USAAVRADCOM-TR-80-D-15

LEVEL II

12

AD A097283

STRUCTURAL INTEGRITY RECORDING SYSTEM (SIRS) FOR U.S. ARMY AH-1G HELICOPTERS

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March 1981

Final Report for Period July 1975 - November 1979

Approved for public release; distribution unlimited.

Prepared for

APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

81 4 3 101

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report was prepared by Technology Incorporated under Contract DAAJ02-75-C-0050. The report documents the design, fabrication, and testing of a Structural Integrity Recording System (SIRS). The SIRS is a total system including a flight recorder, data retrieval unit, and computer software that permits calculation of dynamic component fatigue lives based on the monitored flight condition spectrum of the AH-1G aircraft. Results of this program provide the design data required to develop usage spectrum recording systems for Army helicopters.

Duane M. Saylor of the Structures Technical Area, Aeronautical Technology Division, served as project engineer on this effort.

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: USAAVRADCOM TR-80-D-15	2. GOVT ACCESSION NO.: AD-A097 283
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): STRUCTURAL INTEGRITY RECORDING SYSTEM (SIRS) FOR U.S. ARMY AH-1G HELICOPTERS	5. TYPE OF REPORT & PERIOD COVERED: Final Report, Jul[redacted]75 to Nov[redacted]79
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Thomas G. Farrell, Raymond B. Johnson, Michael C. Tyler	8. CONTRACT OR GRANT NUMBER(s): DAAJ02-75-C-0050
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Technology Incorporated, Dayton Ohio 45431	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62209A 1F262209AH76 00 089 EK
11. CONTROLLING OFFICE NAME AND ADDRESS: Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia 23604	12. REPORT DATE: Mar[redacted]81
	13. NUMBER OF PAGES: 217
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

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

AH-1G HELICOPTERS	FLIGHT CONDITION MONITORING
STRUCTURAL INTEGRITY RECORDING SYSTEM	RECORDING SYSTEMS
FATIGUE-CRITICAL COMPONENTS	FATIGUE (MECHANICS)
FATIGUE DAMAGE MONITORING	MECHANICAL COMPONENTS
DATA ACQUISITION	TEST and EVALUATION

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

A Structural Integrity Recording System (SIRS) was designed and developed to track the fatique damage accumulation on 10 critical helicopter components for the subsequent timely replacement of such components for safer and more economical helicopter operation. SIRS comprises three discrete but interrelated subsystems: an airborne microprocessor-based recorder, a portable flight-line data retrieval unit, and a software system. The validation of SIRS, initially configured for the AH-1G helicopter, consisted of two phases.

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Item 20. (Continued)

Phase I (Development Test and Evaluation - DT&E) covered the design, fabrication, laboratory qualification testing, reliability analysis, and flight-testing of the prototype SIRS recorder. Phase II (Initial Operational Test and Evaluation - IOT&E) covered the evaluation of the entire system operation and the resultant data acquired during a 3-month recording period with five AH-1G's, each equipped with a SIRS recorder. As the documentation of both DT&E and IOT&E, this report describes the characteristics and functions of the entire system and details the successful performance of the SIRS recorder in the laboratory qualification testing and the flight environment. The SIRS recorder performed as designed, operated reliably, and yielded valid data.

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PREFACE

Technology Incorporated, Dayton, Ohio, prepared this report to document the results of validation of the operation of the Structural Integrity Recording System (SIRS). This report covers those activities conducted under Contract DAAJ02-75-C-0050, which was sponsored by the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia. The Army project monitor was Mr. Duane Saylor.

The principal Technology Incorporated personnel on this program were T. G. Farrell, program manager; R. B. Johnson, systems engineer; M. C. Tyler, principal design engineer; G. E. Brazier, principal software programmer; T. L. Cox, flight test engineer; and C. A. Shope, data analysis manager.

Acknowledgement is given to Captain W. Benjamin and Captain J. Pepper, U. S. Army Aviation Test Board, Fort Rucker, Alabama, who supported the Development Test and Evaluation flight test program and contributed to its timely completion. In addition, appreciation is extended to Mr. M. L. Wilker who served as test coordinator during the Initial Operational Test Evaluation flight test program.

The knowledgeable support of Mr. Duane Saylor in his role as project monitor is recognized. His effective direction was central to all activities culminating in the events documented in this report.

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CHAPTER 1.

INTRODUCTION

There is an ever-increasing emphasis throughout the Department of Defense (DoD) on reducing the costs and improving the effectiveness of military equipment. Constraints on military budgets, coupled with inflation and mounting operation and support costs, are prompting a search for positive methods of cost reduction in the acquisition and life cycle of all vehicles and equipment. The traditional effort has been a comprehensive reliability-improvement program involving parts screening, predictions, more stringent specifications, and rigorous demonstration and acceptance testing. While some improvements have been made, such programs have produced less than the desired overall result.

The effort reported here represents one element of a new initiative by the U. S. Army Applied Technology Laboratory to reduce Operating and Support (O&S) costs for Army helicopters.

PURPOSE

U. S. Army Contract DAAJ02-75-C-0050 was performed to develop, qualify, flight test, and demonstrate the Structural Integrity Recording System (SIRS). SIRS incorporates advanced technology hardware to provide a cost-effective method of tracking the accumulation of fatigue damage on critical helicopter dynamic components. The system monitors the variations in fleet utilization on a helicopter-by-helicopter basis so that helicopter components may be replaced according to helicopter usage for safer and more economical operation. The high-value, fatigue-sensitive components selected for the SIRS Development Test and Evaluation (DT&E) and Initial Operational Test & Evaluation (IOT&E) are identified in Table 1. These components were carefully selected since they have been found to be O&S cost drivers through years of service experience that includes operations in Southeast Asia. Illustrations of these components may be seen in Figures 1 through 6. They represent three elements of the AH-1G fatigue-sensitive dynamic assemblies, which are:

- Main Rotor Hub and Blade Assembly
- Main Rotor Control System
- Tail Rotor and Control System

Figure 1. AH-1G Helicopter.

Main Rotor Hub and Blade Assy

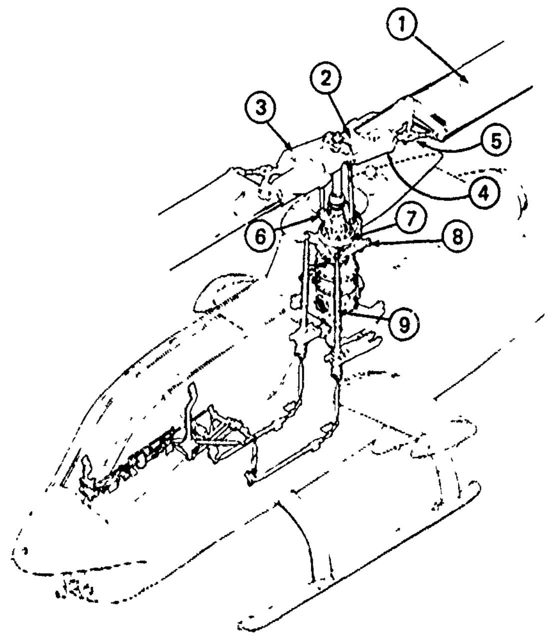
1. Main Rotor Blade
2. Main Rotor Yoke Extension
3. Main Rotor Grip
4. Main Rotor Pitch Horn
5. Main Rotor Retention Strap Fitting/Nut

Main Rotor Control System

6. Swashplate Drive Link (Scissors Assy)
7. Swashplate Outer Ring
8. Swashplate Inner Ring
9. Hydraulic Boost Cylinder Assy

Tail Rotor and Control System

10. Tail Rotor Blade



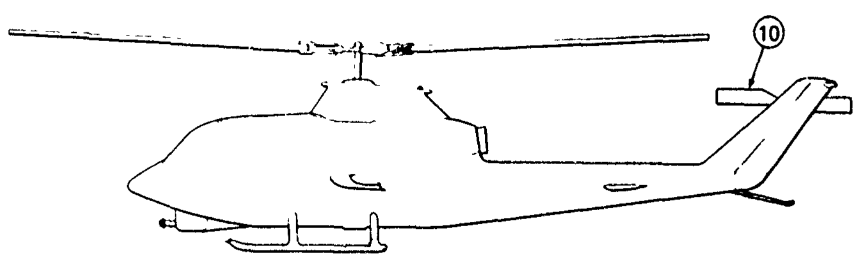


Figure 2. Location of Selected Fatigue-Critical Components for the AH-1G/SIRS Program. (TH-1 helicopter shown)

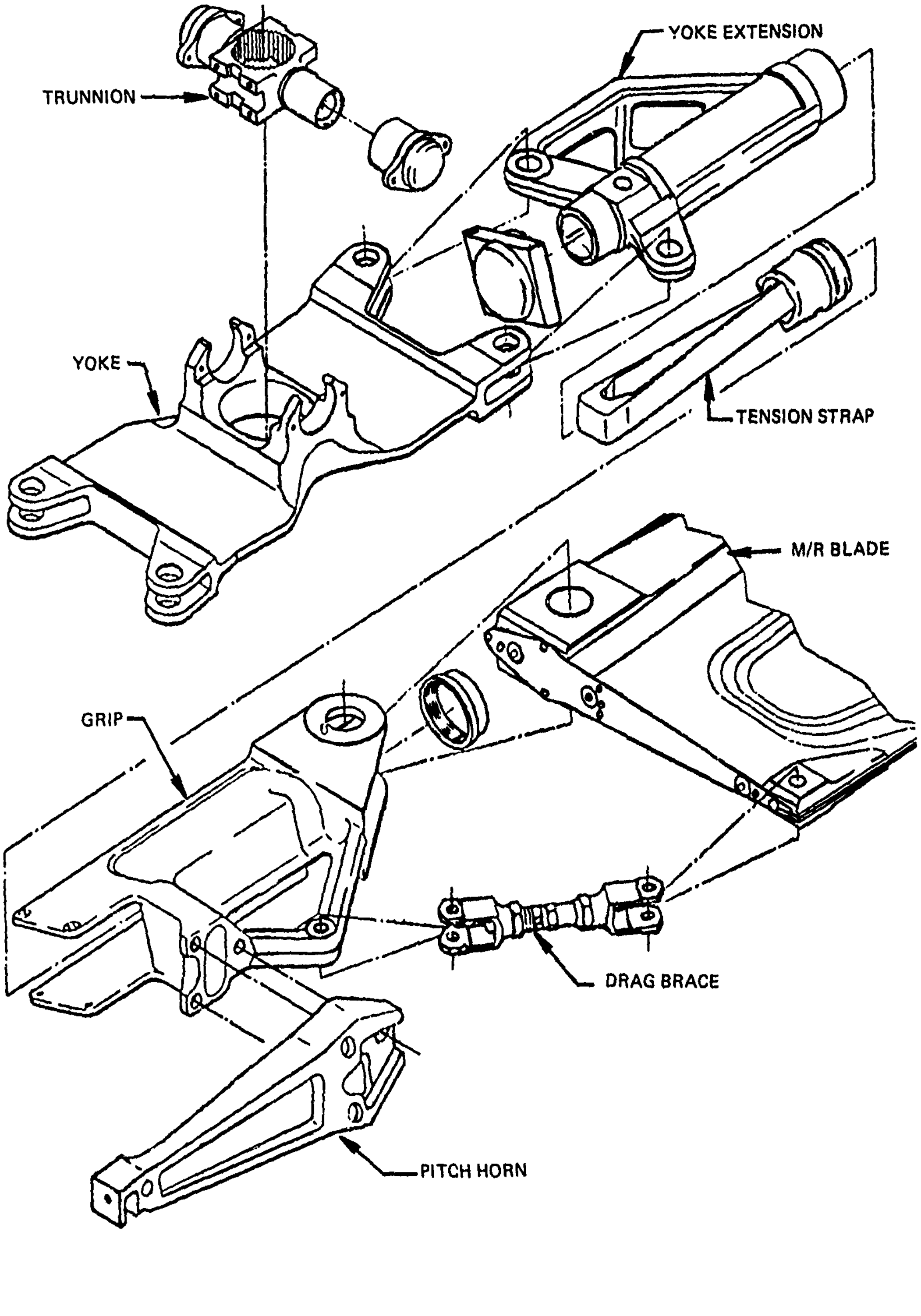


Figure 3. Main Rotor Hub and Blade Assembly.

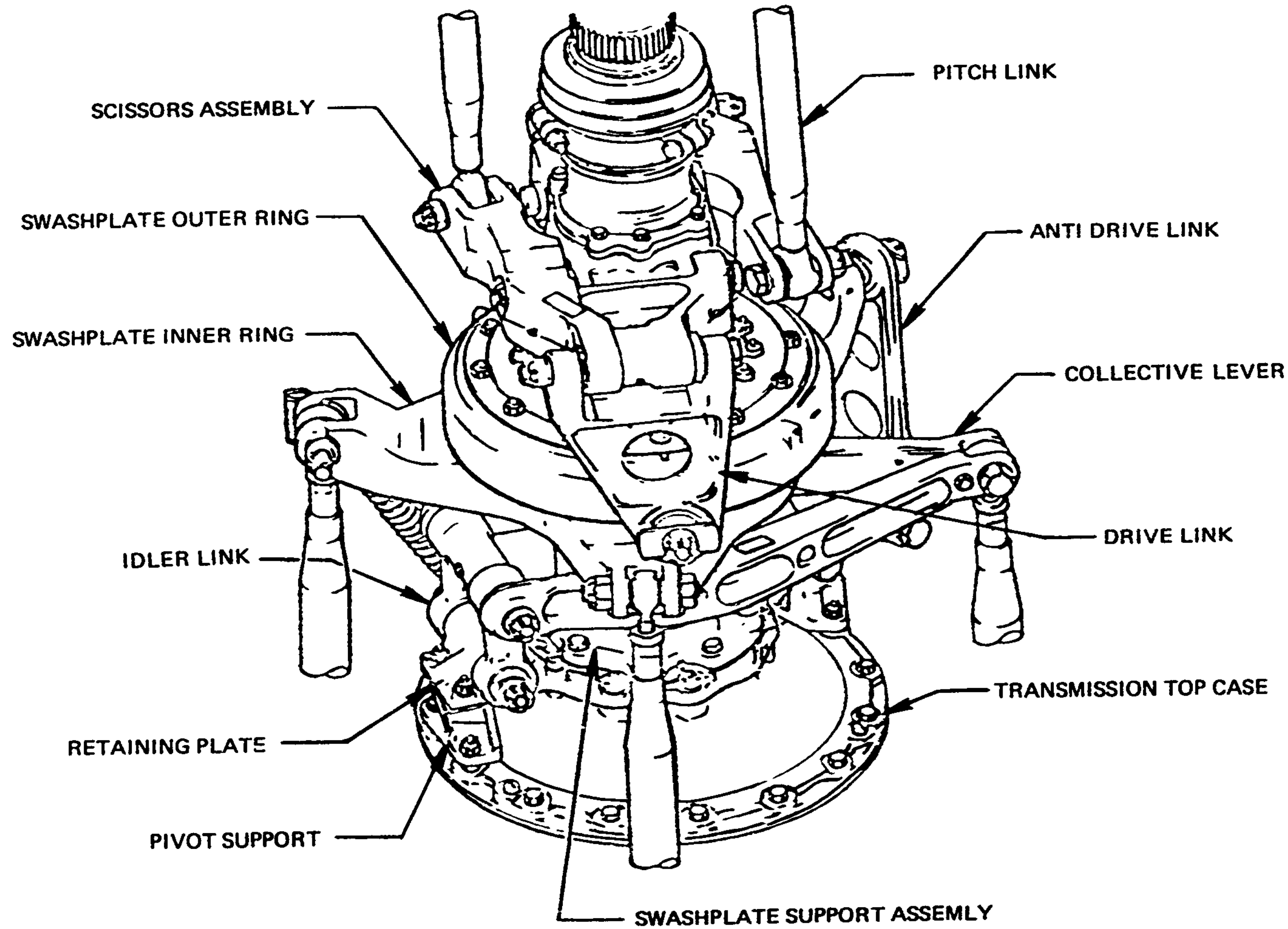


Figure 4. Main Rotor Control System.

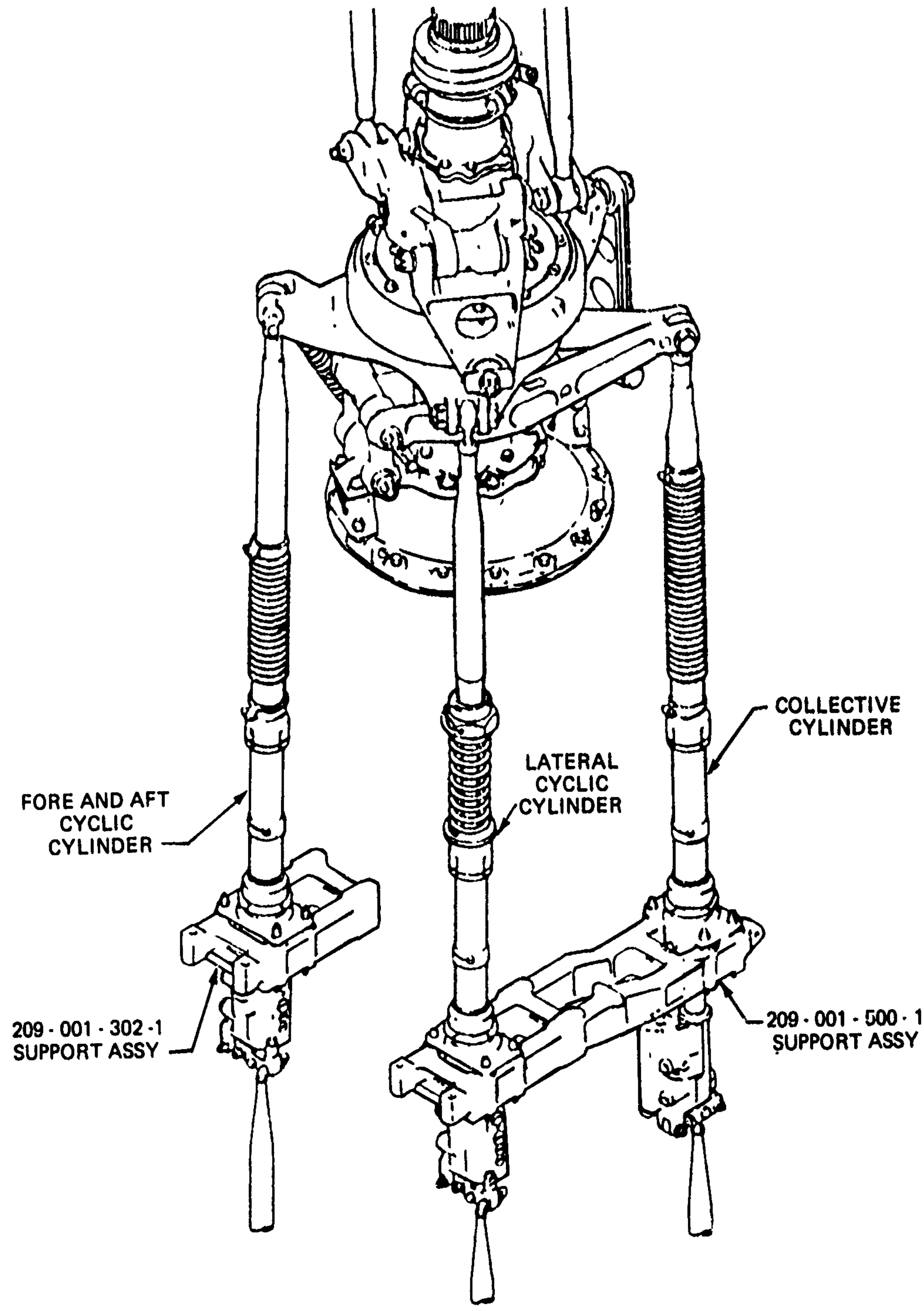


Figure 5. Hydraulic Boost Cylinders and Supports.

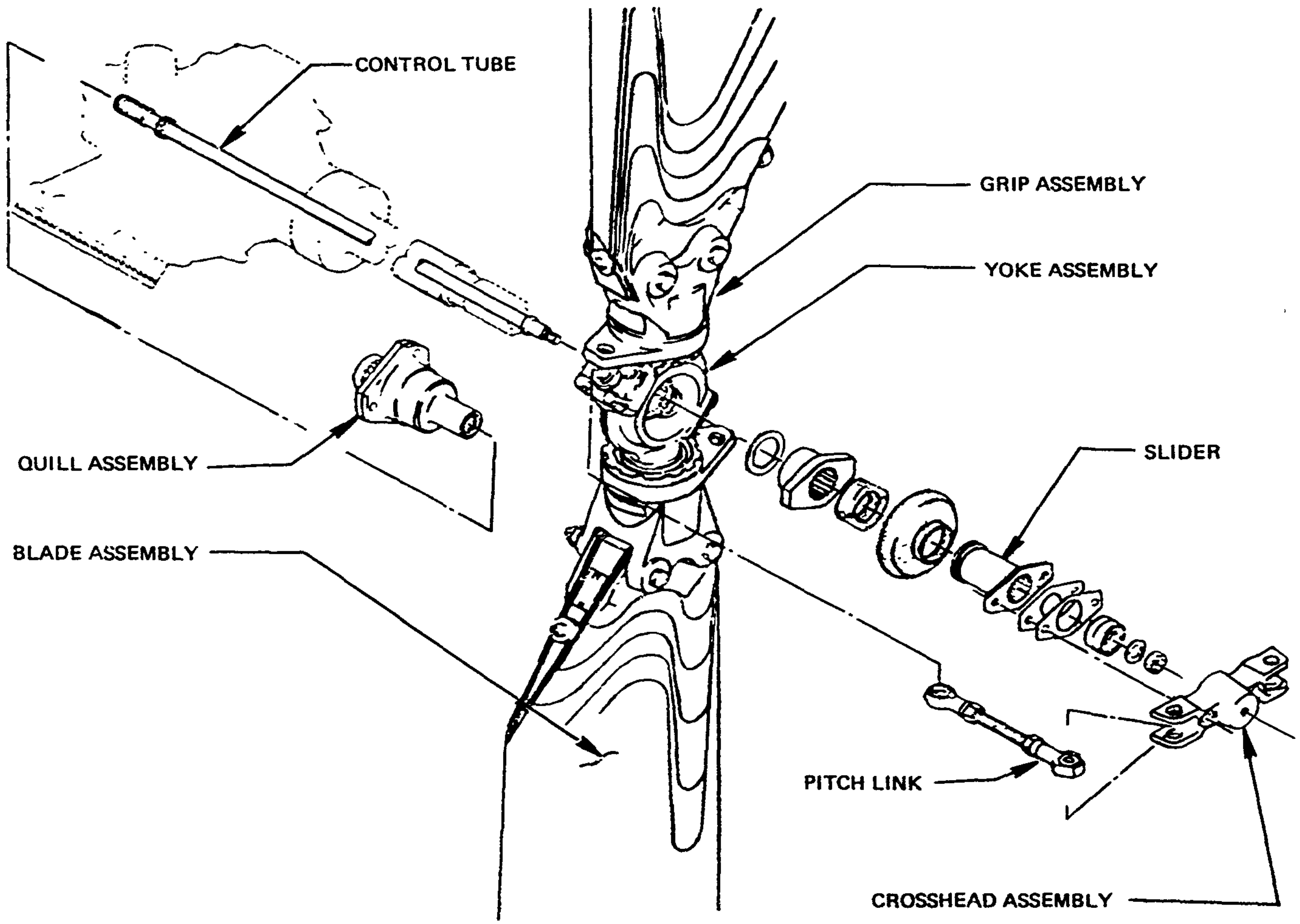


Figure 6. AH-1G Tail Rotor Components

TABLE 1. SELECTED FATIGUE-CRITICAL COMPONENTS FOR THE AH-1G HELICOPTER/SIRS PROGRAM

Nomenclature	Part Number
Main Rotor Blade	540-011-250-1
Main Rotor Yoke Extension	540-011-102-13, -15
Main Rotor Grip	540-011-154-5
Main Rotor Pitch Horn	209-010-109-5
M/R Retention Strap Fitting/Nut	540-011-113-1, -177-1
Swashplate Drive Link	209-010-408-7
Swashplate Outer Ring	209-010-403-1
Swashplate Inner Ring	209-010-402-1
Hydraulic Boost Cylinder Assy	209-076-021-1, -3, -5
Tail Rotor Blade	204-011-702-17

SIRS OVERVIEW

SIRS is a total system comprising an airborne microprocessor-based recorder, a portable flight-line retrieval unit, and a data processing package. The recorder monitors various flight parameters and stores preselected types of operational data within the recorder's solid-state memory. Data are retrieved by a portable flight-line retrieval unit that transfers the recorded data onto removable, miniature, computer-compatible tape cassettes. Each cassette can store the average monthly operational data of 50 helicopters. The data are processed and analyzed automatically by a software system that prints out the results in specifically formatted reports.

APPROACH

The contract performance consisted of two phases. Phase I (DT&E) covered these phases of SIRS: design, fabrication, qualification testing, reliability analysis, and flight testing at Fort Rucker, Alabama, on an AH-1G helicopter. The ultimate objective of Phase I was to verify that the SIRS recorder and data retrieval unit functioned as designed, operated reliably, and yielded accurate data.

In order to determine the fatigue life of any structure, three basic factors must be known. These factors are (1) some knowledge of the fatigue characteristics of the structure, (2) a knowledge of the loads or stresses to be expected in flight, and (3) a knowledge of the frequency of occurrence of these loads or stresses.

The information to fulfill the first item is obtained from the fatigue test program and the information to fulfill the second item is available from the flight loads survey. Information to fulfill the third basic requirement is the purpose of SIRS. Thus, Phase II (IOT&E) was intended to evaluate the entire SIRS in a practical application. To this end, the SIRS recorder was installed in each of five AH-1G helicopters at Fort Rucker, Alabama, while these helicopters performed normal operations during a 3-month period. During Phase II, all processes in the SIRS were evaluated: the in-flight recording and data storage, the data retrieval, and the data processing and analyses. Finally, the resultant data in prescribed formats were evaluated to determine (1) their validity in representing incremental damage rates for the respective helicopter components and (2) their usefulness in indicating the times at which the various components should be replaced.

PROGRAM EXECUTION

Contract DAAJ02-75-C-0050 was issued 26 June 1975 on a cost-plus-fixed-fee basis. The estimated manpower requirement was 31,029 man-hours. The contract was modified eight times during the performance period. These modifications essentially involved detail changes. Residual Government property was transferred to Contract DAAJ02-77-C-0079 upon completion of this effort. Technical objectives were met, and should result in a more cost-effective execution of the Army attack helicopter program through the 1990's time frame. The feasibility of using a flight condition monitoring concept to extend the service life of high-cost parts on the AH-1G fleet was demonstrated. The effort provides a continuum between phasedown of the AH-1G project and initiation of the AH-1S technical support program.

CHAPTER 2.

SYSTEM DEFINITION

INTRODUCTION

As demonstrated in Reference 1, the flight condition monitoring (FCM) method can be used to assess the fatigue damage accrued in critical helicopter dynamic components. The development of an FCM system requires first defining given flight conditions (which describe the mission profile) in terms of flight parameter ranges and then establishing flight condition categories (representing one or more flight conditions) that account for the entire spectrum of fatigue-damaging flight operations. By monitoring the time spent in each flight condition category, the damage accrued by each component may be assessed on the basis of actual operation.

The following sections describe the FCM methodology as well as the development of an FCM system for the AH-1G helicopter.

FLIGHT CONDITION MONITORING METHODOLOGY

The FCM method of fatigue damage assessment is structured as follows: Defined in terms of specific combinations of flight parameter ranges, each flight condition category (FCC) represents one or more flight conditions. The component damage due to each flight condition may be determined when the loads during the flight condition, the number of flight occurrences, and the component fatigue strength are known. To ensure that the damage rate for each flight condition category is conservative, the maximum flight condition damage rate within the given flight condition category is chosen. Then the component damage accrued during a given recording period may be computed by Equation (1), and the flight condition category incremental damage may be summed to yield the total component damage. The total recorded time is calculated by Equation (2), and the fatigue life is predicted by Equation (3).

1. Johnson, R.B., Martin, G.L., and Moran, M.S., A FEASIBILITY STUDY FOR MONITORING SYSTEMS OF FATIGUE DAMAGE TO HELICOPTER COMPONENTS, Technology Incorporated; USAAMRDL Technical Report 74-92, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis Virginia, January 1975, AD A006641.

$$D = \sum_{k=1}^{m} D_k = \sum_{k=1}^{m} C_k T_k \quad (1)$$

$$T_t = \sum_{k=1}^{m} T_k \quad (2)$$

$$FL = \frac{T_t}{D} \quad (3)$$

where D = total damage to a component during the usage spectrum

D_k = component damage accrued during the kth flight condition category

C_k = damage rate in kth flight condition category for a particular component

T_k = amount of flight time spent in kth flight condition category

T_t = total flight time

FL = component fatigue life

m = number of flight condition categories

The FCM method of fatigue damage assessment requires analyzing the manufacturer's fatigue analysis to first define a technically feasible FCM system and then to establish damage rates for each component in each flight condition category. After these data have been developed and substantiated, the selected flight parameters may be monitored to assess the accrued fatigue damage of critical helicopter dynamic components.

ELEMENTS OF AH-1G FATIGUE ANALYSIS PERTINENT TO FCM SYSTEM DEVELOPMENT

As discussed in Reference 2 and summarized in Table 2, the AH-1G design utilization spectrum is defined in terms of specific flight conditions and the percentage of flight time spent in these flight conditions.

2. Seibel, J., FATIGUE LIFE SUBSTANTIATION OF DYNAMIC COMPONENTS OF THE AH-1G HELICOPTER, Report No. 209-099-064, Bell Helicopter Company, Fort Worth, Texas, June 1968.

TABLE 2. DESIGN UTILIZATION SPECTRUM

Flight Conditions		% of Flight Time Total	Gross Weight Breakdown
I. Ground Conditions			
A. Normal Start		0.5000	
B. Shutdown		0.5000	
II. IGE Maneuvers			
A. Takeoff			
1. Normal	L-GW		0.180
	M-GW		0.450
	H-GW		0.270
		0.9000	
2. Jump	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
B. Hovering			
1. Steady	L-GW		0.434
	M-GW		1.085
	H-GW		0.651
		2.1700	
2. Right Turn	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
3. Left Turn	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
4. Control Correction			
(A) Longitudinal	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
(B) Lateral	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
(C) Rudder	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
C. Sideward Flight			
1. To the Right	L-GW		0.050
	M-GW		0.125
	H-GW		0.075
		0.2500	
2. To the Left	L-GW		0.050
	M-GW		0.125
	H-GW		0.075
		0.2500	
D. Rearward Flight	L-GW		0.050
	M-GW		0.125
	H-GW		0.075
		0.2500	

TABLE 2. Continued

Flight Conditions			% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
E. Acceleration Hover to Climb A/S		L-GW		0.100
		M-GW		0.250
		H-GW		0.150
			0.5000	
F. Deceleration				
1. Normal		L-GW		0.140
		M-GW		0.350
		H-GW		0.210
			0.7000	
2. Quick Stop		L-GW		0.050
		M-GW		0.150
		H-GW		0.090
			0.3000	
G. Approach and Landing		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
III. Forward Level Flight				
Airspeed	RPM			
A. 0.50 VH	314	L-GW		0.100
		M-GW		0.250
		H-GW		0.150
			0.5000	
	324	L-GW		0.900
		M-GW		2.250
		H-GW		1.350
			4.5000	
B. 0.60 VH	314	L-GW		0.040
		M-GW		0.100
		H-GW		0.060
			0.2000	
	324	L-GW		0.360
		M-GW		0.900
		H-GW		0.540
			1.8000	
C. 0.70 VH	314	L-GW		0.060
		M-GW		0.150
		H-GW		0.090
			0.3000	
	324	L-GW		0.540
		M-GW		1.350
		H-GW		0.810
			2.7000	
D. 0.80 VH	314	L-GW		0.300
		M-GW		0.750
		H-GW		0.450
			1.5000	
	324	L-GW		2.700
		M-GW		6.750
		H-GW		4.050
			13.5000	

TABLE 2. Continued

Flight Conditions			% of Flight Time: Total	Gross Weight Breakdown
E. 0.90 VH	314	L-GW		0.500
		M-GW		1.250
		H-GW		0.750
			2.5000	
	324	L-GW		4.500
		M-GW		11.250
		H-GW		6.750
			22.5000	
F. VH	314	L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
	324	L-GW		1.800
		M-GW		4.500
		H-GW		2.700
			9.0000	
IV. Non-Firing Maneuvers				
A. Full Power Climb				
1. Normal		L-GW		0.800
		M-GW		2.000
		H-GW		1.200
			4.0000	
2. High-Speed		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
B. Maximum Rate Accel. Climb - Cruise A/S		L-GW		0.560
		M-GW		1.400
		H-GW		0.840
			2.8000	
C. Normal Turns				
1. To the Right				
(A) 0.5 VH		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
(B) 0.7 VH		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	
(C) 0.9 VH		L-GW		0.400
		M-GW		1.000
		H-GW		0.600
			2.0000	
2. To the Left				
(A) 0.5 VH		L-GW		0.200
		M-GW		0.500
		H-GW		0.300
			1.0000	

TABLE 2. Continued

Flight Conditions		% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
(B) 0.7 VH	L-GW		0.200
	M-GW		0.500
	H-GW		0.300
		1.0000	
(C) 0.9 VH	L-GW		0.400
	M-GW		1.000
	H-GW		0.600
		2.0000	
D. 0.9 VH Control Corr.			
1. Longitudinal	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
2. Lateral	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
3. Rudder	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
E. Sideslip	L-GW		0.100
	M-GW		0.250
	H-GW		0.150
		0.5000	
F. Part Power Descent	L-GW		0.510
	M-GW		1.275
	H-GW		0.765
		2.5500	
V. Gunnery Maneuvers			
A. Firing in a Hover	L-GW		0.015
	M-GW		0.038
	H-GW		0.023
		0.0750	
B. Strafing in Accel. From a Hover	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
C. Gunnery Runs			
1. Point Target Runs			
(A) To 0.6 VL	L-GW		0.056
	M-GW		0.140
	H-GW		0.084
		0.2800	
(B) To 0.8 VL	L-GW		0.168
	M-GW		0.420
	H-GW		0.252
		0.8400	
(C) To 0.9 VL	L-GW		0.280
	M-GW		0.700
	H-GW		0.420
		1.4000	

TABLE 2. Continued

Flight Conditions		% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
(D) To VL	L-GW		0.056
	M-GW		0.140
	H-GW		0.084
		0.2800	
2. Spray Fire Dives			
(A) To 0.6 VL	L-GW		0.024
	M-GW		0.060
	H-GW		0.036
		0.1200	
(B) To 0.8 VL	L-GW		0.072
	M-GW		0.180
	H-GW		0.108
		0.3600	
(C) To 0.9 VL	L-GW		0.120
	M-GW		0.300
	H-GW		0.180
		0.6000	
(D) To VL	L-GW		0.024
	M-GW		0.060
	H-GW		0.036
		0.1200	
D. Gunnery Run Pullup			
1. To the Right			
(A) 0.6 VL	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
(B) 0.8 VL	L-GW		0.060
	M-GW		0.150
	H-GW		0.090
		0.3000	
(C) 0.9 VL	L-GW		0.100
	M-GW		0.250
	H-GW		0.150
		0.5000	
(D) VL	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
2. To the Left			
(A) 0.6 VL	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
(B) 0.8 VL	L-GW		0.060
	M-GW		0.150
	H-GW		0.090
		0.3000	
(C) 0.9 VL	L-GW		0.100
	M-GW		0.250
	H-GW		0.150
		0.5000	

TABLE 2. Continued

Flight Conditions		% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
(D) VL	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
3. Symmetrical			
(A) 0.6 VL	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
(B) 0.8 VL	L-GW		0.006
	M-GW		0.015
	H-GW		0.009
		0.0300	
(C) 0.9 VL	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
(D) VL	L-GW		0.002
	M-GW		0.005
	H-GW		0.003
		0.0100	
E. Gunnery Turns			
1. To the Right			
(A) 0.5 VH	L-GW		0.075
	M-GW		0.188
	H-GW		0.113
		0.3750	
(B) 0.7 VH	L-GW		0.075
	M-GW		0.188
	H-GW		0.113
		0.3750	
(C) 0.9 VH	L-GW		0.150
	M-GW		0.375
	H-GW		0.225
		0.7500	
2. To the Left			
(A) 0.5 VH	L-GW		0.075
	M-GW		0.188
	H-GW		0.113
		0.3750	
(B) 0.7 VH	L-GW		0.075
	M-GW		0.188
	H-GW		0.113
		0.3750	
(C) 0.9 VH	L-GW		0.150
	M-GW		0.375
	H-GW		0.225
		0.7500	

TABLE 2. Continued

Flight Conditions		% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
F. S-Turns			
1. At 0.8 VH	L-GW		0.040
	M-GW		0.100
	H-GW		0.060
		0.2000	
2. At VH	L-GW		0.015
	M-GW		0.038
	H-GW		0.022
		0.0750	
VI. Power Transitions			
A. Power to Auto			
1. 0.5 VH	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
2. 0.7 VH	L-GW		0.025
	M-GW		0.063
	H-GW		0.038
		0.1250	
3. 0.9 VH	L-GW		0.035
	M-GW		0.088
	H-GW		0.053
		0.1750	
B. Auto to Power			
1. In Ground Effect	L-GW		0.030
	M-GW		0.075
	H-GW		0.045
		0.1500	
2. 0.4 VH	L-GW		0.020
	M-GW		0.050
	H-GW		0.030
		0.1000	
3. 0.6 VH	L-GW		0.015
	M-GW		0.038
	H-GW		0.023
		0.0750	
4. Max Auto A/S	L-GW		0.005
	M-GW		0.013
	H-GW		0.008
		0.0250	
VII. Autorotation			
A. Stabilized Flight			
1. 0.4 VH	L-GW		0.040
	M-GW		0.100
	H-GW		0.060
		0.2000	
2. 0.6 VH	L-GW		0.280
	M-GW		0.700
	H-GW		0.420
		1.4000	

TABLE 2. Concluded

Flight Conditions		% of Flight Time: Total	% of Flight Time: Gross Weight Breakdown
3. Max Auto A/S	L-GW		0.060
	M-GW		0.150
	H-GW		0.090
		0.3000	
B. Auto Turns			
1. To the Right			
(A) 0.4 VH	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
(B) 0.6 VH	L-GW		0.080
	M-GW		0.200
	H-GW		0.120
		0.4000	
(C) Max Auto A/S	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
2. To the Left			
(A) 0.4 VH	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
(B) 0.6 VH	L-GW		0.080
	M-GW		0.200
	H-GW		0.120
		0.4000	
(C) Max Auto A/S	L-GW		0.010
	M-GW		0.025
	H-GW		0.015
		0.0500	
C. Auto Landing	L-GW		0.050
	M-GW		0.125
	H-GW		0.075
		0.2500	

The manufacturer assumed that the AH-1G operational time would be distributed as follows in three gross weight ranges: (1) 20 percent in a light gross weight (L-GW) range (less than 7750 pounds), (2) 50 percent in a middle gross weight (M-GW) range (7750 to 8750 pounds), and (3) 30 percent in a high gross weight (H-GW) range (more than 8750 pounds). This gross weight distribution was also used in the preliminary development of the FCM system for the AH-1G.

The fatigue-critical AH-1G components to be used in the FCM method were selected by determining those major life-limited components in the main and tail rotor systems that have a significant effect on the AH-1G life-cycle cost. As a result, 10 components were selected. For each of these components, Table 3 lists the part number along with the manufacturer-computed fatigue life and the recommended retirement life. The component fatigue damage data along with other information (e.g., component loads data and component S/N data) needed for performing a fatigue analysis were extracted from the fatigue substantiation report (Reference 2).

TABLE 3. SELECTED FATIGUE-CRITICAL COMPONENTS FOR THE AH-1G HELICOPTER

Nomenclature	Part Number	Calculated Fatigue Life(hr)	Recommended Retirement Life (hr)
Main Rotor Blade	540-011-250-1	2,792	1,100
Main Rotor Yoke Extension	540-011-102-13,15	10,633	3,300
Main Rotor Grip	540-011-154-5	95,057	--
Main Rotor Pitch Horn	209-010-109-5	9,105	6,600
M/R Retention Strap Fitting/Nut	540-011-113-1,-177-1	2,760	2,200
Swashplate Drive Link	209-010-408-7	13,953	11,000
Swashplate Outer Ring	209-010-403-1	9,806	3,300
Swashplate Inner Ring	209-010-402-1	10,453	3,300
Hydraulic Boost Cylinder Assy	209-076-021-1,3,5	3,345	3,300
Tail Rotor Blade	204-011-702-17	3,764	1,100

TECHNICAL ACCEPTANCE CRITERIA FOR FCM SYSTEMS

Basic Definition of Technical Acceptance Criteria

In the development of the FCM system for the AH-1G, the technical acceptance criteria developed in Reference 1 were applied to several candidate systems.

According to these criteria, an FCM system must be capable of predicting, for each component, fatigue lives that fall between a conservative lower bound and realistic upper bounds. One upper bound is defined for mild aircraft usage and another upper bound for severe aircraft usage (see Figure 7). The intent in these criteria of the upper bounds for both mild and severe conditions is to evaluate candidate FCM systems relative to the usage variations in the expected fleet operation spectrum.

The application of the technical acceptance criteria requires the following: (1) the definition of the lower bounds for the component fatigue lives, (2) the substantiation of a fatigue damage assessment model (specifically, the computer program FATHIP) that closely parallels the fatigue analysis used by the AH-1G manufacturer and which may be validly used in the applications discussed later in this section, and (3) the derivation of realistic upper bounds for the component fatigue lives in both a mild and a severe usage spectrum by applying the substantiated fatigue damage assessment model.

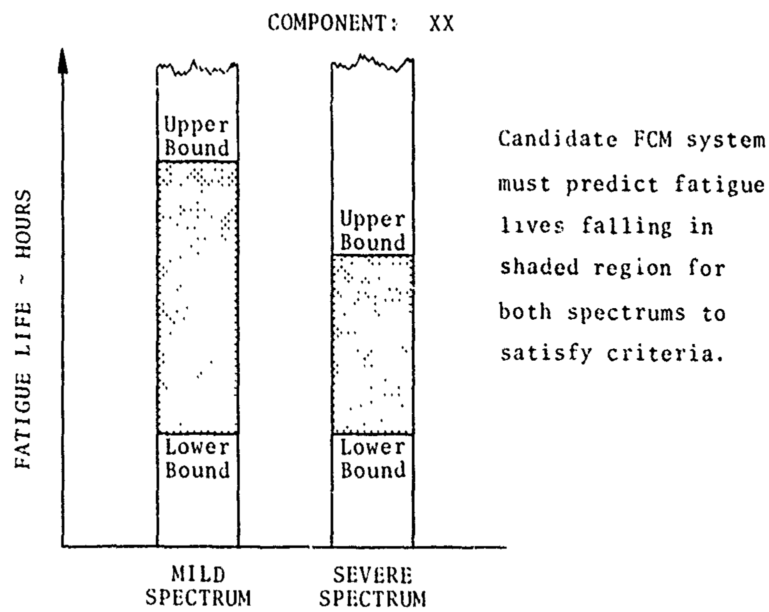


Figure 7. Depiction of Technical Acceptance Criteria.

Definition of Lower Bounds for Component Fatigue Lives

Table 3 includes the manufacturer-computed fatigue lives and the recommended retirement lives for the 10 selected components. The manufacturer's computations were based on the design utilization spectrum summarized in Table 2. Since such a spectrum is conventionally more severe than the actual usage anticipated during the helicopter life, the computed fatigue lives are conservative. As is apparent in Table 2, the recommended retirement lives are generally much shorter than the fatigue lives.

To conform with the philosophy in previous studies, the recommended retirement lives were defined as the lower bounds.

Substantiation of Fatigue Damage Assessment Model (FATHIP)

FATHIP, the fatigue damage assessment model used in the following applications, computes fatigue damage in a manner similar to the AH-1G manufacturer's process. To substantiate this model, the same component load, S/N, and frequency of occurrence data used in the manufacturer's computations were also used as input in FATHIP. Obviously, if FATHIP could yield fatigue lives agreeing closely with those derived by the manufacturer, the model would be substantiated.

For both the manufacturer and the FATHIP computations, Table 4 lists the fatigue damage accrued by each of the 10 selected AH-1G components during 100 hours of operation in the design utilization spectrum. The close correlation of the two sets of data verifies FATHIP as a valid fatigue damage assessment model for the AH-1G helicopter.

TABLE 4. COMPARISON OF MANUFACTURER AND FATHIP FATIGUE DAMAGE AND FATIGUE LIFE COMPUTATIONS

	Design Spectrum			
	Manufacturer's Computations*		FATHIP Results	
Component	Fatigue Damage in 100 hr	Fatigue Life (hr)	Fatigue Damage in 100 hr	Fatigue Life (hr)
Main Rotor Blade	0.035810	2,792	0.035806	2,793
Main Rotor Yoke Extension	0.009404	10,633	0.009403	10,635
Main Rotor Grip	0.001052	95,057	0.001053	95,012
Main Rotor Pitch Horn	0.010983	9,105	0.010982	9,106
M/R Retention Strap Fitting/Nut	0.036232	2,760	0.036232	2,760
Swashplate Drive Link	0.007167	13,953	0.007164	13,959
Swashplate Outer Ring	0.010197	9,806	0.010196	9,808
Swashplate Inner Ring	0.009566	10,453	0.009562	10,458
Hydraulic Boost Cylinders	0.029890	3,345	0.029895	3,345
Tail Rotor Blade	0.026567	3,764	0.026568	3,764

* Reference 2

Derivation of Upper Bounds for Component Fatigue Lives in Both Mild and Severe Utilization Spectra

Without regard at the outset to which might be the more severe spectrum, two utilization spectra were derived independently from separate sources: (1) the AH-1G operational usage data collected in Southeast Asia (Reference 3), and (2) the expected future mission utilization data for attack-type helicopters (also documented in Reference 3). As listed in Table 5, each spectrum was defined in terms of the same flight conditions that were used to define utilization spectrum. In addition, the gross weight distribution assumed in Reference 2 was used for each spectrum.

To assess the relative severity of the two utilization spectra from a fatigue damage standpoint, the two spectra were then processed in FATHIP to predict the fatigue life for each of the 10 selected components. On the basis of the resulting fatigue life predictions, the spectrum representing the Southeast Asia data was judged more severe than the spectrum representing the other data. Consequently, the former was termed the severe spectrum and the latter the mild spectrum. However, these spectra are not to be interpreted as worst-case usage, but rather as the mild and severe usage that would normally occur with some regularity.

The two sets of fatigue lives derived by FATHIP for each of the 10 selected components were defined as the upper fatigue life bounds, one set for the mild and the other set for the severe utilization spectrum. Table 6 lists these bounds. Since this table also includes the lower fatigue bounds as previously listed in Table 3, it summarizes the constraints for the application of the technical acceptance criteria to the candidate FCM systems for the AH-1G helicopter.

Therefore, to be considered technically acceptable, a candidate FCM system must be capable of predicting, for each component, a fatigue life within these bounds when the basic frequency of occurrence data in either the mild or the severe spectrum is the simulated output of an airborne FCM recorder.

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3. Cox, T.L., Johnson, R.B., and Russell, S.W., DYNAMIC LOADS AND STRUCTURAL CRITERIA, Technology Incorporated; USAAMRDL Technical Report 75-9, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, April 1975, AD A009759.

