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FLIGHT CONTROL SYSTEM RELIABILITY AND MAINTAIN-
ABILITY INVESTIGATIONS

John Zipperer, et al

Bell Helicopter Company

Prepared for:

Army Air Mobility Research and Development
Laboratory

March 1975

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**FLIGHT CONTROL SYSTEM RELIABILITY AND MAINTAINABILITY
INVESTIGATIONS**

**Bell Helicopter Company
P. O. Box 482
Fort Worth, Tex. 76101**

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Final Report



**Approved for public release;
distribution unlimited.**

Prepared for

EUSTIS DIRECTORATE

U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY

Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This directorate concurs in the findings presented in this report and recommends their use in future developments or revision of specifications and standards for helicopter flight controls. The reader's attention is directed to the discussion on Design for Reliability (probabilistic design) concepts for flight control components; this technique appears to offer a rational and effective approach for dealing with reliability in design of mechanical components and should be further investigated. Also, the basic design methodology illustrated in the report that closes the loop between the designer and quality control documents is worthy of consideration for implementation in all military documents to make design requirements responsive to R&M objectives for any subsystem or component.

Recommended changes to the specifications in the structures, components, cockpit, and AFSC design handbook areas have been deposited in the Defense Documentation Center as supplements to this report. Also, recommended changes to MIL-C-18244, Control and Stabilization Systems, MIL-H-8501, Helicopter Flying Qualities, and MIL-E-5400, Electronic Equipment Aircraft, can be obtained from DDC. They have not been reviewed or edited technically, but are being made available through DDC as a convenience to the interested reader.

This report has been reviewed by this directorate and is considered to be technically sound.

The technical monitor for this contract was Royace H. Prather of the Military Operations Technology Division.

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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tance. Special emphasis was directed toward requiring those distributional material properties, failure and maintenance time data, and analytical methods which permit "Design for Reliability (Probabilistic Design) and Maintainability" directly into components and thus into the flight control system.

The state of the art for fly-by-wire and fluidic flight control systems and components was also reviewed and specific recommendations were made for future R&D efforts necessary to define quality of design and quality of conformance requirements with emphasis on reliability and maintainability.

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PREFACE

Nonrotating flight control systems, their specifications, standards, design guides, and their state of the art in research and development have been investigated in this report with a particular view toward reliability and maintainability of design. Recommendations have been made for documentation changes and future R&D. This investigation was performed under Contract DAAJ02-73-C-0026, Task 1F162203A11903, under the technical cognizance of Mr. Royace Prather, R&M Division, Eustis Directorate, U.S. Army Air Mobility R&D Laboratory.

The authors wish to acknowledge the technical assistance of various groups of the Bell Helicopter Engineering Design and Engineering Laboratories, and the Hydraulics Research and Manufacturing Company, Valencia, California.

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INTRODUCTION

With increased requirements for mission accomplishment with statistical confidence in the system effectiveness parameters of operational reliability, operational readiness, and tactical readiness under battlefield environmental and performance requirements, design for reliability and maintainability becomes important and cannot be left to subjective evaluation and to chance. Demands on flight control systems reliability and maintainability have particularly increased due to specific improved objectives for:

- Coordination in intra- and intersystem compatibility and the increased complexity of those systems
- Life both with and without maintenance
- Interchangeability at the Aviation Unit and Intermediate Maintenance levels
- Functional performance in the face of increased system complexity, environmental intensity, and requirements for weapons fire control stability
- Safety at all hazard levels

Reliability and maintainability requirements to achieve these objectives should be included in the design and product assurance sections of the system and component specifications. This investigation identifies those areas of Army Helicopter Non-rotating Flight Control System specifications, standards and design handbooks affecting the above design objectives, which relate to reliability and maintainability in which improvement can be made, and recommends revisions based on definitions and criteria established for review. Basic considerations and recommendations are made for changes to specifications, standards, and design handbooks to correct for problems of non-use or for problems of usage where requirements are inadequate, incomplete or nonexistent. Where material failure experience reflects upon present requirements in the above documents, additional requirements were added or the current requirements were revised as applicable to correct for these problems in future systems.

BHC R&M data, DA2407 TAMMS maintenance data, Army R&M reports, Navy 3-M data, BHC quality control records, and Customer Service Department Discrepancy/Malfunction Reports all indicate that present-day nonrotating flight control systems are of relatively high reliability and maintainability, but this is not due to the quality of the specifications, standards, and design guides.

This investigation also reviews the state of the art of fly-by-wire and fluidic flight control system design, evaluates system and component level hardware and documentation available, particularly for R&M, and recommends future R&D efforts.

This report is organized into three main sections: present-day nonrotating mechanical helicopter flight control systems, fly-by-wire systems, and fluidic systems design. The first section on present-day systems assesses design only from the standpoint of the military specifications, standards, and design guides, both existing and not existing. This is done at the system level, limited to augmentation systems, and at the component level. Considered are standard and nonstandard components, castings and forgings, structure, and cockpit arrangement. Special emphasis is placed on the study of the system of planning and control for design objectives and R&M-related product characteristics which are generated in the design through specification requirements. In this process, classification of objectives and traceable characteristics, detailed quality planning, qualification for R&M, statistical quality control, and variables reporting should play a major role in attaining reliability and maintainability in the product.

The second section is devoted to fly-by-wire system design for R&M and has three subsections which consider the system, components developed, and recommendations for future efforts.

The objective of the fly-by-wire investigation is to review existing documentation describing fly-by-wire control systems in order to recommend future R&D efforts which would define design and test requirements, quality assurance provisions, and qualification requirements procedures and practices for fly-by-wire components of future Army aircraft. Although many fly-by-wire prototype research programs have been successfully funded and completed for U. S. Armed Service organizations, to date no U.S.A. fly-by-wire controlled aircraft has been put into production for either commercial or military service. However, based upon current technology trends for the development of aircraft such as demonstrated by the HLH, Space Shuttle, and the General Dynamics Lightweight Fighter, the use of fly-by-wire control systems for production military aircraft appears imminent.

The third section is devoted to fluidic flight control systems. Its objective is identical to that for the fly-by-wire investigation. No complete fluidic flight control systems have been flown to date. Operational subsystems, such as stability augmentation systems, and fluidic components have been flown, however. Comparisons are made with similar fly-by-wire and mechanical systems and components.

The fly-by-wire and fluidics investigations were carried out in two phases. Phase I was the obtaining of DDC and NASA literature search documentation listing existing fly-by-wire and fluidic documents and work in progress. The second phase was the review of selected documents obtained from the literature search for applicable information. In addition, a limited number of Government and aerospace industry personnel were contacted for comments concerning fly-by-wire and fluidic control technology.

Appendixes A-H include a system description for the AH-1G helicopter flight control system as typical; the results of specification, standards, and design handbook review in the categories of system, component, structure, and cockpit arrangement; and an index of fly-by-wire and fluidics on-going investigations.

This investigation has been limited in that it does not consider design for flight control system survivability. Survivability provides the added dimension of reliability in the projectile and missile environment and in the crash environment. A separate investigation of flight control specifications is needed to address this subject.

MECHANICAL FLIGHT CONTROL SYSTEM DESIGN

The typical present-day nonrotating helicopter flight control system is a positive, irreversible mechanical kinematic mechanism, activated by conventional helicopter controls which, when moved, direct the helicopter in various modes of flight. Operation of the system is aided by a stability augmentation system (SAS) which adds electrical input to the pilot's mechanical control to provide a continuous fly-through capability. The system includes a cyclic control stick, used for fore-and-aft and lateral control; a collective pitch control lever, used for vertical control; tail rotor control pedals, used for heading control; and a synchronized elevator connected mechanically to the fore-and-aft cyclic control system to increase controllability and extend cg range.

The forces of a flight control system are reduced to lessen pilot fatigue, by hydraulic servo cylinders which are connected to the control system mechanical linkage and powered by the transmission-driven hydraulic pumps. Force trims (force gradient) connected to the cyclic and directional controls are electrically operated mechanical units used to induce artificial control feel into cyclic and directional controls and to prevent the cyclic stick from moving of its own accord.

The mechanical kinematic mechanism is generally composed of cables, pulleys, sectors, or push-pull or torque tubes with horns, bellcranks, etc. Appendix A presents the AH-1G Flight Control System as a typical system.

Design for reliability and maintainability is concerned with optimization of operational and tactical availability and operational reliability. The flight control system must meet all its design objectives with an established probability of success and an associated confidence. Since components are the building blocks, R&M must be built into them to meet the system allocations. Excellence of design is built upon experience. Experience is retained in the recorded methodology, material, failure and maintenance data of which military specifications, standards, and design guides can be a valuable part.

REVIEW OF SPECIFICATIONS, STANDARDS, AND DESIGN GUIDES

Past R&D investigations by the Army have shown that reliability and maintainability related problems of Army helicopter flight control systems are created basically by innate inadequacies existing in flight control system design and test criteria, quality assurance provisions, maintenance manuals

and training procedures, and lack of adherence to applicable military specifications and requirements.

The approach used in this investigation has been to identify the typical system, the applicable specifications, standards, and design guides, the relation of requirements therein to design objectives for R&M, and to review the retained failure experience resulting from inadequate or nonexistent requirements. The specifications, standards, and design guides were then reviewed and recommendations made to assure that specification requirements and design guides do indeed focus on design objectives for R&M, result in control of all product characteristics having a bearing on R&M, and correct for any R&M problems reported by the failure experience system.

Appendix A describes a typical system for which specifications, standards, and design guides are being reviewed in this study. The scope of the contract, however, excludes hydraulic components, aerodynamic surfaces, components from the swashplate to the main rotor, the swashplate with exception of nonrotating components, and automatic flight control systems with the exception of stability augmentation systems.

The system from the standpoint of specifications, standards, and design guides is presented in the form of the System Specification Tree of Figure 1. Requirements of these specifications are in need of a common bond or focal point.

It is a general assumption, based upon good design practice, that flight control systems will be designed to a set of basic design objectives; however, MIL-F-9490, the Flight Control Systems Design, Installation, and Test Specification, and other flight control system design guidance documents applied to Army helicopters show no evidence of explicit classified listing of design objectives. The classification, suggested here, is divided into the five design objective categories known as the CLIFS, first established by the Navy in OSTD-78, "Ordnance Classification of Defects," in the 1950's. These categories are:

Coordination - Statements of the broadest requirements for system and subsystem interface and compatibility with other systems with which each has an intended interaction.

Examples: Rotor system, pilot and copilot inputs, hydraulic or electrical power inputs, impedance, materials, subsystem connections and other interfaces.

Life - Statements of the broadest requirements for system performance as a function of time, or cycles,

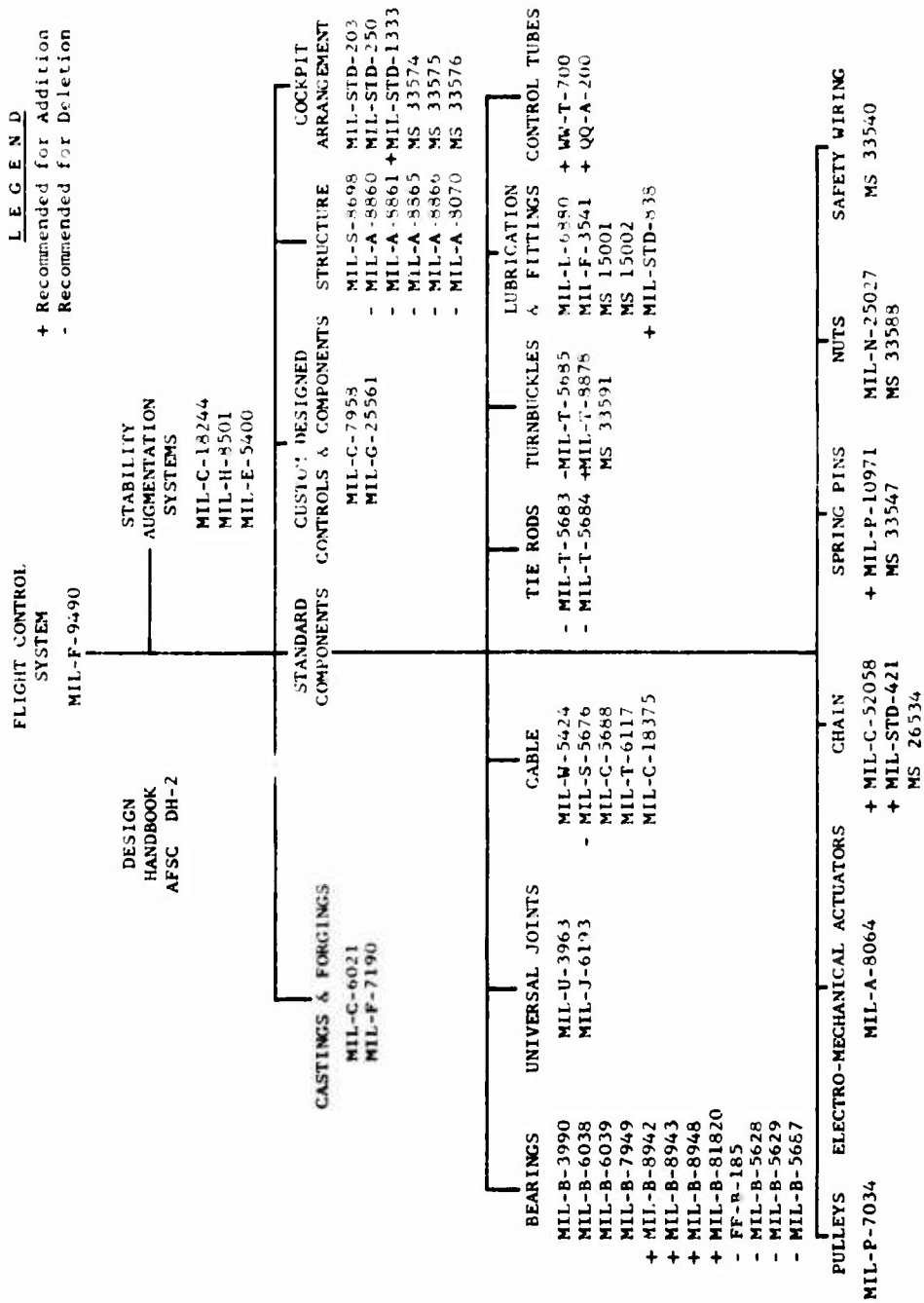


Figure 1. Mechanical Flight Control System Specification Tree.

throughout the system life cycle. This life cycle is generally broken down into three periods having distinct reliability characteristics. These periods are early life, useful life, and wearout.

Examples: MTBF, service life.

Interchangeability - Statements of the broadest requirements for standardization, replaceability, or repairability for system components and parts.

Examples: MTTR failure/downtime relation at organizational level, plug-in features or connectors.

Function - Statement of the broadest requirements for system performance.

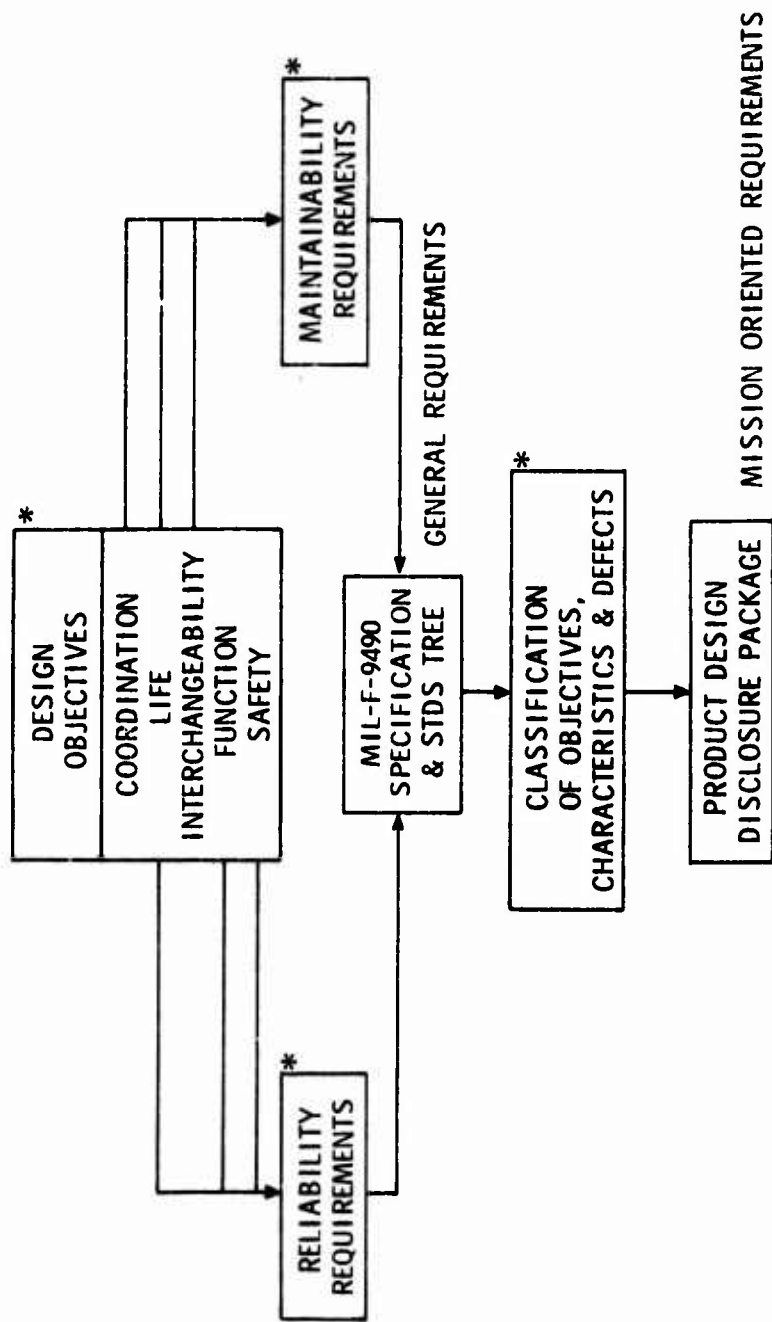
Examples: Response time, stability, dynamic forces, MTBF.

Safety - Statement of the broadest requirements for system operations and maintenance, free from those conditions that can cause injury or death to personnel, damage to, or loss of equipment or property.

Examples: Hazard elimination, fail safe, safe life, MTBF.

The specifications, standards, and design guides for helicopter flight control systems are not now focused on a set of common design objectives reflecting the present-day and near-future state of the art. It must be possible to further refine a classification of design objectives and the specification tree in each specific system specification. The need for establishing this framework is evident when a system and each component therein is considered as a collection of characteristics of variable importance to system reliability and maintainability. To provide for quality of product conformance these characteristics are classified into the categories of critical, major, and minor by WR 43A, MIL-STD-105, and MIL-STD-414 which represent established quality control practice.

To provide system reliability and maintainability with statistical confidence, design objectives through classification must be related to reliability and maintainability requirements and traced through the framework of applicable military specifications and standards to the system specification for the specific product and down to those documents used for manufacture, procurement, qualification, product acceptance, and maintenance in the field. Figures 2 and 3 illustrate



*Presently nonexistent military requirements for helicopter flight control systems

Figure 2. Planning and Control for FCS R&M Requirements.

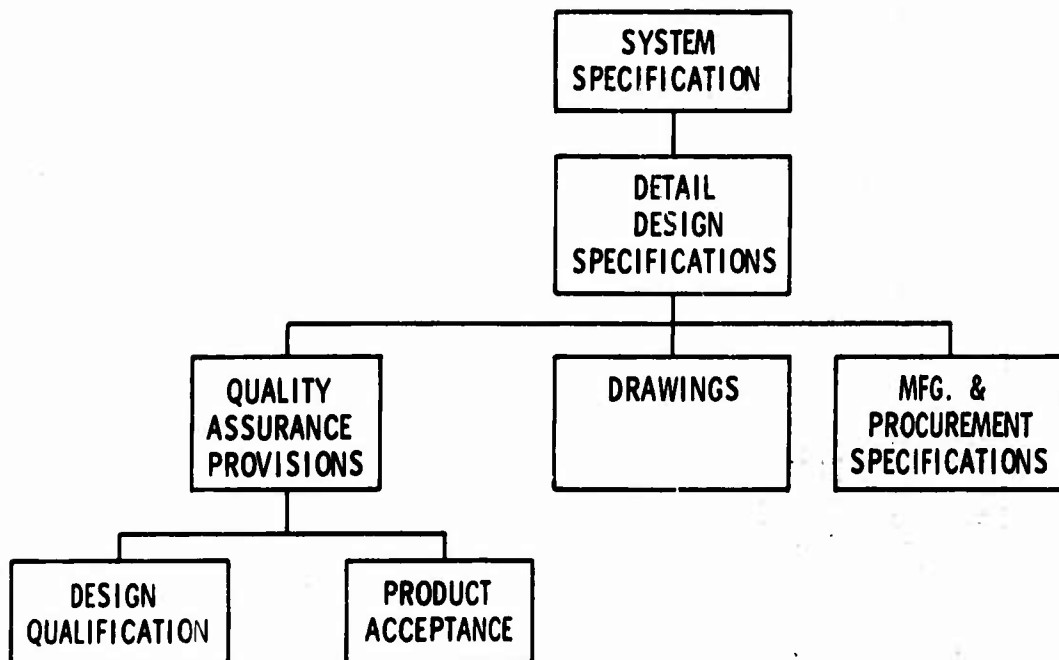


Figure 3. Product Design Disclosure Package.

basic design objective and requirement for function, safety, and life on a one-to-one basis. A critical characteristic, when discrepant, could create a critical defect. The critical characteristic and its associated critical defect must be traceable to the design objectives. This process is illustrated in Figure 7. Also, the process for classifying major and minor characteristics and defects is illustrated in Figures 8 through 11.

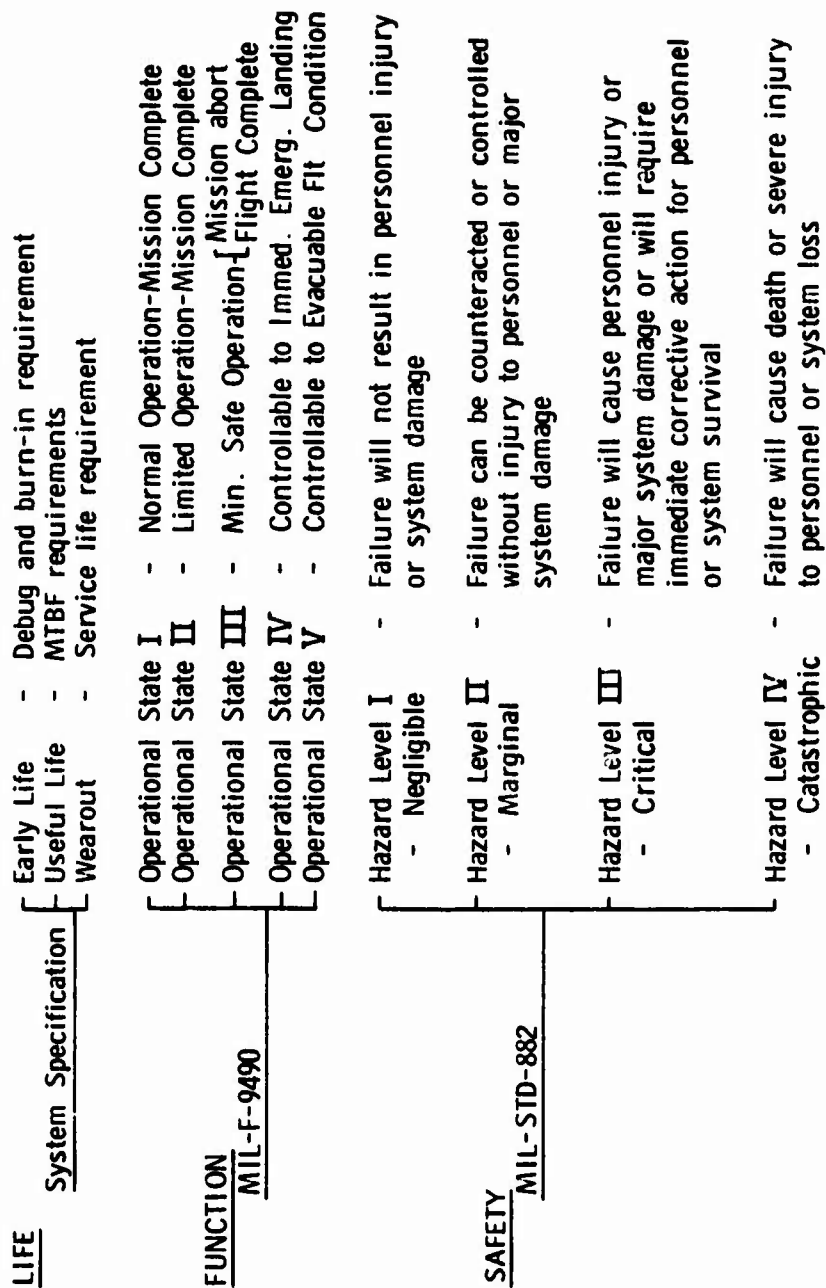


Figure 4. Classification of Reliability Design Objectives.

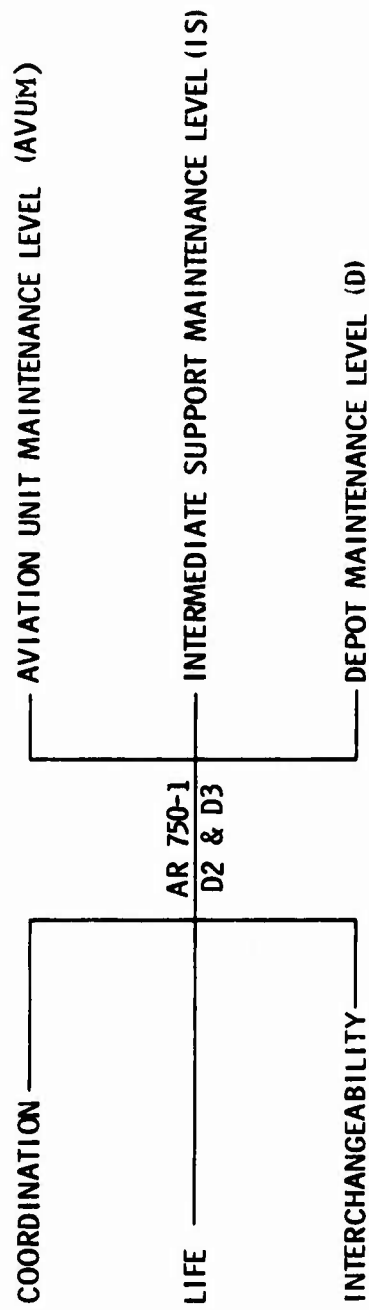


Figure 5. Classification of Maintainability Design Objectives.

WR - 43A

"A critical characteristic is one which, if discrepant, could result in hazardous or unsafe conditions for individuals using or maintaining the product."

MIL-STD-105 & MIL-STD-414

"A critical defect is a defect that judgment and experience indicate is likely to result in hazardous or unsafe conditions for individuals using, maintaining, or depending upon the product, or a defect that judgment and experience indicate is likely to prevent performance of the tactical function of a major end item such as a ship, aircraft, tank, missile or space vehicle."

Figure 6. Definitions for Classification of Critical Characteristics and Defects.

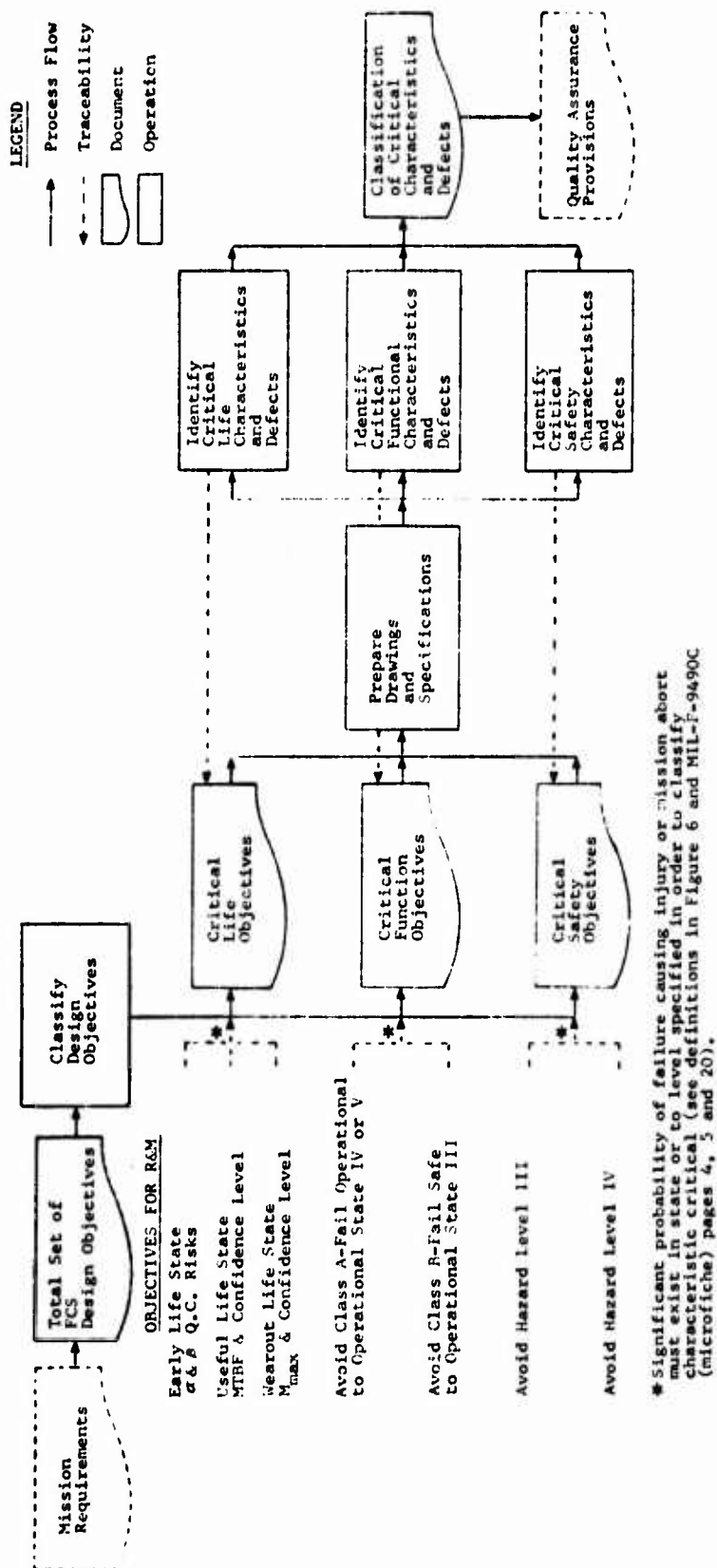


Figure 7. Classification of Critical Characteristics and Defects for Flight Control System R&M.

WR - 43A

"A major characteristic is one which, if discrepant, could result in failure, or materially reduce the usability of the unit of product for its intended purpose."

MIL-STD-105 & MIL-STD-414

"A major defect is a defect, other than critical, that is likely to result in failure, or to reduce materially the usability of the unit of product for its intended purpose."

Figure 8. Definitions for Classification of Major Characteristics and Defects.

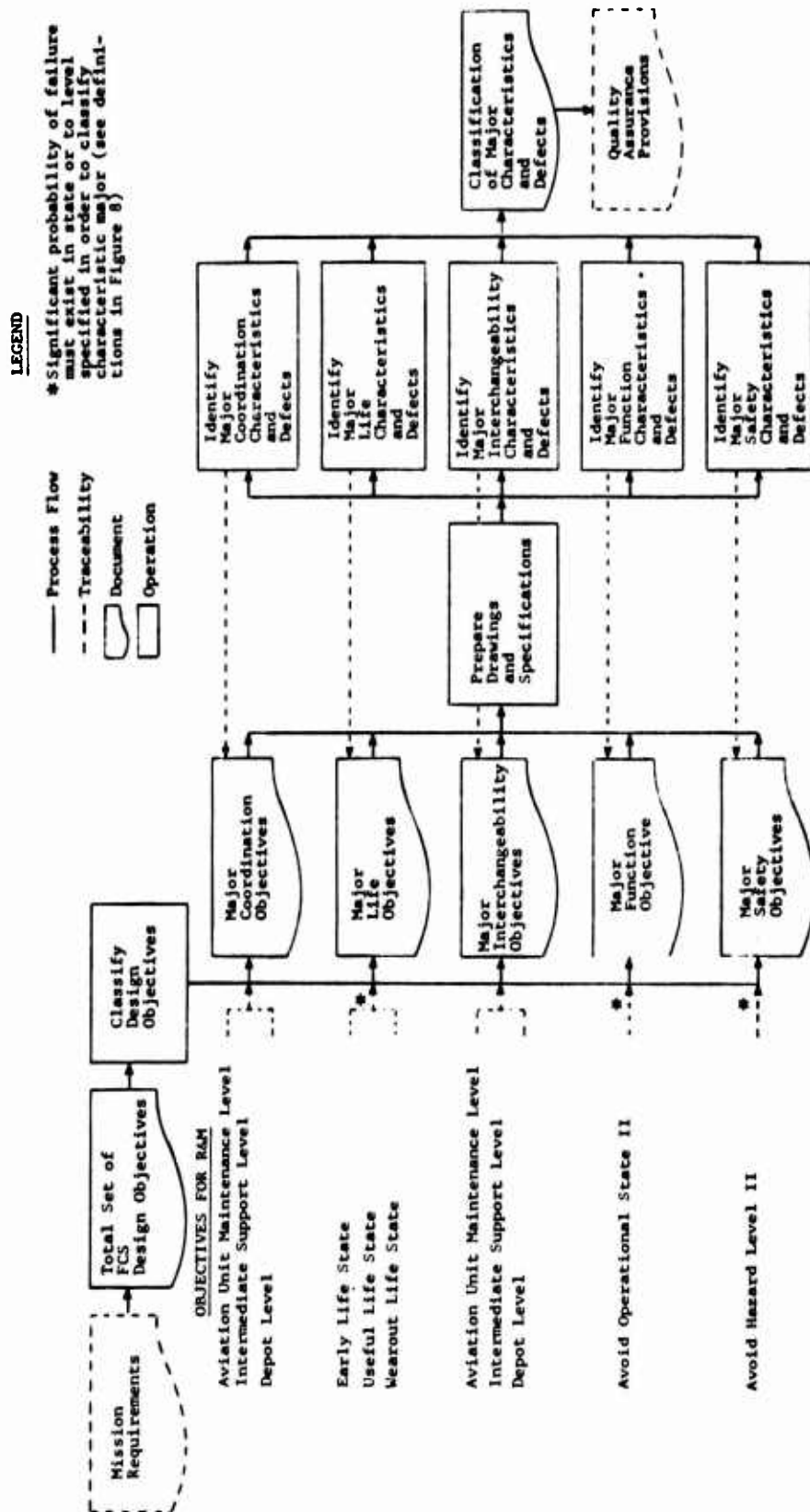


Figure 9. Classification of Major Characteristics and Defects for Flight Control System R&M.

WR - 43A

"A minor characteristic is one which, if discrepant, would not reduce materially the usability of the unit of product for its intended purpose."

MIL-STD-105 & MIL-STD-414

"A minor defect is a defect that is not likely to reduce materially the usability of the unit of product for its intended purpose or is a departure from established having little bearing on the effective use or operation of the unit."

Figure 10. Definitions for Classification of Minor Characteristics and Defects.

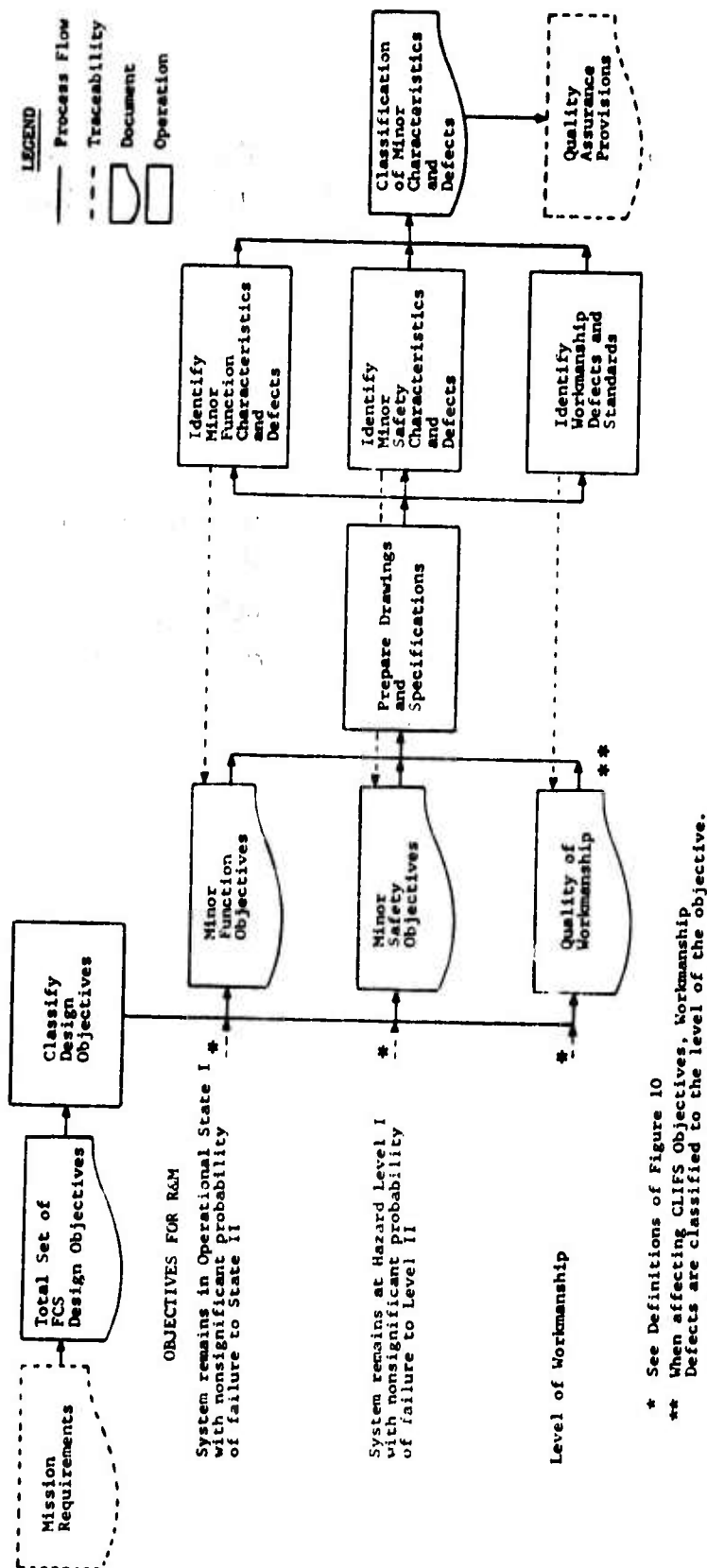


Figure 11. Classification of Minor Characteristics and Defects for Flight Control System R&M.

The Specification Review Procedure

The procedure followed in this investigation began with preparation of a table for each specification. In accordance with MIL-STD-490, the six sections of a specification consist of the following:

1. Scope - shall consist of general information pertaining to the extent of applicability of an item, material or process covered by a given specification and, when necessary, specific detailed classification thereof.
2. Applicable documents - shall include only those government and nongovernment documents referenced in the specification.
3. Requirements - that apply to performance, design, reliability, personnel subsystems, etc., of the item, material or process covered by the specification shall be stated.
4. Quality assurance provisions - shall include all of the examinations and tests to be performed in order to ascertain that the product, material or process to be developed or offered for acceptance conforms to the requirements.
5. Preparation for delivery - includes applicable requirements for preservation, packaging, and packing the item, and marking of packages and containers.
6. Notes.

Table 1 is an example. Requirements were listed in brief, point by point. A test for completeness and continuity required that for each "Quality of Design" requirement reflected in Section 3, there must be a "Quality Assurance Provision" requirement in Section 4. A "Quality of Design" requirement, to be considered complete, had to consist of:

1. Definition of requirement and its relation to design objective.
2. Specification of characteristics to be classified to include:
 - a. Parameters necessary to the requirement
 - b. Objective limits of acceptance

TABLE 1. SPECIFICATION REVIEW TECHNIQUE

MIL-B-6038A								
BEARINGS, BALL, BELLCRANK, ANTIFRICTION, AIRFRAME								
Para	Requirement	Class	Characteristic	Limits	Reference Spec/Std	Para	Requirement Q.A. Prov.	Method of Verification
3.1	(Preproduction)	(L, F)	(QPL)		MIL-S-7420 QQ-S-624 QQ-S-633 Red Std 66 MIL-B-1083	(4.4)	Qualification	(Visual)
3.2	Materials	(L, F)						
3.3	Design and Construction	(I, F)		Drawings	MS 20218	(4.5.1)	Examination of Product	Inspect
3.3.1			Dimensions & Tolerances	Drawings	MS 20218	(4.5.1)	Examination of Product	Inspect
3.3.2			Hardness Raceways Rive ting Flanges	58-62 Rc ≤ Rc 25	MIL-B-1083	4.5.2	Hardness	Test
3.3.3			Surface Roughness Raceways Bore & Ext. Sur- faces Balls	4 μ in 32 μ in Grade 2	MIL-STD-10 MIL-B-1083	4.5.3	Surface Roughness	Test

c. Reference to a specification or standard where more complete description was necessary

Requirements judged to be critical or major characteristics were modified to include:

1. Reliability or maintainability probability statement
2. Success/failure criteria
3. Cross reference to quality assurance provision requirement

Complementary quality assurance requirements were required to consist of inspections and tests specified at two levels:

1. Quality of design (Qualification)
2. Quality of conformance (Production Acceptance)

The qualification requirement statements were required to provide for determination of reliability with established confidence for critical and major failure-governing characteristics. The qualification requirement statements were also required to provide for demonstration of maintainability-related design objectives.

When a requirement having an effect on flight control system R&M was challenged or added to a specification, standard, or handbook, tests for rationale were applied. These are three-part tests contained in the "Fundamental Principles for Attainment of an End" used most familiarly by military planners. Tests include:

1. Suitability - Does the requirement accomplish the R&M objective?
2. Feasibility - Are the resources available to design in and verify the requirement?
3. Acceptability - Is the effort/cost worth the gain in R&M?

These tests were applied to the flight control system specification requirements, and the following summary is representative of the general rationale for change.

1. Suitability Rationale

Flight control system specifications are presently written to provide for a minimum acceptable level of

performance only, and lack objective requirements for R&M and associated workmanship, qualification, design disclosure, and quality assurance planning and control to make R&M a reality.

If an objective of flight control system design is operational mission effectiveness with statistical confidence and minimization of risk, then the addition of R&M requirements to the now-existing performance capability requirements is a necessity and is suitable.

2. Feasibility Rationale

The specifications, standards, and methodology are presently available to design and maintain R&M in flight control systems. Although much data is available, the weakest resource link to design for component and structural reliability is the availability of distributional material properties data under the types of loading encountered in service. This statement also applies to standard maintenance time and other human factors data to be applied to maintainability analysis.

