock up simultaneously in the event of malfunction in any one loop. The hydraulic safety system usually consists of load limiter valves in the hydraulic circuit between the jack ports and the servo-valve. These valves are set to bypass oil flow at a jack port pressure just above the maximum anticipated jack load. The mechanical safety

system consists of "jack stops", which limit the deflection of the test article by limiting the travel of the jack piston to just above the maximum anticipated jack load position:

9-2.2.3 Documentation

The static test program *shall* be conducted in accordance with the contractor's approved test plan. The plan *shall* define the loading methods and schedules to be followed and the instrumentation to be provided, and *shall* identify the critical loading conditions for all components to be tested.

At the conclusion of the static test program, the test results *shall* be reported. The margins of safety for all tests to failure *shall* be reported, and any large discrepancies between the margins of safety established by analysis and those determined by test *shall* be explained.

9-2.3 LANDING GEAR DROP TESTS

The normal landing load factor and the reserve energy-absorption capacity of the landing gear *shall* be demonstrated by conducting drop tests on the landing gear. These tests *shall* be conducted to determine the dynamic load characteristics over a representative range of helicopter weights, angles of attack, and sinking speeds, as applicable to the landing gear type, and *shall* include, for wheel-type landing gear, sufficient wheel spin-up to simulate critical wheel contact velocities. In addition, the shock-absorption performance of the gear *shall* be evaluated with the initial metering configuration and with any changes that will improve overall landing performance characteristics.

9-2.3.1 Test Requirements

The drop tests *shall* be developed and conducted as specified in par. 9-2.3.1.1 for wheel landing gear and in par. 9-2.3.1.2 for skid gear.

The rotor lift throughout the drop tests *shall* not exceed two-thirds of the design gross weight. If considered, the specified rotor lift *shall* be introduced into the drop test by appropriate energy-absorbing devices or by the use of an effective mass. The effective mass method of simulating rotor lift in the drop test provides that the energy-absorption requirements imposed on the landing gear by a dead weight test fixture are the same as would be imposed if the aircraft were dropped at the required weight, CG angle, and height with a specified value of lift being applied simultaneously at touchdown.

When an effective mass method is used and rotor lift is to be simulated in free drop tests, effective drop weight may be determined by Eq. 9-1 (see MIL-T-6053).

$$W_e = W \left[\frac{h + (1 - L) d}{h + d} \right] \quad (9-1)$$

where

- W_e = effective weight to be used in the drop test, lb
- W = effective weight on gear (main, nose, or tail) as determined by design criteria for the test load condition, lb
- h = free drop height, in.
- L = ratio of the assumed rotor lift to the helicopter weight, dimensionless
- d = vertical component of mass travel after gear contact, in.

9-2.3.1.1 Wheel Gear

In accordance with pars. 3.3.2 through 3.3.3.2 of MIL-T-8679, the drop conditions *shall* be expanded, as required, to insure that a representative range of drop weights, contact velocities, and attitudes have been covered adequately for the gear being tested.

The wheel gear drop tests *shall* be conducted on the complete helicopter or on landing gear assemblies which include shock absorbers, wheels, tires, brakes (or inertial simulation, both rotational and translational, of the brakes), and other structural members used on the helicopter landing gear. Backup structure also may be simulated in these tests. Components unnecessary to the drop test evaluations may be deleted from the assembly. In addition, the test assembly mass and inertial characteristics *shall* be representative of the actual helicopter.

The drop tests specified in pars. 3.3.2 and 3.3.3 of MIL-T-8679 *shall* be conducted to include the gross weights and weight distributions specified, and also with alternate combinations of internal and external loads that may be structurally critical by virtue of transient effects. For these specified and alternate combinations of loads, the mass, CG position, and method of support of all internal and external equipment and stores *shall* be accurately simulated. In addition, at least one drop test *shall* be conducted at the sinking

speed, gross weight, and weight distribution at which analysis indicates fuselage bottoming first occurs.

9-2.3.1.1.1 Test Procedures

In performing drop tests on wheel gear assemblies and utilizing the free drop method of impact testing, the test assembly is hoisted, then falls freely from a height which will result in the desired sinking speed at wheel contact. The wheels *shall* be spinning in a reverse direction at the time of platform contact in order to simulate the effect of spin-up drag loads (as an alternate, an inclined reaction plane is sometimes used). A steel grating or other suitable surface *shall* be installed on the reaction platform in the contact area in order to provide a friction coefficient of at least 0.55 or sufficient to produce the required design drag loads. The steps in conducting a given drop test are:

1. Selection of drop weight, sinking speed, and wheel speed
2. Preparation of rotor lift simulation system
3. Positioning of the drop carriage to the required drop height to develop the desired contact velocity
4. Prerotation of the wheel to the desired equivalent landing speed
5. Energizing of the data acquisition system
6. Release of the drop carriage.

9-2.3.1.1.2 Instrumentation and Data Analysis

The information which follows or equivalent data *shall* be recorded for each drop test performed:

1. Platform vertical reaction load
2. Platform drag reaction load
3. Gear drag strut load
4. Rotor lift load
5. Shock absorber stroke
6. Tire deflection normal to reacting surface (if applicable)
7. Mass travel (vertical displacement of carriage assembly)
8. Mass acceleration (drop test load factor n_d)
9. Hydraulic pressure, if applicable.

Items 1 and 2 are not applicable to drop tests using the reduced mass method.

The instrumentation used in obtaining these data *shall* include, but not be limited to, load transducers, deflection gages, and strain gages. The accuracy of all instrumentation used in these tests *shall* be in accordance with MIL-Q-9858 and MIL-G-45662, and *shall* be calibrated against standards traceable to the National Bureau of Standards.

9-2.3.1.2 Skid Gear

The skid gear drop tests *shall* be performed at the basic design gross weight and design alternate gross weight at their critical CG locations for the following three conditions:

1. Condition I. Level landing with vertical reaction.

2. Condition II. Level landing with longitudinally inclined reaction. The vertical ground loads *shall* be combined with a rearward acting drag force equal to one-half the total vertical ground reaction.

3. Condition III. Level landing with laterally inclined reaction. The vertical ground loads *shall* be combined with a laterally acting drag force equal to one-fourth of the total vertical ground reaction.

Limit and reserve energy drop tests *shall* be conducted for each of conditions described. In addition, the yield sinking speed *shall* be determined, utilizing Condition I, by dropping a skid gear assembly in increments of sinking velocity until a permanent set of 0.2% is obtained.

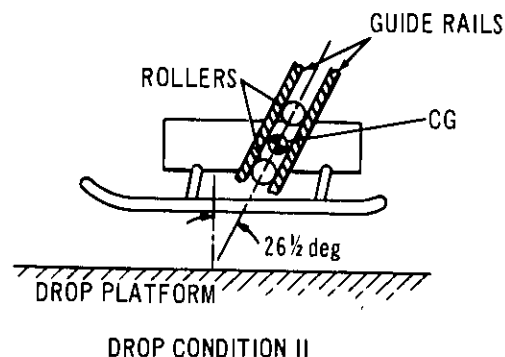
The skid gear drop tests *shall* be conducted on the complete helicopter or on complete landing gear assemblies mounted to a test fixture. The test fixture *shall* simulate within $\pm 5\%$ the actual helicopter pitching mass moment of inertia I_{yy} , rolling mass moment of inertia I_{xx} , and effective weight W_e . The test fixture *shall* be designed so that variations of mass moments of inertia, effective weights, and CG locations could be obtained through minor adjustments of ballast weights.

The requirements of Condition II (illustrated in Fig. 9-1), which specifies a forward reaction equal to one-half of the vertical reaction at ground contact, can be satisfied by providing inclined guide rails to guide the test assembly during the drops.

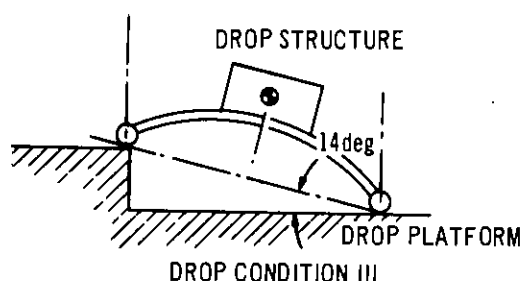
The requirements of Condition III (illustrated in Fig. 9-1), which specifies a lateral drop reaction equal to one-fourth of the vertical reaction, can be satisfied by constructing a sloped platform to provide the lateral reaction. The platform should be high enough to provide an angle of 14 deg (tangent of 14 deg = 0.25) from the horizontal for a line drawn between the points of ground contact of each skid rail. The platform should be long enough to provide support for the entire length of the skid rail.

9-2.3.1.2.1 Test Procedures

In performing drop tests on skid gear and using a drop test fixture that simulates the helicopter, the fixture is first balanced by the adjustment of the ballast weights to obtain the desired moments of inertia, CG



DROP CONDITION II



DROP CONDITION III

Fig. 9-1. Attitude of Skid Gear for Drop Conditions II and III

location, and effective weight. The fixture is then hoisted to the drop height, and, when it is allowed to fall freely, the result will be the desired sinking speed at skid contact. The data acquisition system *shall* be activated at the instant of test fixture release. Drops *shall* be made for vertical and inclined conditions at the design limit sinking speed and at the reserve energy sinking speed. A new skid gear assembly *shall* be used in determining the gear yield sinking speed in accordance with the procedures specified in par. 9-2.3.1.2.

The limit and reserve energy drop test results will be considered satisfactory if the gear deflection is such that the simulated helicopter fuselage minimum ground clearance point does not contact the ground and if no yield is noted during the limit drop test.

9-2.3.1.2.2 Instrumentation and Data Analysis

At least the information which follows or equivalent data *shall* be recorded or computed for each drop test performed:

1. Vertical, drag, and lateral reaction loads
2. Rotor lift load
3. Linear and angular component of mass travel

4. Vertical, longitudinal, and lateral acceleration at the helicopter CG

5. Pitching, rolling, and yawing angular acceleration at the helicopter CG

6. Drop test fixture load factor n_j and helicopter CG load factor n

In addition, physical measurements of the skid gear with reference to the ground level and the skid gear fuselage attachment points *shall* be made both before and after each drop. These measurements *shall* be used to identify skid gear deformations.

Electrical resistance strain gages mounted on the skid gear assembly *shall* be used to measure the induced strain for determination of the yield point.

The instrumentation used in obtaining these data *shall* include linear and angular accelerometers, position indicators, and strain gages. The accuracy of all instrumentation used in these tests *shall* be calibrated to standards traceable to the National Bureau of Standards. Instrumentation *shall* meet the requirements of MIL-Q-9858 and MIL-C-45662.

9-2.3.2 Documentation

The data which follow *shall* be prepared from the recorded measurements:

1. Time history records for all measurements obtained in the gear drop tests

2. Cross plots of vertical load versus strut stroke for gear drop tests except for gears which do not use oleos

3. Tabulation of peak values of load, acceleration, and displacement from measurements obtained during the drop tests. The tabulation *shall* also include values of overall permanent set which may occur during the reserve energy tests, and notes of significant occurrences and observations.

The test report *shall* include:

1. Suitable calibration data

2. A sketch or drawing showing the full details of the final shock absorber metering arrangement

3. A drawing or sketch showing attitudes of the gear with respect to the ground and the test jig for level landing, nosedown, and taildown attitude drops

4. All pertinent calculations made for determination of test conditions and in reduction of test data

5. An inspection analysis of the condition of the gear assembly after the completion of the prescribed tests.

9-2.4 STRUCTURAL DEMONSTRATION

The structural integrity of the helicopter *shall* be proved by:

1. Demonstration of safe operation of the helicopter at maximum obtainable operating limits consistent with design

2. Inflight verification that loads used in the structural analyses and applied to the static test article are not exceeded during operation of the helicopter to the limits of the flight envelope.

The structure of the structural demonstration aircraft *shall* be representative of the proposed production aircraft structure, from the standpoint of both materials and tolerances. The addition of necessary ballast to attain specified CG locations and the installation of special test instrumentation are required during the tests. Dummy equipment having the proper shape and mass properties may be used to simulate externally mounted equipment if service equipment is not available. No special installation or deletion of any kind *shall* be made without written Governmental approval. Distribution of required ballast *shall* be approved by the procuring activity.

The general requirements for the structural demonstration discussed herein may be modified and amplified for specific helicopter models.

The following data *shall* be required to support the structural demonstration:

1. Stress analysis

2. Flight loads

3. Ground loads

4. Effect of weapon delivery (if applicable)

5. Structural description

6. Operating restrictions

7. Flutter analysis

8. Mechanical instability analysis

9. Airframe static tests

10. Landing gear drop tests.

Although the information listed previously is required in the formal reports (Chapter 4), the intent of this paragraph is to indicate the type of data necessary prior to initiation of the structural demonstration flight test. These data may be submitted in preliminary form since formal reports covering these areas may not be available when the structural demonstration is performed.

All combinations of gross weight, airspeed, altitude, load factor, rotor speed, CG position, and control mo-

tions should be investigated by the contractor, for each helicopter configuration so the most critical combination will be demonstrated. These data *shall* be used to determine flight envelope limits and to define the critical conditions of helicopter strength and rigidity, and operating limitations. During these flights, the limits of the flight envelope *shall* be approached in gradual increments compatible with flight safety. The contractor *shall* perform all ground and flight tests within the established flight envelope prior to the formal structural demonstration in order to establish the structural safety of the helicopter system. Compliance with the requirements to demonstrate the critical limits *shall* have been accomplished when any one, or combination, of the limits which follow has been attained and approved by the procuring activity:

1. Limit load factor at design gross weight
2. Rotor blade stall
3. Excessive rates or attitudes of pitch, roll, or yaw
4. Excessive vibratory levels
5. Specified control rates or displacements
6. Control rate as limited by control system
7. Feedback loads in control system
8. Limit forward speed
9. Maximum and minimum rotor speeds
10. Maximum power available to rotor
11. With limits adjusted by altitude, temperature, and turbulence.

9-2.4.1 Test Requirements

There are many parameters involved in the attainment of critical conditions, and each must be considered carefully during the structural demonstration tests. Among these are:

1. Rate and Sequence of Control Input. More rapid control inputs usually generate higher loads, and the sequence of control inputs can affect loads significantly. For this reason, the maneuvers *shall* be performed by appropriate movement of the cyclic, collective, and directional controls in not more than the time required by par. 3-2.1.3 of MIL-S-8698 to the required displacements. Except for Class I helicopters, the time required for control movement *shall* not exceed 0.3 sec. The controls *shall* be held for the time required to obtain the specified load factor, and *shall* be returned in not more than the time previously referenced to the position required for level coordinated flight. Frequently, the attainment of maximum load factor is achieved by initiating the maneuver with cyclic pitch control displacement, quickly followed by collective pitch control displacement.

2. Loading Configuration for the Test Helicopter

Gross Weight and CG Location. Most test conditions will be conducted at basic design gross weight, design alternate gross weight, and/or maximum gross weight. Techniques for performing demonstration tests for a clean configuration helicopter also *shall* be used for a vehicle configured with external stores. The CG of the test helicopter *shall* be at the most critical location for the test condition being investigated. The appropriate external configuration *shall* be duplicated for the weights and CG's tested.

3. Atmospheric Conditions. All flights *shall* be conducted in smooth air. A severe gust upset while performing a maneuver at or near the maximum test conditions could be catastrophic.

4. Trim conditions for the test maneuvers *shall* be as follows:

- a. The helicopter *shall* be trimmed in steady, unaccelerated flight at the required test airspeed ± 5 kt.
- b. The test altitude *shall* be the minimum safe (or higher) altitude for the test condition.
- c. Rotor rpm *shall* be the maximum power-on or maximum power-off rotor rpm, as applicable, unless the contractor has demonstrated that an alternate is more critical.

9-2.4.1.1 Test Maneuvers

The following maneuvers *shall* be required:

1. Symmetrical Pullout. Accomplish at the limit load factor n_L , at airspeeds of $0.4 V_H$, $0.7 V_H$, and V_{DL} , at critical CG, and at maximum design gross weight.

Note:

V_H = maximum level flight speed at the basic design gross weight, using intermediate power, or as may be limited by blade stall or compressibility, kt

V_{DL} = design limit speed, kt

2. Rolling Pullout. From a bank angle of at least 45 deg, roll the helicopter in a direction which will reduce the angle of bank. Should the maneuver produce a more critical loading if initiated from stabilized level flight, the alternate method of performing the rolling pullout *shall* be employed. The maneuver *shall* be performed to both the left and right. The load factor attained *shall* be at least $0.8 n_L$ at airspeeds of $0.6 V_H$ and V_H . The test *shall* be conducted at minimum rotor rpm and at maximum gross weight (i.e., maneuver is entered at maximum rpm but data are recorded at minimum rpm).

3. Climbing Turn (Chandelle). Perform an abrupt

steep climbing turn using the helicopter momentum to achieve a faster rate of climb. Heading *shall* have changed at least 180 deg while accomplishing the maneuver. The load factor attained *shall* be at least $0.8 n_L$ at airspeeds of $0.8 V_H$ and $V_{max RC}$.

4. Pushover. Perform a cyclic pullup followed by a pushover with fixed collective, or an abrupt downward placement of the collective from the trim condition. The limit negative n_z *shall* be attained at airspeeds of $0.8 V_H$ and $V_{max RC}$ or the airspeed required to generate limit negative n_z . The test *shall* be performed at maximum design gross weight.

5. Autorotative Pullout. With the rotor rpm at maximum or the collective pitch at the minimum attainable and with the vertical and forward airspeeds stabilized, apply maximum power concurrently with the movement of the controls to obtain maximum n_z . The test *shall* be conducted at airspeeds of $0.2 V_{MA}$, $0.6 V_{MA}$, and V_{MA} at maximum design gross weight. The maneuver at the minimum airspeed *shall* be accomplished at $0.2 V_{MA}$ or at the minimum airspeed at which the pilot can obtain a stable airspeed indication, whichever is greater. In no case *shall* the airspeed be less than 35 kt. (Note that V_{MA} may not be less than the smaller of V_H or 1.2 times the speed for maximum glide distance.)

6. Jump Takeoff. From the minimum collective pitch setting, displace the collective pitch control and hold. The collective pitch displacement *shall* be held until the maximum load factor has been attained.

7. Steady Sideslip. Displace the directional control until the limit of the airspeed versus sideslip envelope or full displacement is reached. The test *shall* be performed at airspeeds of V_H and V_{DL} at the critical CG, and to both the left and right.

8. Dynamic Yaw. Apply directional pedal, left and right, until the maximum overswing angle of sideslip is attained for the test airspeed. The maneuver is performed by yawing in one direction and then applying full pedal for opposite yaw. The test *shall* be conducted at airspeeds of $0.5 V_H$, $0.8 V_H$, and V_{DL} at design gross weight.

9. Turn Reversals. From a stabilized 45-deg bank (left and right), initiate a turn reversal in the opposite direction. During this maneuver, maximum bank angles and roll rates will be attained. The tests *shall* be conducted at airspeeds of $0.6 V_H$, $0.8 V_H$, and V_H .

10. Quickstop. From a level approach at an airspeed of V_H , displace the controls to bring the helicopter to a hover in the shortest possible distance. The altitude *shall* not change more than 10 ft.

11. Landings. Demonstrate both hover and run-on landings to the limit rate of descent. Forward speed *shall* include the maximum allowable for landing gear design. Instrumentation *shall* be used to document demonstrated rates of descent.

These demonstration test conditions may be tailored to any specific helicopter type. Details of each test condition *shall* be described in detail in the contractor's approved structural demonstration test plan.

9-2.4.1.2 Instrumentation and Data Analysis

Evidence of compliance with the test requirements or prior attainment of one of the critical limits of par. 9-2.4 *shall* be furnished by oscillograph records and/or photopanel films delineating the parameters pertinent to each demonstration maneuver. Telemetering of critical parameters is essential because it provides instantaneous load information, thereby increasing flight safety and expediting test progress. Prior to procurement and installation of instrumentation, the contractor must consider:

1. Compatibility of proposed instrumentation and telemetering equipment with the Advanced Instrumentation and Data Analysis Systems (AIDAS) equipment at the U.S. Army Aviation Systems Test Activity (USAASTA). If possible, existing equipment should be modified to be compatible, and new systems to be purchased *shall* be compatible.
2. Incorporation of backup power source to assure continuity of transmission of telemetered data in the event of power failure
3. Redundant sources of data for critical parameters, where practical, to prevent loss of a data flight due to instrumentation malfunction
4. The extent to which telemetering will be employed during the structural demonstration tests witnessed by the procuring activity.

In addition to telemetering, every practical effort should be made for protection and recovery of the on-board instrumentation records in the event of helicopter loss.

The instrumentation package *shall* include the capability to measure and record all parameters necessary to document the compliance with the demonstration requirements and to substantiate the structural integrity of the vehicle. As a minimum, instrumentation *shall* record:

1. Vertical acceleration (pilot and helicopter CG)
2. Stick positions (longitudinal and lateral)
3. Directional pedal position

4. Collective stick position
5. Attitudes (roll, pitch, and yaw)
6. Rates (roll, pitch, and yaw)
7. Airspeed
8. Altitude
9. Engine(s) parameters
10. Clock
11. Event marker
12. Record number indicator
13. Main rotor and tail rotor blade bending (flapwise and chordwise at critical locations)
14. Actuators or boost tube loads
15. Pitch link, drive arms, drag links, and lift link loads (as applicable)
16. Mast torque
17. Mast bending
18. Rotor azimuth
19. Airframe stress (critical beam caps, floor webs, struts, support fittings, engine mounts, tail boom, control tubes)
20. Landing gear stress
21. Elevator and/or vertical fin stresses (if applicable)
22. Stability augmentation system actuator position (if applicable)
23. Miscellaneous pressures.

The complete instrumentation package should be tailored to fit the specific helicopter.

In addition to the telemetering requirements stated previously, the structural demonstration *shall* include motion picture coverage of the helicopter during compliance tests. Also, chase vehicles *shall* be used for inflight monitoring of the test helicopter during the entire structural demonstration test program.

9-2.4.2 Documentation

As required by par. 4-7.14(1), the instrumentation report *shall* indicate the adequacy of the instrumentation package to document fulfillment of the demonstration requirements. This report should include the instrumentation ranges and accuracies. As a minimum, the structural demonstration report *shall* include time histories, a discussion of pilot technique used in each maneuver, a summary table showing the maximum measured load for each structural component, a complete table of maneuvers with applicable flight data, and the flight log.

9-3 PROPULSION AND POWER SYSTEM DEMONSTRATION

9-3.1 GENERAL

The tests specified herein *shall* be performed to demonstrate the operational and performance characteristics of the helicopter propulsion system both on the ground and in flight. The flight tests *shall* be performed on a single helicopter unless otherwise specified by the procuring activity. Demonstration of the adequacy of the entire propulsion and power system *shall* include assurance of engine/airframe compatibility; and proof of the suitability of the drive system, the lubrication system, and the rotors and propellers.

The contractor test plans for the engine qualification, transmission bench test, ground test vehicle, and flight test programs *shall* include a section describing the tests to be performed on the helicopter lubrication subsystem during the respective test programs. Governmental approval of these plans is required.

Any deviation from the tests which are described subsequently *shall* be approved by the procuring activity. Such deviations *shall* be described briefly, and sufficient data *shall* be submitted to permit comparisons with the standard procedures.

Operation of a complete prototype propulsion subsystem *shall* be the first integrated evaluation requirement. The test set-up *shall* be assembled so that all components are arranged in the proper spatial relationship. Instrumentation *shall* be installed to measure pertinent parameters such as pump rpm, pressures, lubricant temperature, and flow rates. The performance of each of the components *shall* be evaluated relative to the supplier specifications. Any deviations must be investigated.

Following successful operation of the subsystem components in the bench tests, the subsystem performance *shall* be evaluated in the ground test vehicle and, finally, in a flight vehicle. Prior to first flight, sufficient ground operation *shall* be accumulated to assure safe flight operation. The performance of the subsystems *shall* be satisfactory under all modes of operation and compliance with the applicable requirements of MIL-T-25920 *shall* be attained.

The results of the tests *shall* be submitted in the respective test reports, and the subsystem will be considered qualified when the substantiating data have been approved by the Government.

9-3.2 ENGINE/AIRFRAME COMPATIBILITY TESTS

Compatibility of the engine and airframe *shall* be demonstrated during steady-state and transient operation. Generally, compatibility includes considerations such as steady state and transient response characteristics of the engine and engine control in combination with the rotor drive system and rotor(s). The most significant compatibility consideration is torsional stability.

The airframe manufacturer *shall* define requirements and all demonstration tests required to verify compatibility. Although these requirements can be included in the model specification, detailed maneuver or pilot control movements need not be defined. Instead, data recorded in early ground and flight tests *shall* form the basis for compatibility demonstrations.

9-3.2.1 Test Requirements

The essential engine/airframe compatibility requirement is to insure that no self-sustaining torsional oscillations *shall* occur. Therefore, the engine should damp any torsional oscillations above a specified frequency, while the helicopter damping system should prevent excessive rotor shaft/transmission oscillations.

Details of propulsion system stability test requirements are not included in current Military Specifications, but are recognized as being dependent on the specific operating characteristics of the helicopter. This lack of information requires that detailed test requirements be defined by the airframe manufacturer. For instance, the rotor shaft/transmission system will be subjected to torsional oscillations due to rotor dynamics, and acceptable levels of these oscillations will depend upon the size and design of the particular helicopter. Factors which *shall* be considered in determining an acceptable level of these oscillations are:

1. Structural Integrity. The physical endurance of a transmission system having marginal vibratory levels *shall* be demonstrated in accordance with par. 3-4.3 of MIL-T-5955.

2. Pilot Control and Comfort. The effect of transmission torsional oscillations on cockpit vibratory and noise level *shall* not result in vibratory levels which exceed those in MIL-H-8501, or noise levels which exceed those in MIL-A-8806. The torsional oscillations *shall* not cause excursions beyond limits specified by MIL-H-8501.

In military helicopters where engine/rotor transient requirements specify large power changes over a short time period (par. 3.3.11, MIL-E-8593), rapid power response to pilot demands may be essential. This rapid response requires a high-gain/short time-constant engine. This combination is more likely to lead to transient torsional oscillations than one with a slow response. Therefore, consideration *shall* be given to the response of the engine to input signals at different frequencies. The engine should respond to input signals at different frequencies. The engine should respond rapidly to very low frequency signals, such as pilot demand, and should show little or no response to higher frequency signals, such as excitations at the natural frequency of the rotor system. For torsional stability purposes, the engine/airframe response at the natural frequency of the rotor system is of major concern. The damping or attenuation of perturbations at this frequency is specified as a stability requirement.

Fig. 9-2 shows three possible engine transient torque responses to a step demand for torque change. In each case, the torque rises to the demanded level in a relatively short time (dependent on engine response rate) and then oscillates about that level at the natural frequency of the rotor system. Fig. 9-2(A) shows a perturbation time history having a damping ratio greater than 0.11. This damping ratio is considered a design goal for engine response because the amplitude of the oscillation decays by more than half during the first cycle. The perturbation shown in Fig. 9-2(B), having a damping ratio of approximately 0.064, may not be considered acceptable. The undamped oscillation of Fig. 9-2(C) is unacceptable.

Verification of engine/airframe compatibility *shall* be conducted analytically prior to ground testing, as specified by MIL-T-5955, and by testing during ground and flight tests. The ground and flight tests *shall* include the evaluation of propulsion and rotor controls, and *shall* demonstrate:

1. That propulsion control units function satisfactorily under all normal conditions of operation of the helicopter and provide acceptable engine acceleration and deceleration.

2. That the fuel management system, air induction and exhaust system, installation effects, local atmospheric conditions, or vibratory environment do not adversely affect engine power regulation.

3. Satisfactory sensitivity of the gas generator control and the power turbine governor over the range of flight and ground operating conditions.

4. Satisfactory operation of the control functions listed:

- a. Rotor speed (rpm) change
 - b. Governing
 - c. Mechanical stops
 - d. Collective pitch change
5. Accessibility and effectiveness of all propulsion control system field adjustments
 6. Altitude starts and restarts
 7. Optimum alignment and the effect of misalignment and output shaft unbalance.

All engine and rotor components *shall* be installed during the test program. The engine and rotor configuration *shall* be as specified in the engine and helicopter model specifications and include any design changes effective at the time tests are conducted.

Included in MIL-T-5955 are requirements for analytical predictions of the natural frequencies and mode of vibration of the entire engine/rotor drive system. Also required is an analytical demonstration of the torsional stability of the engine and engine fuel control in combination with the rotor drive system and rotor(s). To comply with these requirements, a Holzer analysis (an iterative technique) is suggested for determination of

natural frequencies and modes of vibration, and a Bode frequency response analysis is recommended for determination of torsional stability. The Bode and Holzer methods are discussed in pars. 5-2 and 5-3, respectively, of AMCP 706-201.

9-3.2.1.1 Ground Tests

Engine/airframe compatibility *shall* be evaluated during helicopter ground tests conducted in accordance with MIL-T-8679. The ground demonstrations to be conducted *shall* include both the propulsion and rotor controls. The basic purpose of the test is to collect data which will provide evidence to verify torsional stability. During ground tests the engine and airframe *shall* be subjected to excitations at several different frequencies simultaneously.

Useful data for assessing stability are power/speed perturbations at various average power levels and collective pitch or speed select changes. If the helicopter incorporates power management or power change anticipation devices, which can be operated in an "on" or "off" mode, or if the helicopter is designed to be operable when these devices have failed, stability *shall* be evaluated with the helicopter in each of these modes.

9-3.2.1.1.1 Propulsion Controls

9-3.2.1.1.1.1 Power Lever Controls

Plus and minus limits *shall* be specified for:

1. Lost motion between twist grip and engine power control
2. Lost motion between the actuator and power turbine governor or engine power control
3. The force required to move the twist grip linked to the power turbine governor or the engine power control
4. The force required to move the actuator linkage to the power turbine governor or the engine power control
5. Time of motor actuation and engine power control lever and engine power turbine governor lever response time.

Friction devices or positive locks in the control system *shall* be adjusted to obtain a minimum resistance to motion when the controls are moved throughout their full range. Secure means of locking the levers on the fuel control(s) *shall* be provided. Engaging and disengaging of the lock(s) while the engine is running are required.

The test instruments required include:

1. Indicators to designate position of motor-

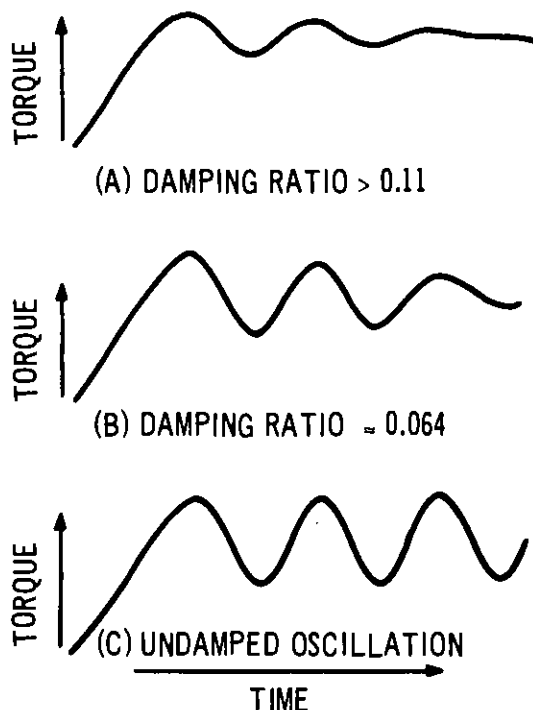


Fig. 9-2. Engine Transient Torque Responses to a Step Demand for Torque Change

operated or twist grip-operated engine power control lever and engine power turbine governor control lever.

2. Devices for measuring the force applied to the actuator linked to the power turbine governor and to the twist grip or actuator linked to the engine power control. The point of application *shall* be the attachment point of the beep actuator linkage and/or the center of the twist grip, respectively.

3. Time recording devices such as oscillographic equipment, tape recorders, and strip charts.

9-3.2.1.1.1.1.1 Engine(s) Stopped

Prior to the initiation of actual ground tests,

1. The engine power lever lock(s) *shall* be disengaged. The power lever *shall* be placed at positions of 10- to 20-deg increments of lever movement through the entire operating range from cutoff to intermediate (30 min) power, and the fore and aft forces required to move the power lever *shall* be recorded.

2. The power turbine governor control lock *shall* be disengaged. The power turbine governor control *shall* be placed at 10- to 20-deg increments of control movement through the entire operating range, and the fore and aft force necessary to move the linkage *shall* be recorded.

3. The engine power lever lock(s) *shall* be engaged with the power lever at approximately midposition. The lost motion at the top of the power lever handle or at the twist grip *shall* be measured when 150% of the maximum fore and aft forces found in Item 1 are applied in the fore and aft directions, respectively, to the power lever handle or at the twist grip.

4. The power turbine governor control lock *shall* be engaged with the control at approximately midposition. The lost motion at the beep actuator *shall* be measured when 150% of the maximum fore and aft forces found in Item 2 are applied in the fore and aft directions, respectively, to the beep actuator linkage.

5. The time of motor actuation and engine power control lever and engine power turbine governor lever response time, during full upbeep and full downbeep, *shall* be determined. At an intermediate position during an upbeep and during a downbeep, any engine power turbine governor lever or power control lever movement after current to the actuator motor has gone to zero *shall* be noted. On multispeed or adjustable-speed motors, these times *shall* be determined for each speed. The listed test procedures *shall* be repeated in manual control mode. To time the sequence of events, a switch from automatic engine control to manual engine con-

trol and from manual engine control to automatic engine control *shall* be performed.

9-3.2.1.1.1.1.2 Engine(s) Running

Following completion of the remaining ground tests outlined in par. 9-3.2.1.1, the tests which follow *shall* be completed with the engines running:

1. The procedure of par. 9-3.2.1.1.1.1, Items 1 and 2 cited previously *shall* be repeated.

2. The procedure of par. 9-3.2.1.1.1.1, Item 4 *shall* be repeated using 150% of the force found in par. 9-3.2.1.1.1.1 (1).

3. The procedure of par. 9-3.2.1.1.1.1, Item 5 *shall* be repeated.

9-3.2.1.1.1.2 Starting and Acceleration to Ground Idle

A start and acceleration *shall* be conducted normally using the starting procedure prescribed by the applicable technical orders or as approved by the procuring activity.

9-3.2.1.1.1.3 Acceleration and Deceleration Tests

Engine gas generator acceleration and deceleration tests *shall* be accomplished with and without contractor-installed air bleed and with automatic and manual engine power control. All tests using the automatic engine power control *shall* be run without moving the power turbine governor beep switch to control engine output shaft speed. All power increase and decrease tests *shall* be performed at the maximum acceleration fuel flow schedule and at minimum deceleration fuel flow schedule, respectively, as provided by the engine power control. The pilot's methods of increasing or decreasing power *shall* be specified for each test. Data *shall* be plotted as a time history in accordance with Table 9-1, from prior to increasing or decreasing power until steady state data are obtained. Specific notations on the time history are required to reveal governor transient response characteristics, torque overshoot or undershoot, transient droop or steady state droop, governor stability, and pilot corrective action, if required.

Engine gas generator acceleration and deceleration tests *shall* include:

1. Increase power from flight idle gas generator speed to 95% maximum engine power.

2. Decrease power from 95% maximum engine power to flight idle gas generator speed.

TABLE 9-1. DATA REQUIREMENTS, ENGINE/AIRFRAME COMPATIBILITY DEMONSTRATION

		PARAGRAPH															
		9-32.1.1.1	9-32.1.1.2	9-32.1.1.3	9-32.1.1.4	9-32.1.1.5	9-32.1.1.6	9-32.1.1.7	9-32.1.1.8	9-32.1.1.9	9-32.1.1.10	9-32.1.1.11	9-32.1.1.12	9-32.1.1.13	9-32.1.1.14	9-32.1.1.15	9-32.1.1.16
N_g	GAS GENERATOR SPEED, rpm																
N_p	POWER TURBINE SPEED, rpm																
W_f	FUEL FLOW, lb/hr																
MGT	ENGINE GAS TEMPERATURE, °C																
θ_c	COLLECTIVE STICK POSITION, deg																
Q_p	ENGINE OUTPUT SHAFT TORQUE, lb/ft																
θ_g	GAS GEN. LEVER																
θ_p	POWER TURB. LEVER																
g	ENGINE VIBRATION, g's																
V	AIRSPEED, kt																
t	TIME, sec																
Ω	MAIN ROTOR SPEED, rpm																
H_p	PRESS. ALTITUDE, ft																
T_a	AMBIENT AIR TEMP., °C																
P_{Sf}	ENG. FUEL INLET PRESS, psia																
P_{S3}	COMPRESSOR DISCH PRESS, psia																
-	BEEP SWITCH CURRENT, amp																
-	PILOTS POWER LEVER, deg																

3. Increase power from 70% transmission takeoff torque limit to 100% transmission takeoff torque limit or from 70% intermediate engine power to intermediate engine power, whichever is lower.

4. Decrease power from transmission takeoff torque limit to 70% transmission takeoff torque limit or from intermediate engine power to 70% intermediate engine power, whichever is lower.

5. Increase power from transmission continuous torque limit to transmission takeoff torque limit or from intermediate engine power to maximum engine power, whichever is lower.

6. Decrease power from transmission takeoff torque limit to transmission continuous torque limit or from maximum engine power to intermediate engine power, whichever is lower.

7. Increase power from ground idle to maximum power position; adjust torque, if required, to maximum transient value without exceeding engine limits.

8. Decrease power from maximum power to ground idle.

9. Return gas generator control to the "off" position to demonstrate satisfactory operation of fuel cutoff provisions.

9-3.2.1.1.1.4 Gas Generator Control and Power Turbine Governor Sensitivities

Steady-state engine data *shall* be recorded at each 10-deg increment of travel of the gas generator control, with the collective pitch held full down. Data *shall* be plotted as a function of the gas generator control lever position.

With the gas generator control in maximum position, the power turbine governor sensitivity *shall* be determined within five increments of power turbine governor travel and within the allowable rotor speed range at three power positions: full down collective pitch, mid-position collective pitch, and maximum gearbox torque position. Data *shall* be plotted as a function of the power turbine governor lever position.

9-3.2.1.1.1.5 Power Control Anticipator and Droop Cam Characteristics

Ground tests *shall* be conducted to record the droop compensation cam characteristics without actuation of the power turbine speed beeper switch or control actuator (see par. 9-3.2.1.2.1.5 for flight tests). The steady-state and transient droop characteristics *shall* be obtained for the range of collective pitch positions from full down to midposition and from midposition to maximum gearbox torque position.

9-3.2.1.1.2 Rotor Controls

9-3.2.1.1.2.1 Helicopter Dynamic System—Engine Compatibility

Dynamic system/engine compatibility *shall* be demonstrated at a minimum of nine combinations of vehicle rotor speed and engine power settings. These nine combinations *shall* include three vehicle rotor speeds, e.g., 85%, 100%, and 115%; and three power settings, e.g., flight idle, engine "topping", and a power setting approximately midway between these two. At each of these nine conditions, the pilot's collective control *shall* be cycled manually at the critical oscillation frequencies of the dynamic system(s) and two frequencies, within 0.1 Hz of critical, on each side of critical. Data *shall* be plotted as a time history, in accordance with Table 9-1. The time response of the test instrumentation for this test *shall* be specified.

9-3.2.1.1.2.2 Alignment and Output Shaft Unbalance

Conditions of optimum alignment and balance, maximum allowable misalignment, and maximum allowable

output shaft unbalance *shall* be demonstrated. Data *shall* be obtained from minimum to maximum allowable rotor speed, at four power settings from flight idle to maximum power. Each speed setting for the demonstration selected *shall* be run with the configurations of alignment and output shaft unbalance which follow:

1. Optimum alignment between engine and output shaft with optimum output shaft balance
2. Maximum allowable misalignment between engine and output shaft with optimum output shaft balance
3. Maximum allowable misalignment between engine and output shaft with maximum allowable output shaft unbalance
4. Optimum alignment between engine and output shaft with maximum allowable output shaft unbalance.

9-3.2.1.2 Flight Tests

Engine/airframe compatibility flight demonstration tests are defined in the paragraphs which follow. Data collected in these tests may reveal instability not detected in the ground tests, and the engine/airframe system may be subjected to excitations at frequencies not encountered previously. Data *shall* be collected and reduced in the same manner as for the ground tests to verify stability.

9-3.2.1.2.1 Propulsion Controls

9-3.2.1.2.1.1 Altitude Restarts

At selected altitude intervals, altitude restarts of the engine *shall* be conducted using the procedure prescribed by the applicable operating instruction. Air starts should not be attempted until autorotative or one-engine-inoperative landing techniques have been developed and demonstrated by the particular test pilot. Tests should be conducted over terrain which permits safe landings. For single-engine helicopters, the test *shall* be conducted at the recommended best glide speed, or alternately, at the air start airspeed recommended by the applicable Technical Order. For multi-engine helicopters, the tests *shall* be conducted using two additional, higher airspeeds at each altitude. Also, for multiengine helicopters, air starts may be demonstrated with one engine inoperative and may be repeated for each engine. Data *shall* be plotted as a time history in accordance with Table 9-1.

9-3.2.1.2.1.2 *Engine Acceleration and Deceleration Tests*

The engine gas generator acceleration and deceleration tests which follow *shall* be performed with and without air bleed, with automatic and manual engine power control at 5000-ft increments of altitude between sea level and maximum altitude over a range of practical airspeeds, and with the gas generator control in maximum position. In each of these tests, the pilot's collective stick *shall* be moved, without the use of the power turbine governor beep switch to control engine output shaft speed, from initial to final positions at a rate to provide maximum acceleration fuel flow schedule or minimum deceleration fuel flow schedule as allowed by the engine power control. For the altitude gas generator accelerations, the airspeed prior to acceleration *shall* be for a minimum rate of descent condition. The flight speed prior to gas generator deceleration *shall* be consistent with minimizing scatter of data which could be attributed to pilot-handling techniques. The pilot's method of increasing or decreasing power *shall* be specified in the test plan. Data *shall* be plotted from prior to control movement until steady-state engine conditions are again obtained. Acceleration and deceleration time *shall* be plotted as a function of pressure altitude.

The tests *shall* include:

1. Application of power from autorotation (engine flight idle) to 95% maximum engine power.
2. Decrease of power from 95% maximum engine power to flight idle engine power.
3. Increase of power from 70% transmission takeoff torque limit to 100% transmission takeoff torque limit, or from 70% of intermediate engine power to intermediate engine power, whichever is lower.
4. Decrease of power from transmission takeoff torque limit to 70% transmission takeoff torque limit, or from intermediate engine power to 70% intermediate engine power, whichever is lower.
5. Increase of power from transmission continuous torque limit to transmission takeoff torque limit, or from intermediate engine power to maximum engine power, whichever is lower.
6. Decrease of power from transmission takeoff torque limit to transmission continuous torque limit or from maximum engine power to intermediate engine power, whichever is lower.
7. Increase of power from ground idle to maximum power and adjust torque, if required, to maximum transient value without exceeding engine limits.

8. Decrease of power from maximum power to ground idle, and adjust collective or controls as required to enter autorotation from transmission torque limit climb condition.

9. Return of the gas generator control to the "off" position to demonstrate satisfactory operation of fuel cutoff provisions and to simulate flameout. This test may be followed by an altitude restart or by an autorotative landing.

9-3.2.1.2.1.3 *Gas Generator Fuel Control*

At maximum gross weight and at three specified altitude conditions, steady-state engine data *shall* be recorded at each 10-deg increment of gas generator control (twist grip rotation or pilot's power lever) and also at three power turbine speeds (minimum, intermediate, and maximum) for each 10-deg increment. Data *shall* be plotted as a function of position.

9-3.2.1.2.1.4 *Power Turbine Governor and Speed Response Time*

Time response of the power turbine governor/beep motor combination *shall* be determined. At three specified gross weights under three flight conditions (at hover OGE and at two specified flight speeds), a power turbine speed response time test *shall* be run. This test *shall* be performed during acceleration from minimum to maximum operational power turbine speed and during deceleration from maximum to minimum operational power turbine speed at specified gas generator speeds (minimum of three) at altitudes from sea level to 15,000 ft. Each test point *shall* record the lag or response time for initial power turbine speed change after beep switch actuation. Data *shall* be recorded at each 5000 ft of density altitude and presented as a function of time. Power turbine speed response time *shall* be plotted as a function of density altitude.

9-3.2.1.2.1.5 *Power Control Anticipator and Droop Compensation Cam Characteristics*

Flight tests *shall* be conducted at two gross weights to record the droop compensation cam characteristics without actuation of the power turbine speed beeper switch or control actuator. The steady-state and transient droop characteristics *shall* be obtained. At sea level and at preselected altitudes in 5000-ft increments through 15,000 ft, the gas generator and power turbine speeds *shall* be preset at fixed values. These fixed

values *shall* be the same at each altitude. Collective pitch (both up and down) *shall* then be applied in increments within one second. The resulting plus/minus droop (underspeed or overspeed) in power turbine speed *shall* be recorded and plotted. The change in rotor speed versus shaft horsepower *shall* be plotted for each altitude as a time history.

9-3.2.1.2.1.6 *Establishment of Minimum and Maximum Power Turbine Speeds*

Minimum and maximum power turbine operational speeds *shall* be established within pilot reaction time limits to prevent overspeed or underspeed. This test *shall* be run at three specified gross weights, at a minimum of three gas generator speeds each under flight conditions of hover IGE, hover OGE, and two specified flight speeds at 5000-ft increments of density altitude from sea level to 15,000 ft. Pilot corrections in power turbine speed *shall* be accomplished during simulated undershoots and overshoots. Steady-state and transient data *shall* be recorded at each point and *shall* be plotted as a time history.

9-3.2.1.2.2 *Helicopter Controls*

9-3.2.1.2.2.1 *Helicopter Dynamic System—Engine Compatibility*

At a safe altitude, with the gas generator control in full open position, hover flight conditions at three N_p (power turbine) speeds *shall* be demonstrated within the flight limits of the rotor. The time response of the test instrumentation for this test *shall* be specified. Data *shall* be plotted as a time history, in accordance with Table 9-1.

To provide three power conditions, the testing *shall* be conducted at maximum, minimum, and one intermediate gross weight. At each of these conditions, the pilot's power lever (i.e., collective control, etc.) *shall* be cycled manually at the critical frequencies of the dynamic system(s) and at two frequencies, within 0.1 Hz of critical, on each side of critical. Oscillation within acceptable limits *shall* be demonstrated. The effect of compressor stall on the dynamic system *shall* be determined.

9-3.2.1.2.2.2 *Alignment and Output Shaft Unbalance*

Tests outlined in par. 9-3.2.1.1.2.2 *shall* be repeated at three specified altitudes.

9-3.2.1.3 *Engine-starting Tests*

Engine-starting tests are conducted to demonstrate the capability of the engine and its components to start within the flight envelope of the helicopter and to determine the adequacy of the engine shutdown and starting procedures in the helicopter operator's manual. The individual components *shall* have been tested functionally to assure compliance with their individual specification requirements and Chapter 7 requirements prior to flight testing. The functioning of the engine-starting system initially may be verified by a laboratory test setup, using the starting system components specified for the production vehicle. In lieu of the engine, a programmed dynamometer simulating the engines may be used. After selection of the test configuration for the laboratory tests, a simulated engine start *shall* be demonstrated under the conditions which follow:

1. Temperature (60°-90°F)
2. Humidity (normal to test site)
3. Battery (fully charged at beginning of test cycle)
4. Reservoirs (hydraulic or pneumatic) at full pressure volume at beginning of test cycle.

Prototype test conditions *shall* be specified in the helicopter detail model specification. The ground and flight tests which follow *shall* be repeated five times (ground starts will be repeated only two times) to assure validity of the results. However, they do not replace environmental hangar tests, which are covered in par. 8-9.7.

9-3.2.1.3.1 *Ground Tests*

The tests described subsequently *shall* demonstrate compliance with component and system specification requirements, installation compatibility, and environmental engine-starting requirements.

9-3.2.1.3.1.1 *Ambient Temperature Tests*

These tests *shall* consist of two phases:

1. Initiation of the start cycle, noting:
 - a. Start rpm
 - b. Adequate voltage at exciter/vibrator
 - c. Lightoff rpm within time limit
 - d. Let-go rpm within time limit
 - e. Adequate engine torque/rpm.

2. Determination of the number of starts possible without recharging or repressurizing the starter system power source. The engine should be allowed to cool approximately 3 min between cycles.

9-3.2.1.3.1.2 Low-temperature Tests

These tests *shall* consist of (1) soaking equipment in a low-temperature environment until all parts have stabilized at the specified temperature, and (2) repetition of the tests specified in par. 9-3.2.1.3.1.1 using the specified low-temperature, engine-starting procedure.

9-3.2.1.3.1.3 High-temperature Tests

These tests *shall* consist of (1) soaking the equipment in a high-temperature environment until all parts have stabilized at the specified temperature, and (2) repetition of the tests specified in par. 9-3.2.1.3.1.1 using the specified high-temperature engine-starting procedure.

9-3.2.1.3.1.4 Ground Power/Ambient Temperature Tests

The tests specified in par. 9-3.2.1.3.1.1 *shall* be performed using the helicopter power system and ground power equipment.

9-3.2.1.3.2 Flight Tests

These tests *shall* demonstrate (1) altitude restarting capability, as detailed in the helicopter model specification, and (2) the adequacy of the airborne engine shutdown and altitude restart procedures as specified in the Operator's Manual.

Altitude restarts *shall* be performed at a minimum of three altitudes from sea level to service ceiling, using the procedure prescribed by the applicable Operator's Manual. For single-engine helicopters, the test *shall* be conducted at the recommended best glide speed or, alternately, at the applicable Operator's Manual air-start airspeed. For multiengine helicopters, an additional test *shall* be conducted using maximum single-engine airspeed for level flight at each altitude.

9-3.2.1.3.3 Instrumentation

Instrumentation for starting tests *shall* be adequate to determine at least the following:

1. Starter temperature
2. Starter rpm
3. Starter current or agent flow, depending on the system
4. Starter terminal voltage or pressure, depending on the system
5. Battery terminal voltage or pressure, depending on the system
6. Time
7. Voltage and current to exciter or vibrator

8. Torque output of starter (if on a dynamometer).

9-3.2.1.4 Lubrication Tests

The lubrication demonstration requirements *shall* be as specified in par. 9-3.4.1.

9-3.2.1.5 Secondary Power System Tests

The demonstration of secondary power systems *shall* be conducted in accordance with the requirements in pars. 9-6 and 9-8.

9-3.2.2 Documentation

Technical data *shall* be recorded in accordance with Table 9-1 and, unless otherwise specified, *shall* be plotted as a time history. Transient engine torque and engine speed data *shall* be reduced by the method outlined in Fig. 9-3.

The test report *shall* be submitted at the conclusion of all tests specified in the approved test plan and *shall* be prepared in accordance with MIL-STD-831.

9-3.3 TRANSMISSION AND DRIVES

In contrast to the freedom of change allowed in the prequalification tests in par. 7-5, the configuration of all components and systems *shall* be established firmly prior to initiating any official qualification test.

MIL-T-5955 outlines the general requirements for transmission systems used in applying primary power. In this specification, the power transmission system is defined as all parts between the engine(s) and the main or auxiliary rotor hubs. This includes gearboxes, shafting, universal joints, coupling, rotor brake assembly, overrunning clutches, support bearing for shafting, and any attendant accessory pads or drives.

The specification sets forth the general design requirements for power train components and covers official qualification bench and acceptance (quality control) test requirements.

MIL-T-8679 covers the ground testing of helicopters and the components peculiar to helicopters. The test requirements for the transmission system are outlined in par. 3.7 of that document. The tests are tiedown tests and include:

1. 50 hr of preliminary flight approval
2. 150 hr of preproduction
3. 250 hr of ground (when required by the procuring activity).

These tests are those required for the substantiation or qualification of the transmission system, i.e., the minimum requirements that must be achieved.

For any helicopter, the test program *shall* demonstrate that the design requirements for performance, safety, reliability, and maintainability are met.

The essential methods used to meet this objective are:

1. The use of multiple specimens to account for the variabilities associated with interfaces, strength, manufacturing, and environments
2. The use of overstress testing to:
 - a. Uncover modes of failure early and demonstrate that they are noncatastrophic and fail-safe by the inspection and detection techniques used in service
 - b. Verify fixes quickly
3. The conduct of official qualification test(s) to verify that the design objectives are met
4. The establishment of logical test scheduling so that there is a high probability that the transmission will be free of major problems before entering higher levels of testing. The ultimate goal is to verify that the design requirements for reliability and maintainability have been achieved by the time helicopters are deployed.

The flight test program *shall* be designed to complete the contractor's helicopter handling qualities, perform-

ance, and structural buildup programs in a minimum number of flight hours and in the shortest possible calendar time. Drive system components must be in an advanced stage of development by this time so as not to delay the flight test program.

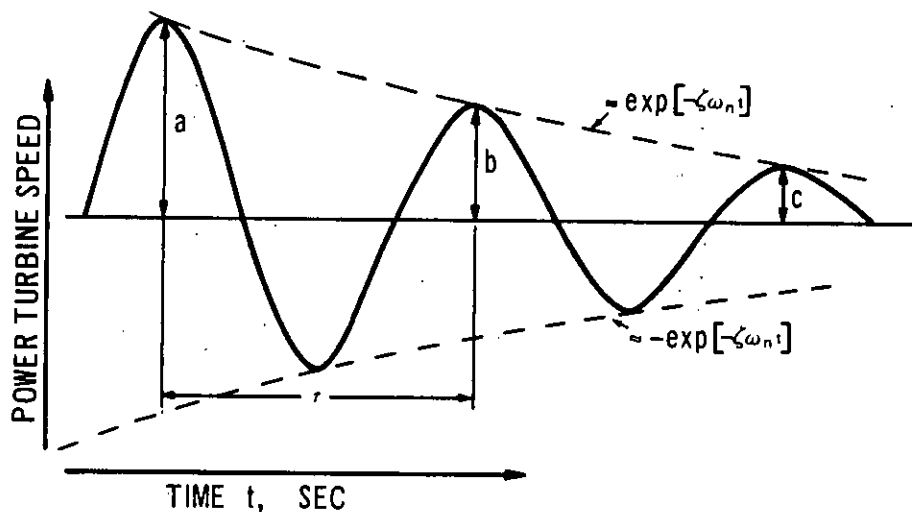
Data obtained from these ground and flight tests can be used to verify the design mission spectrum and to verify the operation and maintainability of the dynamic and airframe components under conditions approaching actual service operation.

9-3.3.1 Test Requirements

9-3.3.1.1 Prequalification Tests

Prequalification tests *shall* precede any attempts to formally qualify helicopter components or systems. Since failures are to be expected during prequalification testing, allowances for delays must be taken into consideration in establishing schedules.

Helicopter transmission prequalification test programs *shall* be designed to uncover problem areas. The major portion of this testing will be accomplished by bench testing of individual components (par. 7-5.1). Initial operation of the complete propulsion system—comprised of the powerplant, transmission, and rotor systems—also is classed as prequalification testing.



$$\text{DAMPING RATIO } \zeta = \frac{1}{2\pi} \ln(a/b) \approx \frac{1}{2\pi} \ln(b/c)$$

$$\text{FREQUENCY } \omega = 2\pi/r \text{ rad/sec}$$

$$\text{NATURAL FREQUENCY } \omega_n = \frac{2\pi}{r\sqrt{1-\zeta^2}} \text{ rad/sec}$$

Fig. 9-3. Data Reduction (Determination of Damping Ratio and Frequency from Time History Recordings)

Whether conducted on a ground test helicopter or dynamically similar test stand ("iron bird"), this testing will investigate component and system compatibility prior to formal surveys and demonstrations.

The tiedown and dynamic test facilities are effective and necessary tools in determining the dynamic response and interface problems between the transmission and other helicopter systems; i. e., control, rotor, engine, and airframe.

9-3.3.1.2 Qualification Tests

A 200-hr official qualification bench test *shall* be conducted in accordance with the contractor's test plan, approved by the procuring activity. The objective of this test is to verify that the prequalification testing has eliminated all of the weaknesses in the transmission. Successful completion of this test will establish a configuration baseline suitable to commit to production. All components in the qualification test transmission *shall* be considered as having zero time. This does not necessarily mean that they have to be new parts; however, any parts which fail during this test *shall* be subjected to rerun during a penalty test. The length of this penalty test *shall* be determined by the procuring activity, based on the nature and severity of the failure. It may be as high as 200 hr.

9-3.3.1.3 Tiedown Tests

The total propulsion system—including all rotors, gearboxes, engine(s), shafting, rotor brake, clutches, accessories, and controls—*shall* be subjected to at least the tests which follow, using either a test bed or the complete tied-down helicopter. A minimum of 50 hr of tiedown testing *shall* be completed prior to first flight of the helicopter. The ratio of ground test time to flight time on any one flight test vehicle *shall* be at least 2:1 during the prescribed ground test program. This will increase the safety of the flight test program by the accumulation of service experience and time on components and systems.

These tiedown tests may be conducted in accordance with the MIL-T-8679 power schedule (par. 3.6.3.3) or with the schedule which follows.

A flight approval test of 50 hr with 50% of the test time at maximum takeoff power, 10% of the time at 110% of maximum takeoff power (within engine limits), and the remaining 40% at maximum continuous power. The test *shall* be divided into five 10-hr cycles with one cycle at 110% of the maximum continuous speed (or maximum possible within engine limits) and four cycles at maximum continuous speed. During the maximum continuous power portion of the test, the main rotor controls and directional controls *shall* be

operated a minimum of 15 cycles per hour in accordance with par. 3.6.3.3(c) of MIL-T-8679 utilizing estimated control movements so as to not exceed the estimated loads to be encountered in flight or ground operation.

The tiedown test of MIL-T-8679 does not consider special power ratings and operating conditions that may exist on multiengine helicopters. Therefore, where special multiengine conditions exist, a tiedown test proposal *shall* be submitted by the contractor and approved by the procuring activity to include these special ratings.

The objective of this test is to demonstrate that the helicopter propulsion system is safe for flight. The requirement for this test is to demonstrate the absence of catastrophic failure modes and the fail-safe features of the dynamic components.

A 150-hr formal qualification test *shall* be conducted in accordance with par. 3.6.5 of MIL-T-8679. The objective of this test is to demonstrate the adequacy of modifications developed for any problems encountered during the 50-hr shakedown ground test and initial flight tests, and to assure reasonable operating intervals without failures.

An additional 250-hr ground test may be required by the procuring activity (par. 3.6.2.3 of MIL-T-8679).

9-3.3.2 Instrumentation

The test instrumentation required is used to measure or record the following parameters:

1. Speed
2. Torque (power)
3. Oil temperature in and out of each gearbox
4. Oil pressure in and out of each gearbox
5. Component temperatures
6. Gearcase pressures
7. Vibration (including noise)
8. Main rotor(s) cyclic and collective pitch position
9. Antitorque rotor pitch position.

Other parameters may be dictated by the test results or in order to define specific problem areas.

High-speed drive shafts often require stringent balancing requirements and special monitoring systems.

Recorded data should include those derived from the normal instrumentation plus the following (and perhaps others):

1. Time
2. Ambient temperature
3. Oil consumption

4. Test events
5. Parts requiring replacement
6. Test personnel.

9-3.3.3 Disassembly

Each period of testing *shall* be followed by disassembly of the component to the smallest indivisible part. The disassembly *shall* be conducted in a suitable area, reasonably protected from contamination, and *shall* insure that parts are accessible for inspection.

Disassembly *shall* be in the presence of an observer designated by the procuring activity unless it is specifically stated otherwise. This observer *shall* have access to all test data and logs, and *shall* be unrestricted in his examination of components.