TABLE 5. MILD AND SEVERE SPECTRUM DEFINITIONS

	FLIGHT CONDITION		DESIGN	MILD	SEVERE
1	NORMAL START/SHUTDOWN (W/COLL.)	(IGE MANEUVER)	1.000	.290	.616
2	NORMAL TAKE-OFF	(IGE MANEUVER)	.900	2.558	.750
3	JUMP TAKE-OFF	(IGE MANEUVER)	.100	.656	.188
4	STEADY HOVER	(IGE MANEUVER)	2.170	11.530	12.958
5	HOVERING RIGHT TURN	(IGE MANEUVER)	.100	2.887	.817
6	HOVERING LEFT TURN	(IGE MANEUVER)	.100	2.887	.817
7	HOVERING LONGITUDINAL CONTROL CORR.	(IGE MANEUVER)	.010	.126	.027
8	HOVERING LATERAL CONTROL CORR.	(IGE MANEUVER)	.010	.126	.027
9	HOVERING RUDDER CONTROL CORR.	(IGE MANEUVER)	.010	.126	.027
10	SIDEWARD FLIGHT TO THE RIGHT	(IGE MANEUVER)	.250	2.110	.409
11	SIDEWARD FLIGHT TO THE LEFT	(IGE MANEUVER)	.250	2.110	.409
12	REARWARD FLIGHT	(IGE MANEUVER)	.250	1.600	.241
13	ACCELERATION HOVER TO CLIMB A S	(IGE MANEUVER)	.500	3.248	.456
14	NORMAL DECELERATION	(IGE MANEUVER)	.700	.823	2.519
15	QUICK STOP DECELERATION	(IGE MANEUVER)	.300	.823	2.519
16	APPROACH AND LANDING	(IGE MANEUVER)	1.000	.385	4.529
17	FORWARD LEVEL FLIGHT 0.50 VH AT 314 RPM		.500	1.550	1.260
18	FORWARD LEVEL FLIGHT 0.50 VH AT 324 RPM		4.500	.180	11.296
19	FORWARD LEVEL FLIGHT 0.60 VH AT 314 RPM		.200	1.040	1.206
20	FORWARD LEVEL FLIGHT 0.60 VH AT 324 RPM		1.800	.115	10.867
21	FORWARD LEVEL FLIGHT 0.70 VH AT 314 RPM		.300	.350	.657
22	FORWARD LEVEL FLIGHT 0.70 VH AT 324 RPM		2.700	.040	5.856
23	FORWARD LEVEL FLIGHT 0.80 VH AT 314 RPM		1.500	.171	.241
24	FORWARD LEVEL FLIGHT 0.80 VH AT 324 RPM		13.500	.020	2.171
25	FORWARD LEVEL FLIGHT 0.90 VH AT 314 RPM		2.500	.313	.013
26	FORWARD LEVEL FLIGHT 0.90 VH AT 324 RPM		22.500	.232	.157
27	FORWARD LEVEL FLIGHT VH AT 314 RPM		1.000	.010	.013
28	FORWARD LEVEL FLIGHT VH AT 324 RPM		9.000	.001	.161
29	NORMAL FULL POWER CLIMB		4.000	5.375	6.172
30	HIGH-SPEED FULL POWER CLIMB		1.000	2.190	2.644
31	MAX. RATE ACCEL. FULL POWER CLIMB TO CRUISE A S		2.800	2.848	8.154
32	NORMAL RIGHT TURN AT 0.5 VH		1.000	6.122	1.116
33	NORMAL RIGHT TURN AT 0.7 VH		1.000	2.188	1.116
34	NORMAL RIGHT TURN AT 0.9 VH		2.000	.438	.248
35	NORMAL LEFT TURN AT 0.5 VH		1.000	5.671	1.116
36	NORMAL LEFT TURN AT 0.7 VH		1.000	2.026	1.116
37	NORMAL LEFT TURN AT 0.9 VH		2.000	.406	.248
38	LONGITUDINAL CONTROL CORR. AT 0.9 VH		.050	.050	.001
39	LATERAL CONTROL CORR. AT 0.9 VH		.050	.050	.001
40	RUDDER CONTROL CORR. AT 0.9 VH		.050	.050	.001
41	SIDESLIP		.500	.113	.013
42	PART POWER DESCENT		2.550	6.471	7.679
43	FIRING IN A HOVER		.075	19.047	.230
44	STRAFING IN ACCEL. FROM A HOVER		.050	.672	.270

TABLE 5. Concluded

FLIGHT CONDITION	DESIGN	MILD	SEVERE
45 GUNNERY RUN-PT. TARGET DIVE AT 0.6 VL	.280	.656	.734
46 GUNNERY RUN-PT. TARGET DIVE AT 0.8 VL	.840	.252	.734
47 GUNNERY RUN-PT. TARGET DIVE AT 0.9 VL	1.400	.051	.201
48 GUNNERY RUN-PT. TARGET DIVE AT VL	.280	.051	.201
49 GUNNERY RUN-SPRAY FIRE DIVE AT 0.6 VL	.120	.656	1.136
50 GUNNERY RUN-SPRAY FIRE DIVE AT 0.8 VL	.360	.252	1.136
51 GUNNERY RUN-SPRAY FIRE DIVE AT 0.9 VL	.600	.051	.300
52 GUNNERY RUN-SPRAY FIRE DIVE AT VL	.120	.051	.300
53 GUNNERY RUN-P/U TO THE RIGHT AT 0.6 VL	.100	.249	.440
54 GUNNERY RUN-P/U TO THE RIGHT AT 0.8 VL	.300	.249	.450
55 GUNNERY RUN-P/U TO THE RIGHT AT 0.9 VL	.500	.062	.120
56 GUNNERY RUN-P/U TO THE RIGHT AT VL	.100	.062	.110
57 GUNNERY RUN-P/U TO THE LEFT AT 0.6 VL	.100	.249	.440
58 GUNNERY RUN-P/U TO THE LEFT AT 0.8 VL	.300	.249	.450
59 GUNNERY RUN-P/U TO THE LEFT AT 0.9 VL	.500	.062	.120
60 GUNNERY RUN-P/U TO THE LEFT AT VL	.100	.062	.110
61 GUNNERY RUN-P/U(SYMMETRICAL) AT 0.6 VL	.010	.055	.100
62 GUNNERY RUN-P/U(SYMMETRICAL) AT 0.8 VL	.030	.055	.100
63 GUNNERY RUN-P/U(SYMMETRICAL) AT 0.9 VL	.050	.014	.025
64 GUNNERY RUN-P/U(SYMMETRICAL) AT VL	.010	.014	.025
65 GUNNERY TURN TO THE RIGHT AT 0.5 VH	.375	1.375	.248
66 GUNNERY TURN TO THE RIGHT AT 0.7 VH	.375	1.375	.198
67 GUNNERY TURN TO THE RIGHT AT 0.9 VH	.750	.306	.100
68 GUNNERY TURN TO THE LEFT AT 0.5 VH	.375	1.375	.248
69 GUNNERY TURN TO THE LEFT AT 0.7 VH	.375	1.375	.198
70 GUNNERY TURN TO THE LEFT AT 0.9 VH	.750	.306	.100
71 GUNNERY S-TURN AT 0.8 VH	.200	.330	.150
72 GUNNERY S-TURN AT VH	.075	.037	.099
73 POWER TO AUTO. TRANSITION AT 0.5 VH	.050	.007	.007
74 POWER TO AUTO. TRANSITION AT 0.7 VH	.125	.013	.01[illegible]
75 POWER TO AUTO. TRANSITION AT 0.9 VH	.175	.013	.017
76 AUTO. TO POWER TRANSITION IGE	.150	.007	.007
77 AUTO. TO POWER TRANSITION AT 0.4 VH	.100	.010	.010
78 AUTO. TO POWER TRANSITION AT 0.6 VH	.075	.007	.007
79 AUTO. TO POWER TRANSITION AT MAX. AUTO. A/S	.025	.007	.003
80 STABILIZED AUTO. FLIGHT AT 0.4 VH	.200	.004	.004
81 STABILIZED AUTO. FLIGHT AT 0.6 VH	1.400	.012	.012
82 STABILIZED AUTO. FLIGHT AT MAX. AUTO. A/S	.300	.004	.004
83 AUTO. TURN TO THE RIGHT AT 0.4 VH	.050	.001	.001
84 AUTO. TURN TO THE RIGHT AT 0.6 VH	.400	.002	.002
85 AUTO. TURN TO THE RIGHT AT MAX. AUTO. A/S	.050	.001	.001
86 AUTO. TURN TO THE LEFT AT 0.4 VH	.050	.001	.001
87 AUTO. TURN TO THE LEFT AT 0.6 VH	.400	.002	.002
88 AUTO. TURN TO THE LEFT AT MAX. AUTO. A/S	.050	.001	.001
89 AUTOROTATION LANDING	.250	.007	.007
	100.000	100.000	100.000

TABLE 6. UPPER AND LOWER BOUNDS FOR TECHNICAL ACCEPTANCE CRITERIA

Component	Lower Fatigue Life Bounds	Upper Fatigue Life Bounds	
	Recommended Lives	Mild Spectrum	Severe Spectrum
Main Rotor Blade	1,100	4,307	3,542
Main Rotor Yoke Extension	3,300	24,917	14,779
Main Rotor Grip	Unlimited	190,042	69,686
Main Rotor Pitch Horn	6,600	17,953	10,596
M/R Retention Strap Ftg./Nut	2,200	9,517	4,488
Swashplate Drive Link	11,000	27,353	16,513
Swashplate Outer Ring	3,300	18,707	12,325
Swashplate Inner Ring	3,300	25,128	15,481
Hydraulic Boost Tube	3,300	8,635	5,145
Tail Rotor Blade	1,100	12,106	7,192

DEVELOPMENT OF A CANDIDATE FCM SYSTEM FOR THE AH-1G HELICOPTER

The development of a candidate FCM system for the AH-1G helicopter requires the following procedure: (1) the identification of those flight conditions that have the greatest fatigue-damaging effect on the critical AH-1G components, (2) the ranking of the fatigue-damaging flight conditions according to both the degree of their damaging effects on the helicopter as a whole and the relative costs to replace the selected components, (3) the selection of the measurable flight parameters whose collective variations will characterize the flight conditions identified in (1), and (4) the final definition of an FCM system in terms of specific combinations of flight parameters and the threshold levels of these parameters.

The following sections summarize the analytical processes used in developing an FCM system for the AH-1G.

Flight-Condition Ranking

Of the 89 flight conditions (each with three gross weight ranges) identified in the AH-1G design fatigue spectrum, some are damaging to the 10 selected components in varying degrees while others are not damaging at all. Consequently, the damaging flight conditions had to be first identified and then ranked according to both the degree of their damaging effects on the helicopter as a whole and the costs to replace the selected components.

As was done previously in Reference 1, the fatigue-damaging (sensitivity) rank of each AH-1G flight condition was computed by Equation (4). With relative expense and complexity of the selected dynamic components being significant factors, this equation provides the means for representing each flight condition relative to its rate of producing fatigue damage to the helicopter as a whole. A normalized rank value was also computed by Equation (5). The results of the ranking procedure are shown in Table 7.

$$R = \sum_{\substack{\text{all} \\ \text{components}}} \left(C_F \cdot \left(\frac{L_R}{L_A}\right) \cdot n \cdot D\right) \qquad (4)$$

$$\bar{R} = \frac{R}{t} \qquad (5)$$

where R = sensitivity rank value

C_F = estimated relative cost factor for each component (each component was normalized to 1.0 for the main rotor blade)

$\frac{L_R}{L_A}$ = ratio of recommended life of each component to an assumed aircraft life of 7200 hours

n = number of components per aircraft

D = percentage of fatigue damage to each component due to a given flight condition

R = normalized rank value

t = flight condition frequency in the design usage spectrum

TABLE 7. RESULTS OF RANKING PROCEDURE

FLIGHT CONDITION	SENSITIVITY RANK VALUE	NORMALIZED RANK VALUE
Gunnery Run P/U (symmetrical) at VL	.4289	12.8916
Gunnery S-turn at VH	2.4017	32.0233
Gunnery Run P/U to the Left at VL	2.6629	26.6288
Gunnery Run P/U to the Right at VL	2.1912	21.9116
Gunnery Run P/U (symmetrical) at 0.9 VL	.7996	15.9910
Gunnery Run P/U to the Left at 0.9 VL	5.0312	10.0623
Gunnery Run P/U to the Right at 0.9 VL	3.6742	7.3485
Gunnery Run P/U (symmetrical) at 0.8 VL	.1522	5.0735
Normal Start/Shutdown (w/coll.)	3.9272	3.9272
Gunnery S-Turn at 0.8 VH	.7270	3.6352
Gunnery Run P/U to the Left at 0.8 VL	.9580	3.1934
Autorotation Landing	.7414	2.9777
Gunnery Run P/U to the Right at 0.8 VL	.8523	2.8409
Gunnery Turn to the Right at 0.9 VH	1.9089	2.5452
Gunnery Turn to the Left at 0.9 VH	1.5982	2.1309
Gunnery Run-Pt. Target Dive at VL	.5653	2.0188
Lateral Control Corr. at 0.9 VH	.0910	1.8191
Gunnery Run-Spray Fire Dive at VL	.2160	1.8001
Auto. to Power Transition at Max. Auto. A/S	.0286	1.1440
Hovering Longitudinal Control Corr. (IGL Maneuver)	.0107	1.0732
Rudder Control Corr. at 0.9 VH	.0435	.8692
Gunnery Run P/U (symmetrical) at 0.6 VL	.0082	.8179
Gunnery P/U to the Left at 0.6 VL	.0794	.7944
Gunnery Run P/U to the Right at 0.6 VL	.0718	.7184
Forward Level Flight VH at 314 RPM	.5478	.5478
Normal Left Turn at 0.9 VH	.9934	.4967
Gunnery Turn to the Left at 0.5 VH	.1675	.4465
Gunnery Turn to the Left at 0.7 VH	.1398	.3728
Gunnery Turn to the Right at 0.7 VH	.1361	.3630
Gunnery Turn to the Right at 0.5 VH	.1087	.2898
Gunnery Run-Spray Fire Dive at 0.9 VL	.1731	.2885
Quick Stop Deceleration (IGL Maneuver)	.0826	.2754
Approach and Landing (IGL Maneuver)	.2285	.2285
High-Speed Full Power Climb	.1247	.1247
Forward Level Flight VH at 324 RPM	1.0412	.1157
Auto. to Power Transition at 0.6 VH	.0077	.1024
Auto. Turn to the Right at Max. Auto. A/S	.0040	.0809
Longitudinal Control Corr. at 0.9 VH	.0037	.0731
Gunnery Run-Pt. Target Dive at 0.9 VL	.0983	.0702
Gunnery Run-Spray Fire Dive at 0.8 VL	.0205	.0569
Normal Right Turn at 0.7 VH	.0384	.0384
Gunnery Run-Pt. Target Dive at 0.8 VL	.0271	.0322
Auto. Turn to the Left at Max. Auto. A/S	.0012	.0235
Normal Right Turn 0.9 VH	.0402	.0201
Hovering Lateral Control Corr. (IGL Maneuver)	.0001	.0088

Selection of Characteristic Parameters and Parameter Thresholds

References 4 and 5 were thoroughly searched for those flight parameters that have a consistent response to specific flight conditions. These documents contain pilot stick and pedal position data, component load data, and helicopter response data (such as roll rate, pitch rate, and pitch attitude). The documented flights, where each flight condition was flown many times in various gross weight-altitude combinations, were examined to detect the behavior of each recorded parameter during the defined flight conditions. (In describing the data reduction procedure, Reference 4 states that the maximum mean helicopter attitude and attitude rate values were measured and processed for each maneuver, but not for the level-flight flight conditions. The mean and oscillatory center-of-gravity vertical acceleration levels were measured and recorded at the maximum mean level for maneuvers and at the maximum oscillatory peak for the level-flight flight conditions.) The flight conditions that had ranked highly were examined very closely.

Each of the measurable flight parameters listed in Table 8 was considered individually or in combination with others to determine their potential in flight condition monitoring.

TABLE 8. CANDIDATE MONITORING PARAMETERS FOR FCM RECORDING SYSTEM

Vertical Acceleration @ c.g.	Pitch Attitude
Indicated Airspeed	Roll Attitude
Main Rotor Velocity	Pitch Rate
Landing Gear Touchdown	Roll Rate
Engine Torque Pressure	Yaw Rate

Table 9 shows sample data extracted from References 4 and 5 for two flight conditions: the gunnery run pullups to the right and left at V_L (V_L indicates limit velocity). These two flight conditions were ultimately considered sufficiently

4. Wettengel, W.O., MODEL AH-1G NONFIRING LOAD LEVEL SURVEY, VOLUMES I THROUGH IX, Report No. 209-099-041, Bell Helicopter Company, Fort Worth, Texas, June 1967.

5. Long, D.B., MODEL AH-1G HELICOPTER ARMAMENT QUALIFICATION TEST AND FIRING LOAD LEVEL SURVEY, Report No. 209-099-031, Bell Helicopter Company, Fort Worth, Texas, November 1967.

similar to be monitored as one flight condition category defined as follows:

Vertical Acceleration at c.g. $\geq$ 1.5g
Airspeed > 0.95 V_L
10° < Roll Attitude < 35°

TABLE 9. SAMPLE LOAD LEVEL SURVEY DATA

Flight Condition: Gunnery Run Pullup to the Right @ V_L

Origin of Data*	Vertical Acceleration @ c.g. (g)	Pitch Rate (deg/sec)	Roll Rate (deg/sec)	Yaw Rate (deg/sec)	Pitch Attitude (deg)	Roll Attitude (deg)
N_1	1.94	8	11	5	25	26
N_2	1.64	6	12	3	9	22
N_3	2.07	9	11	3	18	25
N_4	1.77	7	13	6	23	30
N_5	1.64	7	8	3	8	24
N_6	1.75	7	8	3	8	21
N_7	1.62	6	-3	4	-7	20
N_8	1.21	2	-2	2	-2	7
N_9	1.41	5	10	4	-7	23
N_{10}	1.63	7	13	3	15	25
F_1	2.01	11	18	5	6	26
F_2	2.16	11	17	5	-5	13
F_3	2.09	12	12	6	11	18
F_4	1.94	15	12	7	-5	13
F_5	1.75	11	18	2	1	16
F_6	1.82	10	17	0	1	13
F_7	1.72	8	17	4	-4	33
F_8	2.23	17	-2	8	12	34
F_9	1.82	7	-1	6	11	28
F_{10}	1.79	9	8	5	17	24

* NOTE:

N_i indicates data was taken from nonfiring load level survey

F_i indicates data was taken from firing load level survey

i indicates number of times flight condition was performed in load level survey

TABLE 9. Concluded

Flight Condition: Gunnery Run Pullup to the Left @ V_L

Origin of Data*	Vertical Acceleration @ c.g. (g)	Pitch Rate (deg/sec)	Roll Rate (deg/sec)	Yaw Rate (deg/sec)	Pitch Attitude (deg)	Roll Attitude (deg)
N_1	2.03	10	-9	-6	23	-35
N_2	1.73	8	-12	-5	9	-31
N_3	1.97	8	-14	-4	13	-33
N_4	1.78	8	-12	-4	21	-29
N_5	1.63	6	5	0	16	-21
N_6	1.66	4	11	-5	10	9
N_7	1.56	5	-7	-5	-12	-22
N_8	1.17	2	-4	-3	-5	-4
N_9	1.43	6	7	-4	8	-21
N_{10}	1.59	7	-15	-7	14	-31
F_1	2.19	12	-18	2	6	-24
F_2	2.20	11	-18	4	-6	-11
F_3	1.83	7	-5	-4	4	-9
F_4	1.85	9	-11	0	5	-13
F_5	1.86	10	-9	0	18	-10

* NOTE:

N_i indicates data was taken from nonfiring load level survey.

F_i indicates data was taken from firing load level survey.

i indicates number of times flight condition was performed in load level survey

In Table 2, where all airspeeds are expressed in terms of V_H (the maximum attainable level flight airspeed) or V_L (the limit airspeed), the V_H of 144 KTAS is defined in Reference 6, and V_L is defined in Reference 7 and shown in Figure 8. In

6. Finnestead, R.L., Laing, E., Connor, W.J., and Buss, M.W., ENGINEERING FLIGHT TEST, AH-1G HELICOPTER (HUEY/COBRA), PHASE D PART 2, PERFORMANCE, USAASTA 66-06, U.S. Army Aviation Systems Test Activity, Edwards Air Force Base, California, April 1970, AD 874210.

7. Technical Manual, TM 55-1520-221-10, OPERATOR'S MANUAL: ARMY MODEL AH-1G HELICOPTER, Headquarters, Department of the Army, Washington, D.C., 12 December 1975.

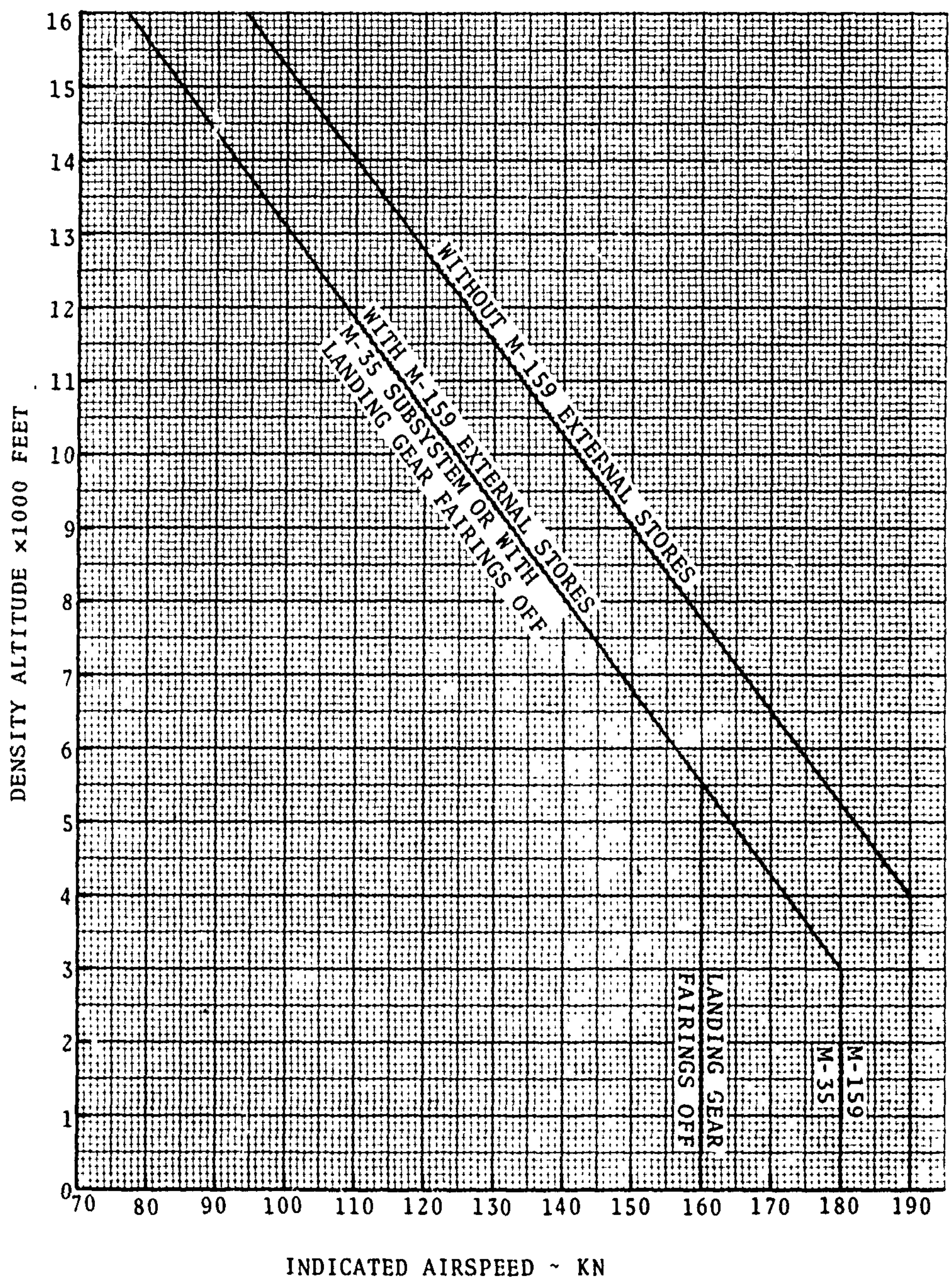


Figure 8. Limit Velocity (V_L) Definition.

this figure the airspeed limitation for the M-159 external stores configuration will be incorporated in the FCM system as a reasonable, although conservative, V_L definition. Since both V_H and V_L are a function of density altitude, pressure altitude and outside air temperature were included among the required parameters so that they could be monitored in conjunction with indicated airspeed. V_H and V_L can be calculated from the following equations:

$$V_H = 144 - \frac{H_d}{500} \qquad (6)$$

and $$V_L = 180 \text{ knots below } H_d = 3000 \text{ ft} \qquad (7)$$

$$V_L = 180 - 8\left[\frac{H_d}{1000} - 3\right] \text{ for } H_d \text{ above } 3000 \text{ ft} \qquad (8)$$

where V_H = maximum level flight airspeed, knots

V_L = limit airspeed, knots

H_d = density altitude, feet

the density altitude is calculated from:

$$H_d = 145{,}447 \left[1 - \left(\frac{9.6307\, P_a}{T + 273.18}\right)^{.235}\right] \qquad (9)$$

where P_a = static pressure, inches mercury

T = outside air temperature, °C.

Since the damage rates for the AH-1G flight conditions vary significantly with gross weight, that parameter was included in the FCM system to further enhance the validity of the FCM system damage assessment model. The ranges chosen to represent the low, medium, and high gross weight categories are listed in Table 10.

TABLE 10. GROSS WEIGHT RANGES

Range Nomenclature	Gross Weight Range (lb)
L-GW	less than 7750
M-GW	7750 through 8750
H-GW	greater than 8750

The following method was chosen as the most practical means of reasonably estimating the instantaneous gross weight: (1) measure the takeoff gross weight by a landing skid deflection technique, and (2) conservatively estimate the instantaneous gross weight of the helicopter by only assuming that the gross weight linearly decreases with fuel burnoff.

Description of Recommended FCM System

The evaluation of all fatigue-damaging flight conditions relative to the previously described flight parameter behavior led to the selection of the parameters listed in Table 11 as the set of coordinated parameters which may best describe the

TABLE 11. SELECTED MONITORING PARAMETERS FOR FCM RECORDING SYSTEM

Directly Monitored Parameters	Symbol
Indicated Airspeed	A/S
Pressure Altitude	H_p
Outside Air Temperature	T
Main Rotor Velocity	MRV
Roll Attitude	β
Pitch Attitude	θ
Vertical Acceleration @ c.g.	n_z
Landing Gear Touchdown	TD
Engine Torque Pressure	ET
Takeoff Gross Weight	TGW

Computed Parameters	Symbol
Rate of Descent	RD
Maximum (Level Flight) Airspeed	V_H
Limit Airspeed	V_L
Instantaneous Gross Weight	GW

fatigue design spectrum in terms of a unique set of flight condition categories (FCC) (See Table 12). Although FCC 83 through 85, 89 through 91, and 95 through 97 do not specifically represent any of the flight conditions defined in the fatigue design spectrum, they enhance understanding of the AH-1G operational usage spectrum. (For example, FCC 96 was intended to measure and record the magnitude of the largest vertical acceleration peak during a recording period.) Table 12 summarizes the resultant FCM system recommended for the AH-1G helicopter. For simplicity, the breakdown of the 89 flight conditions by gross weight range was not shown in this table.

Note in Table 12 that it was necessary to formulate six flight condition categories that are not directly recorded (FCC 98 through 103). These FCC are reserved for estimations of time spent in making control corrections during hover and control corrections at 0.9 V_H. This provision was made because the data in Reference 4 revealed that although these flight conditions could not be confidently detected, their damage rates were of sufficient magnitude to warrant due recognition.

Therefore, since the control corrections occur on a statistical basis, it was decided to account for them by first defining the FCC in which their time would be included (the hovering control correction times would appear in FCC 1, 2, and 3, and the control correction times at 0.9 V_H would appear in FCC 14, 15, and 16). A liberal percentage of time (2 percent was chosen) was deducted from these recorded flight condition categories and assigned to FCC 98 through 103.

TABLE 12. FCM SYSTEM SUMMARY

Flt. Cond. Cat. No.			Flight Condition Category Description	Type[a] Desig.	Flight Conditions Included	
L-GW	M-GW	H-GW			No.[b]	Description
1	2	3	Flight Clock Time	T	2	Normal Takeoff (IGE)
					3	Jump Takeoff (IGE)
					4	Steady Hover (IGE)
					5	Hovering Right Turn (IGE)
					6	Hovering Left Turn (IGE)
					10	Sideward Flight to the Right (IGE)
					11	Sideward Flight to the Left (IGE)
					12	Rearward Flight (IGE)
					13	Acceleration Hover to Climb A/S (IGE)
					14	Normal Deceleration (IGE)
					41	Sideslip
					43	Firing in a Hover
					44	Strafing in Acceleration from a Hover
	4		Rotor Start/Stop	C	1*	Normal Start/Shutdown (IGE)
5	6	7	Quick Stop	T	15*	Quick-Stop Deceleration (IGE)
8	9	10	Normal Landing	C	16*	Approach and Landing (IGE)
11	12	13	Low-Velocity Flight	T	17	Forward Level Flt. @ 0.50 V_H and 314 RPM
					18	Forward Level Flt. @ 0.50 V_H and 324 RPM
					19	Forward Level Flt. @ 0.60 V_H and 314 RPM
					20	Forward Level Flt. @ 0.60 V_H and 324 RPM
					29	Normal Full Power Climb
					32	Normal Right Turn @ 0.50 V_H
					35	Normal Left Turn @ 0.50 V_H
14	15	16	High-Velocity Flight	T	21	Forward Level Flt. @ 0.70 V_H and 314 RPM
					22	Forward Level Flt. @ 0.70 V_H and 324 RPM
					23	Forward Level Flt. @ 0.80 V_H and 314 RPM
					24	Forward Level Flt. @ 0.80 V_H and 324 RPM
					25	Forward Level Flt. @ 0.90 V_H and 314 RPM
					26	Forward Level Flt. @ 0.90 V_H and 324 RPM
					42	Part Power Descent
17	18	19	Maximum Velocity Flight	T	27*	Forward Level Flt. @ V_H and 314 RPM
					28*	Forward Level Flt. @ V_H and 324 RPM
20	21	22	High-Speed Full Power Climbs	T	30*	High-Speed Full Power Climbs
					31	Max. Rate Accel. Full Power Climb to Cruise A/S
23	24	25	Normal (High-Speed) Turns	T	33*	Normal Right Turn @ 0.70 V_H
					36	Normal Left Turn @ 0.70 V_H
26	27	28	Normal (High-Speed) Turns	T	34*	Normal Right Turn @ 0.90 V_H
					37	Normal Left Turn @ 0.90 V_H
29	30	31	Low-Velocity Dives	T	45	Gunnery Run Pt. Target Dive @ 0.60 V_L
					49	Gunnery Run-Spray Fire Dive @ 0.60 V_L
32	33	34	Moderate-Velocity Dives	T	46*	Gunnery Run-Pt. Target Dive @ 0.80 V_L
					50*	Gunnery Run-Spray Fire Dive @ 0.80 V_L
35	36	37	High-Velocity Dives	T	47*	Gunnery Run-Pt. Target Dive @ 0.90 V_L
					51*	Gunnery Run-Spray Fire Dive @ 0.90 V_L
38	39	40	Maximum-Velocity Dives	T	48*	Gunnery Run-Pt. Target Dive @ V_L
					52*	Gunnery Run-Spray Fire Dive @ V_L
41	42	43	Asymmetrical Pullups	T	53*	Gunnery Run P/U to the Right @ 0.60 V_L
					57*	Gunnery Run-P/U to the Left @ 0.60 V_L
44	45	46	Asymmetrical Pullups	T	54*	Gunnery Run-P/U to the Right @ 0.80 V_L
					58*	Gunnery Run-P/U to the Left @ 0.80 V_L
47	48	49	Asymmetrical Pullups	T	55*	Gunnery Run-P/U to the Right @ 0.90 V_L
					59*	Gunnery Run-P/U to the Left @ 0.90 V_L
50	51	52	Asymmetrical Pullups	T	56*	Gunnery Run-P/U to the Right @ V_L
					60*	Gunnery Run-P/U to the Left @ V_L

TABLE 12. Concluded

Flt. Cond. Cat. No. L-GW	M-GW	H-GW	Flight Condition Category Description	Type[a] Desig.	No.[b]	Flight Conditions Included Description
53	54	55	Symmetrical Pullups	T	61*	Gunnery Run-P/U (Symmetrical) @ 0.60 V_L
56	57	58	Symmetrical Pullups	T	62*	Gunnery Run-P/U (Symmetrical) @ 0.80 V_L
59	60	61	Symmetrical Pullups	T	63* 64*	Gunnery Run-P/U (Symmetrical) @ 0.90 V_L Gunnery Run-P/U (Symmetrical) @ V_L
62	63	64	Gunnery Turns	T	65* 68*	Gunnery Turn to the Right @ 0.50 V_H Gunnery Turn to the Left @ 0.50 V_H
65	66	67	Gunnery Turns	T	66* 69*	Gunnery Turn to the Right @ 0.70 V_H Gunnery Turn to the Left @ 0.70 V_H
68	69	70	Gunnery Turns	T	67* 70*	Gunnery Turn to the Right @ 0.90 V_H Gunnery Turn to the Left @ 0.90 V_H
71	72	73	High-Velocity S-Turn	T	71*	Gunnery S-Turn @ 0.80 V_H
74	75	76	Maximum-Velocity S-Turn	T	72*	Gunnery S-Turn @ V_H
77	78	79	Autorotation Clock Time	T	73 74 75 76 77 80 81 82 83 84 86 87	Power to Auto. Transition @ 0.50 V_H Power to Auto. Transition @ 0.70 V_H Power to Auto. Transition @ 0.90 V_H Auto. to Power Transition (IGL) Auto. to Power Transition @ 0.40 V_H Stabilized Auto. Flt. @ 0.40 V_H Stabilized Auto. Flt. @ 0.60 V_H Stabilized Auto. Flt. @ Max. Auto. A/S Auto. Turn to the Right @ 0.40 V_H Auto. Turn to the Right @ 0.60 V_H Auto. Turn to the Left @ 0.40 V_H Auto Turn to the Left @ 0.60 V_H
80	81	82	Auto. to Power Transition	C	78* 79*	Auto. to Power Transition @ 0.60 V_H Auto. to Power Trans. @ Max. Auto. A/S
83	84	85	Auto. to Power Transition	C	--	------------------------------------
86	87	88	High-Speed Auto. Turns	T	85* 88*	Auto. Turn to the Right @ Max. Auto. A/S Auto. Turn to the Left @ Max. Auto. A/S
89	90	91	High-Speed Auto. Turns	T	--	------------------------------------
92	93	94	Autorotation Landing	C	89*	Autorotation Landing
	95		Misc High-G Maneuvers	M	--	------------------------------------
	96		Maximum n_z Experienced	M	--	------------------------------------
	97		Maximum A/S Experienced	M	--	------------------------------------
98	99	100	Hovering Control Corrections	N	7* 8* 9	Hovering Longitudinal Control Corr. (IGE) Hovering Lateral Control Corr. (IGE) Hovering Rudder Control Corr. (IGE)
101	102	103	High-Speed Control Corr.	N	38* 39* 40*	Longitudinal Control Corr. @ 0.90 V_H Lateral Control Corr. @ 0.90 V_H Rudder Control Corr. @ 0.90 V_H

NOTE (a) T = category timer
C = category occurrence timer
M = maximum parameter magnitude attained
N = null recording category (control corrections times are conservatively estimated from other category timers)

NOTE (b) * Indicates Damaging Flight Conditions

DETERMINATION OF FCM SYSTEM TECHNICAL ACCEPTABILITY

The assessment of the technical acceptability of a candidate FCM system, such as the one described in Table 12, requires analyzing the proposed system with the aid of two computer programs, FCMMOD and SIMULE, which are documented in Reference 1.

Program FCMMOD uses the fatigue design spectrum and associated component damage rates, together with the FCM system definition, to compute appropriate fatigue-damage coefficients for each flight condition category. FCMMOD has a degree of built-in conservativeness since it increases the effect of the highly fatigue-damaging flight conditions in the derivation of flight condition category damage coefficients by simply assigning the maximum flight condition damage rate within each FCC as the damage coefficient for that category.

Program SIMULE simulates the operation of an FCM system by computing component fatigue lives from the FCMMOD-generated fatigue-damage coefficients in a given utilization spectrum, namely, the previously described mild and severe spectra in this application.

Fatigue-Damage Coefficients for FCM System

Table 13 presents the fatigue-damage coefficients for the FCM system described in Table 12. Any damage coefficient with a zero value indicates that the corresponding flight condition category is not fatigue-damaging for the particular component. Accordingly, since flight condition categories 95, 96, and 97 are not specifically representative of fatigue design spectrum flight conditions, their damage coefficients are zero.

Proposed FCM System Compliance with Technical Acceptance Criteria

For both the mild and the severe spectrum, Table 14 lists the SIMULE-computed fatigue lives for each of the 10 AH-1G components and the upper and lower fatigue life bounds for these components.

Since all fatigue lives fall within the respective bounds, the proposed FCM system and the associated FCM system damage model satisfy the technical acceptance criteria and therefore are valid means for assessing fatigue damage in AH-1G fatigue-critical components.

Detailed FCM System Description

Although the technically acceptable FCM system described in Table 12 defines the system parameter combinations and associated threshold levels, it does not define a completely workable system. For example, consider flight condition

TABLE 13. FATIGUE DAMAGE COEFFICIENTS FOR EACH COMPONENT IN EACH FLIGHT CONDITION CATEGORY

Flight Condition Category	Main Rotor Blade	Main Rotor Yoke Extension	Main Rotor Grip	Main Rotor Pitch Horn	Retention Strap Ftg./Nut
1	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	.3623E-01
5	0.	0.	0.	0.	0.
6	.4267E-03	0.	0.	0.	0.
7	.1789E-02	0.	0.	0.	0.
8	0.	0.	0.	0.	0.
9	.8420E-03	0.	0.	0.	0.
10	.6800E-03	0.	0.	0.	0.
11	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.
17	.4245E-02	0.	0.	0.	0.
18	.2900E-03	0.	0.	0.	0.
19	.2867E-03	0.	0.	0.	0.
20	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.
22	.1137E-02	0.	0.	0.	0.
23	0.	0.	0.	0.	0.
24	.2100E-03	0.	0.	0.	0.
25	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.
28	.1833E-03	0.	0.	0.	0.
29	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.
34	.5185E-03	0.	0.	0.	0.
35	.2917E-03	0.	0.	0.	0.
36	.2700E-03	0.	0.	0.	0.
37	.1094E-02	0.	0.	0.	0.
38	.4482E-02	0.	0.	0.	0.
39	.1429E-03	0.	0.	0.	0.
40	.6778E-02	0.	0.	0.	0.
41	0.	0.	0.	0.	0.
42	.8200E-03	0.	0.	0.	0.
43	.3700E-02	0.	0.	.6233E-02	0.
44	.2867E-02	0.	0.	.1167E-02	0.
45	.4193E-02	0.	0.	.1400E-02	0.
46	.5567E-02	0.	0.	.9478E-02	0.
47	.1440E-02	.2970E-02	0.	.7500E-03	0.
48	.5904E-02	.7080E-02	0.	.3156E-02	0.
49	.1717E-01	.5107E-02	0.	.1499E-01	0.
50	.3900E-01	.1250E-01	0.	.2400E-02	0.
51	.1640E-01	.2366E-01	0.	.4840E-02	0.
52	.5860E-01	.2437E-01	0.	.2223E-01	0.

TABLE 13. Continued

Flight Condition Category	Main Rotor Blade	Main Rotor Yoke Extension	Main Rotor Grip	Main Rotor Pitch Horn	Retention Strap Ftg./Nut
53	0.	0.	0.	0.	0.
54	.8000E-03	0.	0.	0.	0.
55	.3667E-02	0.	0.	.6333E-02	0.
56	.6667E-03	0.	0.	.3333E-03	0.
57	.5600E-02	0.	0.	.1120E-01	0.
58	.1244E-01	.1044E-01	0.	.1933E-01	0.
59	.1085E+00	.1400E-01	0.	.1050E-01	0.
60	.7780E-01	.1140E-01	0.	.1700E-01	0.
61	.1173E+00	.1153E-01	0.	.3733E-01	0.
62	0.	0.	0.	0.	0.
63	.3467E-03	0.	0.	0.	0.
64	.4053E-02	0.	0.	0.	0.
65	.5333E-03	0.	0.	0.	0.
66	.6880E-03	0.	0.	0.	0.
67	.2267E-02	0.	0.	.3644E-03	0.
68	.4080E-02	0.	0.	0.	0.
69	.7445E-02	0.	0.	.4560E-03	0.
70	.6489E-02	0.	0.	.1204E-02	0.
71	.2900E-02	.9050E-02	0.	0.	0.
72	.5100E-02	0.	0.	0.	0.
73	.1123E-01	0.	0.	0.	0.
74	.1773E-01	.2133E-01	0.	0.	0.
75	.9921E-02	.3605E-02	0.	0.	0.
76	.1245E-01	.1705E-01	.4786E-01	0.	0.
77	0.	0.	0.	0.	0.
78	0.	0.	0.	0.	0.
79	.2511E-02	0.	0.	0.	0.
80	.4000E-03	0.	0.	0.	0.
81	.1600E-03	0.	0.	0.	0.
82	.8667E-02	0.	0.	0.	0.
83	.4000E-03	0.	0.	0.	0.
84	.1600E-03	0.	0.	0.	0.
85	.8667E-02	0.	0.	0.	0.
86	0.	0.	0.	0.	0.
87	0.	0.	0.	0.	0.
88	0.	0.	0.	0.	0.
89	0.	0.	0.	0.	0.
90	0.	0.	0.	0.	0.
91	0.	0.	0.	0.	0.
92	.1114E-01	0.	0.	0.	0.
93	.5320E-02	0.	0.	0.	0.
94	.3947E-02	.1005E-01	0.	0.	0.
95	0.	0.	0.	0.	0.
96	0.	0.	0.	0.	0.
97	0.	0.	0.	0.	0.
98	.8000E-02	0.	0.	0.	0.
99	.1400E-02	0.	0.	0.	0.
100	.1000E-02	0.	0.	0.	0.
101	.8100E-02	0.	0.	0.	0.
102	.1140E-01	0.	0.	0.	0.
103	.5867E-02	0.	0.	0.	0.

TABLE 13. Continued

Flight Condition Category	Swashplate Drive Link	Swashplate Outer Ring	Swashplate Inner Ring	Hydraulic Boost Cylinder	Tail Rotor Blade
1	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.
17	0.	0.	.4450E-03	0.	0.
18	0.	0.	0.	0.	.5340E-03
19	0.	0.	0.	0.	.7467E-03
20	0.	0.	[illegible]	0.	0.
21	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	.2592E-02
28	0.	0.	0.	0.	.4800E-03
29	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	.5667E-03
37	0.	0.	.3952E-03	0.	0.
38	0.	0.	.5893E-03	0.	0.
39	0.	0.	.1657E-02	.2214E-03	.1707E-02
40	0.	.2024E-02	.7655E-02	.1155E-02	.7278E-02
41	0.	0.	0.	0.	0.
42	0.	0.	0.	0.	0.
43	.1567E-02	.1043E-01	.4000E-03	.1500E-02	0.
44	0.	.1067E-02	0.	.1017E-02	.1000E-02
45	.3727E-02	.4087E-02	.2953E-02	.2893E-02	.5067E-03
46	.3222E-02	.1052E-01	.8744E-02	.1322E-01	.5889E-02
47	.1830E-02	.7600E-02	.5640E-02	.3410E-02	.3107E-01
48	.9200E-03	.4536E-02	.3784E-02	.1265E-01	.9344E-02
49	.5420E-02	.4553E-02	.5353E-02	.4299E-01	.1360E-01
50	.4000E-03	.1350E-02	.1300E-02	.1460E-01	.1830E-01
51	.1022E-01	.3400E-02	.3220E-02	.3312E-01	.1916E-01
52	.2693E-01	.6267E-02	.8733E-02	.7277E-01	.3733E-01

TABLE 13. Concluded

Flight Condition Category	Swashplate Drive Link	Swashplate Outer Ring	Swashplate Inner Ring	Hydraulic Boost Cylinder	Tail Rotor Blade
53	0.	0.	0.	0.	0.
54	0.	0.	0.	0.	0.
55	.1667E-02	0.	.6667E-03	.1367E-01	0.
56	0.	0.	0.	.1667E-02	.1167E-02
57	.3267E-02	.6667E-03	.2000E-02	.4867E-02	.1333E-02
58	.6333E-02	.4333E-02	.6667E-02	.1456E-01	.3556E-02
59	.3000E-02	.1000E-02	.2000E-02	.1400E-01	.1000E-01
60	.7800E-02	.1400E-02	.2720E-02	.2040E-01	.7000E-02
61	.1400E-01	.9600E-02	.6333E-02	.3800E-01	.1680E-01
62	0.	0.	0.	0.	0.
63	0.	0.	0.	0.	0.
64	0.	0.	0.	.6844E-03	0.
65	0.	0.	0.	0.	0.
66	0.	0.	0.	.1600E-04	0.
67	0.	0.	0.	0.	0.
68	0.	.2880E-02	.1487E-02	0.	.3327E-02
69	.1453E-02	.2560E-03	0.	.3413E-03	.3840E-03
70	.3289E-03	.5040E-02	.5244E-02	.9556E-03	.6324E-02
71	0.	.2250E-03	.2175E-02	0.	.5750E-03
72	0.	0.	0.	.2000E-04	.2740E-02
73	0.	.1583E-02	.3917E-02	0.	.8333E-03
74	0.	.2600E-02	.4133E-02	.4000E-03	.1667E-01
75	0.	.4737E-03	.2763E-02	.3421E-03	.1866E-01
76	0.	.2273E-02	.1055E-01	0.	.6377E-01
77	0.	0.	0.	0.	0.
78	0.	0.	0.	0.	0.
79	0.	0.	0.	0.	0.
80	0.	0.	0.	0.	0.
81	0.	0.	0.	0.	0.
82	0.	.1200E-02	.8000E-03	0.	.6667E-03
83	0.	0.	0.	0.	0.
84	0.	0.	0.	0.	0.
85	0.	.1200E-02	.8000E-03	0.	.6667E-03
86	0.	0.	0.	0.	0.
87	0.	0.	0.	0.	0.
88	0.	.8000E-03	0.	0.	.5333E-03
89	0.	0.	0.	0.	0.
90	0.	0.	0.	0.	0.
91	0.	.8000E-03	0.	0.	.5333E-03
92	0.	0.	0.	0.	0.
93	0.	0.	0.	0.	0.
94	0.	0.	0.	0.	.5733E-03
95	0.	0.	0.	0.	0.
96	0.	0.	0.	0.	0.
97	0.	0.	0.	0.	0.
98	0.	0.	0.	.1000E-02	0.
99	0.	0.	0.	.5600E-02	0.
100	0.	0.	0.	0.	0.
101	0.	.4000E-03	0.	0.	.1260E-01
102	0.	0.	0.	0.	0.
103	0.	0.	0.	0.	.4667E-03

TABLE 14. TECHNICAL ACCEPTABILITY RESULTS

Component Identification	FCM System Performance Assessed Damage	FCM System Performance Projected Life	Fatigue Life Bounds Lower	Fatigue Life Bounds Upper
Mild Utilization Spectrum				
Main Rotor Blade	.324574E-01	3,081	1,100	4,307
Main Rotor Yoke Extension	.493331E-02	20,271	3,300	24,917
Main Rotor Grip	.526500E-03	189,934	Unlimited	190,042
Main Rotor Pitch Horn	.681070E-02	14,683	6,600	17,953
M/R Retention Strap Ftg./Nut	.105077E-01	9,517	2,200	9,517
Swashplate Drive Link	.458481E-02	21,812	11,000	27,353
Swashplate Outer Ring	.723471E-02	13,823	3,300	18,707
Swashplate Inner Ring	.573742E-02	17,430	3,300	25,128
Hydraulic Boost Cylinder	.161467E-01	6,134	3,300	8,635
Tail Rotor Blade	.118041E-01	8,472	1,100	12,106
Severe Utilization Spectrum				
Main Rotor Blade	.400355E-01	2,498	1,100	3,542
Main Rotor Yoke Extension	.843841E-02	11,851	3,300	14,779
Main Rotor Grip	.143591E-02	69,643	Unlimited	69,686
Main Rotor Pitch Horn	.112521E-01	8,888	6,600	10,596
M/R Retention Strap Ftg./Nut	.223197E-01	4,481	2,200	4,488
Swashplate Drive Link	.747809E-02	13,373	11,000	16,513
Swashplate Outer Ring	.110711E-01	9,033	3,300	12,325
Swashplate Inner Ring	.925062E-02	10,811	3,300	15,481
Hydraulic Boost Cylinder	.233981E-01	4,274	3,300	5,145
Tail Rotor Blade	.190302E-01	5,255	1,100	7,192

categories 50, 51, and 52, which represent high-speed asymmetrical gunnery run pullups. Although these maneuvers are identified by the combination of a vertical acceleration above 1.5g, a roll attitude between 10° and 35°, and an airspeed greater than 0.95 V_L, they are not adequately represented by simply measuring the time within which the parameters are attaining the foregoing values simultaneously. Rather, these maneuvers would likely be better represented by the time duration of the roll attitude while it exceeded and returned to 10° but did not reach 35°, provided that the airspeed is above 0.95 V_L at the initial 10° crossing and that the vertical acceleration exceeds 1.5g within a prescribed time after the initial 10° crossing.

Various considerations, such as the reasoning in the foregoing example, led to the definition of a much more detailed FCM system. Because of the lengthy description needed to define each flight condition category in the resultant FCM system, these flight condition categories are depicted and defined in Appendix A.

Because of the complexity of many of the flight condition categories and the parameter monitoring requirements, the FCM recorder incorporates a microprocessor. During the development of the FCM system, the airborne recorder was flight-tested with an oscillograph recorder capable of monitoring those parameters listed in Table 8. Then the two sets of data were compared to evaluate the functioning of the FCM recorder and to adjust the parameter threshold levels in the FCM system so that the established flight conditions could be better defined.

CHAPTER 3.

SYSTEM DESCRIPTION

The SIRS system consists of three discrete but interrelated subsystems. The airborne SIRS recorder monitors helicopter usage by identifying and storing the occurrences of various flight conditions. The ground-based, portable data retrieval unit transfers the recorder-stored data onto a miniature data tape cassette on a monthly basis. At a central data processing site, the software system automatically processes and analyzes the data, and then generates tailored reports that present the usage and corresponding incremental fatigue damage to each component for each monitored helicopter. The complete system is pictured in Figure 9.

SIRS RECORDER

The SIRS recorder, viewed in Figure 10, incorporates a Motorola Model 6800 microprocessor. This microprocessor monitors the nine flight parameters listed in Table 15 and from them calculates the density altitude and adjusted airspeed limits.

When these flight parameters fall in preset ranges or form certain flight conditions, the microprocessor accumulates their occurrences or the amount of time associated with them in the recorder's data-storage memory. The flight conditions are defined generally as various combinations of flight parameters, each in a preset range. Examples of flight conditions are flight time, rotor starts, and maximum vertical acceleration. Table 16 lists the 22 flight condition categories established for the AH-1G.

