AFWAL-TR-80-3120
Volume II



# FORCE MANAGEMENT METHODS TASK II

## Volume II. Transport/Bomber Aircraft — Evaluation of Potential Improved Methods

D. S. Morcock
K. E. Brown
J. C. Davis
R. L. Johnson

Lockheed-Georgia Company
Marietta, Georgia



November 1980

TECHNICAL REPORT AFWAL-TR-80-3120, Volume II

Interim Report for Period October 1978 to July 1980

Approved for public release; distribution unlimited

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This technical report has been reviewed and is approved for publication.

Robert M. Engle Jr.
Project Engineer

Davey L. Smith, Chief
Structural Integrity Branch

FOR THE COMMANDER:

JOlsen, for

RALPH L. KUSTER Jr., Colonel, USAF
Chief, Structures & Dynamics Division

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/FIBE, W-P AFB, OH 45433 to help us maintain a current mailing list".

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

| | |
|---|---|
| 1. REPORT NUMBER | AFWAL-TR-80-3120 Volume II |
| 2. GOVT ACCESSION NO. | |
| 3. RECIPIENT'S CATALOG NUMBER | |
| 4. TITLE (and Subtitle) | FORCE MANAGEMENT METHODS TASK II - Volume II - TRANSPORT/BOMBER AIRCRAFT - EVALUATION OF POTENTIAL IMPROVED METHODS |
| 5. TYPE OF REPORT & PERIOD COVERED | Interim Report Oct 78 - Jul 80 |
| 6. PERFORMING ORG. REPORT NUMBER | |
| 7. AUTHOR(s) | D. S. Morcock, K. E. Brown, J. C. Davis and R. L. Johnson |
| 8. CONTRACT OR GRANT NUMBER(s) | F33615-77-C-3122 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS | Lockheed-Georgia Company Marietta Georgia |
| 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS | Proj 2401-01-19 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS | Flight Dynamics Laboratory (AFWAL/FIBEC) Air Force Wright Aeronautical Laboratories Wright-Patterson AFB, Ohio 45433 |
| 12. REPORT DATE | November 1980 |
| 13. NUMBER OF PAGES | 221 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | |
| 15. SECURITY CLASS. (of this report) | UNCLASSIFIED |
| 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE | |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Lockheed is a subcontractor to the University of Dayton Research Institute.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Force Management, structures, flight loads, structural life management, fatigue structural integrity, structural maintenance, inspection schedules, data recording, data analysis, damage tolerance, individual aircraft tracking.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents an evaluation of candidates for potentially improving Force Management methods for transport/bomber aircraft. Using the C-141A transport as a baseline, an analytical and conceptual evaluation was performed to assess the applicability of crack growth gages, mechanical strain recorders and microprocessors in Force Management for large flexible aircraft.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

AD-A118859

NOTE

This report is based on information obtained from other Lockheed-Georgia Company programs, FDL, and the University of Dayton Research Institute. The evaluation of candidates for potentially improving Force Management Methods is both conceptual & analytical in nature, using the C-141A transport as baseline, but is intended to address the applicability of the potential improved methods for Transport/Bomber type aircraft. The data presented are not necessarily current and are not to be construed as "hard" data for the C-141A. Also, the results of the evaluation are not to be construed as a Lockheed position regarding use of these methods for the C-141A or any other specific aircraft.

With regard to the use of the C-141A Transport as the baseline for this Task II methods evaluation, it should be noted that IAT/L/ESS/FSM systems can vary over wide extremes depending on the particular aircraft utilization and mission requirements (Reference 1). Therefore, a Force Management method such as the Mechanical Strain Recorder (MSR) may prove usable for one Transport/Bomber category aircraft ASIP and unusable for another. To simplify the evaluation of these methods, the evaluation is based on a system of the complexity of the baseline C-141A and other systems are not pursued further.

## FOREWORD

The contractor team of the University of Dayton Research Institute, Lockheed-Georgia Company, and Vought Corporation has been conducting a program to prepare a handbook for achieving the force management objectives of MIL-STD-1530A. Task 2 of this program was aimed at investigating improved methods with emphasis on the use of mechanical strain recorders, crack growth gages and microprocessors as the primary data recording devices. This report is Volume 2 of the Task 2 final report and presents the results of Lockheed-Georgia's study on improved methods for transport/bomber aircraft.

The program is being conducted under Contract F33615-77-C-3122 for the Air Force Wright Aeronautical Laboratories AFWAL/FIBEC. Mr. Robert Engle is the current Air Force Project Engineer. Dr. Alan P. Berens of the University of Dayton is serving as Program Manager for the contractor team. Mr. Doug S. Morcock is program manager for Lockheed-Georgia.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

## LIST OF FIGURES

LIST OF FIGURES (Con't)

## LIST OF TABLES

SECTION 1

INTRODUCTION

Within the Air Force Aircraft Structural Integrity Program (ASIP) as described in MIL-STD-1530A, a task called "Force Management" is defined. Force Management is defined as "those actions that must be conducted by the Air Force during force operations to ensure the damage tolerance and durability of each airplane". A review of the state-of-the-art methods whereby the Force Management activities are accomplished was made in 1978 as Task I of this contract and documented in References 1 and 2. The Force Management Methods were defined in these documents as the Individual Aircraft Tracking (IAT) program; the Loads/Environment Spectra Survey (L/ESS) program; the Force Structural Maintenance (FSM) program; and the interfaces of these programs with each other and with other ASIP programs to achieve the overall Force Management objectives. The state of the art review was performed by University of Dayton Research Institute as program Manager; Lockheed-Georgia Company for Transport/Bomber aircraft; and Vought Corporation for Attack/Fighter/Trainer aircraft.

Task II of this contract consists of an evaluation of potential improvements through the use of microprocessors, mechanical strain recorders, crack growth gages, and updated versions of the present (usage forms and multichannel recorders) methods in accomplishing the Force Management activities. The Lockheed-Georgia evaluation of these Methods for Transport/Bomber aircraft is presented herein.

At the beginning of this report, it is appropriate to consider the goal of the Task II evaluation of Improved Force Management Methods. Improved methods in the Force Management context indicates methods which are better than the present methods in significant ways. Specifically, the title of Task II implies that for the Transport/Bomber aircraft covered by this report, the methods evaluated (forms crack growth tracking; updated MXU-553A recorder; Mechanical Strain Recorder; Crack Growth Gage; and Microprocessor) are more accurate, less costly, or more cost effective than the current fatigue-based forms tracking program and/or the current MXU-553A recorder program used as the baseline for evaluation. It should be recognized that these methods are being evaluated for their potential as improved methods. The evaluations discussed herein show advantages and limitations of the methods such that no method is clearly an improvement over the baseline method in every case, and some methods are not acceptable replacements for current Transport/Bomber aircraft methods in any of the cases considered.

Guidelines for selection of current IAT, L/ESS, and FSM methods are presented in the Task I current methods report (Reference 2). In considering the improved methods discussed herein, the following comments are felt to be applicable.

1. Each aircraft system has its own distinctive characteristics. Criteria, interfaces, system accuracies, structural sensitivities, and other factors are all related in determining the most appropriate Force Management methods for a particular aircraft.

2. Continuing changes occur during the life of an aircraft model. Examples of these changes are new analysis and inspection techniques, aircraft usage, economic considerations, production status, military priorities, and availability of replacement aircraft. Consequently, there may be continuing changes to the "best" force management methods for that aircraft system.

3. Considerations of the Improved Methods which are the subject of this report are affected by the above realities. The choice of the best method for a particular system must be made by the ASIP Manager of that system, taking into account all of the requirements of the system as compared with the capabilities and qualifications of each method.

# SECTION 2

# FORCE STRUCTURAL MAINTENANCE

The Task I Current Methods Report, Reference 2, and the Task I Coordinated Force Management Report, Reference 1, discuss the current Force Structural Maintenance plan and its relationship to other elements of the Force Management program. The discussion below addresses potential improvements in the FSM plan. Summarized: On-going changes in the FSM plan may be anticipated to occur. Many inspections are presently performed on a calendar time basis for "average" utilization and the system thus is not set up for "truly individual aircraft" FSM such as would seem desirable and attainable from the "truly individual aircraft" IAT output. Improvements in Non-Destructive Inspection (NDI) techniques are changing FSM actions. Durability and Damage Tolerance Assessments (DADTA) are identifying one-time modification and initial and recurring inspection actions. Feedback of inspection results continues to be a vital link in the Force Management Program. The FSM plan should be updated periodically.

## 2.1 STRUCTURAL MAINTENANCE ACTION DETERMINATION

For aircraft designs made prior to MIL-STD-1530A and MIL-A-83444 crack growth requirements, structural inspection procedures and requirements were generally undefined in an initial design stage and once defined, were then modified throughout the remainder of the "cradle-to-the-grave" Aircraft Structural Integrity Program (ASIP). Airframe designs conforming to MIL-STD-1530A and -83444 requirements of crack growth will have more data from which to structure the initial and recurring inspection requirements. Analysis methodology prior to crack growth did not incorporate a 'Time Scale' feature and therefore inspections were simply specified at some percentage of the total damage value. Aircraft with sufficient fatigue testing and service cracking experience could develop inspection programs based on actual crack data.

For many older airframe designs, a crack growth DADTA program will indicate that certain locations are overdue for initial inspections and indeed are in need of a more refined total inspection program. These older designs are under study by the USAF and updated inspection using NDI and crack growth analyses are being implemented into the T.O.'s (-6, -36, and TCTO). A recent change in the inspection program for some USAF aircraft has been the incorporation of the Reliability-Centered Maintenance zonal inspection philosophy into Air Force aircraft maintenance. (See Reference 2, Page 2-130, for additional description.) Inspections of primary structure as determined through structural analyses and/or tests are specified at the required intervals and are conducted by structural inspectors using the appropriate NDI techniques. Zonal inspection of certain areas of the aircraft for hydraulic, electrical, structural, or other discrepancies by one inspector is also performed, with followup by a specialist if a discrepancy is noted, rather than the previous method in which all areas were inspected by one specialist for hydraulic problems, another for electrical items, a third for structural integrity, etc. Also, implementation of the zonal inspection program is preceded by a complete review of the existing inspection requirements in the light of test and service experience, criticality, and the likelihood of discrepancies being found during other flight or ground operations. Special inspections of the specific locations are included as necessary.

Implementation of the zonal inspection program is a current FSM technique. However, it is noted that the definition of inspection requirements continues to be based on 'average' utilization for the entire Force of aircraft and does not recognize, as yet, the IAT program philosophy where individual aircraft usage severity, crack growth, and NDI are all combined to provide a more sensitive device for scheduling periodic inspections. The present system assumes that all aircraft are inspected in the same manner at the same calendar or flight hour interval, except for special inspection requirements. Thus, the special inspection requirements section in T.O. -6 appears to be the present vehicle for accomplishing <u>individualized</u> inspections of aircraft, and it is not considered that it was intended for this purpose. A change to computerized individual aircraft structural maintenance programs should be explored.

The Force Structural Maintenance Program is also affected by test and service experience, IAT results, and other factors such as organizational changes and economics. In addition to the change to a zonal inspection concept, the baseline C-141A FSM Program (cited here as a "typical" example) has been affected recently by these additional activities:

- The Controlled Interval Extension (CIE) program, in which sample aircraft are flown longer between inspections to determine whether a longer interval will provide sufficient inspection coverage. Based on the CIE program, C-141A depot inspections have been changed from 36 to 48 months beginning in 1980.

- Incorporation of the C-141A Durability and Damage Tolerance Assessment (DADTA) recommendations which include the development and implementation of a Fracture Tracking Program (FTP). This program is currently under development for the USAF (Warner Robins ALC) at Lockheed Georgia Company. (See Paragraph 2.2). Similar changes in other aircraft FSM programs may be anticipated.

Another potential improvement in FSM programs is in the field of Non-Destructive Inspection (NDI) techniques. A four-year AFLC program to determine the reliability of Air Force NDI capability was concluded by Lockheed-Georgia Company in 1978. The results (Reference 3) "indicate that Air Force NDI needs improvement in several specific areas in order to meet existing requirements for inspection of Air Force hardware". "Recommendations for making both short-term and long-term improvements in NDI proficiency are presented" in the Reference 3 report. Incorporation of new types of NDI equipment into the Air Force inventory at a faster rate and continued efforts to upgrade the NDI reliability are needed. These activities will affect the FSM requirements and the effectiveness of the NDI in the future.

## 2.2 FSM BY INDIVIDUAL AIRCRAFT

A desired goal of the IAT Program is to provide individual aircraft inspection program requirements to minimize overall inspection costs. The updated crack growth IAT Program can provide these data bases on crack growth safety limits for flight hours to initial inspection and recurring inspection intervals thereafter. However, the present inspection system is not geared to use these data. See Paragraph 2.3.

An extensive review of the ASIP such as the crack growth based Durability and Damage Tolerance Assessment (DADTA) can be anticipated to identify specific one-time modification and initial and recurring inspection actions for existing aircraft beyond those actions defined by the present program. These are best covered by a special inspection and modification program.

## 2.3 INTERFACE WITH MAINTENANCE SCHEDULING AND REPORTING SYSTEMS

### 2.3.1 Scheduling

Inspection actions can be programmed by individual aircraft or for all aircraft, as a function of flight hours IAT output, and/or calendar time. For example, in the baseline C-141A Force Management Program, the basic inspection package is performed on all aircraft as a function of calendar time. IAT data are used to establish the priority for scheduling individual aircraft for the 48-month Programmed Depot Maintenance (PDM) and the sample Analytical Condition Inspection (ACI) program. Special inspections are added to the PDM and ACI Programs or, if more time critical, are covered by Time Compliance Technical Orders (TCTO's) covering all aircraft or individual aircraft by tail number, as applicable. Modifications are also covered by TCTO action.

It is desirable that the improved IAT output include specific inspection requirements by individual aircraft by location. In theory, a computerized program can be used to assemble these data into specific inspection packages for each aircraft for a calendar or flight hours inspection time. In practice, the individual aircraft ASIP may have requirements peculiar to that aircraft which favor continuation of the present isochronal (calendar-time based) system. However, computerized planning of these isochronal inspections by individual tail number may be cost effective, and further study of this method for each aircraft model is recommended.

Retrieval and replacement of data cartridges or components should be performed at an appropriate inspection, preferably at the PDM or ACI (depot level) inspection.

2.3.2 Reporting

The Task I Current Methods Report, Reference 2, discusses the inspection results reporting. An IAT crack growth program which projects time to inspection or modification and calculated crack lengths at a given time after the inspection or modifications is obviously dependent on good feedback regarding these data. Time Compliance Technical Orders (TCTO's)for special inspections or modifications are often worded to require feedback of results and time of modification. Routine inspections generally result in little feedback data except through the AFM 66-1 system, which is intended to provide only general data regarding number of problems encountered in a given region.

Paragraph 3.1.2.1.5.4 discusses the method used for crack growth IAT projections in the absence of specific inspection/ modification feedback data. Significant improvements in all aspects of the Force Management Program would result from developing a system to provide good data. The present reporting system appears to be largely contained in specifically worded TCTO's, resulting in feedback to the ASIP Program Manager which must then be assimilated into the IAT Program manually or through a supplemental computer program. A comprehensive NDI inspection results feedback system is vitally needed to work in conjunction with the crack growth based IAT programs. The safe-use interval of flying based on NDI and crack growth analytics would be severely restricted in usefulness without a working and maintained Feedback System. To our knowledge, such a system is not yet working in the USAF ASIP.

## 2.4 FSM IMPLEMENTATION

The Force Structural Maintenance Plan is discussed in References 1 and 2. For the updated usage forms, MSR, Crack Growth Gage, and Microprocessor IAT Systems discussed in this report, the maintenance plan must include obtaining data, changing cassette cartridges, replacing CGG's, or maintaining equipment as appropriate. Also, the computerized tailoring of inspection requirements to individual aircraft offers a potential improvement to the current maintenance plan. This is discussed in Paragraph 2.3.1.

## 2.5 PERIODIC UPDATE OF FSM PLAN

The current FSM program is updated periodically by revisions to the appropriate Technical Orders (T.O.-06, -6, -23, -36 for each airplane series: For example, T.O. 1B-52D-23 for the B-52D). Special requirements are covered by Safety Supplements (SS) and Time Compliance Technical Orders (TCTO's). This periodic updating is essential to the continued inspection of service aircraft on a current basis.

SECTION 3

INDIVIDUAL AIRCRAFT TRACKING (IAT)

## 3.1 IAT METHODS

### 3.1.1 IAT Parameters

Individual aircraft Tracking Programs for Transport/ Bomber aircraft require sufficient data to perform individual aircraft crack growth calculations and to identify the usage of the aircraft. The detail required will be different for different aircraft. Also, the sensitivities of the aircraft to specific inputs will be different for different aircraft. This is because different aircraft are sensitive to different sources in varying degrees. For example, one aircraft has a more sensitive wing upper surface, another a more sensitive wing lower surface, due to different design stresses and structural configurations. Table 1 summarizes IAT input data and parameters recorded on some of the present Transport/Bomber aircraft. Table 2 summarizes common input data and parameters of these IAT programs. In addition, individual aircraft must have other parameters such as fuel onload, fuel offload, wing sweep angle, aerial delivery, etc., which are necessary because of their individual characteristics and usage. Table 3 identifies these aircraft - peculiar items; Table 4 shows totals by airplane. These data are to be considered approximate but serve to indicate the types of data acquired by present usage forms IAT systems.

Note that the definition of a parameter is not a simple matter. Webster's New Collegiate Dictionary (1976) definition is: "Parameter: 1) an arbitrary constant each of whose values characterizes a member of a system (as a family of curves); 2) any of a set of physical properties whose values determine the characteristics of behavior of something: a characteristic element." In an IAT analysis sense, every item listed in the Tables is felt to be a "Parameter", whether constant or variable, in that it addresses the validity, quality, or use of the data in performing and evaluating the IAT analysis. In a data acquisition sense,

TABLE 1

ROUGH-CUT REVIEW OF USAGE FORM
IAT INPUT DATA AND PARAMETERS

| PARAMETER | C5A | C130 | C/KC 135 | C141 | FB-111A | ENTRY/EVENT OR PARAMETER |
|---|---|---|---|---|---|---|
| ACFT. TAIL NO. | X | X | X | | X | E |
| USAGE LOG NO. | X | | | | | E |
| SEQUENCE NO., SORTIE NO. | X | X | | X | | E |
| AIRFRAME HOURS | X | X | X | X | X | E |
| OMS | X | | | | | E |
| TIME (DAY, MONTH, YEAR, Z) | X | X | X | X | X | E,P |
| INITIAL TAKEOFF EVENT (WHEN) | X | X | X | X | | P |
| GROSS WT. | X | X | X | X | X | P |
| FUEL WT. | X | X | X | X | | P |
| CARGO WT. | | | X | X | X | P |
| C.G. | X | | | | | E |
| ICAO CODE-TAKEOFF: LANDING | X | X | X | | | E |
| CRUISE PERIOD (1,2,3,4) | X | X | X | | | E |
| MACH OR AIRSPEED | X | X | X | X | | P |
| ALTITUDE | X | X | X | X | | P |
| TOUCH & GO EVENTS (WHEN) | X | X | X | X | X | P |
| FULL STOP LDGS & TAKEOFFS (WHEN) | X | X | X | X | X | P |
| INFLIGHT OPERATIONS EVENTS | | | | | | |
| R.A.C.J.FJ-WHEN(START: STOP): | X | | | | | P |
| INCR. WT.: ALTITUDE OR CLEARANCE | | | | | | |
| PLANE | | | | | | |

(abbreviations are shown as IAT usage forms MAC 89, AFTO 151A, etc.)

TABLE 1 (Continued)

ROUGH-CUT REVIEW OF USAGE FORM
IAT INPUT DATA AND PARAMETERS

| PARAMETER | C5A | C130 | C/KC 135 | C141 | FB-111A | ENTRY/EVENT OR PARAMETER |
|---|---|---|---|---|---|---|
| TF-WHEN(START;STOP); INCR. WT:, | X | | | | | P |
| ALT. OR CLEARANCE PLANE: ROUTE | | | | | | |
| TOTAL TIME OF FLIGHT | X | | X | X | | E |
| RUNWAY CODE | | X | | | | E |
| COMMAND, WING, SQUADRON, HOME STA. AFCT. COMMANDER | | X | | X | | E |
| FLIGHT. ENGR. COMPLETED/CHECKED BY | X | X | X | X | | E |
| REMARKS | X | | X | | | E |
| FINAL LANDING EVENT (WHEN) | X | X | X | X | | P |
| NORMAL OR MAX. TAKEOFF, LDG. | | X | | | | P |
| TAXIWAY CODE; TAXI TIME | | X | | | | P |
| FUEL DISTRIBUTION | | X | | | | P |
| AIRDROP/REFUEL WT. | | X | | X | | P |
| CONTOUR FLYING | | X | | X | | P |
| EXTERNAL STORES WT. | | X | | X | | P |
| OPERATIONAL PHASE (CLIMB, CRUISE FUEL ON LOAD, FUEL OFFLOAD, DESCENT, TRAFFIC) | | | X | X | | P |
| RESERVE FUEL (FULL, EMPTY) | | | X | | | P |
| TOTAL LANDINGS | | | X | | | E |

TABLE 1 (Concluded)

ROUGH-CUT REVIEW OF USAGE FORM
IAT INPUT DATA AND PARAMETERS

| PARAMETER | C5A | C130 | C/KC 135 | C141 | FB-111A | ENTRY/EVENT OR PARAMETER |
|---|---|---|---|---|---|---|
| DUTY AF BASE; PHONE | | | X | | | E |
| F.S.L., TOTAL LDGS. AT START | | | | X | | E |
| FUEL WT. ON FINAL LDG. | X | X | X | X | X | P |
| AWLS LDG. | | | | X | | P |
| AIRDROP | | | | X | | P |
| $N_Z$ COUNTS | | | | | X | P |
| MISSION IDENTIFICATION (8) | | | | | X | P |
| LOW-ALTITUDE ROUTE, WT., OB, LAHS | | | | | X | P |
| WING SWEEP ANGLE | | | | | X | P |
| NO. LOW APPROACHES | | | | | X | E |
| NO. GEAR RETRACTIONS | | | | | X | E |
| BARRIER ENGAGEMENT EVENT | | | | | X | E |
| EVASIVE MANEUVERS EVENT | | | | | X | E |
| AR EXTERNAL TANKS EVENT | | | | | X | E |
| TOTAL | 23 | 23 | 21 | 24 | 18 | |

TABLE 2

USAGE FORM IAT - COMMON INPUT DATA AND PARAMETERS

| INPUT DATA (ENTRY/EVENT) | PARAMETER |
|---|---|
| AIRCRAFT TAIL NO. | |
| AIRFRAME HOURS | |
| TAKEOFF BASE | |
| LANDING BASE | |
| TIME (DAY, MONTH, YEAR) | CLOCK TIME (Z) |
| SEQUENCE NO., SORTIE NO. | GROSS WEIGHT |
| | CARGO WEIGHT |
| | FUEL WEIGHT |
| | EXTERNAL STORES WEIGHT |
| | INITIAL TAKEOFF (WHEN, FUEL WT.) |
| | OPERATIONAL PHASE |
| | AIRSPEED |
| | ALTITUDE |
| | TOUCH-AND-GO EVENTS |
| | FULL-STOP LANDINGS & TAKEOFFS |
| | CONTOUR FLYING |
| | AIRDROP/REFUEL WT. |
| | FINAL LANDING (WHEN; FUEL WT.) |
| TOTAL TIME OF FLIGHT | |
| WHO COMPLETED/CHECKED THE FORM | |
| TOTAL 8 | 16 |

"PARAMETER" = ANY ENTRY WHICH MAY HAVE MORE THAN ONE VALUE OR BE ASSOCIATED WITH MORE THAN ONE VALUE OF ANOTHER PARAMETER DURING THE MISSION.

TABLE 3

ROUGH-CUT REVIEW OF USAGE FORM
IAT INPUT DATA AND PARAMETERS

| AIRCRAFT-PECULIAR ITEM | C-5A | C-130 | C/KC 135 | C141 | FB-111A | PARAMETER? |
|---|---|---|---|---|---|---|
| USAGE LOG NO. | X | | | | | |
| SEQUENCE NO., SORTIE NO. | X | X | | X | | |
| C.G. | X | | | | | |
| RUNWAY CODE | | X | | X | | X |
| COMMAND, WING, SQUADRON, HOME STA. | | X | | X | | |
| REMARKS | X | | X | | | X |
| NORMAL OR MAX. TAKEOFF, LDG. | | X | | | | X |
| TAXIWAY CODE | | X | | | | X |
| TAXI TIME | | X | | | | X |
| FUEL DISTRIBUTION | | X | | | | X |
| AIRDROP/REFUEL WT. | | | | | | |
| RESERVE FUEL (FULL, EMPTY) | | | X | | | X |
| DUTY AF BASE; PHONE | | | X | | | |
| AWLS LANDING | | | | X | | X |
| $N_z$ COUNTS | | | | | X | X |
| WING SWEEP ANGLE | | | | | X | X |
| NO. LOW APPROACHES | | | | | X | |
| NO. GEAR RETRACTIONS | | | | | X | |
| BARRIER ENGAGEMENT EVENT | | | | | X | |
| EVASIVE MANEUVERS EVENT | | | | | X | |
| EXTERNAL STORES WT. | | X | | | | X |
| EST. NO. OF PECULIAR ITEMS FOR AUTOMATED IAT | 1 | 7 | 1 | 3 | 7 | |
| NO. OF EVENTS | 1 | 0 | 0 | 0 | 4 | |
| NO. PARAMETERS | 0 | 7 | 1 | 3 | 3 | |

TABLE 4

ROUGH-CUT REVIEW OF IAT PARAMETERS

| | SINGLE ENTRIES OR EVENTS | | | PARAMETERS | | |
|---|---|---|---|---|---|---|
| | COMMON | AIRCRAFT-PECULIAR | TOTAL | COMMON | AIRCRAFT-PECULIAR | TOTAL |
| C-5A | 8 | 1 | 9 | 11 | 0 | 11 |
| C-130 | 6 | 0 | 6 | 11 | 7 | 18 |
| C/KC-135 | 6 | 0 | 6 | 11 | 1 | 12 |
| C-141 | 7 | 0 | 7 | 13 | 3 | 16 |
| FB-111A | 4 | 4 | 8 | 9 | 3 | 12 |

however, some items are repeatedly or continuously recorded (e.g., T-&-G landings; time; fuel weight, whether recorded or calculated; altitude), and others are initial inputs or infrequent events (e.g. sortie no.; barrier engagement). An attempt has been made to classify the input data in this sense, with infrequent entries reasonably independent of other parameters being called entries or events.

### 3.1.2 IAT Monitoring Techniques

#### 3.1.2.1 Usage Forms

Many of the present 'forms-based' Individual Aircraft Tracking Programs use some type of fatigue damage calculation program. Changeovers to crack growth based IAT programs are in development for several of these systems, including the C-141A program conceptually described herein which is used as the baseline Transport/Bomber Aircraft IAT program.

IAT programs which are changed to crack growth programs are affected by the data base which has been acquired through the years in support of the fatigue damage program. For example, the data block size selected for fatigue tracking may be ill suited for crack growth tracking. Also, the sequence of flights or loads or events may not have been maintained for the fatigue tracking program, and the crack growth program may require regenerating this information or finding a way to function without it.

The Force Management Methods Task I state-of-the-art survey revealed several potential improvements to the present systems. These pertained to choice of IAT recording method and equipment; content, format, and frequency of output; number of control points; compatibility with the force structural maintenance plan and using command mission requirements; and flexibility for changes after initial design of the system. See current methods report, Reference 2, Sections 5.1 and 6.1. These potential improvements, and others to the baseline program, should be considered in the process of changing from a fatigue damage program to a crack growth based program.

The evaluation which follows assumes a changeover from a current fatigue damage IAT program to a crack growth IAT program.

The baseline program for the Task II Improved Methods evaluation is conceptually described in this report. The crack growth based program operates on crew data sheet (usage form) entries to define typical "missions", including mission sequence. Provisions for special mission definitions are generally included. Incremental analytical crack length from an assumed initial flaw is calculated for each structural monitor location for each mission in sequence. The incremental crack length adds to the total length produced by the previous missions, and the new total length establishes the parameters for calculation of the incremental length produced by the next mission. The predicted future crack extension is calculated using analytical forecasting usage for that aircraft. Force Maintenance Actions (i.e. time to modification or inspection) are defined based on this prediction. Inspection permits the resetting of the calculated crack length to the NDI detectable crack size in that inspection as appropriate. Usage forms IAT programs (and any other IAT programs also) require supplemental data and cost-effective program design, as discussed below.

- <u>Data Feedback</u>

  The 'Usage Forms' IAT based on crack growth calculations and NDI results requires a 'closed loop' for complete use of the program. As each tail number is inspected at the monitor locations a reporting system is required to feed that data back to the ASIP manager so that the 'next interval' projections can be provided. Without this 'feed back' the NDI results of cracks (if any) will have to be assumed which could adversely affect Force Safety. The 'Closed Loop' concept will require the ALC's to implement the necessary reporting system.

- Data Output

  The usefulness of a 'forms based' IAT and closed loop NDI reporting system is very dependent on the format for all output data to the ASIP manager. A potential limitation exists if the output format is not structured to be responsive to the practical needs of the USAF user.

- Operational Costs

  Usage forms IAT programs required to generate the output needed for Force maintenance 'Actions' requires careful scrutinizing in order to produce data at reasonable costs. Current state-of-the-art crack growth 'damage' calculation routines are available at competitive rates compared to previous routines. Initial costs will obviously be incurred to get the data 'on-line' for the various airframes. A practical and responsive Force Maintenance IAT program based on NDI and crack growth has the potential to achieve lower PDM maintenance burdens than are currently required.

#### 3.1.2.1.1 Advantages and Limitations

The current usage forms Individual Aircraft Tracking (IAT) programs are described in the Task I Current Methods final report, Reference 2. These current and future programs can be based on data block utilization breakdowns or on pre-defined mission descriptions obtained by computer analyses of crew data sheet (usage form) entries. The data base for the analyses includes flight loads and ground loads surveys, loads and environmental stress spectra (L/ESS) data, dynamic response tests and analyses, fatigue tests and analyses, and predicted and actual aircraft utilization data. The programs are updated periodically through Service Life Analyses to include the results of tests, service aircraft utilization, service aircraft corrosion/cracking experience, and analyses of these data obtained subsequent to the last update. Usage forms IAT programs offer significant advantages, which include:

- Updated data base (reanalysis)- The tracking program is recommended to be preceded by a thorough Durability and Damage Tolerance Assessment (DADTA), in which the entire aircraft structure is reviewed in the light of all design, development, test, and service experience obtained to date. Critical locations are defined and crack growth analyses are performed to identify inspection and modification actions based on DADTA crack growth concepts. IAT structural monitor locations and the design of the tracking program are thus structured to the results of the intensive DADTA. The resulting program completes an updating of the total structural analysis to present MIL-STD-1530A Aircraft Structural Integrity Program (ASIP) concepts.

- Refinement - The programs are based on all past and current design, development, testing, and operational aircraft data;

- Consistency - The methods used are consistent with the original design concepts and subsequent development, test, and analysis methods.

- Flexibility - Sufficient data are obtained so that history can be reconstructed or reanalyzed if necessary.

- Simplicity - The basic methodology and calculation routines are straightforward.

- Responsive to General Structural Characteristics - Responsive to crack growth characteiistics, geometry, material, stress levels, environment (moisture, corrosive products, fuel), and design and manufacturing characteristics which are major influences on crack growth rate at a specific location. These are all included in the crack growth analysis on which the IAT program is based.

- Responsive to NDI Results - Scheduled safety inspections for critical areas are responsive to results of NDI. The reliable detectable crack size at a given location by NDI and the crack growth analysis form the basis of establishing the recurring 'Next Interval' of flying for the particular tail number.

- Responsive to Critical Crack Length - The time to inspection or modification is based on crack growth calculations which utilize critical crack length determinations for selected tracking points.

- Current Force Maintenance Action Response - Inspection actions are based on crack growth from a pre-defined 'safety' based initial crack length or an inspection-detectable length, thus providing force safety responsiveness to fly the 'next interval' based on most recent NDI results and the usage of the particular individual aircraft.

A Transport/Bomber 'Usage Forms' IAT program is limited by the effects of:

- Reliance on Average Mission and Environmental Data Any usage forms tracking program must use statistical data for load or stress occurrences per data block or per mission, and the sequencing of these occurrences. The specific loads and sequence experienced by the individual aircraft are not defined.

- Limited Sequencing Data for Past Usage - Historical individual aircraft usage information may not have been stored in flight sequence. Future IAT programs based on crack growth require a recognition and accounting for sequence. Unsequenced historical data can only be reconstructed to an accuracy of so many missions in a given quarter. Random sequencing or other analytical means of reconstructing the history within the quarter is necessary.

3.1.2.1.2 Stress Transfer Functions

Transport/Bomber usage form Individual Aircraft Tracking (IAT) programs generally have individual, independently produced structural monitor location analyses. The individual monitor locations are anticipated to apply to zones or regions of structure whose boundaries are to be determined by detail structural analysis which considers stress level, local geometry and manufacturing/fabrication factors. Normalized crack growth evaluations would be performed to assist in broadening the 'zones' covered by a single monitor location. Stress transfer functions will be used in conjunction with other methods as discussed in a total sensitivity analysis in arriving at the final 'zonal' coverage.

For crack growth IAT, the thorough DADTA which is recommended to precede the design of the IAT program would be used to define specific critical locations for the IAT program. The final number of recommended monitor locations would be selected as necessary in order to obtain the necessary IAT data to respond to the sensitivity of the particular structural configuration and utilization.

3.1.2.1.3 Crack Growth Models/Examples

Figure 1 is a preliminary block diagram showing the crack growth usage form IAT program for the baseline C-141A Transport. This program is presently being considered for implementation into the C-141A ASIP.

Table 5 shows some preliminary headings for tabular output of the C-141A Fracture Tracking Program. Prediction techniques are discussed in Paragraph 3.1.2.4 below. Force Structural Maintenance aspects are discussed in Section 2.

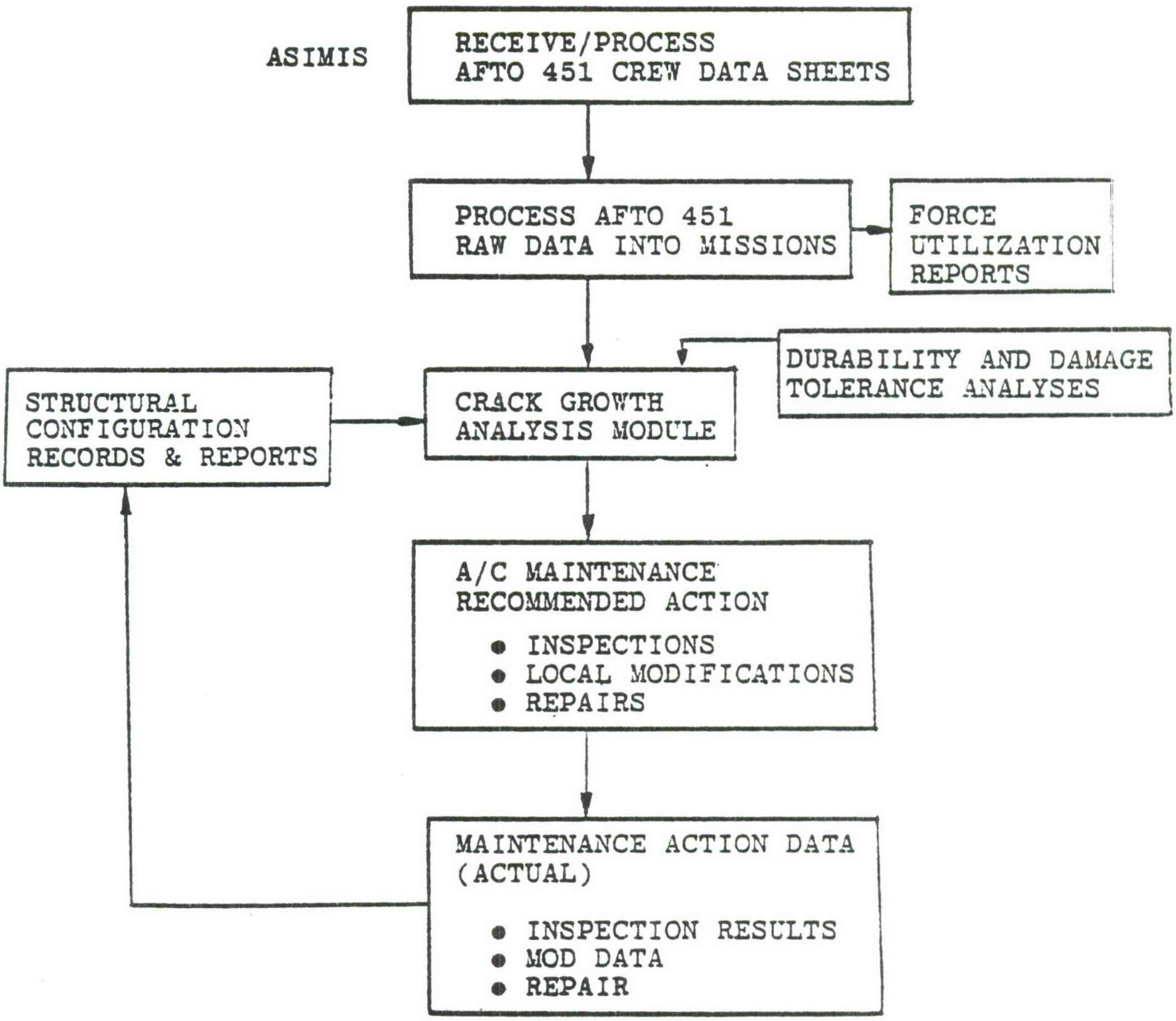



Figure 1. Flow-Diagram Fracture Tracking Program.

TABLE 5

FRACTURE TRACKING PROGRAM CANDIDATE PLANNING
LIST OF DATA OUTPUT ITEMS -PRELIMINARY

- Quarterly Time Period XXX
- Tail Number & Current Base Assignment
- Total F.H. at End of Quarter
- F.H. Accumulated During Quarter
- Total FSL/Total FSL During Quarter
- Total TAGs/Total TAGs During Quarter
- Total Pressurizations/Total Pressurizations During Quarter
- Total F.H. in Training
- Total F.H. in Training During Quarter
- Starting Crack Length at Beginning of Quarter
- Final Crack Length at End of Quarter
- Total Crack Length
- Critical Crack Length
- Last NDI - Date/F.H./Technique/Detectable Crack Size/Results
- Reset Crack Length - Date/F.H./Crack Size
- Time To Next Inspection

| DATE | F.H. | UTILIZATION |
|---|---|---|
| XXX | XXX | Actual Past Usage |
| XXX | XXX | Severe |
| XXX | XXX | Average SLA II |

Figure 2 shows an example of the crack growth Tracking Program for the C141A. The assumed crack growth at the structural location caused by a stress spectra consisting of USAF mission profiles and 'average' utilization is plotted versus study results of actual usage data from a series of individual tail numbers in the Force. This structural location reflects actual usage to be more severe for the study group than the average utilization spectrum.

3.1.2.1.4 Data Collection

Data collection for usage forms IAT programs is described in the Task I Current Methods final report, Reference 2. A means of increasing the percentage return of usable forms, such as pickup and review during debriefing sessions, is desirable. Crack growth based programs recognize mission sequence, and an increase in percentage return improves the analysis accuracy.

3.1.2.1.5 Data Processing

Data processing for fatigue damage usage forms IAT programs is described in the Task I Current Methods final report, Reference 2. Only the emphasis associated with using crack growth based programs rather than fatigue based IAT programs are discussed below.

3.1.2.1.5.1 Logistics

The Usage forms data are converted to a series of predefined missions plus special derivatives of these missions, and sequence of the missions is maintained through the analyses in order to compute incremental crack length by quarter.

3.1.2.I.5.2 Verification/Editing Techniques

Fatigue-based IAT programs may use data block, mission segment, or typical mission bases for the data. It is anticipated that crack growth based IAT programs will generally use typical mission descriptions plus special IAT programs are characterized by the relative insensitivity of the

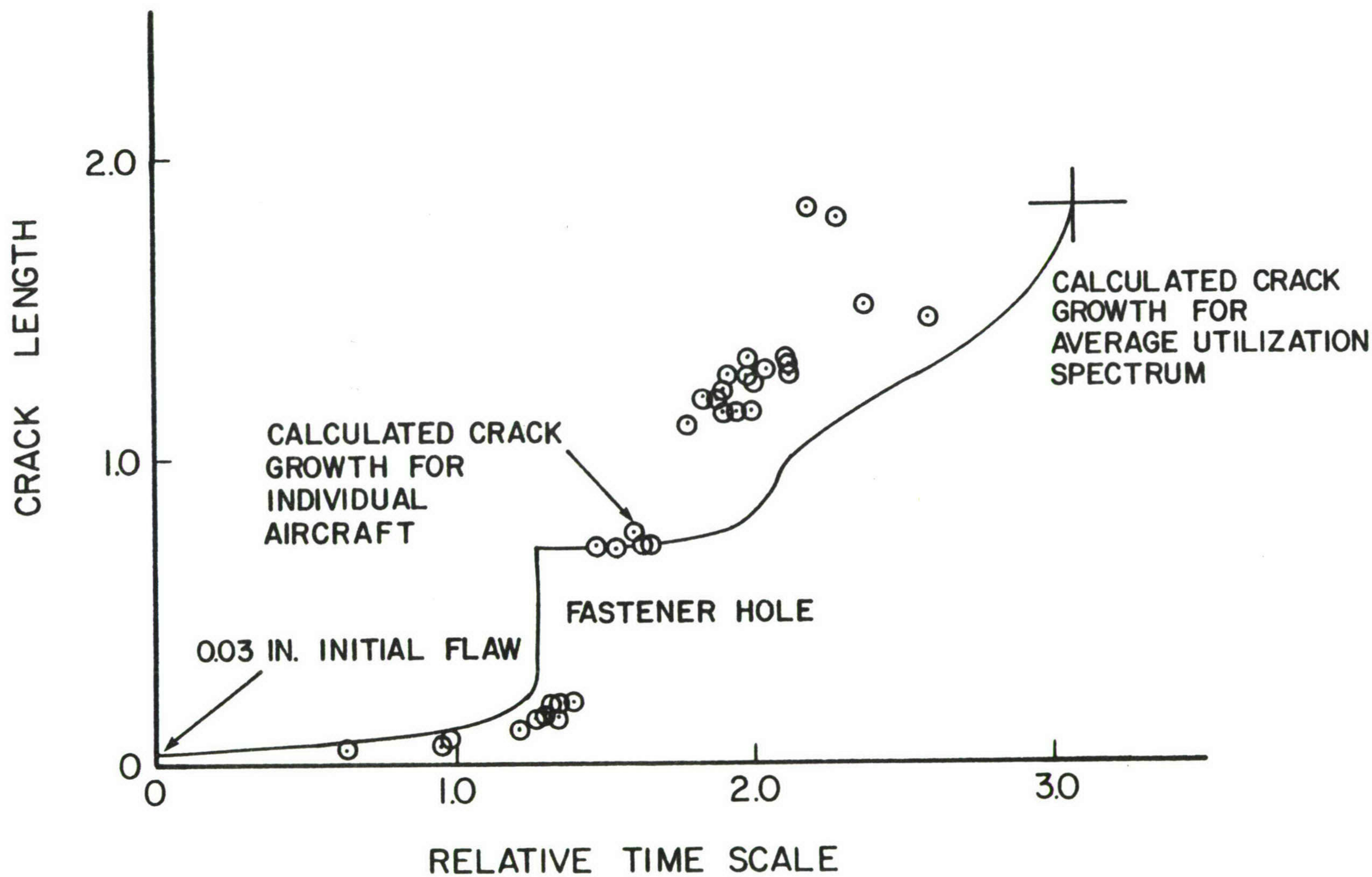



Figure 2. Fracture Tracking Analysis Point W-XX.

cumulative damage theory to low-stress magnitude loading cycles and high sensitivity to the ground-air-ground excursion. These characteristics may be reflected in data block sizing or editing techniques which emphasize the data from which the ground-air-ground excursion is obtained. Crack growth based Transport/Bomber IAT programs are sensitive to high cycle low stress flight and ground loads experience as well as to the ground-air-ground transition; they are also affected by mission sequence. Therefore, the verification/editing techniques may require restructing when an IAT program is changed from fatigue to crack growth methodology.

For the baseline C-141A IAT program, the data block based fatigue tracking program is being replaced with a series of pre-defined missions with provisions for additional special variations. The verification/editing techniques are restructured by revised logic oriented to mission identification rather than the previous data block ("point-in-the-sky") identification plus secondary mission usage identification for overall force usage monitoring.

3.1.2.1.5.3 Gap-Filling Procedures

Fatigue-based IAT program gap-filling procedures are discussed in the Task I Current Methods report, Reference 2. The same basic procedures are applicable to crack growth based IAT programs except that sequencing must be included. For the baseline C-141A Fracture Tracking Program, this consists of computerized sequencing of the missions, determination of gaps via the dates, flight hours, and landings data from the usage forms data, and filling in the gaps with flights selected to match pertinent mission descriptors considered appropriate for the period. (See paragraph 3.1.2.1.5.4 regarding configuration "gap-filling" procedures).

3.1.2.1.5.4 Supplemental Data Requirements

Current IAT programs utilize crew data sheets (usage forms), supplemented if required by other data such as the MAC A38 airframe report. It is advantageous and cost effective to redesign the usage form, if necessary, so that all required information is on the form and is retrievable by an optical scanner or other computer device. For crack growth IAT programs, the required data may be the same or may be different from fatigue-based programs. The baseline C-141A Fracture Tracking Program utilizes the same crew data sheet (usage form) as the current fatigue-based program. The data are retrieved by an optical scanner. However, the form is being redesigned to incorporate the supplemental data previously obtained from the MAC A38 airframe report, which is being discontinued for the C-141A as a cost savings.

Other supplemental data requirements also may be common to the fatigue-based and crack growth based IAT programs or may be additional. These data requirements are:

- structural configuration at each monitor location for each aircraft (original, redesigned, which model, repaired, retrofitted), and
- inspection data (when inspected, how, whether corroded or cracked, extent and details of crack).

These data are difficult to obtain, but are essential to maximum effectiveness of the IAT program. The tendency is to design the program so that in the absence of data to the contrary a scheduled modification/inspection is assumed to have been performed to the requirements specified in the applicable Technical Order, and the resulting configuration has no observable cracks. This method is necessary as a "gap-filling" procedure to ensure that the IAT program can be run. However, it is obviously an undesirable "open loop" method which needs to be improved.

### 3.1.2.1.6 Damage Projection Techniques/ Examples for Establishing Recurring Inspections

Crack growth based IAT projections for establishing periodic recurring inspection intervals (i.e. next safe use interval of flying) are based on calculated crack length and on a projection method. Figure 3 illustrates this.

- The present assumed crack length is either calculated from an assumed initial flaw size plus incremental crack growth to the present time or an inspection-based NDI "maximum undetectable" crack length.

The initial flaw size used in the on-going baseline study is obtained by utilizing a safety concept of a "rouge flaw" initial size as input, resulting in a prediction of crack length based on this initial quality assumption. This prediction produces a safety based time to initial inspection. Predictions can be used in an IAT program which respond to both a 'rogue' safety flaw or a less severe (smaller) initial flaw more representative of the average aircraft. It is recommended that the 'average' crack growth time to a given crack length (durability) be evaluated by the Durability and Damage Tolerance Assessment (DADTA). The baseline C-141A IAT program under development addresses safety inspections at this time. Later evaluations may include 'average' times to reach detectable cracking.

At scheduled points (calendar time or flight hours) NDI would be performed at specified monitor locations/regions/zones. The particular NDI method used at the location will provide discrete data for a 'NDI detectable crack size' ($a_{NDI}$) with a high degree of reliability of not missing the crack size. If the inspection is performed and the detectable crack is not found the IAT program is reset to that crack size ($a_{NDI}$) at the time of performing the inspection. Projections of future analytic crack sizes are then based on this crack size.

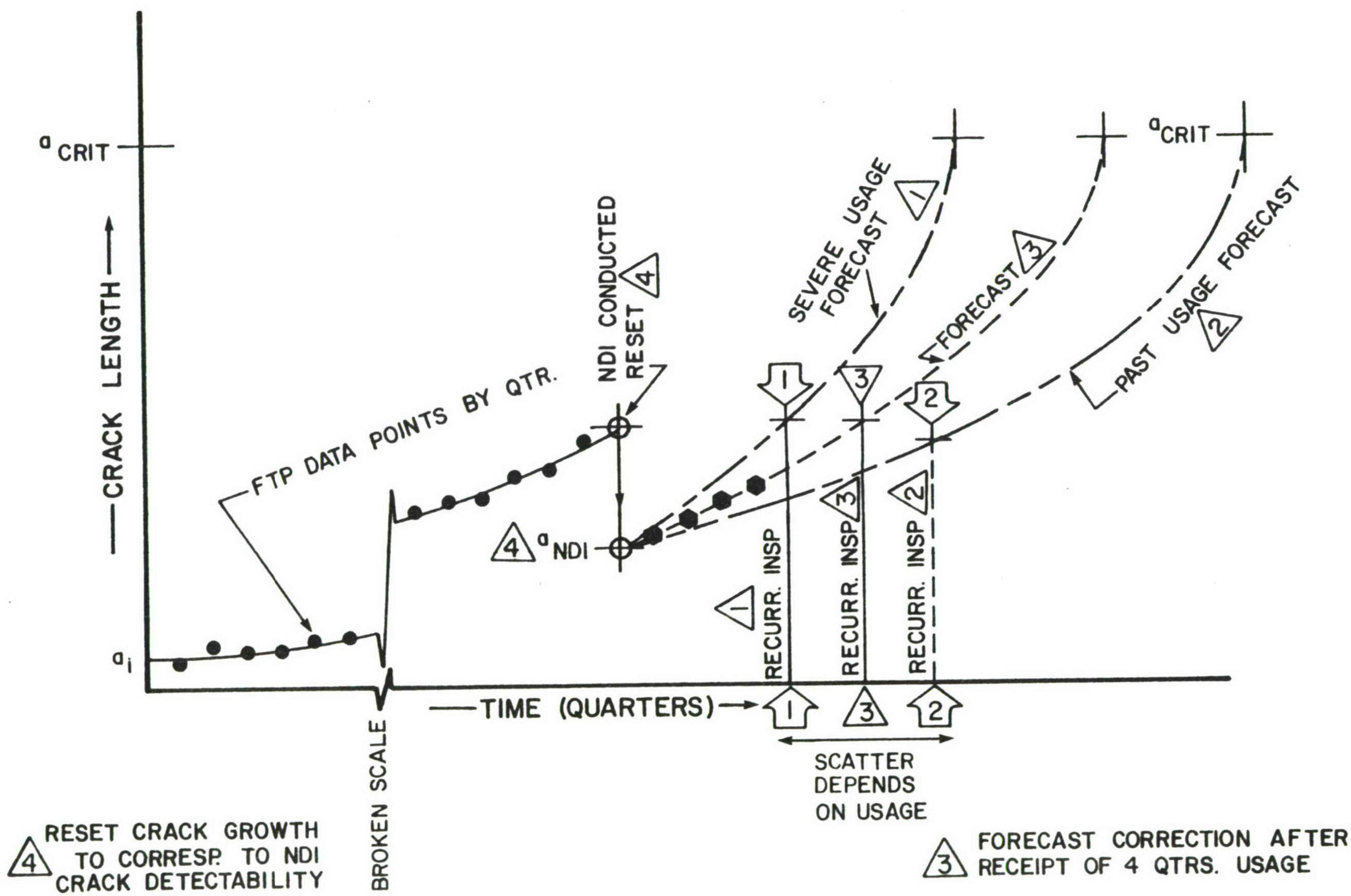



Figure 3. Fracture Tracking Program Example of Projecting Recurring Inspections Based on Forecasting.

The concept of an IAT Program using crack growth and NDI to set recurring inspections (i.e. next safe interval of flying) presupposes the existence of an initial flaw at each of the structural monitor locations/zones. This is a safety feature to account for an unknown defect that could be present at a critical structural location (such as a scratch, gouge, inclusion, etc.). Since the initial flaw could exist in any of the Force aircraft, all aircraft must be periodically inspected to protect safety (sampling inspections will not suffice).

NDI would be conducted at scheduled intervals at the monitor locations based on crack growth using the stress spectra reflecting the Individual Aircraft's usage. If an NDI does not disclose a detectable crack, the aircraft then flies the 'next interval' at the end of which time the NDI is repeated.