9-3.3.4 Inspection

The inspection *shall* be divided into two periods. The first shall involve a "dirty" inspection of all parts immediately after disassembly, while the second *shall* be a "clean" inspection following the contractor's detailed, analytical inspection.

During the "dirty" inspection, the following data *shall* be made available to the procuring activity:

1. Disassembly inspection forms filled out by the contractor listing all observed deficiencies
2. Detailed configuration list of the component or system tested
3. Test logs and list of test events
4. Spectrographic oil analysis report
5. Tabulation of all parts replaced during the test
6. Tabulation of all parts found deficient after disassembly.

After the "clean" inspection, the contractor *shall* present to the procuring activity representative all results of nondestructive tests and recommendations for modification or redesign of deficient parts.

9-3.3.5 Retest

Retest criteria *shall* apply only to "must-pass" qualification tests. The length of a retest *shall* be determined by the procuring activity, depending on the extent or severity of the failure. All factors *shall* be considered. However, any parts installed for a "must-pass" test *shall* be considered as zero-time parts regardless of previous test history. Any arguments stemming from high-time parts failing during an official qualification test *shall* be disallowed.

If a failure is severe enough or if the test results have been compromised by improper test procedures, the entire test *shall* be rerun.

9-3.3.6 Clutches and Brakes

Par. 3.6.3.1 of MIL-T-8679 defines minimum requirements for clutch and brake engagement during the tiedown testing of the transmission system. As mentioned in Chapter 7, qualification of these components is not complete until the transmission system testing has been satisfactorily completed.

9-3.3.7 Shafting, Couplings, and Bearings

Production configuration shafting, couplings, and bearings *shall* be installed for the ground tiedown tests of the transmission system. Since the limit for operation of a bearing is generally a function of its temperature, a temperature measurement of each representative shaft bearing *shall* be a requirement. Monitored temperature measurements plus the vibratory measurements to establish the dynamic characteristic of the shafting system *shall* provide sufficient data to substantiate that the bearings will not impose a restriction on vehicle operation.

During the initial vehicle runups, the steady-state temperature of these bearings should be recorded at an idle speed. These values can be extrapolated to operating speed to identify any possible excess temperature problems. The temperature of a bearing is a function of a number of variables but, for a particular installation, can be simply related to speed. The relationship is $T = CN^{0.5}$ in which T is temperature in °F, C is a lumped constant and a function of the installation, and N is the speed in rpm. This may be plotted as a straight line on a log-log graph. A measured temperature at idle speed will establish the value of the constant C and provide the means to extrapolate to the maximum operating speed. Since load will induce a relatively low temperature increase, the extrapolation will be accurate enough to identify marginal installations for which close monitoring is required. Additional points plotted at successively higher speeds will provide verification of the trends.

At each of the scheduled teardown inspection periods of the ground vehicle endurance program, the couplings and bearings *shall* be examined for signs of deterioration. Approval for disassembly prior to the scheduled teardowns, except for servicing, *shall* first be obtained from the procuring activity.

During prequalification tests, no case of failure *shall* be considered an "isolated case"; therefore, each failure *shall* be cause for corrective action. The shafting, cou-

plings, and bearings *shall* have satisfactorily completed the endurance test when the prescribed test period has been completed with no evidence of distress.

Since a detailed study of the appearance of a failed coupling or bearing generally will indicate the cause of failure, all cases of distress *shall* be examined by knowledgeable contractor personnel and technical representatives of the supplier, as appropriate. Following evaluation, corrective action *shall* be incorporated prior to continued testing. This procedure will be repeated until each coupling and bearing has completed the program satisfactorily.

During the endurance program, the procedures for bearing lubrication *shall* be monitored to establish applicability to the planned service program. These procedures *shall* be published for field use and *shall* include any precautionary conditions. This should include restrictions such as incremental speed increases following greasing to assure proper "channeling" and preclusion of bearing overheating due to grease churning.

The contractor *shall* review the results of service operation of the bearings to check for flaws in the acceptance procedures and to incorporate changes in the servicing procedure.

9-3.3.8 Accessories

Vehicle ground and flight tests *shall* include tests of the accessory-powered subsystems. These tests will determine the compatibility of the components and the capacity of the system to fulfill the performance requirements. Thus, the accessory performance *shall* be evaluated during these tests. The contractor's test program *shall* include all subsystem test requirements. The performance of all accessories *shall* be evaluated primarily by the ground tiedown tests. As appropriate, pertinent environmental data such as temperature, vibratory level, and lubrication *shall* be monitored. Data accumulated shall be compared with the accessory supplier test data for verification of loads, capacities, and, where appropriate, reserve capacity for growth. Any discrepancies *shall* be investigated. The ground tests *shall* be followed by sufficient flight tests to verify the ground test results and to insure satisfactory operation throughout the flight regime.

9-3.4 LUBRICATION AND FUEL SUBSYSTEM DEMONSTRATION

The lubrication subsystem demonstration *shall* be conducted to assure that the system provides adequate lubrication and cooling for the helicopter. The demon-

stration *shall* include evaluation of the lubrication system for each gearbox. The contractor may propose a common lubrication system as an alternative to the separate system for each gearbox required by MIL-T-5955. It *shall* then be necessary to provide substantiation that flight safety with the common system will be equivalent to that of a separate system installation.

The lubrication subsystem includes all components whose primary function is to supply, sense, and control lubricant to the engine, transmission, generator, or gearboxes. A typical subsystem is depicted in Fig. 9-4. The demonstration *shall* verify that the oil systems of the engine, transmission, and gearbox operate satisfactorily, i.e., that they maintain necessary oil pressure and oil cooling and that they are free from excessive discharge at the breather.

Fuel subsystem tests *shall* be conducted to demonstrate the operating characteristics of the system both on the ground and throughout the flight envelope.

The demonstration tests *shall* determine the following:

1. Tank capacities, available fuel, sump capacity, residual fuel, and expansion space for the internal and external fuel tanks
2. Satisfactory operation of the fuel quantity gauging system
3. Satisfactory operation of the fuel system in the fueling and defueling conditions
4. Surge pressure during refueling modes
5. Satisfactory operation of the closed circuit refueling system, if applicable
6. Siphoning characteristics of the fuel system
7. Effects of both internal and external fuel on the CG
8. Operating characteristics of the fuel supply system under various boost pump and transfer pump failure conditions
9. Vapor-to-liquid ratio with boost pumps inoperative
10. Proper operation of the fuel supply and transfer system under specific helicopter operating conditions
11. Acceptable performance of the fuel vent subsystem
12. Fuel jettisoning characteristics
13. Lack of impingement of fuel or fumes on the helicopter from any source
14. Satisfactory fuel tank purging subsystem operation
15. Aerial refueling operation, if applicable

16. The operational effects of climatic conditions on fuel system components or subsystems.

9-3.4.1 Lubrication Subsystem Demonstration

The compatibility of the subsystem components *shall* be established by sufficient testing to assure safety of flight. MIL-T-5955 and MIL-T-8679 primarily define design parameters to which the lubrication subsystem *shall* be substantiated. To assure compliance with these requirements, the subsystem *shall* be evaluated progressively.

The large components of the subsystem—such as a fan, the heat exchanger, and the oil pump—*shall* be tested by the component supplier prior to delivery to the contractor. The tests *shall* include verification of heat exchanger efficiency, fan performance, pump performance, and lubricant tank expansion space.

Prior to installation in the ground tiedown vehicle, the engine and transmission lubrication cooling capabilities *shall* have been evaluated on a component basis during the engine qualification and transmission bench test, respectively. These cooling systems *shall* be rechecked on the ground tiedown and flight vehicles in accordance with the applicable portions of MIL-T-

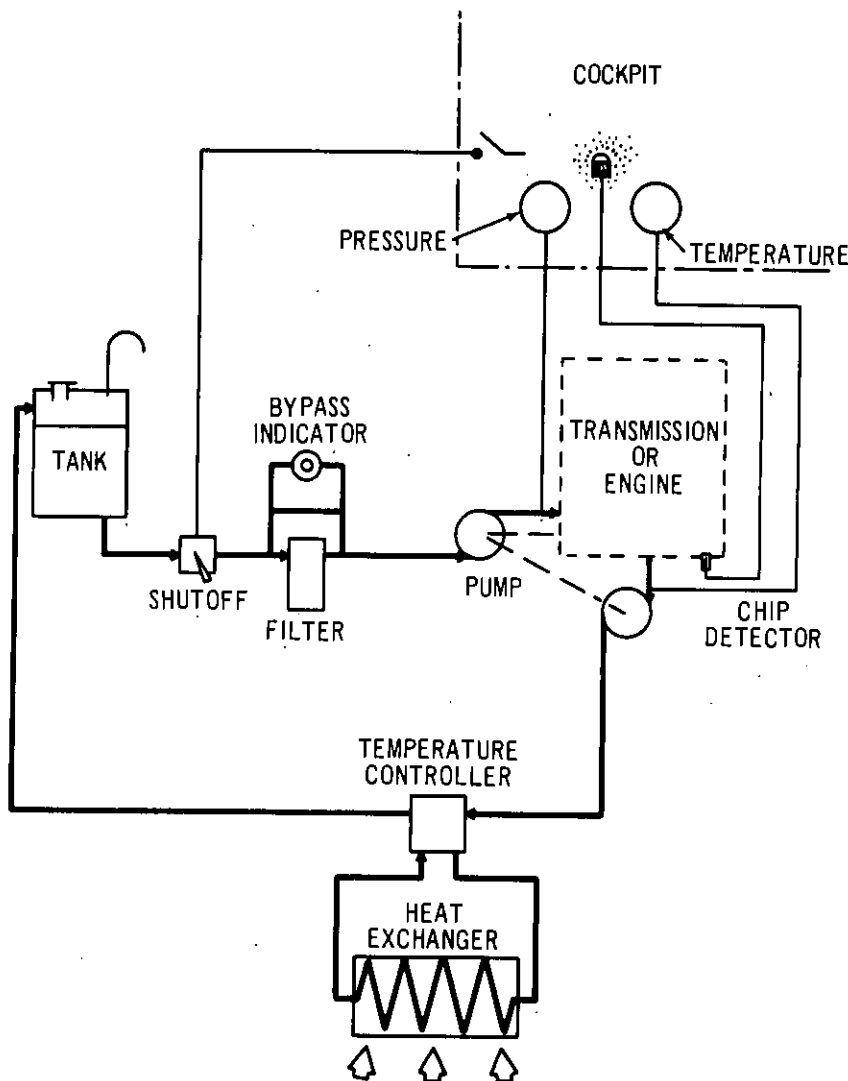


Fig. 9-4. Typical Lubrication Subsystem

25920 to confirm system-to-vehicle compatibility in the actual operating environment.

9-3.4.1.1 Test Requirements

An actual vehicle lubrication subsystem *shall* be substituted for the transmission and/or engine bench test lubrication subsystem as early in the program(s) as possible. As a minimum, the following information *shall* be obtained:

1. Pressure measurements to evaluate line and component pressure drops and effect on the subsystem operating characteristics
2. Dry lubrication pump priming characteristics and scavenge pump capability under all modes of operation
3. System lubricant quantity requirements and development of servicing instructions
4. Temperature measurements to establish the heat dissipation characteristics of the heat exchanger. Any discrepancies or adverse characteristics *shall* be corrected until the subsystem responds to the specification requirements.

Data gathered from the bench tests *shall* provide baselines for the development and subsequent integrated tests of the lubricant cooling and temperature control on the ground test vehicle. Demonstration requirements for ground test and flight vehicle lubrication subsystems *shall* be as follows:

1. Measurement of quantity of usable oil
2. Measurement of oil tank expansion space
3. Oil tank pressure test
4. Oil system bypass demonstration
5. Oil vent system test
6. Oil tank quantity calibration
7. Oil cooling demonstration.

9-3.4.1.1.1 Measurement of Usable Oil

The determination of usable oil is initiated with the lubricant tank filled to spillover. The helicopter is flown in a manner to produce the maximum attitudes for normal maneuvers, and the oil pressure is observed for pressure fluctuations. The oil level is successively lowered by removal of oil until fluctuations are observed. Then, a small quantity of oil is added gradually until the fluctuations cease. During this test the oil temperature should be maintained at the maximum continuous level. The usable oil quantity is equal to the net amount of oil removed.

9-3.4.1.1.2 Measurement of Oil Tank Expansion Space

The expansion space *shall* be measured by filling the tank to spillover and then adding additional oil through the tank vent system. The quantity of oil added is the expansion space. The test oil temperature and specific gravity *shall* be recorded. The expansion space *shall* be either 10% of the tank capacity or 0.5 gal, whichever is greater. Calculations *shall* be submitted to verify adequate expansion space for maximum oil temperature. If the test method used differs from that defined in this handbook, it *shall* be approved by the procuring activity.

9-3.4.1.1.3 Oil Tank Pressure Test

Each conventional metal tank, each nonmetallic tank with walls that are not supported by the helicopter structure, and each integral tank *shall* be subjected to a pressure of 5 psig unless the pressure developed during maximum limit acceleration or emergency deceleration with a full tank exceeds this value. However, the pressure need not exceed 5 psig on surfaces not exposed to the acceleration loading.

9-3.4.1.1.4 Oil System Bypass Demonstration

This test *shall* demonstrate the proper operation of the engine and transmission oil cooler bypass system. It also *shall* show that inadvertent bypass operation cannot occur. The test should be conducted with the engine operating at military cruise and maximum power conditions for maximum gross weight.

Oil is drained from the oil cooler until the bypass warning light is illuminated to indicate actuation of the bypass system. The quantity of oil remaining in the oil system, and the rate of change of oil temperature following bypass actuation, should be determined. During this test the oil *shall* not exceed the oil temperature limits (whether transient or steady-state) as defined in the engine model specification.

The test for inadvertent actuation of the bypass system *shall* be conducted in flight with the helicopter oil level reduced to the minimum. Oil sloshing *shall* not cause inadvertent operation of the bypass system during any normal maneuver or extreme flight attitude peculiar to the maneuver envelope of the particular helicopter design.

9-3.4.1.1.5 Oil Vent System Test

The oil vent system *shall* be tested by providing a means of capturing any oil that flows out of the oil tank breather vent. Flight tests *shall* be performed simultaneously with the oil cooling tests in par. 9-3.4.1.1.7,

and *shall* consist of the execution of all flight maneuvers and extreme flight attitudes required for the oil cooling and fuel system demonstrations. The oil discharge from the vent *shall* not affect materially the quantity of consumable oil.

9-3.4.1.1.6 Oil Tank Quantity Calibration

The oil tank dipstick *shall* be calibrated between the "add oil" mark and the "full" mark in increments of one quart. The oil level *shall* meet the "add oil" mark when the tank holds three-fourths of the usable oil quantity determined in par. 9-3.4.1.1.1. The dipstick *shall* indicate "full" when the tank is filled to spillover, as in the expansion space tests or as in par. 9-3.4.1.1.1.

9-3.4.1.1.7 Oil Cooling

The adequacy of the oil cooling system *shall* be demonstrated for all critical flight modes. These tests may be performed in conjunction with the propulsion system temperature demonstration (par. 9-3.7). All temperatures *shall* be stabilized (i.e., temperature change is less than 2°F/min) for a minimum of 5 min. All data *shall* be corrected to the maximum ambient air temperature stipulated in the detail specification. If such a limit is not defined, a temperature 22°F warmer than those temperatures specified in Table III of MIL-STD-210 *shall* be used.

The temperature measurement equipment *shall* be calibrated in accordance with proper test procedures. The corrected data *shall* not exceed the engine manufacturer's prescribed limitations.

9-3.4.1.1.7.1 Hover Cooling

Oil cooling during hover *shall* be checked, using the power available for the maximum ambient air temperature. Data *shall* be recorded both in and out of ground effect. The wind velocity for these tests *shall* be 8 kt or lower.

9-3.4.1.1.7.2 Climb Cooling

The oil temperatures *shall* be stabilized during hover in ground effect at maximum gross weight. A climb at maximum power *shall* be initiated at best climb airspeed. If a power time limit exists, the power should be reduced to the intermediate and/or maximum continuous rating at the proper time(s). The power setting *shall* be the power available for the maximum ambient air temperature. The climb should continue to the service ceiling.

9-3.4.1.1.7.3 Cruise Cooling

The helicopter *shall* perform level flight at maximum gross weight and maximum continuous power for the maximum ambient air temperature at sea level, 5000 ft, 10,000 ft, and 15,000 ft. Airspeed limits *shall* not be exceeded. The oil temperatures *shall* be stabilized for 5 min at each test altitude.

9-3.4.1.1.7.4 Other Flight Conditions

Oil cooling capability *shall* be checked at flight conditions other than hover, climb, and cruise which are expected to be critical for oil cooling. Examples of other flight conditions that may be critical for oil cooling are pullups and transition flight.

9-3.4.1.1.7.5 Additional Cooling Tests

If the specific design of the oil cooling system or the operational envelope of the helicopter is such that operating conditions other than those discussed previously may be critical, additional tests *shall* be conducted to investigate these conditions.

9-3.4.1.1.7.6 Determination of Cooling Margins

The maximum stabilized oil temperature for the hover and cruise modes and the peak oil temperature for the climb mode *shall* be corrected to the maximum ambient air temperature for the pertinent test altitude. This correction is equal to the numerical difference between the test ambient air temperature and the maximum ambient air temperature specified for the test altitude. It is added algebraically to the stabilized maximum oil temperature read at that altitude for each flight mode tested.

9-3.4.1.1.7.7 Chip Detector Demonstration

The chip detector(s) *shall* be removed from its receptacle and the magnetic terminals shorted together. The cockpit indicator light(s) *shall* function properly.

9-3.4.2 Fuel Subsystem Demonstration

The fuel subsystem configuration *shall* be in accordance with the requirements specified in the engine and helicopter detail specifications plus any requirements imposed by approved design changes effective at the time tests are conducted.

All tests outlined for the fuel subsystem *shall* be conducted using the type and grade of fuel specified in the applicable engine model specification. Laboratory

tests may be used to supplement or replace helicopter ground or flight testing, whenever adequate simulation can be attained. However, these laboratory tests *shall* be approved by the procuring activity. The operational characteristics of the fuel subsystem *shall* be verified for the fuel temperature range of -65° to 135°F for the helicopter operational altitudes. The contractor *shall* submit a proposed test plan for approval by the procuring activity. The most critical elements involved in the fuel subsystem test are described in the paragraphs which follow.

9-3.4.2.1 Internal and External Fuel Tank Capacities

9-3.4.2.1.1 Tank Capacity

The capacity of each internal and external fuel tank *shall* be determined and compared with the design capacity. The tanks *shall* be filled at the normal ground attitude. The amount of fuel added to fill the tanks *shall* be measured during the refueling operation. In addition to the gallon measurement, fuel temperatures and specific gravity *shall* be taken before, during, and after the capacity check. The fuel weight in pounds *shall* then be determined.

9-3.4.2.1.2 Available Fuel

Ground tests *shall* be conducted to determine the quantity of fuel available to the engine at the maximum continuous power fuel flow rate. After the fuel tanks have been filled, fuel *shall* be pumped out of the tanks by the boost pumps until flow stops. The fuel removed from the system subsequent to initial flow fluctuations *shall* be considered available fuel. Both internal and external fuel tanks *shall* be evaluated for this test requirement at the following helicopter attitudes:

1. Normal ground
2. Takeoff
3. Normal flight attitude (low gross weight, low airspeed, low altitude)
4. Landing (touchdown)
5. 10 deg greater angle than landing
6. Left and right roll attitudes.

The remaining fuel, which consists of the sump capacity and any residual fuel, *shall* be considered unavailable fuel.

9-3.4.2.1.3 Sump Capacity

The sump capacity of each internal and external fuel tank *shall* be obtained by measuring the fuel drained from the sump after all fuel possible has been pumped from the fuel system by the aircraft boost pumps. The

internal and external fuel tank sump capacities *shall* be determined at the normal ground attitude condition. This determination *shall* assure:

1. That the capacity meets applicable design requirements specified in MIL-F-38363
2. That all tanks may be satisfactorily drained on the ground.

9-3.4.2.1.4 Residual Fuel

The residual fuel, i.e., the fuel remaining after the tanks and sumps are drained, *shall* be determined for the internal and external fuel tanks in conjunction with the requirements of par. 9-3.4.2.1.2.

9-3.4.2.1.5 Expansion Space

Tests *shall* be conducted to demonstrate that the internal and external fuel systems have adequate expansion space. The helicopter *shall* be fueled to normal capacity, then measured fuel *shall* be added until the expansion space is filled. Special provisions may be required. An analysis *shall* be provided with the test report indicating the adequacy of the expansion space when initial tank fuel temperature is 60°F and when it is increased to 110°F.

9-3.4.2.1.6 Auxiliary Fuel Provisions

Auxiliary fuel provisions *shall* be verified. Proper installation interface with the helicopter fuel system *shall* be established by insuring that the auxiliary tanks fit properly in the installation, that the fuel is delivered from the auxiliary tanks to the main tanks or to the engine, and that the fuel capacity gage accurately indicates fuel level (par. 9-3.4.2.1.8).

Tests to be conducted for auxiliary fuel systems are:

1. The auxiliary fuel tanks (as installed) *shall* be filled with fuel at the normal helicopter attitude. The amount of fuel added *shall* be measured in addition to the fuel temperature and specific gravity.
2. A ground test *shall* be performed at idle-to-maximum power to measure the fuel flowing to the engine and from the auxiliary tank to the main tank.
3. The flow test *shall* be conducted until the auxiliary fuel tanks are empty. The fuel depletion schedule *shall* be compared with the design depletion schedule.
4. Flight testing to jettison the tanks also *shall* be conducted (if applicable) in accordance with the requirements of par. 9-13.

9-3.4.2.1.7 Low-level Fuel Warning System

The minimum amount of fuel available at time of the "Low-level Fuel Warning Light" actuation will be determined. The fuel boost pumps *shall* be operated until

the warning light is activated. The available fuel remaining in the system *shall* then be determined. Attitudes to be evaluated are normal ground, level flight (landing pattern), and landing attitude (touchdown). This test *shall* be conducted in conjunction with the available fuel tests of par. 9-3.4.2.1.2.

9-3.4.2.1.8 Fuel Quantity Gaging Subsystem Tests

The system calibration tests *shall* be conducted in accordance with MIL-G-7940. These tests *shall* not be conducted until the procuring activity has approved the engineering report required in MIL-G-7940.

9-3.4.2.2 Refueling and Defueling Tests

9-3.4.2.2.1 Refueling

Tests *shall* be conducted to determine the time required to service all tanks and to establish compliance with design filling requirements. The time required to refill the tanks through the single point receptacle (if applicable) and the individual tank filler caps (if applicable) *shall* be recorded. The testing *shall* be conducted at refueling nozzle inlet pressures of 20, 30, 40, 50, and 55 psig. Refueling rates and service times *shall* compare with those specified in the helicopter detail specification and of MIL-F-38363. If results are unacceptable, a redesign *shall* be initiated and a retest conducted.

9-3.4.2.2.2 Surge Pressure Test

The refueling manifold or helicopter-mounted adapter *shall* be instrumented to determine surge pressure encountered during refueling operations. There *shall* be a minimum of one pressure probe at each fuel level control valve and each refueling connection. The surge pressures *shall* not exceed the fuel cell design criteria specified in the detail specification, the contractor procurement specification, or MIL-F-38363. The surge pressures *shall* be measured under the following conditions while refueling through the refueling connection with a nozzle pressure of 50 ± 5 psig:

1. Maximum flow—all fuel control valves closed simultaneously
2. Maximum flow—fuel control valves closed singly
3. Maximum flow—all fuel control valves closed as a result of filling to capacity.

9-3.4.2.2.3 Defueling Test

Internal fuel pumps *shall* be utilized to defuel the helicopter. The time required to defuel the internal fuel tanks *shall* be determined for the maximum discharge flow rate. The maximum fuel flow and fuel remaining

in the helicopter after defueling *shall* be recorded, and the results compared with the requirement stated in the detail specification and MIL-F-38363.

9-3.4.2.2.4 Closed Circuit Refueling System Tests

Helicopter refueling *shall* be conducted for the closed circuit refueling system to demonstrate conformance to design requirements and satisfactory operation of the system. The tests (if applicable) may be conducted in conjunction with the refueling tests of par. 9-3.4.2.2.1. The following *shall* be determined and *shall* meet the requirements of the detail specification:

1. Fuel flow rates and nozzle inlet pressures at the time of automatic fuel shutoff
2. Pressure differential across helicopter receiver diaphragm
3. Tank pressures in conjunction with refueling and vent testing
4. System operation under shutoff failure mode (i.e., leakage past float, tank, and vent pressures).

9-3.4.2.2.5 Siphoning Tests

After normal fueling, the helicopter *shall* be placed at normal flight attitude, and the quantity of fuel discharged (if any) from the fuel vent opening *shall* be measured. After normal fueling at ground attitude, fuel *shall* be pumped into the fuel system until a steady stream of fuel is discharged from the fuel vent opening. Then, the fuel being pumped into the system *shall* be shut off and the amount discharged from the vent opening, after shutoff, *shall* be recorded.

9-3.4.2.2.6 Center-of-gravity (CG) Travel Test

Fuel system CG travel tests *shall* be conducted for the normal flight attitude with normal operation of engine fuel feed. The data *shall* illustrate the effects of all external and auxiliary tank fuel as well as total internal fuel. The helicopter *shall* be positioned at normal ground attitude, and refueled to normal capacity. The helicopter then *shall* be positioned in the normal flight attitude, and the reactions at the scales under the landing skids or landing gear recorded. All available fuel *shall* be removed from the helicopter in 50-lb increments, and CG recorded at each increment of fuel level.

9-3.4.2.3 Boost and Transfer Pump Failure Tests

Tests *shall* be conducted to determine the unavailable fuel quantities resulting from various fuel boost pump and transfer pump failures. If internal tank pressurization is used to supplement the boost pump supply system or if tank pressurization constitutes the

primary supply system, testing to explore the intent of the test conditions described subsequently *shall* be conducted by disabling the pressurization system in conjunction with appropriate combinations of inoperative boost and transfer pumps, as applicable (see MIL-F-38363 for acceptance criteria).

9-3.4.2.3.1 *Ground Tests*

The engine(s) *shall* be operated at intermediate power at normal helicopter ground attitude to determine the following conditions:

1. The quantity of unavailable fuel with the boost pumps which normally supply the engine inoperative
2. The amount of fuel which is unavailable with each fuel transfer pump rendered inoperative
3. The amount of unavailable fuel with significant combinations of fuel boost or transfer pumps made inoperative
4. The effects on fuel system operation of fuel filter blockage, as applicable
5. Helicopter landing approach attitude with intermediate power fuel flow rates (by operating engine(s) or by an external pump) and the quantity of unavailable fuel with inoperative boost pumps which normally supply the engine from the sump fuel tank.

9-3.4.2.3.2 *Flight Tests*

The maximum altitude at which intermediate and maximum power operation can be maintained on suction feed *shall* be determined by continuous recording of fuel flow rates, temperatures, pressures at engine inlet, fuel specific gravity, altitude, atmospheric pressure, and temperature data. The temperature of the fuel and a fuel sample for Reid vapor pressure determination *shall* be taken before and after the flights. The temperature of the fuel *shall* be as close to 135°F as possible before takeoff. The tests to be conducted are:

1. A normal takeoff and climb to minimum safe altitude. Turn off all booster and transfer pumps. Climb at intermediate power at best climb speed to service ceiling, until 10% power loss occurs, or until objectionable engine surge occurs.
2. Repetition of Item 1 using maximum power.

9-3.4.2.3.3 *Vapor/Liquid Ratio Tests*

With a fuel temperature of 135°F and the boost pumps inoperative, the vapor/liquid ratio forming characteristics of the fuel system *shall* be determined for intermediate and maximum engine power fuel flow. The vapor/liquid ratio *shall* be measured per SAE ARP 492 at 2000-ft increments from sea level to the

altitude which results in a vapor/liquid ratio in excess of the capability of the engine fuel pump.

9-3.4.2.4 *Fuel Supply and Fuel Transfer Tests*

9-3.4.2.4.1 *Fuel Supply Tests*

The satisfactory operation (per MIL-F-38363 and the engine model specification) of the fuel supply system *shall* be demonstrated in the flight test portion of the vent system testing.

9-3.4.2.4.2 *Internal Tank Switchover and Fuel Transfer Rates*

Internal fuel tank manual switchover provisions *shall* be demonstrated as applicable. Internal fuel tank transfer rate capabilities *shall* be demonstrated under conditions which the contractor considers most critical for the helicopter. Surge pressure resulting from feed and transfer flow fluctuation *shall* be measured and recorded (see MIL-F-38363).

9-3.4.2.4.3 *External Tank Feedout*

The external tank feedout rate characteristics *shall* be investigated under level flight conditions at service ceiling and during maximum power climbout after takeoff. These tests *shall* be consistent with the mission of the helicopter and the intended use of the external tanks. Fuel flow rate and fuel pressure (i.e., boost pump exit) data *shall* be recorded at one-minute intervals.

9-3.4.2.4.4 *Fuel Jettison*

Fuel jettison tests *shall* be performed to establish the quantity of fuel which cannot be jettisoned and average jettison rate, as applicable (see MIL-F-38363 for requirements).

9-3.4.2.5 *Fuel and Vent System Tests*

9-3.4.2.5.1 *Pressurization and Fuel Vent System Tests*

The vent system *shall* contain a pressure probe at each vent outlet, in each tank, and between each bladder tank and tank cavity. The pressure data and other data such as rate of climb, rate of dive, altitude, and quantity of fuel *shall* be recorded in sufficient quantity to demonstrate satisfactory operation of the vent system (see MIL-F-38363). Dyed fluid *shall* be used during the indicated test and maneuver conditions to mark any fuel impingement on the helicopter. The vent system *shall* be evaluated under the following conditions and maneuvers:

1. Maximum rate of climb to service ceiling fol-

lowed by maximum practical rate of descent dive to minimum safe altitude

2. Sideward flight, left and right
3. Hover
4. Rearward flight
5. Autorotation
6. Level flight at V_H
7. Ground taxi, takeoff, and landing with fuel tanks full to demonstrate no spillage
8. Inverted or negative "g" flights, if applicable.

9-3.4.2.5.2 Vent Outlet Icing Tests

The vent outlets *shall* be observed after the helicopter icing tests to determine the extent of ice accumulation or blockage around the vent outlet. The ice accumulation *shall* be photographed. Par. 8-9.5 describes detail requirements of the icing tests.

9-3.4.2.5.3 Vent System Failure Tests

Failure of components of the fuel system *shall* be simulated to cause fuel to flow from the vent outlets. Any impingement of the fuel on the helicopter *shall* be recorded.

9-3.4.2.6 Fuel Tank Purge (if applicable)

9-3.4.2.6.1 Ground Tests

A ground run *shall* be conducted at maximum continuous power for 5 min to determine that the functions of each component of the purge system are accomplished satisfactorily. Data *shall* be recorded at 30-sec intervals (see MIL-P-5902).

Three samples of purge medium in the cells *shall* be taken during the run to determine the oxygen level.

9-3.4.2.6.2 Flight Tests

Flight tests *shall* be conducted to investigate the most critical conditions for which the purge system was designed consistent with the missions of the helicopter. Data, as required in MIL-P-5902, *shall* be recorded at intervals sufficient to demonstrate satisfactory operation of the system. A purge medium sample *shall* be taken near the end of each test.

9-3.4.2.7 Crashworthy Fuel System

Crashworthy fuel tanks, either self-sealing or non-self-sealing, *shall* be tested in accordance with MIL-T-27422. These tests determine the crash-resistant features, material acceptance, and gunfire resistance of the crash-resistant fuel tanks. The fuel valves, lines, and all other fuel system components and features *shall* be tested to determine compliance with crashworthy requirements. The procuring activity *shall* specify all

crashworthy requirements to be attained by the contractor.

9-3.5 ROTORS AND PROPELLERS

Although the operating conditions of rotors and propellers are similar in some respects, significant differences exist. The airflow through a rotor assembly has a relatively large component in the plane of rotation. In the case of a propeller the inplane component of motion usually is relatively small; but since the axial flow is high, a small inplane component can still produce large, inplane airflows. On the other hand, varying angles of inflow cause oscillating bending moments in rotor blades and hubs that are relatively larger than those which occur in propellers. Another difference is that the blades of a rotor are usually slender, and their deflections have a considerable influence on the loads. Furthermore, rotor blades may be attached to the hub through hinges, and their pitch is controlled cyclically as well as collectively.

In both rotors and propellers, a large amount of kinetic energy is stored in the assembly when it is rotating at operating speed. This makes a complete failure catastrophic. While this emphasizes the importance of qualification tests, it also makes these tests difficult and possibly hazardous to perform.

Demonstration of the compliance of these systems with all applicable requirements is accomplished by means of analysis and test. In the paragraphs which follow, the test requirements applicable to rotor systems and to propellers are described.

9-3.5.1 Rotor System Demonstration

9-3.5.1.1 Rotor Whirl Tests

Rotor system whirl tests *shall* be conducted prior to first flight of the helicopter. These tests *shall* be performed in accordance with the contractor's test plan, approved by the procuring activity. The test conditions and durations *shall* be in accordance with MIL-T-8679. As a minimum, the aerodynamic calibration of main rotor static thrust performance and the stress and motion surveys over the design range of combinations of collective and cyclic pitch and rotor speed *shall* be completed prior to start of the 50-hr preliminary flight approval test (par. 9-3.5.1.2). The 110-hr rotor qualification whirl test (MIL-T-8679) *shall* be completed prior to first flight of the helicopter.

9-3.5.1.2 Preliminary Flight Approval Test

A 50-hr preliminary flight approval test (ground tie-down test) *shall* be completed prior to first flight of the

helicopter. This test is performed to demonstrate that the rotor and propulsion systems are qualified for flight, and therefore constitutes a portion of the transmission and drive system demonstration (par. 9-3.3). A stress and motion survey of the rotor hub(s), blades, and other critical components *shall* be conducted during the 50-hr tiedown test.

Following completion of the 50-hr test, the rotor system *shall* be completely disassembled for examination in accordance with MIL-T-8679.

9-3.5.1.3 150-hr Tiedown Test

Each new helicopter model *shall* be subjected to a 150-hr tiedown test in accordance with MIL-T-8679. This test also constitutes a portion of the transmission and drive system demonstration (par. 9-3.3).

Following completion of the 150-hr tiedown test, the rotor system *shall* be completely disassembled for examination in accordance with MIL-T-8679.

9-3.5.2 Propeller System Demonstrations

While there are many useful analytical techniques (such as those described in par. 5-8.2 of AMCP 706-202) for determining during the design stages that propeller system dynamics will probably be satisfactory, dynamic behavior is still difficult to predict accurately. For this reason, and because of the importance of propeller structural integrity to airworthiness, the qualification of propeller system dynamics is mainly experimental. This paragraph describes only the kinds of tests that must be performed for qualification.

The primary goal is to assure that the structural integrity of the propeller is satisfactory, that it meets the specification requirements to withstand certain operating conditions continuously, and to endure specified transient conditions for a given service life. A secondary goal is to acquire background information that can be used to guide future designs and to help qualify similar installations in the future with a minimum of testing.

In propeller system dynamic testing, the initial step is a review of the analytical predictions made during design, the pertinent experimental background data, and the specified performance and life requirements. From this study the test program will be established and the instrumentation selected. The testing must include enough stress and vibratory motion measurements to define satisfactorily the dynamic behavior of the propeller and sufficient additional measurements to define the pertinent operating conditions of the engine and the helicopter. Finally, the test results *shall* be monitored so that appropriate additions or changes can

be made to the test program to accommodate unexpected developments.

For all propeller applications it *shall* be demonstrated, either by actual test or by comparison with tests of similar installations, that dynamic characteristics are satisfactory.

MIL-P-26366 describes design requirements for propeller dynamics and the necessary qualification tests, and requires that fatigue stress levels be satisfactory at the design condition of maximum aerodynamic, one-cycle-per-revolution excitation. It also requires that there be no destructive vibration at rated operating conditions, and that the propeller be free from flutter under static conditions up to 120% of the rated engine speed at a specified power level. In addition, both MIL-P-26366 and FAR Part 35 call for a specific program of endurance testing on an engine test stand.

Military and civilian requirements include flight vibration surveys of the type described subsequently. MIL-P-26366 lists detailed suggestions for measurements and operating conditions to be included in the vibratory stress surveys. MIL-S-8698 and FAR Parts 27 and 29 contain information on helicopter flight conditions to be investigated in such surveys. These are discussed in detail in par. 8-2.

9-3.5.2.1 Test Requirements

Propeller vibratory stress surveys on whirl rigs or engine test stands have two purposes. One purpose is to assure that the propeller is qualified for installation on the aircraft for ground and flight testing. The other is to obtain data relevant to the ultimate flight application. Though aerodynamic excitations in test stands are not representative of flight, appropriate information can be learned about stress distributions, critical speed locations, and the boundary of incipient stall flutter.

The two types of test stands are:

1. Whirl Rigs. An electric motor rig can have the flexibility of speed and power required for finding the operating limitations of a propeller. Runs are commonly made at constant blade angle in increments of not more than 5 deg. At each blade angle, data are taken at increments of 50-100 rpm, as appropriate, up to 120% of maximum rated speed and within horsepower limits specified for the propeller. Smaller increments are used to define stress peaks. If incipient stall flutter is detected, the boundary *shall* be determined.

Because the propeller shaft mounting provisions on a whirl rig may be different from the final engine installation, the whirl rig test may require a modified method for blade angle control. If so, the significance of the

modification to blade torsional behavior should be considered, since the flutter boundary also may be affected.

2. **Engine Test.** When a propeller is to be driven directly by an engine (rather than by remote shafting), their combined dynamic compatibility *shall* be investigated prior to flight. Test stands for this purpose may be located indoors or outdoors, but they should simulate the dynamics of the flight installation.

The test conditions selected depend on the particular characteristics of the engine, so they cannot be tabulated here. In general, the conditions *shall* cover all the normal operating conditions of the engine, plus deviations from normal such as overspeed and underspeed. Throttle bursts, reversals, and other significant transients *shall* be included.

Propeller vibratory stress surveys on helicopters are programmed to encompass all significant service operating conditions, with adequate allowance for variability and, where possible, for future change and growth. Much of the preliminary vibration data can be obtained during tests performed for other purposes during the normal testing of a new helicopter. The formal propeller vibratory stress survey *shall* be performed during the helicopter flight load survey (par. 8-2). As with engine tests, installations vary; accordingly, a comprehensive general set of test conditions cannot be given here, but the comments which follow will be a guide.

9-3.5.2.1.1 Ground Tests

The propeller *shall* be included in the helicopter tie-down testing specified in pars. 9-3.2 and 9-3.3. These tests *shall* include all conditions of normal ground running, including preflight runup and check conditions.

Other variables to be considered are ground winds, the slipstream effects of other rotors, and, for multi-propeller helicopters, the selection of which installation to be tested.

Running in ground winds from several directions as well as in calm air should be included. The turbulence of crosswinds sometimes can cause vibratory stresses severe enough to require an operating limitation at certain rotational speeds. If necessary, ground wind testing may be performed in the slipstream of another aircraft.

9-3.5.2.1.2 Flight Tests

In addition to the mission profile and normal flight conditions of the helicopter, a flight vibratory stress survey (par. 8-2) *shall* include significant investigations of the extremes of the operating envelope. Also included are transient maneuvers such as takeoffs, throttle bursts, roller-coasters, fishtail yaws, and control ex-

tremes—if the propeller is used for helicopter control, and landings with reversals.

In fixed-wing aircraft the most significant variables for a propeller vibratory stress survey in flight are:

1. Power and propeller speed
2. Airspeed
3. Altitude
4. Gross weight and CG location
5. Vertical acceleration
6. Yaw angle
7. Position of flaps and other aerodynamic devices.

In helicopters, the significant variables depend on how the propeller is incorporated into the overall configuration. Therefore, in addition to the significant variables listed for fixed-wing aircraft, consideration should be given to testing a compound helicopter with various yaw rates in hover and with various combinations of main rotor horizontal thrust and propeller thrust, or antitorque rotor thrust and propeller thrust.

The primary goal of these tests is to assure satisfactory structural integrity for the specified requirements. But it also is important to consider the results in the context of appropriate background data and with adequate allowance for future changes—such as growth of power, airspeed, and gross weight—as well as service wear that can cause dimensional blade changes. With such consideration, then, the test results are compared with material fatigue strength.

The fatigue strength characteristics of propeller components are determined by laboratory tests similar to those performed with rotor system components (par. 7-4.2.2.2). Service lives of propeller components also are determined by the methods described in Chapter 4 of AMCP 706-201. For continuous operating conditions, or steady-state flight conditions, the alternating stress levels *shall* be below the endurance limit established for the component.

Stress amplitudes, natural frequencies, critical speeds, and flutter boundaries established by test also should be compared with design predictions. By such a review unsuspected stress mechanisms should be avoided, and analytical and design techniques can be improved.

In most cases, the test results will show that the propeller installation is satisfactory for unrestricted operation. Sometimes, however, operating limitations must be imposed. These may be based on either limiting the vibratory excitation or controlling the response.

On the ground excitation may be limited by avoiding severe crosswinds. In flight a minimum climb speed or

a maximum gross weight and speed relationship may have to be established to limit aerodynamic excitations. Response may be controlled by avoiding critical speeds. By taking into account appropriate allowances for tachometer error and critical speed shifts, typical width of a propeller speed range restriction is about 10% of takeoff speed.

9-3.5.2.2 Special Tests

9-3.5.2.2.1 Whirl Flutter

Before flight of a new helicopter system, the absence of whirl flutter *shall* be assured by design analysis and, if necessary, by model tests. The models often are 1/8 to 1/10 scale dynamically similar models of the helicopter, and they are run in wind tunnels at velocity ratios equal to the square root of the model size ratio. With models, overlimit speeds and installations with intentionally damaged mounts can be investigated under controlled conditions without the danger of catastrophic failures.

9-3.5.2.2.2 Balance

Propeller balance is not considered in propeller system dynamics because the propeller is involved as a nearly rigid body. Also, dynamic balance tests are not routinely performed. Customarily, propeller balance is achieved in production by static tests on knife edge of bubble balance stands, which usually is satisfactory.

When there is a balance problem, it is usually the result of a helicopter installations being peculiarly sensitive to excitations at the 1P frequency. In this case it *shall* be necessary to perform dynamic balancing, sometimes with measurements in flight to include the geometric effect of blade angle changes and the aerodynamic effect of high-speed flight. The instrumentation for such tests consists merely of a vibratory pickup on the propeller gearcase, or elsewhere, and a meter. With several trial applications of balance weights, the magnitude and location of the necessary correction can be determined. An alternative procedure requires the addition of a 1P phase pulser and a meter to measure the phase between the vibration pickup output and propeller rotation. With this instrumentation, the number of runs to achieve balance can be reduced.

9-3.5.2.3 Instrumentation

The instrumentation for propeller dynamic testing is similar to that required for rotor system testing (par. 8-2.4) and consists of transducers, signal transmission equipment, signal conditioning equipment, and recorders. An instrument setup typical of a propeller vibratory stress survey is shown schematically in Fig. 9-5.

Vibratory stresses are measured on the blades and at other locations such as on the propeller shaft, known from experience to require measurement analysis. (Steady stresses on propellers seldom are measured, because they are reliably predictable and need to be known with less accuracy than vibratory stresses.)

Metal foil resistance strain gages are used, connected electrically in a Wheatstone bridge circuit, with a half-bridge arm for each measurement and a single, fixed, half-bridge reference arm. Customarily, gages are placed on the blade shank and at intervals along the blade, oriented parallel to the blade centerline to measure bending. A pair of gages, both wired into one half-bridge circuit in push-pull fashion, is placed at blade station of maximum anticipated shear stress, oriented at 45 deg to the centerline. Careful attention must be given to cements and coatings necessary for proper adhesion and protection of strain gages on the surface of a propeller blade.

The strain-gage lead wires often are run down the camber side trailing edge for the least aerodynamic disturbance. Two or more blades customarily are instrumented.

When there are more gage locations than can be hooked up and recorded at any one time, it is necessary to arrange the gages in several hookup groups and repeat certain test conditions with additional hookups.

On the propeller gearcase or bearing support and elsewhere, accelerometers and velocity pickups are located so as to measure vibratory displacement. These instruments *shall* be installed and used during the total system vibratory survey (par. 8-7).

In addition to the transducers used directly to investigate propeller system dynamics, a number of transducers are used for the measurement and recording of propeller, engine, and helicopter operating conditions. On the rotating portion of the propeller, these transducers include a potentiometer, pulley-driven by a blade shank to measure blade angle, and both a one-per-revolution pulser and a multitooth wheel to produce rotational speed and phase reference signals.

Other operating condition measurements include engine torque and speed, altitude, airspeed, vertical acceleration, pitch and yaw angles, and others required for special purposes. The transducers selected for these measurements depend on whether the data are to be telemetered, recorded with a photopanel camera, or with an oscillograph (or other recorder) used for the strain gages. The typical setup shown in Fig. 9-5 includes a photopanel correlated with the other instruments by a time code generator.

Signals from the strain gages or other rotating transducers are transmitted to the recording instruments

through slip rings. These may be attached to the front of the propeller for testing on the ground or on a whirl rig but, for flight use, they *shall* be located between the propeller and its gearcase. A typical slip ring assembly includes as many as 20 channels, with a number of leaf-spring brushes for each channel riding on silver surfaces, in order to obtain the best possible signal reliabilities.

Many types of signal-conditioning and calibration methods may be selected, as appropriate, to match the types of transducers and equipment available. Some of the functions that may be involved are filtering, balancing, conversion to frequency modulation, multiplexing, and preamplification. Measuring channels are calibrated by bridge shunting, by use of a controlled fraction of the bridge excitation voltage, or by a controlled voltage separately supplied.

Two methods of recording are commonly used, oscillographs and magnetic tape recorders. A typical oscillograph recording from a propeller vibratory stress survey is shown in Fig. 9-6. On the left is a calibration record, and on the right a test record with eight vibratory stress channels and a $1P$ speed-phase pulse. The test record is 0.3 sec long.

As mentioned previously, the measurements of engine and helicopter operating conditions, which do not contain high-frequency information, may be displayed on a photopanel and recorded with an automatic sequence camera.

A setup of recording instruments (complete except for the photopanel) as it is installed in an aircraft is shown in Fig. 9-7.

9-3.5.2.4 Documentation

When data from a vibratory stress survey have been recorded on oscillograph film, the first step in reducing

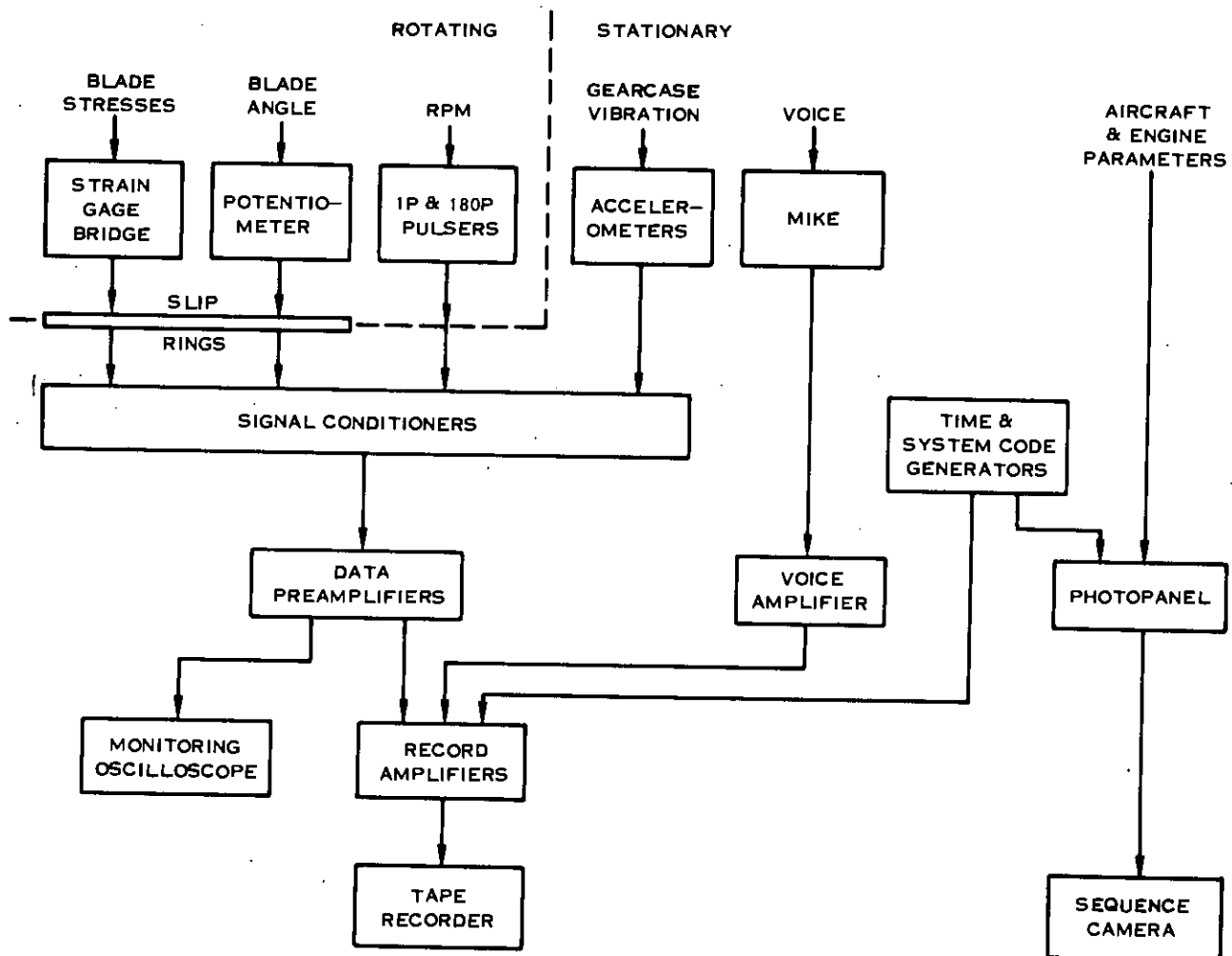


Fig. 9-5. Typical Propeller Vibratory Survey Instrumentation

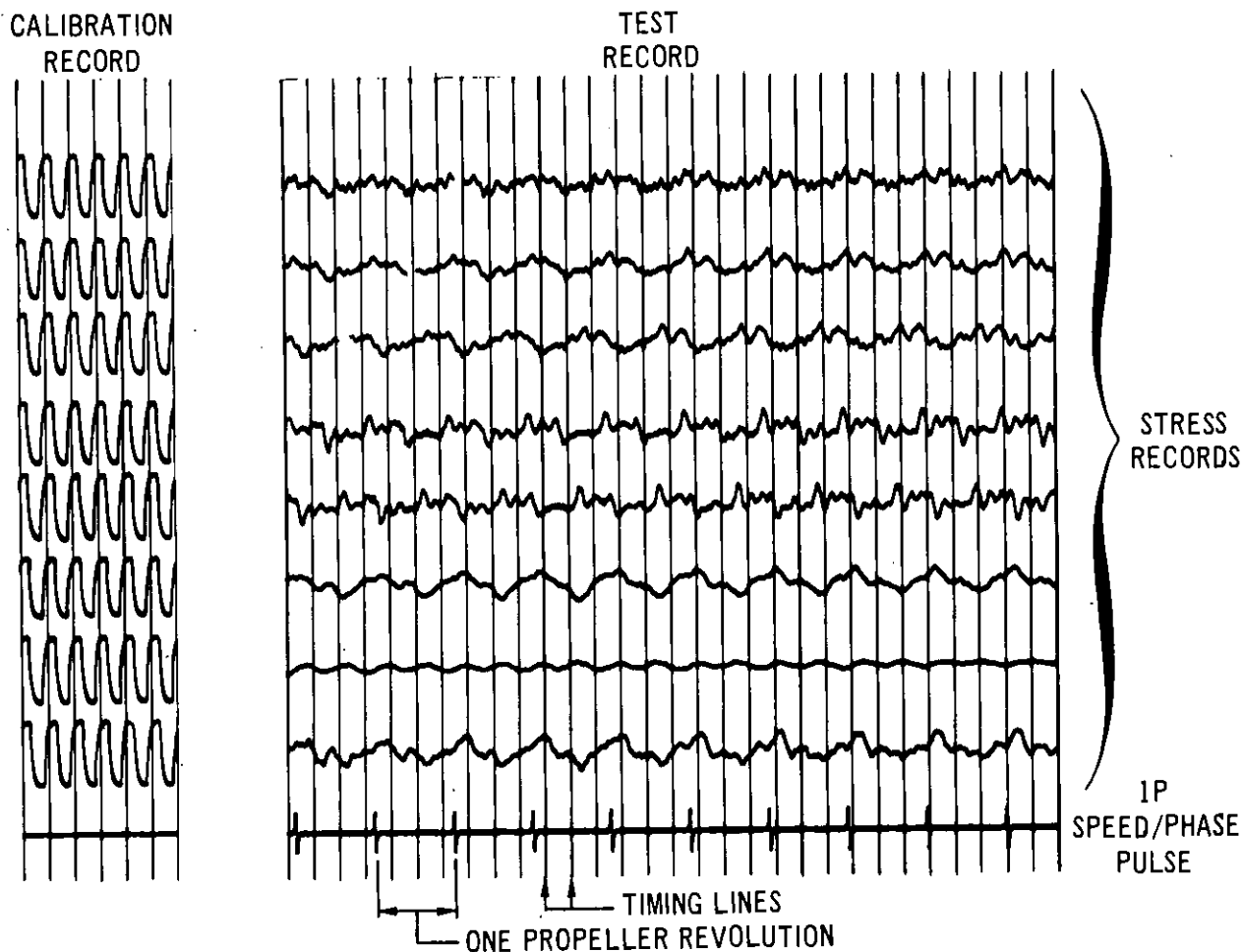


Fig. 9-6. Oscillograph Recording

the data to more manageable form is to measure the total vibratory stress amplitude and draw up worksheets or detail curves. These curves will show plots of vibratory stress against the most pertinent variables—such as propeller speed, airspeed, power, or time. At key points, the frequency components present in the total stress recording are determined by visual analysis. From the detail curves of all the recordings, the most significant data are chosen for presentation on summary curves. These curves usually are selected to show the highest stresses in the tip, the mid-blade, and the shank regions of the blade.

When the data are on magnetic tape, they may be processed by semi-automatic equipment. The usual first step is to play the tape back through peak stress converters and make a strip chart of total vibratory stress amplitude. A portion of such a chart—with three

stress channels, blade angle, and propeller speed—is shown in Fig. 9-8. The dark blobs between the channels form a binary-coded-decimal time indication. The chart length shown in Fig. 9-8 represents about 2.5 min of recording time.

For wave analysis of frequency content, tape-recorded data may be played through narrow-bandpass filters, either fixed frequency or frequency tracking. Curves of stress versus some other recorded parameter, such as propeller speed, may be made with an x-y plotter. If visual analysis is required, tape-recorded data may be rerecorded on an oscillograph.

An example of a vibratory stress survey summary curve is presented in Fig. 9-9.

The reports depend on the nature of the test and the test installation. For vibratory stress surveys of wholly new propeller installations the report *shall* be full and

formal. For tests run to approve modifications to established installations, the report may be in the form of a brief memorandum or letter.

For propeller qualification, MIL-P-26366 calls for reports, properly certified by a Governmental representative, on each test or group of tests. At the completion of all qualification tests, a summary report *shall* be required.

A propeller dynamic test report *shall* contain certain vital material. There *shall* be a statement of purpose, complete documentation of the item being tested, detailed description of the test installation, and a summary of the instrumentation. The test itself *shall* be

described, including comments on deviations from the intended test program. A summary of the significant results *shall* be presented and discussed, and appropriate conclusions and recommendations stated. The report *shall* serve not only to support the qualification of the propeller being tested, but also to document valuable information for future installations.

9-3.6 ENGINE VIBRATION DEMONSTRATION

An engine vibration demonstration *shall* be conducted to determine the engine vibration environment in the helicopter.

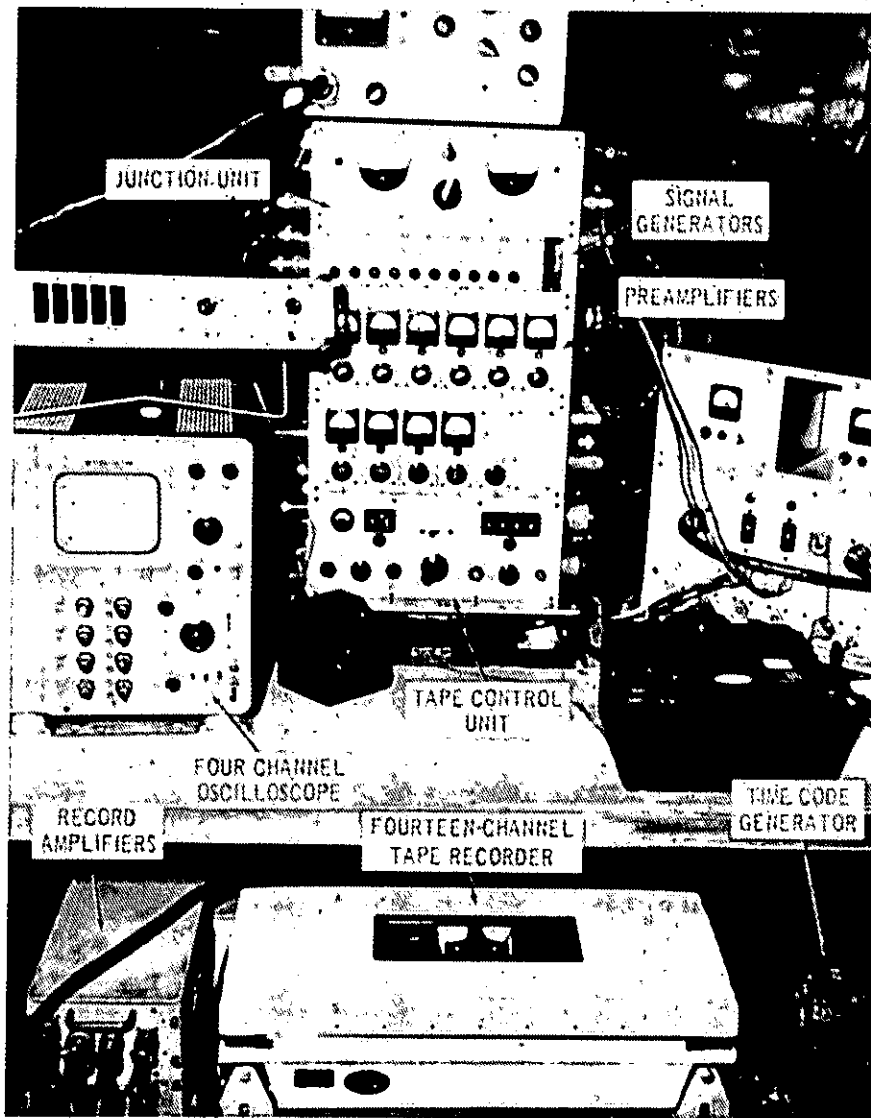


Fig. 9-7. Recording Instrumentation in Aircraft

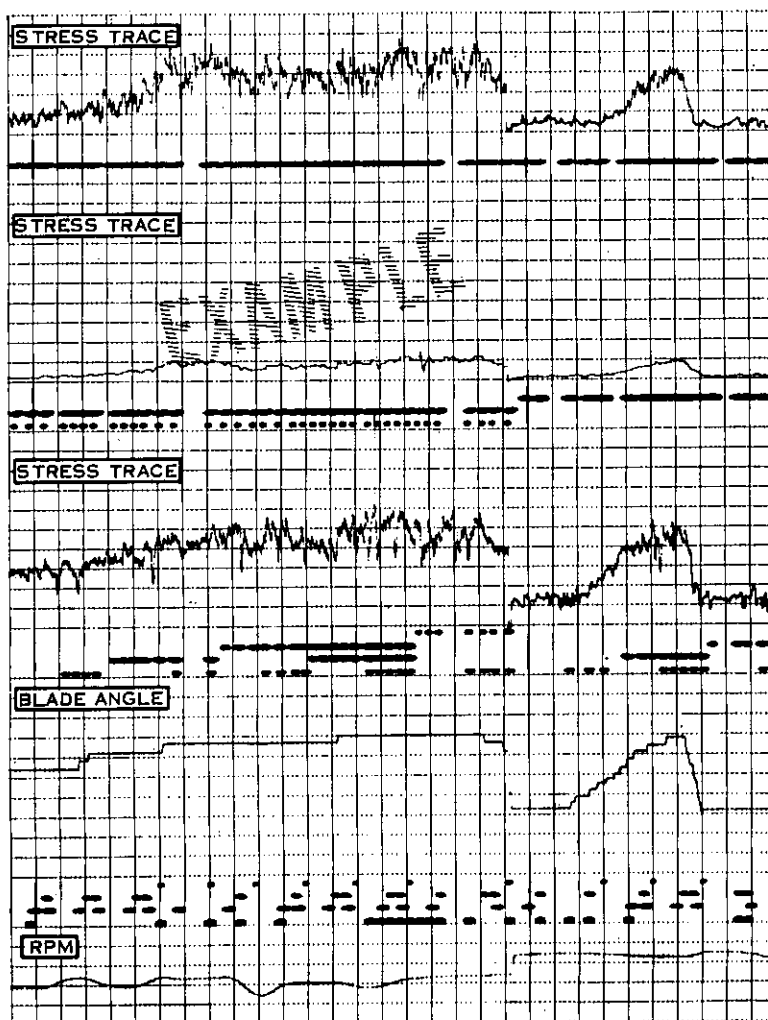


Fig. 9-8. Propeller Stress Survey Strip Chart

9-3.6.1 Engine Vibration Demonstration Plan

The airframe manufacturer *shall* prepare an engine installation vibration test plan which will include the same information required in par. 8-3.2. The coordination required of the engine manufacturer as specified in par. 8-3.2.2 also *shall* apply to the engine vibration demonstration.