As shown in Figure 11, the SIRS recorder processes the inputs from the transducers for the nine monitored parameters. Each of the inputs is conditioned to a desired full-scale signal level, multiplexed, and converted from an analog to a digital signal to be processed by the microprocessor. The recorder software logic identifies the flight conditions by associating the variation and corresponding time of each input parameter with those of the other input parameters. While these conditions are being identified, the microprocessor calculates the density altitude and limit velocities and temporarily stores the calculations in the recorder's scratch pad memory. The programs for these calculations and the flight condition software logic are contained in EPROM (erasable programmable read-only memory) integrated circuits. The time spent in or the number of occurrences of the various flight conditions is stored in the recorder's data-storage memory, which consists of RAM (random access memory) integrated circuits. Since these circuits are volatile, the recorder

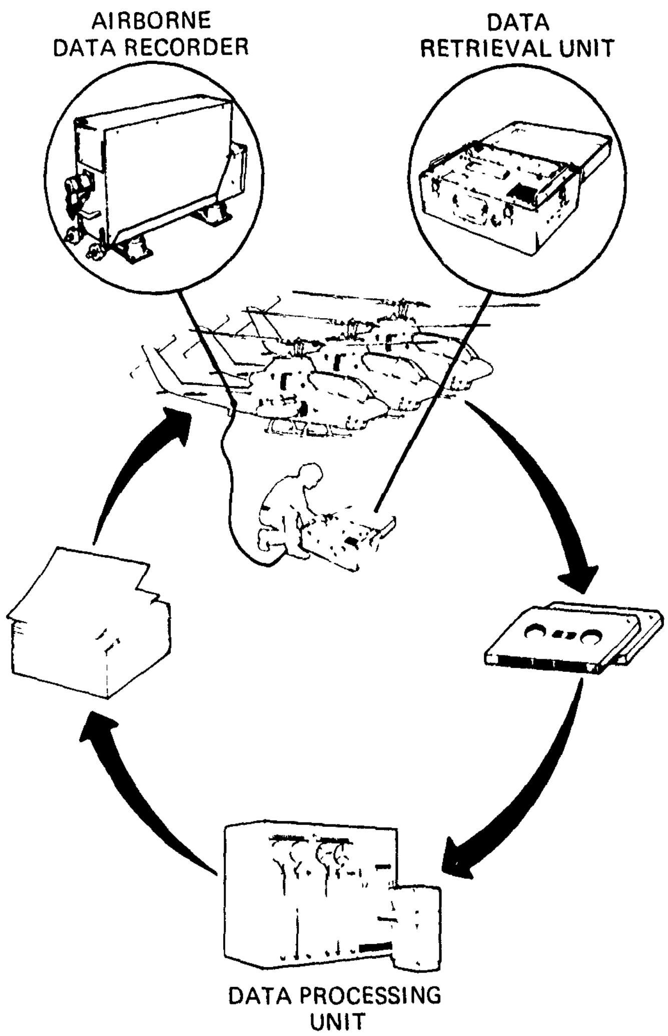


Figure 9. Structural Integrity Recording System.

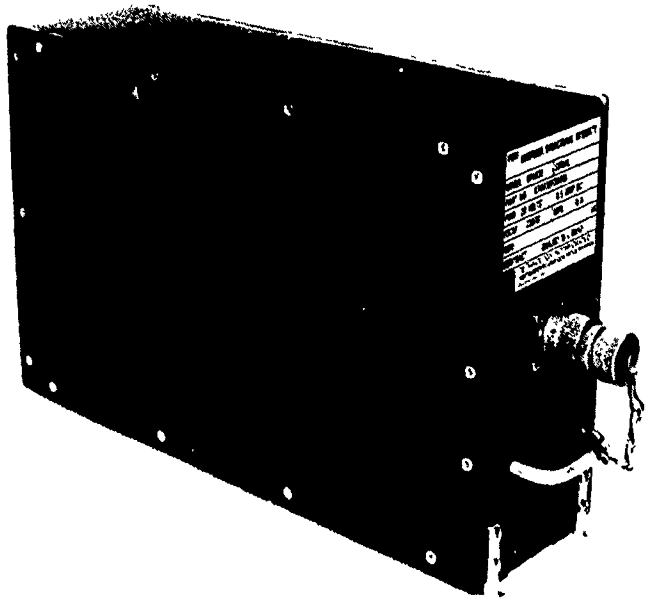


Figure 10. SIRS Recorder.

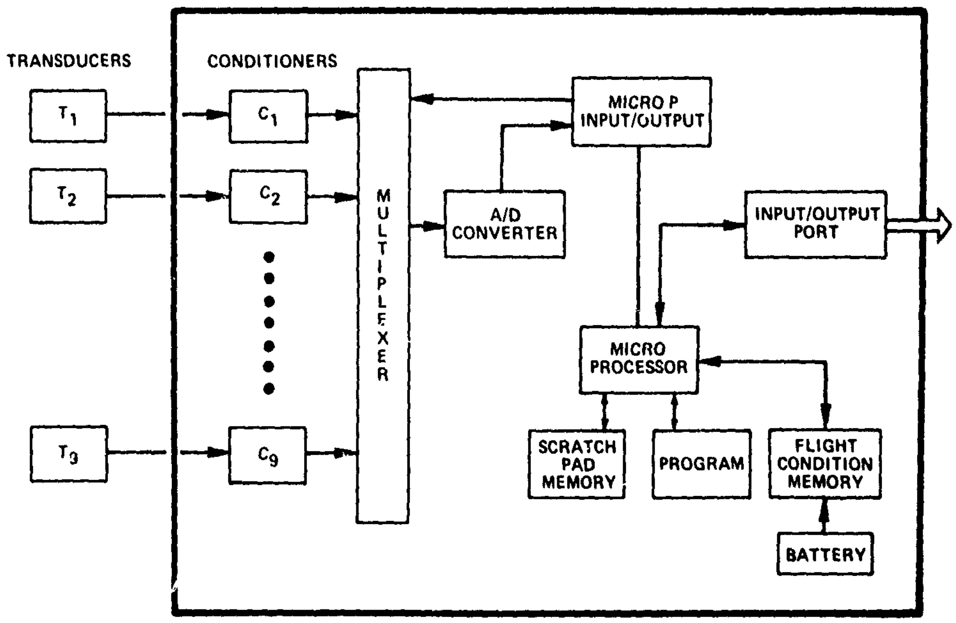


Figure 11. Schematic of Structural Integrity Recorder.

TABLE 15. SIRS PARAMETERS

Measured	Computed
Airspeed	Percent V_L Airspeed
Pressure Altitude	Percent V_H Airspeed
Outside Air Temperature	Density Altitude
Gross Weight	
Pitch Attitude	
Roll Attitude	
Engine Torque	
Main Rotor Speed	
Vertical Acceleration	
Touchdown	

TABLE 16. FLIGHT CONDITION CATEGORIES

Title	Measured Quantity		
	Occurrences	Time	Measured Value
Flight Time		*	
Rotor Start/Stop	*		
Full Power Climb		*	
Low-Speed Flight		*	
High-Speed Flight		*	
Maximum-Speed Flight		*	
Normal High-Speed Turns		*	
Gunnery Turns		*	
Gunnery S-Turns		*	
Gunnery Run Dives-Symmetrical		*	
-Asymmetrical		*	
Symmetrical Pullouts		*	
Asymmetrical Pullouts		*	
High n_z Maneuvers	*		
Normal Landings	*		
Autorotation Time		*	
Autorotation Turns		*	
Autorotation to Power Transition	*		
Autorotation Landings	*		
Quick-Stop Deceleration		*	
Maximum % V_L			*
Maximum n_z			*

incorporates dual batteries with a one-year operational capacity to retain the stored data when aircraft power is turned off. The recorder software package is listed in Appendix B.

The recorder installation, including recorder, shock mount, transducers, and harnesses, weighs 20.3 pounds; a detailed breakdown of the installation's weight is presented in Table 17. The recorder, including mounting rack and electromagnetic-interference-shielded connector, is 17.50 inches long, 6.50 inches wide, and 10.15 inches high; these dimensions include the necessary space for recorder/shock mount sway. The recorder operates on 28 Vdc supplied by the aircraft and consumes approximately 7 watts.

RETRIEVAL UNIT

SIRS is designed so that data need be retrieved only once a month by the portable, flight-line data retrieval unit pictured in Figure 12. During the transcription of the recorder data onto the miniature magnetic tape cassette, the operator interacts with the unit. While the unit displays messages, the operator communicates with the unit through a keyboard. Because of the on-board processing of the flight data, the data recorded during the normal monthly operation of more than 50 helicopters can be stored on a single data cassette. The program used to permit retrieval unit and recorder interactions is called the Initial Processing System (IPS). The data retrieval, including setup, takes less than 5 minutes and can be performed on a flexible schedule. In addition to data retrieval, the data retrieval unit performs diagnostic checks of the recorder, on-board recorder battery, and transducers. It can also be used as a readout device during the transducer calibrations.

During the retrieval process, limited operator inputs listed in Table 18 are requested to supplement data contained within the recorder. The aircraft serial number is entered in the format of fiscal year and aircraft number, xx-xxxxx, and supplements the recorder serial number, which is permanently stored electronically within the recorder. Since retrievals are not performed on a fixed schedule, the retrieval data, in the format of day, month, and year, is another entry; this information is used to indicate trends in the retrieval data. The chronology of the data is identified by a numbering device built into the recorder that increments each time a retrieval is made. Logbook flight hours are entered to track the variation between the actual flight and ground-operating time and the logged time. The operating base is entered to permit analyzing the fleet-wide variation in helicopter usage. Finally, as requested by the display, the operator enters the reason for the data retrieval. There are three acceptable reasons: monthly retrieval, component replacement, and re-

TABLE 17. SIRS RECORDER WEIGHT BREAKDOWN

Component	Weight (lb)
Recorder/Rack	9.25
Airspeed/Altitude Transducer and Brackets	1.6
OAT	0.07
Vertical Acceleration Transducer and Bracket	1.2
Gross Weight Transducer and Bracket	0.14
Harnesses and misc. hardware	8.0
Total	20.26

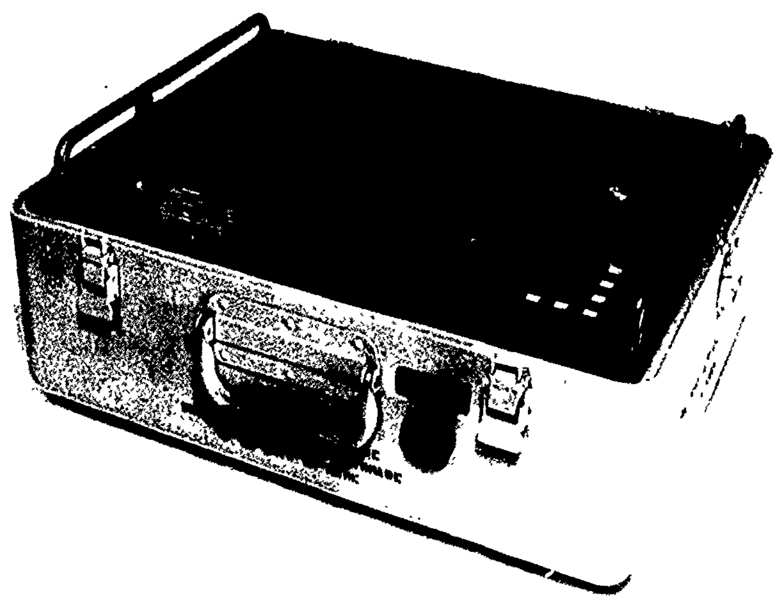


Figure 12. SIRS Retrieval Unit.

corder maintenance. After the operator enters the supplemental data, the data retrieval unit performs a diagnostic check of the recorder including its memory, makes a copy of the recorder data residing in memory, and records the current static values of each of the transducers. These data, together with the supplemental data previously entered by the operator, are recorded on the miniature magnetic tape cassettes. Each time the data is transferred, that is, from the memory in the recorder to that in the data retrieval unit and from the latter to the cassette, it is checked to verify the validity of the transfer.

TABLE 18. SIRS RETRIEVAL UNIT OPERATOR INPUTS

Aircraft Serial Number	Base of Operation
Date of Retrieval	Reason for Retrieval
Log Book Flight Hours	

The various error messages listed in Table 19 are displayed when the diagnostic check detects recorder deficiencies, when data cannot be retrieved or written on the tape cassette, or when the tape cassette is not installed or is full. Each coded error message (instructions for each are mounted inside the cover of the data retrieval unit) leads the operator to the necessary corrective action.

The data retrieval unit is 19.1 inches long, 15.6 inches wide, and 9.8 inches high and weighs 45.4 pounds. The retrieval unit has a rechargeable power system and is housed in a flight-line styled container. The recharging power required is 110 to 120 Vac, 60 Hz.

SOFTWARE

Upon receiving the data from the miniature cassettes, the software system first performs an initial data processing to (1) verify the recorder operation and transducer functioning and (2) to review the long-term trend of the transducer static readings, and then analyzes the data. The analysis includes the data segregation by specific flight condition categories, the data conversion to a 100-flight-hour basis, and the data presentation in terms of a usage spectrum. An example of this data presentation is shown in Figure 13. Next the software system governs three techniques to further analyze the data by calculating the incremental fatigue damage for each critical tracked component. The first technique is based on the relationship of the recorder data with the SIRS fatigue model developed for the AH-1G helicopter. In the second technique the calculations are based on the rates established by current Army-approved component replacement times and the logbook flight hours. The third technique is the same as the second

SIRS SPECTRUM USAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
VALUES PER 100 HOURS WERE COMPUTED USING THE RETRIEVAL TIME.

FLIGHT CONDITION	GROSS WEIGHT (LB)	TIME (HOURS) RETRIEVAL	TIME (HOURS) PER 100 HOURS	OCCURRENCE RETRIEVAL	OCCURRENCE PER 100 HOURS
FLIGHT TIME	TOTAL	0.9	100.0		
1	<7750	0.5	56.9		
2	7750-8750	0.4	43.1		
3	>8750	0.0	0.0		
ROTOR CYCLES	TOTAL			1	113.8
4				1	113.8
QUICK STOPS	TOTAL	0.0	0.0		
5	<7750	0.0	0.0		
6	7750-8750	0.0	0.0		
7	>8750	0.0	0.0		
NORMAL LDGS	TOTAL			1	113.8
8	<7750			1	113.8
9	7750-8750			0	0.0
10	>8750			0	0.0
LOW SPEED FLT	TOTAL	0.0	4.3		
11	<7750	0.0	0.4		
12	7750-8750	0.0	3.9		
13	>8750	0.0	0.0		
HIGH SPEED FLT	TOTAL	0.5	52.6		
14	<7750	0.3	29.5		
15	7750-8750	0.2	23.1		
16	>8750	0.0	0.0		
MAX SPEED FLT	TOTAL	0.0	3.7		
17	<7750	0.0	1.7		
18	7750-8750	0.0	2.0		
19	>8750	0.0	0.0		
HIGH TORQUE FLT	TOTAL	0.0	0.0		
20	<7750	0.0	0.0		
21	7750-8750	0.0	0.0		
22	>8750	0.0	0.0		
LOW SPEED TURNS	TOTAL	0.0	0.0		
23	<7750	0.0	0.0		
24	7750-8750	0.0	0.0		
25	>8750	0.0	0.0		

Figure 13. Sample of Spectrum Generated by SIRS Software.

SIRS SPECTRUM USAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
VALUES PER 100 HOURS WERE COMPUTED USING THE RETRIEVAL TIME.

FLIGHT CONDITION	GROSS WEIGHT (LB)	TIME (HOURS) RETRIEVAL	TIME (HOURS) PER 100 HOURS	OCCURRENCE RETRIEVAL	OCCURRENCE PER 100 HOURS
HIGH SPEED TURNS	TOTAL	0.1	8.3		
26	<7750	0.1	7.0		
27	7750-8750	0.0	1.2		
28	>8750	0.0	0.0		
LOW SPEED DIVES	TOTAL	0.0	0.0		
29	<7750	0.0	0.0		
30	7750-8750	0.0	0.0		
31	>8750	0.0	0.0		
MED SPEED DIVES	TOTAL	0.0	0.3		
32	<7750	0.0	0.2		
33	7750-8750	0.0	0.2		
34	>8750	0.0	0.0		
HIGH SPEED DIVES	TOTAL	0.0	0.1		
35	<7750	0.0	0.0		
36	7750-8750	0.0	0.1		
37	>8750	0.0	0.0		
MAX SPEED DIVES	TOTAL	0.0	0.0		
38	<7750	0.0	0.0		
39	7750-8750	0.0	0.0		
40	>8750	0.0	0.0		
LOW SPD ASYM P/U	TOTAL	0.0	0.0		
41	<7750	0.0	0.0		
42	7750-8750	0.0	0.0		
43	>8750	0.0	0.0		
MED SPD ASYM P/U	TOTAL	0.0	0.0		
44	<7750	0.0	0.0		
45	7750-8750	0.0	0.0		
46	>8750	0.0	0.0		
HI SPD ASYM P/U	TOTAL	0.0	0.0		
47	<7750	0.0	0.0		
48	7750-8750	0.0	0.0		
49	>8750	0.0	0.0		
MAX SPD ASYM P/U	TOTAL	0.0	0.0		
50	<7750	0.0	0.0		
51	7750-8750	0.0	0.0		
52	>8750	0.0	0.0		

Figure 13. Continued

SIRS SPECTRUM USAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
VALUES PER 100 HOURS WERE COMPUTED USING THE RETRIEVAL TIME.

FLIGHT CONDITION	GROSS WEIGHT (LB)	TIME (HOURS) RETRIEVAL	PER 100 HOURS	OCCURRENCE RETRIEVAL	PER 100 HOURS
LOW SPD SYM P/U	TOTAL	0.0	0.0		
53	<7750	0.0	0.0		
54	7750-8750	0.0	0.0		
55	>8750	0.0	0.0		
MED SPD SYM P/U	TOTAL	0.0	0.0		
56	<7750	0.0	0.0		
57	7750-8750	0.0	0.0		
58	>8750	0.0	0.0		
HIGH SPD SYM P/U	TOTAL	0.0	0.0		
59	<7750	0.0	0.0		
60	7750-8750	0.0	0.0		
61	>8750	0.0	0.0		
LOW SPD GUN TURN	TOTAL	0.0	0.0		
62	<7750	0.0	0.0		
63	7750-8750	0.0	0.0		
64	>8750	0.0	0.0		
MED SPD GUN TURN	TOTAL	0.0	0.0		
65	<7750	0.0	0.0		
66	7750-8750	0.0	0.0		
67	>8750	0.0	0.0		
HI SPD GUN TURN	TOTAL	0.1	5.9		
68	<7750	0.0	0.8		
69	7750-8750	0.0	5.1		
70	>8750	0.0	0.0		
GUN S-TURN	TOTAL	0.0	4.4		
71	<7750	0.0	4.4		
72	7750-8750	0.0	0.0		
73	>8750	0.0	0.0		
MAX SPD S-TURN	TOTAL	0.0	0.0		
74	<7750	0.0	0.0		
75	7750-8750	0.0	0.0		
76	>8750	0.0	0.0		
AUTO TIME	TOTAL	0.0	2.1		
77	<7750	0.0	2.1		
78	7750-8750	0.0	0.0		
79	>8750	0.0	0.0		

Figure 13. Continued

SIRS SPECTRUM USAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
VALUES PER 100 HOURS WERE COMPUTED USING THE RETRIEVAL TIME.

FLIGHT CONDITION	GROSS WEIGHT (LB)	TIME (HOURS) RETRIEVAL	TIME (HOURS) PER 100 HOURS	OCCURRENCE RETRIEVAL	OCCURRENCE PER 100 HOURS
LOW NZ AUTO/PWR	TOTAL			0	0.0
80	<7750			0	0.0
81	7750-8750			0	0.0
82	>8750			0	0.0
HIGH NZ AUTO/PWR	TOTAL			0	0.0
83	<7750			0	0.0
84	7750-8750			0	0.0
85	>8750			0	0.0
LOW NZ AUTO TURN	TOTAL	0.0	0.0		
86	<7750	0.0	0.0		
87	7750-8750	0.0	0.0		
88	>8750	0.0	0.0		
HI NZ AUTO TURN	TOTAL	0.0	0.0		
89	<7750	0.0	0.0		
90	7750-8750	0.0	0.0		
91	>8750	0.0	0.0		
AUTO LOGS	TOTAL			0	0.0
92	<7750			0	0.0
93	7750-8750			0	0.0
94	>8750			0	0.0

95	HIGH NZ COUNTER	12
96	MAX NZ VALUE	2.4
97	MAX A/S VALUE	1.0

Figure 13. Concluded

except that the recorder flight time is used instead of the logbook flight time. Figure 14 is a sample of the format used in presenting the data calculated by each technique. The software package permitting these calculations is called the Fatigue Damage Assessment System (FDAS).

TABLE 19. RETRIEVAL UNIT ERROR MESSAGES

LINE ABORT?	-	Denotes that the retrieval unit-to-recorder communications were not properly established or were interrupted.
DATA ABORT?	-	Denotes that there was an error condition during the transmission of the recorder data onto the retrieval unit's temporary data-storage memory.
WRITE ABORT?	-	Denotes that there was an error condition during the data writing on the magnetic tape.
FULL ABORT?	-	Denotes that sufficient space could not be found on the magnetic tape for the data writing.
TAPE ABORT?	-	Denotes that the tape cassette is not capable of reading or writing because of its malfunctioning or improper positioning.
COUNTER	-	Denotes that a bad memory location was detected during the diagnostic check of the recorder's data storage memory.
BATTERY	-	Denotes that the recorder's battery power supply is marginal.

Software Concept

The data processing and management system is composed of three parts: the Initial Processing System (IPS), the Fatigue Damage Assessment System (FDAS), and the Component Tracking Management System (CTMS). Each of the three modules of the system was treated and designed as a separate entity. This allows for ease of maintenance of the system and flexibility in the operation of the system.

COMPONENT DAMAGE

AIRCRAFT: 66-15254 LOG TIME: 1985.6 RETRIEVAL DATE: 50477 REASON: SCHEDULED
RECORDER: 1030 BASE: 1
DELTA LOG TIME: 1.0 HOURS
DELTA RECORDER TIME: 0.9 HOURS

COMPONENT	SIRS DAMAGE	FLIGHT HOUR DAMAGE RECORDER	LOG
MAIN ROTOR BLADE	0.00072	0.00080	0.00091
MAIN ROTOR YOKE EXTENSION	0.00035	0.00027	0.00030
MAIN ROTOR GRIP	0.0	0.00009	0.00010
MAIN ROTOR PITCH HORN	0.00002	0.00013	0.00015
RETENTION STRAP FTG/NUT	0.00009	0.00040	0.00045
SWASHPLATE DRIVE LINK	0.00007	0.00008	0.00009
SWASHPLATE OUTER RING	0.00004	0.00027	0.00030
SWASHPLATE INNER RING	0.00010	0.00027	0.00030
HYDRAULIC BOOST CYLINDER	0.00010	0.00027	0.00030
TAIL ROTOR BLADE	0.00017	0.00080	0.00091

Figure 14. Sample of Component Damage Generated by SIRS Software.

The first two modules, IPS and FDAS, were written in FORTRAN in accordance with contract requirements, but the CTMS was written in COBOL. This was done to maintain a uniformity with the data management techniques being employed by the AVRADCOM computer center. This was in the best interest of the Government, since AVRADCOM is postulated as the eventual user of the system and the development was to be performed on AVRADCOM equipment.

The development was to take place by utilizing a Remote Job Entry terminal located at Technology Incorporated and connected to the AVRADCOM computer via a dial-up communication link.

The following paragraphs briefly describe the main functions of the three modules, and Figures 15, 16, and 17 present system flow.

IPS. The Initial Processing System checks for proper operation of the recorder, the recording medium, and the retrieval unit. This is performed in a number of ways; initially, the IPS checks the parity of the data and the results of the built-in test. The data from the individual counters are then tested for validity to assure that they are within reasonable tolerances.

If the data or any part thereof are determined to be invalid, conservative estimates based on past usage and engineering judgment are made for the erroneous data.

The valid data and/or the estimated data from the various counters are then written on an output tape and identified as actual or estimated for further processing. A printout identifying any equipment problems is also prepared for submittal to the appropriate activity.

FDAS. The Fatigue Damage Assessment System takes each of the forwarded counter values and assigns a damage value to each component according to the model established for the monitored aircraft type. The actual and estimated incremental damages are kept separate for each component.

A data tape is then written and forwarded for further processing. This tape contains the actual or estimated incremental damage for each component type, identified by aircraft serial number. The date of the data is also forwarded.

CTMS. The Component Tracking Management System is the main data management module of the overall system. Its primary function is to update and maintain two tracking files and to generate data reports for field and management usage.

The programs take the data passed on from the FDAS and check the date, in case of removal, to determine with which components the data is associated. The appropriate component's damage fraction is then updated, still retaining the identity of the actual and estimated parts.

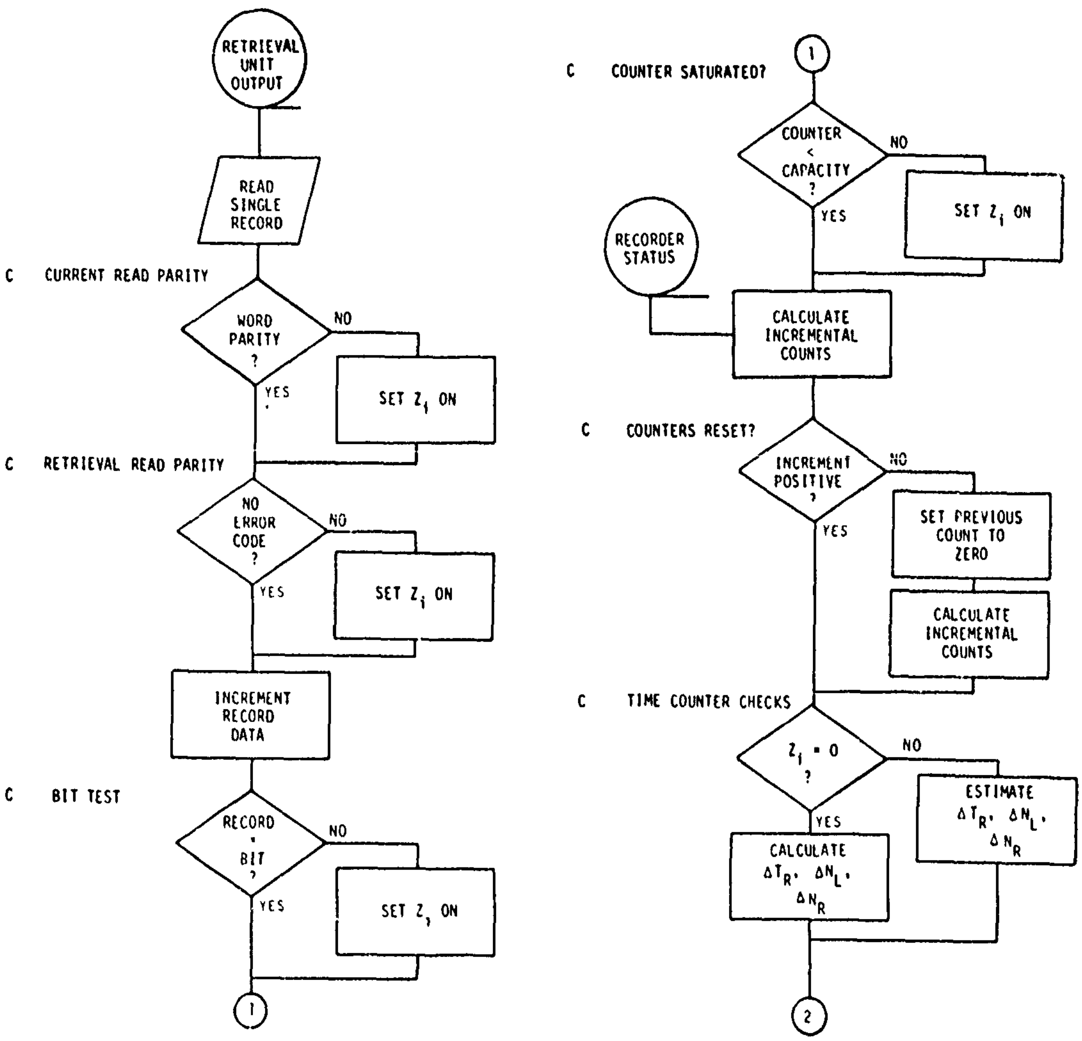


Figure 15. Flow Chart of IPS Processing.

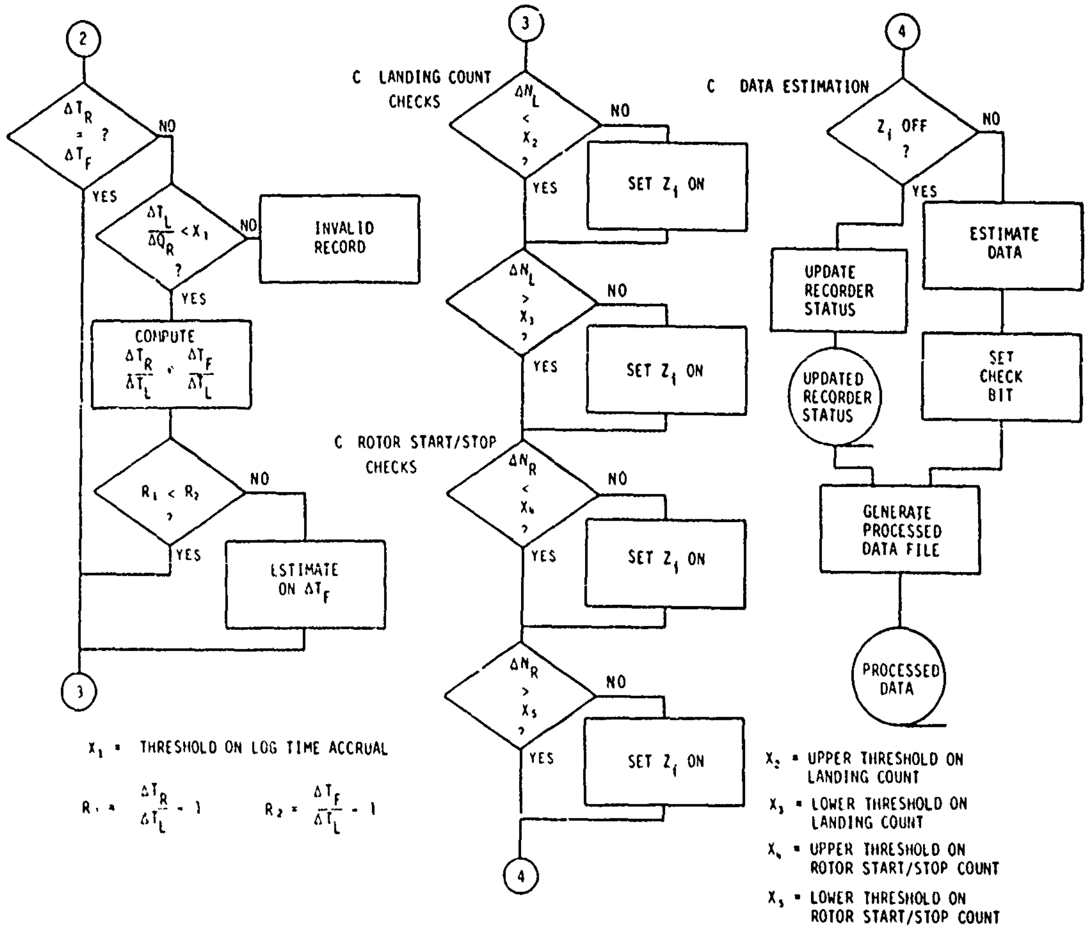


Figure 15. Concluded

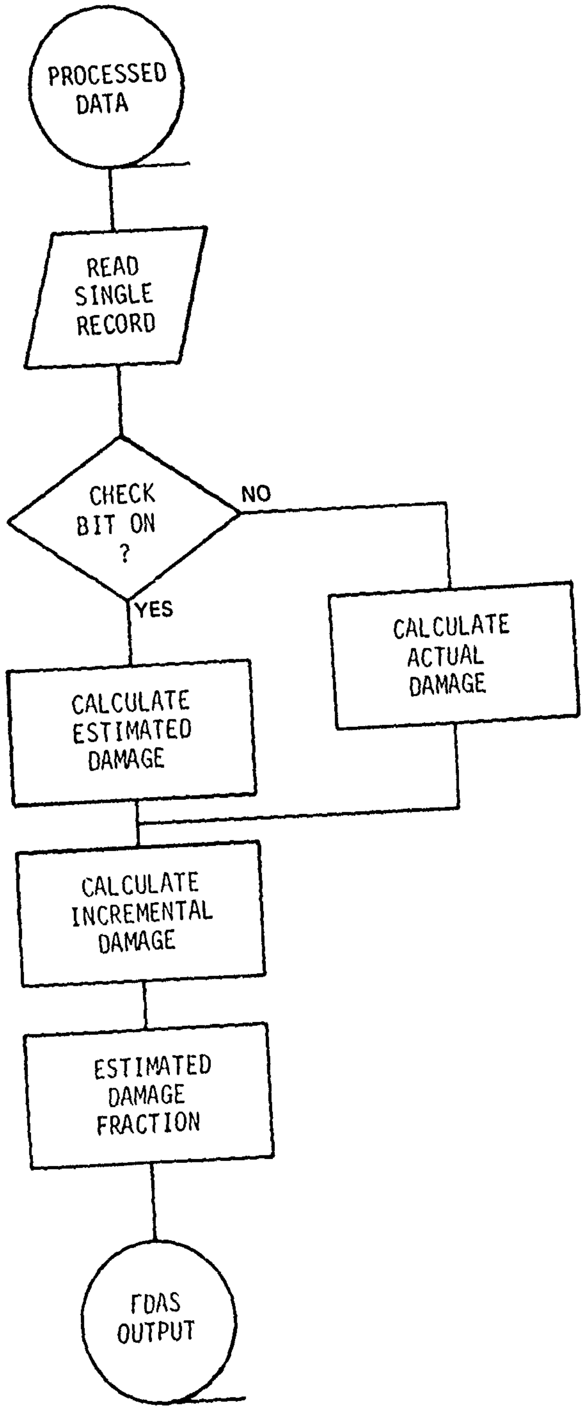


Figure 16. Flow Chart of FDAS Processing.

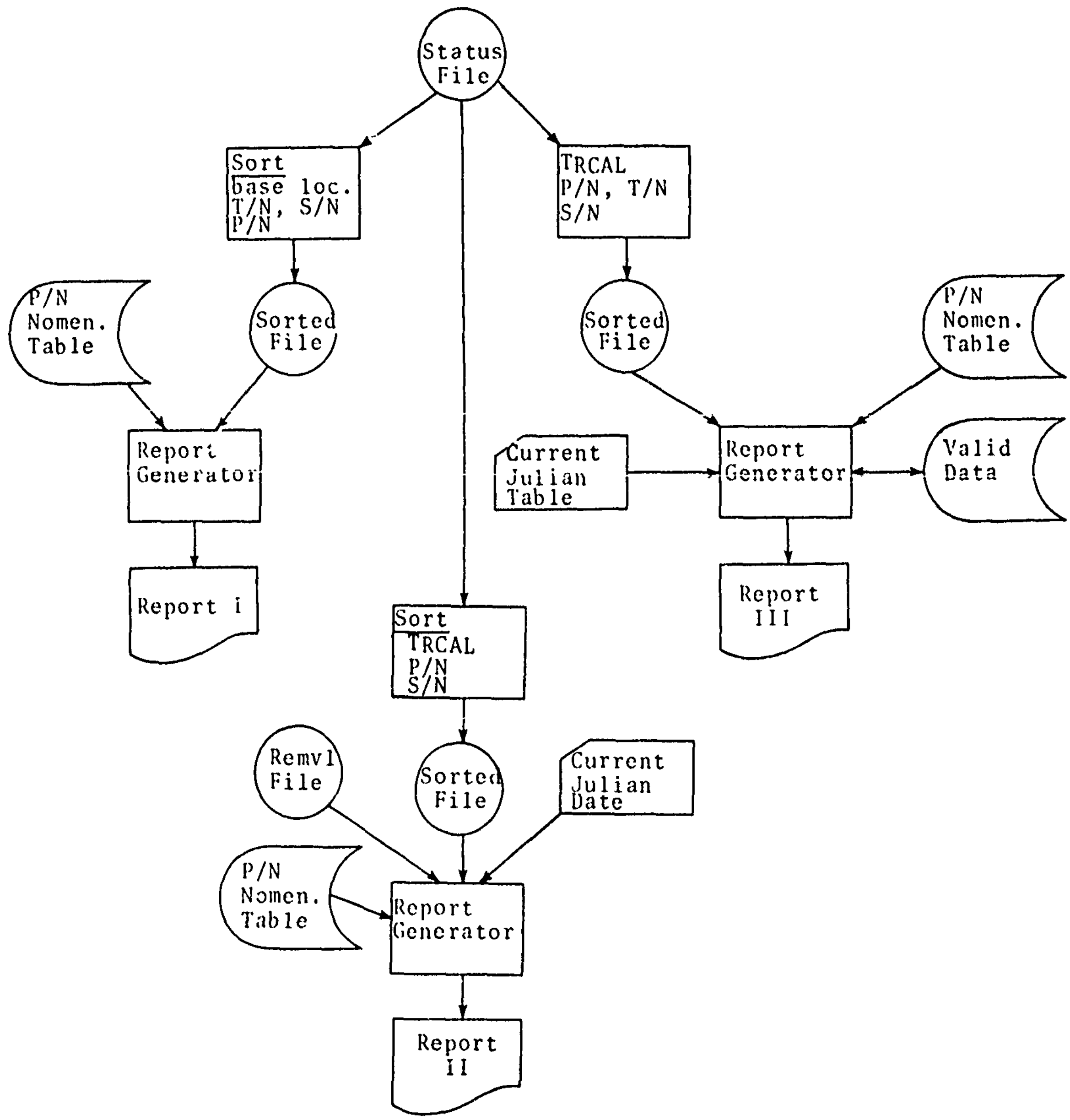


Figure 17. Report Generation Processing.

The status file is then updated with the new damage fractions. The status file contains the historical information concerning each aircraft. This includes the configuration of each aircraft and the time and damage fraction associated with each fatigue-critical component. It is from this file that the majority of the data reports are generated.

A secondary file, the removal file, is maintained for all removed components. This file is used to provide statistical information on removals and to track components removed for overhaul or for other reasons.

It is from these files that the various data reports are generated. Figures 18, 19, and 20 give samples of the reports that will be presented. The reports deal with status of the various components once a certain damage fraction is attained, life projections over selected periods of time, and component replacements due or overdue. The reports will be used for maintenance, management, and planning.

Supplemental Data. In the event of component removals, a supplemental update form (Figure 21) will be completed. This data will be entered into the FDAS to ensure the proper accountability and tracking of the various components.

INSTALLATION KIT

The SIRS recording system was married to the AH-1G airframe via an installation kit consisting of miscellaneous structural hardware, cabling, and specialized instruments. All of the mounting systems were designed to withstand crash loads. This discussion focuses on the sensor suite providing the inputs to the recorder.

The remote sensors required to obtain the data are grouped into the following four categories:

- Pressure transducers
- Accelerometers
- Position potentiometers
- Miscellaneous sensors

Pressure Transducers

The pressure transducers are capacitive type, providing a 0-5 Vdc output signal. For airspeed, a differential pressure transducer that senses the difference between the pitot and static pressures is used. For altitude, an absolute pressure transducer senses the aircraft static pressure.

Accelerometers

The transducer used to sense the normal (vertical) acceleration is a servo force balance type providing a 0-5 Vdc output signal.

SELECTED COMPONENT STATUS
DAMAGE FRACTION GREATER THAN 0.7

A/C TYPE/MODEL: CH-47C
AIRCRAFT NO: 64-13145
BASE: FT RUCKER
DATA THRU: 05/01/74
REPORT DATE: 05/15/74

COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	DAMAGE ACCRUAL RATE	DAMAGE FRACTION	PERCENTAGE OF DAMAGE FRACTION ESTIMATED	REMAINING LIFE (HRS)	REPLACEMENT DATE JULIAN DATE	
114R2196-2	PIN HORIZONTAL HINGE	PL593	.00034 P	0.971	3.2	0	74130	***
114R1543-4	BLADE SOCKET ROTOR HUB	7-5669-1	.00063 P	0.891	4.1	94	74176	*
114R2155	TIE BAR AFT ROTOR HUB	W-411-0	.00056 S	0.733	0.9	388	74330	
114R1502-33	ROTOR BLADE, AFT	5988413	.00074 T	0.784	2.7	224	74217	*
114R1543-3	BLADE SOCKET, FWD HUB	67-33921	.00042 P	0.716	1.4	557	75053	
114D3250	AFT ROTOR SHAFT	SL-4119N	.00055 T	0.711	3.2	435	7-348	

*** THIS MAJOR COMPONENT HAS REACHED OR EXCEEDED 0.95 DAMAGE AND REPLACEMENT IS OVERDUE

* THIS MAJOR COMPONENT IS DUE FOR REPLACEMENT IN 0-3 MONTHS

P - DAMAGE ACCRUAL RATE BASED ON DATA FROM THE PREVIOUS MONTH

S - DAMAGE ACCRUAL RATE BASED ON DATA FROM THE PREVIOUS 6 MONTHS

T - DAMAGE ACCRUAL RATE BASED ON TOTAL PREVIOUS DATA

Figure 18. Report I, Selected Component Status.

SELECTED COMPONENT
USEFUL LIFE PROJECTIONS

A/C TYPE: CH-47C
BASE: FT RUCKER
DATA PERIOD: JAN-MAR 1974
REPORT DATE: 05/15/74

COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	REMOVALS LAST QUARTER	PROJECTED REMOVALS FOR 0-3 MONTHS	PROJECTED REMOVALS FOR 0-12 MONTHS	PROJECTED REMOVALS FOR 12-15 MONTHS	PROJECTED REMOVALS FOR 12-24 MONTHS
114R2050	HEAD ASSY (HUB),ROTARY	13	20	87	39	186
114R2196-2	PIN HORIZONTAL HINGE	54	63	274	110	572
114R2088	PITCH SHAFT AFT ROTOR	49	58	289	131	593
114R1543-4	BLADE SOCKET AFT ROTOR	79	50	265	99	509
114R2155	TIE BAR AFT ROTOR HUB	58	56	256	147	388
114R1502-33	AFT ROTOR BLADE	53	61	269	125	587
114D3250	AFT ROTOR SHAFT	18	22	90	41	202
114R2197	PITCH SHAFT FWD HUB	56	62	257	115	568
114R2155	TIE BAR FWD ROTOR HUB	56	53	263	122	611
114R1543-3	BLADE SOCKET FWD HUB	59	60	272	143	556

Figure 19. Report II, Selected Component Removal Projections.

A/C TYPE/MODEL: CH-47C
DATA PERIOD: MAY-JULY 1974
REPORT DATE: 05/15/74

****
* REPLACEMENTS DUE 0-3 MONTHS *
****

COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	A/C NO.	BASE	REMOVAL DATE
114R2088	PITCH SHAFT AFT ROTOR	M5421	68-43110	FT RUC	05/30/74
114R2088	PITCH SHAFT AFT ROTOR	C4701	67-55462	FT RUC	06/15/74
114R1543-4	BLADE SOCKET AFT ROTOR	VY1022	67-22629	FT RUC	05/30/74
114R2196-2	PIN HORIZONTAL HINGE	A510	68-43110	FT RUC	06/03/74
114R2196-2	PIN HORIZONTAL HINGE	VY4149	67-55462	FT RUC	07/28/74
114R2155	TIE BAR AFT ROTOR HUB	PL248-14	68-43110	FT RUC	06/17/74
114R2155	TIE BAR AFT ROTOR HUB	A1244	67-22629	FT RUC	07/09/74
114R2155	TIE BAR FWD ROTOR HUB	VF0110	67-55462	FT RUC	07/13/74
114R1502-33	AFT ROTOR BLADE	A913	67-55462	FT RUC	06/23/74
114R1502-33	AFT ROTOR BLADE	A84277	68-43110	FT RUC	07/14/74
114R2197	PITCH SHAFT FWD HUB	NL11740	67-22629	FT RUC	07/05/74
114R1543-3	BLADE SOCKET FWD HUB	VEZ0112	67-55462	FT RUC	07/15/74

Figure 20. Report III, Replacements Due in 0-3 Months, by Component Number.

REPLACEMENTS DUE 0-3 MONTHS

A/C TYPE/MODEL: CH-47C
DATA PERIOD: MAY-JULY 1974
REPORT DATE: 05/15/74

A/C NUMBER	BASE	COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	REMOVAL DATE
67-22629	FT RUC	114R1543-4	BLADE SOCKET AFT ROTOR	VY1022	05/30/74
67-22629	FT RUC	114R2197	PITCH SHAFT FWD HUB	NL11740	07/05/74
67-22629	FT RUC	114R2155	TIE BAR AFT ROTOR HUB	A1244	07/09/74
67-55462	FT RUC	114R2088	PITCH SHAFT AFT ROTOR	C4701	06/15/74
67-55462	FT RUC	114R1502-33	AFT ROTOR BLADE	A913	06/23/74
67-55462	FT RUC	114R2196-2	PIN HORIZONTAL HINGE	VY4149	07/28/74
67-55462	FT RUC	114R2155	TIE BAR FWD ROTOR HUB	VE0110	07/13/74
67-55462	FT RUC	114R1543-3	BLADE SOCKET FWD HUB	VEZ0112	07/15/74
68-43110	FT RUC	114R2088	PITCH SHAFT AFT ROTOR	M5421	05/30/74
68-43110	FT RUC	114R2196-2	PIN HORIZONTAL HINGE	A510	06/03/74
68-43110	FT RUC	114R2155	TIE BAR AFT ROTOR HUB	PL248-14	06/17/74
68-43110	FT RUC	114R1502-33	AFT ROTOR BLADE	A84277	07/14/74

Figure 20. Continued

OVERDUE REPLACEMENTS

A/C TYPE/MODEL: CH-47C
REPORT DATE: 05/15/74

COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	A/C NO.	BASE	REMOVAL DATE
114D3250	AFT ROTOR SHAFT	55-3104	67-22629	FT RUC	01/03/74
114D3250	AFT ROTOR SHAFT	T6299	68-43110	FT RUC	04/23/74
114D3250	AFT ROTOR SHAFT	R2327	67-55462	FT RUC	05/01/74
114R2088	PITCH SHAFT AFT ROTOR	VZ10043	65-10143	FT RUC	03/03/74
114R2088	PITCH SHAFT AFT ROTOR	L439218	67-22629	FT RUC	03/28/74
114R2050	HEAD ASSY (HUB), ROTARY	EX124	66-05372	FT RUC	03/18/74
114R1502-33	AFT ROTOR BLADE	4-316-9	66-05372	FT RUC	04/10/74
114R1502-33	AFT ROTOR BLADE	4438	67-22629	FT RUC	05/01/74
114R2155	TIE BAR FWD ROTOR HUB	LB431	65-10143	FT RUC	04/11/74
114R2155	TIE BAR FWD ROTOR HUB	A6464	66-05372	FT RUC	04/30/74
114R2196-2	PIN HORIZONTAL HINGE	VA4335	65-10143	FT RUC	04/23/74
114R2197	PIN HORIZONTAL HINGE	JU52038	66-05372	FT RUC	05/02/74

Figure 20. Continued

OVERDUE REPLACEMENTS

A/C TYPE/MODEL: CH-47C
REPORT DATE: 05/15/74

A/C NUMBER	BASE	COMPONENT PART NUMBER	COMPONENT NOMENCLATURE	COMPONENT SERIAL NUMBER	REMOVAL DATE
65-10143	FT RUC	114R2088	PITCH SHAFT AFT ROTOR	VZ10043	03/03/74
65-10143	FT RUC	114R2155	TIE BAR FWD ROTOR HUB	LB431	04/11/74
65-10143	FT RUC	114R2196-2	PIN HORIZONTAL HINGE	VA4335	04/23/74
66-05372	FT RUC	114R2050	HEAD ASSY (HUB),ROTARY	EX124	03/18/74
66-05372	FT RUC	114R1502-33	AFT ROTOR BLADE	4-316-9	04/10/74
66-05372	FT RUC	114R2155	TIE BAR FWD ROTOR HUB	A6464	04/30/74
66-05372	FT RUC	114D3250	AFT ROTOR SHAFT	R2327	05/01/74
66-05372	FT RUC	114R2197	PIN HORIZONTAL HINGE	JU52038	05/02/74
67-22629	FT RUC	114D3250	AFT ROTOR SHAFT	S5-3104	01/03/74
67-22629	FT RUC	114R2088	PITCH SHAFT AFT ROTOR	L439218	03/28/74
67-22629	FT RUC	114R1502-33	AFT ROTOR BLADE	4338	05/01/74
68-43110	FT RUC	114D3250	AFT ROTOR SHAFT	T6299	04/23/74

Figure 20. Concluded

U.S. ARMY CRITICAL PARTS MANAGEMENT PROGRAM
FATIGUE-CRITICAL COMPONENT REPLACEMENT FORM

BASE:			A/C TAIL NO.		A/C TYPE/MODEL		
REPLACEMENTS ACCOMPLISHED			REASON REMOVED (X)				
A/C HOURS	MO/DAY/YEAR	MECHANIC	TIME EXPIRED	FAILED	PRE-CAUTION	MOD	SERVICE
			1	2	3	4	5

COMPONENT REMOVALS

REMOVED PART P/N ______ S/N ______

INSTALLED PART P/N ______ S/N ______

TSN: ______ TSO: ______

REMARKS:

Figure 21. Update Form for Component Removals.

Flight Control Positions

To sense rudder pedal position, an infinite resolution potentiometer is used. This unit is wired such that the potentiometer acts as two arms of a Wheatstone bridge circuit. Connected by special actuators to the control linkage, this potentiometer senses the movement of the respective control system. The mechanical attachments between the potentiometer and the control linkages are designed so that binding of the mechanisms will cause them to fail; hence, control of the helicopter cannot b inhibited by the instrumentation system.

Miscellaneous Sensors

Several parameters either require sensing the aircraft's flight instruments or cannot be placed in one of the above categories. The following paragraphs discuss these sensors.

Outside Air Temperature. The outside air temperature is monitored with a thermal ribbon. The ribbon is attached to, but insulated from, the outer skin of the aircraft. The ribbon is a resistor whcse resistance varies with the temperature and is used as the active arm of a Wheatstone bridge circuit.

Rotor Speed. To monitor the main rotor rpm, a special circuit was designed and fabricated. The circuit is composed of all solid-state materials and is mounted on a printed circuit board within the signal conditioning section of the recorder. The output of the counter controls a gate which varies a +5 Vdc circuit between +5 Vdc and ground. The resultant voltage is filtered and reduced to a pure dc signal acceptable to the recorder.