This NDI process is repeated as long as no cracks are detected; if a crack is found, repairs are made. Obviously, one hopes cracks do not exist but the concept of 'Inspect and Fly the Next Interval' does provide a safety-based approach for the airframe for continued Flight Operations.

Projections may be based on several approaches which include: aircraft usage determined from the specified mission profiles and average utilization; the most severe usage; or the actual usage of the specific individual aircraft or overall force aircraft for some time interval such as the most recent quarter or year. The actual usage should be bracketed by these projections. In general, it would appear that recent actual and 'severe' usage projections should be included in the IAT program output. Projections based on individual aircraft usage tend to shift each period to the extent that several periods would need consideration together in establishing a forecast slope. Projections based on overall force aircraft for a limited interval would require lenghty program logic. If an aircraft is flying severe missions, a severe projection can be used for special inspection planning for that aircraft. Forcewide inspection plans for individual or overall force aircraft based on an average utilization spectrum such as utilized in the Durability and Damage Tolerance Assessment (DADTA) should be considered as furnishing a general overview trend.

In selecting the projection techniques, the actual use of the data should be kept in mind. Time to inspection for individual aircraft is only useful if individual aircraft inspections are scheduled on the basis of the projections. This subject is discussed further in Section 2.

The C-141A (Baseline) Fracture Tracking Program methods of projection are still in work at this writing. The methods to be selected will be developed through coordination with the ASIP Program Manager in striving for a practical and cost effective system of providing Force Safety.

3.1.2.1.7 Table 6 lists cost elements which may be anticipated for the Usage Forms IAT system. The table is in a common format for use in listing cost elements for the other IAT systems evaluated in this report. The left column lists potential cost elements. A blank in the center column indicates that this cost element is not applicable for the system being discussed. A check indicates that this <u>is</u> a cost element. Words in the right column provide additional information to further describe or scope the cost element for that system.

3.1.2.1.8 Reasonability Factors

Usage Forms IAT programs operate on a pre-defined data block or mission segment descriptors or pre-defined mission definitions. These definitions are determined through structural engineering utilizing analytic and test data. A computer logic is developed to use input from the usage form entries. Therefore, the IAT program is influenced directly by the reasonability of the forms data; included are such factors as:

- Percentage Return of Usable Usage Forms
- Forms Preparation Accuracy

TABLE 6

TRANSPORT/BOMBER IAT COST
ELEMENTS FOR USAGE FORMS

| ELEMENTS | USAGE FORMS | COMMENTS FOR USAGE FORMS SYSTEM |
|---|---|---|
| INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT | | |
| DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE | | |
| QUALIFICATION TESTING | | |
| DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE | X | USAGE FORMS & COMPUTER PROGRAMS |
| T.O. FOR IMPLEMENTATION | X | |
| FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS) | | |
| REPLACEMENT OF DATA ACQUISITION ELEMENTS; TRANSMITTAL TO ASIMIS | X | USAGE FORMS |
| SPECIAL READING OF DATA ACQUISITION DEVICE | | |
| DATA TRANSCRIPTION TO MAGNETIC TAPE | X | OPTICAL SCANNER OR KEYPUNCH |
| COMPUTER ANALYSES OF DATA | X | |
| GAP FILLING | X | COMPUTERIZED |
| SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS | | |
| ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA | | |
| MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT | X | |
| REPORTS OUTPUT | X | |
| ON-BOARD SYSTEMS MAINTENANCE | | |
| TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE | | |

- Forms Data Entry Recognition of Actual/ Realistic Conditions Encountered
- Logic Interpretation of Forms Data (Gap Filling, Erroneous Data Rejection)

Also to be considered in any forms based IAT program is the reasonability by which the computer program operates, calculates and interprets data which is influenced by:

- Mission/Flight Descriptor Formulation Data (i.e. 'Points-in-the-Sky')
- Comparison of Actual Vs. Assumed Pre-Defined Data Characteristics (i.e. Response/Recognition of Unusual Events).
- Structural Analysis Methods (Damage Modules)
- Output Data Reasonability

An IAT Program is a Force Maintenance Safety device developed by incorporating engineering analysis, fatigue and static test, flight test and Force Service experience. The program is based on structural analysis which responds to stress level, geometry, fracture toughness, inspectability and safety. The IAT Program should be designed so as to periodically receive updates as needed based on analysis, test and service experience.

The overall objective is to furnish a forecasting tool for the ASIP Manager for Individual aircraft such that inspection scheduling can be accomplished based on usage severity trends for that aircraft. Based on results of the air-frame inspection, the next 'safe use' interval of flying is established.

### 3.1.2.2 Mechanical Strain Recorders for IAT

The mechanical strain recorder (MSR) provides a direct, sequenced trace of the total strain experience at a specific structural location (within the limits of its accuracy and readability). Therefore, the MSR could potentially provide a very useful data base for a Force Management System IAT Program. An IAT Program using a 'proven' MSR concept would be independent of the use of 'typical' aircraft analytical parameters describing the loads spectra environment. Also the transfer functions of analytical loads-to-stress and flight descriptors such as 'missions', segments, or data blocks would not be required in order to define the strain experience at that location.

Consideration of the potential of the MSR as a Transport/Bomber Individual Aircraft Tracking device points out other aspects of the Force Management System, however. The paragraphs which follow address these considerations, the primary ones being limitations in transfer functions and supplemental data requirements.

Mechanical strain recorders have been available for several years and installations have been made on A-37, F-4, F-5, CF-5, A-10 and F-16 aircraft. Over 400 production MSR systems have been delivered for use on F-16 A/B aircraft, and 96 were installed on A-37E aircraft. These recorders, which have seen extensive Force usage, are manufactured by Leigh Instruments Limited of Ontario, Canada. Three models of the Leigh MSR have been developed, the MSR-1, -2 and -3. The later models were developed with higher recording thresholds so that more of the low amplitude exceedance could be ignored by the MSR, thus resulting in less recording tape required and longer recording periods.

#### 3.1.2.2.1 Advantages and Limitations

The mechanical strain recorder is a simple, light weight device which does not require any external mechanical or electrical power. It does not require any input from the flight crew and only minimum ground crew maintenance. It lessens the dependence on analytical models and gives a history of the strain cycles in sequence. All dependence on average atmospheric and maneuvering data is removed as the MSR records the actual strains experienced by the airframe.

Mechanical strain recorders are limited in that they provide data which are accurate for only a very limited area of structure due to the difficulties of deriving stress transfer functions as discussed in Section 3.1.2.2.2. No mission profile data are available if a mechanical strain recorder is required to stand alone as an individual airplane tracking device (Section 3.1.2.2.5.4). Utilization indicators as to why a particular airplane (or airplanes) cracked cannot be derived from MSR data and must be recorded by the crew or some other device. The tape capacity of present MSR's may be insufficient to record a reasonable flight period for Bomber/Transport type aircraft. Although calculations (Section 3.1.2.2.8) indicate sufficient tape, a flight demonstration is required. The present Data Transcriber Unit (DTU) has a minimum reading threshold of approximately 2300 psi, (Section 3.1.2.2.8). This will require significant change and perhaps development work, as such a threshold would almost totally reject the usage stresses for Bomber/Transport type spectra.

#### 3.1.2.2.2 Stress Transfer Functions

Generally, a single MSR per aircraft has been used on the (fighter aircraft) service installation to date. Results obtained from this MSR are then translated to other structural locations of interest by various analytical methods. Such translations are probably reasonably accurate for small, rigid aircraft structural configurations; however, bomber/transport type aircraft present unique problems for such translations due to significant structural configuration differences of size, area and flexibility. Major structural areas may react to one or more load forces coming from one or more load sources, for example, a wing surface panel splice may have significant load inputs from $P_x$, $P_z$, $M_x$, $M_y$ and $M_z$ resulting from aerodynamic loads on the wing, inertia loads due to landing and ground handling, thrust loads from the engines, and control surface forces from flaps, slats, spoilers and ailerons. Phasing of these various loads is complex and will vary from point to point. Thus, the translation of MSR data from point to point on bomber/transport structure must be done with caution. Generally each structural area for which recorded service strains are required should have its own MSR. Translation of such data will be very limited. Fuselage, empennage, and wing structural areas for each aircraft must be examined for applicability of transfer functions.

3.1.2.2.3 Crack Growth Models/Examples

Development of crack growth analyses from MSR data is demonstrated in Figure 4. Once the strain data have been extracted from the cassette and formatted as a stress spectrum by the DTU, the spectrum data are submitted to a computer routine for crack growth calculations as illustrated in Figure 5. The example shown in this figure is fairly general, but is representative of the C-141A methodology which was used as a baseline for this program. With the addition of the necessary geometric factors ($\beta$) the previously derived spectrum stresses are transformed into stress intensity factors, and progressively into stress intensity ranges. Through the use of the Forman equation incremental crack growth is calculated for each load cycle. Interaction between load cycles of varying mangitudes is accounted for on the C-141 by the Hsu Load Interaction program (although this is a proprietary program with the Lockheed-Georgia Company, most companies have developed their own interaction model). These incremental bits of crack growth are then accumulated (from a specified initial crack size) through an integration routine and presented as total crack lengths versus time.

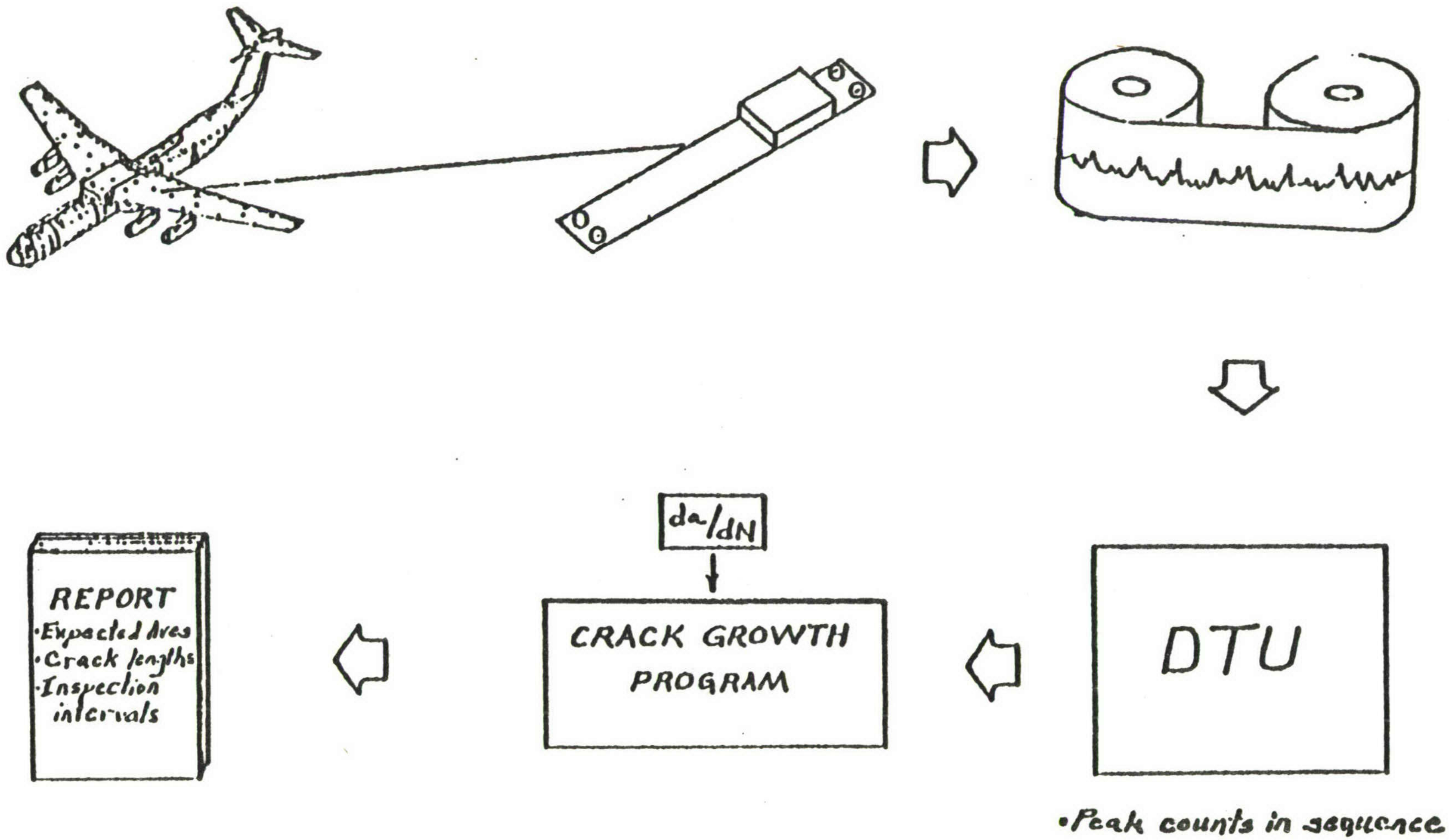



Figure 4. MSR Crack Growth Analysis.

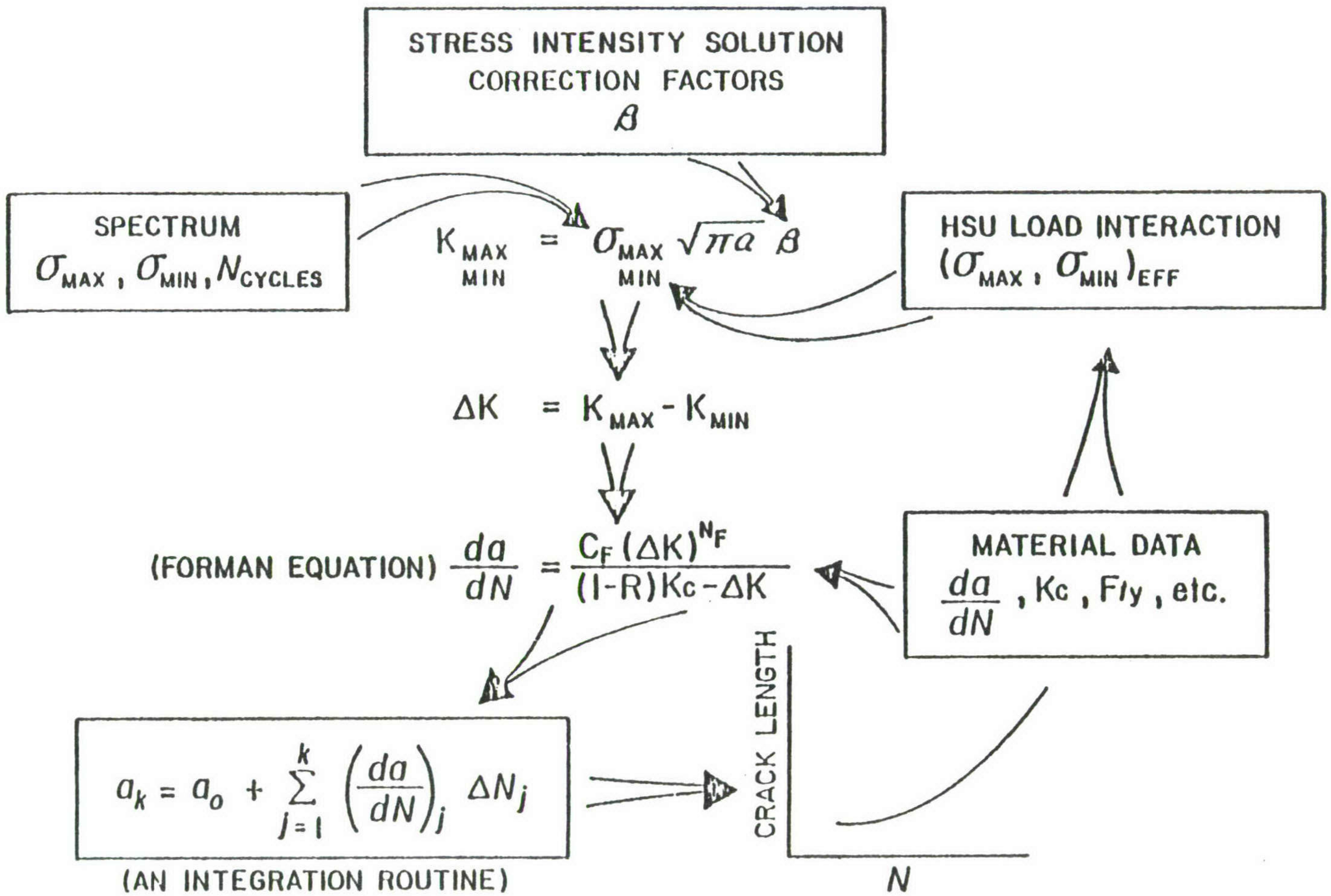



Figure 5. Crack Growth Program Basics.

#### 3.1.2.2.4 Data Collection

The mechanical strain recorders are attached to the aircraft structure by two epoxy-bonded mounting blocks. Straining of the structure is transmitted to the drive mechanism of the recorder and scribed on the metal cassette tape by a diamond stylus. No external power source is required, and service experience on the existing models has indicated that maintenance is minimal.

The metal tape used as a recording medium is contained in a small cassette. To remove a recorded cassette and reload with a blank cassette requires very little time. The period of time to fully utilize the available tape has been previously discussed.

#### 3.1.2.2.5 Data Processing

The only significant piece of support equipment required for the MSR is an automatic data reader/transcriber. Although such a Data Transcriber Unit (DTU) exists and is presently in use, it was designed and developed for use with relatively small, rigid fighter aircraft. In order for such a DTU to be used for bomber/transport aircraft it will be necessary that a unit be developed specifically for this purpose- the reading threshold must be significantly reduced and the ability to discern small amplitude cycles must be improved. (Alternatively, the MSR could be redesigned to provide greater sensitivity and longer tape length. Requalification would be necessary for these changes).

##### 3.1.2.2.5.1 Verification/ Editing Techniques

Since an MSR records only strain peaks resulting from external load inputs, the possibilities for checks and editing of the data are somewhat limited. The first and most obvious check to be made is that cassette tape is being used; that is, data are being recorded. A second check that should be made is to assure that extreme data points, which would represent load conditions beyond the capability of the structure, are not recorded on the tape. The data should also be checked by determining that the number of stress cycles recorded within a given stress range is reasonable for the number of flight hours of data recorded.

#### 3.1.2.2.5.2 Gap-Filling Procedures

If recorded data are missing or determined to be unacceptable for any given period of flying time, an attempt should be made to replace the missing data with a reasonably accurate simulation. Availability of a pilot's log requires only the assumption of average atmospheric data to develop the replacement data. In the absence of a pilot's log, a reasonable simulation of the utilization for this period of time can be derived from the following data which is generally available: number of flights and flight hours, number of full stop landings, and number of touch-and-go landings. If none of the above information sources are available, average data taken from the airplane's home mission base or for the entire model force should be used.

#### 3.1.2.2.5.3 Supplemental Data Requirements

When an indication of severe loading history is obtained from an airplane's IAT, two questions require assessment and evaluation:

- Was the severe loading the result of higher than expected utilization of some particular mission type (training, logistics, aerial delivery, etc)?
- Was the severe loading the result of unusual utilization of some particular loading source (high speed flaps, thrust reversers, excessive engine run-ups, long taxis, high landing gear strut pressures, heavy cargo, heavy fuel loads, light fuel loads, etc.)?

If MSR's alone are used as totally independent tracking devices, tracking results which indicate that a structure is experiencing severe usage will probably not give any indication of the significant contributors to this rapid utilization. Thus, simple operational changes (such as fuel management, speed or cargo restrictions, or g limits), which could minimize future severity of usage of the structure, cannot be determined. The available alternatives for managing the structure are therefore reduced to: probable increased costs in inspection; modification; repair; replacement; or early retirement.

Although L/ESS systems will provide indications of changed usage of the entire force, they will not be useful in identifying abnormal or unusual usage of individual aircraft. Only about twenty percent of the airplanes in a force will contain L/ESS recorders, and reduction of this data for individual tail number tracking is not a part of the L/ESS program.

If MSR's are used in conjunction with a tracking form or a recorder which provides a description of the utilization of the airplane, the loading severity history of the airplane structure can be determined as well as the utilization responsible for that loading history. Discrete events, such as flap extensions, airdrops, fuselage pressurizations, etc., can be counted and used in any necessary analyses. Figure 6 illustrates one way of reporting these data.

The use of the MSR to supplement an IAT Program offers the potential to enhance the overall data base in expanding the understanding of the flight-by-flight stress history at various structural locations. As discussed in the Introduction, the MSR appears attractive when viewed as a supplement to a total program for Bomber/Transport applications.

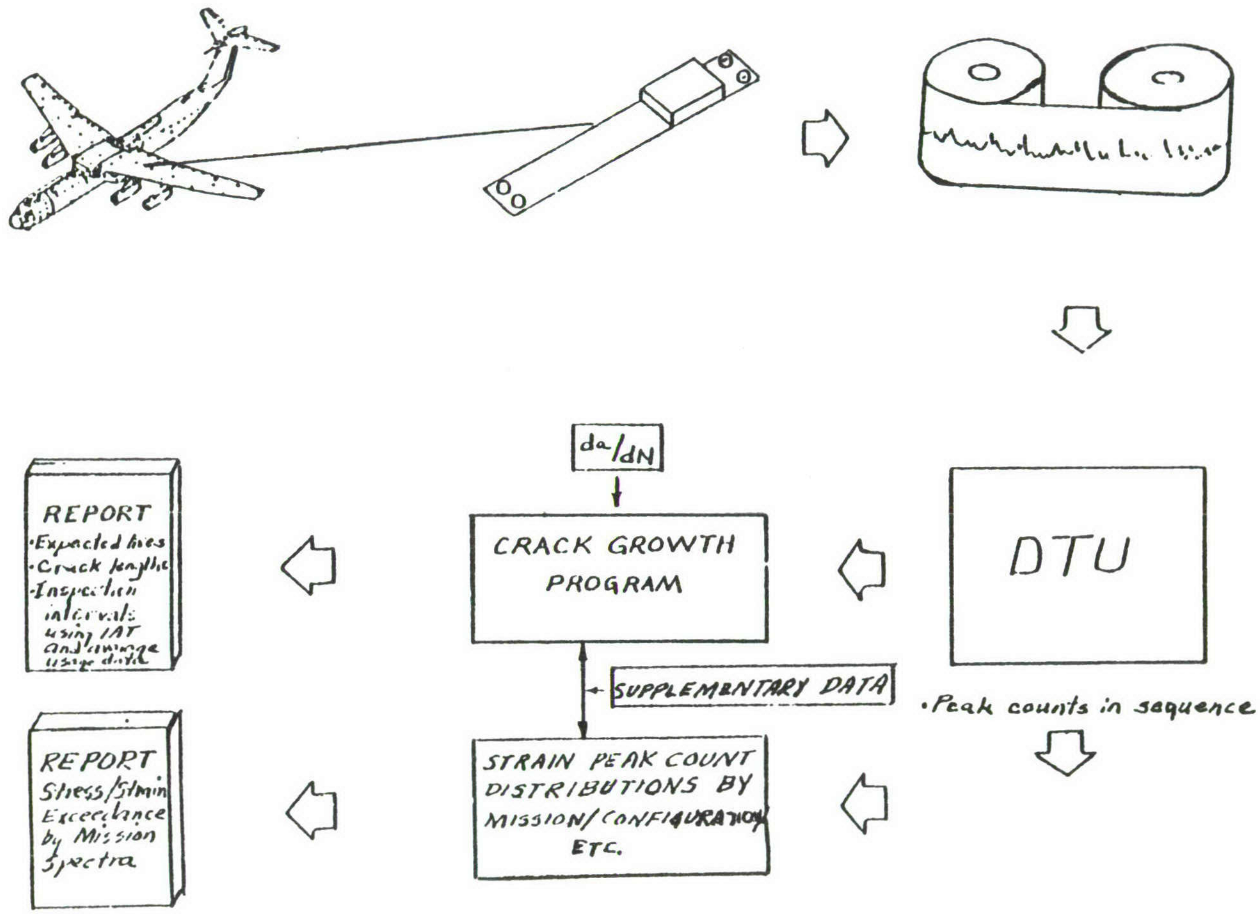



Figure 6. MSR Crack Growth Analysis With Supplemental Data.

### 3.1.2.2.6 Damage Projection Techniques/ Examples

Once the evaluation of the recorded stress cycles has been completed and analytic crack growth determined, it becomes necessary to project future analytic cracking beginning from the existing calculated crack length. Methodologies for such projections are numerous, but among the most common are:

- Projection assuming future usage will be identical to past usage of this airplane.
- Projection assuming future usage will be similar to past usage but with one or more discrete and identifiable variations, such as reduced airspeed, increased cargo, etc.
- Projection assuming this particular airplane will be subjected to usage identical to the previous usage of the most severely used aircraft in the force.
- Projection assuming this particular airplane will be subjected to usage identical to the previous usage of the least severely used aircraft in the force.
- Projection assuming future usage will be according to an analytical set of mission profiles or the fleet average usage. These projection methods are illustrated in Figure 7.

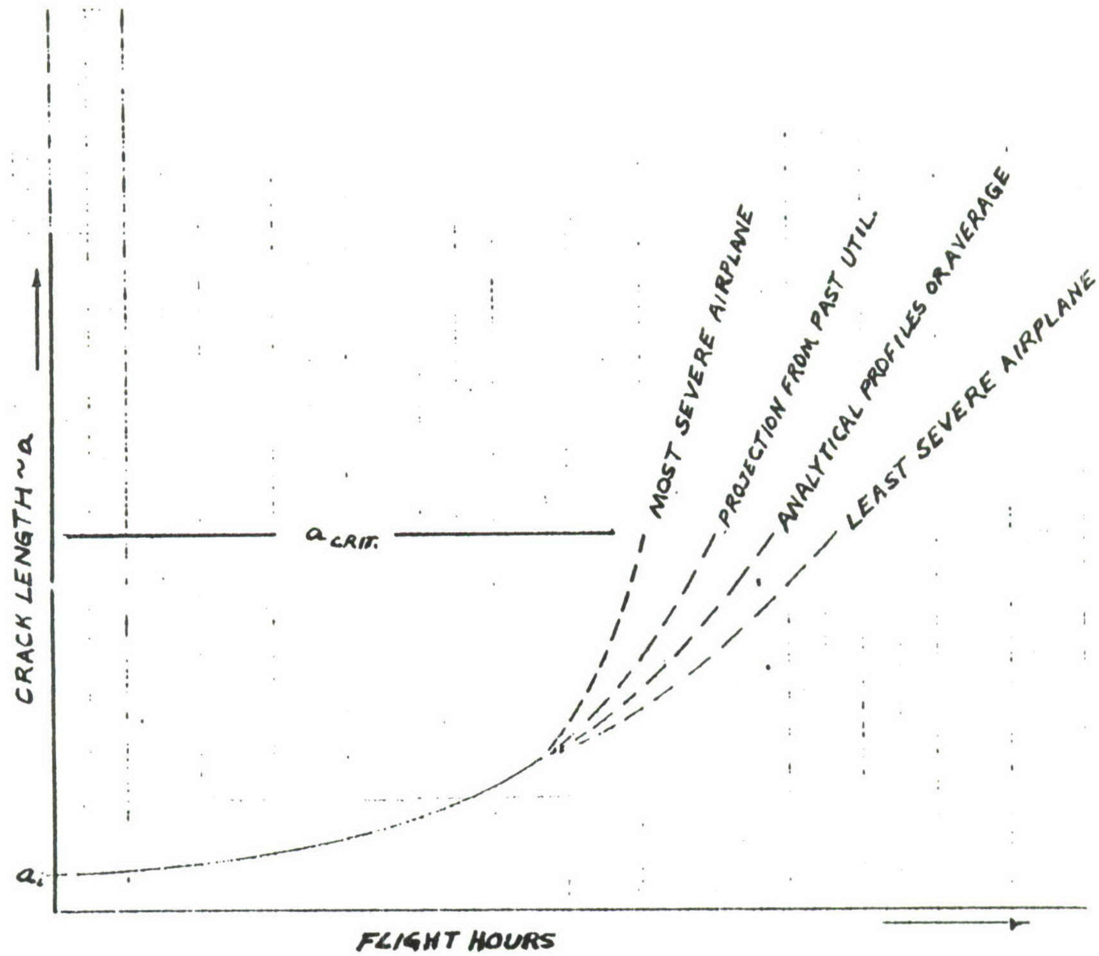



Figure 7. Crack Growth Projection.

3.1.2.2.7 Costs

Table 7 lists cost elements which may be anticipated for the Mechanical Strain Recorder System. Initial costs for Transport/Bomber aircraft include modification and qualification of the DTU so that data can be processed at a lower threshold stress. Also, development may be necessary to provide more tape on the cassettes or higher cassette tape feed rates.

3.1.2.2.8 Accuracy and Reliability

The Leigh mechanical strain recorders scribe on a hard metal tape with a diamond stylus (Figure 8). As strain changes occur, the tape is advanced so that separation of successive peaks is obtained. Approximately thirty inches of this metal tape are stored on the recording cassette. The scribe marks left on the tape by the stylus are approximately .0003 inch wide, thus permitting a reading accuracy of approximately .0001 inch. This translates into an accuracy of approximately 130 psi as follows:

$$\frac{.0001 \text{ inch}}{8 \text{ inch gage length}} \times E(10.6 \times 10^6 \text{ psi}) = 132.5 \text{ psi}$$

As a conservative approximation of manually transcribed system error, parametric crack growth calculations were made to compute the analytical response in crack extension caused by introducing a $\pm$ 132.5 psi variation in the C-141A fracture spectrum. A+132.5 psi variation input to the C-141 mission profiles (SLA II) stress spectra means that the stress range from maximum stress to minimum stress was increased by 265 psi. A minus 132.5 psi variation means that the stress range was decreased by 265 psi. The significance of these variations is shown in Figure 9 for a typical wing upper surface location ("A") and a typical wing lower surface location ("B") on the C-141A. The changes demonstrated in crack growth rate are probably acceptable for 100 to 150 psi deviation. It is likely that the DTU would be set up to minimize this variation. Also in

TABLE 7

Transport/Bomber IAT Cost Elements For
Mechanical Strain Recorders (MSR)

| ELEMENTS | MECHANICAL STRAIN RECORDER | COMMENTS FOR MSR SYSTEM |
|---|---|---|
| INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT | X | REWORK EXISTING MSR AND DATA TRANSCRIBER UNIT FOR TRANSPORT/ BOMBER AIRCRAFT |
| DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE | X | INSTALLATION DETAILS ONLY |
| QUALIFICATION TESTING | X | |
| DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE | X | COMPUTER PROGRAM |
| T.O. FOR IMPLEMENTATION | X | |
| FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS) | X | |
| REPLACEMENT OF DATA ACQUISITION ELEMENTS; TRANSMITTAL TO ASIMIS | X | CASSETTES |
| SPECIAL READING OF DATA ACQUISITION DEVICE | | |
| DATA TRANSCRIPTION TO MAGNETIC TAPE | X | DATA TRANSCRIBER UNIT |
| COMPUTER ANALYSES OF DATA | X | STRAIN TRACE ONLY |
| GAP FILLING | X | COMPUTERIZED |
| SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS | X | |
| ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA | X | |
| MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT | X | |
| REPORTS OUTPUT | X | |
| ON-BOARD SYSTEMS MAINTENANCE | | REPLACE MSR IF MALFUNCTIONING |
| TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE | | |

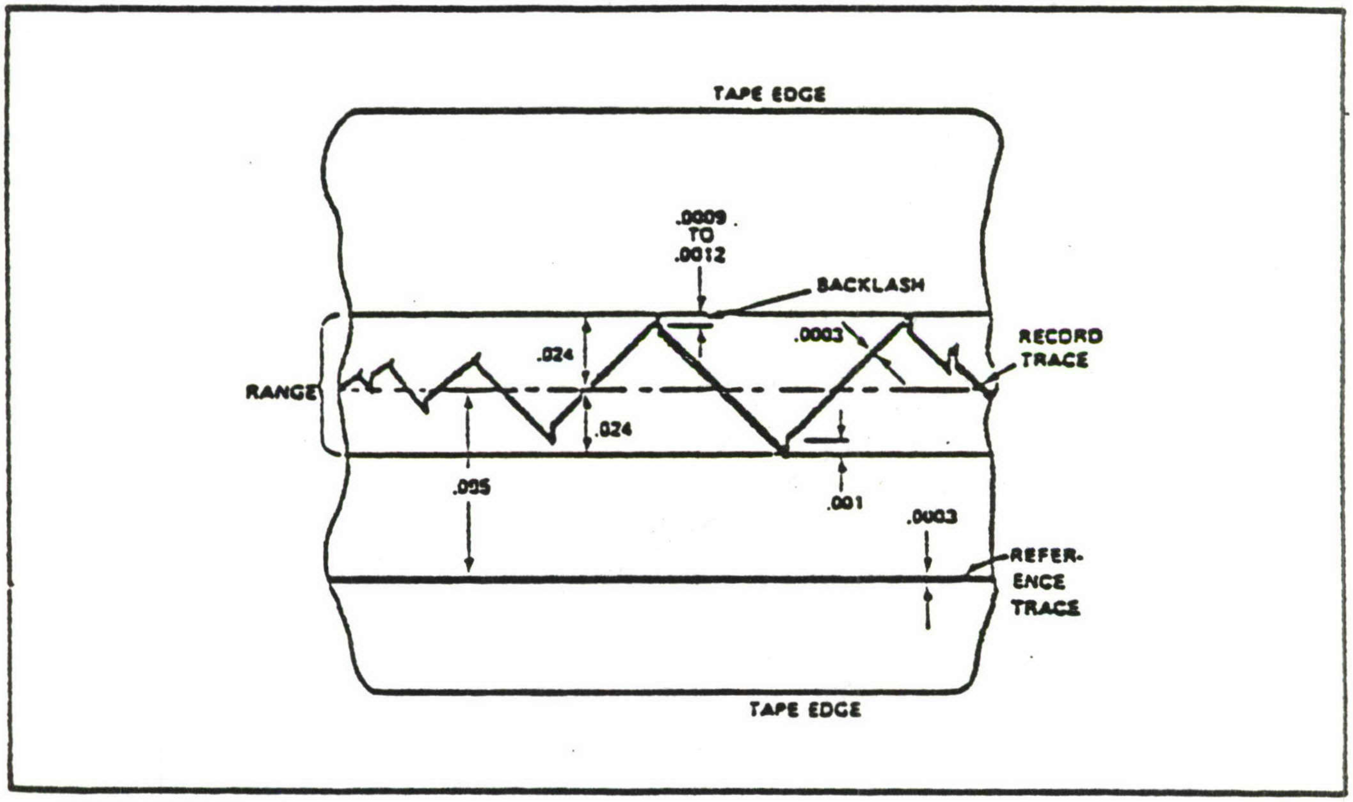



Figure 8. Typical Recording Trace.

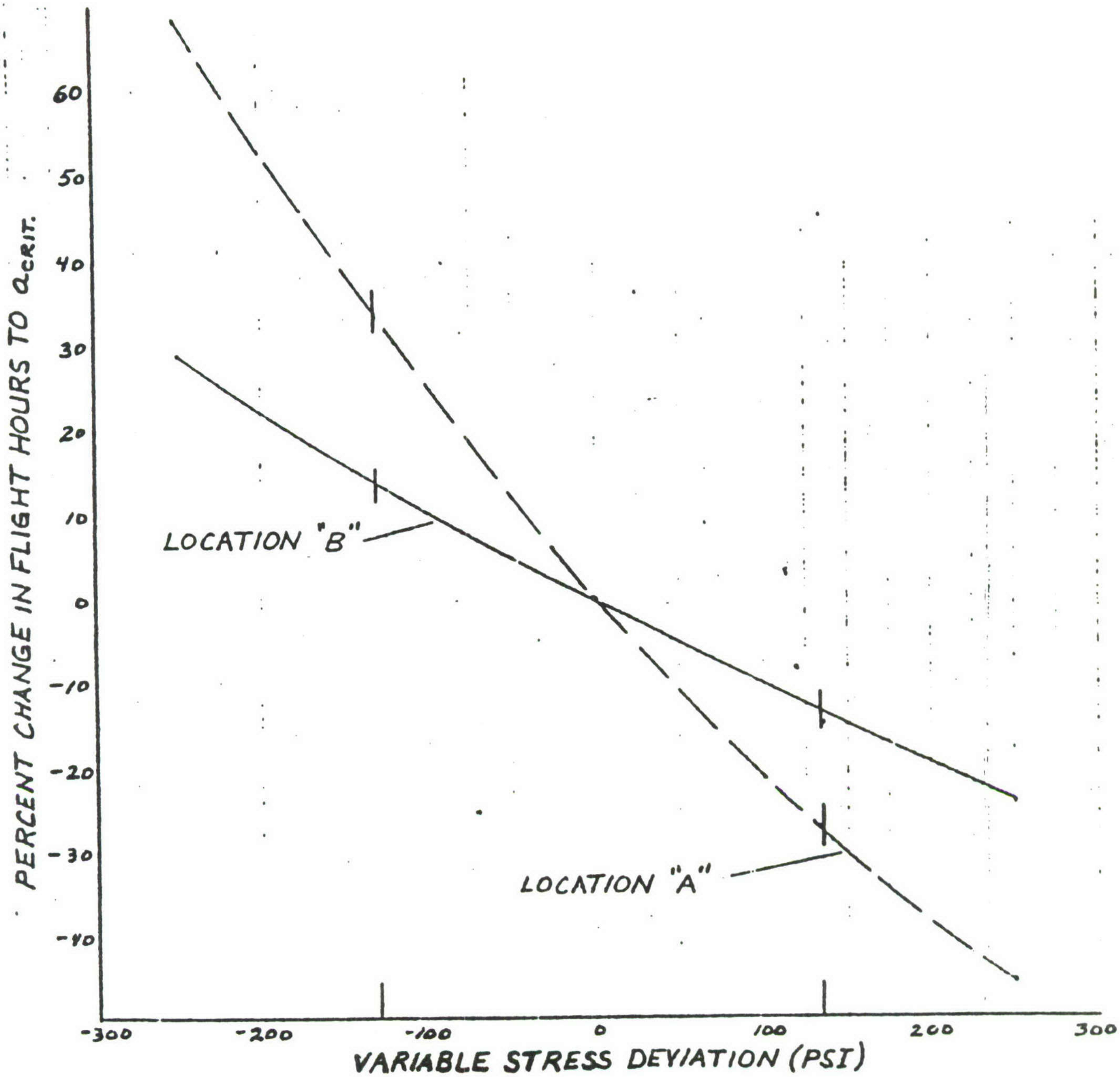



Figure 9. Effects of MSR Recording Accuracy (Sensitivity Analysis).

Figure 9, a given error of "so many psi" is seen to result in greater analysis differences for the wing upper surface where the total 'area under the curve' of tensile $\Delta\sigma$'s and cycles is generally considerably less than a lower surface point. This can be visualized by observing that most of the flight profile for an upper surface point is in a compression $\Delta\sigma$ mode. Thus, the higher the operational tensile stresses, the more accurate the MSR system. In addition to the reading accuracy described above, the tape advancement and mechanical characteristics of the MSR must be considered.

Advancement of the metal cassette tape is achieved by the ratcheting action of a pair of single turn spring clutches, one effective in tension and the other in compression. Mechanical take-up in the clutch mechanisms results in a threshold below which there is no advancement of the tape (Figure 8). This threshold is approximately 560 microinches for the MSR-2 and 900 microinches for the MSR-3. A beneficial result of these thresholds is that the large number of small amplitude cycles (insignificant from a structural viewpoint) which occur do not advance the tape and are not recorded. A study was made of the stress spectrum used for crack growth analysis for a C-141A wing lower surface point for a typical logistics mission (Table 8). The tape advancement for each spectrum condition was calculated for both of the threshold levels mentioned above. Use of the 560 microinch threshold resulted in all significant cycles being recorded, and use of the 900 microinch threshold resulted in the loss of 3.7 very insignificant cycles out of approximately 285 cycles in the mission. Thus, the threshold levels of both the MSR-2 and MSR-3 are adequate to represent those loads expected to occur on the C-141. For typical usage, it was calculated that 425 and 650 flight hours of mission one usage could be stored on a cassette, corresponding to 4-6 months usage.

TABLE 8

MISSION 1 TAPE ADVANCE

| Seg. | Sv | CYCLES PER FLT. | 900 µin. backlash A/CYCLE | A/FLT. | 560 µin. backlash A/CYCLE | A/FLT. | | Seg. | Sv | CYCLES PER FLT. | 900 µin. backlash A/CYCLE | A/FLT. | 560 µin. backlash A/CYCLE | A/FLT. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 703.8 | 6.6062 | .00027 | .00180 | .00084 | .00557 | | 26 | 1010.6 | 64.834 | .00105 | .06807 | .00162 | .10506 |
| | 1111.4 | 2.4860 | .00131 | .00324 | .00188 | .00466 | | | 2031.8 | 9.1401 | .00364 | .03324 | .00421 | .03846 |
| | 1545.3 | 1 | — | .00376 | — | .00296 | | | 2865.0 | 1 | — | .00575 | — | .00632 |
| 10 | 676.2 | 3.1682 | .00020 | .00064 | .00077 | .00245 | | 27 | 789.7 | 7.4114 | .00048 | .00352 | .00105 | .00775 |
| | 1028.5 | 1.5554 | .00110 | .00170 | .00167 | .00259 | | | 1351.0 | 2.6675 | .00191 | .00510 | .00249 | .00662 |
| | 1476.8 | 1 | — | .00223 | — | .00280 | | | 1943.1 | 1 | — | .00341 | — | .00398 |
| 12 | 725.4 | 5.0644 | .00033 | .00166 | .00090 | .00455 | | 28 | 896.7 | 50.151 | .00076 | .03818 | .00133 | .06680 |
| | 1176.2 | 2.1065 | .00147 | .00310 | .00204 | .00430 | | | 1690.2 | 7.4557 | .00277 | .02205 | .00334 | .02659 |
| | 1684.7 | 1 | — | .00276 | — | .00333 | | | 2365.6 | 1 | — | .00448 | — | .00505 |
| 13 | 982.2 | 3 | .00098 | .00293 | .00155 | .00465 | | 29 | 742.7 | 5.4867 | .00037 | .00215 | .00094 | .00545 |
| | 1504.7 | 1 | — | .00231 | — | .00288 | | | 1228.2 | 2.2902 | .00160 | .00367 | .00217 | .00497 |
| 14 | 676.6 | 2.2374 | .00020 | .00046 | .00077 | .00173 | | | 1760.8 | 1 | — | .00295 | — | .00352 |
| | 1029.8 | 1.2295 | .00110 | .00135 | .00167 | .00205 | | 30 | 796.7 | 1 | — | .00051 | — | .00108 |
| | 1531.4 | 1 | — | .00237 | — | .00294 | | 32 | 766.9 | 1 | — | .00043 | — | .00100 |
| 15 | 657.1 | 1 | — | .00015 | — | .00072 | | 34 | 880.9 | 1 | — | .00072 | — | .00129 |
| | 1042.6 | 1 | — | .00126 | — | .00183 | | 36 | 839.3 | 1 | — | .00062 | — | .00119 |
| 16 | 737.1 | 2 | .00036 | .00071 | .00093 | .00186 | | 38 | 1009.0 | 1 | — | .00105 | — | .00162 |
| | 1114.5 | 1 | — | .00131 | — | .00188 | | 39 | 720.2 | 1 | — | .00031 | — | .00088 |
| 17 | 849.7 | 1 | — | .00064 | — | .00121 | | 40 | 737.6 | 2 | .00036 | .00072 | .00093 | .00186 |
| 18 | 680.4 | 1 | — | .00021 | — | .00079 | | | 1124.7 | 1 | — | .00134 | — | .00191 |
| | 1045.4 | 1 | — | .00114 | — | .00171 | | 41 | 624.6 | 1 | — | .00007 | — | .00064 |
| 19 | 426.3 | 1 | — | — | — | .00014 | | 42 | 737.5 | 3.9335 | .00036 | .00141 | .00093 | .00365 |
| 20 | 662.9 | 1 | — | .00017 | — | .00074 | | | 1212.5 | 1.7922 | .00156 | .00280 | .00213 | .00382 |
| | 996.7 | 1 | — | .00101 | — | .00154 | | | 1783.2 | 1 | — | .00301 | — | .00358 |
| 21 | 672.6 | 1 | — | .00019 | — | .00076 | | 43 | 678.2 | 1 | — | .00021 | — | .00078 |
| 22 | 703.1 | 2 | .00027 | .00054 | .00084 | .00118 | | | 1057.8 | 1 | — | .00117 | — | .00174 |
| | 1046.0 | 1 | — | .00114 | — | .00171 | | 44 | 769.6 | 8.8665 | .00044 | .00369 | .00101 | .00895 |
| 24 | 620.0 | 1 | — | .00006 | — | .00043 | | | 1308.8 | 2.9729 | .00181 | .00557 | .00238 | .00706 |
| | 842.8 | 1 | — | .00075 | — | .00132 | | | 1857.5 | 1 | — | .00318 | — | .00375 |
| 25 | 400.6 | 1 | — | — | — | .00008 | | | | | | | | |

Form 1876A-1

TABLE 8 (Concluded)

| Seg. | Sv | CYCLES PER FLT. | 900 µ in. A/CYCLE | backlash A/FLT. | 540 µ in. A/CYCLE | backlash A/FLT. |
|---|---|---|---|---|---|---|
| 45 | 664.7 | 2.2021 | .00017 | .00038 | .00074 | .00164 |
| | 994 | 1.2161 | .00101 | .00123 | .00158 | .00192 |
| | 1465 | 1 | | .00220 | | .00277 |
| 46 | 744.5 | 15.556 | .00038 | .00584 | .00095 | .01472 |
| | 1233.5 | 4.1384 | .00161 | .00660 | .00219 | .00904 |
| | 1682.1 | 1 | .00426 | .00426 | | .00332 |
| 47 | 765.4 | 12.304 | .00043 | .00529 | .00100 | .01131 |
| | 1297.7 | 3.611 | .00178 | .00642 | .00235 | .00848 |
| | 1802.5 | 1 | | .00306 | | .00363 |
| 48 | 596 | 1.7323 | — | — | .00057 | .00099 |
| | 788.1 | 1.0279 | .00049 | .00050 | .00106 | .00109 |
| | 1088.1 | 1 | | .00125 | | .00182 |
| 49 | 774.2 | 2 | .00045 | .00090 | .00102 | .00204 |
| | 1104.3 | 1 | | .00129 | | .00186 |
| TOTAL | | | | .29827 | | .45713 |

A = TAPE ADVANCE (INCHES) = $1.2467 \times 10^{-6}$ (STRESS RANGE) − $\frac{2 \times \text{BACKLASH}}{Z_a - 50^{\circ}}$

Form 1876A-1

Leigh Instruments Limited has also developed a Data Transcriber Unit (DTU) which accepts the analog trace data from the metal tape and reformats the data into a computer compatible digital format on magnetic tape. If an MSR is to be used as an IAT device, some sort of automatic reader is necessary in order to handle the large amount of recorded strain data that will be generated. However, the current DTU automatic reader has a reading threshold of approximately 2300 psi, which makes this reader inadequate for reducing the expected C-141 loads. Development of an automatic reader with a much lower threshold will be necessary if MSR's are to be used for bomber/transport type aircraft.

The reliability in service usage has been adequately demonstrated for the MSR-2, and adequate data for the MSR-3 should be available soon. If any significant changes are made to the above mentioned recorders to adapt them for bomber/transport use, in-service reliability must again be demonstrated. Otherwise, a short flight test demonstration period should demonstrate the reliability of the recorders for bomber/transport usage.

### 3.1.2.3 Microprocessor Based Systems

Microprocessor electronics are undergoing significant development and are expected to be considered viable candidates for use in IAT programs in the future. System reliability and cost will continue to require careful development.

It appears very likely that IAT programs of the future will utilize on-board microprocessors to some extent. The design of the Force Management system and the microprocessor as a part of it can be tailored to provide the specific output required for support of Force Management decisions.

The qualitative evaluation which follows explores the potential uses and goals for the microprocessor for Transport/Bomber IAT programs. A basic assumption is that the required data can be processed as needed by the microprocessor including permanent storage and retrieval of the data. (NOTE: Whether the on-board processing capability of the microprocessor should be utilized to its maximum potential is a matter that needs further study. The paragraphs which follow assume on-board processing. An alternate, using the microprocessor for data acquisition and systems checking (only), is discussed in Section 3.1.2.3.9.)

A microprocessor-based system is conceptually described in Figure 10. The system includes on-board and ground processing of the data obtained from on-board sensors and manual (ground) inputs. It is assumed that both strain data and flight parameters are obtained.

The discussion which follows is based on a number of assumptions, primary of which are:

1. It is desired that the microprocessor be as independent of any manual input as is possible. This is to minimize errors and omissions.

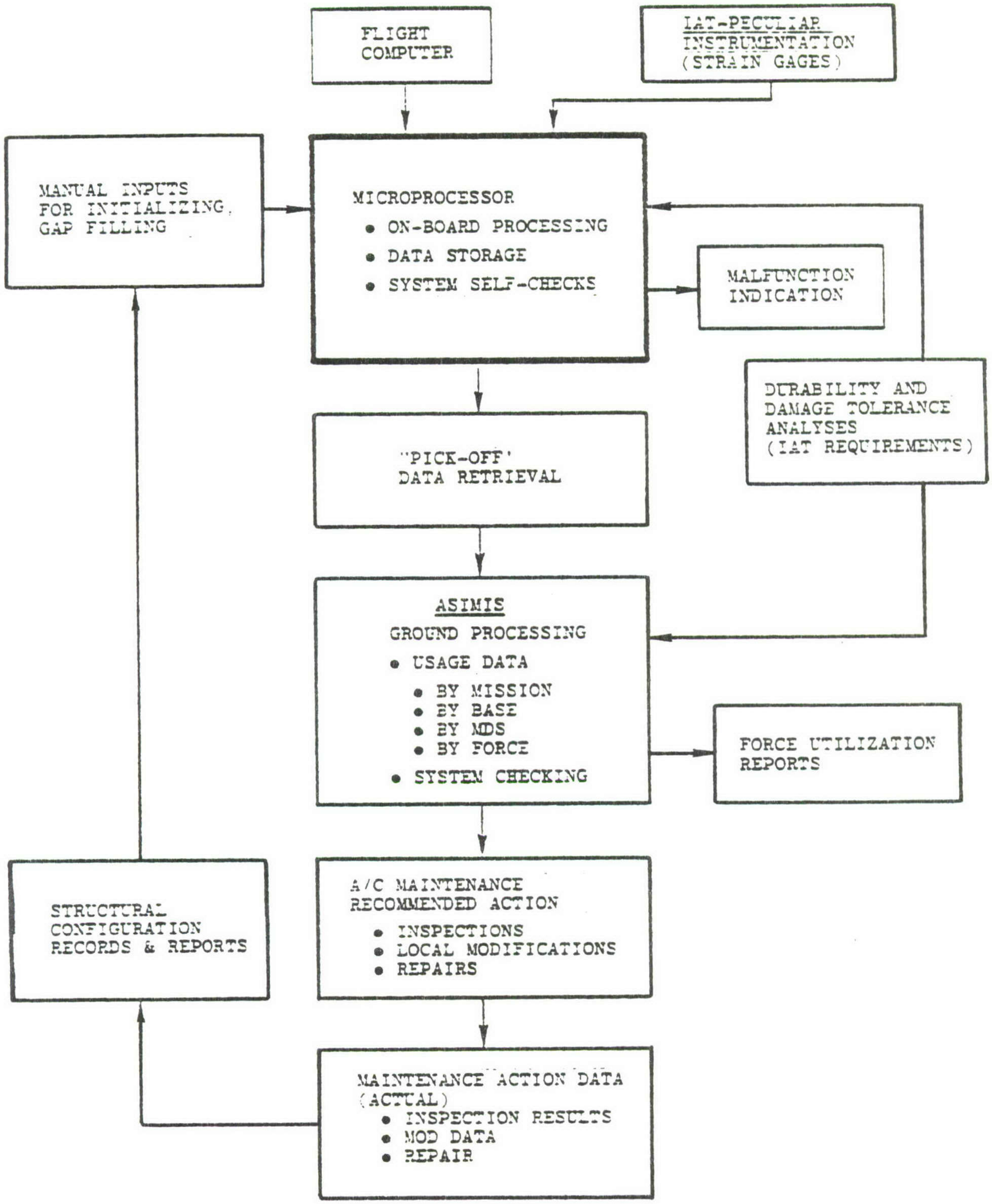



Figure 10. Microprocessor-Based IAT System Concept On-Board Processing.