Military specification requirements for R&M design, if added, will force the generation of such data necessary to design R&M requirements directly into components and thus into systems.

3. Acceptability Rationale

This factor can be evaluated most directly by considering the investment in organization, planning control, methodology, and data and the resultant return in mission effectiveness, crew safety, and logistic cost reduction. To most objectively evaluate this factor, a cost effectiveness study will have to be accomplished as the subject of a separate research contract. Experience with case histories since 1950 has demonstrated, however, that return on investment is tenfold or greater for deployed military systems.

SYSTEM LEVEL HARDWARE AND SPECIFICATION R&M EVALUATION

This section is concerned with helicopter flight control systems built to:

MIL-F-9490 Flight Control Systems, Design, Installation and Test of, Piloted Aircraft, General Specifications for

MIL-C-18244 Control and Stabilization Systems
MIL-H-8501 Helicopter Flying and Ground Qualities
MIL-E-5400 Electronic Equipment, Airborne

It evaluates both the impact of hardware failures which result in mission abort or safety problems and the impact of the need for quantitative R&M assurance on the above specifications.

System Hardware Problems

At the system level, representative failure and maintenance rates for Bell Helicopter flight control systems used in the military environment have been on the order of $\lambda_{\text{SYSTEM}} = 0.020803/\text{flight hour}$, and $\text{MMH/FH} = 0.219141$. These rates include failures of every mode and criticality level, and maintenance at every level to include both corrective and preventive actions. Failures which could be considered critical have occurred with very low frequency, usually on the ground and in the Stability, Control and Augmentation System (SCAS) to date. Those occurring on the ground were classified critical because the pilot aborted the mission without taking off.

The primary failure modes observed from the system view have been:

- erratic roll feedback
- erratic yaw feedback

generally caused by transducer failure or card adjustment in the SCAS. These problems have been essentially eliminated by design changes. Other mission-abort failures of a critical nature which have occurred on a one-time basis have been:

- Severe aircraft oscillation and roll caused by internal failure of lateral magnetic brake
- Tail rotor crosshead bearing frozen to tube assembly caused by suspected lack of grease

Because of the redundancy of components and subsystems, and the fail-safety or operational features, component failures in flight control systems rarely become operational or system safety problems. As a result of the very low failure rate experienced above, the impact of failure problems on the system specifications is minimal.

System Specification Problems

Present-day system level flight control military specifications are essentially limited to requirements directed toward attaining at least a minimum level of acceptance for system performance and do not effectively address requirements for reliability and maintainability.

Lacking are:

- Objective "Design for Reliability" requirements
- Objective "Design for Maintainability" requirements
- Objective R&M supporting requirements in areas of:
 - Workmanship
 - Integrated inspection and test planning at the Qualification level and Production Acceptance level.

The problems of classification in each design objective area must be resolved. For example, classifications for performance, safety, maintenance, and statistical quality control must be made compatible with design for R&M. A solution is indicated by the relationships and traceability indicated in Figures 4 through 11.

Orientation for all specification and drawing documentation must be directed toward design for the mission and overall system effectiveness optimization while at the same time avoiding restricting the designer in any one area, and maintaining uniform standards for "quality of design" and "quality of conformance."

Common Rationale for Added R&M Requirements

1. Suitability Rationale

R&M requirements are necessary in system specifications from the standpoint of controlling those parameters of design which contribute to quantitative answers to the questions of:

- How long is the system capable of working without failure?
- How often is the system ready when needed?

Presently these system specifications are written with only performance capability in mind. That is, the system built to these specifications should result in a proper answer to the question:

- How well does the system perform its job when working properly?

In order to answer the above questions for R&M as they now appear in system specifications, it is entirely suitable that complete specifications be accomplished for:

- (a) Product R&M requirements
- (b) R&M Management System requirements
- (c) R&M Analysis

2. Feasibility Rationale

The following methodology and standards relating to R&M engineering and management are available and are called out in recommendations to the applicable system specifications:

R&M Definition

- MIL-STD-721 - Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety

R&M Management

- MIL-STD-785 - Reliability Program
- MIL-STD-470 - Maintainability Program
- MIL-STD-499 - Systems Engineering Management
- AMCP 702-3 - Reliability Handbook

R&M Analysis

- MIL-STD-217 } - Reliability Prediction
- MIL-STD-756 }
- MIL-STD-472 - Maintainability Prediction

- MIL-STD-1388 - Logistic Support Analysis
- TM 38-703-3 - Maintenance Engineering Analysis Data System (Department of the Army)
- AMCP 706-134 - Maintainability Guide for Design

R&M Testing

- MIL-STD-781 - Reliability Tests Exponential
- MIL-STD-810 - Environmental Test Methods
- MIL-STD-471 - Maintainability Demonstration

R&M Reporting

- MIL-STD-1304 - Reports, R&M Engineering Data

Quality Control Support

- MIL-Q-9858 - Quality Program
- WR-43A - Preparation of Quality Assurance Provisions (Naval Weapons Systems Command)
- MIL-STD-105 - Inspection of Attributes
- MIL-STD-414 - Inspection by Variables

This is a minimum list of supporting standards to R&M technology. None of these now cover "Probabilistic Design for R&M" methodology as reflected in numerous government and commercial research reports, projects, and texts (References 1 through 4). This methodology should be committed to standards under each of the headings above.

WR-43A also has shortcomings, since classification of characteristics, in this limited use standard, depends solely upon subjective use of definitions for critical, major, and minor characteristics (see Figures 6, 8, 10) and does not require traceability of the characteristics back to the design objectives to determine classification. It is recommended that a similar standard to WR-43A be written for helicopters, but employing a classification scheme requiring positive traceability to CLIFS design objectives as illustrated

in Figures 4 through 11. This standard should provide the general classification of design objectives for helicopters reflecting current state of the art, and should be a flexible document requiring this general set of objectives to be supplemented by the system specification which contains the requirements peculiar to the design.

3. Acceptability Rationale

Acceptability is evaluated, as previously stated, in terms of return on investment in R&M specifications, management, analysis, design, and testing. If applied with sufficient discipline, improvements related to the following can be expected in future flight control systems:

- Statistical confidence in
 - Operational reliability
 - Operational readiness
 - Tactical availability
- Crew safety from the knowledge of the effects of material failure, also with statistical confidence
- Reductions in logistics costs many times greater than the investment.

It is difficult to affix a dollar value on investment without performing an extensive study beyond the scope of this study.

As a result of the analysis of this section, the following general recommendations are made:

- Develop a standard covering "Probabilistic Design for R&M" methodology
- Develop a standard covering "Preparation of Quality Assurance Provisions for Helicopter Flight Control Systems"
- In MIL-F-9490 and MIL-C-18244, completely specify
 - Product R&M requirements for each level of:
 - Performance
 - Safety
 - Maintenance
 - Quality

- R&M Management Requirements
- R&M Engineering Analysis Requirements

Appendix B provides the detailed system specification change recommendations and rationale which address the combined hardware/documentation problems related in this section.

COMPONENT LEVEL HARDWARE AND SPECIFICATION R&M EVALUATION

This section is concerned with standard components, non-standard components, and castings and forgings built to the specifications listed in Figure 1. It evaluates both the impact of failure history and the impact of quantitative R&M requirements on the specifications in Figure 1.

Standard Components

Standard Component Hardware Problems

The primary flight control system component R&M problems are summarized in Table 2.

Accelerated wear and fatigue, due to the combined vibration, sand and dust or high humidity environment coupled with oscillatory and intermittent loading, result in strength deterioration and stress buildup in components. Loss of lubricant in bearings due to inadequate sealing further contributes to this case. Improper maintenance and quality control have contributed to reliability deterioration in all components. While the failure rates are low in all cases, further R&M improvements necessary for more complex flight control systems can be made by specific design for reliability and maintainability, and integrated quality assurance planning and control.

Hardware problems associated with flight control system components were not available from most system manufacturers, and the data obtained from data sources were meager.

Standard Component Specification Problems

Military specifications for components used in present-day flight control systems are limited to requirements directed toward attaining at least a minimum level of product acceptance and do not address requirements for reliability and maintainability. In addition, they are oriented toward general military procurement, and not toward use in helicopter systems.

TABLE 2 • FLIGHT CONTROL SYSTEM - COMPONENT LEVEL PRIMARY R&M PROBLEMS				
Component	λ System/Hr*	Failure Modes		Cause
		#1	#2	
Bearings	0.000010	Fretting	Wear	Inadequate Seals Lack of Lubrication
Universal Joints	No data available - not used in BHC systems presently			
Cable	0.000585	Wear	Fatigue	Contamination & Improper Tension
Tie Rods	No data available - not used in BHC systems presently			
Turnbuckles	0.000000			No Failures Reported
Lube Fittings	0.000000			No Failures Reported
Pulleys	0.000050	Fracture	Wear	Misalignment, Improper Tension
Electro Mech Actuators	No data available - not used in BHC systems presently			
Chain	0.000586	Wear	Elongation	Contamination, Improper Tension
Spring Pins	0.000000			No Failures Reported
Nuts	0.000001	Loose	Threads Stripped	Overload or Improper Torque
Safety Wiring	0.000000	Loose		No Failures Reported
Control Tubes	0.000001	Loose Joints		Improper Installation

* Source: BHC R&M Data

Lacking are:

- Objective "Design for Reliability" requirements
- Objective "Design for Maintainability" requirements
- Objective R&M supporting requirements in areas of
 - Workmanship
 - Integrated inspection and test planning at the
 - Qualification level
 - Production Acceptance level

Since component application is very poorly defined for general procurement specification items, it is not completely meaningful to qualify these items for a specific quantitative level of reliability and maintainability. The best that can be done for a standardized component which has not yet met its actual environment is to define its failure-governing strength distributions. These distributions may be determined in the qualification test program, coincident with the proof to a stated probability of success and confidence level that specified qualification levels are being met. Reporting the statistical parameters of the failure-governing distributions with the qualification test data assures that the application or reliability engineer may estimate the reliability of the component with confidence during the design application phase. Reference is made to the literature cited (1 through 4) for the methodology. A side benefit is a significant reduction of design, build, and test iterations to obtain a desired reliability.

A standard is needed for qualifying failure-governing characteristics for reliability-critical components. A probability of success of 0.96 (i.e., .999999) at the 90 percent confidence level is thus recommended for qualification requirements established by specifications for such military components. The assumption is made that the qualification level required by the specification represents the state of the art and the quality of design established for the particular component. It is also assumed that the level stated in the specification is intended to be the minimum qualification level acceptable for the particular characteristic of the component. Probability of 0.96 represents the success rate expected for helicopter components and is consistent with the level

of reliability requirements allocated to components used in other complex military systems today in order to meet total system reliability requirements. Ninety percent represents the normal minimum confidence level expected today and is consistent with the economics of testing.

In testing for determination of parameters of failure governing strength distributions, sample sizes of at least 30 were chosen. This is about the smallest number which will result in a histogram which, when fitted with the proper statistical distribution, will be consistently accepted, or rejected, by a valid goodness-of-fit test at 5 percent level of significance.

Nonstandard Components

Nonstandard Component Hardware Problems

Components such as the grip assemblies, push-pull controls, and control tubes are generally procured or manufactured to the customer's drawing. As such, they are a custom design, fabricated to order. Since these items are produced in a more limited quantity than catalogue items, the costs of qualification become important because they cannot be sufficiently distributed over a large enough quantity to result in reasonable unit costs. From the R&M standpoint, it is desirable to qualify all essential system components to a specified statistical reliability and maintainability level with a specified level of confidence.

These components are also different from standard components, since the expected mission profiles, duty cycles, loads, and environmental conditions are known and it is possible to design for reliability and maintainability mission requirements from the start. Under such circumstances, reliability can be designed into the component using distributional material properties and probabilistic design methodology; then the attained reliability can be verified by using a few samples in a truncated sequential test of MIL-STD-781. Additionally, the customer has control over maintainability features from the beginning.

Of the flight control system components under review, the only procured custom-designed component assembly used by Bell Helicopter Company is the grip assembly designed and fabricated in accordance with MIL-G-25561. A typical failure rate for this component is $\lambda_{\text{GRIP ASSEMBLY}}$
= 0.000129/hour. Historically, the primary failure mode has been a sticking or contaminated trim switch.

Push-pull controls of the MIL-C-7958 type are not used in BHC helicopters since the same function can be performed with bellcranks and control tubes more effectively.

Control tube assemblies, as flight control system components, are not presently covered by a military specification or standard. At BHC, each control tube assembly is custom designed, fabricated and assembled of aluminum tubing, clevis ends or rod end bearings, nuts, and washers. They come in two main types: fixed or adjustable length.

The typical failure rate for this component is $\lambda_{\text{CONTROL TUBE}} = 0.000011/\text{hour}$. The principal failure modes contributing to this rate are freezing or wearout of rod end bearings, and loosening of threaded joints.

Nonstandard Component Specification Problems

The nonstandard components required by MIL-F-9490 for application to flight control systems are push-pull controls conforming to MIL-C-7958 and grip assemblies to MIL-G-25561.

These specifications also lack objective requirements for R&M in the following areas:

- Design for Reliability
- Design for Maintainability
- Design and Production Assurance Support to R&M
 - Workmanship
 - Integrated Inspection and Test Planning at
 - Qualification level
 - Production Acceptance level

Since these components can be designed directly to mission requirements from the start, the R&M problem in design application is minimized and qualification can be verified by MIL-STD-781 and MIL-STD-471 with a minimum sample size. That is, actual failure-governing stress distributions can be estimated during the design process and reliability can be determined in the stress analysis; testing then need only assure that reliability exceeds a certain level. This process requires less samples than for the determination of failure-governing strength distributions for standard component cases where the actual

applied stress distribution is unknown at time of design.

With respect to grip design, it should be pointed out that improved designs are now available not meeting MIL-G-25561, and recommendations are made to consider the most acceptable designs and the need for MIL-specification coverage.

Control tubes are also a special problem. Military specifications and standards do not presently exist for control tube design, fabrication, assembly, and use. Only the tubing itself used in control tubes is covered by specifications. Those for aluminum tubing include WW-T-700 and QQ-A-100 for drawn and extruded processing, respectively. A specification should be written to cover design, fabrication, assembly, and use of control tubes for helicopter flight control systems.

Appendix B provides the specification change recommendations which address the combined hardware/documentation problems related above. The above recommendations are submitted for the following specifications:

MIL-C-7955 - Controls, Push-Pull, Flexible and Rigid

MIL-C-25561 - Grip Assembly, Controller, Aircraft,
Type MC-2

Castings and Forgings

Castings and forgings are procured to customer's drawings and, as such, are custom designed and fabricated to order. Qualification costs must be distributed over the number of units, and could be quite high on a unit basis if few units are used. On the other hand, it is important from the R&M standpoint to qualify those castings and forgings in critical applications to a specified statistical reliability, maintainability, and confidence level.

As with nonstandard components, castings and forgings may be designed for reliability and maintainability tailored to the mission and system from the beginning. Since reliability and maintainability may be designed into castings and forgings, based upon failure-governing strength and stress distributions for reliability, and human factors for maintainability, it is necessary only to verify R&M with a small amount of samples in qualification and production acceptance.

In flight control systems, castings and forgings have been used in the application in Table 3 with typical failure rates and modes.

TABLE 3 . FLIGHT CONTROL SYSTEM-CASTING AND FORGING FAILURES		
	λ /hr	Failure Mode
<u>CASTINGS</u>		
Pedal Pads	.000050	Loosening
Pulley Brackets	.000036	Wear-pin vibration
Chain Guards	.000186	Wear - rubbing
Stops	.000001	Deformation - T/R strike
Bearing Housings	.000001	Loosening
<u>FORGINGS</u>		
Bellcrank Support	.000001	None observed Quality defects only

Forgings have been extremely reliable in structural flight control system applications.

Casting and Forging Specifications

MIL-F-9490 requires the use of MIL-C-6021 for flight control system castings and MIL-F-7190 for flight control system forgings.

MIL-C-6021 is extremely limited in use since it applies to classification and inspection of castings only. In scope, it fails to cover

- "Quality of Design" requirements in entirety
- Quality Assurance Provisions for:
 - Integrated inspection and test planning
 - Control of workmanship characteristics
 - Qualification testing
 - Adequate traceability

In addition, the classification system for castings uses terminology not compatible with MIL-STD-105, 414, 109B, and WR-43A. Grade classifications should be compatible with Acceptable Quality Levels (AQL's) adaptable to MIL-STD-105 or -414 and characteristics classified in accordance with WR-43A to provide a basis for quality control in support of R&M requirements. This specification should be rewritten to correct for the above objections.

MIL-F-7190, "Steel Forgings for Aircraft and Special Ordnance Applications," is a much more complete specification than the casting specification. However, from the R&M requirements standpoint, it has all the standard deficiencies. Lacking are requirements for:

- "Design for Reliability"
- "Design for Maintainability"
- Metallurgical practices affecting R&M
- Quality Assurance Support for R&M in areas of
 - Workmanship
 - Integrated inspection and test planning at
 - Qualification level
 - Production Acceptance level
 - Qualification

Appendix B provides detailed recommendations for casting and forging specification changes based on failure problems, current good metallurgical practice, and specification deficiencies in view of R&M statistical confidence needs for critical components.

As a result of the analysis of this section, the following general recommendations are made:

- Design R&M directly into components using "Design for R&M" methodology.
- Require qualification of failure-governing characteristics to a probability of success consistent with present-day state of the art for helicopters.

- Require publication of statistical parameters for failure-governing strength distributions obtained from qualification testing to permit design for reliability in actual applications.
- Require integrated inspection and test planning in the form of customer-approved "Quality Assurance Provisions" for each component configuration.
- Require traceability means for all components.
- Require objective workmanship standards.
- Require structural design specifications for helicopters employing "Design for Reliability" methodology.
- Develop a "Distributional Materials Properties Handbook" useful to helicopter component designers.
- Conduct detailed review of MIL-STD-810, "Environmental Test Methods," for use in qualifying helicopter components.

Supplementary data provide the detailed component specification change recommendations which address the combined hardware/documentation problems related in this section.

STRUCTURAL AND ASSOCIATED SPECIFICATION R&M EVALUATION

This section is concerned with structural design requirements for helicopter flight control systems. The specifications under evaluation include:

- MIL-S-8698 - Structural Design Requirements, Helicopters
- MIL-A-8860 - Airplane Strength and Rigidity, General Specification for
- MIL-A-8861 - Airplane Strength and Rigidity, Flight Loads
- MIL-A-8865 - Airplane Strength and Rigidity, Miscellaneous Loads
- MIL-A-8866 - Airplane Strength and Rigidity, Reliability Requirements, Repeated Loads, and Fatigue
- MIL-A-8870 - Airplane Strength and Rigidity, Vibration, Flutter, and Divergence

The impact of structural failure history and the present structural analysis methodology on R&M requirements for the above specifications are evaluated.

Structure Problems

Most components and subassemblies of a flight control system are considered as structural members. However, they are lightly loaded internally and usually experience oscillatory and intermittent motion. Externally, members and components are exposed to vibration, sand and dust, and humidity as the principal environmental stresses.

Since the boundary limits for the flight control system, as defined for this investigation, do not include any dynamically or heavily loaded components, stresses may be controlled in the system, at a low level, by design.

Flight control structures have resulted in a typically low failure rate of $\lambda_{\text{FCS STRUCTURAL}} = 0.000286/\text{hour}$ considering all failure modes and levels of criticality. This rate is based upon Bell Helicopter experience with M&R Army Field Failure data. The principal structural failure modes observed have been cracks and fractures of items such as springs, brackets, pulleys, synchronized elevator control tube, or pitch links. Often the failure started with a stress concentration. In flight control system structure, manufacturing defects have been a major contributor to failure, indicating a need for planned attention to details of processing, assembly, maintenance and quality control.

Specification Problems

The structural specifications required by MIL-F-9490 for application to flight control systems are MIL-S-8698, MIL-A-8860, -8861, -8865, -8866, and -8870. These specifications are limited to design requirements and have the shortcoming of not accounting for counterpart "Quality of Conformance" requirements to provide assurance of structural integrity.

In addition, all current applicable structural specifications utilize a design methodology based on safety margins as the means for ensuring a component from structural failure. Safety margins are inadequate for "Design for Reliability" from several standpoints:

- Few design engineers have a feel for the significance of the relative magnitude of safety margins with respect to reliability and definitely not as much feel as they have for the safety factor.

- The safety margin definition used in most design books is

$$SM = SF - 1$$

This means that the safety margin is the amount by which the safety factor exceeds the value of one.

This definition ignores the effects of the mean and standard deviations of the stress and strength distributions on the safety margin. Consequently, the safety margin does not provide a true measure for the ensuing component probability of failure or success. The fallacies in designing by safety factors and safety margins from the reliability viewpoint are well illustrated in an article by Dr. Dimitri Kececioglu and David Cormier in Reference 1.

- The "Design for Reliability" methodology is available for structural design. This methodology employs the failure-governing strength and failure-governing stress distributions, and permits direct calculation of the probability of structural failure or, conversely, reliability. Many references are now available on the methodology and are enumerated in the Literature Cited section of this report.

A third major problem concerns the MIL-A-008860, Airplane Strength and Rigidity series. These specifications were written for fixed-wing aircraft with orientation toward spectrum testing; thus they cannot be effectively used for helicopter design.

Suitability Rationale

The MIL-A-008860, Airplane Strength and Rigidity series of specifications are not suitable for helicopter design for the reasons stated above. Requirements covering the subject matter of these specifications should be developed specifically for helicopter design and incorporated into MIL-S-8698, Structural Design Requirements, Helicopters.

MIL-S-8698 is presently unsuitable with respect to Quality Assurance Provisions, Section 4. This section does not provide complementary coverage to Section 3, "Quality of Design Requirements." In particular, inspections and tests should be described in Section 4, and referenced by the particular design requirement in Section 3.

Safety Factor and Safety Margin methodology employed in this specification is unsuitable for design for reliability. Provisions should be made to gradually replace this methodology with what is known as the "Design for Reliability" or "Probabilistic Design" methodology.

Feasibility Rationale

Helicopter structural designers have the capability to revise MIL-S-8698 and to incorporate the MIL-A-008860 series, but this will require a contracted effort beyond the scope of this contract.

Incorporation of "Design for Structural Reliability" can also be made effective immediately, since the methodology is available. A weakness lies in the availability of "Distributional Materials Properties" which now exist only on a limited scale, but incorporation of the requirement for their use in specifications will provide the impetus for their development by material laboratories around the country, at least in the materials used by aircraft designers in critical applications.

As a result of the analysis conducted for this section, the following general recommendations are made:

- Revise specifications and develop a standard to implement "Structural Design for Reliability" methodology.
- Revise specifications to include adequate "Quality Assurance Provisions."
- For helicopter structural design, replace the MIL-A-008860 Airplane Strength and Rigidity series with more appropriate requirements.
- Develop "Distributional Materials Properties" Military Handbook for use by aircraft structural reliability designers.

Appendix D provides the detailed recommendations and supporting rationale which address the combined structural/documentation problems related to this section.

COCKPIT ARRANGEMENTS AND ASSOCIATED SPECIFICATION R&M EVALUATION

MIL-F-9490 requires flight control systems to be designed to military standards in the area of cockpit controls, location

and actuation, displays, and general aircrew station geometry. These standards have a bearing on flight control system reliability and maintainability. However, the effect is in the human factors aspects for the most part. Systems and components must be designed for interface with the pilot, copilot, and mechanic, and those aspects of biomechanics, sensory processes, and anthropometry which affect reliability and maintainability must be considered.

Flight control system material failures may result from the forces applied by the pilot or copilot to the grips or rudder pedals if the resulting failure-governing stress distributions are not properly controlled by good design for reliability with respect to the failure-governing strength distributions of the material and configuration chosen. Structural specifications must make the same considerations and be compatible with these standards.

Cockpit Control Hardware Problems

The only pilot-induced failure problems in helicopter flight control systems reported to date include what pilots call "mast bumping" and "seat-belt jamming." These have occurred on rare occasions.

"Mast bumping" is caused by the pilot's reaction to engine failure wherein he instinctively pushes the cyclic stick full forward, causing the SCAS to aggravate the stability situation.

The aircraft porpoises, causing the rotor head to bump the mast, resulting in mast damage. The same failure mode may occur without SCAS when several transmission mounts are defective.

"Seat-belt jamming" is a failure mode which occurs when the pilot flies without the copilot and neglects to fasten the copilot's belt over the empty seat. The belt tends to become jammed under the collective stick in certain situations.

Flight control system components in the cockpit require periodic maintenance. Maintainability of these components is dependent upon accessibility, features and interface design, and maintenance resources such as skilled manpower, availability of diagnostic equipment, standard and special tools, and spare parts and materials. The common problems experienced to date, affecting maintainability of cockpit components of flight control systems, have been the number, type, and quality of fasteners and adjustments. These problems have now been minimized.

Cockpit Control Specification Problems

The standards for design of helicopter flight controls in the cockpit required by MIL-F-9490 include:

MIL-STD-203
MIL-STD-250
MS 33574
MS 33575
MS 33576

These standards are restricted to arrangement and geometry utilizing human factors anthropometric data for the most part.

MIL-STD-203 is written for fixed wing and has little application to rotary wing. It references many obsolete specifications and standard drawings.

MIL-STD-250 is an adequate document from the geometric standpoint but, as such, has little effect upon R&M. Standards are required covering the human factors aspects of biomechanics and sensory processes affecting R&M, particularly in designing for location, magnitude, and direction of loads applied to the flight control system from the cockpit under different operating conditions, and in making adjustments during maintenance.

MS 33574 applies to cockpit dimensions of stick-controlled fixed-wing aircraft and is not used for rotary wing. MIL-STD-1333A is used in its place, and should be added to MIL-F-9490. No changes affecting R&M are indicated.

MS 33575 applies to helicopter cockpit dimensions and has also been replaced by MIL-STD-1333A. MS 33575 should be deleted from MIL-F-9490.

MS 33576 applies to cockpits of wheel-controlled fixed-wing aircraft, and is not applicable to helicopters. It must be left in MIL-F-9490 for fixed-wing aircraft cockpit design if it is still current.

The previously mentioned recommendations can be found in Appendix E, which contains the document review change recommendations for the cockpit arrangements.

FLY-BY-WIRE FLIGHT CONTROL SYSTEM DESIGN

INTRODUCTION

The objectives of this study were to:

- Assess and report existing specification and state-of-the-art documentation of fly-by-wire systems.
- Contact technical associations, military agencies and the helicopter flight control industry for developments, unpublished information, and planned and on-going research.
- Prepare a research study report recommending future R&D efforts required to define (1) design and test requirements, (2) quality assurance provisions, and (3) qualification requirements, procedures and practices for these components in future Army aircraft.

The approach to this study included:

- Procurement of a listing of existing fly-by-wire technical research reports and a summary of work in progress from the Defense Documentation Center and NASA
- Review of the literature search results for significant documents and procurement of microfiche copies of those most pertinent published since 1965
- Review of microfiche reports
- Contact with appropriate sources for additional information
- Final review of information obtained from all sources
- Preparation of this summary report with research recommendations

The selected bibliography lists the fly-by-wire research reports which were available and reviewed. Appendix G lists the on-going research and development investigations.

SYSTEM LEVEL HARDWARE AND SPECIFICATION EVALUATION

Definition

The term "Fly-By-Wire" is generally applied to a control system which uses electronic control signals to connect the pilot's control commands to the aircraft control actuators. For an existing aircraft, installing a fly-by-wire control system would mean replacing the conventional flight control system mechanical linkage with an electrical signal mechanization. Since the use of fly-by-wire is an evolutionary process from existing control system mechanization techniques, it is worthwhile to briefly list and describe fly-by-wire techniques and existing control configurations which incorporate electronic mechanizations as part of their normal operation.

The term "Pure Fly-By-Wire" is generally applied to a primary flight control system mechanization which uses only electronic control signals as the control signal transmission method.

The term "Pseudo Fly-By-Wire" is generally used to describe a primary flight control system mechanization in which the normal operating mode uses electronic coupling between pilot and the control actuators, and also carries along a declutched mechanical system as a backup.

The term "Control Augmentation System" or "CAS" is generally applied to a primary flight control system which uses both electrical and mechanical control paths operating together in parallel to transmit control signals from the pilot to the control actuators. If the electrical system is disabled, the mechanical transmission path is used to command the control actuators.

The term "Stability Augmentation System" or "SAS" is applied to the limited authority, electronically controlled portion of the flight control system which is used to add control inputs to the pilot's mechanical input motions. The motion added is commanded by vehicle motion sensors and is used to increase the stability of the aircraft. "SCAS" or "Stability and Control Augmentation System" is a version of the stability augmentation system in which the pilot's inputs are transmitted

and mixed electrically with the output of the aircraft motion sensors so that the stability augmentation system does not oppose aircraft motions commanded by the pilot.

Examples of the "Pure Fly-By-Wire" mechanizations that have been flown in this country are the Air Force 680-J F-4 contracted to McDonnell Douglas, NASA F-8 Digital Fly-By-Wire Aircraft currently under flight test at Edwards Air Force Base, and the space program Gemini, Apollo, and Mercury vehicles. Aircraft under development which use pure fly-by-wire control systems are the Space Shuttle vehicle, General Dynamics Lightweight Fighter and the HLH. A prototype fly-by-wire system for the HLH is currently being flight tested in a smaller Boeing helicopter.

Examples of the "Pseudo Fly-By-Wire" mechanization are the Concorde SST; the MRCA, a fighter bomber developed by Britain, Germany, and Italy; the TAGS CH-47B helicopter; and the Air Force B-47 Fly-By-Wire Test Aircraft.

Examples of the "Control Augmentation System" mechanization are the F-14, F-15, F-111, and A-7 fighter-bomber aircraft.

Stability augmentation systems and/or the variant "SCAS" have been used on most recent commercial and military aircraft which do not use Fly-By-Wire or CAS mechanizations.

Current Fly-By-Wire System Design

The aircraft manufacturers who have built or are building aircraft with fly-by-wire control systems, such as the Boeing Aircraft Company with the HLH and McDonnell Douglas with the 680-J F-4, have generated their own performance and test requirements for the primary fly-by-wire control systems. The control systems for these vehicles have then been subcontracted to flight control suppliers for manufacture. The specifications were generated on the basis of the aircraft requirements for both performance and reliability. This same procedure is being followed on the Space Shuttle Program and will probably be followed on future fly-by-wire programs.

As a standard practice, parallel element redundancy configurations for mechanizing flight control systems have been specified. These particular configurations have been specified primarily because of the high reliability requirements for the fly-by-wire system. To date, no particular configuration has been flight tested in sufficient quantity or for long enough time to obtain an adequate level of statistical confidence in its reliability. The mechanizations generated therefore reflect different approaches

toward minimizing anticipated "common mode" failures by design. Both active-standby and force-sharing parallel redundancy techniques have been used. For example, the Concorde SST uses split control surfaces which are a force-sharing form of parallel redundancy. However, the Concorde's individual control channels for the surfaces also use active-standby redundancy to allow the control channels to tolerate failures and still continue to function.

The fly-by-wire development programs to date have generally not just investigated fly-by-wire as a technique to transmit pilot inputs to control actuators, but have added additional control criteria and techniques to the basic mechanization investigation. For example:

- The 680-J program was used to investigate potential survivability improvement with fly-by-wire techniques.
- The TAGS program was used to investigate helicopter control techniques in addition to using a fly-by-wire control system.
- The Lightweight Fighter Program is intended to demonstrate the characteristics of a lightweight control configured fighter using fly-by-wire flight control systems.
- The NASA F-8 program is being used to demonstrate the characteristics of digital flight control computation techniques in a fly-by-wire system.

In addition to digital flight control computer techniques, the Space Shuttle will incorporate multiplex transmission of the control signals.

Specific Problems Encountered in Fly-By-Wire Programs

The development programs using fly-by-wire flight control systems have not revealed gross problem areas with the mechanization technique. The 680-J program had some wire fraying problems in the system installation. The TAGS program revealed sensor mismatch problems causing computer divergence.

However, since the fly-by-wire system design depends upon high quality cabling and connector techniques for transmission of electrical signals, it appears worthwhile to specify cabling and connector techniques for fly-by-wire systems. AFFDL TR-70-134, Reference 12, addresses this problem and could be incorporated with suitable modifications into a fly-by-wire design manual and specification.

The problem of wiring bundle size for fly-by-wire systems and connector integrity is still being researched by the Air Force. The current Air Force "Di-electric Waveguide" investigation, "Fly-By-Wire Multiplex" investigations, and "Fiber Optic Transmission Techniques" investigations are all directed at improving information transmission characteristics for fly-by-wire systems.

The problem of getting the fly-by-wire system out of the infant mortality reliability period and into the random failure period was solved by McDonnell Douglas by conducting a burn-in testing program for fly-by-wire electrical components.

COMPONENT LEVEL HARDWARE AND SPECIFICATION EVALUATION

The components used in fly-by-wire systems are generally specified by the aircraft manufacturers to conform with flight control system configuration and performance and will vary from aircraft to aircraft.

The electrical components are similar or identical to those used in automatic flight control systems which have been flying for some time. Component specifications and standards, of which the Specification Tree described by Figure 12 is typical, exist along with much more adequate reliability and maintainability data and established methodology than for mechanical components. This is because R&M started with the need to improve electronic equipment, and adequate data bases were established with MIL-STD-217, FARADA, etc., for electronic components.

Applicable electrical and electronic component specifications should be upgraded for use in critical R&M applications in the same manner as recommended by this study for mechanical components.

RESEARCH AND DEVELOPMENT RECOMMENDATIONS

Since NASA, the Air Force, and the Army are currently funding aircraft development programs which incorporate pure fly-by-wire primary flight control systems, monitoring of these programs as to their particular design and test requirements and to their particular approach to some of the following research areas is strongly recommended. The fly-by-wire system reliability problem is a common one to all three programs (HLH, Space Shuttle and Lightweight Fighter), and the procedures used to assure adequate reliability of the flight control system should show some commonality.

In addition, the following research efforts to define design and test requirements are recommended:

- Investigation of techniques to ensure adequately separated, high quality electrical power for fly-by-wire control system channels
- Modification of MIL-F-9490 to include more stringent requirements for component quality and installation procedures for fly-by-wire primary flight controls
- Investigation of problems and constraints using a digital computer as flight control signal processor in a fly-by-wire system

These recommendations are discussed in detail in the following sections.

Electrical Power Supply Integrity Research

The use of multichannel electronic control channels for the primary flight controls requires the establishment of high quality, high reliability, and separated electrical power supplies. This requirement is analogous to the present requirements for separated hydraulic supplies for conventional irreversible hydromechanical flight controls. The techniques currently used in development aircraft, such as separated bridge rectifiers from a common ac source with storage batteries strapped to the output of the bridge rectifiers, incur a significant weight and size penalty.

In fact, the electrical power supply mechanization problem solutions to date have tended to offset completely the normal weight and size advantages of a fly-by-wire mechanization approach compared to conventional mechanizations. The program objective should be to investigate techniques to provide electrical power supply having maximum reliability and minimum cost and weight when compared with normal aircraft power systems.

MIL-F-9490 Fly-By-Wire Modifications

Fly-by-wire is nothing more than a particular method of mechanizing a flight control system, and the functional requirements are generally identical to more conventional mechanical mechanization techniques. Therefore, MIL-F-9490, the general specification for design, installation, and test of flight control systems for piloted aircraft, should be reviewed and modified to include provisions necessary for fly-by-wire primary flight control systems. This specification should include provisions for reference to applicable military electrical specifications for use in designing fly-by-wire systems.

In addition, the specifications and procedure documents then referenced in MIL-F-9490 as applicable to fly-by-wire systems should be updated for fly-by-wire requirements, as performed for mechanical components by this investigation.

Simple System Investigation

The effect of applying a simple fly-by-wire system to a basic Army helicopter with emphasis on dispersion of control channels should be evaluated. The emphasis should be on determining whether fly-by-wire systems would have a significant benefit on survivability of a light and/or medium helicopter with the present state-of-the-art fly-by-wire technology. The study should also determine the general redundancy configurations required to duplicate the helicopter's hydro-mechanical control system reliability.

Digital Computer Utility Investigation

Based on the present trend in small computers, it is probable that a digital computer will eventually be used as a flight control signal processor in conjunction with weapons delivery systems. It is therefore recommended that the problems and design constraints for incorporating a digital computer processor into a helicopter flight control system be documented. Although this has been investigated to some extent in the TAGS program, the reliability constraints, such as what constitutes common mode failure conditions and the redundancy requirements for flight control computers, have not been investigated in any detail. This study should document the interface requirements, reliability range, and performance limitations of flight control type computers.

FLUIDIC FLIGHT CONTROL SYSTEM DESIGN

INTRODUCTION

The objective of this study was to develop the criteria which would assist in the research and development of a primary fluidic flight control system specification. Reliability and redundancy requirements for these systems were also included in the objective.

The study included the following tasks in the approach:

- Assess and report existing specifications and state-of-the-art documentation of fluidic flight control systems.
- Contact technical associations, military agencies and the helicopter flight control industry for developments, unpublished information, and planned and on-going research.
- Prepare a report bibliography on those fluidic R&D efforts that have been related to flight controls.
- Prepare a research study report recommending future R&D efforts required to define (1) design and test requirements, (2) quality assurance provisions, and (3) qualification requirements, procedures, and practices for these components in future Army aircraft.

SYSTEM LEVEL HARDWARE AND DOCUMENTATION EVALUATION

Definitions

Fluidics is the general field of fluid devices or systems that perform sensing, logic, amplification, processing, control, and display functions employing devices with few or no moving parts. Fluidic devices without moving parts are termed flueric devices, while the more general term, fluidic, refers to devices that may or may not have moving parts. Fluidic systems operate either with a gas or fluid and use the various phenomena of fluids in motion to perform these functions.

For the purpose of this study, a flight control system is taken to include the primary controls, stability augmentation, automatic pilot functions and artificial stick feel. In defining a fluidic primary flight control system, three basic elements are known to exist: the signal generator, the signal transmitter, and the power interface.

System Hardware

The evaluation of existing fluidic systems that have or could be applied to helicopter flight control systems revealed that a significant amount of R&D had been done on the secondary controls while little effort had been devoted to the primary controls. The secondary functions are defined as those which include stability augmentation, automatic pilot and artificial feel, while the primary controls are those through which the pilot maintains control of the helicopter.

Much of the fluidic flight control R&D effort to date has been performed by Honeywell, Incorporated, and the General Electric Company.

Since 1965, Eustis Directorate of the U.S. Army Air Mobility Research and Development Laboratory has directed the research and development of fluidic stability augmentation for helicopters. This work has progressed from the demonstration of a yaw damper to the present-day effort which involves an advanced fluidic flight control system. This advanced system includes fluidic stability augmentation with a limited authority electronic autopilot that interfaces with the fluidic system. The procedure established by Eustis Directorate for development and flight test of stability augmentation systems is briefly outlined in the following steps:

1. Establish the technical feasibility of a simple hydrofluidic system.
2. Demonstrate the reliability of hydrofluidic systems.
3. Confirm feasibility with actual flight test of a single-axis system.
4. Prove the merits of hydrofluidics through development and flight test of a three-axis SAS integrated into the helicopter hydraulic system.
5. Demonstrate the capabilities of hydrofluidic systems to provide outer-loop modes, such as heading hold, altitude hold, and attitude hold.

Eustis Directorate is currently on Step Number 5 with the flight test of a system in a UH-1M helicopter. In addition to this test plan, Eustis Directorate and Naval Air Development Center are in a joint effort to install fluidic SAS in a number of helicopters to accumulate 1 year flying time. Resulting from this program will be much needed reliability and maintainability data for fluidic systems.

Fluidic artificial feel systems have been studied by Boeing and the U.S. Navy. These systems are to provide the pilot with a force on the stick position proportional to dynamic flight parameters such as helicopter normal acceleration and forward airspeed.

The system hardware that has been developed includes primary flight control system peripheral equipment only.

The Selected Bibliography lists those efforts related to the above outline and also describes other R&D efforts related to artificial feel and automatic pilot functions. The reports indicate that vortex and laminar rate sensors, fluidic input servo actuators, fluidic servo valves, and fluidic pressure feedback devices have been developed in recent years. It is believed that most of these developments may be applied to fluidic primary flight control systems. The reports further indicate that no research and development directly related to a primary fluidic flight control system has been accomplished to date. In addition, Appendix H, the list of on-going fluidic research, indicates that there are no current projects directed toward research of primary controls.

Several possible fluidic primary flight control system configurations have been found to exist. Some of these applications have not been studied in detail, although the concepts appear to be sound and some of the applications have been demonstrated. Following are those systems which have been researched:

- AC Position Servo. - This system was designed and built by the General Electric Company of Schenectady, New York. It is a fluidic system which operates on air and creates a modulating pressure. The frequency of this pressure is dependent upon the size of a variable volume capacitor. If this modulating pressure is passed through a second variable volume capacitor, a phase shift will occur if the second capacitor is not of the same value as the first. This phase shift can be detected by a phase discriminator and amplified to control an actuator. As depicted by Figure 13, the command resonator (first capacitor) can be connected to the pilot's controls and the feedback resonator (second capacitor) is connected to the actuator. Movement from some neutral position of the command resonator will cause an error signal to drive the actuator. As the actuator moves, the error approaches zero, at which time the actuator ceases to move.

A breadboard model of this fluidic system was evaluated in the laboratories of Bell Helicopter in early 1973. As the system was configured, it was unacceptable for accurate position control. Changes to improve the performance of the system were studied and further work was planned; however, higher priority projects have delayed this effort. The system was evaluated further in a study of the AH-1G flight control system. The study was for a more survivable flight control system. It was determined to be feasible to package the system in the helicopter in parallel with the existing mechanical flight control system. The fluidic system was determined to be less desirable than other systems in this helicopter, primarily because a source of pneumatic power would be required. The power required would have to be derived from either the engine bleed air or from a pneumatic pump added to the aircraft.

- DC Position Control. This system is a mechanization which also has been considered by Bell as a flight control system. The system, shown schematically in Figure 14, uses a tapered spool in a sleeve to create a pressure differential that is proportional to spool position. This system was considered during the study of the AH-1G flight control system, but was eliminated as a candidate system at that time because the state-of-the-art was not sufficiently developed.