Engine Torque. Engine torque data is acquired from the aircraft's torque transmitter by utilizing a differential amplifier input circuit for isolation and a converter to condition the torque signal. The initial signal is a fixed-frequency, varying amplitude, engine torque signal that is converted to an appropriate dc signal. Variations in this signal due to changes in the torque reference are nullified by monitoring the reference and having the recorder perform a division.

Roll and Pitch Attitudes. Attitude data is obtained from the roll and pitch outputs of the aircraft's attitude gyro. This interface uses solid-state, modular, synchro-to-dc converters with the reference and synchro inputs fully isolated to prevent any degradation of the aircraft's attitude indicator system.

Gross Weight (GW) Indicator. The parameters to compute the gross weight of the helicopter were originally measured prior to each takeoff by two Kistler Morse Model DMC-3-FF-4-1-03 piezoelectric beam sensors attached to the midpoint of the fore-and-aft crosstube members of the skid landing gear. While the helicopter was on the ground the rotor speed was less than 250 rpm, the SIRS recorder processed the sensor outputs to yield the gross weight. An algorithm incorporated in the recorder decreased the gross weight value as fuel was burned. No adjustment was made for the decrease in gross weight due to stores or ammunition dispensing. When this procedure was found inadequate, another approach was used.

The second GW sensor system involved bonding strain gauges to the lift links' transmission mounting members. This was intended to give positive, real-time GW data.

Power and Signal Interconnections

A system wiring harness includes all wiring between the recorder, remote sensors, and aircraft power. The 28 Vdc is acquired by installing circuit breakers in the pilot's right-hand breaker panel and connecting to the nonessential dc bus.

CHAPTER 4.

TEST PROGRAM

A test program was conducted to evaluate the concept of flight condition recording as a means of collecting usage spectrum data. The test program consisted of five elements.

- Brassboard Evaluation
- Laboratory Qualification Testing
- Reliability Analysis
- Prototype Flight Test
- Usage Spectrum Data Collection

Brassboard Evaluation

From the outset, critical elements of SIRS were identified for early testing. The final product was quite close to the original conception.

On-Board Recorder. The recorder circuit can be functionally divided into two primary sections, analog and digital. The analog section consisted of a reference voltage source, individual circuits for each input parameter, and the A/D multiplexer. The digital section consisted of the processor system (CPU, memory, serial and parallel I/O ports), a timing circuit, address decoding, power fail-restart, and an aircraft power-to-battery switchover circuit.

Analog circuits for engine torque, temperature, roll attitude, the reference voltage, and A/D multiplexer circuits were provided. The circuit for the main rotor rpm is presented in Figure 22. The circuit for the outside air temperature measurement is presented in Figure 23. Figures 24 and 25 depict circuits used for various buffered circuits.

Preliminary tests of the digital section of the recorder provided FCC counter data to be stored in one MC5-101L-4 CMOS memory chip. Although satisfactory for the 36 flight condition categories presently defined, the possibility that gross weight considerations could double this number led to the suggestion that the digital printed circuit board layout should allow for the addition of a second memory chip. The brassboard configuration was modified to include the additional memory. Laboratory tests confirmed this to be satisfactory.

The flight recorder case size was to conform to Drive 404, 3/8 airborne transmitter rack. The case was constructed of 19-gauge (0.042") 0.1018 cold-drawn steel.

The finish applied to all steel parts was according to QQ-P-416 Type 2, Class 2 (chromium and chromate plating). All parts internal to the flight recorder with the exception of the power filter were mounted on the PC boards. The power

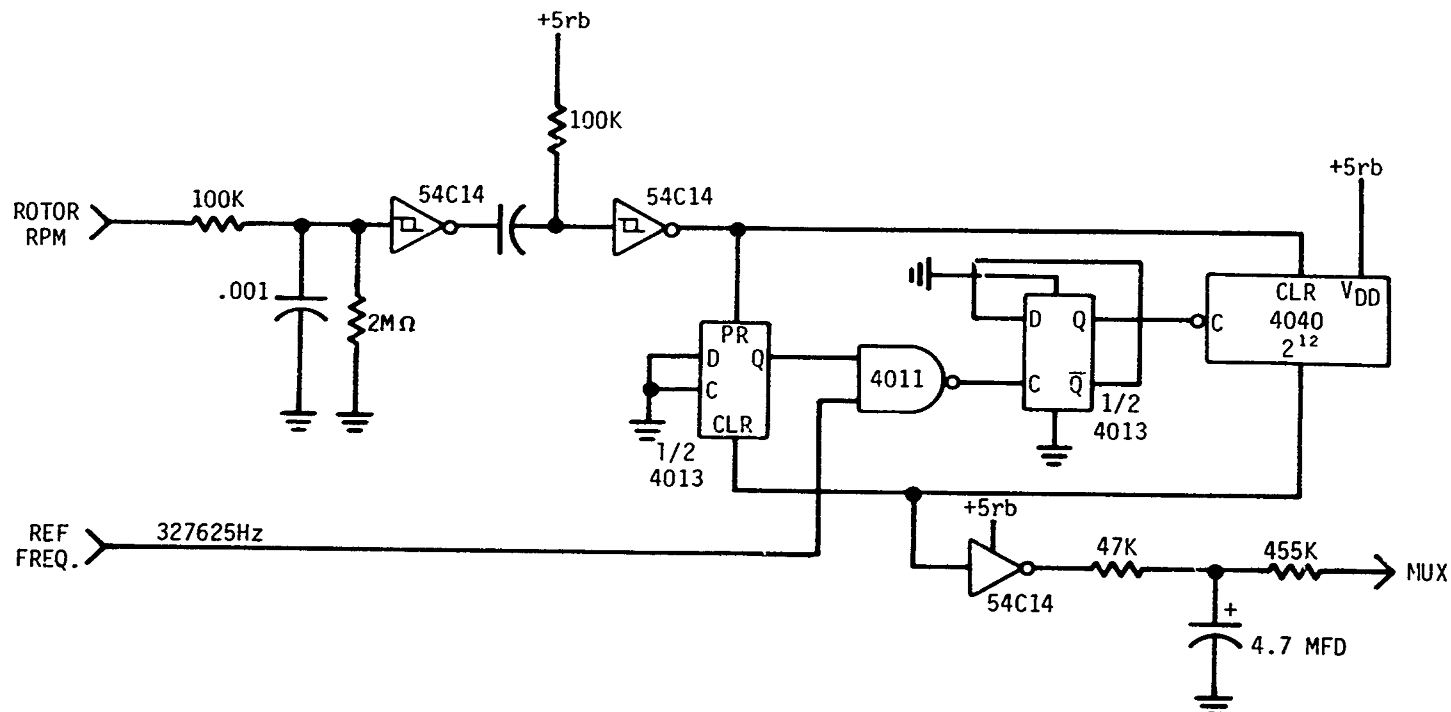
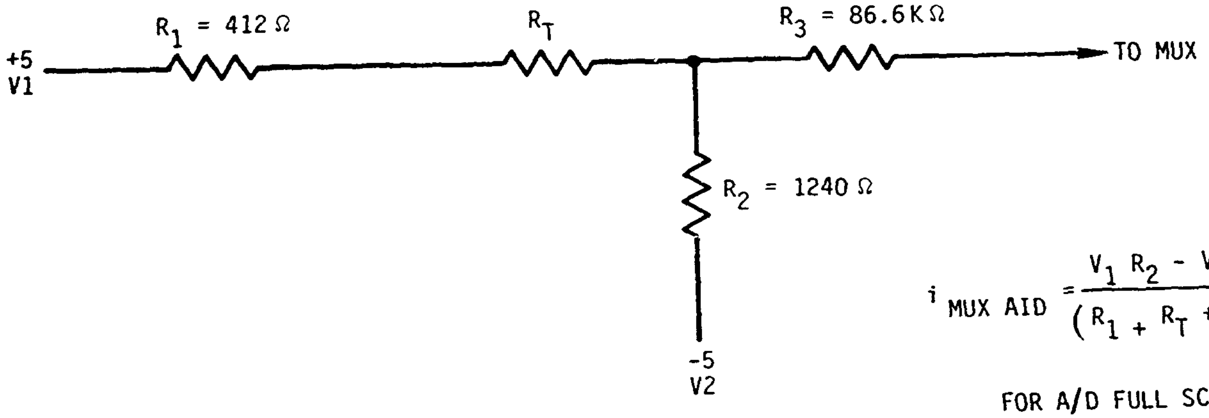


Figure 22. Rotor RPM Measurement.



$$i_{MUX\ AID} = \frac{V_1 R_2 - V_2(R_1 + R_T)}{(R_1 + R_T + R_2)(R_2 + R_3) - R_2^2}$$

FOR A/D FULL SCALE = 10 μ AMPS

$$A/D\ OUT = i_{MUX\ AID} \times 100{,}000 \times 256$$

$$A/D\ OUT = i \times 25{,}600{,}000$$

FOR $R_1 = 412$, $R_2 = 1240$, $R_3 = 86.6K$

$V_1 = V_2 = 5.000$ VDC

$$A/D\ OUT = \frac{256\,(828 - R_T)}{.17568\,R_T + 287.14816}$$

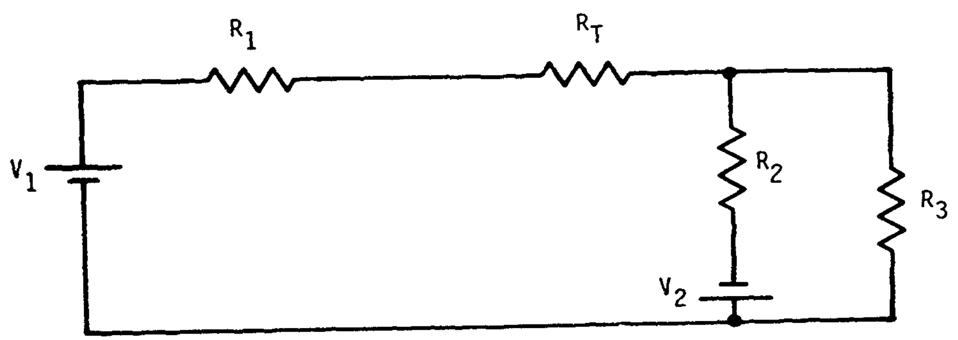


Figure 23. OAT Measurement.

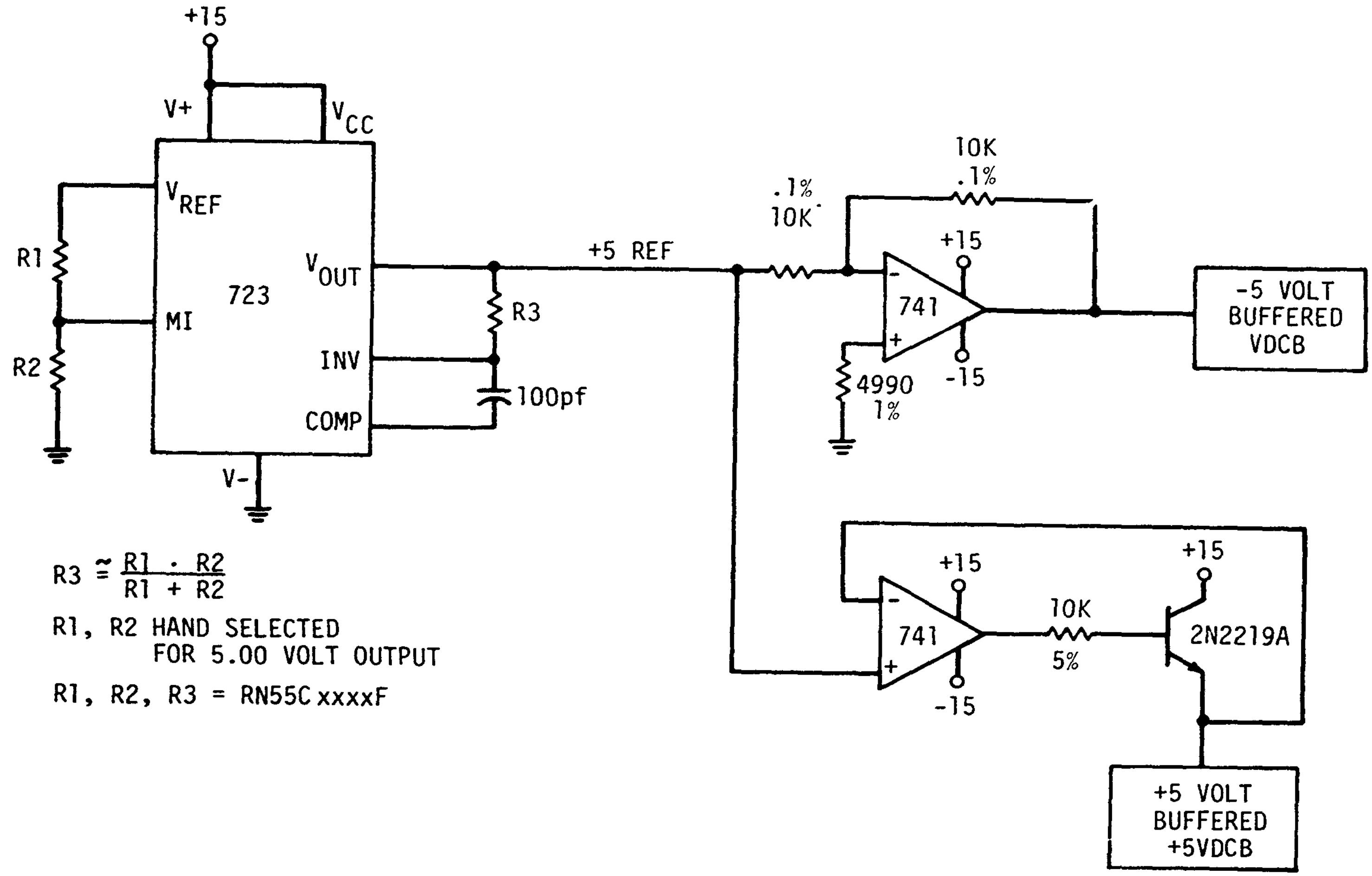
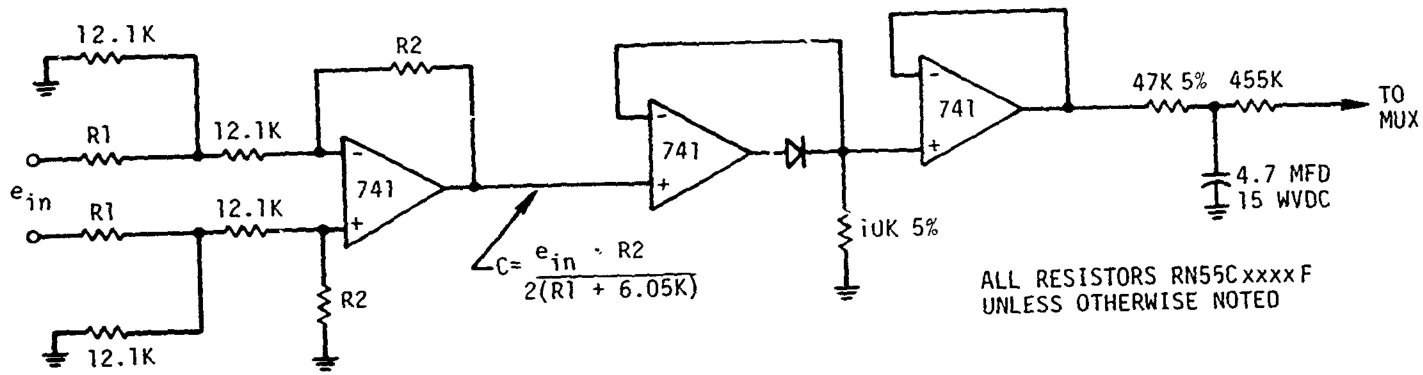


Figure 24. ±5 Volt Buffered Reference Voltages.



$$e_{odc} = \frac{e_{in}\ R2}{2(R1 + 6050)} \cdot \frac{1}{2} \cdot \left(\sqrt{2} \cdot \frac{2}{\pi}\right)$$

$$e_{odc} = \frac{e_{in}\ R2}{\pi\ \sqrt{2}\ (R1 + 6050)} \quad \text{RIPPLE} < 1/256 \text{ F.S.}$$

e_{in} IS RMS MEASUREMENT

Figure 25. Buffered AC-to-DC Circuit for Roll Attitude, Engine Torque, and References.

filter was mounted to a bracket on the bottom of the case.

Two PC boards were used, one for the analog section and one for the digital section of the recorder. The PC boards were mounted to the side cover plates with standoffs positioned to minimize vibrations.

A 3M connector system was used on the PC boards to enhance maintainability. A retention clip was used to lock the plug to the receptacle. A Cannon-type PSE connector on the front panel provided access for the retrieval unit. This connector was normally capped. A Cannon PDP connector mounted on the rear panel of the case provided connection to both the transducers and the input power.

Gaskets on the side covers were a combination of woven Monel for electromagnetic interference (EMI) protection and sponge silicone to provide a moisture/dust seal. The connector gaskets were Monel-impregnated silicone. Metal slugs were provided as part of the cover gaskets to preclude the possibility of overcompensation of the gaskets. All fasteners were specified to MIL-N-25029.

The flight recorder was mounted in a Barry Controls 3/8 ATR tray with helicopter shock mounts.

Data Transfer Unit (DTU). The original design concept required the DTU to serve a dual role - as a retrieval unit in extracting data from the recorder and storing it on cassette tape, and as a test unit to enable an operator to view the extracted data.

As a brassboard retrieval unit, operator inputs would be requested via a six-character alphanumeric display. The operator inputs would be entered through a numeric keyboard. After these operator inputs were accepted, the recorder, on request of the retrieval unit, would send the counter data, all digitized analog channels, and a repeat of the counter data following a test routine. The retrieval unit stored all information and at retrieval conclusion stored it on cassette tape. The alphanumeric display was used to notify the operator of any failures or incorrect inputs. The software flowchart of the communication between recorder and retrieval unit describes the data extraction procedure and is presented in Figure 26.

Following data retrieval, any of the information resident in the retrieval unit was viewed by entering an address via the keyboard.

Data Processing Software. As stated, the data processing software system was to consist of three major elements: the Initial Processing System, the Fatigue Damage Assessment System, and the Component Tracking Management System. Detailed information concerning each of these systems and their operation had been previously planned (Reference 1, p. 76).

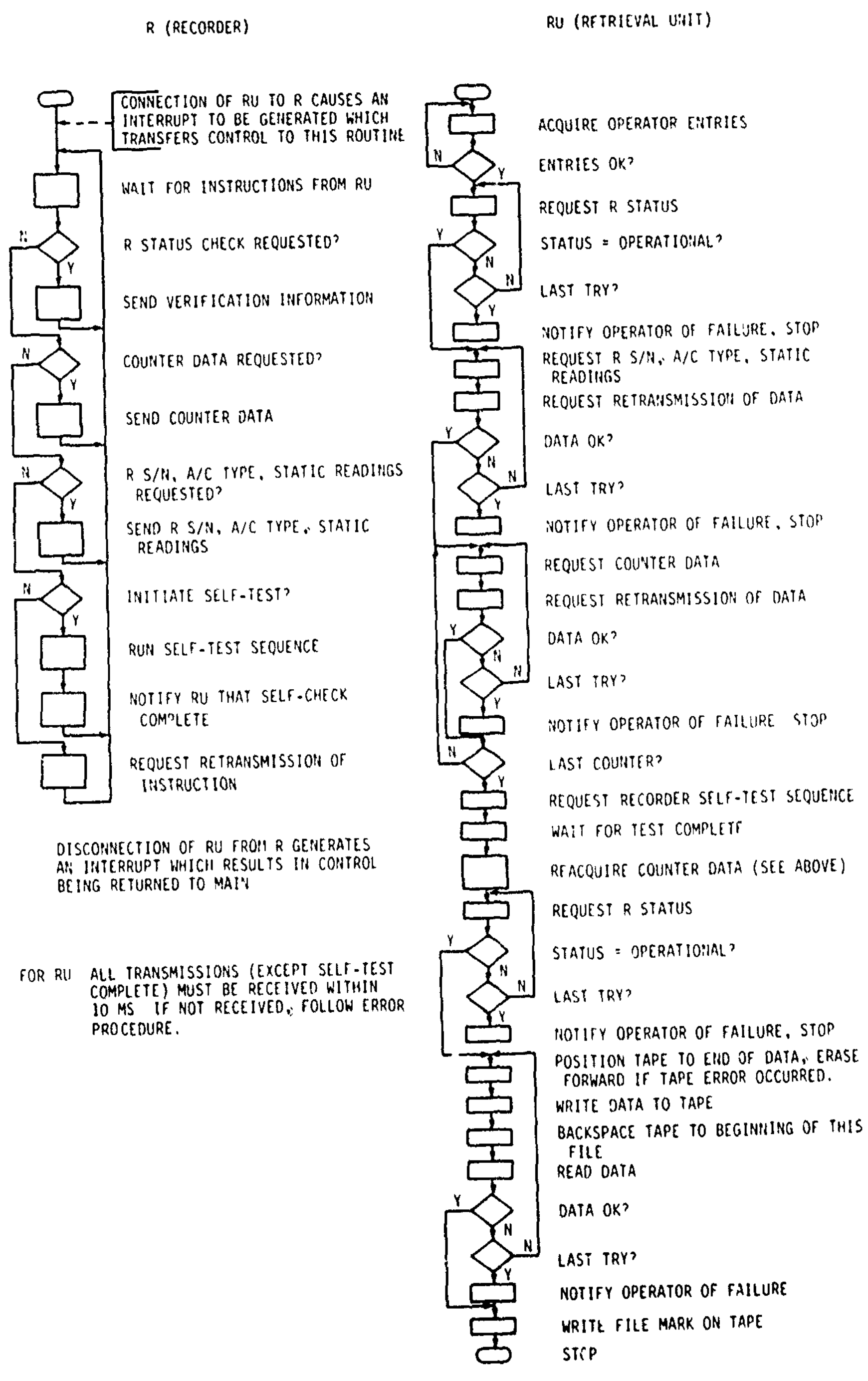


Figure 26. Retrieval Unit Recorder Communications.

The brassboard and supporting software evaluations were essentially complete by the time Critical Design Review was completed. The conceptual approach was found satisfactory and preparation of test articles was begun. It was recognized that reliability was of primary importance to the SIRS equipment. Thus a reliability assessment was provided.

Reliability Analysis

A reliability analysis was performed using MIL-HDBK-217B and the component manufacturers' data to predict the mean-time-between-failure (MTBF) for the SIRS recorder. The results of the analysis are summarized in Table 20. The calculated MTBF of about 7300 hours for the SIRS recorder includes consideration of a helicopter operational environment in a worldwide scenario. As such, the 7300 hours MTBF is considered realistic. The analysis did not include the processor board batteries, which in this application were expected to have a lifetime well in excess of 6 months. Furthermore, although only one such battery is required, a second battery is included in the design as a redundant feature to enhance the operational reliability. The MTBF of the transducers and installation kit is about 1400 hours, resulting in an overall system MTBF of about 1200 hours. However, loss of a transducer input does not result in invalid recorded data. The missing input can be synthesized during data processing. In addition, periodic calibrations and other maintenance actions should identify potential transducer failures before they occur. Operation of four recorders during software development, burn-in prior to qualification test, and qualification and flight tests resulted in an accumulated operating time in excess of 500 hours. Only one failure was recorded. This occurred during the environmental portion of the qualification tests. Upon conclusion of the temperature-humidity-altitude test, the recorder did not operate. The cause was identified as leaking batteries and the resulting contact corrosion.

Laboratory Qualification Testing

The qualification testing was designed to assess the performance of the SIRS recorder in simulated EMI/electromagnetic compatibility and normal airborne environments conforming to MIL-STD-461/462 and MIL-STD-810, respectively. Table 21 summarizes the test conditions for each environment. Figure 27 shows a typical test setup.

Two recorders were subjected to the testing: S/N 005, which was packaged in a steel box, and S/N 1007, which was contained in an aluminum box for potential weight savings if the aluminum base proved adequate during the testing. S/N 005 was used in the normal airborne environment test while S/N 1007 was

TABLE 20. RELIABILITY ANALYSIS SUMMARY

Component	Part No.	Failure Rate(a)	MTBF(hr)
Processor Board	074032D30014	55.9854	17,862
Signal Conditioning Board	074032D30019	50.6592	19,740
Power Supply	C5/T15/165/x	16.6667	60,000
Filter	RF6125	0.0560	17,857,143
Termination Assembly	074032C30011	0.5820	1,718,213
Internal Cables/ Connections	-	11.7040	85,441
Connector	KP5E02A12-10S	1.8630	536,769
SIRS Total		137.5163	7,272
Circuit Breaker	MS22073-3/4	1.9650	508,906
Gross Weight Sensor	DCMC3FF41	254.2370	3,934
OAT Sensor	S6B	97.1930	10,289
Altitude Sensor	1332A3	94.5200	10,580
Airspeed Sensor	1332D1	94.5200	10,580
Accelerometer	SA109-B-1/+3SL	174.1940	5,741
Miscellaneous Connections	-	0.7300	1,369,863
Transducers and Installation Kit Total		717.3590	1,394
System Total (b)		854.8753	1,170

Notes:

(a) Estimated number of failures per million hours.
(b) Excludes aircraft inputs.

TABLE 21. SUMMARY OF QUALIFICATION TESTS

a. MIL-STD-461/462 Tests

Test Method	Description	Remarks
CE01	Conducted Emission, 30 Hz to 20 kHz, Power Leads	Info. Only
CE02	Conducted Emission, 30 Hz to 20 kHz, Control and Signal Leads	Info. Only
CE03	Conducted Emission, 20 kHz to 50 mHz, Power Leads	
CE04	Conducted Emission, 20 kHz to 50 mHz, Control and Signal Leads	Info. Only
CS01	Conducted Susceptibility, 30 Hz to 50 kHz, Power Leads	
CS02	Conducted Susceptibility, 50 kHz to 400 mHz, Power Leads	
CS06	Conducted Susceptibility, Spike, Power Leads	
RE02	Radiated Emission, 0.014 to 10 gHz, Electric Field	
RS02	Radiated Susceptibility, Magnetic Induction Fields	
RS03	Radiated Susceptibility, 14 kHz to 10 gHz, Electric Field	

b. MIL-STD-810 Tests

Test Method	Procedure	Description
504	I	Temperature Altitude: -25°C to 50°C, 0-20,000 ft.
518	I	Temperature, Humidity, Altitude: -40°C to 50°C, 0-95% RH, 0-20,000 ft.
507	I	Humidity: 0-95% RH
513.1	II	Acceleration
511	I	Explosive Atmosphere
510	I	Dust
514.1	I	Vibration (Category C Equipment)

Figure 27. Test Setup for SIRS Recorder Qualification.

used in the EMI/EMC environment test; its test results could be applied to S/N 005 whereas the converse would not be possible.

The tests were successful in that the few operational discrepancies that occurred during the tests could be eliminated by simple corrective actions. The correction actions were such that the high level of confidence in their effectiveness precluded the requirement for retests. Of the five discrepancies observed, four occurred during the EMI tests and three of the four were correctible by proper termination of shields in the signal cable, shorter wire lengths, and improved wire routing. The fourth discrepancy was due to the SIRS recorder logic test program and could not be attributed to the EMI environment. The fifth discrepancy was a leaking battery condition that developed during temperature-humidity-altitude testing. A suitable battery replacement eliminated the problem.

Phase I Prototype Flight Test

The prototype flight test was held and the program was formally introduced to Fort Rucker personnel on 5 November 1976.

Instrumentation System. To obtain the data for the validation of the SIRS recorder, two Century Model 409B oscillograph recorders, each with 14 data channels and capable of recording numerous dynamic parameters on 3-5/8-inch-wide photosensitive paper, were used in this program. One oscillograph was to record FCR (Flight Condition Recognition) data and the other to record SIRS flag data. The FCR oscillograph recorded the dynamic parameters that would permit identifying the various flight conditions encountered during the flight test program. The SIRS flag oscillograph recorded the various SIRS parameter levels that would trigger the logic routine operations and consequently provided the data to verify the functioning of the logic routines.

In general, each oscillograph had 12 channels available for recording the in-flight parameters. Of the remaining two channels, one was used to delineate a time pattern reflecting a 1-minute cycling, and the other was used to trace a static line for measurement reference. Table 22 presents the parameters recorded on each oscillograph. As apparent in this table, several parameters were recorded by both oscillographs so that the two oscillographs could be readily correlated. The FCR oscillograph parameters were recorded as analog values while the flag oscillograph parameters were presented either as analog values for the parameters in common with both oscillographs or as ranged data for the output of the SIRS recorder.

The signal conditioning units used to regulate the voltage signals from the various transducers were the Technology Incorporated Models 074037D30007-1 and -2 for the flag and the FCR oscillographs, respectively.

TABLE 22. RECORDED PARAMETERS

Parameter	FRC Oscillograph	Flag Oscillograph
Airspeed	Analog	Range
Pressure Altitude	Analog	-
Outside Air Temperature	Analog	-
Density Altitude	-	Range
Main Rotor Speed	Analog	Range
Vertical Acceleration	Analog	Analog and Range
Engine Torque	Analog	Analog and Range
Roll Attitude	Analog	Range
Pitch Attitude	Analog	Range
Gross Weight	-	Range
Touchdown	-	Range
Time	Analog	Analog
Reference	Analog	Analog

For a description of the recording system, refer to Chapter 3.

Installation of Recording System. The SIRS recorder was installed in the helicopter's battery compartment on a shelf accessible from the right-hand side of the helicopter. The airspeed and altitude transducers were mounted on the left-hand side of the aircraft in the area adjacent to the pilot's compartment where the aircraft's pitot and static system was accessible. The vertical accelerometer was mounted on a bracket attached to the bulkhead beneath the transmission. The outside air temperature transducer was mounted on the skin of the helicopter on the underside at Station 220. Rotor speed was taken from the helicopter's rotory tach generator. Engine torque was taken from the engine torque transmitter. A circuit breaker was installed in the pilot's right-hand aft circuit breaker panel and was connected to the dc bus to provide 28 Vdc power. Provisions were made to take the roll and pitch attitude signals from the aircraft's roll and pitch gyro located in the same area as the airspeed and altitude transducers. The gross weight sensors were installed at the midpoint of the fore-and-aft skid crosstubes. Cabling between the SIRS recorder and transducers was routed through the compartments along the underside of the helicopter. Figure 28 is an outline drawing of the AH-1G helicopter showing the recorder system component locations.

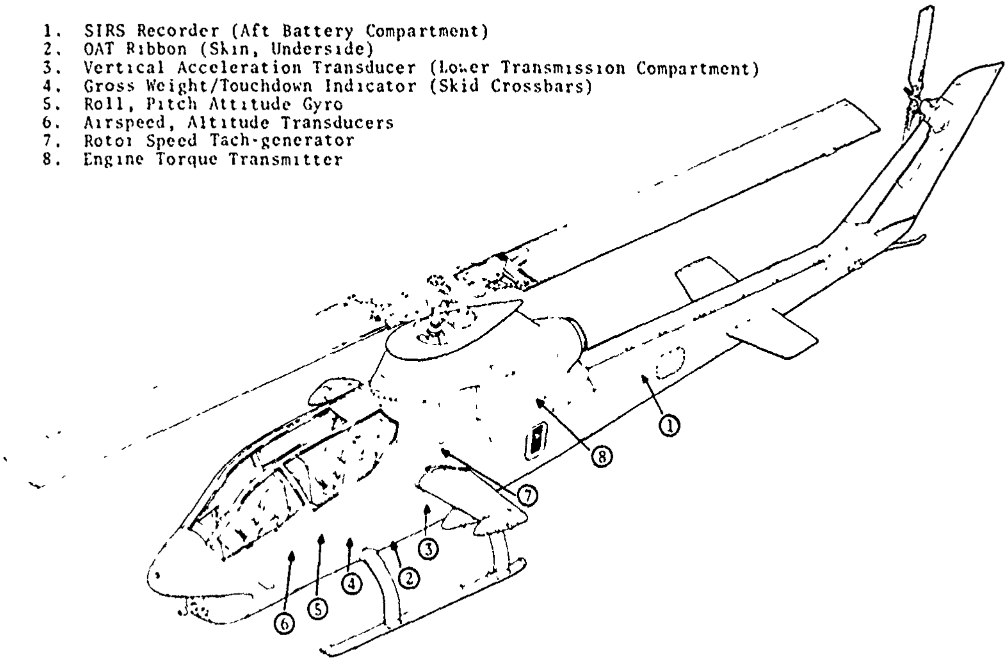


Figure 28. Installation Schematic.

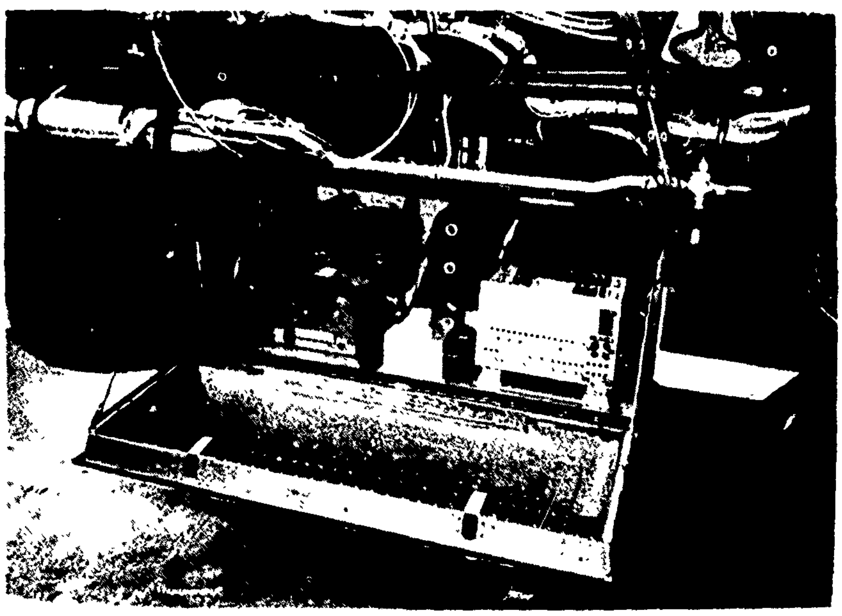


Figure 29. Flight Test Instrumentation System.

The instrumentation system used to evaluate the performance of the SIRS recorder, including the FCR oscillograph, flag oscillograph, signal conditioning system, and digital-to-analog converter, was mounted in the ammunition bay under the pilot and gunner's compartment. In addition, a junction box was installed in the battery compartment to tap into the SIRS recorder's analog and digital flag signals. Figure 29 is a photograph of the flight test instrumentation system.

The SIRS and flight test recording systems were installed and checked between 23 February and 15 March 1977.

Recorder Flight Testing. The flight performance of the SIRS recorder was evaluated by flying various flight conditions and by analyzing the degree to which the SIRS recorder could identify and correctly time the flight conditions. Examples of the flight conditions flown are listed in Table 23. In addition, several nap-of-the-earth flights, both simulated and actual, were performed.

Seven useful data flights, which yielded 7.5 hours of in-flight data, were made during the 4 weeks of the flight test program. An additional 22 flights, yielding 19.9 hours of in-flight data, were made; these flights included instrumentation check flights, nap-of-the-earth training flights flown in conjunction with the test program, and landing check flights. Although limited data from these flights were processed to verify the operation of the SIRS recorder, they were not specifically used to validate the recorder performance. Table 24 summarizes the 29 flights.

During the early portions of the flight test program, each flight generally lasted an hour and most of the flight conditions listed in Table 23 were flown. Beginning on flight 21, the digital-to-analog converter used to establish the signal levels for the flag oscillograph malfunctioned occasionally. The malfunction was a random disruption of all the traces on the flag oscillograph. Consequently, the later flights in the program were generally shorter and designed to investigate fewer flight conditions with only the FCR oscillograph.

Recorder Performance. The following summary of the SIRS recorder performance consists of detailed discussions of how the recorder identified and recorded occurrences of flight conditions, time within certain prescribed flight conditions, and maximum parameter occurrences. Not all of the 22 flight condition categories will be discussed in detail. Rather, examples of each of the three types of data recording techniques, that is, occurrences, times, and maximums, will be presented. In addition, during the test program several of the encountered flight conditions required logic modifications or improvements before they could be identified. These modifications are discussed in general, but an example of a required logic change is illustrated.

TABLE 23. FLIGHT TEST FLIGHT CONDITIONS

- Rotor Start/Stop
- Level Flight
- Hover:
  - IGE
  - OGE
- Quick Stop:
  - IGE
  - OGE
- Full Power Climb
- Maximum Performance Takeoff
- Maximum Rate Acceleration
- Autorotation:
  - Power to Autorotation
  - Steady
  - Turns
  - Landings
- Approach and Landing
- Dive:
  - Symmetric
  - To Left
  - To Right
- Pullout:
  - Symmetric
  - To Left
  - To Right
- Pullup (Cyclic Climb):
  - Symmetric
  - To Left
  - To Right
- Turns:
  - Normal
  - Gunnery
  - S-Type

TABLE 24. FLIGHT LOG SUMMARY

Flt. No.	Predominant Maneuvers	Valid Data			Flight Duration(hr)
		SIRS	FCR	Flag	
1	Ground Run		*		-
2	Functional Check		*		0.4
3	Functional Check		*		0.3
4	Pilot Currency		*		1.0
5	Entire Profile	*	*		1.5
6	Level Flight, Turns	*	*		0.5
7	Level Flight, Turns	*	*		0.7
8	Level Flight, Turns		*		0.7
9	Functional Check	*	*		0.3
10	Level Flight, Turns	*	*	*	0.8
11	Entire Profile		*	*	1.4
12	Entire Profile	*	*	*	1.0
13	IP Check, Auto Landings		*	*	1.8
14	Dives, Turns	*	*	*	1.0
15	Nap-of-Earth		*		1.5
16	Nap-of-Earth		*		1.5
17	Nap-of-Earth	*	*	*	1.6
18	Nap-of-Earth	*	*		1.7
19	Nap-of-Earth		*		1.8
20	Functional Check	*	*		0.8
21	Entire Profile	*	*		1.5
22	Level Flight, Takeoffs		*		0.6
23	Check Flight	*	*		0.8
24	Level Flight, Quick Stops	*	*		0.5
25	Landing Check	*	*	*	0.3
26	High Gross Weight/ Landing Check	*	*	*	0.3
27	Low Gross Weight/ Landing Check	*	*	*	0.4
28	Level Flight/ Airspeed Check	*	*	*	1.5
29	Low Gross Weight/ Landing Checks, Quick Stops	*	*	*	1.2

Of the flight conditions that are recorded as occurrences, rotor start/stop and takeoff/landing cycles are the principal ones discussed in this section. The timed flight conditions to be discussed include total flight time, cruise, and various types of turns. Finally, this section discusses the measurement of peak vertical accelerations.

Computed Parameters. The SIRS recorder monitors airspeed, pressure altitude, and outside air temperature. From these parameters, the SIRS recorder computes the density altitude, the maximum level-flight velocity, and the limit velocity for the helicopter. In addition, the SIRS recorder monitors inputs from the gross weight sensors and computes gross weight ranges during a flight.

Maximum airspeed limit V_H, which represents the maximum level flight limit for the aircraft and the limit velocity V_L, which is the maximum airspeed permitted for the AH-1G helicopter are calculated from Equations 6, 7, and 8. The density altitude is computed in Equation 9.

Each of these calculations is continuously performed within the SIRS recorder, and the various identified flight conditions are categorized by the appropriate percentage of either of these limits.

Table 25 summarizes the airspeed limits, V_H and V_L, calculated by the SIRS recorder as represented on the flag oscillogram and those calculated manually from the FCR oscillogram for Flight 28. This flight was flown at two density altitudes and was typical of the calculating performance of the SIRS recorder.

The SIRS recorder monitors the input from the two piezoelectric beam sensors and computes a takeoff gross weight. During each flight, this gross weight is reduced at a fixed rate to account for fuel consumption. Throughout the flight, the various flight conditions are each categorized as being in one of three gross weight ranges: below 7750 pounds, 7750 to 8750 pounds, and above 8750 pounds.

As shown in Table 26, the system did not reliably compute the takeoff gross weight, since it yielded correct values for only five of the twelve flights. However, it generally computed the correct gross weight for the first flight of the day as evidenced in the data for Flights 11, 21, and 23. These correct values were due to the ability of the skid landing gear to assume its natural position when the helicopter was positioned on the flight line each morning. The flight test log does not indicate whether the helicopter was refueled before or after it was moved for Flights 31 and 26. The system did operate correctly after the wing stores were removed prior to Flight 27. Except for Flight 14, the system did not correctly compute the takeoff gross weight when the mission was the second or third flight of the day. When the helicopter was refueled

TABLE 25. COMPARISON OF PERCENT V_H AND V_L CALCULATIONS FOR LEVEL FLIGHT CONDITIONS (FLIGHT 28)

Indicated Airspeed	Density Altitude	%V_H		%V_L	
		FCR	Flag	FCR	Flag
118	2155	0.84	0.8-0.9	0.66	≤0.7
109	2155	0.78	0.65-0.8	0.60	≤0.7
134	2271	0.96	0.9-0.95	0.74	0.7-0.85
127	2327	0.91	0.8-0.9	0.70	0.7
148	2155	1.06	>0.95	0.82	0.7-0.85
134	2348	0.96	0.9-0.95	0.75	0.7-0.85
140	2325	1.01	>0.95	0.78	0.7-0.85
156	2350	1.12	>0.95	0.86	0.7-0.85
166	2300	1.19	>0.95	0.92	0.85-0.95
153	2275	1.10	>0.95	0.85	0.7-0.85
109	6675	0.84	0.8-0.9	0.73	0.7-0.85
103	6648	0.79	0.65-0.8	0.68	≤0.7
120	6600	0.92	0.9-0.95	0.79	0.7-0.85
114	6664	0.87	0.8-0.9	0.76	0.7-0.85
128	6719	0.98	>0.95	0.85	0.85-0.95
124	6694	0.95	0.9-0.95	0.82	0.7-0.85

TABLE 26. TAKEOFF GROSS WEIGHT COMPARISON

Flight No.	Date	Log	Flag	SIPS
11	31 Mar 77	8317	7750-8750	-
12	"	8317	<7750	<7750
13	5 Apr 77	8317	≥8750	-
14	"	8317	7750-8750	7750-8750
21	12 Apr 77	9500	≥8750	≥8750
22	"	9500	<7750	-
23	13 Apr 77	9500	-	≥8750
24	"	9500	-	7750-8750
26	14 Apr 77	9500	-	7750-8750
27	"	8317	-	7750-8750
28	"	8317	<7750	<7750
29	"	8317	<7750	<7750

between flights, the static friction between the skid landing gear and ground prevented the skid gear from readjusting for the increased weight of the fuel.

The algorithm used to decrease gross weight due to fuel consumption worked correctly. In addition, during one flight after a landing, the rotor speed decreased below 250 rpm, and the gross weight system updated itself correctly.

Occurrences. The SIRS recorder is designed to monitor the various input parameters and, through the microprocessor logic, to identify occurrences of flight conditions. Such typical flight conditions include rotor start/stop cycles, power-on landings, autorotative landings, high n_z maneuvers, and autorotation-to-power transitions. In this section, the first three occurrences will be discussed.

The SIRS recorder identified the eight rotor starts that occurred during the seven data flights shown in Table 27 and one extra cycle on Flight 12. The extra start was counted because of an accidental pulling of the circuit breaker of the instrumentation system, which caused the signal to behave as though a shutdown was occurring.

In general, the SIRS recorder correctly identified the normal landings performed during the flight test program. Table 28 summarizes the normal and autorotative landings detected by the SIRS recorder and identified on the FCR oscillogram. An example of a typical landing is shown in Figure 30, which includes the FCR and flag oscillograms. Table 28 shows differences between the FCR and SIRS data due to two types of problems, one in Flights 12, 28, and 29, and the second in Flights 23, 24, 28, and 29.

The normal landings of Flights 12, 28, and 29 not recorded by the SIRS recorder were missed because the recorder's logic requires 10 seconds of flight before subsequent landing can be considered valid, and 5 seconds on the ground before the landing is considered valid. During Flights 12, 28, and 29, multiple landings were made as part of the investigation of the performance of the gross weight sensing system; not all of these takeoffs and landings satisfied the logic of the recorder. No changes to the recorder logic are planned since this problem is not considered one that will exist in the operational environment.

For the identified autorotative landings of Flights 23, 24, 28, and 29, the logic had to be modified because the SIRS recorder was identifying normal power-on landings performed at high gross weights as autorotative landings. This occurred because the engine torque dropped below 5 psi sometime during the 10 seconds prior to touchdown. The subsequent logic changes will preclude the misidentification of normal landings.

Only three full autorotative landings were performed during the flight test program because of pilot restrictions and availability. All of these landings occurred during

TABLE 27. COMPARISON OF FLIGHT LENGTH AND ROTOR STARTS

Flt.No.	Flt. Time (min) FCR	SIRS	Rotor Starts FCR	SIRS
12	55.60	56.32	1	2 (a)
14	52.57	52.72	1	1
21	73.86	74.69	1	1
23	37.77	38.03	1	1
24	25.29	25.39	1	1
28	85.81	85.69	1	1
29	60.97	61.89	2	2

Note:

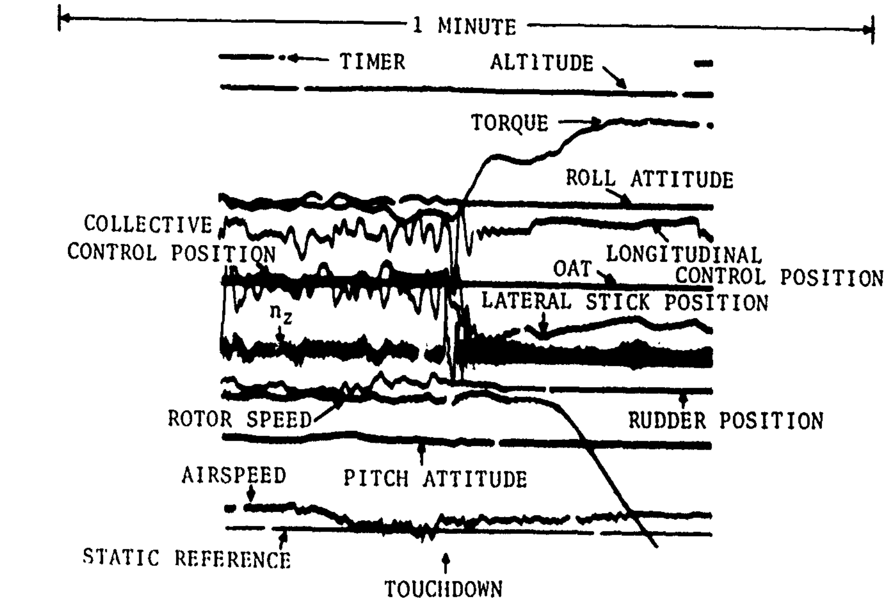
(a) Caused by accidently pulling circuit breaker for the instrumentation's electrical system.

TABLE 28. COMPARISON OF LANDINGS

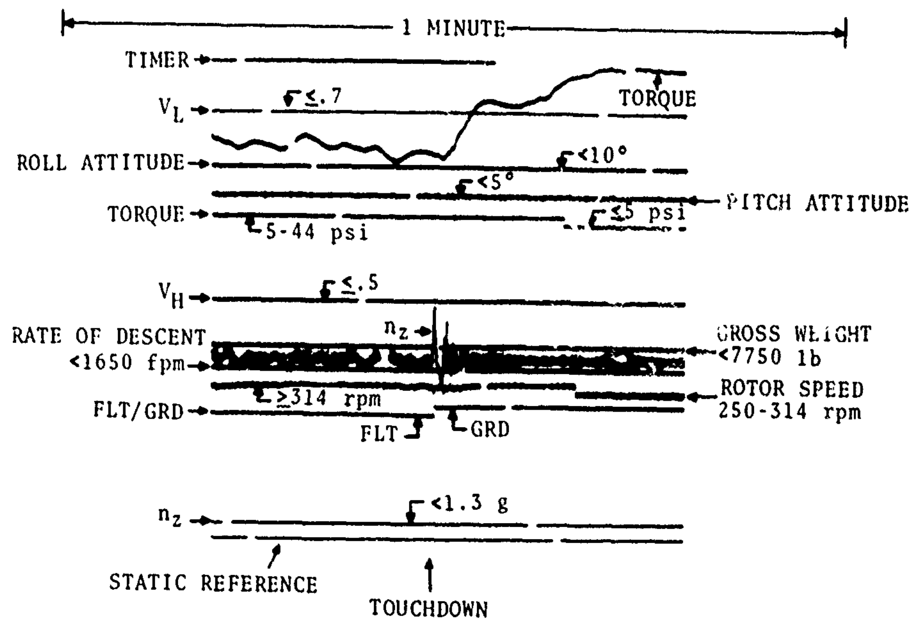
Flt.No.	Normal Landing FCR	SIRS(a)	Autorotative Landing FCR	SIRS(a)
12	4	2	0	0
14	1	1	0	0
21	9	9	0	0
23	5	4	0	1
24	4	3	0	1
28	3	1	0	1
29	13	7	0	2

Note:

(a) Discrepancies in the data are discussed in the text.



(a) FCR Oscillograph



(b) Flag Oscillograph

Figure 30. Normal Landing.

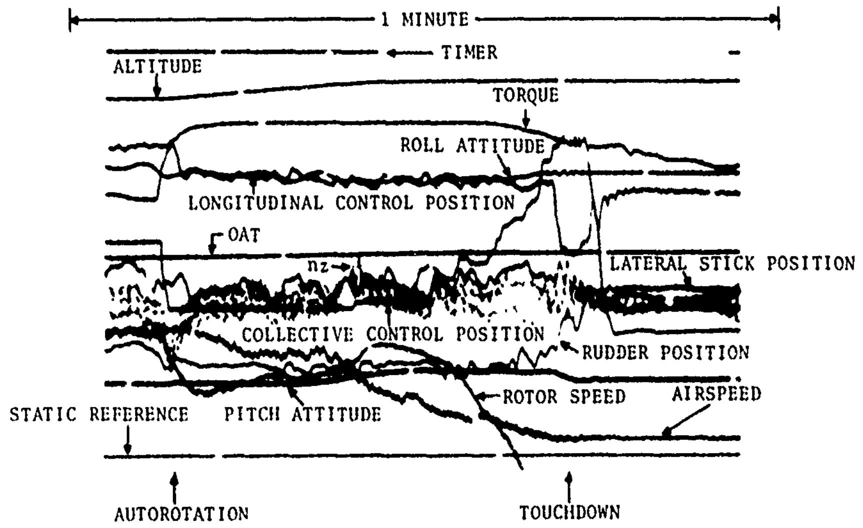
Flight 13. Unfortunately, the temporary mercury batteries, installed after the failure of the lithium batteries in the qualification testing, lost contact in flight and the recorder memory was lost; these slightly undersized batteries were subsequently soldered in place. However, the FCR and flag oscillograms in Figure 31 show that the SIRS recorder would have identified the landing as an autorotative landing since the engine torque was below 5 psi for the entire 10 seconds prior to the landing as required by the SIRS recorder logic.