2. The aircraft is equipped with a flight computer and it is permissible to tie in to it to obtain inputs for the microprocessor. This ensures good primary input data at minimum installation cost.

3. The microprocessor system can be programmed to perform on-board calculations of crack growth data at desired locations based on aircraft flight parameters (V-G-H, events, etc) or based on mission logic determined from these data and on pre-defined crack growth data for the resulting mission definitions and variations. Alternatively, on-board crack growth calculations can be based on inputs and correlation from strain gages mounted at the desired locations or at nearby locations. It is predicted that the microprocessor is designed to output all three sets of data, for these reasons:

A) If a strain channel goes bad, the data will still be available from the V-G-H base, and vice versa;

B) Comparing the output of the strain-based and V-G-H based crack growth calculations will aid in evaluating both sets of data; and

C) Comparison of these data with the output from the mission logic system can provide significant information on the validity of the "average" mission logic based program to calculate the crack growth at individual locations with the specific individual aircraft experience. Since this system can be used for overall force data input for durability and damage tolerance analyses, the variation due to individual aircraft usage can benefit all further evaluations.

4. It is desired that the potential of the microprocessor be used to a significant extent in performing the individual aircraft tracking function, i.e., on-board processing of the data is desired to the extent practical.

5. Quality installations and high reliability of strain gages are assumed.

6. Some ground processing of data will still be required. As a minimum, the individual aircraft tracking program data would be reported by base, by mission, and by Force. The Force Management requirement of the Aircraft Structural Integrity Program (ASIP) Manager indicate that these data are needed. Inspection, maintenance, and operations planning are individual aircraft oriented, but within the context of overall Force requirements.

7. Modification of the microprocessor programs and retrieval of stored data can be accomplished by removing and inserting plug-in modules, referred to as "cards" herein.

The hypothetical on-board microprocessor system described herein obtains input, processes the data, and outputs the following:

A) Cycle-by-Cycle crack growth based on correlated strain gage readings.

B) Cycle-by-Cycle crack growth based on other aircraft flight parameters (V-G-H, event channels, etc.)

C) Crack growth based on interpretation of flight parameters into pre-defined mission descriptions and variations, and pre-programmed crack growth for these missions and variations.

D) Strain and other parameters occurrence data.

E) Mission descriptions and variations.

F) Recurring inspection data for monitor zones based on crack growth, NDI, and forecasting.

#### 3.1.2.3.1 Advantages and Limitations

<u>Advantages of the Microprocessor-Based System</u>:

- Uses actual measured data
- Has potential to record sufficient data to realistically describe the airframe structural response history
- Can process data on-board
- Can combine IAT and L/ESS functions if so designed
- Can obtain inputs from other on-board equipment such as a flight computer
- Can be set up to receive flight crew inputs as keyboard entries
- Automatic monitoring of non-standard flights and unanticipated events
- Can accomplish on-board data compression and storage
- Can accomplish system self-checks and indicate malfunctions for maintenance action
- Potential to produce a high rate of return of data
- Compact data storage can be retained for later ground review or updating
- Stored program updates can be readily accomplished through 'Card' Insert Approach
- Compatible with other elements of Force Structural Management (L/ESS, FSM)
- Can provide data from actual strain experience and also from "calculated" usage.

<u>Limitations and Qualifications concerning Microprocessor-Based Systems</u>:

- Must have proven high reliability through a combination of demonstrated actual on-board performance plus consistent periodic inspection and system maintenance.

- Accuracy and calibration methods of input signals determine accuracy of the system.
- Proper operation depends on installation, quality, and longevity of input transducers (strain gages, accelerometers, altitude sensors, event switches, wiring, etc.).
- Must have initializing and special events data by maintenance personnel or crew if not obtainable from flight computer.
- System design requires definition before aircraft system characteristics are finalized.
- May depend on proper functioning of other equipment such as flight computer.
- System must provide flexibility for future program changes.*
- System must include output methodology and processing for ground-based analyses and summarizing/consolidation of data.*
- Reliable power-down memory is required until data are retrieved.
- Initial system acquisition costs greater than usage forms IAT.
- Requires thorough systems checking methodology/procedure to assure operational readiness of on-board sensors.
- Qualification program for on-board system must be performed.
- Methodology/software changes will be difficult to effect, especially for large numbers of aircraft in series.

---

*These requirements apply to other IAT systems also. However, since data processing for the other systems is ground-based, the microprocessor system must provide this capability as part of the design of the unit.

- Malfunctioning microprocessor computer logic may be very difficult to detect.
- Requires an almost uncompromising commitment on data reduction methodology early in the system development.
- On-board accounting for missing data (gap filling) will be difficult.

The advantages and limitations of the microprocessor-based IAT system result from its basic design characteristic: the microprocessor itself is an electronic minicomputer. Inputs must be keyed in or input electrically. In-place visibility is obtained visually by key querying or by malfunction signal lights. All other visibility must be obtained by reading memory cards using ground equipment, or otherwise evaluating the electrical signals stored in the microprocessor. And finally, the microprocessor monitors only the individual aircraft in which it is installed - it has no ability to combine Force data by base, by mission, by Force, etc.

It must be cautioned that the microprocessor <u>not</u> be considered a panacea for all IAT problems; it still shares most of the basic overall system characteristics of the usage forms IAT, and has additional considerations such as electronics complexity and initial cost of development, hardware, and installations. However, the present usage forms IAT system cannot reflect direct actual flight environment and response; in this respect, the microprocessor system can provide valuable data. Both systems require much forethought and software planning; crew inputs of some amount; some amount of ground processing and data; structural inspection data feedback and input; and manual ("people") review, assessment, and implementation of results from the data. Self-checks and trouble lights must be designed into the microprocessor since the calculations cannot be monitored. Flexibility for updates to the system must be provided. The advantages of the microprocessor lie in the area of on-board sensors and capability for electronic data gathering and processing. The quality of program output could potentially improve operational aircraft safety through more individually responsive inspection calculation data. Whatever system is utilized in the future IAT programs will always require experienced structural engineers to monitor and interpret the data. The use of electronic means for data gathering can provide useful information for decisions on safely managing an airframe system.

3.1.2.3.2 Stress Transfer Functions

Transfer functions to base analyses at one location on data acquired at another location will depend on the parameters and type of analyses involved.

A) The microprocessor system can be programmed to calculate crack growth data at desired locations based on aircraft flight parameters (V-G-H, events etc.). These inputs would be translated into loads/stress exceedance and crack growth using structural Load/Stress/Deflection characteristics based on data from the aircraft design and structural analysis, flight test, and L/ESS programs. Each monitor location could have its own program logic, and usage of transfer functions between locations are not envisioned to any large extent.

B) The aircraft parameters of (A) above can be translated by mission logic into "standardized" missions and variations thereof, and crack growth calculations, made after the flight by the microprocessor (or, alternatively, by later ground processing) would use stored crack growth data for each location, and no transfer functions would be used.

C) Crack growth can be calculated "on board" using correlated strain gage signals as the only input. Transfer functions to relate the strain at one location to that at another nearby location might be possible in a limited sense using the predicted strain relationship between the desired location and the gage location; detail stress and crack growth analysis for the various airframes would be required in assessing this possibility. Dynamic response, natural frequencies, and six-component loading effects may seriously limit the applicability of such transfer functions; however, the crack growth calculations may still be more realistic than the calculations of method (B) using statistical environmental loads and response data.

3.1.2.3.3 Crack Growth Models/Examples

Figure 11 is a conceptual flow diagram for a microprocessor based crack growth IAT. On-board processing and mission-definitions crack-growth calculations are shown.

3.1.2.3.4 Data Collection

Microprocessor-based IAT systems can be designed to be relatively independent of crew input. Prior to each flight, initializing data not obtainable from aircraft sensors such as cargo weight and stores weight (if these are not obtainable from a flight computer) could be input. Certain data are efficient and practical as performed by hand input; however, an overall goal is to obtain as much required data (including time) automatically as is practical. The purpose of this method is to minimize errors and omissions. The complexity of the individual system and data that are available from the flight computers will affect the decisions on how to address specific parameters or events.

The microprocessor can be designed to obtain and process certain data on-board and also to store other data for later ground processing and analysis.

Changes to the program such as configuration status changes and inspection results (resetting

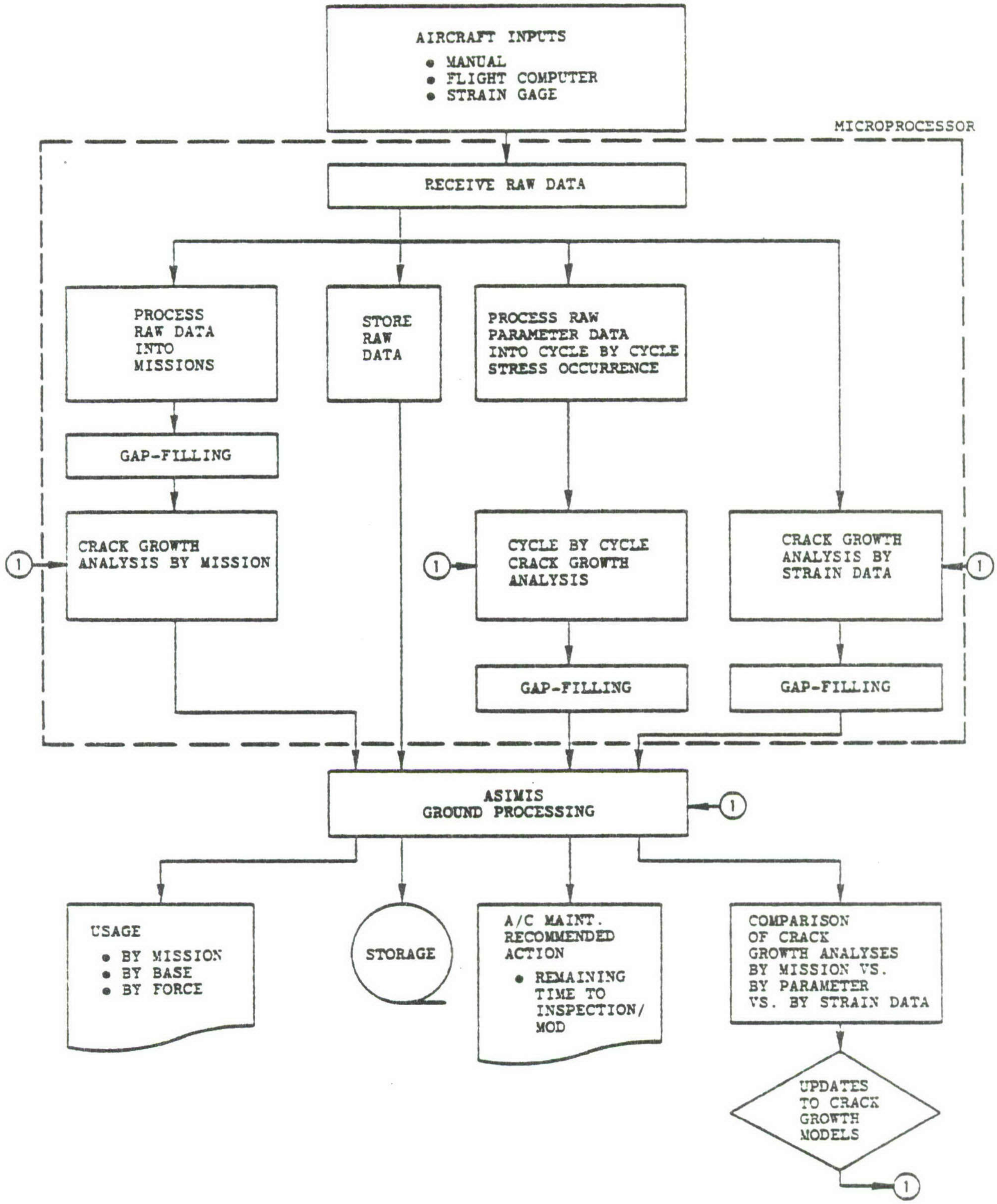



Figure 11. Microprocessor Crack Growth Model-Conceptual Flow Diagram.

calculated crack lengths to detectable length) could be accomplished by the maintenance crew, using pre-printed cards provided by ASIMIS or the ALC.

3.1.2.3.5 Data Processing

3.1.2.3.5.1 Logistics

At the appropriate interval, some system, such as a "pick-off" hookup that sends the data to ASIMIS by telephone line and erases the memory card, could be employed to transmit the preprocessed data to a ground facility for calculations of Force usage by mission, by base, etc. Computerized output of the same basic data as is obtained from the usage forms IAT (Table 5), with output variations to show such items as calculated crack growth based on recorded strains or on other parameters and predefined mission crack growth, could be programmed.

3.1.2.3.5.2 Verification/ Editing Techniques

Verification and editing capability can be designed into the microprocessor and accomplished onboard. This checking should consist of reasonability checks and operational boundaries similar to those presently included in the ASIMIS IAT and L/ESS computer programs. Appendix C to this report describes some of the checks for the C-141A L/ESS program.

In addition, verification and editing checks presently utilized in the ASIMIS IAT computer programs should be employed to check the microprocessor output. The memory of the microprocessor should include data check information on non-automatic (manual) inputs such as the basic crack length for the calculation, in order that later ground processing can check these data.

#### 3.1.2.3.5.3 Gap-Filling Procedures

Gaps in microprocessor IAT data may be caused by various factors such as: malfunctioning equipment; aircraft usage exceeding the memory capacity of the microprocessor; or by data cards not being read/replaced or programs updated at the proper time. (Program updating could consist of resetting the initializing crack length when an inspection has been performed, such as is illustrated in Figure 3). Gap-filling procedures will therefore fall into two classifications: procedures for on-board calculations and procedures for ground processing/verification/ compilation operations.

For the on-board microprocessor, several approaches to gap-filling may be considered:

1. Gap-filling can be omitted. This results in "pure" data for later ground processing, but the on-board processing may be unconservative, i.e., the output may not reflect the total usage of the airplane.

2. Gap-filling can be based on force average mission profiles or on the most severe usage predictions, applied to the gap in flight hours which is to be filled. This will require that predefined data or a damage projection equation be included in the microprocessor.

3. Gap-filling can be based on the actual usage recorded by the microprocessor in the near past. The crack growth gap-filling projection can be a linear extrapolation of the crack growth increment over the near past; a curve-fit extrapolation; or some other method appropriate to the crack growth calculations methodology. The usage (mission descriptions) data stored in the microprocessor can also be incremented based on the recently acquired usage data for that airplane.

In any of the above cases, storage of information to identify the gap-filled segments is needed. Also, the microprocessor logic for gap-filling must be carefully designed. The microprocessor must recognize that some data are erroneous, reject these data, and then gap-fill based on the flight hours missed. Assuming that strain data are being processed on-board and that a significant gap could extend from time of occurrence until the malfunction was corrected by ground maintenance, it would appear that the gap-filling should all be accomplished at the time the maintenance is performed. Logic based on flight hours at the beginning of the gap and at the end (input by card or keying in flight hours after the maintenance) could trigger the microprocessor to gap-fill.

The ground processing activity should also have gap filling considerations. The percent of flight hours of required gap filling could be output for individual aircraft; by base; by mission; and by overall fleet or force as an indication of the "impurity" of the data. For verification and studies of the data, however, the ground processing system could operate on the "pure" stored usage data from the microprocessor.

#### 3.1.2.3.5.4 Supplemental Data Requirements

Supplemental data requirements include:

- Structural configuration at each monitor location for each aircraft (original, redesigned, which model, repaired, retrofitted), and
- Inspection data (when inspected, how, NDI crack size, whether corroded or cracked, extend and details of crack and repair).

These supplementary data should be reviewed and analyzed by the ASIP manager and translated into structural safety inspection data for input to the microprocessor.

3.1.2.3.6 Damage Projection Techniques/ Examples

Crack growth projections can be made from: strain data-based calculations; from other parameters (V-G-H, etc.); or from mission usage based calculations. (See Section 3.1.2.3.2.) Projections can be made on-board or by ground processing.

On-board crack growth projections by the microprocessor at the time of retrieval could be based on similar logic as used for gap-filling (Section 3.1.2.3.5.3). These projections could be retrieved and input to the ground processing system at a specified time.

The crack growth projections could be based on beginning crack lengths defined by the logic presented in Section 3.1.2.1.6 for the (baseline) usage forms IAT program. Revised crack lengths would be input to the microprocessor after inspections were perforemd, as discussed in Section 3.1.2.3.4. For any current point in time (time of retrieval), the projected remaining time in calendar quarters from last inspection to critical crack length would be calculated by the microprocessor, divided by two, and the result stored (output) as the remaining time to the next recurring inspection.

Ground calculations of the crack growth projections may be necessary. The same projection techniques used for the (baseline) usage forms IAT crack growth program could be employed. Figure 3 is an example of this technique. Also, if the incorporation of inspection results (resetting of crack length) into the microprocessor were done late, a ground calculation of a new value could be performed and this new value input to the microprocessor to bring it up to current status.

3.1.2.3.7 Costs

Table 9 lists cost elements which may be anticipated for a microprocessor based system. It is assumed that the microprocessor system is to be used on an aircraft which already has a flight computer, i.e., all inputs can be obtained from existing instrumentation except the strain gage channels.

Initial costs will be higher than for the (baseline) usage forms IAT system because of the cost of the microprocessor and the installation. Later ground processing costs can be reduced if data are kept but not analyzed. Data yield and realism may be improved over the baseline usage forms IAT program if the reliability of the total system is achieved. Also, if the microprocessor is used in a combined IAT and L/ESS system, the cost projection becomes more favorable. (See Section 4.1.2.1).

The requirements of microprocessor based IAT may vary for different aircraft from a minimum strain gage or V.G.H. based system to the system described herein but independent of a fight computer, i.e., requiring that all instrumentation inputs be installed specifically for the IAT system. Also, the IAT system can be independent from the L/ESS system or the two can be combined. The best approach for each aircraft must be determined on its own needs.

For existing aircraft, the decision of substituting a microprocessor-based system for the present usage forms (and MXU 553A L/ESS) system must also be determined for each aircraft. In general, it is considered that existing or near-term Fracture Tracking (IAT) Programs should be retained. Should a microprocessor system become

TABLE 9

Transport/Bomber IAT Cost Elements for Microprocessor

| ELEMENTS | MICROPROCESSOR | COMMENTS FOR MICROPROCESSOR SYSTEM |
|---|---|---|
| INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT | X | MICROPROCESSOR AND DATA PICKOFF DEVICE |
| DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE | X | MICROPROCESSOR CIRCUITS, SENSOR INST'L, TIE-IN TO FLIGHT COMPUTER |
| QUALIFICATION TESTING | X | |
| DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE | X | GROUND PROCESSING AND ON-BOARD CHANGEABLE COMPUTER PROGRAMS |
| T.O. FOR IMPLEMENTATION | X | |
| FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS) | X | |
| REPLACEMENT OF DATA ACQUISITION ELEMENTS; TRANSMITTAL TO ASIMIS | X | PICKOFF OF DATA |
| SPECIAL READING OF DATA ACQUISITION DEVICE | | |
| DATA TRANSCRIPTION TO MAGNETIC TAPE | X | PICKOFF DIRECTLY TO MAG. TAPE |
| COMPUTER ANALYSES OF DATA | X | SOME ANALYSES MAY BE ON-BOARD |
| GAP FILLING | X | ON-BOARD (MANUAL INPUT-COMPUTERIZED OR ON GROUND (COMPUTERIZED) |
| SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS | | |
| ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA | | |
| MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT | X | |
| REPORTS OUTPUT | X | |
| ON-BOARD SYSTEMS MAINTENANCE | X | |
| TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE | X | |

available in the near future, it could be used in conjunction with existing IAT's as a developmental phase; candidates could include C-141B, C-141, C5A, B52, KC-10.

Force Management planning should assume that both usage forms IAT and microprocessor IAT systems will be run concurrently for sufficient time to establish the reliability and characteristics of the new system. This will increase initial costs due to duplication of effort and comparative analyses.

The data obtainable from the microprocessor IAT system respond to in-flight strain or load conditions and are therefore more realistic than the "average" data used for the usage forms IAT. On-board, cycle by cycle processing will accomplish directly what the usage forms IAT approximates in predefined data. However, it should be recognized that additional costs will be attendant to evaluating these data in the initial stages of the microprocessor IAT program. As later generation microprocessors become available, more of the ground processing burden can be reduced as on-board processing is accomplished with a minimum of ground checking.

3.1.2.3.8 Realism

Three analysis methods are recommended to be used by the microprocessor (See Section 3.1.2.3.3): strain gage based calculations; IAT parameter-based calculations; and mission classification/crack growth by mission calculations. The realism of each method depends on the accuracy and calibration of the input data (strain gages, accelerometers, etc.) and the characteristics of the analysis programs. However, the actual individual aircraft experience is reflected by the strains, accelerations, and other parameters which are translated by the microprocessor into IAT data (occurrences, crack growth calculations and projections, and mission definitions).

Therefore, the realism will be improved relative to predefined data from the usage forms IAT programs. Also, the data yield of the microprocessor system can be better than that of the usage forms system, assuming that high sensor reliability is achieved. The possibility of improved data yield (due to less manual input of data) for most aircraft may also increase the realism because less gap-filling may be necessary. As compared with a system based on "g" counters, the microprocessor not only allows "g" consideration but also uses the aircraft configuration and loading source for each "g" encounter, thus improving the realism of the crack growth analyses for the structural monitor locations.

The realism of crack growth calculations from strain gage data depends on the accuracy and calibration methods for the strain gage channels. Calibration can be set initially and checked at specific intervals (such as yearly) by on-loading known fuel weights. Between calibrations, the microprocessor can automatically check the calibration at each fueling. Zero shift corrections can be made automatically at an appropriate time in each flight, based on known flight parameters and a 1g flight condition. Despite these procedures, however, it should be recognized that the reliability of strain gage data tends to be somewhat questionable.

#### 3.1.2.3.9 Alternate Approach: Microprocessor for IAT Data Acquisition and On-Board System Checking

A viable alternate to the microprocessor system described above, which maximizes on-board processing of the IAT data, is to automate the data acquisition by the microprocessor but to continue ground processing of the data. The microprocessor can also be used for on-board systems checking and malfunction indication, to improve the quality of data and minimize "gap-filling" by alerting the maintenance crew to systems problems needing correction. This system is described in the paragraphs which follow.

Figure 12 is a concept diagram of an IAT system using a microprocessor for data acquisition and on-board systems checking. Desirable design goals for such a system could be:

- An optimum mix of manual (keyed-in) and automatic data inputs.
- Tie in to the flight computer, for good primary input data at minimum installation cost.
- On-board checking of the sensor systems and visual indicators for malfunctions.
- Acquisition and "pick-off" output of sequenced strain peaks and sequenced parameter/event data against a time base.
- All data processing and evaluation is accomplished at ground facilities.

The primary features of this system are the same as those for the "on-board processing" system. However, this system has the advantage that computer logic, updates, program changes, gap-filling, evluations, etc., are all accomplished at a central (ASIMIS) ground facility. It is not necessary to update or change the many microprocessors in the many service aircraft throughout the country when these changes are necessary. Also, it is logical to assume that the advances in electronics technology which permit the development of these microprocessors with greatly increased storage capacity will also produce ground processing computers which can handle the processing for all the data acquired by these microprocessors.

The primary disadvantage of this system is the cost of performing all processing at the ground facility.

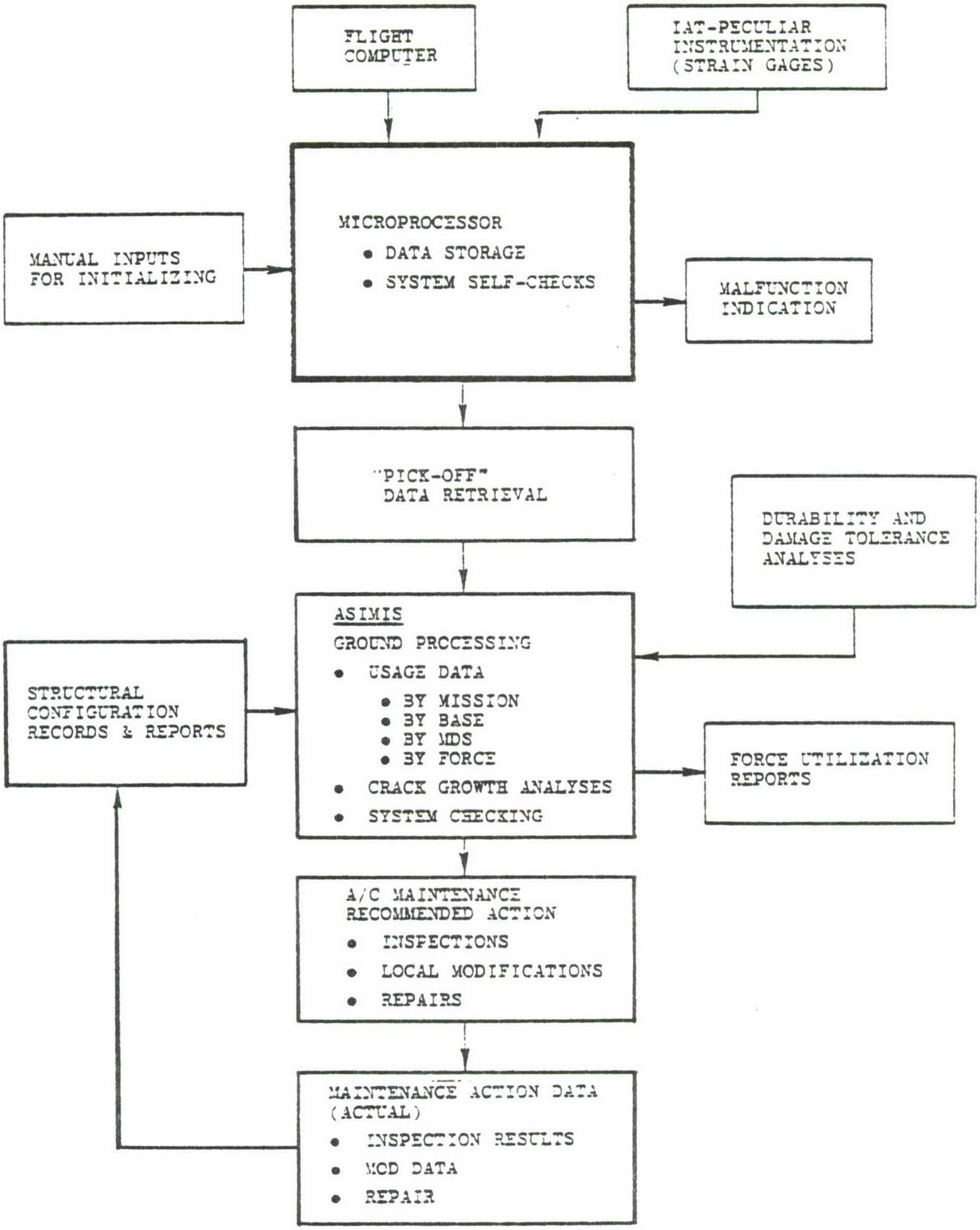



Figure 12. Microprocessor Concept for Iat Data Acquisition and On-Board Systems Checking.

Inputs for the microprocessor in this system are the same as for on-board processing except that initializing data for crack growth calculations and gap-filling are not necessary. The microprocessor functions and the required crew inputs are both simplified significantly by this approach. Other advantages and limitations as for the "on-board processing" system, listed in Paragraph 3.1.2.3.1 also apply with the obvious modifications resulting from a data acquisition rather than an "on-board processing" concept.

Inputs and outputs of the ground processing for the microprocessor system are the same as for the present usage forms IAT program, except that the microprocessor output (input to the ground processing system) will be much more extensive and detailed than that from the present usage forms. More extensive data logic and more extensive storage will be necessary to handle these data. The IAT microprocessor output (input to the ground processing system) will be somewhat like that from the present MXU-553A L/ESS output, including strain peak counts and parameter combinations.

In general, other Paragraphs of the "on-board processing" system apply for the data acquisition microprocessor system also. The differences between the systems relate to flexibility and cost. It would appear that the best use of a microprocessor for Transport/Bomber IAT programs would be for data acquisition and on-board systems checking, in order to retain the flexibility of the ground processing. "On-board processing" may be desirable after the IAT program is thoroughly worked out; however, future cost analyses are needed to compare/evaluate the cost savings of on-board processing (with respect to ground processing) against the added initial expense and complexity of the "on-board processing" microprocessor and the inputting to it of initializing and gap-filling data.

Additional study is recommended to determine whether the "on-board processing" system or the data acquisition/systems checking microprocessor is more appropriate for a particular aircraft IAT. It should be noted that continuing advancements in microprocessor and computer state-of-the-art are so rapid that any evaluation at the present time is premature. However, these rapid changes in state-of-the-art also lead to the conclusion that the data acquisition/systems checking microprocessor approach is more appropriate as a near-term method. Parallel operation of this system and the usage forms IAT system would provide experience with the microprocessor system while retaining the known characteristics and reliability of the usage forms program. The installation and maintenance costs and the lack of confidence in the strain gage channels are major reservations in the use of a microprocessor based IAT system. A very practical solution to this problem is to delete the strain channels and use only the available flight computer data and the necessary supplementary data. Strain data could be obtained and utilized as part of the L/ESS Program (only). This solution appears to have merit beyond the more idealistic IAT System presented in this Section 3.1.2.3.

It must be noted that to the extent that they are installed solely for the IAT, the use of a microprocessor system entails the additional complexity of maintaining sensors and electronic equipment. Experience with the present MXU-553A L/ESS system indicates that for these non-flight-critical installations, adequate sensor maintenance is difficult to obtain in the "real life" situation. The microprocessor can be designed to signal a need for maintenance, but the maintenance itself will be an added burden over the present usage forms IAT system and is not much more likely to be performed in a timely and effective manner for the IAT system than it has been to date for the existing L/ESS systems.

Paralleling the flight-critical flight computer systems where possible will minimize this problem.

Certain data inevitably must be keyed in or obtained from a supplementary data sheet regardless of the sophistication of the microprocessor system. If these supplementary data are to be logged on a data sheet, the conclusion naturally follows that the present usage forms are an excellent means of gathering the supplementary data. It would not be necessary to process the data paralleling the microprocessor output unless the microprocessor output were missing or a comparative evaluation were desired.

#### 3.1.2.4 Crack Growth Gage

The crack growth gage (CGG) method involves the attachment of a small precracked coupon to aircraft primary structure at a designated location. Crack growth from assumed initial flaws in the aircraft can then be related to the CGG crack growth (see Appendix B). The use of a crack growth gage (CGG) can provide a direct response to actual cyclic strain experience of the airframe at a specific structural location. If the crack growth experience of the gage can be correlated to the crack growth characteristics of the actual structure to which it is attached, then a potential exists to obtain very useful data to supplement a Total Fracture Tracking Program. One of the principal advantages of such a system would be in providing a relatively low cost means of 'Fine Tuning' the periodic inspection requirements of a given tail number at a series of structural monitor locations. This assumes that a reliable CGG system can be perfected and 'flight hardened' and that analytic correlation can be developed at each of the necessary structural monitor locations. It is further assumed at this stage that the CGG is intended to respond to the safety-based periodic inspection range of crack growth. For instance, this corresponds to crack size intervals from 0.15" to 1.5" on the actual airframe structure (C-141A wing example).

Development of the CGG to date has shown some problems of repeatability and spectrum sensitivity. The qualitative analytical evaluation presented in this Section is predicated on the assumption that these problems can be resolved through additional CGG hardware development, i.e., the gage will give predictable results (within "acceptable" limits). This assumption is necessary to a viable crack growth gage system. Two other assumptions are made:

- The CGG response to various spectra displays spectrum sensitivity effects, but these efforts are "reasonably small". (This is discussed further in Section 3.1.2.4.2.)
- The crack growth in the gage is different from the growth in the monitored airplane structure, but the relationship between them can be "reasonably" established.

Figure 13 illustrates the crack growth gage concept on which this evaluation is based.

1. A Crack Growth Gage (CGG) installed on a structural element of an individual aircraft is removed at the end of a PDM interval and broken open to determine initial and final lengths (upper left sketch).

2. These lengths are input to curves of crack growth gage response from laboratory tests of benign, average, severe usage spectra (lower left) to determine the severity of usage indicated by the CGG.

3. This severity of usage is used with the analytical crack growth characteristics of the aircraft structure at a given structural location and the previously determined analytical length of the structural crack at that location at the beginning of the PDM interval to determine the present analytical crack length in the structure (lower right).

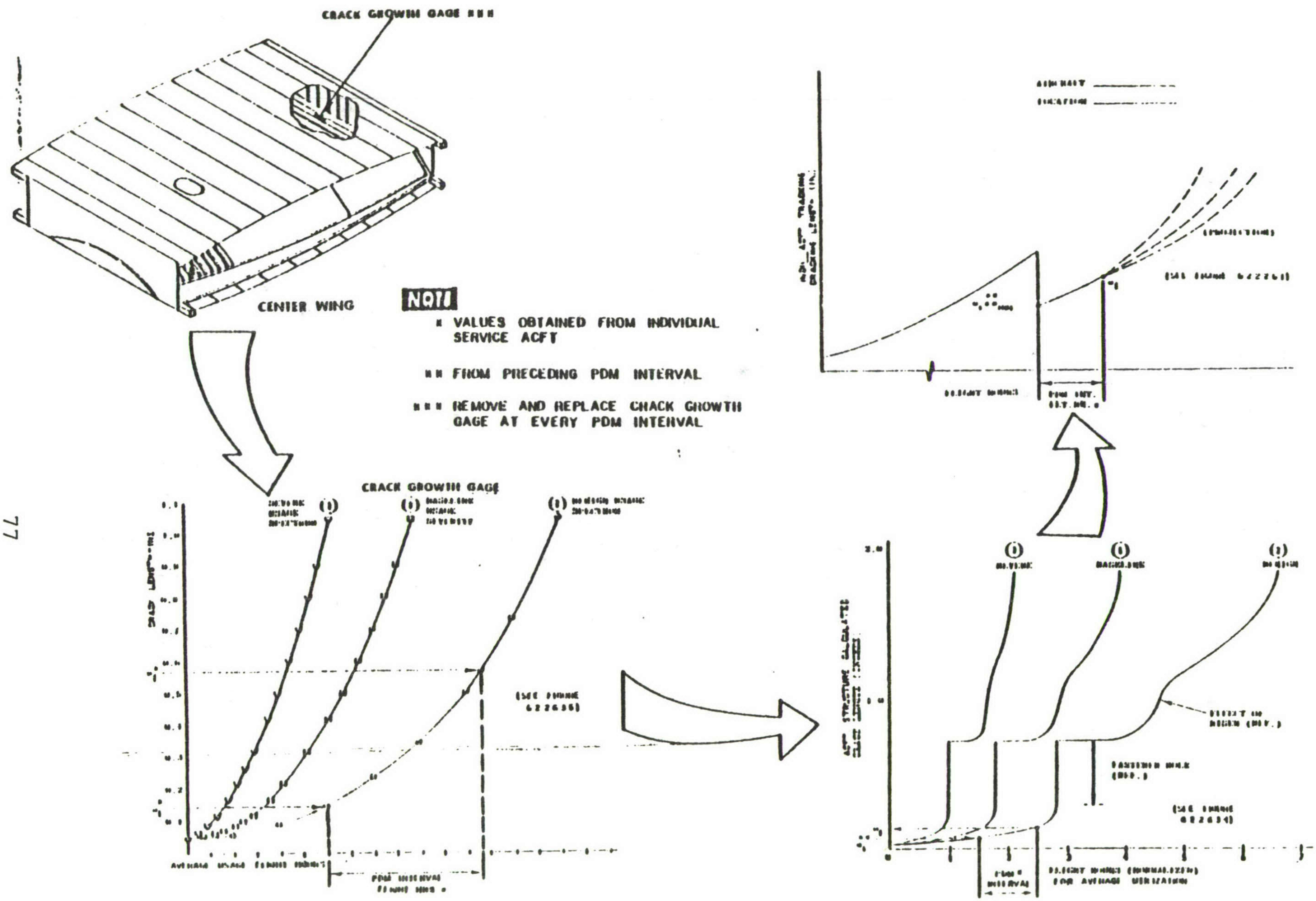



Figure 13. Crack Growth Gage Concept for Individual Aircraft Tracking.

4. The crack lengths in the structure over successive PDM intervals define the crack growth history and projections for that aircraft at that location (upper right). Maintenance action recommendations are based on this information. When an inspection is performed, the analytical crack length is reset to the NDI detectable length as described in Figure 3 for Usage Forms IAT.

The (2), (3), (4) procedures can be computerized. Inputs are initial and final CGG length, flight hours, and inspection date and type (i.e., $a_{NDI}$).

Of several ways in which the crack growth gage system can be structured, this hypothetical system has the following characteristics:

- The crack growth gage is sized to produce measurable crack growth during a normal base level inspection interval, but not to crack apart in this interval.
- The crack growth gage is removed and replaced at the base level inspection. The removed gage is sent to a laboratory where the initial and final length of the crack are determined. Determination of the initial crack length is necessary to 'fix' the relationship of aircraft flight hours when the CGG was installed vs. initial CGG crack size. The precise methods of pre-cracking the CGG and establishment of the initial crack size have not yet been finalized by the various companies who technically support the USAF airframe inventory.
- The initial and final length for the flight hours flown during the measured interval are used as indicators of the severity of usage of the individual airplane at the specific monitor location(s).

- The safety based analytical crack length in the individual airplane structure is incremented based on the usage severity indicated by the crack growth gage. This may be accomplished by automated computer routines, which reflect the proper correlation between the CGG and the actual airframe hardware.

Appendix B describes a Lockheed-Georgia Company trial installation of four CGG's on the C-141A Full-Scale Durability Test article. This system permits reading of the CGG at intervals during the fatigue test program by photographing the crack through a transparent viewing plate. However, experience with crack growth test coupons under laboratory conditions indicates that large scatter is obtained in externally reading both the initial crack length and the present crack length. Other methods of obtaining crack length data without removing the crack growth gage are available, such as laboratory examination of crack face impressions made using Faxfilm replicating tape. (See Reference 5, page 108.) However, it is considered desirable for Transport/Bomber aircraft to remove and replace the crack growth gage at intervals in order to use a sufficiently responsive gage design. (See Section 3.1.2.4.8.) Therefore, it is considered that destructive inspection of the CGG crack surface should be planned to obtain crack growth measurements with sufficient precision to use the data for correlating with analytical crack length calculations at specific structural monitor locations on individual aircraft on which the CGG's are mounted.

One possible approach (which might be termed the "traditional" or "idealized" approach) to the design of a CGG system is to use the usage severity indication of the CGG as a direct monitor of the airplane's experience, and to take inspection/modification action when the CGG crack reaches a specified length or cracks across. The design of the CGG is tailored to the specific aircraft structural location where it is mounted, and its crack growth characteristics with respect to the aircraft structure are established by correlation analyses. The approach is not used as the baseline of this report section, however, because of practical problems for Transport/Bomber aircraft such as are discussed throughout this section. The problems relating to spectrum sensitivity (Section 3.1.2.4.3), logistics difficulties in determining the length of the CGG crack (Section 3.1.2.4.4), and confidence in performing service aircraft inspection/maintenance action based on the CGG results (Section 3.1.2.4.8) appear to be more severe for this "idealized" approach, in which one crack growth gage is bonded to the airplane one time, crack length is determined by on-the-airplane measurements or Faxfilm methods, and service inspection/maintenance action is based on CGG length without resort to any supplementary data, than for the method described herein.

#### 3.1.2.4.1 Advantages and Limitations

Advantages of the Crack Growth Gage (CGG) are:

- Responds to temperature, creep, load environment as does the basic aircraft structure.
- Simple mechanical system - "no moving parts".
- Potentially can be designed to minimize field level maintenance.
- Compact, self-contained unit.
- No power source is necessary.

Limitations of the CGG are:

- Repeatability and spectrum sensitivity problems are not yet resolved.
- Must be installed at a structurally significant, accessible location.

- Bond line variations (installation techniques) must be perfected.
- Reliable, accurate readout method must be established.
- Missing or unreliable data can affect a significant time span of usage.
- Requires supplementary data for Transport Bomber Aircraft.
- Long time interval between data readouts if accomplished at base level intervals.
- Readout may be out of phase with inspection actions by up to one base level (PDM) inspection interval.
- Methodology of pre-cracking and establishment of initial crack size not yet finalized.
- Correlation methods to relate CGG crack growth to actual airframe crack growth not yet finalized.

3.1.2.4.2 Stress Transfer Functions (STF)

For the crack growth gage system described herein, the gage operates as a "usage severity indicator" and a gage at one structural monitor location can potentially represent the usage severity at other locations having similar basic severity parameters. The analytics necessary to relate one structural monitor location to another is termed herein as a "stress transfer function" (STF).

Additional crack growth gage installations may be necessary for locations where other usage severity parameters apply. For example, an aft fuselage structural monitor location which is sensitive to pressurizations, empennage loads, and ground loads would not be expected to be well represented by a wing mounted crack growth gage. Additionally, outer wing structure affected by aileron inputs, load alleviation control systems, and aerial refueling operations would respond differently from wing root structure. Study of the individual aircraft is required to determine the extent to which a crack growth gage at one location can be considered representative for such other locations.

3.1.2.4.3 Crack Growth Models/Examples

Figure 14 is a conceptual flow diagram for a crack growth gage based IAT. Figure 13 shows hypothetical crack growth curves for a transport/bomber (based on C-141A) wing structure and for a hypothetical crack growth gage. The approach of using these curves is shown in the Figure. Table 10 is a table heading list to show a conceptual tracking program approach for one individual aircraft at one location.

The approach shown can be operated manually using parametric curves for several usage severities, or it can be computerized with curve fit or tabular data matching routines.

In this approach, the usage severity is classified into 'bands' for analysis. For the example shown, three levels or 'bands' of spectrum severity are selected and crack growth characteristics of the specific structural monitor location for each spectrum 'band' are analytically determined (shown conceptually in Figure 5). (If implemented, about five levels of severity would probably be needed.) Corresponding crack growth characteristics of the CGG are determined by correlation analysis and experimental test data. The usage severity indicated by CGG response vs. actual airframe structural response forms the base for the IAT calculations. (Note that a usage increment such as flight hours is necessary as a base for the analyses. See Section 3.1.2.4.5.4.)

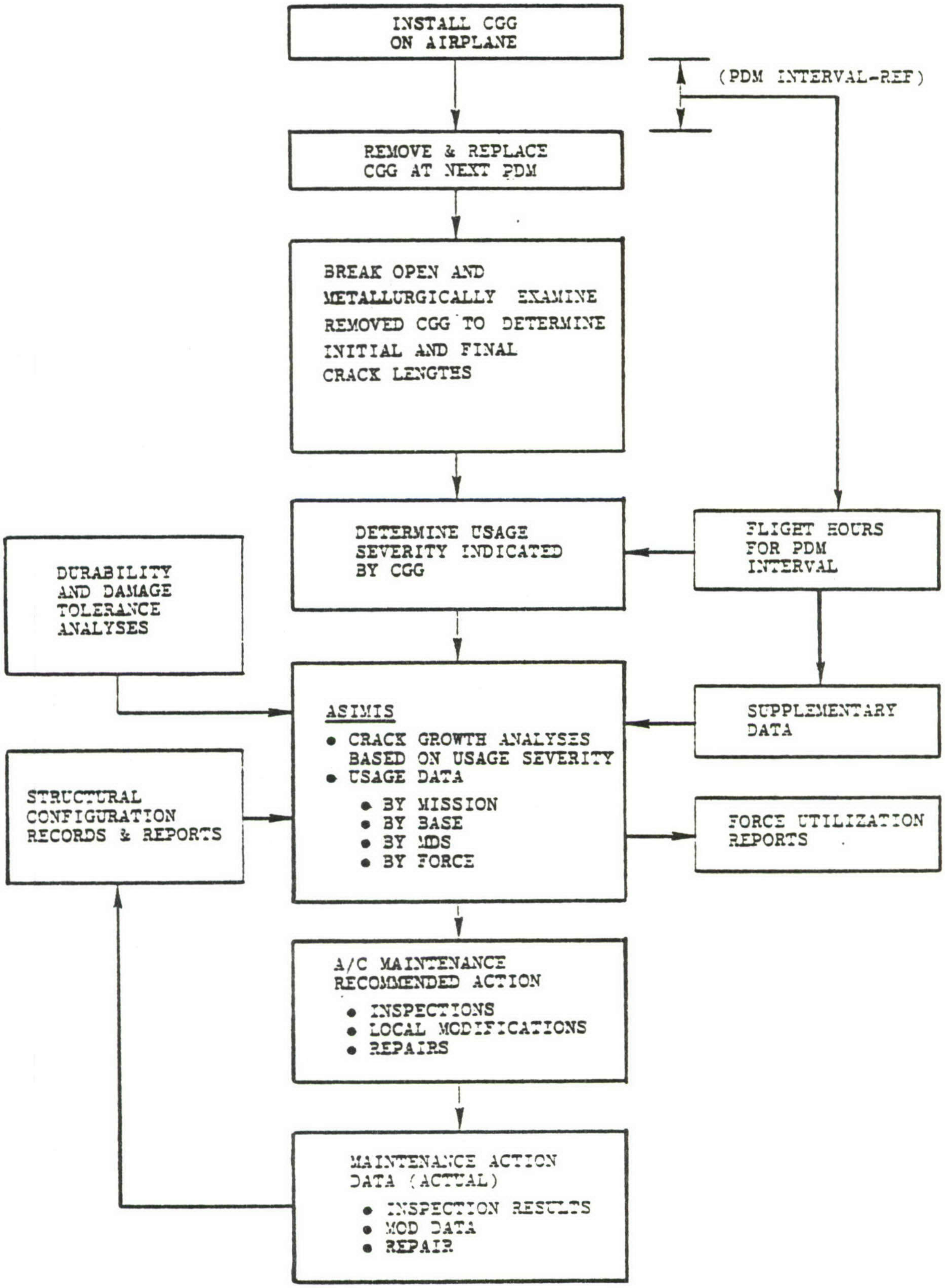



Figure 14. Crack Growth Gage-Flow Diagram.

TABLE 10

CRACK GROWTH GAGE-HYPOTHETICAL CALCULATIONS TABLE

INDIVIDUAL AIRCRAFT NO. ______

| PDM DATE | INITIAL CRACK LENGTH | PRESENT (FINAL) CRACK LENGTH | INITIAL FLIGHT HOURS | PRESENT (FINAL) FLIGHT HOURS | Δ FLIGHT HOURS | USAGE SEVERITY CURVE |
|---|---|---|---|---|---|---|
| | | | | | | |

AIRCRAFT CRACK GROWTH CALCULATIONS

| PDM DATE | ANALYTICAL INITIAL CRACK LENGTH AT TIME OF PDM | USAGE SEVERITY CURVE FROM CRACK GROWTH GAGE | ANALYTICAL CRACK LENGTH AT END OF USAGE INTERVAL | ANALYTICAL TIME REMAINING TO $A_{CR}$ | TIME REMAINING TO MOD/INSPECTION ACTION | RECOMMENDED MOD/INSPECTION ACTION |
|---|---|---|---|---|---|---|
| STRUCTURAL LOCATION | | | | | | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |

The method is affected by the sequence of loadings that result from various combinations of mission severity and mix. This spectrum sensitivity is shown schematically in Figure 15 and 16. The actual aircraft spectrum sensitivity will be different from the crack growth gage spectrum sensitivity (Figure 17 and 18) because of their different geometry effects. Since each individual aircraft will experience different usage, a "reasonable" relationship between the CGG spectrum sensitivity and the aircraft structure spectrum sensitivity is necessary to achieve a meaningful aircraft analysis from the CGG results. These spectrum sensitivity effects and also material and geometry variations between aircraft, between gages, and between aircraft and gages will all contribute to "scatter" in the analyses. Evaluations of the effects of variations such as these must be worked out for each aircraft series. The accuracy of the system is discussed in Section 3.1.2.4.8.

3.1.2.4.4 Data Collection

At base level inspection intervals, the crack growth gage is removed from the airplane and a new gage installed. The used gage is sent to the laboratory for determination of crack length. Note that the removal/reinstallation is necessary to keep the system going because the usage severity is based on the crack length measurements and the flight hours for the interval involved. Alternate methods for obtaining readings without removal of the crack growth gage are available, such as the Faxfilm replication method (Reference 5, page 108); using these on-the-airplane measurements would provide the necessary data in conjunction with the flight hours data for the same interval. However, the gages will be designed for one-interval crack growth under the most severe conditions (see Section 3.1.2.4.8) and therefore should be replaced even if they can be read on the airplane.

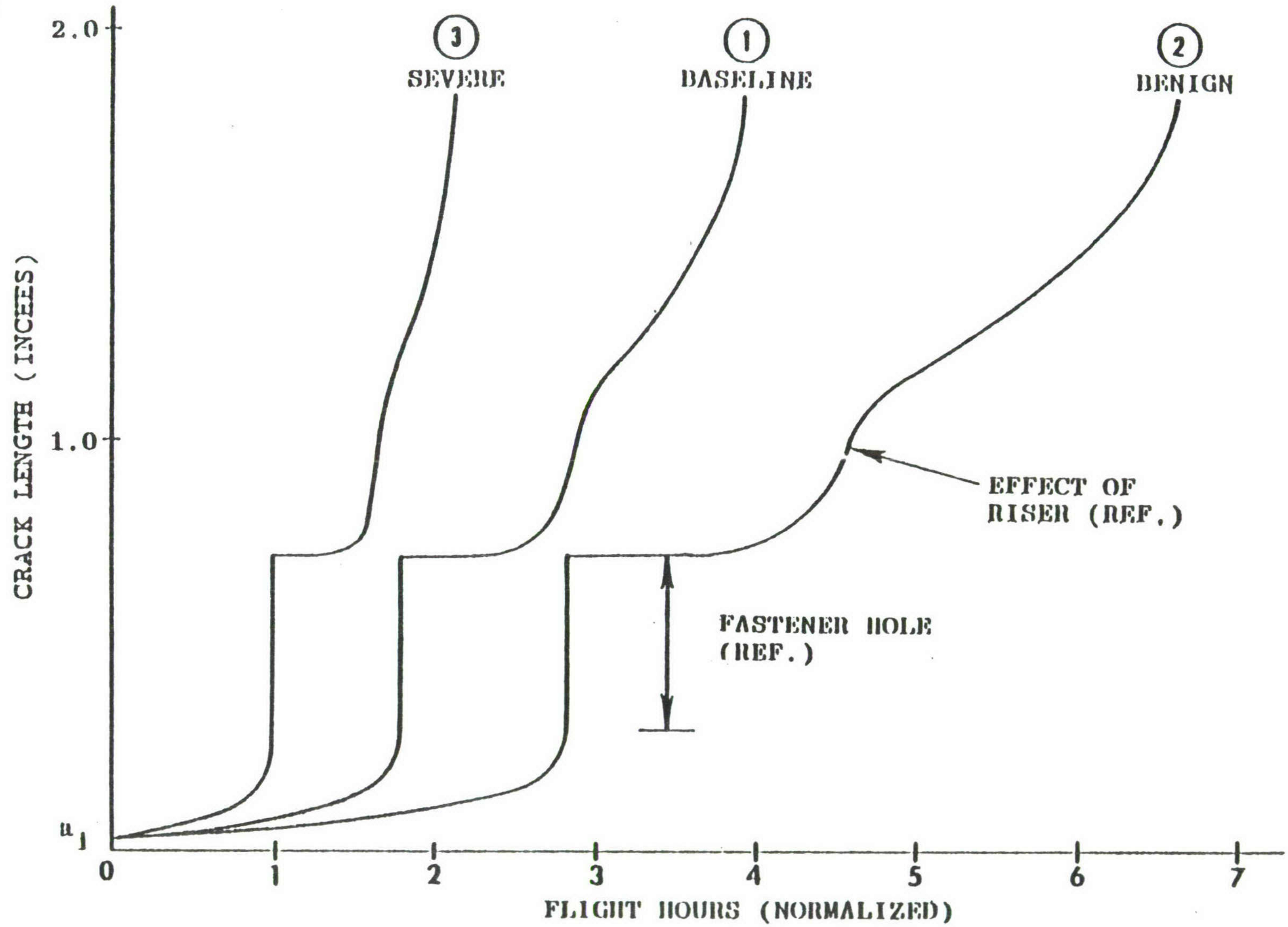



Figure 15. Transport/Bomber Wing Structure Example Crack Growth For Three Usage Severities.