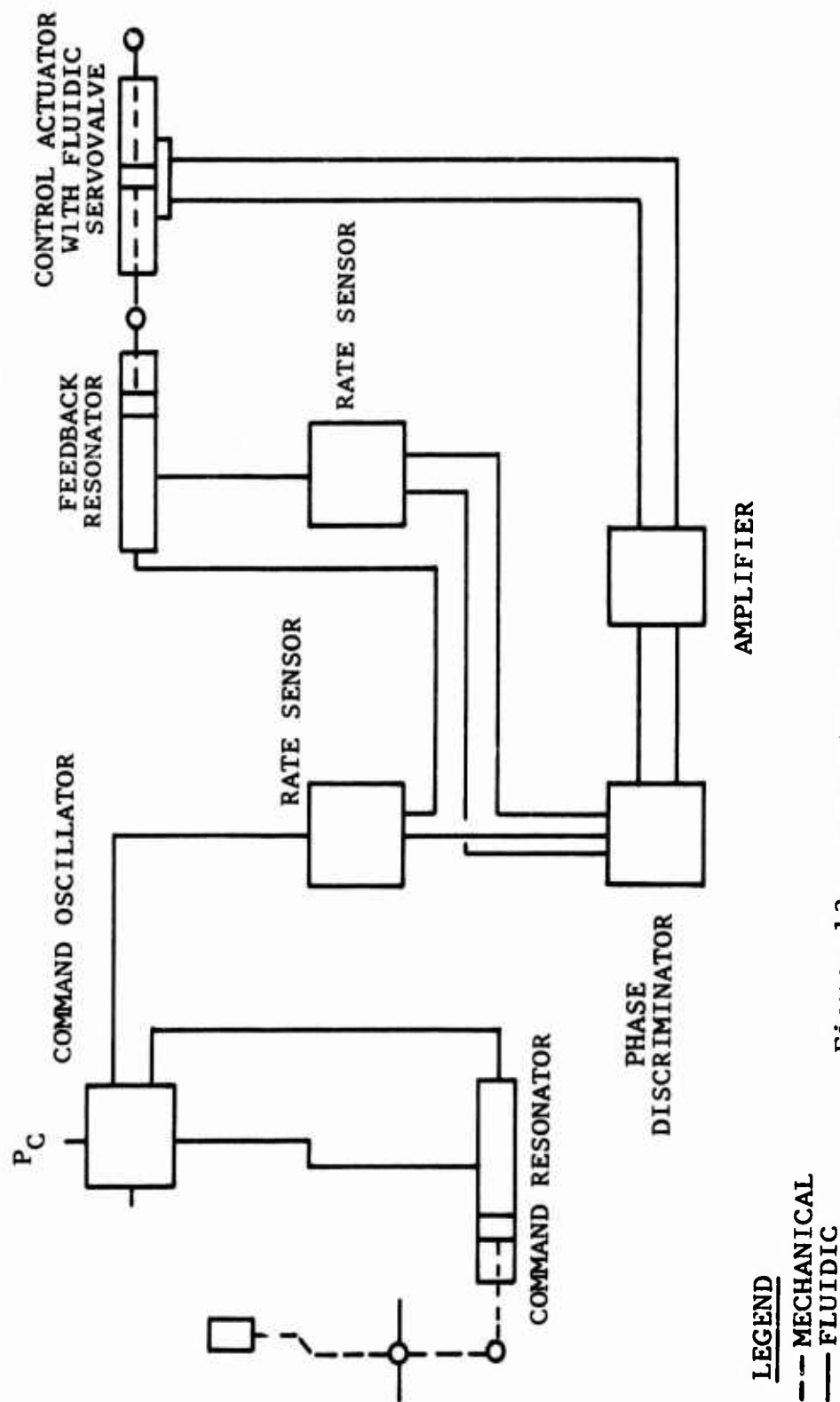


Figure 13. AC Position Servo Designed and Developed by General Electric.

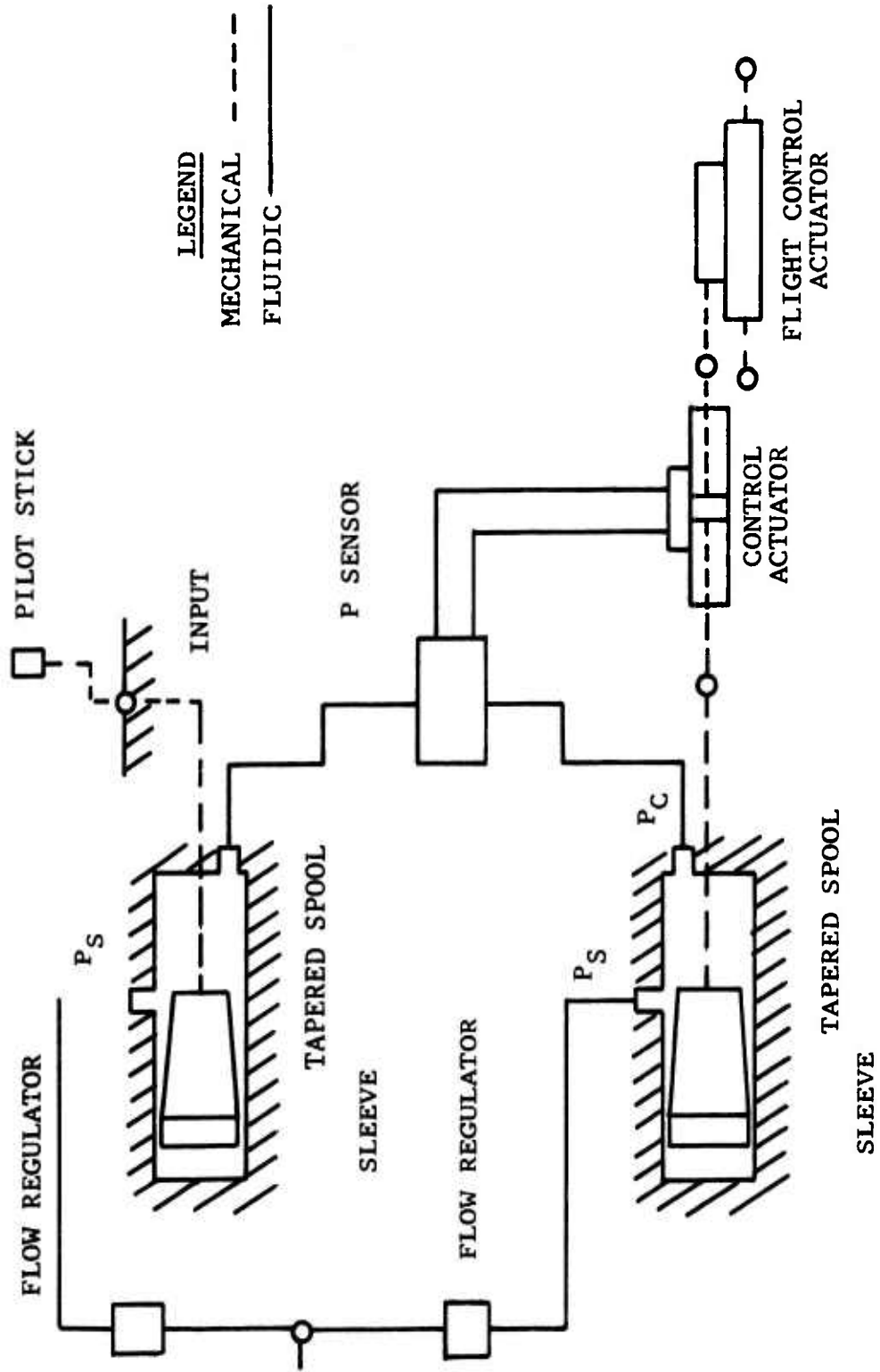


Figure 14. DC Fluidic Controls.

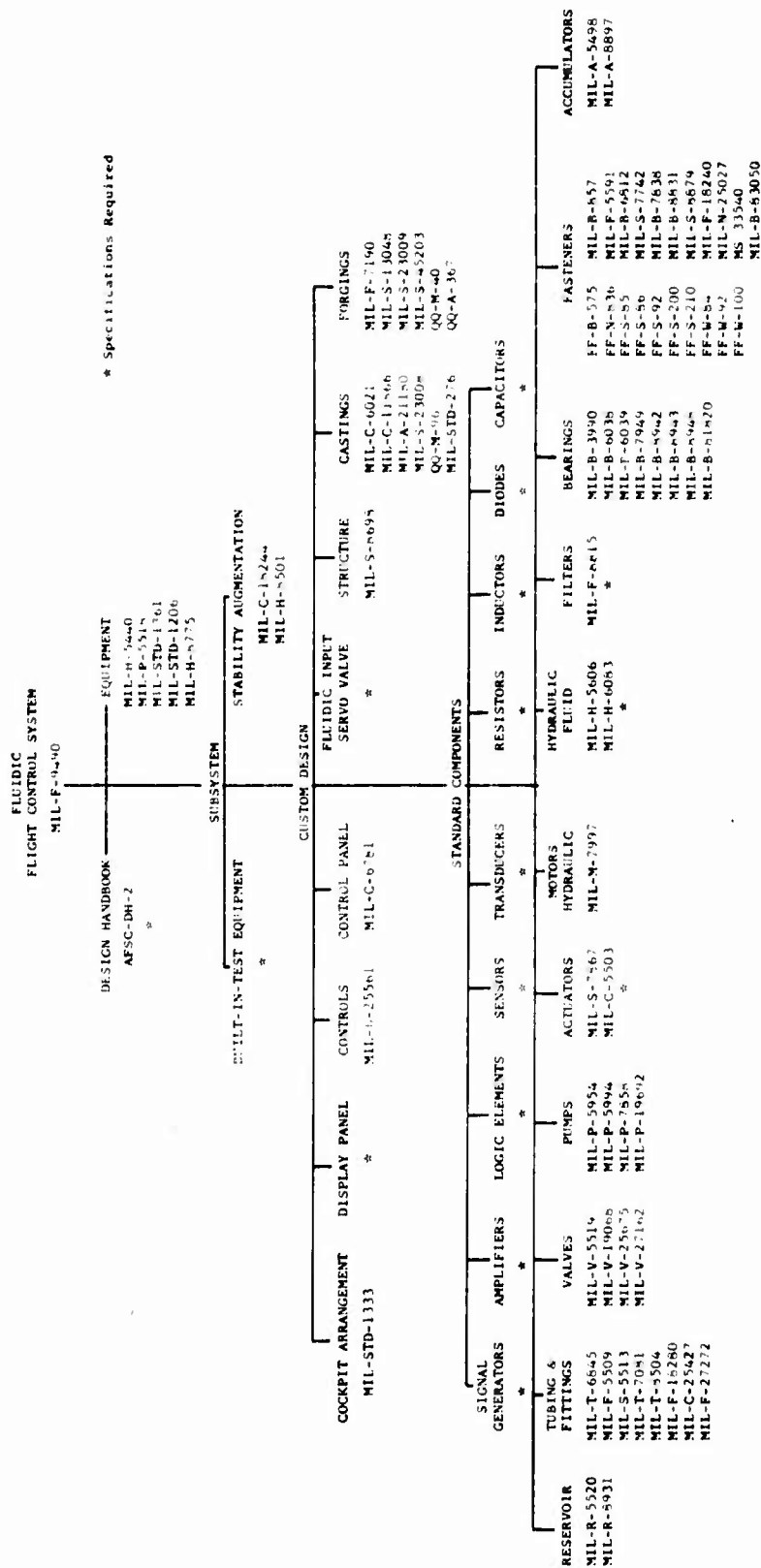
- Hydraulic Slave System. This self-contained system utilizes a fluid as an incompressible link from the pilot to the flight control actuator. The pilot's stick positions a master actuator that moves fluid to position a slave actuator. Bell designed and fabricated this system and completed laboratory tests early in 1973. The concept was determined to be feasible and is currently being considered as a candidate flight control system in the AH-1G helicopter.
- Remote Servo Valve System. This arrangement is one wherein the conventional mechanical input servoactuator is modified. The servo valve is removed from the actuator and is placed at the pilot's stick. Hydraulic tubes are used to transmit the fluid from the servo valve to the actuator. This concept also replaces all the mechanical linkage with hydraulic tubes.
- Flapper-Nozzle Servo Valve. This conceptual system is very similar to the one described above except that the servo valve is replaced with a mechanical input flapper-nozzle servo valve.
- Fly-By-Tube. Presently, Honeywell is under contract to study this concept. Apparently, this is similar to the Hydraulic Slave System that was developed by Bell.

System Specification

Currently, no system specification exists for a primary fluidic flight control system. Specification MIL-F-9490 is used by the Army for definition of mechanical flight control systems, but this specification does not directly address a fluid system. Those specifications that cover hydraulic and pneumatic systems, namely MIL-H-5440 and MIL-P-5518, generally apply to systems that supply power. These would not be sufficient definition for a fluidic flight control system.

Only two documents are known to exist that deal directly with fluidics. MIL-STD-1306 concerns the terminology and symbols for fluidics, while MIL-STD-1361 defines standard methods for the test of fluidic devices. These two documents will complement a fluidic system specification.

Figure 15 is a proposed Specification Tree which indicates the areas where a fluidic system specification is needed.



* Specifications Required

Figure 15. Fluidic Flight Control System Specification Tree.

COMPONENT LEVEL HARDWARE AND SPECIFICATION EVALUATION

Hardware Evaluation

Little hardware has been developed to date which may be applied specifically to the design of a fluidic primary flight control system. Most of the hardware which has been developed was designed for use in secondary flight controls. The prime examples of this secondary system hardware are the fluidic stability augmentation systems which have been developed. The hardware for these systems is now being qualified to the requirements of MIL-STD-810. The fluidic input servo valve is an example of one of the more important recent developments which can be used in the mechanization of a fluidic primary flight control system. Components which may be developed today for fluidic primary flight control systems are somewhat common devices and of the current state of the art.

Component Documentation Evaluation

As shown in the Specification Tree in Figure 15, few specifications exist for fluidic components. In the case of an actuator, which probably is best termed a hydraulic or pneumatic component, applicable specifications do exist. MIL-C-5503 is a military specification covering utility actuators and can be used as a guide in the design of an actuator for a fluidic application. The pure flueric devices are not covered by design documentation, although MIL-STD-1361 can be used as a guide for functional tests.

FLUIDIC FLIGHT CONTROL SYSTEM AND COMPONENT RELIABILITY AND MAINTAINABILITY

The premise that a device with no or few moving parts that performs a function by virtue of low pressure fluids in motion is inherently reliable and requires little maintenance seems to be plausible. Early testing of fluidic devices met with enough success that good reliability and maintainability seemed inevitable.

In 1967, the U.S. Army awarded a contract to determine the reliability of a fluidic stability augmentation system and the components of that system. Resulting from the contract was USAAVLABS TR 68-36. This report predicted a mean-time-between-failures of 83,000 hours for a single-axis fluidic stability augmentation system. The report also predicted the reliability of a comparable electromechanical system at 9,000 hours MTBF. Some aspects of the evaluation are:

- Small time base. The components and systems were operated without failure for approximately 45,000 hours.
- No failure occurred. This results in an undefinable failure rate.
- The Poisson distribution was used to establish theoretical failure rates. These rates were determined at the 50 percent confidence level.
- Improved failure rates used to predict 83,000 hours MTBF were derived by decreasing the failure rates defined by the Poisson distribution. Adequate justification for improving those failure rates was not included in the report.
- Some of the hardware tested was prototype and some design changes were required in order to satisfactorily complete the tests.

It is for the above reasons that the failure rates derived from the test report are without adequate substantiation.

Table 4 lists those fluidic components that either have no published failure rate data or for which inadequate data were found. In those cases where data were found, they are listed.

The task of establishing a reliability and maintainability data bank is not unique to a fluidic flight control system and must be accomplished for R&M design of such systems. This task is included in the research and development recommendations. It is recommended that periodic R&M results of the system and component testing be published and periodically updated.

The documentation, literature and industry surveys of this study have resulted in the following conclusions:

1. Specifications do not exist for fluidic systems and flight control components.
2. Adequate component reliability and maintainability data do not exist.
3. Fluidic position controllers are available that might be applied to flight control system design.
4. Aircraft criteria to establish interface, redundancy/reliability and fail-safety requirements as addressed to fluidic primary flight control systems have not been defined.

The general conclusion is that extensive research and development remains to be performed in order to define a primary fluidic flight control system. Some expertise in the fluidic technology is required in this R&D. The helicopter manufacturers and the U.S. Army must obtain this expertise in addition to those instrument and control companies already developing controls and jointly define the system requirements and design criteria for these systems.

RECOMMENDATIONS FOR FUTURE RESEARCH AND DEVELOPMENT

The information gained in this study indicates that very little research and development has been directed toward fluidic primary flight control systems even though some fluidic hardware has been developed which can be applied. Based upon these findings then, and upon the evolutionary needs for flight control system development, the following recommendations are made:

- Conduct design studies of flight control systems, as indicated by this investigation.
- Designate most favorable systems for hardware test and evaluation, and fabricate test bed systems.
- Conduct design and test evaluation on selected fluidic components such as for signal generation, signal transmission and power interface.
- Initiate both system and component R&M tests and evaluations using the test bed simulators.
- Develop specifications which will include R&M requirements sufficient to develop a fluidic flight control systems specification tree as the technology advances.

Figure 16 is a suggested flow chart for a Fluidic Flight Control System R&D program. This investigation is the initial block in the diagram, entitled Fluidic FCS Study. The alternate paths to the Fluidics FCS specification are numbered to facilitate visibility.

Path 1

This is the mainstream of R&D that should follow from these recommendations. Several possible primary system mechanizations are mentioned in the prior description of system hardware. These and other mechanizations should be considered for further research and study in the phase depicted by the block noted as Fluidic-FCS Definition.

TABLE 4 . FLUERIC/FLUIDIC COMPONENT FAILURE RATES

Component	Failure Rate %/1000 Hours
1. Amplifier	1.25 ¹
a. Closed Jet-Deflection	-
b. Vented Jet-Deflection	-
c. Boundary Layer	-
d. Impact Modulator	-
e. Turbulence	-
f. Vortex	-
g. Wall Attachment	-
h. Digital	-
i. Analog	-
2. Logic Elements	
a. Flip-Flop	-
b. Binary Counter	-
c. OR-NOR	-
d. AND-NAND	-
e. Schmitt Trigger	-
f. Exclusive OR	-
g. 2/3 AND	-
h. Exclusive OR	-
i. Passive OR	-
3. Sensors	
a. Vortex Rate Sensor	1.44 ¹
b. Laminar Rate Sensor	-
4. Transducers	
a. Pressure (U-Tube)	-
5. Circuit Elements	
a. Capacitor	1.42 ¹
b. Resistor	-
c. Diode	-
d. Inductor	-
¹ Table II of USAAVLABS TR 68-36.	

At this point, contracts should be initiated to study fluidic primary flight control system mechanizations.

Path 2

Also, the U.S. Army should establish helicopter flight control system design criteria. In order to establish goals and to compare various means of mechanizing these systems, a criterion must be established. This criterion should include but not be limited to the following items:

1. Interface
 - a. Stability augmentation
 - b. Automatic pilot functions
 - c. Artificial feel
2. Reliability Requirements
 - a. Required mean-time-to-failure
 - b. Redundancy
3. Maintainability Requirements
 - a. Required maximum repair time with stated confidence, mean-time-to-repair, or maintenance hours per flight hour
 - b. Failure detection
 - c. Built-in test equipment
 - d. Standardization
4. Survivability
5. Performance

Path 3

Component evaluation should include any miscellaneous tests required to support the overall development of a fluidic primary flight control system. At this time, the following items require further evaluation.

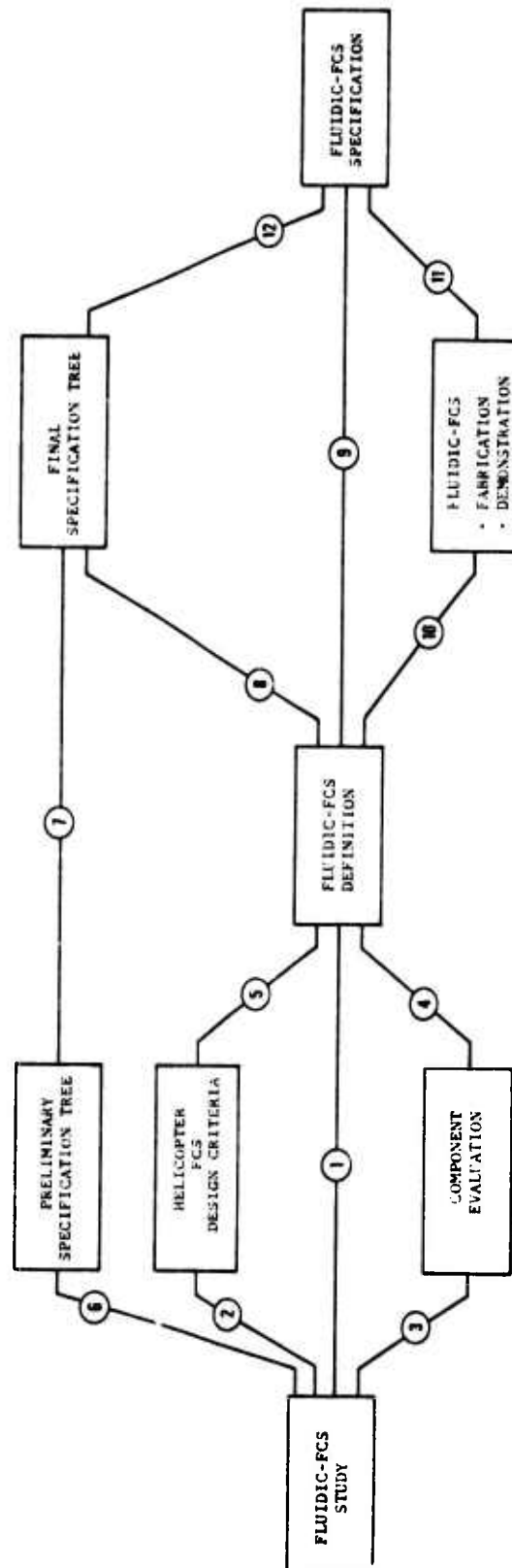


Figure 16. Recommended Fluidic Flight Control System R&D Program - Flow Chart.

<u>Component</u>	<u>R&M</u>	<u>Performance</u>
Power Interface	X	X
All Fluidic Components (amplifier, gates, etc.)	X	
Position Transducer	X	X
Signal Transmission	X	X

As shown, some items require evaluation and development for performance while others primarily require reliability testing. This reliability data requirement is not considered unique to the development of a fluidic primary flight control system specification, but is common to the development of most system specifications.

Path 4

The results of the component evaluations should be reported on a periodic basis in order to make this information available to the system mechanization studies.

Path 5

The aircraft flight control system criteria should be a basis for the studies of the fluidic primary flight control system definition.

Paths 6, 7

Resulting from this study, and shown in Figure 15, is a preliminary specification tree. As R&D progresses, this tree should be completely defined.

Paths 8, 9

The results of the system definition studies should be used to update the specification tree and to create the system specification.

Paths 10, 11

Those systems that warrant fabrication and further development should be built for testing on a simulator. This could either be a simulator supplied by the Army or it could be an inexpensive breadboard. A simulator should

also be available for reliability and maintainability demonstration tests. These tests and demonstrations should provide inputs to the design, test, and quality assurance sections of the system specification.

Path 12

As the specifications of the tree become completely defined they will become a set of general requirements for all aspects of fluidic system and component design, qualification, and product acceptance.

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APPENDIX A

TYPICAL HELICOPTER FLIGHT CONTROL SYSTEM (AH-1G)

In order to improve today's helicopter flight control system from the R&M standpoint, it would be helpful to consider a typical system. The Bell AH-1G has been chosen as a typical example of present-day helicopter flight control system design, and it contains most of the types of components required of this study.

The AH-1G primary flight control subsystems are the main rotor collective, fore-and-aft cyclic and lateral cyclic, and the tail rotor controls. Each of these is a system of mechanical linkage assisted by hydraulic servo cylinders, connecting the pilot's and gunner's control sticks and pedals to those mechanisms which rotate with and directly control the main rotor and tail rotor. Main rotor cyclic and tail rotor controls incorporate electrically operated force trims to steady the stick and pedals against movement of their own accord and to induce artificial control feel, and also provide optional use of a stability and control augmentation system (SCAS) when a mission requires more stable flight than is possible with normal manual control. A secondary system of control linkage connects the synchronized elevator to the fore-and-aft cyclic controls at the swashplate.

Collective Controls

The collective control system, Figure A-1, includes gunner's and pilot's stick assemblies, push-pull tubes, bellcranks, and a dual hydraulic servo cylinder, connected to a lever which actuates the mast-mounted sleeve and scissors assembly and its linkage to the main rotor.

Pilot's collective control stick is on the left side console. The stick assembly includes a switch box and electrical cable, a knobbed friction nut and rotating throttle grip for manual setting of the fuel control power lever, a knurled nut for control stick friction, a protective cover and boot, and a support assembly containing friction devices and having a bellcrank and throttle lever for control linkages. A strap with snap attachment is provided on the console to secure the control stick in low pitch position.

Gunner's Collective Control Stick

The collective control stick mounted in the gunner's left side console is a dual control for occasional or emergency

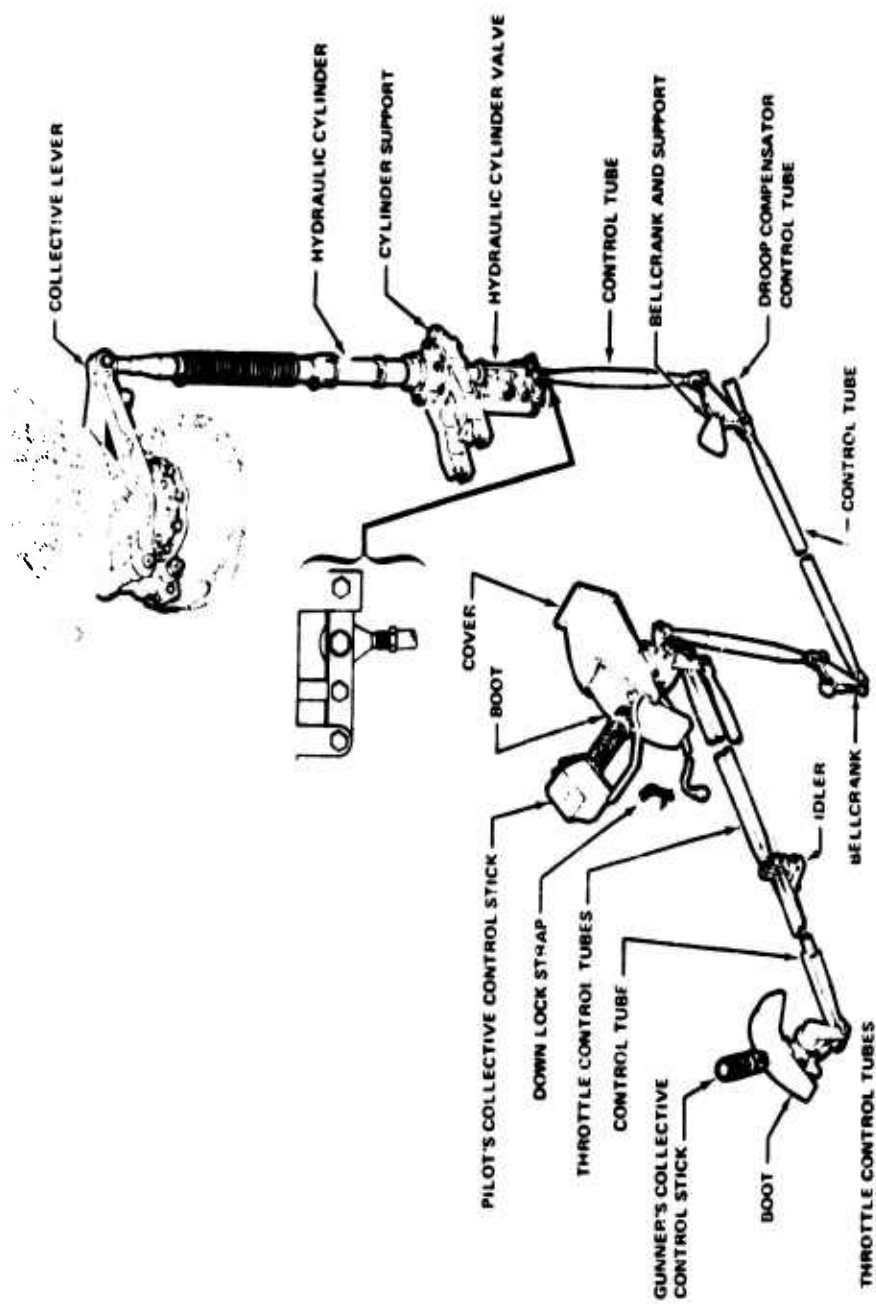


Figure A-1. Collective Control Installation.

use, and has only the essential functions of collective pitch control and throttle control. There are no friction adjustments or electrical switches.

Collective Control Reliability and Maintainability

Figure A-2 represents the Collective Control Reliability Block Diagram and Mathematical Model. Tables A-1 through A-3 show the typical failure rates for the linkage element groups for use with Figure A-2. The predicted 1-hour flight reliability for the collective control installation using these typical failure rates is

$$R(1 \text{ Hr.}) = 0.999715 \\ \text{COL}$$

Navy 3-M data appears to be the only data source for the AH-1G maintainability evaluation. The AH-1G collective system has a reported maintenance man-hours/flight hour, based on 34,259 flight hours through January 1973, of MMH/FH = 0.021551. The hydraulic components contributed MMH/FH = 0.013770 to this figure.

Cyclic Controls

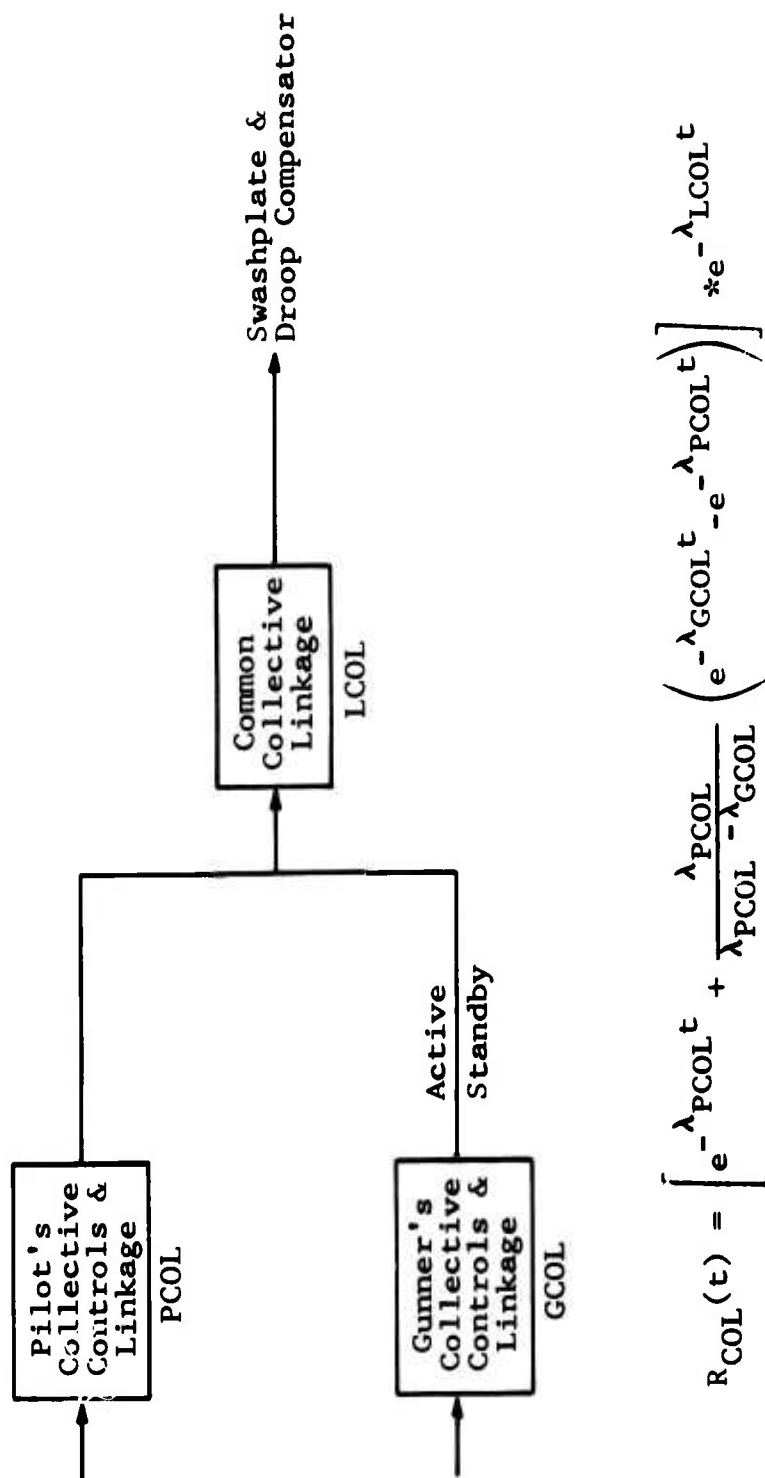
The main rotor cyclic controls consist of interconnected control sticks in pilot's and gunner's compartments, and two separate systems of linkage to the swashplate. Each of the cyclic systems includes a dual hydraulic cylinder, a servo actuator and a transducer of the SCAS, and a force trim magnetic brake connected to control linkage through a spring-loaded force gradient assembly.

The fore-and-aft cyclic controls, Figure A-3, extend aft from the control sticks to a jackshaft, then downward at the right side of fuselage to pass aft below the forward fuel cell, then upward to the hydraulic cylinder which is connected on the right forward horn of the swashplate.

The lateral cyclic controls, Figure A-4, are interconnected between control sticks at the right side of the fuselage, then extend aft and to the left side, passing downward and aft below the forward fuel cell, then upward to the hydraulic cylinder which is connected on the left forward horn of the swashplate.

Pilot's Cyclic Control Stick

The conventional type control stick, mounted in the floor ahead of the pilot's seat, consists of a grip with control



$$R_{COL}(t) = \left[e^{-\lambda_{PCOL} t} + \frac{\lambda_{PCOL}}{\lambda_{PCOL} - \lambda_{GCOL}} \left(e^{-\lambda_{GCOL} t} - e^{-\lambda_{PCOL} t} \right) \right] * e^{-\lambda_{LCOL} t}$$

Figure A-2. AH-1G Collective Control Reliability Block Diagram and Mathematical Model.

Table A-1. AH-1G GUNNER'S COLLECTIVE CONTROLS AND LINKAGE - FAILURE RATES

Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Collective Control Stick	29	1	29
Control Tube	19	5	95
Idler	10	1	10
Bearings	10	12	120
Lever Assembly	10	1	10
TOTAL		$\lambda_{GCOL} = 264*$	
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

TABLE A-2. AH-1G PILOT'S COLLECTIVE CONTROLS AND LINKAGE - FAILURE RATES

Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Collective Control Stick	29	1	29
Cover	10	1	10
Lever Assembly	10	1	10
Bearings	10	4	40
$\lambda_{PCOL} = 89^*$			
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

TABLE A-3. AH-1G COMMON COLLECTIVE LINKAGE - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Control Tubes	19	4	76
Bellcranks	1	2	2
Supports	1	1	1
Bearings	10	8	80
Hydraulic Valve & Cylinder	126	1	126
$\lambda_{LCOL} = 285^*$			
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

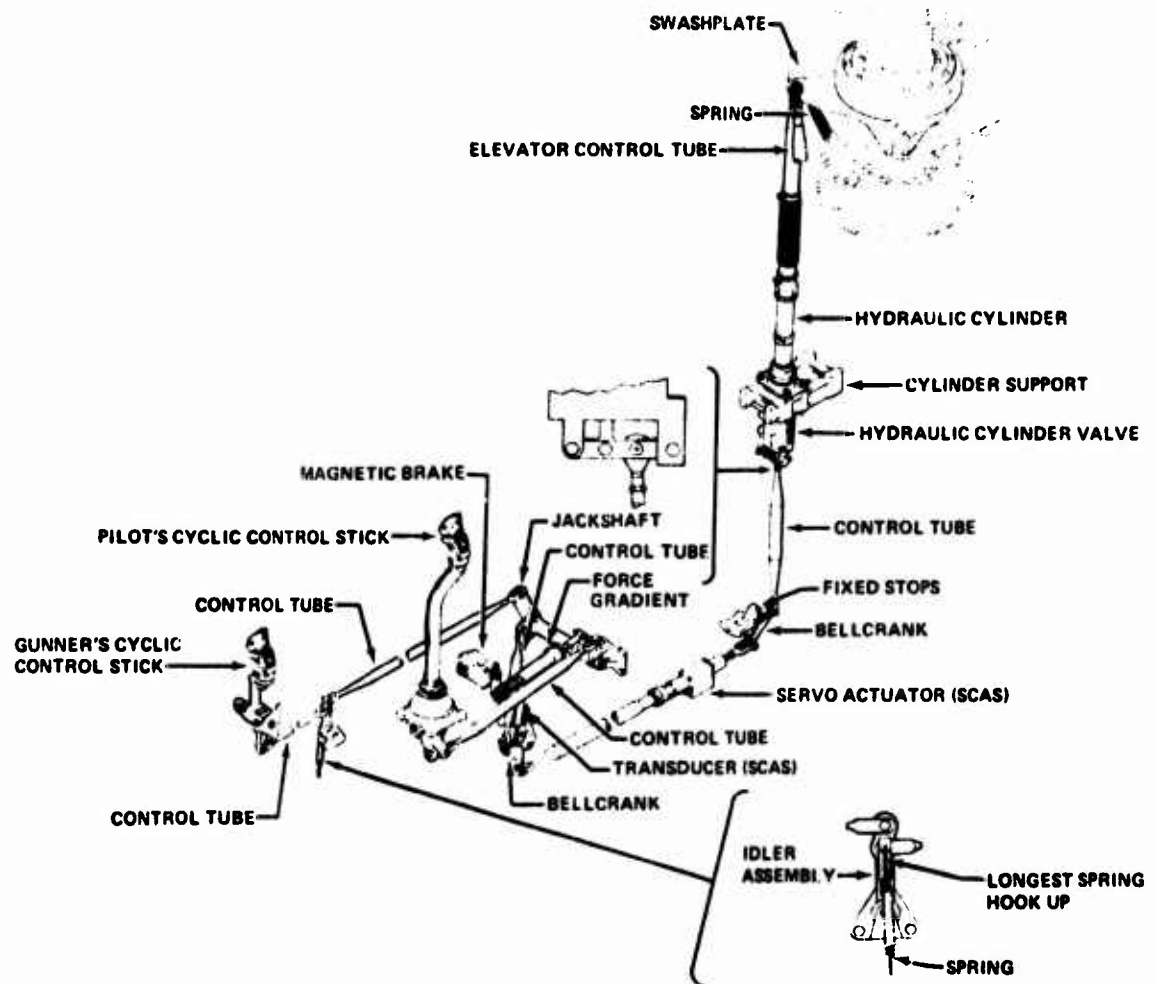


Figure A-3. Fore-and-Aft Cyclic Controls.

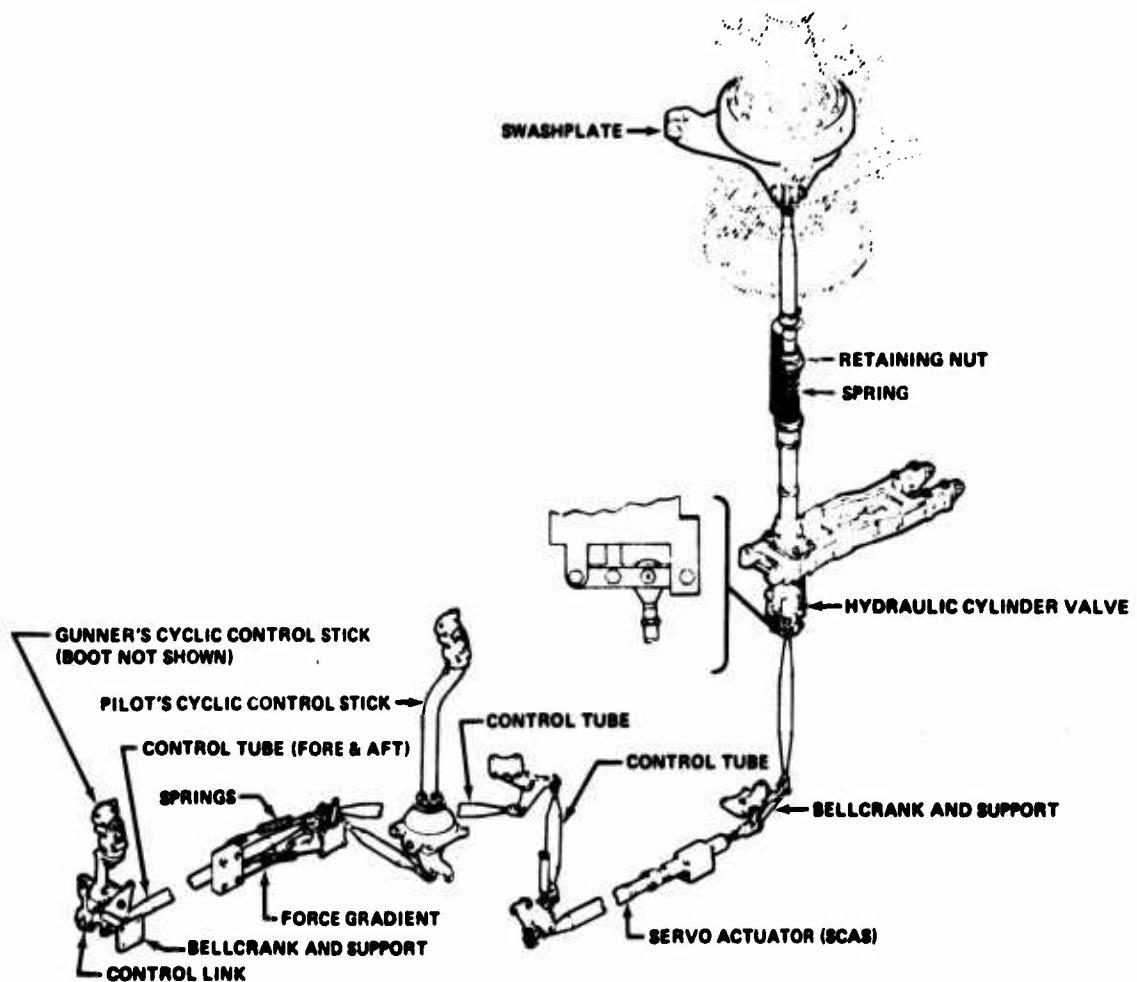


Figure A-4. Lateral Cyclic Controls.

switches on a stick assembly which is mounted through gimbal bearings in a bell-shaped support.

Gunner's Cyclic Control Stick

The cyclic control stick, mounted on the gunner's right side console, consists of a grip with control switches on a short stick, attached on a support through pivots which allow fore-and-aft and lateral movements.

Cyclic Control Force Trim

A magnetic brake and force gradient installation is used, in each of the two cyclic control systems, for stick centering and force trim functions. The brake is secured to the airframe structure and has an arm on its rotary shaft. The arm is free to move when the force trim switch on either cyclic stick is depressed. The arm can be braked and held at any point in its travel by releasing the switch. The force gradient is a link equipped with an internal spring, and connects the brake arm to a jack-shaft or bellcrank in the cyclic control system. The brake and force gradient assemblies are alike for the lateral and fore-and-aft cyclic systems.