Timed Flight Conditions. The SIRS recorder can record the duration of flight conditions in a manner similar to the recognition of occurrences procedure. The microprocessor logic identifies the flight conditions according to the individual or collective flight parameter changes, each within a preset range. For example, the duration of flight time is determined by the length of time that the touchdown indicator indicates an airborne condition. Likewise, a turn is identified as the duration of time that roll attitude is beyond the threshold if a vertical acceleration peak in excess of 1.3g occurs sometime during the period; the turn is then characterized by the airspeed and gross weight at which it was performed.

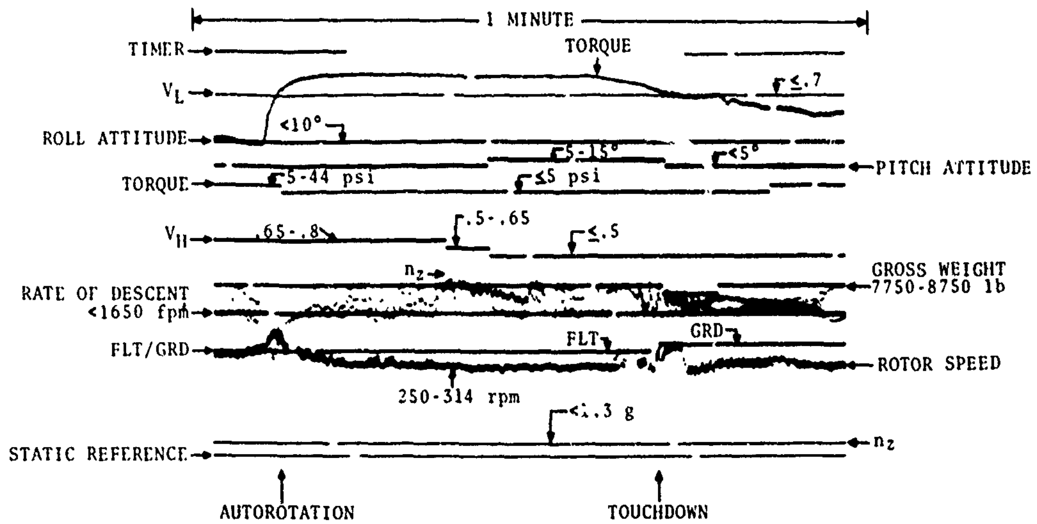
The durations of the seven data flights as measured by the FCR oscillograph and the SIRS recorder are listed in Table 27. The maximum variation in the two measurements is 1.5 percent; it should be noted that the potential for error in measurement is greater with the oscillograph than with the SIRS recorder because of the mechanical aspects of the oscillograph.

In addition to the total flight time, the SIRS recorder also measured the time spent in cruise at various airspeed levels. Low-speed flight is defined by speeds of 50 to 65 percent V_H; high-speed flight is defined by speeds of 65 to 95 percent V_H; and maximum-speed flight is defined by speeds in excess of 95 percent V_H. For all level flight conditions, the airspeed is converted to the equivalent percent V_H for that gross weight and density altitude condition. As presented in Table 29, the SIRS recorder accurately measured the time in various cruise conditions. For the same flight, a comparison of measured and recorded values for V_H throughout the cruise conditions are presented in Table 30.

As discussed earlier, the SIRS recorder includes logic to identify various types of turns, including normal, gunnery, and gunnery S-turns. The turns are categorized by airspeed and vertical acceleration for a given gross weight condition. For Flight 14, normal, gunnery, and S-turns were analyzed by processing data from the FCR and flag oscillographs and comparing these data with the output of the SIRS recorder. As shown in Table 31, the agreement is very good between the flag and SIRS data.



(a) FCR Oscillograph



(b) Flag Oscillograph

Figure 31. Autorotative Landing.

TABLE 29. COMPARISON OF CRUISE TIMES FOR FLIGHT 14

	Flag Oscillograph	SIRS
Low-Speed Flight	11 sec	12 sec
High-Speed Flight	934 sec	934 sec
Max. Speed Flight	53 sec	54 sec

TABLE 30. COMPARISON OF PERCENT V_H CALCULATIONS DURING CRUISE FOR FLIGHT 14

Flight Condition	Indicated Airspeed	Density Altitude	$\%V_H$ FCR	$\%V_H$ Flag
Low-Speed Flight	91	2410	0.65	0.5-0.65
"	84	1048	0.59	0.5-0.65
High-Speed Flight	100	2492	0.72	0.65-0.8
"	133	2724	0.96	0.9-0.95
"	125	2807	0.91	0.8-0.9
"	100	2409	0.72	0.65-0.8
"	124	2291	0.89	0.8-0.9
"	131	2256	0.94	0.9-0.95
"	110	2208	0.79	0.65-0.8
"	124	2291	0.89	0.8-0.9
"	127	2005	0.91	0.8-0.9
"	113	2009	0.81	0.65-0.8
"	132	1969	0.94	0.9-0.95
"	115	2005	0.82	0.65-0.8
"	120	2005	0.86	0.8-0.9
"	131	1995	0.94	0.9-0.95
"	126	1969	0.90	0.8-0.9
"	124	1900	0.89	0.8-0.9
"	134	1827	0.96	0.9-0.95
"	135	1298	0.95	0.9-0.95
"	124	1252	0.88	0.8-0.9
"	106	1174	0.75	0.65-0.8
Max. Speed Flight	140	2800	1.01	>0.95
"	140	2020	1.00	>0.95
"	142	2030	1.01	>0.95
"	143	1703	1.02	>0.95

TABLE 31. COMPARISON OF VARIOUS TURNS FOR FLIGHT 14

Type	Gross Weight	Duration (sec) FCR	Flag	SIRS
Normal Turn	<7750	234	222	222
"	7750-8750	40	39	39
Gunnery Turn	<7750	28	27	27
"	7750-8750	167	158	161
Gunnery S-Turn	7750-8750	140	139	138

The measurement accuracy of the FCR and flag oscillographs is less than that of the SIRS recorder because the crystal clock in the recorder functions more precisely than the mechanical drives in the oscillographs. Minor variations in the drive speed of the oscillographs cause corresponding variations in the timed events. For illustrative purposes, Figure 32 presents the FCR and flag oscillograms for a typical turn. This turn, as recorded by the SIRS recorder lasted 39.2 seconds. In comparison, by analyzing when the roll flag changed from within threshold to outside threshold and then back again, the turn duration would be 39 seconds. Note that near the end of the turn, the n_z flag changed from threshold to the range of 1.3 to 1.5g. In the FCR chart, the turn duration is slightly longer, 40 seconds, since the turn was identified at the instant of roll attitude change rather than when it passes through 10°.

Maximum Parameter Value. The SIRS recorder can identify the maximum value of a parameter during the interval between data retrievals. During the flight test program, the maximum values of vertical acceleration and V_L (limit velocity) were recorded. Table 32 compares the maximum n_z peaks identified by the SIRS recorder during each flight with the corresponding values read from the FCR oscillograph. The largest positive peak recorded during the program was 2.73g, which occurred during a turn at an airspeed of 97 percent V_H and with a roll angle greater than 50°, as shown in Figure 33. The lowest positive peak recorded during the program was 1.08g, which occurred in a hover during Flight 25.

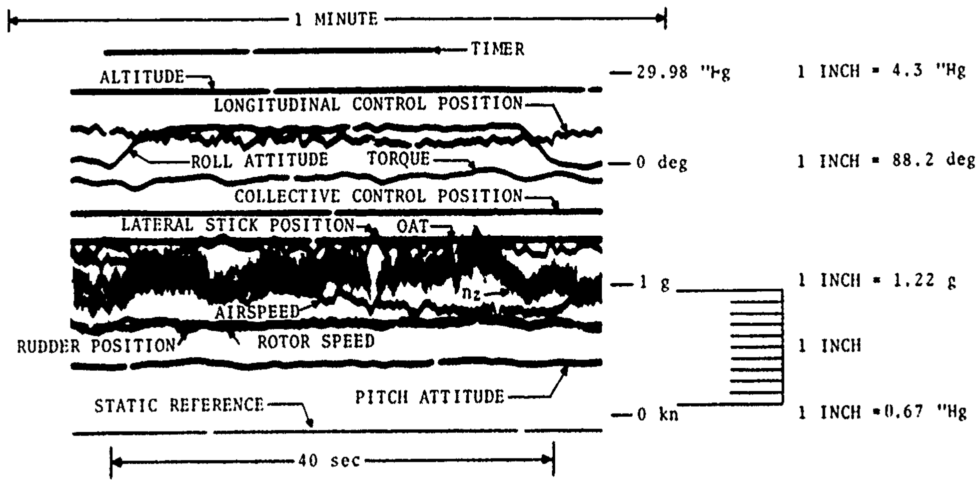
TABLE 32. COMPARISON OF MAXIMUM n_z VALUES

Flight No.	Flight Condition	Maximum n_z (g)	
		FCR	SIRS
10	Turn	1.4	1.4
12	Dive	2.2	2.3
14	"	2.3	2.3
21	Turn	2.7	2.7
23	Dive	2.5	2.5
24	Quick Stop	1.6	1.6
25	Hover	1.1	1.1
26	"	1.1	1.1
27	Turn	1.7	1.7
28	Cyclic Pullup	1.6	1.6
29	Autorotation to Power	1.5	1.4

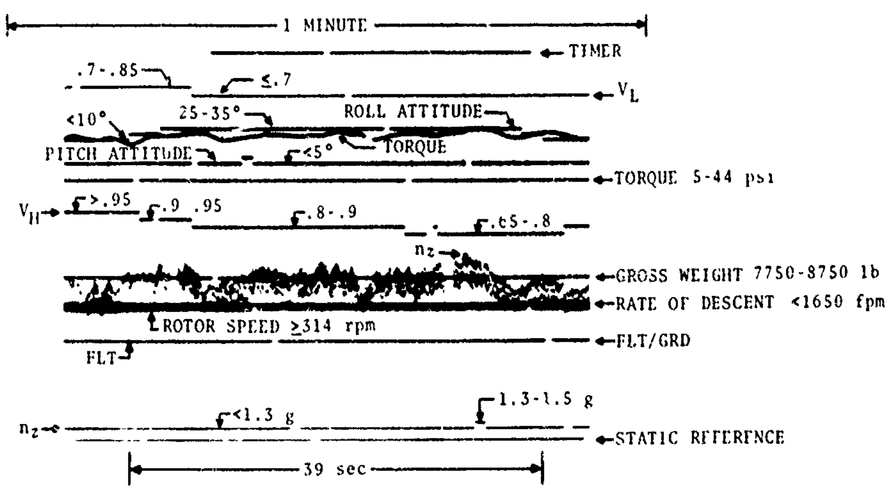
Although the SIRS recorder was programmed to also identify the maximum V_L condition, the lack of a time delay in the recorder caused false V_L values as the recorder and transducers were powered up. Since the altitude transducer has an equivalent altitude of 21,200 feet at zero volts, during the power-up cycle the recorder incorrectly calculated the V_L value. The software logic has since been changed to include a time delay that will prevent erroneous calculations. The recorder capability of measuring maximum V_L peaks has since been demonstrated in the laboratory. In addition, follow-on IOT&E flight tests with the AH-1S have confirmed the laboratory findings.

Summary and Conclusions. The purpose of the Phase I testing was to verify that the SIRS recorder would operate reliably in an operational helicopter environment and yield flight data. The SIRS recorder successfully demonstrated that it can perform its intended function.

Minor improvements recommended for the SIRS recorder hardware and software were incorporated in the SIRS recorders assigned to the Phase II Operational Evaluation. No major changes in the recorder design were required.



(a) FCR Oscillograph



(b) Flag Oscillograph

Normal Turn Time	
SIRS	39 sec
Flag Oscillograph	39 sec
FCR Oscillograph	40 sec

Figure 32. Normal Turn.

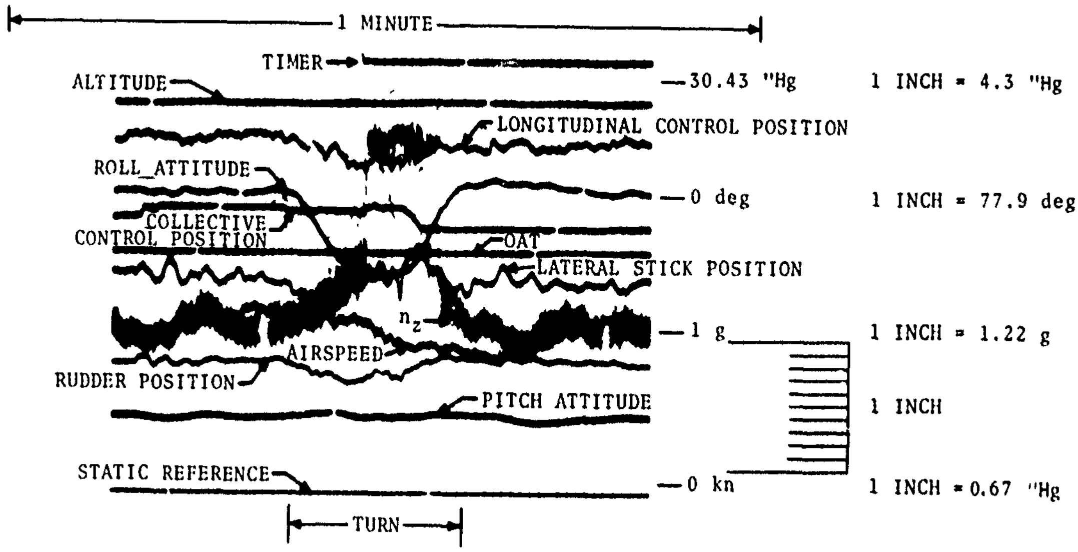


Figure 33. FCR Oscillograph Showing the Largest Positive n_z Peak Recorded During the Program.

The application of the lift link system to the AH-1G was to be researched further; if acceptable results were obtained, it would be incorporated into the SIRS recorder system. In addition, the measurement of pitch in conjunction with the lift link should be considered as a method for decreasing the sensitivity of the lift link system to center-of-gravity changes.

With the incorporation of the recommended hardware and software improvements, the SIRS recorder was declared acceptable for the Phase II Operational Evaluation.

IOT&E

The IOT&E was entitled "Phase II Operational Flight Test for the SIRS AH-1G Program." It was concerned with determining if there were any deficiencies that would inhibit or limit the operational employment of the system. In addition, this was the opportunity to show the user the design that his original concepts produced, what he could expect to accomplish with the system, and, more importantly, what it would cost the user in terms of resources and manpower to accomplish his operational task.

The major objectives of the IOT&E were to:

- Estimate the operational effectiveness and suitability of the system as well as other operational aspects of its military utility.
- Identify any operational deficiencies.
- Recommend and evaluate desirable changes and trade-offs in production configuration.
- Obtain operational information for:
  - Refinement of official program operating and support cost estimates.
  - Identify system characteristics or deficiencies that significantly impact O&S costs.

IOT&E Test Support

During October 1977 the test article installation was essentially completed. At the time of departure of the installation team from Fort Rucker, four of five SIRS recorders were installed and operational. The fifth recorder was not installed because of a malfunctioned vertical accelerometer that was being repaired. The helicopters in which the recorders were installed are listed below:

Aircraft	Recorder Serial Number
66-15254	1008
66-15252	1009
66-15286	1010
66-15473	1011
66-15356	Installation of 1012 completed December 1977

A data collection trip was made on 15-17 November 1977 to Fort Rucker to retrieve data from the four SIRS recorders and to perform any required maintenance. The status of each recorder was summarized by aircraft tail number. The report at that time was as follows:

"66-15254 - System Functioning properly."

"66-15252 - Aircraft is in maintenance hangar for replacement of rotor mast. System was inoperative due to large unbalance in the strain gauge bridge. We were unable to compensate for the unbalance and traced the problem to a faulty strain gauge. It will require the installation of a new instrumented lift link."

"66-15286 - Attempted to retrieve data prior to the morning mission and found the system inoperative. Investigation showed that the strain gauge bridge had been destroyed during aircraft maintenance. The strain gauge bridge appeared to have been hit with a wrench. It will require the installation of a new instrumented lift link."

"66-15473 - System functioning properly."

"66-15356 - System inoperative due to faulty n_z transducer. (Sent to factory for repair.)"

A data collection trip was made on 27-29 December 1977 to Fort Rucker to retrieve data and to perform any required maintenance. The status of each recorder was summarized by aircraft tail number. The report of findings at that time was as follows:

"66-15254 - Retrieved data on 28 December 1977. Upon checking the static gross weight parameter, a zero condition was found. Further investigation found a negative 0.3-volt signal from the gross weight in-line amplifier. Rebalancing of the strain gauge bridge produced a 70-count static indication on the Retrieval Unit. While closing up the aircraft, the Retrieval Unit was left on (approximately 3 minutes) and the 70-count reading drifted down to 46 counts. The 46-count reading did not drift over the next 1-minute interval. The Retrieval Unit was turned off for approximately 2 minutes and back on to monitor gross weight. A 54-count reading was observed this second time and a slow drift downward to 50 counts took an estimated 52 seconds. It appears that the strain gauge bridge is drifting."

"66-15252 - Aircraft is still in maintenance hangar awaiting rotor mast change. The strain gauge bridge is still unbalanced due to a faulty bridge. The system is still inoperative and will need a new instrumented lift link."

"66-15286 - System inoperative due to a completely destroyed strain gauge on the lift link. This system will need a new instrumented lift link."

"66-15273 - Data retrieved and static condition checkout show this system functioning properly."

The IOT&E flight test continued into the February 1978 time frame. By that time the AH-1G program had been phased down and replaced by the follow-on IOT&E with the AH-1S used as the test vehicle.

Evaluation of an AH-1G Fleet Operating Parameter That Impacts O&S Costs

It was noted that conventional calculated component damage was arrived at by using official logbook hours reported on each airframe. Further, it was observed that calculated SIRS spectrum damage and component damage arrived at by using recorder clock time would both lead to extended service lives of the

10 high-value, fatigue-sensitive components under study in this program. This is attributed to the fact that the recorder electronics is made to function only at the onset of events leading to component damage. This typically begins at rotor start. Component damage is not accumulated during engine run-up although the aircrew would be expected to include all operating times in logbook hours independent of whether they contribute to component damage. An example of the results for aircraft 66-15473 is reproduced in Table 33. A statistical treatment of the calculated component damage throughout this limited flight test program may be seen in Table 34.

The planned DT&E and IOT&E programs for the SIRS concept were completed in December 1977. The follow-on IOT&E was phased in at that time with the AH-1S as the test vehicle. While the AH-1G DT&E and IOT&E programs were quite compressed, a number of significant findings were derived from the effort.

TABLE 33. CALCULATED COMPONENT DAMAGE

Component	SIRS Spectrum	Predicted Spectrum	
		Recorder Hours	Logbook Hours
Main Rotor Blade	0.00706	0.05477	0.08227
Main Rotor Yoke Extension	0.0	0.01826	0.02742
Main Rotor Grip	0.0	0.00602	0.00905
Main Rotor Pitch Horn	0.00002	0.00913	0.01371
Retention Strap Ftg/Nut	0.02563	0.02738	0.04114
Swashplate Drive Link	0.00001	0.00548	0.00823
Swashplate Outer Ring	0.00025	0.01826	0.02742
Swashplate Inner Ring	0.00007	0.01826	0.02742
Hydraulic Boost Cylinder	0.00080	0.01826	0.02742
Tail Rotor Blade	0.00130	0.05477	0.08227

TABLE 34. STATISTICAL EVALUATION OF CALCULATED COMPONENT DAMAGE (ALL FLIGHTS)

	SIRS Damage Spectrum	S_x	Flight Hour Damage			
			Recorder Spectrum	S_x	Logbook Spectrum	S_x
Main Rotor Blade	0.01041	0.01139	0.04386	0.02679	0.08491	0.01206
Main Rotor Yoke Extension	0.000594	0.01314	0.01462	0.00893	0.02833	0.00400
Main Rotor Grip	0.01106	0.02957	0.00514	0.00317	0.00910	0.00177
Main Rotor Pitch Horn	0.00023	0.00091	0.00779	0.00480	0.01379	0.00269
Retention Strap Ftg/Nut	0.03272	0.01732	0.02338	0.01439	0.04137	0.00807
Swashplate Drive Link	0.00020	0.00081	0.00468	0.00288	0.00828	0.00161
Swashplate Outer Ring	0.01870	0.06998	0.01559	0.00960	0.02758	0.00538
Swashplate Inner Ring	0.00320	0.00709	0.01694	0.00992	0.02923	0.00432
Hydraulic Boost Cylinder	0.00037	0.00035	0.01462	0.00893	0.02830	0.00402
Tail Rotor Blade	0.02723	0.04352	0.05080	0.02976	0.08771	0.01296

CHAPTER 5.

FINDINGS

DT&E FLIGHT TEST (PHASE I PROTOTYPE FLIGHT TEST)

Software Modifications

During the flight test program, several flight conditions were identified that required computer logic modification to properly identify or time them. These flight conditions are identified in Table 35.

Hardware Modifications

Several findings resulted from the qualification program. Assorted internal wire routing and terminations were shown to need improvement. The lithium battery failed during the temperature-altitude-humidity test. The gross weight system operated correctly during the flight test program in all modes except one. When the helicopter landed at a low gross weight and then refueled, an error was introduced because the skid landing gear could not assume a new position due to the static friction between the skid gear and the ground. This problem could be solved by requiring a brief lift-off and touchdown before flight takeoff so that the skid gear could assume its normal positon for the existing gross weight. This solution, however, is not considered practical in the operational environment.

IOT&E (PHASE II OPERATIONAL EVALUATION)

Following satisfactory completion of the prototype flight testing, it was determined that the follow-on operational test program would be pursued. Five AH-1G aircraft were selected to participate in this program. The aircraft identified for participation in the program were: 66-15254, 66-15252, 66-15286, 66-15473, and 66-15356.

Before the flight test was initiated, a number of modifications to the SIRS equipment were implemented to improve its performance. After transmission lift links were strain gauged and calibrated, and software modifications were made to the EPROM resident software, the mission equipment was installed on the five test aircraft. On aircraft 66-15356, the n_z transducer was inoperative for the first three months of operation. This negated effective data gathering on this airframe for the entire operational test program. During the data retrieval of 15-17 November, the strain gauge deficiencies were noted on the lift links of two aircraft. Aircraft 66-15286 had a defective strain gauge that appeared to have been damaged during a routine

TABLE 35. FLIGHT CONDITION LOGIC MODIFICATIONS

Flight Condition	Modification
Normal/Autorotation Landing	Minor changes to lengthen period required for low torque and average torque values
Gunnery Run Dive	Major logic change (see Chapter 4)
Pullup - Symmetrical and Asymmetrical	Major logic change to be compatible with Dive Logic (see Chapter 4)
Autorotation Time	Minor change to correct software coding error
Full Power Climb	Minor change to provide category for low-speed, high-power climb
Maximum V_L	Minor change to require time delay prior to start of recorder operation
Quick Stops	Minor change to require decrease in airspeed during maneuver

;41

maintenance operation. Aircraft 66-15252 was found to have a defective strain gauge bridge. Thus, three aircraft were essentially unable to provide useful data during the operation test program.

Aircraft 66-15473, and 66-15254 systems were operational for the entire test period from 1 October to 28 December 1977. During that 90-day period, 132.3 hours of data were captured on aircraft 66-15254. A total of 128.7 hours were retrieved from aircraft 66-15473.

Explicit Determination of Gross Weight (GW)

As noted previously, the attempt to determine AH-1G gross weight by strain gauging the landing gear was unsuccessful. During the IOT&E flight test program (Phase II Operational Flight Test), an alternate approach was to strain gauge the lift links to explicitly measure gross weight. The gross weight parameter is important to calculation of fatigue lives of the 10 parts under consideration.

From the R&D standpoint, it was found to be possible to determine GW by instrumenting the lift links. However, the concept produced consistently erratic data, required close technical attention, and was failure prone. The concept involved bonding strain gauges to the lift link. This was generally found unsatisfactory due to lack of good mechanical bond to the shot-peened surfaces. When operative, this was found to be marginally unsatisfactory due to the high vibration environment. Thus from an R&D standpoint, the lift link concept of instrumentation appeared feasible but from an operational viewpoint (IOT&E) the scheme was judged a failure. This short IOT&E suggests that the technique is too exotic for successful fleet-wide, operational deployment.

Tracking of High-Value, Fatigue Sensitive Parts

During the IOT&E flight test program the practical matter of keeping track of the 10 selected parts became difficult. Nevertheless, as parts are installed or removed for whatever reason, SIRS logistical integrity requires close attention to service lives of all parts on all aircraft that are involved. This IOT&E flight test program, while short, was adequate to sharply focus on the need for a simple, effective parts tracking procedure.

DTU Packaging

DTU operators were required to travel from contractor facilities to the responsible test organization at Fort Rucker throughout this limited IOT&E program. The mode of transportation selected, normally commercial air, resulted in considerable experience with operator transportation of the DTU. Early in the program, operator observations began to accumulate as to the unwieldy nature of the packaging concept selected for this ground support equipment. Flight test time was inadequate for thorough evaluation of this equipment. Thus it was not determined whether an alternative packaging concept would be a nice-to-have operational attribute or a mission-essential factor.

DTU Tape Drive

During the course of this limited IOT&E program, the use of a one-way controller on the DTU tape drive was found to be a defective design concept. During DTU operations requiring tape search, the design concept that uses rewind times to find a specific record consistently resulted in selection of the incorrect record. This was due to system hysteresis from wear and varying ambient temperature, which caused inconsistent operation of the mechanical elements of the winding and rewinding mechanisms.

Use of DTU During Battery Charging Operation

The design concept was found to preclude DTU operations for other tasks during battery recharging operations. This was of no particular import in the R&D environment during DT&I. However, the operational import became clear during the IOT&E phase of this testing. Corrective action is indicated as this attribute of the design reduces maintenance productivity.

Logistics of Data Reduction

The IOT&E portion of the AH-1G flight test program was an opportunity to proof-test the original data reduction concept. In that capacity the contractor emulated the postulated Data Processing Center. The concept is summarized as follows:

> At the Data Processing Center, the recorded data would be converted into assessment of fatigue damage. The effort would be divided into three tasks: initial processing (IPS), fatigue damage assessment (FDAS), and component tracking management (CTMS). Each task, as described in Chapter 3, was developed as a separate system, with appropriate interfaces, to form the data processing system.

During this IOT&E both the IPS and FDAS were satisfactorily demonstrated. No attempt was made to test or evaluate the CTMS.

Statistical Evaluation of Calculated Component Damage

From the test data reported in Chapter 4, it seems apparent that the damage values for the 10 components under consideration differ according to the technique used to calculate the cumulative damage. Here we will statistically test that observation. Three null hypotheses will be tested:

$H_0(1)$: Component damage recorder-derived = Component damage logbook-derived

$H_0(2)$: Component damage SIRS-derived = Component damage logbook-derived

$H_0(3)$: Component damage recorder-derived = Component damage SIRS-derived

The approach used is to take the smallest difference between the respective values for the test of these hypotheses. From Table 34 the smallest delta was found. Table 36 summarizes the deltas and associated calculations. $H_0(1)$ is tested via Main Rotor Grip data. $H_0(2)$ will be tested with Swashplate Drive Link data, and $H_0(3)$ will be tested with Swashplate Outer Ring data. All null hypotheses were rejected at the 5-percent significance level. Sample Calculation 1 using small sampling theory is shown.

Sample Calculation 1

Test Null Hypothesis $H_0(1)$: 0.00514 = 0.00910 (from Reference 8, p. 261) to a 5-percent level of significance:

$N_1 = 16$ $\qquad$ $N_2 = 16$

$\bar{x}1 = 0.00514$ $\qquad$ $\bar{x}2 = 0.00910$

$S_{\bar{x}_1} = 0.00317$ (Std. Error) $\qquad$ $S_{\bar{x}_2} = 0.001777$ (Std. Error)

$V_1 = 0.0000100489$ $\qquad$ $V_2 = 0.0000031577$

8. Tintner, G., MATHEMATICS AND STATISTICS FOR ECONOMISTS, New York: Holt, Rinehart, and Winston, 1965.

$$S^2_{\bar{x}_1-\bar{x}_2} = \frac{[(N_1-1)V_1 + (N_2-1)V_2](N_1+N_2)}{N_1 N_2(N_1+N_2-2)}$$

$$= \frac{[(16-1)0.0000100489 + (16-1)(0.0000031577)](16+16)}{16(16)(16+16-2)}$$

$$= \frac{[15(0.0000100489) + 15(0.0000031577)](32)}{16(16)(30)}$$

$$= \frac{(0.0001507335 + 0.0000473655)(32)}{7680}$$

$$= \frac{(0.000198099)32}{7680} = \underline{\underline{0.0000008254}}$$

$$t(\text{empirical}) = \frac{(0.00514-0.00910)}{8.254 \times 10^{-7}} = 4797.60$$

n (degree of freedom) $= N_1 + N_2 - 2 = 16 + 16 - 2 = 30$

t (at 5-percent significance) $= 2.042$

Since t(empirical) >> t(required at 5-percent significance), null hypothesis is rejected.

Of final concern is whether the standard deviations observed during the IOT&E flight test are statistically substantiative. Therefore three additional hypotheses will be tested:

$$H_0(4): \sigma \begin{pmatrix}\text{Component damage} \\ \text{recorder-derived}\end{pmatrix} = \sigma \begin{pmatrix}\text{Component damage} \\ \text{logbook-derived}\end{pmatrix}$$

$$H_0(5): \sigma \begin{pmatrix}\text{Component damage} \\ \text{SIRS-derived}\end{pmatrix} = \sigma \begin{pmatrix}\text{Component damage} \\ \text{logbook-derived}\end{pmatrix}$$

$$H_0(6): \sigma \begin{pmatrix}\text{Component damage} \\ \text{recorder-derived}\end{pmatrix} = \sigma \begin{pmatrix}\text{Component damage} \\ \text{SIRS-derived}\end{pmatrix}$$

The same methodology previously used is repeated here. $H_0(4)$ will be tested via swashplate drive link data. $H_0(5)$ will be tested with main rotor blade data, and $H_0(6)$ will be tested with swashplate drive link data. Table 37 shows the smallest ΔS_x selected. Sample Calculation 2 is similar to that previously shown (Reference 8).

TABLE 36. EVALUATION OF $\Delta\bar{x}$ FOR CALCULATED COMPONENT DAMAGE

	(1) SIRS Spectrum	(2) Recorder Spectrum	(3) Logbook Spectrum	(2)-(3) Absolute Value	(1)-(3) Absolute Value	(1)-(2) Absolute Value
Main Rotor Blade	0.01041	0.04386	0.08491	0.04105	0.0745	0.03345
Main Rotor Yoke Extension	0.000594	0.01462	0.02833	0.01371	0.027736	0.014026
Main Rotor Grip	0.01106	0.00514	0.00910	0.00396	0.00196	0.00592
Main Rotor Pitch Horn	0.00023	0.00779	0.01379	0.006	0.10356	0.00327
Retention Strap Ftg/Nut	0.03272	0.02338	0.04137	0.01799	0.00865	0.00934
Swashplate Drive Link	0.00020	0.00468	0.00828	0.0036	0.00808	0.00448
Swashplate Outer Ring	0.01870	0.01559	0.02758	0.01199	0.00888	0.00311
Swashplate Inner Ring	0.00320	0.01694	0.02923	0.01229	0.02603	0.01374
Hydraulic Boost Cylinder	0.00037	0.01462	0.02830	0.01368	0.02793	0.01425
Tail Rotor Blade	0.02723	0.05080	0.08771	0.03691	0.06048	0.02357

TABLE 37. EVALUATION OF ΔS_x FOR CALCULATED COMPONENT DAMAGE

	(1) SIRS Spectrum	(2) Recorder Spectrum	(3) Logbook Spectrum	(2)-(3) Absolute Value	(1)-(3) Absolute Value	(1)-(2) Absolute Value
Main Rotor Blade	0.01139	0.02679	0.01206	0.01473	0.00067	0.0154
Main Rotor Yoke Extension	0.01314	0.00893	0.00400	0.00493	0.00914	0.00421
Main Rotor Grip	0.02957	0.00317	0.00177	0.0014	0.0278	0.0264
Main Rotor Pitch Horn	0.00091	0.00480	0.00269	0.00211	0.00178	0.00389
Retention Strap Ftg/Nut	0.1732	0.01439	0.0080[illegible]	0.00632	0.00925	0.00293
Swashplate Drive Link	0.00081	0.00288	0.00161	0.00127	0.0008	0.00207
Swashplate Outer Ring	0.06998	0.00960	0.00538	0.00422	0.0646	0.06038
Swashplate Inner Ring	0.00709	0.00992	0.00432	0.0056	0.00277	0.00283
Hydraulic Boost Cylinder	0.00035	0.00893	0.00402	0.00491	0.00367	0.00858
Tail Rotor Blade	0.04352	0.02976	0.01296	0.0168	0.03056	0.01376

Sample Calculation 2

$N_1 = 11$ $N_2 = 11$

$\bar{x}_1 = 0.01139$ $\bar{x}_2 = 0.01206$

$S_{\bar{x}_1} = 0.00343$ (Std. Error) $S_{\bar{x}_2} = 0.00364$ (Std. Error)

$V_1 = 0.00001176$ $V_2 = 0.0000132496$

$$S^2_{\bar{x}_1 - \bar{x}_2} = \frac{[(N_1 - 1)V_1 + (N_2 - 1)V_2](N_1 + N_2)}{N_1 N_2 (N_1 + N_2 - 2)}$$

$$= \frac{[10(0.00001176) + 10(0.0000132496)](22)}{121(20)}$$

$$= \frac{(0.0001176 + 0.000132496)22}{2420}$$

$$= \frac{(0.000250096)22}{2420}$$

$$= 0.000022736$$

$$t(\text{empirical}) = \frac{(0.01139 - 0.01206)}{2.2736 \times 10^{-6}}$$

$$= \underline{\underline{-294.68}}$$

n (degrees of freedom) = $N_1 + N_2 - 2 = 11 + 11 - 2 = 20$

t (at 5-percent significance) = 2.086

Since t(empirical) >> t(required at 5-percent significance), null hypothesis is rejected.

In summary, $H_0(1)$, $H_0(2)$, $H_0(3)$, $H_0(4)$, $H_0(5)$, and $H_0(6)$ are rejected at the 5-percent level of significance. This means that the deltas are due to a systematic assignable difference and cannot be attributed to a random phenomenon. The relationships of each technique to the implied service lives of these high-value, fatigue-sensitive assemblies may be observed in Figures 34 through 43.

It will be noted that the "greater than" ogives used in the figures imply a normal distribution. In an attempt to determine whether a normal distribution represented a good fit for a given data, normal curve graph paper was used to check closeness of fit on four randomly selected samples of the SIRS data. The plotted points fell reasonably close to a straight line. Hence the data was treated as normally distributed for purposes of the preliminary evaluation.

The means for each type of failure calculation are significantly different. The standard deviations for each type of failure calculation are significantly different. The standard deviations found for the SIRS throughout this test series must be considered marginally satisfactory.

Software

Three software concepts were open for evaluation during the IOT&E. The IPS, FDAS, and CMTS require close examination prior to a SIRS deployment decision. The IPS and FDAS were both exercised with satisfactory results. The CMTS remains untested in the IOT&E environment.

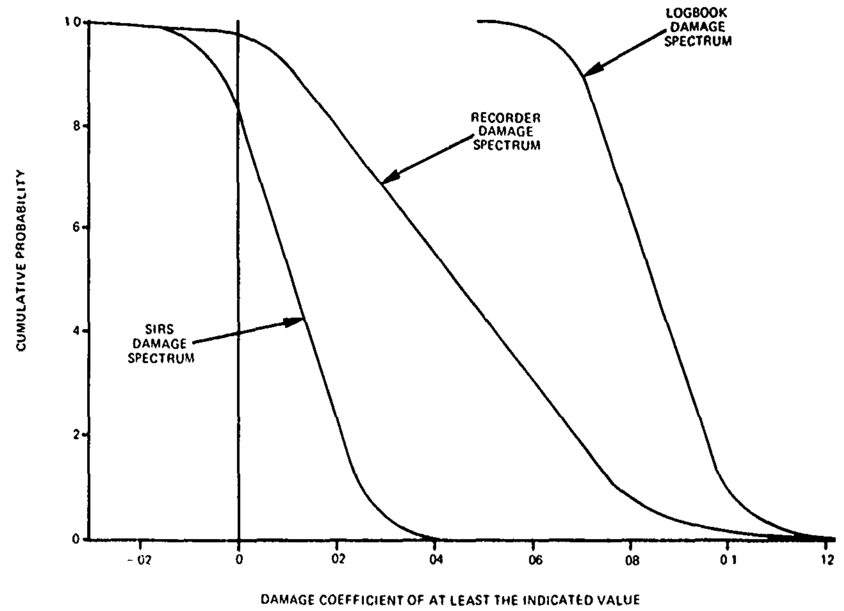


Figure 34. Main Rotor Blade Damage Spectrums.

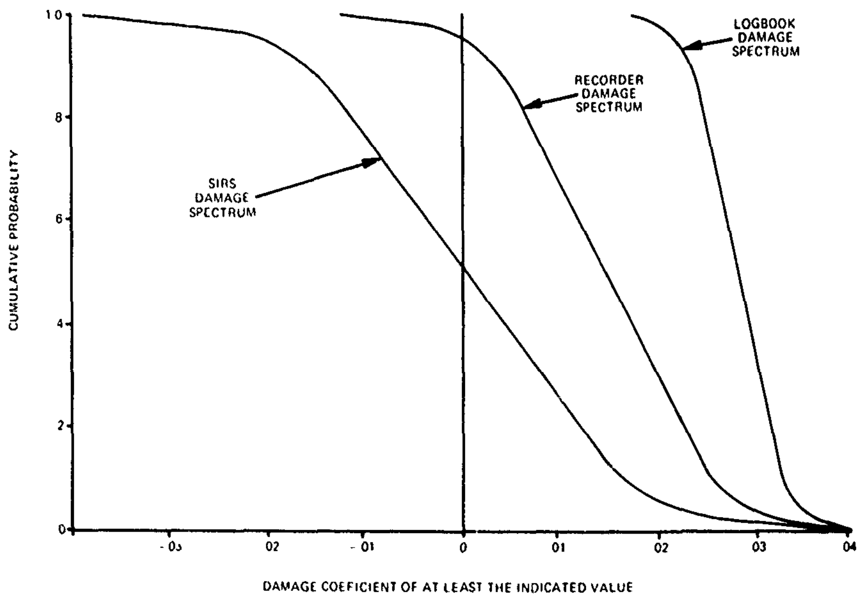


Figure 35. Main Rotor Yoke Extension Damage Spectrums.

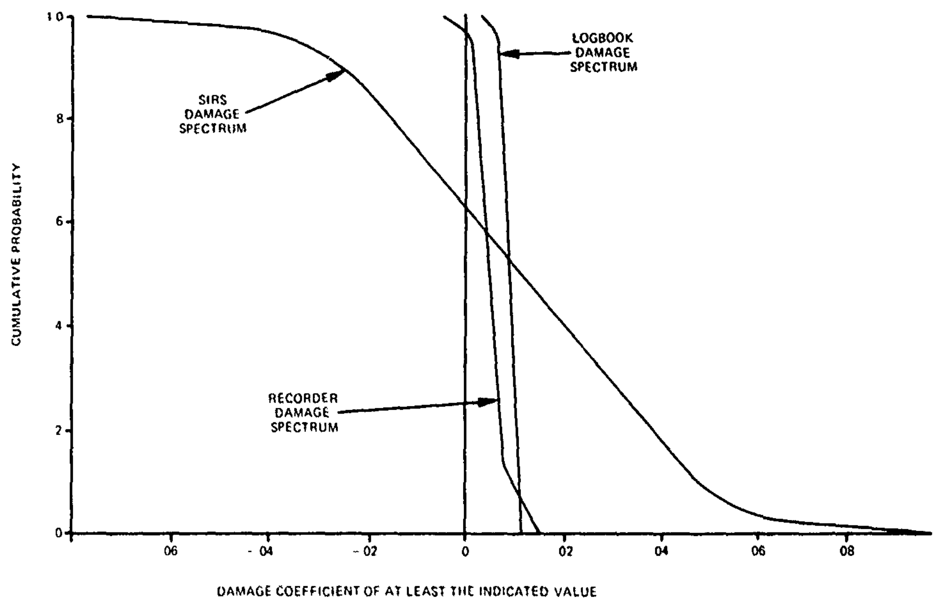


Figure 36. Main Rotor Grip Damage Spectrums.

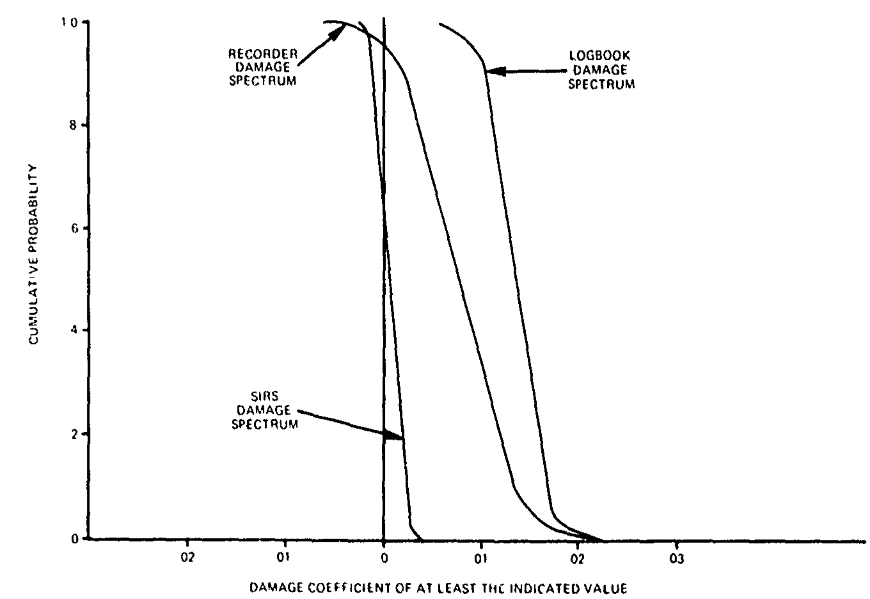


Figure 37. Main Rotor Pitch Horn Damage Spectrums.

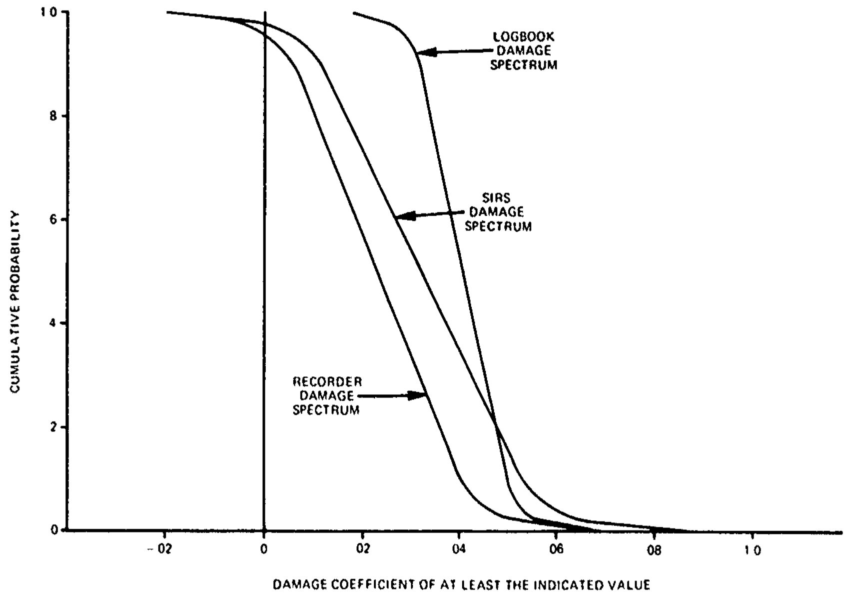


Figure 38. Retention Strap Fitting/Nut Damage Spectrums.

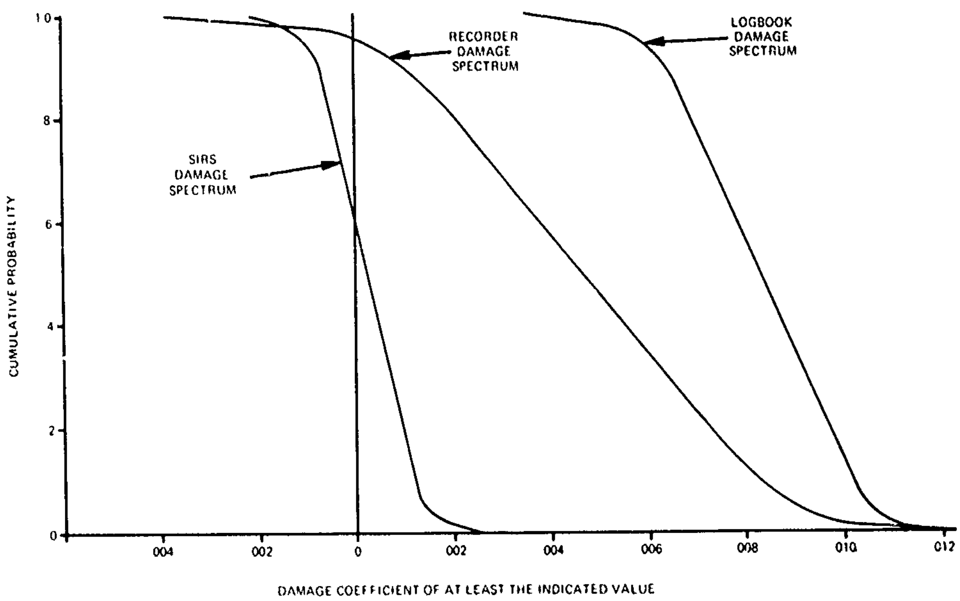


Figure 39. Swashplate Drive Link Damage Spectrums.

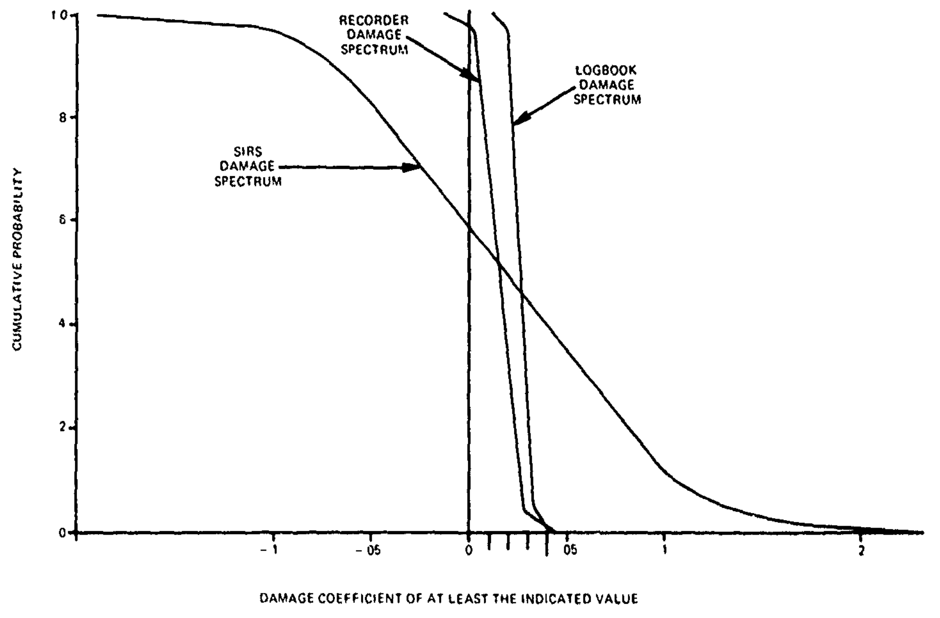


Figure 40. Swashplate Outer Ring Damage Spectrums.

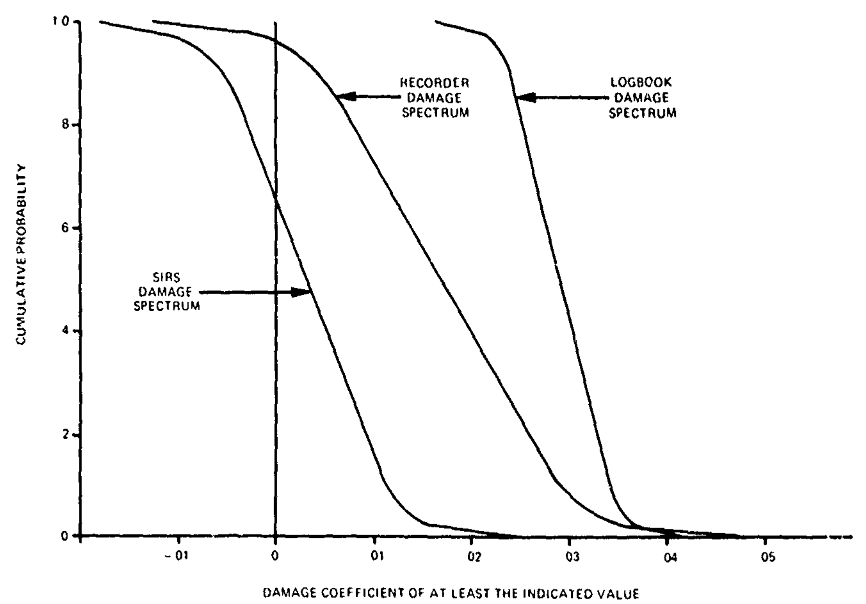


Figure 41. Swashplate Inner Ring Damage Spectrums.