The engine manufacturer will define acceptable installation vibration limits by amplitude and applicable frequency for each sensor location. These vibration limits will reflect considerations of frequency of occurrence of vibration magnitudes which are representative of both steady-state and transient flight within a typical

helicopter mission spectrum. The test cell vibration limits for engine acceptance will be identified and compared with the installation vibration limits over the applicable frequency range. The engine manufacturer will describe the sensors, data acquisition system, and data analysis methods which may be used.

9-3.6.2 Test Requirements

9-3.6.2.1 Ground Tests

Ground tests *shall* be conducted to record data for the most critical engine vibration conditions. The same conditions specified for the vibration survey are applicable for this demonstration and are:

1. Idle rpm

2. Slow sweep from idle rpm to maximum power-on rotor speed at low collective pitch
3. Continuous operation at rotor speed specified for engine warmup, if applicable
4. Steady-state operation at any rotor speed of Item 2 at which the engine responds significantly and at which the helicopter can be operated continuously.

The ground tests *shall* be conducted for the final design configuration at mission gross weight and at midrange CG unless otherwise specified. The effects of any kits or other configuration variations *shall* be evaluated.

9-3.6.2.2 Flight Tests

Flight tests of the engine installation(s) *shall* cover specific extremes of the flight envelope—to be specified in the test plan—which induce the highest vibrations.

These tests should include the combinations of gross weight, CG, external stores, power, and flight conditions for which the helicopter is to be qualified.

The procedure to evaluate the vibratory environment specified in par. 8-3.3.2 also may apply for this demonstration. For a clean helicopter, the flights presented in Table 8-1 for the range of helicopter configurations illustrated in Fig. 8-1 also may apply here.

The full spectrum may be flown with typical mission loading at a gross weight/CG configuration estimated generally to produce the highest engine vibrations (see Table 8-1). Data should be acquired at the normal, maximum, and minimum rotor speeds. The 20% of the total flight spectrum which produces the highest vibrations should then be repeated at three other gross weights and CG extremes (Fig. 8-1).

The qualification of special intake or exhaust duct configurations or other kits which must be qualified and which significantly change the engine vibratory

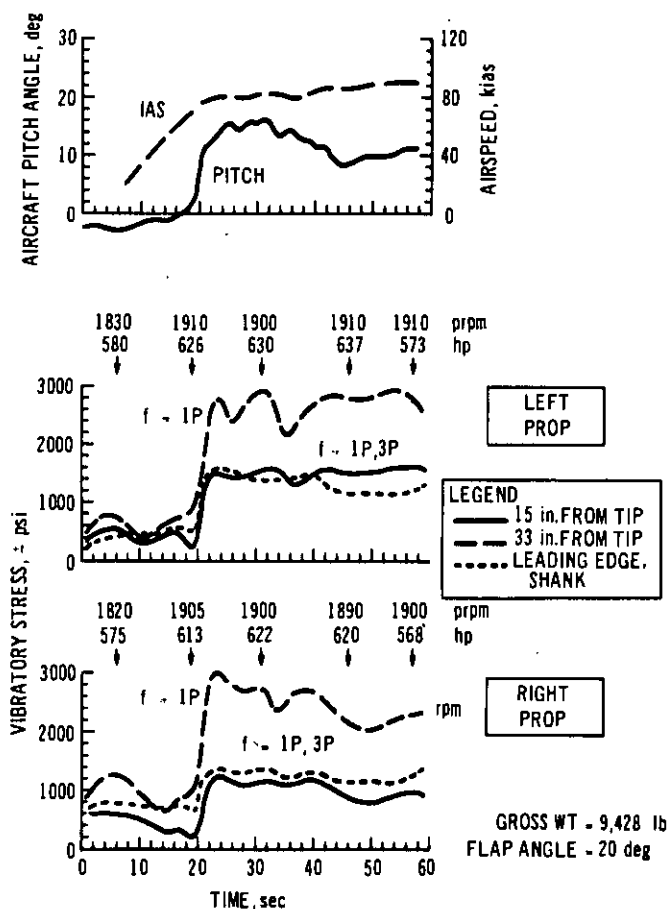


Fig. 9-9. Vibratory Stress Survey Summary

characteristics *shall* be evaluated in those regimes which, based upon the baseline data and calculation estimates, will produce the highest vibrations.

9-3.6.3 Instrumentation and Data Analysis

Instrumentation requirements for the engine vibratory demonstration are the same as those for the survey specified in par. 8-3.4.

9-3.6.4 Documentation

As with the engine vibration survey (par. 8-3.5), a final report *shall* be published by the airframe manufacturer, and submitted to the procuring activity and the engine manufacturer. The engine manufacturer should write a critique of the report to be supplied to the procuring activity and to the airframe manufacturer. Final evaluation and directives for corrective action will be made by the procuring activity. The engine vibration survey report and the demonstration report may be combined into a single volume when permitted by timely test reporting.

9-3.7 PROPULSION SYSTEM TEMPERATURE DEMONSTRATION

A propulsion system temperature demonstration *shall* be conducted to determine the temperature requirements specified.

9-3.7.1 Propulsion System Temperature Demonstration Plan

When a separate demonstration plan is required, it *shall* include, as a minimum, the items specified in par. 8-4.2. Specific temperature cooling margins *shall* be required for demonstration of each propulsion system installation qualification. The determination of such margins may actually have been made during the propulsion system temperature survey (par. 8-4). If such is the case, testing need not be repeated for demonstration purposes.

9-3.7.2 Test Requirements

Tests *shall* be conducted to investigate the cooling characteristics of the helicopter structure and of the helicopter and engine-mounted components, for certain critical conditions. Critical cooling—such as that associated with the use of auxiliary power units, heavy gross weight operation, inflight refueling, engine or component malfunction, and cooling airflow null points—*shall* be investigated as applicable. Operation of special features in the cooling system—such as suck-

in doors, flowout doors or panels, controllable air inlets, and cooling air ejectors—*shall* be demonstrated.

9-3.7.2.1 Ground Tests

Ground cooling demonstration tests *shall* be conducted at the same conditions as specified in par. 8-4.3.1

9-3.7.2.2 Flight Tests

The flight test demonstration *shall* be conducted in accordance with the requirements in par. 8-4.3.2.

9-3.7.3 Instrumentation and Data Analysis

The detailed instrumentation requirements of par. 8-4.4 also apply for this demonstration. Generally, thermocouples are used as temperature-sensing devices because of their simplicity, low cost, and accuracy. Other temperature-sensing methods such as thermistors and temperature-sensitive paint are highly inaccurate in determining temperatures and may be used only to add confidence that overheating does not exist, e.g., in an area washed by the exhaust gas.

This propulsion system temperature demonstration should be conducted in conjunction with the lubrication system cooling demonstration (par. 9-3.4.1) and the exhaust system survey (par. 8-6.3) since much of the data is pertinent to all of them.

As for the engine temperature survey, for all test conditions, temperature data *shall* be corrected to hot atmospheric conditions. Hot atmospheric air temperatures are 22°F warmer than the temperatures in Table III of MIL-STD-210. Applicable cooling data *shall* be presented for the flight conditions tested for all individually cooled accessories along with the manufacturer's specified cooling requirements. Allowable operating temperature limits *shall* be those specified in the applicable helicopter design specifications or those established with Army approval by the engine or component manufacturer.

9-3.7.4 Documentation

A report of the results of the demonstration *shall* be prepared in accordance with the reports of par. 8-4.5. When the demonstration is accomplished in conjunction with the temperature survey, a single test report is desired.

9-3.8 ENGINE AIR INDUCTION SYSTEM DEMONSTRATION

The engine air induction system demonstration is conducted to determine the engine airflow conditions and to relate these quantities to free stream conditions.

Particular requirements are for detailed measurements of air temperature and total and static pressures at the engine inlet, from which mean pressures and pressure variations across the engine inlet face can be established.

9-3.8.1 Engine Air Induction System Demonstration Plan

The engine air induction system demonstration plan *shall* define ground and flight test programs which will investigate conditions to be expected throughout the operating envelope. Because of the many combinations of gross weight (power required), flight speed, maneuver, altitude, and ambient temperature, it is desirable to perform this demonstration in conjunction with other flight tests to reduce the number of flights needed for the demonstration.

Special consideration *shall* be given to evaluating all features associated with the induction system and the possible operating combinations that might occur during normal operation or following the failure of a system. Such systems may include an inlet sand and dust separator with a secondary scavenge system. Operations *shall* be considered with and without screens, with and without secondary scavenge air, and with bypass closed and open. Barrier filters should be tested in a clean and a simulated dirty condition. Each system may have a restricted operating regime, perhaps at take-off, hover, and landing; however, it is important that all operating anomalies be uncovered throughout the flight envelope. In a configuration where hot anti-icing air is discharged into the induction system, additional data *shall* be obtained. This hot air may have an adverse effect on the compressor due to temperature gradients and local separation in the duct.

9-3.8.2 Test Requirements

9-3.8.2.1 Ground Tests

Ground tests *shall* be conducted in accordance with the requirements in par. 8-5.3.1.

9-3.8.2.2 Flight Tests

For acceptable results, all flights should be performed in smooth air, and at least two data records should be taken at each condition. The flight condition *shall* be steady to provide representative records. In addition to recording inlet pressures and temperatures, it will be necessary to record basic flight and engine data, including pressure altitude, flight speed, outside air temperature (OAT), gas generator speed, engine measured gas temperature, engine torque, and rotor speed.

Flight test requirements are as specified in par. 8-5.3.2.

9-3.8.2.2.1 Inlet Pressure Recovery

Determination of pressure loss is most important at the performance guarantee condition or conditions. Fig. 9-10 shows the effects of pressure loss on power and fuel flow at various forward speeds.

This illustration is typical of a rated power condition (with an engine measured gas temperature limit) and shows an approximately 2% drop in power and a 1% drop in fuel flow for a 1% inlet pressure loss. In the case of a fuel flow-limited engine (derated or flat-rated), the effect would be a loss of approximately 0.5% in power for a 1% pressure loss. In this case, gas generator speed and engine measured gas temperature can increase, providing a partial restoration of power. At partial power, the effect of pressure loss is an increase in fuel flow for a given power, which *shall* be considered in range calculations.

It is useful to note that inlet pressure loss results in a drop in both airflow (on a one-for-one basis) and overall engine pressure ratio.

9-3.8.2.2.2 Inlet Temperature Level

Engine performance is based on the total temperature at the engine inlet. The free stream total temperature cannot be used in performance determinations due to an increase (usually) in the total temperature of the air as it flows through the induction system. The resulting change in available power depends on the relationship among limiting parameters such as gas generator speed, fuel flow, and measured gas temperature. At partial power, or when engine output is restricted by either helicopter or engine limitations on torque or power, there is no degradation of power output, and the effect of inlet temperature on specific fuel consumption should be negligible.

9-3.8.2.2.3 Other Inlet Pressure and Temperature Distortion Effects

In general, pressure and temperature gradients at the engine face will affect governing characteristics of the engine. Compressor stall may be induced, and the engine may or may not recover from this condition, depending upon its characteristics. In extreme cases of distortion, steady-state stall may be induced. Also, compressor or turbine blades may be excited by the pressure pulses and experience stress levels that are higher than allowable.

$\bar{P}_{t1}$ = MEAN TOTAL ABSOLUTE PRESSURE AT ENGINE INLET FACE

P_{t0} = FREE STREAM TOTAL PRESSURE

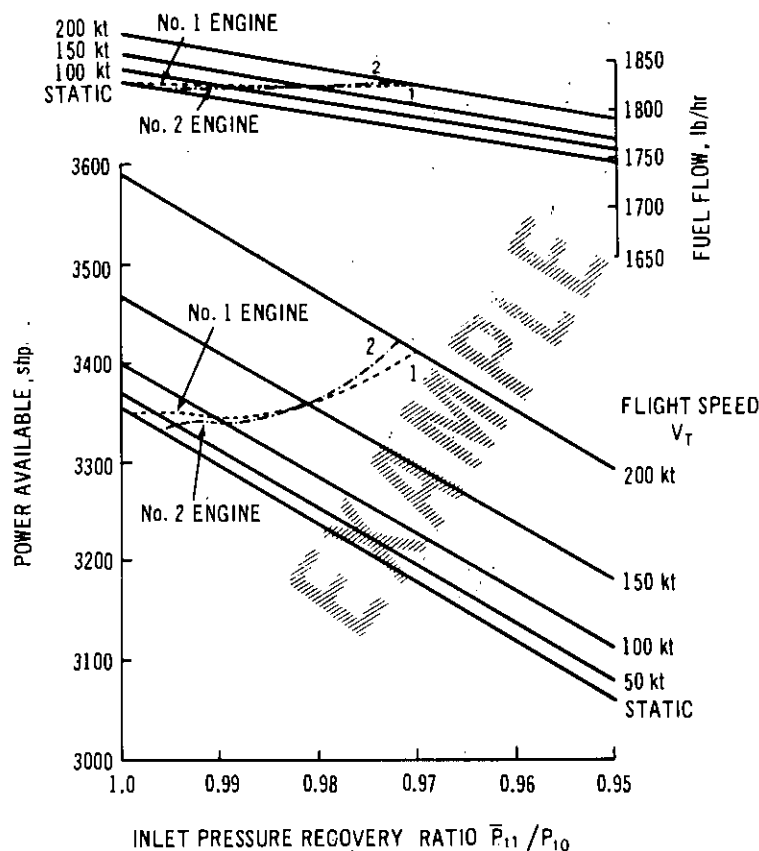


Fig. 9-10. Effect of Pressure Recovery on Engine Performance

9-3.8.3 Instrumentation and Data Analysis

The instrumentation required for the inlet demonstration is prescribed in MIL-T-25920, and is the same as required for the inlet survey of par. 8-5. In some cases, the installation may dictate the need for instrumentation additional to the minimum required in the specification. In others, the engine manufacturer may define special instrumentation requirements for that particular engine installation. In addition, the engine manufacturer may supply special instrumentation peculiar to his design, or provide an instrumented engine inlet section.

Installations where hot gas ingestion from the engine or other sources is suspected will dictate the use of additional probes.

The inlet total temperature probes should be balanced against a free stream probe of known recovery

factor in the same bridge circuit.

Pressure recovery is defined as the mean total pressure (absolute) $\bar{P}_{t1}$ at the engine inlet face divided by the free stream total pressure (absolute) P_{t0} .

Free stream total pressure usually is obtained from an instrument boom sensing free stream conditions (ahead of the helicopter). The pressure recovery of the air induction system $\bar{P}_{t1}/P_{t0}$ may exceed unity at low forward speed due to the influence of the rotor's downwash component.

The method used to show compliance with pressure distortion limits dictated by the engine manufacturer will depend upon the definition provided in the engine specification. It may vary from a simple statement of percent pressure variation about the mean pressure to a complex evaluation of the period and amplitude of the pressure variation around the engine inlet face. Re-

ardless of the definition used, a convenient method of showing pressure distortion is to plot isobars over the inlet annulus, mapping lines of constant $P_{t1}/\bar{P}_{t1}$. From these plots, peaks and troughs are easily identified relative to the mean pressure level in the duct. Such a plot is shown in Fig. 8-5 of Chapter 8.

The typical plot shown in Fig. 8-5 illustrates regions of minimum and maximum pressure of a current engine inlet.

Inlet temperature usually is greater than free stream static temperature due to converting kinetic energy to heat and to the heat added by other sources inherent in the design.

Although inlet-temperature distortion limits usually are not identified in the engine specification, it is recommended that a distortion of 10°F be reported to the procuring activity. Among sources of additional heat to be considered are ingestion of exhaust gases from main engines, auxiliary power units, and guns.

9-3.8.4 Documentation

The engine air induction system demonstration *shall* be prepared in accordance with par. 8-5.5 and may be combined with the engine air induction system survey when permitted by timely test completion.

9-4 DYNAMIC INSTABILITY DEMONSTRATION

9-4.1 GENERAL

Par. 9-4 covers demonstration procedures necessary to insure freedom from instabilities in the helicopter system throughout the flight envelope. The instabilities to be considered include unstable, self-excited vibrations which, once triggered, require no periodic force to maintain the vibration level. The prime examples of this type of instability are ground resonance and blade flutter. A subharmonic vibratory mode also has become an instability factor with the advent of high-performance helicopters.

9-4.2 GROUND RESONANCE

Ground resonance is a self-excited vibratory mode which involves a coupling between the lead-lag motion of the rotor blades and the motion of the helicopter on its landing gear. When the frequency of the lead-lag motion approaches that of the natural frequency of the landing gear spring system and inadequate damping is present, a violent unstable oscillation can occur. Helicopters with oleo gear historically have been most sus-

ceptible to ground resonance; however, it is possible that helicopters with the skid gear might encounter this violent oscillation. Accordingly, all helicopters with lead-lag motion of the main rotor blades *shall* demonstrate freedom from instability if the frequency of this mode is below operating rotor speed.

It is advisable to employ devices and design features which prevent or control ground resonance. The incorporation of lead-lag dampers on the rotor blades and air-oil shock struts with damping valves in the landing gear are methods of providing a combined energy dissipation capacity which is sufficient to prevent instability from occurring under most conditions. Design considerations for preventing ground resonance are discussed in Chapter 5 of AMCP 706-201.

9-4.2.1 Test Requirements

Because mechanical instability involves a rotating system coupled with a series of springs, the tests to demonstrate freedom from this instability must include all combinations of operational variables of the rotating and landing gear spring systems.

The rotating parameter which has the most pronounced effect is the rotor speed. All other parametric changes should be evaluated through a rotor speed sweep. The entire rotor speed range should be considered, including the low speeds associated with starting and the maximum governing rotor speed.

The variables comprising the landing gear spring system should be evaluated individually for all types of helicopters. When applicable, the oleo strut pressure *shall* be varied throughout the normal servicing range. Also, the tire pressures *shall* be varied throughout the service range, including the case of a flat tire. The tests *shall* demonstrate that the helicopter is free from objectionable mechanical instability for all weight and CG configurations.

Extremes of terrain also must be considered because of the differences in effective spring constants. Initial runs *shall* be conducted on concrete or asphalt, and a check run then made on sand and/or turf. Each run *shall* be conducted to determine the effect of the runway on the frequency response of the helicopter for that particular configuration.

The following is a list of parameters which, if applicable, should be measured during testing:

1. Gear oleo position
2. Thrust lever position
3. Longitudinal stick position
4. Lateral stick position
5. Directional pedal position

6. Stability augmentation system actuator position
7. Lead-lag angle
8. Flap angle
9. Rotor rpm
10. Gear loads.

Acceptable methods and features to consider in conducting tests to demonstrate freedom from ground resonance are described in the paragraphs which follow.

If manual inputs are used to excite the rotor, it is usually found that different test phases cannot be compared directly with each other due to variations in the amount of control input. An automatic method is recommended for rotor excitation since such a system provides accuracy and repeatability of control input and also input frequency. Because the instability is self-excited, no excitation other than the rotor speed change is required; however, usual practice is to provide excitation through lateral stick doublets.

Hover to landing tests *shall* be conducted over the operational range of gross weight and CG conditions, with landing gear swivels locked and then repeated with swivels unlocked. Comparable tests *shall* be conducted performing roll-on landings. In the swivels-locked condition, the vertical and lateral stiffness of the tire and gear contribute to roll-lateral constraint. When the swivels are unlocked, the landing gear provides minimum lateral stiffness.

If a stability augmentation system is installed, testing will be required with the system "on" and "off". Stability augmentation system "off" is the more critical condition, from a mechanical instability viewpoint, because the function of the system is to attenuate or correct severe inputs.

Motion picture coverage *shall* be required during the test. Stroboscopic equipment *shall* be utilized in order to obtain real time measurement of rotor motion. Helicopters of new or unfamiliar configurations should be restrained by tiedown cables between the highest substantial structure of the helicopter and ground rings.

To insure that there is no unstable response in the helicopter during normal rev-up, it is recommended that a series of slow, medium, and fast manual lateral control excitations be applied during accelerations and decelerations at each of the test gross weights.

9-4.2.2 Documentation

A test report *shall* be submitted and *shall* include plots of roll angular velocity, transmission lateral velocity, and any other measurement which responds

to a roll motion as a function of rotor speed. Oleo strut position *shall* be plotted as a function of rotor speed when oleo strut-type helicopters are evaluated. A matrix of the relative responses of the variables considered *shall* be constructed to infer compliance at the most critical combination of these variables.

9-4.3 BLADE FLUTTER

The helicopter system must be free from flutter at speeds of up to 1.15 times the design limit speed (see par. 3.6.2 of MIL-S-8698). Flutter is a self-excited vibration. Normally, blade torsion, flap bending, or other rotating blade measurements will be monitored throughout the development of the flight envelope. The presence of, or freedom from, flutter is determined by monitoring these measurements during the other demonstrations required in the test program. This eliminates the need for additional specific tests to demonstrate freedom from flutter. When the analysis indicates a possible flutter problem, it is recommended that a wind tunnel test be conducted to supplement the flight test program. See Chapter 5 of AMCP 706-201.

9-4.4 SUBHARMONIC VIBRATORY MODE

The low-frequency, subharmonic oscillation, which has become a factor on the latest generation of high-speed helicopters, *shall* be adequately damped throughout the flight envelope.

The normal method of exciting this mode is with a control pulse or doublet (control input in one direction followed by a similar size input in the opposite direction). The particular axis which provides maximum excitation of the mode *shall* be determined experimentally and used for demonstration. The frequency of maximum excitation also *shall* be determined experimentally by noting the response for a range of input frequencies. The vehicle damping of this mode *shall* be defined in matrix form to imply compliance for all combinations of gross weight, CG, rotor speed, airspeed, main rotor lift, and external store configuration (vehicle inertia changes). The demonstration *shall* include excitation both in one "g" level flight and while pulling load factor. Historically, damping of this mode has been critical at conditions of high airspeed so the demonstrations *shall* concentrate on this flight regime; however, spot checks should cover the entire operating range including climb and autorotation. Hazards of testing and demonstrating high-speed helicopter should be recognized and safe practices outlined in the detail test plan. When the analysis indicates a possible subharmonic problem, a wind tunnel test should be

conducted to supplement the flight test program. These tests are discussed in Chapter 5 of AMCP 706-201.

9-5 AERODYNAMIC DEMONSTRATION

9-5.1 GENERAL

Par. 9-5 covers the demonstration procedures and test requirements necessary to substantiate the aerodynamic performance of the helicopter, and includes the performance substantiation and the flying quality demonstration.

9-5.2 PERFORMANCE SUBSTANTIATION

The performance flight testing conducted by the airframe contractor normally is less than that accomplished by the Army in both formally substantiating guaranteed performance and gathering data for inclusion in the operating handbooks. However, it is important for the contractor to gather valid performance data early in the program in order to assure the validity of the configuration. Also, the practical and operational value of early definition of best climb and autorotational speeds, airspeed system position error, and other performance parameters is obvious for the conduct of stability and control and structural tests. In recognition of these requirements, the paragraphs which follow will discuss accepted methods of gathering and normalizing helicopter flight test performance data. AMCP 706-204 should be used as a guide for data reduction and formats for data presentation. Data *shall* be normalized to the standard day atmosphere defined in the U.S. Standard Atmosphere, 1962.

9-5.2.1 Test Requirements

The importance of testing in calm, stable air cannot be overemphasized. Testing under turbulent conditions can result in significant errors. The accurate measurement of power is the key to performance testing. Power measurements *shall* be made with a calibrated engine with the torquemeter dynamically calibrated at the time of engine calibration. Strain gage measurements of main rotor and tail rotor shaft torsions also are useful, both as a check on engine power and to define the power distribution. During the performance tests, engine performance should be tracked by using referred parameters to insure that no shift or change has occurred in the power measurement system. Post-test calibration of the engine may be required for lengthy tests.

Additional instrumentation required should be of flight test quality, and calibrated before and after the tests. The free-air temperature probe should be calibrated to obtain an adiabatic temperature rise recovery factor. USAASTA Pamphlet 700-1, *Standard Practice and Procedures for Instrument Calibration*, may be used as a guide.

9-5.2.1.1 Level Flight Performance

The most widely accepted method of defining the level flight performance of helicopters is a density-altitude technique which is based on the fact that rotor performance can be uniquely described in nondimensional form with thrust and power coefficients and advance ratio. This method is reliable within the normal helicopter flight envelope. However, when compressibility effects or rotor blade stall are encountered, the data may become inconsistent. If compressibility is a factor, testing should be accomplished at several constant advancing tip Mach numbers.

Each speed-power polar is flown at a constant thrust coefficient C_T , shown in Eq. 9-2 as

$$C_T = \frac{W_t}{\rho_t A (\Omega R)^2} \quad (9-2)$$

where

W_t = test weight, lb

ρ_t = test air density, slug/ft³

A = rotor disk area, ft²

ΩR = rotor tip speed, fps

This involves selecting a mid-test target weight and density altitude, and then maintaining the ratio of weight to density constant by increasing density altitude between test points as fuel is consumed. Sufficient level flight airspeed points should be chosen to define adequately the speed-power polar. A minimum of five polars (five values of thrust coefficient) is required to define the vehicle performance. As wide a range of thrust coefficients as possible should be selected. In addition to weight and density altitude, rotor speed can be varied to increase the thrust coefficient spread.

The power required for each test point is converted to the nondimensional power coefficient C_P

$$C_P = \frac{550 SHP_t}{\rho_t A (\Omega R)^3} \quad (9-3)$$

where

SHP_t = test shaft horsepower

The power coefficient then is plotted against the advance ratio μ

$$\mu = \frac{1.6878 V_T}{\Omega R} \quad (9-4)$$

where

V_T = true airspeed, kt

for each polar flown. A cross plot then is prepared by obtaining the appropriate values of thrust and power coefficients at constant values of advance ratio. This summary plot of power coefficient versus thrust coefficient along lines of constant advance ratio will describe the vehicle level flight performance. A level-flight, power-required curve can be constructed from this curve by selecting any gross weight, density altitude, and rotor speed combination, and then solving for the power required to maintain a selected airspeed.

The power-required curves thus obtained, when intersected with the power-available curves, will determine performance parameters such as maximum airspeed and speed at maximum continuous power. The engine model specification will be used for installed fuel flow data at the selected conditions for the calculation of range, endurance, etc. This procedure for level flight performance measurement becomes inappropriate for values of advance ratio below approximately 0.15. For measurements in the range of flight speeds $0 < \mu < 0.15$, appropriate procedures are described in the AGARD flight test manual (Ref. 1).

9-5.2.1.2 Climb Performance

Airspeeds for best rate and angle of climb and maximum rate of climb and the service ceiling *shall* be determined during climb tests.

The tests normally are conducted using the sawtooth climb technique. A gross weight (normally design gross weight), a power setting, and a density altitude are selected. A series of climbs at different airspeeds is conducted through an increment of altitude bracketing the selected altitude. Sawtooth climbs should be conducted through at least three altitudes. The helicopter should be flown at 90 deg to the prevailing wind, with reciprocal headings flown on alternate points to minimize the significant energy changes associated with wind gradients. The observed (indicated) rate of climb $(R/C)_i$ is obtained for each airspeed from the faired slope of a curve of pressure altitude versus time. The

test tapeline rate of climb $(R/C)_{TL}$ is obtained from the expression

$$(R/C)_{TL} = (R/C)_i \left(\frac{T_{S_t}}{T_{STD}} \right) \quad (9-5)$$

where

T_{STD} = standard ambient temperature, °R

T_{S_t} = test ambient temperature, °R

The test data *shall* be corrected for the installed engine model specification power available on a standard day at the test density altitude, and also for individual test point gross weight variances from the standard gross weight selected. An accepted method for accomplishing these corrections is the semi-empirical K factor method, where the power K_p and weight K_w factors are obtained in partial derivative fashion from flight test data, or specifically

$$K_p = \frac{W_t}{33,000} \left(\frac{\Delta(R/C)_{TL}}{\Delta SHP_t} \right) \quad (9-6)$$

where

$$\begin{aligned} \Delta(R/C)_{TL} &= (R/C)_{TL1} - (R/C)_{TL2} \\ \Delta SHP_t &= SHP_{t1} - SHP_{t2} \end{aligned}$$

$$K_w = \frac{W_{t2} \times W_{t1}}{33,000 SHP_{STD}} \left(\frac{\Delta(R/C)_{TL}}{\Delta W_t} \right) \quad (9-7)$$

where

$$\Delta W_t = W_{t2} - W_{t1}$$

Once the K factors are determined, Eqs. 9-6 and 9-7, rewritten in Eqs. 9-8 and 9-9, can be used to determine the increments of rate of climb attributable to deviations in power $\Delta(R/C)_p$ and weight $\Delta(R/C)_w$ from standard.

$$\begin{aligned} \Delta(R/C)_p &= (R/C)_{STD} - (R/C)_i \\ &= \frac{K_p \times 33,000 \times \Delta SHP}{W_{STD}} \end{aligned} \quad (9-8)$$

where

$$\Delta SHP = SHP_{STD} - SHP_t$$

$$\Delta(R/C)_w = (R/C)_{STD} - (R/C)_t \quad (9-9)$$

$$= \frac{K_w \times 33,000 \times SHP \times \Delta W}{W_{STD} \times W_t}$$

where

$$\Delta W = W_t - W_{STD}$$

The addition of these corrections to the test tapeline rate of climb results in the definition of the climb performance at the test density altitude and true airspeed at standardized weight and power.

Cross plotting the optimum rate of climb and airspeed for best rate of climb against altitude will permit determination of service ceiling, maximum sea level rate of climb, and an optimum climb airspeed schedule. The selected standardized gross weights reflect the fuel burnoff expected during a climb from sea level.

9-5.2.1.3 Hover Performance

An accepted method for defining the hover performance of helicopter makes use of the nondimensional thrust coefficient C_T , Eq. 9-2, and power coefficient C_P , Eq. 9-3, which define the hover performance at a given rotor height above the ground. Out-of-ground effect data should be obtained at a height of at least two rotor diameters above the ground. The importance of obtaining hover data under calm wind conditions cannot be overstated. Even light winds can cause significant errors in performance evaluation. If testing is confined to one altitude, the test gross weights and rotor speeds should be chosen to result in as large a spread of thrust coefficient as possible. Historically, out-of-ground effect hover, without ground reference, has provided unreliable data.

There are two widely used techniques for gathering test data. The first technique involves hovering at several exact heights above the ground. A weighted cord is used to fix the height above the ground, with a ground observer talking the pilot into the exact height. Data normally are recorded for three rotor speeds at each height on a given flight. Tests then are repeated at a different gross weight to obtain the desired thrust coefficient spread. The second technique involves hovering at a selected height above the ground while the helicopter is tethered to a load cell on the ground. A wide range of rotor thrust coefficients can be obtained with this technique using a single test merely by changing the rotor thrust with collective pitch. The effective rotor thrust is the sum of the vehicle and tethering

equipment weights and the load cell output.

The data from both test techniques are reduced in the same manner. The power and rotor thrust are converted into coefficient form using the test rotor speeds and measured ambient conditions. All data are summarized on a plot of power coefficient versus thrust coefficient along lines of constant height above the ground. Once constructed, this plot will permit the definition of power required as a function of height above the ground for any combination of vehicle weight, rotor rpm, pressure altitude, and free air temperature. The maximum gross weight at which hover can be accomplished at a selected wheel/skid height and at selected atmospheric conditions can be determined by calculating the power coefficient from the installed engine power available at the selected atmospheric conditions. The nondimensional plot is entered at this power coefficient and at the selected wheel height to obtain a thrust coefficient. The maximum gross weight at which hover at the selected conditions can be accomplished then is calculated from the thrust coefficient.

By use of these reduction techniques, useful summary plots of maximum hover gross weight versus pressure altitude along lines of constant temperature can be prepared. Each plot will be valid for one hover height, rotor speed, and engine power rating. As in forward flight performance testing, if compressibility is a factor, it will be necessary to perform testing at several constant advancing tip Mach numbers.

9-5.2.1.4 Autorotational Performance

There are three considerations in evaluating the power-off characteristics of a helicopter. The first is steady-state autorotative performance as a function of rotor speed, airspeed, density altitude, and gross weight. The second is the height-velocity envelope outside of which an entry to autorotation, followed by a power-off landing, can be safely accomplished without exceptional pilot skill or damage to the helicopter. The resulting height-velocity curve is derived not only from performance aspects, but also is strongly influenced by vehicle handling qualities and structural considerations. The third is partial power descents.

At low forward speeds in descent with partial power, there may be a condition of disturbed flow through the rotor which manifests itself in two ways: (1) the sinking speed may not be directly related to the power setting, and (2) control effectiveness is poor. The boundaries of this condition should be determined as a "region of roughness" to be avoided in landing and to be considered when establishing the height-velocity relationship for safe landing after power failure.

The steady-state autorotation performance normally is established by use of the sawtooth descent test technique, which involves descending through an increment of altitude at each of several airspeeds. Test should be flown at 90 deg to the wind, with reciprocal headings flown on alternate points to minimize the significant energy changes associated with wind gradients. It is important that the engine-transmission clutch be disengaged for these tests because a relatively small engine power increment has a large effect on autorotation performance. On many turbine engine installations, clutch disengagements can be facilitated by setting the engine idle to the low side of the recommended range.

A technique for conducting the autorotation sawtooth test is to fly at each airspeed with the collective lever at the downstop, accepting the resulting rotor speed. At the airspeed for minimum rate of descent, several higher collective settings are tested through the same increments of altitude to determine the change of rate of descent with respect to rotor speed. In an alternate technique, the pilot varies the collective setting at each airspeed to maintain the design rotor speed. This method is satisfactory only on vehicles with positive rotor speed control; otherwise, the pilot will end up "chasing" the rotor speed while trying to stabilize at the design value.

The combination of airspeed and collective setting recommended for operational use will not necessarily be that for minimum rate of descent, but will consider additional factors such as flare energy available at the end of the descent, ability to increase rotor speed in the flare, and pilot visibility. Ordinarily, these tests are conducted at the lightest and heaviest normal service loadings at an altitude near sea level, and are repeated near the service ceiling at the heavier gross weight. The lightweight condition at low altitude normally will be critical with respect to obtaining a safe operating rotor speed with full down collective. The heavy-weight, high-altitude condition will be critical with respect to possible overspeed of the rotor at full down collective.

The descent should be reduced to an observed (indicated) rate of descent $(R/D)_i$ from the slope of a faired curve of altitude versus time. The test tapeline rate of descent $(R/D)_{TL}$ is obtained from the expression

$$(R/D)_{TL} = (R/D)_i \left(\frac{T_{SI}}{T_{STD}} \right) \quad (9-10)$$

Historically, weight corrections to autorotation performance data have proved unreliable, so the data normally are presented at the average test gross weight. Plots of tapeline rate of descent versus true airspeed are prepared which are valid for the test density-altitude and test average gross weight. An additional plot of rate of descent as a function of rotor speed is prepared at the airspeed for minimum rate of descent.

Since the determination of the height-velocity curve historically has been a most dangerous helicopter demonstration test, a very conservative buildup to each final point is required. In order to make the height-velocity curves more meaningful for the average pilot and to reduce the danger inherent in the demonstration, the curves as developed should represent operational envelopes. An adequate margin of safety for variations in pilot proficiency should be included rather than having the envelopes represent maximum helicopter performance and maximum pilot proficiency. Calm air conditions are required for testing. The test is conducted by initially entering autorotation at a safe height above the ground, delaying corrective action for 2 sec, establishing autorotation, and landing at maximum ground speed. The initial point normally is in level flight at the recommended autorotational airspeed. The height above the ground is determined by a ground observer using a visual theodolite. The pilot is guided by the ground observer to successively lower heights above the ground until some limiting condition establishes a point on the height-velocity curve. The shape of the high side of the height-velocity curve is established by repeating this same procedure for progressively higher altitudes and lower airspeeds. The shape of the lower portion of the diagram also is developed in a buildup fashion. Initially, power chops are made while hovering at increasing wheel/skid heights until some limit is reached. The test is repeated at increasing forward speeds until the entire airspeed range has been covered.

Generally, the definition of the high altitude side of the curve requires acceleration to the best autorotation airspeed and then execution of the landing. In the low altitude portion of the curve, forward velocity of the vehicle and the rotational energy of the main rotor are used to decelerate the vehicle to an acceptable touchdown speed. In addition to the autorotation from level flight, the height above the ground required for a safe landing following an engine failure in a climb at the best climb speed, also should be determined. The height-velocity curve should be defined at the heaviest normal service loading at both sea level and high altitude test sites.

The height-velocity data from these tests may be obtained with a flight analyzer or a similar type of camera. Height above the ground at the power chop is presented as the ordinate and true airspeed as the abscissa. The touchdown speed for the landing from each point is also noted next to the plotted point. A curve is faired through the data, using pilot comments and structural load criteria (e.g., touchdown sink rate) as the basis for the fairing of the recommended height-velocity diagram.

9-5.2.1.5 Airspeed Calibration

The production airspeed indication system *shall* be calibrated to define the installation position error for all steady-state flight conditions.

Presently available standard airspeed systems are inaccurate and unreliable in the lower airspeed range. Therefore, a test boom airspeed system (incorporating a swiveling pitot-static head) normally is installed on the test helicopter. The swiveling feature makes the boom system position error independent of sideslip angle and angle of attack up to angles of about 30 deg. Calibrated airspeed values during flight tests are determined from the boom system, if it is installed. Depending on the location of the test boom, the airflow characteristics at the standard system ports may be affected by the boom installation. Accordingly, calibration of the helicopter standard airspeed system should be performed with the test boom removed.

The accepted method of calibrating a helicopter airspeed system below 80 kt is by using the ground speed course method, which involves flying a constant indicated airspeed along a measured ground course. The time to cover a known distance will determine the true airspeed. The test is conducted in reciprocal directions at each airspeed to average out wind effects. The true airspeed, averaged for the reciprocal heading runs, is converted to an equivalent calibrated airspeed using the measured free air temperature and pressure altitude. This calibrated airspeed, when compared to the indicated airspeed corrected for indicator error, will determine the position error. The ground speed course also is a reliable method of calibrating the airspeed system at higher airspeeds.

There are other methods of calibrating airspeed systems at higher airspeeds:

1. The trailing bomb or cone method involves an aerodynamically shaped body containing a pitot-static system (or sometimes only a static system) of known position error which is towed from the vehicle and its indication of calibrated airspeed is compared with the indicated airspeed corrected for indicator error of the vehicle to determine its airspeed position error. The

trailing bomb also is valuable for static pressure source determination, altimeter calibration, and climb calibration. The cable of the trailing bomb may be unstable at some speeds and should be checked carefully to preclude whipping the bomb into the rear rotor.

2. An aircraft with a calibrated pitot-static system is flown in close formation with the vehicle to be calibrated, with the calibrated airspeed of the pacer aircraft compared with the indicated airspeed of the vehicle to determine the position error.

3. The altitude depression method involves flying the vehicle at a constant indicated airspeed and altitude near the ground. The tapeline altitude H_{TL} , in feet, of the vehicle is obtained by using optical or photographic methods. This tapeline height above the ground is converted to altimeter indicated height ΔH_i above the ground from the equation

$$\Delta H_i = H_{TL} \left(\frac{T_{STD}}{T_{st}} \right) \quad (9-11)$$

This height increment plus the measured ground pressure altitude will result in a calibrated pressure altitude which, when compared with the vehicle altimeter, will result in the vehicle altimeter position error. The altimeter position error then can be converted into an equivalent airspeed position error. This method is reliable only at the higher airspeeds. This method also assumes all of the position error originated at the static source and none at the pitot head, so a cross-check with another calibration technique is mandatory to verify this assumption.

The airspeed calibration data normally are presented as position error plotted versus instrument corrected indicated airspeed. The position error should be defined throughout the speed range in level flight, climb, and autorotation. Variation of position error with sideslip angle also should be determined. TIAS versus IAS also should be plotted.

9-5.2.1.6 Determination of Power Available

The basis for all power available *shall* be the "paper" engine mathematically described in the engine manufacturer's model specification. This engine represents the minimum guaranteed performance. Experience has shown that the typical new engine has better performance than the engine model specification requires. Power available and fuel consumption for performance data purposes *shall* be determined by applying measured installation, accessory, and bleed air losses to a

computer program furnished by the engine manufacturer which mathematically models the specification engine. Installation losses—including compressor inlet pressure recovery losses, compressor inlet temperature rise, and exhaust pipe pressure losses—*shall* be measured on the vehicle. The magnitude of the accessory and bleed air losses to be used in the determination of power available normally will be as proposed by the contractor and approved by the procuring activity. These losses will be based on secondary power requirements for normal missions. By use of the inputs previously mentioned, maps of maximum, intermediate, and maximum continuous power available and fuel flows are constructed to cover all combinations of airspeed, altitude and free air temperature. Installation losses also can be measured by reproducing the installation and by calibrating an engine in the engine manufacturer's test cell.

9-5.3 FLYING QUALITIES DEMONSTRATION

The discussion which follows defines the procedures necessary to substantiate and verify the flying qualities and handling characteristics of the helicopter system. Included are the normal loading and flight conditions for each demonstration, and the techniques employed for evaluation of flying qualities for all possible combinations of gross weight, altitude, rotor rpm, and CG location.

In order to minimize testing and still provide proof of compliance throughout the flight envelope, the procedure which follows is recommended.

9-5.3.1 Test Requirements

A baseline configuration of weight (normally design gross weight), CG (normally forward and aft limits), rotor rpm (design value), and altitude (normally near sea level) will be chosen. The required tests will be conducted initially at these conditions, with the effects of the parameters evaluated individually by changing one variable at a time. The stability derivatives then can be treated as partial derivatives and plotted against the parameter being varied to imply compliance throughout the envelope (e.g., the effect of CG on static longitudinal stability could be shown by plotting the partial derivative of longitudinal cyclic stick position with respect to airspeed against CG position for the range of loadings evaluated). External stores or other allied equipment, if applicable, should be added as variables, and their effect on stability and control should be evaluated using a similar logic. There is no specific number of tests required to define the effect of any configura-

tion change on handling qualities. However, the limit conditions for the configuration change being investigated should be explored.

9-5.3.1.1 Static Longitudinal Stability

The apparent static longitudinal stability indicated by the gradients of longitudinal stick position and force with respect to airspeed *shall* be positive about the trim conditions specified. Control position stability is of secondary importance to control force stability. This derivative normally is critical at the most aft CG loading. Rotor rpm, gross weight, and altitude usually have a lesser effect, although their effect should be evaluated. Changes in configuration and loading can have a marked effect on the static longitudinal stability. Therefore, investigations conducted with the helicopter in its clean configuration must be repeated for the critical configurations and loadings.

The vehicle should be trimmed at the specified flight condition. Altitude for each trim condition should be adjusted slightly to maintain a constant thrust coefficient. Without altering collective position, trim setting, or throttle setting, the vehicle should be stabilized at incremental airspeeds both above and below the trim airspeed, using the cyclic and directional controls as required. Any resulting rate of climb or descent should be accepted. The cyclic control should be released slowly at both the upper and lower untrimmed airspeeds to evaluate the tendency of the vehicle to return to the trim condition.

To define the hysteresis loop of the control system and/or control force system, both the disturbance from and return to trim airspeed should be accomplished in increments of airspeed, stabilizing at each airspeed. Care should be taken not to reverse the direction of application of control force during either the disturbance from, or the return to, trim. This hysteresis loop will show the tendency of the vehicle to return to the trim condition.

9-5.3.1.2 Static Lateral-directional Stability

Satisfactory lateral-directional handling qualities will require the demonstration of positive stability for the following:

1. Directional stability (slope of pedal position and force versus sideslip angle)
2. Effective dihedral (slope of lateral stick position and force versus sideslip angle)
3. Sideforce characteristics (slope of bank angle versus sideslip angle)
4. Longitudinal trim change (slope of longitudinal stick position versus sideslip angle). Although there is

no specified requirement for this trim change, the longitudinal stick position/sideslip angle gradient should be evaluated with respect to both excessive trim change with sideslip and control margin.

Ordinarily, these apparent stability derivatives (1 through 3) are only slightly affected by CG loading and rpm, with demonstration at the aft CG loading sufficient to show compliance. For static lateral-directional characteristics, critical lateral CG position(s) also must be demonstrated. External stores can have significant effect on these derivatives.

The vehicle should be stabilized and trimmed in zero sideslip flight. The vehicle then will be stabilized—without retrimming, or changing throttle, or collective settings—at incremental sideslip angles to both the left and the right using the controls as required to maintain constant headings. The airspeed should be maintained constant during this test with any resultant climb or descent rate being accepted.

9-5.3.1.3 Sideward and Rearward Flight

The ability of the helicopter to hover in winds is simulated by flying sideways and rearwards to the specified speeds. The control requirements and margins are clearly stated in Chapter 6 of both AMCP 706-201 and -202. These characteristics normally are critical at the heaviest gross weight at the most forward CG loading.

The effect of altitude and lateral CG location also *shall* be evaluated.

The demonstration should include sufficient azimuth angles of relative wind to insure that compliance has been demonstrated for the most critical wind direction.

The helicopter should be stabilized at incremental speeds in left and right sideward flight and rearward flight using a calibrated ground pacer vehicle for a speed reference. The helicopter will be trimmed in a hover and the controls will be used as required to stabilize on each speed while maintaining a constant height above the ground.

9-5.3.1.4 Trim Requirements

The intent of the trim requirement is that the pilot *shall* be able to trim all control forces to zero for any sustained flight condition. No “stick jump” or other undesirable transients should occur during the trim procedure. Compliance *shall* be shown over the entire weight and CG envelope, and for all airspeeds, altitudes, and power settings. The pilot uses his trim controls for “hands-off flight” at each specified flight condition.

9-5.3.1.5 Controllability

Par. 6-3.1 of AMCP 706-201 defines the controllability design requirements. The control power and damping requirements pertain primarily to hover. However, the response of the vehicle to step control inputs *shall* be demonstrated throughout the flight envelope. In order to allow precise, rapid step inputs, an adjustable and quickly removable inflight control stop fixture should be used. External stores, particularly those which significantly change the vehicle inertia, can have a sizable effect on the controllability characteristics. The specified hover requirements *shall* be demonstrated at a high altitude as well as at sea level.

The pilot *shall* rapidly apply and maintain a step input at each specified condition in one control direction. The other controls *shall* not be moved. Recovery *shall* be made when a steady-state rate is reached or an excessive attitude is being approached. Ordinarily, four inputs of different magnitudes should be made in each direction about each control axis.

9-5.3.1.6 Dynamic Stability

Satisfactory vehicle handling qualities require that, following a gust disturbance, forces are set up so the vehicle tends to return to trim. These stability requirements (par. 6-3.4 of AMCP 706-201) normally are critical at combinations of aft CG loadings and high altitude. However, compliance should be demonstrated throughout the airspeed envelope for climb, level flight, and autorotation.

The pilot will simulate external disturbances by applying a rapid pulse control input about a single axis. The vehicle controls then are held at the trim position until the vehicle motion damps out or recovery becomes necessary. A minimum of three pulses of different magnitudes in each direction and about each control axis is required to examine adequately the dynamic stability.

The phugoid mode is evaluated by slowing the vehicle from trim approximately 10 kt using the longitudinal control, then slowly returning the control to its trim position and holding it fixed, using an appropriate control jig, and noting the ensuing vehicle motions. A time history of airspeed, altitude, and pitch attitude following the return of the longitudinal control to trim will define the phugoid mode.

9-5.3.1.7 Maneuvering Stability

The precision flying requirements of Army missions necessitate positive gradients of longitudinal stick position and force with respect to load factor. These maneuvering stability requirements normally will be criti-

cal at combinations of high altitude and aft CG loadings. However, the maneuvering stability should be demonstrated throughout the airspeed range, with emphasis on high speed, at load factors up to the maximum allowable.

The tests for "pitch-up" are accomplished in a manner similar to the controllability tests described previously (par. 9-5.3.1.5). However, several rates of longitudinal control motion are used. The control is deflected, held fixed for at least 1 sec, and then returned to its initial position. The elapsed time for start to return should vary from 1 to 6 sec. The maneuvering stability characteristics are best obtained using the wind-up turn test technique. The vehicle is stabilized and trimmed in 1-g level flight; then, without changing power or retrimming, the vehicle is rolled into banked turns (both left and right) and stabilized at incremental load factors up to the maximum for the helicopter. The airspeed and rotor speed are maintained constant during these maneuvers, and altitude is allowed to vary.

9-5.3.1.8 Roll Characteristics

Specification requirements for roll handling characteristics are described in par. 6-3 of AMCP 706-201. Satisfactory roll characteristics are particularly important on gunnery missions and precision "nap-of-the-earth" flying. Although no minimum roll rate is specified, the roll-rate-per-inch of stick displacement should be documented for use in mission analysis. These characteristics should be demonstrated throughout the airspeed range. If external stores are involved, those which result in the highest lateral inertia will be the most critical.

The roll characteristics should be evaluated by abruptly rolling from at least a 30-deg bank angle in one direction to approximately a 30-deg bank angle in the opposite direction. As a minimum, three lateral step inputs of different magnitudes should be used in each direction. The directional control pedals should remain fixed during these maneuvers to demonstrate the adverse yaw characteristics. The maximum magnitude input should then be repeated using pedal position changes as required to coordinate the maneuver.

9-5.3.1.9 Autorotation Entries

Pars. 6-2.5 and 6-3 of AMCP 706-201 require satisfactory handling quality and safe rotor decay characteristics following engine failure. Simulated engine failure *shall* be demonstrated throughout the flight envelope at all combinations of flight conditions and power settings in order to substantiate that safe transition is possible under the conditions which follow.

For each entry condition to be demonstrated, the pilot *shall* make a rapid power reduction (throttle chop) to simulate engine failure. Following initiation of the simulated engine failure, collective pitch control motion *shall* be delayed 2.0 sec. The delay time for all other controls *shall* be 1.0 sec, except for control axes where disturbances from trim exceed 5 deg/sec within 0.3 sec following the simulated failure. The delay time for the controls associated with these axes *shall* be 0.5 sec. If an engine failure warning system is installed, the delay for all controls *shall* be the system reaction time plus 0.5 sec.

9-5.3.1.10 Stability Augmentation System Failures

When stability augmentation systems are included, the contractor *shall* demonstrate augmentation system disengagement and engagement, stability augmentation systems "off" flight, and simulated stability augmentation system failures. Applicable requirements of MIL-H-8501 will be applied. Stability augmentation system tests should be performed in level flight, climbs, descents, turns, sideward and rearward flight, and take-offs and landings throughout the flight envelope.

9-5.3.1.11 Qualitative Pilot Evaluation

The importance of qualitative evaluation by the pilot cannot be overemphasized. Flight characteristics *shall* be investigated thoroughly by both pilot evaluation and instrumented engineering flight tests. Pilot evaluation *shall* encompass all modes of operation: taxi, ground handling, mechanical instability characteristics, takeoff and landing characteristics (including hover, sideward and rearward flight, climbout, and transition), climb, cruise, maneuvering, descent and autorotation, buffet, vibration and noise, normal and emergency operating techniques and procedures, and smooth and rough air characteristics.

9-5.3.2 Documentation

Data *shall* be presented in the form of time histories of the transient control forces and motions, helicopter motions, load factors, and similar parameters for the maneuvers for which qualitative pilot evaluations are presented.

Longitudinal cyclic stick positions and force should be plotted as a function of calibrated airspeed for each trim condition evaluated, with the return to trim points marked. A summary plot of the changes of longitudinal stick force and position with respect to airspeed as a function of CG loading and thrust coefficient should be prepared for each condition evaluated. This plot will allow a prediction of the stick-fixed and stick-free neu-

tral points, or the CG loading at which neutral position and force gradients can be expected, if the thrust coefficient was held constant. Longitudinal stick position and force, lateral stick position and force, pedal position and force, and bank and pitch angles also should be plotted as a function of sideslip angle for each of the specified conditions. The slopes of these curves directly reflect compliance with specification requirements.

All control positions and forces as well as bank and pitch attitudes should be plotted against sideward or rearward flight velocity. The control travel limits should be shown clearly on the plot.

The control positions for trim should be plotted as a function of calibrated airspeeds for all required loadings and flight conditions. This plot should include fuselage pitch attitude as a function of calibrated airspeed. The available trim should be shown clearly on each plot. An analysis of these data also will show compliance with the trim change requirement; i.e., at a given airspeed, altitude, and loading, the longitudinal control for trim *shall* not change more than 3 in. and the lateral control more than 2 in. when the collective pitch lever is varied through the available range. Time histories of control positions, vehicle rates, vehicle attitudes, normal CG acceleration and, if possible, angular accelerations of the vehicle should be prepared for representative step inputs. The vehicle control response rate is best shown by plots of attitude change after 1 sec (0.5 sec for roll inputs), steady-state rates, and maximum angular accelerations as a function of control step displacement from trim. Time histories of control positions, vehicle rates, vehicle attitudes, and CG acceleration following pulse inputs *shall* be prepared and the motion compared with specification damping requirements.

Time histories of control positions, vehicle rates, and CG acceleration following each type of longitudinal control input should be prepared. The maneuvering stability can be presented best by plots of longitudinal control position and force versus load factor. The partial derivatives of longitudinal stick position and force with respect to load factor can be plotted as a function of CG position to determine the maneuvering neutral points or the CG loading at which neutral maneuvering stability can be expected.

The roll performance can be summarized best by plots of the steady-state roll rate, maximum angular acceleration, and maximum sideslip angle. The time from control input to attainment of these values should be shown as a function of the lateral control deflection from trim. Summary plots can be prepared showing how these parameters vary with airspeed, gross weight, or lateral inertia for each inch of control travel.

Time histories of autorotation entries should include airspeed, altitude, rotor speed, engine power, control positions and forces, vehicle rates and attitudes, and CG normal acceleration.

9-6 ELECTRICAL DEMONSTRATION

9-6.1 GENERAL

The contractor *shall* demonstrate the performance of the helicopter electrical system, including all components and interconnecting circuitry provided for the generation, regulation, storage, control, conversion, and distribution of electrical power. Electrical components will include the generators, regulators, control panels, batteries, conversion equipment, motors, generator cutout relays, power receptacles, wiring, resistors, rheostats, switches, meters, lighting, and circuit protective devices. If an onboard auxiliary power unit (APU) is specified, the tests discussed subsequently also *shall* be conducted. The test helicopter, with the electrical system and all utilization equipment installed, will be identical in design, construction, and configuration to the production vehicle. Utilization equipment is defined as any device, unit, or complete system which uses electrical power to accomplish its functions. The demonstration *shall* consist of ground and flight tests, and *shall* determine the capability of the system to perform adequately the functions directed by the required missions.

The contractor must include a demonstration of the accessibility of units for test, adjustment, removal, and handling for servicing. It must be demonstrated that the installation meets the general and specific requirements of MIL-E-7080, unless otherwise specified by the detail specification or contract.

The contractor also *shall* demonstrate:

1. That the operating temperatures of all electrical power and conversion equipment are within the specification design limitations. Operating temperatures *shall* be determined at the full rated output of the equipment or with loads which the contractor is applying to the equipment, whichever temperature is greater.
2. That the prime mover has adequate capacity to maintain rated generator loads and overloads to the limits defined in the applicable specifications.
3. The generation and conversion of adequate electrical power. This *shall* be accomplished under all engine speeds from minimum ground idle to maximum rpm.
4. That voltage regulation, frequency regulation,

transient performance, and wave form of the AC system are within specified limits of MIL-STD-704

5. That the voltage regulation and the amount of ripple voltage present in the DC system are within the limits specified in MIL-STD-704. These parameters *shall* be recorded at the power input terminals of representative utilization equipment.

6. That the emergency power available and that the alternate and emergency electrical circuits are satisfactory under all flight conditions. This demonstration *shall* include performance for voltage regulation, frequency regulation, and waveform of the AC system, and voltage regulation and ripple voltage content for the DC system.

7. Satisfactory performance of the fault protection system and detection equipment under specified fault conditions.

Additionally, the generator vibrational environment (both frequency and amplitude) on the three major axes *shall* be measured and recorded. The vibrational pickups *shall* be installed on the generators as far from the mounting pad as practical; their weight *shall* not exceed one percent of the generator weight.

9-6.2 ELECTRICAL ANALYSIS REPORT

The contractor *shall* prepare an electrical analysis data report and submit it to the procuring activity 30 days prior to the start of the electrical system airworthiness qualification tests. The report(s) will include:

1. An up-to-date copy of all electrical wiring diagrams showing cable designations and lengths
2. A description of the electrical system operation during normal, emergency, and abort procedures
3. An electrical load analysis (AC and DC) compiled in accordance with MIL-E-7016, and a description of the instrumentation and procedures used in conducting the analysis and measurements
4. Data, methods, and instrumentation pertaining to the contractor's flight and ground evaluations of the capabilities of the total electrical system. These reports must contain a comprehensive discussion of the results obtained and emphasize any operational limitations imposed by the system design.

9-6.3 ELECTRICAL SYSTEM AIRWORTHINESS QUALIFICATION TESTS

Electrical system airworthiness qualification tests *shall* consist of ground and flight tests.

Ground tests *shall* include all electrical system performance tests and demonstrations which can be performed satisfactorily with the helicopter on the ground. These tests *shall* include, as a minimum:

1. Installation compliance
2. Electrical load measurements
3. Primary power system tests
4. Conversion power tests
5. Emergency power tests
6. Fault protection and detection
7. Engine-starting system tests
8. Auxiliary power unit tests.

With prior approval of the procuring activity, the electrical load measurements and fault protection and detection can be substantiated by electrical system mock-up tests.