Cyclic and Elevator Control Reliability and Maintainability

Figure A-5 represents the Cyclic Control Reliability Block Diagram and Mathematical Model. Tables A-4 through A-7 show the typical failure rate for the linkage element groups for use with Figure A-5. The predicted 1-hour flight reliability for the cyclic control installation using these typical failure rates is

$$R(1 \text{ Hr.}) = 0.999377 \\ \text{CYC}$$

Navy 3-M data reports maintenance man-hours/flight hour, based upon 34,259 flight hours through January 1973 for the AH-1G cyclic controls of MMH/FH = 0.083401. The hydraulic components contributed MMH/FH = 0.041310 to this figure.

Tail Rotor Controls (Figures A-6 and A-7)

Two sets of control pedals are provided, for pilot and gunner, with mechanical linkage extending aft along the lower right side of fuselage to a hydraulic cylinder, which is mounted just ahead of the tail boom. From the hydraulic cylinder, push-

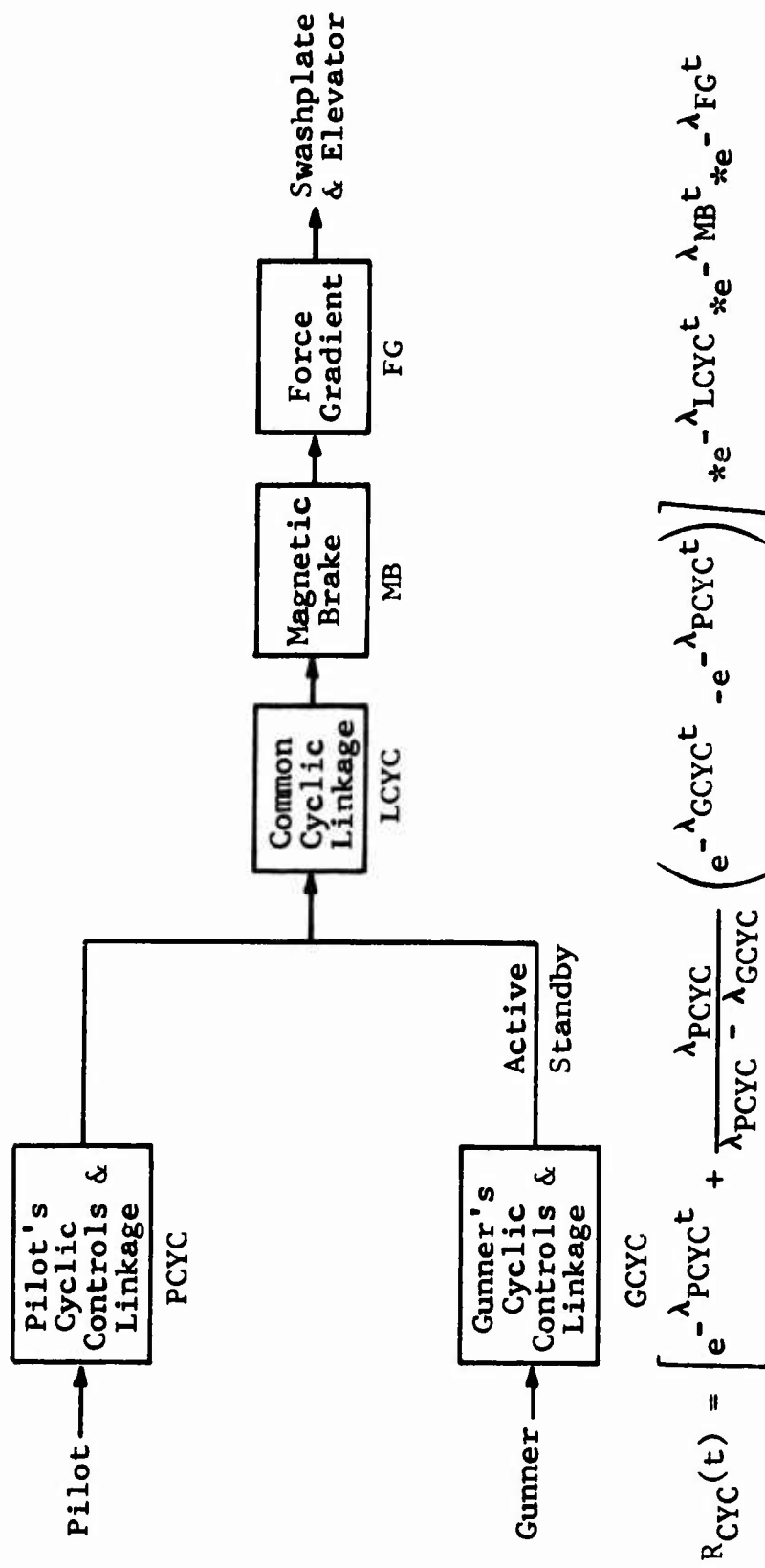


Figure A-5. AH-1G Cyclic and Elevator Control Reliability Block Diagram and Mathematical Model.

TABLE A-4. AH-1G PILOT'S CYCLIC CONTROLS AND LINKAGE - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Pilot's Cyclic Control Stick	29	1	29
Control Tubes	19	1	19
Bearings	10	2	20
$\lambda_{PCYC} = 68^*$			
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

TABLE A-5. AH-1G GUNNER'S CYCLIC CONTROLS AND LINKAGE - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Cyclic Control Stick	29	1	29
Control Tubes	19	4	76
Bearings	10	14	140
Idler	10	1	10
Bellcrank	1	1	1
Supports	1	1	1
$\lambda_{GCYC} = 257^*$			
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

TABLE A-6. AH-1G COMMON CYCLIC LINKAGE - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Jackshaft	1	1	1
Control Tubes	19	15	285
Bellcranks	1	9	9
Supports	1	8	8
Fixed Stops	10	1	10
Lift Beam	10	1	10
Guides	1	4	4
Hydraulic Valve & Cylinder	126	2	252
$\lambda_{LCYC} = 579*$			
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

TABLE A-7. AH-1G CYCLIC CONTROL COMPONENTS - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Magnetic Brake	29	1	29
Force Gradient	10	2	20
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

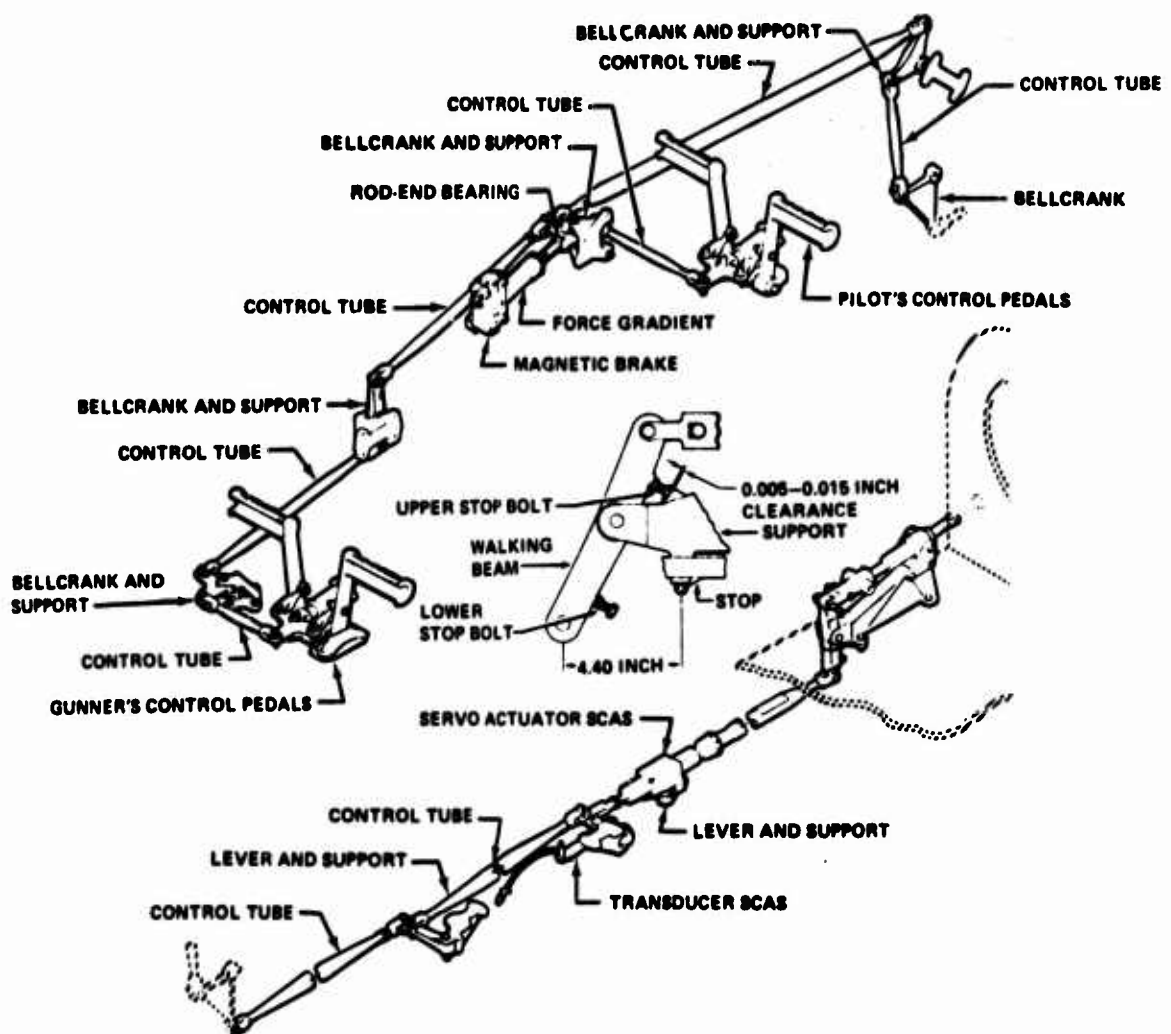


Figure A-6. Tail Rotor Controls - Forward.

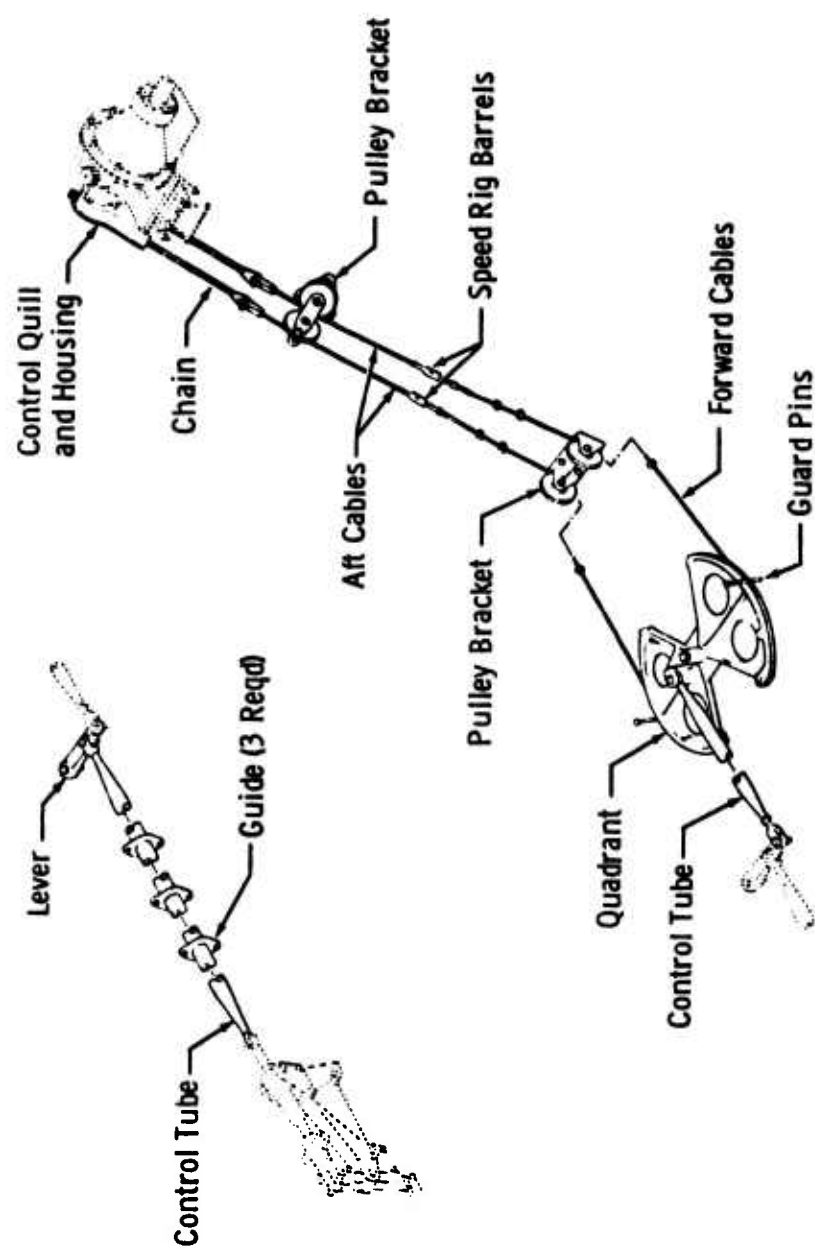


Figure A-7. Tail Rotor Controls - Aft.

pull tubes extend through the right side of the tail boom to a horizontally mounted cable quadrant. Cables from the quadrant are routed aft and up on the vertical fin to a roller chain operating over a control quill sprocket on the right side of the tail rotor 90-degree gearbox. The control quill actuates a rod within the tail rotor shaft, causing control movements of the crosshead and attached links to the tail rotor blades.

Tail Rotor Pedals

Pilot's and gunner's pedal installations are alike, each having a pair of pedals pivoted in a support attached under the floor. Pedals are connected by short links to a bellcrank mounted on an adjuster, which allows pedal settings according to the operator's reach. A protective boot covers openings around pedals.

Tail Rotor Control Force Trim

A magnetic brake and force gradient installation is used in tail rotor controls for centering and force trim functions. The brake is secured on the right main beams, and has an arm on its rotary shaft. The arm is free to move when the force trim switch on either cyclic stick is depressed. The arm can be braked and held at any point in its travel by releasing the switch. The force gradient is a link with an internal spring, and connects the brake arm to a bellcrank in the tail rotor control system.

Tail Rotor Control Cables and Quadrant

The cable quadrant is located immediately aft of the elevator mounting point, and is accessible through a door in the underside of the boom. Two sets of cables, joined by speed-ring turnbuckles, are installed through fairleads and pulleys between the quadrant and the control quill roller chain. Cables are prestretched and proof-loaded assemblies, made of corrosion-resistant steel 1/8 inch diameter, 7 x 19 cable. The forward pair are approximately 99.3 inches long, each with a ball-and-washer terminal and a threaded terminal. The aft pair are approximately 27.3 inches long, each with a speed-rig body terminal and a ball-and-fork end strap.

Tail Rotor Control Quill

Tail rotor blade pitch control is accomplished by means of a control quill mounted into the right side of the tail rotor 90-degree gearbox, with a control rod extending

through the hollow rotor shaft to a crosshead attached by links to the tail rotor blades. The control quill is actuated by the control cables through a roller chain operating over a sprocket. This rotary motion acts through worm threads to cause linear movement of the control tube, crosshead and pitch change links. The chain and sprocket are protected by a guard, and enclosed in a metal housing pan with a removable cover.

Directional Control Reliability and Maintainability

Figure A-8 represents the Directional Control Reliability Block Diagram and Mathematical Model. Tables A-8 through A-11 show the typical unscheduled maintenance failure rates for the linkage element groups for use with Figure A-8. The predicted 2-hour flight reliability for the directional control installation using these typical rates is

$$R(1 \text{ Hr.}) = 0.996536.$$

DIR

Navy 3-M data reports maintenance man-hours/flight hour, based upon 34,259 flight hours through January 1973, for the AH-1G directional controls of MMH/FH = 0.009919.

Elevator Controls

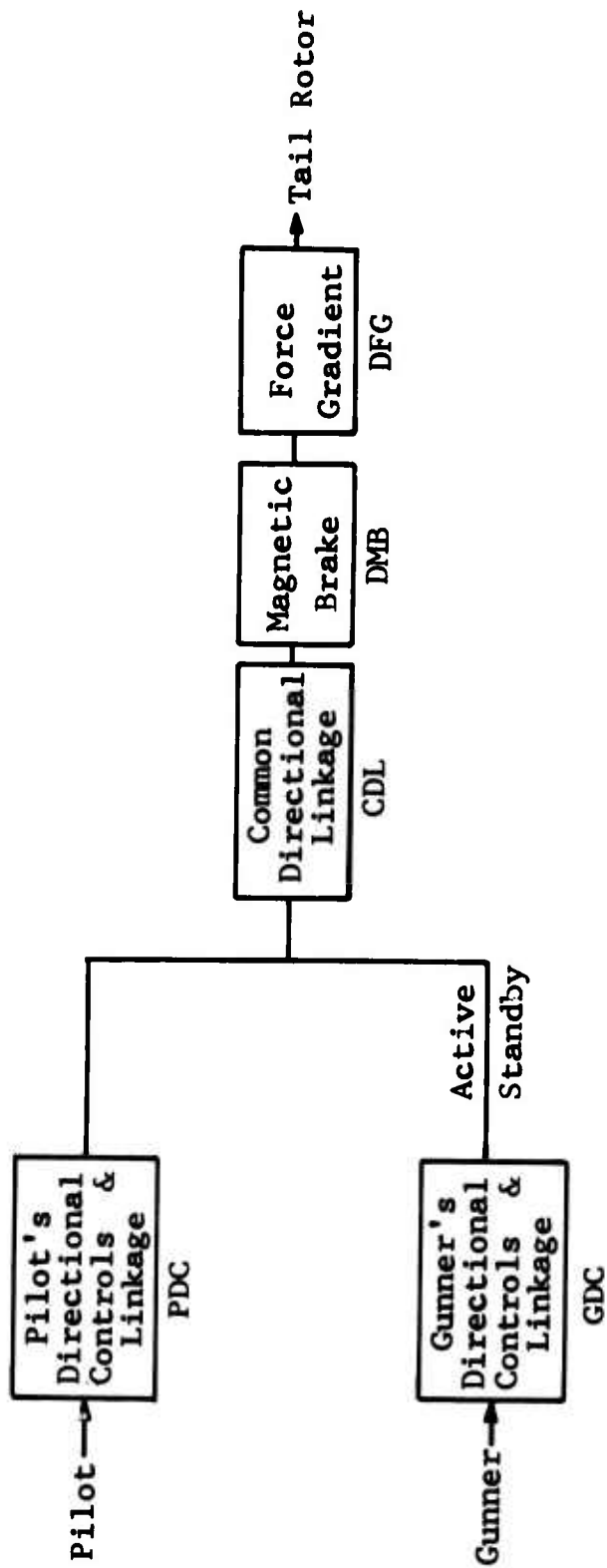
The elevator, Figure A-9, is actuated by movements of the fore-and-aft cyclic controls, through a series of control tubes and bellcranks between the elevator control horn in the tail boom and the right forward horn of the swashplate. Reliability for elevator controls is considered integral with fore-and-aft cyclic controls in Figures A-3 and A-5.

The AH-1G Stability and Control Augmentation System (SCAS)

This is described as a three-axis stability and control augmentation system, integrated into the conventional helicopter fore-and-aft, lateral and directional flight controls. SCAS provides a highly damped airframe for external disturbances and maintains high quality flight handling characteristics.

The Cobra possesses many of the UH-1 features but has added new and improved designs, among which are a stable weapons delivery platform, increased speed, increased armor and increased and improved armament capabilities.

One of the primary requirements for an Armed Aerial Fire Support Weapons System is a stable weapons delivery platform. The development of SCAS for the AH-1G centered around providing this capability.



$$R_{DIR}(t) = \left[e^{-\lambda_{PDC}t} + \frac{\lambda_{PDC}}{\lambda_{PDC} + \lambda_{GDC}} \left(e^{-\lambda_{GDC}t} - e^{-\lambda_{PDC}t} \right) \right] * e^{-\lambda_{COL}t} * e^{-\lambda_{DMB}t} * e^{-\lambda_{DFG}t}$$

Figure A-8. AH-1G Directional Control Reliability Block Diagram and Mathematical Model.

TABLE A-8. AH-1G PILOTS DIRECTIONAL CONTROLS AND LINKAGE - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Pedals	50	2	100
Control Tube	19	1	1
Bellcrank	1	1	1
Support	10	2	20
Bearings	10	9	90
			$\lambda_{PDC} = 212^*$
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

TABLE A-9. AH-1G GUNNER'S DIRECTIONAL CONTROLS AND LINKAGE - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Pedals	50	2	100
Control Tubes	19	3	57
Bellcranks	1	2	2
Supports	10	3	30
Bearings	10	12	120
			$\lambda_{GDC} = 309^*$
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

TABLE A-10. AH-1G COMMON DIRECTIONAL LINKAGE - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Control Tubes	19	7	133
Bellcranks	1	2	2
Supports	10	3	30
Lever	1	3	3
Guides	1	3	3
Quadrant	50	1	50
Cables	585	4	2340
Pulleys	50	4	200
Brackets	10	2	20
Chain	586	1	586
Control Quill & Housing	58	1	58
$\lambda_{CDL} = 3425*$			
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

TABLE A-11. AH-1G DIRECTIONAL COMPONENTS - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Magnetic Brake	29	1	29
Force Gradient	10	1	10
* Failure Rate per 1,000,000 flight hours BHC M&R Data (All Maintenance Levels)			

Airframe movement and attitude changes that result from weapons firing or recoil, or from wind gust conditions, are dampened to give the helicopter the needed stability to become a weapons delivery platform.

The stability system retains positive high-quality flight control response characteristics or flight handling characteristics for pilot inputs to the flight control system. In other words, the pilot has the capability of "flying" the helicopter at all times, without working against the stability system.

The SCAS components consist of two circuit breakers for protection and power, a control panel, the sensor amplifier unit containing three rate gyros, three electrohydraulic servo actuators containing a servo valve, three control motion transducers, three solenoid-controlled hydraulic valves and the associated electrical network.

The control panel provides the pilot operational control of SCAS. The sensor-amplified unit is operationally the center of SCAS. The servo valves are positioned by electrical signals to port hydraulic pressure to extend or retract the three servo actuators. The control motion transducers sense pilot control input to feed in an electrical signal to SCAS. The solenoid valves are energized open to furnish airframe hydraulic power to operate actuators.

Rate gyros provide the electrical signals for airframe dampening against external disturbances. Control motion transducers provide a compensating electrical signal during pilot control inputs to prevent the SCAS from opposing the pilot's inputs.

A pylon compensator unit is located aft and above the sensor amplifier unit, and two pylon transducers are mounted on the transmission for retardation of pylon oscillation. Pylon position information is provided by the transducers to the compensator unit, which in turn uses the pitch pylon motion to apply corrective signals into the roll channel.

The two transducers that were installed on the pylon have been changed to a single transducer mounted between the fifth mount and the tail rotor drive shaft quill. This provides pitch motion but does not sense roll, and eliminates one transducer and still provides the pylon position information.

SCAS Reliability and Maintainability

Table A-12 represents typical failure rates for the element groups which compose the SCAS. These groups, for

TABLE A-12. AH-1G SCAS - FAILURE RATES			
Component	Failure Rate * Per Component	Quantity	Failure Rate Per Group
Control Panel	175	1	175
Sensor Amplifier Unit	2244	1	2244
Control Motion Transducer	75	3	225
Electrohydraulic Actuator	60	3	18
Electric Solenoid Valve	10	3	30
Pylon Compensation Unit	145	1	145
Pylon Motion Transducer	75	1	75
TOTAL SCAS		$\lambda_{SCAS} = 3481^*$	
* Failure Rate per 1,000,000 flight hours Navy 3-M Data			

the purpose of estimating reliability, may be considered in series. The predicted 1-hour flight reliability for the SCAS installation would then be

$$R(1 \text{ Hr.}) = 0.996519.$$

SCAS

Navy 3-M data reports maintenance man-hours/flight hour, based upon 34,259 flight hours through January 1973 for the AH-1G SCAS of MMH/FH = 0.012362.

AH-1G Flight Control System Reliability and Maintainability

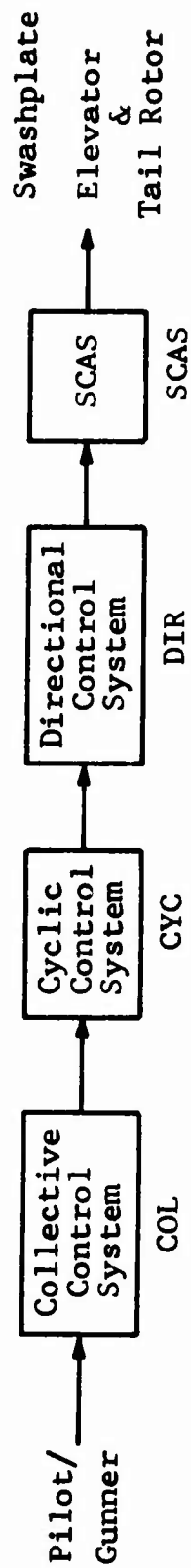
Figure A-10 represents the AH-1G Flight Control System Reliability Block Diagram and Mathematical Model. Using the reliabilities calculated for each of the subsystems in Figures A-1 through A-10 and Tables A-1 through A-10, the

$$R(1 \text{ Hr.}) = .992165.$$

AH-1G

This estimate is based upon all unscheduled maintenance-type failures and includes defects which may be classified major and minor not requiring mission abort or causing hazard levels III or IV.

Navy 3-M data reports maintenance man-hours/flight hour, based upon 34,259 flight hours through January 1973, for the AH-1G flight control system of MMH/FH = 0.183231.



$$R_{FCS}^{AH-1G}(t) = R_{COL}(t) * R_{CYC}(t) * R_{DIR}(t) * R_{SCAS}(t)$$

Figure A-10. AH-1G Flight Control System Mission Reliability Block Diagram and Mathematical Model.

APPENDIX B

SPECIFICATION REVIEW CHANGE RECOMMENDATIONS -
SYSTEM

Recommended changes to the following specifications are available from the Defense Documentation Center. When requesting information from DDC, the title "Supplement to Appendix B, USAAMRDL TR 74-57" and accession number "AD A009151 " should be cited.

- MIL-C-18244 - Control and Stabilization Systems:
Automatic Piloted Aircraft, General
Specification for
- MIL-H-8501 - Helicopter Flying Qualities,
Requirements for
- MIL-E-5400 - Electronic Equipment Aircraft,
General Specification for

MIL-F-9490C(USAF)
Amendment 1
9 March 1966

MIL-F-9490C
13 March 1964

COMMENTS TO
MILITARY SPECIFICATION
FLIGHT CONTROL SYSTEMS - DESIGN, INSTALLATION
AND TEST OF, PILOTED AIRCRAFT,
GENERAL SPECIFICATION FOR

1. SCOPE

1.1 Scope - This specification covers the general requirements for the design, installation and test of the operating mechanism of all flight control systems for all ^{military} ~~V/S/X~~ ~~For~~ piloted aircraft. In the event of conflict between this specification and other referenced documents, the requirements of this specification shall govern.

1.2 Classification - The flight control systems shall include the following:

1.2.1 Primary Flight Control Systems - These are used for controlling the aircraft flight path by means of the primary flight control surfaces, helicopter rotor blades and tail rotor, reaction controls, engine orientation or thrust deflection controls, etc. (The systems shall be defined as including all components of the system required to provide the above functions ~~and/including/the/actuating means,/but/not/including/the/control/surfaces/or/corresponding/devices/~~ in order to control the flight path of an aircraft in completing a flight or mission successfully, and including actuation means, but not including control surfaces or corresponding devices. The controls for the actuation of the primary flight control system may be of the following types: (Any type system not in these classifications shall be discussed with the procuring activity during the preliminary stages.)

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Type I - Mechanical Flight Control System - A reversible control system wherein the pilot actuates the primary control surface or corresponding devices of the aircraft through a set of mechanical linkages consisting of cables, pulleys, sectors, or push-pull or torque tubes with horns, bell-cranks, etc.

Type II - Power Boosted Flight Control System - A reversible control system wherein the pilot effort, which is exerted through a set of mechanical linkage, is at some point in these linkages boosted by a power source.

Type III - Power Operated Flight Control System - An irreversible control system wherein the pilot, through a set of mechanical linkages or other means, actuates a power control package which actuates the main control surfaces or corresponding devices.

Rationale:

The successful completion of a mission on a functional basis can be viewed as the criteria for reliability estimates, rather than just successful flight (no loss of aircraft), and on a mission basis, the level of complexity of the control system increases over the level necessary for a safe flight completion. For example, the feel system may be necessary from a mission standpoint, but not safety of flight.

1.2.2 Secondary Flight Control Systems - These include all controls which are used to supplement the primary flight control system, but which are not included in the primary flight control system. Systems such as trim, flaps, drive recovery devices and brakes may be secondary flight control systems. No system shall be so categorized until analysis demonstrates that lack of performance or malfunction will not affect safety of flight.

1.2.3 Automatic Flight Control Systems - These systems are used to automatically augment or control, or both, the stability, handling characteristics, and flight path of an aircraft. These systems may be categorized as part of the primary or secondary systems, depending on their function in relation to successful completion of the mission and/or safety of flight.

Rationale:

AFCS systems may be required for mission completion.

1.2.4 Classification of the operational state of the aircraft and the control systems is as follows:

Operational State I - Normal operation with respect to mission completion and flight safety. In this state, the aircraft satisfies MIL-F-8785 and/or MIL-F-83300 Level I flying quality requirements.

Operational State II - Limited operation which results

in an increase crew workload, reduction of safety and/or mission effectiveness. However, the mission can be completed. This state satisfies as a minimum MIL-F-8785 or MIL-F-83300 Level 2 flying qualities.

Operational State III - Minimum safe operation with degraded performance which prevents successful mission completion but allows safe completion of flight. This state satisfies at least MIL-F-8785 and/or MIL-F-83300 level 3 flying qualities.

Operational State IV - Controllable to an immediate emergency landing.

Operational State V - Controllable to an evacuable flight condition - limited flight control operation to reach a flight condition where crew evacuation can be accomplished.

Rationale:

To carry out a reliability failure mode analysis, the operational condition of the flight control systems need to be identified in relation to the aircraft flying capability.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

FF-B-185 Bearings, Roller, Cylindrical, and
Bearings, Roller, Self-Aligning

Military

MIL-C-172	Cases, Bases, Mounting, and Mounts, Vibration (for use with Electronic Equipment in Aircraft)
MIL-F-3541	Fittings, Lubrication
MIL-S-3950	Switches, Toggle
MIL-U-3963	Universal Joint, Antifriction Bearings
MIL-B-3990	Bearings, Roller, Needle, Airframe Antifriction
MIL-E-4682	Electron Tubes and Transistors, Choice and Application of
MIL-W-5088	Wiring, Aircraft, Installation of
MIL-E-5400	Electronic Equipment, Aircraft, General Specification for
MIL-C-5424	Cable, Steel (Corrosion-Resisting), Flexible, Preformed (for Aeronautical Use)
MIL-H-5440	Hydraulic Systems, Aircraft Types I and II, Design, Installation, and Data Requirements of
MIL-C-5503	Cylinders, Aeronautical, Hydraulic Actuating, General Requirements for
MIL-P-5518	Pneumatic Systems, Aircraft, Design, Installation and Data Requirements for
MIL-B-5628	Bearings, Plain, Airframe
MIL-B-5629	Bearings, Rod End, Plain, Airframe
MTL-S-5676	Splicing, Cable Terminal, Process for, Aircraft
~~MIL-B-5683~~	~~Terminals, Cable, Threaded Cable, Type, Aircraft~~

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MIL-T-5684 ~~MIL-T-5685~~	Tie Rods, Streamline, Round and Square, Aircraft ~~Turnbuckles, Aircraft~~
MIL-B-5687	Bearings, Sleeve, Washers, Thrust, Sintered, Metal Powder, Oil-Impregnated
MIL-C-5688	Cable Assemblies, Aircraft, Proof Testing and Prestretching of
MIL-C-6021	Castings, Classification and Inspection of (for Aeronautical Applications)
MIL-B-6038	Bearings, Ball, Bellcrank, Anti-Friction, Airframe
MIL-B-6039	Bearings, Ball, Rod End, Antifriction, Self-Aligning
MIL-E-6051	Electrical-Electronic System Compatibility and Interference Control Requirements for Aeronautical Weapon Systems
MIL-T-6117	Terminal-Cable Assemblies, Swaged Type
MIL-J-6193	Joints, Universal, Plain, Light and Heavy Duty
MIL-S-6743	Switches, Push Button and Limit
MIL-C-6781	Control Panel, Aircraft Equipment, Rack or Console Mounted
~~MIL-L-6980~~	~~Classification of Aircraft, General Specification of~~
MIL-P-7034	Pulleys, Groove, Antifriction-Bearing, Grease-Lubricated, Aircraft
MIL-I-7064	Indicator, Position, Elevator Trim Tab
MIL-E-7080	Electric Equipment, Piloted Aircraft Installation and Selection of, General Specification for
MIL-F-7190	Forgings, Steel, for Aircraft and Special Ordnance Applications
MIL-V-7915	Valves, Hydraulic, Directional Control, Slide Selector
MIL-B-7949	Bearing, Ball, Airframe, Antifriction
MIL-C-7958	Controls, Push-Pull Flexible and Rigid

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MIL-M-7969	Motors, Alternating Current, 400-Cycle, 115/200-Volt System, Aircraft, Class A and Class B, General Specification for
MIL-A-8064	Actuators and Actuating Systems, Aircraft, Electro-Mechanical, General Requirements for
MIL-I-8500	Interchangeability and Replaceability of Component Parts for Aircraft and Missiles
MIL-H-8501	Helicopter Flying and Ground Handling Qualities, General Requirements for
MIL-S-8512	Support Equipment, Aeronautical, Special, General Specification for the Design of
MIL-B-8584	Brake Systems, Wheel, Aircraft, Design of
MIL-M-8609	Motors, Direct-Current, 28-Volt System, Aircraft, Class A and B, General Specification for
MIL-S-8698	Structural Design Requirements, Helicopters
MIL-I-8700	Installation and Test of Electronic Equipment in Aircraft, General Specification for
MIL-F-8785	Flying Qualities of Piloted Airplanes
MIL-A-8860	Airplane Strength and Rigidity, General Specification for
MIL-A-8861	Airplane Strength and Rigidity Flight Loads
MIL-A-8865	Airplane Strength and Rigidity Miscellaneous Loads
MIL-A-8866	Airplane Strength and Rigidity Reliability Requirements, Repeated Loads, and Fatigue
MIL-A-8870	Airplane Strength and Rigidity Vibration, Flutter, and Divergence
<u>MIL-T-8878</u>	<u>Turnbuckle, Positive Safetying</u>
MIL-S-9419	Switch, Toggle, Momentary, Four-Position on, Center off
<u>MIL-C-18244</u>	<u>Control and Stabilization Systems</u> <u>Automatic Piloted Aircraft</u>
MIL-C-18375	Cable, Steel (Corrosion-Resisting, Non-Magnetic,) Flexible, Preformed (for Aeronautical Use)

MIL-F-9490C(USAF)

MIL-S-19500	Semiconductor Devices, General Specification for
MIL-N-25027	Nut, Self-Locking, 250 Deg. F., 450 Deg. F., and 800 Deg. F.
MIL-L-25142	Luminescent Material, Fluorescent
MIL-E-25499	Electrical Systems, Aircraft, Design of, General Specification for
MIL-G-25561	Grip Assembly, Controller, Aircraft, Type MC-2
MIL-P-26292	Pitot and Static Pressure Systems, Installation and Inspection of
MIL-I-26600	Interference Control Requirements, Aeronautical Equipment
MIL-V-27162	Valves, Servo Control, Electro-Hydraulic, General Specification for
~~MIL-R-26667~~	~~Reliability and Longevity Requirements, Electronic Equipment, General Specification for~~
<u>MIL-F-83300</u>	<u>Flying Qualities of Piloted V/STOL Aircraft</u>

STANDARDS

Military

<u>MIL-STD-105</u>	<u>Sampling Procedures and Tables for Inspection by Attributes</u>
MIL-STD-130	Identification Marking of U. S. Military Property
MIL-STD-203	Cockpit Controls; Location and Actuation of, for Fixed Wing Aircraft
MIL-STD-250	Cockpit Controls; Location and Actuation of, for Helicopters
<u>MIL-STD-414</u>	<u>Sampling Procedures and Tables for Inspection by Variables for Percent Defective</u>
<u>MIL-STD-470</u>	<u>Maintainability Program Requirements (For Systems and Equipment)</u>
<u>MIL-STD-471</u>	<u>Maintainability Demonstration</u>
<u>MIL-STD-704</u>	<u>Electric Power, Aircraft, Characteristics and Utilization of</u>
<u>MIL-STD-781B</u>	<u>Reliability Tests, Exponential Distribution</u>
<u>Change I</u>	
<u>MIL-STD-785</u>	<u>Requirements for Reliability Program</u>
MIL-STD-810	Environmental Test Methods for Aerospace and Ground Equipment

STANDARDS

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Military (Cont)

<u>MIL-STD-831</u>	<u>Test Reports, Preparation of</u>
<u>MIL-STD-838</u>	<u>Lubrication of Military</u>
	<u>Equipment</u>
<u>MIL-STD-1304A</u>	<u>Reliability Report</u>
<u>MS15001</u>	<u>Fittings, Lubrication (Hydraulic)</u>
	<u>Surface Check, 1/4-28 Taper</u>
	<u>Threads, Steel, Type 1</u>
MS15002	<u>Fittings, Lubrication (Hydraulic)</u>
	<u>Surface Check, Straight Threads,</u>
	<u>Steel, Type II</u>
MS25128	<u>Switches, Toggle, Single Pole,</u>
	<u>4 Position Three-Hole Mounting</u>
MS26534	<u>Chain, Roller, Aircraft</u>
MS33540	<u>Safety Wiring, General Practices</u>
	<u>for</u>
MS33547	<u>Pins, Spring, Functional</u>
	<u>Limitations of</u>
MS33558	<u>Numerals and Letters, Aircraft</u>
	<u>Instrument Dial, Standard Form of</u>
MS33572	<u>Instrument, Pilot, Flight, Basic,</u>
	<u>Standard Arrangement for</u>
	<u>Helicopters</u>
MS33574	<u>Dimensions, Basic, Cockpit, Stick-</u>
	<u>Controlled, Fixed Wing Aircraft</u>
MS33575	<u>Dimensions, Basic, Cockpit,</u>
	<u>Helicopter</u>
MS33576	<u>Dimensions, Basic, Cockpit, Wheel</u>
	<u>Controlled, Fixed Wing Aircraft</u>
MS33588	<u>Nuts and Plate Nuts, Self-Locking,</u>
	<u>Aircraft, Design and Usage</u>
	<u>Limitations of</u>
MS33591	<u>Turnbuckles, Lock Wiring of</u>

PUBLICATIONS

<u>Air Force System Handbook of Instructions for</u>	
<u>Command Manual BO-1 Aircraft Designers</u>	
<u>MIL-HDBK-472</u>	<u>Maintainability Prediction</u>
<u>AR-56</u>	<u>Structural Design Requirements</u>
	<u>for Service Helicopters</u>
<u>AFSC DH 1-2</u>	<u>General Design Factors Air Force</u>
	<u>Systems Command Design Handbook</u>
<u>AFSC DH 1-4</u>	<u>Electromagnetic Compatibility</u>
<u>AFSC DH 1-5</u>	<u>Environmental Engineering</u>
<u>AFSC DH 1-6</u>	<u>System Safety</u>
<u>AFSC DH 2-1</u>	<u>Airframe</u>
<u>AFSC DH 2-2</u>	<u>Crew Station & Passenger</u>
	<u>Accommodations</u>

PUBLICATIONS

DH 2-1

NAS 1638

Design Handbook Series 2-0,
Aeronautical Systems, Airframe
Cleanliness Requirements of
parts used in Hydraulic systems

(Copies of specifications, standards, and drawings required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other Publications - The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or requests for proposal shall apply.

NATIONAL AIRCRAFT STANDARDS:

NAS 509

Nut, Drilled Jam

NAS 513

Washer, Rod End Locking

(Copies of National Aircraft Standards may be obtained from the Aircraft Industries Association of America, Inc., Shoreham Building, Washington, D. C.)

3. REQUIREMENTS

3.1 System Design Requirements - Flight control systems shall be the most simple, direct and foolproof possible with respect to the design, operation, inspection, and maintenance. Early in the design of the airplane, careful consideration shall be given to the overall system design of the control system in view of type aircraft concerned and the mission which the aircraft is to perform. A mean time between failure (MTBF) shall be assigned to the flight control system, which will meet the reliability requirements of the weapon system. A MTBF shall be assigned to each individual subsystem and component within the overall system in order to yield an effective or overall system MTBF equal to or better than that required. In assigning subsystem MTBF's, consideration shall be given to the relative importance of the function being performed to the mission and safety of the aircraft. MTBF requirements may, therefore, vary for the various subsystems depending on their utilization, complexity and alternate modes of operation. Unless otherwise noted in the detail specification, the required MTBF shall have a confidence level of at least 0.9.

A MTBF will be assigned for progression through each operational state of the flight control systems.

Rationale:

To establish mission reliability and safety of flight reliability, the MTBF time to each operational state must be defined.

3.1.1 Primary Flight Controls - Wherever the magnitude and linearity of hinge moments permit, and there is no requirement for irreversibility or power controls, direct mechanical control shall be used. Otherwise, boosted or powered controls shall be used, depending upon the requirements for irreversibility. *In general, irreversibility is required when nonlinearities of aerodynamic hinge moments require masking by an artificial feel system, when hinge moments may be so large that an impractical boost ratio would be necessary, or when dynamic flutter conditions dictate that the control surfaces be rigidly held in their proper positions.*

Rationale:

Power control and/or irreversibility requirements are too broad to limit to the stated conditions. For a given control system function, restriction to limitations may actually decrease reliability when using mechanical controls as opposed to boosted or powered controls for a particular mission.

3.1.1.1.1.1. Power/Operated/and/Power/Boosted/Systems/-/Power
 for/these/systems/shall/be/supplied/by/hydraulic/electric/
 mechanical/or/pneumatic/means//Whenever/power/is/required
 for/flight/controls/a/completely/separate/integral/and
 adequate/power/system/shall/be/provided/to/supply/only/the
 primary/flight/controls//This/power/system/shall/not/be
 used/to/supply/any/other/system/or/component/in/the/air-
 plane/unless/approval/is/obtained/from/the/procur-ing
 activity//In/the/case/of/an/electrical/power/system/the
 separation/requirement/is/waived/provided/adequate/means
 are/included/in/the/electrical/system/to/isolate/any
 faults/in/related/equipment/which/could/result/or
 impair/flight/control/capability/

Rationale:

The necessity of non-shared power systems is directly determined by the MTBF requirements. Incorporating separate supplies without MTBF requirement is adversely affecting maintainability. Final specification shall require paragraph renumbering.

3.1.1.1.1.2. Power/System/Failure/-/Following/a/failure/of
 the/primary/flight/control/power/system/control/shall/be
 adequate/to/meet/the/emergency/control/requirement/of
 MIL-F-8783, and/other/changes/shall/be/within/the/allowable
 values/specified/herein.