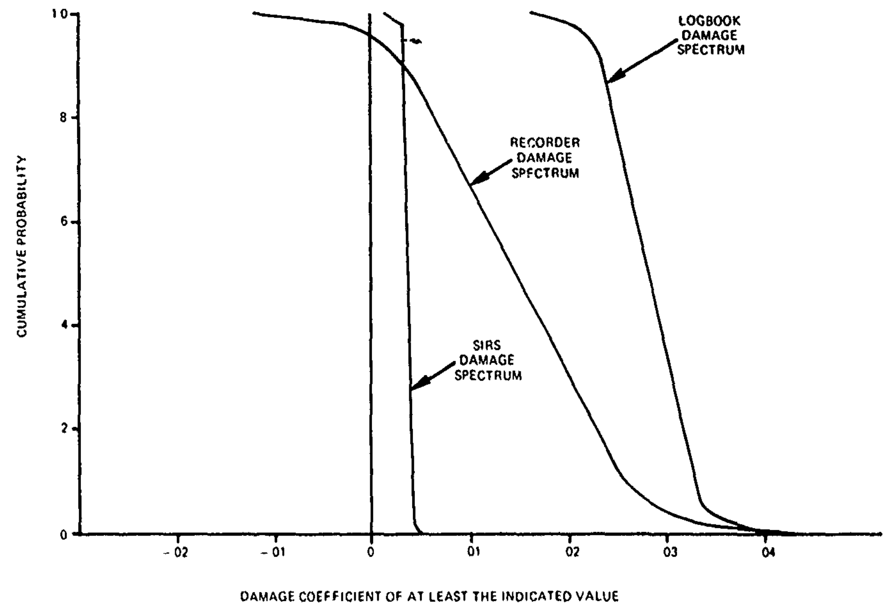


Figure 42. Hydraulic Boost Cylinder Damage Spectrums.

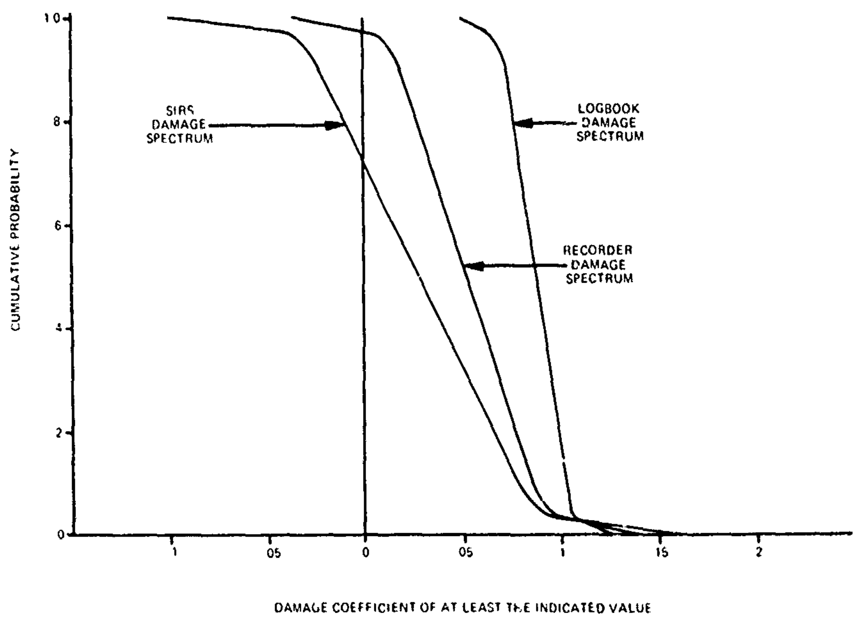


Figure 43. Tail Rotor Blade Damage Spectrums.

CHAPTER 6.

CONCLUSIONS

DT&E FLIGHT TEST (PHASE I PROTOTYPE FLIGHT TEST)

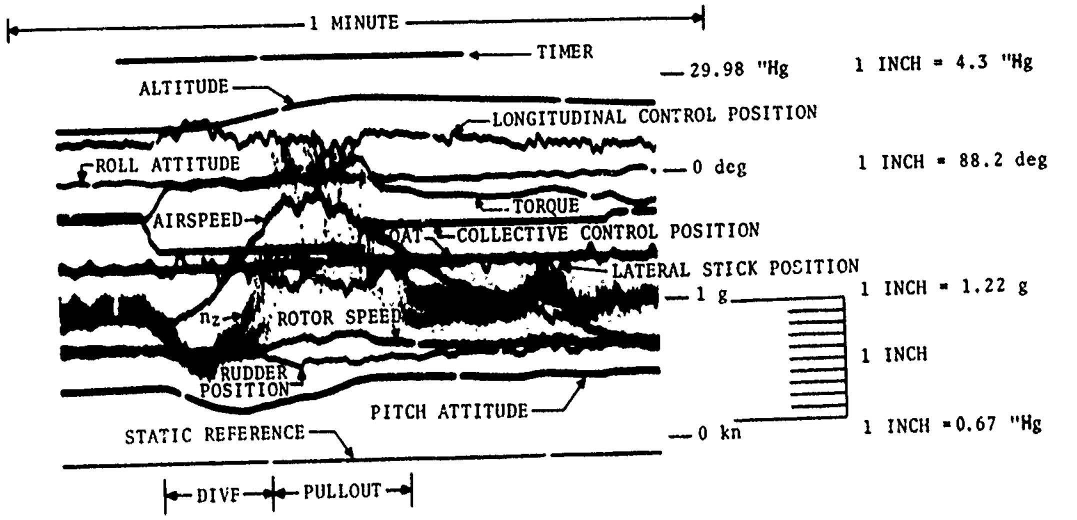
Software Modifications

Of the seven modifications identified, two have already been discussed, i.e., normal versus autorotational landing and maximum V_L detection. The logic change for measuring autorotative time was required because the software had a design error. That is, the logic included a timer designed to filter transients from the torque transducer output, but the logic did not properly clear this timer, thereby causing random amounts of time to be put into this flight condition category whenever a transient occurred. For the full-power climb condition, additional memory was allocated to permit recording both low-speed and high-speed climbs at high power settings. A minor change was made to the software, defining a Quick Stop so that the airspeed would have to decrease during the maneuver before it could be recorded.

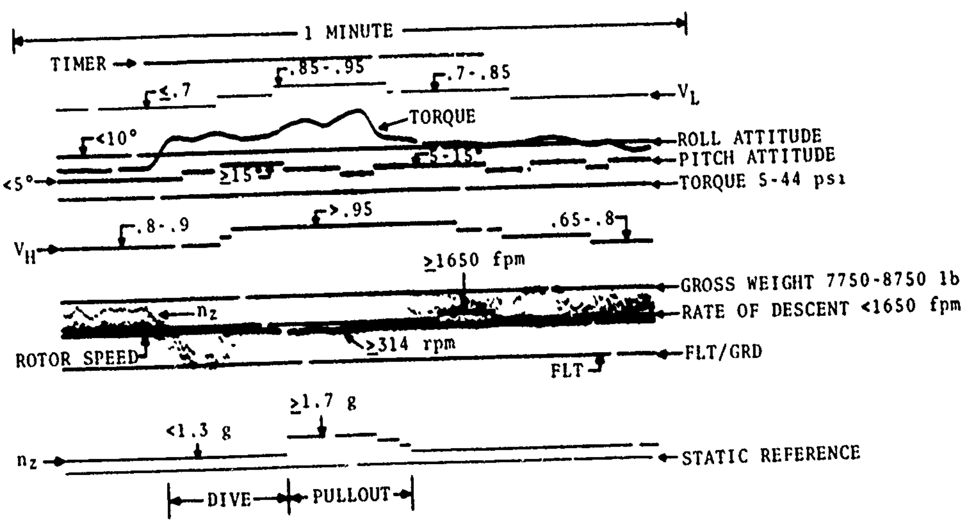
During the flight test program, numerous dives and corresponding pullouts were performed, but very little time was recorded by the SIRS recorder in either type of flight condition. In most instances, the logic relationships between rate of descent, airspeed, and vertical acceleration did not correlate with the actual relationships. A review of the data collected during the various symmetrical and asymmetrical dives and the resulting pullouts, such as the example shown in Figure 44, led to a simple method for identifying the dives. The SIRS recorder logic now "looks for" a negative vertical acceleration greater than 0.8g followed by a positive vertical acceleration of 1.3g or greater; during this interval, the airspeed must increase and the altitude must decrease by certain prescribed amounts. The dive is then categorized by the gross weight, airspeed, and vertical acceleration levels once it has been determined to be a symmetrical or asymmetrical (roll attitude outside of threshold) dive. The resulting pullout from a dive is defined as the duration that the vertical acceleration is between 1.3g and 1.1g; it is categorized by airspeed, gross weight, and its symmetrical or asymmetrical configuration.

Hardware Modifications

An alternate gross weight monitoring approach that measures gross weight in flight was identified during a joint in-house investigation conducted by Bell Helicopter Textron and Technology Incorporated. This system would measure the axial load within the lift link, a transmission mounting member. Such a system



(a) FCR Oscillograph



(b) Flag Oscillograph

Figure 44. Dive/Dive Pullout.

would update the aircraft gross weight of the helicopter whenever the helicopter is in level, unaccelerated flight. Consequently, this system would measure the gross weight more accurately than the skid landing gear technique because it could detect gross weight changes due to weapons firing.

IOT&E (PHASE II OPERATIONAL EVALUATION)

Explicit Determination of Gross Weight

During the DT&E and IOT&E program two procedures were evaluated to explicitly measure the GW parameter during flight operations of the AH-1G. One was found to be marginally satisfactory from a technical standpoint (DT&E). Both were unsatisfactory from an operational standpoint (IOT&E).

It must be recognized that the GW parameter is important in calculating fatigue lives of the 10 selected parts. However, it is additionally recognized that explicit measurement of this parameter comprises a state-of-the-art challenge. In addition, explicit measurement will be expensive. A fresh look at the problem is in order.

A cursory examination of the fatigue life calculations and the recommended service lives of the 10 selected parts implies a large error budget. This is not surprising due to the empirical nature of the phenomena. It is suggested that within the existing error budget, the GW parameter could be imputed with a priori knowledge of the part usage. Finally, all possible instrumentation options should be considered if explicit GW measurement is essential.

Tracking of High-Value, Fatigue-Sensitive Parts

The need for a simple, effective parts tracking procedure for the many high-value, fatigue-sensitive parts under surveillance by the SIRS concept became apparent during this short IOT&E flight test program. In addition, the process must minimally impact the logistics support of the U.S. Army aviation program.

DTU Packaging

The reported unwieldy nature of the DTU package was noted during this brief IOT&E flight test program. This package requires more in-depth evaluation. A number of alternate DTU packaging concepts could be postulated; for example, a two-package concept with rugged elements in one box and the more sensitive elements in another.

DTU Tape Drive

The selected design concept using a single capstan controller was found to be operationally inadequate and demanded corrective action. The tape drive vendor was contacted on this matter. It was determined that an applicable cure would be to adjust the design, providing for dual-direction capstan controllers and thus ensuring positive authority over the operation of the tape location at all times. This would enable effective data manipulation and reference in a time-efficient manner.

Use of DTU During Battery Charging Operation

The inoperability of the DTU during battery charging operations was noted. The adverse impact on productivity was deemed unnecessary since a relatively minor design adjustment would readily render the DTU available for other tasks during DTU battery charging operations.

Logistics of Data Reduction

The time invested in this short IOT&E was inadequate to completely or accurately assess the logistics of the original SIRS data reduction concept.

Statistical Evaluation of Calculated Component Damage

The test results of Chapter 4 and findings reported in Chapter 5 demonstrate that the method selected to calculate service lives of the 10 selected assemblies significantly influences the economics of AH-1G life-cycle cost for those parts.

Use of logbook data to calculate component fatigue damage produces an extravagant replenishment spares requirement.

Use of recorder data to calculate component fatigue damage will yield a significantly more economical approach to logistical support of the 10 parts under consideration. This is attributed to the fact that the recorder electronics only count fatigue-damaging phenomena beginning after rotor start. Engine run time and mission planning times, for example, are not included in calculations. Thus it may be concluded that the Army might consider a counting device (recorder values) rather than operational logbook times to arrive at component retirement lives.

The optimum service life for the 10 high-value, fatigue-sensitive parts was yielded by SIRS spectrum monitoring.

Finally, it must be concluded that the scatter of SIRS component damage data during this brief IOT&E is systematic. Examination revealed a single-point failure mechanism within the recorder; i.e., the GW sensor channel was multiplexed such that it affected all other channels. Further, the GW sensor was quite troublesome throughout the IOT&E as reported in Chapter 4. Thus SIRS performance will be significantly enhanced by implementing corrective action on the GW sensing channel and the recorder multiplexing scheme.

Software

Since the IPS and FDAS have been demonstrated and found to be satisfactory, they are considered ready for OT&E testing. It is noted that the CMTS package remains untested in the DT&E and IOT&E mode.

CHAPTER 7.

RECOMMENDATIONS

As a result of the DT&E and IOT&E flight testing, several modifications of the SIRS concept are recommended. These recommendations include software logic changes to better identify certain flight conditions and hardware modifications to better survive the operational environment. In addition, operational considerations are recommended.

DT&E FLIGHT TEST (PHASE I PROTOTYPE FLIGHT TEST)

Software Modifications

A total of seven needed software changes that were recommended were made to the SIRS recorder logic and tested in the laboratory on a SIRS recorder simulator. No further action is required on this recommendation.

Hardware Modifications

As a result of the qualification program, several hardware modifications were recommended for incorporation into the recorders to be used during the Phase II Operational Evaluation. These modifications include the improvement of some of the internal wire routing and terminations. In addition, the lithium battery that failed during the temperature-altitude-humidity test was replaced by an improved, qualified lithium battery. No retesting was contemplated since this battery has been successfully tested under similar environmental conditions.

Flight testing on a Bell Model 212 helicopter equipped with both a SIRS recorder and a magnetic tape instrumentation system indicated that the in-flight gross weight measuring system would yield valid data if the center-of-gravity excursions were not large. Because the c.g. excursion on operational AH-1G helicopters is about 5 inches for gross weights ranging between 7000 and 9500 pounds, it was felt that the lift link measurement system could be adjusted for these excursions. Moreover, this system would yield data more accurately than the skid landing gear system since the latter has the limitation of an assumed fuel burn-off rate and a fixed weight for all weapons configurations.

All of these recommended alterations were executed and were successful except for the GW sensing scheme. Details of those results are cited under the IOT&E flight test program findings (Chapter 5).

IOT&E (PHASE II OPERATIONAL EVALUATION)

Explicit Determination of Gross Weight

Since the two sensor techniques selected to explicitly measure GW were unsatisfactory, a new approach is recommended for determining this important parameter. The scheme should conform to the error budget existing within the theoretical calculated fatigue life and recommended service lives of the 10 parts under evaluation in the SIRS program. In addition, a clamped-on, piezoelectric strain gage approach should be used for instrumenting the AH-1S lift link. This will eliminate the need to mechanically bond the sensor to the shot-peened lift link surface. Thorough concept testing by follow-on IOT&E with confirmed, satisfactory results prior to implementation/deployment is recommended.

Tracking of High-Value, Fatigue-Sensitive Parts

As the DT&E program merged into the IOT&E program the importance of tracking the high-value, fatigue-sensitive parts under SIRS surveillance became unmistakable. It is recommended that the SIRS DTU be modified to provide for operator inputs when a part is changed. This will minimize the need for additional paperwork at the organizational level while capturing this vital data essential to operational utility of SIRS. This concept should be tested and evaluated via a follow-on IOT&E, with using command and logistical command inputs to the evaluations.

DTU Packaging

The reported unwieldy nature of the DTU packaging should be investigated within the operational environment. The selected design is inconvenient to the operator from the standpoint of transportation. Nevertheless, execution of alternative packaging concepts entails life-cycle-cost implications. Further IOT&E of the DTU packaging should be accompanied by a cost-benefit evaluation of postulated alternatives.

DTU Tape Drive

The single DTU tape drive capstan control concept required rectification. The appropriate corrective action was to provide for dual wind/rewind capstan controllers. This recommendation was implemented and was subsequently found to be satisfactory. The DTU employed in the follow-on IOT&E flight test program of AH-1S employs this design concept. No further action is required.

Use of DTU During Battery Charging Operation

It is recommended that the DTU circuitry be redesigned to provide for operability during the battery recharging operation and that the redesign be evaluated during follow-on IOT&E.

Logistics of Data Reduction

The postulated data processing system in support of the SIRS concept was inadequately tested or evaluated due to the compressed time schedule. Complete and thorough testing and evaluation of the system via an appropriate extension of the IOT&E period is recommended. The IPS, FDAS, and CTMS should be closely examined as an integral part of the AVSCOM RAMMIT system.

Statistical Evaluation of Calculated Component Damage

The use of operational logbook hours to calculate component fatigue damage for high-value, fatigue-sensitive assemblies yields extravagant results. It is recommended that SIRS be used to compute service lives of these parts.

Since the standard deviations of SIRS results can be reduced by altering the GW sensor methodology and recorder multiplexing scheme, these changes should be implemented.

The alterations should be carefully and adequately tested via a follow-on IOT&E. Assessments by using command and logistical command should be provided prior to a deployment decision.

Software

The IPS and FDAS packages are operational. The CMTS concept should be reviewed to ensure its capability with U.S. Army aviation program needs.

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ABBREVIATIONS

ATR	Airborne Transmitter Rack
BIT	Built-In Test
CTMS	Component Tracking Management System
DoD	Department of Defense
DT&E	Development Test and Evaluation
DTU	Data Transfer Unit
EMI	Electromagnetic Interference
EMC	Electromagnetic Compatability
EPROM	Erasable Programmable Read-Only Memory
FCC	Flight Condition Category
FCM	Flight Condition Monitoring
FCR	Flight Condition Recognition
FDAS	Fatigue Damage Assessment System
GW	Gross Weight
H-GW	High Gross Weight
IOT&E	Initial Operational Test and Evaluation
IPS	Initial Processing System
L-GW	Light Gross Weight
M-GW	Medium Gross Weight
MTBF	Mean-Time-Between-Failures
O&S	Operating and Support
PC	Printed Circuit
R&D	Research and Development
RAM	Random Access Memory
RAMMIT	Reliability and Maintainability Management Improvement Techniques

ABBREVIATIONS - Concluded

RJE	Remote Job Entry
SIRS	Structural Integrity Recording System
V_H	Maximum Attainable (Level Flight) Velocity
V_L	Limit Velocity

APPENDIX A

DETAILED FCM SYSTEM DESCRIPTION

This appendix describes the flight condition categories in terms of the pertinent flight parameters by indicating the criteria that govern (1) the definition and identification of each flight condition category, and (2) the requirements for monitoring the flight condition categories. These criteria are defined by sample (theoretical) time-history traces and written descriptions.

The 103 flight condition categories are summarized in Table A-1. The letters in the column entitled "Type" are defined as follows:

T = accumulated time spent in the flight condition category during a specified recording period

C = accumulated occurrences of the flight condition category during a specified recording period

M = maximum parameter magnitude during a specified recording period

N = null recording category

The system parameters, both those directly recorded and those computed, are summarized in Table A-2.

TABLE A-1. FCM SYSTEM SUMMARY

Flt. Cond. Cat. No. Gross Weight (lb)					
<7750	7750-8750	>8750	Parameters	Type	Thresholds
1	2	3	Clock Time	T	....
	4		Rotor Speed Above or Below Threshold	C	100 RPM
5	6	7	Vertical Accel. Below Threshold A/S Below Threshold Roll Attitude Below Threshold Pitch Attitude Above Threshold Engine Torque Press. Above Threshold	T	$n_z < 1.3g$ $A/S < 0.50\ V_H$ $\beta < 10°$ $\theta > 15°$ $ET \geq 5$ psi
8	9	10	Engine Torque Press. Above Threshold Touchdown Occurs	C	$ET > 5$ psi
11	12	13	Vertical Accel. Below Threshold A/S Between Threshold Roll Attitude Below Threshold Rate of Descent Below Threshold	T	$n_z < 1.3g$ $0.50\ V_H \leq A/S < 0.65\ V_H$ $\beta \leq 10°$ $RD < 1650$ fpm
14	15	16	Vertical Accel. Below Threshold A/S Between Threshold Roll Attitude Below Threshold Rate of Descent Below Threshold Engine Torque Press. Between Thresholds	T	$n_z < 1.3g$ $0.65\ V_H \leq A/S < 0.95\ V_H$ $\beta \leq 10°$ $RD < 1650$ fpm $5\ psi < ET \leq 44\ psi$
17	18	19	Vertical Accel. Below Threshold A/S Above Threshold Roll Attitude Below Threshold Rate of Descent Below Threshold	T	$n_z < 1.3g$ $A/S \geq 0.95\ V_H$ $\beta \leq 10°$ $RD < 1650$ fpm
20	21	22	Vertical Accel. Below Threshold A/S Between Thresholds Roll Attitude Below Threshold Rate of Descent Below Threshold Engine Torque Press. Above Threshold	T	$n_z < 1.3g$ $0.50\ V_H \leq A/S < 0.65\ V_H$ $\beta \leq 10°$ $RD < 1650$ fpm $ET > 44$ psi
23	24	25	Vertical Accel. Between Threshold A/S Between Thresholds Roll Attitude Above Threshold	T	$1.3 \leq n_z < 1.5$ $0.65\ V_H \leq A/S < 0.80\ V_H$ $\beta \geq 10°$
26	27	28	Vertical Accel. Between Threshold A/S Above Threshold Roll Attitude Above Threshold	T	$1.3 \leq n_z < 1.5$ $A/S \geq 0.80\ V_H$ $\beta \geq 10°$
29	30	31	Vertical Accel. Below Threshold A/S Below Threshold Roll Attitude Below Threshold Rate of Descent Above Threshold	T	$n_z < 1.3g$ $A/S \leq 0.70\ V_L$ $\beta \leq 10°$ $RD \geq 1650$ fpm
32	33	34	Vertical Accel. Below Threshold A/S Between Thresholds Roll Attitude Below Threshold Rate of Descent Above Threshold	T	$n_z < 1.3g$ $0.70\ V_L < A/S \leq 0.85\ V_L$ $\beta < 10°$ $RD \geq 1650$ fpm
35	36	37	Vertical Accel. Below Threshold A/S Between Thresholds Roll Attitude Below Threshold Rate of Descent Above Threshold	T	$n_z < 1.3g$ $0.85\ V_L < A/S \leq 0.95\ V_L$ $\beta < 10°$ $RD \geq 1650$ fpm
38	39	40	Vertical Accel. Below Threshold A/S Above Threshold Roll Attitude Below Threshold Rate of Descent Above Threshold	T	$n_z < 1.3g$ $A/S > 0.95\ V_L$ $\beta < 10°$ $RD \geq 1650$ fpm
41	42	43	Vertical Accel. Above Threshold A/S Below Threshold Roll Attitude Between Threshold	T	$n_z \geq 1.5g$ $A/S \leq 0.70\ V_L$ $10° \leq \beta < 35°$
44	45	46	Vertical Accel. Above Threshold A/S Between Thresholds Roll Attitude Between Threshold	T	$n_z \geq 1.5g$ $0.70\ V_L \leq A/S < 0.85\ V_L$ $10° < \beta < 35°$
47	48	49	Vertical Accel. Above Threshold A/S Between Thresholds Roll Attitude Between Thresholds	T	$n_z \geq 1.5g$ $0.85\ V_L \leq A/S < 0.95\ V_L$ $10° < \beta < 35°$
50	51	52	Vertical Accel. Above Threshold A/S Above Threshold Roll Attitude Between Thresholds	T	$n_z \geq 1.5g$ $A/S \geq 0.95\ V_L$ $10° \leq \beta < 35°$

TABLE A-1. Concluded

Flt. Cond. Cat. No. Gross Weight (lb) <7750	7750-8750	>8750	Parameters	Type(*)	Thresholds
53	54	55	Vertical Accel. Above Threshold A/S Below Threshold Roll Attitude Below Threshold Pitch Attitude Above Threshold	T	$n_z \geq 1.3g$ $A/S \leq 0.70\ V_L$ $\beta \leq 10°$ $\theta > 5°$
56	57	58	Vertical Accel. Above Threshold A/S Between Thresholds Roll Attitude Below Threshold Pitch Attitude Above Threshold	T	$n_z \geq 1.3g$ $0.70\ V_L \leq A/S \leq 0.85\ V_L$ $\beta < 10°$ $\theta > 5°$
59	60	61	Vertical Accel. Above Threshold A/S Above Threshold Roll Attitude Below Threshold Pitch Attitude Above Threshold	T	$n_z \geq 1.3g$ $A/S \geq 0.85\ V_L$ $\beta \leq 10°$ $\theta > 5°$
62	63	64	Vertical Accel. Above Threshold A/S Below Threshold Initial Roll Attitude Above Threshold Subsequent Roll Attitudes Below Threshold	T	$n_z \geq 1.5g$ $A/S \leq 0.65\ V_H$ $\beta \geq 35°$ $\beta \leq 25°$
65	66	67	Vertical Accel. Above Threshold A/S Between Thresholds Initial Roll Attitude Above Threshold Subsequent Roll Attitudes Below Threshold	T	$n_z \geq 1.5g$ $0.65\ V_H \leq A/S \leq 0.80\ V_H$ $\beta > 35°$ $\beta \leq 25°$
68	69	70	Vertical Accel. Above Threshold A/S Above Threshold Initial Roll Attitude Above Threshold Subsequent Roll Attitudes Below Threshold	T	$n_z \geq 1.5g$ $A/S \geq 0.80\ V_H$ $\beta > 35°$ $\beta \leq 25°$
71	72	73	Vertical Accel. Above Threshold A/S Below Threshold Initial Roll Attitude Above Threshold Subsequent Roll Attitude Above Threshold	T	$n_z \geq 1.5g$ $A/S \leq 0.90\ V_H$ $\beta > 35°$ $\beta \geq 25°$
74	75	76	Vertical Accel. Above Threshold A/S Above Threshold Initial Roll Attitude Above Threshold Subsequent Roll Attitudes Above Threshold	T	$n_z \geq 1.5g$ $A/S \geq 0.90\ V_H$ $\beta \geq 35°$ $\beta \geq 25°$
77	78	79	Flight Clock Time Engine Torque Press. Below Threshold	T	.... $ET \leq 5$ psi
80	81	82	Vertical Accel. Between Thresholds A/S Above Threshold Engine Torque Press. Crosses Threshold (4-6 psi)	C	$1.3 \leq n_z < 1.5$ $A/S \geq 0.65\ V_H$ 5 psi
83	84	85	Vertical Accel. Above Threshold A/S Above Threshold Engine Torque Press. Crosses Threshold (4-6 psi)	C	$n_z > 1.5$ $A/S > 0.65\ V_H$ 5 psi
86	87	88	Vertical Accel. Between Thresholds A/S Above Threshold Engine Torque Press. Below Threshold Roll Attitude Above Threshold	T	$1.3 \leq n_z < 1.5$ $A/S \geq 0.65\ V_H$ 5 psi $\beta > 10°$
89	90	91	Vertical Accel. Above Threshold A/S Above Threshold Engine Torque Press. Below Threshold Roll Attitude Above Threshold	T	$n_z > 1.5g$ $A/S > 0.65\ V_H$ 5 psi $\beta \geq 10°$
92	93	94	Engine Torque Press. Below Threshold Touchdown Occurs	C	5 psi ....
	95		Vertical Accel. Above Threshold A/S Above Threshold	C	$n_z \geq 1.7g$ $A/S \geq 0.50\ V_H$
	96		Maximum n_z Magnitude Attained	M	....
	97		Maximum A/S Magnitude Attained	M	$A/S = f(V_L)$
98	99	100	Not Recorded Directly	N	Not Applicable
101	102	103	Not Recorded Directly	N	Not Applicable

TABLE A-2. SYSTEM PARAMETERS

System Parameters		Directly Recorded	Computed	Sign Convention for Positive Number
Indicated Airspeed	(A/S)	X		------------------
Max. Level Flight	(V_H)		$V_H = f(T, H_p)$	------------------
Limit Velocity	(V_L)		$V_L = f(t, H_p)$	------------------
Pressure Altitude	(H_p)	X		------------------
Outside Air Temperature	(T)	X		------------------
Rate of Descent	(RD)		$RD = f(H_p, Time)$	Decreasing Altitude
Main Rotor Velocity	(MRV)	X		------------------
Roll Attitude	(β)	X		------------------
Pitch Attitude	(θ)	X		------------------
Vertical Acceleration	(n_z)	X		Ship Accelerates Up
Landing Gear Touchdown	(TD)	X		------------------
Engine Torque Pressure	(ET)	X		Increasing Torque
Takeoff Gross Weight	(TGW)	X		------------------
In-Flight Gross Weight	(GW)		$GW = f(TGW, Time)$	------------------

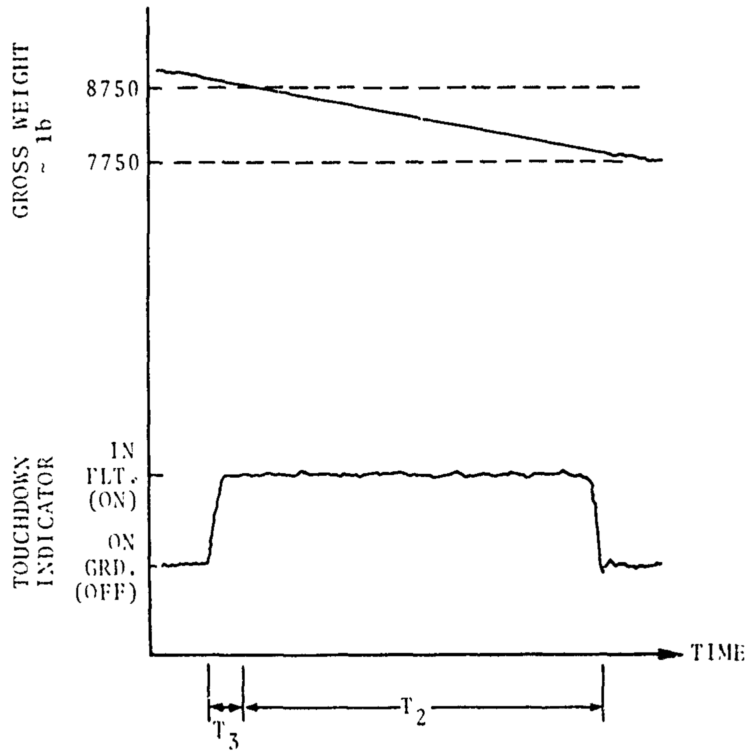
Each type of flight condition category is depicted in Figures A-1 through A-20. In examining these figures, the following statements are applicable to all flight condition categories:

1. Unless otherwise indicated, the engine torque pressure in each flight condition category must be greater than 5 psi.

2. Whenever a roll or a pitch attitude threshold is defined (e.g., $\beta > 10°$), it represents the absolute value of roll or pitch attitude (i.e., $|\beta| \geq 10°$).

Represents: Flight Clock Time

FCC Applicability	TD ON/OFF
FCC #1	GW < 7750 lb
FCC #2	7750 lb ≤ GW ≤ 8750 lb
FCC #3	GW > 8750



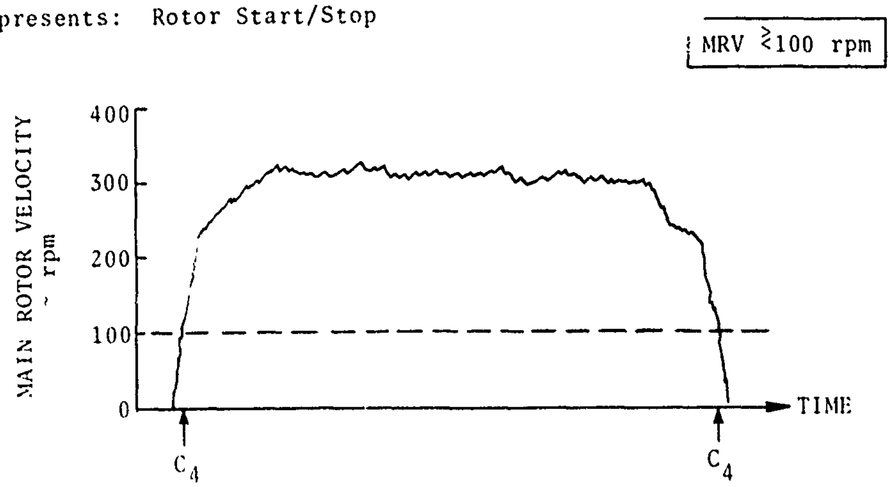
T_1 = FCC #1 Timer
T_2 = FCC #2 Timer
T_3 = FCC #3 Timer

Description

Monitor the clock time accrued by the helicopter while airborne.

Figure A-1. Flight Condition Categories 1, 2, and 3 (In-Flight Time).

Represents: Rotor Start/Stop



C_4 = FCC #4 counter

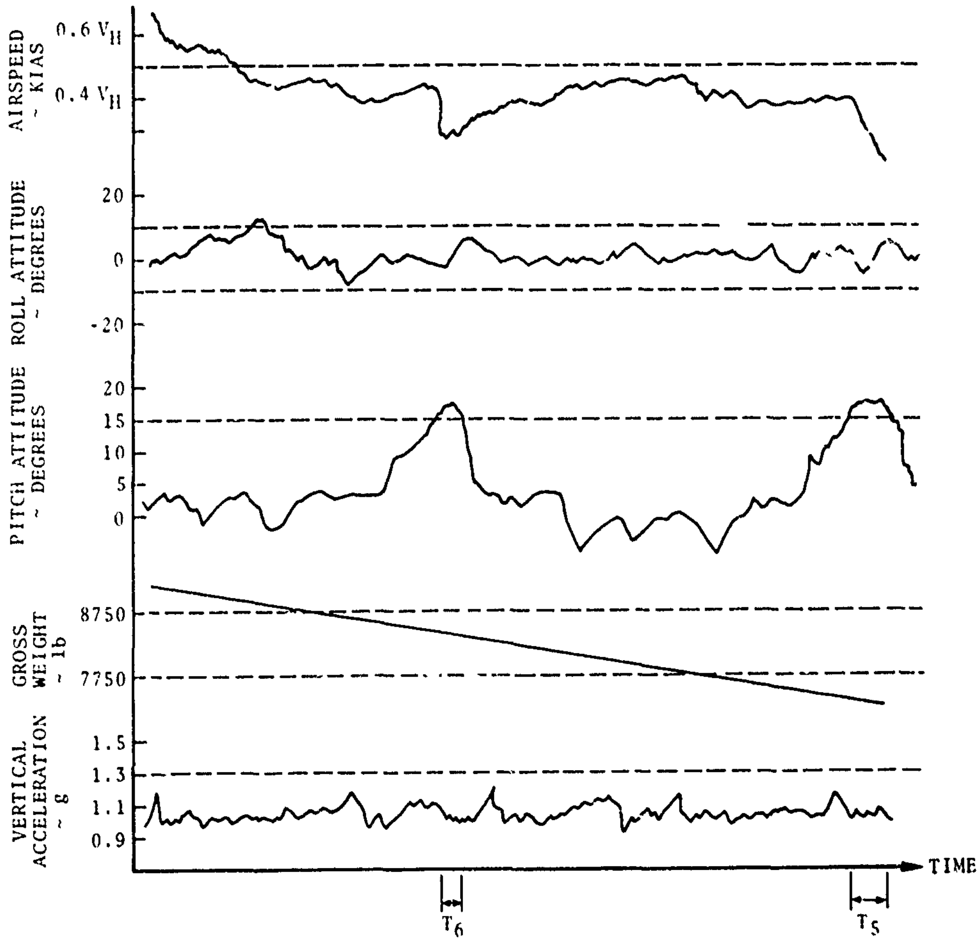
Description

Monitor the number of times the main rotor velocity passes through the 100 rpm regime. To ensure against extra C_4 counts due to small perturbations of the main rotor velocity, require that all C_4 events must occur at least 10 seconds apart.

Figure A-2. Flight Condition Category 4 (Rotor Start/Stop).

Represents: Quick-Stop Deceleration

	$n_z \leq 1.3g$
	$A/S \leq 0.50\ V_H$
	$\beta < 10°$
	$\theta \geq 15°$
FCC Applicability	ET > 5 psi
FCC #5	GW < 7750 lb
FCC #6	7750 lb < GW ≤ 8750 lb
FCC #7	GW > 8750 lb



T_5 = FCC #5 Timer
T_6 = FCC #6 Timer
T_7 = FCC #7 Timer

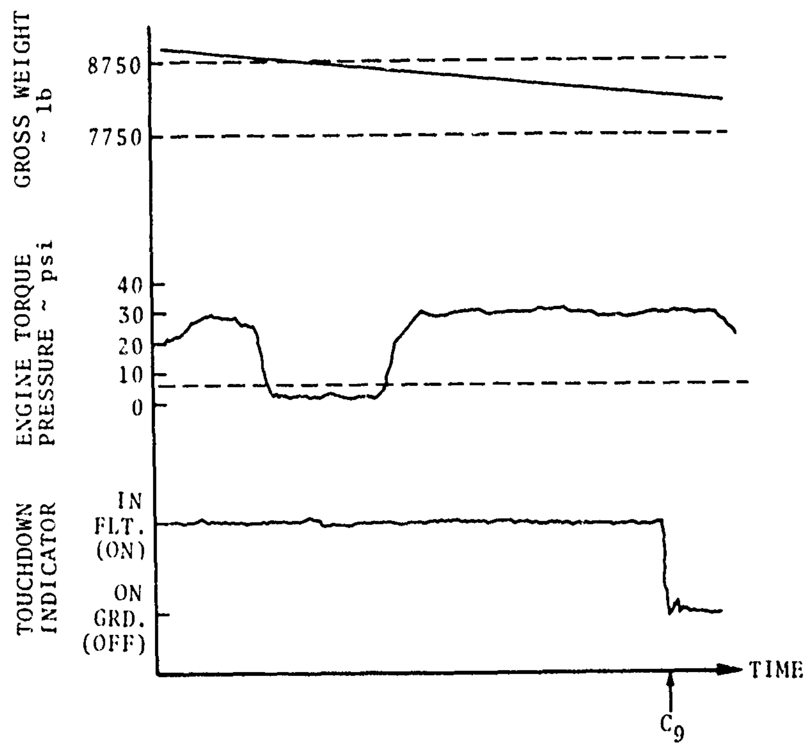
Description

Monitor the clock time accrued by the helicopter during which all six parameter threshold definitions are being satisfied simultaneously. The airspeed requirement is based on maximum attainable velocity at constant altitude (V_H), which is a function of density altitude.

Figure A-3. Flight Condition Categories 5, 6, and 7 (Quick-Stop Deceleration).

Represents: Normal Landing

FCC Applicability	ET > 5 psi TD ON/OFF
FCC #8	GW < 7750 lb
FCC #9	7750 lb < GW ≤ 8750 lb
FCC #10	GW > 8750 lb



C_8 = FCC #8 Counter
C_9 = FCC #9 Counter
C_{10} = FCC #10 Counter

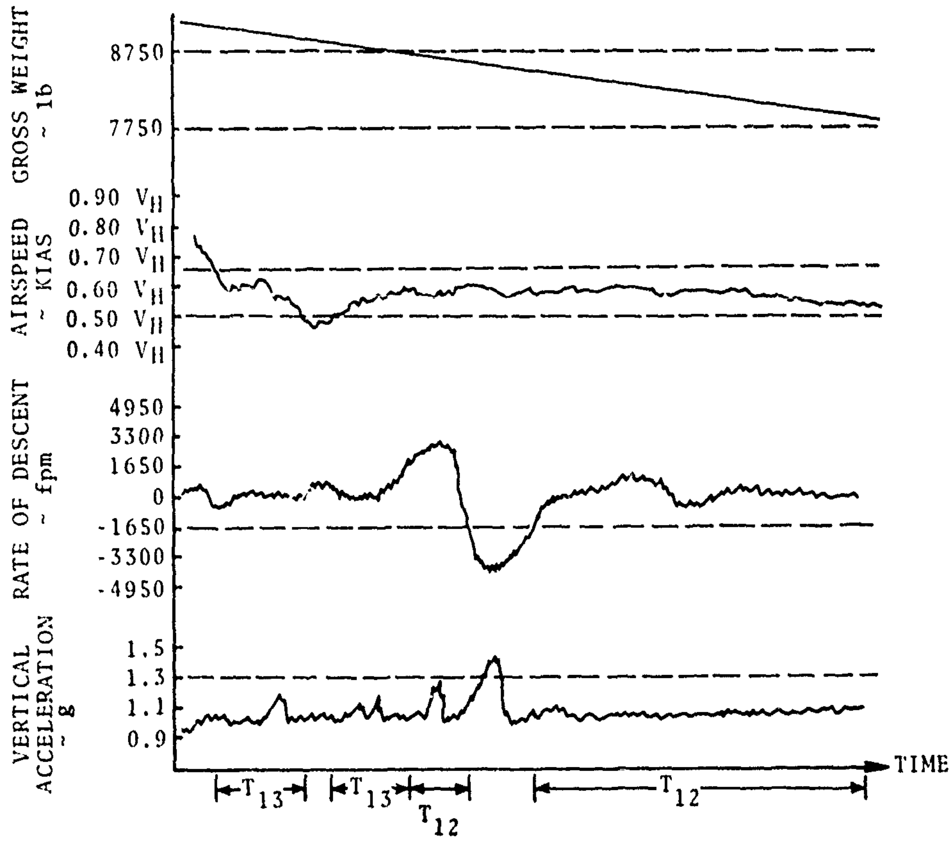
Description

The engine torque pressure must be above threshold immediately prior to (at least 10 seconds), and at the time of, touchdown. Once a touchdown has been recorded, a rebounding helicopter should not register additional counts.

Figure A-4. Flight Condition Categories 8,9, and 10 (Normal Landing).

Represents: Low-Velocity Flight Conditions
(e.g., Forward Level Flight, Normal Full Power Climbs, and Low-Speed Turns)

FCC Applicability	$n_z < 1.3g$ $0.50\ V_H \le A/S < 0.65\ V_H$ $\beta < 10°$ RD < 1650 fpm
FCC #11	GW < 7750 lb
FCC #12	7750 lb ≤ GW ≤ 8750 lb
FCC #13	GW > 8750 lb



T_{11} = FCC #11 Timer
T_{12} = FCC #12 Timer
T_{13} = FCC #13 Timer

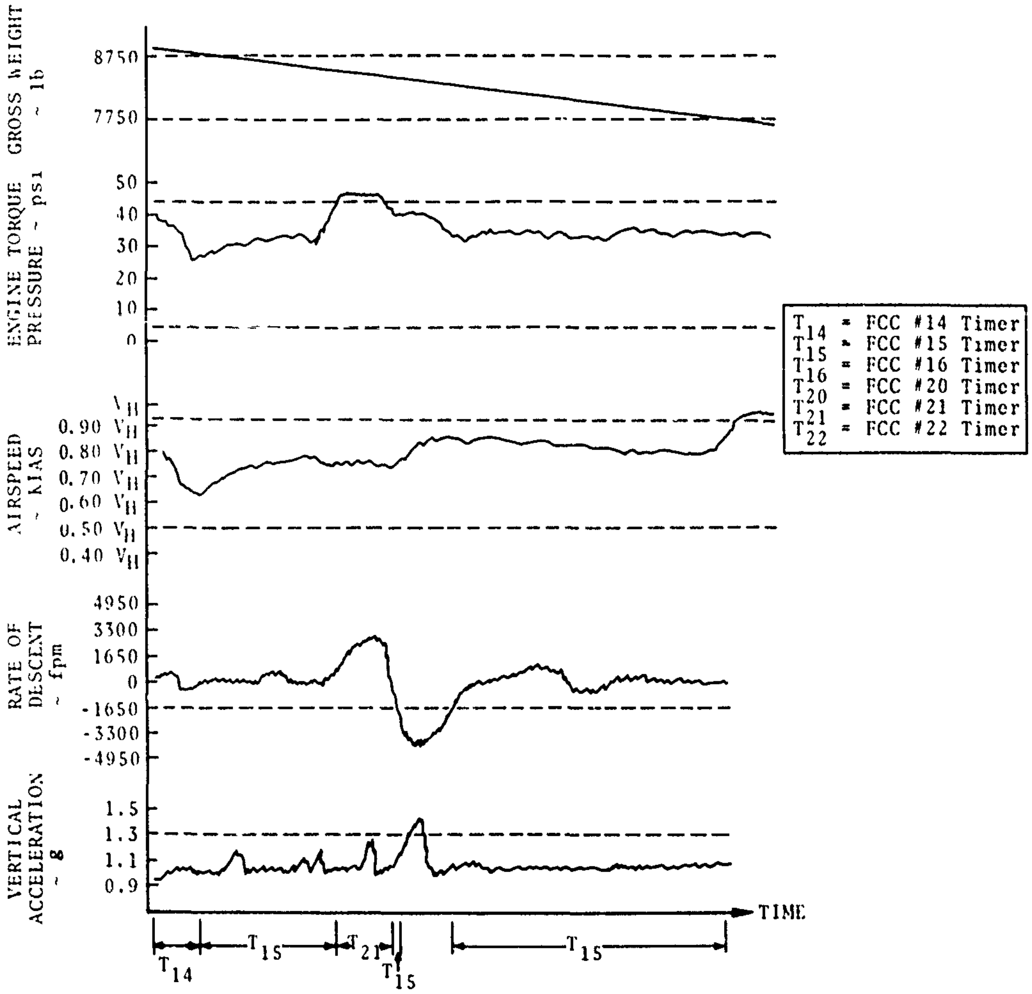
Description

Monitor the clock time accrued by the helicopter during which all five parameter threshold definitions are being satisfied simultaneously. The airspeed classification is based on maximum attainable velocity at constant altitude (V_H), which is a function of density altitude.

Figure A-5. Flight Condition Categories 11, 12, and 13 (Low-Velocity Flight).

Represents: High-Velocity Flight Conditions
(e.g., Forward Level Flight, Part Power Descent, High-Speed Control Corrections, and High-Speed Full Power Climbs)

FCC Applicability		
—For— 5<ET≤44	—For— ET>44	$n_z < 1.3g$; $0.50\ V_H \leq A/S \leq 0.95\ V_H$; $\beta < 10°$; RD < 1650 fpm
FCC #14	FCC #20	GW < 7750 lb
FCC #15	FCC #21	7750 lb < GW ≤ 8750 lb
FCC #16	FCC #22	GW > 8750 lb



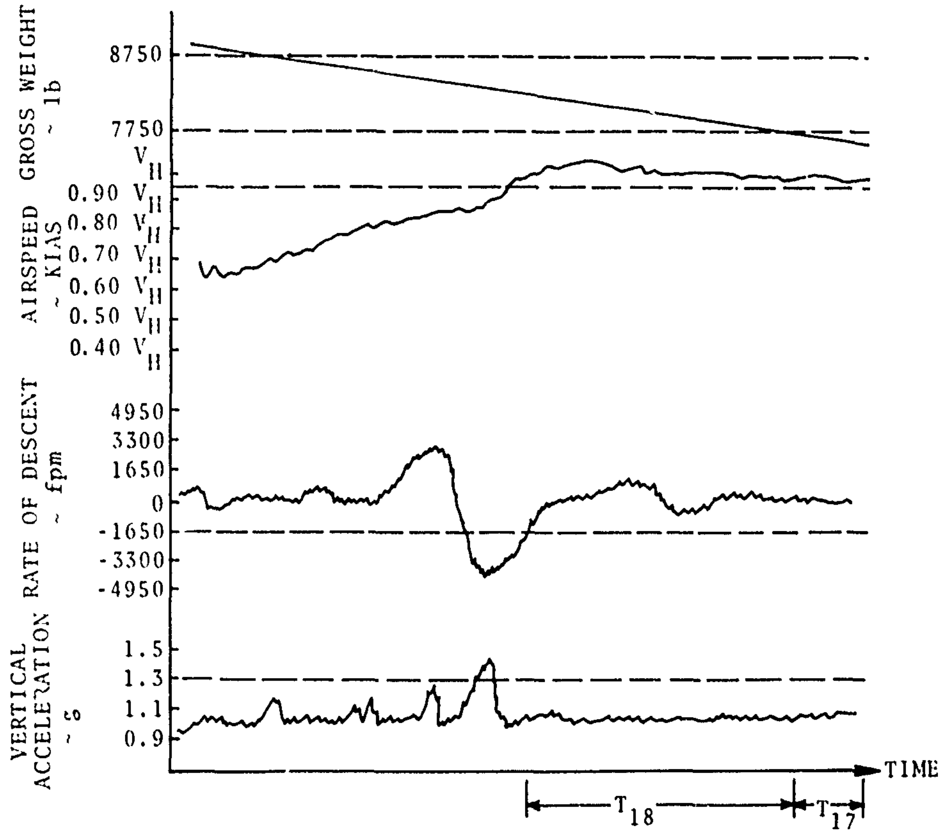
Description

Monitor the clock time accrued by the helicopter during which all six parameter threshold definitions are being satisfied simultaneously. The airspeed classification is based on maximum attainable velocity at constant altitude (V_H), which is a function of density altitude.

Figure A-6. Flight Condition Categories 14, 15, 16, 20, 21, and 22 (High-Velocity Flight).