EXAMPLE WING STRUCTURE
TOTAL CALCULATED CRACK LENGTH

| FLIGHT HOURS (NORMALIZED) | ○ SEQUENCE 1-1-1 (REF.-BASELINE) | △ SEQUENCE 3-1-2 (SEVERE-AVG.-BENIGN) | □ SEQUENCE 2-1-3 (BENIGN-AVG.-SEVERE) | ◇ SEQUENCE 1-2-3 (AVG.-BENIGN-SEVERE) |
|---|---|---|---|---|
| 1 | .08 | .72 | .06 | .08 |
| 2 | .72 | .86 | .72 | .16 |
| 3 | 1.11 | 1.26 | 1.80 | 1.33 |

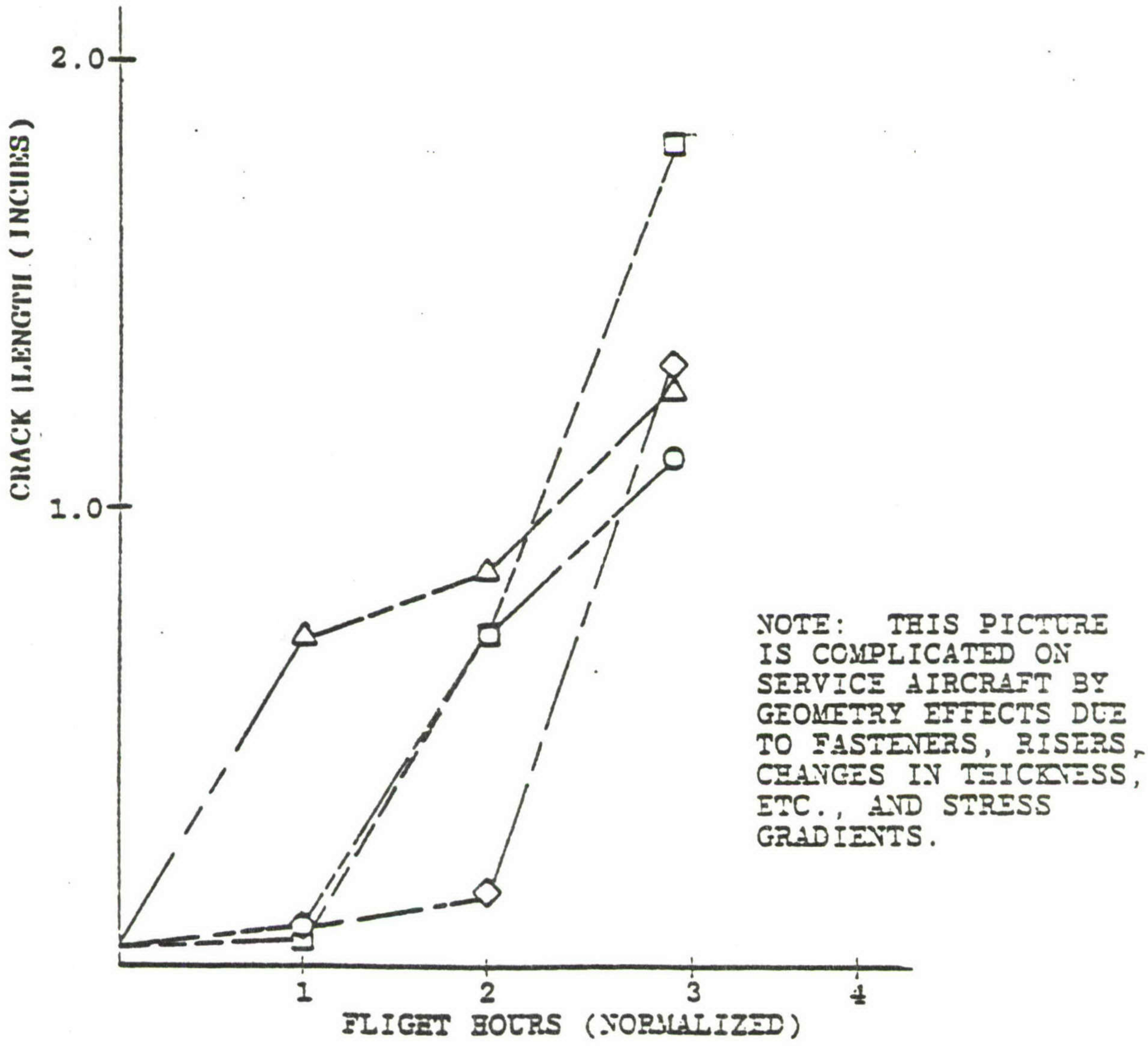



Figure 16. Example of Spectrum Sensitivity Effects.

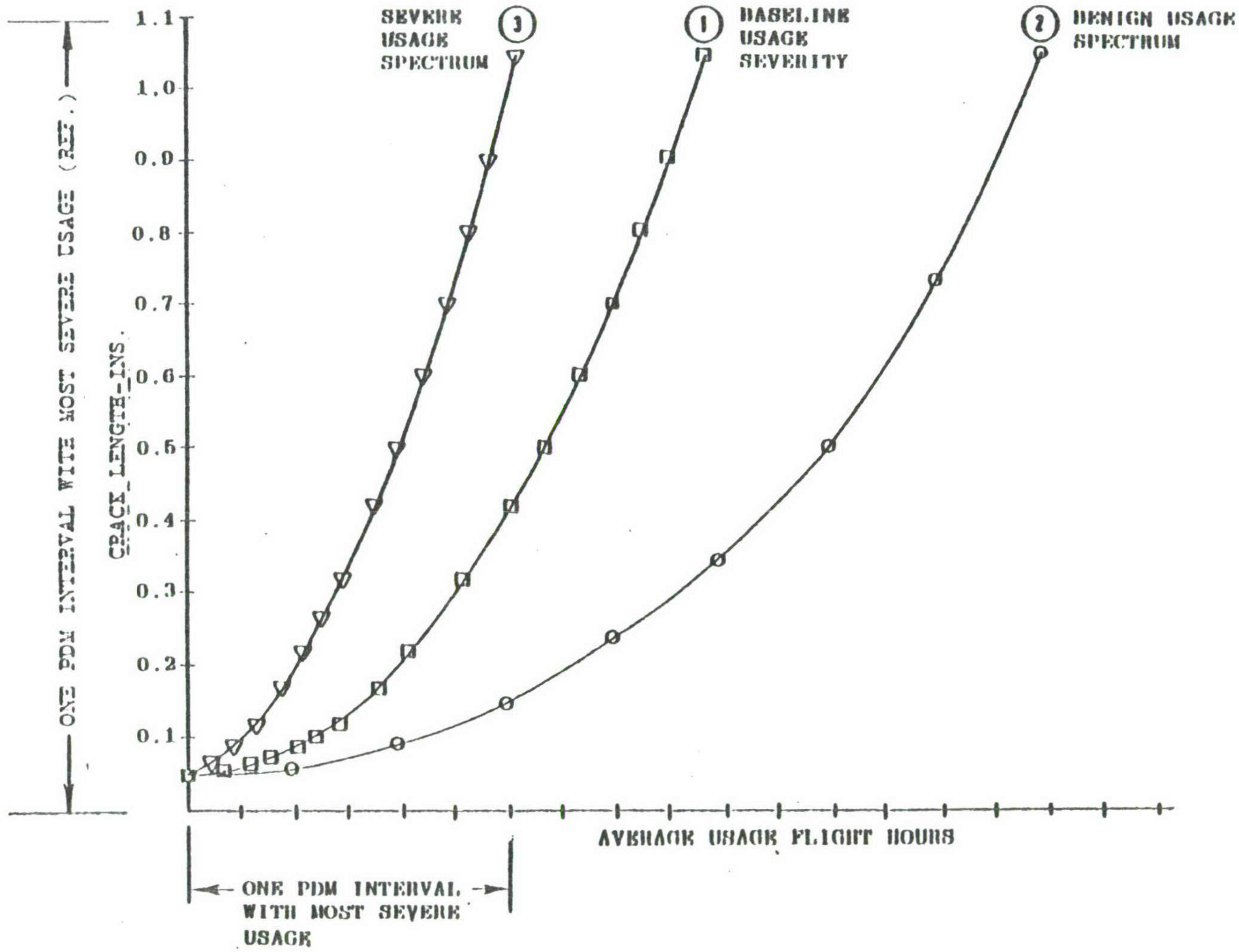



Figure 17. Crack Growth Gage Characteristics (Hypothetical Example).

| TIME FRAME (ONE FRAME = 1 UNIT ON SH.1 | CRACK GROWTH GAGE TOTAL CRACK LENGTH ○ SEQUENCE 1-1-1-1-1-1 (REF) (BASELINE) | △ SEQUENCE 3-3-1-1-2-2 (SEVERE-AVG.-BENIGN) | □ SEQUENCE 2-2-1-1-3-3 (BENIGN-AVG. SEVERE) | ◇ SEQUENCE 1-1-2-2-3-3 (AVG.-BENIGN-SEVERE) |
|---|---|---|---|---|
| 1 | .07 | .12 | .05 | .07 |
| 2 | .11 | .28 | .07 | .11 |
| 3 | .20 | .43 | .11 | .15 |
| 4 | .33 | .62 | .20 | .21 |
| 5 | .49 | .80 | .39 | .41 |
| 6 | .70 | 1.01 | .66 | .68 |

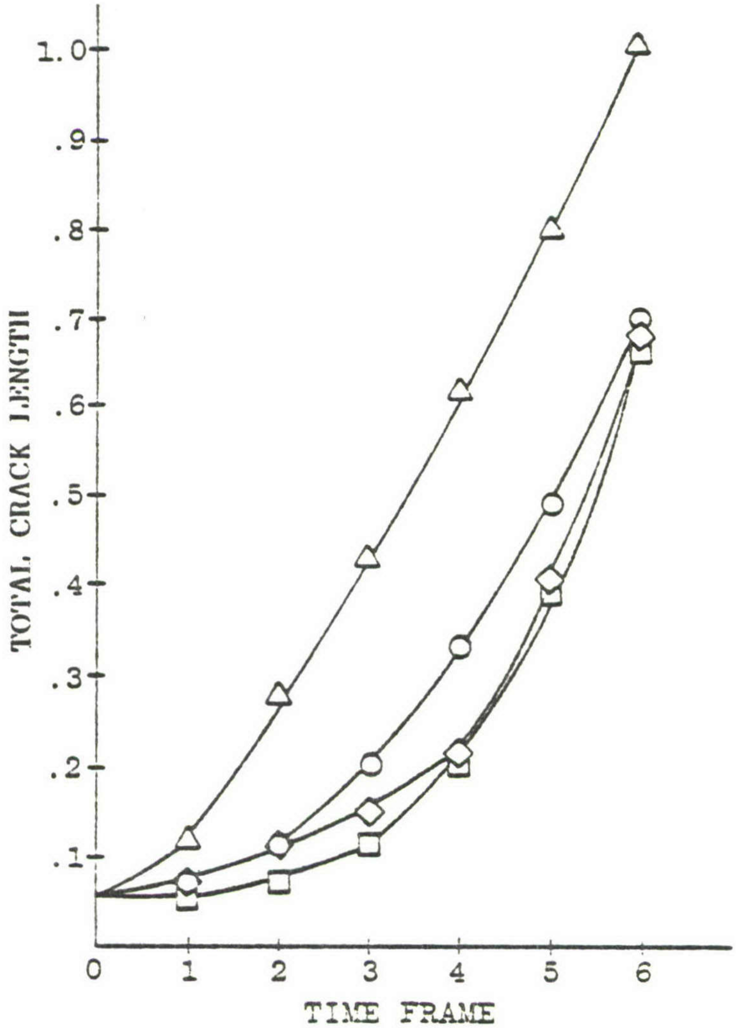



Figure 18. Example of Spectrum Sensitivity Effects.

3.1.2.4.5 Data Processing

3.1.2.4.5.1 Logistics

Figure 14 illustrates the data flow.

3.1.2.4.5.2 Verification/ Editing Techniques

Verification may consist of such actions as examination of the crack face for evidence of anomalies, and analytical reasonability checks when the usage severity is determined. Editing is simply elimination of data considered to be erroneous.

3.1.2.4.5.3 Gap Filling Procedures

Gap filling consists of projecting the aircraft structure analytical crack length from its previous value through the time frame to be gap filled, using several variations of crack growth severity projections reflecting variations in usage severity.

3.1.2.4.5.4 Supplemental Data Requirements

The concept described herein requires an incremental usage increment such as flight hours in order to relate the usage severity as indicated by the CGG to the crack growth effects on structure for that severity and that amount of incremental usage (flight hours). Additional supplementary data are necessary in order to interpret the data. If the CGG indicates severe usage, it will be desired to determine if this indication is the result of higher than expected utilization of some particular mission type (training, logistics, aerial delivery, etc.); of a new type of utilization; or of a peculiarity in the crack growth gage response. (See Paragraph 3.1.2.2.5.4 for additional discussion of this need for supplementary data for an MSR-based system. The same needs apply for the CGG). Supplementary data are also necessary for other IAT usage descriptions and to furnish more visibility for updating other analyses such as Durability and Damage Tolerance Assessments (DADTA) or Service Life Analyses (SLA). These data consist of the information presently obtained by the usage forms IAT.

#### 3.1.2.4.6 Damage Projection Techniques/ Examples

Figure 13 and Figure 3 conceptually illustrate examples of service aircraft crack growth projection techniques for CGG and usage forms systems, respectively. These methods are the same except that the crack growth gage projections are on a depot level (PDM - 4 years) inspection interval and the data are only acquired at each depot level inspection.

Upon inspection, Fracture Tracking Program (FTP) analyses are "reset" to a crack length "$a_{NDI}$" corresponding to the Non-Destructive Inspection (NDI) crack detectability for the NDI method used. The same method is appropriate for the CGG system. However, the CGG analyses are based on data obtained at the same time as a scheduled NDI is performed. Therefore, the value of the CGG approach appears to be in defining whether the NDI is needed to be performed at the <u>next</u> base level PDM interval. At the PDM in which the NDI is performed, no CGG analysis is needed; the analytical crack length can simply be reset to a NDI detectable crack length.

#### 3.1.2.4.7 Costs

Table 11 lists cost elements which may be anticipated for the crack growth gage based IAT system. The supplemental data requirements are the data presently acquired by the Usage Forms IAT System.

TABLE 11

Transport/Bomber IAT Cost Elements For
Crack Growth Gage (CG)

| ELEMENTS | CRACK GROWTH GAGE | COMMENTS FOR CGG SYSTEM |
| --- | --- | --- |
| INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT | X | |
| DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE | X | INSTALLATION DETAILS ONLY |
| QUALIFICATION TESTING | | |
| DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE | X | COMPUTER PROGRAM |
| T.O. FOR IMPLEMENTATION | X | |
| FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS) | X | |
| REPLACEMENT OF DATA ACQUISITION ELEMENTS; TRANSMITTAL TO ASIMIS | X | REMOVE AND REPLACE CGG's |
| SPECIAL READING OF DATA ACQUISITION DEVICE | X | LAB MEASUREMENT OF INITIAL, FINAL CRACK LENGTH |
| DATA TRANSCRIPTION TO MAGNETIC TAPE | X | |
| COMPUTER ANALYSES OF DATA | X | |
| GAP FILLING | X | COMPUTERIZED |
| SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS | X | |
| ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA | X | |
| MANUAL CHECKING, ANALYSES, DEBUGGING OF COMPUTER OUTPUT | X | |
| REPORTS OUTPUT | X | |
| ON-BOARD SYSTEMS MAINTENANCE | | |
| TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE | | |

### 3.1.2.4.8 Accuracy (Realism)

An apparently ideal goal for a CGG system would be to develop a gage whose crack growth characteristics duplicate precisely the growth rate of the actual structure to which it is attached. If this were attainable, the gage crack length could be set at 1/2 the length from the NDI detectable size $a_{NDI}$ to critical length at limit load and repeat inspections on the actual airframe structure would then be made at the time required to achieve this growth interval. If inspections did not disclose any cracking on the airframe (which is hopefully the case, since any structural cracks might be much less than $a_{NDI}$), a new CGG would be installed and the process repeated until such time as cracking was present (at which time repairs could be installed). This approach is consistent with DADTA slow crack growth approach to establishing safe-use intervals of flying based on NDI results and crack growth analysis. However, this ideal of a CGG which cracks at the same specific rate as the aircraft structure is not yet available with a simple gage attached to a complex structure. Also, a CGG designed in this manner would exhibit little crack growth at the short ($a_{NDI} \approx 0.15"$ for baseline C-141A example) crack lengths. Therefore, if the gage or bonding were faulty, it might not be apparent for a long period of flying. The more desirable method described herein uses a Crack Growth Gage designed to crack almost (but not all the way) across during one depot inspection interval under the most severe usage anticipated for the airplane. This maximum permissible crack growth sensitivity requires replacement of the gage at each inspection interval but provides increased accuracy in interpreting the data.

The "idealized" approach also depends solely on the proper operation of the CGG with respect to the airplane structure, i.e., no supplementary data are necessary. However, if rapid crack growth in the CGG is experienced, additional information would probably be sought prior to initiating special inspection/maintenance action based solely on the CGG evidence. Conversely, if no crack growth were experienced in the CGG, the CGG or the installation would be considered suspect. Thus, the confidence in performing service aircraft inspection/maintenance action is related to the examination of supplementary data as well as of the CGG response.

The approach described herein is the result of a conceptual evaluation of possible CGG methods. However, the accuracy of this system is dependent on all the yet-to-be-defined relationships and scatter characteristics between the designed, fabricated, installed, and measured CGG and the aircraft structure it is being used to monitor. The accuracy (Realism) is also dependent on the analysis method, which uses a PDM interval of data at a time and relates the "usage severity" indication of the CGG to the corresponding "usage severity" bands defined for the aircraft structure analysis.

Extensive study and testing would be necessary to establish the characteristics of a CGG based system. All in all, it appears that the best description of the CGG is that it is an "activity indicator" with attractive theoretical potential but with many unresolved matters in execution.

### 3.1.3 Comparison of Monitoring Techniques

The present usage forms IAT programs are operational and providing fatigue damage theory based data for existing Transport/Bomber aircraft. Updates of these programs are in process to incorporate crack growth methodology and Durability and Damage Tolerance Safety Criteria. These changes to the programs are anticipated to not affect the design of the usage forms and the logistics of the existing systems, i.e., they are software program changes which can be accomplished at ASIMIS. The usage forms IAT method provides simplicity, visibility, flexibility, familiarity to the users, and compatibility with the analysis methods on which it is based.

Mechanical strain recorders provide direct strain data in a straightforward manner, and can be a useful adjunct to a usage forms or microprocessor based IAT System. For Transport/Bomber aircraft, the MSR is not considered to provide sufficient data for IAT, i.e., supplementary data such as usage forms data are required.

Microprocessor based IAT systems offer advantages of new-generation technology and direct responsiveness to the actual environment and sequence of loading experience of the individual aircraft. The system requires fewer manual inputs than the usage forms method, and these may be keyed in. By tieing in to the flight computer, most of the necessary data can be obtained by the microprocessor without additional sensor installations. The microprocessor may be used for data acquisition only, or for on-board data processing as well. Some amount of ground processing will be necessary with either system. Further study is needed to define which method is more desirable.

The crack growth gage, assuming further development for sufficient repeatability of crack growth response to applied strains, can be useful as an "activity indicator", but is not considered to provide sufficient data to support overall Force Management needs for Transport/Bomber aircraft in general.

Table 12 shows cost elements for each system in a common matrix to aid in comparing these systems. Additional detail is provided in the preceding discussions of each system.

## 3.2 IAT SYSTEM IMPLEMENTATION

The implementation of any IAT System should consider overall Force Management Program requirements. Section 3.1.2.1 and Section 3.1.2.3, which discuss the Usage Forms and Microprocessor methods, indicate the data presently considered needful for Force Management. Each aircraft system must be considered on its own needs. Figure 19 illustrates the differences in aircraft systems which may result in different IAT system requirements.

The two primary purposes of the IAT program are to provide usage data and to address individual aircraft safety inspection, modification actions (i.e., Force Structural Maintenance). Therefore, the design of the IAT program is related to the design of the L/ESS program, which also produces usage data for a percentage (normally 10-20%) of Force aircraft, and to the design of the Force Structural Maintenance program which uses the IAT and DADTA output. If the FSM is accomplished by individual component, then individual component IAT is necessary. If aircraft are all inspected identically on a chronological or flight hours basis, then detailed IAT output for each individual aircraft may not be cost effective. Section 2.3 addresses FSM aspects of this subject. A need is indicated for further study of the FSM use of the individual aircraft maintenance action recommendations output by the IAT.

To summarize: The IAT is a segment of the overall Force Management program and should be designed and implemented to be compatible with other related segments. The IAT for one aircraft may need to be much more complex than the IAT for another aircraft. Familiarity with other aircraft programs can be helpful in designing the program for a new aircraft.

TABLE 12

Transport/Bomber IAT Cost Elements - Comparison

| | COST ELEMENT APPLICABLE FOR SYSTEM | | | |
|---|---|---|---|---|
| | USAGE FORMS | MSR | MICROPROCESSOR | CRACK GROWTH GAGE |
| INITIAL DESIGN AND DEVELOPMENT OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT | | X | X | X |
| DESIGN OF HARDWARE SYSTEM FOR SPECIFIC AIRPLANE | | X | X | X |
| QUALIFICATION TESTING | | X | X | |
| DESIGN OF SOFTWARE SYSTEM FOR SPECIFIC AIRPLANE | X | X | X | X |
| T.O. FOR IMPLEMENTATION | X | X | X | X |
| FAB. AND INSTALLATION OF DATA ACQUISITION DEVICE AND SUPPORTING EQUIPMENT (SENSORS) | | X | X | X |
| REPLACEMENT OF DATA ACQUISITION ELEMENTS: TRANSMITTAL TO ASIMIS | X | X | X | X |
| SPECIAL READING OF DATA ACQUISITION DEVICE | | | | X |
| DATA TRANSCRIPTION TO MAGNETIC TAPE | X | X | X | X |
| COMPUTER ANALYSES OF DATA | X | X | X | X |
| GAP FILLING | X | X | X | X |
| SUPPLEMENTARY DATA ACQUISITION; TRANSMITTAL TO ASIMIS | | X | | X |
| INSPECTION/MODIFICATION DATA | X | X | X | X |
| ADDITIONAL COMPUTER ANALYSES OF SUPPLEMENTARY DATA | | X | | X |
| MANUAL CHECKING, ANALYSIS, DEBUGGING OF COMPUTER OUTPUT | X | X | X | X |
| REPORTS OUTPUT | X | X | X | X |
| ON-BOARD SYSTEMS MAINTENANCE | | | X | |
| TEST EQUIPMENT FOR ON-BOARD SYSTEMS MAINTENANCE | | | X | |

- PARAMETERS = f (DETAILS OF IAT PROGRAM) FOR EACH TRANSPORT/BOMBER AIRCRAFT

- IAT PROGRAM FOR EACH TRANSPORT/BOMBER AIRCRAFT = f [
  - BACKGROUND OF AIRCRAFT DESIGN (E.G., COMMERCIAL DERIVATIVE)
  - FORCE SIZE (INVESTMENT)
  - SENSITIVITIES TO VARIOUS PARAMETERS
  - MISSIONS AND MISSION USAGE
  - OTHER CONSIDERATIONS (L/ESS)
  ]

Figure 19. Transport/Bomber Force Management Method Evaluation Individual Aircraft Tracking (IAT) Parameters.

## SECTION 4

## LOADS/ENVIRONMENTAL SPECTRA SURVEY (L/ESS)

### 4.1 L/ESS METHODS

#### 4.1.1 L/ESS Parameters

L/ESS programs tend to vary from one aircraft generation to another. Increasing knowledge of the aircraft environment leads to a need to know still other information about the environment. For example, lateral gust and response data have been a focal point of recent L/ESS programs. Also, vertical gust and maneuver separation has been of major interest in a recent L/ESS program. (See Appendix C, Section C5.4). For crack growth analyses, added emphasis is being placed on sequencing and phasing of the loads. And with the coming of such refinements as load alleviation systems, variable-sweep wings, elevons, fuel management, and control-configured vehicles, there will be additional data needed in the future beyond that obtained in present L/ESS systems.

These changes will result in the designation of new L/ESS parameters in future generation aircraft. The L/ESS program is the means of obtaining service aircraft data to support analyses of new designs. Initial data obtained from flight test programs may not represent the service environment, and may even identify a need for further data not obtained during the development program.

L/ESS parameters should be selected to obtain data addressing the analysis needs of the specific aircraft involved. However, as indicated above, the parameters required for one aircraft may be different from those required for another, and future generation aircraft may require parameters not included in present L/ESS programs.

Just as IAT parameters differ from one aircraft to another (see Section 3.1.1), so L/ESS parameters can also differ. Appendix C Table 17 lists L/ESS parameters included in the (baseline) C-141A L/ESS program. The C-141A L/ESS program is discussed as a "typical" example of the type of program used in Transport/Bomber aircraft. The complexity and specific parameters selected will be different for each aircraft. Other sections of this Appendix discuss the data obtained from these parameters and the usefulness of the parameters for the C-141 analyses. It is concluded that not all channels of data presently recorded are essential to the present analyses. Table 13 summarizes these findings. Two major conclusions which may be reached from a review of these data are addressed herein;

A. Not all the (baseline) C-141A L/ESS channels produced essential data. This implies that some of the parameters could have been omitted from the L/ESS program. It should be noted in this regard for all Transport/Bomber aircraft that parameters selected are sometimes intentionally redundant, in order to obtain check data and backup data for other channels. Also, parameters selected initially are based on all the data available at the time. However, when service aircraft data are obtained and further analyses have been performed, it may be found that other parameters and revisions to locations of sensors may be necessary to obtain more meaningful data. This inherent nature of the L/ESS program, which may be viewed as an extension of the development phase into the operational service aircraft phase, is appropriate to recognize when discussing parameter selection.

B. Strain channels as a group gave low quality data. These channels are not identified as critical channels in determining usability of the L/ESS

TABLE 13 - SUMMARY OF

C-141 L/ESS REVIEW - PARAMETERS*

| PARAMETER** | RECOMMENDATIONS FROM REVIEW | |
|---|---|---|
| Pitot Static Pressure | Critical data | |
| Pitot Total Pressure | Critical data | |
| Ground Speed | Critical data | |
| Normal Acceleration | Needed for criteria checks | |
| Cabin Pressure | Needed for criteria checks | |
| Pitch Rate | Compress and store for future use | |
| Yaw Rate | Compress and store for future use | |
| Rudder Position | Compress and store for future use | |
| Elevator Position | Compress and store for future use | |
| Flap Position | Needed for criteria checks | |
| Nose Gear Angle | Compress and store for future use | |
| Lateral Acceleration | Needed for criteria checks | |
| Wing Joint Strain | Relocate | or eliminate |
| C.W.S. 53.2 Strain | Relocate | or eliminate |
| MLG Bogie Beam Strain | Relocate to Wing Lower Surface | or eliminate |
| F.S. 1108 Stringer Strain | Relocate to Wing Lower Surface | or eliminate |
| Landing Gear Event (Up or Down) | Critical Data | |
| Landing Gear Strut (extended or compressed) | Critical Data | |
| Spoilers | Compress and store for future use | |
| | Add a Fuel Totalizer Channel | |
| | Add a Refueling Event Channel | |

Notes or Recommendations

Strain gage relocations result from Durability and Damage Tolerance reassessment of critical locations. Addition of fuel totalizer and refueling event channels results from addition of aerial refueling capability.

Reference: Appendix C, Table 17 and Section C 10.0

* The C-141A L/ESS program is shown as a "typical example of Transport/Bomber programs. The complexity and specific parameters will be different for each aircraft.

** See Appendix C Table 17 and Figure 24 for additional description of parameters.

data. The implication is that strain channels could be omitted from the L/ESS program. Significant cost savings in instrumentation, maintenance, and data processing could result. However, a more desirable solution is to improve the strain data by initial design installation and maintenance of the instrumentation so that the strain channels output can be used for the intended purpose. With good strain data to compare with data from other L/ESS channels, improved analyses for all Force Management programs (IAT, L/ESS, FSM, and periodic Durability and Damage Tolerance Assessment updates) may be realized.

Table 13 indicates that five of twenty parameters are essential L/ESS data. Four more parameters are needed to provide criteria checks and/or updates to the Durability and Damage Tolerance Assessment as to the C-141A IAT. The five strain gages need to be relocated and upgraded. Two new channels are needed due to a change in airplane configuration and usage. Six channels are not used at present but the data should be compressed and stored for future use.

### 4.1.2 L/ESS Monitoring Techniques

#### 4.1.2.1 Multichannel Recorder

The Task 1 Current Methods final report, Reference 2, describes the present MXU-553A multichannel recorder programs for Transport/Bomber aircraft. For the Task II Force Management Methods evaluation, the C-141A MXU-553A system is used as the baseline current methods program. A review of this program and recommendations for an update to increase the yield and cost-effectiveness has been completed, and is now being considered by Warner Robins ALC for implementation. The problems encountered by the C-141A program and addressed in the review are typical of the majority of the Transport/Bomber L/ESS programs. Therefore, the results of this review are discussed herein. The basic C-141A MXU-553A program and the evaluation of 300 flight hours of data from the program are described in considerable detail in Appendix C to this report.

4.1.2.1.1 Advantages and Limitations

The MXU-553A and related multichannel recorder systems were developed for the purpose of obtaining L/ESS data for USAF aircraft. The basic system components already exist and are common to most of the current Air Force aircraft models. Significant advantages in inventorying, maintenance, familiarity with the basic system, and similarity of basic data acquisition, retrieval, and transcription methods accrue from this commonality. The data processing system is centrally established at the Air Force Aircraft Structural Integrity Management Information System (ASIMIS) facility at Oklahoma City, providing a production oriented, dedicated computer center for Air Force IAT and L/ESS data. Since the several aircraft L/ESS programs are handled in this central facility, improvements in one aircraft program can be considered for applicability to other programs. Also, a data bank from all programs can be obtained through this centrality. Thus, the primary advantages of the current multichannel recorder system are:

- Systems already exist and are in operation
- Force-Wide commonalities
- Central computer processing facility
- Central data bank
- Cost savings from the above

The benefits of the centralized ASIMIS computer processing facility would exist for other L/ESS methods also, i.e., for the MSR, Microprocessor, and other multichannel recorder programs, but to varying degrees depending on the amount of ground processing which is performed. Since the MXU-553A system relies almost totally on ground processing at ASIMIS, this activity is an integral part of the overall current multichannel recorder method.

The MXU-553A and related current multichannel recorder systems have significant limitations, also:

- Only a portion of the Force aircraft are instrumented.
- Input signals to the recorder are often unusable.
- Hardware maintenance is insufficient.
- Data yield from recorders is low (Logistics and Maintenance problems due to low priority).
- Usable data is low.
- Use of the data is ill defined by present MIL specifications.
- Duration for obtaining data is ill defined by present MIL specifications.
- Computer software is complex and generally requires extensive checkout before implementation.
- Some channels of data of little use are recorded and other channels of needful data are omitted in the original program due to implementation schedule.
- Relatively inflexible for updating later to correct data channel selection.

The Task 1 current methods report discusses advantages, limitations, and organizational interfaces for the current L/ESS systems in additional detail. Potential improvements defined in the Task 1 report (Reference 2, Sections 5.2 and 6.2) include choice of parameters to record;

independency of channels to minimize computations; methods to improve data yield and quality; improved software development and checkout methods; and compatibility with IAT and Force Structural Maintenance (FSM) programs. These are addressed in the C-141A (Baseline) L/ESS update review and evaluation in Appendix C, to the extent applicable.

#### 4.1.2.2 Microprocessor Based Systems

Potentially, an on-board microprocessor (MP) can perform the same data acquisition functions as the present MXU-553A multichannel recorder. In order to accomplish this task, however, a lengthy and complex set of instructions would need to be programmed into the MP.

A more viable alternate usage of the microprocessor might be to design the microprocessor as a system checking and malfunction indicator for use in conjunction with the existing MXU-553A recorder system. No additional instrumentation should be necessary for this function, but the quality and quantity of the output data should be improved and ground processing of unusable data should be reduced.

Ground processing as for the existing MXU-553A multichannel recorder system is assumed for L/ESS programs.

##### 4.1.2.2.1 Advantages and Limitations

Advantages of the microprocessor - based system with respect to the existing MXU-553A multichannel recorder based system are:

- Solid-state circuitry
- Can combine IAT and L/ESS functions if so desired
- Can be set up to receive flight crew inputs as Keyboard entries
- Can accomplish on-board data compression

- Can accomplish system self-checks and indicate malfunctions for maintenance action.

Disadvantages of the microprocessor - based system with respect to the existing MXU-553A multichannel recorded based system are:

- Reliable power-down memory is required until data are retrieved.
- New system must be developed, qualified, checked out. Flight hardening (qualification) may be difficult.

As a general statement, the microprocessor may be viewed as a next generation multichannel L/ESS recorder. The data inputs and outputs are the same as for the existing MXU-553A recorder. The inherent advantages and disadvantages of being new but untried apply.

4.1.2.2.2 Data Collection

Data inputs to a microprocessor based L/ESS system are the same as those for the present MXU-553A recorder. However, the new system can be used for IAT output as well as for L/ESS output, and the systems can be designed for flight crew keying in of inputs for both purposes.

4.1.2.2.3 Data Processing

4.1.2.2.3.1 Logistics

Logistics are the same as for the present MXU-553A system except that data retrieval is accomplished by a "pick-off" hookup to ASIMIS or by replacing memory cards (rather than a cassette tape) which are then sent to ASIMIS for pickoff of data, erasing, and returning to the field.

4.1.2.2.3.2 Verification/ Editing

The L/ESS ground processing program for microprocessor data would be the same as for the present multichannel recorder data. However, the microprocessor can be designed to accomplish on-board compression. Also the system can be designed to accomplish on-board data checks and turn on malfunction indicator lights to indicate needs for maintenance. Response to these signals (i.e., performing the needed maintenance) can improve the data yield and data quality. These features can reduce ground processing time per flight hour of usable data. Editing of L/ESS data as currently obtained from most MXU-553A Systems is a relatively complicated process and it is accomplished largely by manual procedures. It would be very difficult to program the microprocessor for all the editing procedures on these L/ESS programs.

4.1.2.2.3.3 Gap Filling Procedures

Gap-filling procedures are the same as for the present MXU-553A multichannel digital recorder system. See Appendix C, Section C2.0 and C4.0. In general, limited data editing and the selection of tapes having valid desired data are preferred over gap filling for L/ESS programs.

4.1.2.2.3.4 Supplemental Data Requirements

Supplemental data requirements for the microprocessor used in a L/ESS system are the same as for a multichannel recorder based L/ESS system, except that if system self-checks are desired, supplementary data boundaries and/or data checking logic must be designed into the microprocessor.

#### 4.1.2.2.4 Costs

Table 9 lists cost elements for a microprocessor based IAT system. These elements are also applicable for a microprocessor based L/ESS system used on a new aircraft as a next generation of the present MXU-553A multichannel recorder based system. The L/ESS system will generally require more channels of data than the IAT system, however.

Several other uses for microprocessors are to be noted. One is a replacement for the existing MXU-553A recorder on existing aircraft. Another is an on-board system checking (malfunction indicator) device for use in conjunction with the present MXU-553A recorder. Still another alternate is to use a microprocessor as the core of a ground based system checking device for maintaining the on-board L/ESS components. Further study of the cost effectiveness of these several alternate uses of the microprocessor is recommended.

### 4.1.2.3 Mechanical Strain Recorder Based Systems

#### 4.1.2.3.1 Advantages and Limitations

The MSR offers the potential benefits in a L/ESS program of a direct, sequenced trace of all aircraft strain experience at a given location, within the limits of its accuracy and readability. The data are usable for both IAT and L/ESS programs. Complete coverage of service aircraft is economically feasible. However, supporting data must be obtained for Transport/Bomber aircraft if the MSR output is to be related to any aircraft usage parameters.

The advantages and limitations of the MSR for IAT, Paragraph 3.1.2.2.1, apply for the MSR as a L/ESS device. The MSR can provide strain history at a specific location and is relatively independent in operation, but detailed supplementary data are necessary in order to interpret the output. Additional ambiguity arises because the MSR gives no definable time base. Periods of activity below the recording threshold are not shown on the MSR tape. Therefore, the relation of the strain peaks to data blocks or mission segments can only be surmised.

4.1.2.3.2 Data Collection

MSR data collection for L/ESS is the same as for IAT data collection. See Paragraph 3.1.2.2.4. MSR data can be used for both IAT and L/ESS programs if the supplementary data are appropriate.

4.1.2.3.3 Data Processing

4.1.2.3.3.1 Verification/Editing

Logistics and verification/editing procedures are the same as for MSR IAT programs. See Paragraphs 3.1.2.2.5.1 and 3.1.2.2.5.2.

4.1.2.3.3.2 Gap Filling Procedures

Gap filling procedures are essentially the same as for MSR in IAT usage, Paragraph 3.1.2.2.5.3. However, L/ESS data are used to verify aircraft utilization and response. Therefore, missing data for "typical" flights must be identifiable but need not be gap-filled for L/ESS. The data from these flights should be reviewed for possible special information, but otherwise, flights with missing data should be discarded and no gap-filling performed.

4.1.2.3.3.3 Supplemental Data Requirements

MSR data provide sequenced strain at a specific location for the time of the cassette installation, with no other time base (see Paragraph 4.1.2.2.4.1) and no other data. For transport/bomber

L/ESS programs, supplementary data are necessary to utilize this information. The required supplementary data depend on the intensity and depth of the L/ESS program for each specific aircraft model. The objective of the L/ESS programs is "to obtain time history records of those parameters necessary to define the actual stress spectra for the critical areas of the airframe" (MIL Standard MIL-STD-1530A, Paragraph 5.4.4). For some transport/bomber aircraft models, the L/ESS data are used in defining the missions used in the IAT program and also for detecting changes in these mission descriptions and as a data source for performing Service Life Analyses (updates) for a Force with an IAT already going on. The MSR stress spectra data would be an effective tool in defining the baseline stress spectra, detecting changes, and defining the new spectra. But without supplementary data, there would be no information from which to determine whether and how mission usage, maneuver spectra, gust RMS velocities, climb/descent profiles, landing impact sink rates, or other mission segment characteristics should be updated. As a minimum, a service life analysis and IAT update would require the present usage forms data plus VGH type data (speed, altitude, c.g., load factor) for specifically identifiable IAT recorded flights. The MSR data must also be identifiable to these same flights and, for some analyses, to segments of the flights.

From the above, it is evident that for transport/bomber aircraft such as the baseline C-141A, the MSR should be considered as a supplement to an existing or simplified (VGH minimum) L/ESS program rather than as a free-standing method with certain supplementary data requirements. In the absence of data, the L/ESS objectives could be met with the other data and no MSR, but not vice versa. However, the MSR can provide potentially valuable data as a supplement, and for some aircraft models might permit simplification of the existing L/ESS programs.

4.1.2.3.4 Costs

Table 7 lists cost elements which may be anticipated for a Mechanical Strain Recorder based IAT system. These cost elements are applicable for the MSR used in the L/ESS system also. Supplemental data requirements are those supplied by the present L/ESS system.

4.1.3 Comparison of Monitoring Techniques

The existing MXU-553A multichannel recorder system accomplishes its intended purpose. Data yield has been low due to hardware maintenance problems and to assimilation of software programs into ASIMIS before sufficient data were available from service aircraft to permit thorough checkout of the software. Current reviews and updates which address these problems should result in improved data yield and quality of data.

Microprocessor based systems may be used to supplement or replace the multichannel recorder system. As a supplement, the microprocessor could be used for on-board systems checking and malfunction indication, or as the core of a ground-based maintenance test device. As a replacement, the microprocessor may be viewed as a next generation multichannel recorder with on-board systems checking and malfunction indication if desired.

The mechanical strain recorder may be viewed as a single strain channel of a multichannel recorder or microprocessor based system. Its best use in L/ESS programs would appear to be as a supplement to these systems. As such, the MSR has the attractive feature of direct, independent strain recording. It would appear redundant to use the MSR to duplicate a present strain channel, however.

It may be noted that a Mechanical Strain Recorder can be used as an "activity indicator" to sense when the aircraft usage has changed to the extent that another set of L/ESS data should be acquired. This approach has several problems, however,

A. If such a change is detected, the desire is to know why <u>that</u> change occurred rather than to start at that point to determine <u>future</u> usage.

B. Once initiated, L/ESS programs tend to continue until they are stopped. Once stopped, however, they are not easily started again. (This is true of many force management functions.)

Therefore, it is more desirable to obtain L/ESS data continually and vary the amount of data reduction than to undesirably stop and restart the data acquisition based on MSR (or any other) data.

Further studies are recommended to determine the appropriate L/ESS data acquisition method for each aircraft system. The existing multichannel recorders are in Air Force inventory and are being used in programs which are already operational. The microprocessor-based system is a logical next generation multichannel recorder; however, microprocessor technology is advancing rapidly at this time and its relative position with respect to the multichannel recorder is constantly changing. It would appear that a "simple" microprocessor development such as a trial ground testing unit or on-board systems (sensors) checking and malfunction indicator for an existing multichannel recorder system should precede the development of a more complex microprocessor-based L/ESS system. Also, further consideration of using a microprocessor in a combined IAT and L/ESS system is needed. Cost savings through this combination may be effected.

## 4.2 L/ESS IMPLEMENTATION

Because of the rapidly changing state of the art in microprocessors, ground-based computers, flight computers, and crack growth methodology, the choice of the ideal L/ESS system for a particular airplane will be a difficult task. The following guidelines are offered.

A. Future aircraft with flight computers appear to be ideal candidates for microprocessor-based L/ESS Systems. The L/ESS system can use the same sensor information as the flight computer (plus strain channels), and should be implemented concurrently with the flight computer system design.

B. Continuing use of MXU-553A or other systems already operational in existing aircraft is more cost-effective than changing those systems to a microprocessor base. Possible exceptions are the KC-10 and the C-5A, both being relatively new in inventory and well instrumented.

C. A trial installation of a microprocessor based system in a single C-141A in addition to the present MXU-553A recorder is desirable. The data base of the C-141 would aid in evaluating this installation.

D. The use of a microprocessor for on-board systems checking and malfunction indication for L/ESS sensors is a concept to contribute to improved data quality and data yield. However, it would be more cost-effective to upgrade the present maintenance procedures. A microprocessor-based item of test equipment would be more appropriate.

E. The logistics of the system should be recognized in the design of the L/ESS equipment. For example, maintenance and cassette retrieval from aircraft stationed at front line bases may be more difficult than from CONUS home bases, yet the front lines data may be more needful. For aircraft to be used in this manner, greater storage capacity, more redundancy in channels, and a higher percentage of aircraft with L/ESS instrumentation may be needed.

F. The percentage of aircraft with L/ESS instrumentation may be greater for smaller force (fleet) sizes and for wider diversities of usage. A technically ideal solution to this would appear to be to combine IAT and L/ESS functions into 100% coverage with a single microprocessor based installation. The amount of L/ESS instrumentation and/or the amount of L/ESS data processed could be varied with need.

G. Whatever the design of the L/ESS system, flexibility for possible future changes is needed and differences between different model aircraft are to be expected.

# SECTION 5
# SUMMARY

The Task I Current Methods and Coordinated Force Management reports present a review of the 1978 state-of-the-art methods whereby the MIL-STD-1530A Force Management activities are accomplished. Task II, reported herein, presents an evaluation of potential improvements in these methods for Transport/Bomber aircraft. The results of this evaluation by Lockheed-Georgia Company Force Management personnel are summarized below.

1. The most appropriate Force Management methods for a particular aircraft are related to certain characteristics of that aircraft: design criteria, structural sensitivities, analysis and inspection techniques, aircraft usage, and other factors.

2. Significant improvements in all aspects of the Force Management Program would result from developing a system to provide good feedback of inspection results. A comprehensive Non-Destructive Inspection (NDI) results feedback system is vitally needed to work in conjunction with the crack growth based Individual Aircraft Tracking (IAT) systems.

3. The present usage forms Individual Aircraft Tracking (IAT) programs are operational and providing fatigue damage theory based data for existing Transport/Bomber aircraft. Updates of these programs are in process to incorporate crack growth methodology and Durability and Damage Tolerance Safety Criteria. The usage forms IAT method provides simplicity, visibility, flexibility, familiarity to the users, and compatibility with the analysis methods on which it is based.

4. Mechanical strain recorders provide direct strain data in a straightforward manner, and can be a useful adjunct to a usage forms or microprocessor based IAT System for Transport/Bomber aircraft. The MSR is not considered to provide sufficient data for IAT and supplementary data, such as usage forms data, are required.

5. Microprocessor based IAT systems offer advantages of new-generation technology and direct responsiveness to the actual environment and sequence of loading experience of the individual aircraft. The microprocessor may be used for data acquisition only, or for on-board data processing as well. Some amount of ground processing will be necessary with either system. Further study is needed to define which method is more desirable. For Individual Aircraft Tracking Systems (IAT), it is concluded that the microprocessor is a likely next generation system but should be developed and used concurrently with the present Usage Forms IAT method until it is fully checked out by in-service operation. Although the microprocessor can be designed to perform on-board processing of the data, it appears that the best method for the initial system would be to use the microprocessor for data acquisition and on-board systems checking (only), and to continue performing the IAT data processing at a ground facility (ASIMIS).

6. The crack growth gage may be useful as an "activity indicator", but is not considered to provide sufficient data to support overall Force Management needs for Transport/Bomber aircraft in general.

7. The existing Loads Environmental Stress Survey (L/ESS) MXU-553A multichannel recorder system accomplishes its intended purpose. Current reviews and updates which address certain problems should result in improved data yield and quality of data.

8. Microprocessor based L/ESS systems may be used to supplement or replace the multichannel recorder system. The microprocessor is concluded to be a likely next generation recorder for L/ESS systems. Guidelines are offered in this report (Section 4.2) to aid in selecting the "best" L/ESS system for a particular aircraft.

9. The mechanical strain recorder may be viewed as a single strain channel of a multichannel recorder or microprocessor based system. Its best use in L/ESS programs would appear to be as a supplement to these systems.

## REFERENCES


1. "Informal Coordinated Force Management Report," UDR-TM-78-02, University of Dayton Research Institute, Dayton, Ohio, February, 1978.

2. Clay, L. E., Sandlin, N. H., Morcock, D. S., Brown, K. E., Johnson, R. L., and Davis, J. C., "Force Management Methods, Task I Report - Current Methods," AFFDL-TR-78-183, Air Force Flight Dynamics Laboratory, WPAFB, Ohio, December, 1978.

3. Lewis, W. H., Dodd, B. D., Sproat, W. H., and Hamilton, J. M., "Reliability of Nondestructive Inspection - Final Report," SA-ALC/MME 76-6-38-1, San Antonio Air Logistics Center, Kelly Air Force Base, Texas, December, 1978.

4. Craig, L. E. and Goranson, U. G., "Airworthiness Assessment of Boeing Jet Transport Structure," 10th ICAF Symposium, Brussels, Belgium, May, 1979.

5. Saff, L. R., "F-4 Service Life Tracking Programs (Crack Growth Gages," AFFDL-TR-79-3148, Air Force Flight Dynamics Laboratory, WPAFB, Ohio, December, 1979.

6. Anon, "Military Standard, Aircraft Structural Integrity Program, Airplane Requirements," MIL-STD-1530A, December, 1975.

7. Lambert, G. E. and Bryan, F. G., "The Influence of Fleet Variability on Crack Growth Tracking Procedure for Transport/ Bomber Aircraft," AFFDL-TR-78-158, Air Force Flight Dynamics Laboratory, WPAFB, Ohio, November, 1978.

## APPENDIX A

## DESCRIPTION OF LOCKHEED-GEORGIA COMPANY ON-BOARD STRUCTURAL COMPUTER (MICROPROCESSOR)

NOTE:

This section describes an operational microprocessor development by the Lockheed-Georgia Company C-5 Test and Technical Services Division for which a United States patent has been applied. The algorithms used in this microprocessor are not necessarily those used in the C-5A analyses. (For example, the C-5A analysis loads are based on the Mean-Crossing-Peak-Counts method rather than the Rainflow method in the microprocessor.) Any differences may cause anomalies which would require engineering evaluation. Also, it must be recognized that a primary objective of an IAT program is to maintain the capacity to reconstruct the flight-by-flight history of the individual aircraft. The present development processes the input data but provides only limited reconstruction capability or other visibility for system checking ground processing with other parameters, or transferring the analysis to other structural locations. The evaluation of microprocessors for IAT and L/ESS will be addressed later in the Force Management Improved Methods Program. However, the Lockheed OBSC described herein is significant as a flying prototype which shows the potential and also points out additional considerations for design of microprocessor based systems for Force Management programs.

### CONCEPT AND DEVELOPMENT OF PROTOTYPE OBSC-1 MICROPROCESSOR

Beginning in 1977, Lockheed-Georgia Company developed a microprocessor which demonstrates the potential of these devices for real-time processing of fatigue and/or crack growth damage on individual service aircraft. This system has been flown on a C-5A aircraft and data have been obtained. Limited acquisition of L/ESS data has also been demonstrated. As is the case for L/ESS and IAT programs, the concept of the On-Board Structural Computer (OBSC) envisions a device to evaluate the fatigue and crack growth parameters of an individual airframe and provide data for accurate usage comparisons within the fleet. These comparisons will permit management of the fleet for better utilization or scheduling of inspections and repair activities. Data for tracking of such parameters as damage by mission type, route, crew training or weather would be available by individual aircraft. The technology to do this task is now available as microprocessors from the computer field. Developments hold the promise of providing even more capability or smaller and less expensive devices in the near future. The OBSC is a small, relatively low cost, self contained computer device which operates on inputs from conventional transducers which have proven reliable for aircraft use. For the prototype, fatigue and crack growth computations and monitoring of strain occurrences were performed based on strain input only.

The fundamental advantage offered by the OBSC concept is that data can be processed to information as it is generated by the airframe. This immediate conversion of data to information is possible using the microprocessor. Since the structural response frequency of a large wing is in the range of 1-2 cycles per second, the OBSC has the capability to process and store the data in real time. By this on-board processing, the present problems of data compression, transfer to a ground-based computer, and subsequent ground-based data reduction are minimized and possibly eliminated. Also, the data return should be much greater than for present IAT and L/ESS methods.

The necessary computer elements for an OBSC are readily available from manufacturers.

However, full MIL-Spec qualification of some of these components presents a problem and may continue to be a problem for several years.

The software or programming of the system is divided into two main tasks. One is the collection and transfer of the input/output data, the other is the program that converts this raw data to structural engineering information such as fatigue damage and crack growth predictions. The OBSC-1 prototype was configured to monitor the wing structure as it was thought to be of most concern and should serve as an active element.

Another fundamental decision was required before a fatigue damage and crack growth analysis could be written. This decision was which method of counting cycles should be used. Classic fatigue and crack growth analyses require a method of defining reversals in the stress state,or "Cycles". A cycle is a simple sounding event, but the complex stress history of random occurring loads results in cycles overlaid with longer period cycles and mean level variations that are very difficult to sort out. An effective method which accounts for all these "cycles" is the "rainflow" counting method. This method was selected for the OBSC prototype and was found to be easily handled by the microprocessor. This is discussed in more detail in later paragraphs.

The OBSC-1 prototype flight version microprocessor, shown in Figure 20 and 21 was developed to test the OBSC concept under actual flying conditions. The OBSC-1 prototype flight version was installed on a USAF C-5 and connected to two strain bridges on the outside of the lower surface inner wing. (All strain gage installations for the C-5 were installed under carefully controlled conditions, with multiple channels to provide backup capability and have proved to be very reliable in L/ESS and OBSC-1 usage.) These OBSC-1 strain gages were adjacent to gages being read by the ship's MADAR System. During the checkout on the initial flights the MADAR and OBSC-1 gage wire connections were interchanged to compare output and found to give the same response.

The prototype version was programmed to provide the following information:

1. Retarded Crack Growth - initial 0.01 inch length
2. Linear Crack Growth - Initial 0.01 inch length
3. Retarded Crack Growth - Initial 0.05 inch length
4. Linear Crack Growth - initial 0.05 inch length
5. Fatigue Damage - KT6, 7075-T6 joint S/N data
6. Peak Counts of Strain Data
7. Occurrence Matrix of Strain Data -5 mean and 15 Variable levels.