3.1.1.1.1 Power System Failure - The effect of failures of the primary flight control power systems shall be specified in terms of the number and types of failures and the corresponding operational states of the flight control system, based upon the mission and safety of flight reliability requirements specified for the aircraft.

Rationale:

Specification in terms of the aircraft requirements rather than arbitrary failure effects allows more efficient design and improved maintainability.

3.1.1.1.1.1 Type I and Type III Single Power Control System Power Failure - A single power system may be employed providing an emergency manual primary flight control system, or an emergency flight control power system, is available. When a failure occurs in a single power system, it shall be possible to operate the flight controls through mechanical linkage to obtain aircraft controllability within the minimum requirements of MIL-F-8785. Where a mechanical advantage change device is used, no hazardous lags or transients shall occur during the change over. If an emergency manual primary flight control system is not available, an emergency source of power, supplying only the primary flight control system, shall be provided to meet these requirements. The means of engaging the

emergency/power/system/may/be/either/manual/or/automatic;
however, it/should/be/the/simplest/and/most/reliable
possible,/consistent/with/actual/requirements.//Manual
engagement/is/preferred,/when/suitable.//If/the/airplane
is/single/engine,/the/emergency/source/may/be/independent
of/the/operation/of/this/engine.//On/multi-engine
airplanes,/the/emergency/power/source/should/at/least
be/on/a/different/engine/than/the/primary/source.//In
some/cases,/it/is/possible/to/utilize/the/utility
power/system/as/the/emergency/source/of/power/if/it/is
accomplished/in/such/a-way/that/there/is/no/interconnection
with/the/flight/control/power/system/and/no/single/failure
can/cause/loss/of/both/systems.//Consideration/shall/be
given/to/the/possibility/of/out-of-fuel/landings/wherein
none/of/the/engines/are/operating.//Inasmuch/as/some
turboprop/engines/will/not/windmill/enough/to/provide
adequate/flight/control/power/supply/during/landing,/it/may
be/necessary/to/provide/emergency/power/sources/not
dependent/upon/engine/operation.//In/aircraft/which/are
susceptible/to/out-of-fuel/landings,/this/condition/shall
not/be/considered/an/emergency/and/provisions/may/be
made/for/landings/with/one/of/the/power/systems/failed
while/out-of-fuel.//When/designing/for/this/condition,
extreme/care/may/be/exercised/to/not/reduce/the/reliability
of/the/power/systems.//It/shall/always/be/possible/to/re-
engage/the/flight/controls/or/return/them/to/normal
following/operation/on/the/emergency/system.

|Rationale: Covered by 3.1.1.1.1|

3.1.1.1.1.2 //Type III/Dual/Power/Control/System/Failure/
When/one/system/of/a/dual/system/fails,/the/performance
of/the/aircraft,/with/a/single/system/in/operation,/shall
meet/the/emergency/requirements/of/MIL-F-8783/

Rationale:

Covered by 3.1.1.1.1

3.1.1.1.2 Power System Checkout - The power system shall include provisions for checking emergency operation of the flight control systems, during flight, and during ground operation. For checkout purposes, where ^{redundant} ~~dual~~ power systems are used, the design shall permit only one system to be turned off at a time. This requirement does not apply to power systems using manual reversion for emergency operation.

Rationale:

Where reliability requirements dictate more than two power systems, word "dual" does not apply.

3.1.1.1.3 Pilot Warning Systems - Pilot warning systems shall be installed to indicate the operating condition of the control systems.

3.1.1.1.4 Control Device Actuators - In the case of control device actuators which are essential to flight of the aircraft, ~~the/actuators/shall/be/duplicated/to~~ ~~provide/protection/against/failures//Where/dual~~ ~~actuators/are/used,/the/control/valves/shall/also/be/~~

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duplicated to maintain maximum reliability. If tandem hydraulic or pneumatic cylinders are used, dual O-rings shall be provided between the two portions with a vent between the O-rings (where loss of the control actuator results in possible loss of the aircraft), actuator redundancy techniques consistent with the MTBF and operational states required for the aircraft shall be used to insure satisfactory reliability.

Rationale:

The duplication of control components on an arbitrary basis without direct correlation with the reliability requirements of the aircraft adversely effects maintainability.

3.1.1.1.5 Flight Control Hydraulic Systems - In all cases, except as noted herein, hydraulic systems shall conform to MIL-H-5440.

3.1.1.1.6 Flight Control Pneumatic Systems - In all cases, except as noted herein, pneumatic systems shall conform to MIL-P-5518.

3.1.1.1.7 Power Control Override Provisions - For Type II or Type III primary control systems which incorporate mechanical control system linkage from the pilot to the control actuator, provisions shall be made to permit direct pilot effort to be applied to a control valve in

the event the valve becomes jammed or frozen. In other words, any spring or load relieving device between the pilot and the valve, which is designed to prevent excessive loads being applied to the valve, shall become a solid link.

efforts to the control valve which will allow applying a force 2 times that sufficient to shear the largest piece of hardened music wire the control valve will accept through its control ports. The pilot shall be able to apply this force before full pilot control travel is reached.

Rationale:

Without a stated limit to the pilot effort to be applied, linkage design reliability cannot be established.

3.1.1.1.8 Flight Control Electrical Systems - In all cases, except as noted herein, electrical systems shall conform to MIL-E-25499. The following requirements also apply:

a. Any electronic subsystem or equipment which utilize low level signals below one volt shall be designed for a single point weapon system ground and the signal circuits between components shall utilize shielded twisted pairs.

b. The system shall have a maximum unattenuated response of 20 cycles per second either side of the reference frequency. Signals at double and one-half the reference frequency shall be attenuated by a factor of 100 (40db). The response to signals on all leads other than the input shall be a maximum of 1/1,000 (60db down) of the amplifiers response to the reference frequency when applied to the input terminals.

c. The flight control system shall be capable of operating without objectionable characteristics in a RF field with the following characteristics:

- (1) A strength of 20 volts/meter (.1 milliwatts/ CM^2).
- (2) A frequency from 2 to 30 megacycles.
- (3) A modulation of at least 30%.

(4) Modulation frequencies within two cycles per second of the servo system reference frequency.

3.1.1.2 Control System Duplication - In general, any aircraft which may carry a large number of passengers, is used primarily for training purposes, will be subjected to damage from enemy fire, weighs over 7,500 pounds, or has a critical mission which requires maximum reliability, will have all flight control systems duplicated to the maximum practicable degree. The level of redundancy for the flight control system will be selected to meet the reliability and survivability

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requirements specified for the particular aircraft.
However, as a minimum, redundancy will be provided
for the following levels of flight control system
criticality:

<u>Critical Class A</u>	<u>Fail-Operational</u>
<u>Critical Class B</u>	<u>Fail-Safe</u>
<u>Critical Class C</u>	<u>Fail-Passive</u>

Where: Critical Class A applies to control functions
whose loss reduces the control of the aircraft
below Operational State III

Critical Class B applies to control functions
whose loss can reduce the control of the air-
craft to State III but no lower.

Critical Class C applies to control functions
whose loss can reduce the control of the air-
craft to State II but no lower.

Fail-Operational implies continued operation
after any single probable failure with no change
of operational state of the flight control system.

Fail-Safe implies failure to an output condi-
tion which does not actively affect control of
the aircraft and the simultaneous application
of limits to protect against prohibited maneu-
vers.

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Fail-Passive implies failure to an output condition which does not actively affect control of the aircraft.

In transferring from one control system operating condition to another, the transfer effect on the structural loading of the aircraft and the aircraft's attitude and altitude shall not cause a safety of flight hazard anywhere in the normal flight envelope of the aircraft.

To provide for survivability of the aircraft with onboard failures, the flight control system shall have sufficient redundancy to maintain at least State III operational capability after:

1. A single engine failure for 2 engine aircraft and two engine engine failure for 3 or more engine aircraft.
2. Failure of any single equipment item or structural member which by itself does not cause degradation below State III.
3. Failures of equipment caused by probable weapons impact as specified in the system performance specification.

In addition, the flight control system shall have sufficient redundancy to maintain State IV operational capability after:

1. Failure of all engines
2. Failures of equipment caused by probable weapons impact as specified in the system performance specification.

Rationale:

Until greater commonality of flight control components and confidence in the MTBF values for the components exists, general minimum levels of redundancy are required to prevent catastrophic loss with critical control system failures.

Design of the control system redundancy has to meet the flight safety requirements. This affects reliability and maintainability.

Survivability requires minimum redundancy levels not associated directly with the MTBF of the control system. The survivability requirements for the aircraft subjected to weapons fire will vary from aircraft to aircraft and is best specified by the procuring agency.

3.1.1.2.1. Longitudinal Control (Hydraulic and Pneumatic) -
 If artificial feel is used, centering spring action
 shall take place at, or near, the control valve and
 the device shall be connected in a manner so that it
 will perform its normal function regardless of a
 failure in the system at any point. The control valve,
 in turn, shall be located on or near the control
 actuator. When required, the control actuating
 cylinders shall be duplicated by providing side-by-side
 or tandem cylinders and by supplying the cylinders from
 separate power sources. If each cylinder will provide
 full hinge moment, the primary flight control power system
 may be connected to one cylinder, and the emergency/
 flight control power system to the other cylinder.
 If the emergency system requirements of MIL-F-8785
 can be met with one-half hinge moment with the aircraft
 loaded at any permissible cg location, the cylinders
 may each be designed to supply one-half hinge moment
 and be connected to two separate primary flight
 control power systems, or the second cylinder may be
 connected to the utility power system as well as the
 primary system which would serve both cylinders in
 this case. In either of the above cases, means shall
 be provided for connecting the emergency flight control
 power system to a cylinder normally serviced by the
 primary flight control power system.

3.1.1.2.1 Flight Control System Status Test Provisions - Provisions within the flight control system shall allow preflight, maintenance and troubleshooting and periodic operating status tests. It shall be possible to perform all preflight tests by manipulation by the pilot of the following:

a. Aircraft controls.

b. Controls on a flight control system test and display panel. The results of the tests shall indicate to the pilot the proper functioning of the flight control system. Required crew participation in the preflight tests shall by design be kept to a minimum.

Rationale:

Section 3.1.1.2.1 as previously stated is covered in general terms in 3.1.1.1.1 (changed) and 3.1.1.2 (added to). Preflight tests are required since reliability estimates for mission success assume starting with a normally operating system.

3.1.1.2.2 Lateral/Control/Hydraulic/and/Pneumatic - The/control/system/in/the/wings/need/not/be/duplicated/overboard/from/the/center/section, but/shall/be/designed and/installed/so/that/failure/of/any/component/will not/prevent/lateral/control/of/the/aircraft//Careful/consideration/shall/be/given/to/the/characteristics/of

the/aircraft/will/regard/to/controllability/and/landing
 capabilities/will/only/one/lateral/control/device/
 operable/prior/to/the/decision/regarding/duplication/of
 lateral/control/actuating/cylinders/and/control/system/
 action/upflow,/lateral/stability,/adverse/yaw,/control
 surface/buzz,/utilization/of/spoilers,/etc,/shall/also
 be/considered/in/this/determination./Emergency/lateral
 control/capabilities/shall/be/as/specified/in/MIL-F-8783/
 if/it/is/determined/that/full/control/is/required/at
 all/times,/the/lateral/control/cylinders/shall/be
 duplicated/and/approximately/connected/to/the/power
 system,/and/the/remainder/of/the/control/systems/should
 be/duplicated./If/adequate/lateral/control/is/available
 from/one/wing,/it/may/be/possible/to/use/a/single
 actuating/cylinder/in/each/wing/with/these/cylinders
 connected/to/separate/power/sources/and/provisions
 made/to/connect/at/least/one/cylinder/to/the/emergency
 flight/control/system/

3.1.1.2.2 Inflight Control System and Status Display

Emergency Selection - Flight control system status
shall be displayed to the pilot and/or crew concerned.

Display shall indicate the operational status of

Class A, B, C Critical control functions. For emergency

operation, inflight manual selection (and disengagement) of critical Class A flight control system functions is permissible as a backup operating mode when allowed by the procuring agency for the particular aircraft.

Rationale:

3.1.1.2.2 presently in 9490C is covered by 3.1.1.1.1 (changed) and 3.1.1.2 (added to). For a redundant control system, the operational status is required to allow aborting mission, etc. Emergency select provisions could be acceptable on low response aircraft. In others, engaging and disengaging a failed channel would be more hazardous than an immediate emergency landing. This additional equipment affects the maintainability of the aircraft, but is required on a functional basis.

3.1.1.2.3 // Elevon and Rudder/Control (Hydraulic and Pneumatic) // Extreme care shall be used in the design of fixed controls, as required on delta wing and V-shaped type airplanes, since a failure can result in loss of control in two axes. // The actuating cylinders shall be duplicated and connected to the power system in a manner similar to that specified for longitudinal control actuators.

Rationale:

Covered in changed 3.1.1.1.1 and 3.1.1.2.

3.1.1.1.1.1 // Directional Control // It // can // be // shown // that
 sufficient // directional // control // following // failure // of
 the // primary // power // control // system // is // available // to
 meet // the // alternate // control // requirements // of // MIL-F-8783,
 duplication // shall // not // be // required // // The // control // actuator
 shall // be // controlled // to // the // power // systems // in // a // manner
 similar // to // and // compatible // with // the // longitudinal
 and // lateral // control // systems //

Rationale:

Covered in changed 3.1.1.1.1 and 3.1.1.2.

3.1.1.3 Artificial Feel Systems - Where pilot control
 MIL-F-83300
 forces adequate to meet the requirements of MIL-F-8783
 are not provided by aerodynamic means, these forces
 must be supplied (or the aerodynamic forces augmented)
 by suitable artificial feel devices. The artificial
 feel system shall provide a force gradient which will
 permit the aircraft to meet its contract requirement.
 Any failure in the system shall not result in control
 forces that are either so high or so low as to be
 hazardous. Artificial feel system design shall provide
 positive control centering to the trim position, as
 MIL-F-83300
 required by MIL-F-8783, without overtravel or control
 oscillation.

Rationale:

Current applicable specification.

3.1.1.4 Control Sensitivity - Control sensitivity

and breakout forces shall be in accordance with MIL-F-83300

~~MIL-F-8788~~, and, at the same time, the control shall not be too sensitive to permit precision pilot control at high values of "q". To keep the response high and dead spots small, it is necessary to keep the control system tight throughout with a minimum of free play, keep the number of links and joints to a minimum, etc.

To prevent overcontrolling of the aircraft, control system breakout forces should be the minimum possible, within the permissible values given in ^{MIL-F-83300}~~MIL-F-8788~~.

To provide proper control system sensitivity over the entire speed range, it may be necessary to provide "q" feel, variable slope stick deflection vs control device deflection curve, or a ratio changing mechanism. By utilizing proper control linkages, a stick deflection vs control device deflection curve can be obtained which gives relatively small control device deflections for large stick motions near the neutral position and large control device deflections for small stick motions near the extreme of travel. Ratio changing mechanisms, operated by landing gear pressure, pilot controlled switch, or

other means, may be used to alter control system sensitivity where other means are not adequate or suitable. However, ratio changers shall not be used unless necessary. When improper positioning of the ratio changer can result in a safety of flight hazard, necessary provisions for monitoring and emergency positioning shall be incorporated.

Rationale:

Current applicable specification.

3.1.1.5 Compatibility - The performance characteristics of the primary flight control system shall be adequate to permit the automatic control system to achieve its required performance. For example, high gain control valves shall be used and, if they are too sensitive for pilot control, the control linkage shall be appropriately modified to make the overall system compatible with pilot capabilities.

3.1.1.6 Combined Functions - The automatic control system requirements shall be considered when locating devices such as nonlinear linkages, ratio changers, feel devices, trim devices, etc. For example, structural protection devices which are installed for use during manual control mode may also be usable during the automatic control modes.

3.1.2 Secondary Flight Controls - Power used for these controls shall be derived from the utility power system(s) in a manner consistent with the reliability requirements of the primary flight control systems. If satisfactory primary flight control system reliability and survivability cannot be obtained due to the secondary flight control systems sharing power systems with the primary flight controls, then separate power systems can be used for the secondary system.

Rationale:

Depending on the redundancy level and mission requirements of the aircraft, using a separate power supply for the primary and secondary systems may not be required. Arbitrarily requiring separated supplies when not required increases maintainability requirements.

3.1.2.1 Trim Systems - A suitable trim system shall be provided for each of the primary control axes. The trim system shall be irreversible, so that loads or vibratory conditions will not alter the trim setting, and shall maintain a given setting until changed by the pilot. The trim systems shall be designed to meet the performance requirements

MIL-F-83300

herein as well as those specified in ~~MIL-F-8788~~. The requirements of the automatic flight control system for trim specified in 3.1.3.5.6 and 3.1.3.5.7 shall also be complied with. Electrical trim systems shall be designed with a trim range not in excess of absolute total requirements for the airplane. To provide sufficient, but no more than necessary, trim travel, trim limit switches shall be designed to permit adequate adjustment in trim travel. Trim surfaces, or other trim devices, with authority greater than the primary control system shall not be used. Aircraft which have provisions for primary system manual control in the event of power failure, and which use artificial feel system trim when power is available, shall have provisions for manual trim in the event of power failure. The proper trim setting shall be automatically retained during reversions. The irreversible mechanism shall be located and designed to minimize free play and maintain rigidity in the control. In two-place aircraft with electrical trim systems, it may be necessary to provide inter-locks in the circuitry to prevent attempts to trim in both directions simultaneously or to permit an instructor to override a student.

Rationale:

Current applicable specification

3.1.2.1.1 Emergency Systems - Where a failure of a power-operated trim control system would result in marginal or unsafe control characteristics, a completely separate emergency trim system, and means to override the failed system, shall be provided. Overriding may be provided by an override trim switch installed in the cockpit to permit de-energizing the normal trim circuit and emergency actuation of the trim. A four-position "on-off-momentary on-momentary-on" switch in accordance with MS25128 is recommended for this purpose. In some cases, it may be desirable to install load sensing switches in the trim system to prevent trim application in the direction opposing pilot stick load in order to prevent serious runaway trim.

3.1.2.1.2 Trim Switches - Electrical trim switches, of the five-position, center off, toggle type, shall be in accordance with MIL-S-9419. Control stick grips in accordance with MIL-G-25561 shall already have the trim switches, conforming to MIL-S-9419, installed. Three-position trim switches shall be approved switches similar or equivalent to the MIL-S-9419 switches.

3.1.2.1.3 Trim Rate - On aircraft utilizing electric trim, the use of two-speed trim actuators to satisfy manual flight trim requirements shall be avoided; however, a

second speed may be provided for automatic flight control use. In determining an acceptable trim rate to meet the manual flight requirements, the following shall be considered in addition to the requirements of MIL-F-83300 ~~MIL-F-8785~~:

- a. The maximum average trim rate required to maintain stick forces near zero during final approach in configuration PA (see MIL-F-8785). Trim rate to flareout for landing is not pertinent since the pilot can hold these forces for the short time required.
- b. The maximum trim rate required to keep stick forces near zero during maximum rate of change in airplane speed, such as in dives.
- c. The maximum rate required to maintain zero stick forces during operations which give trim changes, such as speed brake or wing flap extension.
- d. The minimum trim rate which, if used to control the flight control device, could create a maneuver to give limit airframe load in 2 seconds of trim operation. Unless excessive trim sensitivity is encountered, the trim rate should be not less than the values of "a", "b", and "c" in order to permit adequate control. It should not exceed the value of "d" since it is desired that a runaway trim system not be able to create a limit load condition before

the pilot can react. It is to be noted that it is not desired that the pilot be able to trim the airplane into any desired maneuver, and, therefore, trim rates should be kept as low as possible, consistent with "a", "b", and "c" above. Rates of application shall be such that preciseness of control is obtained for landing, takeoff, and inflight conditions without creating a hazard.

Rationale:

Current applicable specification

3.1.2.1.4 Series Trim - If series trim is used, the system shall be designed to insure manual control through the pilots' control stick in the event that the actuator becomes inoperative in any position. *In series trim the trim actuator is located in the control system linkage so that the stick neutral does not move during trimming when used in the longitudinal axis, this type system will alleviate the problem of having the stick too far aft during takeoff and landing.*

Rationale:

Description does not add to specification in terms of specifying performance (and indirectly reliability associated with recommendation).

3.1.2.1.5 Trim Position Indicators - Suitable indicators shall be provided to indicate the neutral position and the range of travel or each trim device. On manual type systems,

a mechanical type indicator on or near the cockpit control is considered satisfactory. Aircraft which require takeoff longitudinal trim setting in accordance with cg location shall have suitably calibrated trim position indicators. Where suitable, trim indicators shall be in accordance with MIL-I-7064. In aircraft which may use a single trim setting for all takeoff conditions, a "trim for takeoff" light shall be provided. Where movable surfaces are used for trimming, the sensing devices for the indicator shall be operated by the surface actuator in power-operated systems, except when surface position is a true indication of trim position, in which case the sensor may be attached directly to the surface. A position sensing device is not required on the surface, or a mechanical link directly connected to the surface, if the system is entirely manual, unless an electrical instrument type indicator is used. Where suitable, trim indicators shall be in accordance with MIL-I-7064.

Rationale:

Specification applies to trim indicators, the subject of this section.

3.1.2.1.6 Takeoff Trim - On aircraft subject to short alerts, a takeoff trim switch, either momentary push

button or momentary toggle, shall be provided to return all trim systems to the takeoff position. When all systems are at takeoff position, a "take-off" light shall come on and following release of the switch, the light shall go out.

3.1.2.1.7 Trim Control and Indicator Location - The location and actuation of the trim controls and indicators shall be as indicated in MIL-STD-203.

3.1.2.1.8 Manually Operated Trim Control System - The necessary control shall be available with a minimum amount of input motion consistent with acceptable operating forces.

3.1.2.2 High Lift Controls - A suitable control system shall be provided for actuating the manually operated high-lift devices (flaps, slats, etc.). Performance of the control system shall meet the requirements of the system specification.

Rationale:

Section 3.1.2.2 doesn't state performance requirements, since there is no specification, systems specification must be used.

3.1.2.2.1 Synchronization - High lift devices shall be mechanically interconnected, unless it can be demonstrated that no hazardous flight attitude will result from unsynchronized operation. In the event of a failure of the high lift control system actuators such as a screwjack, hydraulic cylinder, etc., the high lift device shall maintain synchronization, or remain synchronized without motion. There are several methods of providing systems which will comply with this requirement, such as providing duplicate push/pull rods, torque/tube systems, cable systems, etc., duplicating the drive unit and installing separate actuators at each high lift device segment and interconnecting the actuators, and providing an automatic shutoff system which receives position signals from each of the segments or from the outer ends of the torque/tube system, or a ratchet whose landing roll becomes critical, with respect to normal runway lengths and zero wind conditions, if high lift devices are not available, are not suitable for usage of automatic shutoff systems which may deprive them of the use of these devices. The degree of asymetry and the flight conditions used for synchronization acceptability shall be those most critical for inducing hazardous flight attitudes.

Rationale:

Deletion of the part of present statement telling possible solutions is consistent with the specification stating "REQUIREMENTS" but not "HOW".

3.1.2.2.2//Emergency/operation//An/emergency/means
for/operating/the/high/lift/devices/shall/be/provided
on/directly/where/safe/operational/landings/cannot/be
accomplished/without/use/of/the/high/lift/devices/
The/emergency/system/shall/be/completely/independent/of
the/primary/system/

Rationale:

Covered in 3.1.2 (added) as a critical Class
A system.

3.1.2.2.3 Operating Time - At the maximum limiting aircraft speed for which the flaps may be operated, the rate of operation for lowering power-operated landing flaps shall not be greater than 10 degrees per second. Complete lowering of the flaps shall be accomplished in a time not greater than $10 + 40/n$ seconds where n is the design limit load factor of the aircraft. Insure that time of operation specified applies at all ambient air temperatures between -20 degrees F (-29 degrees C) and +120 degrees F (+49 degrees C). Outside this range of temperature, but

between -65 degrees F (-54 degrees C) and +160 degrees F (+71 degrees C), insure that the time of operation is not more than 50 percent greater than the normal speed selected with all components of the flap actuating mechanism stabilized at the specified extreme temperature, and without assuming time for warmup of the components. Raising of the flaps should be accomplished at such a rate that the resultant loss of lift coefficient can be compensated for by the increase in speed resulting from the application of full military power, as in go-around, so that there is no loss in altitude. In no case shall the flaps be designed to rise in less than 10 seconds.

3.1.2.2.4 Indicator - An approved type indicator shall be provided in the cockpit to indicate flap positions.

3.1.2.2.5 Actuation of High Lift Devices - The pilot's operating mechanism shall be as specified in the detail specification. Actuation of the mechanism shall be in accordance with MIL-STD-203.

Rationale:

Identification clarity

3.1.2.3 Speed Brakes and Dive Brakes - The control system for these devices must be capable of withstanding

frequent operation at all flight speeds up to the terminal velocity of the airplane. In some cases, blowback features may be desirable to prevent structural failure of the components. Satisfactory control system performance shall be defined by the procuring agency.

Rationale:

Need definition of what the speed and dive brake control system must accomplish on a functional basis.

3.1.2.3.1 Emergency Systems - Emergency retraction is required on those devices that will not automatically retract, as a result of airloads, when the control is moved to the retract position.

3.1.2.3.2 Asymmetric Operation - Where asymmetric operation of these devices would cause uncontrollable aerodynamic moments on the airplane, provisions shall be made to prevent this condition. Where these devices perform functions requiring asymmetric use, provisions shall be made to prevent asymmetric operation except at the proper time.

3.1.2.3.3 Positioning - The control system shall be of such design as to permit infinitely variable positioning.

3.1.2.3.4 Actuation - The pilot's actuating mechanism shall be a three-position device with a stop position in neutral, momentary aft position to extend, and a maintained forward position for retraction.

3.1.2.3.5 Indicator - An approved type indicator shall be provided in the cockpit to indicate the position of the speed brakes, or similar devices.

3.1.2.3.6 Operating Time - It shall be possible to completely extend the speed brakes in not less than 2 seconds and not more than 3 seconds. Time of operation specified shall apply at V_t at sea level and at all ambient air temperatures between -20 degrees F (-29 degrees C) and -65 degrees F (-54 degrees C) and between 120 degrees F (+49 degrees C) and +160 degrees F (+71 degrees C), the time of operation shall not exceed 4 1/2 seconds. The above values shall be met with all components of the actuating mechanism stabilized at the extreme temperature, and without assuming time for warmup of the components.

3.1.3 Automatic Flight Control Systems (AFCS)

3.1.3.1 Categories of Operation - The control function or functions to be performed by automatic flight control

systems or components shall be determined from the military characteristics or the requirements of the aircraft, or class of aircraft, in which the equipment shall be used. By definition, the automatic control functions shall fall within the following categories:

3.1.3.1.1 Augmentation - The augmentation category shall include those control functions which are required to improve the stability and handling characteristics of the the air vehicle. Unless the damping of the airframe - AFCS System is specifically given in the detail specification or mission requirements for the various operational functions, or if specified requirements are less stringent than the requirements of MIL-F-8785, the damping of the longitudinal, or directional-lateral, oscillatory mode shall be governed by the requirements specified in MIL-F-8785.

3.1.3.1.2 Pilot Assist or Pilot Relief - The pilot assist, or pilot relief, category shall include those automatic control functions which simplify, or ease, the control of the flight path of the aircraft. These functions may include, but shall not necessarily be limited to, the following:

- a. Pitch and roll attitude hold

- b. Heading hold
- c. Altitude hold
- d. Airspeed and Mach hold
- e. Rate of climb and descent hold
- f. Control stick steering

3.1.3.1.3 Guidance - The guidance category shall include those control functions which provide automatic flight path control in accordance with steering signals generated by guidance and control systems external to the flight control system. The category may include, but shall not necessarily be limited to, the following types of control functions:

- a. Enroute navigation
- b. Rendezvous and station keeping
- c. Terminal guidance for bomb delivery
- d. Search and tracking for fire control
- e. Automatic takeoff, approach and landing

3.1.3.2 Integration - Automatic flight control systems, subsystems and components shall be designed so that a maximum of integration is accomplished between those components providing the automatic control function and components or parts comprising or providing any other function of a weapon system consistent with system reliability, operation, and safety.

3.1.3.3 Reusability - In development of automatic flight control systems or subsystems, components required to perform the functions of the system shall not be designed nor constructed until studies have proven that the required components are not available nor the required performance and characteristics obtainable from modification of existing components in the system or subsystem with which the automatic flight control system will be integrated or into which it will be tied. During concurrent development of subsystems by separate contractors, development of mutually required components shall be accomplished around the component requiring the most stringent performance. Applications requiring the use of systems already developed or in production which contain similar components, shall require use of the systems component requiring the most stringent performance, with modifications, if required to that component, and both systems, to achieve integration.

3.1.3.4 Details - Details concerning each system integration requirement shall be as specified in the system or component specification or procurement document.

3.1.3.5 Functional Requirements

3.1.3.5.1 Conditions for Engagement - Unless the AFCS is properly energized and synchronized, it shall not be possible to engage the system or to switch from one functional category or mode of operation to another. It shall be possible to engage the augmentation mode independently of any function or mode of the AFCS. No control transients, which exceed the limits of 3.1.3.6.3, shall occur when switching from one functional mode of operation to another or when disengaging the system. Unless otherwise specified in the system specification, all control axes shall be engaged and disengaged simultaneously. Means shall be provided so that the pilot can visually determine the operational status of the system.

3.1.3.5.2 Warmup - After the application of power, the warmup time required shall be not more than 90 seconds for fighter aircraft and not more than 3 minutes for other types of aircraft. If a shorter warmup time is necessary to meet operational requirements, the particular system specification shall specify this requirement.

3.1.3.5.3 Synchronization - The system design shall be such that, upon engagement, the aircraft's attitude

or other control mode will be maintained, or the aircraft will be displaced at a predetermined rate to a predetermined attitude as defined in the system specification covering the particular AFCS. Synchronization indication, if required, shall be as specified in the system specification. The synchronization rate shall be such that no transients exceeding the limits of 3.1.3.6.3 shall occur due to system engagement or mode switching 2 seconds after the completion of any maneuver up to the maneuver limits of the aircraft.

3.1.3.5.4 Overpower - With the AFCS engaged and operating, it shall be possible to manually overpower or countermand the control action of the system on all axes. For fixed-wing aircraft, additional force, at the point of pilot application, required to maneuver the aircraft due to overpowering the servos of the automatic flight control system shall not exceed the following values:

Rudder	-	120 pounds
Elevator		35 pounds for stick 50 pounds for wheel
Aileron		25 pounds for stick 40 pounds for wheel

The overpower force for helicopters shall be in accordance with the requirements of Specification MIL-H-8501.

3.1.3.5.5 Cockpit Control Motion - The control device motion required to accomplish augmentation shall not be reflected at the aircraft's cockpit control. If other control device motions are not to be reflected at the cockpit controls, the proposed system shall be discussed with and approved by the procuring activity prior to proceeding beyond the initial design phase. Full freedom of operation of cockpit control shall be possible at all times stability augmentation is in use.

3.1.3.5.6 Automatic Trim - Means shall be provided to automatically reduce the control system trim error to essentially zero. Such a means shall operate at a rate which does not significantly affect the transient performance of the AFCS. Automatic trim shall be operational during the guidance and pilot assist modes only.

3.1.3.5.7 Manual Trim - Powered manual trim shall be made inoperative when the AFCS is engaged. The circuitry shall be arranged so as to minimize the effect of a failure in the AFCS on the manual trim operation after the AFCS is disengaged.

3.1.3.5.8 Control Stick (or Wheel) Steering - Where control stick steering is a system requirement, provisions shall be made so that the pilot shall have full capability to maneuver the aircraft within control forces and maneuver limits specified in Specifications MIL-F-8785 for fixed wing aircraft, MIL-H-8501 for helicopters or the applicable system specification. This maneuvering capability shall be possible at any time when the AFCS is engaged by using the normal aircraft controls. Unless otherwise specified in the applicable system specification, design shall be such as to allow the pilot to superimpose his control stick steering commands over those of external guidance system signals. Cross control between the pitch and roll force sensors shall not exceed 1 percent of the applied force.

3.1.3.5.8.1 Vernier Control - When control stick steering is a requirement, means shall be provided to apply vernier attitude control, unless changes commensurate with the minimum maneuver requirements can be added by control stick steering commands.

3.1.3.5.9 Interlocks - Interlocks to prevent engagement of the AFCS in the absence of electrical power of the proper voltage and frequency, proper gyro rotor speed, adequate warmup, and normal overall operation shall be provided as part of the AFCS. It shall not be possible to engage incompatible functions. Interlocks shall also be provided to prevent power from being applied to the system if lack of power to the servo units prevents synchronization. In the event of failure of any one of the power sources, the AFCS shall become disengaged within 0.3 second.

3.1.3.5.10 Disengagement - Provisions shall be made for fail safe inflight disengagement and reengagement of the AFCS. Disengagement shall be positive under any and all load conditions. Disengagement switches shall be normally closed and shall be located in accordance with the requirements of Standard MIL-STD-203. A disengagement not initiated by the pilot shall be indicated by a visual warning to the pilot and the copilot. In the event that servo disengagement should result from action of the structural protective means, the circuitry shall provide for immediate re-engagement at the pilot's discretion. Particular attention shall be given to reducing the amount of friction and inertia contributed by the AFCS to the manual flight control system when the AFCS is disconnected. The specific value of friction the AFCS can contribute when disconnected shall be defined in the AFCS performance specification.

3.1.3.5.10.1 Series Actuators - The series actuators shall, after deactivating, be positively centered and capable of transmitting full control system load without creep. The rate of centering shall be such that no undesirable transients will be introduced. (Unless

~~A DEL/cross/monitoring/system, including, del/separate/actuators, is/used, series/actuators/having/more/than/40 per/cent/primary/control/authority/shall/not/be/used.~~

Rationale: Covered in critical classifications 3.1.1.2 and ... redundancy techniques can eliminate failed single actuators with acceptable transients.

3.1.3.5.11 Structural Protection - Means shall be provided to prevent AFCS malfunctions from producing airplane loads in excess of the airplane limit load factor. Due consideration shall be given to the fact that during rapid roll maneuvers the load factor of one of the wings is higher than that determined by the center of gravity acceleration. Unless proven unnecessary, the protective device for high roll performance aircraft shall respond to an appropriate combination of lift, roll velocity, and roll acceleration.

3.1.3.5.11.1 Ground Check - The structural protective means shall be such that it can be conveniently ground-checked by the pilot.

3.1.3.5.11.2 Fail Safety - The structural protective means shall be designed for maximum fail safety and shall be selfmonitoring. Electrical power applied within the limits

shown in 3.2.16 shall not cause the structural protective means to become inoperative.

3.1.3.5.12 Protection Against Prohibited Maneuvers - Devices which protect against prohibited maneuvers, whether initiated by the pilot or by the AFCS (i.e. command signal limiting as a function of velocity normal load limits, pitch-up inhibitors, etc.), shall be provided as specified in the applicable system specification. The design of the protective devices shall be similar to 3.1.3.5.11.

3.1.3.5.13 Dynamic requirements. The flight control system shall be so designed as to permit only a minimum of system degradation as a result of flight in turbulent air. In all cases, the effect of control system design on dynamic flight loads shall be a prime consideration. Unless otherwise specified in the weapon system specification, the following shall apply:

a. Degradation of augmented vehicle damping ratios will not be tolerated for $(1-\cos)$ discrete gusts up to a velocity of 40 feet per second. The discrete gusts shall be tuned to the air vehicle short period and Dutch roll natural frequencies. Where maximum expected gust velocities define the air vehicle strength, 75 percent degradation from still air

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values will be allowed provided a damping ratio of at least .15 is maintained.

b. System performance for large excursions of the flight vehicle will be demonstrated by computer simulation analysis correlated with flight test in lieu of flight test at the specified gust environment.

3.1.3.6 General Tie-in Requirements - Provisions shall be made for the acceptance to the extent specified by the system specification of external guidance signals from subsystems generating the necessary commands in attitude, speed, altitude, flight path rate, acceleration, etc., to control the aircraft's flight path.

3.1.3.6.1 Reference Voltage - Reference and command signals to the AFCS shall be based on the same voltage source as the corresponding feedback signal of the AFCS. This shall prevent the voltage variations from changing the correlation between the commanded and actual value.

3.1.3.6.2 Command Signal Limiting - Means shall be provided to limit the command signals from external guidance systems, so that the AFCS will not cause the aircraft to exceed maneuver limits that are inconsistent with the external guidance function and flight conditions.

3.1.3.6.3 Switching - Switching with zero command signal input from external guidance systems shall not cause transients greater than ± 0.05 g normal acceleration at the center of gravity in pitch or ± 1 degree in the roll attitude.

3.1.3.6.4 Noise Compatibility - The AFCS shall be so designed that the noise content in the external guidance signal, as specified in the applicable system specification, shall not saturate any component of the AFCS, shall not impair the response of the aircraft to the proper guidance signals, and shall not cause objectionable control motion or attitude variation. If the specified noise content is too great to achieve this goal, additional noise filtering shall be employed. Since additional noise filters impair the guidance performance, an optimum compromise between performance and noise filtering shall be determined by the procuring activity, the AFCS contractor and the contractor responsible for the guidance computer and the overall guidance performance.

3.1.3.6.5 Data Link - If the steering information is transmitted to the AFCS via a digital data link, the sampling frequency and number of bits per signal shall be compatible with the accuracy and dynamic performance requirements of the guidance loop, and the noise resulting from the sampling and digitalizing process shall not cause a total noise which

will be incompatible with 3.1.3.6.4. If the steering information is transmitted to the AFCS via an analog data link, the gain variation and the zero shift of the data link shall be compatible with the performance and accuracy requirements of the guidance loop and the data link noise shall not cause a total noise which will be incompatible with 3.1.3.6.4.

3.1.3.7 Performance Requirements - The aerodynamic and flight configurations, external stores configuration, and aircraft performance range through which the AFCS shall be required to provide the specified performance shall be as defined in the flight control system specification. The performance requirements specified herein shall apply to all aircraft, aerospace craft, helicopters, and VTOL aircraft.

3.1.3.7.1 Augmentation - The augmentation system shall provide handling characteristics which will satisfy, as a minimum, the requirements of Specification MIL-F-8785 for all fixed-wing aircraft and VTOL aircraft in the forward configuration and Specification MIL-H-8501 for helicopters. During turn maneuvers, the augmentation system shall provide turn coordination as specified in 3.1.3.7.2.4. The control authority of the augmentation system shall be limited as far as possible to insure that "hard-over" signal will not cause the aircraft to exceed its limit load factor. If

this is not possible because of the demands of the augmentation system, additional requirements shall be specified in the applicable system specification to insure the safety of the weapons system operation.

3.1.3.7.2 Pilot Assist Function

3.1.3.7.2.1 Attitude Hold (Pitch and Roll) - Except as noted in 3.1.3.6.2, or unless otherwise specified in the applicable system specification, an established pitch and roll attitude up to maneuvering limits of $\pm 60^\circ$ in roll and $\pm 15^\circ$ in pitch shall be maintained within $\pm 1^\circ$ over the entire flight regime. Upon completion of a pilot controlled maneuver, the attitude maintained by the AFCS shall be the airplane attitude at the time the commanded forces were removed if this attitude is within the limits of the attitude hold mode. For bank angles of less than $\pm 7^\circ$ in control stick steering applications, the airplane shall return to wings level attitude on release of the lateral control force. When using a flight controller, the airplane shall return to a wings level attitude when the turn knob is placed in the detent position.

3.1.3.7.2.1.1 Pitch Transient Response - The pitch response shall be smooth and rapid. After the AFCS has been manually overpowered to change the pitch attitude by at least ± 5

degrees, the aircraft shall return to the reference attitude with the first overshoot not exceeding 20 percent of the initial deviation. The period of overpowering shall be short enough to hold the airspeed change to within 5 percent of the trim airspeed. Acceleration limits shall be as specified in the AFCS system specification.

3.1.3.7.2.1.2 Residual Oscillations During Steady State Flight - Residual oscillations as measured in the cockpit during steady flight shall not produce normal accelerations, a_n , lateral accelerations, a_y , attitude amplitudes, (pitch), (yaw) and (roll) greater than the following:

a_n	0.02 g
a_n	0.01 g
	$\pm 0.1^\circ$
	$\pm 0.15^\circ$
	$\pm 0.1^\circ$

3.1.3.7.2.2 Heading Hold - During the control stick or control wheel steering mode, the heading hold shall engage automatically when the AFCS is engaged, and the bank angle is less than $\pm 7^\circ$. When the heading hold is engaged, the AFCS shall maintain the aircraft at its existing heading within a static accuracy of ± 1.0 degrees with respect to the gyro accuracy. When using a flight controller, heading

hold shall be automatically engaged while in the detent position and the existing heading, as indicated by the gyro, shall be maintained as specified herein.

3.1.3.7.2.2.1 Transient Response - The heading response shall be smooth and rapid. After the AFCS has been manually overpowered to generate a sideslip angle of approximately $\pm 5^\circ$, the aircraft shall return to the reference heading with the first overshoot not exceeding 20 percent of the initial deviation. Acceleration limits shall be as specified in the AFCS system specification.

3.1.3.7.2.3 Heading Select - In the heading select mode the AFCS shall automatically turn the aircraft through the smallest angle to a heading either selected or preselected by the pilot and maintain that heading as in the heading hold mode. The heading selector shall have 360 degrees control. The bank angle while turning to the selected heading shall be established to provide a satisfactory turn rate and to preclude stall.

3.1.3.7.2.3.1 Transient Response - Entry into and termination of the turn shall be smooth and rapid. The aircraft shall not overshoot the selected heading by more than 1.5 degrees.

3.1.3.7.2.4 Automatic Turn Coordination - Automatic turn coordination shall be provided ~~whenever any function of the AFCS, including stability augmentation, is engaged~~ as required by the procuring agency during designated AFCS functions and as required for handling qualities.

Rationale: The arbitrary requirement for turn coordination when any function of the AFCS is engaged incurs unnecessary mechanism complexity.

3.1.3.7.2.4.1 Lateral Acceleration Limits, Steady Bank - When automatic turn coordination is used the uncoordinated side-slip angle shall be not greater than 2 degrees and the lateral acceleration shall not exceed 0.03 g, whichever is the more stringent requirement, while at steady state bank angles up to 60 degrees. Lateral acceleration in all cases shall refer to body-axis acceleration at the center of gravity.

Rationale: See 3.1.3.7.2.4 (changed)

3.1.3.7.2.4.2 Lateral Acceleration Limits, Rolling - When automatic turn coordination is used for aircraft having a roll rate capability up to 60 degrees per second, the lateral acceleration, while the aircraft is in essentially constant altitude flight and rolling from 60 degrees on one side to 60 degrees on the other up to this roll rate, shall be

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maintained within ± 0.1 g by the AFCS. For aircraft having a roll rate capability in excess of 60 degrees per second, the lateral acceleration, while the aircraft is rolling at rates up to its roll rate limit, shall be maintained within 0.2 g.