Flight tests *shall* be conducted to demonstrate the performance of the electrical system in flight throughout the various regimes and conditions existing during a typical mission. The objectives to be accomplished during the flight tests are:

1. To obtain the operating temperatures of electrical power generating and conversion equipment for typical flight regimes and conditions
2. To demonstrate the adequacy of the electrical power and conversion equipment under actual flight conditions, including altitude
3. To demonstrate the capability of the prime mover to maintain the required generator loading
4. To determine the vibrational environment of each generator during flight conditions, with each of the three major axes of each starter-generator monitored for vibrational amplitudes and vibrational frequency.

9-6.3.1 Ground Tests

9-6.3.1.1 Electrical Load Measurements

The electrical load imposed on the power system by each individual electrical system or unit *shall* be measured, and the total load on each electrical power system determined. With prior approval of the procuring activity, the load measurements can be made on an individual bus rather than on individual units. Any system or unit with more than one mode of operation must be operated in each mode, or in the mode requiring maximum power. The power requirement must be the steady-state demand for the particular mode being considered.

Primary power system total load will include the input power to conversion equipment. The conversion

(or secondary) power will be supplying its normal loads when its input power is determined. Each individual load imposed on the conversion power system *shall* be measured, and the total load on the conversion equipment determined.

Emergency and alternate power system loads *shall* be identified and individually measured. The total load on each emergency power source *shall* be determined. Each DC load *shall* be measured in terms of voltage input and amperes of current flow, or watts consumed; each AC load *shall* be measured in terms of phase-to-neutral input voltage, amperes of current flow, and either power factor (phase angle) or volt-amperes.

9-6.3.1.2 Primary Power System Tests

The primary electrical power system may be either an AC or DC system. An AC primary power source is normally an AC generator or alternator driven by the engine or transmission of the helicopter. A DC primary power source may be an engine or transmission-driven DC generator, or a battery.

The primary electrical system tests *shall* demonstrate the operational features and the performance capabilities of the system.

The tests *shall* also determine that the power system characteristics meet the criteria established in MIL-STD-704.

9-6.3.1.2.1 AC Primary Electrical System Tests

The contractor *shall* demonstrate that the design, operation, and performance of the AC primary electrical system meets the requirements established by the detail specification and contract documents. These tests must be designed to demonstrate any special operational and design characteristics that may differ from other helicopter models. The tests *shall* demonstrate:

1. Single generator operation and capability
2. Multiple generator operation and capability
3. Load equalization capability
4. Power transfer capability
5. Load transfer capability
6. Supervisory and control functions
7. Operational temperatures
8. Any special features.

It *shall* be demonstrated that the AC primary electrical system and utilization equipment power characteristics are within the specified limits of MIL-STD-704. Unless not applicable to the particular system under test, these characteristics *shall* include:

1. Steady-state voltage, individual phase

2. Steady-state voltage, three phase
3. Phase displacement
4. Unbalance
5. Wave-form:
 - a. Crest factor
 - b. Total harmonic content
 - c. Individual harmonic content.
6. Steady-state frequency
7. Transient performance.

9-6.3.1.2.2 DC Primary Electrical System Tests

The contractor *shall* demonstrate that the design, operation, and performance of the DC primary electrical system meets the requirements established by the detail specification and contractual documents. In addition to demonstrating any special operational and design characteristics, the tests *shall* demonstrate, if applicable:

1. Single generator operation and capability
2. Multiple generator operation and capability
3. Generator load capability
4. Load equalization capability
5. Power transfer capability
6. Load transfer capability
7. Switching and control functions
8. Operational temperatures.

It *shall* be demonstrated that the DC primary electrical system and utilization equipment power characteristics also *shall* be within the specified limits of MIL-STD-704, including:

1. Steady-state voltage
2. Ripple amplitude
3. Ripple frequency components
4. Transient performance.

9-6.3.1.3 Conversion Power Tests

Conversion of secondary power is accomplished by transforming or converting the primary power to another type in order to supply the particular needs of utilization equipment. Conversion power is entirely dependent upon a primary power source.

The contractor *shall* demonstrate any peculiar design, control or operational features of the conversion power system by appropriate tests.

9-6.3.1.4 Emergency Power Tests

An emergency or alternate source of power is provided when the primary system is unable to supply ade-

quate electrical power. It *shall* be demonstrated that the available emergency power and the emergency circuits are satisfactory for all required flight operating conditions of the helicopter. Emergency power tests *shall* prove compliance with the requirements of MIL-STD-704, including voltage regulation, frequency regulation, and waveform of an AC system, and voltage regulation and ripple voltage content of a DC system.

If the emergency DC source is a battery, adequacy of the battery to provide the required power to the emergency circuits for a specified time period must be demonstrated.

9-6.3.1.5 Fault Protection and Detection

The satisfactory performance of the fault protection and detection systems and devices *shall* be demonstrated.

The demonstration will normally consist of introducing an actual or a simulated fault into the electrical system and observing the reaction of the protection and detection system or device. These devices and systems include, but are not limited to:

1. Individual load circuit protection
2. Circuit fault protection
3. Overvoltage protection
4. Undervoltage protection
5. Reverse current protection (cutout)
6. Primary power failure detection
7. Conversion power failure detection
8. Reversed polarity detection
9. Reversed phasing detection
10. External power protection.

Note: Not all of these devices or systems normally are present on any one helicopter.

9-6.3.1.6 Electrical System Installation

A complete installation environmental test is required to be conducted on prototype or early production helicopters. Installation testing can prevent later problems which could require an expensive field modification.

Installation surveys should be conducted with the complete helicopter starter generator system, and *shall* include the following demonstrations:

1. Voltage Regulator Control Frequency. The steady-state or transient voltage regulator control frequency should not be coincident with the calculated torsional natural frequency of the starter generator shaft.
2. Starter Drive Shaft Torsional Test. To insure that the starter shaft is not operating in torsional reso-

nance condition in either the starter or generator mode, a complete torsional test should be conducted. Strain gage instrumentation should be installed on the starter drive shaft so that both steady-state and oscillatory torque values can be measured. A slip ring device is required on the starter shaft for signal transmittal. Oscillatory torque conditions will exist in a complicated drive system such as the combination of the engine accessory drive train system and the starter drive shaft system. A reasonable maximum oscillatory torque limit is 10% of the engine starter pad maximum static torque limit. The strain gage instrumented starter would be very useful in measuring starter performance in combination with measuring starter input voltage and amperage.

9-6.3.1.7 Electrical Engine-starting System Tests

The capability and adequacy of the electrical starting system and installed starting power sources of the helicopter *shall* be demonstrated to show that the starting power capability meets the requirements of the detail specification (see the discussion in par. 9-3.2.1.3 for additional details).

9-6.3.2 Flight Tests

The test helicopter will be prepared for complete flight readiness in accordance with the established pre-flight and flight test procedures, including operational checks on all electrical and electronic equipment. Installed instrumentation *shall* be checked functionally and calibrated prior to flight.

The parameters which follow *shall* be monitored and their values recorded by appropriate instrumentation throughout the flight regimes and altitudes of a typical mission and as required by the detail specification. The recorded data *shall* be adequate for obtaining plots of the time histories of these parameters, which include:

1. Rpm of each engine
2. Rpm of each primary electrical power source (generator or alternator)
3. Operating temperatures of each primary electrical primary source
4. Vibrational amplitudes and frequencies on each of the three major axes for each primary power source
5. Voltage output of primary electrical power source
6. Current output of primary electrical power source
7. Frequency of primary source power (if AC)
8. Voltage output of conversion equipment

9. Current output of conversion equipment
10. Frequency of conversion power (if AC)
11. Operating temperatures of each conversion power source
12. Output voltage of emergency (or alternate) power source
13. Output current of each emergency (or alternate) power source
14. Frequency of emergency power (if AC)
15. Operating temperatures of each emergency power source
16. Current supplied to each load circuit bus
17. Outside air temperature
18. Equipment compartment and/or individual component temperatures (if required)
19. Altitude
20. Airspeed
21. Pressurization of battery installation.

Sufficient flights must be conducted and data obtained to demonstrate the performance and capabilities of the electrical system in flight and to meet the objectives cited in par. 9-6.3. The helicopter will be flown through the various flight regimes, conditions, and altitudes that can reasonably be expected to occur during the performance of the missions required by the detail specification and contract.

9-6.4 DOCUMENTATION

Electrical system test reports, including all pertinent results, *shall* be submitted to the procuring activity. A flight test report, including all pertinent results, *shall* be written after the electrical system tests are completed and *shall* be submitted to the procuring activity. MIL-STD-831 defines the format and content criteria for the preparation of the test reports.

9-7 AVIONIC DEMONSTRATION

9-7.1 GENERAL

The demonstration requirements necessary to insure that the helicopter avionics (classified as either communication or navigation equipment) perform the functions specified in the contract will be defined in this paragraph. Specific avionic demonstration tests are the airworthiness qualification, antenna performance, communication and navigation equipment, and electromagnetic compatibility tests.

9-7.2 AVIONIC AIRWORTHINESS QUALIFICATION

The avionic tests *shall* be conducted on a production helicopter, preferably the first. The test helicopter *shall* include all completely provisioned avionic equipment. The tests are conducted to demonstrate that the design of the installation is satisfactory, and that the avionic performance meets the minimum requirements and performs in a manner commensurate with the tactical capabilities of the equipment. For most military contracts the basic criteria for avionic airworthiness qualification tests are established by MIL-I-8700, and consist of both ground and flight tests. All avionics *shall* be given a bench test in accordance with an approved test procedure before being installed on the test helicopter. The ground or preflight tests *shall* include voltage standing wave ratio (VSWR), system performance, and maintainability. The avionic airworthiness qualification flight tests *shall* include antenna pattern, range, system performance, vibration, and cooling. The system performance, vibratory, and cooling tests *shall* be accomplished to evaluate the design parameters of the system during actual inflight conditions under all flight regimes.

9-7.2.1 Avionic Airworthiness Qualification Test Ground Station

The type of ground station antenna and the antenna ground plan will be described, and the height of all test station antennas stipulated in the contractor's avionic test plan. The characteristics of the ground station transmitters and receivers will be detailed, particularly the power output of the transmitters and the sensitivity of the receivers. For performance testing of communication equipment, it is desirable to use the same type of receiver-transmitter for the ground test station as is being tested on the helicopter.

9-7.2.2 Production Tests

The production bench and preflight tests *shall* be conducted on each system and helicopter to be delivered under the contract. These tests may be abbreviated but will be thorough enough to control the integrity of the design. Production flight tests also will be conducted on each helicopter but generally will not require quantitative checking of antenna patterns, interference levels, and maximum ranges. The production flight tests are performance tests to demonstrate that the avionic system in the helicopter has not been degraded through inadequate production or installation techniques. Sufficient data *shall* be recorded during these

production acceptance tests to make judgments of system acceptability.

9-7.2.3 Avionic Test Specifications

The avionic test specifications, prepared by the contractor, include bench, preflight, production flight, and avionic airworthiness qualification test procedures. These test specifications *shall* include minimum requirements and must be submitted to the procuring activity for approval. In those cases where a military test specification is not available, the contractor *shall* prepare the procedures for any required test and incorporate them into the avionic test specification for approval by the procuring activity.

9-7.2.4 Electrical Power Verification

The electrical power required by each avionic system *shall* be measured to verify power consumption, thereby partially evaluating the helicopter power generation and distribution system. The procedures and requirements described in par. 9-6 will be followed to complete the evaluations.

9-7.3 ANTENNA PERFORMANCE SUBSTANTIATION

An antenna subsystem, as defined in MIL-STD-877, is the complete interconnection of the antenna, the transmission line (coaxial line and connectors), radome, and all parts which serve to match, tune, isolate, erect, interconnect, and protect the subsystem. From the standpoint of design and operational characteristics, the term "antenna subsystem" also includes the entire flight vehicle since the helicopter is an essential portion of that subsystem and may contribute to its characteristics, particularly to the distribution of RF energy. From the standpoint of location and installation, the term "antenna subsystem" will include only the parts and modification added to the flight vehicle to provide satisfactory avionic system operation.

9-7.3.1 Scale Model Antenna Test Program

In order to substantiate that the antenna design criteria have been met and that the optimum polarization locations and efficiency have been selected for the helicopter antennas, antenna model studies *shall* be required during the early development of the subsystems. The size of the scale model, unless dictated by the detailed antenna subsystem specification, *shall* be determined by the contractor.

In general, reduced scale dimensions of the model should not differ by more than 2% or 1/16 in., which

ever is greater, from the correct dimension. Modeling details, such as external stores and canopy constructions, should be similar enough to full-scale details to permit measurement of reasonably accurate radiation patterns.

All other antennas in the immediate vicinity of the model antenna under test *shall* be installed and terminated properly to insure that normal coupling effects are reflected in the pattern data.

The type of construction and metallic surfacing should permit maximum versatility for testing new antenna locations.

As part of the model program, sufficient analytical studies *shall* be performed to supplement the design approach for each antenna system. The study *shall* include propagation analysis, required gain, isolation requirements, and effects of rotors (main and tail) throughout the operational range. An integral set of patterns in the proposed location *shall* be required for each antenna element used separately, and for an antenna system utilizing two or more antenna elements. When the latter is the case, it is necessary to measure the patterns of each, using the same gain setting of the pattern-measuring equipment. When not defined by the detailed antenna subsystem specification, test frequencies *shall* be chosen in increments to give a good representative coverage across the antenna operational range. Impedance plots for the antenna system be provided.

A test plan, including detailed procedures and methods for conducting all necessary tests, *shall* be prepared by the contractor and submitted to the procuring activity for approval. Antenna model patterns, analytical studies, and other engineering data *shall* be documented as test results and submitted to the procuring activity for approval. In addition, the test results *shall* include photographs and dimensional drawings of the model used in the test.

9-7.3.2 Antenna Subsystem Qualification

In addition to the scale model tests, each antenna *shall* be qualified to the individual specification covering that antenna. Required tests *shall* include, but not be limited to, the following:

1. Electrical performance
2. Voltage standing wave ratio (VSWR)
3. Mechanical performance
4. Environmental tests
5. Radiation patterns
6. Lightning protection.

Particular attention will be given to qualifying the antenna in its operational environment. MIL-STD-877 should be used as a guide but the contractor must demonstrate satisfactory performance of each specific antenna application in the operational environment specified. Test results of the antenna subsystem qualification tests *shall* be documented and submitted to the procuring activity for approval.

9-7.3.3 Antenna Performance Tests

Helicopter performance tests *shall* demonstrate that the antenna design and location are satisfactory, and that all contractual antenna specifications have been met.

9-7.3.4 Ground Tests

Ground tests of antenna systems will be limited because of reflections and ground effects. However, tests such as VSWR, electrical bonding, mutual interference, impedance, and limited operational tests are required. In the case of navigation antennas, such as an automatic direction finding (ADF) sense antenna, impedance measurements are necessary to verify that proper matching has been accomplished. Each antenna *shall* be checked, as a minimum, at the low, middle, and high end of its operational range for compliance with the specified performance requirements.

9-7.3.5 Flight Tests

The antenna flight tests to be conducted on the helicopter *shall* consist of radiation pattern, range, and operational tests; the radiation pattern and range tests *shall* be performed on several frequencies across the operational range of the antenna.

9-7.3.5.1 Antenna Pattern Tests

Antenna pattern tests *shall* be conducted on the helicopter to substantiate the preproduction model antenna radiation patterns and insure that there are no undesired nulls.

Patterns may be measured by flying a cloverleaf flight plan, as shown in Fig. 9-11, or by flying a flat, 360-deg flight turn (circular pattern). The advantage of the cloverleaf flight plan is the radial accuracy of the different headings flown during the test. The disadvantage is that a signal null might exist between two of the selected headings and would not be detected. By flying a circular pattern, a continuous monitoring of the antenna signal can be accomplished. If the circular pattern is used, the diameter must be small compared with the distance to the measuring station, e.g., a ratio of 1 to 20. On some helicopters a 360-deg pedal turn can be

performed, reducing the diameter to almost zero. It is also important that the center of the helicopter circle be maintained over a known geographical point. Unless the contract specifies otherwise, horizontal patterns *shall* be flown during the test program. The altitude of the helicopter above the ground must be as low as is necessary to maintain line of sight and good signal reception.

For airborne transmitter antennas, the signal-receiving and -measuring equipment may be installed at the ground station. However, for antennas to be used with receivers, it may be necessary to install the signal-receiving and -measuring equipment on the helicopter if the power-handling capability of the antenna is less than the output power of the test transmitter.

The most desirable and informative antenna patterns are those plotted from continuously recorded data for the entire 360-deg turn. This can be achieved by connecting the x-axis of an x-y plotter to the output of the field intensity receiver and meter. The x-axis of the x-y plotter must be fed with a signal proportional to the helicopter heading so that the antenna signal strength recorded at the y-axis is related to the nose of the helicopter. After the x-y plot of the antenna pattern is recorded, it should be converted to polar coordinates and presented in dB above one microvolt per meter, and in microvolts per meter. The antenna pattern maximum and minimum signal level points can then be compared. In most cases, to receive continuously the signal through the entire 360-deg turn, it is necessary to use a test receiver with a dynamic range of about 40 dB.

9-7.3.5.2 Maximum Range Tests

A test *shall* be conducted to determine the outbound and inbound range.

Also, acceptable performance is required during an entire 360-deg turn. This will give a practical demonstration of the maximum performance and, in addition, will show what effect the null points of the antenna pattern have on the operating range of the helicopter antenna. Since all frequencies above 30 MHz are dependable only out to the radio line-of-sight range, the line-of-sight range for the altitude being flown is acceptable as the maximum obtainable range.

Since received signals at frequencies below 30 MHz may be a combination of space waves, surface waves, and ionospherically reflected waves, range tests should be carefully planned to minimize the uncertainty resulting from this multimode propagation.

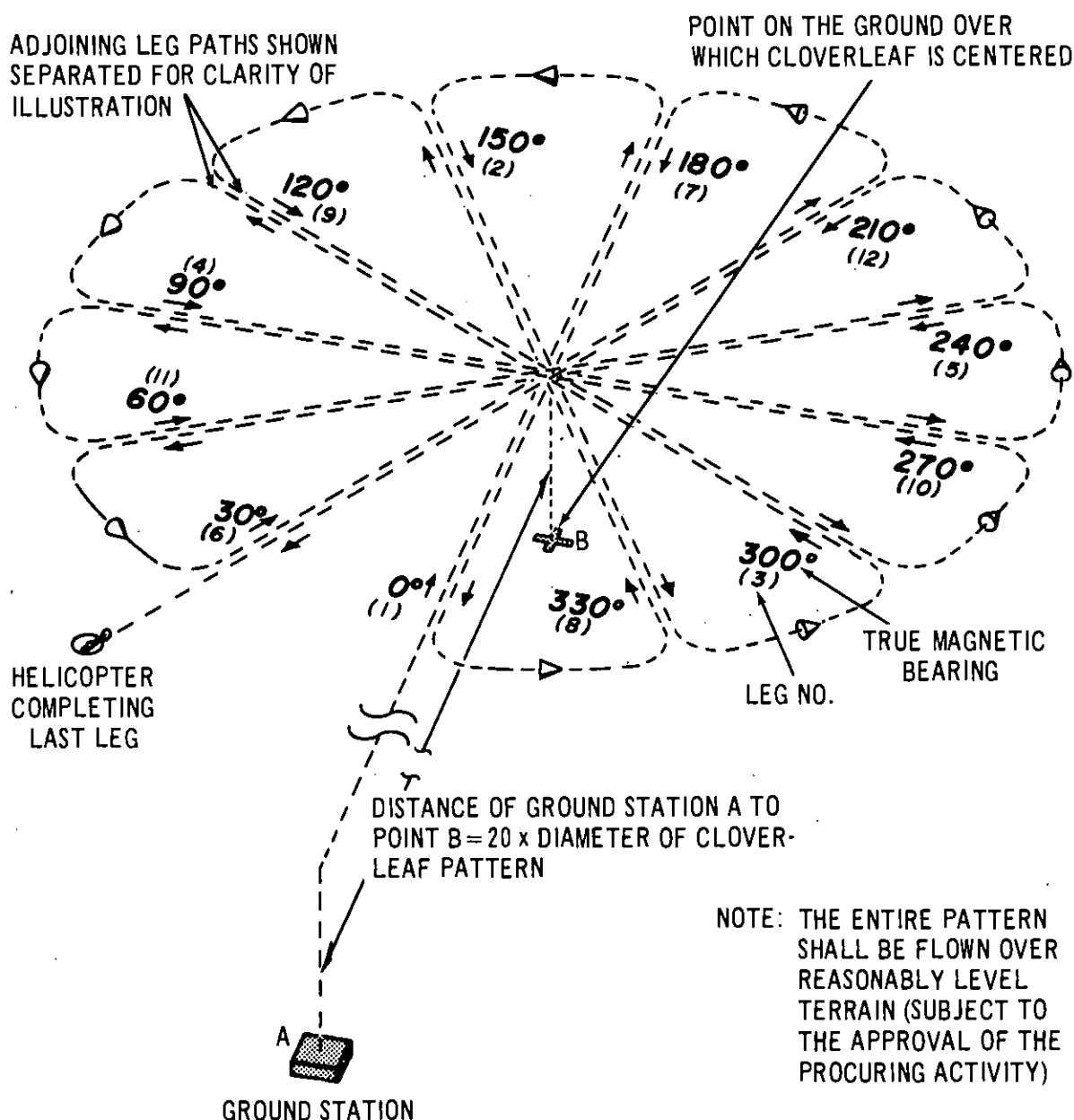


Fig. 9-11. Example of a Cloverleaf Flight Plan, 30-deg Intervals

9-7.3.6 Operational Tests

The required operational tests *shall* be conducted as part of the Avionic Airworthiness Qualification Tests, and *shall* be designed to check adequately the electrical and mechanical design parameters of the antenna system. Criteria for acceptable operational antenna performance *shall* be satisfactory inflight performance of the associated subsystem.

9-7.3.7 Documentation

The test plan for the helicopter antenna performance tests may be included as part of the Airworthiness Qualification Test specification for the avionics of the helicopter, described in par. 9-7.2. The plan *shall* include all required performance criteria and methods to be used in conducting the test, and *shall* be submitted to the procuring activity for approval. Test results *shall* be reported as part of the Avionic Airworthiness

Qualification Test results and *shall* be submitted to the procuring activity for approval. In addition to the antenna patterns and engineering data, the test results *shall* include photographs and drawings of the installation.

9-7.4 COMMUNICATION EQUIPMENT

This paragraph sets forth the general test criteria required to substantiate the performance of helicopter communication equipment. Radio equipment used primarily for the purpose of transmitting and receiving information by voice or code is classed herein as communication equipment. These include: HF radio sets, VHF/AM radio sets, VHF/FM radio sets, UHF/AM radio sets, interphone equipment, and related antennas. It also *shall* include identification friend or foe (IFF) equipment. The contractor *shall* satisfactorily demonstrate any IFF equipment and modes, utilizing appropriate ground facilities in accordance with the selected system specification.

9-7.4.1 Component Tests

Component tests *shall* be conducted in accordance with the requirements in Chapter 7.

9-7.4.2 Avionic Subsystem Ground Tests

Communication equipment ground tests are included in both the airworthiness qualification and production tests. The airworthiness qualification ground test program consists of a basic preflight test, plus those tests that are necessary to establish that the avionic system installation design is satisfactory for the airworthiness qualification flight tests and for the system maintainability requirements. The production ground tests, in general, are preflight tests and are performed to insure that there are no malfunctions due to equipment handling, that the equipment has been installed properly, and that the overall system performance is in accordance with the established criteria.

9-7.4.2.1 Test Requirements

A ground test procedure *shall* be written for each communication set and submitted to the procuring activity for approval. All military test specification requirements covered in the contract will be included in the ground test procedure. The procedure *shall* include all required test equipment, necessary performance limits, and all subsystem ground test criteria discussed in this paragraph. Test results and engineering data *shall* be reported as part of the Avionic Airworthiness

Qualification Test results and *shall* be submitted to the procuring activity for approval.

9-7.4.2.2 Airworthiness Qualification Ground Tests

The airworthiness qualification test helicopter *shall* be fully configured as specified in the helicopter contract and detail specification unless deviations are approved by the procuring activity. Airworthiness qualification ground tests *shall* include:

1. Visual inspection
2. Cooling
3. RF (radio frequency) output power and VSWR
4. Transmitter modulation
5. Operation
6. Maintainability
7. Rejection criteria.

The bonding of the avionic components and antenna systems *shall* be checked in accordance with MIL-B-5087 or other applicable specifications, prior to beginning the airworthiness qualification tests.

9-7.4.2.2.1 Visual Inspection

Prior to the operational preflight tests, a visual inspection *shall* be made to insure that each component is properly installed and properly fastened, and that the interconnect cable assemblies are properly mated and secured.

9-7.4.2.2.2 Cooling Tests

Tests *shall* be conducted to establish the maximum temperature obtainable in the compartment for each communication set under test during service conditions. (This test *shall* be repeated during flight.) If air conditioning or external cooling air is provided to avionic equipment, the testing *shall* include operation of the avionics with simulated failures of the air-conditioning equipment and/or blowers. In addition, the outside air temperature (OAT), cockpit ambient temperature, and the compartment temperature *shall* be recorded as a time history. The latter *shall* be recorded during an acceptable duty cycle of the communication set with the helicopter stationed on a runway and with the equipment turned on and then off. These temperature readings are necessary to establish that the actual operating and storage temperatures of the helicopter do not exceed the design limits of the communication set under test. In order that a comparison may be made, the temperature data *shall* be corrected to the maximum helicopter operating ambient design temperature. Operating capability of the communication equip-

ment under conditions of maximum helicopter operating temperatures *shall* be verified.

9-7.4.2.2.3 RF Output Power and VSWR Tests

The forward RF output and reflected power *shall* be measured at all frequencies to be used during the performance flight test. These measurements *shall* be taken as close as possible to both the transmitter and the antenna in order to obtain the power loss of the transmission line, the VSWR at the antenna element, and the VSWR of the entire antenna subsystem. It is necessary to measure the power on all of the flight test frequencies for comparison of the maximum operating range with actual power output of the transmitter. The test specifications *shall* stipulate the VSWR requirement.

9-7.4.2.2.4 Transmitter Modulation Checks

The transmitter modulation *shall* be checked for specific tolerances by using a normal speaking voice into each microphone from each control station. If the modulation percentage does not meet the specified tolerance at any control station, the cause will be determined and corrected to insure that the design of audio input circuits to the transmitter is correct. If the audio input to the transmitter is the same from all control stations, and the modulation percentage is out of tolerance, the bench test procedure will be changed to incorporate the modulation adjustments.

9-7.4.2.2.5 Operational Tests

Operational tests *shall* be performed to demonstrate reliable and satisfactory two-way communications on all flight test frequencies. The communication quality and signal strength *shall* be recorded during communication with the test ground station that is to be used during the airworthiness qualification performance flight tests. If the communication subsystem contains retransmission capabilities, the retransmission performance quality and levels also *shall* be determined.

9-7.4.2.2.6 Maintainability Tests

Maintainability tests *shall* be conducted as specified in par. 10-2.

9-7.4.2.2.7 Rejection Criteria

The performance limits *shall* be included in the test procedure, and any subsystem or component not successfully meeting these requirements *shall* be rejected.

9-7.4.3 Production Ground Tests

The production ground preflight tests *shall* be conducted on each helicopter and *shall* consist of the following checks:

1. Visual inspection
2. RF output power and VSWR
3. Operations.

9-7.4.3.1 Visual Inspection

Prior to production preflight tests, a visual inspection will be performed as in par. 9-7.4.2.2.1.

9-7.4.3.2 RF Output Power and VSWR Tests

RF output forward and reflected power *shall* be measured at several frequencies. When the number of frequencies is not given in a military test subsystem specification, the power measurements *shall* be taken at the low, middle, and high portions of the subsystem frequency range. The exact frequencies to be used on both preflight and flight tests must be requested and obtained through the applicable Governmental agencies. The subsystem test specifications *shall* stipulate the VSWR requirement. The VSWR is determined from the forward to reflected power ratio.

9-7.4.3.3 Operational Tests

Operational tests *shall* be performed to demonstrate satisfactory two-way communications on the assigned production flight test as in par. 9-7.4.2.2.5.

9-7.4.3.4 Rejection Criteria

Rejection criteria *shall* be as set forth in par. 9-7.4.2.2.7.

9-7.4.4 Avionic Subsystem Flight Tests

Communication subsystem flight tests *shall* be conducted for both the airworthiness qualification and production tests. The airworthiness qualification tests *shall* be conducted on a helicopter in the production configuration, preferably the first. The production flight tests *shall* be conducted on all production helicopters for all installed subsystems.

9-7.4.4.1 Airworthiness Qualification Flight Tests

The airworthiness qualification tests *shall* be conducted with equipment installed and operating on one helicopter representative of the production vehicle unless otherwise specified in the contract.

An avionic airworthiness qualification flight test procedure *shall* be written for each communication set and submitted to the procuring activity for approval.

All test specification requirements stipulated in the contract *shall* be included in the test procedure, which *shall* comprise all required test equipment, ground station requirements, necessary performance limits, and all subsystem performance and antenna pattern test criteria. Test results and engineering data *shall* be reported as part of the Avionic Airworthiness Qualification Test results and *shall* be submitted to the procuring activity for approval.

9-7.4.4.1.1 Antenna Patterns

Antenna pattern tests *shall* be conducted for all new antenna installations on helicopters. Antenna pattern test requirements are stated in par. 9-7.3.5.1. Antenna pattern tests *shall* be performed on several frequencies across the required frequency range of each antenna. If anomalies are observed in comparing developmental model antenna patterns, it may be necessary to check antenna characteristic impedance over its operating bandwidth. The pattern test results *shall* be converted to polar coordinates and presented in dB above one microvolt per meter and also in microvolts per meter. If the subsystem design criteria have not been met, then it may be necessary to relocate the antenna or use other means to fulfill the contractual requirements.

9-7.4.4.1.2 Range Tests

A test of the complete subsystem *shall* be conducted to determine the maximum outbound and inbound range. All performance parameters *shall* already have been determined through analytical calculation and measurements during the ground checks. Ground station parameters, as defined in par. 9-7.2.1, *shall* be considered in the analyses which are used to calculate the capabilities of the subsystem.

Acceptable performance is required during an entire 360-deg turn or a cloverleaf. This will give a practical demonstration of the maximum performance and, in addition, will show what effect the null points of the antenna pattern have on the operating range of the helicopter communication system. As all frequencies above 30 MHz are dependable only out to the radio line-of-sight range, the line-of-sight range for the altitude being flown is acceptable as the maximum obtainable range.

Since received signals at frequencies below 30 MHz may be a combination of space waves, surface waves, and ionospherically reflected waves, range tests *shall* be planned to minimize the uncertainty resulting from this multimode propagation.

9-7.4.4.1.3 Performance Tests

Performance flight tests of communication equipment *shall* include measurements of communication quality and signal strength over a specified range and altitude to demonstrate that reliable two-way communication can be maintained to all points of the azimuth. Quality and signal strength levels are described as follows:

1. Quality
 - a. Unreadable
 - b. Barely readable
 - c. Readable, occasionally difficult
 - d. Readable, no difficulty
 - e. Perfectly readable.
2. Signal Strength:
 - a. Faint to very weak
 - b. Weak to fair
 - c. Fair to good
 - d. Good to medium, strong
 - e. Strong to extra strong.

Speech intelligibility by using phonetically balanced monosyllabic word lists and other similar techniques also *shall* be measured. The contractor *shall* define the test approach to be used.

Satisfactory performance of the communication subsystems *shall* be demonstrated in all flight regimes; i.e., takeoff, hover, normal flight (line-of-sight ranges versus altitudes), and landing. A 360-deg turn *shall* be made near maximum range, so that the effect of rotor modulation on the signal quality can be recorded. Communication performance levels for systems with retransmission capabilities also *shall* be performed utilizing ground communication stations with the helicopter acting as a relay link. Retransmission performance parameters *shall* be determined as a function of range, altitude, and frequency spacing.

9-7.4.4.1.4 Vibratory Tests

Vibratory tests *shall* be conducted on each communication component during typical operating conditions (startup, hover, takeoff, normal flight at several typical altitudes, landing, and shutdown) at two or more typical gross weights. The components to be tested will be instrumented for the vertical, longitudinal, and lateral planes. Helicopter vibration generally extends to lower frequencies and to greater amplitude at these low frequencies than that of conventional aircraft. Therefore, test results will be obtained in this area to ascertain that the subsystem is compatible with the helicopter.

9-7.4.4.1.5 Cooling Tests

A temperature survey *shall* be conducted to establish the maximum temperature obtainable in the compartment for each communication component during typical operating conditions. The temperature readings required during ground tests (see par. 9-7.4.2.2.2) *shall* be recorded in flight.

9-7.4.4.2 Production Flight Tests

Production flight tests *shall* be conducted on each helicopter to be delivered under a contract but, generally, quantitative checking of areas such as antenna patterns and maximum ranges is not required. Production flight tests of communication subsystems will be conducted to establish that the performance in production has not been degraded.

9-7.4.4.2.1 Test Requirements

Production flight test procedures for communication subsystems *shall* be as detailed in par. 9-7.2.2.

9-7.4.4.2.2 Operational Tests

The main function of operational flight tests for communication subsystems is to demonstrate reliable and satisfactory two-way communications during a typical flight on the assigned production flight test frequencies. Procedures *shall* be as detailed in par. 9-7.4.2.2.5.

9-7.4.4.2.3 Rejection Criteria

Rejection criteria *shall* be based on the standard detailed in par. 9-7.4.2.2.7.

9-7.5 NAVIGATION EQUIPMENT

The tests required to qualify a navigation system are an extension of those performed on communication systems. In many cases the tests will be accomplished concurrently since the equipment performs both communication and navigation functions. Generally, however, navigation tests will be more quantitative than communication tests. Also, a greater variety of signal sources and types of outputs are utilized in airborne navigation. This results in a greater variation in test procedures from system to system than is found among communication systems.

The three types of tests required to demonstrate thoroughly the qualification of an airborne navigation system are bench, preflight, and flight tests.

The bench tests, which are checks of the operational status of the system components, are discussed in Chapter 7. The preflight tests are required to assure the adequacy of the installation. The ability of a system to

perform a particular mission can be determined only by flight test, which both simulates operational usage of the system and allows the collection of accurate performance data. Environmental tests also are required to determine the adaptability of the equipment to its area of installation.

Types of helicopter navigation systems to be considered include VHF omnidirectional range (VOR) receiving systems, low-frequency ADF systems, FM homing systems, and gyromagnetic compass systems.

9-7.5.1 Component Tests

Component tests *shall* be conducted in accordance with the requirements in Chapter 7.

9-7.5.2 Navigation Subsystem Ground Tests

Navigation equipment ground tests *shall* be included in both the airworthiness qualification and production tests. The airworthiness qualification ground tests consist of a basic preflight test plus those additional tests necessary to establish that the navigation system is satisfactory for the airworthiness qualification flight tests and that system maintainability requirements can be met. The production ground tests normally are preflight tests and are performed to insure that there are no malfunctions due to handling of the equipment, that the equipment has been properly installed, and that the overall system performance meets established criteria.

9-7.5.2.1 Test Procedures

A ground test procedure *shall* be written for each navigation set and submitted to the procuring activity for approval. All military test specification requirements defined by the contract *shall* be included in the ground test procedure. Either a separate procedure should be written for the airworthiness qualification and production tests or it should be made clear which tests are for the airworthiness qualification test only. The procedure will be complete, including all required test equipment, necessary performance limits, and all subsystem ground test criteria discussed in this paragraph.

9-7.5.2.2 Avionic Airworthiness Qualification Ground Tests

The avionic airworthiness qualification test helicopter *shall* be fully configured as specified in the helicopter contract and detail specification unless deviations are approved by the procuring activity. The following tests are included in the airworthiness qualification ground tests:

1. Visual inspection
2. Cooling
3. Maintainability
4. Operation
5. Rejection criteria.

9-7.5.2.2.1 Visual Inspection

A visual inspection *shall* be made prior to the operational preflight tests. Each component of the installed system will be checked to insure that it is properly installed and properly fastened. A check also will be made for proper mating of the interconnect cable assemblies to the equipment and to insure that they are properly secured.

9-7.5.2.2.2 Cooling Tests

Tests *shall* be conducted to establish the maximum temperature obtainable in the compartment for each navigation set under test during service conditions, i.e., with the engine running and the equipment operating. (This test *shall* be repeated during flight.) If air conditioning or external cooling air is provided to avionics equipment, the cooling tests *shall* include operation of the avionics with simulated failures of the air-conditioning equipment and/or blowers. In addition, the OAT and cockpit ambient temperature will be recorded. The temperatures will be recorded as a time history, and during an acceptable duty cycle of the navigation set — with the helicopter stationed on a runway and with the equipment turned on and then off. These temperature readings are necessary to establish that the actual operating and storage temperatures of the helicopter do not exceed the design limits of the navigation set under test. In order that a comparison may be made, the temperature data *shall* be corrected to the maximum helicopter operating ambient design temperature.

9-7.5.2.2.3 Operational Tests

Airworthiness qualification ground operational tests *shall* be performed to determine that the helicopter navigation systems are operational prior to flight. In addition, the compass system *shall* be swung as a part of the ground procedure. The procedures required for each system are given in the paragraphs which follow.

9-7.5.2.2.3.1 VOR Systems

Ground tests of a VOR system *shall* include the following parameters:

1. Bearing accuracy (manual and automatic)
2. "To-from" flag operation

3. Warning flag operation
4. Audio quality and control.

These tests will be performed using a signal radiated from the ramp test set, thus also checking the integrity of the VOR antenna system. Bearing accuracy tests will be performed with at least three simulated VOR bearings from the test set and on at least two frequencies in the 108.0 to 118.0 MHz range.

9-7.5.2.2.3.2 ADF Systems

ADF system ground tests *shall* be performed utilizing local radio stations as test sources, rather than using a test set. The minimum tests required *shall* consist of:

1. Sense antenna matching
2. Reception using sense antenna
3. Frequency accuracy
4. Beat frequency oscillator (BFO) operation
5. Tune meter operation
6. Manual loop operation
7. Aural null in manual mode
8. Appropriate indication action in automatic (ADF) mode.

Neither Test 6 nor Test 7 may be used to check bearing accuracy, but needle action will be checked for firm and positive response. Frequency and pointing tests *shall* be performed using at least three ground stations spread in both frequency and bearing. Care will be exercised during the running of Test 1 to insure that the effects of ground proximity to the sense antenna are properly accounted for.

9-7.5.2.2.3.3 Gyromagnetic and Standby Compass Systems

Gyromagnetic compass ground tests consist of a general operational check and the swinging (compensation) procedure. Operational checks *shall* include at least synchronization, slaving, and warning flag operation.

Compass swinging *shall* be accomplished on a surveyed compass rose in a manner conforming to the intent of MIL-STD-765. Standby magnetic compasses *shall* be compensated for at the same time as the gyromagnetic compass system. However, air swinging of the standby compass may be required.

Residual compass errors remaining after compensation will be recorded on compass calibration cards to

be displayed in the helicopter near the compass indicators.

9-7.5.2.2.4 *Rejection Criteria*

The necessary performance limits *shall* be included in the test procedure, and any subsystem or component not successfully meeting these requirements *shall* be rejected.

9-7.5.2.3 *Production Ground Tests*

The production ground preflight tests *shall* be conducted on each helicopter and *shall* consist of the tests of par. 9-7.5.2.1 except for those contained in pars. 9-7.5.2.2.2 and 9-7.5.2.2.3, and the ADF sense antenna matching tests.

The necessary performance limits *shall* be included in the test procedure, and any subsystem or component not successfully meeting these requirements *shall* be rejected.

9-7.5.3 *Navigation Subsystem Flight Tests*

Navigation subsystem flight tests are necessary for both the airworthiness qualification and production tests. The airworthiness qualification tests *shall* be conducted on a production helicopter, preferably the first. The production flight tests *shall* be conducted on all production helicopters for all installed subsystems.

9-7.5.3.1 *Airworthiness Qualification Flight Tests*

The avionic airworthiness qualification tests *shall* be conducted on one helicopter representative of the production helicopter, unless otherwise directed by the contract. All installed and completely provisioned avionic equipment *shall* be included in the airworthiness qualification tests for newly designed helicopters.

9-7.5.3.1.1 *Test Requirements*

An airworthiness qualification flight test procedure *shall* be written for each navigation set and submitted to the procuring activity for approval. All contractually stipulated military test specification requirements *shall* be included in the test procedure. The procedure will be complete, including all required test equipment, ground station requirements, necessary performance limits, and all subsystem performance test criteria discussed in this paragraph. Test results and engineering data *shall* be reported as part of the Avionic Airworthiness Qualification Test results and *shall* be submitted to the procuring activity for approval.

9-7.5.3.1.1.1 *VOR Systems*

Airworthiness qualification flight tests of VOR systems *shall* consist of the checks which follow, to be performed at a range and altitude determined by the detailed system performance requirements:

1. Manual bearing accuracy
2. Automatic bearing accuracy
3. "To-from" operation
4. Warning flag operation
5. Audio quality
6. Rotor modulation effects.

Each of the listed items *shall* be checked throughout a 360-deg turn on at least low-, mid-, and high-band frequencies. Rotor modulation tests *shall* be performed over the entire operational rotor rpm range.

9-7.5.3.1.1.2 *ADF Systems*

Airworthiness qualification flight tests for ADF systems consist of loop compensation data flights and tests to prove acceptable performance.

The following tests *shall* be performed in the order given:

1. ADF bearing accuracy without loop compensation
2. ADF bearing accuracy with loop compensation installed
3. ADF performance flight test at range and altitude
4. Over-station passage accuracy.

During flight tests to evaluate ADF performance, bearing pointer accuracy *shall* be determined for relative bearings of 0 to 360 deg in steps not to exceed 30 deg. Data to be determined include accuracy, stability, bearing tracking, and audio quality. Range tests *shall* be performed in all modes of the ADF set. Over-station passage tests *shall* be run in ADF mode.

Flights to determine the required loop compensation, and to check accuracy after compensation, may be performed using only one ground facility but range tests *shall* be repeated on at least three different frequencies.

9-7.5.3.1.1.3 *Gyromagnetic and Standby Compass Systems*

Airworthiness qualification flight tests of the gyromagnetic compass *shall* include as a minimum free gyro

drift, slaved mode accuracy, and system settling. Air swinging of the standby compass may be required.

9-7.5.3.1.1.4 Vibration Tests

Vibration tests *shall* be conducted for each navigation component during typical operating conditions — start up, hover, takeoff, normal flight at several typical altitudes, landing, and shutdown. These tests should be performed at two or more typical gross weights. The components to be tested will be instrumented for the vertical, longitudinal, and lateral planes. The vibration of helicopters generally extends to lower frequencies and to greater amplitude at these low frequencies than that of fixed-wing aircraft. Therefore, test results will be obtained in this area to ascertain that the subsystem component is compatible with the helicopter.

9-7.5.3.1.1.5 Cooling Tests

Tests *shall* be conducted to establish the maximum temperature obtainable in the compartment for each navigation component during typical operating conditions for ground temperature tests. In addition, the outside air temperature and cockpit ambient temperature will be recorded. The temperatures *shall* be recorded as a time history and during an acceptable duty cycle of each navigation set under test with the helicopter in flight. If air conditioning or external cooling air is provided to the avionic equipment, the test *shall* include operation of the avionics with simulated failure of the air-conditioning equipment and/or blowers. These temperature readings are necessary to establish that the actual operating and storage temperatures of the helicopter do not exceed the design limits of the navigation set under test. In order that a comparison may be made, the temperature data *shall* be corrected to the maximum helicopter operating ambient design temperature. The data *shall* be reported as part of the airworthiness qualification test results.

9-7.5.4 Production Flight Tests

Production flight tests *shall* be conducted on each helicopter to be delivered under a contract. Production flight tests, in general, do not require quantitative checking of antenna patterns, maximum ranges, etc. Navigation subsystem production flight tests are conducted to establish that the subsystem performance in production has not been degraded.

A complete production flight test procedure *shall* be written for each navigation subsystem and submitted to the procuring activity for approval. All military test

specification requirements defined in the contract *shall* be included in the test procedure.

The main function of operational flight tests for navigation subsystems is to demonstrate reliable and satisfactory navigation performance during a typical production acceptance flight.

The necessary performance limits *shall* be included in the test procedure, and any subsystem or component not successfully meeting these requirements *shall* be rejected.

9-7.6 ELECTROMAGNETIC COMPATIBILITY (EMC)

Electromagnetic compatibility tests *shall* demonstrate control of the electronic interference environment. These tests also *shall* demonstrate that performance will not be compromised when the equipment is subjected to the combined electromagnetic environment produced by the simultaneous operation of the onboard electrosystems.

Detail requirements for these tests *shall* be specified in the contractor's control and test plan (see par. 9-11 for a discussion of the helicopter system EMC demonstration requirements).

9-8 HYDRAULIC AND PNEUMATIC SUBSYSTEM DEMONSTRATION

9-8.1 GENERAL

The guidelines discussed herein will satisfy the requirements of MIL-T-5522. Hydraulic and pneumatic system testing is necessary to qualify the installation, to verify the performance capability of the components operating together as a system, and to demonstrate proof of compliance with the design functions. This testing *shall* follow logically component prequalification and qualification testing. This assures at least some confidence that the components are ready to be assembled together and tested as a system, and that the component interactions and compatibility can be evaluated. If a component does not meet design requirements during the component tests required in Chapter 7, it probably would be a weak point in the system if it were subjected to system tests.

Also, conducting system tests after at least a portion of the component qualification test has been performed assures that the system qualification represents the final design as nearly as possible. This minimizes the possibility of repetition of many tests and provides more knowledge pertinent to the final configuration.

The hydraulic and pneumatic system test programs consist of both ground and flight tests. Ground testing on a hydromechanical/structural mock-up *shall* be planned and initiated first. The data can then be reduced, and necessary design changes made. The validity of the changes can be confirmed prior to initiation of flight tests. Ground testing permits considerably more monitoring of system parameters as well as ease of making changes and/or modifications.

Flight testing allows determination of system performance under actual conditions and environments. Although many simulated conditions and modes of operation can be provided during ground testing, there are interactions in the system which can be proven only in an actual flight.

For a detailed discussion of hydraulic fluids, refer to AMCP 706-123.

Pneumatic subsystem installations normally are verified by ground tests with subsequent demonstrations used to verify operation of the subsystem. Pneumatic subsystems operating as emergency backups for other subsystems also may require flight testing. Generally, all of these tests are to determine that the installation functions properly under adverse conditions and does not exceed the specified maximum leakage rate, peak pressure, and temperature. The system temperature should be determined during ground tests.

9-8.2 HYDRAULIC SUBSYSTEM

9-8.2.1 Ground Tests

Ground testing is discussed in four parts: (1) hydraulic subsystem mock-up, (2) system provisions, (3) contamination protection, and (4) the specific test requirements and desired objectives.

9-8.2.1.1 Hydraulic Subsystem Mock-up

The actual system installation *shall* be simulated in a mock-up. This mock-up *shall* incorporate the hydraulic system components with associated plumbing. Hydraulic plumbing *shall* approximate actual helicopter requirements in terms of lengths, diameters, bends, and fittings; "production run" lines and hoses *shall* be used.

Cyclic, collective, and directional control actuators *shall* be installed with provisions to simulate both the load and no-load operations. The mechanical linkages, levers, and cabling of the control system *shall* be provided to allow inputs from cyclic stick, collective lever, and tail rotor pedals. The use of production hardware is mandatory. Since these control functions operate continuously and require synchronization and response, the test mock-up *shall* include a multichannel oscillograph with the associated pressure, flow, and

temperature transducers necessary to allow monitoring of transient conditions during testing. The instrumentation response *shall* be flat to a minimum of 1000 Hz.

The mock-up also *shall* include provisions for testing armament or utility functions such as weapon turret or elevation, cargo hoist, doors, and landing gear. However, since the utility functions are discrete, noncontinuous, and relatively independent of other hydraulic system functions, they may be evaluated with a less complex test than the flight control and other mission systems.

Fig. 9-12 shows a typical system schematic setup for ground testing with pressure and temperature monitoring points included. Temperature-monitoring capability should be incorporated at the:

1. Pump outlet
2. Pump case drain outlet
3. Pump suction
4. Reservoir return
5. Actuator supply
6. Actuator return.

Other temperature-sensing locations may be desirable, especially if a system heat exchanger is required as part of the system design.

Pressure transducers should be provided at appropriate circuit locations. It is desirable to avoid major changes in system plumbing. Key points for monitoring pressure include:

1. Reservoir bootstrap pressure
2. Reservoir return
3. Pump suction
4. Pump outlet
5. Branch circuit supply at using component
6. Branch circuit return at using component
7. Accumulator charge.

Installation of flowmeters as a part of the original setup may be difficult because they must be in-line and hence are added restrictions. Also, different flowmeters may be required at a single location because of variations of flow rate in different test sequences. Flowmeters, therefore, are best utilized as required—incorporated at specific points and removed as demanded by the test objectives.

9-8.2.1.2 System Provisions

The hydraulic system pumps *shall* be connected to the system in a manner which closely approximates the actual helicopter installation, insuring the shortest possible distance between the pump and the system. The pump(s) *shall* be equal in type and quantity to

those to be installed on the helicopter itself. They *shall* be driven by electric variable speed motors equipped with tachometers. This permits simulation of reduced-power and reduced-speed operating conditions.

The setup *shall* include evaluation of various maintenance functions such as:

1. Adjustment of mechanisms and linkages
2. Lubrication
3. Reservoir servicing and bleeding
4. Accumulator charging
5. Filter draining and cleaning.

In addition, the test setup should be elevated, supported, and flexed—through the use of suitable scaffolding, structure, and jacks—to simulate relative movement of the helicopter structure. This support and adjustment structure *shall* take into account static and dynamic loads imposed by various test conditions to be

applied as well as the static load of the system, test instrumentation, and personnel.

Pressure relief and/or pressure compensation and reservoir pressurization *shall* be representative of the actual system design, but may be accomplished by simulation.

Simulated loading of flight control surfaces may be by any means, but *shall* be capable of calibration.

9-8.2.1.3 Contamination Protection

All components of the test system *shall* be cleaned thoroughly prior to installation. Before or after use in the test setup, tubing and hoses *shall* be cleaned and dried internally, and shrink fit end coverings or end caps used. Components, when not installed or connected in the system, *shall* have fluid ports capped. External connections and quick disconnects *shall* be kept clean and capped when not in use. Hydraulic fluid introduced into the system via ground carts can be the

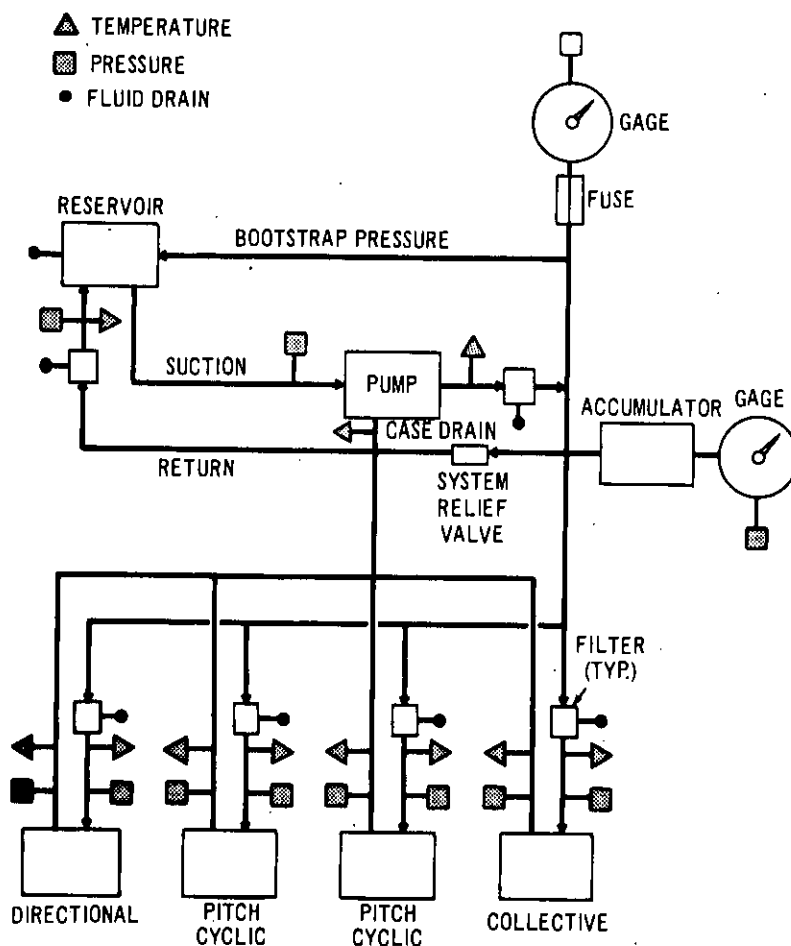


Fig. 9-12. System Setup and Instrumentation

source of considerable contamination. Such carts shall incorporate filters equal to or better than the system. Hydraulic cart filters *shall* be cleaned or changed on a regular schedule. However, cleaning and reuse of paper elements should be avoided.

In no case *shall* test system filtration be better than that required by the actual design requirements. In a typical system, filters *shall* be located at the pump pressure outlet, at the pump case drain line, at the entrance to servo valves, and in the main return line upstream of the reservoir. Fig. 9-12 shows filters and associated drain locations. In addition, MIL-H-5440 requires that:

1. Pump pressure outlet filter *shall* be incorporated downstream of the ground test pressure connection points.
2. Filters *shall* protect all vent openings.
3. Where pressure drop indicator button-type filters are used, they *shall* be installed so that the indicator is readily visible to servicing personnel.
4. When a protective filter is provided internally or in close proximity to a component, provisions *shall* be made for removal for cleaning or replacement.
5. Sintered or depth-type elements *shall* not be used. These requirements *shall* be adhered to in the setup to insure that the provisions do exist and to allow revisions as necessary.

Evaluation of system filtration and measurement of contamination generated *shall* be a part of the ground test evaluation to determine the inherent cleanliness of the system configuration. Several methods may be used for counting, grading, and/or weighing contaminants. ARP 598 can be used to determine contaminants of 5 microns or larger. Various types of automatic particle counters are available which make counting and measuring easier. However, these counters can only be evaluated against the ARP 598 procedure. This procedure is known to give imprecise results. The counters correlate with ARP 598 results within $\pm 20\%$ at each particle size level.

Other tests such as those specified in MIL-F-8815 and MIL-F-27656 may be used to measure degree of filtration. In these tests, a known weight of contaminant is added to the test fluid. After the fluid is forced through the filter, the effluent is strained through a membrane to determine the weight of the contaminant which passed through the filter.

Another method is the bubble point test. This represents a quick and easy method of determining the largest pore of a filter medium. Results of the bubble point

test can be correlated to the size of the largest bead passed.

9-8.2.1.4 Test Requirements

The functional mock-up *shall* be subjected to the tests outlined in the subsequent paragraphs to determine system performance. Emergency and auxiliary functions as well as normal modes of operation *shall* be tested. These tests *shall* be conducted prior to the first flight of the helicopter.

9-8.2.1.4.1 Peak Pressure

Peak pressures resulting from any phase of system operation *shall* be in accordance with the requirements of pars. 3.5.5.1 and 3.5.5.2 of MIL-H-5440. The peak pressures can be generated by water hammer effects due to fast-closing valves, assisting external loads, actuators with a relatively high area unbalance ratio (2:1 or more), and inadequate pump response to "stop flow" signals. The test procedure *shall* specify the specific test points and techniques to be used in checking for peak hydraulic pressures. Also, "standing waves" *shall* be considered, and additional transducers considered necessary *shall* be installed to locate the peak points. At least three cycles for each test point *shall* be recorded.

9-8.2.1.4.2 System Temperature Determination

The system temperatures *shall* be determined and converted to the standard day conditions in accordance with MIL-T-5522. The stabilized temperatures *shall* be determined for steady-state null flight control and utility system conditions. The system cooling *shall* duplicate that of the helicopter configuration as nearly as possible.

The flight control system characteristics can be defined further by cycling continuously at 1/4, 1/2, and maximum rate until system temperatures stabilize. Utility functions identical to flight control systems may be evaluated in a similar manner.

9-8.2.1.4.3 Subsystem Cycling

The performance of all systems and subsystems *shall* be evaluated and compared with design requirements. Control system rates under maximum, no-load, and intermediate loads *shall* be determined. Normal utility functions *shall* be cycled at no-load and maximum loads to determine parameters such as operating times. Emergency operation modes also *shall* be evaluated in a similar manner. Critical points such as low-temperature operation *shall* be included in the test evaluation program.

Three cycles of operation for each design evaluation point *shall* be recorded and analyzed. Failures *shall* be simulated and their effects evaluated. Single-system operation in a dual system, and failure of one or more hydraulic pumps in a multipump system, *shall* be evaluated.

9-8.2.1.4.4 Minimum Reservoir Level and Pressure

The reservoir *shall* be positioned at its minimum acceptable takeoff attitude, fuel level, and pressurization. Selected critical test points *shall* then be recorded and analyzed. This effort may include service ceiling ambient pressures and operation at specified minimum fluid temperatures. Again, the results *shall* be compared with the design objectives. Significant deficiencies may result in system redesign.

9-8.2.1.4.5 Auxiliary Pump Operation

Where auxiliary hydraulic pumps are a part of the system, their function *shall* be evaluated, and selected critical design points recorded and analyzed. Also, low fluid temperature operation may be quite critical. The most efficient means of evaluating this and other subfunctions may involve use of a test setup separate from the complete helicopter hydraulic system mock-up.

9-8.2.1.4.6 Starting Systems

Evaluation of hydraulic starting system capability probably will require a separate test setup because engine inertia and/or required torque parameters requiring simulation do not lend themselves to normal mock-up simulation.

High-, intermediate-, and low-temperature starts *shall* be recorded and analyzed. Where accumulators are involved, the precharge associated with minimum pressure anticipated in service *shall* be simulated and evaluated. The starting system demonstration is discussed in par. 9-3.2.

9-8.2.1.4.7 Brake Subsystem Tests (Wheel and Rotor)

Means of simulating the system inertia and loads *shall* be incorporated into the mock-up. The critical performance points *shall* be defined, simulated in test, and recorded for analysis.

9-8.2.2 Flight Tests

The primary objective of the flight test program is to confirm the theoretical analysis and ground test results. For the flight control systems this is performed in conjunction with the evaluation of the handling qualities of the helicopter described in par. 9-5.3. Although the

ground tests may have included load simulation, evaluation under actual operational conditions is still a potentially critical final step prior to general service usage.

The load effects, system operating characteristics, ambient and fluid thermal characteristics, pilot-system interactions, and performance in the total flight or mission envelope *shall* be evaluated.

Pressure transients are important and the load effects can be evaluated in a final manner. Performance parameters such as adequacy of control rates *shall* be checked, including the operation at minimum pump rpm's.

The time of operation or rate of utility functions under normal and emergency conditions *shall* be evaluated. The emergency modes include loss of pumps in a multipump system.

Altitude effects *shall* be evaluated with emphasis on the pump suction pressure-flow characteristics.

The impact on flight safety should be emphasized; the added instrumentation, particularly pressure transducers, must be completely assessed. For full-power (no manual reversion), redundant flight control systems, safety considerations may demand that at least one system at a time is not instrumented.