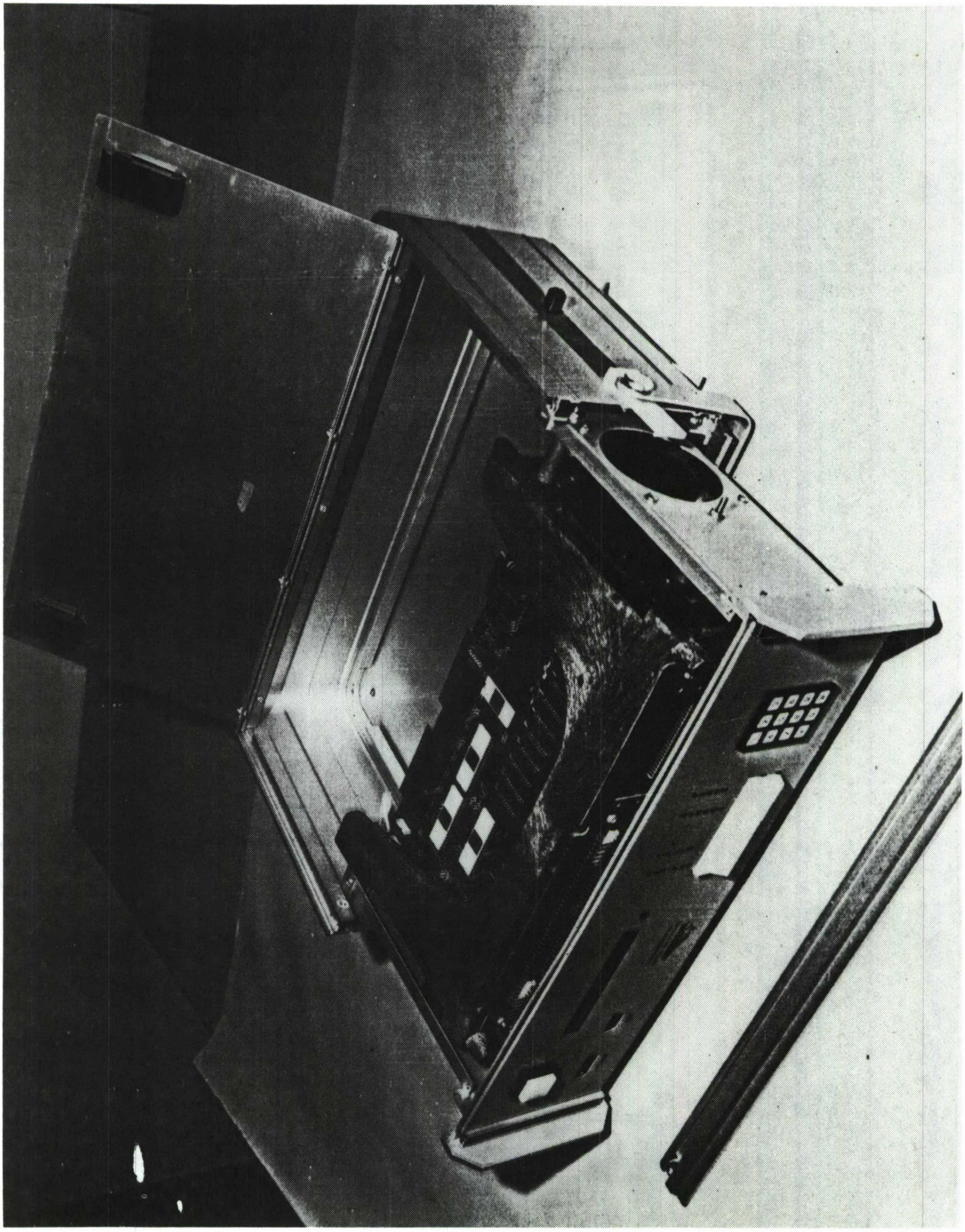


Figure 20. First Prototype Lockheed OBSC-1 Microprocessor.

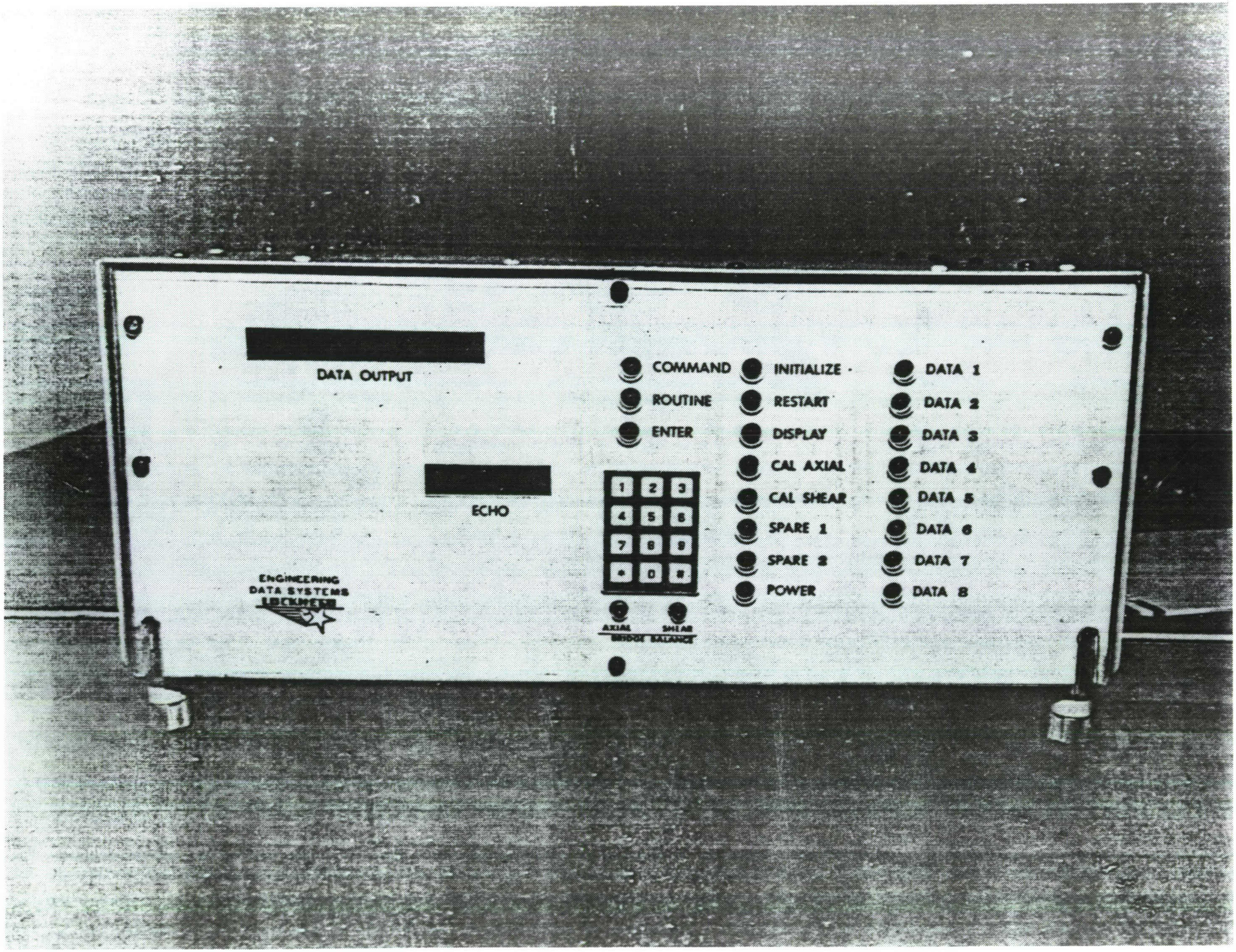



Figure 21. Second (Flying) Prototype Lockheed OBSC-1 Microprocessor.

The algorithms used for crack growth and fatigue calculations were identical to those used in C-5A service missions analyses at the time of OBSC-1 development. All of the electrical components are "off-the-shelf" and were in no way flight hardened devices.

FLIGHT RESULTS - OBSC-1 PROTOTYPE

The basic purpose of installing the prototype version of OBSC-1 on a service aircraft was to gain some actual flight experience with a microprocessor based system and evaluate the problems of developing a tracking device that would use the potential power of real time calculations.

The number one problem that was experienced was the old one of electrical noise from some unknown source. The principal value of the flight program has been in defining the OBSC features that need improving and those that are good as is.

The following results and conclusions were obtained from reviewing the flight history of about 400 flight hours which included long range, training, and aerial refueling missions.

1. The built-in automatic start-up and shut-down system performed well.
2. The power-off memory functioned properly.
3. The fatigue and crack growth programs worked and the overall speed was more than adequate to keep up with the A/C structural response.
4. The balance point and gain of the strain readout remained stable during the test lasting several months without requiring manual rebalances.
5. False, full-scale readings will be recorded if the strain gage cables are unplugged while the OBSC-1 is powered-up. This appears to account for some of the full-scale problems but does not explain other full-scale readings.

6. The designed key pad readout is a poor way to extract the data from the system.

7. The OBSC-1 history matrix is too coarse. A history matrix of damaging cycles with a resolution of $\pm$ 500 psi is required to compare with other analysis methods.

8. Data by flight is required as well as cumulative data to accurately assess operation.

9. A remote readout and checkout device to plug into the flight unit would allow the flight unit to be located behind other equipment or in closed areas.

10. A time reference is needed to identify certain events for later correlation.

11. Redundancy of strain gage input and computer processing is needed to eliminate noise spiking and detect failed or marginal components.

12. Software data checking can be used for self calibration and adjustments within the system.

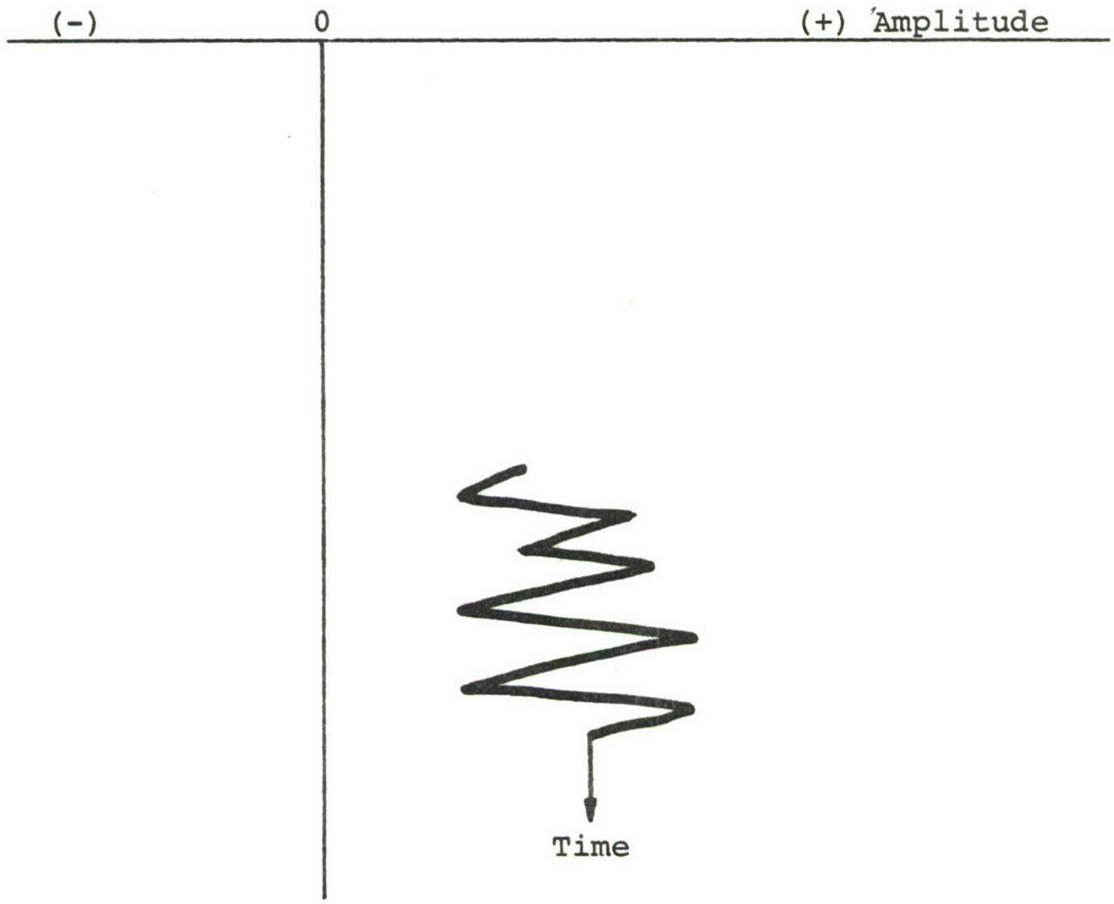
Erratic peak counting near the end of the flight check span occurred and prompted the removal of the system for ground check. The unit was shipped by air and suffered damage in transit. It appears that the baggage hold of an airline flight is a much more damaging location than on the flight deck of a C-5A. A teardown check did reveal a loose main power supply connection that might have caused erratic operation. It was impossible to confirm this but no other problem was found that appeared to have existed before the return flight.

OBSC-RAINFLOW COUNTING OF CYCLES

The "rainflow" algorithm provides a method of accounting for "cycles" of stress at the selected location as they occur without regard for how they will form in the future and yet not lose the value of the past sequences.

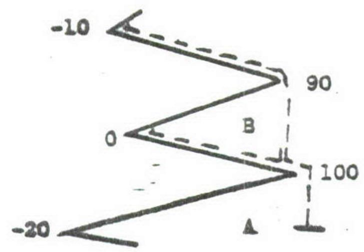
Rainflow methods have been used in a number of analyses theories but for the OBSC system only the cycle counting is done by this technique with all fatigue analysis being linear cumulative methods.

The rainflow algorithm is based on an analogy of rain dripping off multiple roofs arranged by peak amplitude with rain flowing with the time axis as in the following sketch.



A set of rules is applied to test for 1/2 cycle formation.

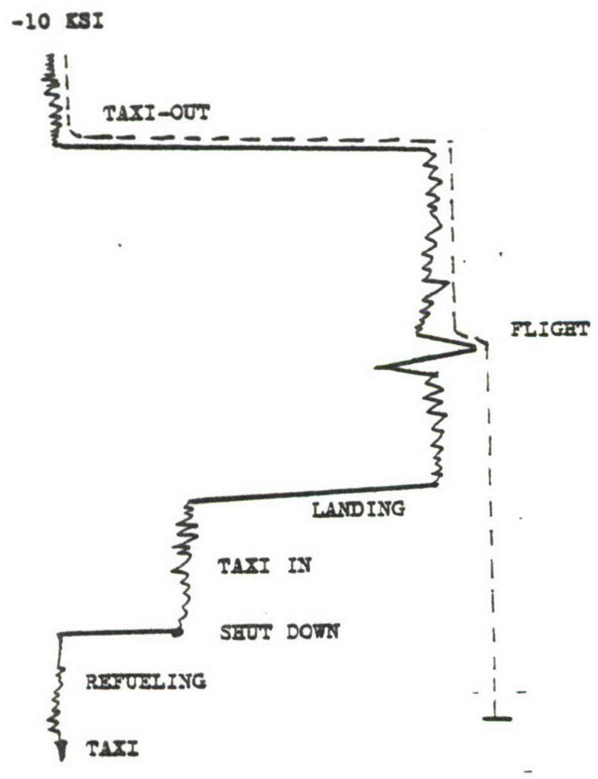
- Flows are considered positive and negative
- Flows start in the apex.




- Considering only the positive side, flow A starts at an amplitude of -10 and stops when it comes opposite to -20 peak. This forms a 1/2 cycle equal to 100 - (-10) = 110 units from minimum peak to maximum peak.
- Flow B starts at 0 and runs until it encounters the flow of A from above. This forms a half cycle of (90-0) = 90 units from minimum peak of 0 to max peak of 90.
- Following these same rules will account for all segments of the spectrum and, with rare exception, there is a negative half cycle to match with every positive half cycle. The OBSC-1 program deals only with positive flows and doubles them to account for the negative flows.

- The full range cycle of flight to flight accounts for the GAG cycle.

START AT FULL FUEL DOWN BENDING




A TYPICAL FLIGHT SHOWING GAG CYCLE

Other features of the OBSC-1 are described by Mr. M. L. Strickland of Lockheed-Georgia Company in a paper presented at the Instrument Society of America meeting in Albuquerque, New Mexico, in 1978. The system is a prototype, and therefore does not require full flight hardening. Figure 21 shows the special front panel which was designed for use in the system. Basically, the front panel consists of a keypad, a data display and indicators which provide feedback of all keys pressed. The front panel utilizes a Texas Instruments CRU interface which is a bit-serial type interface. The computer used in this system has been used at Lockheed on similar aircraft installations and has exhibited excellent reliability and performance.

Some precautions that were taken to ruggedize the system as much as possible included reinforcing points subject to vibration and using a silicon rubber potting compound to assure that all socketed chips remain in place. Requirements for ruggedizing the system were carefully considered, and no difficult problems were encountered.

The computer's power supply operates on 400 hertz A. C. power so no modifications were necessary to the power supply system. The only mofidication required to adapt to aircraft power was to change the cooling fans. The primary processor used in this system is the Texas Instruments 9900 microprocessor. The prototype system uses the Texas Instrument 990/4 processor board which uses the 9900 chips. Current development plans include designing a more compact processor board which is more suitable to a continuous flight environment. The 990/4 processor board contains 4096 16-bit words of semiconductor RAM memory. In the final version of the analysis software, this amount of RAM memory is quite excessive with the actual total requirements in the order of 512 words or less. Since the contents of this semiconductor RAM memory are destroyed upon loss of power, it is used only for working registers and variables which do not require retention during power losses. A standby memory is used for retention of calculated results and critical variables which cannot be lost during normal power losses.

The standby memory consists of 256 words of low-power CMOS RAM. The Intel 5101 RAM chip was used because it has a very low standby power mode, allowing its contents to be retained for very long periods of time with very little power being consumed.

The analysis programs are stored in an 8K EPROM board. The EPROM chips are quite suitable for this application since they do not lose their contents when powered down and can be easily altered as software modifications become necessary. Approximately 6,000 words of the 8,000 available are used for the entire program and all of its associated subroutines.

The system is a totally self-contained,multi-processor, monitoring and analysis system which, even in prototype form, is compact and lightweight enough for aircraft use. Further miniaturization will take place as the system is refined.

The system in its prototype configuration monitors a single area of the aircraft structure utilizing readings from a strain gage bridge which measures axial strains. A peak detector unit continuously samples the strain gage bridge and determines peak readings. These peak readings are then sent to the main processor which performs a real-time calculation of fatigue damage. The fatigue damage calculation assumes an initial damage figure of zero.

Interrogation of the system is accomplished through the use of a front panel keypad and data display. The operator uses the keypad to set up data requests with the system acknowledging all correct entries by indicating the commands entered. The system is interrogated only infrequently by the operator, therefore the panel normally appears to be inoperative.

The peak detector is a functionally independent unit within the overall system. It uses an Intel 8080 microprocessor to provide the necessary data acquisition and peak detection processing in software. Basically, the peak detector software monitors the digitized strain gage data. The data for the axial bridge is run through a peak detector routine which determines when a true peak load has occurred. A true peak load is a reversal of loading direction which exceeds a deadband tolerance, e.g., a load increasing in the tension direction which begins to decrease and then decreases by more than the deadband tolerance becomes a load peak. Once a peak has been detected, it is output along with the corresponding shear bridge reading to FIFO (first-in-first-out) register to provide an elastic data buffer. The peak detector operates totally asynchronously from the main processor and is free-running. During times of rapidly changing data, the peak detector can "outrun" the main processor temporarily, hence, the need for an elastic buffer to take up the slack as required. A hardware FIFO buffer was chosen here rather than software to reduce the amount of software overhead as much as possible. If the FIFO buffer should overflow, the main processor is notified and immediately takes action to reinitialize the peak detector and FIFO. Some data is lost in this case, but the chances of this happening have been determined to be quite remote. If the main processor is ever notified of an overflow, it "remembers" the occurrence and turns on an overflow indicator to notify the operator during routine interrogation.

The operation of the system is completely automatic, requiring no action by the pilot. It is programmed to properly initialize itself and begin running as soon as aircraft power is applied. Likewise, a power fail routine sees to it that the system is properly shut down on a loss of power. This assures proper system operation in the event of intermittent power failures, as, for example, when the aircraft is switched from ground power to aircraft power system, and during long-term power shutdown when the aircraft is not in use.

The only operation requiring operator action is the initialization and interrogation of the system. This is accomplished by a sequence of key-strokes which are used to set up the desired operation.

Each correct key pressed results in an indicator being lighted to provide positive feedback of the entry while incorrect key entries are ignored. Once the keyboard setup has been made, a security code (to prevent tampering) is entered and a key pressed to activate the system request. The main program then reads the keyboard setup and performs the requested action or displays the requested data. The action of interpreting the sequence of keypad entries and transmitting the desired command or data request to the system executive routine is performed by a parsing routine. This routine is called by an interrupt which is generated whenever key is pressed.

Improved Version - OBSC-2

A new version designated as OBSC-2 is being built and the experience with OBSC-1 is being used to improve this new model. The OBSC-2, Figure 22, should be completed in early 1980.

At the present development stage, the most important feature must be the confidence in the accuracy and completeness of the reported data. A redundance of strain gage input and the use of fault detection methods will be used to provide this measure of confidence in the system.

OBSC-2 will differ from OBSC-1 concept by a physical separation of the airborne device and a ground readout unit that will plug in for data transfer to ground based equipment.

The data to be provided by OBSC-2 is detailed below. OBSC-2 is slanted somewhat to obtaining the information needed to develop the final system rather than to be the final system itself.

This data will be available for each of four locations on the airframe, one each on the wing upper surface; wing lower surface; fuselage; and empennage. At each location will be physically mounted four strain gages providing three channels of data.

For Each of Up to 32 Flights

Take Off Time (Yr.) Month Day Hour Min. (Sec.)

Landing Time (Yr.) Month Day Hour Min. (Sec.)

Delta Damage

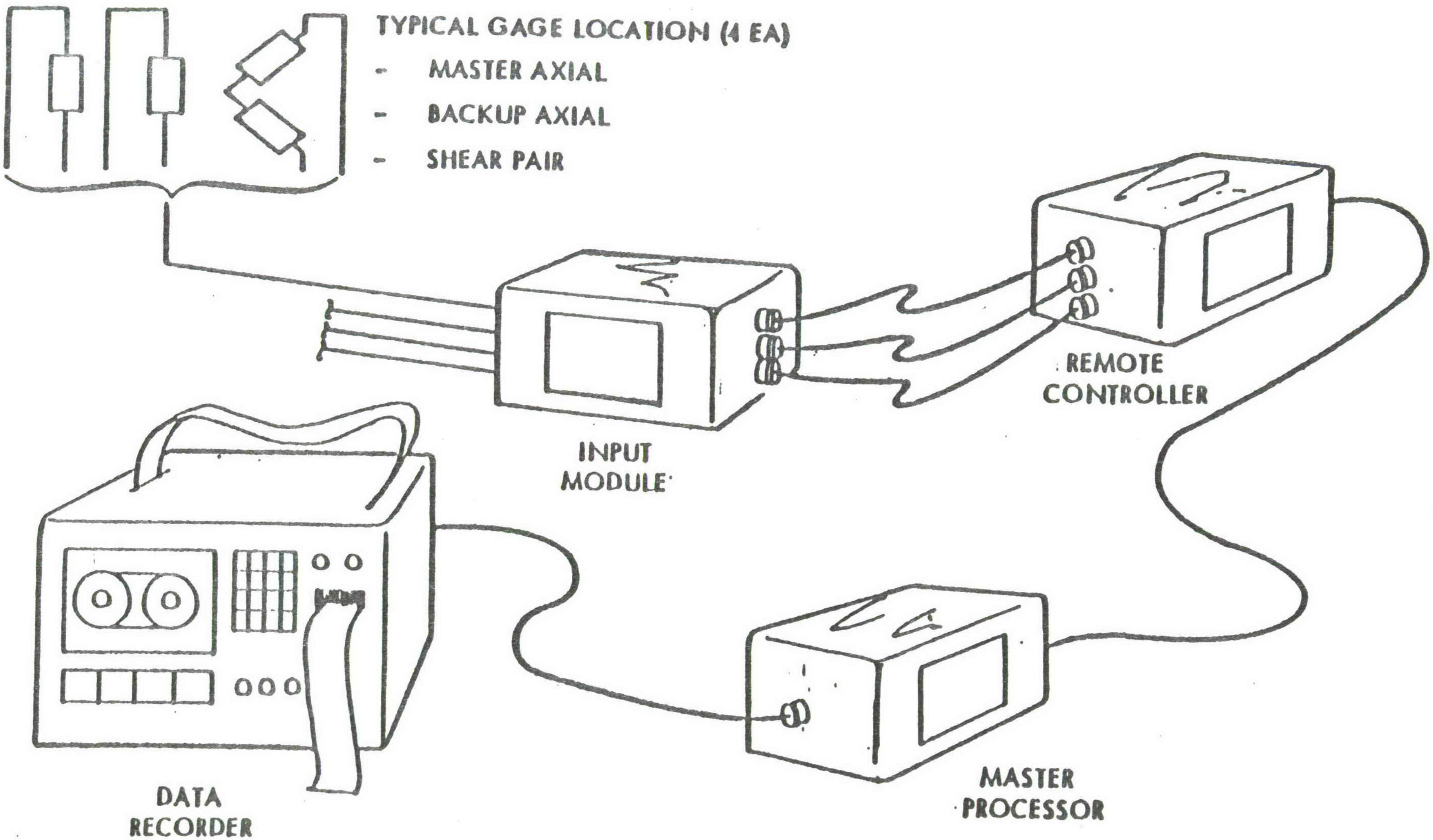



Figure 22. On-Board Structural Computer-II.

Delta Crack (Linear)
Delta Crack (Retarded)
Half Cycles
Touch-Go-Count

<u>For All Flight To Date</u>

Total Damage
Total Crack (Linear)
Total Crack (Retarded)
Total Flight Time
Total Half Cycles
Matrix of Max - Min Cum for One Location

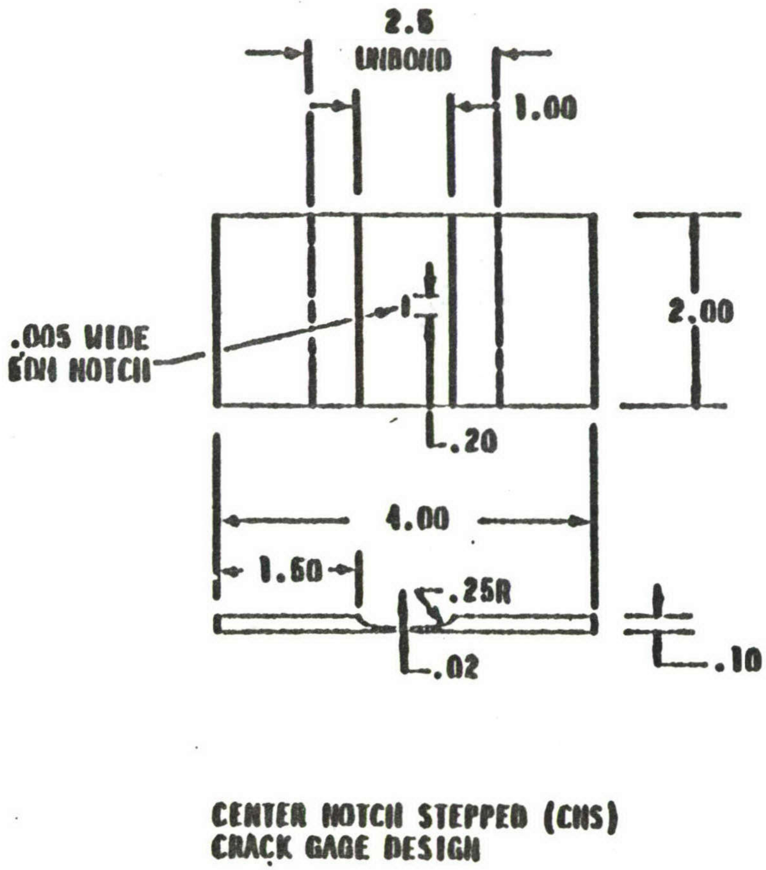
This paper has described a system which is considered to be a significant development in the area of instrumentation for structural durability analysis. This system is significant because it illustrates the emerging development of a powerful class of instrumentation devices which are capable of combining complex analysis techniques with instrumentation in a real-time environment.

## APPENDIX B

## CRACK GROWTH GAGE TRIAL INSTALLATION ON LOCKHEED-GEORGIA COMPANY FULL-SCALE C-141A WING/FUSELAGE DURABILITY TEST SPECIMEN "A"

Structural durability analyses based on present fracture mechanics techniques require accurate representations of both the magnitude and the sequence of applied loads. Existing (and currently planned) fracture-based IAT programs for Transport/Bomber aircraft utilize flight data records such as crew entry forms to quantify and consolidate each flight in terms of preset missions or mission segments. This consolidation process is required because a true "cycle-by-cycle" random load measurement and crack growth calculation system is not economically feasible at this time. The Crack Growth Gage (CGG) concept has been proposed as a relatively simple and inexpensive means of monitoring individual aircraft usage based on actual aircraft load histories and environments. This method involves the attachment of a small precracked coupon to aircraft primary structure at a designated location. Crack growth from assumed initial flaws in the aircraft can then be related to the gage crack growth through "transfer functions" derived from analysis and test. Much of the CGG developmental work to date has centered on the investigation of different gage designs and the establishment of aircraft/gage transfer functions for various spectrum types. The purpose of this program, however, is to study the more physical aspects of CGG installations on Transport/Bomber aircraft, such as attachment and measurement techniques. Durability, and susceptibility to corrosion. Thus, the gage configuration is assumed to be already specified, and analytical derivations of transfer functions are beyond the scope of this program.

The CGG trial installation program consists of attaching four gages to the inner wing of the C-141A Full-Scale Durability Test Article, located at Lockheed-Georgia. The gage design (Figure 23) was developed and fabricated by Boeing-Wichita as a part of another program (Reference 7) and supplied to Lockheed by AFFDL. The test article, designated Specimen 'A', is a structurally complete C-141A wing/fuselate configuration which is currently undergoing durability testing under contract to Warner Robins ALC. The gages are adhesively bonded to the inside surface




- GAGE SOURCE: BOEING-WICHITA
- 7075-T6 BARE SHEET
- 'HOT' AND 'COLD' BOND METHODS USED
- TEFLON TAPE USED TO DEFINE UNBONDED WIDTH
- GAGE INSTALLATIONS OVERCOATED WITH MIL-S-8802 SEALANT
- MICROSCOPE GLASS SLIDES USED TO COVER CRACK
- PHOTOGRAPHY USED TO MEASURE CRACK LENGTH

Figure 23. Crack Growth Gage Design.

of the integrally-stiffened machined wing panels between adjacent risers, as shown in Figure 24.

## Surface Preparation

The exposed surfaces of the crack gages were prepared for installation by cutting microscope glass slides to fit over the crack areas. The glass covers and the areas where the glass covers were to be bonded on the crack gages were cleaned with methyl ethyl ketone. These areas were coated with primer and a silicone rubber adhesive was used to bond the glass covers to the crack gages. Crack gages were prepared for bonding on Specimen A by cleaning the bonding surfaces as follows: (1) removing all finishes on the bond areas, (2) scrubbing the areas with scotch brite and alconox, (3) rinsing, acid etching, rinsing and allowing to air dry, and (4) coating with EC 3921 primer Teflon tape was used to define the unbonded areas under the notches. The areas on the wing surface for bonding on number one and three crack gages were prepared for bonding as follows: (1) stripping the existing polyurethane paint and sulfuric acid anodize coating from the areas by using number 120 aluminum oxide grit and a vacuum blast machine, (2) scrubbing the areas with scotch brite pads and alconox, (3) rinsing, acid etching, rinsing and allowing to air dry, and (4) coating with EC 3921 primer. The wing surface areas for gages two and four were prepared per the above procedures, except that the bonding areas of the wing surfaces were stripped of the existing polyurethane paint finish by lightly grit-blasting the surfaces until the polyurethane coating was removed, and the EC 3921 primer was removed from the bonding areas on the wing surface and the crack gages. (The anodize coating was not removed from the wing surface for installation of gages two and four.)

## Crack Growth Gage Installation

The gages were bonded to the surfaces of the Specimen 'A' wing as follows: Gage Numbers 1 and 3 (Hot Bond) - AF 127-3 adhesive tape (.010" thick w/scrim) was applied to the bonding surfaces. A heat blanket and vacuum bag were than installed and the adhesive

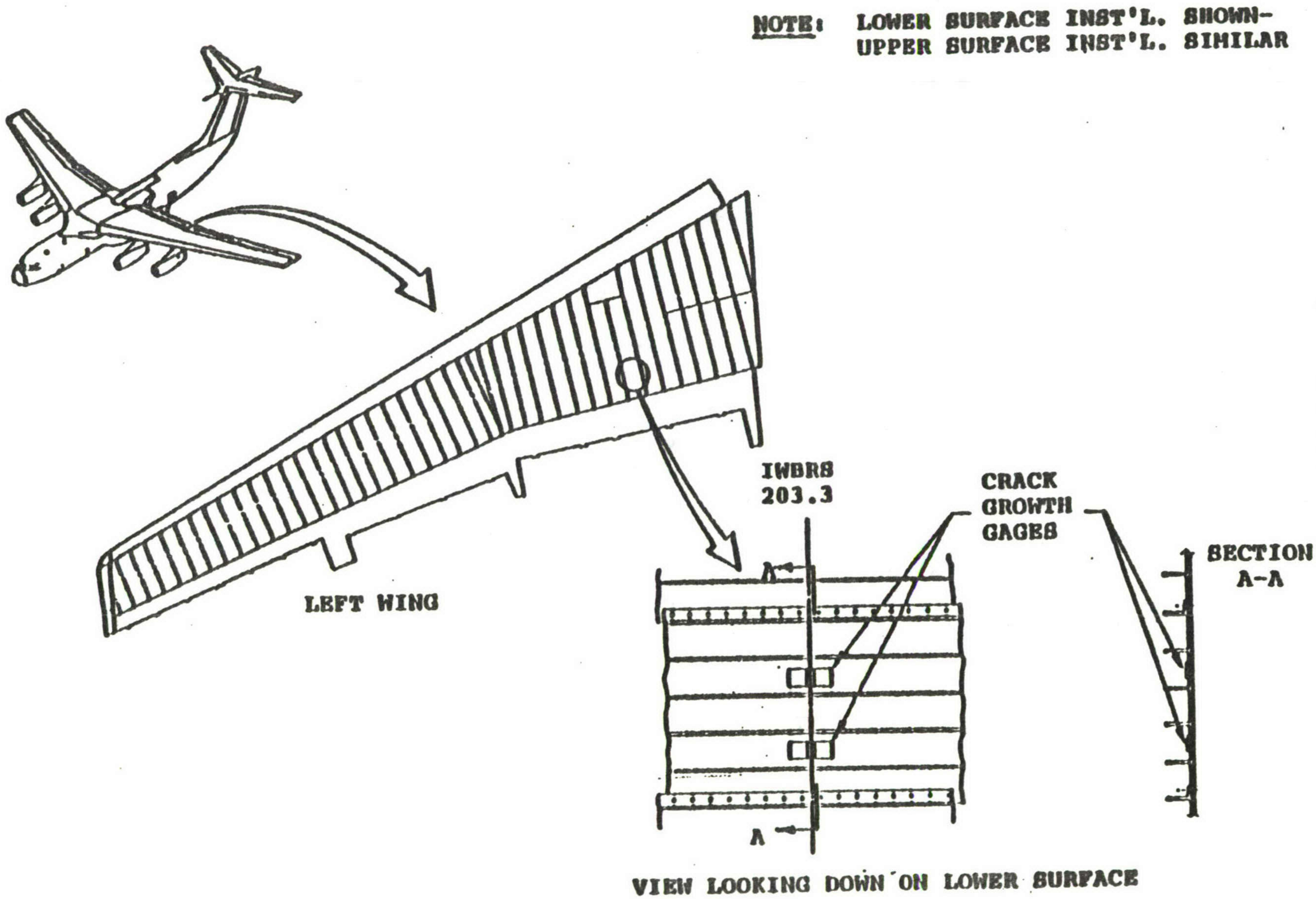



Figure 24. Crack Growth Gage Trial Installation.

was cured for two hours at 225°F and 5 psig vacuum pressure. A metal plate was placed over each cover glass and a relatively low bondline pressure was utilized in order to avoid breaking the glass during the bond cycle.

Gage Numbers 2 and 4 (Cold Bond) - A two-part room temperature curing epoxy adhesive (EA 9309.1) was mixed and applied to the mating surfaces. During this process, several strands of fiberglass cloth were placed in the adhesive layer to maintain a uniform bond thickness. Vacuum pressure (5 psig) was applied during the entire 24-hour cure time. A corrosion-inhibitive sealant (MIL-S-8802) was applied to the exposed surfaces of all four gages, except for approximately one square inch of glass area over the cracks.

Measurement of Crack Length

Precision 35 mm macrophotographs at a magnification of 3.2 were made of the gage cracks prior to installation on Specimen 'A'. Following the application of 3000 cyclic test hours (CTH) of C-141A flight-by-flight spectrum testing (80,000 total cycles representing 819 flights) the gages were again photographed at various magnifications and the crack growths measured. Table 14 summarizes the measured crack growth to date.

TABLE 14: CGG CRACK LENGTH

| GAGE NO. | WING SURFACE | BOND TYPE | INITIAL LENGTH, IN | LENGTH AT 3000 CTH, IN | NET GROWTH, IN |
|---|---|---|---|---|---|
| 1 | UPPER | HOT | .201 | .201 | NONE |
| 2 | UPPER | COLD | .200 | .375 | .175 |
| 3 | LOWER | HOT | .200 | .200 | NONE |
| 4 | LOWER | COLD | .202 | .490 | .288 |

## Preliminary Findings

As shown in Table 14, the gages attached with the cold bond method (2 and 4) exhibited a nominal amount of crack growth, while the hot bond gages (1 and 3) did not propagate. Although the specific cause of this difference in crack growth is not yet known, the following factors may have contributed to the discrepancy:

1) Possible disbond of gages 1 and 3
2) Improper cure cycle, resulting in bondlines which are too thick to properly transfer load.
3) Possible precracking of gages 2 and 4 (in addition to notches) prior to testing.

At this time, it is impossible to determine whether any of these conditions are present on the Specimen 'A' CGG installations. The gages will remain attached for an additional 3000 cyclic test hours; they will then be removed and evaluated further in order to resolve the apparent difference in growth rates between the hot and cold bonding techniques.

## Final Findings

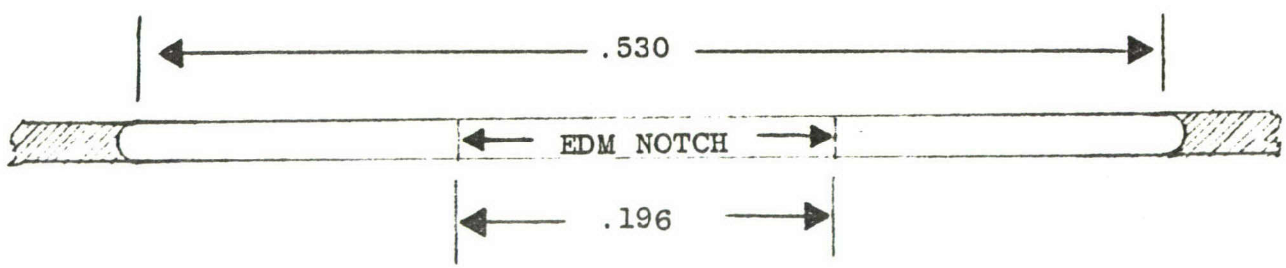
Following an additional 3,000 Cyclic Test Hours (CTH) of testing, the crack growth gages were removed from Specimen "A". The bond lines were examined and the gages were broken open to determine crack lengths at the surface and crack face characteristics using a scanning electron microscope (SEM). Results are shown in Table 15.

No fractographic evidence was seen on any of the specimens which would explain the differences in growth rates between them. Gage 1 was found to have 30 - 50% of the bond surface which did not bond. Gage 3 had 5-10% of the surface which did not bond. The lack of bonding in these hot bonded gages was attributed to air being trapped in the bondlines due to the low vacuum used to apply bondline pressure. Low bondline pressures were used to avoid breaking the observation glass covers over the gages. The bond thickness of all gages was considered normal.

TABLE 15: CGG TRIAL INSTALLATION RESULTS

| GAGE NO. | WING SURFACE | BOND TYPE/ % BOND | INITIAL LENGTH, PHOTO MEASURE | INITIAL LENGTH, MICRO-SCOPE MEASURE | LENGTH AT 3000 CTH, IN PHOTO MEASURE | LENGTH AT 6000 CTH, IN MICROSCOPE MEASURE |
|---|---|---|---|---|---|---|
| 1 | UPPER | HOT/50-70% | .201 | .196 | .201 | .196 |
| 2 | UPPER | COLD/100% | .200 | .196 | .375 | .530 |
| 3 | LOWER | HOT/90-95% | .200 | .199 | .200 | .264 |
| 4 | LOWER | COLD/100% | .202 | .198 | .490 | .561 |

TYPICAL CROSS SECTION (GAGE 2)



APPENDIX C

DESCRIPTION OF C-141A (BASELINE)
MXU-553A MULTICHANNEL RECORDER PROGRAM AND REVIEW

## C.1.0 INTRODUCTION

The current C-141A Life History Recording Program (LHRP) is a multi-channel recording program which is installed on twenty seven aircraft of the C-141A Force. These multi-channel recorders were installed in the C-141A aircraft during 1973-74 as part of the Air Force's Aircraft Structural Integrity Program (ASIP) for the purpose of recording and subsequent analyzing and reporting of operational data from the C-141A Force.

The computer software for analyzing the C-141A LHRP data was developed by Lockheed-Georgia. A review of this program and recommendations for an update to increase the yield and cost-effectiveness has been completed, and is now being considered by Warner Robins ALC for implementation.

This Appendix describes the basic system and the results of those analyses and evaluations. The data are presented in considerable detail to give the reader perspective regarding the true complexity of the L/ESS programs software and the data to be assimilated. This description is taken from a report submitted under a contract to WR/ALC. Consideration of these findings for possible implementation in the C-141A LHRP is in process.

## C.2.0 BACKGROUND

The C-141A LHRP recording system was installed on twenty seven aircraft during 1974 at Warner Robins AFB. A list of their serial numbers, their MAC A-38 flight hours, and base of assignment as of July 1979, is shown in Table 16. The instrumentation consisted of a MXU-553/A recorder, an ECU-67/A Converter/Multiplexer, and some 20 sensors at various locations of the aircraft. In addition, seven pieces of information are logged in by the flight crew on thumb wheels on the recorder.

The logistical system for recording and processing the C-141A LHRP data is shown in Figure 25. The data is recorded on tape cassettes which have a 15 hour recording capacity. When the tape cassettes are recorded to capacity, they are removed and mailed to Oklahoma City ALC for processing. At Oklahoma City ALC the tape cassette data is recorded onto an IBM 360 compatible digital tape by a ground playback unit called the Reformatter/Transcriber. The reformatted data is processed by two IBM 360 computer programs to yield usage by data blocks, load factor peak counts by data block, and fatigue damage by data block data. The program has the capability to reformat the flight-by-flight time history tapes and compress them in order to save storage space when stored for possible future use.

The computer software for the C-141A LHRP was developed by Lockheed-Georgia Company under Air Force Contract.

All of the recording equipment and instrumentation was Air Force procured and installed. Specifications of the recording equipment and computer software output as well as sample checkout data were given to Lockheed-Georgia by the Air Force.

The development of the C-141A LHRP software was to be based on 500 hours of recorded data which would be available for checking out the computer software before delivery to the Air Force. However, because of equipment delivery problems, it was not possible for the Air Force to provide this amount of data. Also, the sample data received by Lockheed was of very poor quality because of

TABLE 16

C-141A LHRP AIRCRAFT

| SERIAL NUMBER | FLIGHT HOURS* | BASE ASSIGNMENT* |
|---|---|---|
| 63-8075 | 27,854 | Travis |
| 63-8078 | 26,051 | Charleston |
| 63-8081 | 18,119 | McChord |
| 63-8087 | 20,333 | Norton |
| 64-0617 | 17,928 | Norton |
| 64-0619 | 19,095 | Norton |
| 64-0636 | 21,784 | Norton |
| 64-0638 | 19,989 | McGuire |
| 64-0649 | 20,303 | Charleston |
| 64-0650 | 21,307 | McGuire |
| 65-0217 | 22,581 | Charleston |
| 65-0218 | 21,547 | Charleston |
| 65-0220 | 21,599 | Charleston |
| 65-0223 | 20,657 | McGuire |
| 65-0232 | 22,701 | McChord |
| 65-0233 | 22,409 | Travis |
| 65-0237 | 22,548 | McChord |
| 65-0238 | 21,498 | Travis |
| 65-0242 | 22,293 | Travis |
| 66-0126 | 21,159 | McGuire |
| 66-0155 | 18,333 | McGuire |
| 66-0167 | 19,538 | Charleston |
| 67-0018 | 15,821 | McChord |
| 67-0022 | 15,536 | Altus |
| 67-0023 | 16,659 | McChord |
| 67-0029 | 16,942 | Norton |
| 67-0030 | 16,535 | Travis |

*As of 23 July 1979. Based on Lockheed Georgia Field Service Records.

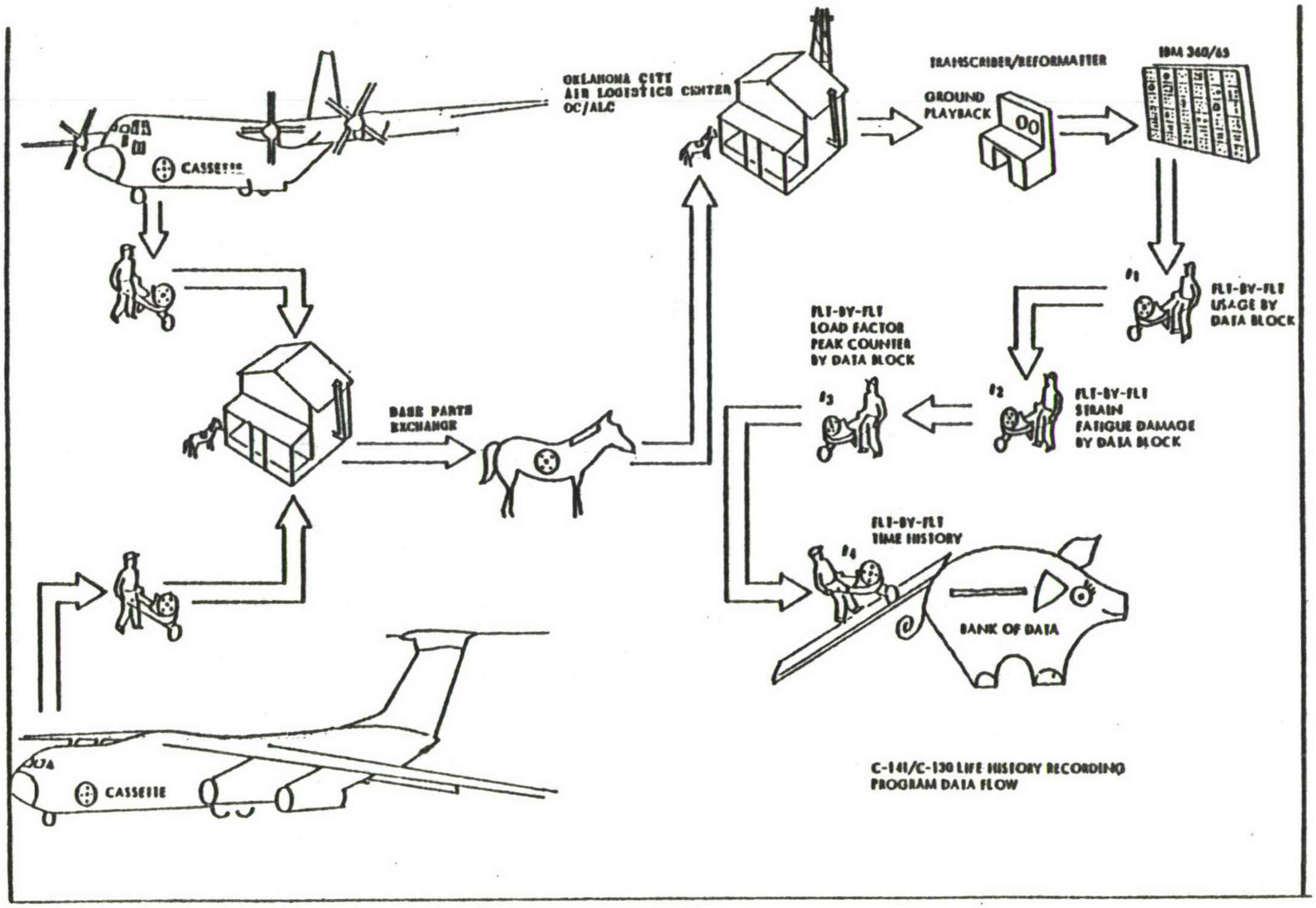



Figure 25. Logistics for C-130/C-141 Life History Recording Program.

equipment/instrumentation problems. Consequently, after delivery of the C-141A LHRP software to Oklahoma City ALC two things became evident. First, even though the computer software was checked out on the data available with no malfunctions, additional data which was processed through the programs by Oklahoma City ALC showed program "bugs". The C-141A LHRP software was designed to reduce and analyze data and print several reports for a number of aircraft flying fifteen different types of missions. In order to have these capabilities, there was necessarily a voluminous and complex set of subroutines. In order to adequately check out the decision logic in these programs, a large amount of data needed to be exercised so as to test all the logic branches within the programs.

Additionally, a new methodology of separating gust and maneuver load factor time histories was introduced within the software. Previously, the separation of gust and maneuver load factor data was based primarily upon a time related rule that basically stated that if the c.g. load factor deviates from the mean value for a period of longer than 2.0 seconds, then it was identified as a maneuver load factor peak. Any peak occurring in an excursion less than 2.0 seconds was attributed to gusts. Recognizing the fact that gusts and maneuvers are not exclusive events, but rather often occur simultaneously, a refinement of this method was introduced. The C-141A LHRP software provided for the frequency spectral analysis of the c.g. load factor data so that a low pass cutoff frequency of approximately 1/4 cps could be applied in order to separate the maneuver time history from the gust time history. The impact of this change in methodology and its application toward assessing gust and maneuver criteria on future fatigue and durability analyses on C-141A force was never established.

It also was apparent that more data quality assessment and/or data edit capability was needed for the C-141 LHRP than existed. It was proposed that this assessment and edit capability take on two forms. The first form is logic within the C-141A LHRP software. There are several data checks built in the original computer software, but these were generally passive in nature and were oriented towards data activity rather than data quality. Very little automatic data edit capability (that is, detect an error and correct it, if possible) was provided within the program. The second form of data assessment was accomplished by personnel at OC/ALC by examining sample output data from the programs on a flight by flight basis. Depending upon the type errors found, the technicians at OC/ALC used a program named SHUPDATE to correct or modify the data so that it would execute through the Data Reduction Program.

In order to update the computer software and to evaluate the total system performance and applicability to the objectives of the C-141A ASIP, Lockheed-Georgia entered into contract with Warner Robins ALC and the results are reported herein. The objectives of this contractual study are summarized as follows:

1. Exercise up to 300 flight hours of C-141A LHRP data in the existing software in order to identify and correct programming deficiencies and also to evaluate and/or analyze the program logic and criteria.

2. Specifically analyze the gust and maneuver load factor separation methodology logic. This was to include a comparison with the separation methods used in previous C-141A VGH programs.

3. Analyze recorded strain data to determine its accuracy and usability.

4. Make recommendations for any additional improvements in the C-141A LHRP system in order to support the C-141A Individual Aircraft Service Life Monitoring Program and to provide necessary data for future service life analyses.

## C3.0 C-141A LHRP DATA SYSTEM DESCRIPTION

This section is included for the purpose of providing a convenient source of somewhat detailed information about the C-141A LHRP system.

The C-141A LHRP data system consists of a recorder, converter/multiplexer, and some 20 sensors at various locations on the aircraft. A list of these sensors is found in Table 17. The location of these sensors is shown in Figure 26. The multiplexer scales the analog signal from the sensors so that an eight bit binary word may be written on the magnetic tape to represent the data value. This eight bit word may vary between the decimal values of 0 and 255 (or $2^8$-1). The nominal instrument calibration data which converts these decimal values to engineering units are shown in Table 18.

### C3.1 MXU-553/A RECORDER

The MXU-553/A signal recorder is a standard Air Force equipment item which is used on several other aircraft multichannel recorder programs. These include the C-130, KC/C-135, B-52, as well as many others. It is manufactured by Conrac. The general specifications of the MXU-553/A recorder are shown in Table 19. The signal recorder is a specially designated digital magnetic tape recorder that records all of the sampled data on a removable tape cartridge. The cartridge contains sufficient tape to record 15 hours of data in a nine track 1000 bit per inch format. Since one track is used for parity checks, this enables the recorder to record digits from 0 to 255.