Rationale: See 3.1.3.7.2.4 (changed)

3.1.3.7.2.5 Sideslip Limiting - Where sideslip limiting is a system requirement, the static accuracy while the aircraft is in straight and level flight shall be maintained within a sideslip angle of 1 degree or a sideslip angle corresponding to a lateral acceleration of 0.02 g, whichever is lower.

3.1.3.7.2.6 Altitude Hold - Engagement of the altitude hold function at rates of climb or dive less than 2000 fpm shall select the existing barometric altitude and control the aircraft to this altitude as a reference.

3.1.3.7.2.6.1 Control Accuracy - After engagement and stabilization on altitude control, a constant barometric altitude shall be maintained within the following limits:

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55-80	+0.1% at 55 varying linearly to $\pm$ 0.2% at 80	$\pm$ 60 ft or +0.3% whichever is greater	$\pm$ 90 ft or +0.4% whichever is greater
30-55	$\pm$ 0.1%		
0-30	$\pm$ 30 ft		
	0	0-30	30-60
Bank Angle (degrees)			

Any periodic residual oscillation within these limits shall have a period of at least 20 seconds.

3.1.3.7.2.7 Mach Hold - After engagement and stabilization on Mach hold, the AFCS shall maintain the selected Mach number. The steady state Mach number error shall not exceed 0.01 Mach. Provisions shall be made for trimming over a range of at least $\pm$ 0.05 Mach. Any periodic oscillation within these limits shall have a period of at least 20 seconds.

3.1.3.7.3 Automatic Guidance Functions - During the automatic guidance functions, the AFCS-aircraft combination is an element within the overall guidance loop. The requirements which this combination has to meet depend upon the performance requirements of the guidance loop, the guidance method and the particular guidance computer. Unless specific performance data are established in the applicable system specification, the following requirements shall be met.

3.1.3.7.3.1 Automatic Instrument Low Approach System - Since, in general, the guidance computer for the automatic instrument low approach system, i.e., the coupler between the receiver and the AFCS, is considered part of the AFCS, the overall guidance performance is specified herein rather than the performance of the AFCS-aircraft combination alone.

3.1.3.7.3.1.1 Localizer Coupler Mode - The localizer coupler shall provide a smooth entry into the localizer beam, with beam intercept angles of 45 degrees at 8 miles out increasing linearly to 60 degrees at 18 miles out. Consideration shall be given to provide automatic engagement. During bracketing, the initial overshoot, as indicated by the localizer indicator, shall not exceed 50 percent of full scale deflection. The second overshoot shall not exceed the requirement for steady state and transient errors. The steady state error shall not exceed 10 percent of full scale of deflection, and the transient errors shall not exceed 20 percent of full scale deflection.

3.1.3.7.3.1.2 Approach Coupler Mode (Localizer and Glide Path Mode) . The approach coupler mode shall automatically engage when the glide path indicator is approximately centered. Incompatible pitch flight path functions which are engaged shall automatically revert to the OFF position upon engagement of the glide path function. The initial overshoot during bracketing of the glide path beam shall not exceed 40 percent of full scale deflection. The second overshoot shall not exceed the requirement for steady state and transient errors. The glide slope steady state error shall not exceed 10 percent of full scale deflection. Glide slope transient errors shall not exceed 20 percent of full scale deflection. The glide path coupler shall provide stable control down to 75 feet above the approach end of the runway or until disengaged under normal crosswind or gust conditions.

3.1.3.7.3.1.3 Repeatability - Ten consecutive completed approaches shall demonstrate that no dangerous attitudes or characteristics are exhibited and normal landing shall be possible, if desired, at completion of each approach.

3.1.3.7.3.2 Navigational Control Function - The features of the AFCS designed to provide automatic stability and flight path control in navigating from point to point, from steering commands initiated by various navigational computers, shall be as defined in the system specification. Specific performance required shall be as defined in the system specification.

3.1.3.7.3.3 Tracking Control Function - The features provided by the AFCS to give automatic stability and flight path control during search for, or tracking of, a target, either from pilot initiated commands or from steering commands initiated by a tracking control

system such as a bombing system computer, shall be as defined in the system specification. Specific performance required shall be as defined in the system specification, however, minimum acceptable performance for those features contained within the system shall not exceed the tolerances specified herein. Attention shall be directed toward achieving high rates of response, safe limits of performance of the aircraft, high degree of tracking accuracy and adequate stability in order to achieve accuracy of weapon release and maximum kill probability.

3.1.3.7.3.4 Bombing System Tie-In - Automatic flight control systems, which may require integration with, or tie-in to, a bombing system computer, shall contain provisions for acceptance and shaping the command signal to achieve the desired tracking control performance.

3.1.3.7.3.5 Take-off and Landing Control Functions - The functions provided by an AFCS designed to provide automatic stability and flight path control during take-off, catapult or launch and initial climb, as well as during approach and landing, shall be as defined in the system specification. Specific performance required shall be as defined in the system specification; however, minimum acceptable performance for those features contained within the system shall not exceed the tolerances specified herein.

3.1.3.8 General Requirements

3.1.3.8.1 Gain Control - Adequate means shall be incorporated for automatically changing the parameters of the AFCS either in accordance with airspeed or altitude, or both, or by selfadaptive means to provide acceptable and fail-safe performance over the operational range of the AFCS-aircraft combination. No single failure shall result in an uncontrollable aircraft or in a dangerous flight condition.

3.1.3.8.2 Internal Noise - There shall be no noticeable high frequency motion of the controls due to noise signals generated within the AFCS. Control device oscillations which are a necessary feature of certain selfadaptive automatic flight control systems shall not exceed the limits of the applicable specification.

3.1.3.8.3 Parameter Ground Adjustment - Controls may be provided to facilitate ground adjustments of the AFCS parameters. Such control provisions, however, shall be held to a minimum and shall not be readily accessible to flight crews.

3.1.3.8.4 Service Life Design Objective - Service life design objectives for automatic flight control systems and components shall be such that the mean time between failures shall not decrease when operated under flight conditions in the operational environment for a total of 1,000 hours. This requirement shall be met with

normal maintenance, but without the necessity for equipment overhaul.

3.1.3.8.5 Shelf Life - The equipment shall be capable of immediate service use without operational conditioning or maintenance during storage periods up to 24 months.

3.1.4 Pilot's Controls - The pilot's cockpit controls for fixed-wing aircraft shall be designed and located in accordance with MIL-STD-203, MS33574, and MS33576. Strict adherence to the prescribed location and maximum ranges of motion of these controls is required.

3.1.4.1 Control Sticks - If a control stick is used, and is removable, it shall be positively latched in place when installed. It shall be possible to install the stick only in the correct manner, and suitable means shall be provided to prevent rotation of the stick. If pilot's control sticks, other than the conventional center located sticks, are utilized, demonstration of their adequacy and suitability is required prior to installation in an aircraft. Demonstration by installation on a flight control simulator or in the second cockpit of a trainer aircraft, or both, may be acceptable.

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3.1.4.2 Rudder Pedals - Rudder pedal size, shape, motion, and adjustment mechanism for fixed-wing aircraft shall conform to the requirements of MS33574, MS33576, MIL-B-3584, and MIL-STD-203, the foot pedals shall be interconnected to insure positive movement of each pedal in both directions. In an aircraft capable of long range in which the pilot cannot move from the seat, folding rudder pedals may be required to permit the pilot to stretch his legs. In the design of these, it is essential to insure that the pilot is able to return the pedals to their normal position and will not catch or injure his feet during use of the mechanism. If a kick type rudder pedal adjustment is incorporated, a numerical index on each pedal should be provided to indicate rudder pedal position.

3.1.4.3 Pilot's Control Forces - The control forces required at the pilot's control shall be in accordance with the requirements of MIL-F-8785 , MIL-F-83300, and MIL-H-8501. These values apply at all ambient temperatures and include all sources of control force including friction, artificial feel, bobweight, etc.

Rationale: Added specs apply to V/STOL and helicopters.

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3.1.5 Control Surface Locks - All flight control surfaces shall be provided with locks or snubbers designed to prevent damage from ground wind loads as specified MIL-A-8865. The control surfaces of any airplane which can be nosed over or up by high winds when the control surface is displaced from the neutral position shall be locked in the neutral position. Power control actuators which do not have pressure operated bypass provisions may be adequate for snubbing in many cases. Servo tab and spring tab type surfaces need not have locks or snubbers installed if it can be shown that the connecting springs and linkages are sufficient to prevent gust damage to any of the components.

3.1.5.1 Internal Locks - Internal locks shall either engage the surfaces directly or lock the controls as near to each surface as practicable to obtain maximum benefit.

3.1.5.2 External Locks - The control surface lock system shall be internal in the airplane; external locks on the surface shall not be used.

3.1.5.3 Pilot's Control - Control for the internal lock system shall be in accordance with the requirements of MIL-STD-203. Means shall be provided to lock the pilot's control

in the unlock position. In addition to the provisions of MIL-STD-203 it may be desirable to provide for automatic locking of some control surfaces upon application of thrust reversal. Particular care must be exercised to ascertain that it is not possible for pilots to manipulate the surface lock controls to get a condition wherein takeoff power can be applied with the control surfaces locked. In the unlocking sequence, the throttle must be unlocked after all control surfaces are unlocked.

3.1.5.4 Locking Range - The range of movement of the pilot's control shall be sufficient to insure complete locking or unlocking of the control surface under the most adverse conditions of structural and system deflections. In unlocking the surface locks, a maximum of the first 50 percent of the range of motion of the pilot's control shall directly and positively unlock the control surfaces.

3.1.5.5 In-Flight Engagement - These locks shall be so arranged that they cannot be engaged during flight for any reason, such as inadvertent operation of the cockpit control lever, relative deflections between the lock control system and the aircraft, component failure, combat damage, etc. Locking mechanisms or snubbers which might create a condition of locked controls if failure occurs shall be installed

with a disconnect device which can be operated from the cockpit to release the entire locking mechanism, or at least shall be provided with some type of emergency release.

3.1.6 Control Stops - Adjustable control stops shall be located near the cockpit controls to prevent pilot inputs in excess of that which can be tolerated by the other components in the system or which the airframe can structurally tolerate. If it is possible for maladjustments, misrigging, or other conditions to result in damage to the control surfaces, or main surfaces due to overtravel, adjustable surface stops shall also be provided adjacent to the surface itself. The use of the power control system actuators for control stops is permitted if the actuator is designed for this purpose.

3.1.6.1 Adjustable Stops - All adjustable stops shall be positively locked or safety wired in the adjusted position. Jam nuts (plain or self-locking type) are not considered adequate as locking devices for this application.

3.1.7 Additional Requirements for Rotary Wing Aircraft - These requirements are in addition to the previous specifications with the exception that the applicable flying qualities specification shall be MIL-H-8501, and MIL-F-83300, and the

applicable structural design requirements specification shall be MIL-S-8698.

Rationale: MIL-F-83300 applies to rotary wing aircraft.

3.1.7.1 Primary Flight Controls - In general, the overall requirements for helicopter control systems are specified in MIL-H-8501 and MIL-F-83300 and should be adhered to, except as approved by the procuring activity. Wherever blade feathering moments permit, and control force feedback to the pilot is not objectionable, manual control may be used. Consideration should be given to steady and unsteady stick forces and associated free stick motions of the system under all flight conditions, and in particular when the controls are released momentarily, such as for bailout, to determine what requirements exist for irreversible control systems.

Rationale: MIL-F-83300 applies to rotary wing aircraft.

3.1.7.1.1 Flight Control Hydraulic Systems - In addition to previous requirements for the flight control hydraulic system, the emergency hydraulic pump, if required, shall be driven from the main rotor, or gear box, so that it will be operative during autorotative landings. In dual power control systems at least one power source shall be rotor driven.

3.1.7.2 Pilot's Controls - The pilot's cockpit controls shall be designed and located in accordance with the applicable portions of MS33575, MS33572, and MIL-STD-250. Strict adherence to the prescribed location and range of motions of these controls is required unless otherwise approved by the procuring activity.

3.1.7.2.1 Cyclic Pitch Control Stick - If the control stick is removable it shall be positively latched in place when installed. It shall be possible to install the stick only in the correct manner, and suitable means shall be provided to prevent rotation of the stick.

3.1.7.2.2 Throttle Interconnection - The collective pitch control shall be interconnected with the throttle control, and synchronized to provide the proper throttle setting as collective pitch is increased or decreased. Means shall also be provided to permit throttle control independent of lever movement, by rotation of the grip on the lever.

3.1.7.2.3 Collective Pitch Lever Locks - An adjustable friction type lock, or equivalent, shall be provided to retain the collective pitch lever in any desired position as specified in MIL-STD-250. In addition, a lock shall be provided to lock the collective pitch lever in the down position.

3.1.7.3 Blade Coning Restrainers - Suitable provisions shall be made to restrain coning of the blades when starting or stopping the rotor. It shall be possible to start or stop the rotor in wind velocities up to 60 knots, from any horizontal direction, without physical contact of the rotor blades with any part of the airframe. Means shall also be provided to prevent contact of the blades and airframe during flight maneuvers and hard landings.

3.1.7.4 Control Surface Locks - If it is considered that damage to any of the control surfaces or control mechanisms may result from gusty air while the aircraft is parked, suitable control surface locks shall be provided in accordance with the detail requirements of 3.1.5, except that rotor parking locks may be external.

3.1.7.5 Helicopter Automatic Flight Control Systems - In addition to the applicable requirements of 3.1.3 helicopters automatic flight control systems shall meet the following requirements.

3.1.7.5.1 Control Force Steering - Where force steering is a system requirement, the relationship between cyclic stick force and attitude or attitude rate in pitch and roll shall be as specified in the applicable system specification, the

yawing velocity shall be proportional to the pedal force during hovering, and unless otherwise specified, the rate of climb or descent shall be proportional to the collective stick force and the helicopter shall maintain the established altitude when no force is applied. To reduce the collective servo load, the friction lock of the collective stick (see 3.1.7.2.3) may be automatically removed during this mode of operation.

3.1.7.5.2 Coordinated Turn - Unless otherwise specified in the system specification, automatic turn coordination shall be operative for the airspeed range between 30 knots and the maximum airspeed.

3.1.7.5.3 Groundspeed Hold - Where groundspeed hold is a system requirement, provision shall be made to insert radar groundspeed signals to the cyclic pitch and roll control. After engagement of the groundspeed hold mode, the groundspeed existing at the time of engagement shall be held in calm air within +5 knots or +10 percent, whichever is greater.

3.1.7.5.4 Vernier Control for Hovering - Vernier control shall be provided for accurate positioning of the helicopter during hovering, unless control commensurate with the minimum accuracy requirements can be obtained with the regular controls.

3.1.7.5.5 Stability Augmentation - The stability augmentation system shall provide, as a minimum, those flying qualities specified in Specification MIL-H-8501 and MIL-F-83300.

Rationale: MIL-F-83300 applies to rotary wing aircraft.

3.1.7.5.6 Attitude Hold (Pitch, Roll and Yaw) - During the attitude hold mode, the attitude, in calm air, shall be kept within +1 degree of the reference attitude. After the AFCS has been overpowered to change the attitude by 5 degrees, the helicopter shall return to the reference attitude with the first overshoot not exceeding 20 percent.

3.1.7.5.7 Altitude Stabilization

3.1.7.5.7.1 Barometric Altitude Stabilization - The requirements of 3.1.3.7.2.6 shall be met when the helicopter is outside the ground effect. In addition, the transient after a displacement of approximately 100 feet shall not exhibit a first overshoot in excess of 20 percent.

3.1.7.5.7.2 Radar Altitude Stabilization - The operational range of the radar altitude control mode shall be as specified in the applicable system specification. Within this range, the helicopter shall be controlled to the indicated radar altitude with an accuracy, in calm air, of +7 feet or +10 percent, whichever is greater.

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3.1.7.5.7.3 Altitude Select - Where altitude select is a system requirement, the transition from any engaged altitude within the operational range of the altitude stabilization mode to the preselected altitude shall be smooth and shall not show a first overshoot in excess of 20 percent.

3.1.8 Additional Requirements for Convertiplane Aircraft, Vertical Takeoff Aircraft, Etc. - The requirements of these special type aircraft are, in most cases, identical to the requirements for other conventional and rotary wing aircraft. Where two different separate sets of flight controls exist, such as in a convertiplane, it may be possible to eliminate part of the duplication in one, or both, of the systems provided that control of the system normally used for landing is maintained in the event of engine failure.

3.1.8.1 Conversion Mechanisms - Conversion mechanisms, if required, shall be powered in such a way that conversion can be accomplished at any time, regardless of engine failure, hydraulic system failure, etc.

Rationale: Covered in 3.1.1.2 (added)

3.1.8.2 Automatic Flight Control System, Hovering Flight - The AFCS shall control the moment generating devices (reaction controls, thrust modulation controls, etc.) and possibly

thrust to provide stability augmentation, attitude hold, altitude hold, control stick steering or other modes of operation as specified in the applicable system specification.

3.1.8.2.1 Attitude Hold (Pitch, Roll and Yaw) - During the attitude hold mode, the aircraft's selected attitude in the pitch, roll, and yaw shall be maintained within a static accuracy ~~of ± 1 degree, with respect to the gyro reference~~ as specified in the applicable system specification. The attitude transients in pitch, roll, and yaw shall be well damped ~~and shall not exhibit a damping factor of less than 0.5~~ with a minimum damping factor as specified in the applicable system specification.

Rationale: Arbitrary limits for all aircraft can penalize the mechanization for some aircraft and would be inadequate for others, depending on the mission.
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3.1.8.2.2 Stick Steering - The steady state relationship between stick force and pitch and roll rate or pitch and roll attitude shall be as specified in the applicable system specification. If the pitch and roll rate of the aircraft is proportional to the stick force, the aircraft shall maintain its existing pitch and roll attitude when the stick force is released. Where proportionality between stick force

and pitch and roll attitude is required, trim button command shall be provided to obtain and hold any desired pitch and roll attitude. The rate of yaw shall be proportional to the pedal force and the aircraft shall maintain its existing heading after release of the pedal force. Unless otherwise specified in the applicable system specification, a force supplied to the thrust control shall cause a proportional climb, or sink, rate of the aircraft and the aircraft shall maintain its existing altitude when the force is released.

~~The transient caused by a sudden application of control forces shall be well damped.~~ Sudden application of control forces shall have a minimum damping factor as specified in the system specifications.

Rationale: Words "well damped" do not allow specific mechanization criteria ... without adequate specifications, the mechanization can have reliability and maintainability penalties.

3.1.8.2.3 Transition - The transition from one set of controls to another set shall be smooth and shall not cause undesirable transients.

3.2 System Installation Requirements

3.2.1 Strength - The overall strength of the flight control systems shall be in accordance with the applicable portions of ~~MIL-A-8860~~ MIL-A-8860. The components of the systems shall be designed ~~in accordance with the strength requirements of MIL-A-8860, MIL-C-6021, and MIL-F-7190. Care shall be exercised to assure no parts of the system or components will be subjected to operation, either intermittently or continuously, at loads greater than for which the part has been designed.~~ to the strength requirements of the military specifications pertaining to those items.

Rationale: MIL-A-8860, MIL-C-6021, MIL-F-7190 do not cover all components.

3.2.2 Rigidity - The rigidity of the flight control systems shall be sufficient to provide satisfactory operation and to enable the aircraft to meet its stability, control, and flutter requirements as defined in the ~~applicable portions of MIL-F-8783, MIL-A-8870, and MIL-A-8860.~~ system performance specification. Individual components shall be sufficiently rigid to withstand normal handling and servicing and shall not become adversely deformed under operating loads or airframe structural deflections. If, due to the use of high gain control systems or very flexible aircraft structure,

or both, it appears that structural deflections can cause undesirable control system inputs, it may be necessary to provide structural compensation in the control system. This may be accomplished by several means, such as structurally tying pivot points in the control linkage to the control valve or cylinder. It is also possible to design structural compensation systems which tend to remove part of the control input signal as high load factors are approached, this acting as a structural protection device.

Rationale: Requirements over those of MIL-F-8785, MIL-A-8870, and MIL-A-8865 may be applicable for the particular aircraft.

3.2.3 Fatigue - The fatigue life of the flight control systems shall be designed in accordance with MIL-A-8866 and shall ~~be equal to, or better than, that of the airframe structure~~ meet the life requirements defined in the system performance specifications.

Rationale: The fatigue life of aircraft does not relate directly to cycles and stress levels on the flight control components; therefore, the particular cycle and stress loading life as well as the fatigue life hours must be specified in order that the design meet the required reliability.

3.2.4 Friction and Free Play - Friction and free play in primary control systems shall be kept to a practicable minimum. In no case shall the friction and free play values exceed those given in MIL-F-8785.

3.2.5 Control System Routing - Within the limitations and requirements contained elsewhere in this specification,

ALL/PORTIONS/OF/THE/CONTROL/SYSTEM//INCLUDING/CABLES//PUSH/PULL/RODS//FLUID/LINES//AND/ELECTRICAL/WIRING/SHALL/BE/ROUTED/THROUGH/THE/AIRCRAFT/IN/THE/MOST/DIRECT/MANNER/OVER/THE/SHORTEST/POSSIBLE/DISTANCES/BEFORE/POINTS/BEING/CONNECTED//IT/IS/NECESSARY/THAT/PUSH/ROD/AND/CABLE/ROUTING/BE/DETERMINED/EARLY/IN/THE/DESIGN/STAGE/OF/THE/AIRCRAFT/PRIOR/TO/SELECTION/OF/THE/LOCATION/FOR/THE/LARGE/EQUIPMENT/SO/THAT/IT/WILL/NOT/BE/NECESSARY/TO/ROUTE/THE/CONTROL/SYSTEM/AROUND/THIS/EQUIPMENT//DIRECT/ROUTING/WILL/IMPROVE/CONTROL/SYSTEM/RESPONSE//REDUCE/FRICTION/VALUES//REDUCE/WEIGHT//AND/INCREASE/RELIABILITY//WHERE/POSSIBLE//CONTROL/DEVICE/ACTUATORS/SHALL/BE/ATTACHED/DIRECTLY/TO/THE/CONTROL/DEVICE/TO/AVOID/TRANS-MITTING/HIGH/LOADS/THROUGH/OTHER/PORTIONS/OF/THE/CONTROL/SYSTEM/ the control system routing will be through the aircraft in the most direct manner, consistent with the survivability and reliability requirements for the aircraft.

Rationale: Routing affects survivability and reliability of the flight control system. Depending on the aircraft requirements, the routing can vary from direct to very indirect.

3.2.5.1 System Separation - Where duplicate cable, push rod, electrical, or fluid systems are provided, these systems shall be separated as far as possible to obtain the maximum advantage of the duplicate system with regard to vulnerability from gunfire, engine fires, ice formation, jamming by foreign objects, etc. Where possible, parallel systems should be on opposite sides of the fuselage, opposite sides of the wing spar, or similarly separated. Adequate consideration should be given to the clearance between flight control system components and structure or other components to insure that no possible combination of temperature effects, air loads, structural deflections, build-up of manufacturing tolerances, etc., can cause binding or jamming of any portion of the control systems.

3.2.5.2 Vulnerability - Maximum advantage shall be taken of the shielding afforded by heavy structural members, existing armor plate or other equipment for the protection of important components of the control systems, where necessary.

3.1.2.6//Accessability//and//Serviceability//The//flight//control
systems//and//components//shall//be//assigned//for//easy//accessability
and//servicing//Components//shall//be//designed//installed//
located//and//provided//with//access//doors//so//that//inspection//
rigging//removal//repair//and//lubrication//can//be//readily
accomplished//without//major//disassembly//of//the//aircraft//Swivel
able//provision//for//rigging//pins//or//the//equivalent//shall
be//made//for//locating//and//holding//each//control//system//component
to//facilitate//correct//rigging//of//the//control//system//and//to
permit//removal//of//components//including//the//control//surface//
without//disturbing//the//rigging//Special//tools//required//for
installation//and//rigging//of//the//control//systems//shall//be//kept
to//a//minimum//and//shall//be//in//accordance//with//MIL-STD-883C
Care//shall//be//taken//to//avoid//installation//of//items//which//may
require//replacement//in//areas//where//removal//and//reinstallation
is//not//possible//such//as//torque//nuts//in//wings//

3.1.2.7//Safety//Systems//and//components//shall//be//designed
to//provide//a//maximum//of//safety//to//personnel//during//the//course//
of//maintenance//maintenance//and//pre-flight//checking//Adequate
provisionary//warnings//and//information//shall//be//affixed//to
components//when//ordered//essential//and//shall//be//supplied
with//instructions//or//maintenance//provisionary//warnings//and
information//shall//be//available//to//the//systems//or//components

operating/installations/used/for/preflight/testing//Safety
 factory/provisions/shall/be/made/to/prevent/personnel/from
 being/accidentally/subjected/to/injurious/voltages/or/current/
 temperatures/or/motions/of/component/parts/

3.2.7/Maintenance/Provisions/+/Systems/and/components/shall
 be/designed/to/provide/for/ready/accessibility/and/for/connection
 of/such/test/equipment/as/may/be/required/for/field/maintenance/
 Design/of/equipment/should/include/provisions/for/the/connection
 of/circuit/or/other/test/facilities/by/test/point/terminals
 or/connections/leading/to/selected/positions/in/the/system
 or/components//Actual/locations/should/be/determined/by
 the/system/or/component/design/and/as/specified/in/the/detail
 system/or/component/specification//Sufficient/test/points
 should/be/provided/to/facilitate/location/of/the/most/probable
 malfunction/which/may/be/expected/to/be/encountered/in/service
 usage//Excessive/numbers/of/test/points/shall/be/avoided
 as/well/

3.2.8/Foolproofness/+/All/control/systems/shall/be/designed
 so/that/incorrect/assembly/and/reversed/operation/of/controls
 is/impossible/

Rationale: These paragraphs should be a part of the
 new maintainability section 3.3.38.

3.2.9 Fouling Preventing - All elements of the flight control system shall be suitably guided, protected, or covered in all compartments where it is possible for them to be fouled by dropping of articles, loading of cargo, changing of engines, etc.

3.2.10 Drainage - Adequate provisions shall be made to drain control system components subject to the accumulation of moisture or fluid leakage.

3.2.11 Hydraulic Systems - Hydraulic systems shall be in accordance with the requirements of MIL-H-5440, and shall comply with the design objectives of 3.1. Cylinders and actuating systems should be designed to obtain minimum cylinder movement to alleviate the need for hydraulic hoses or swivel joints. Hydraulic line routing shall be such that slack control cables cannot hook or chafe on tubing loops during tightening of the cables. In order to obtain the desired action from the control systems, hydraulic bypass provisions may be necessary to prevent fluid lock or excessive friction loads when failure of the hydraulic system occurs. Bypassing should normally occur automatically when system pressure drops below the minimum acceptable value for actuation. When manual control is possible following hydraulic failure, provisions

should be made to permit bypassing of the hydraulic systems for checkout purposes and to permit pilot training of the emergency manual system. When dual hydraulic systems are provided, there shall be adequate provisions or methods for readily checking the condition of both systems prior to flight without the benefit of ground support equipment.

3.2.11.1 System Pressure - Systems which use a pressure lower than the full hydraulic system pressure shall be designed to withstand and operate under the full pressure system or shall have a relief valve installed after the pressure reducer if the full pressure would be detrimental or dangerous.

3.2.11.2 Pilot Warning - Warning of hydraulic system failure shall be provided to the pilot in the form of a red or amber warning light.

3.2.11.3 Filters - ~~Five/ten/micron/filters/shall/be/installed immediately/ahead/of/each/power/control/valve/unless/it/can be/shown/that/silting/will/not/occur/~~ Filters of a micron rating sufficient to prevent silting shall be installed ahead of each control valve unless it can be shown that silting will not occur with the normal aircraft hydraulic system cleanliness rating. "Sifting" is the deposition of fine particles of dirt and other contaminates in power control valves causing

high breakout forces and poor performance, particularly if valve leakage rates are low.

Rationale: 5-10 micron filters may not prevent silting. Silting depends on valve clearnace plus particular cleanliness of the hydraulic system. Inclusion of filters on an arbitrary basis of a arbitrary rating degrades reliability/maintainability.

3.2.11.4 Ground Checkout - The hydraulic systems shall be designed and installed in such a manner that ground checkout of all systems, including automatic control systems, can be made by the use of a standard dual system hydraulic test stand without the necessity of reservicing any of the systems after completion of testing.

3.2.12 Torque Transmission Systems

3.2.12.1 Flexible Shafting - Flexible shafting may be used in flight control systems provided that minimum bend radius, rated rotational speed, and rated torque are not exceeded, and a testing program shows that extreme temperatures and other operational variations and environments do not adversely affect the installation. Flexible shafts shall be installed with the fewest possible bends and shall be securely fastened to supporting structure at close intervals. Installations

which require high response rates shall normally not utilize flexible shafting.

3.2.12.2 Torque Tube Systems - In the design of torque tube systems, consideration must be given to airframe deflections, differences in linear expansion due to temperature, impact loadings due to actuators contacting positive stops, etc., to provide adequate compensation for these effects. A minimum of parts, joints and related components shall be used to accomplish the required purpose; however, it must be possible to remove the torque tube sections from the airframe and replace them readily. Attachment bolt size, location in torque tubes, and attached components, shall be designed to give maximum strength and durability while keeping the number of attaching bolts to the minimum. In some cases one large bolt is as strong as two small bolts, and the larger bolt installation weakens the torque tube fitting less than two small bolts. Clearance holes through structure should be adequate to insure clearance of the torque tubes throughout the maximum airframe deflections.

3.2.12.2.1 Supports - All torque tubes shall be mounted on anti-friction bearings (preferably self-aligning) spaced at close enough intervals to prevent undesirable bending or whipping, or both, of the torque tubes.

3.2.12.2.2 Tubes - Tubes shall have a minimum wall thickness of 0.035 inch and shall be seamless, except that steel tubes, seam welded by the electrical resistance method may be used. Consideration shall be given to the natural frequency of vibration of the tubes with respect to vibrations set-up in the aircraft.

3.2.12.3 Universal Joints - Universal joints or flexible couplings shall be installed as required to prevent binding of systems due to misalignment of the supports, or deflection of the aircraft structure. Universal joints shall not be used for angularities greater than that recommended for the specific component by the manufacturer.

3.2.12.4 Slip Joints - Splined slip joints or suitable means shall be used to absorb linear dimensional changes due to structural deflection. Adequate engagement shall be provided to insure that disengagement will not occur.

Rationale: Restriction to spline slip joints is too limited and does not allow use of potentially more reliable techniques.
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3.2.12.5 Warning Placards - When torque tubes are located where maintenance personnel or crew members can (or "are able

to") use them for hand holds or steps, placards shall be installed warning against this practice.

3.2.13 Cable Systems - Cable systems, in addition to meeting the other requirements of this specification, shall meet the following additional requirements.

3.2.13.1 Clearance - Clearance between adjacent cables shall be at least 3 inches to facilitate proper installation, to insure easy maintenance, and to prevent cables from chafing. Suitable fairleads or guides shall be provided as required.

3.2.13.2 Fairleads - Fairleads shall be used wherever necessary to keep cables from chafing and slapping against each other and adjacent parts of the aircraft. Fairleads shall not cause any angular change in the direction of the cable. Fairleads shall be split to permit easy removal unless the size of the hold is sufficient to permit the cable with swage terminals to be threaded through. Where space permits, the fairleads should clear the primary flight control cables by a minimum of 1/4 inch. The cables may rest against the lower edge of the hole in fairleads on long straight cable runs where the cables would normally sag due to their own weight even though properly rigged.

3.2.13.3 Guards - Guards shall be installed at all sheaves (pulleys, sectors, drums, etc.) to prevent the cable from jumping out of the groove of the sheave. Guards shall be installed at the approximate point of tangency of the cable to the sheave. Where the cable wrap exceeds 90 degrees, one or more intermediate guards shall be installed. To prevent binding of the sheave due to relative deflections in the aircraft structure, all guards shall be supported by the supporting brackets of the part which they guard. Additional guards shall be installed on sectors at the point of entry of the cable into the groove from its attachment. The design of the rubbing edges of the guard and the selection of materials shall be such as to minimize cable wear and prevent jamming even when the cable is slack.

3.2.13.4 // Cable Loads // Cable loads shall be within the limits specified in AFSC M80-1 // Cables shall not be subjected to critical bends at the junction with cable terminals or other attaching points such as drums, horns, etc.

Rationale: AFSC M80-1 is obsolete.

3.2.13.5 Cable Alignment - Cable alignment with fixed mounted pulleys shall be within the limits specified in AFSC M80-1 // Handbook DH-2-1.

Rationale: AFSC M80-1 is obsolete.

3.2.13.6 Attachments - Terminals, disconnect fittings, turnbuckles, etc. shall be provided as necessary to facilitate rigging and maintenance of the cable systems.

3.2.13.7 Location of Attachments - Cable disconnects shall be located and designed so that it is physically impossible to misconnect in any manner, either cables in the same system or the cables of different systems. Cable disconnects and turnbuckles shall be so located that they will not hang up on adjacent structure or equipment or on each other and will not snag on cables, wires, or tubing.

3.2.13.8 Turnbuckles - Turnbuckle terminals shall not have more than three threads exposed at either end. All turnbuckle assemblies shall be properly safetied in accordance with MS33591.

3.2.13.9 Cable Tension - Cable tension regulators shall be provided, as required, to insure positive cable tension under all operating conditions. In the interest of reducing control system friction, initial tensions should be held to the lowest practicable values that provide safe and satisfactory operation considering probable application of limit loads to the system and the effect of temperature variations.

3.2.13.10 Cable Size - Cable size shall be adequate to meet the load requirements of the system with ample safety factors to compensate for wear and deterioration where pulleys, fairleads, etc., are encountered. However, cable size shall also reflect permissible cable stretch, pulley friction values, and other variables which effect system performance.

3.2.13.11 Sheave Spacing - In any given cable run, sheaves (pulleys, sectors, drums, etc.) shall not be installed closer together than the maximum length of cable travel so that no portion of the cable shall ever pass over more than one sheave.

3.2.14 Push-Pull Rod Systems - Push-pull rods shall be designed to accommodate easy servicing and rigging and shall not have more than one adjustable end. Push-pull rods shall not be used to carry heavy compression loads, but where both tension and compression loads exist, the greatest load should place the rod in tension.

3.2.14.1 Terminals - The fixed end of the rod and its attachment must be such that rotation of the rod is prevented at all times. The adjustable end must be of the clevis type or join a clevis type in such a manner that it is also prevented from rotating.

3.2.14.2 Supports - All push-pull rods shall be supported by suitable levers, bellcranks or roller guides to aid in preventing buckling and to prevent fouling in the event of rod failure.

3.2.14.3 Clearance - In general, the clearance between push-pull rods and torque transmission components and aircraft structure and equipment shall meet the requirements of 3.2.13.1. In complex assemblies such as mixer mechanisms, gear ratio changers, etc., a minimum clearance of 1/16 inch between adjacent moving components is permissible. Consideration shall be given to the effect of tolerances in manufacture, assembly, installation, rigging, normal wear, and normal deflection.

3.2.15 Control Chain - Control chain may be used in those applications where other means of power transmission are not suitable. When it is used, it will be of standard aircraft quality and shall conform to MS26534. The connecting links shall not use spring clips for retention, but shall use standard AN, non-hardened, cotter pins. Roller chain shall be subject to the approval of the procuring activity.

3.2.16 Electrical and Electronic Systems - Electrical and electronic installations as required for the components of

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the flight control systems shall be designed and installed in accordance with MIL-STD-704, MIL-E-7080, MIL-E-25499, MIL-I-8700, MIL-E-5400 and all other existing system and component specifications. Systems which are especially critical for aircraft flight control, or which would jeopardize safety of flight if malfunction occurred, shall, to the greatest extent possible, be provided with built-in limiting devices, emergency disconnects, alternate systems, and other safety measures as required to insure safe operation of the systems. Systems for use as primary flight control systems shall, except for power source, have no interconnection with any other electrical system. Radio interference created by the systems and components shall be within the limits of MIL-E-6051 and MIL-I-26600, respectively.

3.2.16.1 Overload Protection - Overload protection of the primary power wiring to the system or component shall be provided by the airplane contractor. Installation requirements of the system or component specification shall specify the values of starting current versus time, surge currents if applicable, normal operating current and recommended protective provisions. Additional protection as necessary shall be provided within the system or component. Such

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circuit protection shall not be provided in signal circuits or other circuits where opening of the protective device will result in the application of an unsafe control motion of the aircraft.

3.2.16.2 Electrical Power - The AFCS shall operate satisfactorily in accordance with the performance requirements specified herein when supplied power conforming to the applicable requirements of MIL-STD-704.

3.2.16.2.1 Emergency Limits - Reduced AFCS operational performance is permissible under emergency conditions provided safety of flight is not compromised and no damage shall result to the AFCS equipment. The AFCS shall resume normal operation automatically when the specified values return to the operating limits.

3.2.16.2.2 Phase Separation - In systems affecting safety of flight, which use ac power, the phase connections shall be separated throughout the systems sufficiently that phase reversal is impossible, and that incorrect electrical connections are readily apparent to the pilot.

3.2.17 Calibration Adjustments, Controls and Knobs

3.2.17.1 Controls and Knobs - Controls and knobs requiring manipulation in flight shall operate smoothly with negligible backlash or binding. Means shall be provided to prevent movement due to shock or vibrations encountered in service. Controls and knobs shall be readily accessible and of a size and shape for convenience and ease of operation under all service conditions. The direction of motion of the knob or control and the location within the cockpit shall be in accordance with the requirements of MIL-STD-203.

3.2.17.2 Calibration Adjustments - Calibration adjustments required for ground maintenance of the system or component shall be kept to a minimum. The system objective shall be to concentrate all required ground adjustments in one major component of the system. It is preferred that the removal of an auxiliary cover plate be necessary for access to calibration adjustment. Suitable means shall be provided to prevent a change in adjustment from occurring due to shock or vibrations encountered in service. These adjustments shall be labeled, indexed, and marked in such a manner that only visual means are necessary for setting the desired adjustment.

3.2.18 Dynamic and Static Pressure Systems and Air Data Systems - Whenever flight control system components require connection to pitot tubes or static ports, the required performance shall be obtainable from pitot tube and static port installations conforming to the requirements of MIL-F-26292. Compensation of static or dynamic signals, which may be required to obtain desired performance, shall be accomplished within the system or components. Whenever the AFCS requires outputs from a central air data system, the characteristics

of the outputs, both static and dynamic, shall be submitted by the AFCS contractor at the earliest possible date in order to insure compatibility between the AFCS and the air data system.

3.3 System Component Design Requirements

3.3.1 General - The design of components which are used in flight control systems shall conform to Government specifications if specifications exist for that particular component. If component specifications do not exist, all pertinent general Government specifications regarding materials, workmanship, processes, etc., shall be adhered to where possible. AN standard or previously approved components shall be used where possible and when suitable for the purpose. Components shall be designed to meet the reliability requirements of the component specification as determined by the system reliability requirements specified in 3.1.

3.3.2 Bearings

3.3.2.1 Antifriction - Approved type ~~ball~~ bearings, in accordance with MIL-B-3990, MIL-B-6038, MIL-B-6039, ~~and~~ MIL-B-7949, MIL-B-8942, MIL-B-8943, or MIL-B-81820 shall be used throughout the flight control system, except as

indicated in the following paragraphs. ~~In the event design limitations do not permit the use of ball bearings, prelubricated, shielded roller or needle bearings may be used in accordance with MIL-B-3990 and FF-B-183.~~ Where needle or roller bearings are used, consideration shall be given relubrication provisions. The inner race of the bearing shall be clamped to prevent rotation of the inner race with respect to the pivot bolt. Bearing installation shall be arranged in such a manner that failure of the rollers or balls will not result in a complete separation of the control. Direct axial application of control forces to a bearing shall be avoided if possible. In the event such an arrangement is necessary, a fail-safe feature shall be provided.

3.3.2.2 Spherical Bearings - Where design limitations preclude the use of antifriction bearings, spherical type, plain bearings approved by the USAF may be used. When used, spherical bearings shall have adequate provisions for lubrication.

3.3.2.3 Journal Bearings - The use of plain type journal bearings shall be avoided. However, where substantiated, and where play and friction are not major consideration, journal or plain bearings in accordance with MIL-B-5628 and MIL-B-5629 with adequate and accessible provisions for lubrication may be used.

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3.3.2.4 Sintered Bearings - Sintered type, or oil impregnated bearings shall not be used in those parts of the flight control systems which have slow moving or oscillating motions. Fast moving rotating applications such as in qualified motors and actuators are permissible. Bearings shall conform to MIL-B-5687.

3.3.3 Cable - Cable used for the actuation of flight controls shall be in accordance with MIL-C-5424. Nonmagnetic, corrosion-resistant cable, when required, shall conform to MIL-C-18375. Cable assemblies using swaged type terminals shall be proof load tested in accordance with MIL-C-5688.

3.3.3.1 Cable Terminals - Standard AN cable fittings in accordance with MIL-T-6117 and MIL-S-5676 shall be used whenever possible.

3.3.4 Turnbuckles - Turnbuckles used in flight control cable systems shall be in accordance with MIL-T-5685.

3.3.5 Pulleys - Approved MS standard pulleys in accordance with MIL-P-7034 shall be used in flight control systems.

3.3.6 Push-Pull Rods - Push-pull rods must be designed to meet the requirements of 3.2.14 with regard to preventing rotation of the members. Rod ends in accordance with 3.3.2

shall be installed as required and shall be locked with NAS 513 washers and NAS 509 nuts.

3.3.7 Tie Rods - Tie rods and terminals, if required, shall be in accordance with MIL-T-5684 and MIL-T-5683.

3.3.8 Universal Joints and Flexible Couplings - Universal joints and flexible couplings shall be in accordance with MIL-J-6193 and MIL-U-3963. Other flexible couplings may be used following approval of the procuring activity and determination by the contractor that they are adequate from static, dynamic, impact, and fatigue considerations. The design shall be such that assembly, installation, and maintenance can be readily accomplished with little possibility of error.

3.3.9 Actuating Cylinders - Hydraulic cylinders used for actuating flight control devices shall be designed in accordance with MIL-C-5503 with the exception of the life cycling test which shall be as required in 3.3.9.1 and 3.3.9.2.

3.3.9.1 Manually Controlled Systems - Manually controlled primary flight control systems shall have the actuating cylinders and valves (see 3.3.10) cycled for ~~at least~~ 2,000,000/cycles/under the following schedule

10,000/cycles/+full/stroke/and/load

290,000/cycles/+one-half/stroke/and/load

700,000/cycles/+10/percent/stroke/and/load

1,000,000/cycles/+2/percent/stroke/and/load

The/cycles/day/be/intermixed/as/desired/and/packing

changes/are/permittred/after/each/300,000/cycles/

the number of cycles and schedule specified in the
system performance specification in order to establish
a nominal reliability consistent with the system
performance requirements.

Rationale:

Reliability requirements and demonstration
of the same vary from aircraft to aircraft.