9-8.2.2.1 Servicing

The hydraulic system servicing *shall* be in accordance with the appropriate manuals for the helicopter being tested. In addition to flight test instrumentation (par. 9-8.2.2.2), items such as subsystem rigging and travel must be checked and modified, if necessary. The system fluid level and air content *shall* be checked, additional bleed and filling accomplished, and the accumulator precharge checked and serviced, as necessary. Areas such as rod-end bearings *shall* be inspected and lubricated as necessary. The system *shall* be pressurized, by using a ground cart, and checked for external leaks. Any leaks *shall* be corrected. Operation of subsystems *shall* be accomplished in an orderly sequence and pertinent data recorded on the log-checkout procedure prepared previously. The travel, time of operation, function of normal system instrumentation (lights, gages), and any other pertinent information required *shall* be observed and recorded. Items such as flight test instrumentation and recording equipment and pilot-operated switches also *shall* be checked for proper operation. The flight test instrumentation *shall* be calibrated and adjusted as necessary, and the resistance calibration and any other pertinent information observed and recorded.

9-8.2.2.2 Instrumentation

The flight test instrumentation *shall* be in exactly the same location and of the same type as that used in the ground test survey conducted on the mock-up. This is required for adequate correlation between ground and flight test results. Additional instrumentation may be required to evaluate the vibration characteristics of the system and the associated or adjacent structure.

This is likely to be the first time that the system support structure is similar to the helicopter. Vibration pickups are required at the components and the adjacent mounting structure. In addition, the fluid transmission lines and the structure adjoining the support points, particularly any suspected critical areas, *shall* be adequately instrumented.

The number of points at which instrumentation is desired, including all parameters, may be beyond the capability of airborne simultaneous recording. Therefore, recording in a series (on different flights) may be necessary.

The response characteristics of the instrumentation are very important, particularly where system and performance dynamics are involved. All channels requiring significantly high response such as pressure, vibration, and position information should have no significant attenuation out to at least 1000 Hz. Temperature pickups usually need not be as responsive because the rate of change of temperature is quite slow. This may apply to other system performance characteristics as well. For these parameters the recording of the outputs in sequence at discrete time intervals, in seconds or minutes, will be adequate.

Adequate system information for analysis and comparison includes the parameters or system characteristics which follow:

1. Power measurement (in current and voltage) may be required for electrically operated or controlled components, and is particularly important for electric motor-operated components and those items associated with primary flight control functions.
2. System temperature pickups, which are required at the following points:
 - a. Reservoir
 - b. Heat exchanger (inlet and outlet, if applicable)
 - c. Pump (outlet, inlet, case drain outlet)
 - d. Adjacent structure for points considered critical (primary consideration here is possible heat sources)
 - e. Components (inlet and outlet). In special

cases component wall temperatures also may be desirable.

- f. Ambient air in closed compartments or the vicinity of heat sources

3. System pressure instrumentation required at:
 - a. Pump outlet section
 - b. Pump case drain
 - c. Inlet and outlet ports of each flight control cylinder
 - d. Inlet and outlet parts of utility system cylinders or actuators.

The reservoir also *shall* be instrumented; if it is a bootstrap-type, it *shall* be instrumented at the pressurization port in addition to the low pressure side. If a heat exchanger is used, it *shall* be instrumented to ascertain if return transients are excessive or higher than the design requirement. If standing waves have been discovered as a result of ground tests, the specific points defined *shall* be instrumented for flight test evaluation. Control surface or subsystem output *shall* have adequate instrumentation evaluation of system rate and response capability.

Flight safety is a primary consideration in the instrumentation of flight control systems. Installation of pressure transducers in particular probably will involve system modification by installation of special fittings or the use of additional bosses on components. Extra seals and their possible adverse effects on fatigue life and structural integrity are of primary concern. If both portions of a dual system are instrumented identically, a weak point in both systems possibly could fail in flight and result in the loss of the helicopter.

The preceding discussion emphasizes the need for a thorough consideration of dual instrumentation. The minimum approach is to keep the instrumentation installation dissimilar. The recommended approach is the "series" installation and flight test of the system; i.e., the instrumentation, and flight test *shall* be accomplished on one flight control system and the instrumentation removed prior to the evaluation of a companion system.

9-8.2.2.3 Preflight Tests

9-8.2.2.3.1 Ground Tests

Prior to flight, a performance check of the helicopter systems and subsystems is required. In general the systems will be checked using a ground cart. In the case of a starting system, at least three starts *shall* be made to record instrumentation output. If accumulators are used, the precharge may be set to simulate the minimum expected in service due to temperature, and at

least one start demonstrated under this condition. Obviously, checkout of the flight controls must precede flight. At this point, the instrumentation circuits and output *shall* be checked to ascertain that the vehicle operational and vibration environments do not adversely affect their capability.

9-8.2.2.3.2 Taxi and Hover Tests

These tests *shall* be secondary to those covering control system dynamics and stability, and hover handling quality tests. The pressure, temperature, vibration, and position transducer outputs *shall* be recorded during the hover testing. The vibration data may be significant and, therefore, *shall* be analyzed closely to ascertain that there are no obvious problems. Since the maximum rate capability of the system will not be checked at this time, the pressure data probably will not indicate any problems. The severity of the ground test makes unanticipated problems highly unlikely. However, temperature data could be significant since the actual vehicle can have a much different thermal environment than the operation of the ground test setup.

9-8.2.2.4 Flight Tests

As mentioned previously for the flight control functions associated with dual systems, each system should be evaluated in a "series" during the flight test program. Initial flight tests after the hover program *shall* be conducted at altitudes which provide a safe margin for recovering from inadvertent maneuvers.

9-8.2.2.4.1 Flight Control System Flight Test

A significant part of the hydraulic flight control system evaluation *shall* be a part of the stability and control flight program as discussed in par. 9-5.3, including the collective, cyclic, and directional control functions. The pressure, temperature, position, and vibration transducer readouts *shall* be recorded and analyzed. The evaluation *shall* be conducted in accordance with a detailed flight test procedure developed prior to initiation of the flight test program. This procedure *shall* conform to the requirements of MIL-T-5522.

In this procedure the critical points of the flight envelope *shall* be defined, and various stick rate techniques and maximum rate cycling outlined. The following points *shall* be evaluated: maximum actuator rate (no-load or near no-load), maximum load, and at least two intermediate loads. In addition, performance at altitude *shall* include service ceiling, cruise altitude, at 2000 ft, and at any other critical points. The system performance *shall* be evaluated at maximum, normal, and minimum speeds of the hydraulic pump. Simulated failure effects of one system in a dual system and/or

one or more pumps in a multipump system *shall* be evaluated at all test conditions.

For each test point developed, at least three test cycles *shall* be recorded for evaluation and analysis. In addition to the basic performance evaluation, the system test results *shall* be evaluated for conformance with the applicable specifications including MIL-H-5440.

9-8.2.2.4.2 Utility Subsystem Flight Test

The utility subsystem flight tests *shall* be similar to the flight control system flight test program previously outlined in par. 9-5.3. All utility functions used in flight *shall* be evaluated during this phase—including landing gear, door, winch, armament, wheel brake systems, and any other functions. In addition, any emergency backup functions—manual release and pneumatic, pyrotechnic, and hydraulic operations—*shall* be evaluated relative to the specified performance requirements.

The pressure, temperature, position, and vibration transducer readouts *shall* be recorded and analyzed. The flight test program *shall* be conducted in accordance with a detailed flight test procedure to be developed prior to flight testing. This procedure *shall* include at least the test points specified and conform to the requirements of MIL-T-5522. In this procedure the critical points of the flight envelope *shall* be defined. The various helicopter altitudes, and forward, vertical, and side velocities at the start of each cycle *shall* be specified. Any special techniques *shall* be outlined and submitted to the procuring activity for review and approval.

The following points *shall* be evaluated:

1. Performance of the maximum, intermediate, and no-load or near no-load, points at the critical altitudes specified, including service ceiling, cruise altitude, and at 2000 ft unless otherwise specified
2. Performance at maximum, normal, and minimum at hydraulic pump power (speed) points (if the speed is variable)
3. Simulated failure effects of one or more pumps in a multipump at all points
4. Emergency modes of operation for all design attitudes and altitudes.

9-8.3 PNEUMATIC SUBSYSTEM DEMONSTRATION

9-8.3.1 Ground Tests

To make the ground tests as realistic as possible, MIL-T-5522 specifies that the test stand or apparatus *shall* be connected to the helicopter system in a manner

which approximates the actual system installation. All special test equipment *shall* be installed, and any approved system modifications completed. The pneumatic subsystems *shall* be properly lubricated, with all system components and attached linkages and mechanisms properly adjusted. The helicopter *shall* be suitably elevated, if necessary, and safely anchored in place to permit full operation of all pneumatically operated subsystems.

The following basic test equipment may be needed in the ground tests:

1. An air compressor equal to that installed on the helicopter
2. Clean, dry compressed air supply capable of charging the system to the maximum operating pressure
3. Calibrated pressure gages (mechanical or electronic as necessary)
4. Suitable jacks and/or scaffolding to support the helicopter in an elevated position
5. External electrical power supply equivalent to the helicopter supply
6. Air shutoff valves as required
7. Hydraulic test stand.

Other devices or equipment may be used in addition to those just specified, provided the equivalent results are obtained.

If artificial loading of any subsystem is necessary, adequate provision to accomplish such loading *shall* be installed and calibrated. For normal system testing, nominal system pressure *shall* be applied to the whole installation, and each selector valve and control valve *shall* be operated for at least two complete cycles. During this operation, inspection *shall* be made to determine whether:

1. The various functions are accomplished satisfactorily in accordance with MIL-P-5518, MIL-T-5522, and MIL-P-8564.
2. The movement of all components is smooth and positive.
3. Relief valves, automatic devices for terminating an operation, pressure controls, switches and signals, audible or other warning devices, and similar installations function as intended. Relief valves need not blow off but *shall* not bypass air during normal operation of any component.
4. All indicating devices function and synchronize with the movement of the respective component as specified.
5. The specified functioning pressures are con-

trolled and not exceeded. This may need to be determined at only one or at numerous locations in the system, but should not receive major consideration at any point where unrealistic pressures are obtained on ground test as compared with entirely different pressures in flight, unless the unrealistic pressures will adversely affect the systems during operational use. Pressures may be obtained by normal system pressure gages, or electronic equipment as applicable.

6. All tubing and fitting joints and component external seals are free from leaks.

7. All lines, fittings, and components are free from excessive movement and chafing.

8. There is full engagement of mechanical locks and catches.

9. The clearance for all moving parts throughout the entire range of movement is such that fouling of adjacent parts cannot occur. Particular attention *shall* be given to flexible connections to insure that pinching or stretching does not occur.

10. All pneumatically operated doors and closures are flush with surrounding surfaces within limits specified.

11. Simulated normal flight operating conditions, or any possible inadvertent operations, will not cause system malfunctions.

12. Ambient temperatures are within permissible limits.

All emergency operations *shall* be tested on all subsystems normally operated by the pneumatic system or operated by the system during the emergency. Each subsystem *shall* be inspected for smooth, continuous operation during the changeover from normal to emergency operation.

9-8.3.1.1 High-pressure Pneumatic Subsystems

High-pressure pneumatic subsystems requiring ground tests are of the airborne compressor-charged and ground-charged storage bottle types. Hot gas subsystems normally are not reusable (at least not without refurbishment) and are considered a "one-shot" operation, in which case verification is accomplished through qualification and acceptance testing on a component basis. Another high-pressure pneumatic source is a sealed gas storage bottle which can be used as an emergency backup system; but this is also a "one-shot" operation. This type of sealed gas storage bottle is verified to contain its correct pressure by periodic weighing, as loss of pressure would be indicated by a decrease in weight.

Ground testing of the integrity of an airborne compressor-charged system (Fig. 9-13) requires a preliminary flushing of the system with clean dry air. Manual shutoff valves may be installed in each subsystem pressure line. With a high-pressure pneumatic external source connected to the ground charging valve, each shutoff valve is left open until there is evidence that no foreign matter is exhausting from the subsystem. Components such as subsystem pressure regulators and actuators must be bypassed or disconnected during the flushing operation. If an excessive amount of oil is exhausting from a shutoff valve, all lines and components in the circuit *shall* be removed, inspected, and cleaned or replaced. Air storage bottle drain valves should be opened until all foreign material and moisture have been discharged, then closed. During the flushing period, the system also may be checked for leaks. With the bleed lines closed, relief cracking and reseal pressures may be verified by raising the source pressure. After the flushing procedure is completed, components that were removed or bypassed *shall* be properly reinstalled in the system.

With the helicopter positioned for testing, an external source of clean, dry air *shall* be connected to the ground charge valve. A manual bleed valve and an accurately calibrated pressure gage should be installed

near the ground charge valve. With the air source pressure regulator set to deliver the nominal system operating pressure, each subsystem *shall* be operated to verify operation. A leak check *shall* be made. During charging of the pneumatic system, the pressure gage on the instrument panel *shall* be compared with the external calibrated pressure gage. The system pressure gage located near the ground charge valve (Fig. 9-13) also *shall* be verified for accuracy. A detailed ground test procedure *shall* be established for each subsystem with maximum regard for safety to test and maintenance personnel.

For tests using the helicopter airborne air compressor, all external pneumatic power *shall* be removed. The system may be charged to a pressure slightly below the compressor "cut-in" pressure before removal of the external pressure source. Electrical and hydraulic power (if the compressor is hydraulic motor-driven) *shall* be connected to the external power connectors. The pressure at which the compressor "cuts out" *shall* be recorded. The pressure *shall* be bled down slowly through the bleed valve and the "cut-in" pressure of the compressor recorded. This test should be repeated for five cycles with the accuracy of the cockpit gage also checked. When the compressor shuts down, there should be condensate drainage from the moisture

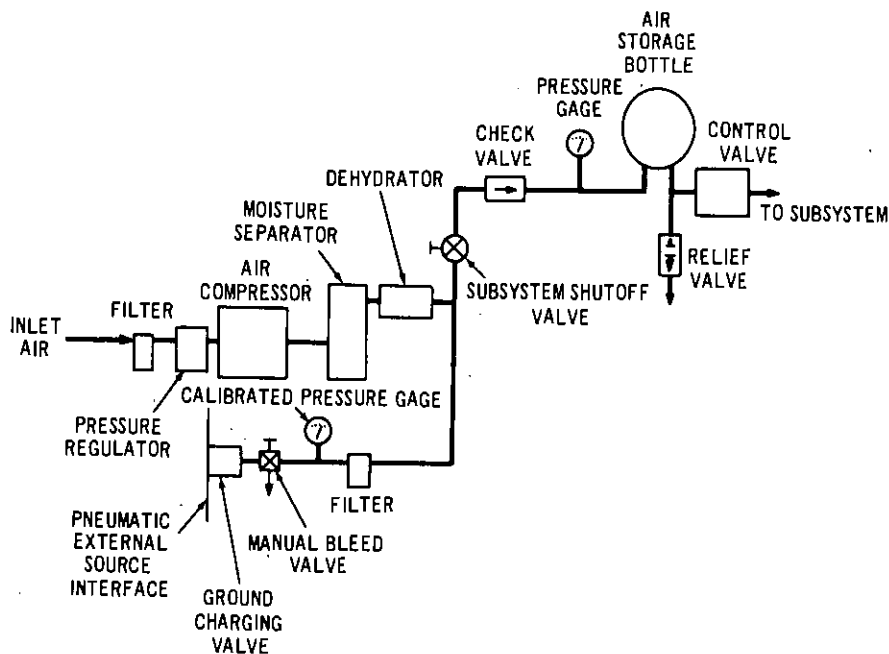


Fig. 9-13. Airborne Compressor-charged System

separator. Lack of drainage indicates a malfunction. External power sources then *shall* be disconnected.

To pressure leak test the system, ground charge it to the maximum operating pressure and disconnect the ground charge supply. The permissible leakage rate *shall* not exceed that specified, which usually is measured over a one-hour period. During the test, the ambient air temperature should be kept constant. The temperature of the air inside the system usually is higher than the ambient air temperature due to the reverse Joule-Thompson effect (i.e., the air heats up when charged through a valve). The cooling of this air may result in a pressure decline, and therefore give a false leak indication. Consequently, a temperature pickup *shall* be attached to the skin of the air bottles or the system.

Ground-charged air bottle subsystems are tested in the same manner as the airborne compressor-charged subsystem.

9-8.3.1.2 Low-pressure Pneumatic and Vacuum Subsystems

Low-pressure pneumatic and vacuum subsystems commonly are supplied by bleed air from the engine compressor (see Fig. 9-14). The bleed air is normally at a very high pressure when exiting the compressor and, by necessity, the ducting is insulated.

Extreme caution should be exercised by personnel in handling these subsystems. Safety precautions *shall* be outlined by the contractor.

A typical low-pressure pneumatic subsystem is shown in Fig. 9-15. This is representative of supplying pressure for an air-conditioning system, pressurizing a hydraulic reservoir or any desired low pressure pneumatic system. The bleed air pressure of the helicopter engine is regulated to the desired operating pressure with a pressure regulator. Ground testing normally re-

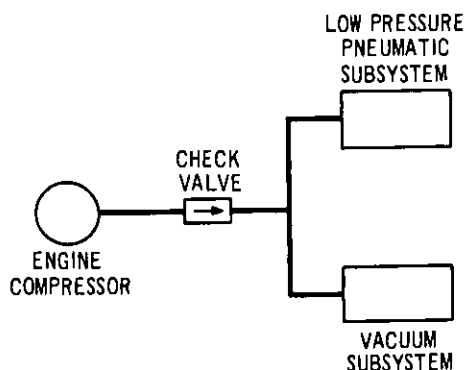


Fig. 9-14. Low-pressure Pneumatic Supply

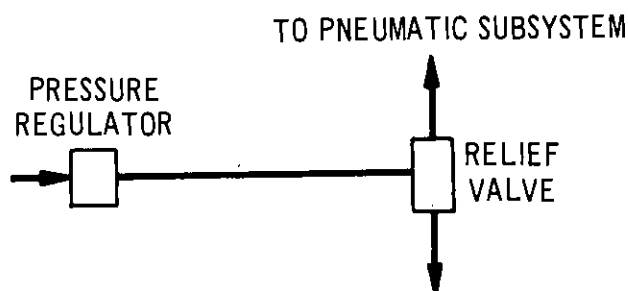


Fig. 9-15. Low-pressure Pneumatic Subsystem

quires disconnecting the helicopter electrical power from the pressure regulator. External electrical power and hydraulic power (for hydraulic-related subsystems) are required.

An external pneumatic source *shall* be connected to the bleed air connector of the inlet. The outlet pressure of the source *shall* be regulated to the maximum design bleed air pressure into the subsystem pressure regulator. A schematic of the required test apparatus is shown in Fig. 9-16.

The test shutoff valve normally is closed. By opening the shutoff valve, pressure is allowed to enter the subsystem, and a check for leakage and pressure drop can be made. To verify relief valve operation, the subsystem pressure regulator must be bypassed to allow the higher pressure to the downstream subsystem. Specified relief valve cracking pressure and reseal pressure *shall* be verified. Leakage is verified by pressuring the subsystem to the maximum operating pressure and disconnecting the pneumatic supply. Acceptable pressure drops *shall* be specified in the test procedures. The bleed valve is used for removing system pressure before disconnecting the test apparatus.

A typical vacuum subsystem is shown in Fig. 9-17. Bleed air is ported through the pressure regulator, and through the air ejector and overboard.

The air passing through the air ejector provides a vacuum at its secondary port. Air is drawn through the vacuum regulator as it regulates the vacuum pressure in the vacuum subsystem. As the air from the pressure regulator enters the air ejector outlet nozzle, the air is accelerated to supersonic velocity, inducing a vacuum at the secondary port. A test procedure and apparatus similar to that described for the low-pressure pneumatic subsystem may be utilized. With the ground pneumatic source connected to the bleed air connector, the inlet pressure *shall* be regulated at its minimum and then its maximum pressure. A calibrated gage *shall* be placed in the vacuum subsystem line to verify the pres-

sure. After testing, all test components *shall* be removed, the normal helicopter components reinstalled, and all interfacing systems reconnected.

9-8.3.2 Flight Tests

The satisfactory completion of ground testing *shall* be followed by flight testing, in accordance with MIL-T-5522. The helicopter *shall* be instrumented to measure and record (manually or automatically, as applicable) all necessary pressures, ambient air and system temperatures, component time of operation, and other data required on any individual system. The system(s) *shall* be properly serviced for adjustments. All necessary special components *shall* be installed and checked for proper and safe function. With the engine running, all pneumatic subsystems operating from engine bleed air or the airborne air compressor system *shall* be operated to insure proper operation. In flight, each pneumatic normal operating subsystem *shall* be operated three times at required altitudes with the helicopter flying at the maximum speed for the subsystem. For these conditions, the helicopter should be flown until system temperatures have stabilized prior to testing.

All necessary operating pressures—such as the airborne pneumatic compressor inlet, outlet, and regulating pressures—*shall* be verified. The temperature of the compressor outlet *shall* be instrumented along with inlet temperatures of the air bottles. All instrumentation *shall* be calibrated according to the test procedures. It *shall* be demonstrated that the temperatures do not exceed those to which the components are designed, with consideration given to the percentage of operating time to be encountered at various temperatures and conditions.

All pneumatically operated services *shall* be checked to ascertain the number of consecutive full cycles of operation possible before the air bottle(s) are discharged to a pressure below which operation is impossible. For airborne compressor-charged air bottles, the time required to recharge the air bottle(s) to cutout pressure *shall* be verified.

The operation of all pneumatic control valves *shall* be checked for possible malfunctions. Any possible inadvertent operation should be checked to determine any malfunctioning which could be encountered.

There *shall* be at least one operation of each pneumatic emergency system. These operations *shall* be

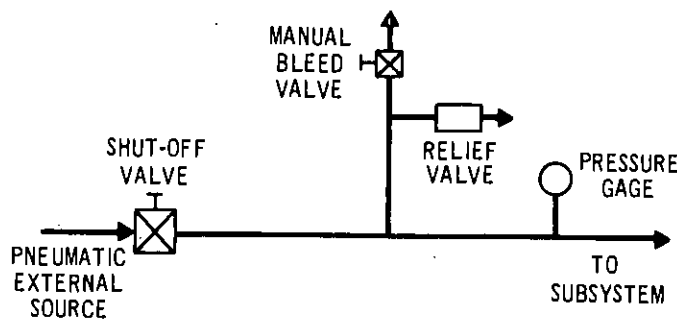


Fig. 9-16. Test Apparatus Schematic

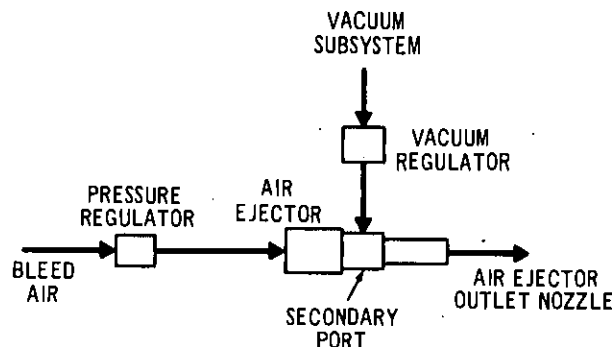


Fig. 9-17. Typical Vacuum Subsystem

made at applicable altitudes and speeds. Necessary pressure and elapsed time of operation *shall* be determined.

All auxiliary systems *shall* be suitably tested with the applicable features of tests herein employed for verification.

9-8.3.3 Documentation

Detailed data *shall* be supplied in accordance with MIL-P-5518, while test reports *shall* be furnished according to MIL-STD-831.

9-9 INSTRUMENT DEMONSTRATION

9-9.1 GENERAL

Par. 9-9 defines the instrumentation system substantiation requirements. The verification requirements defined herein include each of the following types of instrumentation:

1. Flight
2. Communication
3. Navigation
4. Engine
5. Warning systems
6. Armament/weapon delivery
7. Environment.

The inspection and testing of all helicopter instruments *shall* be classified as either qualification or acceptance tests.

Each of these tests is described in detail in the basic Military Specification written for that instrument (see Table 9-2). The individual tests normally are used to determine performance acceptability. Items such as electrical nulls, proper calibration, oscillation damping, sensitivity, followup rate and accuracy, and power warning all are part of the individual tests. Equivalent tests *shall* be required for the qualification of new instruments for which no Military Specification is applicable.

Demonstration of the adequacy of the instrument installation is required to verify that all instruments perform satisfactorily in the helicopter, and that necessary maintenance and servicing of the instruments can be performed without undue difficulty.

9-9.2 QUALIFICATION TESTS

The qualification testing *shall* include three instruments and all the items tested under acceptance tests (primarily environmental conditions and performance

requirements) plus reliability and mean-time-between-failure (MTBF) tests and demonstrations. These tests are detailed in the basic Military Specification which covers the particular instrument.

If the instrument has been previously qualified and is on the Qualified Products List (QPL), the qualification testing need not be repeated unless additional requirements have been imposed on the basic specification (see Chapter 7). Qualification testing may include a longevity test, in which one indicator that has already met the basic reliability test *shall* continue to be tested for an additional period of time. The purpose of this additional testing is to gain data on the wearout period of parts which may not be affected by the normal MTBF.

The qualification tests *shall* consist of:

1. All tests specified under "Individual tests", in par. 9-9.3
2. All tests specified under "Sampling Plans A and B", in par. 9-9.3
3. Reliability and MTBF
4. Longevity.

9-9.3 ACCEPTANCE TESTS

Acceptance tests consist of individual tests, and sampling plans and tests.

1. Individual Tests:

- a. First series: Each indicator *shall* be subjected to a series of tests as follows:

- (1) Examination of product
- (2) Starting
- (3) Pitch and bank zero
- (4) Pitch trim
- (5) Zeroing adjustments
- (6) Sensitivity
- (7) Followup rate
- (8) Followup accuracy
- (9) Gimbal freedom
- (10) Leak rate
- (11) Power warning indicator

TABLE 9-2. SPECIFICATIONS FOR FLIGHT, NAVIGATION, AND ENGINE INSTRUMENTS

TYPE	INSTRUMENT	SPECIFICATION
FLIGHT	ATTITUDE INDICATOR	IND-A5-UH-1 MIL-I-38258 MIL-I-27680 MIL-I-27710 MIL-I-83188
	TURN AND SLIP INDICATOR	MIL-I-25941
	INDICATED AIRSPEED INDICATOR	MIL-I-38135 MIL-I-5417 MIL-I-5721
	TRUE AIRSPEED INDICATOR	MIL-I-27673
	BAROMETRIC ALTIMETER	MIL-A-23395 MIL-A-19679 MIL-A-83212
	ELECTRONIC ALTIMETER	MIL-A-23887
	ALTITUDE RATE INDICATOR	MIL-I-5098 MIL-I-18804 MIL-I-58067
	ANGLE OF ATTACK INDICATOR	MIL-I-83117
	RADIO MAGNETIC INDICATOR (RMI)	ID-1351
NAVIGATION	BEARING-DISTANCE-HEADING INDICATOR (BDHI)	MIL-I-38357 MIL-I-22075
	HORIZONTAL SITUATION INDICATOR	MIL-I-83034 MIL-I-23366
	DISTANCE MEASURING EQUIPMENT (DME)	MIL-I-8692
	TACHOMETER (GAS GENERATOR)	MIL-G-9398 MIL-I-27202
ENGINE	TACHOMETER (POWER TURBINE AND ROTOR)	MIL-I-23832 MIL-I-8580 MS-18099
	TORQUEMETER INDICATOR	MIL-I-27683 MIL-I-22126 MS-90323
	MEASURED GAS TEMPERATURE (MGT)	MIL-I-25026 MIL-I-27552
	OIL PRESSURE INDICATOR	MIL-I-38133 MIL-T-5790 MIL-T-7748 MIL-T-38230 MIL-I-8138
	OIL TEMPERATURE INDICATOR	MIL-T-7990 MIL-I-7071 MIL-I-25852
	VERTICAL SCALE PROPULSION INSTRUMENTS	MIL-E-27669 MIL-E-27675

(12) Fogging

(13) Lighting.

b. Second series:

(1) Examination of product

(2) Case leakage

(3) Diaphragm capsule leakage

(4) Scale error at room temperature

(5) Friction

(6) Other tests specified in MIL-L-25467 or MIL-L-27160.

2. Sampling Plans and Tests:

a. Sampling Plan A: One indicator *shall* be selected at random from each 100 or less produced on the contract or order and subjected to the following tests:

(1) Individual tests

(2) Power consumption and weight

(3) Power variation

(4) Followup operation (except damping)

(5) Magnetic effect

(6) Acceleration (with power applied)

(7) Dielectric strength

(8) Vibration error

(9) Horizontal line and bank index null position shift

(10) Low-temperature operation

(11) High-temperature operation

b. Sampling Plan B: Three indicators *shall* be

selected at random from the first 15 items produced on the contract or order and subjected to the following tests:

(1) Sampling Plan A tests

(2) High temperature exposure

(3) High altitude-low temperature

(4) Temperature-shock

(5) Humidity

(6) Fungus

(7) Rain

(8) Salt fog

(9) Dust

(10) Vibration failure

(11) Acceleration (without power applied)

(12) Pressurization

(13) Electromagnetic Compatibility in accordance with MIL-STD-461

(14) Damping.

3. Reliability and MTBF Tests. Procedures for reliability and MTBF tests are discussed in par. 10-1.

4. Longevity Tests. Longevity tests normally are imposed on those instruments which have previously passed qualification testing but which have undergone significant design changes in materials (rather than concept). Longevity tests can be expected for design changes such as the use of solid state display components (light emitting diode (LED), electro-luminescence (EL), neon, etc.) to replace electromechanical counters and DC versus AC systems.

9-9.4 ENVIRONMENTAL TESTS

Requirements for environmental testing of components are discussed in Chapter 7.

9-9.5 INSTALLATION TESTS

There are few quantitative requirements which help in defining the substantiation procedures for helicopter instrument installations. The portions of individual instrument specifications dealing with installation requirements usually are confined to shock and vibration requirements but do not cover a group of instruments. Consequently, they have little application to a system configuration such as an entire helicopter instrument panel.

9-9.5.1 Shock and Vibratory Qualification

When normally mounted (with vibration isolators in place, if applicable), panel-mounted instruments should operate satisfactorily when subjected to vibration within the frequency range and amplitude of Curves III or IV of MIL-E-5400. Due to the characteristics of their rotor/transmission systems, most helicopters have significant vibrations so that vibration isolators frequently are placed on the entire instrument panel. In such cases, the instrument panel and related instruments can be considered as a unit for analysis of the vibration environment.

Shock tests and requirements also are specified in applicable individual instrument specifications as well as in MIL-E-5400. In MIL-E-5400, shock requirements are stated as a resistance to damage when subjected to three shocks in opposite directions along each of the three axes. These impact shocks are at 15 g's for 11 ± 1 msec. Such requirements apply only to the individual instruments; and shocks imposed by hard landings, which are amplified by dynamic loading, are not considered. In most cases, the aforementioned vibration analysis takes into consideration the necessary dynamics of the helicopter so that damage to panel- and console-mounted instruments is minimum.

9-9.5.2 Functional Tests

Functional tests on all Government-furnished flight, propulsion, and miscellaneous instruments and systems *shall* be conducted according to the applicable procedures and tolerances set forth in MIL-I-5949.

9-9.5.3 Maintainability Qualification

Maintainability qualification *shall* be in accordance with par. 10-2.

9-10 FURNISHING AND EQUIPMENT DEMONSTRATION

9-10.1 GENERAL

This demonstration is intended to insure that the crew can accomplish all required functions necessary for the accomplishment of assigned helicopter missions. The demonstration *shall* include personnel accommodations and cargo provisions. For an early design review of normal operational conditions, a wooden mock-up which is an accurate three-dimensional representation of the crew compartment and all displays, controls, seats, support equipment, etc., can be used. The mock-up is discussed in detail in Chapter 5. While wearing worst condition equipment and clothing, which normally would be body armor and Arctic clothing, seated at each normal flight station, and with shoulder harness and seat belt fastened, a man who is in the 5th percentile in seated height and in reach, as well as a man who is in the 95th percentile in seated height and in reach, must be able to perform all functions required. A complete mock mission *shall* be conducted, including execution of all tasks for normal flight. All emergency and escape procedures also *shall* be performed in simulation.

Demonstration tests for helicopter cargo provisions *shall* confirm operational procedures and envelopes, and assure system compatibility. Qualification of individual components and subsystems, as required by their governing specifications, are to have been completed before demonstration tests are begun. Such qualification tests include necessary load, endurance, and environmental tests for the components, and need not be repeated during the demonstration tests. Strength tests of attachments of cargo furnishings and fittings to the helicopter structure are to be completed prior to demonstration tests. These normally are accomplished by laboratory bench tests or on the static test helicopter. It also *shall* be demonstrated that cargo loading provisions maintain the helicopter CG position within the approved limits, and that CG movement associated with cargo air drop is within limits.

9-10.2 PERSONNEL ACCOMMODATIONS

9-10.2.1 Personnel Visibility

MIL-STD-850 outlines the general requirements for aircrew station vision for military helicopters and *shall* apply to Army helicopters.

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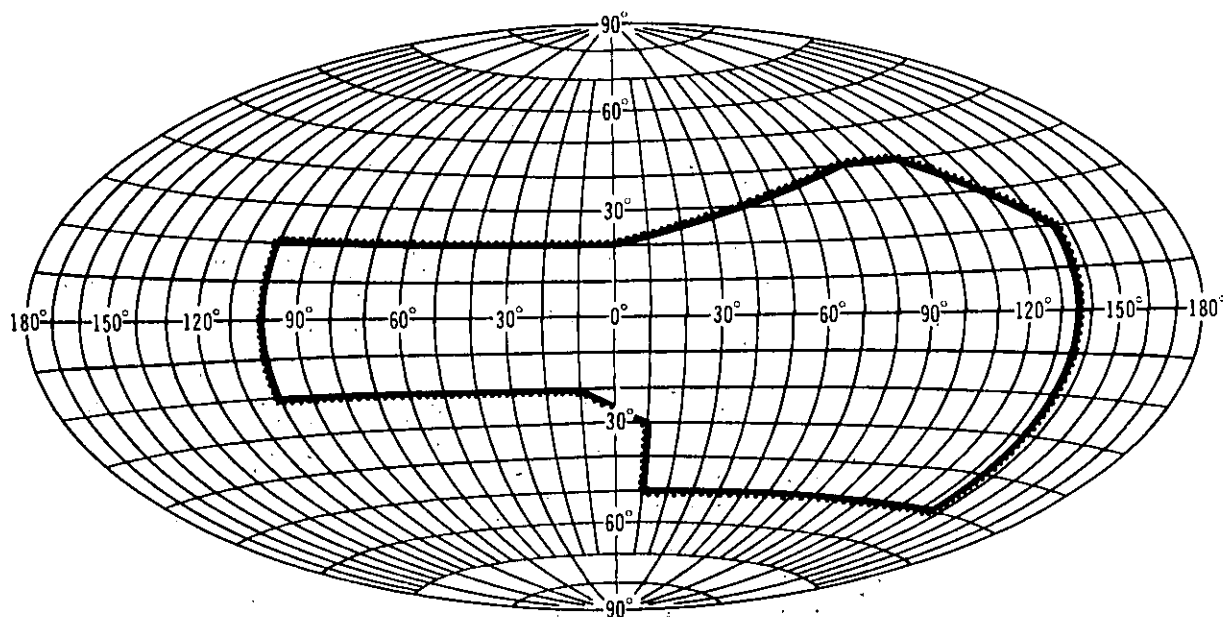


Fig. 9-18. Side-by-side Helicopter Vision Plot

9-10.2.1.1 Side-by-side Pilot Helicopter

Although MIL-STD-850 applies in total, some of the more important requirements applicable to side-by-side pilot/observer helicopters are included here for emphasis. These are given relative to the longitudinal fuselage reference line.

Controls, consoles, and instrument panels *shall* be located so that they do not restrict vision with particular emphasis on adequate over-the-nose visibility. Inspectors will insure that mounting and reinforcing frames or strips which divide transparent areas and form obstructions to vision are not more than 2 in. wide when projected onto a plane perpendicular to a line between the structure and the pilot's eyes at the design eye position. Such obstructions should be located to avoid the critical vision areas.

The contractor *shall* demonstrate that the minimum angles of unimpaired vision illustrated in Fig. 9-18 are available to the pilot from the design eye position.

The particular helicopter and mission requirements may necessitate external vision angles greater than those specified in MIL-STD-850 due to approaches over critical barriers, confined autorotations, etc. If greater angles are required, it should be stated in the individual contract requirements.

9-10.2.1.2 Single Pilot/Tandem Pilot or Observer

The forward cockpit position, if occupied by other than the primary pilot, also *shall* comply with the requirements cited previously. In addition, the minimum angles of unimpaired vision illustrated in Fig. 9-19 *shall* be available to the pilot from the design eye position.

Visibility in elevation of at least 90 deg *shall* be provided. The restrictions on horizontal structure of not more than 2 in. in width along or above the elevation boundary, and vertical structural members of not more than 2 in. in width located as defined in par. 9-10.2.1.1 also *shall* apply to the single/tandem pilot arrangement helicopter.

9-10.2.2 Crew Station Environmental Control System (ECS)

The qualification of the crew station environmental control system may be demonstrated during the crew environmental survey described in par. 8-8.

9-10.2.3 Internal Acoustical Environment

The noise within the crew compartments *shall* not be in excess of the maximum allowable levels prescribed in HEL Standard S-1-63, MIL-STD-740, or MIL-A-

8806, as applicable. The acoustical noise survey requirements are specified in par. 8-9.6.2.1.

9-10.2.4 Toxicology

Short-term, high-concentration toxic elements can be generated by materials aboard the helicopter such as fuel, lubricants, or armament; or as a result of external concentrations in the atmosphere surrounding the helicopter during enemy actions.

There should be a comprehensive investigation of the materials used to construct the helicopter to determine the existence of possible toxic elements. Consideration *shall* be given to the removal and the detection of any toxic elements which may enter into or be generated within the crew compartments or the cockpit. Further, the contractor *shall* demonstrate that the toxic elements do not exceed the limit specified in U.S. Air Force Specification Bulletin 526.

9-10.2.5 Seating/Furnishings

Evaluation of the seating and furnishings of the helicopter *shall* be accomplished insofar as is possible through detailed mock-up evaluation. Chapter 5 details the mock-up requirements. Structural integrity is demonstrated through engineering tests which involve stress analysis, laboratory tests (shake table, etc.), and

any destructive testing required by the procuring activity. The structural integrity demonstration is discussed in par. 9-2. Further considerations to be evaluated are:

1. Escape provisions
2. Comfort features
3. Restraint system
4. Adjustment features
5. Passenger accommodations as they vary from pilot and crew accommodations
6. Protective armor, if applicable.

Guidelines appropriate to the furnishing requirements are found in Military Specifications which include MIL-S-5822, MIL-M-8650, MIL-S-18471, MIL-S-18619, MIL-S-25073, MIL-S-7832, and MIL-S-9479.

9-10.2.6 Ingress and Egress

Ingress and egress for crew members and passengers should be effected with minimum difficulty and with minimum probability of damage to or fouling of the equipment, clothing, etc. of personnel and must be demonstrated to be satisfactory. Doors and hatches should be tested, with the possibility of jamming being shown to be remote. Personnel participating *shall* wear

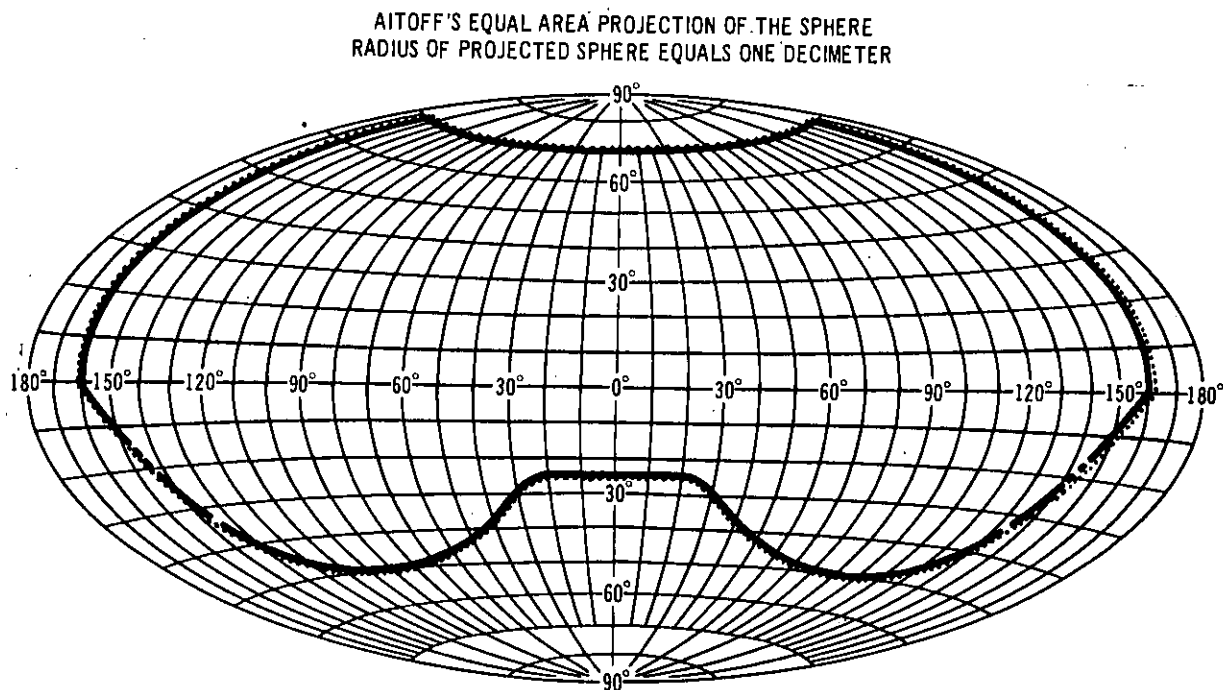


Fig. 9-19. Single Pilot/Tandem Pilot Helicopter Vision Plot

the heaviest clothing and carry the maximum equipment consistent with the mission of the helicopter.

9-10.2.7 Emergency Evacuation

Demonstration of emergency evacuation procedures *shall* include:

1. General Considerations:

- a. **Simplicity.** Is the simplest escape mode, consistent with safety and effectiveness, provided?
- b. **Evacuation Time.** Is emergency evacuation by all crew members after crash landing possible within 20 sec, using only one-half the exits? Can all passengers and crew members be evacuated within 45 sec after crash landing using only one-half the exits?
- c. **Cutaway Areas.** Are areas of the vehicle structure which can be chopped through in emergencies clearly marked? Are axes provided and adequately labeled?
- d. **Movable Articles.** Has provision been made for securing movable articles within the vehicle prior to a crash landing?
- e. **Contact With Exterior Vehicle Protrusions.** Do the escape system and provisions for escape preclude personnel contact with exterior vehicle protrusions during emergency evacuation?
- f. **Evacuation Aids.** In the case of the large helicopter in an unusual attitude, if hatches or door sills are more than 72 in. above the ground, are evacuation aids provided? Are handholds which will accommodate personnel wearing gloves or mittens provided in order to assist escape after crash landing or ditching?
- g. Are doorways, hatches, etc., obstructed by seats, cargo, or equipment during normal operations?

2. Escape Exits:

- a. **Lighting.** Has emergency lighting been provided at or near each emergency exit?
- b. **Doors and Hatches.** Are doors and hatches quick-opening and easily operated, require no more than 30 lb force to operate, and are they operable with either hand with no more than two distinct and different motions? Are handles and controls protected from inadvertent contacts? Are openings smooth-edged and free of obstructions?
- c. **Survival Requirements.** Has survival equipment been provided?

9-10.3 CARGO PROVISIONS

9-10.3.1 Cargo Compartment Floors

A proof test of the cargo compartment floor to limit loads is required. Design limit loads, both distributed and concentrated, are to be applied to walkways, treadways, and general cargo and passenger area floors. Static tests are discussed in par. 9-2.2.

9-10.3.2 Tiedown Fittings and Devices

Proper operation of all tiedown fittings and devices *shall* be demonstrated. Representative demonstration cargos *shall* be made up and secured in the helicopter using the procedures that are defined in the Operator's Manual. Particular emphasis is to be placed on accessibility and ease of operation of tiedown provisions.

9-10.3.3 Cargo Doors and Ramps

All cargo doors and ramps *shall* be demonstrated through six complete operations in the normal mode; e.g., manual, electrical, or hydraulic. Alternate modes, or procedures to be followed in emergencies, *shall* be demonstrated through one operation. All control devices, including limit switches and overload sensor, *shall* be operated. Procedures contained in the Operator's Manual *shall* be followed.

Doors and ramps that are used as cargoways during loading and unloading operations *shall* be subjected to proof tests at limit loads. Design limit loads, both distributed and concentrated, are to be applied to any areas that are used for walkways, treadways, or cargoways (see par. 9-10.3.8 for flight demonstration requirements).

9-10.3.4 Winch Systems

Winch systems *shall* be demonstrated through a minimum of six operations at maximum rated capacity. Winch operation at the limits of acceptable angular displacement of the load from the drum or sheave *shall* be included in the demonstration (see Fig. 9-20).

Compliance with the detail specification requirements for winch speeds also is required. A minimum of four load/speed combinations is to be demonstrated, namely minimum or zero load, 50%, 75%, and maximum rated load.

The demonstration is to cover all normal and emergency modes of operation. Proper functioning of all control devices, limit switches, and overload sensors used in the system *shall* be demonstrated. Quick disconnect devices and cable cutters in the winch system are to be actuated at 25%, 50%, 75%, and maximum

rated load. Devices or methods of operation to increase the mechanical advantage of the winch also *shall* be demonstrated (see Fig. 9-21).

The winch *shall* be operated from each station from which it can be controlled. Procedures contained in the Operator's Manual are to be followed during the demonstration.

9-10.3.5 Conveyors and Tracks

All conveyors and tracks installed in the helicopter *shall* be subjected to proof tests. Limit loads and concentrated loads *shall* be applied, and the loads *shall* be moved along the conveyor or track at maximum permissible speed. Proof tests also *shall* be conducted at any other critical load/speed combinations.

9-10.3.6 Hoist Systems

Hoist systems *shall* be demonstrated through a minimum of six operations at maximum rated capacity. The demonstration is to cover all normal and emergency modes of operation; e.g., hydraulic, electrical, or manual. The hoist is to be manipulated from each operating station from which it can be controlled.

An inflight demonstration of the hoist system is required for helicopters designed to carry loads externally on the hoist. The vehicle is to be flown to the extremes of the applicable maneuver flight envelope and all conditions which are critical to strength, maneuverability, stability and control, or any other factor affecting airworthiness are to be included. Maximum hoist system rated load is to be used for these tests, unless a lesser load is more critical for dynamic stability.

A minimum of four load/speed combinations also *shall* be demonstrated to determine compliance with the helicopter detail specifications. Speeds at minimum or zero load, 50%, 75%, and maximum rated load are to be used.

The demonstration *shall* include operation of all control devices, limit switches, and overload sensors used in the hoist system. Quick disconnect devices and cable cutters *shall* be actuated at the most critical load condition.

Operating procedures defined in the Operator's Manual *shall* be followed throughout the demonstration.

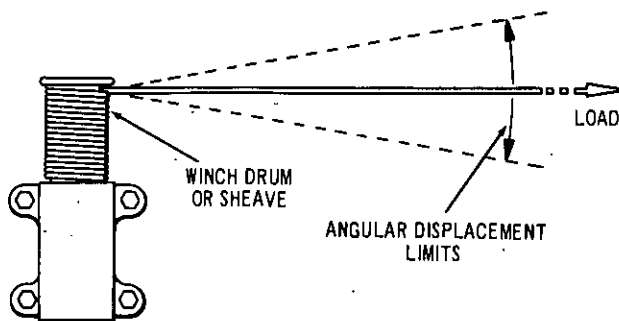


Fig. 9-20. Winch System Angular Displacement

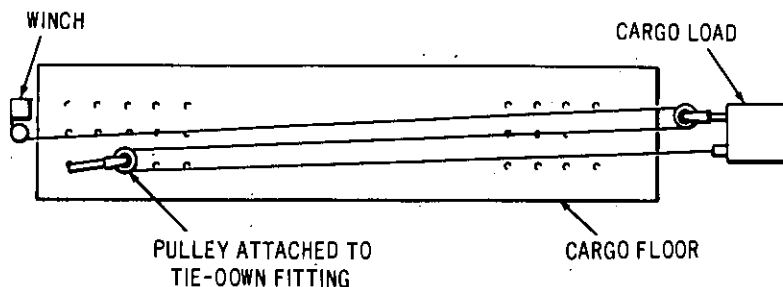


Fig. 9-21. Winch System Operational Demonstration

9-10.3.7 Cargo Hook Systems

The cargo hook *shall* be demonstrated with the helicopter in flight. Automatic and semi-automatic hook engagements of a load *shall* be made. All release modes including normal, automatic touchdown, manual, ground, and emergency *shall* be shown. Emergency release *shall* be demonstrated during turns at maximum allowable bank angle and speed, and while carrying hoist system maximum rated loads. These tests may be carried out jointly with tests of the hoist system (see par. 9-10.3.6).

Relatch features are to be operated, and proper operation of safety or warning devices such as unlatched load beam indicator lights are to be verified. The demonstration *shall* follow procedures defined in the Operator's Manual.

9-10.3.8 Inflight Demonstration

All cargo doors and ramps intended for airborne operation *shall* be demonstrated in flight. The outer limits of the operational flight envelope of the cargo door and ramp *shall* be demonstrated as well as any other critical points within the envelope.

The demonstration *shall* cover all normal modes of operation as well as emergency procedures. Doors and ramps that are blown off or otherwise ejected or lost from the helicopter in an emergency need not be included in this demonstration. However, it *shall* be demonstrated that door or ramp separation from the helicopter does not result in additional hazard such as a separated object or debris striking the tail rotor, or adverse aerodynamic loading as a result of the new external aerodynamic configuration. All control devices, including limit switches and overload sensors, are to be exercised. The procedures in the Operator's Manual *shall* be used.

9-10.4 ENVIRONMENTAL CONTROL SYSTEMS

9-10.4.1 Heating, Ventilating, and Air-conditioning Systems

Cabin heating, ventilating, and air-conditioning systems *shall* meet the requirements of par. 3-1.4 of AMCP 706-202 or the helicopter detail specification. Ground and flight demonstrations *shall* be conducted using procedures defined in MIL-H-18325 and MIL-T-18606.

Suitable instrumentation *shall* be installed to measure the system airflow (pounds per minute), the temperature differential, and the pressure drop across each major component of the system, including the elec-

tronic equipment and equipment bays. The accuracy of these measurements should be within $\pm 5\%$.

System performance tests *shall* be conducted with a minimum of 75% of the passenger and crew accommodations occupied during cooling tests, and a maximum of 10% of the passenger accommodations occupied during heating tests. Instrumentation *shall* be provided to determine the temperature distribution within all occupied spaces of the helicopter, all electronic equipment bays, and compartments. Instrumentation *shall* be provided to determine the velocities of flow in all occupied compartments under all flight conditions.

An investigation of the cleanliness of air supplied to the cabin *shall* be made by collecting air samples in an evacuated container and by analyzing the contents in a laboratory. Sufficient samples *shall* be obtained to cover all flight conditions under which contamination may exist. The moisture content of the air in both crew and passenger compartments also *shall* be determined. Tests shall be conducted to demonstrate safe and satisfactory performance of the system and component equipment under the following conditions:

1. Climb
2. Descent
3. Level flight
4. Maneuvering flight
5. Hover (IGE and OGE).

Smoke or gas removal procedures *shall* be demonstrated to prove conclusively that proposed methods are adequate to clear all areas occupied by passengers and crew of hazardous concentrations of smoke or gas within a safe period of time. The removal of odors from sanitation areas *shall* be demonstrated during actual use of these facilities.

Tests on ventilating and cooling systems *shall* be conducted during the daytime to determine the capability of the system with the full effect of solar radiation and with the maximum daylight electrical load in use within the helicopter crew compartment.

Nighttime tests of heating systems *shall* be conducted to demonstrate the adequacy of the system in the absence of solar radiation and with minimum electrical load applied within the helicopter cabin.

If the flights cannot be made under the most critical design atmospheric temperatures, sufficient test data *shall* be obtained and an accurate extrapolation made to the design condition. Critical design temperatures *shall* be specified in the helicopter detail specification. The moisture content for the standard hot atmosphere *shall* be taken as 0.019 lb of water per pound of dry air at all altitudes until saturation value is reached, after

which it *shall* be the saturation value corresponding to the design atmospheric temperature. The design atmospheric conditions in par. 3.9 of MIL-T-5842 *shall* apply to flight testing of defogging and defrosting systems. Sections of duct in the normal duct system, as calibrated for the helicopter installation, *shall* be used to determine the airflow in each component part of the air-conditioning system wherever possible. Calibrated orifices or venturis may be used in duct systems where added pressure drop does not affect distribution or restrict airflow. If calibrated sections of the duct or orifices cannot be used, the use of calibrated pitot-static tubes is permissible. Icing of the pitot heads may occur if this type of instrumentation is located downstream of the refrigeration units, in which case erroneous data may result. All pressures, referred to as standard pressure, *shall* be recorded simultaneously at regular intervals.

All true air temperatures *shall* be measured by the use of thermocouples. Cabin temperatures *shall* be determined by using both shielded and unshielded thermocouples in order to exclude and include, respectively, the effect of solar radiation. Duct and surface temperatures *shall* be determined with shielded thermocouples to minimize the effect of radiation. All temperatures *shall* be recorded at regular intervals, and thermocouples *shall* be located so as to determine all temperatures necessary for evaluation of the system operation.

For pressure measurements, all pressure taps *shall* be located so as to minimize the effect of turbulence caused by valves, elbows, or orifices in the system, and to determine all pressures required for a complete evaluation of system operation. Humidity measurements *shall* be taken within the cabin at regular intervals, using a reliable type of psychrometer.

Air velocities *shall* be determined by using a suitable velometer in passenger and crew compartments. Air velocities across the cabin thermostat-sensing element and temperature-indicating instrument (if the latter is installed) also *shall* be determined.

Time histories of temperature and pressure *shall* be recorded so that the rates of temperature and pressure changes and time intervals required to obtain stabilized conditions can be noted. All test results, measurements, and instrumentation descriptions *shall* be submitted for approval to the procuring activity.

9-10.4.2 Defogging, Defrosting, and Anti-icing/Deicing Systems

The defogging and anti-icing systems *shall* be inspected to determine compliance with the requirements

specified in MIL-T-5842 and MIL-T-18607, including a visual inspection of the general construction and serviceability of the system.

Prior to the installation of an anti-icing/deicing defrosting, or defogging system, the contractor *shall* submit to the procuring activity for approval a report showing a schematic drawing of the proposed system(s) and all design data necessary for compliance with requirements. These data *shall* be detailed and *shall* show the methods used in arriving at the necessary capacity of the system(s), an explanation or description of system operation, the heat requirements and the heat distribution and airflow considering various altitudes, conditions of flight and ground operation, and effect on personnel comfort as outlined in MIL-T-5842. The report also *shall* include items such as an outline of the type and location of the instrumentation, conditions of test, and methods of tests. Test instrumentation *shall* be adequate to determine heat flows through the area, to determine the dew point at each transparent area, and to insure that any area will not be overheated. The windshield anti-icing tests *shall* consist of laboratory and flight tests which demonstrate compliance with the heating requirements specified by par. 3.7.1 of MIL-T-5842. The quantity of heat applied to the windshield *shall* be checked in flight to insure that the quantity required (determined during laboratory tests) actually is available. An accepted method of determining heat flow is to measure the inside and outside surface temperature of the transparent area and measure the effect of the OAT. If the thermal properties of the transparent area are known, the heat flow then can be determined. Accuracy of this method will depend upon the available temperature differential, the external heat transfer coefficient, and the ice accumulation rate, and if steady-state conditions have been attained.

When ducting is used in any part of the system(s), it *shall* be tested for flow rates, temperature drops, pressure drops, and duct leakage; and the methods and instrumentation used by the contractor *shall* be outlined. A report required for final approval of the installation system(s) *shall* consist of a compilation of the flight test and laboratory test data, and a comparison of these data with the theoretical information compiled.

For tests of wing and empennage thermal anti-icing/deicing equipment, a representative item of each type of equipment *shall* be used to indicate suitability of the design for the mission. These tests *shall* be in accordance with the manufacturer-approved equipment specifications, and *shall* include life and performance tests plus the applicable environmental tests required by MIL-E-5272. Wherever possible, it is

desirable to conduct prototype tests on ground mock-ups to preclude damage to the helicopter.

Ground and flight tests *shall* be conducted to demonstrate proper operation of the temperature sensors, overheat warning and control, distribution of available airflow, and to demonstrate general security and safety of the system for flight testing. As a minimum, flight conditions *shall* include normal takeoff and climb to operating altitude, normal descent and landing, level flight, and hover.

Instrumentation *shall* be installed to determine the quantity and temperature of air from each heat source and the temperature and quantity of airflow in all main distribution ducts. Appropriate surfaces *shall* be instrumented to provide a chordwise profile of exterior and interior skin temperatures as well as temperature drop and airflow through the double skin passages. The surfaces to be instrumented *shall* be subject to approval of the procuring activity.

Sufficient structural temperatures *shall* be measured to insure that overheating does not occur. Shielded thermocouples *shall* be used to measure air temperatures at locations where there is a substantial difference between air temperature and the surrounding metal. If there are discontinuities in the heated areas, sufficient temperature measurements to determine the effect of the heat flow from the heated to the unheated areas *shall* be made. Instrumentation results and layout *shall* be submitted for approval by the procuring activity.

9-10.4.3 Oxygen System

The oxygen system, if required, normally will be Type A-2, and installed, tested, and demonstrated in accordance with MIL-I-8683, except as amended by par. 13-1.4 of AMCP 706-202 or the helicopter detail specification. The system *shall* be tested during simulated tactical operations at its minimum and maximum altitudes. The oxygen system and all material entering into its manufacture *shall* be subjected to inspection by the procuring activity to insure compliance with Military Specifications and Standards.

Functional tests *shall* be in accordance with par. 6 of MIL-I-8683, including checks of pressure reducers, line blockage, emergency valve turnoff, and operation in both "100% oxygen" and "normal" positions of the system control.

Leakage tests *shall* be conducted to insure proper system efficiency. The maximum allowable leakage is a function of the helicopter's oxygen endurance, and has been established in terms suitable for use in testing for leakage by the pressure drop method.

Resistance to flow tests *shall* be performed on Type A-2 reduced pressure systems to demonstrate that, when the oxygen pressure in the reduced pressure side of the distribution system is 60 lb/in.² at the pressure reducer, the flow through any outlet—without the diluter demand regulator installed—*shall* not be less than 100 liters per minute and the outlet pressure not less than 56 lb/in.² Measurements of flow pressure *shall* be made at each outlet by using a suitable flowmeter and pressure gage.

Flight tests on the oxygen system of the first flying model of any helicopter design or modification involving the oxygen system *shall* be conducted to determine visually the proper functioning of all oxygen equipment. In addition, the suitability of the arrangement of the items—from the standpoint of accessibility, visibility, and convenience to all crew members during their combat or flight duties—*shall* be determined.

Results of pressure flow, pressure drop, and leakage tests *shall* be submitted for approval to the procuring activity in the form of a test report. Installation inspection test results also should be included in this report.