Output data from the sensors, in a multiplexed serial binary format, are received from the Converter/Multiplexer mixed with the documentary data and converted to the parallel eight bit binary channels recorded on tape. The documentary data is entered manually through the use of 24 thumbwheel switches. Incorporated in the signal recorder are self test features and an automatic calibration sequence which checks the recorder and converter/multiplexer by applying known voltages at the analog input of each channel.

TABLE 17

C-141 LHRP MEASURED PARAMETERS

| PARAMETER | SAMPLES/ SEC. | FILTER | NAME | RANGE | UNITS |
|---|---|---|---|---|---|
| PITOT STATIC PRESSURE | 1 | - | PS | 31.02 to 3.42 | In. Hg. |
| PITOT TOTAL PRESSURE | 1 | - | PT | 0 to 13.78 | In. Hg. |
| GROUND SPEED | 2 | - | VG | 0 to 103 | Knots |
| NORMAL ACCELERATION | 30 | 6HZ | NZ | -1 to +4 | g's |
| CABIN PRESSURE | 1 | - | DELP | 0 to 9.77 | P.S.I. |
| PITCH RATE | 20 | 4 HZ | PITCH | -30 to +30 | DEG/SEC |
| YAW RATE | 20 | 4 HZ | YAW | -30 to +30 | DEG/SEC |
| RUDDER POSITION | 10 | 2 HZ | DELR | 72R to 72L | DEG |
| ELEVATOR POSITION | 10 | 2 HZ | DELE | 41 up to 42 Dn | DEG |
| FLAP POSITION | 5 | 1 HZ | DELF | 16 Up to 106 Dn | PERCENT |
| NOSE GEAR ANGLE | 5 | 1 HZ | DELNG | 94 R to 93L | DEG |
| LATERAL ACCELERATION | 30 | 6 HZ | NY | -2 to +2 | g's |
| WING JOINT STRAIN | 20 | 4 HZ | STR 2 | -2147 to +1743 | $\mu$ in./in. |
| C. W.S. 53.2 STRAIN | 20 | 4 HZ | STR 3 | -1945 to +1945 | $\mu$ in./in. |
| MLG BOGIE BEAM STRAIN | 20 | 4 HZ | STR 4 | 0 to +3862 | $\mu$ in./in. |
| F.S. 1108 STRINGER STRAIN | 20 | 4 HZ | STR 5 | 0 to +1945 | $\mu$ in./in. |
| NLG BULKHEAD STRAIN | 10 | 2 HZ | STR 6 | -307 to +3583 | $\mu$ in./in. |
| LANDING GEAR | 1 | - | E1 | Up or Down | - |
| LANDING GEAR STRUT | 1 | - | E2 | Ext. or Compr. | - |
| SPOILERS | 1 | - | E3 | Up or Down | - |

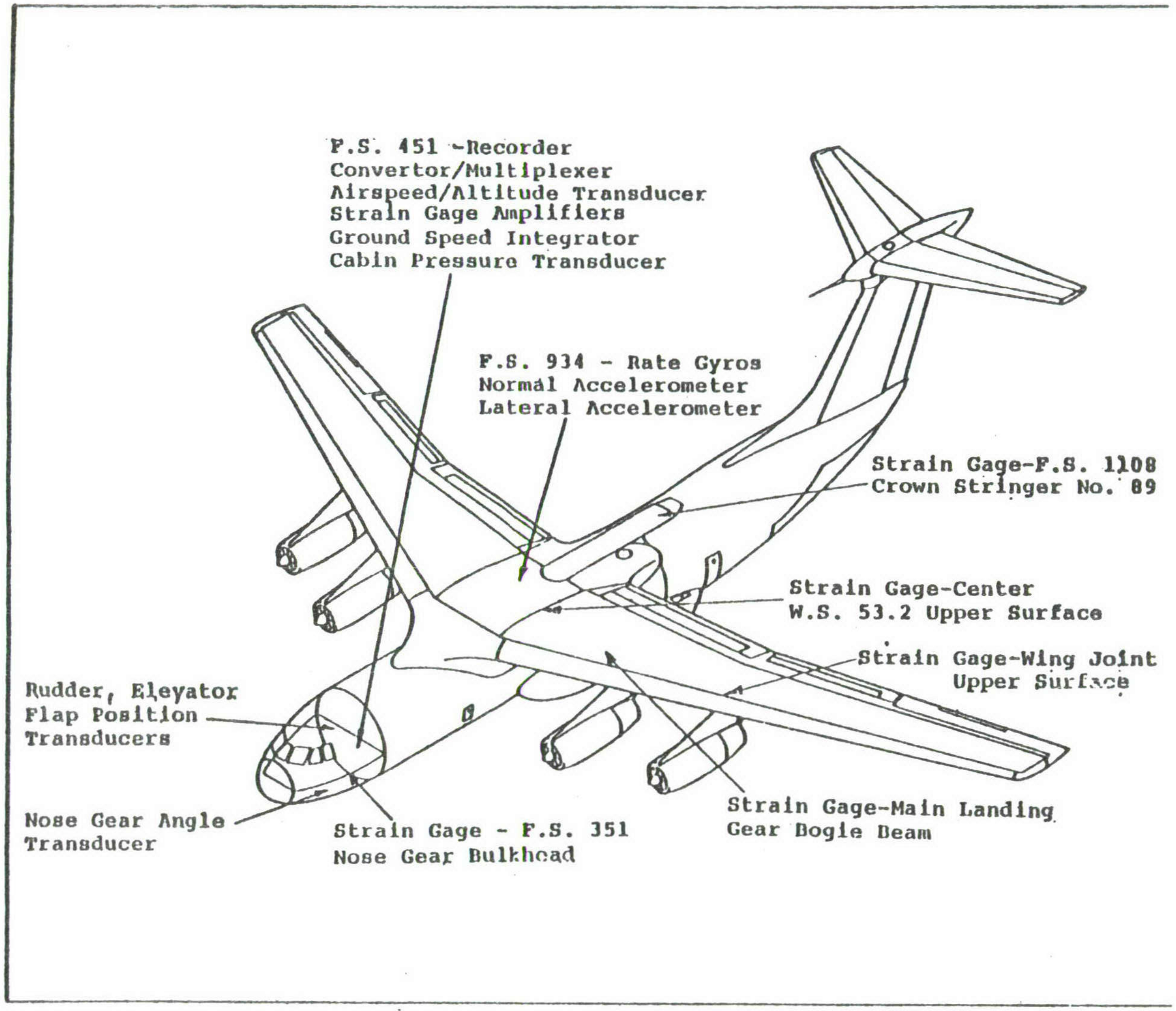



Figure 26. C-141 LHRP Recorder System Installation.

TABLE 18

NOMINAL INSTRUMENT CALIBRATION DATA

| PARAMETER | OFFSET A | SLOPE B | ENGINEERING UNITS |
|---|---|---|---|
| PS | 31.0 | -0.10781 | In. Hg |
| PT | 0.0 | 0.05381 | In. Hg |
| VG | 0.0 | 0.40234 | Knots |
| NZ | -1.0 | 0.01953 | g's |
| DELP | 0.0 | 0.03816 | PSI |
| PITCH | -30.0 | 0.23437 | Deg/Sec |
| YAW | -30.0 | 0.23437 | Deg/Sec |
| DELR | -72.1 | 0.56124 | Deg. |
| DELE | 41.5 | -0.32447 | Deg. |
| DELF | -16.3 | 0.47705 | Percent |
| DELNG | -93.9 | 0.73158 | Deg. |
| NY | -2.0 | 0.01562 | g's |
| STR2 | -2147.2 | 15.19509 | $\mu$ in/in |
| STR3 | -1945.0 | 15.19509 | $\mu$ in/in |
| STR4 | 0.0 | 15.08758 | $\mu$ in/in |
| STR5 | 0.0 | 7.59755 | $\mu$ in/in |
| STR6 | -306.5 | 15.19509 | $\mu$ in/in |

ENG. UNITS = A + Bx (INTEGER COUNTS)

TABLE 19

GENERAL SPECIFICATIONS OF THE MXU-553/A RECORDER

| | |
|---|---|
| Volume | 10" W x 10" D x 8" H maximum |
| Weight | 25 pounds including cartridge & accessories |
| Record Time | 15 hours minimum |
| Cartridge (Size) | 8-1/4" W x 8-19/32" D x 1-7/32" H |
| Cartridge (Weight) | 3.75 pounds |
| Tape Length | 12000 feet, 1/2 inch magnetic tape |
| Number of Tracks | 9 tracks utilizing 1 record head |
| Record Method | Multi-rack serial biphase encoded, 8 data bits plus parity/character |
| Power | 115 Volts 400 Hz 100 watts maximum<br>28 VDC 20 watts maximum |
| Documentary Encoder | 24 independent data inputs utilizing thumbwheel switches |
| Density | 1000 characters/inch (9 bits/character) |
| BIT | Isolate failure to Converter/Multiplexer, Recorder or Documentary Data Encoder |

## C3.2 ECU-67/A CONVERTER/MULTIPLEXER

The ECU-67/A converter/multiplexer is also a standard Air Force equipment item which is used in conjunction with the MXU-553/A recorder on several LHRP systems. The function of the converter/multiplexer is to interface between the sensors and the recorder in order to scale and filter the analog signal, digitize the analog signal to an eight bit binary value, and to multiplex the data in a pre-determined 240 word per second serial output. The converter/multiplexer also supplies the reference voltage for the surface position indicator and the strain gages. The general specifications for the ECU-67/A converter/multiplexer are shown in Table 20.

## C3.3 A/A24J-16 AIRSPEED TRANSDUCER

Static and total head pressures from the co-pilot's pitot system are measured by the airspeed/altitude transducer. The transducer has a maximum range of 31.019 inches Hg (mercury) to 0.810 inches Hg on static pressure corresponding to -1.000 feet to 80,000 feet in altitude. The range of total head pressure is 42.938 inches Hg corresponding to 800 knots calibrated airspeed. These values are re-scaled by the converter/multiplexer to a maximum value of 3.425 inches Hg static pressure and 13.775 inches Hg total head pressure corresponding to 50,000 feet altitude and 500 knots calibrated airspeed respectively. The basic instrument accuracy is ±1% of full scale or ±0.302 inches Hg static pressure and ±0.429 inches Hg total head pressure. Actual airspeed and altitude accuracy vary because of the non-linear relationships to pressure. Recorded airspeed accuracy varies from ±50 knots at 100 knots to ±10 knots at 400 knots. Recorded altitude accuracy varies from ±50 feet at sea level to ±1100 feet at 40,000 feet. All altitudes referred to above are for the standard ICAO atmosphere. Airspeed and altitude calculations in the computer programs are based upon the standard ICAO equations.

TABLE 20

GENERAL SPECIFICATIONS OF THE
ECU-67/A CONVERTER MULTIPLEXER

| | |
|---|---|
| Volume | 6" W x 8" D x 5-7/8" H |
| Weight | 7.5 pounds maximum |
| Sampling Rate | 1-30 samples maximum per parameter, 240 samples per second total |
| Number of parameters | 26 parameters maximum |
| Analog Inputs | DC, AC, strain gage potentiometric |
| Discrete Inputs | 28 VDC |
| Active Filters | 0 to 1, 2, 3, 4, 6, 8 Hz band-pass |
| Accuracy | ±0.8% F.S. over environmental range |
| Resolution | 8 bits binary |
| Power | Supplied by Signal Data Recorder |
| BIT | Automatic and manual pushbutton |

## C3.4 TRU-106/A NORMAL ACCELEROMETER

The normal (NZ) accelerometer is mounted on the aircraft centerline at the nominal center of gravity (F.S. 934) and is attached to the lower surface of the center wing structure. The accelerometer has a range of -1g to +4g and a nominal accuracy of ±1% of full scale or ±.05g. The normal acceleration is peak counted as a total data value and also is separated into its gust and maneuver portion and peak counted. A detailed study of this separation method is discussed in Section C5.4, C5.5 and C6.0.

## C3.5 SBU-13A RATE GYROSCOPE ASSEMBLY

The rate gyroscope assembly contains roll, pitch and yaw rate gyros in a single package. Only the pitch and yaw rate gyros are connected on the C-141A. This unit is also mounted on the aircraft centerline at F.S. 934. The maximum instrument range for both the pitch and yaw axes is ±50 degrees/second which is re-scaled to ±30 degrees/second. At the present, the pitch and yaw rates are not used in the C-141A data processing. These channels are checked for the amount of activity on each and provisions are made to compress the data and save it on tape for later use.

## C3.6 TRU-107/A LATERAL ACCELEROMETER

The lateral accelerometer is mounted along with the normal accelerometer and rate gyroscopes at F.S. 934 on the center wing lower surface at the aircraft centerline. Range of measurement is ±2g's with an accuracy of ±1% or ±.04g. Due to the mounting location of the accelerometer being approximately 30 inches above the aircraft nominal center of gravity location, any roll acceleration will be detected by the lateral accelerometer as lateral acceleration. This would amount to approximately .0014g's/degree/(second)$^2$. The lateral accelerometer data is processed identically as the vertical accelerometer data. The lateral acceleration is peak counted as a total data value and also is separated onto its gust and maneuver portions and peak counted.

## C3.7 STRAIN GAGES AND AMPLIFIERS

The general location of five strain gages is shown in Figure 26, Strain Damage Calculation. Each installation consists of a single active gage wired in a two-arm bridge configuration with a nearby "dummy gage for temperature compensation. The strain gage installed on the main landing gear bogie beam is compensated for steel and has a gage factor of 2.120. The remaining four gages are temperature compensated for aluminum and have a gage factor of 2.105.

The strain gage data is peak counted by data block and converted to stresses by the calibration constants found in Table 18. The peak counted stresses are then used to calculate fatigue damage for each gage location.

## C3.8 POSITION TRANSDUCERS

The positions of the rudder, flaps, elevator and nose wheel are indicated by cable position transducers which are powered by the reference voltage from the converter/multiplexer.

A cable position transducer with a maximum travel of 15 inches is connected to the left side input cable to the nose gear steering assembly at F. S. 302.5. The maximum input cable travel is $\pm 4.8$ inches for maximum nose gear angle of $\pm 60$ degrees. An instrument accuracy of $\pm 0.1\%$ of full scale or $\pm 0.09$ inches cable travel in conjunction with the reference voltage accuracy results in steering angle accuracy of $\pm 1.1$ degrees. Cable position transducers are also connected to the elevator, rudder and flap control cables in the vertical cable in the vertical cable run at F. S. 442 immediately behind the flight deck. A fifteen inch travel transducer is used on the elevator control cable where total cable travel is 7.2 inches for elevator travel from full up (25 degrees) to full down (15 degrees). Instrument and reference voltage accuracy of 0.6% result in a recorded signal occurrence of $\pm 0.5$ degrees. Although the autopilot input does result in input cable motion at the flight deck which will be detected by the cable position transducer.

The rudder input cable which travels ±2.4 inches for full rudder of ±35 degrees, utilizes a ten inch travel cable position transducer. Signal accuracy is ±0.9 degrees. The rudder control system differs from the elevator system in that the auto-pilot as well as yaw damper signals are input directly to the rudder power package and will not result in input cable motion. As much as 17 degrees of rudder may be input through these systems which will not be detected or recorded.

The flap cable position transducer has a maximum travel of five inches. The flap system cable travel is 3.8 inches for 100 percent flaps and the signal accuracy is ±0.8 percent flaps. Of the above data channels, only the flap position is used in the reduction of the LHRP data. The flap data is used to differentiate between those flight Ground-Air-Ground data blocks which have the flaps deployed and those which do not. The activity on the rudder, elevator, and nose wheel steering is examined and a channel status based on the amount of activity is printed. The data is also compressed and output on tape for later use if desired.

### C3.9 CABIN PRESSURE TRANSDUCER

A differential pressure transducer with one side connected to the co-pilots pitot static pressure port and the other side vented to the flight deck is used to measure cabin differential pressure. The transducer is a four arm bridge type with excitation supplied by the reference voltage from the converter/multiplexer and signal amplification provided by an amplifier identical to those used with the strain gages. With a transducer accuracy of ±0.3% of full scale (10 P.S.I), an amplifier accuracy of ±1%, and a reference voltage accuracy of ±0.5%, the signal accuracy is ±2.1% or ±0.1 P.S.I. based on a full scale recorded value of 5 P.S.I.

At the present time, the data from the cabin pressure transducer is not used by the C-141A LHRP. The channel is checked for the amount of activity and the data are compressed for output onto tape for later use if desired.

## C3.10 EVENT INDICATORS

Three of the nine available event channels in the recorder system are used. Event No. 1 is connected to the common of the main landing gear up and locked relay such that voltage applied to the Event No. 1 input is gear down. This results in a binary one in bit one of words 64 and 304 (Event 1-4). Event two is connected to touchdown relay No. 9 resulting ain a binary one in bit two of words 64 and 304 for strut extended or liftoff. Event three is connected to the spoilers unlocked indicator such that spoilers retracted results in a binary one in bit three of words 64 and 304.

The event data are used extensively by the data reduction program and are considered to be critical data items. They are used primarily by the "EVENT" subroutine which determines which part of the flight profile the aircraft is flying in order to properly data block the information.

## C3.11 GROUND SPEED TRANSDUCER

The output of the main landing gear anti-skid transmitter, which is a twelve pole generator, is a pulse signal with six pulses per tire revolution. A pulse rate integrator is utilized to convert these pulses to a signal proportional to ground speed. Using an effective tire rolling radius of 20 inches, the maximum reading capability is 103 knots. Variations in tire rolling radius due to loading conditions, wear, and taxi speed will change the rolling radius approximately $\pm$1.0 inches. The pulse rate integrator accuracy is $\pm$5.2% or $\pm$5 knots.

The ground speed channel is also considered to be a critical data channel. The ground speed channel is used to determine a landing event instead of using the event word number two. The reason for this is the delay which occurs between wheel/ground contact and the touch down relay channel. Also, there are times during touch-and-go landings when the touch down relay channel is not activated at all during the ground roll.

A shortcoming of the wheel speed channel on the C-141A LHRP is that the calibration of the channel is such that the maximum ground speed which can be measured is 103 knots. This value is frequently below the ground liftoff speed so that neither the lift off time nor speed can be accurately determined.

## C3.12 DATA RECORD FORMAT

The flight record on the tape cartridge is an eight bit binary format recorded on nine tracks at a density of 1000 bits per inch (BPI). The ninth track records a parity bit that is added by the Converter/Multiplexer.

In transcribing a flight record from cartridge to computer compatible tape, the Reformatter/Transcriber performs the following:

1. Reads the data in two second frames, checks for parity error, short frames and adds seven diagnostic words at the end of the frame;
2. Groups the data in either 10 second logical records for nine track tape or twenty second logical records for seven track tape,
3. Writes the logical records spaced with three-quarter inch gaps between at 800 BPI on the nine track tape with a parity bit added, and adds a header record at the beginning of the tape.

## C4.0 SUMMARY OF DATA TAPES USED IN UPDATE

Of 2200 flight hours recorded on 206 tapes of C-141A data from the third quarter of 1977, 26 tapes were selected to provide 300 flight hours for processing. These tapes had moderate $N_Z$ activity and valid data on critical channels. However, several of these tapes would not process. Additional candidate tapes from the first quarter of 1978 were obtained. These tapes were screened as before but greater emphasis was placed on eliminating candidates with discrepancies that would halt the program and require editing. An overall total of 36 tapes were selected for the evaluations.

Table 21 lists these 36 tapes with their individual flight times. The total flight time processed was approximately 315 hours. The one-per-second time histories from eighteen of the tapes were analyzed to illustrate the condition of the data channels from those aircraft recordings. A typical summary of these data is shown in Table 22.

The tapes processed in this program were from only nine of the twenty seven LHRP aircraft. This group should have been expanded but, in general many of the LHRP aircraft were producing tapes that were either not usable or would require a significant amount of editing and updating prior to use.

## C5.0 DATA REDUCTION PROGRAM CHECKOUT

The DATA REDUCTION PROGRAM (DRP) is the first of the two programs which operate on the C-141 LHRP data. Its main functions are to read the flight-by-flight history tapes, data block the flight profiles, separate the gust and maneuver load factors, peak count the appropriate channels, and finally output a tape of these results. It is the most complex of the two programs, and as a consequence, most of the effort was involved in testing and checking this program. A functional flow diagram of this program is shown in Figure 27.

## C5.1 EVENT SUBROUTINE

Changes have been recommended to update the event routine, as described below.

### C5.1.1 Contour Flying

The altitude parameter available with the LHRP system is pressure altitude, whereas altitude above ground level is required to identify contour flying. Therefore, the contour flying logic in the program should be eliminated.

TABLE 21

C-141A LHRP USAGE TAPES

| DATA TAPE | QTR. | NO. OF FLIGHTS | FLT.1 | FLT.2 | FLT.3 | FLT.4 | FLT.5 | FLT.6 | INCREMENTAL HOURS | CUMULATIVE HOURS |
|---|---|---|---|---|---|---|---|---|---|---|
| RCL63 | 3Q77 | 3 | 2.874 | (A) | 4.239 | | | | 7.113 | 7.113 |
| RCK96 | 3Q77 | 2 | 9.303 | 5.433 | | | | | 14.736 | 21.849 |
| RCQ11 | 3Q77 | 5 | (B) | 2.611 | 2.789 | 2.540 | 2.264 | | 10.114 | 31.963 |
| RCO36 | 3Q77 | 2 | 5.903 | 7.163 | | | | | 13.066 | 45.029 |
| RAF58 | 1Q78 | 2 | 8.278 | 3.758 | | | | | 12.036 | 57.065 |
| RBB20 | 1Q78 | 3 | 7.361 | 1.344 | 4.436 | | | | 13.141 | 70.206 |
| RAE28 | 1Q78 | 3 | (C) | 4.041 | 2.383 | | | | 6.424 | 76.630 |
| RAQ63 | 1Q78 | 6 | (C) | (C) | 3.226 | (C) | 1.319 | (C) | 4.545 | 81.175 |
| RAF57 | 1Q78 | 4 | 4.018 | 1.359 | 2.689 | (D) | | | 8.066 | 89.241 |
| RBT87 | 1Q78 | 3 | 4.368 | 3.986 | 4.752 | | | | 13.106 | 102.347 |
| RAL54 | 1Q78 | 4 | 2.600 | 3.188 | 0.903 | 0.802 | | | 7.493 | 109.840 |
| RBA47 | 1Q78 | 2 | 4.916 | 9.496 | | | | | 14.412 | 124.252 |
| RAE26 | 1Q78 | 4 | 2.051 | 8.403 | 1.398 | 0.699 | | | 12.551 | 136.803 |
| RAS60 | 1Q78 | 4 | 3.167 | 0.932 | 2.638 | (D) | | | 6.737 | 143.540 |
| RBS06 | 1Q78 | 4 | 0.358 | 3.569 | 2.352 | 3.177 | | | 9.456 | 152.996 |
| RBS07 | 1Q78 | 5 | 0.253 | 0.278 | (E) | (E) | (F) | | 0.531 | 153.527 |
| RBS10 | 1Q78 | 4 | 6.625 | 3.382 | 2.876 | (D) | | | 12.883 | 166.41 |
| RCC72 | 1Q78 | 3 | 4.848 | 5.958 | (B) | | | | 10.806 | 177.216 |
| RCC77 | 1Q78 | 6 | (B) | 2.566 | 1.764 | 0.597 | 1.541 | (B) | 6.468 | 183.684 |
| RBB03 | 1Q78 | 6 | 2.117 | 1.907 | 5.267 | (G) | (B) | (D) | 9.291 | 192.975 |
| RBS76 | 1Q78 | 6 | 1.733 | (H) | (H) | (E)(C) | (E)(C) | (D) | 1.733 | 194.708 |
| RAE34 | 1Q78 | 3 | (I) | 3.441 | 2.751 | | | | 6.192 | 200.900 |
| RAE33 | 1Q78 | 2 | 4.042 | 2.383 | | | | | 6.425 | 207.325 |
| RAD96 | 1Q78 | 6 | 1.421 | 2.492 | 2.092 | 1.537 | 5.614 | (D) | 13.156 | 220.481 |
| RBT64 | 1Q78 | 4 | 5.347 | 1.169 | 4.257 | 0.357 | | | 11.130 | 231.611 |
| RBR87 | 1Q78 | 4 | 1.664 | 6.772 | 4.428 | (C)(D) | | | 12.864 | 244.475 |
| RCC82 | 1Q78 | 4 | 1.246 | (F) | (F) | 2.377 | | | 3.623 | 248.098 |
| RBU38 | 1Q78 | 3 | 1.393 | 7.994 | (D) | | | | 9.387 | 257.485 |
| RBU18 | 1Q78 | 3 | (C) | 2.779 | 1.943 | | | | 4.722 | 262.207 |
| RBJ01 | 1Q78 | 5 | (I) | 1.239 | 1.672 | 1.964 | (J) | | 4.875 | 267.082 |
| RAF29 | 1Q78 | 6 | 2.891 | (K) | (K) | (K) | (K) | (K) | 2.891 | 269.973 |

TABLE 21 (Concluded)

C-141 LHRP USAGE TAPES

| DATA TAPE | QTR. | NO. OF FLIGHTS | FLT.1 | FLT.2 | FLT.3 | FLT.4 | FLT.5 | FLT.6 | INCREMENTAL HOURS | CUMULATIVE HOURS |
|---|---|---|---|---|---|---|---|---|---|---|
| RAK01 | 1Q78 | 4 | 0.541 | 4.134 | 0.954 | 0.618 | | | 6.247 | 276.220 |
| RAS85 | 1Q78 | 3 | 3.921 | 3.447 | 5.149 | | | | 12.517 | 288.737 |
| RAT06 | 1Q78 | 3 | (C) | 3.488 | 0.936 | | | | 4.424 | 293.161 |
| RAS93 | 1Q78 | 2 | 1.675 | 8.048 | | | | | 9.723 | 302.884 |
| RBE13 | 4Q78 | 3 | 2.144 | 1.956 | 2.268 | | | | 6.368 | 309.252 |
| RCR55 | 2Q79 | 3 | 1.557 | 1.979 | 2.006 | | | | 5.542 | 314.794 |

NOTES:

(A) AIRSPEED OUT OF RANGE

(B) RECORDER TURNED ON IN FLIGHT

(C) FUEL WEIGHT NO GOOD

(D) TAPE RAN OUT IN FLIGHT

(E) GROSS WEIGHT OUT OF RANGE

(F) GROUND SPEED OUT OF RANGE

(G) INVALID CALIBRATION CHECK

(H) UNDEFINED EVENT

(I) FLIGHT CODE BEFORE TAXI

(J) EXCESSIVE BAD FRAMES

(K) STOPPED PROCESSING

TABLE 22

DATA CHANNEL STATUS OF C-141A LHRP TAPE RCL63

S/N 67-0023 FLIGHT DATE: 7-14-77

| DATA CHANNEL | STATUS |
|---|---|
| PITOT STATIC PRESSURE | O.K. |
| PITOT TOTAL PRESSURE | O.K. |
| GROUND SPEED | O.K. |
| NORMAL ACCELERATION | O.K. |
| CABIN PRESSURE | Channel out-no data |
| PITCH RATE | O.K. |
| YAW RATE | 1 count high |
| RUDDER POSITION | Channel active - no numerical checks made |
| ELEVATOR POSITION | Channel active - no numerical checks made |
| FLAP POSITION | Showed 69% @ liftoff, 75% nominal |
| NOSE GEAR ANGLE | Showed $-3^{o}$ @ liftoff, $0^{o}$ nominal |
| LATERAL ACCELERATION | Showed ÷.3g's @ preflight, 0 g's nominal |
| WING JOINT STRAIN (S2) | Channel active - response no good |
| C.W.S. 53.2 STRAIN (S3) | Channel out - no data |
| MLG BOGIE BEAM STRAIN (S4) | Channel out - no data |
| F.S. 1108 STRINGER STRAIN (S5) | Channel out - no data |
| NLG BULKHEAD STRAIN (S6) | Channel active - no numerical checks made |
| LANDING GEAR | O.K. |
| LANDING STRUT | O.K. |
| SPOILERS | O.K. |

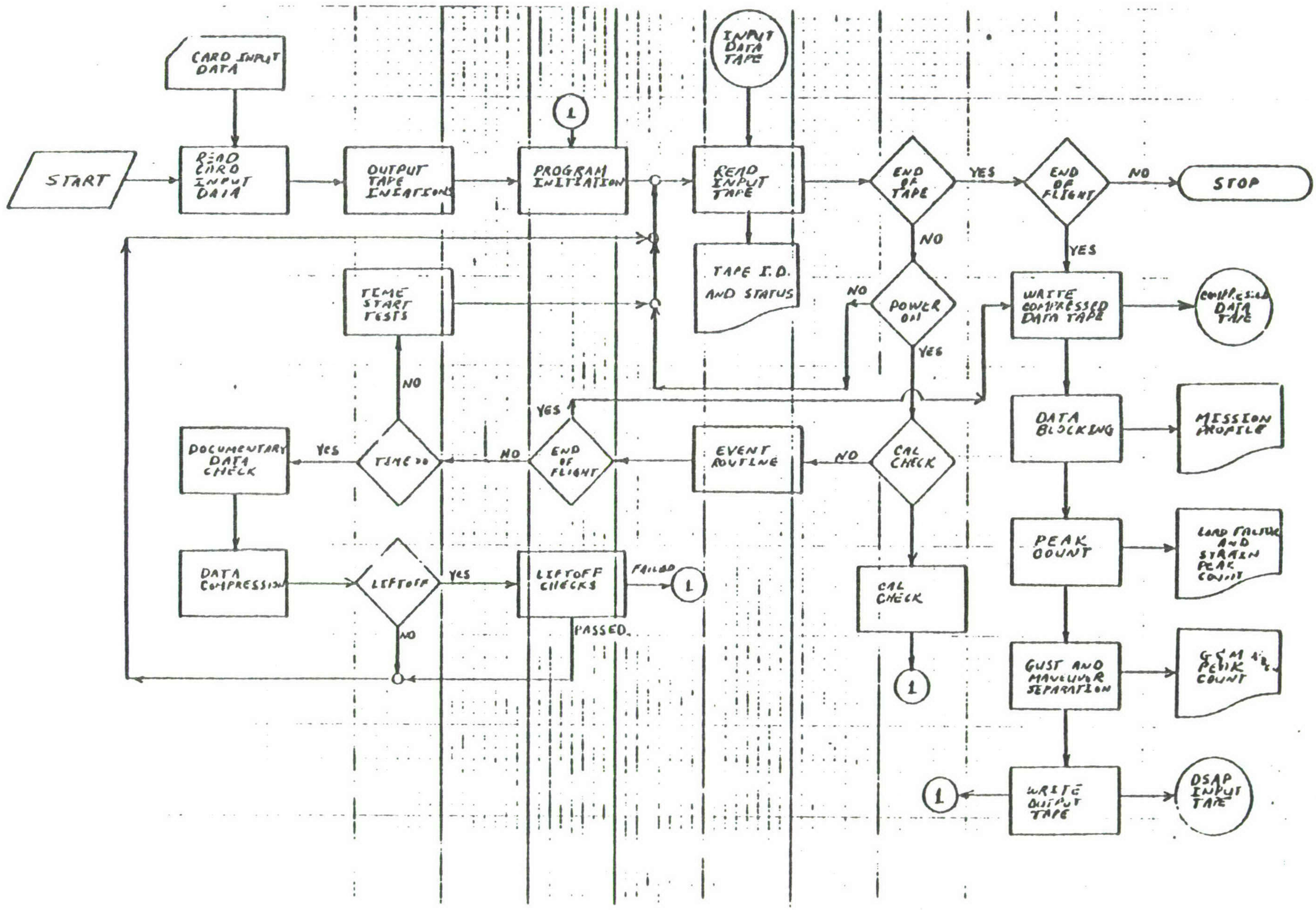



Figure 27. DRP Flow Diagram.

### C5.1.2 Ground Operation

The sortie profiles from several flights showed that the takeoff event was triggered a number of times both prior to the actual takeoff and after touch down and rollout. The original program logic for interrelated ground events was:

(a) Takeoff-strut compressed, ground velocity greater than thakeoff threshold, and last event not rollout.

(b) Rollout-ground velocity greater than takeoff threshold, last event rollout, or last event third second of landing impact.

(c) Taxi - strut compressed, and ground velocity greater than or equal 2 counts but less than or equal to takeoff threshold; 50 counts (approx. 21 kt.)

In effect, each time the aircraft exceeded 21 kt., the takeoff threshold, during taxi, the takeoff event was produced by the program. After evaluating several approaches, wheel acceleration. or rate of change of ground velocity was determined to be the most reliable takeoff indicator. The time histories of several takeoffs at various gross weights and runway altitudes were generated to determine minimum acceleration rate. These time histories (Figure 28 is a typical plot) showed that the acceleration during takeoff is generally constant with a minimum value at the heaviest gross weight of about 9 kt /sec. This was incorporated in the new program logic, as summarized below:

(a) Takeoff-strut compressed, rate of ground velocity change greater than 8.5 kt/sec for 8 seconds (observed in two 4 second intervals).

(b) Rollout-last event third second of landing impact, strut compressed, time duration is 60 seconds.

(c) Taxi - all ground operation with ground velocity greater than two counts and not takeoff, landing impact or rollout.

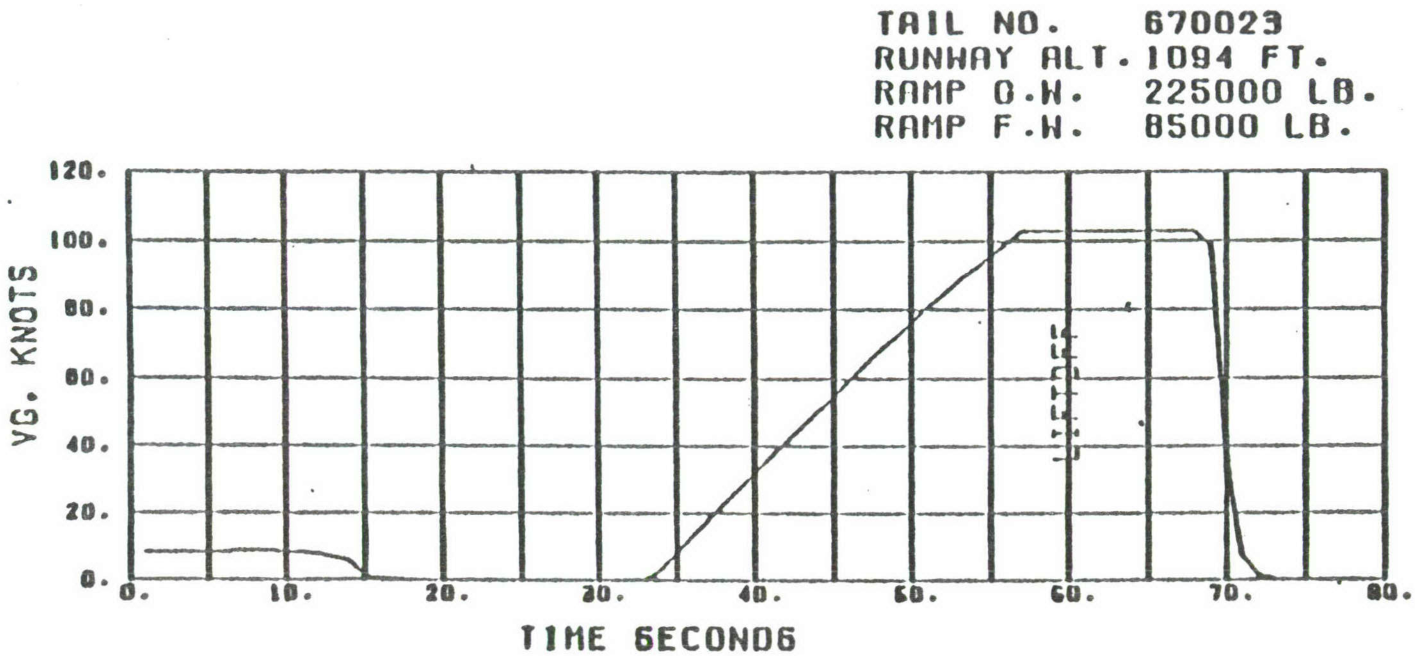



Figure 28. C-141A LHRP Wheel Speed Vs Time at Takeoff.

This revised subroutine has been successfully used to process both long range sorties and those with several TAG events. The previous ground event errors were eliminated and the accuracy of the sortie flight profiles was verified by reference to the one-per-second flight time histories.

## C5.2 FUEL BURN

### C5.2.1 Equation Method

The amount of fuel consumed during flight is calculated at a one minute interval using an equation derived from the C-141A Flight Manual performance data. This equation has two terms, one that calculates level flight consumption at the current airspeed, altitude, and gross weight and another which provides a climb or descent correction value if the aircraft is not in level flight.

$$\text{CRUISE-LB.} = .59667+(.27583)\left(1+\frac{.03237}{.891-\text{FMACH}}\right)\times$$

$$(\text{PS})^{1.2}(\text{FMACH})^{2} + \frac{(6.1083\times10^{-5})(\text{GWP})^{2}}{(\text{PS}1.2)\ (\text{FMACH})^{2}}\ (60)(\text{R})(\text{M})$$

$$\text{CLIMB/DESCENT}=(9038.82)\left(\text{PS}_{i}^{.1902546}-\text{PS}^{.1902546}\right)\times$$

$$\left(\frac{\text{GWP}}{V_T}\right)$$

where:

FMACH = Mach Number

GWP = A/C Gross Weight - Hundreds of Pounds.

PS = Static Pressure - In. Hg.

$PS_1$ = Static Pressure of Preceeding Calculation - In. Hg.

$V_T$ = (FMACH) (478.4295) $(\text{PS})^{.0951273}$

M = Multiplier

R = Number of minutes since preceeding calculation normally equals one.

### C5.2.2 Cruise Term Multiplier

The cruise term for fuel burn includes a multiplier (M) with a value of 1.5 that was added to correct an underburn problem at the beginning of the LHRP program. To reduce cruise consumption, the multiplier was varied incrementally during repetitive evaluation runs. Figure 29 shows results from one of these runs. The optimum level for the multiplier was established as 1.14, which produced total calculated fuel consumed values within $\pm3\%$ of the reported figures.

### C5.2.3 Climb/Descent Term

The equation logic contains a reduced cruise fuel usage multiplier. With the aircraft operating at low speed and moderate descent rates below 10,000 ft., the climb/descent term would achieve numerical values larger than the cruise term. As this term is negative during descent, fuel was added to the aircraft. This logic was corrected by restricting the total calculated burn rate to a minimum value of 80 lb./min., which is an average rate for these descent conditions.

### C5.2.4 TAG Fuel Burn Increment

After implementing the equation changes discussed in previous sections, errors were within $\pm5\%$ for several single G.A.G. sorties processed with DRP. Low altitude training sorties with several TAG events, however, produced calculated fuel consumption levels that were several thousand pounds low. After reviewing the burn equation and event logic, it was concluded that during the T.A.G. maneuver; (1) engine idle-power burn rates are used for the entire ground run with no allowance for takeoff power operation, (2) from lift-off to clean-up, cruise and climb rates are used instead of take-off power rates, and (3) the equation does not increase the cruise fuel consumption rate during slow flight with flaps and gear extended. The additional logic and complexity required to modify the fuel burn subroutine to accommodate these effects was considered excessive. Therefore, a simpler change was derived that adds a constant amount of consumed fuel when a T.A.G. event is identified.

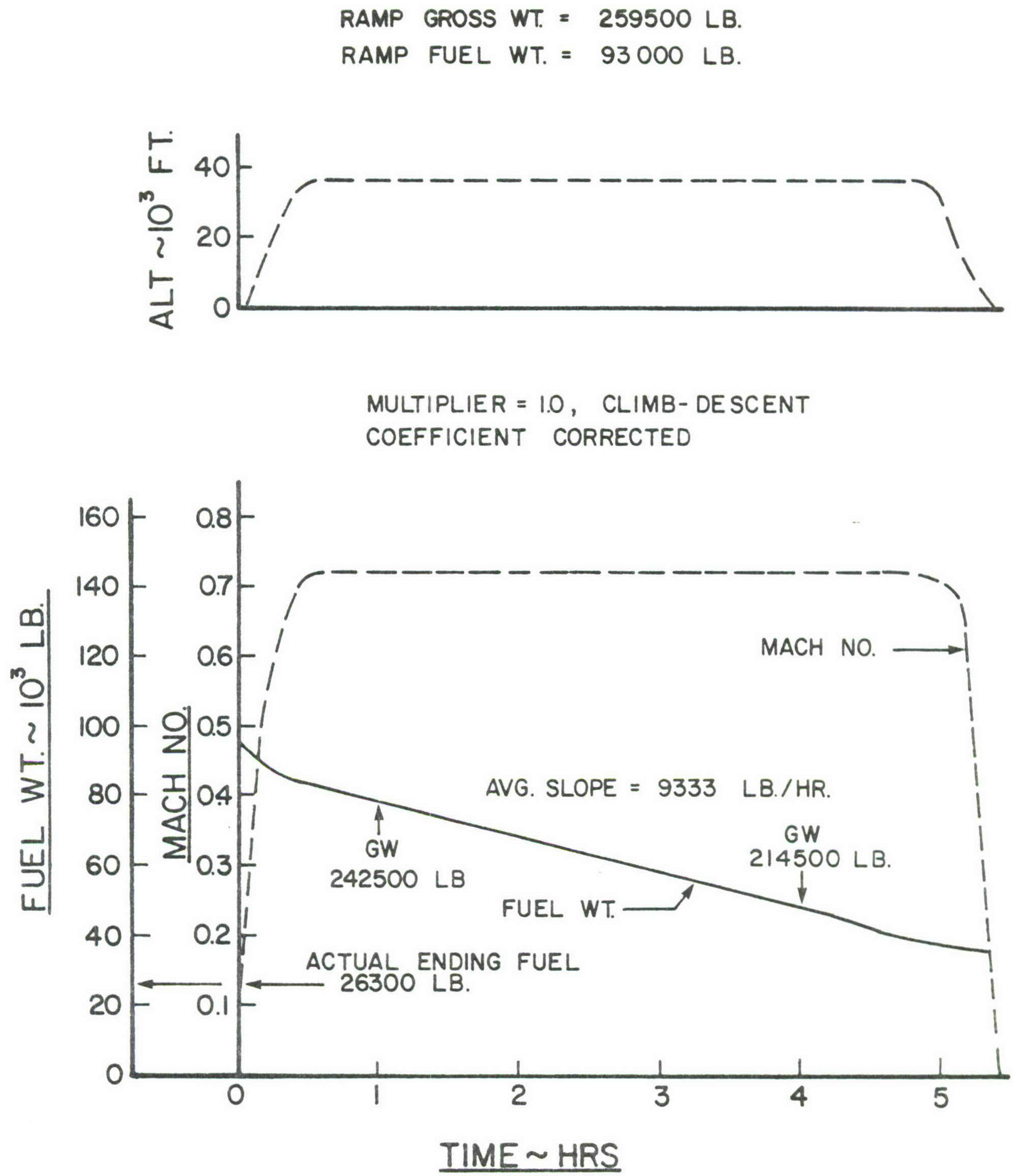



Figure 29. RCK 96 Sortie 2.

This constant amount was derived by constructing an average flight profile from the time histories of twenty three T.A.G. events. The following time segments, which encompass 80% of occurrences, were established.

| | | |
|---|---|---|
| (a) | Approach flaps extended | 31 sec |
| (b) | Approach flaps and landing gear extended | 342 sec |
| (c) | Landing flaps & landing gear extended | 214 sec |
| (d) | Groundroll-deceleration after touchdown | 24 sec |
| (e) | Groundroll-acceleration to liftoff | 7 sec |
| (f) | Lift off to clean up | 75 sec |

Average pattern altitudes, mach numbers, and gross weights were used to calculate the fuel consumed for each segment using the existing equation and then, rational performance factors. The under-burn was determined to be approximately 1300 lb. This value was incorporated in the fuel burn subroutine and is added to the fuel consumed when the T.A.G. event is identified.

C5.2.5 Summary

The fuel burn subroutine has been significantly improved by the following changes:

(a) A minimum burn rate was incorporated to eliminate negative values during aircraft descent.

(b) The cruise term multiplier was reduced to eliminate large overburns when processing long range sorties.

(c) Fuel consumed during T.A.G. events was increased by a constant value to correct an inherent deficiency in the logic.

These improvements have eliminated gross errors in the calculated fuel consumption, however any further improvement will require changes in the methodology. For instance, engine throttle angle could be monitored to provide realistic performance information. The most direct method would require a fuel totalizer for the LHRP recorder and this is an eventual necessity as the C-141B configuration includes in-flight refueling capability.

## C5.3 PEAK COUNT SUBROUTINE

This subroutine was updated to eliminate the generating of possible erroneous large peaks in measured strain data under special conditions.

## C5.4 GUST AND MANEUVER SEPARATION SUBROUTINE

The separation of vertical and lateral accelerations (or load factors) into gust and maneuver time histories and subsequent peak counting is performed in the NZGMS and FFT subroutines. Figure 30 shows a spectral plot of cumulative occurrences of gust peaks obtained from the first and third flights on C-141A tape RCL63 using these subroutines.

In the analysis of time history data, the inflight portion of the data are input to the FFT (Fast Fourier Transform) subroutine in sequential sets of $2^N$ points (i.e., 512 points when N = 9). The middle 2 (N-1) points are subsequently processed and passed back to the NZGMS as separate gust and maneuver arrays ready for peak counting. The original NZGMS contained a procedure whereby "extra points", that is, those remaining after dividing the flight segment into sets of $2^N$ points, are deleted by removing that many points lying within the deadband area around the mean value. For all practical purposes, this procedure is acceptable, however, it is possible to define special cases where minor errors could be produced.

The method of handling extra points was updated to a method which basically creates "mirror image" data in the first and last or last two inputs to FFT for each flight segment. It is necessary to have "extra" data in addition to the flight time at the beginning and end of the flight in order for the FFT to perform properly. The mirror image concept is used on the theory that it contains a similar frequency content as the actual data and therefore does not "contaminate" the frequency spectrum. In the case of the first points in the flight, $2^{N-2}$ data points beginning with the second point are folded back about the first point. This is illustrated in Figure 31. The procedure for handling the points in the

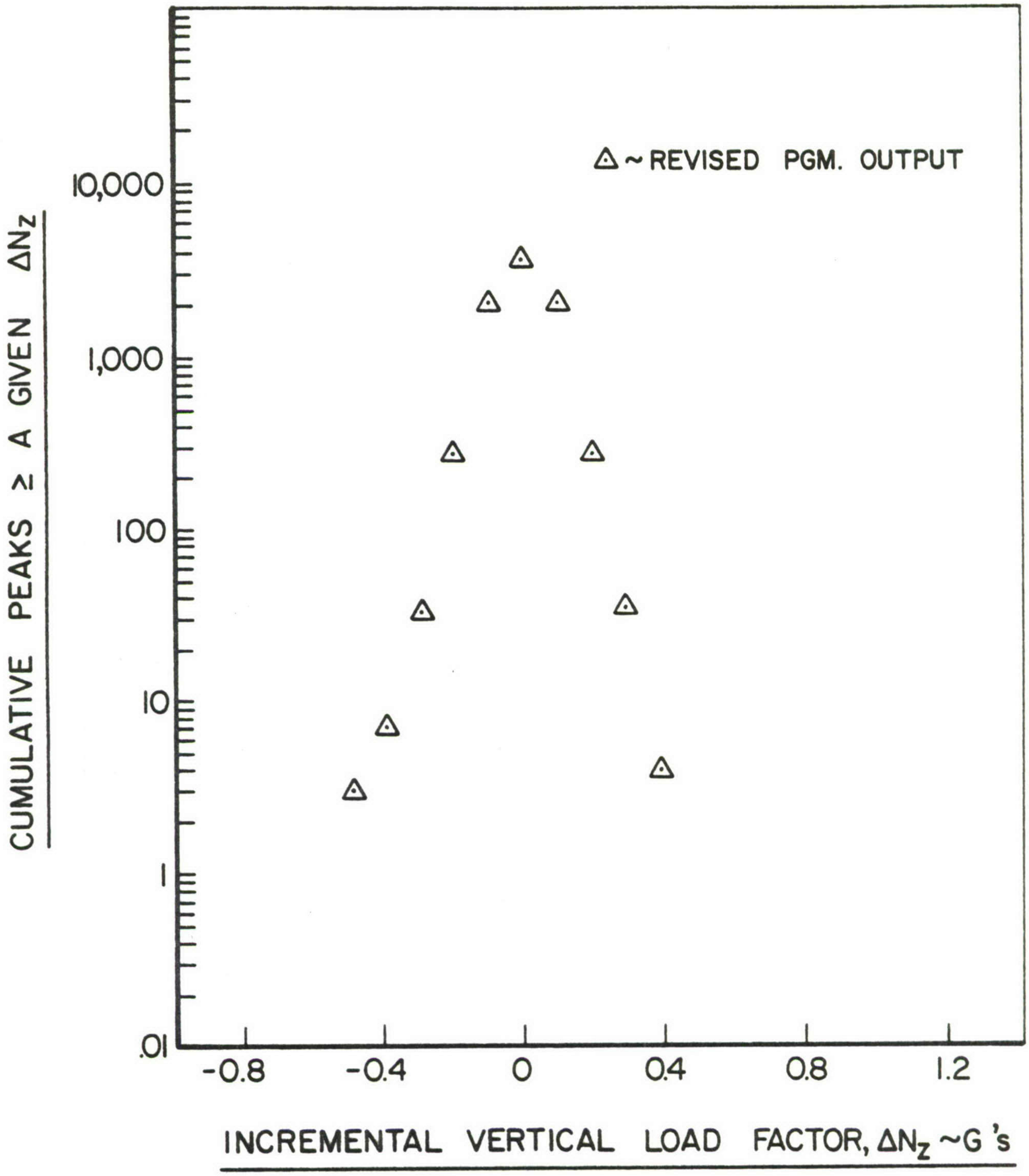



Figure 30. Gust Peaks.

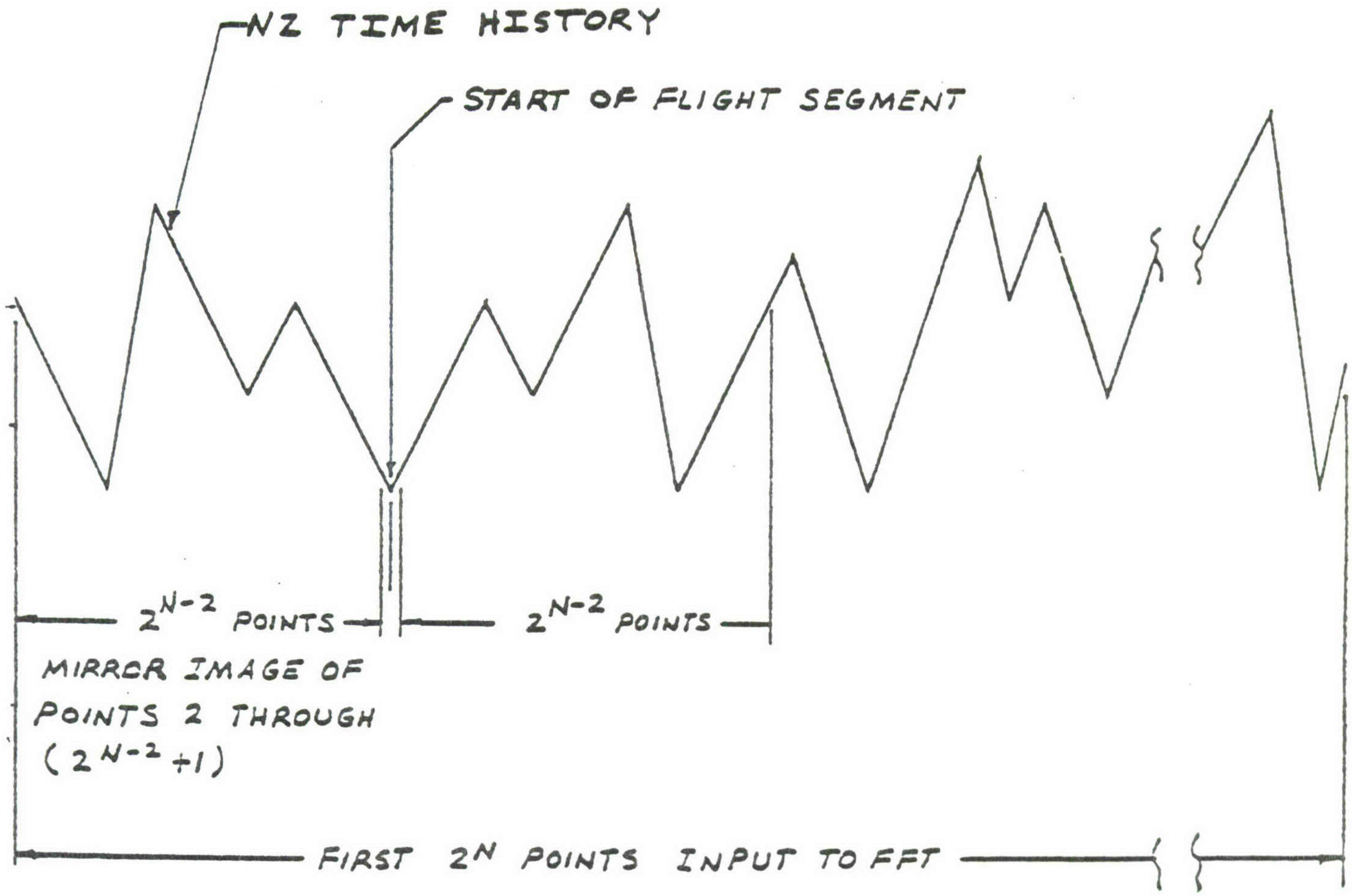



Figure 31. Method of Handling First Points in Flight Segment.

last flight segment is similar. Additional $N_Z$ data points to fillout the FFT input are generated as mirror image points relative to the last $N_Z$ value in the last flight segment. In all cases, logic within the program insures no peak counting of points within the mirror image areas. At the same time, all recorded points are subject to peak counting with none being lost as in the original procedure.