3.3.9.2 Automatically Controlled Systems - In systems
which receive inputs from an AFCS, the requirements
will be as in 3.3.9.1 except *that/the/number/of/cycles
required/at/2/percent/load/and/stroke/shall/be
increased/10/4,000,000/* for modifications stated in
the system specification.

Rationale:

Reliability requirements and demonstration of
the same vary from aircraft to aircraft.

3.3.9.3 Environmental Conditions - During the life cycling, the ambient temperature conditions and the hydraulic fluid shall be as expected to exist in the aircraft. In addition to the test requirements specified in MIL-C-5503, the tests specified in MIL-STD-810 shall be accomplished.

3.3.9.4 Design Details - If bypass provisions are necessary, they shall be provided integrally in the cylinder and valve assembly. Bypass mechanisms shall operate from the system pressure and shall be automatic in opening and closing as hydraulic pressure drops or increases to a value specified in the detail specification. Where dual cylinders are required, they may be designed as tandem cylinders, in one barrel, provided there is no interconnection between the two which will permit interflow and permit one failure to jeopardize both systems. Retaining rings shall not be used in assembling the cylinders, but rather, all end caps, etc., shall be secured by threading to the barrel or other components and be lock wired. Cylinder rod ends shall be appropriately fastened to the piston rod and suitably safetied to prevent relative rotation.

3.3.10 Mechanical Hydraulic Power Control Valves - Specification MIL-V-7915 shall be used as a general guide for the design and testing of the power control valve utilized for mechanically controlling the control device hydraulic actuators. These valves shall be designed to give smooth operation with flow rate vs spool displacement curves as linear as possible. Internal leakage shall be a practicable minimum, consistent with permissible operating forces, extreme temperature effects, control sensitivity, and other governing factors. The control valves shall be connected or attached to the actuating cylinders during the endurance, extreme temperatures, vibration and salt spray tests.

3.3.11 Electro-Hydraulic Power Control Valves - Electro-hydraulic power control valves shall be designed in accordance with MIL-V-27162. Complete environmental testing is required for these components.

Life and environmental tests shall be consistent with those required for the other parts of the system, such as the actuating cylinder.

3.3.12 Electromechanical Actuators and Electric Motors -

Electro-mechanical actuators and actuating systems shall be designed in accordance with MIL-A-8064. Electric motors shall be in accordance with MIL-M-8609 and MIL-M-7969. The life test shall ~~normally include 100,000 cycles as specified in MIL-A-8064. However, in the event that an automatic flight control system injects autortrim signals into the actuator, the life cycling shall be at least 1,000,000 cycles at suitable frequency, amplitude, and load while exposed to the anticipated aircraft environmental conditions. Greater amounts of cycling shall be used if appropriate and reasonable, be consistent with the required system reliability requirements as specified in the system specification.~~

Rationale:

Life test needs to reflect reliability requirements of the particular aircraft.

3.3.13 Flexible Controls - In installations where they are approved, flexible push-pull controls shall conform to MIL-C-7958.

3.3.14 Cable Tension Regulators - Tension regulators shall be of a size which will insure that the cable system being regulated will remain at the proper tension at all times. Lock wire provisions for the adjusting mechanism shall be provided. The design shall be as simple as possible to accomplish the desired result and shall permit easy adjustment of the cable tension. Integral calibration shall be provided to show proper cable tension without the use of external tensimeters or other equipment.

3.3.15 Retaining Rings - Standard retaining rings may be used in locations where they are not subjected to heavy loads and where their loss would in no way compromise control of the aircraft. Each installation utilizing retaining rings must be approved by the procuring activity. Utilization of nonstandard retaining rings is subject to the approval of the procuring activity.

3.3.16 Electrical and Electronic Components - All electrical equipment in the control systems shall be designed and installed in accordance with MIL-E-5400, MIL-E-7080, MIL-E-25499, MIL-W-5088, MIL-A-8064, MIL-M-8609, MIL-E-4682, MIL-M-7969, and any other applicable specifications. Specific consideration shall be directed toward achieving simplicity, producibility, and maintainability of equipment. Internal construction techniques shall include, but not be limited to, the following items:

- a. Passive elements shall be mounted on a base so that the leads do not cross other leads or connections.

- b. Electronic parts shall be mounted so that ease of producibility and maintainability is assured. Whenever feasible,

parts such as resistors, capacitors, etc., shall be mounted in an even, regular, row type arrangement.

c. Electronic parts shall be derated to conform with service life, reliability, and confidence requirements.

d. Heavy electronic parts and assemblies shall be solidly mounted so that adverse effects when subjected to vibration and shock will be minimized.

e. Connectors shall be rigidly mounted and shall be of such construction that they will not warp or cause intermittent operation when subjected to large temperature differentials, vibration, and shock.

f. Cables shall be securely mounted and be so arranged as to cause negligible strain or stress on the connectors, and to minimize noise pickup.

g. Wiring cables shall be routed away from hot parts, such as resistors, etc., so as to minimize the possibility of damage or deterioration of the insulation.

h. When cooling air or heat sink techniques are not used, circuitry shall be so arranged as to insure as even a distribution of heat per unit area as is possible

i. When cooling air or heat sink techniques are used for heat dissipation, care shall be exercised to insure that the relatively cool operating parts are not adversely affected.

j. Redundant circuits shall be isolated to preclude catastrophic failure of one portion of the circuit from affecting any other portion of the circuit.

3.3.16.1 Electron Tubes - The number of tube types shall be kept to a minimum consistent with obtaining the specified performance with best design practices. The selection and application of electron tubes shall be governed by the applicable requirements of MIL-E-4682. Where tubes are used, the related circuit design shall be such that the tubes will be operated at ratings and under conditions which will provide uniform performance and the best reliability during the life expectancy of the tube.

3.3.16.2 Electrical Tape - No pressure-sensitive (adhesive or friction) fabric or textile tape shall be used. Nonmoisture absorbing tape may be used for mechanical purposes, with the approval of the procuring activity.

3.3.16.3 Switches

3.3.16.3.1 Toggle Switches - Toggle switches shall conform to the requirements of MIL-S-3950. The operating position requirements of MIL-E-5400 shall normally apply.

3.3.16.3.2 Rotary Switches - The use of rotary switches shall not be permitted unless specifically approved by the procuring activity.

3.3.16.3.3 Pushbutton Switches - The use of pushbutton switches shall require specific approval of the procuring activity. The design shall comply with the requirements of MIL-S-6743.

3.3.16.3.4 Special Switches - The design of manually actuated special switches shall be subject to the approval of the procuring activity. All applications of special design switches shall comply with the performance and environmental requirements of this specification and the detail specification.

3.3.16.4 Semiconductors - Semiconductors selected for use in automatic flight control systems and components shall be in accordance with MIL-S-19500. They shall exhibit no transient or permanent change in operational rating which may affect the performance of the system or component when the system or component is subjected to the extremes of environmental and operating conditions specified herein and in detailed system and component specifications. Such operational ratings shall be considered as those characteristics pertinent to the system or component performance.

3.3.16.5 Saturable Reactors - Saturable reactors used in automatic flight control systems and components shall comply with the environmental and performance requirements specified herein and in detail system and component specifications.

3.3.16.6 Printed Circuits - Printed circuits and other similar miniaturization processes and packaging techniques used in automatic flight control systems and components shall comply with the environmental and performance requirements specified herein and in detail system and component specifications.

3.3.16.7 *Modular Design of Electronic Components - Modular construction should be used only to the extent that it will provide greater ease of maintenance or servicing with no compromise of reliability.*

3.3.16.7 Modularization - The equipment shall be functionally modularized at all levels of assembly/disassembly. Additionally, the following requirements apply to the entire equipment:

(1) The system replaceable assemblies shall be packaged in modular form easily removable for repair by replacement. As a design objective, system replacement assemblies shall weigh less than 40 pounds. No more than 10 percent of the system replaceable assemblies shall exceed 40 pounds in weight and no system replaceable assemblies shall exceed 80 pounds in weight. Each system replaceable assembly system shall be designed to have a Mean Time Between Failures (MTBF) as specified in the reliability allocation.

(2) Where feasible, components shall be packaged into discrete replaceable modules of such cost and reliability that disposal-on-failure rather than module repair is the most cost effective logistic support action. Performance, operability, design complexity, reliability, system life, functional use, supply support, equipment cost, fault isolation, repair costs, and equipment availability are typical trade-off factors to be considered when determining whether a module shall have several or many micro-electronic circuits, discrete components parts, etc.

Any module costing dollars or less (see
System Design Spec), having a reliability of 50,000
hours or greater MTBF shall be designed for disposal-
on-failure. Other modules require procuring activity
approval if the module is to be designed as
non-repairable.

Rationale: This is an important concept to organizational level maintenance. Failures are quickly remedied when the failed part can be unplugged and replaced by another unit with a minimum of analysis. Parts must be designed with the human factors in mind as well as the logistic costs.

3.3.16.7.1 Modules or subassemblies should not be smaller than that required to perform a single function. (As an example, an amplifier or power supply.)

3.3.16.7.2 Since connectors and receptacles represent a high percentage of electronic equipment failures, special emphasis shall be given to proper selection and application of those devices and their number shall be kept to a minimum.

3.3.16.7.3 Possible requirements for complex test equipment and test procedures shall be considered prior to adopting a modular design.

3.3.16.7.4 Modules intended for field replacement shall be so constructed that electronic parts or connector pins shall not be exposed outside the frame of the module.

3.3.17 Fastenings - In general, fastenings and other miscellaneous hardware used in flight control systems such as nuts, bolts, switches, relays, etc., shall be those for which Air Force, AN or MS standards exist. In cases where it is not obvious why nonstandard parts are used, justification shall be required prior to procuring activity approval. In applications for which no suitable AN standard part is available on the date of invitation for bids, commercial parts may be used provided they conform to all of the requirements of this and the detail specification. When nonstandard parts are used, the contractor shall maintain a file containing a data sheet in accordance with Figure 1 on each nonstandard part. This file shall be available for examination by the procuring activity at any time during the life of the contract. Particular care must be exercised in the selection of fasteners to insure ease and reliability of maintenance and to eliminate the possibility of their loss from critical connections. Ability to inspect installed fasteners to insure integrity and security must be assured.

3.3.17.1 Bolt Retention - Self locking nuts, drilled bolts, castellated nuts, cotter pins, plate nuts, safety wire, or some equivalent positive means of bolt retention, shall be used throughout the flight control systems. Self locking nuts shall not be used for critical applications such as attachment of rod ends to bellcranks, attachment of pulleys or quadrants to brackets, and attachment of trim actuators to structure, where a single attaching bolt is used to retain the component or connect the system. Alternate means of locking might include such devices as using drilled bolts with cotter pins installed below the nuts or using drilled head bolts and drilled nuts to permit installation of lock wire. When self locking nuts are used, they shall be in accordance with MIL-N-25027 and MS33588.

3.3.17.2 Spring Pins - Spring pins will not be permitted in primary flight control systems unless they are positively retained by some means other than their own spring effect. When they are used, they shall be installed in accordance with MS33547.

3.3.17.3 Bolts - Bolts smaller than 1/4 inch shall not be used to make single bolt connections, or connections which are essential to the proper functioning of the systems. They may be used in attaching brackets to airframes, etc., when several of the bolts are used in a single application.

3.3.17.4 Lock Wiring - All hardware and components which are not positively secured by other means, shall be secured by lock wire or cotter pins in accordance with MS33540 and MS33591. Turnbuckles shall be lockwired in accordance with MS33591.

3.3.18 Fairleads and Rubbing Strips - Fairleads shall be designed of suitable nonabrasive, nonhygroscopic material. Fairleads shall have holes of sufficient size to permit the passage of cable end fittings or shall be of the split type for easy removal. The design of the rubbing edges shall be such as to minimize cable wear and prevent jamming. Rubbing strips shall meet the same general requirements as fairleads.

3.3.19 Control Stick Grips - Unless otherwise specified, pilots control stick grips shall be in accordance with MIL-G-25561.

3.3.20 Control Wheels - Unless otherwise specified, control wheels shall be of the W type, 14 to 16 inches in diameter. They shall be constructed of a light-weight, nonhygroscopic, nonslippery, nonsticky black material with a low heat conductivity. The forward face of the portions gripped by the hand shall have corrugations to fit the fingers and provide a good finger-type grip surface.

3.3.21 Control Stick and Surface Dampers - Control surface and control stick dampers, if required, shall be completely defined by a detail specification in accordance with the requirements of each specific application. Such dampers will generally be either hydraulic or electro-mechanical and will conform to applicable specifications for those types of equipment. Dampers shall be designed so that they can be overpowered by the pilot in the event of failure or malfunction and shall have very low breakout friction and inertia forces. ~~(All dampers shall be life tested in accordance with the requirements for flight control cylinders in MIL-C-2503 and in addition, surface dampers which will be subjected to flutter conditions shall be subjected to cycling at the anticipated frequencies, amplitudes and loads for at least 10 million cycles. The dampers shall be capable of at least 500 hours flight time 1/2 of the 10 million cycles) without reserficing.~~

Amplitudes and loads for the number of cycles shall be specified in the system specification. The dampers shall be capable of an operational time without servicing which is consistent with the MTBF specifications for the particular aircraft.

Rationale:

Arbitrary cycling does not realistically reflect requirements of the particular aircraft.

3.3.22 Stability Augmentation System Servo Actuators -

Servo actuators for stability augmentation systems, either electro-mechanical or hydraulic, shall be designed and tested in accordance with the specifications covering that general type of equipment. ~~except that the~~ Life cycling shall be ~~increased to at least 3 million cycles at the anticipated frequencies, amplitudes, and loads.// Environmentally conditions during cycling shall be those expected in the aircraft installation~~ specified by the system specification to insure component life consistent with the MTBF requirements of the aircraft. Servicing or minor repair of the servo will be ~~permitted after one half of the 3 million cycles have been completed~~ allowed as specified by the system specification.

All other mechanical components of the stability augmentation system shall be cycled with the servo actuator to prove their integrity.

NONSTANDARD PART DATA SHEET

1. Part is used in _____ (Designation of major assembly)
2. Applications _____
3. Prime Contractor _____ 4. Contract No. _____
5. Description of Part:
6. Prime Contractor's Drawing No. _____ 7. Part No. _____
8. Actual Manufacturer _____ 9. Actual Mfgs Part
or Dwg No. _____
10. Previously used in _____ (Designation of major assembly)
_____ on Contract _____.
- (NOTE: Attach list of all known previous applications.)
11. Comparison between nonstandard part and standard part whose
characteristics are nearest to those required for the application:
(include reasons for not using standard part.)
12. Test Data and Comments: (Test data sheets and comments shall be
attached as necessary.)
- As the designated representative of the contractor I certify
that to the best of my knowledge the above information and data
are correct and the nonstandard part is suitable for its intended
use.
13. Authorized Contractor's Representative's Signature _____
14. Date: _____

FIGURE 1

3.3.23 Lubrication - Where applicable, lubrication of the components and systems shall be in accordance with MIL-L-6880. Lubrication fittings shall be in accordance with MIL-F-3541, MS15001, and MS15002-1 and -2.

3.3.24 Materials - The materials utilized in the components and systems shall be entirely suitable for the service and purpose intended. When Government specifications exist for the type material being used, the materials shall conform to these specifications. Nonspecification materials may be used if it is shown that they are more suitable for the purpose than specification materials.

3.3.24.1 Nonmagnetic Materials - Nonmagnetic materials shall be used for components for the automatic pilot, except magnetic materials may be used for screw fastenings, etc., where necessary for proper performance of the component or automatic pilot system, or both.

3.3.24.2 Shielding and Bonding on Finished Surfaces - Nonconductive oxides or other nonconductive finishes shall be removed from the actual contact area of all surfaces required to act as a path for electric current and from local areas to provide continuity of electrical shielding and bonding. All mating surfaces shall be clean and shall be carefully fitted to minimize radio frequency impedance at joints, seams and mating surfaces. The resultant exposed areas, after assembly at such joints or spots, shall be kept to a minimum.

3.3.25 Cleaning - The AFCS shall be thoroughly cleaned of loose, spattered or excess solder, metal chips or other foreign material after assembly. Burrs and sharp edges as well as resin flash which might crumble shall be removed.

3.3.26 Failure Analysis - All components and mechanisms in the flight control system shall be designed to present a minimum of possibilities for jamming due to foreign objects, such as on bell-cranks where an open area exists between the attaching member and the bellcrank in which foreign objects can lodge; linkages floating under negative "g"; hard-over signals caused by a mechanical or electrical failure; etc. Failure ~~analyses~~ modes, effects, and critically analysis (FMECA) shall be conducted on all systems to determine the end effects if any given component fails. A fault tree analysis should be utilized to determine these effects.

3.3.27 Control Devices and Attachments - Control devices and attaching means shall be structurally designed in accordance with MIL-A-8861. The rigidity of the surfaces and attachments shall be adequate to eliminate flutter or other undesired effects. If the surfaces are not balanced to prevent flutter in the event the surface actuator becomes disconnected, extra precautions, such as dual actuating rods, shall be taken to insure that the surface will not become disconnected from the actuators. Bearings, hinges, rod ends, etc., used in attachments shall be in accordance with the requirements of 3.3.2.

3.3.28 Pressurized or Sealed Equipment - Whenever pressurization or hermetic sealing is utilized to meet the requirements of this specification, and the design is such that the case must be opened for maintenance, the following provisions shall be met.

3.3.28.1 Case - The case shall be of a type that will permit opening and clearing for access to the equipment for repair and maintenance. The operation and performance of the equipment shall be unaffected by replacement and resealing in the case. The case shall be capable of withstanding any atmospheric pressure and temperature change developed under the required external operating conditions.

3.3.28.2 When possible and advantageous, external means shall be provided for observing performance or operationally checking the equipment without removal from the case.

3.3.28.3 Whenever the filling medium is a gas, it shall be noncombustible, of at least 98 percent purity, free of dust particles, and containing not more than 0.006 mg of water per litre. The filling medium shall be 100 percent helium, or a mixture of 88 to 92 percent nitrogen with the remainder helium. Whenever practicable, 100 percent helium shall be used. The absolute pressure of the filling medium shall be between one half and one atmosphere.

3.3.28.4 A filling tube of a malleable type metal shall be provided which can be formed into a recess in the case so as to be flush with the surface.

3.3.29 Control Panels - Unless otherwise defined in the detail system or component specification, engaging, transfer, selector and maneuvering switches and controls not designed for installation on the aircraft's control column, nor to fulfill other special installation requirements, shall be designed to comply with the applicable requirements of MIL-C-6781.

3.3.29.1 Dial Markings - The style and proportion of numerals and letters used on dials shall conform to MS33558. Such markings shall be visible from any point within the frustrum of a cone, the side of

which makes an angle of 30° with the perpendicular to the dial and the small diameter of which is the dial aperture. Parallax shall be kept to an acceptable limit.

3.3.29.2 Fluorescent-Luminescent Material - All makings requiring fluorescent-luminescent materials shall conform to MIL-L-25142, type I or III as applicable.

3.3.30 Identification of Product - Equipment components, assemblies and parts of flight control systems shall be identified in accordance with MIL-STD-130.

3.3.31 Interchangeability - Like assemblies, subassemblies, and replaceable parts shall meet the requirements of MIL-I-8500 regardless of manufacturer or supplier. Items which are not functionally interchangeable shall not be physically interchangeable unless specifically approved by the procuring activity.

3.3.32 Moisture Pockets - Pockets, well, traps and the like into which water, condensed moisture or other liquids can drain or collect shall be eliminated, or properly drained.

3.3.33 Cooling - The design and location of each component shall be consistent with the maximum permissible operating temperature expected under all conditions of service as defined by the requirements of this and other applicable specifications.

3.3.33.1 Components Located in High Ambient Temperatures - Components which, when installed in aircraft, can reasonably be expected to be subjected to high ambient temperatures during ground or flight operation of the aircraft, shall be so designed that such temperatures shall result in no damage or impairment of performance of the component. Forced cooling, air blast cooling, or other similar cooling aids shall not be considered in the design without prior approval of the procuring activity. Such approval shall be predicated upon the feasibility of a considerable size and weight reduction and assurance that adequate cooling provisions shall be provided at the anticipated aircraft installation location.

3.3.33.2 Heat Dissipation - Components, which under operation, dissipate heat shall be operable over the temperature range encountered in service. The following design techniques shall be employed, in order of preference as listed, to maintain heat rise within operable limits:

a. Use of thermal characteristics of finishes, induced draft and ventilation by means of baffles, internal vents and louvers and packaging in heat dissipating fluids.

b. Air vents with adequate protection against climatic and environmental service conditions to all exposed parts.

c. Forces cooling, if above means are still insufficient, or if a significant reduction in overall size or weight can be realized. Fans or blowers employed shall operate from the aircraft's a-c power supply.

d. If heat dissipation requirements are such that the use of heat exchangers, liquid, air blast or evaporative coolants must be resorted to, or must be provided in the aircraft installation, prior approval of the procuring activity shall be required. Such approval shall be predicated upon availability of required provisions at the anticipated aircraft installation location.

3.3.34 Orientation - Normal installation position or range of positions shall be as specified in the equipment specification. However, partial or complete inversion of the equipment, as encountered during flight, with the equipment either nonoperative, in standby operation, or in full operation shall result in no permanent detrimental effect on the equipment's performance.

3.3.35 Cases and Racks - In the design of AFCS components, minimum size, shape, weight and number of components, and integration with other system components where possible, shall be the governing factors. Electronic and electrical components, where feasible, shall be designed for installation in aircraft in accordance with the requirements of the electronic equipment rack system, unless otherwise defined in the equipment specification. The electronic equipment rack system requirements are defined in MIL-C-172.

3.3.36 Standardization - When possible, contractor designed equipment which has been approved for use in some models of aircraft shall also be used in later model airplanes if the installation and requirements are similar. This procedure will reduce supply problems, test and qualification expenses, and provide tried and proven equipment .
~~which should be more reliable.~~

3.3.37 Reliability - The design of equipment and components shall meet as a minimum the numerical reliability and confidence level specified in the contract. This specification shall completely define the reliability in terms of a conditional probability, at a given confidence level, for the equipment to perform its intended functions, with specified success and failure criteria, within specified performance limits, at a given age, for a specified length of time when used in the manner and for the purpose intended while operating under a specified application and operation environment, or while under specified stress conditions. MIL-STD-781 Reliability definitions shall apply.

Rationale:

A requirement is needed for complete definition of reliability heretofore usually missing from systems and equipment specifications. Reference should be made to the contract as the source for qualitative and quantitative reliability and confidence requirements; to be complete reliability must be defined in terms of:

- (1) Conditional probability
- (2) Confidence level

- (3) Intended functions
- (4) Success and failure criteria
- (5) Performance limits
- (6) Age of equipment (at specific number of hours or cycles)
- (7) Life and manner of use
- (8) Stress application factors
- (9) External stress or environmental operation factors

3.3.37.1 Reliability program - The contractor shall prepare and conduct a reliability program using MIL-STD-785 or comparable specification as a guide. The contractor's reliability program shall be presented in preliminary form with the proposal and in final form 30 days after receipt of contract or purchase order.

Rationale:

The management system used to create the hardware is just as important as attention to the hardware system itself in obtaining reliability goals throughout the equipment life cycle. The disciplines for both systems should be carefully planned and integrated.

3.3.37.2 Reliability Analysis - All life, safety, and function requirements related design characteristics of the system, and components covered by this specification shall be subject to reliability analysis. Reliability requirements shall be established at each level of design and certified to a designated confidence level under specified environmental conditions.

Rationale:

Reliability analysis is at the heart of reliability engineering. Reliability requirements stem from design objectives for life, safety, and function, thus all should be traced, identified, and analyzed at each level of the system down to piece parts.

3.3.37.2.1 Systems Reliability Analysis - System reliability analysis shall be based on:

- (1) System design objectives for life, safety and function
- (2) Functional configuration and boundaries of the system desired
- (3) Anticipated use conditions
- (4) Mission profiles

(5) Duty cycles

Consideration as defined in the system procurement specification shall be made for optimization along with maintainability, availability, survivability, and vulnerability. Inherent in the procedure will be the establishment at each design level of failure and success criteria and preparation of failure modes, effects, and criticality analysis. These shall be used in the development of systems block diagrams and mathematical models which shall be supplied to the designer at all system levels to permit an optimized design for overall system effectiveness.

Rationale:

The basis for reliability systems analysis should be identified and the requirements for the scope of analysis established in order to get a thorough job.

3.3.37.2.2 Mechanical Component Reliability Analysis -

Unless otherwise specified in the system procurement specification, the contractor shall estimate the reliability of mechanical components used in the system based upon the following information supplied by the component manufacturer.

(a) The failure governing statistical strength (allowable stress) distribution of critical and major component strength characteristics presented over the entire life of the component for each configuration described herein.

(1) These distributions shall be measured under each form of loading likely to be encountered in service. Considered shall be constant cyclic, wide-band and narrow-band random loading, combinations as applicable.

(2) These distributions shall be presented for the entire life of the component and shall include the early life, useful life, and wearout periods as appropriate. Distributional S-N and Goodman diagrams shall be prepared where applicable.

(3) As a minimum, the distributions shall be measured at the beginning of early life, at the beginning, midpoint, and end of the useful life, and at the midpoint of the wearout life periods.

(4) At each distribution measurement point, the best distribution shall be matched to the strength data and the best estimate for the location, scale, and shape parameters presented.

(5) Goodness of fit of the selected distribution to the data shall in each case be indicated at the 5 percent significance level.

(a) A set of strength distribution data shall be presented for each operational environment indicated in each system design specification. Consideration shall include, but not be limited to, corrosive or abnormal temperature environment.

(b) The component manufacturer shall specify success and failure criteria for the components of this specification. Failure modes and mechanisms shall be described for each class service based upon test experience.

The system designer shall obtain similar information as above for the failure governing stress distribution to result from product application. The algebra of normal or other functions shall be applied to obtain the numerical reliability estimate.

Rationale:

Reliability should be designed directly into components. For mechanical elements, the failure governing strength and stress distribution methods are the most direct and scientific approach and cuts down the number of design-build-test interaction

loops, and the costs associated. The method is also identified as "probabilistic design" or "design by reliability".

To know the expected reliability throughout the equipment life cycle, we must measure reliability at each of the three stages of life. These stages, early life, useful life, and wearout can be modeled mathematically. In systems this is important because we need to know how long to burn in or debug, how long we can go during useful life before maintenance, how to select an optimum maintenance policy, and when to retire the system.

By establishing the strength distributions, or better yet, the response surface, we know how to load the system at each stage of life to minimize probability of failure.

3.3.38 Maintainability - The design of equipment and components shall provide for all maintenance to be accomplished with a minimum of technical skills. Interchangeability and coordination design characteristics of the components shall be standardized to enhance maintainability.

Rationale:

In order to improve equipment availability, the maintenance time, skill levels, amount of support equipment, and associated costs must all be reduced. If those features of designs which relate to part interchangeability and coordination of interface characteristics between subsystems and systems are standardized, the amount of maintenance training, the chance for error, and the maintenance time should be reduced.

By attention to maintenance methods and associated features in design, the skill levels required should be reduced along with the other maintenance faults above. Maintainability is a valuable feature in maintained designs, and specific requirements must be established so as to make availability a realizable goal.

3.3.38.1 Organizational Level Maintainability - The characteristics of the equipment shall be such that in 95 percent of the cases of failure it will be possible to perform all corrective organization level maintenance actions, other than combat damage repair,

within a period not exceeding (See System Design Spec.) minutes. This corrective action time shall include all elements except system access time. As here applied, an organizational corrective maintenance action includes the following:

- (1) Verification of a fault
- (2) Location of the fault to a system replaceable assembly
- (3) Correction or repair
- (4) Adjustment or alignment (when required)
- (5) Check out of the repair

Rationale:

In an operating group, such as an aircraft squadron, this is the work that must be performed by the ground crew within the operation schedule. It is corrective action in the field upon experiencing field failures. It is usually important to perform this action in (See Design Specification) minutes or less in order not to incur operation delays. This requires advance design and planning to make such response possible.

3.3.38.2 Maintainability Program - The contractor shall prepare and conduct a maintainability program

using MIL-STD-470 or comparable specifications as a guide. The contractor's maintainability program plan shall be presented in preliminary form with the proposal and in final form 30 days after receipt of contract or purchase order.

Rationale:

As with reliability or quality control, the management system is just as important as the hardware system in accomplishment of maintainability goals. The two systems should be compatible and integrated. The management system should be planned and executed in accordance with MIL-STD-470.

3.3.38.3 Maintenance Analysis - A maintenance engineering analysis shall be performed in accordance with MIL-STD-1388 concurrent with detailed design. It shall provide for:

- (1) Optimization of failed equipment accessibility with regard to equipment failure rates.
- (2) An engineering data package covering all scheduled and unscheduled maintenance functions, tasks, and support requirements for the equipment.
- (3) A systematic check on equipment design for maintainability prior to design freeze.

(4) Criteria for the design of support and training equipment.

Rationale:

The heart of maintainability engineering is maintenance analysis. Maintainability is a function of equipment reliability. The expected failure modes, effects, and criticality and failure rates are important in establishing what, where, when, and how much maintenance must be performed. The how is a time and motion and methods problem.

3.3.38.4 Maintainability Prediction - The contractor shall perform analytical time studies of maintenance tasks in a manner representative of system or equipment characteristics in actual operation, and in accordance with MIL-HDBK-472. For the prediction at Organizational Level, Procedure I of MIL-HDBK-472 shall be adapted to fit the particular design. For the prediction at Intermediate Level, Procedure IV shall be adapted to fit the particular design. The maintainability prediction shall include the effects of a malfunction of the built-in-test (BIT) features. The prediction shall include only direct maintenance

time. All periodic preventive maintenance times
(including calibrate/adjust times) shall be included.

Rationale:

Maintainability analysis and optimization is also based on mathematical modeling and prediction techniques. In order to be effective, reliable maintenance data is required. Quantative maintainability goals and requirements must be established at each system level.

3.3.38.4.1 Equipment Mounting - In preparation for
the tasks of the maintainability prediction, the
contractor shall prepare a description of installation
and removal procedures including:

(1) The equipment mount, including fasteners.

(2) Functional and test connectors at the system
replaceable assembly level and at all lower levels.

(3) Any other aspects of the equipment installation,
such as cooling lines or ducts, which will influence
maintainability.

Rationale:

This is an essential feature in design for maintenance. Special requirements are necessary to establish details of installation and removal design and procedure to make maintenance analysis and prediction possible.

3.3.38.4.2 Test Equipment Assumptions - In estimating the time to perform maintenance tasks, the contractor shall assume that at organization level fault recognition and fault location is normally performed without the use of ground support equipment. Accordingly, the time to test, fault locate, repair, and check out shall be used in these estimates. Data shall also be included for the time it will take to test the system or equipment and locate faults to an individual system replaceable assembly when the BIT is inoperative. At the intermediate level, maintenance tasks shall include verification, location, repair, and checkout based on the use of the designated or planned operational test equipment.

Rationale:

Designs for complex systems, which must be repaired in a hurry by air crews organizational maintenance in combat situations require built-in-test equipment. This is becoming standard practice in the solution of this kind of maintenance problem and is made possible by miniturization. Since it is expected BIT will be used in future Flight Control Systems, maintenance analysis and prediction should consider BIT as an internal part of FCS.

3.3.38.4.3 Maintainability Data - To enable the contractor to estimate the maintainability of the system to which the components of this specification become a part, the following information shall be provided by the supplier on applicable components:

(a) The maintenance time distribution, with respective parameters, where applicable. Specify the number of men, skill levels and the standard and special tools required.

(b) If component is not maintainable, specify special features enhancing replacement, and replacement time distribution with parameters and values therefor.

Rationale:

Component manufactureres must measure and statistically analyze the maintenance time for their own components and provide this data to the customer to permit reliable systems analysis.

3.3.38.5 Standarization - Non-standard parts shall require approval by the procuring activity.

Rationale:

This concept reduces the number of parts and support equipment in the logistic system and simplifies procedures and training.

3.3.39 Workmanship. Characteristics and standards shall be established by the manufacturer in his Quality Planning. Skill levels and other human factors shall be measured in the product on a MIL-STD-414 sampling basis as applicable and justified, and in the workman and inspector on a periodic certification basis subject to acceptance by the procuring activity.

Rationale:

Objective requirements for workmanship are needed, if quality of conformance is to be measured and controlled. Workmanship is normally interpreted as those product characteristics which are imparted by the workman for the most part and are dependent upon human factors such as trained senses, particularly manual skills and visual judgment. Quantitative and visual standards must be developed for these factors and both the workman and inspector trained to work within established acceptable limits.

4. QUALITY ASSURANCE PROVISIONS

4.1 Test/Requirements//Appropriate/testing/as outlined/herein,/shall/be/conducted/throughout/the development/and/production/of/flight/control/systems/in/order/to/ensure/proper/design/and/performance and/also/containing/quality/throughout/production/The/specific/tests/required/shall/be/specified/in the/detailed/specifications/for/the/components and/systems//If/the/tests/required/by/the/detailed specifications/are/inadequate/to/prove/that/the flight/control/system/and/flight/control/system installation/incorporate/the/specified/requirements,/the/contractor/shall/propose/amendments/to/the contract/to/include/tests/which/will/provide/adequate proof//If/applicable/tests/are/available,/the contractor/shall,/in/lieu/of/repeating/tests,/propose amendments/to/the/contract/to/require/the/submittal of/these/data,/supplemented/by/sufficient/information to/substantiate/their/applicability/

4.1 Quality Assurance Planning - Quality assurance provisions shall be prepared in accordance with WR-43A and incorporated in drawings, specifications and other design disclosure documents. Product

characteristics shall be directly traceable to design objectives and positively identified and classified in design specifications. Objectives shall be classified into the categories of coordination, life, interchangeability, function, and safety (CLIFS), and numbered; i.e., C-1, C-2, L-1, etc. Product characteristics in components shall be traced to each design objective and classified critical, major or minor accordingly and identified C-10x/S-x, M-20x/C-x, M-301/L-x, etc., as appropriate, showing source of classification. Critical characteristics shall be traceable to safety and functional mission abort (Reliability) objectives and to failure modes effects and criticality analysis (FMECA) when performed. Major characteristics shall be traceable to coordination and interchangeability (Maintainability) design objectives, and other functional and life objectives. Minor characteristics need not be traceable to establish CLIFS design objectives and will generally encompass defects and workmanship characteristics which may accumulate to cause problems at various levels of criticality. Where minor characteristics are traceable to CLIFS they shall be so identified. Quality assurance provisions shall form part of the design disclosure

package and be approved by the Government reliability and quality assurance representative before system production procurement is initiated.

Rationale:

Product quality control to obtain the level intended by the requirements for quality of design in 3.0 can only be obtained effectively if a system and discipline are carried out in detail which assures each design objective is properly translated to its product characteristics at each level of the design. The quality control system, for product reliability and maintainability, should be dependent upon a precise classification of essential product characteristics. Essential characteristics are interpreted to mean, those product parameters, which if out of certain established limits, will cause failures in meeting design objectives.

Reliability and maintainability of the product, which is designed in, is dependent upon quality control to keep it in during manufacturing, and during the life cycle before and after maintenance actions.

A logical planning process should start with precise design objectives, classified by some process such as the well established CLIFS System. CLIFS are objectives broken down into the categories of coordination, life, interchangeability, function and safety. Coordination and interchangeability objectives, if properly pursued in the design, result in Maintainability. Life, function, and safety objectives result in the level of Reliability. Classified design objectives may be directly translated into product characteristics. These product characteristics may be classified critical, major, or minor in accordance with MIL-STD-105 or MIL-STD-414, if they are traced back to the design objective. WR-43 describes the process, but is not explicit on the business of traceability and leans on definitions for critical majors and minors too heavily. The old OSTD-78 was more explicit on the process.

Once characteristics are properly classified levels of quality control can be applied which are meaningful. Systematic coverage is also assured.

4.2 Responsibility for Inspection and Test - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any other commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.3 Classification of Inspection and Test - The examination and testing of flight control systems shall be classified as follows:

(a) Quality of Design (4.4)

(1) Development (4.4.1)

(2) Qualification (4.4.2)

(b) Quality of Conformance (4.5)

(1) First Article (4.5.1)

(2) Production Acceptance (4.5.2)

4.4 Quality of Design - Appropriate product examination and testing, as outlined here, shall be conducted throughout development of flight control system and

its installation to assure a fully qualified system, meeting all the design objectives for coordination, life, interchangeability, safety, and function at the culmination of the design process. The specific tests required are classified as developmental and qualification. If the tests required by the system specifications are inadequate to prove that the flight control system installation incorporate the specified requirements, the contractor shall propose amendments to the contract to include tests which will provide adequate proof. If applicable test data are available, the contractor shall, in lieu of repeating tests, propose amendments to the contract to require the submittal of these data, supplemented by sufficient information to substantiate their applicability.

4.1.1.1//Test/Witnesses//Before conducting a required test, an authorized procurement activity representative shall be notified so that he or his representative may witness the test and verify results and observations contained in the test reports.//When the procuring activity representative is notified, he shall be informed if the test is such that interpretation of the behavior of the test article is likely to require

engineering/knowledge/and/experience, in which case
he/will/provide/a/qualified/engineer/who/will/witness
the/test/and/certify/the/results/and/observations
during/the/test.

Rationale:

Covered under 4.4.2 and 4.4.2.1.4

4.4.1

~~4.4.1~~ Developmental Tests - Developmental tests are those tests accomplished on a sample, or samples, to determine compliance with the requirements of an investigation, study, research, development or test contract or purchase order and specifications, exhibits, or other requirements applicable thereto. For Type II, Type III, and automatic flight control systems, a functional mockup or simulator shall be constructed and appropriate tests shall be conducted to insure that the operational and dynamic characteristics of the systems and components meet the requirements which have been established and are satisfactory in their performance characteristics.

4.4.1.1

~~4.4.2.1~~ Functional Mockup and Simulator Testing - The functional mockup or simulator of the flight control system shall be constructed using actual production components and electronic computing equipment to determine system performance. Pending availability of production components, prototype components or suitable laboratory models may be used. A sufficient quantity of test data shall be collected to give reasonable assurance that the systems are suitable for the purpose intended. When the system is to include an AFCS, the complete physical characteristics of the primary control system, such as response time, inertia, damping, system stretch, rates, operating forces, etc., must be determined to permit AFCS design. Preliminary testing of components or subassemblies may be required to assure reasonable success of the entire system design.

~~4.4.1.1.1~~

~~4.4.2.1.1~~ Type II and Type III Systems - For Type II and Type III systems, tests shall be conducted to check out the operation and stability of the system under simulated flight conditions.

4.4.1.1.2

~~4.4.2.1.2~~ Automatic Flight Control Systems - Tests shall be made with equipment mounted on a simulator and with gains adjusted as recommended by the manufacturer. The simulator shall include all relevant control rigging, hinge moments, artificial feel devices, and tilt tables, if required. In addition, it shall include a computer to simulate aircraft response, selectable for all conditions of flight.

4.4.2 Qualification - Each manufacturer desiring to furnish flight control systems which satisfy this specification shall subject his product to a qualification test. Qualification shall consist of all the inspections and tests specified in 4.1 and the Systems Design Specification. Product shall be representative of the production process. Each part number system for which qualification is desired, must pass the qualification test. A successful supplier product will remain on the qualified products list (QPL) until objective evidence to the contrary is present to warrant removal.

Tests shall be conducted at a laboratory designated by the procuring activity or, when so stated in the contract, at the contractor's plant under the supervision of the procuring activity.

Rationale:

Rigorous rules for product qualification should include inspection and testing so as to statistically confirm the accomplishment of objectively stated and identified design objectives.

These rules and requirements should include a standard qualification control procedure applied

to each configuration and manufacturer which results in complete product disclosure, including reliability and maintainability of design. A qualified product implies a process associated also qualified. If the process or the product design changes in any of its major or critical characteristics, the product should be requalified.

4.4.2//Preproduction Tests//The preproduction tests shall be conducted by the producing activity or contractor at the location or locations as specified in the contract or purchase order.

4.4.2.1 Qualification Sampling

4.4.2.1.1 System Level - At least three systems shall be made available to accomplish systems qualification in accordance with the approved planning prepared for 4.1. Qualification for reliability and maintainability shall be in accordance with MIL-STD-781 and MIL-STD-471 respectively, unless otherwise noted in the detailed specification, and should be initiated during the development test phase to

achieve the reliability growth and confidence level required.

4.4.2.1.2 Component Level - Sample sizes of at least 30 shall be used to determine values of statistical parameters for failure governing strength distributions for standard parts. Where other than strength characteristics or custom designed parts are being qualified smaller sample sizes may be used. Samples shall consist of specimens of the same configuration and part number representative of the same manufacturing process.

Rationale:

When qualification is required for reliability related design objectives, it is important that design disclosure give a complete description of how the product fails under the loading types and for the design life for which the product is to function. Disclosure should include failure modes, mechanisms, and failure governing strength distributions.

To verify any statistical distribution and obtain reliable values of its statistical parameters, experience shows that at least 30

specimens are required. The goodness of fit test will not work decisively at the 5 percent significance level until this number of specimens or sample readings is reached.

Reliability with confidence is a statistical phenomena and dependent upon adequate product data. In the case of mechanical components, with structural design involved, it is necessary to have good failure governing strength distributions so reliability may be computed with confidence when failure governing stress distributions later become available through mission and system definition. Component application defines external and internal stresses to be applied. Until application is completely defined, it is meaningless to calculate reliability. The best we can do for a standardized component which has not yet met its actual environment is to define its failure governing strength distribution.

4.4.2.1.3 Data To Accompany Qualification Test
Samples - Drawings, specifications, and first article
inspection and test records shall be submitted with

the qualification test samples providing for complete design disclosure. Measurement for all classified characteristics shall be in accordance with the required planning for 4.1. Drawings shall show complete external dimensions, tolerances, construction, material, hardness, and configuration status. Classification shall be identified on the drawings, in specifications, and in pre-qualification test procedures and records.

4.4.2.1.4 Test Witnesses - Before conducting a required test, an authorized procurement activity representative shall be notified so that he or his representative may witness the test and certify results and observations contained in the test reports. When the procuring activity representative is notified, he shall be informed if the test is such that interpretation of the behavior of the test article is likely to require engineering knowledge and experience, in which case he will provide a qualified engineer who will witness the test and certify the results and observations during the test.

4.4.2.1.5 Qualification Test Reports - Qualification test results for qualified products shall be made

public record in a form, usable in design for reliability in product application, and for precise definition of qualification level attained. Failure governing strength and stress data shall be presented in statistical distribution format with values for applicable statistical parameters.

Whether or not the tests are conducted by the procuring activity, the testing activity shall prepare test reports in sufficient detail to assure complete product disclosure. The configuration, method of testing, including all statistical techniques and considerations, product conformance, and compliance with this specification and the detail specification shall be thoroughly defined. Test reports shall be prepared in accordance with MIL-STD-831 and MIL-STD-1304.