9-11 ELECTROMAGNETIC COMPATIBILITY (EMC) DEMONSTRATION

9-11.1 GENERAL

The EMC demonstration is a means of insuring that a maximum effort has been made to reduce the susceptibility of the helicopter electrical, electronic, and armament subsystems to electromagnetic interference and of insuring compatible operation of these subsystems. Moreover, it demonstrates safety and assures optimum subsystem and helicopter system operation and efficiency. EMC demonstration also serves to insure a minimum level of radiated interference. EMC testing, including development and qualification, *shall* be conducted on components, subsystems, and systems within the helicopter. The EMC testing capability for the helicopter should be mobile to permit field tests at remote locations, and where the ambient electromagnetic levels do not interfere with the tests to be conducted. EMC testing of components and subsystems of the helicopter *shall* be performed in a shielded enclosure to examine interference with the parameters by electromagnetic sources. The shielded enclosure also can generate electromagnetic environments within the enclosure for testing of the components and subsystems. To obtain optimum performance for all electrical and electronic

systems of a helicopter, an EMC master plan is required for controlling the electromagnetic environment and the testing of all components and subsystems that are part of the total electromagnetic environment. MIL-STD-461, -462, and -463 *shall* be used for the component and subsystem requirements, and MIL-E-6051 *shall* be used to demonstrate that the components and subsystems, which have met their individual interference requirements, are compatible within the total helicopter system.

For additional information, see AMCP 706-235.

9-11.2 HELICOPTER ELECTROMAGNETIC COMPATIBILITY PROGRAM

The helicopter prime contractor designated in the contract *shall* establish an overall integrated electromagnetic compatibility program for the helicopter. This overall program *shall* include the necessary approach, planning, technical criteria, demonstration, and management controls, and *shall* be based on the specifications and requirements described in the statement of work, helicopter specification, and other applicable contract documents.

9-11.3 ELECTROMAGNETIC COMPATIBILITY BOARD

An electromagnetic compatibility board, composed of EMC engineers, *shall* provide the means of expediting solutions to problems and *shall* establish high-level channels of coordination. The details of operation and proposed membership for the board *shall* be included in the helicopter system EMC control plan. Typical members of the board *shall* include the contractor, invited subcontractors, and the procuring activity. The board *shall* insure that each participating associate, subcontractor, and vendor establishes an individual effort for compliance with the overall EMC objectives. EMC program design reviews *shall* be scheduled periodically, and deficiencies noted in these reviews corrected.

9-11.4 SUBSYSTEM INTERFERENCE CONTROL

9-11.4.1 Applicable Specification

MIL-STD-461 *shall* govern subsystem interference control. This standard encompasses the requirements and test limits for the measurement and determination of the electromagnetic interference characteristics of electronic, electrical, and electromechanical equipments. The equipment *shall* be designed to meet the

requirements set forth in MIL-STD-461. When the contractor is considering the use of commercial, off-the-shelf equipment or equipment certified to FAA Technical Standard Orders, all applicable tests required by MIL-STD-461 *shall* be performed. The test data *shall* be submitted to the procuring activity for determination of the (electromagnetic interference) EMI/EMC suitability in the helicopter system. If the equipment has met other emission and susceptibility requirements, the test procedures and reports may be submitted for evaluation by the procuring activity as evidence of meeting equivalent portions of MIL-STD-461.

When production equipment designed prior to the implementation of MIL-STD-461 and certified to supersede specifications or standards is used, the equipment *shall* meet the appropriate requirements of the Appendix of MIL-STD-461.

The impact of these requirements on helicopter effectiveness, cost, and weight will be considered fully.

9-11.4.2 Interference Control Plan

The interference control plan *shall* outline in detail the interference control or reduction program, and the engineering design procedures and proposed techniques that will be used to determine conformance with the requirements of MIL-STD-461 and will enable the equipment to perform its operational function without interference from its parts or subassemblies. Approval of the control plan and compliance *shall* not relieve the contractor of the responsibility of meeting the applicable requirements set forth in MIL-STD-461.

9-11.4.3 Subsystem Test Plan

Prior to testing a subsystem to the requirements of MIL-STD-461, a plan detailing the test methods used to verify compliance with the requirements of the standard *shall* be submitted to the procuring activity for approval. The test plan *shall* describe the frequencies to be checked on equipment where selected frequencies are required, such as radio receivers and transmitters. Test setups *shall* comply with the requirements of MIL-STD-462. All test methods *shall* comply with MIL-STD-462 in order that correlation can be accomplished if additional testing is required by another agency at some future date.

9-11.4.4 Laboratory Test

The interference test on equipment, which *shall* be accomplished after the approval of the test plan, *shall* demonstrate compliance with the requirements of MIL-STD-461 when using the appropriate methods

outlined in MIL-STD-462. During the tests, complete log sheets describing the test performed, date of test, test results and anomalies, and names of individuals involved with the tests *shall* be recorded.

9-11.4.5 Subsystem Test Report

The test report *shall* contain the factual data compiled during the testing program. The report format *shall* follow the outline in MIL-STD-831, other than the exceptions specified in MIL-STD-461. A graphical presentation of data is preferred to tabulated listings of test results because such a display of the interference levels with specification limits superimposed makes possible immediate interpretation of test results. Photographs showing the test setup will be included in the test report for information purposes.

9-11.5 INSTALLATION OF EQUIPMENT IN HELICOPTERS

Once the subsystems have met the requirements of their individual specifications, they will be installed in the helicopter. Proper installation—which includes bonding, area selection, and wire routing—is extremely important at this stage of the EMC program because equipment that meets the requirements of MIL-STD-461 may be degraded if improperly installed in the helicopter (see Chapter 7 of AMCP 706-202).

9-11.6 HELICOPTER SYSTEM COMPATIBILITY

Testing of the complete helicopter as a system for electromagnetic compatibility *shall* verify that all EMI precautions, design criteria, and individual subsystem requirements were adequately imposed. For compatibility tests to be realistic, the test procedures and implementing instrumentation will be designed to complement, and be compatible with, both the helicopter system and data requirements of the test program. Test plans and monitoring equipment will permit the helicopter to be operated as an integrated system through an operational sequence that reflects the intended tactical operation as much as possible.

9-11.6.1 Applicable Specification (System)

MIL-E-6051 establishes the compatibility requirements for a weapon system, based primarily on unacceptable response, no malfunction, and margin of safety criteria. Unlike requirements in other Military Specifications dealing with control of electromagnetic interference, the test procedures and instrumentation necessary to conduct realistic electromagnetic compatibility

tests are not defined by MIL-E-6051 but are instead the responsibility of the helicopter system contractor.

9-11.6.2 Helicopter System Test Plan

The test plan *shall* encompass all testing required to show conformity to the overall electromagnetic compatibility requirement of the helicopter. The test plan *shall* include diagrams, schematics, and wiring diagrams in sufficient detail to evaluate test adequacy. The electromagnetic compatibility requirements of MIL-E-6051 essentially are that all elements of a helicopter system operate properly, individually and collectively, with a signal-to-noise ratio of 2:1 (6 dB) in the electromagnetic interference resulting from the operation of the total helicopter system. There are two basic approaches that may be followed in setting up compatibility demonstration tests, namely:

1. Injecting interference at critical system points at a level of 6 dB higher than predetermined system levels. Appropriate system points are then monitored for malfunction.
2. Sensitizing the system to raise its susceptibility level to interference by 6 dB while monitoring for malfunctions.

The test plan *shall* include helicopter support equipment where such equipment is capable of contributing to the electromagnetic environment. The test plan also *shall* encompass the total operational profile of the helicopter system and insure that all loops and subsystems are exercised through their total dynamic range. The test plan will specify the sequence of tests to be performed, the applicable frequency ranges and set frequencies, and a list of all instrumentation to be used. The test plan should be divided into three categories: ground test with auxiliary power, ground test with helicopter power, and flight test.

The electromagnetic compatibility test *shall* demonstrate all combinations of frequencies (fundamental and harmonic) which are common to equipment installed on the helicopter; i.e., transmitter, RF output, oscillators, multiplier stages, audio, etc.

As a minimum, the following EMC tests *shall* be performed:

1. Interreaction of the electrical systems and equipment on the helicopter flight instruments
2. Interreaction within the helicopter intercommunication system. These tests will verify the compatibility of cross talk levels between the various voice circuits and intercommunication stations.

3. Interreaction of the various flight instruments with each other

4. Interreaction of the electrical systems and equipment on the various navigation and communication receivers

5. Interreaction of the navigation and communication receivers

6. Interreaction of communication and other transmitters with flight instruments

7. Interreaction of communication and other transmitters with navigation and communication receivers

8. Interreaction of the communication and other transmitter outputs

9. Interreaction of special avionics with the equipment types listed in Items 1 through 8. Other tests *shall* be added as necessary to verify the helicopter system compatibility.

9-11.6.3 System Test

Prior to beginning the formal EMI/EMC demonstration, the contractor *shall* verify, by testing, that the test vehicle, all equipment, and all subsystems have been bonded in accordance with MIL-B-5087. The bonding data *shall* be submitted to the procuring activity as part of the EMI/EMC demonstration.

The testing sequence *shall* be as specified in the test plan. Test methods and procedures *shall* be compatible with the instrumentation and the helicopter under test. Instrumentation calibration *shall* be specified in the test plan indicating the pretest and post-test calibration requirements. In some cases, helicopter system elements *shall* be monitored for the effects of noise, rather than the noise itself (in effect using system elements as noise detectors), thus achieving maximum realism and minimum disturbance to the system under test. The test site for such testing *shall* be in an area which is as free as possible from extraneous interfering signals. Tests *shall* not be conducted in an area or at any time when the electromagnetic environment at the test site would affect the validity of the tests. Prior to starting the formal EMI/EMC demonstration, the electromagnetic environment at the test site *shall* be measured. The ambient electromagnetic levels *shall* be recorded and the site survey submitted to the procuring activity for approval. Photographs should be made showing the test equipment setups and the general configuration of the test. In many cases a photograph of a test setup or configuration eliminates much conflict in after-the-fact discussions.

9-11.6.4 System Test Report

At the conclusion of EMC testing, a complete test report describing the electromagnetic compatibility test *shall* be written. The test report *shall* be in accordance with MIL-STD-831 and *shall* contain the complete information on all applicable tests and other pertinent information that is required. Complete records and photographs kept during the EMC testing *shall* be included in the test report in the format outlined by MIL-STD-831. Any comments concerning the operating conditions or events during the testing processes by the test report author *shall* be included with the test data. Test reports *shall* be submitted as required by the contract.

9-12 ARMOR AND ARMAMENT SUBSYSTEM DEMONSTRATION

9-12.1 GENERAL

When the helicopter configuration includes armor and/or armament subsystems, the contractor *shall* demonstrate that the armor is adequate to assure mission completion in the event of impact by specified projectiles, and that the armament subsystem will meet the design requirements of operations and safety as defined in the design specification.

These tests will include determinations of helicopter performance degradation as well as personnel and environmental considerations. Safety considerations *shall* be paramount in the evaluation and demonstration of the armor and the armament subsystems.

9-12.2 ARMOR DEMONSTRATION

There are a number of helicopter components which must be able to continue to function when a helicopter is impacted by small arms fire. Armor is installed to assure that the mission can still be accomplished. For example, vulnerable hardware such as engines, fuel cells and pumps, hydraulic and pneumatic components, transmissions, and controls must be armored since they frequently cannot be masked or protected by less vulnerable components. A certain amount of armor will be used even though some degradation of helicopter performance results. However, in order to minimize this performance degradation, the quantity of armor *shall* be limited, with protection being provided only for vital areas. Consideration also should be given to the design of redundant systems in lieu of armor

plate. The selection and placement of armor require that attention be paid to the relation between vulnerable areas and survivable performance for any mission and threat.

Helicopter damage from ground fire has been defined according to the following categories:

1. "K"-damage that causes loss of control immediately (usually taken as 30 sec or less)
2. "A"-damage that causes the helicopter to become uncontrollable in 5 min or less
3. "B"-damage that requires the mission be terminated and the helicopter be landed as soon as possible
4. "C"-damage that reduces ability to perform the assigned mission.

9-12.2.1 Test Program

The qualification of the armor selected in the design phase of the helicopter system development should include a careful study and analysis for any defined threat level. Such a qualification program *shall* provide quick and inexpensive verification, while also providing the ability for upgrading to a higher threat level. The procedures to be used are:

1. State-of-the-art graphical data:
 - a. Range versus velocity of enemy ordnance
 - b. Armor material protection ballistic limit (V_{50} PBL) areal density
 - c. Bullet splash patterns
 - d. Spall patterns
 - e. Ballistic equivalent of vulnerable components to aluminum
 - f. Ricochet
 - g. Residual velocity
 - h. Normal penetration nomographs
 - i. Oblique penetration nomographs
2. Analytical studies:
 - a. Areal density versus aspect angle
 - b. Trade-off study of weight, cost, and threat
3. Model of helicopter (mock-up):
 - a. Scale model of helicopter with all components, structure, etc., scaled and color-coded
 - b. Photographs to establish projected vulnerable areas. The color-coded vulnerable components will be easily identified.
 - c. Planimeter measurement of projected area at each of the 18 aspect angles. Select 45-deg segments about each coordinate axis for a total of 18 views. (Eight 45-deg segments are required for the 360 deg of one coordinate

- axis. Three axes with eight views each, less repetitions along the axes, totals 18 views.)
- d. Verification of the masking of "A", "K", and "B"-type damage for vulnerable components. From line of sight trajectories, compute penetration, bullet splash, armor spall, and damage to the helicopter.
- e. Verification of the armor protection design for 3a
- f. Improvement of the masking of vulnerable components through relocation
- g. Improvement of the armor protection of vulnerable components and minimization of the effects of bullet splash and armor spall
4. Preparation of armor installation specification for helicopter
5. Gunfire tests for final system qualification
6. Review of proof testing and final verification.

The discussion of Items 1 and 2 of the plan for qualifying the armor installation as it relates to the survivability/vulnerability design requirement for the helicopter is provided in Chapter 14 of AMCP 706-202. Additional information can be found in AMCP 706-170 and Ref. 2. Qualification of armor components is described in Chapter 7.

9-12.2.2 Test Requirements

9-12.2.2.1 Helicopter Performance Tests

The effect of the armor installation on the helicopter performance *shall* be included in the demonstrations of the helicopter set forth in this chapter and in the surveys described in Chapter 8.

9-12.2.2.2 Armor Compatibility

The armor installation *shall* not interfere with the operation of the helicopter or its systems. The armor also *shall* be integrated with the life support equipment and *shall* not contribute to aircrew discomfort or restrict the ability of the crew to perform their required tasks.

The initial evaluation of the armor installation *shall* be conducted with the mock-up. Armor then *shall* be installed in an early flight vehicle. During the flight test program the installation *shall* be inspected for interference of armor with flight systems; for wear on cables passing through holes in the armor plate; for wear of equipment components (e.g., gears, gearbox housings, links) which have been fabricated from armor materials; and for interference with air circulation. The inspection *shall* also include examination of all armor

attachment fittings to establish that none are loosened due to vibration or other flight conditions.

9-12.2.2.3 Ballistic Tests

The armor installation should be demonstrated to provide the required level of protection to the critical components by gunfire tests on a complete helicopter. If required, this testing will be performed by the procuring activity (see Chapter 11).

9-12.2.3 Validation

Validation of the armor installation, with respect both to the ballistic protection required to achieve the required survivability and to the integration of the armor installation into the overall helicopter system, *shall* be demonstrated to the procuring activity through a series of tests and reports.

9-12.2.3.1 Survivability

The probability of a kill on a helicopter is equal to the probability of receiving a hit multiplied by the probability that the hit results in a kill. Armoring components alters the probability that a hit from any particular weapon will result in a kill. This paragraph considers only the armor effects on the terminal ballistic vulnerability of the vehicle.

Careful analysis is required for the estimation of the terminal ballistic parameter. Restraint must be exercised in the adoption of simplified damage laws until the extent of their reliability is established. The analysis or demonstration tests of vulnerability can be based partially upon empirical relationships for the vulnerability of the major helicopter components.

9-12.2.3.2 Vulnerable Area Determination

A scale model or mock-up of the helicopter *shall* be fabricated. All component parts—including structure, engine(s), gearbox(es), fuel cells and lines, and controls—*shall* be built of wood, plastic, or some other inexpensive material. All parts of the model will be color-coded; e.g., aircrew red, fuel cells orange, engines black, structure white. The model *shall* be assembled and color photographs taken of the helicopter at every 45 deg, for a total of 18 views. Color coding will permit the identification of both masked (protected) and unmasked components.

Vulnerability values for a helicopter may be presented in several forms. One may present the probability that a hit at random on the presented area of the target results in a "B", "A", or "K" kill for a given line of fire, projectile, and striking velocity. However, it will be convenient to present vulnerability in terms of "total vulnerable area (A_v)".

For impacting projectiles, the vulnerable area is simply the presented area times the probability that a hit on the area is a kill. A slight modification is required for consideration of vulnerable areas of components. For example, the vulnerable area of a pilot to an impacting, high explosive projectile may be larger than the presented area of the pilot. Another modification is required when the presented areas of two components overlap.

Thus, if the target were replaced by an area which is totally vulnerable, this area would be the vulnerable area. When one considers the auto correlation of impacts from guns with high rates of fire, it may not be totally correct simply to add the vulnerable areas of the respective components. The geographical arrangement of components is important in calculating the various hit probabilities. This is one reason why it is necessary to calculate the vulnerable areas for the respective major components of the target plane. These vulnerable areas also are required for the proper combination of probabilities where there are duplicate components.

In the case where the whole item consists of a single part, the total vulnerable area is merely that of the part, and is defined as $A_v = pA$ where p is the probability of obtaining the type of damage being considered, assuming a hit has been scored on the part, and A is the projected area of the part.

In the case where the whole target consists of non-overlapping parts, the vulnerable area of the target, assuming it has been hit, is simply the sum of the vulnerable areas of the nonoverlapping parts, or Eq. 9-12

$$A_{vt} = p_1 A_1 + p_2 A_2 + \dots + p_n A_n \quad (9-12)$$

$$= \sum_{i=1}^n p_i A_i = \sum_{i=1}^n A_{vi}$$

where

- A_{vt} = vulnerable area of the target
- A_n = projected area of the n -th part
- p_n = probability of damage per hit on the n -th part
- A_{vi} = vulnerable area of the i -th part

In the case where the target consists of one part completely masking another, the additional vulnerable area contributed by the masked part is

$$\Delta A_v = (1 - p_{\text{masking}}) (p_{\text{masked}} A_{\text{masked}}) \quad (9-13)$$

where

$p_{masking}$ = probability of damage to the masking part when it is hit

p_{masked} = probability of damage to the masked part when it is hit through the masking part

A_{masked} = projected area of the masked part

Hence, the vulnerable area of the target in this case would be

$$A_{vt} = A_{v\text{masking}} + (1 - p_{masking})(p_{masked}A_{masked}) \quad (9-14)$$

$$= A_{v\text{masking}} + A_{v\text{masked}} - \frac{A_{v\text{masked}} A_{masking}}{A_{v\text{masking}}}$$

where

$A_{v\text{masking}}$ = vulnerable area of the masking part

It should be noted that where a part α masks only a portion of part β then the masking part equals α and the masked part equals that portion of β masked by α . The A_v of this combination is then added to the vulnerable area of that portion of β not masked by α .

Vulnerable areas will be obtained for a single hit by any of the given ammunition types. However, the helicopter may have redundant components, more than one of which must be destroyed in order to disable the helicopter. The fuel cells and airframe structure of the helicopter usually are singly vulnerable.

9-12.2.3.3 Penetration Data

Determination of probabilities of kill or given cate-

gory of damage must be based upon knowledge of the ability of the impacting projectile to penetrate. The penetration of components and the velocity degradation of bullets upon passing through various structures and components should be verified by gunfire tests. In the absence of gunfire tests, the methods described in Chapter 14 of AMCP 706-202 can be used.

9-12.2.4 Survivability Analysis Report

A comprehensive survivability analysis *shall* be submitted for acceptance to the procuring activity upon completion of the helicopter design. If the procuring activity subsequently approves a change in component location and such a change alters the results of the survivability analysis, the analysis report *shall* be updated as required.

The survivability analysis report *shall* include, but not be limited to:

1. Total vulnerable area for each threat specified by the procuring activity (see typical format in Fig. 9-22)
2. Priority listing of the individual vulnerable areas, by critical component, that constitute the total
3. List of components, normally critical, that are no longer considered critical due to use of improved materials and/or design considerations
4. Ballistic test data to support Item 3
5. Total weight of armor required
6. Material(s) selected and their location within the helicopter

DAMAGE CATEGORIES	AMMUNITION														
	— CAL 7.62 mm —			— 12.7 mm —			— 14.5 API- —			— 23 mm API —			— 37 mm —		
	AP-B30						BS41			(ZU-23)			(M1939)		
	K	A	B	K	A	B	K	A	B	K	A	B	K	A	B
PILOT															
ENGINE(S)															
STRUCTURE															
CONTROL															
ETC.															
TOTAL															

Fig. 9-22. Typical Format for Specifying Vulnerable Areas

7. Presentation of five (5) allocations of armor by weight of material and position:

- a. One-quarter (1/4) of the total armor weight
- b. One-half (1/2) of the total armor weight
- c. Three-quarters (3/4) of the total armor weight
- d. The total armor weight
- e. No armor added.

The cost and survivability against the specified threat for the five (5) allocations of armor should be shown (see Fig. 9-23 for a typical graphical presentation). Methods other than ballast for maintaining the CG should be provided, but in any case the effect upon helicopter empty weight CG of the four increments of armor *shall* be indicated.

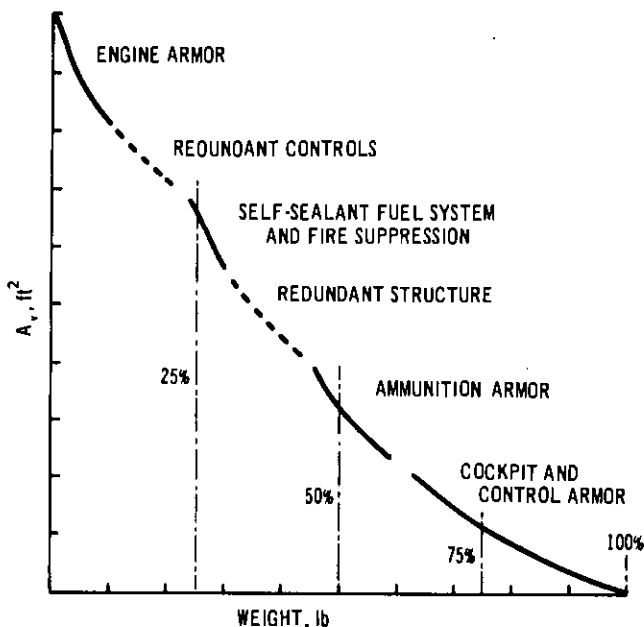


Fig. 9-23. Vulnerable Area vs Weight

9-12.3 ARMAMENT SUBSYSTEM DEMONSTRATION

The armament demonstration is conducted to determine the ability of the weapon system to perform the functions required by the detail specification and *shall* include ground and flight testing of the complete weapon system to demonstrate compliance with the requirements of the detail specification. The complete weapon system is defined as a prototype or production model helicopter equipped with a complete installation of the armament subsystem to be tested. The armament subsystem installation is to be configured as nearly as possible to the production installation including all

functioning elements of the subsystem as well as fairings and any other nonfunctioning element of the subsystem.

The test program *shall* include provisions for the following determinations:

1. Accuracy:
 - a. System boresighting
 - b. Dispersion at maximum effective range
2. Arming or Rearming Time
3. Environmental Compatibility:
 - a. Temperature
 - b. Salt fog
 - c. Sand and dust
 - d. Vibration
 - e. Shock
 - f. Blast overpressure
 - g. Icing
 - h. Toxic gases
 - i. Noise levels
 - j. Explosive atmosphere
4. System Safety:
 - a. Provision of adequate safety devices for ground crew protection and inflight operational safety
 - b. Jettison
 - c. Electromagnetic compatibility (par. 9-11)
5. Flight Handling Qualities, Performance
6. Maintenance Requirements, Reliability.

In addition to the foregoing requirements, the contractor *shall* demonstrate the structural integrity of the armament subsystem throughout the operating regime of the helicopter.

The test program is to include any or all of the following:

1. Static Test (par. 9-2)
2. Ground Test:
 - a. Vibratory survey
 - b. Electromagnetic energy survey
 - c. Arming/rearming time and motion study
 - d. Firing tests
 - e. Environmental tests
3. Flight Test:
 - a. Handling qualities (par. 9-5.3)
 - b. Nonfiring load survey
 - c. Firing load survey
 - d. Jettison (par. 9-13)
 - e. Vibratory survey (data gathered during 3a, 3b, and 3c testing).

All armament subsystem tests required *shall* be performed unless the procuring activity concurs that the

requirement has been demonstrated on an identical or dynamically similar armament subsystem. Any armament subsystem change which represents a departure from the existing design, or which embodies major features not previously tested, *shall* be tested to demonstrate compliance with the requirements of this handbook or the detail specification.

Armament subsystems are classified in four categories: (1) gun installation, fixed and flexible; (2) missile and rocket installations; (3) droppable chemical, pyrotechnic, and miscellaneous (armament) store installation; and (4) fire control systems and/or armament controls.

9-12.3.1 Test Requirements

Ground and flight test requirements for armament subsystems installed in the helicopter are described in the paragraphs which follow. This series covers the full scope of testing required for all subsystems listed previously. General test requirements for specific armament subsystems are shown in Table 9-3. The final test requirements will be included in a test specification for each subsystem to be prepared by the contractor and approved by the procuring activity.

In addition, the test specification for system qualification should list specific instrumentation for the tests required. However, general parameters are listed with each test in pars. 9-2 and 9-5.

The development agency for each armament subsystem should submit to the procuring activity a safety statement, in accordance with AMCR 385-12, which should include the Technical Characteristics and results of qualification tests of the subsystems. This information will be provided to the contractor for his use in the design and qualification of the subsystem installation.

The armament subsystem test safety requirements should include provisions to prevent collision of explosive projectiles in the proximity of the helicopter and to demonstrate adequate clearance between both fired projectiles and expended materials and the helicopter. Proper functioning of the cockpit safe/arming controls and indicators, flash suppression devices for night operations, and laser safety provisions must be demonstrated. In addition, provisions for the safe ingress/egress of the crew when the armament is in an armed position must be demonstrated.

9-12.3.1.1 Failure Analysis

A failure analysis *shall* be made, which will consider each of the functioning elements of the armament subsystem: its test history, its reliability, and the potential

hazard resulting from its failure or malfunction (including malfunction of the ammunition and links, etc.). This analysis may produce recommendations for additional ground or bench testing to support the flight test program and safe practices to be followed while the testing is under way. These recommendations may vary greatly, depending on the complexity of the subsystem, the potential hazard, and the extent of testing already conducted.

9-12.3.1.2 Ground Tests

9-12.3.1.2.1 Cockpit Procedures

The armament subsystem *shall* be installed and placed in simulated operation without firing or releasing the munition. Cockpit procedures will be demonstrated, including cockpit switching, safety, and all pilot-gunner interactions.

9-12.3.1.2.2 Armament and/or Fire Controls

Armament subsystem controls such as cockpit controls, switches, instruments, sights, control junction boxes, control heads, etc., which are part of the subsystem must be subjected to the demonstration and qualification requirements for that subsystem. These requirements also must include an evaluation of cockpit systems and their interactions, to ascertain that manual or automatic interaction controls are logical, reliable, and adequate to account for all possible variables.

9-12.3.1.2.3 Sighting and Boresighting

Boresighting procedures *shall* be demonstrated in accordance with the appropriate procedures. Any special tools or devices required to accomplish boresighting will be used in the demonstration. Boresighting will be rechecked periodically throughout the firing tests to determine if boresight alignment is retained and if the contractor's design and procedures are adequate.

9-12.3.1.2.4 Arming Procedures

Procedures for the loading of ammunition or stores *shall* be demonstrated, as well as the safety procedures to be followed during the loading process. The time required to rearm must be determined and documented. Operational ground handling equipment or other special equipment must be used in the demonstration, which also must include ground maintenance and system troubleshooting procedures.

9-12.3.1.2.5 Firing Tests

The armament subsystem must be fired during ground flight tests. During this demonstration, the ammunition or store propellant will be conditioned to the operational temperature extremes specified in the appropriate specification. Sufficient instrumentation *shall* be provided to measure the following parameters:

1. Airframe response to blast effects and weapon rate of fire throughout the coverage of the subsystem
2. Recoil loads and airframe response to weapon rate of fire throughout the range of which the subsystem is capable
3. Cockpit noise level
4. Electrical and hydraulic loads
5. Gas accumulation in the cockpit and in the vicinity of the weapon
6. Debris dispersion characteristics
7. System accuracy
8. Temperature profile of tail boom.

Firing safety procedures *shall* be demonstrated. A preliminary EMC check *shall* be conducted to assure that operation of communication equipment in the frequencies to be employed during the test program will not inadvertently activate the firing circuit or adversely

affect any other functioning element of the armament subsystem. Also, activation of the armament *shall* not adversely affect the helicopter flight controls, instrumentation, and communication equipment.

9-12.3.1.2.6 Environmental Considerations

Compatibility of the weapon system with its anticipated environment (temperature-altitude, salt spray, vibration, dust, shock, blast, icing, explosion-proof, etc.) *shall* be demonstrated.

9-12.3.1.2.7 Blast Effects

The ground tests *shall* determine the helicopter structural response to blast pressures generated by firing the armament subsystem. Normal instrumentation may include stress gages, single-axis accelerometers, and a pressure transducer.

A single firing normally determines the maximum pressure level. The position of the weapon, missiles, or rockets and the location of the instrumentation will be defined in the test specification.

9-12.3.1.2.8 Flash Intensity

Static night firing should be conducted to determine if muzzle flash affects the crew, gunsight, or cockpit

TABLE 9-3. ARMAMENT SUBSYSTEM TEST REQUIREMENTS

TESTS		SUBSYSTEMS				
		GUN AND TURRET	ROCKETS AND MISSILES	DROPPABLE STORES	CHEMICALS, PYROTECHNICS	ARMAMENT CONTROL
GROUND	COCKPIT PROCEDURE					
	ARMAMENT CONTROLS					
	SIGHTING, BORESIGHTING					
	ARMING PROCEDURES					
	FIRING TEST					
	ENVIRONMENTAL CONSIDERATIONS					
	BLAST EFFECTS					
	FLASH INTENSITY					
NONFIRING FLIGHT	HANDLING QUALITIES					
	PERFORMANCE					
	JETTISON					
	LOADS VIBRATION					
FIRING FLIGHT	NOISE LEVEL DETERMINATION					
	GAS CONTAMINATION MEASUREMENT					
	DEBRIS					
	HANDLING QUALITIES					
	LOADS VIBRATION					
	ACCELERATED SERVICE TEST					
	POWER PLANT PERFORMANCE					
	SYSTEM ACCURACY					
	TEMPERATURE PROFILE DETERMINATION					
	ELECTROMAGNETIC COMPATIBILITY					

instrument lighting. Photographs of the crew and cockpit instrument lighting are desirable to determine flash intensity. Muzzle flash also should be photographed when possible.

9-12.3.1.3 Flight Tests

9-12.3.1.3.1 Nonfiring Flight Tests

The complete armament subsystem installation, including dummy munitions, *shall* be required for the tests listed subsequently.

9-12.3.1.3.1.1 Handling Qualities and Performance

The helicopter *shall* be flown throughout its full operating envelope to determine the effect of the armament subsystem on handling qualities; to identify any restriction imposed by the subsystem; and to ascertain if the subsystem has any effect upon helicopter performance characteristics (see par. 9-5.3 for handling quality and performance test).

9-12.3.1.3.1.2 Jettison

The jettison envelope *shall* be established, based on factors such as store clearance and helicopter response characteristics. All possible store loadings and stabilized flight attitudes must be considered in defining the jettison envelope. Ground and flight tests should be conducted. Jettison instrumentation normally consists of airframe-mounted motion picture cameras for clearance studies, but also can include jettison release or firing signal information for true delay studies as in the case of sequenced, multiple-store jettisons or deliveries (see par. 9-13 for jettison test).

9-12.3.1.3.1.3 Loads and Vibration

Flight-induced loads *shall* be measured on any member or component that may be affected by the subsystem installation. Sufficient flight conditions must be evaluated to assure structural integrity throughout the operating envelope of the helicopter for the critical mass of the armament subsystem. The vibration environment of the armament subsystem will be evaluated (see pars. 8-2 and 8-7 for flight load and vibratory tests).

Load and vibration test instrumentation may include the following:

1. Strain gages for loads, moments, stresses, and frequency of occurrence studies

2. Accelerometers for dynamic environment studies in conjunction with the strain gages

3. Pressure transducers for blast and exhaust pressures

4. Airframe-mounted cameras and position potentiometers for clearance studies and system accuracy.

9-12.3.1.3.2 Firing Flight Tests

Live firing of the armament subsystem *shall* be conducted in flight. Demonstration requirements include the tests which follow.

9-12.3.1.3.2.1 Noise Level Determination

The noise level in the cockpit and cabin areas *shall* be measured during live firing tests. These tests *shall* be conducted in a hover, and with those doors removed and windows open as are permitted during flight (see par. 8-9.6 for acoustical test). Peak impact overall and/or frequency-controlled noise press levels should be recorded. Noise pressure levels in the vicinity of the crew stations also should be recorded.

9-12.3.1.3.2.2 Gas Contamination Measurement

The level of explosive or toxic gas accumulation in the cockpit and cabin area and any other enclosed area subjected to such accumulation *shall* be measured while firing tests are being conducted. The amount of ammunition to be expended will be defined in the Technical Characteristics of the armament subsystem. The effects of gas on engine and other critical component operations *shall* be determined (see par. 9-12.3.1.3.2.7 for effects of gas on power plant or drive system performance).

9-12.3.1.3.2.3 Debris Dispersion

Dispersion patterns of all debris (links, cartridges, casings, dispensed munitions, launch motor exhaust, etc.) *shall* be documented photographically during firing throughout the operating envelope of the helicopter to assure that safe clearance margins exist for airframe, rotors, and control surfaces. (Debris dispersion patterns from launch motor and rocket exhausts are determined during ground firing only.) The type and extent of recording depend on the individual installation.

9-12.3.1.3.2.4 Handling Qualities

The effect of armament subsystem firing on helicopter handling qualities *shall* be documented (see par. 9-5.3 for handling quality tests).

9-12.3.1.3.2.5 Loads and Vibration

Loads *shall* be measured on all components of the armament subsystem and the helicopter that may be affected by firing. Firing will be conducted under the critical helicopter/armament subsystem flight conditions. The critical condition for lateral response on the helicopter using a flexible subsystem normally is firing at a 90-deg azimuth to the left or right and 0-deg elevation. The critical condition for vertical response on the helicopter using a flexible weapon subsystem is 0 deg azimuth and maximum depression or elevation. Sufficient data points must be obtained during firings to assure structural integrity throughout the operational envelope of the helicopter and the armament subsystem. The effects of loads on the operation of the armament also *shall* be determined. The vibratory environment of sensitive components will be measured during firing (see pars. 8-2 and 8-7).

9-12.3.1.3.2.6 Accelerated Service Tests

An accelerated program for live firing flight tests will be conducted on the complete production armament subsystem. Testing will be conducted under realistic tactical conditions and must continue for a sufficient number of rounds to identify and correct any system discrepancies that might occur, and to verify a mean-round-to-stoppage (MRTS) value. The test requirements *shall* be detailed in the test specification.

9-12.3.1.3.2.7 Engine Performance

The temperature of the engine *shall* be recorded during the firing tests to assure that allowable transient over-temperature conditions are not exceeded. There must be no evidence of compressor stall, foreign object damage, adverse ingestion of gun gases, or engine flameout. Engine performance instrumentation may include engine inlet pressure and temperature distributions, compartment zone temperature, and engine and drive system cooling.

9-12.3.1.3.2.8 Temperature Profile Determination for Armament Subsystem Controls

If the armament control box or other weapon controls are located in the tail boom, the temperature environment experienced by the armament control box *shall* be determined. This test should be performed at a high ambient temperature.

9-12.3.1.3.2.9 System Accuracy

The accuracy of the armament subsystem must be demonstrated during flight. The range, altitude, flight maneuvers, and accuracy measurement will be furnished in the detail test plan.

9-12.3.1.4 Electromagnetic Compatibility (EMC) Tests

A complete electromagnetic compatibility test *shall* be conducted with the entire production armament subsystem installed and functioning. All communication equipment must be operated throughout its frequency range to assure against inadvertent activation or deactivation of the armament subsystem. Antenna patterns and radio communication must be checked with the armament subsystem functioning in order to assure that adequate voice transmission clarity is maintained (see par. 9-7.6 for EMC tests).

9-12.3.2 Documentation

The armament subsystem test *shall* define the report requirements and test criteria for the armament subsystem tests.

9-13 EXTERNAL STORE SEPARATION DEMONSTRATION**9-13.1 GENERAL**

Flight tests *shall* be conducted to demonstrate the separation characteristics of all droppable external stores. Where several configurations of external stores may be used, all feasible combinations should be tested. Testing should be conducted under all appropriate combinations of operating conditions.

A droppable external store *shall* be defined as any item that is not an essential part of the basic helicopter and is affixed outside the airframe with provisions for quick release. Droppable external stores may include—but are not limited to—bombs, mine dispensers, torpedoes, rocket pods, fuel tanks, pyrotechnic de-

vices, grenades and grenade launchers, or other podded weapons.

9-13.2 SEPARATION CHARACTERISTICS

Satisfactory separation characteristics *shall* be defined by the minimum criteria which follow and other criteria which may be specified:

1. Immediate operation of the jettison device
2. No damage to the helicopter during or following actuation of the jettison device
3. A jettison trajectory clear of the helicopter
4. No inherent instability of the jettisoned store while in proximity to the helicopter
5. No adverse or uncontrollable helicopter reactions at the time of jettison
6. Stability and control characteristics after jettison consistent with MIL-H-8501 and other appropriate military flying qualities specifications
7. No unusual degradation of the helicopter performance characteristics after jettison.

9-13.3 JETTISON REQUIREMENTS

Complete jettison of all external stores *shall* be demonstrated at sufficient combinations of flight conditions to establish and verify a jettison envelope for each type of external store configuration. Complete jettison is the intentional simultaneous, or nearly simultaneous, release of all stores in a preset sequence, normally to achieve safer operation in an emergency situation. Selective jettison of stores *shall* be demonstrated for those conditions which may result in adverse operational characteristics of the helicopter and remaining external stores. Selective jettison is the intentional release, normally at optimum jettison conditions, of specific stores of a total store configuration, normally to dispense with portions of the store configuration no longer required for the helicopter mission.

9-13.4 RELEASE SYSTEMS

All jettisons *shall* use the release method provided, except that each available secondary or redundant release system should be utilized at least once during these demonstrations.

9-13.5 RECOVERY OF STORES

Where possible, jettisoned stores should be recovered and reused. Before reuse of any store, sufficient examination should be made to determine that the mass prop-

erties of the store have not changed and that any damage to the store incurred during jettison or ground contact is marked and recorded previous to reuse. Provisions may be included for a parachute delivery system to minimize damage due to ground contact. Such a system may not change the aerodynamic or mass properties of the basic store and may only be actuated after the store is well clear of the helicopter.

9-13.6 FAILURE MODE

A failure analysis of the jettison system(s) *shall* be performed to show that any single failure of the system(s) will not result in an unsatisfactory flight characteristic. For system failures resulting in asymmetric loading conditions, the helicopter *shall* be shown to meet the appropriate portions of MIL-H-8501. All system failures *shall* also be shown to not adversely affect the helicopter characteristics or the jettison capability of remaining stores.

9-13.7 TEST REQUIREMENTS

The flight conditions for jettison demonstrations *shall* be as agreed upon between the helicopter contractor and the procuring activity for each helicopter and store configuration. Maximum use should be made of previously available test data to help define the flight conditions required, to determine the critical stores configurations, and to minimize testing of comparable store configurations. The requirements in the paragraphs which follow are offered as guidelines.

9-13.7.1 Weight and CG Locations

All demonstrations *shall* be conducted at the extreme or critical combinations of weight and longitudinal and lateral CG conditions within the helicopter mission. When external stores contain dispensable items such as rockets, the demonstration should be conducted at intermediate loadings from full to empty at the extreme or critical weight and conditions. Sufficient demonstration *shall* be performed to verify that partial use of dispensable items does not create unsatisfactory separation characteristics.

9-13.7.2 Speed Envelope

Jettison demonstrations *shall* be performed at sufficient airspeeds to establish the airspeed restrictions for satisfactory separation characteristics. The maximum and minimum airspeed limits for safe separation *shall* be determined. The initial envelope of sideslip as a function of airspeed *shall* be determined from the side-

force stability parameter $d\phi/d\beta$ (where ϕ is bank angle and β is sideslip angle) and the sideforce required to recognize uncoordinated flight. The sideforce stability parameter is obtained during stability and control testing as a function of calibrated airspeed. The sideforce required to recognize uncoordinated flight is determined during initial testing. The sideforce requirement fixes an equivalent bank angle which, when applied to the sideforce stability parameter, yields a limit sideslip angle as a function of calibrated airspeed (see Fig. 9-24).

9-13.7.3 Altitude

Jettison demonstrations *shall* be performed at altitudes consistent with the operational envelope of the helicopter and with the maneuvering requirements necessary to overcome any adverse effects of the jettison.

9-13.7.4 Attitude

Jettison demonstrations *shall* be performed from all helicopter attitudes appropriate to normal operational usage. Where the attitudes of external stores with re-

spect to the helicopter may be varied, the most critical attitude consistent with operational usage *shall* be demonstrated.

9-13.7.5 Flight Modes

Jettison demonstrations *shall* be performed in different flight modes. As a minimum, jettisons *shall* be demonstrated at the power for level flight and during autorotative flight. Other flight modes may be specified if considered critical to jettison requirements.

9-13.8 DOCUMENTATION

Suitable documentation of all demonstrated separation characteristics *shall* be provided.

This documentation should include—but not be limited to—photographic documentation of each jettison, quantitative data and qualitative comments for each jettison, an analysis of the separation characteristics for each condition tested, and information suitable for inclusion in the appropriate Technical Manuals on each helicopter/store configuration.

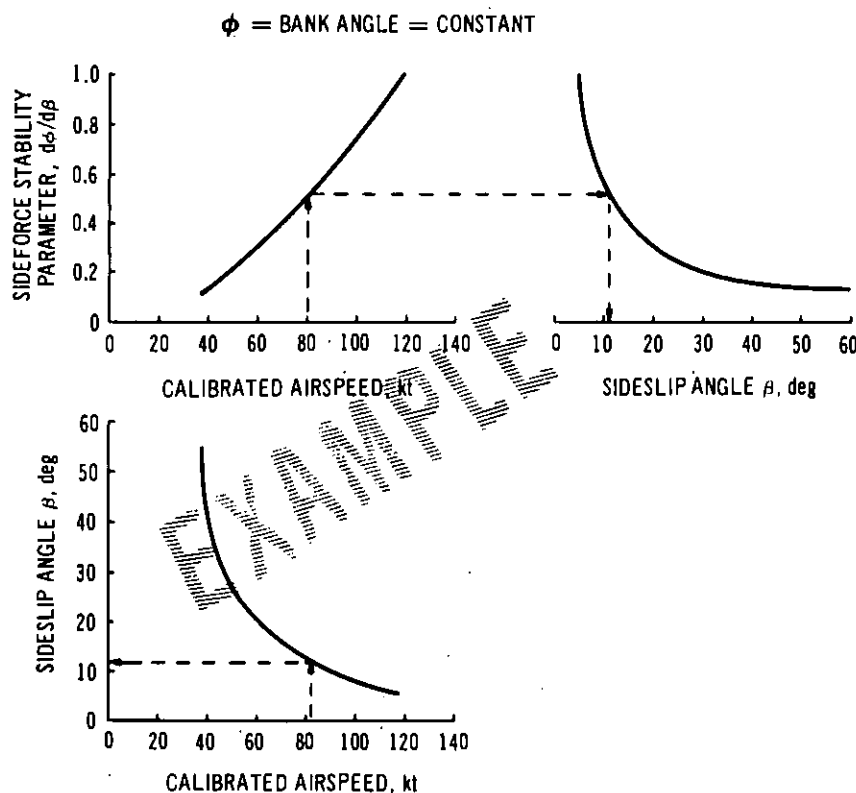


Fig. 9-24. Jettison Envelope Calculation

High-speed motion picture photography *shall* be used to document the external separation characteristics of all external store configurations tested. Sufficient still photography *shall* be used to document the location, shape, and method of attachment of all external store configurations. All damage to the helicopter caused by store jettison and any coincident damage to the jettisoned store (if recoverable) *shall* be documented by still photography.

Data *shall* be recorded during each jettison test for analysis and as historical information for future jettison testing. As a minimum, the data acquisition system should contain those instruments necessary for basic stability and control testing, the cameras required to fulfill the photographic documentation requirements, and other instrumentation which may be useful in further defining the separation characteristics of jettisoned stores.

The separation characteristics of each store configuration *shall* be examined to determine if any common conditions or trends exist. Empirical relationships describing the trajectory of the jettisoned store *shall* be derived if possible. General conditions resulting in unsafe separation characteristics *shall* be determined.

The result of the store jettison demonstrations *shall* be documented in a technical report containing qualitative comments, tabulation of quantitative data, and analysis and discussion of the data. This report should contain the information necessary to develop jettison envelope information on each store configuration

tested. This envelope information should be included in the appropriate Technical Manuals.

9-14 HELICOPTER ENDURANCE TEST

After completion of all other demonstrations required to be performed, an endurance test *shall* be conducted by the contractor. The purpose of this test is to provide an early indication of the endurance and the reliability of the helicopter. The test vehicle *shall* be representative of the production aircraft, including all design changes necessary to correct deficiencies revealed during the development and airworthiness qualification tests. The test *shall* be conducted on an accelerated basis and *shall* consist of a minimum of 300 flight hours. The contractor *shall* prepare an endurance test plan for approval by the procuring activity prior to commencement of the test. The plan will include a detailed description of the proposed test vehicle, the identification of all data to be recorded during the test, and an outline of the test report.

REFERENCES

1. *AGARD Flight Test Manual, Volume I, Performance*, Pergamon Press Ltd., Oxford, England, and Long Island City, N.Y., 1968.
2. NWC-TP-4532, *Ballistic Dynamics of AP Projectiles*, China Lake, California, 1967.

CHAPTER 10

RELIABILITY AND MAINTAINABILITY

10-0 LIST OF SYMBOLS

- e = Napierian logarithmic base,
2.71828
 $P(A)$ = probability of event A
occurring
 $P(B)$ = probability of event B occurring
 $P(B/A)$ = conditional probability of event
 B occurring, given that event A
already has occurred
 $P(BA)$ = joint probability of both A and
 B occurring
 $R(A)$ = reliability of component A
 $R(B)$ = reliability of component B
 $R(C)$ = reliability of component C
 $R(T)$ = reliability of total system
 $R(t)$ = point estimate of component
reliability, for time t
 t = mission duration
 λ = component failure rate

10-1 RELIABILITY

The overall reliability requirements of the helicopter will be specified by the procuring activity, while the requirements for the subsystem elements will be included in end-item specifications. Those values not established by the procuring activity *shall* be established by the contractor at contractually specified control points prior to detail design, as described in MIL-STD-785. Achievement of minimum acceptable hardware reliability requirements *shall* be demonstrated by the contractor through tests and analyses required by the contract and defined in the reliability plan developed in accordance with MIL-STD-785. The procuring activity *shall* define the documentation required to substantiate the reliability of prototype and production helicopter, in the contract data package.

The contractor's reliability analysis *shall* be initiated at the start of the contractual effort. A reliability plan *shall* be developed to define the contractor's program to achieve the required reliability. This plan *shall* in-

clude provision for preparation of a mathematical model.

10-1.1 RELIABILITY MATHEMATICAL MODELS

A reliability mathematical model is an equation stating the probabilistic relationship of the reliability of the helicopter as a whole, to the reliabilities of its subsystems and components.

The model, constructed by the contractor, will be used for the following purposes:

1. Allocation of helicopter reliability contractual requirements to the subsystems and components
2. Prediction of helicopter reliability based on analysis of subsystem designs
3. Measurement of anticipated helicopter reliability based on component and subsystem test results.

The contractor's reliability program *shall* include model inputs, model outputs, model updating, and utilization of the model for apportionment and prediction, in accordance with the detailed requirements of MIL-STD-785, MIL-STD-1304, and MIL-STD-756.

10-1.1.1 Success Criteria

System reliability is defined as the probability of successfully performing a specified function or mission under a specified condition for a specified time. In this definition, a key word is "successfully". Formulation of a meaningful mathematical model requires a precise definition of what constitutes success.

In helicopter applications, two types of success criteria have received emphasis. The first, operational readiness, involves the probability of completing all required maintenance prior to the next helicopter flight. The second, mission reliability, is the probability that a helicopter declared "ready" will be able to start and complete its mission without a delayed or cancelled takeoff, unscheduled landing, or turnback due to one or more malfunctions. Mission reliability, therefore, is the measure of success for the system when it is operational

at the start of an assigned mission. Operational readiness, on the other hand, requires that, at any point in time, the system either be operational or be capable of being made so within a given warning period. However, it does not imply successful mission completion.

Regardless of the criterion selected, a clear definition of the mission times and profiles, system performance requirements, equipment essentialities, duty cycles, and critical failure modes must be accomplished by the contractor before the mathematical models can be constructed.

10-1.1.2 Reliability Block Diagrams

An essential step in constructing the reliability mathematical models for the helicopter is the preparation of the reliability block diagrams by the contractor. The diagrams reflect the equipment elements which are essential to "success" during each phase of the mission. Further, the block diagram shows any alternate success paths (redundant components) that allow the mission to be accomplished after failure of a normally essential component. Details of constructing a reliability block diagram are discussed in MIL-STD-756 and MIL-HDBK-217.

The reliability block diagrams and the mathematical models *shall* be revised as the design is refined.

10-1.1.3 Model Construction and Combining Reliabilities

A basic concept in the study of probability is the definition of conditional probability. The conditional probability of event *B*, given that event *A* has occurred, is equal to the probability of events *B* and *A* occurring, divided by the probability of event *A* occurring. Symbolically,

$$P(B/A) = \frac{P(BA)}{P(A)} \quad (10-1)$$

where

$P(B/A)$ = conditional probability of event *B* occurring, given that event *A* already has occurred

$P(BA)$ = joint probability of both *A* and *B* occurring

$P(A)$ = probability of event *A* occurring

By algebraic operation, this can be rewritten

$$P(BA) = P(B/A) \cdot P(A) \quad (10-2)$$

Another fundamental concept in probability study is the concept of independence, which is described as

$$P(B/A) = P(B) \quad (10-3)$$

where

$P(B)$ = probability of event *B* occurring

That is, event *B* is just as likely to occur when event *A* occurs as when event *A* does not occur. If events *A* and *B* are independent, the probability of *A* and *B* both occurring is derived from

$$P(AB) = P(A/B) \cdot P(B) \quad (10-4)$$

Since

$$P(A/B) = P(A), \text{ then} \quad (10-5)$$

$$P(AB) = P(A) \cdot P(B) \quad (10-6)$$

Here we have the rudiments of a reliability mathematical model. If components *A* and *B* must operate for system *C* to satisfy the success criteria, and operation of each is independent of the other, then the following mathematical model is appropriate:

$$R(C) = R(A) \cdot R(B) \quad (10-7)$$

where

$R(A)$ = reliability of component *A*

$R(B)$ = reliability of component B

$R(C)$ = reliability of system C

Extending this concept to n components, the reliability $R(T)$ of the total system T is

$$R(T) = \left[\prod_{i=1}^n R(A_i) \right] \quad (10-8)$$

Many systems do not require that all elements operate in order for the system to successfully accomplish its intended function. Section 3.0 of MIL-HDBK-217 describes the construction of mathematical models for systems requiring all components to operate for success, and for systems that contain alternate success paths (i.e., where some components may fail without causing the system to fail).

10-1.2 INITIAL APPORTIONMENTS

Allocation of the helicopter numerical reliability design objectives or contractual requirements to the subsystem and component level is referred to as "reliability apportionment". It is accomplished by the contractor to provide detail design targets for suppliers and subsystem designers, and to facilitate evaluation of variations in detailed designs.

The process of apportionment requires utilization of the mathematical model. During the design and development phases, the helicopter reliability contractual requirements are held constant. The apportionment of these values may vary to reflect changes in concept, configuration, and detail design.

The first step in apportionment is to rationally subdivide the helicopter using a hardware breakdown structure, in accordance with par. 5.1.1 of MIL-STD-1304. A reliability block diagram and mathematical model are constructed to reflect the success criteria, as discussed in par. 10-1.1.1. Initial apportionment of the reliability requirements for the helicopter then is accomplished by using historical data from similar aircraft and considering advances within the state of the art in design. Subsequent reapportionments, performed as detail design progresses, reflect the adjustments of apportioned values deemed necessary to provide compatibility with the reliability predictions for the design.

10-1.3 RELIABILITY PREDICTIONS

A reliability prediction is a mathematical estimate of reliability resulting from an engineering analysis of the

design and developed in accordance with MIL-STD-756. These analyses *shall* be performed repetitively during the design phase by the contractor, at intervals specified by the procuring activity, to establish the degree to which a design satisfies the reliability requirements and to identify those areas requiring reliability improvement. If specified by the contract, the prediction may be used in lieu of a demonstration that reliability requirements have been satisfied.

The process of prediction is one of combining previously identified component reliabilities and, using the reliability block diagram and resulting mathematical model, to obtain reliability estimates for the subsystems and, finally, the helicopter. Ideally, these component failure data come from previous usage in similar helicopter environments. Useful sources for these data include MIL-HDBK-5 and the Interservice Data Exchange Program (IDEP). Where no such data exist, data from relatively similar components in other environments are used. These data customarily are extrapolated to reflect the effect on reliability of the anticipated helicopter environment. Where Government-furnished equipment is to be used, the necessary reliability *shall* be furnished by the procuring activity. When failure rate data are not available, these data must be developed through part testing. Then testing specifications and procedures of Military Specifications for similar parts *shall* be used, as defined in MIL-STD-785.

Data sources normally provide component failure rates expressed as average events per unit of time. During the design phase it is customary to assume that the failures are distributed exponentially with time, allowing use of the following expression to calculate component reliability:

$$R(t) = e^{-\lambda t} \quad (10-9)$$

where

e = Napierian logarithmic base,
2.71828

λ = component failure rate, failures
per flight hour

t = mission duration, flight hours

$R(t)$ = point estimate of component
reliability, for time t

The initial reliability prediction for the helicopter may be compared with the helicopter reliability requirement by the contractor. If the value predicted is

substantially better than the required value, major hardware redesign will not be required. The predicted value may fall short of satisfying the requirement, in which case a comparison of subsystem predictions and apportionments becomes appropriate to identify potential problem areas. Prior to actual hardware redesign, however, it is advisable to revise the apportionment.

This revision by the contractor requires using the predicted subsystem failure probabilities to update the subsystem failure contribution percentages so that a more accurate reliability apportionment may be performed. The comparison of the revised apportionment values with the predicted values then forms a solid base for indicating which subsystems require further efforts to assure that the reliability requirement will be met. These efforts generally fall into one of the following three categories:

1. Hardware and/or system redesign to improve system reliability, e.g., redundancy and higher quality parts
2. System redesign which does not reduce failure probability, but prevents failures from affecting system operation, e.g., safety devices
3. In-depth evaluation of the mathematical model and failure data to confirm that the analytical results accurately reflect a "real life" problem. For example, if only certain modes of component failure are critical to "success", the failure rate for this component should be adjusted to reflect only the frequency of the critical mode. An analytical tool that identifies critical failure modes and their consequences is the failure mode and effect analysis.

An integral part of these evaluations is the verification of the assumed mathematical model. As early as possible in the design, the validity of the model *shall* be ascertained through tests of hypotheses, as in Ref. 1.

Efforts in all three categories are followed by further analysis and predictions until the design evolves to the point that not only does the prediction meet the reliability requirement, but also the contributions of components at a sufficiently low level of subsystem breakdown are included to provide a high degree of engineering confidence in the predicted reliability. Further detailed information on reliability prediction may be found in MIL-STD-756.

Critical reliability items—whose failure significantly affects the ability of the helicopter to perform its function—are identified through reliability prediction, and failure mode and effect analysis. The contractor *shall* include in his reliability program plan the establishment of a program to identify, control, and provide

special handling of critical items from design through final acceptance.

Contractor design reviews *shall* include review of current reliability estimates derived from reliability analyses, failure mode and effect analysis results, and potential problem areas identified through reliability analysis.

10-1.4 RELIABILITY ANALYSIS— DEVELOPMENT AND TEST PHASES

10-1.4.1 Test Plans

Testing accomplishes three major reliability functions:

1. Confirmation of the noncriticality of certain components and failure modes
2. Identification of unsuspected or "hidden" failure modes
3. Generation of a data base which allows prediction of helicopter reliability with a measure of statistical confidence in that prediction.

The reliability test plan, an integrated test and demonstration plan, *shall* be prepared by the contractor and submitted for approval by the procuring activity. The contractor *shall* have a closed loop system for collecting, analyzing, and recording all failures that occur during tests prior to final acceptance of the helicopter by the procuring activity. The contractor *shall* describe his proposed system for initiating failure reports, analysis of failures, and feedback of corrective action as a part of the program plan. The contractor's failure reporting system *shall* be compatible with the procuring activity's data collection system. The contractor *shall* submit failure report summaries as specified in the contract by the procuring activity (MIL-STD-785 and MIL-STD-1304(AS)).

In order to assure that these functions *shall* be performed adequately, the following should be considered:

1. Identification of assumed noncritical failure modes to be inserted into the system for confirmation of effect
2. Identification of operational conditions such as environmental and system states for which the likelihood of system failure is unknown or uncertain and thus are likely to reveal hidden failure modes
3. Identification of those test procedures which are mandatory if customer reliability testing requirements are to be met
4. Determination of producer and consumer risks for each test proposed in accordance with MIL-STD-

781, and test durations necessary to reduce these risks to acceptable levels

5. Identification of test data collection requirements essential to prediction of helicopter reliability with a measure of statistical confidence—e.g., number of elements, number of tests, test time accumulated on nonfailed elements, time of failure for each failed element, mode or type of failure, and test conditions.

10-1.4.2 Reliability Considerations for Development Testing

Development tests allow evaluation of the reliability of the parts which will actually be used on the helicopter. Thus, complex interaction factors automatically are included in the prediction. Further, many development tests are conducted under simulated helicopter environmental conditions which allow confirmation of the effect of helicopter environment on reliabilities. Finally, although analytical predictions give an estimate of reliability, they give no indication of the amount of variability of that estimate. The use of development test data gives not only an estimate of reliability but also an interval of likely variation above and below the basic estimate.

In order to accomplish the reliability requirements, the following contractor activities should be included in development programs:

1. Recording data required for statistical evaluation of tested item reliability
2. Evaluation and classification, in terms of effect on complete helicopter, of test failures for inclusion in reliability estimates
3. Calculation of item reliability estimates using test data as an input to the mathematical model, and comparison with prediction to evaluate reliability growth
4. Prediction and subsequent evaluation of the impact upon reliability of design changes and changes in operational requirements which occur during development testing
5. Periodic reliability reports on these activities during the course of development testing
6. Final reliability status report at the conclusion of developmental testing, as required by MIL-STD-1304.

10-1.4.3 Reliability Demonstration

The purpose of a reliability demonstration is to provide evidence that the complete helicopter system meets its reliability requirement. This objective normally is obtained by conducting a series of tests on the

complete helicopter system and calculating helicopter reliability solely on the basis of the results of those tests. The specific criteria for termination of testing may vary, but the basic intention is to reduce the producer and consumer risks (par. 10-1.4.1(4)) to an acceptably low level. For some programs, the cost, schedule, and other constraints may not allow adequate testing at the complete helicopter level. In this case, a number of tests at a lower level of assembly or analysis may be combined to estimate complete helicopter reliability. The latter technique should be avoided since there is no industry standard for this technique, and both the engineering and mathematical implications of such a combining technique are not well understood.