C5.5 FAST FOURIER TRANSFORM SUBROUTINE

The "Fast Fourier Transform" subroutine in the C-141A DRP, which is labeled as "FFT", has two main functions:

(1) It removes the linear trend from the time history.

(2) It separates the gust from the maneuver using the complex conjugate of a low pass filter

The functional form of the filter in the methodology report is:

$$Hp\ (f_i) = \frac{1.0}{1.0 + \left(\frac{\tan \pi \Delta t\ f_i}{\tan \pi \Delta t\ f_c}\right)^{16}}$$

The exponent in the program is a shaping parameter for the filter function. A more detailed study of the filtering methodology is discussed in Section C6.1

C5.6 VALID DATA CHECKS

A number of changes were introduced and checks were made to implement the goal of reducing manual editing and re-runs required to successfully process the tapes. These include; (1) extending the valid gross weight and fuel weight range to accommodate gross weights over 324,999 lb. and fuel weights over 149,999 lb., (2) reducing the valid minimum ground speed at lift-off to 80 kt. (200 counts) to accommodate light gross weight-high head wind operation, and (3) insuring that the lack of one level in the three-level calibration check does not stop the program.

Several flights would not process without manual edits to correct errors by the flight crew in entering ramp fuel weight. This weight is entered in hundreds of pounds, as only four digits are available. All errors involved the most-significant-digit being entered to the right or left of its' true position, i.e., either ten times or one tenth of the true value. The following program statements were added to test for and correct these errors:

(a) If ramp fuel weight is less than 99 (9900 lb.), multiply by ten, continue processing.

(b) If ramp fuel weight is more than 1610 (161,000 lb.), divide by ten, continue processing.

All of the changes described in this section have been incorporated in the data reduction program and several tapes have been processed to verify their effect.

## C5.7 DATA BLOCKING

The LHRP data block assignments as defined in the present program are unchanged, with the exception of the elimination of contour flying as described in Section C5.1. Figures 32 through 35 summarize the gross weight, fuel weight, airspeed, and altitude bands that comprise the system. The hierarchy of the bands and equations used to calculate the data block identification numbers are also shown. The flight profiles from two typical tapes in conjunction with one-per-second time histories of each, were used to verify the following calculations:

(a) Mach number

(b) Altitude

(c) Data Block I.D.

Finally, the validity of the program clock which generates sortie clock time was verified. This varies slightly from true time because of the static pressure 2 count window and total pressure 3 count window. The verification was accomplished by printing the static and total pressure tables generated by the program and comparing their time table with the one-per-second time history of the flight.

| FUEL (KIPS) | CARGO (KIPS) | MACH NUMBER | ALTITUDE(1000 FT) |
|---|---|---|---|
| $6 < F_1 \leq 25$ | $0 < C_1 \leq 10$ | $0.0 < M_1 \leq 0.37$ | $0 < H_2 \leq 1.0$ |
| $25 < F_2 \leq 50$ | $10 < C_2 \leq 20$ | $0.37 < M_2 \leq 0.45$ | $1.0 < H_3 \leq 2.5$ |
| $50 < F_3 \leq 75$ | $20 < C_3 \leq 35$ | $0.45 < M_3 \leq 0.535$ | $2.5 < H_4 \leq 7.5$ |
| $75 < F_4 \leq 100$ | $35 < C_4 \leq 50$ | $0.535 < M_4 \leq 0.61$ | $7.5 < H_5 \leq 12.5$ |
| $100 < F_5 \leq 125$ | $50 < C_5 \leq 70$ | $0.61 < M_5 \leq 0.71$ | $12.5 < H_6 \leq 17.5$ |
| $125 < F_6 \leq 153.3$ | $70 < C_6 \leq 89$ | $0.71 < M_6 \leq 0.80$ | $17.5 < H_7 \leq 22.5$ |
| | | $0.80 < M_7 \leq 0.892$ | $22.5 < H_8 \leq 32.5$ |
| | | | $32.5 < H_9 \leq 39.9$ |

**SEQUENCE OF PARAMETERS:**

**CONTOUR FLYING**

$$\sum_{I=1}^{1} \sum_{J=1}^{7} \sum_{K=1}^{6} \sum_{L=1}^{6} H_{(I)} \, (M_{(J)} \, C_{(K)} \, F_{(L)}$$

**FLIGHT WITH MANEUVER OR GUST**

$$\sum_{I=2}^{9} \sum_{J=1}^{7} \sum_{K=1}^{6} \sum_{L=1}^{6} H_{(I)} \, M_{(J)} \, C_{(K)} \, F_{(L)}$$

**DATA BLOCK EQUATION**

$$DB_F = F_L + (C_K - 1)\,6 + (M_J - 1)\,36 + (H_I - 1)\,252$$

Figure 32. Flight Data Block System.

| FUEL (KIPS) | CARGO (KIPS) | R-CATEGORY | OPERATIONAL TYPE |
|---|---|---|---|
| $6 < F_1 \leq 25$ | $0 < C_1 \leq 10$ | I SS | 1. TAKEOFF |
| $25 < F_2 \leq 50$ | $10 < C_2 \leq 20$ | II SR | 2. LANDING RUNOUT |
| $50 < F_3 \leq 75$ | $20 < C_3 \leq 35$ | III US | 3. CONSTANT SPEED TAXI |
| $75 < F_4 \leq 100$ | $35 < C_4 \leq 50$ | IV UR | |
| $100 < F_5 \leq 125$ | $50 < C_5 \leq 70$ | | |
| $125 < F_6 \leq 153.3$ | $70 < C_6 \leq 89$ | | |

**SEQUENCE OF PARAMETERS:**

**CONSTANT SPEED TAXI**

$$\sum_{I=1}^{1} \sum_{J=1}^{4} \sum_{K=1}^{6} \sum_{L=1}^{6} O_{(I)}\, R_{(J)}\, C_{(K)}\, F_{(L)}$$

**LANDING RUNOUT**

$$\sum_{I=2}^{2} \sum_{J=1}^{4} \sum_{K=1}^{6} \sum_{L=1}^{6} O_{(I)}\, R_{(J)}\, C_{(K)}\, F_{(L)}$$

**TAKEOFF**

$$\sum_{I=3}^{3} \sum_{J=1}^{4} \sum_{K=1}^{6} \sum_{L=1}^{6} O_{(I)}\, R_{(J)}\, C_{(K)}\, F_{(L)}$$

**DATA BLOCK EQUATION**

$$DB = 2268 + F_L + (C_K - 1)6 + (R_J - 1)(36) + (O_I - 1)(144)$$

Figure 33. Taxi, Runout and Takeoff Data Block System.

| FUEL (KIPS) | CARGO (KIPS) | LANDING TYPE |
|---|---|---|
| $6 < F_1 \leq 25$ | $0 < C_1 \leq 10$ | NORMAL |
| $25 < F_2 \leq 50$ | $10 < C_2 \leq 20$ | AWLS |
| $50 < F_3 \leq 75$ | $20 < C_3 \leq 35$ | |
| $75 < F_4 \leq 100$ | $35 < C_4 \leq 50$ | |
| $100 < F_5 \leq 125$ | $50 < C_5 \leq 70$ | |
| $125 < F_6 \leq 153.3$ | $70 < C_6 \leq 89$ | |

SEQUENCE OF PARAMETERS:

NORMAL

$$\sum_{I=1}^{1} \sum_{J=1}^{6} \sum_{K=1}^{6} T_{(I)} C_{(J)} F_{(K)}$$

ALL WEATHER LANDING SYSTEM

$$\sum_{I=2}^{2} \sum_{J=1}^{6} \sum_{K-1}^{6} T_{(I)} C_{(J)} F_{(K)}$$

DATA BLOCK EQUATION

$$DB = 2268 + 432 + F_K + (C_J - 1)(6) + (T_I - 1)\, 36$$

WHERE:

NORMAL, $I = 1$; AWLS, $I = 2$

Figure 34. Landing Impact Data Block System.

| FUEL (KIPS) | CARGO (KIPS) | CYCLE IDENTIFICATION |
|---|---|---|
| $6 < F_1 \le 12.5$ | $0 < C_1 \le 5.0$ | AIR-GROUND-AIR |
| $12.5 < F_2 \le 25.0$ | $5.0 < C_2 \le 10.0$ | GROUND-AIR-GROUND I |
| $25.0 < F_3 \le 37.5$ | $10.0 < C_3 \le 15.0$ | GROUND-AIR-GROUND II |
| $37.5 < F_4 \le 50.0$ | $15.0 < C_4 \le 20.0$ | |
| $50.0 < F_5 \le 62.5$ | $20.0 < C_5 \le 27.5$ | |
| $62.5 < F_6 \le 75.0$ | $27.5 < C_6 \le 35.0$ | |
| $75.0 < F_7 \le 87.5$ | $35.0 < C_7 \le 42.5$ | |
| $87.5 < F_8 \le 100.0$ | $42.5 < C_8 \le 50.0$ | |
| $100.0 < F_9 \le 112.5$ | $50.0 < C_9 \le 60.0$ | |
| $112.5 < F_{10} \le 125.0$ | $60.0 < C_{10} \le 70.0$ | |
| $125.0 < F_{11} \le 137.5$ | $70.0 < C_{11} \le 80.0$ | |
| $137.5 < F_{12} \le 153.3$ | $80.0 < C_{12} \le 89.0$ | |

SEQUENCE OF PARAMETERS:

AIR-GROUND-AIR

$$\sum_{I=1}^{1} \sum_{J=1}^{12} \sum_{K=1}^{12} I_{(I)} C_{(J)} F_{(K)}$$

GROUND-AIR-GROUND II

$$\sum_{I=3}^{3} \sum_{J=1}^{12} \sum_{K=1}^{12} I_{(I)} C_{(J)} F_{(K)}$$

GROUND-AIR-GROUND I

$$\sum_{I=2}^{2} \sum_{J=1}^{12} \sum_{K=1}^{12} I_{(I)} C_{(J)} F_{(K)}$$

DATA BLOCK EQUATION

$$DB = 2268 + 432 + 72 + F_K + (C_J - 1)(12) + (I_1 - 1)\,144$$

Figure 35. Ground-Air-Ground and Air-Ground-Air Data Block System.

## C6.1 FILTER OPTIMIZATION

The filter function in the C-141A LHRP methodology report is of the form,

$$Hp\ (f_i) = \frac{1.0}{1.0 + \left( \frac{\tan\ (\pi\ \Delta t\ f_i)}{\tan\ (\pi\ \Delta t\ f_c)} \right)^{16}}$$

The exponent in the actual computer software was 8 instead of 16. This exponent is a shaping parameter for the filter function. A study was made when the FFT subroutine was originally programmed in order to determine the most optimum value for the parameter. A comparison of various filter shapes of this type is shown in Figure 36. The ideal filter would be the step function, with the step occurring at 0.26 hz. (The cutoff frequency of 0.26 was originally chosen as being halfway between the discrete frequencies obtained from the sample rate of the c.g. load factor and processing 17.067 seconds of data). In order to use this ideal filter, however, an infinite time increment would be required to be processed in each filtering step by the program, which is not possible. The filtering process in the frequency domain is of the form

$$F(w) = H(w) * G(w)$$

where G(w) is the time history to be filtered and H(w) is the filter function such as those shown in Figure 36. This is equivalent to the evaluation of the following function in the time domain

$$f(t) = \int_{\infty}^{\infty} g(t-\tau)\ h\ (\tau)\ d\tau$$

The transformation of the ideal filter to the time domain produces a function of the following form

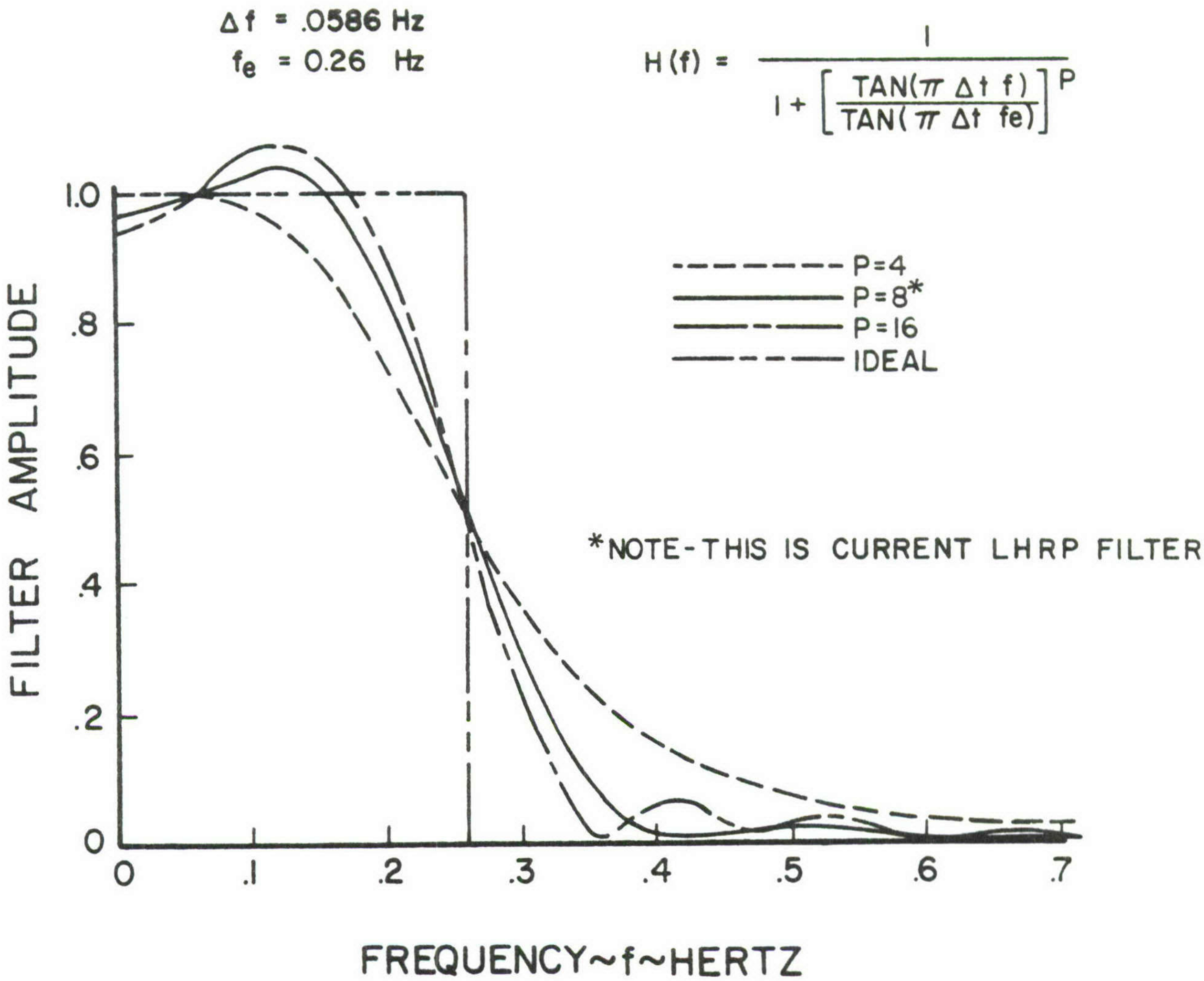
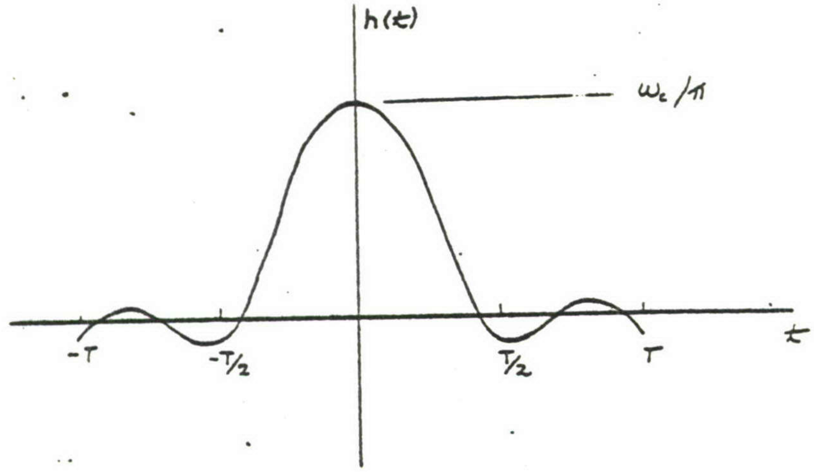



Figure 36. Filter Shape Characteristics.




In order to process finite amounts of data from $-T \leq t \leq T$, the side loges of the function H(t) are set to zero from $-T \leq t \leq -T/2$ to $T/2 \leq t < T$ resulting H (w) function is used to perform the filtering process. The choice of a functional form of the filter

$$H(f) = \frac{1}{1.0 + \left( \dfrac{(\tan \pi \ \Delta t \ f_i)}{(\tan \pi \ \Delta t \ f_i)} \right)^{16}}$$

reduces the magnitudes of the side lobes which are set to zero, although a trade-off is involved since the attenuation of $f_c$ is not a step function as with the ideal filter. A choice of an infinitely large value for the exponent would increase the rate of attenuation at the $f_c$, however, oscillations of the filter function about 1.0 below $f_c$ and about 0.0, above $f_c$ become more pronounced. Therefore a tradeoff is involved, and a compromise is made on the optimum choice for the value of exponent. As can be seen from Figure 36, the differences between an exponent of 8 and 16 are slight. However, the exponent value of 16 is considered to be slightly better than the value of 8 for the C-141 LHRP and will be changed accordingly in the final updated version of FFT.

A comparison of the filter shapes for a larger time increment size is shown in Figure 37. These are filter shapes which would be possible if 1024 load factor points were processed at a time rather than 512 points as are now processed. This increase in the number of points would double the frequency resolution, reducing the incremental frequency from 0.0586 Hz. down to 0.0293 hz.

As can be seen in Figure 37, the filter shape for an exponent value of 16 is clearly superior to the one for a value of 8. Moreover, the decrease of the frequency increment down to .0293 Hz. provides 9 coefficients to describe the power content of the load factor time history near or below 0.26 Hz. rather that the 4 or 5 possibles with a frequency resolution of .0586 Hz. This smaller frequency resolution will provide for a more accurate description of the maneuver content of the time history. There is also the added benefit that the computer will analyze 1024 points slightly faster that 512 points twice in succession, thereby reducing computer run time. There is, of course, an increased requirement for computer storage space. An evaluation of the effects of increasing the time "bite sizes" on the final $N_z$ peak count distribution has been made and is found in Section C6.2.

Several tests on the FFT subroutine were performed to assure the reliability and accuracy of both the methodology and the programming. These tests are summarized here.

First, a simple $N_z$ sinusoidal function of the form

$$N_z = 1.0 + \sin(.1172\ \pi\ t)$$

was tested to compare the frequency resolution of this time history by the FFT subroutine as it currently exists with the program. The frequency of .1172/2 = 0.0586 Hz corresponds to the lowest Fourier frequency coefficient.

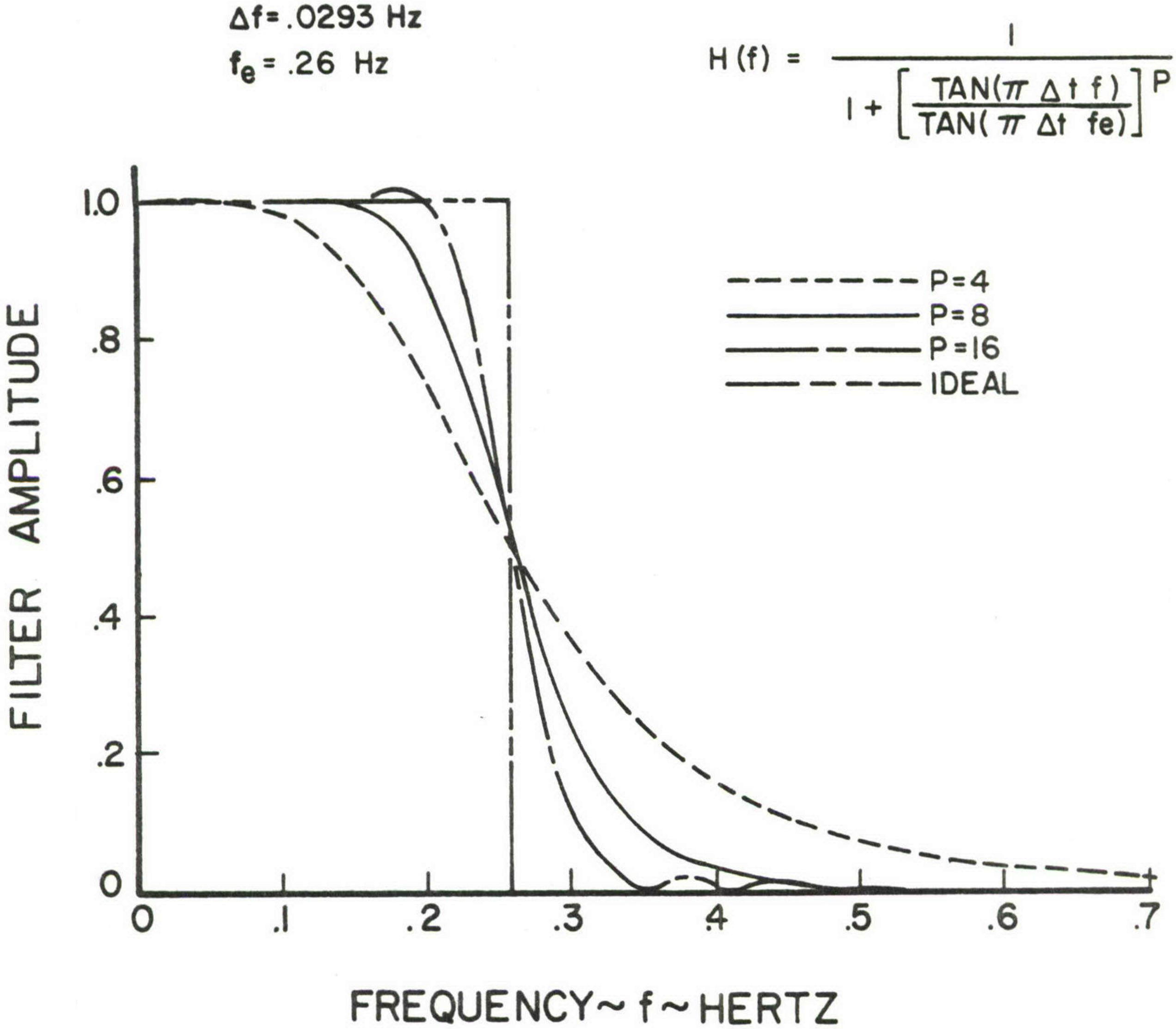



Figure 37. Filter Shape Characteristics.

The only non-zero Fourier coefficient obtaind by FFT was exactly the one for f = 0.0586 and was a value of 1.0. The filtering process of this function yielded almost exactly the original function.

Next, a function of the form

$$N_z = 1.0 + \sin(.2344\ \pi t)$$

was filtered using the same version of FFT. This function has a frequency of 0.1172 Hz. The results demonstrated the effectiveness of the FFT to filter this discrete frequency signal very well.

The results of filtering a combination of two discrete frequency functions representing a maneuver is shown in Figure 38. The $N_z$ function is of the form

$$N_z = 1.0 + \sin(.4\ \pi t) + 0.5 \sin(.2\ \pi t)$$

Note that these two discrete frequencies, 0.2 and 0.1 Hz, do not exactly correspond to the discrete frequencies in the FFT. The part of the filtered function which is greater than 0.26 Hz would be considered an error function in the filtering process which is caused by the filter function not being the ideal step function as discussed previously.

Filtering of the same function with the filter exponent parameter changed to the value of 16 results in an error which is slightly smaller for this case. Filtering the same function with a set of 1024 points giving a discrete frequency resolution of 0.0293 Hz instead of 0.0586 Hz, as is expected, also yields a smaller error function than the standard production FFT which handles 512 points since the discrete frequencies are nearer in value to the sample analytical function frequencies.

A third sample analytical Nz maneuver function was analyzed using the production FFT subroutine. This function was of the form

$$N_z = 1.0 + .02344t + \sin(.4t) + .5 \sin(.2t).$$

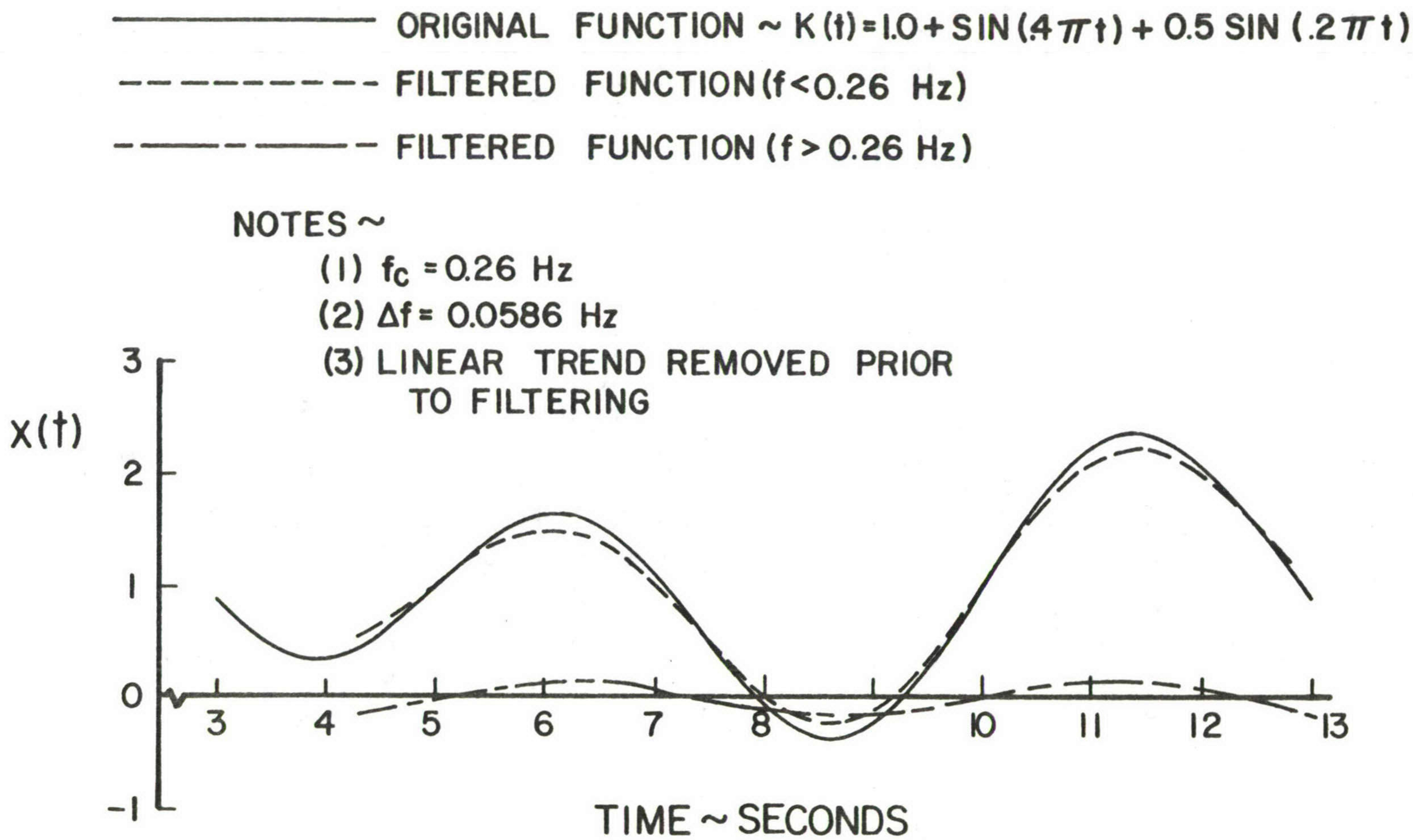



Figure 38. Filter Check.

This function second term is a representative linear trend which sometimes occurs in the $N_z$ case factor data. The results of filtering this signal with and without removing the linear trend, shown in Figure 39 (trend removed), show no substantial difference in the resultant filtered data. However, it is recommended that the linear trend removal be retained since it will remove a more significant linear trend if it exists and also the linear trend removal is not very costly.

As a point of interest, an analytical case was simulated, as occasionally happens, when a step occurs in the $N_z$ signal due to some electrical or accelerometer problem to see how the FFT would handle this situation. Such a step function is shown in Figure 40. The $N_z$ function is composed of the previous function

$$N_z = 1.0 + \sin(.4\pi t) + 0.5 \sin(.2\pi t)$$

imposed upon the step function. It is interesting to note that the result of the filtering technique yields a positive and negative gust peak, the sum of which are equal to the step input to the $N_z$ signal, whereas, with a linear trend removal, the maneuver time history does not change appreciably and would probably have very little effect on the resultant maneuver peak counts.

In summary, the current production FFT subroutine which performs the separation of the gust and maneuver portions of the total c.g. load factor was found to perform according to expectations. However, at this point it is conditionally recommended that the filter shaping exponent parameter be changed from eight to sixteen and that the number of points processed be increased from 512 to 1024. The results of a detailed parameter study of these changes on actual recorded data is presented in Section C6.2.

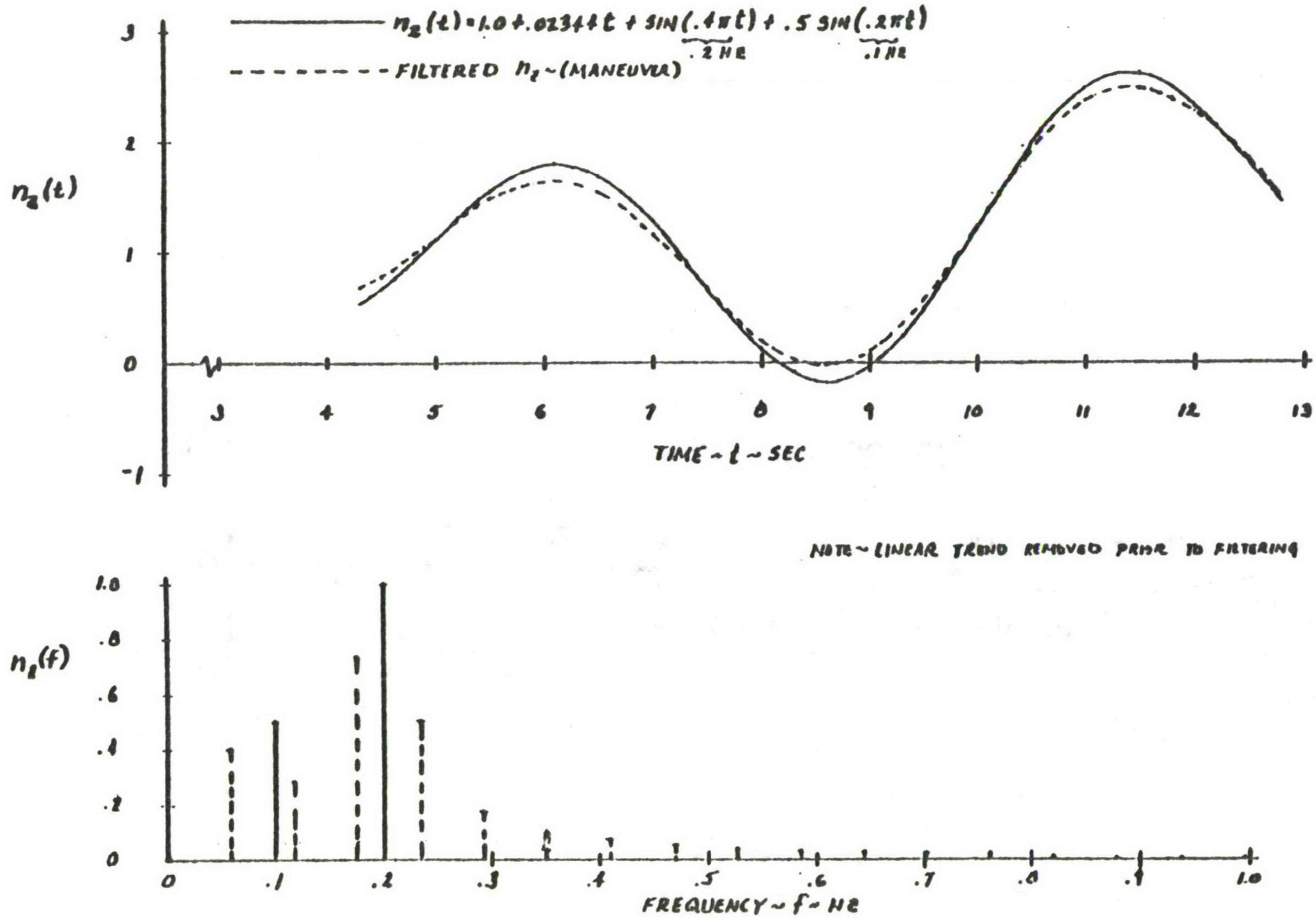



Figure 39. Gust/Maneuver Separation Test Production Filter.

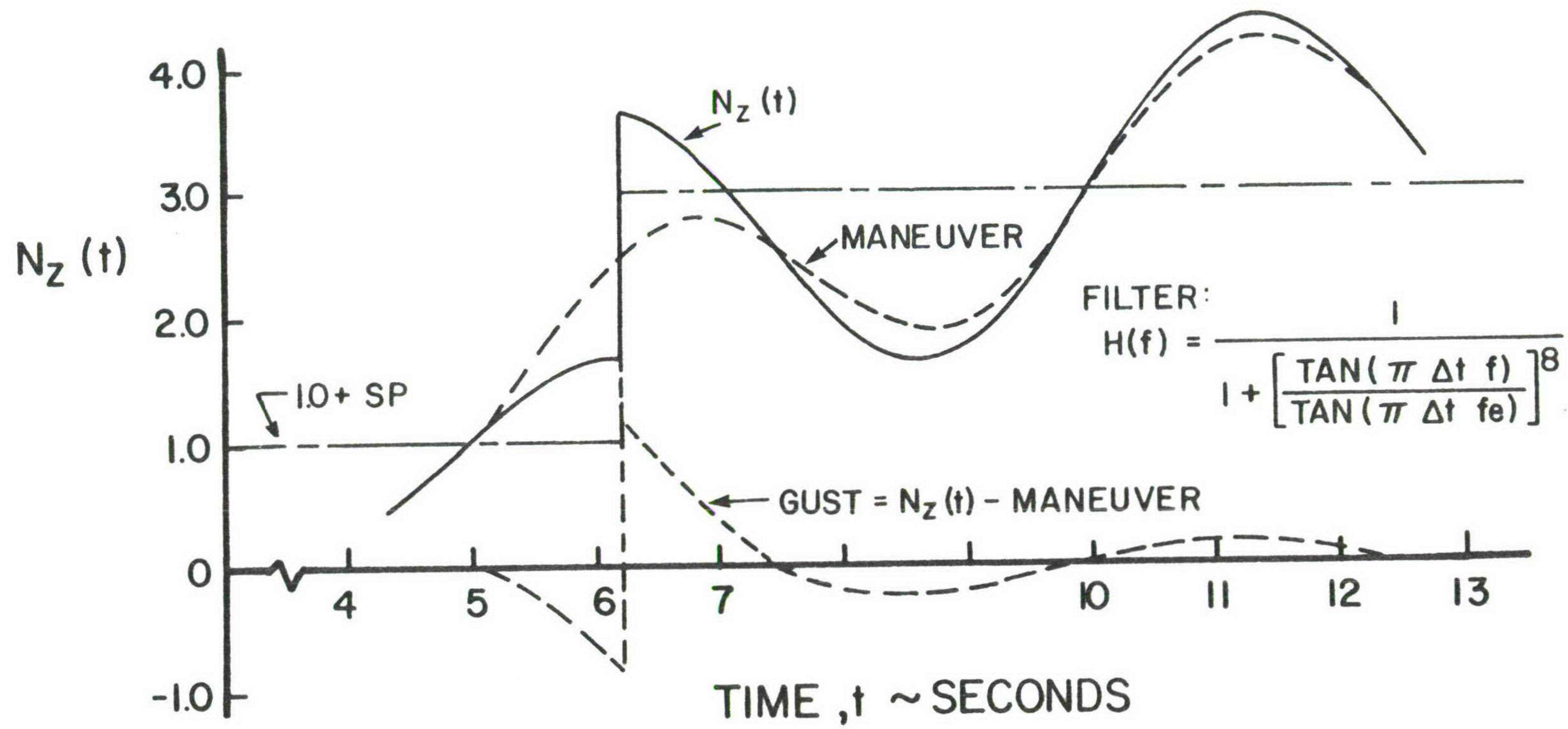



Figure 40. Gust/Maneuver Separation Test.

## C6.2 TIME SEGMENT AND SAMPLE RATE STUDY

In the latter phases of the DRP development, a study was undertaken to evaluate the relative effects on load factor gust and maneuver spectra of (1) increasing the data size of the FFT input from 512 to 1024 points per call, (2) decreasing the sample rate of analyzed data from 30 or 15 to 10 points per second, and (3) increasing the sample size and decreasing the sample rate simultaneously. The study consisted of four variations of the gust/maneuver separation procedure for each of seven C-141 LHRP tapes as follows:

| PROCEDURE NO. | FFT INPUT SAMPLE SIZE | RECORDED DATA SAMPLE RATE |
|---|---|---|
| 1 | 512 | 30 |
| 2 | 1024 | 30 |
| 3 | 1024 | 15 |
| 4 | 1024 | 10 |

Procedure Number 1, 512 points at 30 points per second, represents the current production version of the DRP. To facilitate rapid turn around of the computer runs, the program was modified so that values of N and NSPS, the variables controlling sample size (i.e. $2^N$) and sample rate respectively, would be read in on a new input card.

Procedure 2 differed from Procedure 1 only in the number of points contained in each call to the FFT subroutine. The larger sample size of 1024 points not only halved the number of calls to the FFT but also resulted in a finer frequency resolution in subsequent transformations. Procedures 3 and 4 differed from Procedure 2 and each other only in the effective sample rates. The frequency resolution is calculated from the following equation:

$$\Delta f = \frac{\text{sample rate}}{\text{number of points}}$$

Thus the frequency resolution for the current methodology is 30/512 = .0586 hertz. Increasing the sample size to 1024 points lowers this resolution to .0293 hertz. To obtain a sample rate of 15, every other point in the 30 points per second time history was deleted. To obtain a sample rate of 10, two out of every three points were deleted.

The eight tapes utilized in this study contained a total of 38.5 hours of flight data suitable for gust-maneuver separation. Two of the tapes (RCL63 and RCR55) contained periods of high activity producing gust and maneuver peaks in the larger bands. A summary of the NZ peak count results for these runs is presented in Table 23. As can be seen in Table 23 the peak count distributions for (512,30), 1024,30) and 1024,15) are not significantly different. Of these three sets, the (1024,30) set is considered the more accurate since it possesses a lower frequency resolution (0.293 hertz compared to 0.586 hertz) than the (512,30) set and is better able to pick up higher frequency signals than the (1024,15) set. When the sample rate is dropped to 10 samples per second (i.e. every third point), several gust peaks are missed.

In Table 24 are shown the CPU times for each of the DRP runs. As expected, there is a dramatic drop in run time with a reduction in the data sample rate. Increasing the sample size from 512 points to 1024 points increased the run time by about 10%, but a further change in the sample rate from 30 to 15 per second gave a net overall run reduction of about 20%. The run times referred to here are total DRP times. It is therefore recommended on the basis of accuracy as well as economy that the sample size be increased to 1024 points and that the sample rate be reduced to 15 points per second.

C6.3 COMPARISON WITH REVISIONS VGH SEPARATION METHODS

In all previous VGH programs conducted on the C-141A Force, the task of separating the gust and maneuver load factors was accomplished by the following methodology:

A c.g. load factor was due to gust if,

a) the airspeed trace was rough
b) the load factor trace was rough, and peaks were sharp and irregular.
c) the peaks exhibited a rapid rise and exponental decay
d) The duration of the peak was less than two seconds.

TABLE 23

COMPARISON OF THE EFFECTS OF VARYING
SAMPLE SIZE AND SAMPLE RATE OF
GUST/MANEUVER SEPARATION

| | GUST SUMMARY | | | | MANEUVER SUMMARY | | | |
|---|---|---|---|---|---|---|---|---|
| NO. OF FFT POINTS | 512* | 1024 | 1024 | 1024 | 512* | 1024 | 1024 | 1024 |
| SAMPLE RATE/SEC | 30 | 30 | 15 | 10 | 30 | 30 | 15 | 10 |
| $N_z$ BAND RANGE | | | | | | | | |
| 1.88 TO 1.98 | | | | | 4 | 4 | 4 | 3 |
| 1.78 TO 1.88 | | | | | 4 | 4 | 4 | 3 |
| 1.68 TO 1.78 | | | | | 6 | 6 | 6 | 5 |
| 1.59 TO 1.68 | 2 | 2 | 2 | 2 | 9 | 9 | 9 | 8 |
| 1.49 TO 1.59 | 9 | 9 | 6 | 8 | 19 | 18 | 18 | 17 |
| 1.39 TO 1.49 | 77 | 78 | 71 | 67 | 42 | 41 | 41 | 39 |
| 1.29 TO 1.39 | 459 | 461 | 437 | 414 | 144 | 144 | 144 | 146 |
| 1.20 TO 1.29 | 2370 | 2368 | 2247 | 2159 | 553 | 549 | 543 | 548 |
| 1.10 TO 1.20 | 10659 | 10687 | 10386 | 9952 | 1771 | 1760 | 1770 | 1780 |
| 1.00 TO 1.10 | 17766 | 17875 | 17395 | 16826 | 2534 | 2535 | 2554 | 2556 |
| 0.90 TO 1.00 | 17781 | 17891 | 17409 | 16843 | 2480 | 2484 | 2514 | 2509 |
| 0.80 TO 0.90 | 10653 | 10665 | 10333 | 9983 | 1446 | 1440 | 1457 | 1452 |
| 0.71 TO 0.80 | 2369 | 2357 | 2251 | 2122 | 251 | 247 | 246 | 246 |
| 0.61 TO 0.71 | 445 | 449 | 422 | 397 | 31 | 31 | 30 | 29 |
| 0.51 TO 0.61 | 96 | 89 | 85 | 78 | 6 | 6 | 6 | 6 |
| 0.41 TO 0.51 | 18 | 18 | 18 | 17 | 1 | 1 | 1 | 1 |
| 0.32 TO 0.41 | 5 | 4 | 3 | 2 | | | | |
| 0.22 TO 0.32 | | | | | | | | |
| 0.12 TO 0.22 | | | | | | | | |
| 0.02 TO 0.12 | | | | | | | | |

* CURRENT LHRP PROGRAM

38.48 TOTAL FLIGHT HOURS

TABLE 24

COMPARISON OF THE EFFECTS OF VARYING
SAMPLE SIZE AND SAMPLE RATE ON
COMPUTER RUN TIME

| | CPU TIME - MINUTES | | | | TOTAL FLIGHT HOURS |
|---|---|---|---|---|---|
| NO. OF FFT POINTS → | 512* | 1024 | 1024 | 1024 | |
| SAMPLE RATE/SEC → | 30 | 30 | 15 | 10 | |
| DATA TAPE | | | | | |
| RCL63 | 45.36 | 52.85 | 35.66 | 12.81 | 6.077 |
| RAE28 | 36.36 | 37.09 | 29.56 | 23.31 | 5.800 |
| RCR55 | 38.76 | 39.98 | 28.52 | 24.84 | 4.978 |
| RCQ11 | 36.97 | 41.13 | 30.91 | 27.45 | 9.358 |
| RBU18 | 26.77 | 31.47 | 21.75 | 19.86 | 4.279 |
| RAL54 | 40.64 | 44.92 | 32.53 | 28.42 | 6.888 |
| RCC82 | 9.51 | 10.87 | 7.76 | 6.53 | 1.097 |
| TOTAL | 234.37 | 258.31 | 186.69 | 143.22 | 38.477 |

*CURRENT LHRP PROGRAM

A c.g. load factor was due to maneuver if,

a) it did not meet the above gust criteria.
b) it exhibited a smooth, long-duration shape.
c) it corresponded with a change in altitude or airspeed.
d) the duration exceeded two seconds.

As might be deduced the above procedure was originally conceived for reducing the data by visual inspection of oscillograph tracing of the tape recordings. It is to be noted that gusts and maneuvers were considered to be exclusive events by the above criteria, that is, either a peak was entirely due to gust or entirely to maneuver with no intermix. With this separation methodology, the sum of the gust peaks and the sum of the maneuver peaks obviously equaled the sum of the total load factor peaks.

The current C-141 LHRP gust and maneuver load factor separation methodology is different from the VGH method. The current LHRP method of separation is to remove the linear trend from the load factor signal and filter the remaining signal with all that part nominally above 0.25cps being defined to be due to gusts and all that below 0.25cps assumed to be due to maneuvers.

The VGH method of separating gusts and maneuvers as defined above was temporarily programmed into the DRP in order to compare the results of the two separation methods. As an aid to see what is happening with these two peak counting methods, a sample time history is shown in Figure 41. In this vertical load factor time-history trace, a 2.21g load factor occurred just prior to the end of the sortie. The principal source of this load factor is a turning maneuver; however, since it occurred at a low altitude, there is, as to be expected, a certain amount of turbulence and/or buffeting present. Looking at Figure 41, the total duration of the load factor excursion is from approximately 28.6 seconds. This is well within the 2 second criteria of the VGH separation methods and therefore the peak occurring in this time increment would be defined as a maneuver peak. The peak for this time increment occurs at about T = 29.2 seconds and has a value

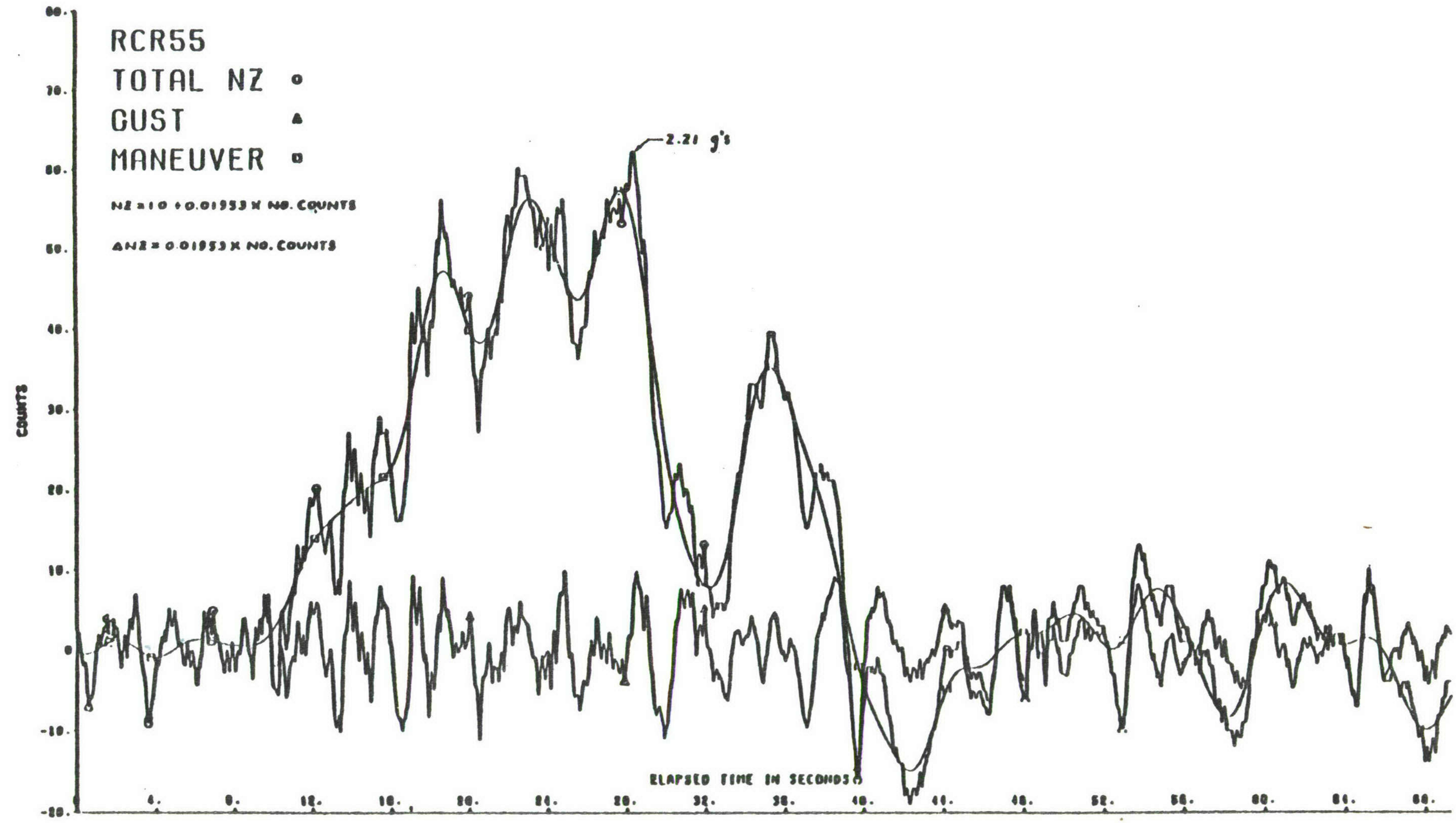



Figure 41. Sample Gust/Maneuver Separation Results.

of 62 counts. This is a load factor of approximately 2.21 g's. Superimposed upon the trace in Figure 41 are the results of separating the total load factor into its gust and maneuver components according to the C-141A methodology yield a maneuver peak of approximately 2.11 g's at T = 27.8 seconds. Numerous gust peaks are defined for this time increment.

Figure 41 typifies the differences in the two separation methodologies. Within LHRP separation methodology, the number and magnitude of the peaks attributed to maneuver decreases while the number (but not necessarily the magnitude) attributed to gusts increases. This trend is clearly shown in the results of applying the two separation methodologies to seven C-141A LHRP data tapes. Figure 42 shows a typical comparison of the gust load factor peak counts. In almost every flight, the number of the low gust factors increases while the number of high gust load factors decreases from the VGH method to the LHRP method. Notice that the sum of the negative and the sum of the positive peaks for maneuver are not equal for the VGH method, whereas it is for the LHRP frequency filter method. The reason they are not equal for the VGH method is that even though positive and negative peaks occur one after another, the division of the peaks between gusts and maneuver for the positive and negative peaks is not equal. A typical comparison of maneuver peaks is shown in Figure 43. The comparison of the methodologies for the total of the seven LHRP tapes (about 44 flight hours) is shown in Figures 44 and 45 for gust and maneuver respectively.