Represents: Maximum-Velocity Flight Conditions
(e.g., Forward Level Flight)

FCC Applicability	$n_z < 1.3g$ A/S $\geq$ 0.95 V_H $\beta < 10°$ RD < 1650 fpm
FCC #17	GW < 7750 lb
FCC #18	7750 lb < GW $\leq$ 8750 lb
FCC #19	GW > 8750 lb



T_{17} = FCC #17 Timer
T_{18} = FCC #18 Timer
T_{19} = FCC #19 Timer

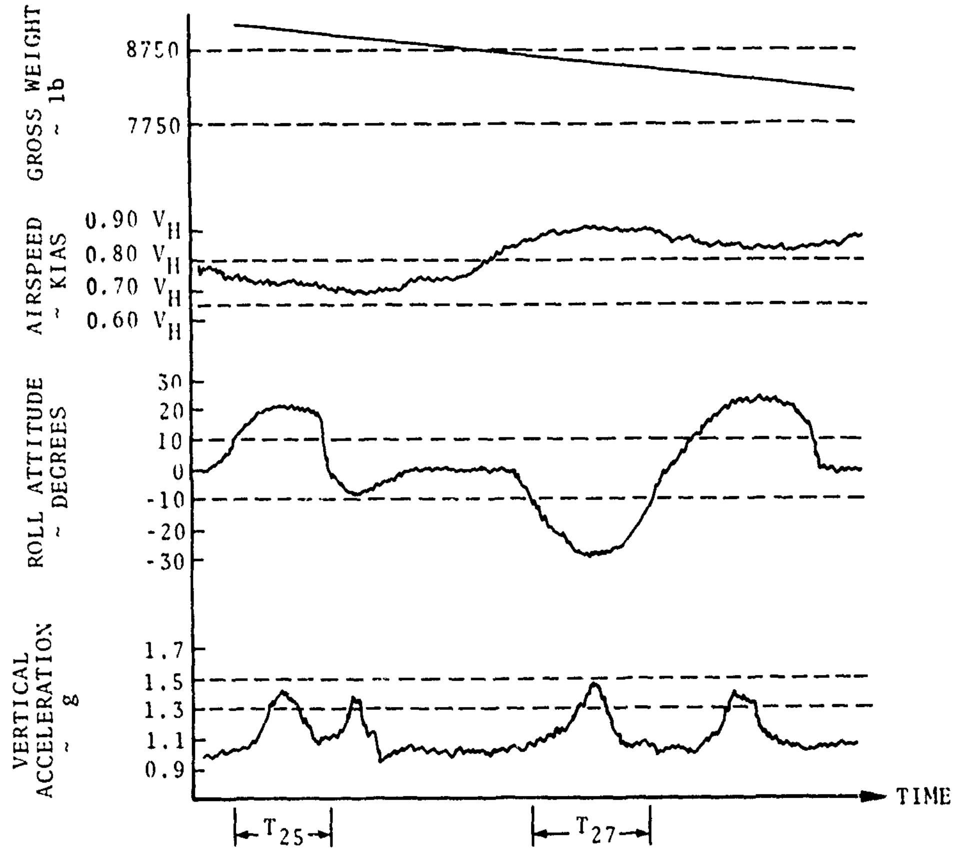
Description

Monitor the clock time accrued by the helicopter during which all five parameter threshold definitions are being satisfied simultaneously. The airspeed classification is based on maximum attainable velocity at constant altitude (V_H), which is a function of density altitude.

Figure A-7. Flight Condition Categories 17, 18, and 19 (Maximum-Velocity Flight).

Represents: Normal (High-Speed) Turns

FCC Applicability		
For $0.65V_H < A/S < 0.8V_H$	For $A/S \geq 0.8V_H$	$1.3g \leq n_z < 1.5g$, $\beta > 10°$
FCC #23	FCC #26	GW < 7750 lb
FCC #24	FCC #27	7750 lb < GW ≤ 8750 lb
FCC #25	FCC #28	GW > 8750 lb

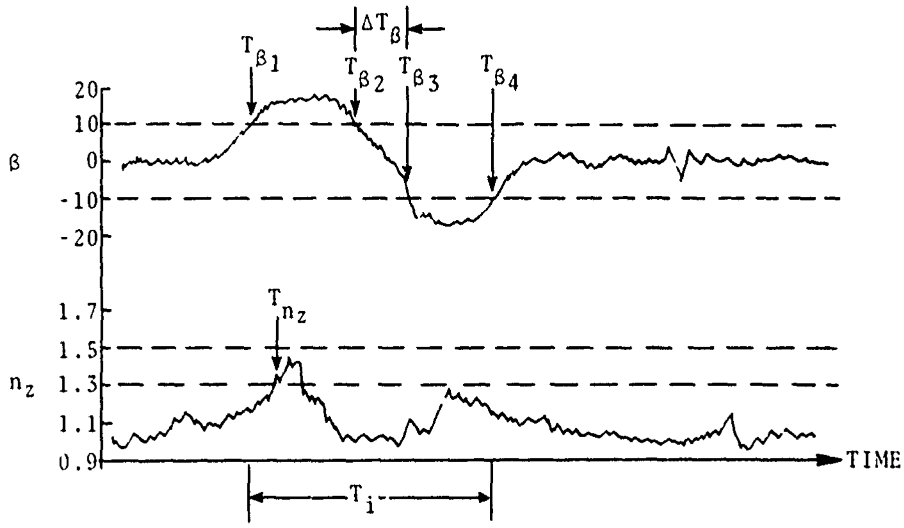


T_{23} = FCC #23 Timer
T_{24} = FCC #24 Timer
T_{25} = FCC #25 Timer
T_{26} = FCC #26 Timer
T_{27} = FCC #27 Timer
T_{28} = FCC #28 Timer

Figure A-8. Flight Condition Categories 23 through 28 (Normal (High-Speed) Turns).

Description

The following graphical characterization demonstrates how the time spent in normal turns should be defined.



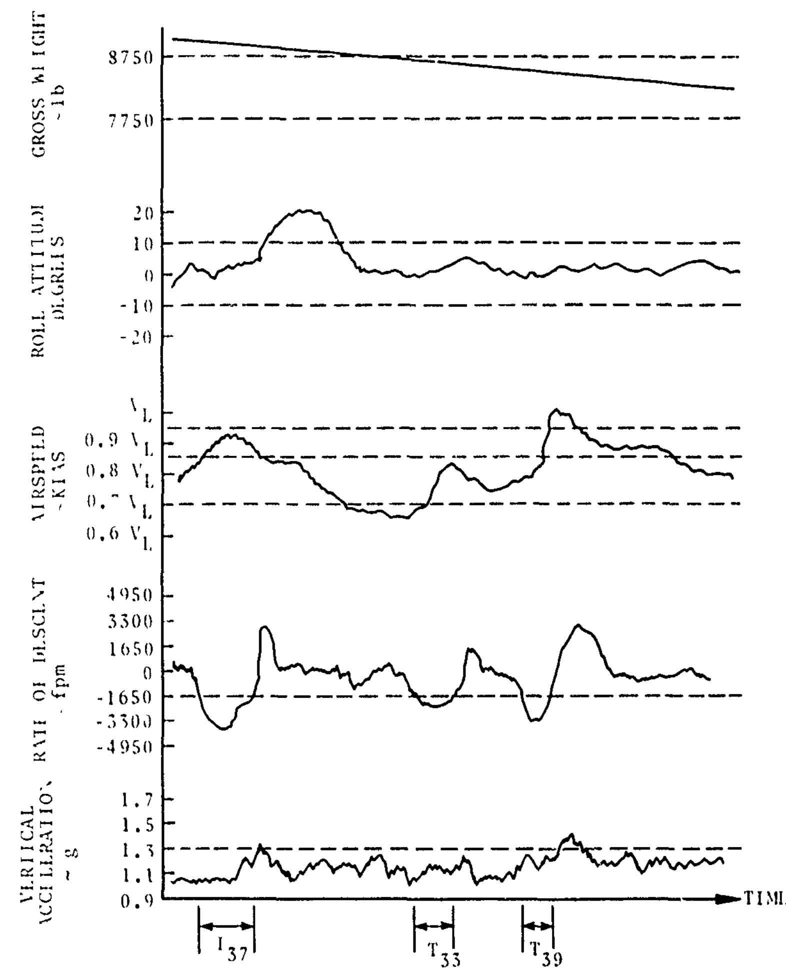
$T_{\beta 1}$ = time at which roll attitude first exceeds 10° threshold
$T_{\beta 2,3,4}$ = respective times at which roll attitude crosses 10° threshold
T_{n_z} = time at which vertical acceleration exceeds threshold
ΔT_β = time between roll attitude threshold exceedances (see figure)
T_i = normal turn occurrence timer for FCC #i, i = 23,28

The time between $T_{\beta 1}$ and T_{n_z} is defined at less than 10 seconds. Upon confirmation that the roll attitude peaks at a magnitude greater than 10° and the vertical acceleration also peaks between 1.3 and 1.5 g within the prescribed time, the timer (T_i) should be initiated at $T_{\beta 1}$. If ΔT_β is subsequently less than 10 seconds, T_i should be allowed to continue timing until the roll attitude again returns below threshold (at $T_{\beta 4}$); otherwise, terminate T_i and $T_{\beta 2}$. The airspeed classification is based on maximum attainable velocity at constant altitude (V_H) which is a function of density altitude. The airspeed categorization, for a given turn, is defined at $T_{\beta 1}$. If the gross weight classification should change during the turn, the entire T_i should be entered in the category corresponding to the greater gross weight.

Figure A-8. Concluded

Represents: Gunnery Run Dives

FCC Applicability				$n_z < 1.3g$, $\beta < 10°$
For $A/S \leq 0.70V_L$	For $0.70V_L \leq A/S \leq 0.85V_L$	For $0.85V_L \leq A/S \leq 0.95V_L$	For $A/S > 0.95V_L$	RD > 1650 fpm
FCC #29	FCC #32	FCC #35	FCC #38	GW $\leq$ 7750 lb
FCC #30	FCC #33	FCC #36	FCC #39	7750 lb < GW $\leq$ 8750 lb
FCC #31	FCC #34	FCC #37	FCC #40	GW > 8750 lb



T_{29} = FCC #29 Timer
T_{30} = FCC #30 Timer
T_{31} = FCC #31 Timer
T_{32} = FCC #32 Timer
T_{33} = FCC #33 Timer
T_{34} = FCC #34 Timer
T_{35} = FCC #35 Timer
T_{36} = FCC #36 Timer
T_{37} = FCC #37 Timer
T_{38} = FCC #38 Timer
T_{39} = FCC #39 Timer
T_{40} = FCC #40 Timer

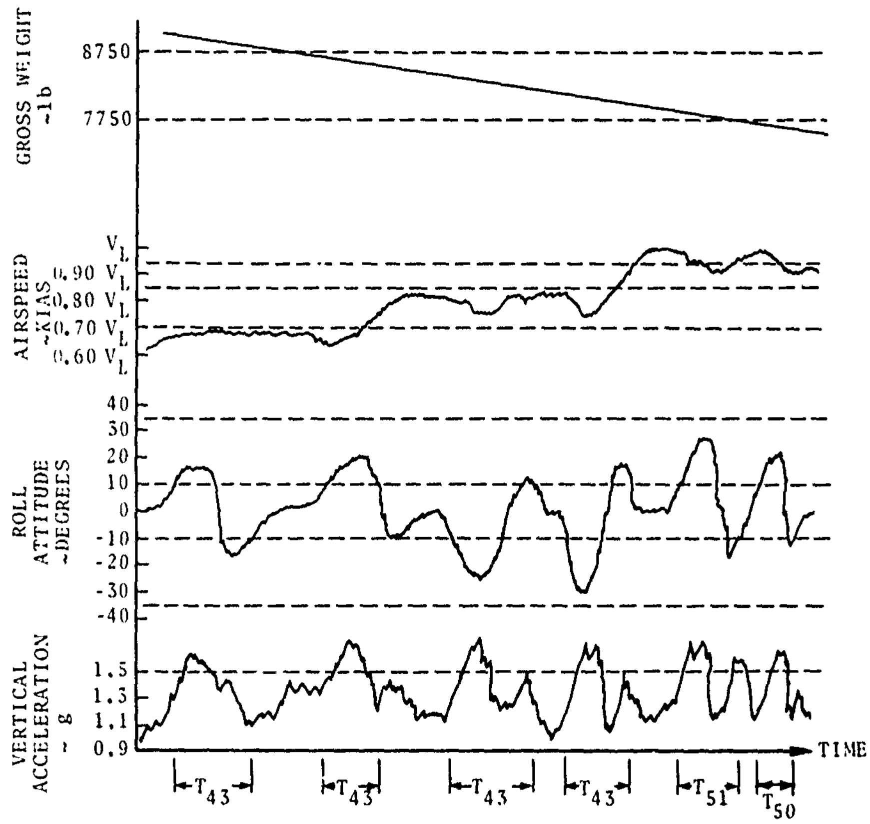
Description

Monitor the clock time accrued by the helicopter during which all parameter threshold definitions are being satisfied simultaneously. The airspeed classification is based on percentage of limit velocity (V_L), which is a function of density altitude. Airspeed is categorized near the end of the dive.

Figure A-9. Flight Condition Categories 24 through 40 (Gunnery Run Dives).

Represents: Asymmetrical Pullups

FCC Applicability				
For $A/S \leq 0.70V_L$	For $0.70V_L < A/S \leq 0.85V_L$	For $0.85V_L < A/S \leq 0.95V_L$	For $A/S > 0.95V_L$	$n_z \geq 1.5g$ $10° < \beta < 35°$
FCC #41	FCC #44	FCC #47	FCC #50	GW < 7750 lb
FCC #42	FCC #45	FCC #48	FCC #51	7750 lb < GW ≤ 8750 lb
FCC #43	FCC #46	FCC #49	FCC #52	GW > 8750 lb



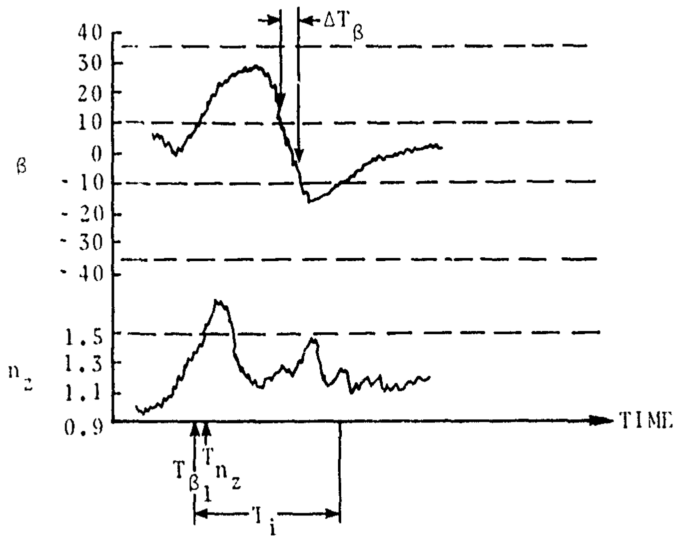
T_{41} = FCC #41 Timer
T_{42} = FCC #42 Timer
T_{43} = FCC #43 Timer
T_{44} = FCC #44 Timer
T_{45} = FCC #45 Timer
T_{46} = FCC #46 Timer

T_{47} = FCC #47 Timer
T_{48} = FCC #48 Timer
T_{49} = FCC #49 Timer
T_{50} = FCC #50 Timer
T_{51} = FCC #51 Timer
T_{52} = FCC #52 Timer

Figure A-10. Flight Condition Categories 41 through 52 (Asymmetrical (Gunnery Run) Pullups).

Description

The following graphical characterization demonstrates how the time spent in asymmetrical pullups should be defined:



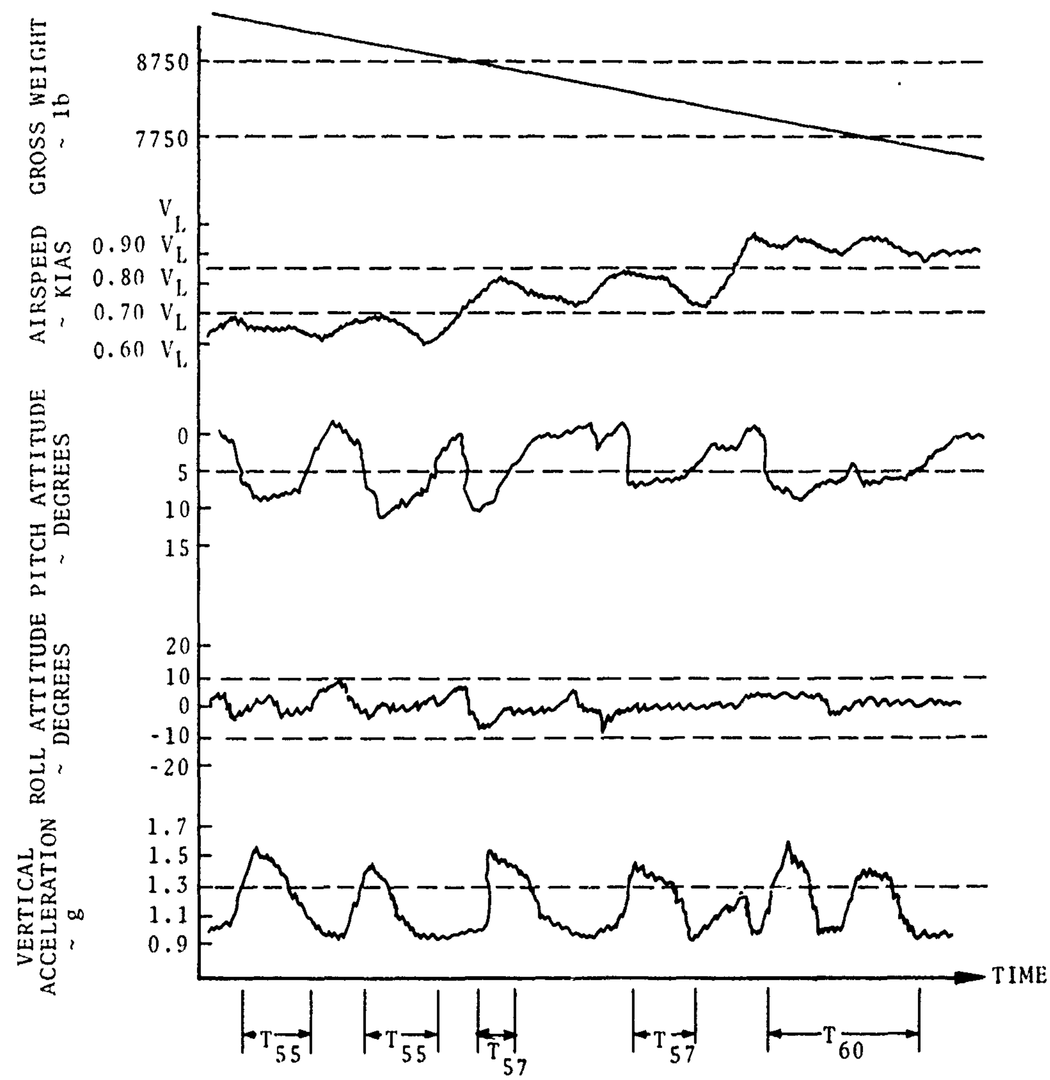
T_i = asymmetrical pullup occurrence timer for FCC #i, i = 41,52
$T_{\beta i}$ = time at which roll attitude first exceeds 10° threshold
T_{n_z} = time at which n_z exceeds 1.5 g threshold
ΔT_β = time between roll attitude threshold exceedances

The time between $T_{\beta 1}$ and T_{n_z} should be defined at less than 10 seconds. The timer (T_i) initiates at $T_{\beta 1}$. If ΔT_β is less than 10 seconds, T_1 should be allowed to continue timing until the roll attitude once again drops below threshold; otherwise, terminate T_i at the time the roll attitude first drops back across the 10° threshold. Recall that the roll attitude peak must fall between 10° and 35°; if it peaks above 35° it will be categorized as a different flight condition. The airspeed classification is based on percentage of limit velocity (V_L), which is a function of density altitude. The airspeed categorization, for a given pullup, is defined at $T_{\beta 1}$.

Figure A-10. Concluded

Represents: Symmetrical (Gunnery Run) Pullups

FCC Applicability			
For A/S≤0.70V_L	For 0.70V_L<A/S≤0.85V_L	For A/S>0.85V_L	$n_z \geq 1.3g$, $\beta \leq 10°$, $\theta > 5°$
FCC #53	FCC #56	FCC #59	GW < 7750 lb
FCC #54	FCC #57	FCC #60	7750 lb ≤ GW ≤ 8750 lb
FCC #55	FCC #58	FCC #61	GW > 8750 lb

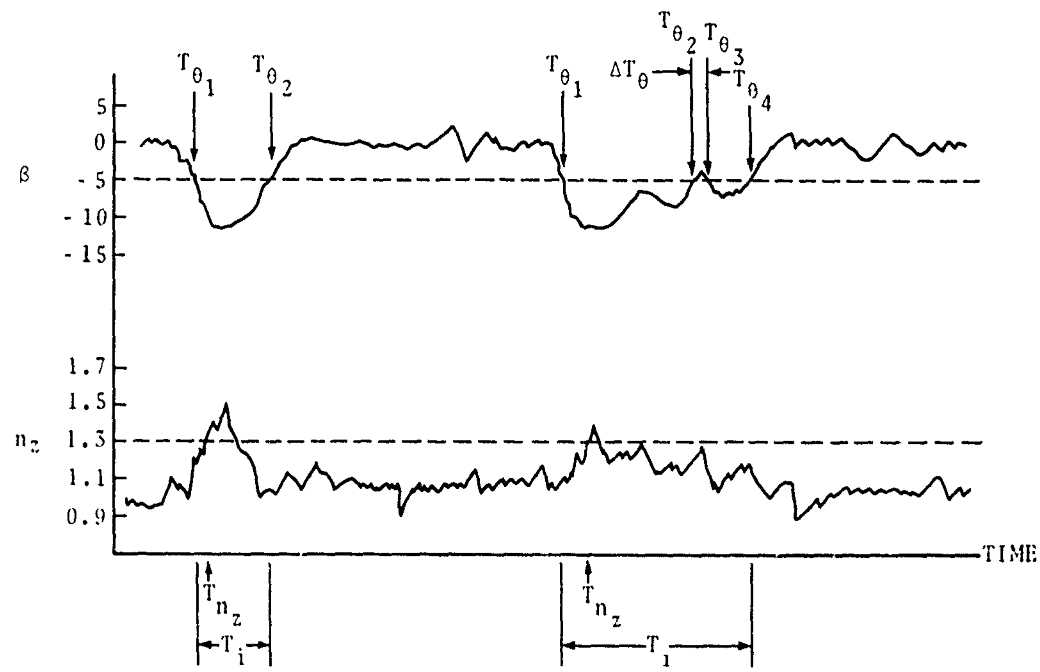


T_{53} = FCC #53 Timer
T_{54} = FCC #54 Timer
T_{55} = FCC #55 Timer
T_{56} = FCC #56 Timer
T_{57} = FCC #57 Timer
T_{58} = FCC #58 Timer
T_{59} = FCC #59 Timer
T_{60} = FCC #60 Timer
T_{61} = FCC #61 Timer

Figure A-11. Flight Condition Categories 53 through 61 (Symmetrical (Gunnery Run) Pullups).

Description

The following graphical characterization demonstrates how the time spent in symmetrical pullups should be defined.



T_{θ_1} = time at which pitch attitude first exceeds -5°

$T_{\theta_{2,3,4}}$ = second, third, and fourth times the pitch attitude exceeds the -5° threshold

T_{n_z} = time at which n_z exceeds 1.3g threshold

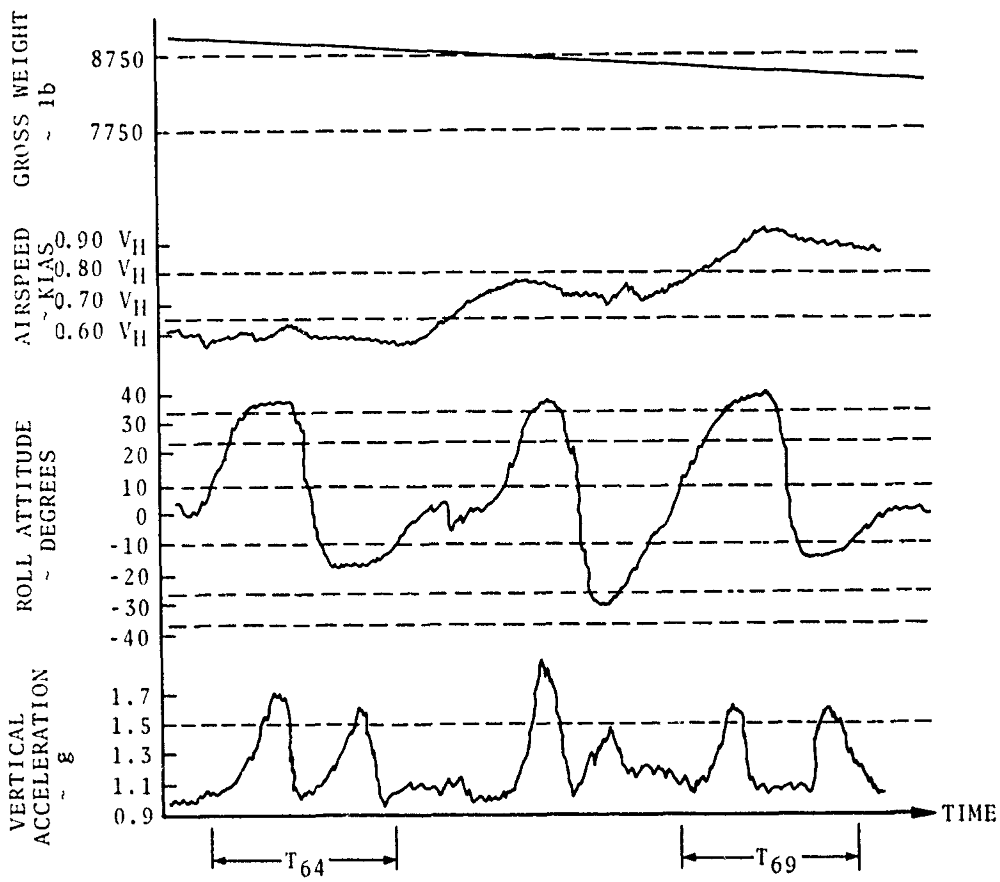
ΔT_θ = time between pitch attitude -5° threshold exceedances

A gunnery run symmetrical pullup is confirmed when, and only when, T_{n_z} is sensed within 10 seconds after T_{θ_1} is sensed. The timer T_i initiates at T_{θ_1} and terminates at T_{θ_2}. The exception is when the pitch attitude briefly crosses inside the -5° threshold and then immediately returns outside threshold (ΔT_θ < 5 seconds). In this case the threshold crossing defined by ΔT_θ is ignored and T_i continues to time the maneuver until a normal termination is sensed. The airspeed classification is based on percentage of limit velocity (V_L), which is a function of density altitude. Airspeed is categorized at the time the vertical acceleration exceeds 1.3g.

Figure A-11. Concluded

Represents: Gunnery Turns

FCC Applicability			$n_z \geq 1.5g$
For $A/S \leq 0.65V_H$	For $0.65V_H < A/S \leq 0.80V_H$	For $A/S > 0.80V_H$	$\beta_{initial} \geq 35°$ $\beta_{subsequent} < 25$
FCC #62	FCC #65	FCC #68	GW < 7750 lb
FCC #63	FCC #66	FCC #69	7750 lb < GW ≤ 8750 lb
FCC #64	FCC #67	FCC #70	GW > 8750 lb



T_{62} = FCC #62 Timer
T_{63} = FCC #63 Timer
T_{64} = FCC #64 Timer

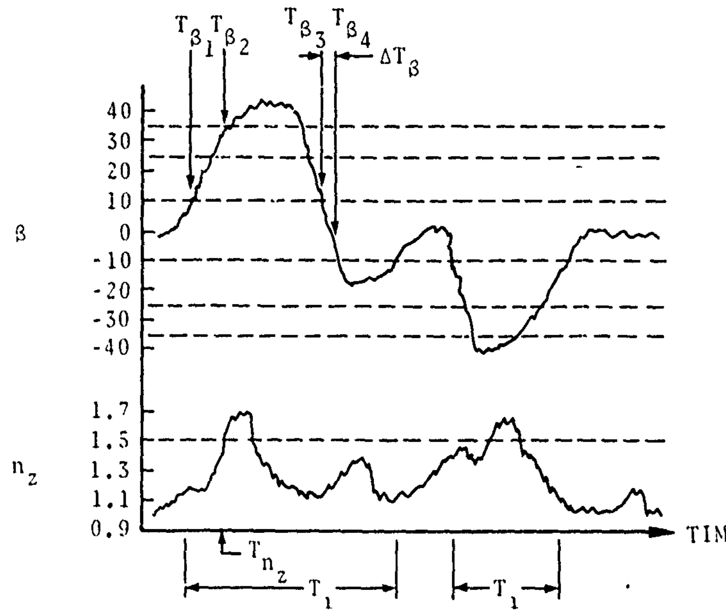
T_{65} = FCC #65 Timer
T_{66} = FCC #66 Timer
T_{67} = FCC #67 Timer

T_{68} = FCC #68 Timer
T_{69} = FCC #69 Timer
T_{70} = FCC #70 Timer

Figure A-12. Flight Condition Categories 62 through 70 (Gunnery Turns).

Description

The following graphical characterization demonstrates how the time spent in gunnery turns should be defined:



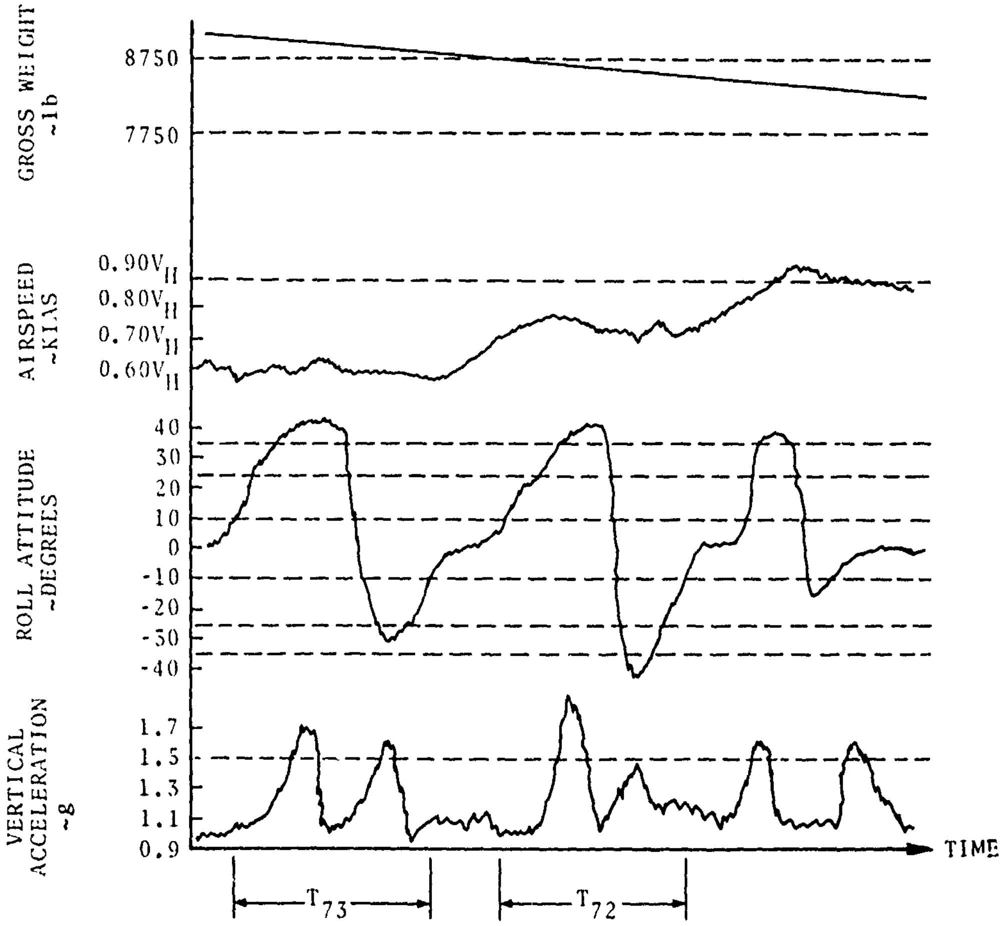
$T_{\beta 3,4}$ = second and third times the roll attitude crosses the 10° threshold level
T_i = gunnery turn occurrence timer for FCC #i, i = 22,24
$T_{\beta 1}$ = time at which roll attitude first exceeds 10° threshold
$T_{\beta 2}$ = time at which roll attitude first exceeds 35° threshold
T_{n_z} = time at which n_z exceeds 1.5g threshold
ΔT_β = time between roll attitude 10° threshold exceedances

The time between $T_{\beta 2}$ and T_{n_z} should be defined at less than 10 seconds. Upon confirmation that the roll attitude crosses the 35° threshold (the time between $T_{\beta 1}$ and $T_{\beta 2}$ should also be less than 10 seconds), the timer (T_i) initiates at $T_{\beta 1}$. If ΔT_β is less than 10 seconds, T_i should be allowed to continue timing until the roll attitude, once again, drops below the 10° threshold (at $T_{\beta 4}$), if and only if, the second roll attitude peak does not exceed 25°. Otherwise, terminate T_i at $T_{\beta 3}$. (The "subsequent peak" requirement is designed to differentiate gunnery turns from gunnery S-turns.) The airspeed classification is based on maximum attainable velocity at constant attitude (V_H), which is a function of density attitude. The airspeed categorization, for a given turn, is defined at $T_{\beta 1}$.

Figure A-12. Concluded

Represents: Gunnery S-Turn

FCC Applicability: For A/S < 0.90 V_H	FCC Applicability: For A/S ≥ 0.90 V_H	$n_z \geq 1.5g$; $\beta_{initial} \geq 35°$; $\beta_{subsequent} \geq 25°$
FCC #71	FCC #74	GW < 7750 lb
FCC #72	FCC #75	7750 lb ≤ GW ≤ 8750 lb
FCC #73	FCC #76	GW > 8750 lb

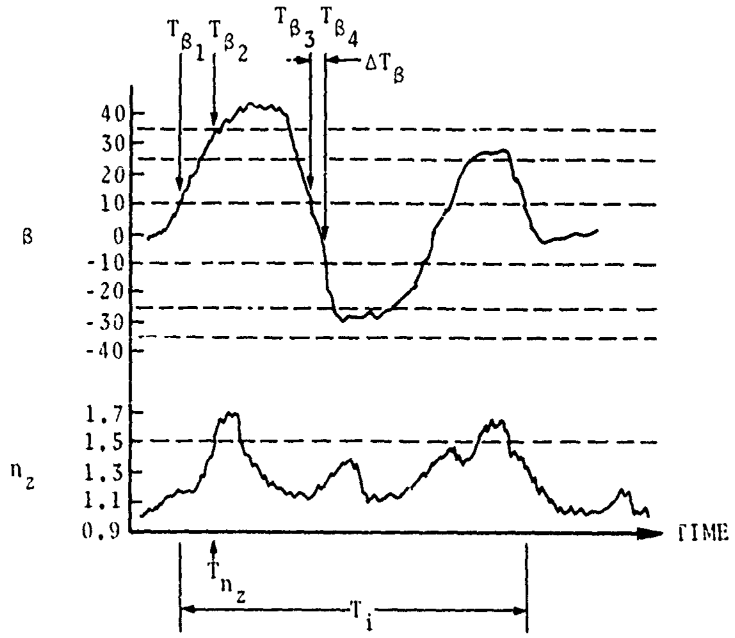


T_{71} = FCC #71 Timer
T_{72} = FCC #72 Timer
T_{73} = FCC #73 Timer
T_{74} = FCC #74 Timer
T_{75} = FCC #75 Timer
T_{76} = FCC #76 Timer

Figure A-13. Flight Condition Categories 71 through 76 (Gunnery S-Turns).

Description

The following graphical characterization demonstrates how the time spent in gunnery S-turns should be defined:



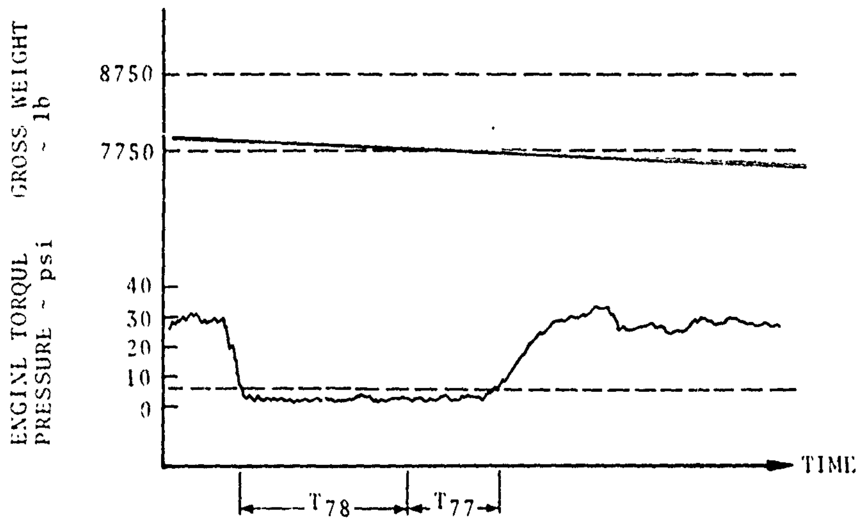
$T_{\beta 3,4}$ = second and third times the roll attitude crosses the 10° threshold level
T_i = gunnery turn occurrence timer for FCC #i, i = 22,24
$T_{\beta 1}$ = time at which roll attitude first exceeds 10° threshold
$T_{\beta 2}$ = time at which roll attitude first exceeds 35° threshold
T_{n_z} = time at which n_z exceeds 1.5g threshold
ΔT_β = time between roll attitude 10° threshold exceedances

The time between $T_{\beta 2}$ and T_{n_z} should be defined at less than 10 seconds. Upon confirmation that the roll attitude crosses the 35° threshold (the time between $T_{\beta 1}$ and $T_{\beta 2}$ should also be less than 10 seconds), the timer (T_i) initiates at $T_{\beta 1}$. If ΔT_β is less than 10 seconds, T_i should be allowed to continue timing until the roll attitude, once again, drops below the 10° threshold (at $T_{\beta 4}$), if and only if, the second (and any subsequent) roll attitude peaks exceed 25°. By definition, the gunnery S-turn is characterized by at least two excessive roll attitude peaks occurring in rapid succession. Therefore, the foregoing criteria concerning "subsequent peaks" was designed to differentiate the gunnery S-turn from normal gunnery turns. The airspeed classification is based on maximum attainable velocity at constant attitude (V_H), which is a function of density attitude. The airspeed categorization, for a given turn, is defined at $T_{\beta 1}$.

Figure A-13. Concluded

Represents: Clock Time in Autorotation

FCC Applicability	ET ≤ 5 psi
FCC #77	GW ≤ 7750 lb
FCC #78	7750 lb < GW ≤ 8750 lb
FCC #79	GW > 8750 lb



T_{77} = FCC #77 Timer
T_{78} = FCC #78 Timer
T_{79} = FCC #79 Timer

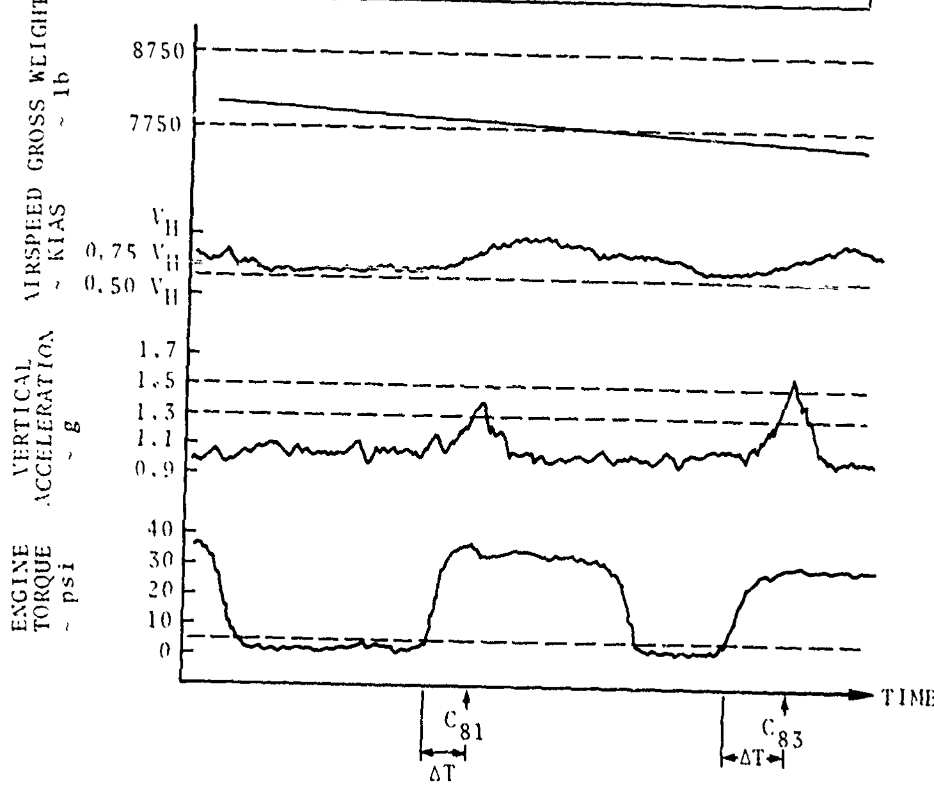
Description

Monitor the total flight spent in the autorotation mode of operation. Small perturbations in engine torque pressure (such as the torque pressure jumping above the 5 psi threshold for very short periods of time) of less than 2-second duration are ignored.

Figure A-14. Flight Condition Categories 77, 78, and 79 (Time in Autorotation).

Represents: Autorotation to Power Transition

FCC Applicability		
For $1.3g \le n_z \le 1.5g$	For $n_z > 1.5g$	$A/S > 0.65\ V_H$ ET crosses 5 psi (+)
FCC #80	FCC #83	GW < 7750 lb
FCC #81	FCC #84	7750 lb $\le$ GW $\le$ 8750 lb
FCC #82	FCC #85	GW > 8750 lb



T_{80} = FCC #80 Counter
T_{81} = FCC #81 Counter
T_{82} = FCC #82 Counter

T_{83} = FCC #83 Counter
T_{84} = FCC #84 Counter
T_{85} = FCC #85 Counter

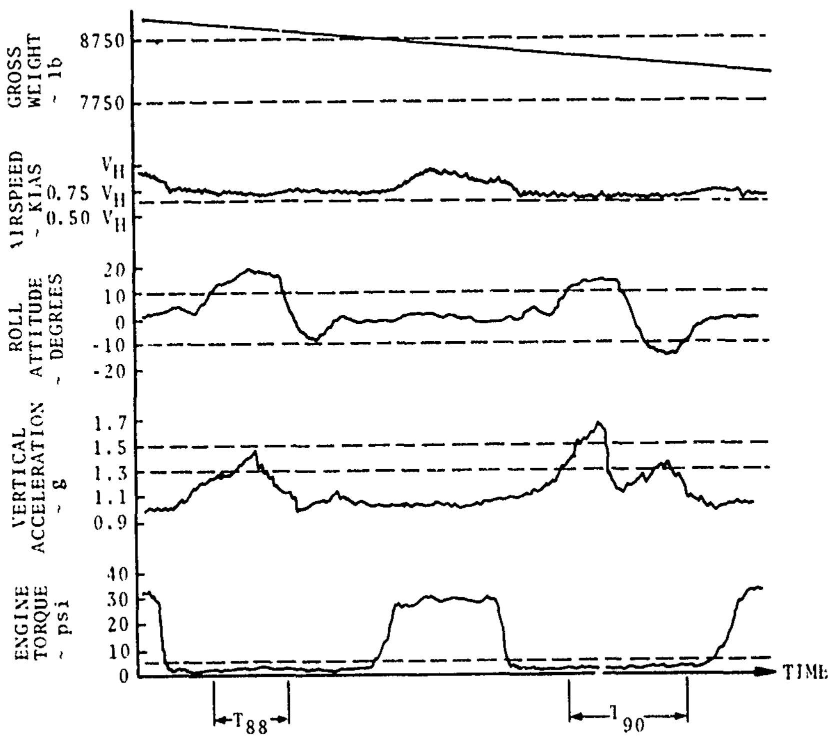
Description

Whenever the engine torque pressure crosses the 5 psi threshold in a positive direction and is followed (ΔT less than 5 seconds) by a vertical acceleration satisfying the threshold definition, the event should be recorded. The airspeed classification is based on a maximum attainable velocity at constant altitude (V_H), which is a function of density altitude. The airspeed categorization is defined at the time the vertical acceleration exceeds threshold.

Figure A-15. Flight Condition Categories 80 through 85 (Autorotation-to-Power Transition).

Represents: High-Speed Autorotation Turns

FCC Applicability		
For $1.3g \le n_z \le 1.5g$	For $n_z > 1.5g$	A/S > 0.65 V_H ET < 5 psi β > 10°
FCC #86	FCC #89	GW < 7750 lb
FCC #87	FCC #90	7750 lb < GW ≤ 8750 lb
FCC #88	FCC #91	GW > 8750 lb



T_{86} = FCC #86 Timer
T_{87} = FCC #87 Timer
T_{88} = FCC #88 Timer
T_{89} = FCC #89 Timer
T_{90} = FCC #90 Timer
T_{91} = FCC #91 Timer

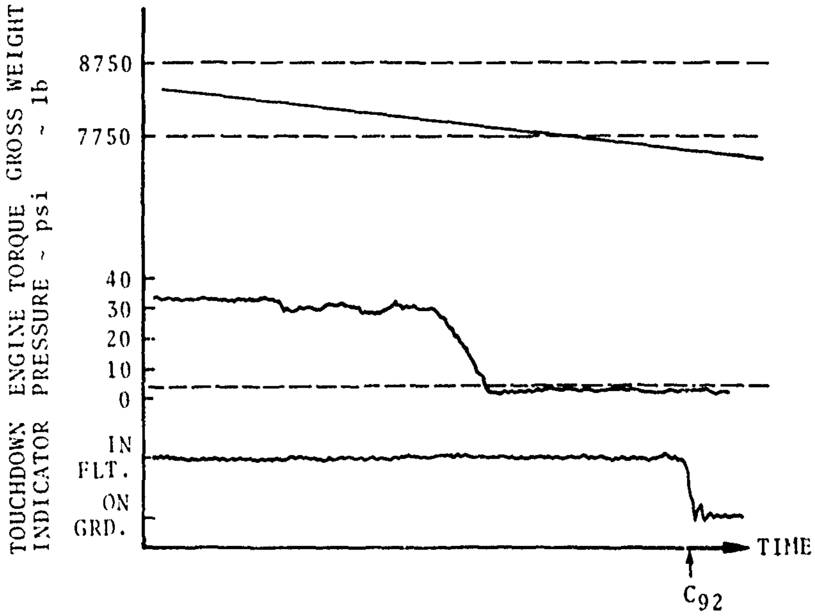
Description

Monitor the clock time accrued by the helicopter in autorotation while its roll attitude is greater than 10° only if it is accompanied by a vertical acceleration peak (within 5 seconds) in the prescribed threshold levels. The duration of the maneuver is defined the same as the Normal High-Speed Turn (FCC #23 through 28). The airspeed classification is based on maximum attainable velocity (V_H), which is a function of density altitude. The airspeed categorization for a given turn is defined at the time the roll attitude exceeds 10°.

Figure A-16. Flight Condition Categories 86 through 91 (High-Speed Autorotation Turns).

Represents: Autorotation Landing

	ET < 5 psi
FCC Applicability	TD ON/OFF
FCC #92	GW < 7750 lb
FCC #93	7750 lb ≤ GW ≤ 8750 lb
FCC #94	GW > 8750 lb



C_{92} = FCC #92 Counter
C_{93} = FCC #93 Counter
C_{94} = FCC #94 Counter

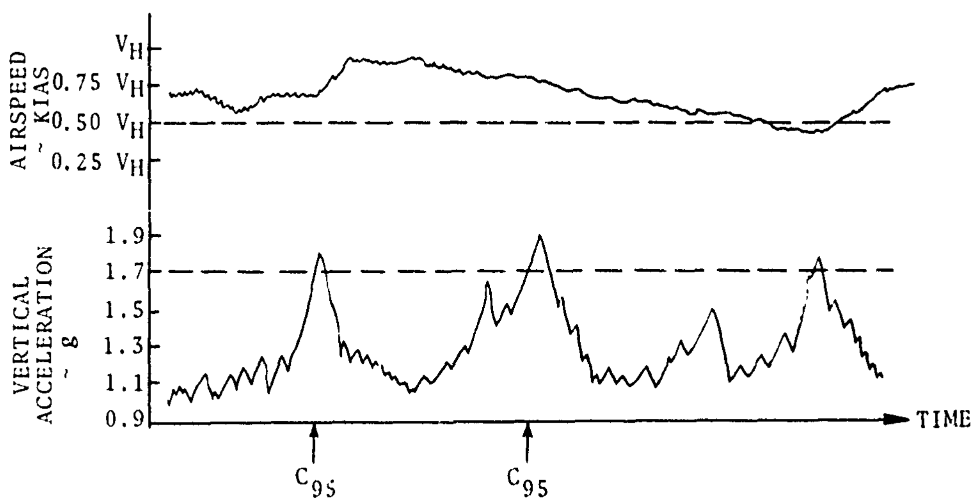
Description

The engine torque pressure must be below threshold immediately prior to (at least 10 seconds), and at the time of, touchdown. Once a touchdown has been recorded a rebounding helicopter should not register additional counts.

Figure A-17. Flight Condition Categories 92, 93, and 94 (Autorotation Landing).