The contractor *shall* prepare, for procuring activity approval, a plan for formal demonstration of achieved reliability at specified milestones. This plan will reflect the following elements, which normally are specified by the procuring activity:

1. Number of test articles
2. Specified numerical reliability
3. Discrimination ratio or associated confidence or risk levels
4. Test levels and test plans (per MIL-STD-781)
5. Ground rules for reducing or tightening test severity for production demonstration
6. Requirements for retest
7. Disposition of test articles
8. Degree to which analyses can represent demonstration.

The plan also will reflect the following, which normally are proposed by the contractor, for procuring activity approval:

1. Milestone at which demonstration *shall* be initiated
2. Parameters to be measured and frequency of measurement
3. Definition of failure
4. Standards for item burn-in
5. Standards for replacement of deteriorated items
6. Detailed test procedures, including duty cycle, temperature/vibration/voltage cycling, and standards for preventive maintenance
7. Accept-reject-continue decision points
8. Corrective action requirements
9. Standards for excluding events
10. Maximum and minimum test times
11. Use of results from related testing and operational use

12. Records and reporting
13. Relationship of subsystem level test failures to helicopter system failure
14. Mathematical model used to combine subsystem level data to estimate helicopter system data.

10-2 MAINTAINABILITY

10-2.1 MAINTAINABILITY CRITERIA

Maintainability is a characteristic of equipment which is expressed as the probability that an item will be retained in, or restored to, a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources. Achievement of the required level of maintainability *shall* be demonstrated in accordance with the contractor's approved plan. Preparation of this plan *shall* include consideration of the items discussed in the paragraphs which follow.

The procuring activity *shall* provide the contractor with the operational information necessary to establish the maintenance and support concept. This information also provides the basis for the quantitative maintainability requirements for the helicopter. These data *shall* include, but not be limited to:

1. Planned deployment (type of units, quantity, and mission assigned)
2. Desired turnaround or servicing time requirements
3. Reaction time requirements
4. Mission reliability requirements (expressed with respect to mission and environment)
5. Availability (operational readiness) rate requirements
6. Operational and maintenance environment
7. Duration of mission
8. Utilization
9. Maintenance capability
10. Historical data on similar systems
11. Maintenance man-hour-per-flight-hour requirements
12. Maintenance personnel skill level.

10-2.1.1 Maintainability Analysis

Maintainability analyses accomplished during the proposal and/or definition phase *shall* serve as the starting point for maintainability design and result in the allocation of specific maintainability quantitative

factors and basic design criteria of system/components. Based on the results of analyses, trade-offs, and the design, the support concept defines the maintenance policy.

10-2.1.2 Maintenance Policy

The procuring activity *shall* establish the frequency of maintenance needs, level of maintenance support, facility and publication requirements, and the required quantity and type of maintenance personnel. The contractor *shall* furnish maintenance task requirements; spares, support equipment, and tool requirements; and the definition of maintenance procedures, in accordance with Chapter 4.

10-2.1.3 Maintenance Engineering Analysis Data System (MEADS)

Within the given parameters, the contractor *shall* perform a maintenance analysis for each identified task utilizing MEADS (see TM 38-703-3). This system constitutes a systematic evaluation of the relationship of each component to the quantitative maintenance requirement established by the procuring activity.

10-2.2 MAINTAINABILITY DEMONSTRATION

The objective of the maintainability demonstration is the verification of the portion of the quantitative goal which has been applied to each task. These goals apply to tasks assigned to the prime or subcontractor components as an entity (see pars. 10-2.2.2 to 10-2.2.3); as a segment of a system utilizing the mock-up (pars. 10-2.2.4 to 10-2.2.4.2); and as the portion of the operational helicopter (pars. 10-2.2.5 to 10-2.2.6.3).

10-2.2.1 Change Approval Policy

If a significant difference exists between predicted and measured data, corrective action *shall* be recommended by the contractor and submitted to the procuring activity.

Conditions for acceptance of the corrective action by the procuring activity should consist of the following:

1. Written approval by the procuring activity of the corrective recommendations and the impact statement
2. Implementation of the change in the component mock-up or helicopter by the contractor
3. Verification of the stated effect of the change on the total system maintainability by utilizing the mock-up. If verification cannot be performed on the mock-up, one of the Category I test helicopter *shall* be used.

10-2.2.2 Contractor Component Verification

Initial verification of the component *shall* begin prior to its integration into the system.

10-2.2.2.1 Component Repair

The contractor *shall* perform each maintenance action which has been established on the component as early as possible in its development. The customer-defined facilities and requirements, man-hours, elapsed time, skill level, tools, publications, and parts required for shop checkout, malfunction verification, fault location, repair, or part replacement and final checkout *shall* be recorded and assessed relative to the maintenance analysis allocation. The results *shall* be provided to the procuring activity. If a significant difference between predicted and measured data exists, the submittal to the procuring activity *shall* include a description of the action necessary to reconcile these data. Approval and verification *shall* be completed before the component can be qualified (see par. 10-2.2.1). Actions may include, but are not limited to, one or more of the following:

1. Change to the published instructions and/or procedures
2. Change to the required skill level and/or repair level
3. Change to the special tools and support equipment
4. Change to the design of the component
5. Change to the maintenance concept
6. Determine the effect on system maintainability.

10-2.2.2.2 Component Overhaul

Subsequent to the repair and checkout evaluations, a simulated or actual overhaul *shall* be performed. Data submitted to the procuring activity *shall* be the same as in par. 10-2.2.2.1.

10-2.2.3 Vendor and Subcontractor Maintainability

The prime contractor *shall* have established and controlled the maintainability efforts of vendors and subcontractors as an integral part of the maintainability program. Initial procurement specifications to the vendors and subcontractors *shall* have contained the appropriate maintainability requirements.

Compliance with the requirements for component verification is under the cognizance of the prime contractor and is monitored by the procuring activity. Successful demonstration of checkout, repair, and overhaul by comparing predicted and measured

requirements *shall* be made a requirement for qualification of the component. Justification for acceptance or rejection *shall* be documented and submitted to the procuring activity. Data submitted on a component which is accepted with a deviation from the predicted data *shall* include a statement of impact on the total maintainability program.

If a significant difference between predicted and measured data exists, the submittal *shall* include a description of the action necessary to reconcile these data. Approval and verification *shall* be completed before the component can receive qualification (see par. 10-2.2.1).

10-2.2.4 Mock-up

The next phase of the maintainability demonstration and verification *shall* take place on the full-scale mock-up, where three-dimensional analysis, including physical size, access, and clearances resulting from the integration of the component into the system can be examined. From examination and analysis, an area of congestion or complexity either may be evident or can be anticipated so that expeditious resolution of difficulties can be initiated and implemented prior to the production configuration.

10-2.2.4.1 System Verification

Successful mock-up demonstration of all servicing, removal, installation, adjustment, and repair techniques *shall* be documented and submitted to the procuring activity.

If a significant difference between predicted and measured data exists, the mock-up demonstration report *shall* include a description of the action necessary to resolve the differences through improved techniques and/or design (see par. 10-2.2.1).

10-2.2.4.2 Configuration Review

After the contractor has defined the final configuration and modified the mock-up, and after approval of all changes, the procuring activity *shall* review the helicopter maintainability characteristics. At this review, the contractor *shall* be prepared to present the analysis of each system and demonstrate those items which were requested by the procuring activity. Demonstration requests *shall* be submitted to the contractor no less than two weeks prior to the review. All demonstrations *shall* be limited by the capability of the mock-up.

10-2.2.5 Category I Tests (Contractor)

The maintenance support of the Category I flight test provides the first opportunity to evaluate the maintainability of an actual flight helicopter. Consideration

shall be given to downtime and man-hours expended because of the experimental flight test environment; i.e., instrumentation, engineering inspections, more stringent tolerances, and levels of acceptance.

The man-hours required to maintain the helicopter *shall* be monitored by the contractor and evaluated against the established goals.

10-2.2.5.1 Preventive Maintenance (PM)

The servicing and inspection tasks performed during the flight test program *shall* be monitored and data recorded that will allow a direct comparison with the maintenance analyses of the task. These data will include, but not be limited to, the following:

1. Task element description and justification
2. Elapsed time to complete by task element
3. Men required by task element
4. Skill level of individuals
5. Requirement for special training
6. Standard tools required
7. Support equipment and/or special tools required
8. Facilities utilized
9. Publications utilized and adequacy
10. Frequency of the task
11. Part utilization.

Accumulated data *shall* be compared with the maintenance analysis as a means of verifying the time estimates and the support requirements.

Results of the comparisons and change recommendations *shall* be submitted to the procuring activity as the evaluation of each major inspection is completed. Resolution of differences *shall* be directed by the procuring activity.

10-2.2.5.2 Corrective Maintenance

Corrective maintenance tasks *shall* be monitored only as failures and malfunctions occur. During the initial phases of Category I flight test, demonstrations of specific items *shall* not be required. The data elements recorded in par. 10-2.2.4.1 are necessary for each of the steps which follow in the correction of an actual malfunction:

1. Indication of problem
2. Fault isolation procedure sequence and effectiveness of diagnostics
3. Verification
4. Checkout and return to service.

The recorded data *shall* be compared with the maintenance analysis for each task, as a means of verifying the time estimates and the support requirements.

10-2.2.6 Category II Tests (Government Test Agency)

Compliance with contract requirements *shall* be demonstrated during this phase.

10-2.2.6.1 Task Selection

The contractor *shall* use MIL-STD-471 as the guide for selection of maintenance tasks to be demonstrated. This method provides a representative sample of the total population of tasks.

The corrective action for a large number of the selected tasks will be the removal of a specified component and replacement of it with a like serviceable item. On these components, the repair and/or overhaul also *shall* be demonstrated. The contractor *shall* perform the detailed scheduling and planning of this phase, but all tasks *shall* be completed prior to the end of Category II tests. All preventive maintenance, servicing, and mission reconfiguration tasks *shall* be verified during the demonstration.

Appendix B of MIL-STD-471 outlines six test methods for determination of achievement of specific quantitative maintainability requirements. The choice of a particular method *shall* be made by the procuring activity, with primary consideration given to the specified maintainability parameters and goals and secondary considerations for time, cost, and risks.

10-2.2.6.2 Contractor Maintainability Demonstration

After the corrective maintenance tasks and the method of evaluation have been identified, the contractor *shall* be provided sufficient time to perform each task before the formal demonstration for contract compliance. The purpose of this effort is to verify that the tasks can be accomplished within the defined parameters (MEADS) and to determine the inherent maintainability of the helicopter. The procuring activity *shall* monitor this demonstration.

10-2.2.6.3 Contract Compliance Demonstration

The contractor *shall* use MIL-STD-471, pars. 4.1 and 4.2, as the guide for preparation and submittal of the demonstration proposal. This demonstration *shall* be performed by personnel from the procuring activity. Therefore, the demonstration may be initiated subsequent to the approval of the proposal and concurrence by the contractor and the procuring activity in order

that the training of the personnel who will perform the tasks is satisfactory.

A number of conditions of the demonstration *shall* be given particular consideration:

1. The environment *shall* be representative of the working conditions, tools, GFE, and publications that would be expected during normal operation at that maintenance level.

2. Each item *shall* be checked for condition, prior to inducement of the failure.

3. Secondary failures inherently caused by the primary failure are considered a part of the repair time to be demonstrated.

4. Appropriate test equipment, tools, spares, and publications *shall* be available in the test area; however, their presence *shall* not assist in fault isolation by prematurely identifying work to be done. Test time includes obtaining this equipment only from the work area.

5. Resources *shall* be the same as those used in the operational environment, or a reasonable substitute that is acceptable to both the contractor and the procuring activity.

6. For GFE components, the contractor is responsible for determining the maintainability characteristics and values applicable to his system and for assuring that they are not downgraded unless compensated for by the demonstrated characteristics and values for other equipment. The procuring activity *shall* be made aware of any areas which cannot be compensated for, and *shall* have resolved the situation prior to the demonstration.

7. All work required to prepare for the simulation of maintenance tasks *shall* be accomplished by the contractor.

8. Refurbishment of the equipment used in the induced failure portion of the maintainability demonstration *shall* be accomplished by the contractor or subcontractors, as applicable.

9. The contractor *shall* monitor the demonstration for the purpose of providing technical guidance, identifying areas of additional training requirements, and assuring that proper maintenance procedures and techniques are practiced.

Retest requirements *shall* be in accordance with the demonstration proposal.

10-2.3 TRANSPORTABILITY

10-2.3.1 Transportability Criteria

The procuring activity will provide the contractor with the operational deployment information upon which he bases the transportability goals.

10-2.3.2 Transportability Demonstration

The contractor *shall* consider the modes listed:

1. Self-deployment (ferry). Total distance, length of longest leg, equipment, and personnel to be carried, and availability of inflight replenishment

2. Aerial Movement. Type of aircraft and whether the helicopter will be transported internally or externally

3. Land Movement. Designation by model of vehicles available, area of operation (military, commercial, or combination), and maximum distance

4. Sea Movement. Designation by model of ships available, size and location of area available (above or below deck), and length of time onboard.

The procuring activity *shall* define the minimum size component which will receive special consideration. Information listed in par. 10-2.2.2 *shall* be provided as applicable to the components.

The contractor *shall* insure that the helicopter and its components are designed, engineered, and constructed so they can be effectively transported by the modes defined by the procuring activity.

A detailed analysis *shall* be performed to determine the specialized materials, tasks, tools, and equipment necessary to disassemble, transport, reassemble, and check out the helicopter. Special instructions *shall* be provided if required.

The procuring activity *shall* provide actual vehicles for demonstration when items exceed the 80% load capability. Demonstration of those items with critical clearance may be performed on the actual helicopter or on a mutually agreed-upon mock-up or simulation of the helicopter.

All demonstrations *shall* be monitored by a representative of the procuring activity. If a demonstration is unsuccessful, the contractor *shall* submit the corrective action; i.e., changes to the item, to the disassembly procedure, or to the loading procedures. Final disposition and retest requirements *shall* be made by the procuring activity.

REFERENCE

1. A. H. Bowker and G. J. Lieberman, *Engineering Statistics*, Prentice Hall, 1959.

CHAPTER 11

GOVERNMENTAL TESTING

11-0 LIST OF SYMBOLS

- n_L = design positive limit load factor
 O_p = magnitude of peak overshoot
 % of steady-state, or
 magnitude of second peak to
 first peak, % of first peak
 T_i = time to reach specified
 threshold value in proper
 direction
 β = angle of sideslip
 τ = time to reach 63% of
 steady-state value initially or
 time to reach 63% of initial
 peak for oscillatory modes
 initially with a period longer
 than 3 sec
 ζ = damping ratio

11-1 INTRODUCTION

The concepts, objectives, policies, and techniques of Governmental development testing are specified in AR 70-10. The objectives of Governmental testing are:

1. To determine the degree to which a component meets the specification and performance necessary to its application in the proposed system
2. To determine on a timely basis whether or not design and development of critical components are progressing satisfactorily
3. To determine the degree to which new materiel for Army use meets each characteristic of an approved requirement document
4. To provide a preliminary investigation of the compatibility of the new materiel with current doctrine, basis of issue, organization, and tactics
5. To provide a complete maintenance evaluation of the materiel and its maintenance test package (AR 750-6) to include maintainability of the equipment, validity of the maintenance support concept, and the

adequacy of logistic support planning as exemplified in the maintenance test package

6. To determine if any changes are required to make new or existing materiel safer or more suitable for Army use prior to item production

7. To investigate the validity of provisions for human factors and requirements used to develop training and maintenance support plans, and qualitative and quantitative personnel plans

8. To evaluate and specify equipment characteristics (or functional constructed facility) in order to provide a basis for preparing individual and unit training objectives, methods and plans, for developing training aids and devices, for formulating maintenance concepts, and for preparing documentation

9. To provide for the evaluation and refinement of task description, qualitative and quantitative personnel requirements (QQPRI), training objectives, instructional methodology, training aids/devices, and training course content to insure an effective training program upon the fielding of new equipment

10. To provide data to be used in the determination of the overall military worth of developmental materiel at appropriate times in the development cycle

11. To ascertain if value engineering proposals are feasible.

11-1.1 COORDINATED TEST PROGRAM (CTP)

AR 70-10 requires a Coordinated Test Program (see par. 2-1) for each development project or task initiated to satisfy a stated requirement. This program will list and discuss the objectives of all tests intended to be performed on the helicopter. Tests are not always performed separately and may be combined or omitted as appropriate. The CTP will note the omitted or combined tests and will specify which tests will serve the objectives of those that have been omitted. The CTP will include the test objectives established by all agencies (industrial or Governmental) within their appropriate areas of responsibility.

Test design will be based on the objectives specified for the system, its intended operational use, the operational availability to be achieved, special design features of the item, scientific testing methodology, the cost of the system, and the urgency for deployment.

11-1.2 GENERAL TEST REQUIREMENTS

Although the test cycle for Army helicopters generally follows that for other Army equipment, the special characteristics of helicopters require that testing follow a different pattern at several places during development. A CTP similar in concept to that described previously is prepared and includes the test programs defined subsequently.

11-1.2.1 Contractor's Development and Airworthiness Qualification Tests

Tests are conducted by the contractor, normally at his facilities, on a prototype sample. The development portion of the tests is used to prove out the individual parts, components, subsystems, and total aircraft systems including separately developed allied equipment. The qualification portion of these tests is used to demonstrate to the Army the adequacy of the aircraft to function satisfactorily when used within prescribed limits. The objective of the contractor's tests is to demonstrate a flight envelope and determine operational limitations. For onboard allied equipment being separately developed, and for which working samples are unavailable, a correctly positioned load of proper weight and cube representative of this equipment will be aboard the aircraft for contractor tests. Governmental witnessing/monitoring of the tests will be conducted and a joint contractor/Governmental effort is required for flight envelope expansion testing. This joint participation effort will insure maximum usage of all available flight test data and thereby reduce/eliminate any duplicatory test requirements. The contractor's detailed test plans for accomplishment of this qualification program will be Government-approved in accordance with specific requests of appropriate contract(s).

11-1.2.2 Army Preliminary Evaluations (APE)

Army Preliminary Evaluation tests usually are conducted on the prototype sample in the early stages of the development to:

1. Provide quantitative and qualitative engineering flight test data
2. Serve as a basis for an estimate of the degree to which the helicopter is suitable for its intended mission

3. Assist in determining the flight envelope to be used by Army pilots for future tests and for flight operations

4. Detect and allow for early correction of deficiencies

5. Provide a basis for evaluation of changes incorporated to correct deficiencies

6. Provide preliminary helicopter performance data for operational use.

These evaluations may be conducted in various phases until the procuring activity determines that the helicopter is acceptable for commencement of service tests. These APE's are equally effective in achieving the same objectives when conducted on already-developed helicopters which are undergoing significant modifications.

The scope of the APE will depend on the type of system being evaluated, the period of time allotted for the test, the stage of development of the material, and the helicopter itself (prototype or production model). Testing normally is performed at the contractor's facilities.

11-1.2.3 Endurance Tests

Endurance tests are conducted by the contractor, normally at his facility, on a prototype sample or production helicopter. This test will be on an accelerated basis, encompassing a minimum of 300 flight hours, for the purpose of determining the endurance and reliability of the basic design and to determine the adequacy of design changes to correct deficiencies revealed during the other tests. Monitoring or participation by the Government may be required.

11-1.2.4 Airworthiness and Flight Characteristic Tests

Airworthiness and flight characteristic tests are conducted initially on prototype and later on production helicopters, usually at Governmental facilities. The objective of these tests is similar to engineering tests and preproduction tests for nonair items. The objectives of the airworthiness and flight characteristic tests are to obtain final determination of:

1. Contract compliance in appropriate areas
2. Compliance with the Military Specifications and/or the Helicopter Engineering Handbook
3. Detailed information on performance, stability and control, handling characteristics, structures, and integrated system characteristics
4. Feasibility of operational techniques for inclusion in technical manuals and other publications.

11-1.2.5 Climatic Tests

Controlled environment climatic tests are conducted on development prototypes or production helicopters by the Government or by the contractor (under Governmental supervision) (see pars. 11-4 and 8-9.7). These tests are performed at extreme environmental conditions, primarily those of temperature and humidity, often beyond the normal operating limits. These qualification tests demonstrate to the Army the adequacy of the total helicopter system, component parts, and subassemblies to function satisfactorily throughout the full range of the required operations environment; further, they establish the limits of safe operation at unusual temperatures. The climatic laboratory test is a prerequisite for arctic service tests.

11-1.2.6 Service Tests

Service tests are conducted on either development or production prototypes under simulated or actual operational conditions to determine to what degree the helicopter meets the characteristics stated in the requirement document. These tests also will include the maintenance portion of service tests outlined in AR 750-6. In addition, the service test will include certain other tests designed to facilitate the gathering of data to aid the following:

1. Determination of component service life and the development of inspection cycles
2. Development of quick-change kits and modifications
3. Determination of refinement of manpower, equipment, skill, and training requirements
4. Development of repair part consumption data for use during provisioning and supply control
5. Verification of source coding and refinement of supply authorization documents
6. Development of maintenance and operating costs.

11-2 ARMY PRELIMINARY EVALUATION (APE)

11-2.1 APE PREREQUISITE

Prior to an APE the contractor *shall* demonstrate to the procuring activity—with the results of ground, fatigue, and vibration tests and with other analytical data—that, within the allowable flight envelope, the helicopter is aerodynamically, structurally, and func-

tionally safe for an evaluation by Army test pilots. The contractor *shall* configure the test helicopter to be as it was during the contractor's flight test program or as specified by the procuring activity. Recording instrumentation *shall* not be changed from that used by the contractor unless specifically requested by the procuring activity. The contractor *shall* furnish such services, materials, and logistical support necessary to keep the helicopter in satisfactory operation during the evaluation; instructions will be provided on the operation of equipment, operating techniques, handling qualities, emergency procedures, and other information necessary to insure safe operation. For new helicopters, sufficient flight instruction *shall* be provided to satisfy test pilot training requirements for tests of this type.

Prior to the start of the APE, a Safety-of-Flight Release must be issued by the U.S. Army Aviation Systems Command (USAAVSCOM) to establish the flight envelope and other operating instructions for the test. This release will be based upon the determination of contractor compliance with demonstration requirements and any appropriate information derived by the Army during the contractor's program.

The test activity will prepare a test plan based on APE test objectives and specific objectives defined in a test directive. The test plan will be submitted for approval no later than 60 days prior to the start of the test.

Not later than four weeks prior to the start of the APE, a preevaluation conference will be held with representatives from the procuring activity, the test activity, the contractor, and any other Governmental organizations concerned with the program. The purpose of the conference is to:

1. Review the extent to which preevaluation requirements have been completed
2. Review the contractor's recommended flight envelope (this may differ from the approved envelope in the Safety-of-Flight Release)
3. Verify the helicopter configuration
4. Finalize contractor support requirements, coordinate data reduction facility needs, define office space requirements, and define other services and supplies to be provided by the contractor.

A complete preevaluation inspection of the helicopter will be performed prior to the APE by qualified maintenance and instrumentation technicians from the test activity. Representatives of the military office charged with plant cognizance at the contractor's facility should participate. The primary purpose of this inspection is to locate and correct any safety-of-flight

discrepancies in the test helicopter (emphasis is placed on inspection of special test installations).

11-2.2 DETAILS OF TEST

11-2.2.1 Functional Tests

Functional checks of all subsystems and operating equipment in the test helicopter (engine, flight controls, and hydraulic, electrical, and other major systems) will be conducted to determine conformance with the applicable specifications. An evaluation of the cockpit and cabin, including equipment installation and crew ingress/egress, will be performed.

11-2.2.2 Handling Qualities

The first APE normally will concentrate on evaluation of longitudinal, lateral, and directional stability and control at design gross weight. Center-of-gravity (CG) locations will be selected to achieve normal mission operating conditions within the flight envelope and investigate the effects of CG variations. The following characteristics normally will be investigated:

1. Ground handling and ground resonance
2. Takeoff, landing, hovering, and sideward and rearward flight
3. Climb, cruise, maneuvering, and descent, including the effects of power and configuration changes, and acceleration, deceleration, and autorotation
4. Low and high speed, including stall, compressibility, and instability effects
5. Buffet, vibration, and noise in steady unaccelerated flight in increments throughout the speed range of the helicopter
6. Control, with alternate and/or emergency systems in operation
7. Other characteristics determined to be appropriate.

11-2.2.3 Performance

The second APE usually will consist of sufficient testing to provide preliminary performance data for operational use and to enable an estimate of contract guarantee compliance. Evaluation normally will be conducted at the design gross weight and mid-CG for:

1. Hover performance both in and out of ground effect
2. Climb performance, including service ceiling
3. Level flight performance, including maximum cruise speed at normal rated power and determination of the maximum level flight airspeed as limited by

power available, structural consideration, or other factors.

4. Engine inoperative performance (multiengine helicopter)

5. Autorotational descent performance

6. Other characteristics determined to be appropriate.

11-2.3 SUBSEQUENT ARMY PRELIMINARY EVALUATIONS

Subsequent APE's normally will be considered as necessary to accomplish:

1. Evaluation of mission-essential equipment not previously tested such as weapons, navigation system, night vision system, etc.
2. Evaluation of characteristics which were not satisfactorily investigated or fully evaluated during the initial APE
3. Reevaluation of characteristics affected by changes or modifications installed since the completion of the initial APE.

11-2.4 ARMY PRELIMINARY EVALUATION REPORTS

Reporting requirements will be specified in the test directive and should include:

1. Upon completion of the testing a TWX report will be sent to the procuring activity specifying the major conclusions and recommendations.
2. Within two weeks after completion of the testing, an interim report containing preliminary data and discussion to substantiate conclusions and recommendations will be forwarded to the procuring activity, and a debriefing scheduled for the contractor.
3. A final report should be prepared to incorporate results of all APE's conducted on the helicopter unless the test directive requires separate reports.

11-3 FINAL AIRWORTHINESS AND FLIGHT CHARACTERISTIC TESTS

11-3.1 GENERAL

The final airworthiness and flight characteristic tests are conducted as directed by the procuring activity on prototype or production helicopters to obtain final determination of:

1. Contract compliance as applicable

2. Compliance with the applicable Military Specifications

3. Detailed information on performance, stability and control, power plant operation, and integrated system characteristics

4. Feasibility and development of operation techniques for technical manuals and other publications

5. Adequacy of the helicopter systems and subsystems including separately developed allied equipment under extreme temperature conditions

6. Verification of the recommended flight envelope for other ensuing test and operational use.

The procuring activity will issue a test directive to the test activity at the earliest possible date. The test directive will specify the objectives, define the scope, and outline the required and available resources. The test directive will establish the test equipment to be used, the required schedule, and the test site location.

The test activity will develop a suitable test plan to show the testing necessary to achieve the objectives. A detailed schedule will be established and milestones specified. Estimates will be made of costs, material, and support requirements. This test plan will be approved by the procuring activity and published by the test activity.

Special test instrumentation will be provided to accumulate the precise quantitative data essential to the accomplishment of the test objectives. Provisions will be made for the inflight measurement and recording of basic flight parameters such as pressure altitude, ambient temperature, and airspeed. In addition, measurements and recordings will be made for engine power parameters (rpm, temperatures, pressures, torques), rotor speed, angles of attack and sideslip, control forces and positions, helicopter attitudes, rates, angular and linear accelerations about all three axes, vibration transducers, noise-measuring equipment, and other pertinent parameters. All instrumentation will be calibrated prior to the start of the test and at regular intervals during the program.

11-3.2 TEST PROGRAM

The test program will consist of performance tests, stability and control tests, and any other tests which may be required to evaluate compliance with contract specifications which have not previously been demonstrated.

In general, data are obtained under carefully controlled flight conditions and at a selected atmospheric environment. Engineering flight test techniques, data to be recorded, methods of data reduction, and typical

data presentation are contained in AMCP 706-204 and are outlined herein for other tests normally conducted.

11-3.2.1 Performance Tests

Testing will be conducted to determine the helicopter performance characteristics throughout the flight envelope. Specific tests will be included to assure positive determination of compliance with all stated contract performance guarantees. Such guarantees may vary, depending on the design mission, but normally include items such as maximum speed, cruise speed, range, endurance, hover ceiling, service ceiling, and rate of climb. Tests will be conducted at various altitudes and gross weights to include the maximum and minimum obtainable. In addition, the following performance characteristics will be determined quantitatively to provide a basis for the preparation of Chapter 14 of the Flight Manual:

1. Hover
2. Takeoff
3. Climb
4. Speed, range, and endurance
5. Autorotational descent
6. Landing (both normal and autorotational)
7. Turning
8. Acceleration and deceleration.

11-3.2.2 Stability and Control Tests

These tests are conducted to verify compliance with MIL-H-8501, quantitatively define handling qualities, identify shortcomings and deficiencies, if present, and develop operational techniques. Normally, all deficiencies (i.e., those items which make the helicopter unsuitable to perform its intended mission) require correction prior to service use whereas shortcomings can be corrected with desirable changes. These tests are conducted at altitudes and gross weights throughout the operational envelope as well as at the CG limits. The specific mission may dictate certain unique tests which must be conducted but, as a minimum, the following characteristics are determined:

1. Static trim
2. Static longitudinal stability
3. Static lateral-directional stability (including dihedral effect)
4. Dynamic stability
5. Maneuvering stability
6. Controllability
7. Trim changes associated with configuration or power changes

8. Autorotational entry
9. Sideward and rearward flight
10. Control system mechanical characteristics
11. Failure modes of stability and control augmentation devices.

11-3.2.3 Miscellaneous Tests

In addition to the performance and stability and control tests listed previously, other tests may be conducted. Depending on the helicopter mission, some or all of the following tests may be conducted:

1. Pitot static system calibrations (see AMCP 706-204)
2. Vibratory surveys
3. Internal and external noise level surveys
4. Sling load operations
5. Weapon firings
6. Store jettisons.

11-3.2.3.1 Vibratory Test Surveys

Helicopter vibratory testing is conducted primarily to determine the magnitude and waveform of the rotor-induced vibrations in order to evaluate their effect on pilot and passenger comfort, engine/air frame compatibility, structural integrity, etc. The predominant fuselage vibrations caused by the rotor are vertical; inplane, rotor-induced vibrations also occur and primarily cause lateral fuselage vibrations. Longitudinal fuselage vibrations are usually small. MIL-H-8501 limits for the vibrations at the controls, the pilot's station, and the passenger stations usually are made specification requirements.

The source of low-frequency vibrations in the helicopter is the rotor. Forces transmitted to the rotor hub are at frequencies which are integral multiples of the number of rotor blades. Thus, for a three-bladed rotor, the vibrations transmitted to the controls and fuselage occur at frequencies of three cycles per rev, six cycles per rev, nine cycles per rev, etc. Significant rotor-induced vibrations can occur up to the 10th harmonic order. Generally, low-frequency vibrations for a two-bladed rotor, on the order of two per rev or four per rev, are found to be the most annoying to the pilot and passengers.

11-3.2.3.1.1 Test Requirements

Parameters which must be recorded for vibration tests include vibratory accelerations, amplitudes, frequencies, pressure altitude, airspeed, free air temperature, rotor rpm, gross weight, and mass distribution.

The magnitude of the vibrations is determined primarily by rotor speed/airspeed, load factor, mass distribution and CG, and gross weight. The mass distribution is determined by the configuration, fuel weight and location, and cargo or ballast weight and location. Vibratory levels usually increase as airspeed and load factor are increased. Rotor rpm affects both the magnitude and the frequency of the vibrations. Changing the mass distribution while keeping the gross weight constant can cause significant changes in the vibratory levels. This is particularly important in large helicopters which have more loading configurations and more fuselage elasticity than smaller models.

Vibratory data usually are recorded during stabilized flight conditions throughout the flight envelope. Typically, data would be recorded in level flight at approximately 10-kt intervals from $V_{\text{Best Endurance}}$ to $V_{\text{Max Level Flight}}$ in dives to V_{NE} in maximum power climbs from $V_{\text{Max Rate of Climb}}$ to $V_{\text{Cruise Climb}}$ and in minimum power descents from $V_{\text{Min Sink Rate}}$ to $V_{\text{Best Glide Distance}}$. Vibratory levels usually are less significant in a hover. However, vibration in translation from or to a hover often is a severe vibration area. The effect of changing gross weight, rotor rpm (if there is an allowable range of rotor rpm for power-on flight), and mass distribution for different configurations and different types of cargo loads should be investigated.

The effect of load factors can be investigated by first stabilizing at the desired airspeed in level flight. The helicopter then can be put into a constant load factor coordinated turn with airspeed kept constant by losing altitude. Data are recorded when the helicopter is stabilized in the turn.

11-3.2.3.1.2 Instrumentation

Accelerometers usually are used to record vibratory data. The accelerometers, which must have a response covering the frequency range of interest, are mounted on a fixture and oriented to sense vibrations along the vertical and lateral axes since the major vibrations occur on these axes. If measurements of longitudinal vibrations are desired, three accelerometers can be mounted in a group, or triaxial accelerometers can be used. It is usually desirable to use a cutoff filter on the accelerometer output to eliminate higher frequency vibrations from those of interest. This simplifies the data analysis by limiting the frequency range which needs to be analyzed.

Data can be recorded on an oscillograph run at high speed or on a magnetic tape recorder.

11-3.2.3.1.3 Documentation

The objective of the data reduction is to determine the vibratory spectrum by finding the amplitudes and frequencies of each of the several harmonic waveforms present in the acceleration trace.

Since it is assumed that vibratory data are harmonic and that the frequencies are integral multiples of the number of rotor blades, some type of harmonic analysis technique should be used. It is possible to reduce the data graphically from a time history trace of the acceleration. Digital Fourier analysis techniques are used with data recorded on magnetic tape; oscillograph data can be digitized, and also can be analyzed by Fourier analysis. Automatic spectral analysis equipment accepts the magnetic tape data and determines the frequencies and amplitudes composing each waveform.

The data usually are presented as the peak of levels occurring at the frequencies which are integral multiples of the number of rotor blades. For example, there might be a two per rev at 0.12g for a particular condition in a two-bladed rotor helicopter. The data are presented as a plot of "g" level versus true airspeed for a constant frequency, gross weight, rotor, altitude, and mass distribution as shown in Fig. 11-1. However, the "g" level or frequency can be plotted versus any of the other independent variables.

11-3.2.3.2 Static Longitudinal Stability Tests

Static longitudinal stability characteristics are determined by recording the control positions necessary to balance pitching moment about the helicopter CG. This pitching moment is caused by forces and moments developed on various components of the helicopter in flight. Flight tests are conducted to determine whether this moment is stabilizing or destabilizing as a function of airspeed.

Two types of static stability related to pitching moments produced on the helicopter are speed stability and angle-of-attack stability. Speed stability is associated with pitching moments resulting from a change in forward speed. Normally, an increase in forward speed produces a noseup moment on single-rotor helicopters. The resulting attitude tilts the rotor thrust rearward, tending to decrease the forward speed back to trim. This indicates the rotor possesses positive stability with speed. However, the fuselage makes an unstable contribution. Often, the unstable fuselage contribution will override the stable rotor contribution in the higher forward speed regime. In these cases, horizontal stabilizers may be provided to make a stable contribution to speed stability.

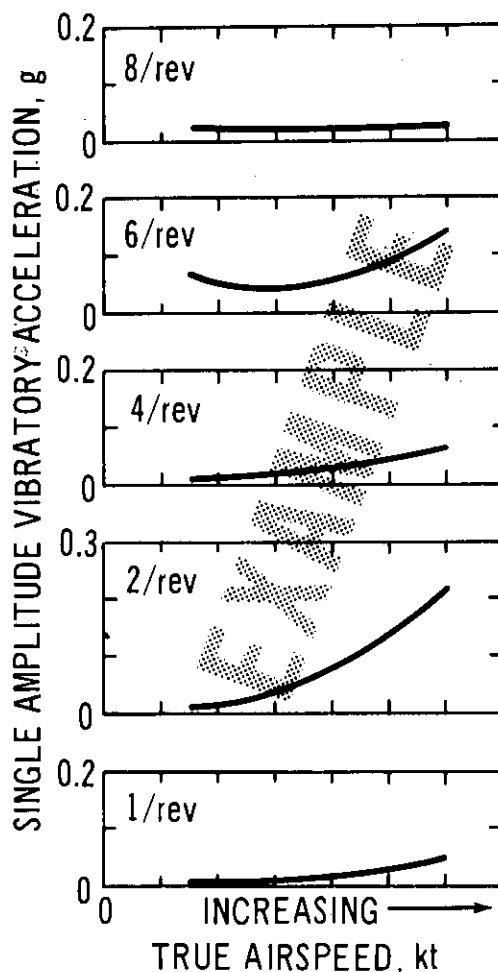


Fig. 11-1. Vibratory Level

Acting in the same manner as a single rotor, the individual rotors of a tandem rotor tend to produce speed stability. However, variation of rear rotor thrust with speed due to the downwash from the front rotor causes an unstable moment. Therefore, the tandem rotor arrangement is usually unstable with speed.

Angle-of-attack stability is associated with the pitching moment resulting from a change in angle of attack. The helicopter rotor is unstable with angle of attack. An additional contribution is made by the fuselage which also is unstable with angle of attack.

The instability with angle of attack of a tandem rotor is due to the rear rotor operating in the downwash field of the front rotor. An increase in angle of attack results in less thrust increase in the rear rotor which is influenced by the increased downwash of the front rotor. The result is a noseup, or unstable, moment about the helicopter CG.

Control position stability reflects the combined effects of speed stability and angle-of-attack stability. It

is affected by all contributions to the pitching moment about the helicopter CG. Control position stability implies a definite relation between control position and flight speed. Positive control position stability is displayed by a positive variation of pitching moment with forward speed. An increase in pitching moment will require forward movement of the longitudinal control.

A neutral gradient implies that the helicopter requires no trimming after a speed change in order to maintain the speed. Control forces associated with the increase or decrease in airspeed from trim are more important than the control position investigation of the static stability. Forces are what the pilot feels and are the real guide, whereas he has little indication of the control position. These factors become of prime importance in the part they play in the overall flying quality investigation from a mission standpoint.

Unstable longitudinal static stability characterized by a negative gradient implies a more rearward control trim position for increased forward airspeed and a more forward control trim position for decreased forward speed. The problem from the standpoint of the pilot is apparent. Also, any disturbance from trim which is not compensated for by the pilot results in a divergent response.

Aside from the need for positive control position stability, acceptable control forces associated with control displacements are important. Proportionality between the control force required and the control displacement from trim position is desirable. A stable force gradient indicates that the control tends to return to the trim position if released after a control input. This gives the pilot a continuous indication in steady flight by control pressure whether he is faster or slower than trim speed. Breakout forces, friction, and asymmetric and/or nonlinear gradients also are important factors affecting control forces.

11-3.2.3.2.1 Test Requirements

Parameters which must be recorded during the static longitudinal stability test include indicated airspeed, longitudinal control position and control force, outside air temperature, rotor speed, engine torque, vertical speed, pitch attitude, pressure altitude, and fuel rate.

The general procedure for forward flight static longitudinal stability testing is as follows:

1. Stabilize the helicopter for a selected trim airspeed.
2. Fix the collective position.

3. Increase indicated airspeed 5-10 kt with longitudinal control and stabilize the helicopter without retrimming.

4. Record the data.

5. Repeat Items 3 and 4 until the desired upper speed range is completed.

6. Decrease indicated airspeed 5-10 kt below trim speed with longitudinal control, and stabilize the helicopter without retrimming.

7. Record the data.

8. Repeat Items 6 and 7 until the desired lower speed range is completed.

11-3.2.3.2.2 Instrumentation

Test instrumentation required to conduct the static longitudinal stability test includes airspeed, altitude, OAT, rotor rpm, fuel counter, engine torque, longitudinal stick position and force, pitch attitude, and vertical speed.

11-3.2.3.2.3 Documentation

Typical results from data obtained during the static longitudinal stability test may be presented in the format shown in Figs. 11-2 and 11-3.

11-3.2.3.3 Dynamic Longitudinal Stability Tests

There are two longitudinal modes of free motion of helicopters in flight: the short period and the long period, or phugoid, mode. The short period mode describes the response of the helicopter to a sharp edge pulse control displacement or to a gust. The long period mode describes the response to an out-of-trim condition or step input.

For helicopters in hovering flight, the short period mode is usually heavily damped and nonoscillatory, and the long period mode divergent and oscillatory. In forward flight, the short period mode is heavily damped and hard to investigate. Effects from the rotor, fuselage, and horizontal tail offer varying contributions affecting stability.

In a short period mode, the longitudinal response to a gust may cause a helicopter to pitch up. Rotor forces during gust provide additional forces which add to the pitching moment. The effect of these moments upon the attitude and airspeed is apparent. If the degree of gust is minute, the corresponding change in attitude and airspeed may be unnoticed by the pilot. If the pitch response to a gust is very rapid, damping provided by longitudinal stability augmentation may be required. Similarly, damping in the form of augmentation may be

employed to cope with the main rotor contribution. The effect of gust in hovering flight may be measured by the extent to which the helicopter is upset from trim, and the ease with which the pilot is able to restore the initial attitude. In forward flight, the analysis of the

response to gusts includes vertical gusts as well as horizontal gusts.

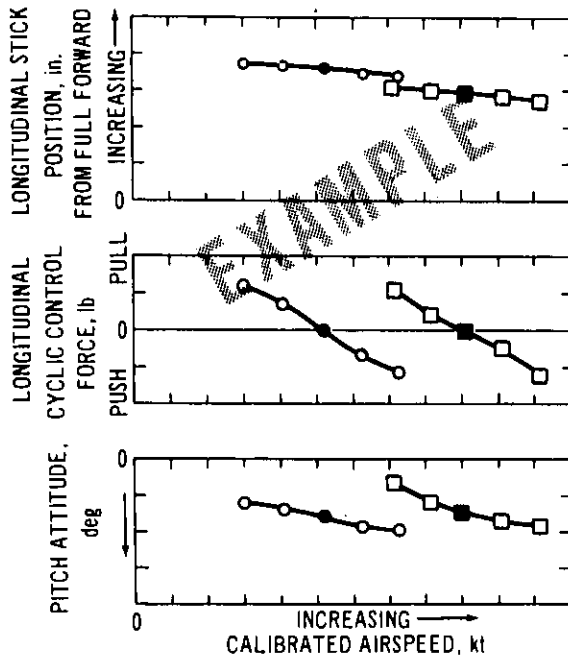
Long period responses may be shown as time histories of parameters denoting the helicopter attitude. The fundamental characteristics of the long period response may be indicated by the control position information acquired during static stability tests. Positive static stability generally indicates a convergent oscillatory response. Negative static stability usually indicates a periodic divergence. Long period responses are not always sinusoidal. Stability augmentation contributes to many of the nonsinusoidal responses.

11-3.2.3.3.1 Test Requirements

Parameters which must be recorded for both the long period and short period modes during the dynamic longitudinal stability test include longitudinal control position, collective control position, normal acceleration, airspeed, pitch attitude, rate and acceleration, and elapsed time.

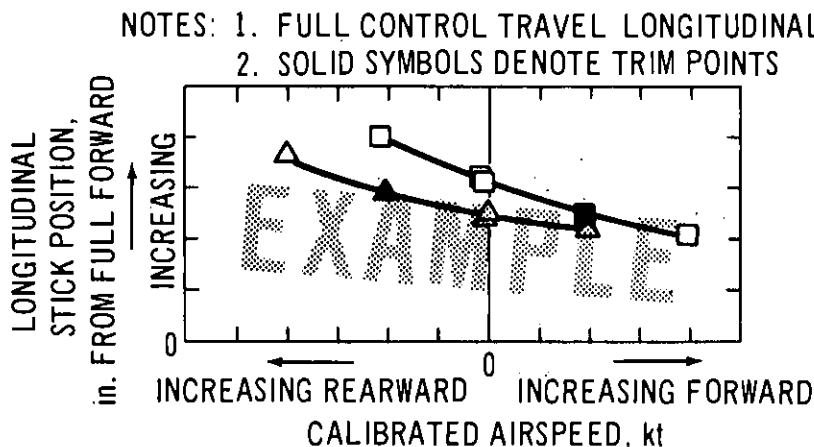
11-3.2.3.3.1.1 Short Period Mode

The longitudinal response to gust in hovering flight is evaluated by trimming the hovering helicopter and recording conditions. The longitudinal control position is recorded. Holding the collective control and power fixed, the helicopter is stabilized in forward flight at 5 kias. The longitudinal control position is recorded with reference to the amount of displacement from the hovering position. The helicopter is returned to a hover and retrimmed. With the oscillograph active, a rearward longitudinal control input of the same displacement as



- NOTES: 1. FULL CONTROL TRAVEL LONGITUDINAL = 14 in.
2. SOLID SYMBOLS DENOTE TRIM POINTS

Fig. 11-2. Static Longitudinal Collective Fixed Stability



- NOTES: 1. FULL CONTROL TRAVEL LONGITUDINAL = 14 in.
2. SOLID SYMBOLS DENOTE TRIM POINTS

Fig. 11-3. Static Longitudinal Hovering Stability

for forward flight is made. The input time is about 1 sec or the appropriate period of the gust. The oscillograph is deactivated after several cycles of the long period response are experienced. This test may be repeated with a control displacement measured for a greater forward speed representing a larger magnitude of gust.

The response to gust in forward flight is evaluated by trimming the helicopter at a stabilized test condition. With the recording equipment on, a measured aft longitudinal control input is made. After the effect of the long period response is experienced, the recording equipment may be turned off. Gust response in forward flight may be evaluated by pulsing the collective control to introduce a 0.25 g normal acceleration input.

The short period control evaluation is made by attaining a stabilized test condition, and recording with an oscillograph the rearward control displacement against the force gradient followed by control release. The test then is conducted in a similar manner with a forward control displacement.

11-3.2.3.3.1.2 Long Period Mode

The long period test is accomplished by stabilizing at test conditions and applying trim. The long period response is excited by displacing the longitudinal control to decrease the airspeed 5 kt and returning the control to trim. Considerable effort may be required to excite the long period response properly. The control-free long period test is conducted in the same manner as the previously mentioned test except the control is not held fixed during the long period response. Particular attention is given to movement of the control after release, since the long period response will differ from the control-fixed response if free movement is detected.

11-3.2.3.3.2 Instrumentation

Instrumentation required for the dynamic longitudinal stability tests includes oscillograph or magnetic tape, control position indicators, accelerometers, sensitive airspeed indicator, and pitch indicator.

11-3.2.3.3.3 Documentation

Data reduction is accomplished using standard conversion and calculation methods. Typical results of the tests are presented in Figs. 11-4 and 11-5.

11-3.2.3.4 Maneuvering Stability Tests

Because present-day helicopters are capable of high load factors at high speeds, the stability characteristics during maneuvering flight have become as important as

those of fixed-wing aircraft. This is especially true with the introduction of armed attack helicopters.

To insure adequate maneuvering stability, flight tests are conducted to determine the longitudinal control force or control position displacement required to develop a steady state acceleration or pitch rate in a level pullup. The same data also are acquired during steady turning flight. Turns to the right may produce very different characteristics than turns to the left so maneuvering steady-state stability must be checked in both directions.

The characteristics determined may depend on the control system and the stability augmentation system installed. In helicopters having artificial force systems, a control force is provided as a function of control displacement from trim regardless of the normal acceleration acting on the helicopter. (Therefore, a control force per "g" characteristic is present, but is affected by the control system breakout, friction, control displacement per "g", and control forces.)

Maneuvering the helicopter also is greatly affected by the transient longitudinal response characteristics. These characteristics often will determine the degree of difficulty in accurately controlling pitch rate and normal acceleration. The control power and sensitivity variation with airspeed and stick force per "g" characteristics can determine the usefulness of the helicopter as a weapon platform.

In addition, several phenomena associated with maneuvering flight have been experienced with Army helicopters. These include lateral stick migration with load factor, lift-roll coupling, rpm buildup with noseup pitch attitude, and transient torque surge accompanying left roll rates. Maneuver flight testing should be comprehensive enough to identify the existence and characteristics of any of these phenomena.

11-3.2.3.4.1 Test Requirements

The following parameters should be recorded:

1. Indicated airspeed
2. Pressure altitude
3. Ambient air temperature
4. Fuel
5. Rotor speed
6. Engine torque or power parameter
7. Longitudinal control displacement and force
8. Lateral, directional, and collective control displacement
9. Lateral and directional control force
10. Angle of sideslip

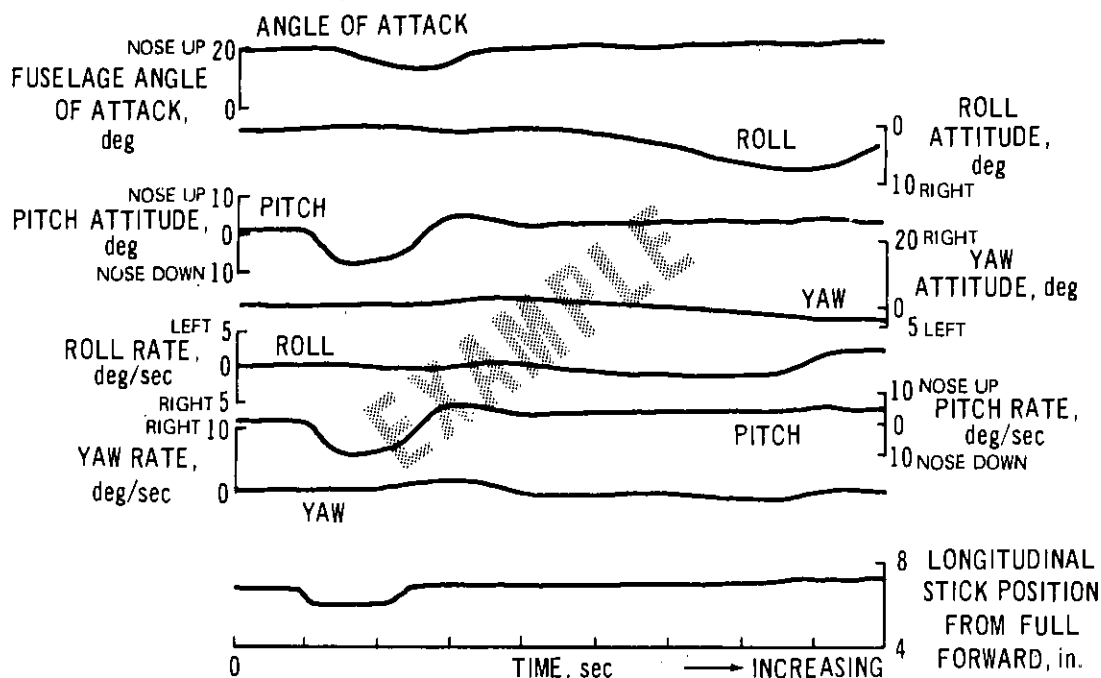


Fig. 11-4. Forward Longitudinal Pulse

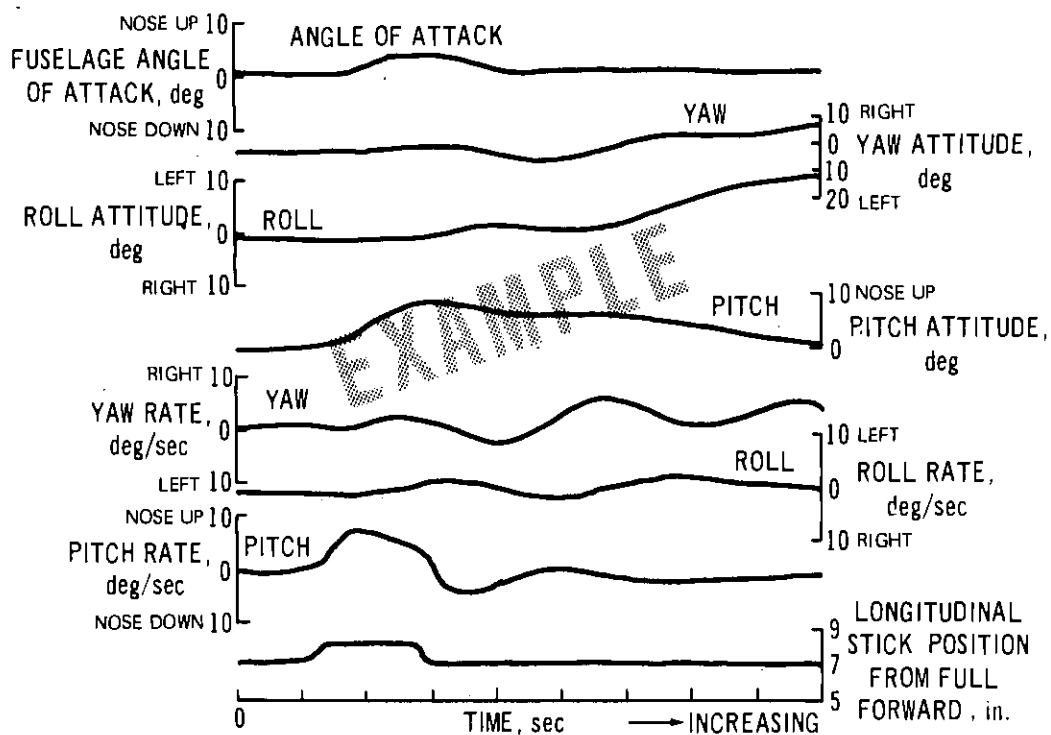


Fig. 11-5. Aft Longitudinal Pulse

11. Normal acceleration at pilot station and rotor CG

12. Rate of climb/descent in turns

13. Pitch and roll attitudes

14. Pitch, roll, and yaw rates.

11-3.2.3.4.1.1 Symmetrical Pullups

Data from symmetrical pullups and stabilized turning flight can be used to evaluate the longitudinal characteristics during maneuvering flight. The symmetrical pullup tests are performed by establishing a level flight trim airspeed, altitude, and power setting. Without disturbing the trim settings, a cyclic climb to a slightly higher altitude is initiated. Following the climb, a push-over to trim airspeed allows the helicopter to be maneuvered so that it is level at the trim altitude and airspeed, with some amount of normal acceleration, depending upon the amount of aft cyclic originally applied. Tests are conducted for each trim airspeed over a range of normal acceleration values. Applicable to both symmetrical pullup and turning flight, the maneuvering control force per "g" should be between $35 n_L - 1$ and $60 n_L - 1$ with a target of $50 n_L - 1$ for all helicopters (n_L is used here as design positive limit load factor). The slope (of the curve of control force per "g") should be essentially linear throughout the maneuvering envelope; however, the slope may be as much as 50% greater than $0.8 n_L$ and n_L (positive and negative n_L).

11-3.2.3.4.1.2 Stabilized Turning Flight

Execution of the test requires trimming level at assigned airspeed as well as at the power required for level flight. Trim point data should be recorded. With longitudinal control force trimmed to zero, a constant airspeed descending turn is executed at 15-deg bank angle increments up to a bank angle of 60 deg, or onset of blade stall. When the desired bank angle is established, it is held and control position and force are recorded. To have positive stick force per "g", the stick force should increase as the normal acceleration is increased. If a push force for forward control motion is required, the helicopter is unstable. A plot of typical data required is presented in Fig. 11-6 representing stick-fixed (control position) and stick-free (control force) maneuvering stability. Data should be recorded in both left and right turns.

The effect of airspeed and power changes on the stick force per "g" gradient also should be investigated during turning flight. These changes become evident during maneuvers such as a high-speed turning pullout in

which airspeed is traded for altitude at the same time that power is added. If the helicopter exhibits positive static speed stability, decreasing airspeed as the load factor is increased will result in an increase in the slope of stick force versus "g"; i.e., more aft stick will be required for a given load factor. The test technique utilized to determine airspeed effects requires holding constant power and allowing indicated airspeed to decrease with each incremental increase in bank angle. The resulting data are presented in the same manner as stabilized turning flight.

Increasing power by increasing load factor can produce considerable change in the stick force per "g" characteristics. This is caused by the trim changes required by power changes. The test technique for determination of power effects requires both holding the indicated airspeed constant and increasing power to maintain constant altitude for each incremental increase in stabilized bank angle.

11-3.2.3.4.2 Instrumentation

In addition to a special boom which is installed for measuring airspeed, altitude, angle of sideslip, and angle of attack; the instruments which follow are required for the maneuvering stability tests: airspeed indicator, altimeter, ambient temperature indicator, rotor ta-

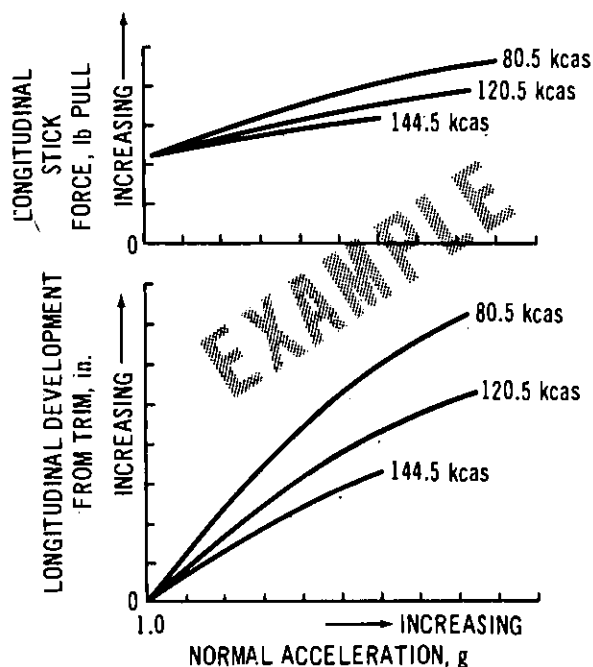


Fig. 11-6. Maneuvering Stability

chometer, fuel totalizer, power measurement indicator, potentiometers, strain gages, attitude gyros, rate gyros, and normal accelerometers.

11-3.2.3.4.3 Documentation

Standard data reduction methods and practices are employed. Typical results of these tests are presented in Fig. 11-6.

11-3.2.3.5 Static Lateral-directional Stability Tests

Three characteristics discussed in conjunction with static lateral-directional stability are dihedral effect, directional stability, and sideforce. Dihedral effect is reflected by the lateral cyclic displacement required to maintain a steady heading sideslip. Directional stability is reflected by the pedal displacement required to maintain a steady heading sideslip. Static lateral-directional stability flight tests are designed to determine the variation of lateral control position, directional control position, and helicopter bank angle as functions of sideslip angle.

Lateral moments result from several rotor and airframe characteristics. As the rotor gains lateral speed, a rotor sideforce develops in opposition to the direction of motion. The rotor sideforce can be approximated by a force passing through the rotor hub. The lateral rotor drag force, then, produces an airframe rolling moment away from the sideslip. To maintain a steady heading sideslip, lateral control displacement into the sideslip is necessary, tilting the rotor thrust and balancing the airframe rolling moment. The tail rotor thrust also can contribute a rolling moment if the helicopter is not in a level attitude.

The geometry of most helicopters is such that the lateral center of aerodynamic pressure is below the CG. When the helicopter experiences lateral motion to the right, a fuselage rolling moment develops which tends to roll the helicopter to the right. This unstable roll into the sideslip is described as a negative dihedral effect.

Static directional moments are produced by the tail rotor. Normally the geometry of the tail rotor is such that an increase in lateral velocity from the right reduces the tail rotor force, while an increase in lateral velocity from the left increases the tail rotor thrust. The variation in tail rotor thrust is such that the tail rotor will return to its initial equilibrium position, a characteristic of a stable moment in the absence of pilot pedal inputs. The fuselage contribution to the static directional stability of the helicopter may be either stabilizing or destabilizing.

Tandem helicopters must depend on the fuselage for static directional stability. In many cases the fuselage, and therefore the helicopter, is unstable. In such cases stability augmentation is used to cause the helicopter to appear to be stable to the pilot.