What does this mean to the application of the LHRP load factor peak count data to the C-141A ASIP? It means that the present method of generating stress peak spectra for analyses such as the C-141A DADTA or the C-141 Fracture Tracking Program will no longer be directly applicable for gust and maneuver peak counts obtained by the LHRP. Presently, for any flight segment, the stress peak spectra is generated first for gust and then for maneuver. The two spectra are then summed to yield the total spectra for each flight segment. But it has been shown that, for the new LHRP methodology, the simple sum of the gust and the maneuver spectra will not equal the total. Therefore, new methods which express

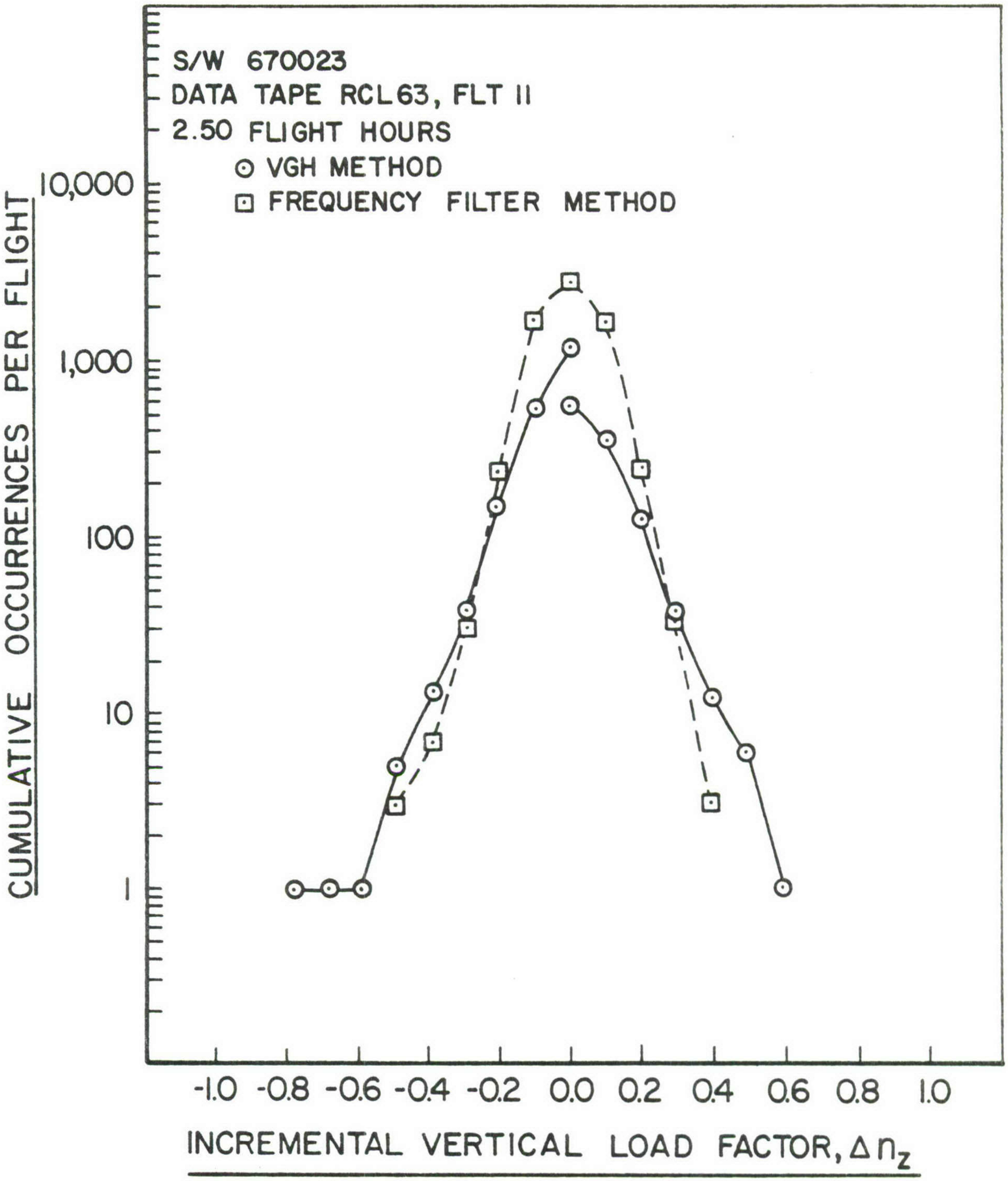



Figure 42. Comparison of Gust/Maneuver Separation Methods Gust Load Factor.

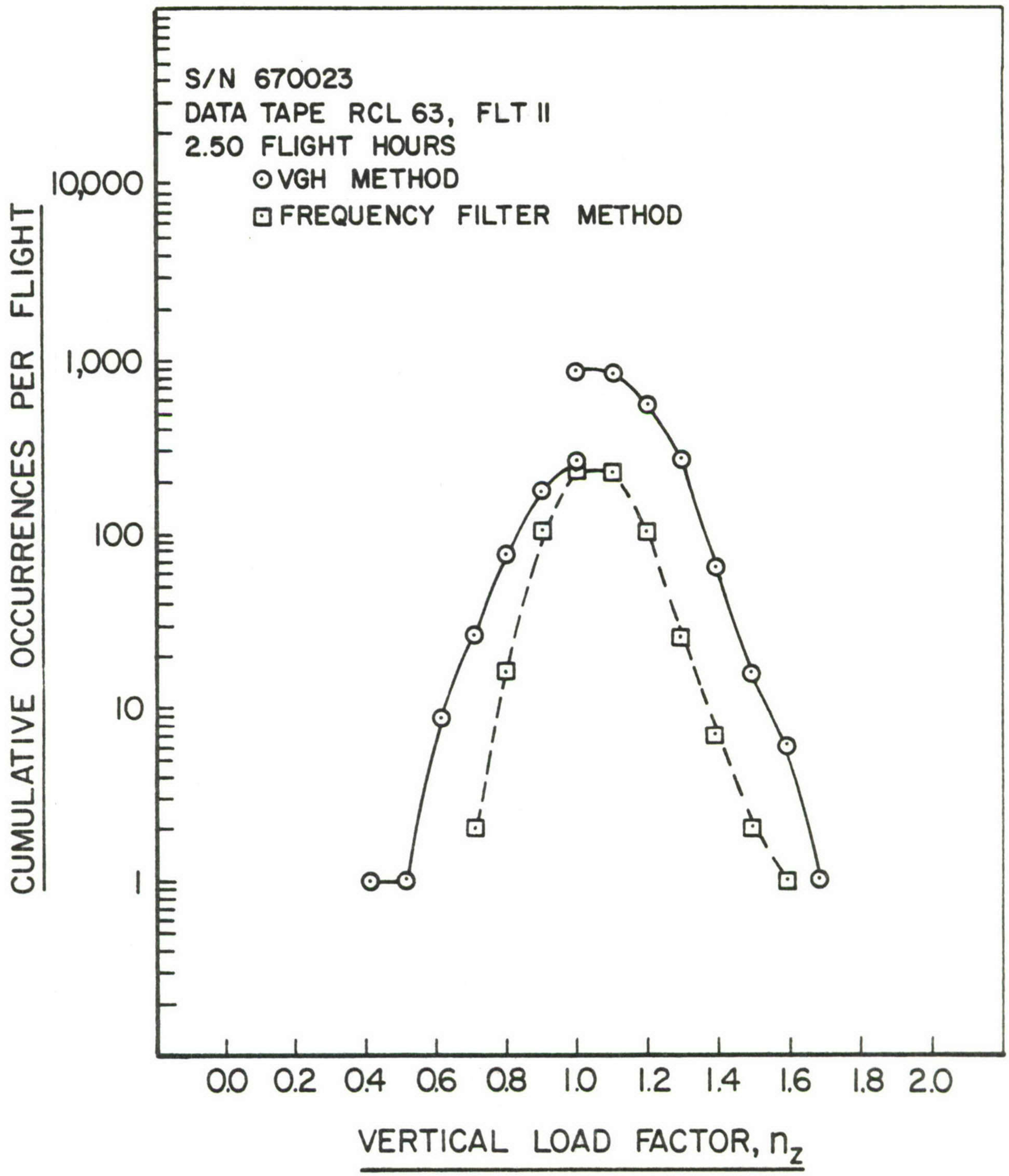



Figure 43. Comparison of Gust/Maneuver Separation Methods Maneuver Load Factor.

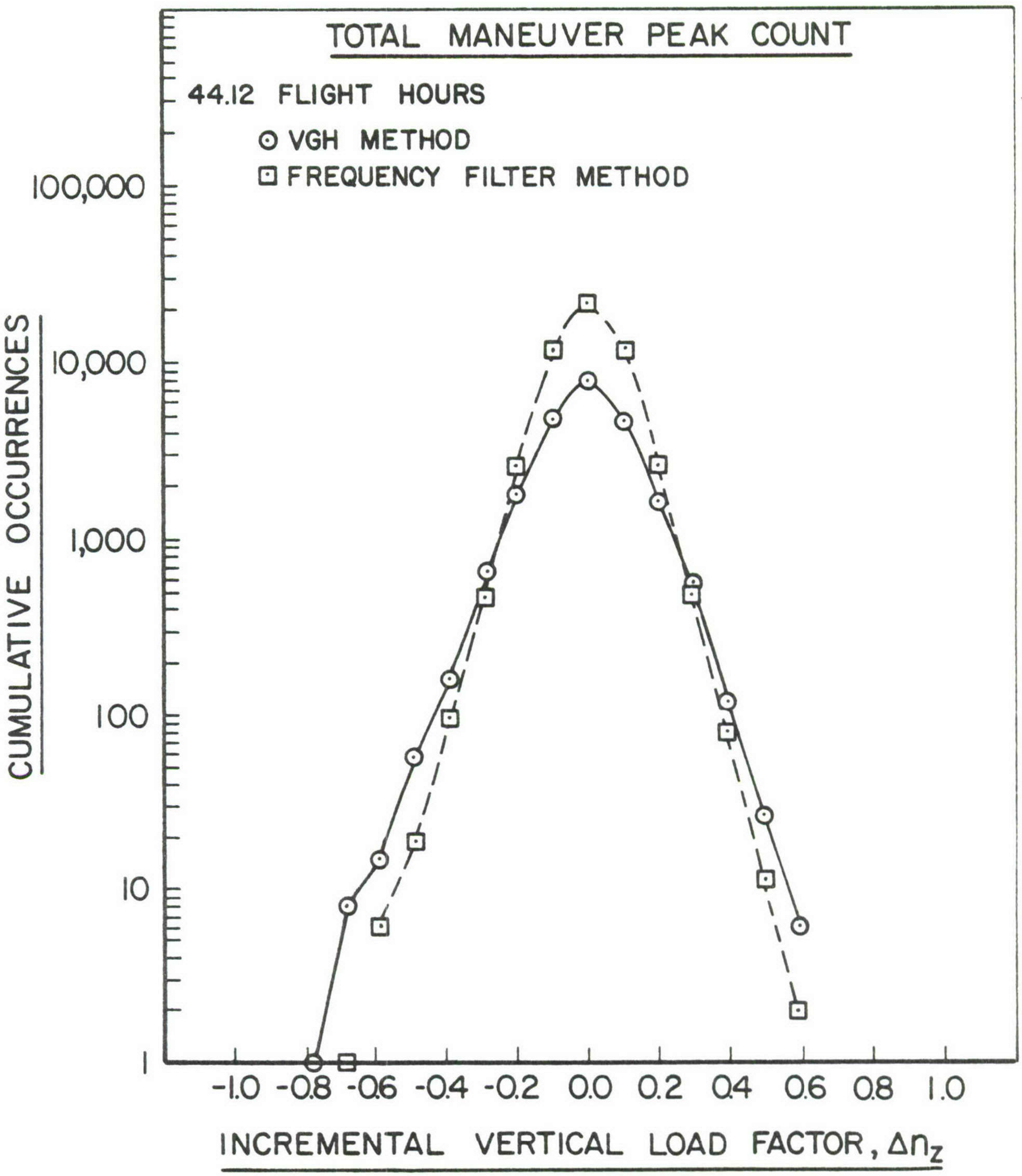



Figure 44. Comparison of Gust/Maneuver Separation Methods Gust Load Factor.

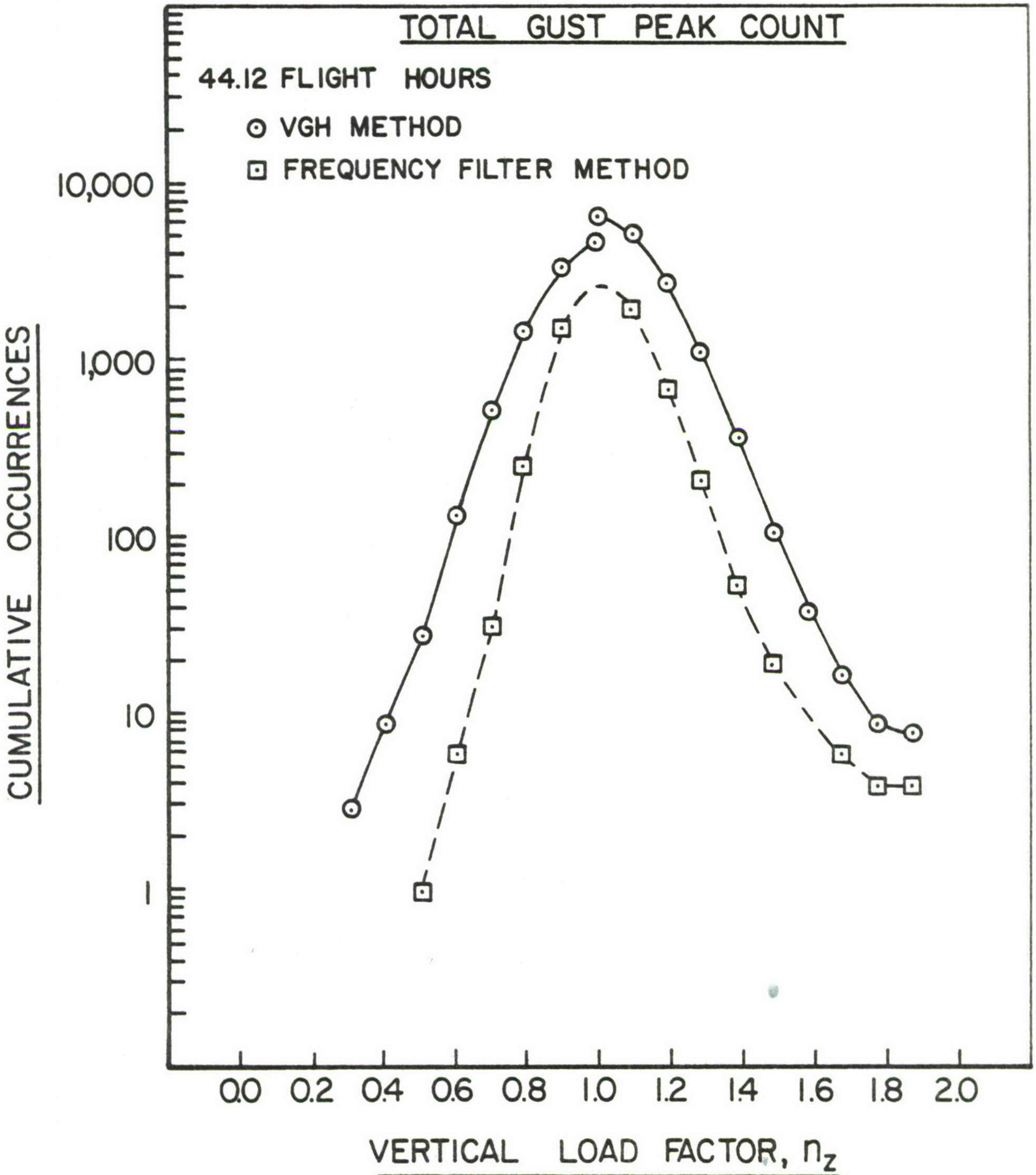



Figure 45. Comparison of Gust/Maneuver Separation Methods Maneuver Load Factor.

joint probability of occurrence of the gust and maneuver load factors would have to be installed in the fracture analyses programs in order to incorporate the LHRP load factor peak count data.

## C7.0 DAMAGE, SORT, AND ACCUMULATE PROGRAM CHECKOUT

The Damage, Sort, and Accumulate Program is the second of the two C-141 LHRP programs. Its main functions are as its name implies. It sorts the data output by the DRP, computes fatigue damage from the strain peak counts, prints a load factor peak count report, and outputs a usage tape for the IASLMP. A functional flow diagram of the C-141A DSAP is shown in Figure 46.

The Damage, Sort and Accumulate Program was checked out using the data generated by the DRP with the input data tapes listed in Table 21.

## C8.0 EVALUATION OF STRAIN DATA

### C8.1 OVERALL STATUS OF STRAIN CHANNELS

The five LHRP strain channels are:

Strain 2 Wing Joint Strain, IWBRS 374.4
Strain 3 Center Wing Strain, CWS 53.2
Strain 4 MLG Bogie Beam Strain
Strain 5 F.S. 1108 Stringer Strain
Strain 6 NLG Bulkhead Strain

An overview of the number of strain channel discrepancies experienced for the third quarter, 1977 and first quarter, 1978 are shown below.

PERCENT STRAIN CHANNEL DISCREPANCIES

| BASE | 3Q77 | 1Q78 |
|---|---|---|
| Altus | 65 | 49 |
| Charleston | 68 | 57 |
| McChord | 55 | 64 |
| McGuire | 30 | 24 |
| Norton | 53 | 60 |
| Travis | 45 | 53 |

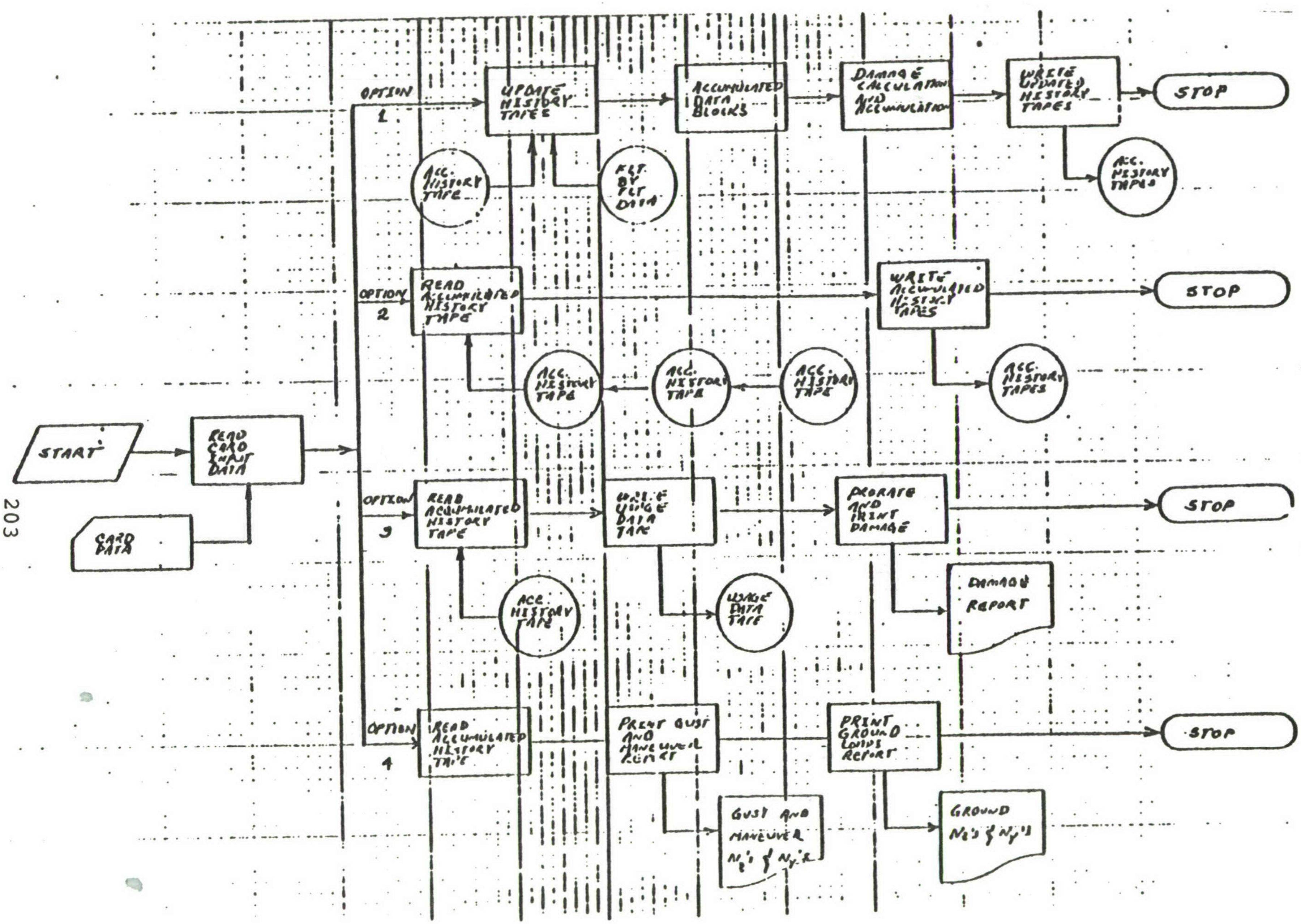



Figure 46. DSAP Flow Diagram.

These data were produced during the manual edit of flight tapes at OC/ALC prior to processing and the discrepancies are categorized as; non-operative, intermittent, data norm shifted, data invalid, channel frozen 0, and channel frozen full scale. This edit does not address the total validity of the strain levels, but is a general assessment of channel activity.

## C8.2 ACTIVE CHANNEL STRAIN VALIDITY

The time histories from over 50 flights (nineteen tapes) by five aircraft were examined with primary emphasis on the response of the two wing strain channels. In the initial screening, Strain 3 appeared responsive during twenty-eight flights and Strain 2 was active during seven flights. Approximately two hundred ground and flight points at $N_z = 1.0g$ were selected from these flights and component loads were calculated for each. Stress-load ratios were used to convert the analytical load cases to total strain at the two gage locations and measured strain levels were compiled for comparison. Figure 47 shows typical flight profile data. The comparison of calculated versus analytical strain for the eight flights selected for analysis indicate that severe low gain problems exist in the strain channels and no correlation is noted between measured and calculated level trends. It was concluded that the strain data from the selected flights were also not usable for damage calculations because of the following discrepancies:

(a) Ground strain levels were randomly offset from nominal values.

(b) Channel gains were unacceptably low.

(c) Analytical trends with varying fuel loads and flight conditions were not reflected in the measured data.

(It should be noted in this regard that the C-5A program has produced very useful strain data. This indicates that such data are usable for LHRP if the system is properly designed and installed.)

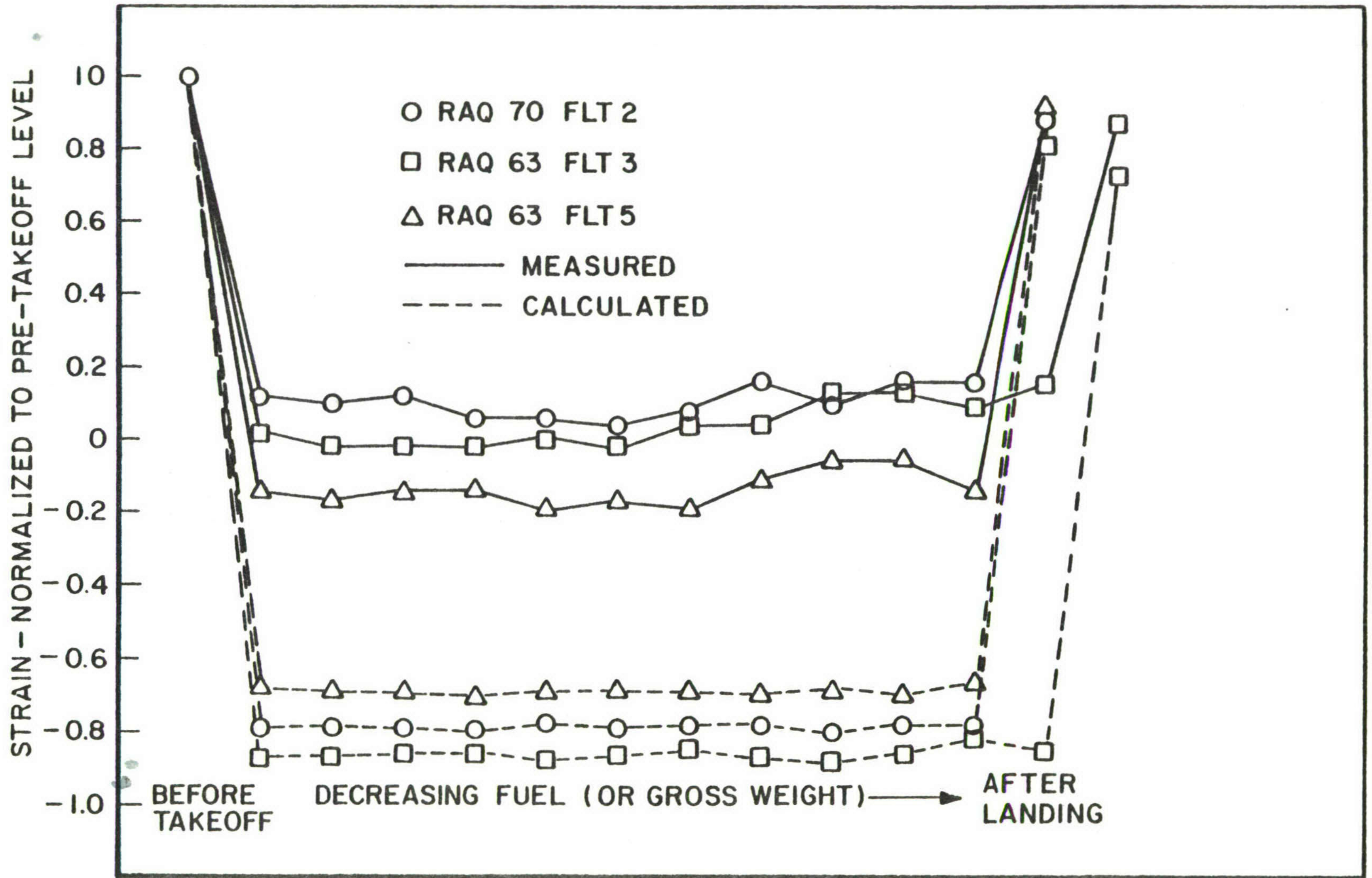



Figure 47. Strain 8, OWS 58.2 Flight Time History $N_z$ = 1.0g.

## C9.0 EVALUATION OF EDITING CRITERIA

Specific data checks were present within the C-141A DRP software when the program was originally delivered to OC/ALC. These data checks were as follows:

* (1) The internal automatic calibration sequence check, commonly called the BIT (built in test) sequence.
  (2) $N_z$ check for 1.0g $\pm$0.1.
* (3) Serial number check.
* (4) Fuel weight check.
* (5) Gross weight check.
* (6) Static pressure at liftoff.
* (7) Total pressure at liftoff.
* (8) Ground speed at liftoff.
  (9) Flap position at liftoff.

The tests marked with an asterisk were critical data tests, that is, if these tests were not passed, execution of the DRP was terminated.

## C9.1 INTERNAL CALIBRATION SEQUENCE

The internal calibration sequence is automatically activated 30 seconds after the recorder is turned on in the BIT mode. The BIT sequence consists of the sequential application of three discrete voltage levels to the input of the analog to digital converter on all the data channels. A subroutine was included in the DRP to check this calibration sequence for each channel, print the results of this check, and flag those channels which did not pass the test so that they would not be processed. Occassionally however, one or more of the calibration levels as written on the tape will be unusable because of a short frame or parity error. Part of the standard manual editing procedure at OC/ALC is to "dub in" the calibration levels which are erroneous or missing for obviously good data channels. This manual editing is probably the most efficient and accurate way to evaluate the calibration checks and should be continued. The program software which checks the calibration sequence should be left intact so that obviously bad data channels can still be flagged so as not to be processed.

C9.2 $N_z$, $N_y$ CHECK

Presently the $N_z$ channel is checked after the calibration sequence has occurred. A check is made to determine if the $N_z$ count is between 101 and 103 counts. However, whether or not the $N_z$ count is within the prescribed limits, the processing of the channels continues. It is recommended that the process/no-process flag be set such that $N_z$ data is not processed if this test is not passed. It is also recommended that the $N_y$ channel be similarly tested. The DRP as delivered to OC/ALC will have these tests in the logic. Offset and slope corrections may be applied to those data channels as described in Section C9.10.

C9.3 SERIAL NUMBER CHECK

The serial number check is made during the first or second second of initial taxi. The serial number in the documentary data (DDI and DD2) is simply checked against a master list of C-141A LHRP serial numbers, and if there is no match, the sortie is not processed. It is essential that all LHRP data be associated with a particular aircraft serial number for later sorting in the DSAP. Presently these data are checked during the manual editing at OC/ALC and corrected or inserted if they are incorrect or missing. It is recommended that this current procedure continue.

C9.4 FUEL WEIGHT CHECK

Presently the fuel weight dialed into the recorder is automatically checked to determine if it is between 8000 and 153,000 pounds. As discussed in Section C5.6 this test was not always valid since very occasionally a full fuel load was dialed in at over 153,000 pounds. Also, the fuel weight is supposed to be dialed in hundreds of pounds. The most prevalent error in the fuel weight data is that it is dialed in with the significant digit shifted either one place to the right or one place to the right or left. A procedure has been devised and programmed to eliminate this occurrence automatically in the program and is described in Section C5.6. It is recommended that the card input fuel weight lower and upper bound check values be 80 and 1600 hundreds of pounds respectively.

C9.5 GROSS WEIGHT CHECK

The gross weight check is also made during the first one or two seconds of initial taxi after recorder turn on. This is also a critical data item as it is used to calculate effective cargo weight which is essential for identifying the sortie data blocks. It is recommended that the lower and upper bounds of this check be 1400 and 3300 hundreds of pounds respectively.

C9.6 STATIC PRESSURE AT LIFTOFF, PS

Presently the DRP checks the static pressure at liftoff. The current editing limits used are 5 to 66 counts which represent -521 to 6063 feet respectively. This check cannot realistically be precise since no information is available on the geographical location of the aircraft operations from the LHRP data tapes. It is therefore conditionally recommended that these checks be continued.

C9.7 TOTAL PRESSURE AT LIFTOFF, PT

The check limits for total pressure at liftoff used by the DRP are 5 and 22 counts for the lower and upper bounds. These limits are approximately between 73 and 169 knots at sea level for the nominal calibrations. The takeoff speeds of the C-141A are well within these limits, so that if the PT reading is outside these limits, it should be considered to be bad.

C9.8 GROUND SPEED AT LIFTOFF, VG

The ground speed at liftoff is checked automatically by the DRP for a lower and upper bound. If this test is failed, the processing of the sortie by the DRP is discontinued. Presently the limits on ground speed at liftoff are 230 and 255 counts, which correspond to 92.5 and 102.6 knots respectively.

As mentioned preveiously, 255 counts is the maximum reading available on any one channel. Since most C-141A liftoffs are greater than 102.6 knots, the VG count reading at liftoff is unobtainable with the current calibration for most of the takeoffs. The lower limit of 92.5 knots occasionally is too low, so a lowering of this limit to 200 counts (about 80 knots) is recommended. It must be remembered that a reading on the VG channel of 200 counts would not necessarily be the accurate liftoff airspeed due to such variables as normal instrument tolerance and head wind velocity. A cross-check between ground speed and airspeed can be made with some caution. Figure 48 shows the correlation between ground speed counts (VG) and total pressure counts (PT) at sea level for zero head wind and nominal instrument calibration.

## C9.9 FLAP POSITION

Flap position is checked by the DRP, but if the check fails, the program continues to execute anyway. The current limits in the programs are 178 and 197 counts, which correspond to 68% and 77% flaps for the nominal calibration. The flap position is used to identify TAG events for which the flaps are always kept partially deflected. If the flap position goes to less than 51 counts, they are considered retracted for data blocking purposes.

These data, however, are not critical, and since the program makes a continuous check of the data from frame to frame, it would be difficult to correct bad data or dub in correct data. Also the DRP currently does not provide the capability to automatically correct this data.

## C9.10 STRAIN DATA AND LOAD FACTOR DATA CORRECTION

The strain data quality has been evaluated and is discussed in Section C8.0. For the most part, the quality of this data is very poor. However, on occasion use of an offset or slope correction factors may render the data useful. The DRP provides the mechanisms to apply offset and slope corrections. The expected strain readings as a function of aircraft parameters such as fuel weight, cargo weight, airspeed, and altitude are obtainable via computer output. These data may be used to compare with the measured data to determine its correctness. These data may also be used to apply offset or slope correction to the strain as necessary by input to the DRP.

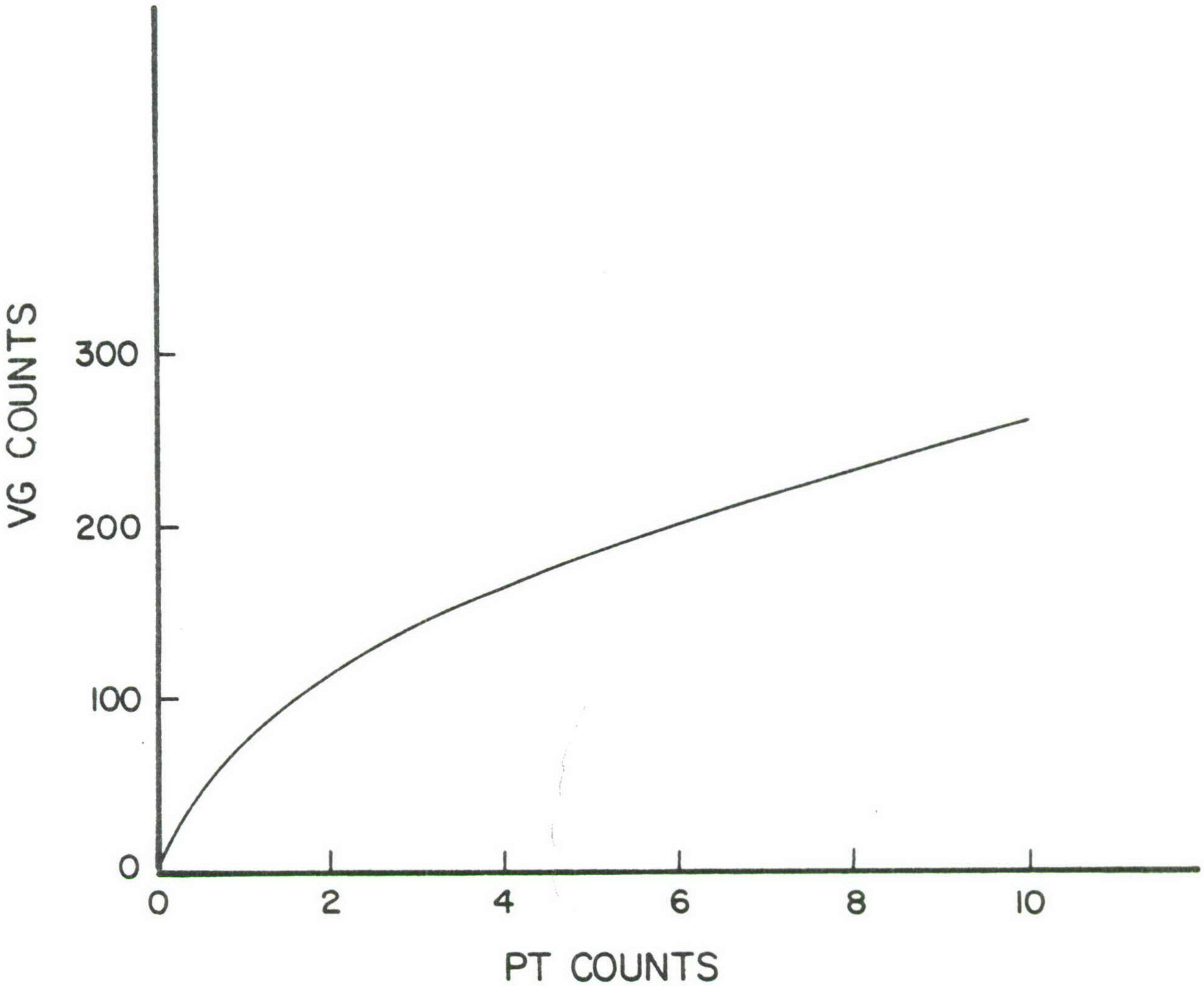



Figure 48. Nominal Relationship Between Groundspeed (VG) and Total Pressure (PT) Readings.

It is very difficult to determine slope errors and the necessary correction for the load factor data, $N_z$ and $N_y$. The offset correction, however, may easily be determined by observing these channel readings when the aircraft are motionless on the ground just prior to takeoff. Offset corrections to $N_z$ and $N_y$ may also be applied by DRP inputs.

## C10.0 RECOMMENDATIONS

In making these recommendations for the C-141A LHRP, the objectives of the C-141A ASIP must be given the prime considerations. Among those objectives established in Air Force Regulation 80-13 (16 July 1976), the C-141A LHRP is primarily used to "acquire, evaluate, and utilize operational usage data to provide a continual update of the in-service structural integrity of the aircraft".

MIL-STD-1530A(11) sets forth the requirements of AF Reg. 80-13 for aircraft recording programs. In this standard, the objective of the LHRP's is defined to be "to obtain time history records of those parameters necessary to define the actual stress spectra for the critical areas of the airframe." These time history records are to be used to assess the applicability of the design and durability loads/environment spectra and also to assess the baseline operational spectra.

More specifically, the C-141A LHRP data may potentially be utilized as follows in support of these objectives:

(1) Assessment of aircraft usage. This would include types of missions flown, mission mix, and fuel/cargo/speed/altitude combinations. These data can be used to assess durablility mission profiles, to compare with the individual aircraft tracking program in order to assess the accuracy thereof, and to assess criteria established for individual tracking programs such as speed/altitude profiles for climb and descent operations.

(2) Assessment of aircraft operational criteria. These would include the maneuver loads for both flight and ground operations, landing impact sink rates and aerial refueling loads.

(3) Assessment of the environmental criteria used for the durability analysis and the individual aircraft tracking program. This assessment would include the criteria for flight gusts and ground surface roughness.

(4) Assessment of the stress spectra generated for fatigue or crack growth calculations for the individual aircraft tracking program. This is accomplished by using the direct measurement of strain data at representative points on the airframe.

## C10.1 GUST AND MANEUVER SEPARATION

he loads/stress spectra generation for the C-141A IASLMP is based upon the statistical prediction of load factor occurrences at the aircraft c.g. For flight, the two sources of loads are maneuver operations and atmospheric gusts. A third source will be added when aerial refueling capability is achieved on the C-141B. As discussed previously in Section C6.0, the present C-141A LHRP method of updating the gust and maneuver contribution to the load factor utilizes a band pass filter on the load factor data signal. All load factor data above 0.25 Hz is defined to be gust in origin, everything below 0.25 Hz is assumed to be maneuver.

From 1967 through 1971 about 27,000 hours of VGH flight data were collected on the C-141A. These data were used to establish the current C-141A IASLMP gust and maneuver criteria. The method of separating gust and maneuver load factors in the VGH program, while sounding familiar to the current LHRP method, is in reality drastically different. Gust encounters and maneuvers were assumed to be mutally exclusive events in the VGH data reduction, that is, a c.g. load factor peak was solely due to either a gust or a maneuver. The rules for determining the source of load factor peaks in the VGH programs are listed in Section C6.0.

One of the rules states that if the mean-to-mean crossing of the c.g. load factor was 2 seconds or greater, the peak occurring between these mean crossings was a maneuver peak. This represents a half wave length for a 0.25 Hz or less signal. In recognizing that (1) maneuver operations and gust encounters often times occur simultaneously, and (2) differences in loads/stress spectra are realized depending on whether the source is gust or maneuver, the LHRP used the frequency separation method by which the gust and maneuver load factor separation may be accomplished.

As can be seen from the results of comparing the peak count data in Section C6.0, the plotted peak count distributions from the two methods is drastically different. However, as it was also discussed in this section, the statistical parameters derived from these peak count distributions would be utilized differently in order to predict load factor exceedance data. Nevertheless, the exclusive use of the present LHRP frequency separation method presents some difficulties to comparing the LHRP data with the past VGH data and with the current IASLMP criteria. These data may be conveniently compared at two levels; they are (1) the statistical parameters derived from the peak counted data or (2) the expected load factor exceedances obtained from these statistical parameters. This means that the c.g. load factor data from the C-141A LHRP could be compared with past VGH programs and current criteria only by generating expected total c.g. load factor exceedances. Direct comparison of statistical parameters would not be possible.

It is therefore recommended that temporary program changes made in the Data Reduction Program (DRP), which provided for gust and load factor separation by the VGH method, be permantly incorporated into this program while retaining the current frequency separation method. It is also recommended that further DRP modifications be made in order to provide the capability to output this load factor data by data block to the Damage, Sort, and Accumulate Program (DSAP) and that the DSAP also be modified in order to print the load factor reports for this method. After these program changes have been made and a sufficient amount of data processed, it is recommended that a final study and determination be made as to which one, or perhaps both, methods should be continued. The ramification of the effect on the C-141A/B IASLMP fracture tracking methodologies and the accurate prediction of the c.g. load factor exceedances should be the foremost considerations in this determination.

## C10.2 STRAIN DATA AND DAMAGE CALCULATIONS

Summarizing the analysis of the strain data as reported in Section C8.0, the strain data as currently obtained in the C-141A LHRP is extremely poor, both from a quality and a quantity viewpoint. Being such, some changes are mandatory in regards to the future measurement and processing of this data.

Three alternatives seem to be in order. The first and most recommended alternative is to upgrade the strain data through increased emphasis in the LHRP system maintenance. Reliable and accurate strain data can be obtained from the C-141A LHRP as evidenced from other C-141 flight recording programs. It is believed that the particularly poor return of data from the C-141A LHRP stems from improper initial installation of some of the gages. Therefore the increased efforts to improve the C-141A LHRP strain data would be mainly in the areas of repair and/or replacement of malfunctioning gages and some type of periodic recalibrations of the gages. In various discussions with Air Force personnel, it appears that this alternative has been difficult to achieve on the C-141A LHRP system. No part of the C-141A LHRP recording system is flight critical, that is, no part of the system is necessary for safe flight operations. Hence, the LHRP system receives very low priority in scheduling maintenance. If this course of action is taken, it is also recommended that a relocation of the strain gages be effected as they are replaced. The existing five gages are located as follows:

1) Wing Joint Upper Surface
2) W.S. 53.2 Upper Surface
3) MLG Bogie Beam
4) F.S. 1108 Stringer
5) NLG Bulkhead

It is recommended that the strain gages be relocated as follows:

| | POINT | WING SURFACE | ZONAL "INDICATOR" COVERAGE |
|---|---|---|---|
| 1 | W23 | Upper | Inner & Center Wing (Spanwise+Chordwise Splice) |
| 2 | W35F | Upper | Inner & Outer Wing (Spanwise+Chordwise Splice) |
| 3 | W47B | Lower | Inner & Outer Wing (Spanwise+Chordwise Splice) |
| 4 | W41 | Lower | Inner/Center Wing Rear Spar + Spanwise Splices + F.S. 958 Strap |
| 5 | A12B | Fuselage | Upper Crown + Empennage |

Of these recommended LHRP strain gage locations, W23, W35F, and A12B were recommended for the update C-141A/B Fracture Tracking Program. It is planned that W47B and W41 will be added as recommended tracking locations to the Fracture Tracking Program at a later date.

The second possibility would be to eliminate processing of the current strain data altogether. This obviously would be the most economical decision insofar as the direct operating costs of the LHRP are concerned. Any maintenance now performed on the strain gages could cease, and no more expenditures for spare parts in support of these channels would be required. Since the multiplexer and recorder are "hardwired" for the number of channels as described in Section C3.0, data would still be recorded on the magnetic tapes for these then open channels; however, a considerable computer savings would be realized by bypassing the strain data analysis in the programs. While this decision would eliminate the possibility of measured and predicted strain data comparison, the remaining data obtained by the C-141A LHRP would provide all those parameters necessary to estimate the actual stress spectra on the aircraft as is required of it by MIL-STD-1530A(11). The transfer from c.g. load factors to external aircraft loads is a well established procedure and has been used extensively on the C-141A IASLMP since 1969 as well as on the C-141A, YC-141B and C-141B Durability and Damage Tolerance Assessment. These transfer relationships are supported by data from the C-141A Dynamic Response Tests, the Yc-141B/C-141B flight tests and the C-141A Fatigue Test Program. The confidence level in these transfer relationships, while not as good as accurately measured direct strain data, is much better than the prima faci acceptance of the current LHRP strain data. Therefore, the processing of the strain data could be eliminated from the C-141A LHRP and the program would still meet the requirements of AF Reg 80-13 and MIL-STD-1530A(11).

A third possibility is to augment the current strain data with analytical and/or test measured strain data. The objective would primarily be to increase the quality of the measured data by providing offset and slope error corrections. There are, however, two strong arguments against this procedure for the C-141A LHRP. The first is that the data must be of sufficient quality so that the corrections applied to direct strain measurements are small. If gross error corrections are required, there is still no confidence in the data. This would be the case for the C-141A LHRP strain data analyzed in conjunction with this report. The second argument is that if the corrections are based upon data parameters other than the measured strain data (i.e. c.g. load factor, speed, etc.), then one might as well use these exclusively to predict stress/strain spectra since it has been established that they may be used for this purpose.

C10.3 PRESENT RECOMMENDATIONS FOR DATA RECORDED AND PROCESSED

The data recorded by the C-141A LHRP system can be divided into two categories. These are (1) critical data and (2) non-critical data. The critical data are as follows:

(1) Pitot Static Pressure
(2) Pitot Total Pressure
(3) Ground Speed
(4) Landing Gear Event (Up or Down)
(5) Landing Gear Strut Event (Extended or Compressed)

The Data Reduction Program (DRP) presently will not function unless the critical data channels are operational. The critical data are used to determine the sortie profiles and the data blocks.

The non-critical data are not essential for the DRP software to process a LHRP data tape. If none of the non-critical channels are functioning, the software will still accumulate usage data (time by data block) for later reporting. The non-critical data channels which are currently being used in the C-141A LHRP are as follows:

(1) Normal Acceleration
(2) Flap Position
(3) Lateral Acceleration
(4) Wing Joint Strain
(5) CWS 53.2 Strain
(6) MLG Bogie Beam Strain
(7) F.S. 1108 Stringer Strain
(8) NLG Bulkhead Strain

The non-critical data which are currently not being used are as follows:

(1) Cabin Pressure
(2) Pitch Rate
(3) Yaw Rate
(4) Rudder Position
(5) Elevator Position
(6) Nose Gear Angle
(7) Spoilers

In order to provide <u>criteria</u> checks and/or updates to the C-141A Durability and Damage Tolerance Analysis or to the C-141A Individual Aircraft Service Life Monitoring Program (IASLMP), the data required from the LHRP would be the five critical channels as listed above, the normal and lateral c.g. accelerations, the flap position, and the cabin pressure. This set of data would provide a basis for checking and updating all the criteria for the aforementioned program with exception of the landing impact criteria. The C-141A LHRP system as it exists cannot measure landing impact sink rates. However, an indirect measurement of ground contact sink rates are measured by the c.g. accelerometers as this data can be used to evaluate the landing impact criteria.

It is to be noted that presently the C-141A LHRP system does not process the cabin pressure data channel. However, all five of the C-141A DADTA analysis points for the forward fuselage area were pressure critical; the lowest safety limit of 25,560 flight hours was calculated for analysis point F-4, the forward pressure diaphragm support tee.

At the present time there would be no requirements for the non-critical data channels which are not being processed with the exception of cabin pressure as discussed above. However, this does not rule out any future needs for this data, especially if hot spots or trouble areas later develop in the area of the empennage. It is observed that the amount of data measured from these non-critical channels which are not being processed is much higher than the amount of strain data measured.

There are two additional data items essential for future C141 service life analyses which are not currently measured by the LHRP system. These data items are: (1) aerial refueling event indicator and (2) a fuel totalizer. These two additional data items will be required in order for the computer software to be able to identify and separate the flight data for aerial refueling operations. Presently the amount of fuel remaining onboard is calculated from the takeoff fuel, which is dialed into the recorder, less the fuel consumed during the flight. The fuel consumption is calculated from various flight profile parameters as measured by the LHRP system.

The following recommendations are therefore made in regards to the selection of and processing of the LHRP data channels.

(1) The future disposition of strain data processing should be decided according to the recommended alternative as discussed in Section C10.2

(2) The number and magnitude of the cabin pressure cycles should be retained by the DRP for output onto tape for later reporting in DSAP.

(3) A fuel totalizer channel should be added in order to enable the DRP to more accurately determine the fuel weight, especially for aerial refueling events.

(4) An event channel should be added in order for the DRP to determine a refueling operation.

(5) All other data channels have not been processed at the present time. It is recommended that OC/ALC begin utilizing the data compression subroutine and store and save this data for future use.

## C10.4 RECOMMENDATIONS FOR OTHER SOFTWARE DATA REDUCTION CAPABILITIES

It is recommended that the Damage, Sort, and Accumulate Program (DSAP) history tape output format be revised so as to provide more detailed information in order to be able to perform service life analyses on the C-141A Force. Presently the load factor peak count distributions are not output by the airspeed band - only by gross weight and altitude band. It is also recommended that this load factor peak data be separated as either normal or refueling flight operations. This data should also continue to be separated by possession base and mission type for each aircraft.

## C10.5 RECOMMENDATIONS FOR FUTURE LHRP SOFTWARE MODIFICATIONS AND STUDIES

At the present time the C-141A Force is being modified by adding aerial refueling capability. The assessment of aerial refueling operation on the C141B Crack Growth Operational Safety Limits was accomplished during the C141B Durability & Damage Tolerance Analyses (DADTA) but this was done with a very limited amount of flight data to estimate loads criteria along with projected usage. The methodology of the C141A/B IASLMP dictates the prediction of aircraft loads by means of statistical criteria; therefore it is necessary to obtain a sufficient amount of flight data from service operations in order to satisfy these requirements. The C-141A LHRP is the ASIP tool to provide this data.

It is therefore recommended that software modifications begin as soon as possible on the C-141 LHRP, DRP, and DSAP computer programs to provide for processing aerial refueling data. These software modifications should proceed on the following assumptions:

(1) The aerial refueling event will be defined by the opening/closing of the fuel probe door. An event channel should be added to the LHRP for this purpose.

(2) A fuel totalizer channel will be added to the LHRP system.

The LHRP software should be modified so as to provide for the separation of usage data and the peak counting of c.g. load factors by a set of data blocks established for aerial refueling. This set of data blocks should be established for compatibility of concurrent operations in the C-141B LHRP and the C-141B IASLMP.

Presently the DRP software will not function if the ground speed channel is inoperative. This results in the loss of all the flight data as well as the ground data unless laborious manual revision are made to the data tapes in order to trick the program. It is proposed therefore that a revision be made to the DRP software to provide for alternate logic in case the ground speed channel is inoperative. This would be accomplished by a small amount of additional card input and by program monitoring of the event channels. These program modifications would be relatively minor and would greatly improve the data retrieval on those aircraft with faulty ground speed channels.

It is also recommended that a study be made and proposal submitted to WR/ALC concerning the installation of new strain gages on the C-141A LHRP aircraft. These new gage locations would reflect the studies and results of the C-141B DADTA as well as a review of types of strain gages available and technique of installation so as to provide for more reliable data than has been obtained from the present gages.

## C10.6 GENERAL

It is Lockheed-Georgia's opinion that the continued and reliable operation of the C-141A LHRP data system is vital in order to be assured of the continued safe life operation of the C-141A Force for its remaining service life. The LHRP recording system is only means for providing measured service flight loads for the C-141A Force. This data is needed for the continued assessment of the safe life analyses made on the aircraft, the augmentation of scarce aerial refueling data, and the detection of severe usages in special exercises or missions. Because of its importance in proper fleet management, it is believed that an upgrade in data reliability is immediately necessary.

The upgrading of the LHRP data should be initially concentrated into three main areas for maximum effectiveness. These areas are:

(1) Provisions for a periodic system calibration check. It is recommended that the calibration checks be performed a minimum of every 1000 flight hours. It is believed that an adequate procedure could be initiated so that this task could be accomplished at field level.

(2) Provision for increased maintenance of the LHRP equipment. All too often C-141 LHRP aircraft continue to operate months or even years with malfunctioning data channels.

(3) Provisions for back up data channels. Providing for alternate data channels would greatly enhance the data retrieval rate, provided that items (1) and (2) above are followed.

With the initiation of the above items, the C-141 LHRP should provide data for assessing safe life operations of the C-141 for the remainder of its service in the Air Force.