4.4.3 Preproduction and qualification tests

~~4.1.3.1 Supplier, usually, three systems or components shall be made available to accomplish the preproduction tests. Allocation of the additional or different quantities required shall be as specified in the contract or purchase order.~~

~~4.1.3.1~~

~~4.1.3.2~~ Reliability Test - A reliability test shall be conducted in accordance with MIL-R-26667 unless otherwise noted in the detailed specification. System reliability requirements should be verified to the extent possible by the tests performed in 4.1.2, augmented by the results of the component or subsystem reliability tests and flight tests.

~~4.1.3.3~~ Service Condition Tests - Service condition tests shall consist of at least the following series of tests to determine suitability and performance under the various conditions which may be encountered in service usage. The service condition tests may be allocated among the three test systems or components. A suggested order of tests is as follows:

<u>System or Component No. 1</u>	<u>System or Component No. 2</u>	<u>System or Component No. 3</u>
a. Individual tests	a. Individual tests	a. Individual tests
b. Power supply stability	b. High temperature	b. Acceleration
c. Dielectric strength	c. Low temperature	c. Shock
d. Radio Interference	d. Altitude	d. Explosion proof
e. Vibration	e. Composite altitude- temperature	e. Humidity

<u>No. 1 Con't</u>	<u>No. 2 Con't</u>	<u>No. 3 Con't</u>
f. Structural	f. Composite rain-ice	f. Fungus resist- ance
g. Sand and dust	g. Salt spray	
h. Miscellaneous		

breakdown of tests where additional or a different quantity of systems or components is allocated for preproduction test shall be as specified in the contract or detail specification.

4.4.3.3

~~4.1.3.4~~ Contractor Testing - With the consent or request of the contractor, and at the discretion of the procuring activity, any service condition tests conducted by the contractor and witnessed by an authorized procurement activity representative prior to submission for preproduction approval may be acceptable as preproduction tests.

4.4.3.4

~~4.1.3.5~~ Performance Tolerances - In conducting service condition tests, performance tolerances shall be as specified in the system or component specification.

4.4.3.5

~~4.1.3.6~~ Test Conditions - Appropriate environmental tests shall be conducted on all components which are subject to deterioration or malfunction due to any environmental condition. Where possible, and applicable, the environmental testing shall be in accordance with the requirements of MIL-STD-810. Modification to the MIL-STD-810 test procedures should be submitted for approval by the procuring activity prior to actual usage.

4.4.3.5.1

~~4.1.3.6.1~~ Power Supply Variation - Each component shall be tested individually, or assembled, or both, into a system in a manner as specified in the component or system specification. Rated electrical, hydraulic and other required power sources, shall be applied and all calibration settings placed at maximum rated positions. After completion of the warmup period, the power sources shall be varied and modulated, throughout their specified limits. The performance of the components shall be observed in the manner defined in the component or system specification. No steady state or transient modulation changes in the power source, within permissible limits, shall cause a variation or modulation in the systems performance which may result in undesirable or unsatisfactory operation. With rated power applied, the system's switches, controls and components shall be operated as in actual service. Observation of the rated power source shall note no variation or modulation of the power source beyond permissible

operational limits when the system is operated against load conditions varying from no load to full load conditions.

4.4.3.5.2

~~4.4.3.5.2~~ Dielectric Strength - Each circuit of electrical and electronic components shall be subjected to a test equivalent to the application of a root mean square test voltage of three times the maximum (but not less than 500V) surge dc, or maximum surge peak ac, voltage to which the circuit will be subjected under service conditions. The test voltage shall be of commercial frequency and shall be applied between ungrounded terminals and ground, and between terminals insulated from each other, for a period of 1 minute. Tests shall be accomplished at normal ground barometric pressure. No breakdown in insulation or air gap shall occur. Circuits containing capacitors or other similar electronic parts which may be subject to damage by application of the above voltages shall be subjected to twice the surge peak (but no less than 100V) operating voltage for the specified period. If the maximum peak operating voltage is greater than 700 V, the rms value of the test voltage shall be 1050 V greater than 1.5 times the maximum peak operating voltage. Electrical and electronic components shall also be tested for resistance to air gap breakdown at the maximum altitude specified in the altitude test.

4.4.3.5.3

~~4.4.3.5.3~~ Radio Interference Limits - The AFCS and components, or both, shall be assembled and arranged in a manner as specified in the system or component specification with interconnecting cables and supporting brackets representative of an actual installation. Provisions shall also be made for inverting all components with respect to the ground plane, or positioning in such a manner as to permit measurements from the bottom of all components. Measurement of radiated and conducted interference limits shall be made in accordance with MIL-I-26600 and MIL-E-6051 with the system switches, controls, and components operated as in actual service. Measured values shall not exceed the limits specified in MIL-I-26600 and MIL-E-6051.

4.4.3.5.4

~~4.4.3.5.4~~ Sand and Dust - Each component, with simulated external connections attached, shall be subjected to a sand and dust test in accordance with MIL-STD-810, method 510. The component shall be subjected to individual tests before and after exposure. Any dust film or dust penetration shall not result in a deterioration of the performance of the component.

4.4.3.5.5

~~4.4.3.5.5~~ Structural Tests - In addition to the normal static structural tests, tests are required to insure that the requirements of 3.2.1 and 3.2.3 are met and that structural deformations of the control system do not impair the controllability of the aircraft. The control system dynamic characteristics under all possible combinations of loads should be determined.

4.4.3.5.6

~~4.4.3.5.6~~ Fungus - Equipment which has parts of organic material, or other materials which may grow fungus, shall be subjected to a fungus resistance test, method 508, of MIL-STD-810. The component shall be subjected to individual tests before and after exposure. Any fungus present shall not result in a deterioration of the performance or service life of the component.

4.4.3.5.7

~~4.4.3.5.7~~ Extreme Temperature Tests - High and low temperature tests and temperature shock tests shall be conducted on all components subject to binding or malfunction resulting from:

- a. Differential contraction of mating parts.
- b. Deterioration of lubricant.
- c. Deterioration of hydraulic fluid.
- d. Deterioration of any type seal device.
- e. Deterioration of electrical parts.
- f. Altered hydraulic or electrical characteristics.
- g. Change in performance functions.
- h. Inability to meet duty cycle.

These tests shall be performed in accordance with high temperature tests, method 501; low-temperature tests, method 502 ; and temperature shock tests, method 503, respectively, of MIL-STD-810. Prior to low-temperature tests, a 72-hour soak at -54 degrees C (-65 degrees F) shall be required. The high-temperature range shall be specified by the detail specification. The component shall be subjected to tests and a visual examination there shall be no evidence of damage or deterioration which will prevent the component from meeting its operational requirements.

4.4.3.5.8

~~4.4.3.5.8~~ Humidity and Corrosion - Components subject to failure due to corrosion, entrance of moisture, or formation of ice shall be given humidity tests, method 507, and salt spray tests, method 509, in accordance with MIL-STD-810. In addition, if ice formation might be detrimental to the equipment, an icing test shall be conducted as follows:

- a. Cool test items to -12 degrees C (10.4 degrees F) or lower.
- b. Reduce ambient air pressure to simulate 40,000 feet pressure altitude and maintain for at least 15 minutes.

c. Increase ambient air pressure to ground level by introducing warm moist air at a temperature of at least 49 degrees C (120 degrees F) and a relative humidity of 95 (±5) percent. Continue circulating warm moist air until the test item temperature is at least 5 degrees C (41 degrees F). Items a, b, and c constitute one cycle of testing. Twenty-five cycles shall be performed to determine acceptability. Following each five cycles, the test item shall be functionally checked while at a -12 degrees C (10.4 degrees F) temperature. At the conclusion of the 25 cycles, and following the functional check, the equipment shall be examined for evidence of internal moisture, corrosion, or other defects, any of which is considered as failure to pass the test.

4.4.3.5.9

~~4.4.3.5.9~~ Altitude - Electrical equipment and other flight control system items which may be adversely affected by high-altitude operation shall be tested in accordance with the high-altitude test, method 500, of MIL-STD-810. A percentage of the life test cycles, consistent with service requirements of the component, and not less than 25 percent shall be conducted at the high-altitude condition.

4.4.3.5.10

~~4.4.3.5.10~~ Vibration, Shock, and Acceleration - All equipment subject to failure or malfunction due to vibration, shock, or high accelerations shall be tested in accordance with methods 514, 516, and 513 of MIL-STD-810. Realistic values shall be specified in the contractor's detailed specification if different from those specified in MIL-STD-810.

4.4.3.5.11

~~4.4.3.5.11~~ Explosion Proof - Electronic or electrical components not hermetically sealed shall be subjected to MIL-STD-810, method 511, procedure I. Additional tests in accordance with MIL-STD-810, method 511, procedure II, shall be required of those components which may be installed in areas in which explosion mixtures normally occur.

4.4.3.5.12

~~4.4.3.5.12~~ Combined Temperature - Altitude Tests - Components and systems subject to leakage, or which may experience cooling problems, shall be subjected to the following tests:

4.4.3.5.12.1

~~4.4.3.5.12.1~~ System Operation Test - When applicable, each system specification shall specify a composite temperature-altitude test to be conducted on the system, or separately on each component, in accordance with MIL-STD-810, method 504. The temperature-altitude-time schedule shall simulate as accurately as possible the conditions to be encountered during operational use of the weapon system. Should the exposure periods, temperature ranges and altitude ranges of the temperature-altitude-time schedule equal or exceed the requirements of either the high-temperature, low-temperature, or altitude tests, the respective individual environmental tests shall not be required.

4.4.3.5.12.2

~~4.4.3.5.12.2~~ Leakage Test - All components, or subassemblies of components, which are hermetically sealed and contain a fluid other than a gas shall be subjected to a leakage test in accordance with the following procedure. With rated power applied the component shall be operated in an ambient temperature of 79.4 degrees C (175 degrees F) and an ambient pressure equivalent to 55,000 feet altitude. The period of exposure shall be for 2 hours, or until the internal temperature of the component has stabilized, whichever is the longer time. Throughout the exposure period the component shall be observed for leakage. No leakage of the fluid shall occur during the test.

4.4.3.5.13

~~4.4.3.5.13~~ Life Tests - Life tests shall be performed as the longevity portion of the reliability tests, to meet the longevity requirements of the detail specification.

4.4.3.5.13.1

~~4.4.3.5.13.1~~ Component Life Testing - Components which are subject to wear, fatigue, or other deterioration due to usage, shall be life tested under realistic environmental conditions for a number of cycles representative of the desired life expectancy of the component. In most cases, life test requirements are defined in Government specifications.

4.4.3.5.13.2

~~4.4.3.5.13.2~~ System Life Testing - The mechanical portion of the complete flight control system, such as pulleys, cable, rods, torque tubes, control sticks or wheels, etc., should be tested as a complete system to a number of cycles equivalent to that required in 3.3.9.1. It is considered that the best way to do this is in a complete system mockup in which loads, relative distances and locations and other characteristics are realistic. The information required by 4.1.2 can thus be readily obtained and the structural testing required by 4.1.3.6.5 can also be accomplished while the life cycling is in progress.

4.4.3.5.13.3

~~4.4.3.5.13.3~~ AFCS Life Tests - One AFCS or component shall normally be selected at random from those delivered on the purchase order or contract and subjected to the life test. The system shall be assembled and operated for 1,000 hours in the manner described in the system or component specification. Provisions shall be made for cyclic loading of parts or components subject to such operation and for intermittent operation of parts or components subject to such operation. Provisions shall likewise be made to subject the system or component to vibration as well as to elevated and reduced temperatures during the course of the test. At the completion of the test no deterioration of performance or the physical condition of the equipment shall be evident beyond that permitted in the system or component specification. The first 200 hours of testing shall be

conducted without the necessity for routine servicing or maintenance. The following test condition schedule shall be adhered to:

<u>Time Period</u>	<u>Condition</u>
First 400 hrs.	At room ambient conditions.
Next 200 hrs.	Subject system to vibration of 0.001 inch amplitude at 10 cps. Reduce ambient temperature to -29 degrees C. (-20.2 degrees F.)
Next 100 hrs.	Subject system to vibration of 0.005 inch amplitude at 10 cps. Increase ambient temperature to +60 degrees C (140 degrees F).
Next 200 hrs.	Subject system to vibration of 0.005 inch amplitude at 20 cps. Reduce ambient temperature to -40 degrees C (-40 degrees F). Increase altitude to 30,000 feet.
Next 100 hrs.	Subject system to vibration of 0.005 inch amplitude at 20 cps. Increase ambient temperature to +71 degrees C (159.8 degrees F.)

4.4.3.5.14

~~4.4.3.6.14~~ Miscellaneous Tests - Equipment which is located so that it is subjected to rain, sunshine, and sand and dust shall be tested in accordance with sunshine tests, method 505; rain tests, method 506; sand and dust tests, method 510; and immersion tests, method 512; of MIL-STD-810. Any additional tests as deemed necessary by the contractor should be included and defined in the detail equipment specification.

4.4.3.6

~~4.4.3.6.7~~ Higher Category of Service Application - Components to be used under a particular category of service application, which have previously been subjected to and accepted under the requirements of a lower, or less severe, category of service application, either as an individual component or as a component of the same or a different system shall be subjected to a rerun of those service condition tests which vary with category of service application.

4.4.3.7

~~4.4.3.7.8~~ Instrumentation - During the conductance of dynamic performance tests, sufficient instrumentation shall be provided to record all input and output quantities fundamental to the function or basic design concept of the system's or component's operation. All instrumentation used shall be accurately calibrated prior to, and at the completion of, all tests. In addition, ambient conditions, power supplied, voltage and frequency variations shall be noted, or recorded as the nature of the test may warrant.

4.4.3.8

~~4.4.3.8~~ Special Test Equipment - Special test equipment used shall be accurately calibrated. Calibration data or curves shall be included in the test report, or shall accompany the test equipment when submitted to the procuring activity for conductance of tests.

4.4.3.9

~~4.4.3.9~~ Test Technique - Dynamic performance of systems and components shall be demonstrated by using transient response or frequency response testing techniques, or both.

4.4.3.9.1

~~4.4.3.9.1~~ Physical Characteristics of Transients - Applied transients shall be step or ramp functions in displacement, rate of displacement, or other suitable inputs.

4.4.3.9.2

~~4.4.3.9.2~~ Application of Transients - Where feasible, transients shall be applied physically to inertial sensing elements by actual displacement or rotation of the unit. Electrical inputs, such as command inputs, as well as other types of inputs, shall be applied in any convenient manner, such as rotation of a signal generator, switching, or use of an electronic integrator.

4.4.3.9.3

~~4.4.3.9.3~~ Variation of Transient Amplitudes and Rates - A sufficient number of displacement transients of different amplitudes, as well as rate of displacement transients of different rates, shall be applied to the system or component under test to adequately define its dynamics in the region of threshold, linear operation, saturation, and velocity limit.

4.4.3.9.4

~~4.4.3.9.4~~ Variation of Gain - For those systems or components in which loop gains may be varied, either automatically or manually, the dynamic tests shall be accomplished over a sufficient number of gain settings to adequately define the system's or component's dynamics throughout the obtainable range of gain variation.

~~4.4.4.1 Acceptance Tests - When acceptance tests are appropriate, they will be required by the procurement document or detail specification. Contractor's records of all inspection work and tests, giving the quantitative results of tests required to determine compliance with the requirements and tests specified herein, and in the system or component specifications, shall be kept complete and shall be available to the procuring activity representative at all times. The record or report of inspection and tests shall be signed or approved by a responsible person specifically assigned by the contractor. Acceptance or approval of material during the course of manufacture shall in no case be construed as a guaranty of the acceptance of the finished article.~~

~~4.4.4.1 Sampling Tests - One each component or system shall be selected at random by the procuring activity representative, as a~~

representative sample from each 100 systems or components, or fraction thereof, delivered on the contract or purchase order and subject to the sampling tests. When the component or system fails to meet the specified sampling tests, acceptance of all components or systems will be withheld until the extent and cause of failure is determined. Additional components may be selected and tested, if required, to aid in determination of extent and cause of failure. For operational reasons, individual tests may be continued pending completion of investigation of a sampling test failure, but the final acceptance of components or systems is contingent upon the producing activity's inspector's decision regarding the overall compliance of the product with specification requirements. If investigation indicates that the defect(s) may exist in items presently accepted, fully acceptable considering the defect(s) found, including recommendations for correction, shall be furnished to the producing activity.

4.5 Quality of Conformance (Production Acceptance) -
Inspection and tests for quality of conformance shall
be in accordance with classification of characteristics,
sampling plans, methods, procedures, and sequences as
defined by planning developed for 4.1. Quality of
conformance shall include first article and production
acceptance inspection and tests.

4.5.1 First Article Inspection - Small samples
representative of production shall be submitted to
the customer to be inspected 100 percent by variables
and by attributes, where necessary, for all classified
characteristics prior to release of production type
purchase orders. First article sample size shall
be specified in the planning required by 4.1.

4.5.2 Acceptance Inspection and Test - Sampling plans
and tests shall be applied in accordance with detailed
Quality Assurance Provisions developed in accordance
with 4.1. Contractor's records of all inspections and
tests providing the quantitative results of tests
which determine compliance with requirements of this
system and related component specifications shall be
kept complete and available to the procuring activity
representative at all times. The record or report of

inspection and tests shall be signed or approved by a responsible person specifically assigned by the contractor. Acceptance or approval of material during the course of manufacture shall in no case be construed as a guarantee of the acceptance of the finished article.

4.5.2.1 Sampling Plan and Tests - Samples shall be selected in accordance with MIL-STD-105 or MIL-STD-414 at the levels and AQLs for major characteristics and minor characteristics specified in the contract.

4.5.2.2

~~4.1.1.2~~ Individual Tests - Each component or system shall be examined to determine conformance to this specification and the system or component specification with respect to material, workmanship, dimensions and markings, in addition to the individual tests specified by the system or component specification in the sequence specified therein.

4.5.3

~~4.1.3~~ Flight Tests - Flight testing shall consist of those tests required to demonstrate the functional suitability and consistency of operation, and the accuracy of performance, of the equipment-airplane combination for the condition specified. Test data shall be observed visually or by recording, as may be required to determine compliance with the requirements specified. The operation and performance observed or recorded shall be equal to or better than the minimum acceptable specified in the applicable performance specification. Flight testing of the primary and secondary flight control systems shall be in accordance with the current accepted testing procedures. Flight testing of the AFCS equipment shall be in accordance with the following paragraphs.

4.5.3.1

~~4.1.3.1~~ Flight Test Conditions - Flight test operation and performance demonstrations shall consist of a schedule program complying with the requirements applying to one or more of the following conditions, as may be applicable:

- a. Developmental
- b. Preproduction
- c. Safety

d. Installation

e. Production

When so warranted by a specific test configuration, flight test operation and performance demonstrations shall also include any other requirements considered essential by the procuring activity, in addition to those specified herein and in the system or component specification, to demonstrate acceptability of operation and performance of the specific system-aircraft combination.

4.5.3.2

~~4.1.5.2~~ General Performance - During the course of tests and during operation of the flight control system, no objectionable jitter of cockpit controls or parts of the aircraft's control system shall occur. Actuation of knobs, switches and other controls shall result in a smooth response and no objectionable lag in response shall be encountered. Range of control obtained from actuation of switches, knobs or other controls shall be within the limits and tolerances specified in the system or component specifications.

4.5.3.3

~~4.1.5.3~~ Operational Checks - Operational checks of system synchronization, engagement, disengagement, interlocks, switching functions, transfer of control, limiting and cutoff devices shall demonstrate performance in compliance with the limit and tolerance requirements of the system or component specification. In checking such operational features, no abrupt, undesirable or unsafe control action shall occur.

4.5.3.4

~~4.1.5.4~~ Instrumentation - Completeness and type of instrumentation required shall depend upon the modes of operation under test, as well as the test condition. Instrumentation shall include sufficient visual, photopanel, telementering, and oscillographic recording provisions to permit accurate comparison and analysis of performance and characteristics obtained with those specified. The aircraft shall be suitably instrumented such that time histories of each flight can be recorded. The following records are mandatory:

- a. Roll, pitch, and yaw rates and attitudes.
- b. Attitude controlling device position.
- c. Altitude.
- d. Airspeed or Mach No. or both.

4.5.3.4.1

~~4.1.5.4.1~~ Accuracy of Instrumentation - When feasible, aircraft performance shall be obtained from instrumentation operating independently from the component or system under test. The response and

accuracy characteristics of any instrumentation used shall be equal to or better than, as required, that of the performance of the functions to be recorded.

4.5.3.4.2

~~4.5.3.4.2~~ Report of Instrumentation - A report covering the details of the instrumentation used and the instrument installation in the test aircraft shall be submitted to the procuring activity prior to conducting demonstration test flights.

4.5.3.5

~~4.5.3.5~~ Tests - Prior to the conductance of any demonstration test flights to be accomplished under the requirements of this specification, the component or system installation, and any test instrumentation used, shall be subjected to a preflight inspection and test in accordance with the procedure established by the equipment and test aircraft manufacturer. No malperformance shall be present. When dynamic performance is to be observed, demonstrated, or recorded under the application of a forced transient, the applied transient shall be introduced by a ramp, step, or other suitable input resulting in a linear control displacement. The amplitude, frequency and time duration of the forced transient shall be as specified for each specific test.

4.5.3.5.1

~~4.5.3.5.1~~ Developmental Flight Tests - Developmental flight tests of a component or system shall demonstrate that the equipment-aircraft combination is performing within the specified operational requirements. For the primary control systems, those tests shall be designed to point out, and aid in correcting, deficiencies in the basic airframe handling qualities. For AFCS, these tests will be used for component and subsystem development.

4.5.3.5.2

~~4.5.3.5.2~~ Preproduction Flight Tests - These tests consist of a series of specific tests designed to prove functional suitability, consistency of operation and the accuracy of performance of the AFCS and all of its related functions and modes of operation prior to committing the equipment to full production.

4.5.3.5.3

~~4.5.3.5.3~~ Safety Flight Tests - Safety flight tests, conducted to demonstrate and evaluate the suitability and safety of operation of a component or system, shall demonstrate that the equipment-aircraft combination is protected by sufficient interlock features to prevent improper operation and that adequate warning features and control limitation protection is provided to prevent entering a hazardous or unsafe flight condition in the event of a malfunction or failure.

4.5.3.5.3.1

~~4.5.3.5.3.1~~ Scope of Tests - Safety flight tests shall be conducted on these areas found critical by ground test to demonstrate the following:

- a. Under all automatic control conditions it shall be possible for the pilot to obtain sufficient control surface motion to control the aircraft by application of force to the manual controls.
- b. That system control, setting, or calibration shall not be adversely affected by any flight conditions.
- c. That the AFCS will not impose control motion such as to compromise the structural integrity of the aircraft.
- d. That the pilot shall have sufficient time to disconnect the AFCS, the AFCS shall be automatically disengaged, or that the aircraft shall remain in a safe configuration in the event of any of the following:
 - (1) Loss of elements that will cause abrupt changes in flight path.
 - (2) Complete, partial, or intermittent loss of power to the system or component.
 - (3) Loss of power to automatic trim actuator.
 - (4) Short or open in signal circuit, tube, or synchro-wiring.
 - (5) Open in feedback circuit.
- e. That the system can be easily disengaged with actuators under maximum load.

4.5.3.5.4

~~4.5.3.5.4~~ Installation Flight Tests - Installation flight tests shall consist of a demonstration of the suitability and consistency of performance of the system, using recommended production calibration settings, in an installation representative of that which may be expected in production when installed in an aircraft representative of those to be delivered for service use. Performance for each functional category of operation throughout the flight regime shall comply with that specified in the applicable system or component specifications as well as can be observed with the standard instrumentation available to the pilot.

4.5.3.5.5

~~4.5.3.5.5~~ Production Flight Tests - Production tests shall consist of the preflight and functional flight checks accomplished on each production installation submitted for acceptance. Production flight tests shall be accomplished in accordance with preflight and flight test procedure prepared by the aircraft contractor and approved by the procuring activity.

4.5.3.6

~~4.5.3.6~~ Features To Be Tested - The following AFCS features and functions shall be tested as applicable:

- a. Short and long period stability with the AFCS operative in the various modes.
- b. Pilot assist function tests.
- c. Navigational control function tests.
- d. Tracking control function tests.
- e. Automatic takeoff function tests.
- f. Automatic landing function tests.
- g. Synchronization.
- h. Engagement.
- i. Disengagement.
- j. System interlocks.
- k. Switching or control transfer functions.
- l. Limiting and cutoff devices.
- m. Additional features as required by the procuring activity.

4.5.3.6.1

~~4.5.3.6.1~~ Flight Test Conditions - Tests shall be accomplished under the following conditions:

- a. Over the aircraft's speed range for which the system has been designed to perform, both under constant speed flight and speed varying over this range.
- b. Over the aircraft's altitude range for which the system has been designed to perform, both under constant altitude and altitude varying over this range.
- c. The aircraft's allowable variation in weight range and center-of-gravity position.
- d. With and without representative combinations of external pods or stores, when applicable.

e. With flaps, slots, bomb-bay doors, landing gear, turrets, and other similar protuberances operated as required for their particular service configuration, when applicable.

f. Sudden application of asymmetric power or thrust conditions when applicable.

g. Under sudden configuration changes as may be encountered in service, such as tank or pod drop or large rapid speed changes.

h. Under smooth and rough air conditions.

i. Under crosswinds (steady and gusts) up to the maximum considered safe for manual controlled takeoff or launching.

5. PREPARATION FOR DELIVERY

5.1 Packaging Requirements - Components shall be delivered complete, tested, and ready for installation. All receptacles, ports, and delicate protruding shafts or parts which may be damaged during handling shall be protected by dust-tight covers, caps, or plugs during shipping storage, and handling.

6. NOTES

6.1 Intended Use - The requirements of this specification are general as applicable to flight control systems and are based on service experience to date. Deviations to the requirements of this specification may be granted following presentation and approval of substantiating data.

6.2 Reordered Equipment or Second Source Procurement - Where models or drawings of components of systems are furnished by the procuring activity on a contract to facilitate interchangeable construction, or where procurement is for equipment to provide interchangeable use with equipment previously procured, and the requirements for interchangeability contradict the current requirements of one or more MIL specifications, the contract requirements for interchangeability shall govern without additional approval by the procuring activity.

~~6.3 Workmanship - Workmanship shall be sufficiently high grade throughout to insure proper operation and service life of the systems and components. The quality of the items being produced shall be uniformly high and shall not depreciate from the quality of qualification test items.~~

Rationale: See 3.3.39

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6.4 International Standardization Agreement - Terminology used in this specification is the subject of international standardization agreement ABC Air STD 10/16B. When amendment, revision, or cancellation of this specification is proposed, the departmental custodians will inform their respective Departmental Standardization Offices so that appropriate action may be taken respecting the international agreement concerned.

International interest (see section 6)

BHK/pah
SEDFC (11)

APPENDIX C
SPECIFICATION REVIEW CHANGE RECOMMENDATIONS -
COMPONENTS

Recommended changes to the following specifications are available from the Defense Documentation Center. When requesting information from DDC, the title "Supplement to Appendix C, USAAMRDL TR 74-57" and accession numbers "AD A009152 and A009153" should be cited.

A. STANDARD COMPONENTS:

1. BEARINGS

MIL-B-3990
MIL-B-6038
MIL-B-6039
MIL-B-7949
MIL-B-8942
MIL-B-8943
MIL-B-8948
MIL-B-81820
FF-B-185
MIL-B-5628
MIL-B-5629
MIL-B-5687

2. UNIVERSAL JOINTS

MIL-U-3963
MIL-J-6193

3. CABLE

MIL-W-5424
MIL-S-5676
MIL-C-5688
MIL-T-6117
MIL-C-18375

4. TIE RODS

MIL-T-5683
MIL-T-5684

5. TURNBUCKLES

MIL-T-5685
MIL-T-8878
MS 33591

6. LUBRICATION & FITTINGS

MIL-L-6880
MIL-F-3541
MS 15001
MS 15002
MIL-STD-838

7. CONTROL TUBES

MIL-C-7958

8. PULLEYS

MIL-P-7034

9. ELECTRO-MECHANICAL
ACTUATORS

MIL-A-8064

10. CHAIN

MIL-C-52058
MIL-STD-421
MS 26534

11. SPRING PINS

MIL-P-10971
MS 33547

12. NUTS

MIL-N-25027

13. SAFETY WIRING

MS 33540

14. GRIP ASSEMBLY

MIL-G-25561

15. CASTINGS AND FORGINGS

MIL-C-6021
MIL-F-7190

APPENDIX D

SPECIFICATION REVIEW CHANGE RECOMMENDATIONS - STRUCTURE

Recommended changes to the following specifications are available from the Defense Documentation Center. When requesting information from DDC, the title "Supplement to Appendix D, USAAMRDL TR 74-57" and accession number "AD A009154 " should be cited.

- MIL-S-8698 - Structural Design Requirements, Helicopters
- MIL-A-008860 - Airplane Strength and Rigidity, General Specification for
- MIL-A-008861 - Airplane Strength and Rigidity, Flight Loads
- MIL-A-008865 - Airplane Strength and Rigidity, Miscellaneous Loads
- MIL-A-008866 - Airplane Strength and Rigidity, Reliability Requirements, Repeated Loads, and Fatigue
- MIL-A-008870 - Airplane Strength and Rigidity, Flutter, Divergence and Other Aeroelastic Instabilities

APPENDIX E

SPECIFICATION REVIEW CHANGE RECOMMENDATIONS,
COCKPIT ARRANGEMENT

Recommended changes to the following specifications are available from the Defense Documentation Center. When requesting information from DDC, the title "Supplement to Appendix E, USAAMRDL TR 74-57" and accession number "AD A009155 " should be cited.

- MIL-STD-203 - Aircrew Station Controls and Displays for Fixed Wing Aircraft
- MIL-STD-250 - Cockpit Controls: Location and Actuation of, for Helicopters
- MS 33574 - Dimensions, Basic Cockpit, Stick Controlled, Fixed Wing Aircraft
- MS 33575 - Delete
- MS 33576 - Dimensions, Basic, Cockpit, Wheel Controlled, Fixed Wing Aircraft
- MIL-STD-1333 - Aircrew Station Geometry for Military Aircraft

APPENDIX F

Recommended changes to the following specification are available from the Defense Documentation Center. When requesting information from DDC, the title "Supplement to Appendix F, USAAMRDL TR 74-57" and accession number "AD A009156 " should be cited.

DESIGN HANDBOOK CHANGE RECOMMENDATIONS, AFSC DESIGN HANDBOOKS, DH 2-1, DH 2-X

APPENDIX G

ON-GOING FLY-BY-WIRE RESEARCH AND DEVELOPMENT

Title: (U) Program Analyses and Studies in Support of the HLH Flight Control System Advanced Technology Component Program

Performing Organization: Massachusetts Institute of Technology, Cambridge, Massachusetts

Government Organization: U.S. Army Air Mobility R&D Laboratory Fort Eustis, Virginia 23604

Contract No.: DAAJ02-72-C-0029

Completion Date: December 1974

Description: The objective of this program is to support the Army and Boeing Vertol during the conduct of the Heavy Lift Helicopter (HLH) Advanced Technology Component Program. This contract covers the flight control portion of the overall program. The approach is to transfer technology gained under previous contracts to the HLH Advanced Technology Component Program, provide technical assistance in the areas of analytical design and analysis by the use of their hybrid simulator, and perform work in order to recommend to the Government possible solutions of technical difficulties pertaining to the HLH flight control system for the HLH experienced by Boeing.

Title: (U) Heavy Lift Helicopter

Performing Organization: Boeing Vertol Philadelphia, Pennsylvania

Government Organization: U.S. Army Air Mobility R&D Laboratory Fort Eustis, Virginia 23604

Contract No.:

Completion Date:

Description: The Heavy Lift Helicopter design includes the use of a primary fly-by-wire flight control system. Fabrication of the fly-by-wire

system is subcontracted to the General Electric Company, Johnson City, New York, for the electronic equipment and to Bertea, Los Angeles, California, for the electro-hydraulic actuation elements. Flight test of the Prototype Fly-By-Wire Systems for the HLH aircraft has begun.

Title: (U) Military Transport Fly-By-Wire Flight Test Evaluation

Performing Organization: Honeywell, Inc.
Minneapolis, Minnesota

Government Organization: AF Flight Dynamics Laboratory
FGL Wright Patterson Air Force Base, Ohio

Contract No.: F33615-71-C-1286

Completion Date: August 1973

Description: The objective of this program is to show that fly-by-wire control can alleviate the critical controllability problems of large military jet transports in such mission tasks as station-keeping for formation para-drop. A properly designed fly-by-wire flight control system should improve the control precision and handling qualities of such aircraft, particularly in flight control problem areas such as the heavy wake turbulence of preceding aircraft in formation. The effort will use the C-141 as a typical current large military transport and should indicate the benefits of, and the approach for, designing fly-by-wire into future transports. The approach is to design, fabricate, hardware flightworthiness test, install, and flight test a two-axes (pitch and roll) fly-by-wire system for an AFC-141. The system will have a side stick controller for pilot inputs and will be limited in redundancy to automatic safety reversion to the normal flight control system. Outer loop control modes will be investigated.

Title: (U) Multiplexed Flight Control System
Flight Evaluation for Military Aircraft

Performing Organization: General Dynamics Corporation
Fort Worth, Texas

Government Organization: AF Flight Dynamics Laboratory
FLG Wright Patterson Air Force Base, Ohio

Contract No.: F33615-71-C-1147

Completion Date: June 1973

Description: Mechanical flight control systems of all military high performance aircraft are necessarily complex, difficult to design, limit performance, and are highly vulnerable to ground fire. Fly-by-wire flight control systems, for which design criteria are now being developed, have the capability of minimizing the above deficiencies; however, the quadruple redundancy requirements of such a system in turn impose a requirement for a great many transmission wires if a hardwired system is used. Studies to date indicate that multiplexing is feasible and can eliminate this deficiency. The objective of this work unit is to demonstrate the feasibility and practicability of a multiplexed flight control system, with its attendant wire and weight savings, by flight testing a representative flightworthy system which, in turn, will provide an initial design criteria base for multiplexing fly-by-wire flight control systems for future military aircraft.

The initial phase will consist of design, fabrication, bench test, and simulation test of a representative system. Secondly, the system will be flightworthiness tested, installed in a flight test aircraft, and flight tested.

Title: Space Shuttle

Performing Organization: North American Rockwell
Downey, California

Government Organization: NASA
Houston, Texas

Contract No.:

Completion Date:

Description: The Space Shuttle design incorporates fly-by-wire primary flight controls, including the use of digital processing computers and multiplex signal transmission methods. Minneapolis Honeywell (St. Petersburg, Florida) is subcontractor on the flight control configuration. IBM (Oswego, N. Y.) is responsible for the data processing computers. The fly-by-wire configuration has been generally defined and some component fabrications have been issued for proposal quotation.

Title: Direct Drive Fly-By-Wire

Performing Organization: North American Rockwell
Columbus, Ohio

Government Organization: Naval Air Development Center
Warminster, Pennsylvania 18974

Contract No.: N62269-72-C-0108

Completion Date:

Principal Investigator: J. N. Demanchi (614-239-2713)

Description: This program is intended to investigate the use of high pressure, modular hydraulic systems in conjunction with direct drive servo actuators for fly-by-wire primary flight control systems. The intended application is the XV-12A aircraft which North American Rockwell is under contract to build. Development hardware has been fabricated with testing to occur in the first part of 1974.

Title: Digital Actuation Survey

Performing Organization: North American Rockwell
Columbus, Ohio

Government Organization: NASA Langley Research Center
Hampton, Virginia 23665

Contract No.: NAS-1-12718

Completion Date:

Principal Investigator: R. Hupp (614-239-2713)

Description: This program is a six-month effort to establish the state of the art in digital input electro-hydraulic flight control actuators and to recommend a particular configuration for fabrication and test as part of one on-going NASA F-8 fly-by-wire flight control system research effort.

Title: Fiber Optic Investigation

Performing Organization: Sperry Flight Systems
Phoenix, Arizona

Government Organization: AFFDL
Wright Patterson Air Force Base, Ohio

Contract No.:

Completion Date:

Project Engineer: Capt. L. Roberts (513-255-4607)

Description: The program effort is to investigate the use of fiber optics to transmit control signals in a fly-by-wire primary flight control system in order to improve transmission reliability. A single channel of a Sperry-designed fly-by-wire simulator has been converted to fiber optics and has been operated successfully.

Title: Dielectric Waveguide

Performing
Organization: AFFDL
Wright Patterson Air Force Base, Ohio

Government
Organization: AFFDL
Wright Patterson Air Force Base, Ohio

Contract No.:

Completion Date:

Project Engineer: A. DeThomas (513-255-4504)

Description: This internally conducted Air Force research program is investigating high frequency waveguide techniques to improve the information-carrying capability and reliability of electrical transmission methods for fly-by-wire systems.

Title: Digital Fly-By-Wire Program

Performing
Organization: NASA Flight Test Center
Edwards Air Force Base, California

Government
Organization: NASA Research Center
Hampton, Virginia

Contract No.:

Completion Date:

Description: This program is intended to investigate the use of fly-by-wire and digital processing in flight control systems. An F-8 aircraft has been modified with a fly-by-wire system and successfully flight tested. A second phase of the program will be the installation of an AP-101 (IBM) computer in place of the Apollo Lem computer currently being used and the changing of the current analog back-up system to a digital backup. Included in the program plan is installation of a digital actuator in one control axis and investigation of the fly-by-wire control system to cope with maneuver load and low stability control problems.

APPENDIX H

ON-GOING FLUIDIC RESEARCH AND DEVELOPMENT

Title: (U) Development and Flight Test Evaluation of an Advanced Hydrofluidic Stabilization System for Army Helicopters

Performing Organization: Honeywell, Inc.
Minneapolis, Minnesota 55413

Government Organization: U.S. Army Air Mobility R&D Laboratory
Fort Eustis, Virginia 23604

Contract No.: DAAJ02-72-C-0019

Completion Date: January 1974

Description: The objective is to develop an advanced hydrofluidic stabilization system with the capability of assisting the pilot in performing the majority of all control system functions necessary to more effectively execute the many all-weather tactical missions and incorporating all of the many advantages inherent in fluidic systems.

Honeywell is to design, fabricate, laboratory test, and flight test evaluate an advanced hydrofluidic stabilization system, incorporating altitude hold, heading hold, and attitude hold.

Title: (U) Hydrofluidic Stability Augmentation System (SAS) Suitability Demonstration for Army Helicopters

Performing Organization: Honeywell, Inc.
Minneapolis, Minnesota 55413

Government Organization: U.S. Army Air Mobility R&D Laboratory
Fort Eustis, Virginia 23604

Contract No.: DAAJ02-72-C-0051

Completion Date: March 1973

Description: The long range objective of this program is to determine the operational suitability

of a hydrofluidic stability augmentation system for Army helicopters. The objective of this phase of the overall program is to design and develop the integrated sensor/controller/series servo actuator package, which will be used to demonstrate operational suitability during a later phase of the program.

The approach is to design, fabricate, and performance test one miniaturized, integrated hydrofluidic stability augmentation system designed for the yaw axis of an OH-58/TH-57 type helicopter. A system design specification will be developed.

Title: (U) Army Helicopter Flight Control System Reliability and Maintainability (R&M) Investigations

Performing Organization: Bell Helicopter Company
Fort Worth, Texas 76101

Government Organization: U.S. Army Air Mobility R&D Laboratory
Fort Eustis, Virginia 23604

Contract No.: DAAJ02-73-C-0026

Completion Date: March 1974

Description: The objective is to recommend revisions to helicopter flight control system specifications, standards, procedures and practices which, if incorporated, should eliminate deficiencies which are contributing significantly to reliability and maintainability (R&M) shortcomings for Army aircraft. The results of this effort will be used to ensure that adequate consideration is given to the R&M aspects of flight control systems for future Army aircraft.

The contractor will perform this flight control system investigation by conducting a data analysis, analyzing design requirements, conducting design reviews, recommending document revisions and preparing drafts of any new flight control specifications required. Additionally, the

contractor will recommend future R&D efforts necessary to define design and test requirements, quality assurance provisions and qualification requirements, procedures and practices for fly-by-wire and fluidic flight control systems for future Army aircraft applications.

Title: Hydrofluidic Stability Augmentation System (SAS) Suitability Demonstration for Army Aircraft

Performing Organization: Honeywell, Inc.
2600 Ridgway Parkway
Minneapolis, Minnesota 55413

Government Organization: U.S. Army Air Mobility R&D Laboratory
Eustis Directorate
Fort Eustis, Virginia 23604

Contract No.: DAAJ02-73-C-0046

Completion Date: August 1975

Description: The long range objective of this program is to determine the operational suitability of a hydrofluidic stability augmentation system for Army aircraft systems. The objective of this phase of the overall program is to accumulate sufficient flight data on the hydrofluidic yaw stability augmentation system so as to demonstrate the operational suitability as compared with existing systems.

The approach is to fabricate, laboratory test, install and flight evaluate a quantity of miniaturized integrated hydrofluidic yaw stability augmentation systems. The program is a joint effort by the U.S. Navy and the U.S. Army.

Title: (U) Operational Suitability of Production Fluidic Systems

Performing Organization: Naval Air Development Center
Air Vehicle Technol Dept. 30424
Warminster, Pennsylvania 18974

Government Naval Air Systems Command 52022
Organization: Washington, D.C. 20360

Contract No.:

Completion Date:

Description: The objective is to fabricate 12 hydro-fluidic yaw dampers for laboratory and flight evaluation to obtain performance, reliability, and maintainability data required to establish the operational suitability of production fluidic systems.

Title: (U) Fluidic Roll Rate Damping System - Improved Unit

Performing General Electric Company
Organization: Missile and Space Division
 P. O. Box 8555
 Philadelphia, Pennsylvania 19101

Government Naval Air Systems Command 52022A
Organization: Washington, D.C. 20361

Contract No.: N00019-73-C-0370

Completion Date: July 1973

Description: The objective is to develop, design, fabricate and evaluate a RAM air fluidic roll rate damping system with one moving part.

The approach is the utilization of development efforts for a flueric roll rate damping system produced under Naval Weapons Center Contract N00123-72-C-1968. The contractor will design and fabricate a roll rate damping system with one moving part. This prototype will be subjected to extensive test and evaluation.

Title: (U) Fluidic Autopilot for Navy Tactical Missiles

Performing General Electric Company
Organization: Missile and Space Division
 P. O. Box 8555
 Philadelphia, Pennsylvania 19101

Government Organization: Naval Air Systems Command 52022A1
Washington, D.C. 20361

Contract No.: N00019-73-C-0254

Completion Date: February 1974

Description: The objective is to provide very low cost, highly reliable, rugged, long lifetime guidance and control systems for missiles based on unique characteristics of fluidic components. This effort will direct fluidic technology to address problems critical to airborne fluidic systems.

The contractor is directed to develop and evaluate a complete fluidic autopilot control system for a Naval missile based on laminar flow fluidics. The design will cover sensing, amplification, signal processing, power and actuator control and the fluidic power supply. The development will be directed ultimately to a flight test in a Sparrow III missile.