For a helicopter with a horizontal stabilizer, the angle of sideslip also affects longitudinal moments. Right sideslips cause a noseup attitude and left sideslips cause a nosedown attitude. The horizontal stabilizer can become ineffective in countering the longitudinal moments if it is masked by sideslip. The bank angle necessary to maintain a specific sideslip angle is indicative of the lateral fuselage drag and the tail rotor or side forces.

It should be emphasized that sideslips can cause a substantial airspeed position error. It is important that the proper corrections are made during flight testing. The use of a swiveling, pitot-static source mounted ahead of the helicopter on a boom normally will eliminate the change in position error.

11-3.2.3.5.1 Test Requirements

Parameters which must be measured during the static lateral-directional stability test include indicated airspeed, ambient air temperature, rotor speed, engine power, vertical speed, pressure altitude, longitudinal control force and control position, lateral control force and control position, pedal force and position, sideslip angle, roll attitude, pitch attitude, yaw attitude, and fuel used.

For steady heading sideslips, the following maneuvers will be conducted:

1. Stabilize the helicopter at the assigned calibrated airspeed and note the standard system indicated airspeed (IAS) as well as the boom airspeed.
2. Record the trim conditions, including inherent sideslip.
3. Yaw the helicopter to one direction in 3- to 5-deg increments with directional control, and bank the helicopter into the required sideslip.
4. As soon as a steady heading sideslip has been established and the helicopter stabilized, record all control positions, indicated airspeed, rate of descent, rotor speed, attitude, and sideslip angle.
5. Repeat Items 3 and 4 until the required increments have been obtained.
6. Return to near original trim, retrim, and repeat the test in the opposite direction.

11-3.2.3.5.2 Instrumentation

Test instrumentation includes equipment suitable for measuring and recording the parameters listed in par. 11-3.2.3.5.1.

11-3.2.3.5.3 Documentation

Standard data reduction practices and methods are used. Typical results from data obtained during static lateral-directional stability tests are presented in Fig. 11-7.

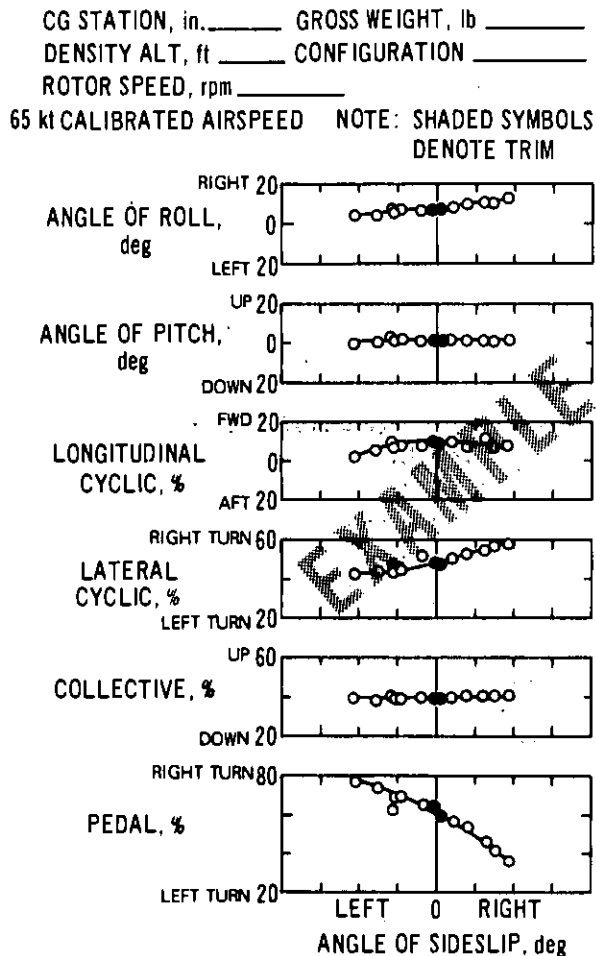


Fig. 11-7. Static Lateral-direction Stability

11-3.2.3.6 Dynamic Lateral-directional Stability Tests

The dynamic and maneuvering lateral-directional stability is investigated to determine helicopter response to gust disturbances and to evaluate the

general flying qualities associated with lateral-directional control. This requires a study of the characteristics of the three lateral-directional modes of motion: the Dutch roll, roll, and the spiral. The effects of these characteristics on turning maneuvers, on the dynamic coupling of the main rotor thrust, and on longitudinal, lateral, and directional control are of particular interest.

One of the more noticeable oscillatory lateral-directional flying qualities is the Dutch roll, particularly in cases where the Dutch roll is easily excited and/or lightly damped. The Dutch roll mode consists of oscillations in roll and yaw. The frequencies generally are identical, but roll follows yaw by a finite phase angle. The ratio of magnitude of the roll oscillation to yaw oscillation is known as the roll-to-yaw ratio. Phasing between the roll and yaw mixing, and the ratio of roll to yaw are dependent upon the effective dihedral and the static directional stability as well as the inertia of both axes of motion. As a general rule, large roll-to-yaw ratios are undesirable since pilots tend to have more trouble controlling roll than yaw.

The Dutch roll can be excited by either gusts or helicopter maneuvering. When the damping of the Dutch roll is adequate, the oscillations excited by gusts do not require any action by the pilot. Also during maneuvering flight the pilot may damp the Dutch roll through control inputs, even though he may not be aware that he is doing so. The lightly damped case, where precise turning maneuvers become difficult to accomplish and require additional attention, is the most objectionable to the pilot. The frequency of the Dutch roll also is important in influencing the pilot's opinion of the helicopter. The low-frequency range is the most objectionable and requires the pilot to devote considerable attention to heading control. Because of the slow initial response of the helicopter to deliberate heading changes, the pilot may experience considerable difficulty in determining the final magnitude of the heading change. This lack of predictability makes rapid and precise heading changes virtually impossible.

The helicopter roll response to lateral cyclic input is another important factor influencing a pilot's opinion of a helicopter because heading changes normally are accomplished by rolling to a desired bank angle, holding the bank angle until the desired heading change occurs, and rolling back to level attitude. Except for a helicopter equipped with an attitude hold type of autopilot, the lateral cyclic control essentially is a roll rate control; i.e., a given lateral cyclic deflection from trim commands a certain roll rate. Using such a control, the pilot displaces the cyclic control as required to achieve the desired roll rate, holds the cyclic control in the

displaced position until the desired bank angle is achieved, and then returns the lateral cyclic control to the trim position. The initial roll acceleration following a lateral cyclic input, the maximum roll acceleration, the final steady-state roll rate, and the time required to achieve a steady-state roll rate resulting from a given lateral cyclic deflection all are important factors governing the pilot's opinion of the roll control of the helicopter. If the roll acceleration is too slow, the pilot probably will resort to pulsing the controls to get the roll started and stopped. Such a piloting technique requires additional effort and pilot compensation to achieve the desired helicopter response to a control input.

A third factor influencing a pilot's opinion of the helicopter lateral-directional dynamic stability is the spiral stability or trim holding characteristics. If the trim bank angle is disturbed, one of three things will occur: the helicopter will return to the original trim (stable), it will remain at the new bank angle (neutral), or its bank angle will diverge further from the original trim (unstable). For maneuvering flight in visual conditions, a moderate degree of spiral instability is acceptable to a pilot because the tendency to diverge from trim is masked by control inputs. However, this instability may be highly objectionable to the same pilot when he is cruising, particularly in instrument flight conditions. A stable spiral mode generally contributes to desirable instrument flight characteristics, provided the stability is not too high.

Other characteristics which are of interest in the dynamic lateral-directional flying qualities are directional divergency, lateral-control-only turns, adverse/proverse yaw, collective-to-yaw coupling, and engine-to-yaw coupling. The directional divergence can occur in tandem-rotor helicopters with weak or negative directional stability in forward flight. In single-rotor helicopters, it can occur if the fuselage contribution is destabilizing at high forward airspeeds. The significance of dynamic directional stability should be obvious as far as safety of flight. Suitability of helicopters dynamically unstable in yaw depends on the rate of divergence, the control moment available, and the pilot's ability to trim the vehicle in the directional axis. The ability to enter and sustain a banked turn using only lateral and longitudinal control is an indication of the helicopter's directional stability. Adverse yaw refers to the yaw attitude change in a direction opposite to the direction of roll during a lateral-control-only roll. Proverse yaw is in the direction of the roll. The magnitude of the yaw is dependent upon the rate of control displacement. Excessive adverse yaw will reduce the turning performance of a helicopter. Other characteristics which can

degrade the lateral-directional flying qualities are collective-to-yaw or engine-to-yaw coupling. The importance of this coupling is dependent upon the maneuver being considered and the severity of the control motion applied. Rapid collective motions or power changes during emergency maneuvers can produce severe coupling. Helicopters being evaluated for instrument flight rule (IFR) maneuvers may be degraded significantly by even small amounts of collective- or engine-to-yaw coupling. During low rate turns at small bank angles, a small change in power could cause the helicopter to roll into a sideslip causing an increase in bank.

11-3.2.3.6.1 Test Requirements

Measurement and recording of the following data parameters are required:

1. Indicated airspeed
2. Pressure altitude
3. Ambient air temperature
4. Fuel quantity
5. Rotor/engine speed
6. Torque or manifold pressure
7. Collective control position
8. Longitudinal control position and force
9. Lateral control position and force
10. Directional control position and force
11. Pitch, roll, and yaw attitudes
12. Pitch, roll, and yaw rates
13. Sideslip and bank angles
14. Time.

In addition to these quantitative data, pilot qualitative comments relating to the ease or difficulty of performing typical mission tasks should be included. Such comments are best obtained by having the pilot fly simulated mission tasks under conditions that duplicate the operational environment of the helicopter as closely as possible. Pilot opinions, formed in flight during the day in good weather with smooth air, may differ significantly from those formed flying at night, in bad weather, or in turbulence.

The Dutch roll response is obtained by trimming at the desired airspeed and altitude, and recording the trim conditions. After the oscillograph or other recording device is turned on, the Dutch roll motion is excited by a suitable technique. Some techniques are release from a sideslip, collective pulse, lateral control pulse, directional control pulse, lateral control doublet, or directional control doublet. Generally, a directional control doublet applied at the correct frequency is the

most effective. Once the motion is excited, all controls are returned to trim and data are recorded while the motion subsides.

The helicopter roll response to lateral control inputs is determined by stabilizing the helicopter at the desired airspeed and altitude. An abrupt lateral control input of a given size is made and held while a time history of roll rate is recorded until the resulting bank angle approaches a maximum safe limit. Recovery from the maneuver is then made. To eliminate the inaccuracies introduced by the fact that the control input requires a finite time to accomplish, control reversal may be used. Using this technique, an input is made in the opposite direction to start a roll rate in that direction. The control then is rapidly returned to the desired position for the input. Thus, the control input is completed while the roll rate is in the opposite direction. The test is repeated for different size control inputs. Testing is conducted both to the left and to the right.

Spiral stability testing is conducted by carefully trimming the helicopter in a wings-level attitude at the desired airspeed and altitude. After recording the trim conditions and turning the recording devices on, the helicopter is placed in a bank in either direction (the magnitude of the bank angle required will vary as a function of the nature of the spiral mode). When the helicopter is stabilized at the desired bank angle, the controls are returned to trim in a manner that minimizes excitation of Dutch roll and a time history of bank angle is recorded. Because of the influence of airspeed on lateral-directional trim, longitudinal control must be utilized as required to maintain trim airspeed during the maneuver.

The characteristics of dynamic directional stability, adverse/proverse yaw, and collective- or engine-to-yaw coupling normally are observed and recorded with the pilot comments.

11-3.2.3.6.2 Instrumentation

Control positions, helicopter attitudes, helicopter motions, and sideslip angle are recorded best by oscillograph or magnetic tape, either aboard the helicopter or by telemetry. Recording the remaining data manually from cockpit instruments is generally satisfactory. A swiveling pitot-static source with a yaw vane normally is mounted on a boom attached to the helicopter to provide sideslip angle and inputs to the airspeed indicator and altimeter.

11-3.2.3.6.3 Documentation

Data reduction of the Dutch roll mode is best accomplished from time histories of bank angle and sideslip angle. The period, frequency, damping, and roll-to-yaw ratios are analytically determined from these traces. The time and number of cycles required for the oscillation to subside to half amplitude also can be determined from these same time histories. Data may be presented in tabular form, shown in Table 11-1, or by annotation of the bank angle and sideslip angle time histories, presented in Fig. 11-8. If sufficient testing is accomplished to establish a significant variation of the various Dutch roll characteristics as functions of some other parameter such as airspeed, altitude, or gross weight, this variation may be presented graphically.

The roll rate response to lateral cyclic input is analyzed from roll rate time histories. The peak roll acceleration, time to peak roll acceleration, roll rate after one second, bank angle change after one second, peak or steady-state roll rate, and time to 63% peak roll rate are determined analytically and presented graphically as functions of the magnitude and direction of the control input.

The spiral stability is determined from the bank angle time history. The time required to achieve one-half the initial bank angle, if the motion is stable, or the time to double the initial bank angle, if the motion is unstable, is determined analytically. If the degree of spiral stability varies significantly as a function of some other variable, the time to double or half the amplitude may be presented graphically as a function of the other variable.

If the pilot encounters difficulty performing some mission task, a time history of the helicopter motion and the control motions required would be appropriate for presentation along with the pilot qualitative comments.

Typical results from data obtained during the dynamic lateral-directional stability test are shown in Fig. 11-8.

11-3.2.3.7 Controllability Tests

Controllability about the longitudinal, lateral, and directional helicopter axes is treated in three parts: sensitivity, response, and control power. Sensitivity is defined as the maximum angular acceleration (deg/sec^2) of the helicopter per inch of deflection of cockpit control. Time to reach the maximum acceleration is also of interest. Response is defined as the maximum angular velocity (deg/sec) of the helicopter per inch of deflection of the cockpit control. Time to reach the maximum rate is recorded. Control power is the

TABLE 11-1. LATERAL-DIRECTIONAL DYNAMIC STABILITY

LATERAL	CONFIG	AVG GW, lb	AVG ALT, ft	AVG LONG CG, in.	SCAS	0.8V _H (LEVEL FLT)			V _H (LEVEL FLT)			V _L (DIVE)			AH-1G USA S/N
						ω_d	DESCRIP	AIRSPED, cas	ω_d	DESCRIP	AIRSPED, cas	ω_d	DESCRIP	AIRSPED, cas	
						ζ			ζ			ζ			
CLEAN SKID FAIRINGS OFF	8630	3700	199.5 (AFT)	DN	0.20 1.4	HEAVILY DAMPED	110	143	0.31 1.6	HEAVILY DAMPED	143	NA NA	DEAD BEAT	165	615247
				OFF	NF	NF			0.29 -0.1	UN- DAMPED		0.29 0.1	UN- DAMPED		
CLEAN	7300	4100	201 (AFT)	ON	0.57 1.8	HEAVILY DAMPED	106	142	NA NA	DEAD BEAT	142	0.44 1.5	HEAVILY DAMPED	180	715695
				OFF	0.19 0.6	HEAVILY DAMPED			0.25 0.1	LIGHTLY DAMPED		0.27 0.1	LIGHTLY DAMPED		

DIRECTIONAL	CONFIG	AVG GW, lb	AVG ALT, ft	LONG CG, in.	SCAS	0.8V _H (LEVEL FLIGHT)			V _H (LEVEL FLIGHT)			V _D (DIVE)			AH-1G USA S/N
						ω_d	DESCRIP	AIRSPED, cas	ω_d	DESCRIP	AIRSPED, cas	ω_d	DESCRIP	AIRSPED, cas	
						ζ			ζ			ζ			
CLEAN SKID FAIRINGS OFF	8650	3700	199.5 (AFT)	ON	NA NA	HEAVILY DAMPED	115	143	0.29 0.5	HEAVILY DAMPED	143	0.41 0.5	HEAVILY DAMPED	165	615247
				OFF	0.25 -0.1	UN- DAMPED			0.25 -0.2	UN- DAMPED		NF	NF		
CLEAN	7210	4200	201 (AFT)	ON	NA NA	DEAD BEAT	107	138	0.29 0.6	HEAVILY DAMPED	138	0.21 0.9	HEAVILY DAMPED	180	715695
				OFF	0.27 0.2	LIGHTLY DAMPED			0.27 0	NEUTRAL DAMPED		0.27 0	NEUTRAL DAMPED		

NOTES: 1. ω_d IS THE DAMPED NATURAL FREQUENCY IN Hz
 2. ζ DAMPING RATIO
 3. NA DENOTES THAT ω_d AND ζ ARE NOT AVAILABLE
 4. NF DENOTES THAT THE CONDITION WAS NOT FLOWN

5. DESCRIPTION DENOTES DEGREE OF DAMPING BASED
 ON THE FOLLOWING DEFINITIONS
 a. DEAD BEAT ($\zeta > 1.8$)
 b. HEAVILY DAMPED ($\zeta = 0.5$ TO 1.8)
 c. LIGHTLY DAMPED ($\zeta = 0.1$ TO 0.4)
 d. NEUTRALLY DAMPED ($\zeta = 0$)
 e. UNDAMPED ($\zeta < 0$)

attitude change 1 sec after a 1-in. control displacement. The control deflections used to achieve these reactions are sudden, step inputs. The step input is made by rapidly displacing the control from trim, using a mechanical fixture to insure precise inputs. The input is maintained until maximum acceleration is reached or recovery is necessary. A controlled program of increasing step inputs is conducted to avoid dangerous recovery positions.

11-3.2.3.7.1 Test Requirements

The parameters which follow should be recorded:

1. Indicated and boom airspeeds
2. Pressure altitude
3. Ambient air temperature
4. Fuel
5. Rotor
6. Collective position

7. Control positions (longitudinal, lateral, and directional)

8. Control forces (longitudinal, lateral, and directional)

9. Helicopter attitude (pitch, roll, and yaw)

10. Helicopter rates (pitch, roll, and yaw)

11. Helicopter accelerations (pitch, roll, and yaw)

12. Normal accelerations

13. Angle of sideslip.

11-3.2.3.7.1.1 Longitudinal Controllability

The dynamic response of the helicopter to a sudden pullup is investigated to determine safety-of-flight margins and the characteristic shape of the normal acceleration/pitch rate response time history. MIL-H-8501 requires that the time histories of normal acceleration and angular velocity *shall* become concave downward within 2 sec and remain until attainment of maximum acceleration. To induce the development of normal acceleration, the longitudinal control is displaced rear-

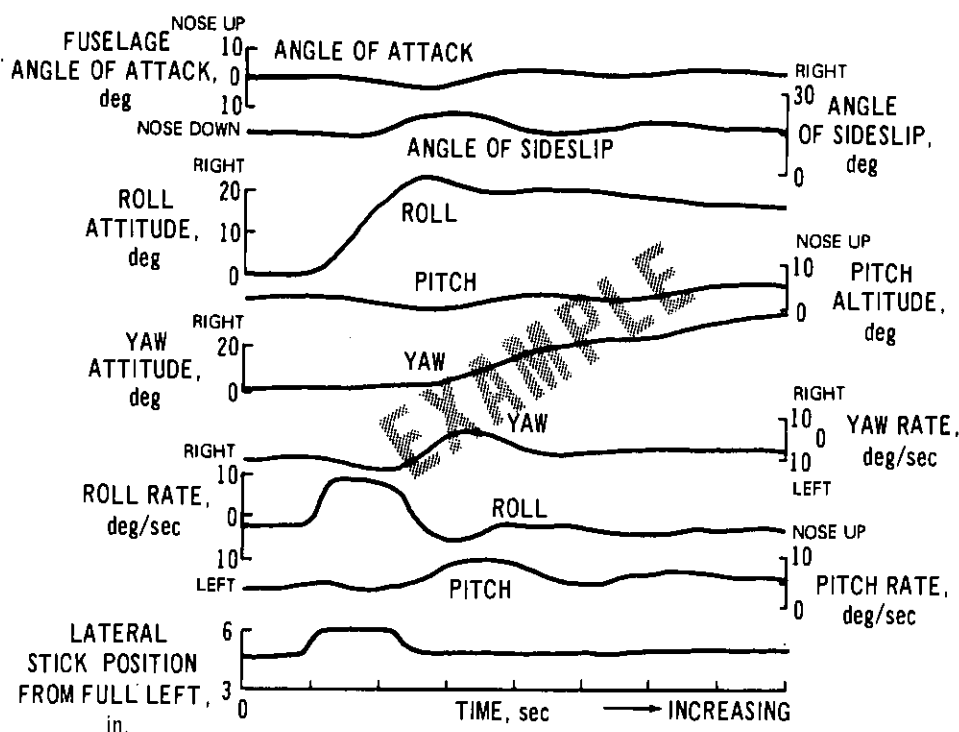


Fig. 11-8. Right Lateral Pulse

ward which produces a change in rotor angle of attack before the helicopter develops any significant pitch rate response. The initial normal acceleration developed then becomes a function of the vertical damping of the rotor system. The initial response is a combination of the initial normal acceleration developed due to the control displacement and the normal acceleration which follows as a result of the pitch rate. An example of this initial response is presented in Fig. 11-9, which shows an initial peak in normal acceleration followed by a temporary decrease and an increase.

The increase in normal acceleration is developed as the helicopter starts to achieve an angular displacement with time. Additional development of normal acceleration will be due to further increase in angle of attack produced by growth of pitch rate. MIL-H-8501 requires that the response of the helicopter to motion of the longitudinal control shall be such that the resulting normal acceleration always increases with time until the maximum acceleration is approached, except that a decrease not perceptible to the pilot may be permitted.

The maximum normal acceleration produced by an aft step input may be greater than the normal acceleration produced during a symmetrical pullup. After the

step input, the helicopter decelerates and the speed stability characteristics become effective and cause the normal acceleration to decrease toward 1 g. The re-

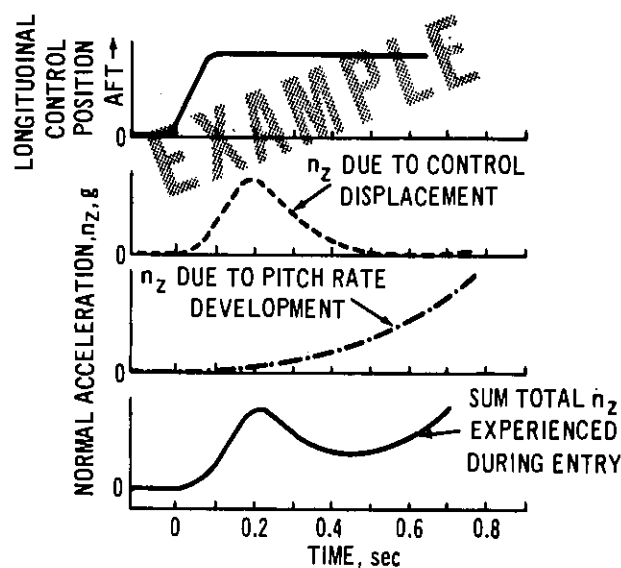


Fig. 11-9. Normal Acceleration Development During Sudden Control Displacement

requirements for response characteristics after abrupt control inputs of various magnitudes sufficient to cover up to 80% design flight envelope limits are:

1. $T_i < 0.4$ sec to reach 0.5 deg/sec pitching or 0.01 g (target, 0.1 sec)
2. τ between 0.1 and 1.0 sec (target, 0.3 sec)
3. $O_p = 30\%$ except that with input for $0.8n_L$, the normal acceleration overshoot *shall* not exceed n_L .

where

T_i = time to reach specified threshold value in proper direction, sec

τ = time to reach 63% of steady-state value initially or time to reach 63% of initial peak for oscillatory modes initially with a period longer than 3 sec

O_p = magnitude of peak overshoot % of steady-state, or magnitude of second peak to first peak, % of first peak

n_L = limit load factor for a given loading, based on structural considerations (normally at design gross weight), dimensionless.

4. Meet where possible the damping characteristics shown on the "Target" curve of Fig. 11-10. However, the damping for normal flight shall never be less than that indicated by this curve.

11-3.2.3.7.1.2 Lateral and Directional Controllability

Lateral and directional controllability is investigated in the same manner as longitudinal controllability. Requirements for lateral transient and maneuver characteristics are as follows:

1. Lateral

- a. $T_i < 0.3$ sec to reach 0.5 deg/sec rolling velocity (target, 0.1 sec)
- b. τ between 0.1 and 1.3 sec (target, 0.25 sec)
- c. $O_p = 30\%$ (target, 5%)
- d. ζ as required by Fig. 11-10.

2. Directional

- a. $T_i < 0.3$ sec to reach 1.0 deg/sec, or $\beta = 0.5$ deg, whichever comes first, where β = angle

of sideslip, deg

- b. τ between 0.1 and 1.5 sec (target, 0.5 sec)
- c. $O_p = 30\%$
- d. ζ as required by Fig. 11-10.

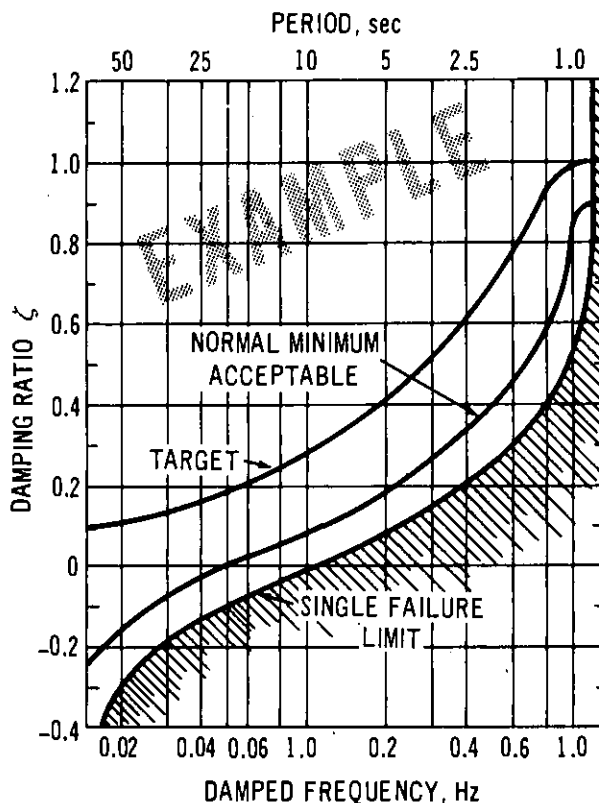


Fig. 11-10. Damping Characteristics vs Frequency

11-3.2.3.7.2 Instrumentation

Test instrumentation will include all equipment necessary to measure and record the parameters listed in par. 11-3.2.3.7.1.

11-3.2.3.7.3 Documentation

Standard data reduction practices and methods are used. Controllability data about all axes are presented in the same manner. Representative plots are shown in Figs. 11-11 through 11-15. Control power information is presented with response data as well as a summary plot of control power as a function of airspeed in Fig. 11-15.

Time histories which provide an example of the typical or most interesting response should be presented.

11-3.2.3.7.4 Control Harmony

Harmony of control in a helicopter is achieved when the forces and effectiveness of the controls are such that all normal maneuvers can be performed without the pilot being aware of using markedly different effort on any one of the controls required to execute the maneuver. Because a pilot is capable of applying considerable force with his legs, the rudder forces should be higher than those he exerts with his hand. Further, his capability in the longitudinal plane is greater than that in the lateral direction. For this reason, "harmony" will be achieved when the lateral forces required are less than the longitudinal requirements.

In addition, the pilot is able to apply pull forces of greater magnitude than he can push. This is in keeping with his capability and the tolerance of negative and positive accelerations of the helicopter. In a lateral direction, the pilot's physical conformation permits a greater force to be applied to the left than to the right. Actual values of the ratio of the longitudinal lateral and rudder forces have been established. These values are not realistic unless applied to a specific maneuver,

because the deflections (and consequently the forces) are a function of the stability and control characteristics of the helicopter. Because of this, it is considered that the ideal harmony ratio should be applicable to only one maneuver, the rolling pullout.

Another facet of the control harmony investigation is the consideration of the relationship of friction force to breakout force in a given control. In an aircraft where friction force is low and breakout force relatively high, the pilot encounters unexpectedly high forces when executing maneuvers, and eventually resorts to the aggravating technique of continuously retrimming during maneuvers. Consequently, the control harmony investigation should include tests to determine the ratio of friction force to breakout force.

The control harmony of a helicopter will be most noticeable during the period in which the pilot is checking out in the helicopter. For this reason, control harmony should be evaluated in the early stages of the flying qualities test program, and repeated at a later stage of the project to check the pilot's ability to become accustomed to the ratio of forces present.

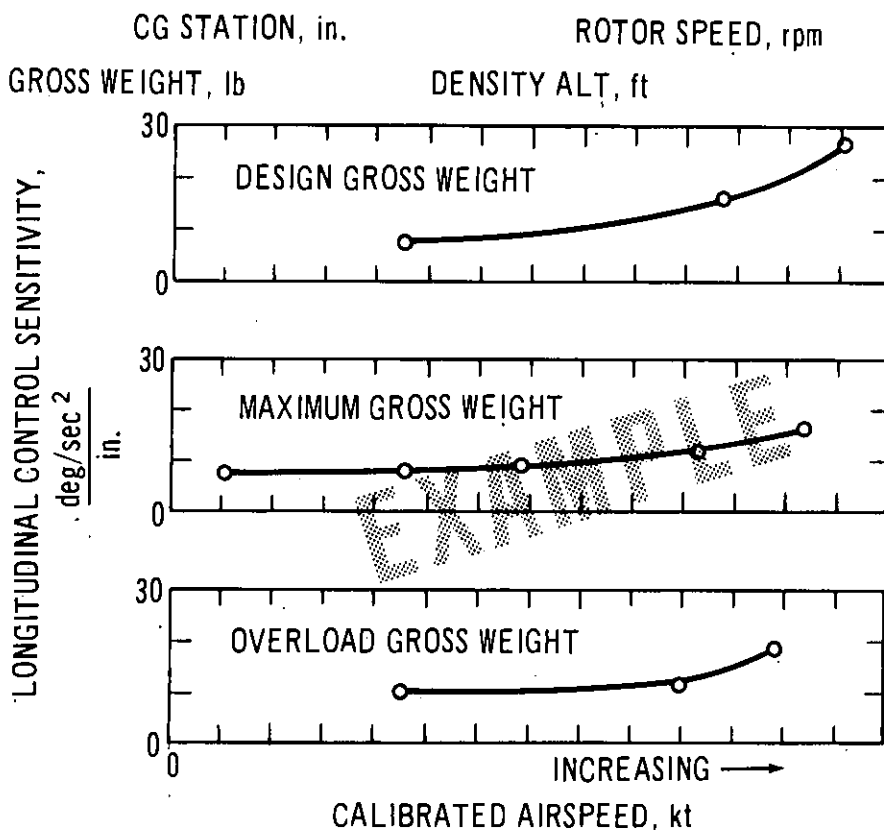


Fig. 11-11. Longitudinal Control Sensitivity Summary

11-4 CLIMATIC TESTS

Climatic tests will be performed under simulated conditions (engineering tests) and in actual climatic zones (service tests). During the engineering tests, both environmental and helicopter operations will be carefully controlled, monitored, and recorded by sensitive instrumentation. The climatic service test is basically qualitative, due to limited instrumentation, and is subject to the weather conditions existing during the test period.

The climatic engineering tests, which are a prerequisite for the climatic service tests to be conducted by various climatic boards (arctic, tropic, etc.), will be conducted in the development cycle of prototype or preproduction helicopters. When it is warranted, these tests may be repeated for production items. Helicopter system tests will be conducted to evaluate total effectiveness and operational procedures throughout a predetermined range of conditions. The subsystem effectiveness and operation will be evaluated at the same conditions, and the results used to (1) demonstrate adequate safety of operation so that airworthiness releases may be issued for climatic service tests; (2) determine compliance with applicable specifications; and (3) formulate necessary recommendations for design changes

to maintain acceptable performance standards throughout the operating range.

The most suitable facility for simulating environmental test conditions is the Climatic Laboratory at Eglin Air Force Base, Florida. The prime airframe contractor has the overall responsibility for the climatic laboratory engineering test. The procuring activity provides test pilots and engineers for active participation in the tests. Major subsystem contractors (i.e., engine, armament) also will provide participating personnel. When required, climatic laboratory reevaluation or retests will be performed by the procuring activity, probably without prime contractor or subsystem contractor participation.

The requirements for the Climatic Laboratory survey are contained in par. 8-9.7.

11-5 DOCUMENTATION

A final report is published by the test activity at the completion of these tests. Data are corrected by suitable procedures and presented graphically in dimensional or nondimensional form. Appropriate analyses and discussions of test results are presented, and specific conclusions and recommendations are included.

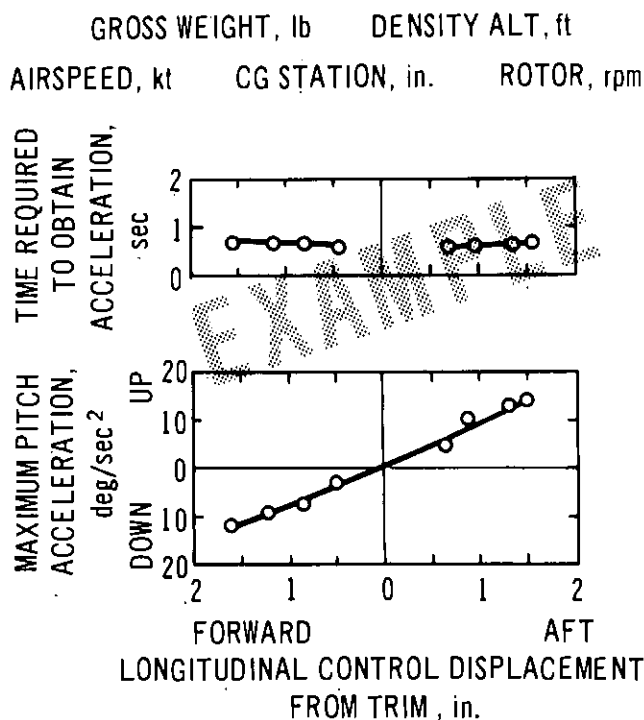


Fig. 11-12. Longitudinal Control Sensitivity

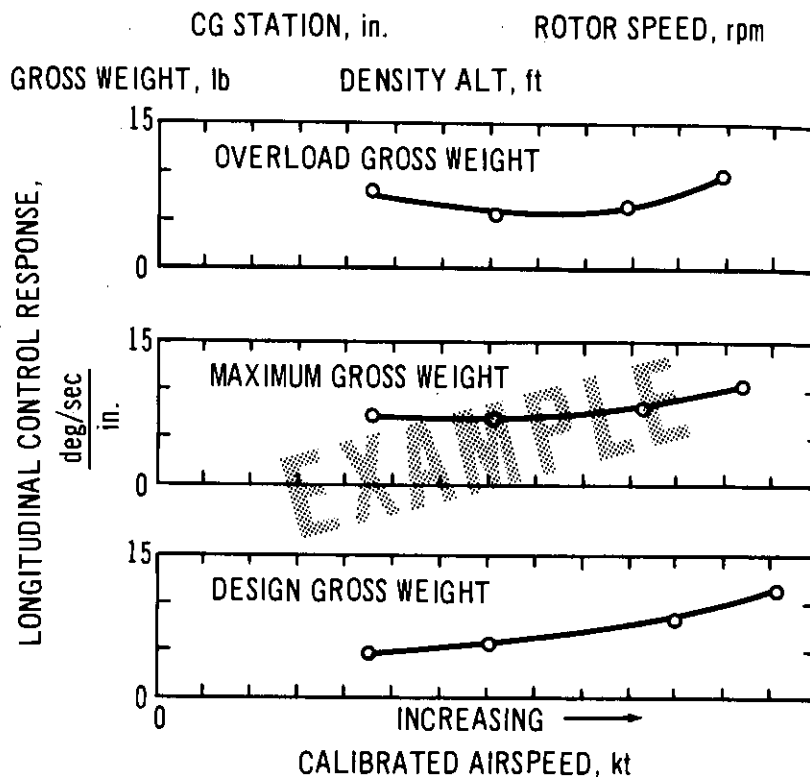


Fig. 11-13. Longitudinal Control Response Summary

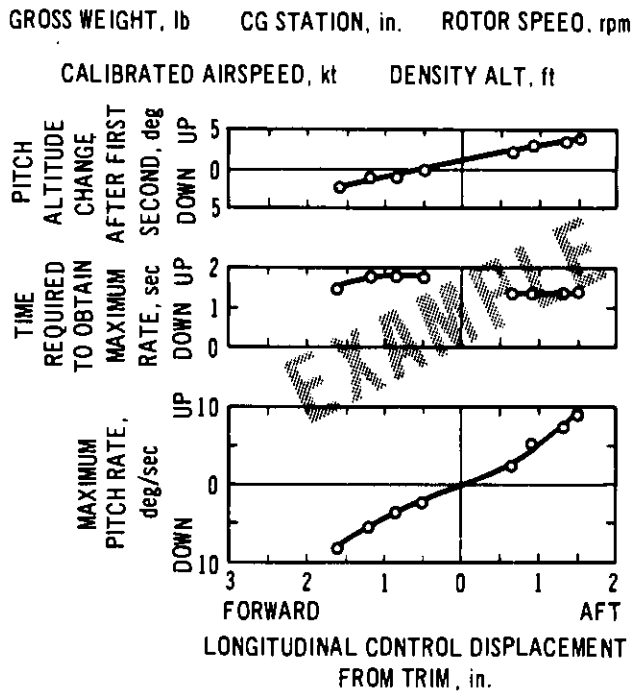


Fig. 11-14. Longitudinal Control Response, Level Flight

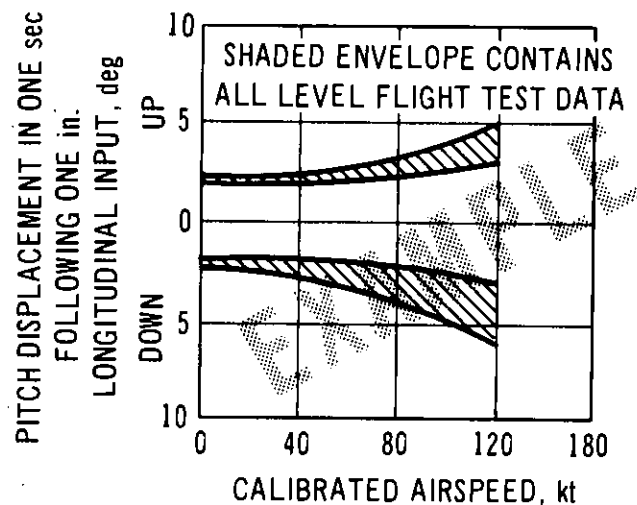


Fig. 11-15. Longitudinal Control Power

GLOSSARY

- Airworthiness.** A demonstrated capability of an aircraft or aircraft subsystem or component to function satisfactorily when used within the prescribed limits.
- Availability.** The probability that a system or equipment used under stated conditions shall operate satisfactorily at any given time. Availability can be achieved, inherent, or operational. Achieved availability pertains to an ideal support environment (i.e., available tools, parts, etc.). Inherent availability is without consideration for any scheduled or preventive maintenance in an ideal support environment. Operational availability prevails in an actual supply environment.
- Composite construction.** A combination of two or more materials joined by bond to provide an efficient structural unit; e.g., honeycomb, sandwich, etc.
- Confidence level.** A concept of statistics which states, as a percentage, the probability that a true value of a quantifiable parameter is to be found between prescribed limits (termed confidence limits) in relation to a quantitative evaluation of a statistical sample. Obviously, the higher the confidence level, the wider the span between confidence limits.
- Crashworthiness.** The quality of a helicopter design which aims at assuring the safety of pilot and passengers in the event the vehicle encounters a condition of abnormally high sinking speed, or an extreme attitude at landing impact.
- Environment.** The aggregate of external conditions and influence which surround and offset a helicopter system or subsystem. It includes natural phenomena—temperature, humidity, solar radiation, etc.—and conditions introduced by the operation of the system—vibration level, and other outside influences such as nuclear radiation.
- Erichsen test.** A quality assurance test conducted on sheet metal specimens to check deep drawing qualities.
- Fail-safe.** A design principle to assure continued safe operation following failure of a structural component until the failure is detected and corrected.
- Failure Mode and Hazardous Effect Analysis (FMHEA).** A largely qualitative analysis designed to isolate those components of a system or subsystem which offer the greatest probability of failure.
- Fatigue-critical component.** A structural component or part which, upon failure due to physical or mechanical deterioration caused by random or periodic repeated loading, will critically limit operational capability of the helicopter or cause injury to pilot or passenger.
- Fatigue life.** The cumulative number of cycles (or hours of operation) for which a structural system or component can sustain prescribed fatigue loads without failure.
- Fault Tree Analysis.** A quantitative analysis which establishes the probability that a given safety hazard will occur when a helicopter system or subsystem is operated in a prescribed set of conditions.
- Fire control.** That subsystem of a helicopter which consists of elements—other than the pilot and basic vehicle—which contribute to the aiming, release, and guidance of airborne weapons including guns, rockets, and missiles to their targets.
- Flight idle.** The gas generator speed established automatically by the engine control to hold governed power turbine speed under no-load conditions (zero torque).
- Flight load survey.** The instrumented structural flight tests which are used to determine structural component stress levels resulting from operational flight conditions. These data are used in calculation of fatigue life.
- Flight spectrum.** A descriptive array, including estimates of the frequency of occurrence, of each maneuver type which a given helicopter design is expected to perform in operational use.
- Flight test, Category I.** Those flight tests conducted on the production helicopter design by the contractor.

- Flight test, Category II.** Those flight tests conducted on a production helicopter design by a Governmental agency.
- Flutter.** An oscillatory motion of an elastic restrained subsystem (e.g., rotor blade) or surface of a helicopter resulting from aerodynamic driving forces acting in conjunction with elastic and inertial restoring forces.
- Functional diagram.** A graphic and descriptive display which portrays the purposes of and interrelationships among several components of a mechanical, hydraulic, pneumatic, or electrical system.
- Functional tests.** Tests performed to demonstrate that a helicopter system, subsystem, or component will perform its intended purpose within prescribed environmental and operating requirements.
- Ground idle.** The control lever spindle position used for ground starting and the operating condition that is consistent with satisfactory power transients and at which the output power is substantially zero under static conditions.
- Ground resonance.** A self-excited vibratory mode resulting from a coupling between the lead-lag motion of the rotor blade(s) and the motion of the helicopter on its landing gear.
- Human factors engineering (HFE).** That portion of the human factors science which deals with the design of equipment to achieve optimum man/machine integration and utilization. HFE includes consideration of operator task load; maintenance task load; work crew station layout; anthropometric influences on control positioning and work space requirements; sensory and perceptual capacities; motor skills coordination and muscle strength; information handling; group communication; and human performance under conditions of stress, fatigue, and abnormal environments, and speeds.
- Intermediate engine power.** The highest power which the engine will deliver consistently at specific ground or flight conditions for an incremental duration of at least 30 min, and for the total duration specified in the engine model specification for demonstration during qualification or preliminary flight rating tests.
- Load factor.** The ratio of a given load to the weight of the structural element which serves as the load reference.
- Load, limit.** The maximum static or dynamic load that may be placed on a helicopter system, subsystem, or component as specified for the design.
- Load, ultimate.** The limit load multiplied by the design ultimate factor of safety.
- Maintainability.** A quantitative expression of design and installation which describes the probability that a helicopter system or subsystem can be retained in, or restored to, a specific operational condition within a given period of time, when maintenance is performed in accordance with prescribed procedures and resources.
- Margin of safety.** The ratio of the maximum allowable unit stress to the unit stress due to ultimate design load, minus 1.0. If the maximum allowable unit stress is the larger in the ratio, the margin of safety will be positive and the member is satisfactory.
- Mathematical model.** A quantifiable representation of a system operating in a prescribed context. A mathematical model generally can be expressed by a set of equations where the known factors are constants, the independent variables are inputs, and the data sought are the dependent or output variables.
- Maximum engine power.** The highest power which the engine will deliver consistently at specific ground or flight conditions for the durations (incremental and total) specified in the model specification for demonstration during the qualification or preliminary flight rating tests.
- Mechanical instability.** A self-excited mode of vibration of helicopter rotor blades coupled with rotor hub deflections in the plane of rotation (see Ground resonance).
- Mock-up.** A model, often full-scale, of an aircraft subsystem or installation constructed to expose its physical arrangements for study, testing, or training.
- Off-the-shelf component.** Only those components applicable to a new helicopter design which have been employed successfully on a previously qualified helicopter system.
- Preliminary Flight Approval Tests (PFAT).** Tests conducted by the contractor to demonstrate the suitability of the helicopter for limited use in development testing.
- Prequalification tests.** Tests conducted to evaluate the potential of a helicopter system, subsystem, or component to meet qualification requirements. The objective of the prequalification test is to evaluate the design rather than prove that the design has met the requirements.

Qualification tests. Tests including ground and flight test of structural and performance requirements to demonstrate compliance of a helicopter system, subsystem, or component with design specifications.

Reliability. A quantitative expression of probability that an item or system of items will perform its intended function for a specified duration under stated conditions.

Reliability apportionment. The process of allocating quantitative reliability goals to components or subsystems of a system. The process is used to control the attainment of the quantitative reliability objective for the total system design.

Service life. A specified period of time during which a helicopter system, subsystem, or component is to remain in service without deterioration when maintained in accordance with prescribed procedures.

Service tests. The tests which simulate sustained operational usage of the helicopter.

S-N curve. The term normally applied to the form of presentation of fatigue test results. The curve displays failure stress level S plotted against number of cycles to failure N and is used to establish the service life of the test item.

System life cycle. A quantitative estimate, usually expressed in years beyond the delivery of the first production unit, of the expected or intended period of operation of a helicopter system.

Temperature, Dry Bulb. A temperature measured with a shaded thermometer.

Temperature, Wet Bulb. A temperature which is measured using only ambient convection for evaporation.

Thermometer, Black Globe. A thermometer at the

center of a 6-in. diameter copper sphere whose exterior surface has been painted flat black.

Transmission continuous torque limits. The maximum torque a transmission can tolerate continuously without risk of exceeding component fatigue endurance limits while maintaining temperatures within operating limits. This limit may be different from engine continuous limit.

Transmission takeoff torque limit. Usually the same as continuous torque limit. However, temperatures could build to never-exceed limits under certain torque/ambient temperature conditions. This limit is dependent on specific transmission characteristics; if required, the limit is stated in terms of time, usually from 10 min to 30 min.

Transportability. A characteristic of a helicopter design which maximizes the efficiency with which the helicopter may be transported over railway, highway, airway, waterway, or ocean by means of a carrier, towing, or self-propulsion.

Turnaround time. The time required to service a helicopter for prescribed maintenance requirements and resources.

Vulnerability. The probability that a hit of a prescribed helicopter target area will sustain a kill when hit by a projectile from a prescribed weapon striking at a specified direction with a specified velocity.

Vulnerable area. The product of a designated geometric area of a helicopter or part multiplied by the probability that that area would sustain a given level of damage when hit by a designated projectile.

LIST OF ABBREVIATIONS

Abbreviations and Acronyms

AC — advisory circular	AWS — American Welding Society
AC — alternating current	BDHI — bearing-distance-heading indicator
ADS — Aeronautical Design Standard	BFO — beat frequency oscillograph
ADF — automatic direction finder	BOM — Bill of Materials
ADTC — Armament Development and Test Center	BTU — British thermal unit
AFB — Air Force Base	cas — calibrated airspeed
AGARD — Advisory Group Aeronautical Research & Development (NATO)	CD — contractor demonstration
AIDAS — Advanced Instrumentation and Data Analysis Systems	CFE — contractor-furnished equipment
AM — amplitude modulation	CG — center of gravity
AMB — ambient	CL — center line
AMC — Army Materiel Command	CP — complete penetration
AMCP — AMC Pamphlet	CSPA — Cognizant Service Plant Activity
AMCR — AMC Regulation	CTP — Coordinated Test Program
AMS — Aerospace Material Specification	dB — decibel
AN — Air Force-Navy	DBT — Dry Bulb Temperature
ANA — Air Force-Navy-Aeronautical	DC — direct current
AND — Air Force-Navy Design	DL — design limit
ANSI — American National Standards Institute	DME — distance-measuring equipment
APE — Army Preliminary Evaluation	DOD — Department of Defense
APU — auxiliary power unit	DWG — drawing
AQP — Airworthiness Qualification Program	ECS — environmental control system
AQS — Airworthiness Qualification Specification	EDT — Engineering Design Tests
AQSR — Airworthiness Qualification Substantiation Report	EGT — exhaust gas temperature
AQT — Airworthiness Qualification Tests	EL — electroluminescence
AR — Army Regulation	EMC — electromagnetic compatibility
ARP — Aerospace Recommended Practice	EMI — electromagnetic interference
ASA — American Standards Association	ENG — engine
ASTM — American Society for Testing Materials	ENGRG — engineering
ATO — assisted takeoff	EP — environmental protection
AVG — average	EPNdB — effective perceived noise, decibels
AVLABS — Aviation Materiel Laboratories	ET — Engineering Tests
AVSCOM — Aviation Systems Command	FAA — Federal Aviation Administration
	FAR — Federal Aviation Regulation
	FED — federal
	FM — frequency modulation
	FMHEA — Failure Mode and Hazardous Effect Analysis
	FOD — foreign object damage
	FTMS — Federal Test Method Standard
	FWD — forward
	g — acceleration due to gravity
	GFAE — Government-furnished aeronautical equipment

GFE	— Government-furnished equipment	prpm	— propeller rpm
GR	— ground run	QA	— quality assurance
GTV	— ground test vehicle	QPL	— Qualified Products List
GW	— gross weight	QQPRI	— Qualitative and Quantitative Personnel Requirements Information
HDBK	— handbook	R/C	— rate of climb
HEL	— Human Engineering Laboratories	R/D	— rate of descent
HF	— high frequency	RDAT	— Research and Development Acceptance Tests
HFE	— human factors engineering	RF	— radio frequency
HSI	— horizontal situation indicator	RFP	— Request for Proposal
I	— inertia	RFQ	— Request for Quotation
IAS	— indicated airspeed	RMI	— radio magnetic indicator
IDEP	— Interservice Data Exchange Program	RMS	— root mean square
IFF	— identification friend or foe	SAC	— Standard Aircraft Characteristics
IFR	— instrument flight rules	SCAS	— stability and control augmentation system
IGE	— in-ground effect	SE	— single engine
IR	— infrared	SHP	— shaft horsepower
kcas	— knots calibrated airspeed	SL	— sea level
kias	— knots indicated airspeed	SLM	— sound level meter
ktas	— knots true airspeed	S/N	— serial number
LED	— light-emitting diode	S-N	— stress-number of cycles
MAX	— maximum	SPEC	— specification
MEADS	— Maintenance Engineering Analysis Data System	SPL	— sound pressure level
MED	— medical	SSP	— System Safety Program
MGT	— measured gas temperature	SSPP	— System Safety Program Plan
MIL	— military	STD	— standard
MIN	— minimum	STOL	— short takeoff and landing
MRT	— Modified Rhyme Test	TB	— Technical Bulletin
MRTS	— mean rounds to stoppage	TBO	— time between overhaul
MS	— Military Standard	TD	— Technical Document
MTBF	— mean time between failures	TE	— twin engine
MTBR	— mean time between removals	TECOM	— Test and Evaluation Command
NACA	— National Advisory Committee for Aeronautics	TIAS	— true indicated airspeed
NASA	— National Aeronautics and Space Administration	TR	— Technical Report
NATO	— North Atlantic Treaty Organization	TWX	— Teletype Exchange Service
NAVAER	— Naval aeronautical	UHF	— ultra high frequency
OAT	— outside air temperature	USAASTA	— U.S. Army Aviation Systems Test Activity
OBA	— octave band analyzer	USAAVSCOM	— U.S. Army Aviation Systems Command
OGE	— out-of-ground effect	USAF	— United States Air Force
OST	— Operational Service Tests	VFR	— visual flight rules
PB	— phonetically balanced	VHF	— very high frequency
PBL	— Protection Ballistic Limit	VOR	— VHF omnidirectional range
PFAT	— Preliminary Flight Approval Test	VSWR	— voltage standing wave ratio
PL	— parts list	VTO	— vertical takeoff
PM	— preventive maintenance	VTOL	— vertical takeoff and landing
PNdB	— perceived noise, decibels	WBGT	— Wet Bulb Globe Temperature
pp	— partial penetration	WBT	— Wet Bulb Temperature
		WT	— weight

SPECIFICATIONS AND STANDARDS, AND OTHER GOVERNMENTAL DOCUMENTS

The listed Governmental documents are referenced in the text.

MILITARY SPECIFICATIONS

1. MIL-A-148, *Aluminum Foil*
2. MIL-D-1000, *Drawings, Engineering and Associated Data*
3. MIL-C-5011, *Charts, Standard Aircraft Characteristics and Performance, Piloted Aircraft (supersedes 40749)*
4. MIL-T-5021, *Tests, Aircraft and Missile Welding Operators' Qualifications*
5. MIL-L-5057, *Lights, Instrument, Individual, General Specification for*
6. MIL-B-5087, *Bonding, Electrical, and Lightning Protection, for Aerospace Systems*
7. MIL-W-5088, *Wiring, Aircraft, Installation of*
8. MIL-I-5098, *Indicator, Rate of Climb*
9. MIL-E-5272, *Environmental Testing, Aeronautical and Associated Equipment, General Specification for*
10. MIL-I-5289, *Instrumentation Installation for Climatic Test of Aircraft, General Specification for*
11. MIL-E-5400, *Electronic Equipment, Airborne, General Specification for*
12. MIL-G-5413, *Generator, Tachometer, Four-pole*
13. MIL-I-5417, *Indicator, Indicated Airspeed, 40-400 Knots*
14. MIL-T-5422, *Testing, Environmental, Aircraft Electronic Equipment*
15. MIL-H-5440, *Hydraulic Systems, Aircraft Types I and II, Design, Installation, and Data Requirements for*
16. MIL-D-5480, *Data, Engineering and Technical, Reproduction Requirements for*
17. MIL-G-5485, *Glass, Laminated, Flat, Bullet-resistant*
18. MIL-C-5503, *Cylinders, Aeronautical, Hydraulic Actuating, General Requirements for*
19. MIL-P-5518, *Pneumatic Systems, Aircraft, Design, Installation, and Data Requirements for*
20. MIL-T-5522, *Test Procedure for Aircraft Hydraulic and Pneumatic Systems, General*
21. MIL-T-5578, *Tank, Fuel, Aircraft, Self-sealing*
22. MIL-I-5721, *Indicator, Indicated Airspeed, Pitot Static, 20-250 Knots*
23. MIL-T-5790, *Transmitter, Pressure, Oil, Synchron, 0-200 Psi 320-Degree Movement, 26V, Single Phase, 400 Cycles (Asg)*
24. MIL-S-5822, *Seat, Pilots' Adjustable, Short Range Aircraft Types A-8, A-9, A-10, and A-11*
25. MIL-T-5842, *Transparent Areas, Anti-icing, Defrosting and Defogging Systems, General Specifications for*
26. MIL-P-5902, *Purging Gas Systems, Aircraft Fuel Tanks, Internal and External, General Specification for*
27. MIL-I-5949, *Instrument, Flight and Engine, Aircraft, Functional Test and Tolerances of*
28. MIL-T-5955, *Transmission Systems, VTOL-STOL, General Requirements for*
29. MIL-C-6021, *Castings, Classification and Inspection of*
30. MIL-E-6051, *Electromagnetic Compatibility Requirements, Systems*
31. MIL-T-6053, *Tests, Impact, Shock Absorber, Landing Gear, Aircraft*
32. MIL-H-6088, *Heat Treatment of Aluminum Alloys*
33. MIL-S-6144, *Sound and Thermal Insulation for Aircraft, General Specification for the Installation of*
34. MIL-I-6181, *Interference Control Requirements, Aircraft Equipment*
35. MIL-W-6729, *Watertightness of Aircraft, General Specification for Testing*
36. MIL-L-6730, *Lighting, Equipment, Exterior, Installation of Aircraft (General Specification)*
37. MIL-I-6866, *Inspection, Penetrant Method of*
38. MIL-I-6868, *Inspection Process, Magnetic Particle*
39. MIL-I-6870, *Inspection Requirements, Nondestructive, for Aircraft Materials and Parts*

40. MIL-H-6875, *Heat Treatment of Steels (Aircraft Practice, Process for)*
41. MIL-E-7016, *Electrical Load and Power Source Capacity, Aircraft, Analysis of*
42. MIL-I-7071, *Indicator, Temperature, Thermocouple Hermetically Sealed, General Specification for*
43. MIL-E-7080, *Electrical Equipment, Aircraft Selection and Installation of*
44. MIL-T-7101, *Transmission, Power, Constant Speed, General Specification (Aircraft Use)*
45. MIL-S-7124, *Sealing Compounds, Elastic, Accelerator Required, Aircraft Structure*
46. MIL-F-7179, *Finishes and Coatings: General Specification for Protection of Aerospace Weapons Systems, Structures and Parts*
47. MIL-H-7199, *Heat Treatment of Wrought Copper-Beryllium Alloys, Process for*
48. MIL-T-7378, *Tanks, Fuel, Aircraft, External, Auxiliary, Removable*
49. MIL-S-7502, *Sealing Compound, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion, Accelerator Required*
50. MIL-T-7748, *Transmitter, Pressure, Synchro, Aircraft, 320-Degree Movement, High Temperature, General Purpose*
51. MIL-A-7772, *Antenna Systems, Airborne, General Specifications for the Design, Location, and Installation of*
52. MIL-S-7780, *Starter, Electric, Constant Current, DC*
53. MIL-S-7832, *Seats, Pilots' Adjustable, Short Range Aircraft*
54. MIL-P-7858, *Pump, Hydraulic, Power Driven, Fixed Displacement*
55. MIL-F-7872, *Fire and Overheat Warning Systems, Continuous, Aircraft, Test and Installation of*
56. MIL-B-7883, *Brazing of Steels, Copper, Copper Alloys, Nickel Alloys, Aluminum and Aluminum Alloys*
57. MIL-G-7940, *Gage, Liquid Quantity, Capacitor Type, Installation and Calibration of*
58. MIL-T-7990, *Transmitter, Temperature, Electrical Resistance, -70*
59. MIL-C-8073, *Core Material, Plastic Honeycomb, Laminated Glass, Fabric Base, for Aircraft Structural Applications*
60. MIL-I-8318, *Indicators, Pressure, Synchro, Dual, 0-35 Scale (Asg)*
61. MIL-I-8500, *Interchangeability and Replaceability of Component Parts for Aircraft and Missiles*
62. MIL-H-8501, *Helicopter Flying and Ground Handling Qualities, General Requirements for*
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178(C)	+Properties of Explosives of Military Interest, Section 2 (U) (REPLACED BY -177)	292	Surface-to-Air Missiles, Part Two, Weapon Control
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189	Military Pyrotechnics, Part Five, Bibliography	335(SRD)#	*Design Engineers' Nuclear Effects Manual, Volume I, Munitions and Weapon Systems (U)
190	*Army Weapon System Analysis	336(SRD)#	*Design Engineers' Nuclear Effects Manual, Volume II, Electronic Systems and Logistical Systems (U)
191	System Analysis and Cost-Effectiveness	337(SRD)#	*Design Engineers' Nuclear Effects Manual, Volume III, Nuclear Environment (U)
195	*Development Guide for Reliability, Part One, Introduction, Background, and Planning for Army Materiel Requirements	338(SRD)#	*Design Engineers' Nuclear Effects Manual, Volume IV, Nuclear Effects (U)
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		355	The Automotive Assembly
		356	Automotive Suspensions
		357	Automotive Bodies and Hulls
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