Represents: Misc. High-G Maneuvers

$n_z \geq 1.7$ g
A/S$\geq$.50 V_H



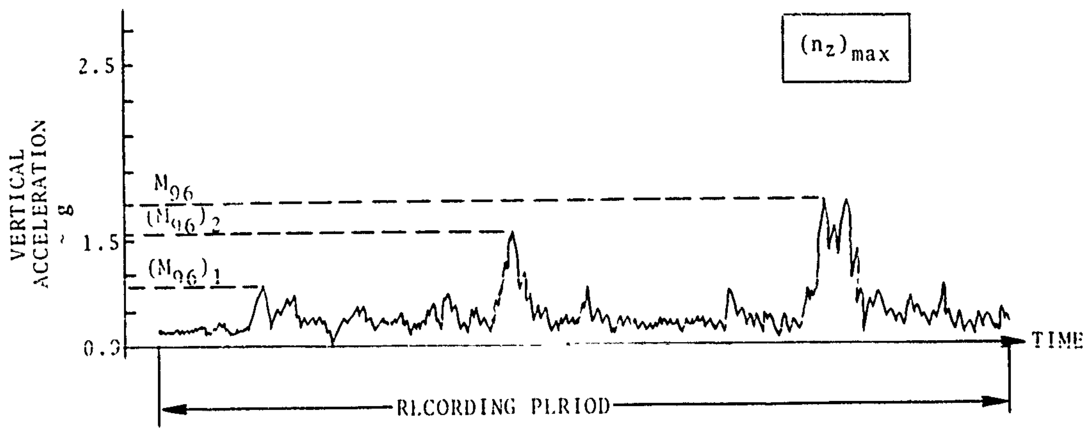
C_{95} = FCC #95 counter

Description

It is simply intended to count the number of times the helicopter experiences vertical accelerations in excess of 1.7 g while flying at significant airspeeds. This implies that the touchdown indicator must be registering in-flight operation.

Figure A-18. Flight Condition Category 95 (Miscellaneous High-G Maneuvers).

Represents: Maximum Vertical Acceleration



M_{96} = maximum n_z magnitude recorded during prescribed period

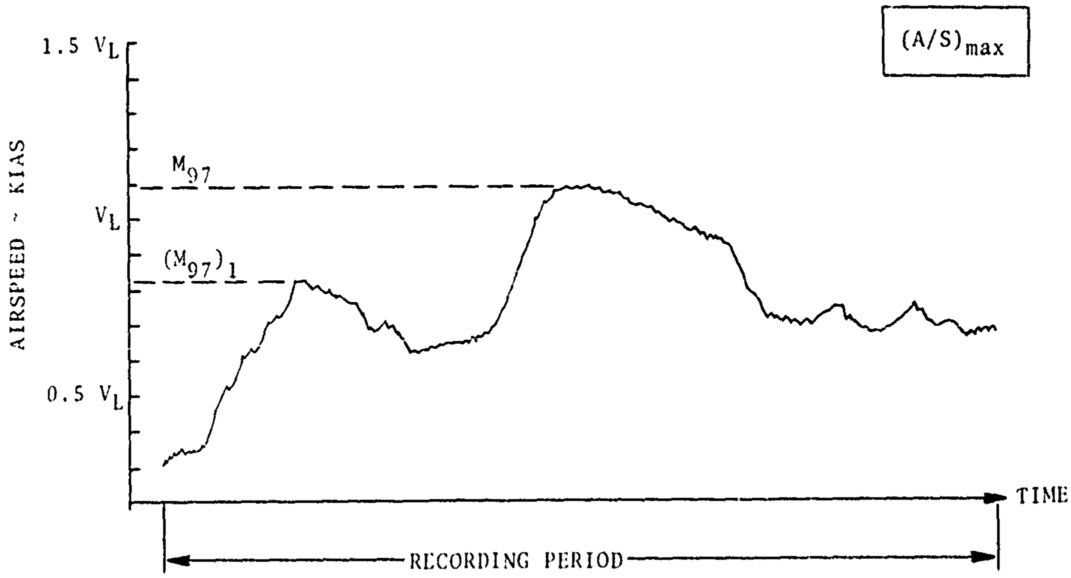
$(M_{96})_{1\&2}$ = intermediate maxima whose n_z values were subsequently surpassed during the recording period

Description

Record the magnitude of the largest vertical acceleration experienced during the recording period. The $(n_z)_{max}$ may occur in any flight condition category (which implies that the in-flight indicator must be registering in-flight operation).

Figure A-19. Flight Condition Category 96 (Maximum Vertical Acceleration).

Represents: Maximum Airspeed Attained During All Flight Conditions



M_{97} = maximum airspeed magnitude recorded during prescribed period

$(M_{97})_1$ = intermediate maxima whose airspeed values were subsequently surpassed during the recording period

Description

Record the magnitude of the highest airspeed experienced during the recording period expressed in terms of percent of V_L. The $(A/S)_{max}$ may occur in any flight condition category. (Recall that the value of V_L is a function of density altitude.)

Figure A-20. Flight Condition Category 97 (Maximum Airspeed (V_L)).

APPENDIX B

SIRS RECORDER SOFTWARE

PAGE 001 SIRSR

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                     NAM    SIRSR
                     OPT    NOG
               *********************************************
               ****  STRUCTURAL INTEGRITY RECORDING SYSTEM  ****
               ****            RECORDER PROGRAM             ****
               *********************************************


        2000   AD     EQU  $2000      A/D INPUT REGISTER
        2001   ADCR   EQU  $2001      A/D CONTROL REGISTER
        2002   MUX    EQU  $2002      MUX OUTPUT REGISTER
        2003   MUXCR  EQU  $2003      MUX CONTROL REGISTER
        1000   ACIACS EQU  $1000      ACIA CONTROL/STATUS REGISTER
        1001   ACIAXR EQU  $1001      ACIA TRANSMIT/RECEIVE REGISTE
        000F   MUXIO  EQU  $0F        PB3 - PB0 ARE OUTPUTS
        0034   ADCW   EQU  %00110100  A/D CONTROL WORD
        003C   ADSTRT EQU  %00111100  A/D START WORD
        0004   MUXCW  EQU  %00000100  MUX CONTROL WORD
        0089   ACIACW EQU  %10001001  ACIA CONTROL WORD
        0310   GWTIME EQU  $0310      TIME TO DECREASE GROSS WT
        00AF   GW7750 EQU  175        7750 LB THRESHOLD
        00E1   GW8750 EQU  225        8750 LB THRESHOLD
        000D   PT05   EQU  13         13/256 = 0.05
        001A   PT10   EQU  26         26/256 = 0.10
        0026   PT15   EQU  38         38/256 = 0.15
        00F3   PT95   EQU  243        243/256 = 0.95
        0016   DEG5   EQU  22         PITCH = 5 DEG THRESHOLD
        002C   DEG10  EQU  44         ROLL = 10 DEG THRESHOLD
        0040   DEG15  EQU  64         PITCH = 15 DEG THRESHOLD
        006E   DEG25  EQU  110        ROLL = 25 DEG THRESHOLD
        0093   DEG35  EQU  147        ROLL = 35 DEG THRESHOLD
        000A   PSI5   EQU  10         LOW TORQUE THRESHOLD
        00DC   PSI44  EQU  220        HIGH TORQUE THRESHOLD
        0014   GWGND  EQU  20         GROUND THRESHOLD
        00C8   RPM200 EQU  200        RPM = 200 THRESHOLD
        0064   RPM100 EQU  100        RPM = 100 THRESHOLD
        01F7   GROSWT EQU  $01F7      GROSS WEIGHT LOCATION
        01F8   NZPK   EQU  $01F8      NZ PEAK LOCATION
        01F9   VLPK   EQU  $01F9      VL PEAK LOCATION
        01FA   NZINT  EQU  $01FA      NZ CORRECTION INTERCEPT
        01FB   NZSLP  EQU  $01FB      NZ CORRECTION SLOPE
        01FC   ALTINT EQU  $01FC      ALTITUDE CORRECTION INTERCEPT
        01FD   ALTSLP EQU  $01FD      ALTITUDE CORRECTION SLOPE
        01FE   ASINT  EQU  $01FE      AIRSPEED CORRECTION INTERCEPT
        01FF   ASSLP  EQU  $01FF      AIRSPEED CORRECTIO SLOPE
        00FF   STACK  EQU  $00FF      START STACK HERE
```

```
*************************
**  PARAMETER CODES   **
*************************
* THE FOLLOWING CODES ARE SETUP BY THE DATA
*  ACQUISITION PORTION OF THE SIRSP PROGRAM. THEY
*  ARE USED BY THE EVENT RECOGNITION ROUTINES
*  IN THE DEFINITION OF SIGNIFICANT FLIGHT
*  CONDITIONS.
*  PARAMETER   CODE   INTERPRETATION
*    CVL        -1      A/S<=.7VL
*                0      .7VL<A/S<=.85VL
*                1      .85VL<A/S<=.95VL
*                2      .95VL<A/S
*
*    CVH        -2       A/S<.5VH
*               -1      .5VH<=A/S<.65VH
*                0      .65VH<=A/S<.8VH
*                1      .8VH<=A/S<.9VH
*                2      .9VH<=A/S<.95VH
*                3      .95VH<=A/S
*
*    CROL       -1      ROLL<10 DEG
*                0      10<=ROLL<25 DEG
*                1      25<=ROLL<35 DEG
*                2 S    35<=ROLL
*
*    CQ          0 S    TORQUE<=5 PSI
*                1      5<TORQUE<=44 PSI
*                2      44<TORQUE
*
*    CRD        -1 S    NOT VALID
*                0      RD<1650 FPM
*                1      RD>=1650 FPM
*
*    CRPM       -1      RPM<100
*                0      100<=RPM<=200
*                1 S    RPM>200
*
*    CT          0 S    FLIGHT
*                1      GROUND
*
*    CNZ        -1      NZ<=1.3 G
*                0      1.3<NZ<=1.5 G
*                1      1.5<NZ<=1.7 G
*                2 S    NZ>1.7 G
*
*    CGW         0 S    GW<7750 LB
*                1      7750<=GW<=8750 LB
*                2      GW>8750 LB
*
*    CPIT       -1      0<PITCH<=5 DEG
*                0      5<PITCH<=15 DEG
*                1 S    PITCH>15 DEG
```

```
0000                ORG    $0
                    *
                    * PARAMETER VALUE CODES
0000 0001     CVL     RMB    1        0
0001 0001     CVH     RMB    1        1
0002 0001     CROL    RMB    1        2
0003 0001     CQ      RMB    1        3
0004 0001     CRD     RMB    1        4
0005 0001     CRPM    RMB    1        5
0006 0001     CT      RMB    1        6
0007 0001     CNZ     RMB    1        7
0008 0001     CGW     RMB    1        8
0009 0001     CPIT    RMB    1        9
                    * MISC FLAGS AND SWITCHES
000A 0001     IFLAG   RMB    1        10
000B 0001     ARM2    RMB    1        11
000C 0001     OTIM    RMB    1        12
000D 0001     AIR     RMB    1        13
000E 0001     T77     RMB    1        14
000F 0002     T23A    RMB    2        15
0011 0001     MODE    RMB    1        17
0012 0001     TOHI    RMB    1        18
0013 0001     TOLO    RMB    1        19
0014 0001     M       RMB    1        20
0015 0001     NZE     RMB    1        21
0016 0001     NZHI    RMB    1        22
0017 0001     NZLO    RMB    1        23
0018 0001     HIROL   RMB    1        24
0019 0001     SVH     RMB    1        25
001A 0001     IVL     RMB    1        26
001B 0001     IGW     RMB    1        27
001C 0002     T86     RMB    2        28
001E 0001     RMOD    RMB    1        30
001F 0001     ASF     RMB    1        31
0020 0001     PUFLAG  RMB    1        32
0021 0001     T80     RMB    1        33
0022 0001     NZF     RMB    1        34
0023 0001     APM31   RMB    1        35
0024 0001     LOAS    RMB    1        36
0025 0002     ASV     RMB    2        37
0027 0002     NDX     RMB    2        39
0029 0002     INDX    RMB    2        41
002B 0001     GTS     RMB    1        43
002C 0003     BAA     RMB    3        44
002F 0001     PUFCTM  RMB    1        47
0030 0001     NOPUFG  RMB    1        48
0031 0001     PU10    RMB    1        49
0032 0001     GSV53   RMB    1        50
0033 0001     VSV53   RMB    1        51
0034 0002     T23     RMB    2        52
0036 0001     YSPUFG  RMB    1        54
0037 0004             RMB    4        (55-58-SPARE)
003B 0001     AIPTIM  RMB    1        59
003C 0003     CONE    RMB    3        60
```

13
B

```
00155 003F 0001     ONEVH  RMB     1          63
00156 0040 0001     DENOM  RMB     1          64
00157 0041 0001     ZERO1  RMB     1          65
00158 0042 0001     ANS    RMB     1          66
00159 0043 0001     NUM    RMB     1          67
00160 0044 0001     SHFTCT RMB     1          68
00161 0045 0002     SAVADR RMB     2          69
00162 0047 0002     SAVCNV RMB     2          71
00163 0049 0001     RTUFLG RMB     1          73
00164 004A 0010     CNVTAB RMB     16         74
00165 005A 0001     KNOTS  RMB     1          90
00166 005B 0001     ALTFT  RMB     1          91
00167 005C 0001     GWTH   RMB     1          92
00168 005D 0001     GWTL   RMB     1          93
00169 005E 0001     GWCNT  RMB     1          94
00170 005F 0001     GW1ST  RMB     1          95
00171 0060 0001     GWH    RMB     1          96
00172 0061 0001     GWL    RMB     1          97
00173 0062 0044     DVTABL RMB     68         98
00174 00A6 0001     AVGDVH RMB     1          166
00175 00A7 0001     AVGDVL RMB     1          167
00176 00A8 0001     AVGDVC RMB     1          168
00177      003F     ONEVL  EQU     ONEVH
00178      0045     SAVSTK EQU     SAVADR


00


00181 0100 0100     CNTPS  RMB     256
00182 0200 0100     ACNTR  RMB     256
```

```
3000                    ORG     $3000

3000 0F          ADPTAB FCB     15          ( 0)RPM
3001 01                 FCB     1           ( 1)ROLL ATTITUDE
3002 02                 FCB     2           ( 2)ROLL REFERENCE
3003 08                 FCB     8           ( 3)PITCH
3004 09                 FCB     9           ( 4)TORQUE
3005 0B                 FCB     11          ( 5)TORQUE REFERENCE
3006 03                 FCB     3           ( 6)VERTICAL ACCEL. (NZ)
3007 04                 FCB     4           ( 7)ALTITUDE
3008 07                 FCB     7           ( 8)AIRSPEED
3009 0A                 FCB     10          ( 9)OUTSIDE AIR TEMP. (OAT)
300A 00                 FCB     0           (10)GROSS WEIGHT
300B 05                 FCB     5           (11)BATTERY VOLTAGE
300C 0E                 FCB     14          (12)RECORDER S/N LO
300D 0C                 FCB     12          (13)RECORDER S/N HIGH
300E 06                 FCB     6           (14)SPARE 1
300F 0D                 FCB     13          (15)SPARE 2

3010 8E 00FF     RESTAR LDS     #STACK      SET UP STACK
3013 86 0F              LDA A   #MUXIO      PB0 - PB3 OUTPUTS
3015 B7 2002            STA A   MUX         FOR MUX ADDRESS
3018 86 34              LDA A   #ADCW       CA2 IS OUTPUT
301A B7 2001            STA A   ADCR
301D 86 04              LDA A   #MUXCW
301F B7 2003            STA A   MUXCR
3022 86 89              LDA A   #ACIACW
3024 B7 1000            STA A   ACIACS
3027 CE 02FF            LDX     #$02FF

302A 4F                 CLR A               ********************
302B A7 00       CLRMOR STA A   0,X         *       CLEAR      *
302D 09                 DEX                 * SCRATCHPAD MEMORY *
302E 26 FB              BNE     CLRMOR      ********************

3030 0E                 CLI                 ENABLE INTERRUPT

3031 CE 0203     CLRFLG LDX     #$0203
3034 DF 00              STX     CVL         CVL+1 = CVH
3036 CE 0200            LDX     #$0200
3039 DF 02              STX     CROL        CROL+1 = CQ
303B CE 0001            LDX     #$0001
303E DF 04              STX     CRD         CRD+1 = CRPM
3040 7A 0004            DEC     CRD
3043 DF 08              STX     CGW         CGW+1 = CPIT
3045 08                 INX
3046 DF 06              STX     CT          CT+1 = CNZ

3048 8D 02              BSR     ADCNVT
304A 20 43              BRA     CORNZ
```

```
                       ************************
                       *MAKE A/D CONVERSIONS *
                       *STORE RESULTS IN     *
                       *CONVERSION TABLE     *
                       ************************
                       *    SUBROUTINE       *
                       ************************

304C 4F       ADCNVT CLR A             **********************
304D 86 0B           LDA A  #11        *GET # OF CONVERSIONS*
304F D6 49           LDA B  RTUFLG     *11 DURING RECORDING *
3051 26 02           BNE    SKP1       *16 DURING RETRIEVAL *
3053 86 10           LDA A  #16        **********************

3055 CE 3000 SKP1    LDX    #ADRTAB    MUX ADDRESS TABLE
3058 DF 45           STX    SAVADR
305A CE 004A         LDX    #CNVTAB    TABLE FOR RESULTS
305D DF 47           STX    SAVCNV
305F DE 45   REPEAT  LDX    SAVADR     GET MUX ADDRESS
3061 E6 00           LDA B  0,X
3063 F7 2002         STA B  MUX        SEND MUX ADDRESS
3066 5F              CLR B
3067 09      DELAY   DEX               ***************
3068 08              INX               *DELAY FOR MUX*
3069 5A              DEC B             *TO SETTLE    *
306A 26 FB           BNE    DELAY      ***************
306C F6 2000         LDA B  AD         CLEAR A/D DONE
306F C6 3C           LDA B  #ADSTRT    ********************
3071 F7 2001         STA B  ADCR       * START CONVERSION *
3074 C6 34           LDA B  #ADCW      *READY FOR NEXT TIME*
3076 F7 2001         STA B  ADCR       ********************
3079 7C 0045         INC    SAVADR     PREPARE FOR NEXT ADDRESS
307C DE 47           LDX    SAVCNV
307E F6 2001 ENDCVT  LDA B  ADCR
3081 2A FB           BPL    ENDCVT     WAIT FOR END OF CONVERSION
3083 F6 2000         LDA B  AD         GET CONVERSION
3086 E7 00           STA B  0,X        STORE IN CONVERSION TABLE
3088 7C 0047         INC    SAVCNV     PREPARE FOR NEXT CONVERSION
308B 4A              DEC A             CHECK FOR LAST CONVERSION
308C 26 D1           BNE    REPEAT
308E 39              RTS
```

```
                         ***********************
                         *     CORRECT NZ      *
                         ***********************

308F B6 01FA CORNZ  LDA A  NZINT     INTERCEPT CORRECTION
3092 D6 50          LDA B  CNVTAB+6  NZ CONVERSION
3094 97 43          STA A  NUM       STORE INTERCEPT FOR XCER
3096 B6 01FB        LDA A  NZSLP     SLOPE CORRECTION
3099 8D 48          BSR    XCER      PUTS CORRECTED NZ IN ACC A
309B 97 50          STA A  CNVTAB+6  RETURN CORRECTED NZ

                         *************************
                         *     SET CNZ FLAG      *
                         *************************

309D CE 30AA        LDX    #NZTABL
30A0 A1 00   LOOP   CMP A  0,X       (NZ 1.7, 1.5, 1.3, OR 0)
30A2 24 0A          BCC    NZPEAK    BR IF NZ > TABLE VALUE
30A4 7A 0007        DEC    CNZ
30A7 08             INX
30A8 20 F6          BRA    LOOP

30AA 5A      NZTABL FCB    90,64,38,0  1.7,1.5,1.3 G THRESHOLDS

                         *****************************
                         *     CHECK NZ PEAK FCC     *
                         *****************************

30AE F6 01F8 NZPEAK LDA B  NZPK      GET PEAK NZ VALUE LDX #NZPK
30B1 11             CBA              (PRESENT NZ - FCC PEAK)
30B2 25 03          BCS    ASCOR     BR IF PEAK > PRESENT VALUE
30B4 B7 01F8        STA A  NZPK      STORE IF LARGER
```

```
                        ****************************
                        *CORRECT DIFFERENTIAL PRESSURE*
                        ****************************

30B7 B6 01FE ASCOR  LDA A  ASINT    INTERCEPT CORRECTION
30BA D6 52          LDA B  CNVTAB+8 DIFFERENTIAL PRESSURE
30BC 97 43          STA A  NUM      STORE INTERCEPT FOR XCEP
30BE B6 01FF        LDA A  ASSLP    SLOPE CORRECTION
30C1 8D 20          BSR    XCEP     PUTS CORRECTED PDIFF IN ACC A
30C3 97 52          STA A  CNVTAB+8 RETURN CORRECTED PDIFF

                        **************************
                        *    CONVERT TO KNOTS    *
                        *STORE RESULTS AT "KNOTS"*
                        **************************

30C5 CE 33B3        LDX    #ASTABL
30C8 8D 2F          BSR    LINEAR
30CA D7 5A          STA B  KNOTS


                        **************************
                        *CORRECT ABSOLUTE PRESSURE*
                        **************************

30CC B6 01FC        LDA A  ALTINT   INTERCEPT CORRECTION
30CF D6 51          LDA B  CNVTAB+7 ABSOLUTE PRESSURE
30D1 97 43          STA A  NUM      STORE INTERCEPT FOR XCEP
30D3 B6 01FD        LDA A  ALTSLP   SLOPE CORRECTION
30D6 8D 0B          BSR    XCEP     PUTS CORRECTED PABS IN ACC A
30D8 97 51          STA A  CNVTAB+7 RETURN CORRECTED PABS

                        ********************
                        *CONVERT TO FEET   *
                        *12 COUNTS = 1000 FT*
                        ********************

30DA CE 3398        LDX    #ALTABL
30DD 8D 1A          BSR    LINEAR
30DF D7 5B          STA B  ALTFT
30E1 20 28          BRA    DALT1
```

```
                         ************************************
                         *TRANSDUCER CORRECTION SUBROUTINE *
                         *SLOPE & INTERCEPT ARE IN ACC'S   *
                         *INTERCEPT IS AT "NUM"            *
                         *RESULT RETURNED IN ACC A         *
                         ************************************

30E3 8D 59    XCER   BSR    MPY7
30E5 4D              TST A         TEST FOR OVERFLOW
30E6 26 0E           BNE    ALLONE BR IF OVERFLOW
30E8 96 43           LDA A  NUM    GET INTERCEPT
30EA 4D              TST A         + OR - INTERCEPT?
30EB 2A 06           BPL    PLUSA  BR IF INTERCEPT POSITIVE
30ED 1B              ABA           -INTERCEPT
30EE 25 08           BCS    END    BR IF RESULT IS NOT < 0
30F0 4F       ZERO   CLR A         RESULT < ZERO
30F1 20 05           BRA    END
30F3 1B       PLUSA  ABA           + INTERCEPT
30F4 24 02           BCC    END    BR IF RESULT IS   256
30F6 86 FF    ALLONE LDA A  #$FF   RESULT > 255
30F8 39       END    RTS

                         **************************
                         *LINEARIZE SUBROUTINE    *
                         *INX PRESET AT TABLE     *
                         *INPUT IN ACC A          *
                         *RESULT RETURNED IN ACC B*
                         **************************

30F9 A1 00    LINEAR CMP A  0,X
30FB 24 05           BCC    DELTA
30FD 08              INX
30FE 08              INX
30FF 08              INX
3100 20 F7           BRA    LINEAR
3102 A0 00    DELTA  SUB A  0,X
3104 E6 02           LDA B  2,X    SLOPE
3106 8D 3D           BSR    MPY5
3108 EB 01           ADD B  1,X
310A 39              RTS
```

```
                    ************************
                    *DENSITY ALTITUDE RTN  *
                    *ALTFT IS IN ACC B     *
                    *RESULT STORED ON STACK *
                    ************************

3108 86 54   DALT1  LDA A  #84
310D 8D 28          BSR    MPY8
310F 86 6E   NXT1   LDA A  #110
3111 1B             ABA
3112 D6 53          LDA B  CNVTA3+9 GET TEMPERATURE
3114 10             SBA
3115 24 0D          BCC    PLSCOR
3117 40             NEG A
3118 C6 BF          LDA B  #191
311A 8D 1B          BSR    MPY8
311C 96 5B   NXT2   LDA A  ALTFT
311E 11             CBA
311F 25 0E          BCS    NEGALT
3121 10             SBA
3122 20 10          BRA    GO
3124 C6 AE   PLSCOR LDA B  #174
3126 8D 0F          BSR    MPY8
3128 96 5B   NXT3   LDA A  ALTFT
312A 1B             ABA
312B 25 05          BCS    HIALT    BR IF DALT > 255
312D 20 05          BRA    GO
312F 4F      NEGALT CLR A
3130 20 02          BRA    GO
3132 86 FF   HIALT  LDA A  #$FF
3134 36      GO     PSH A
3135 20 41          BRA    VL
```

```
                  ******************************************
                  *    MULTIPLY SUBROUTINE ACC A X ACC B    *
                  *MOST SIG. HALF OF RESULT RETURNED IN ACC A*
                  *LEAST SIG. HALF RETURNED IN ACC B        *
                  ******************************************

3137 36        MPY8    PSH A               *               *
3138 86 08             LDA A   #8          *  ZERO1 NOT 0  *
313A 97 41             STA A   ZERO1       *ROUNDOFF RESULT*
313C 20 0D             BRA     MPY         *               *
313E 36        MPY7    PSH A               *STORE NUMBER OF*
313F 86 07             LDA A   #7          *  FINAL SHIFTS *
3141 97 41             STA A   ZERO1       *               *
3143 20 06             BRA     MPY         *               *
3145 36        MPY5    PSH A               *   ZERO1 = 0   *
3146 86 05             LDA A   #5          *DO NOT ROUNDOFF*
3148 7F 0041           CLR     ZERO1       *               *
314B 97 44     MPY     STA A   SHFTCT
314D 86 08             LDA A   #8
314F 36                PSH A
3150 DF 29             STX     SNDX
3152 30                TSX
3153 4F                CLR A
3154 56                ROR B
3155 24 02     M3      BCC     M4
3157 AB 01             ADD A   1,X
3159 46        M4      ROR A
315A 56                ROR B
315B 6A 00             DEC     0,X
315D 26 F6             BNE     M3
315F 31                INS
3160 31                INS
3161 7D 0044           TST     SHFTCT    ANY FINAL SHIFTS
3164 27 0F             BEQ     RTN
3166 44        SHIFT   LSR A
3167 56                ROR B
3168 7A 0044           DEC     SHFTCT
316B 26 F9             BNE     SHIFT     BRANCH FOR ANOTHER SHIFT
316D 24 06             BCC     RTN       BR IF FRACTIONAL PART OF
               *                         MULTIPLICATION < 0.5
316F 7D 0041           TST     ZERO1
3172 27 01             BEQ     RTN       BR IF NO ROUNDOFF
3174 5C                INC B

3175 DE 29     RTN     LDX     SNDX
3177 39                RTS
```

```
                     ***********************
                     *   CALCULATE ONEVL   *
                     *DALT STARTS IN ACC A *
                     ***********************

3178 80 24      VL     SUB A  #36
317A 25 09             BCS    LOW        BR IF DALT < 36 (3000 FT)
317C C6 AB             LDA B  #171
317E 8D B7             BSR    MPY8
3180 86 B4             LDA A  #180
3182 10                SBA
3183 20 02             BRA    ENDVL
3185 86 B4      LOW    LDA A  #180
3187 97 3F      ENDVL  STA A  ONEVL
                     **************
                     *SET CVL FLAG*
                     **************
3189 C6 F3             LDA B  #PT95
318B 8D AA             BSR    MPY8       .95VL RET'N IN ACC B
318D D1 5A             CMP B  KNOTS      .95VL - KNOTS
318F 25 14             BCS    VLPEAK     BR IF KNOTS > .95VL
3191 C6 26             LDA B  #PT15
3193 96 3F             LDA A  ONEVL
3195 8D A0             BSR    MPY8       .15VL RET'N IN ACC B
3197 96 3F             LDA A  ONEVL
3199 7A 0000    AGAIN1 DEC    CVL
319C 2B 07             BMI    VLPEAK     BR IF CVL = -1 (<.7VL)
319E 10                SBA
319F 91 5A             CMP A  KNOTS
31A1 25 02             BCS    VLPEAK     BR IF %VL < KNOTS
31A3 20 F4             BRA    AGAIN1

                     ******************
                     *CHECK VL PEAK FCC*
                     ******************

31A5 96 5A      VLPEAK LDA A  KNOTS
31A7 D6 3F             LDA B  ONEVL
31A9 8D 48             BSR    DIVIDE     %VL IN ACC A
31AB F6 01F9           LDA B  VLPK
31AE 11                CBA               PRESENT VL - PEAK VL
31AF 25 03             BCS    VH         BR IF PEAK > PRESENT
31B1 B7 01F9           STA A  VLPK
```

```
00520                  *****************
00521                  *CALCULATE ONEVH*
00522                  *****************

00524 31B4 32        VH      PUL A             GET DENSITY ALTITUDE
00525 31B5 C6 2B              LDA B  #43
00526 31B7 BD 3137            JSR    MPY8
00527 31BA 86 90              LDA A  #144
00528 31BC 10                 SBA
00529 31BD 97 3F              STA A  ONEVH
00530                  **************
00531                  *SET CVH FLAG*
00532                  **************

00534 31BF 9F 45              STS    SAVSTK
00535 31C1 86 26              LDA A  #PT15
00536 31C3 D6 3F              LDA B  ONEVH
00537 31C5 BD 3137            JSR    MPY8
00538 31C8 37                 PSH B             .15 VH ON STACK
00539 31C9 86 1A              LDA A  #PT10
00540 31CB D6 3F              LDA B  ONEVH
00541 31CD BD 3137            JSR    MPY8
00542 31D0 37                 PSH B             .10 VH ON STACK
00543 31D1 86 0D              LDA A  #PT05
00544 31D3 D6 3F              LDA B  ONEVH
00545 31D5 BD 3137            JSR    MPY8       .05 VH IN ACC B

00547 31D8 96 3F              LDA A  ONEVH
00548 31DA 8D 0E              BSR    CMPKN      1   - .05 = .95
00549 31DC 8D 0C              BSR    CMPKN      .95 - .05 = .90
00550 31DE 33                 PUL B             .1
00551 31DF 8D 09              BSR    CMPKN      .9  - .1  = .8
00552 31E1 33                 PUL B             .15
00553 31E2 8D 06              BSR    CMPKN      .8  - .15 = .65
00554 31E4 8D 04              BSR    CMPKN      .65 - .15 = .5

00556 31E6 9E 45        PLENTR LDS    SAVSTK
00557 31E8 20 2B              BRA    ROLL

00559 31EA 10        CMPKN   SBA
00560 31EB 91 5A              CMP A  KNOTS
00561 31ED 25 F7              BCS    PLENTR    BR IF KNOTS > %VH
00562 31EF 7A 0001            DEC    CVH
00563 31F2 39                 RTS
```

```
                       ************************
                       * DIVIDE SUBROUTINE    *
                       ************************
                       * NUMERATOR IN ACC A   *
                       * DENOMINATOR IN ACC B *
                       *(NUM X 128)/DEN = ANS *
                       ************************

31F3 D7 40    DIVIDE STA B  DENOM
31F5 5F              CLR B
31F6 D7 41           STA B  ZERO1
31F8 D7 42           STA B  ANS       CLEAR ZERO & ANS
31FA 97 43           STA A  NUM
31FC 44              LSR A
31FD 56              ROR B
31FE 4D              TST A
31FF 26 04           BNE    SUBT      BR IF NUM WAS   1
3201 D1 40           CMP B  DENOM
3203 25 0F           BCS    SMALL     BR IF DENOM > (NUM X 128)
3205 D0 40    SUBT   SUB B  DENOM
3207 7C 0042         INC    ANS
320A 92 41           SBC A  ZERO1     SUBTRACT POSSIBLE BORROW
320C 26 F7           BNE    SUBT      BR IF NOT ZERO
320E D1 40           CMP B  DENOM
3210 24 F3           BCC    SUBT      BR IF ACC B   DENOM
3212 96 42           LDA A  ANS
3214 39       SMALL  RTS
```

```
                      ************************
                      *    CORRECT ROLL      *
                      ************************

3215 D6 4C    ROLL    LDA B   CNVTAB+2 SYNCHRO REFERENCE
3217 96 4B            LDA A   CNVTAB+1 ROLL
3219 C1 91            CMP B   #145
321B 24 31            BCC     OUT1       BR IF REF > 145
321D C1 6F            CMP B   #111
321F 25 2D            BCS     OUT1       BR IF REF < 111
3221 8D D0            BSR     DIVIDE     CORRECT ROLL RETN IN ACC A
                      ***********************
                      *    SET CROL FLAG    *
                      ***********************
3223 81 93            CMP A   #DEG35
3225 24 11            BCC     PITCH      BR IF ROLL > 35
3227 7A 0002          DEC     CROL
322A 81 6E            CMP A   #DEG25
322C 24 0A            BCC     PITCH      BR IF ROLL > 25
322E 7A 0002          DEC     CROL
3231 81 2C            CMP A   #DEG10
3233 24 03            BCC     PITCH      BR IF ROLL > 10
3235 7A 0002          DEC     CROL

                      *************************
                      *    CORRECT PITCH      *
                      *************************

3238 D6 4C    PITCH   LDA B   CNVTAB+2 SYNCHRO REFERENCE
323A 96 4D            LDA A   CNVTAB+3 PITCH
323C 8D B5            BSR     DIVIDE     CORRECT PITCH RETN IN ACC A

                      ************************
                      *    SET CPIT FLAG     *
                      ************************

323E 81 40            CMP A   #DEG15
3240 24 12            BCC     CORRTQ     BR IF PITCH > 15
3242 7A 0009          DEC     CPIT
3245 81 16            CMP A   #DEG5
3247 24 0B            BCC     CORRTQ     BR IF PITCH > 5
3249 7A 0009          DEC     CPIT
324C 20 06            BRA     CORRTQ

324E 86 FF    OUT1    LDA A   #$FF
3250 97 09            STA A   CPIT
3252 97 02            STA A   CROL
```

```
                        **************************
                        *     CORRECT TORQUE     *
                        **************************

3254 D6 4F     CORRTQ LDA B   CNVTAB+5 TORQUE REFERENCE
3256 96 4E            LDA A   CNVTAB+4 TORQUE
3258 C1 91            CMP B   #145
325A 24 16            BCC     OUT2     BR IF REF > 145
325C C1 6F            CMP B   #111
325E 25 12            BCS     OUT2     BR IF REF < 111
3260 8D 91            BSR     DIVIDE

                        *****************************
                        *        SET CO FLAG        *
                        *****************************

3262 91 0A            CMP A   PSI5
3264 25 0F            BCS     SETCT    BR IF TQ < 5 PSI
3266 7C 0003          INC     CO
3269 91 DC            CMP A   PSI44
326B 25 08            BCS     SETCT    BR IF TQ < 44 PSI
326D 7C 0003          INC     CO
3270 20 03            BRA     SETCT
3272 4F        OUT2   CLR A
3273 97 03            STA A   CO
                        **************************
                        *    SET CT FLAG         *
                        **************************

3275 96 54     SETCT  LDA A   CNVTAB+10  GROSS WEIGHT TRANSDUCER
3277 81 14            CMP A   #GWGND   GROSS WEIGHT - GND THRESHOLD
3279 25 03            BCS     RPM      BR IF GW < GND THRESHOLD
327B 7C 0006          INC     CT

                        *************************
                        *    SET CRPM FLAG      *
                        *************************

327E 96 4A     RPM    LDA A   CNVTAB   RPM
3280 81 C8            CMP A   #RPM200  RPM - 200
3282 24 0A            BCC     AVGGW    BR IF RPM > 200
3284 7A 0005          DEC     CRPM
3287 81 64            CMP A   #RPM100  RPM - 100
3289 24 03            BCC     AVGGW    BR IF RPM > 100
328B 7A 0005          DEC     CRPM
```

```
                      ********************************
                      *     AVERAGE GROSS WEIGHT     *
                      ********************************

328E 5F       AVGGW   CLR B
328F 96 05            LDA A   CRPM
3291 2B 23            BMI     SKPCLR    BR IF RPM < 100

3293 CE 005E          LDX     #GWCNT    ***********************
3296 E7 00    CLRGW   STA B   0,X       *        CLEAR        *
3298 08               INX               *GWCNT, GW1ST, GWH, GWL*
3299 8C 0062          CPX     #GWL+1    *     IF RPM > 100    *
329C 26 F8            BNE     CLRGW     ***********************

329E 7C 005D          INC     GWTL      ***************************
32A1 26 03            BNE     SK2       *INCREMENT FUEL BURN TIMER*
32A3 7C 005C          INC     GWTH      *    (GWTH & GWTL)        *
32A6 DE 5C    SK2     LDX     GWTH      *                         *
32A8 8C 0310          CPX     #GWTIME   *   IF EQUAL TO (GWTIME   *
32AB 26 47            BNE     SETCGW    *  DECREMENT GROSS WEIGH) *
32AD 7A 01F7          DEC     GROSWT    *  (GROSWT) & CLEAR TIMER *
32B0 D7 5C            STA B   GWTH      *                         *
32B2 D7 5D            STA B   GWTL      *                         *
32B4 20 3E            BRA     SETCGW    ***************************

32B6 D7 5C    SKPCLR  STA B   GWTH      *     CLEAR
32B8 D7 5D            STA B   GWTL      *FUEL BURN TIMER
32BA 96 54            LDA A   CNVTAB+10  GROSS WEIGHT
32BC 9B 61            ADD A   GWL       *********
32BE 97 61            STA A   GWL       *ADD FOR*
32C0 24 03            BCC     NXT4      *AVERAGE*
32C2 7C 0060          INC     GWH       *********
32C5 7C 005E  NXT4    INC     GWCNT     #INPUTS FOR AVERAGE
32C8 86 07            LDA A   #7
32CA 95 5E            BIT A   GWCNT
32CC 26 26            BNE     SETCGW    BR IF NOT 8 INPUTS

                      ************************
                      *     DIVIDE SUM OF    *
                      *     8 INPUTS BY 8    *
                      ************************

32CE 86 03            LDA A   #3
32D0 97 44            STA A   SHFTCT
32D2 96 60            LDA A   GWH
32D4 D6 61            LDA B   GWL
32D6 BD 3166          JSR     SHIFT
```

```
                   ***********************************
                   *    CHECK PREVIOUS GROSS WEIGHT  *
                   *    UPDATE IF DIFFERENCE < 4     *
                   ***********************************
32D9 17                   TBA               PUT AVG GROSS WEIGHT IN ACC A
32DA 97 61                STA A  GWL
32DC D6 5F                LDA B  GW1ST      GET PREVIOUS AVERAGE
32DE 27 0B                BEQ    TO1ST      BR IF NO PREVIOUS AVERAGE
32E0 10                   SBA               GET DIFFERENCE OF AVERAGES
32E1 2A 01                BPL    TST1       BR IF PLUS
32E3 43                   COM A             MAKE IT PLUS
32E4 80 04         TST1   SUB A  #4
32E6 24 03                BCC    TO1ST      BR IF DIFFERENCE > 3
32E8 F7 01F7              STA B  GROSWT     UPDATE GROSS WEIGHT
32EB 96 61         TO1ST  LDA A  GWL        *    BUMP PRESENT GW
32ED 97 5F                STA A  GW1ST      *    TO "PREVIOUS" LOCATION
32EF 4F                   CLR A
32F0 97 61                STA A  GWL
32F2 97 60                STA A  GWH

                   ************************
                   *     SET CGW FLAG     *
                   ************************

32F4 B6 01F7       SETCGW LDA A  GROSWT
32F7 81 AF                CMP A  #GW7750
32F9 25 0A                BCS    DECENT      BR IF GW < 7750
32FB 7C 0008              INC    CGW
32FE 81 E1                CMP A  #GW8750
3300 25 03                BCS    DECENT      BR IF GW < 8750
3302 7C 0008              INC    CGW
```

```
                         ****************************************
                         *     GET 1 SECOND ALTITUDE AVERAGE    *
                         *     LOAD DIVE TABLE FOR TIME 0       *
                         ****************************************

3305 96 02   DECENT LDA A  CROL
3307 2B 03          BMI    SK5      BR IF ROLL : 10
3309 7C 0066        INC    DVTABL+4
330C 96 03   SK5    LDA A  CQ
330E 26 03          BNE    SK6      BR IF TORQUE   5
3310 7C 0065        INC    DVTABL+3
3313 96 07   SK6    LDA A  CN2
3315 2B 03          BMI    SK7      BR IF N2 < 1.3
3317 7C 0067        INC    DVTABL+5
331A 7C 00A8 SK7    INC    AVGDVC   INC AVERAGE COUNTER
331D 96 A8          LDA A  AVGDVC
331F 81 09          CMP A  #9
3321 24 11          BCC    CHK10    BR IF 9 OR 10 AVERAGE INPUTS
3323 7F 00A8        CLR    AVGDVC
3326 D6 5E          LDA B  ALTFT    **********************
3328 DB A7          ADD B  AVGDVL   *                    *
332A D7 A7          STA B  AVGDVL   *   AND FOR AVERAGE  *
332C 24 03          BCC    SKP4     *                    *
332E 7C 00A6        INC    AVGDVH   **********************
3331 7E 366F SKP4   JMP    F1

3334 81 0A   CHK10  CMP A  #10
3336 25 5E          BCS    BRAF1    BR IF AVGDVC = 9
3338 86 03          LDA A  #3
333A 97 44          STA A  SHFTCT
333C 96 A6          LDA A  AVGDVH
333E D6 A7          LDA B  AVGDVL
3340 BD 3166        JSR    SHIFT    AVG RET'N IN ACC B
3343 D7 68          STA B  DVTABL+6 1 SEC ALTFT AVERAGE
3345 5F             CLR B
3346 D7 A7          STA B  AVGDVL
3348 D7 A6          STA B  AVGDVH
334A D6 01          LDA B  CVH
334C D7 63          STA B  DVTABL+1
334E D6 00          LDA B  CVL
3350 D7 64          STA B  DVTABL+2
3352 96 5A          LDA A  KNOTS
3354 D7 69          STA B  DVTABL+7
```

14
B

```
                        ********************************
                        *     SET DELTA FLAG IF        *
                        *     ALT(-6) - ALT(0) > 1     *
                        ********************************

3356 CE 0062                LDX     #DVTABL
3359 6F 00                  CLR     0,X
335B E6 06                  LDA B   6,X         ALT(0)
335D CB 02                  ADD B   #2
335F A6 36                  LDA A   54,X        ALT(-6)
3361 10                     SBA                 ALT(-6) - ALT(0) - 2
3362 25 02                  BCS     CHK9        BR IF ALT DID NOT DECREASE
                        *                       BY 2 CNTS IN LAST 6 SEC
3364 6C 00                  INC     0,X

                        *********************
                        *   SET CRD FLAG    *
                        *********************
3366 5C                 CHK9 INC B              ALT(0) + 3
3367 A6 3C                  LDA A   60,X        ALT(-9)
3369 10                     SBA                 ALT(-9) - ALT(0) - 3
336A 25 27                  BCS     SKP3        BR IF ALT DID NOT DECREASE
                        *                       BY 3 CNTS IN LAST 9 SEC


336C E6 43                  LDA B   67,X        A/S(-12)
336E CB 23                  ADD B   #35
3370 A6 37                  LDA A   55,X        A/S(-6)
3372 10                     SBA                 A/S(-6) - A/S(-12) - 35 KNOTS
3373 25 1E                  BCS     SKP3        BR IF A/S DID NOT INCREASE BY
                        *                       35 KNOTS FROM (-12) TO (-6)


3375 5F                     CLR B
3376 86 F8              LP5 LDA A   #$F8        (-9)
3378 EB 00                  ADD B   0,X
337A 08                 LP6 INX                 *
337B 4C                     INC A               *INC X BY 8
337C 26 FC                  BNE     LP6         *
337E 8C 009A                CPX     #DVTABL+56
3381 26 F3                  BNE     LP5         BR IF THEPE MORE DELTHS
3383 C1 05                  CMP B   #5
3385 25 0C                  BCS     SKP3        BR IF SUM OF DELTAS < 5


3387 96 5B                  LDA A   ALTFT       ALTITUDE IN FEET
3389 81 78                  CMP A   #120        10,000 FEET
338B 24 06                  BCC     SKP3        BR IF ALTITUDE > 10,000 FT
338D 7C 0004                INC     CPD
3390 BD 3600                JSR     $3600       BUMP
3393 7C 0004 SKP3           INC     CRD
3396 20 39    BRAF1         BRA     DLOOP8
```

U

```
3398 FC        ALTABL FCB    252,255, 0
339B E5               FCB    229,      225, 44
339E C7               FCB    199,      187, 40
33A1 9C               FCB    156,      138, 36
33A4 7C               FCB    124,      105, 34
33A7 5A               FCB    90,       74, 30
33AA 40               FCB    64,       51, 29
33AD 25               FCB    37,       29, 26
33B0 00               FCB    0,        0, 25
33B3 FA        AITABL FCB    250,      202, 0
33B6 B0               FCB    176,      171, 14
33B9 70               FCB    112,      137, 17
33BC 50               FCB    80,       116, 21
33BF 32               FCB    50,       92, 26
33C2 1E               FCB    30,       71, 32
33C5 15               FCB    21,       59, 47
33C8 0C               FCB    12,       45, 54
33CB 05               FCB    5,        29, 77
33CE 00               FCB    0,0,196
```

```
33D1 CE 2800 DLOOPB LDX    #MES2
33D4 BD 3554        JSR    PRT
33D7 BD 35C1        JSR    INP
33DA CE 2869        LDX    #MES7
33DD BD 3559        JSR    PRTR
33E0 CE 286E        LDX    #BUFFR
33E3 A6 00          LDA A  0,X
33E5 81 4E          CMP A  #$4E      N?
33E7 27 12          BEQ    JF4X
33E9 81 4C          CMP A  #$4C      L?
33EB 27 11          BEQ    JLO
33ED 84 4F          AND A  #$4F
33EF 81 09          CMP A  #$09
33F1 2F 0E          BLE    DLOOPJ
33F3 CE 281C        LDX    #MES3
33F6 BD 3559        JSR    PRTR
33F9 20 D6          BRA    DLOOPB
33FB 7E 3499 JF4X   JMP    JF4
33FE 7E 345A JLO    JMP    DLOOPS
3401 B7 340D DLOOPJ STA A  DLOOPK+1
3404 B7 3456        STA A  DLOOPQ+1
3407 CE 0000        LDX    #CVL
340A C6 30          LDA B  #$30
340C A6 00   DLOOPK LDA A  0,X
340E 2A 04          BPL    DLOOPM
3410 43             COM A
3411 4C             INC A
3412 C6 2D          LDA B  #$2D
3414 8A 30   DLOOPM ORA A  #$30
3416 CE 286E        LDX    #BUFFR
3419 E7 02          STA B  2,X
341B A7 03          STA A  3,X
341D 5F             CLR B
341E E7 04          STA B  4,X
3420 C6 2A          LDA B  #$2A
3422 E7 00          STA B  0,X
3424 C6 20          LDA B  #$20
3426 E7 01          STA B  1,X
3428 BD 3554        JSR    PRT
342B CE 282F        LDX    #MES4
342E BD 3554        JSR    PRT
3431 BD 35C1        JSR    INP
3434 CE 2869        LDX    #MES7
3437 BD 3559        JSR    PRTR
343A CE 286E        LDX    #BUFFR
343D A6 00          LDA A  0,X
343F 81 0D          CMP A  #$0D
3441 27 14          BEQ    DLOOPR
3443 81 2D          CMP A  #$2D
3445 26 01          BNE    DLOOPN
3447 08             INX
3448 E6 00   DLOOPN LDA B  0,X
344A C4 0F          AND B  #$0F
344C 81 2D          CMP A  #$2D
```

```
344E 26 02             BNE     DLOOPP
3450 53                COM B
3451 5C                INC B
3452 CE 0000 DLOOPP    LDX     #CVL
3455 E7 00   DLOOPQ    STA B   0,X
3457 7E 33D1 DLOOPR    JMP     DLOOPB
345A 7F 2855 DLOOPS    CLR     COUNT
345D 7A 2855           DEC     COUNT
3460 CE 0000 DLOOPT    LDX     #CVL
3463 7C 2855           INC     COUNT
3466 B6 2855           LDA A   COUNT
3469 81 09             CMP A   #9
346B 2E EA             BGT     DLOOPP
346D B7 3476           STA A   DLOOPU+1
3470 8A 30             ORA A   #$30
3472 B7 286E           STA A   BUFFR
3475 A6 00   DLOOPU    LDA A   0,X
3477 CE 286E           LDX     #BUFFR
347A C6 20             LDA B   #$20
347C E7 01             STA B   1,X
347E E7 02             STA B   2,X
3480 C6 30             LDA B   #$30
3482 E7 03             STA B   3,X
3484 4D                TST A
3485 2A 06             BPL     DLOOPV
3487 C6 2D             LDA B   #$2D
3489 E7 03             STA B   3,X
348B 43                COM A
348C 4C                INC A
348D 8A 30   DLOOPV    ORA A   #$30
348F A7 04             STA A   4,X
3491 5F                CLR B
3492 E7 05             STA B   5,X
3494 BD 3559           JSR     PRTR
3497 20 C7             BRA     DLOOPT
3499 CE 2835 JF4       LDX     #MES5
349C BD 3554           JSR     PRT
349F BD 35C1           JSR     INP
34A2 CE 2869           LDX     #MES7
34A5 BD 3559           JSR     PRTR
34A8 5F                CLR B
34A9 F7 34C9           STA B   JF4D+1
34AC CE 286E           LDX     #BUFFR
34AF A6 01   JF4B      LDA A   1,X
34B1 81 0D             CMP A   #$0D
34B3 27 06             BEQ     JF4C
34B5 7C 34C9           INC     JF4D+1
34B8 08                INX
34B9 20 F4             BRA     JF4B
34BB CE 286E JF4C      LDX     #BUFFR
34BE A6 00   JF4C1     LDA A   0,X
34C0 84 0F             AND A   #$0F
34C2 FF 2882           STX     SAVEX
34C5 CE 284F           LDX     #*1
```

```
3408 EB 00     JF4D   ADD B  0,X
34CA 4A               DEC A
34CB 26 FB            BNE    JF4D
34CD B6 34C9          LDA A  JF4D+1
34D0 27 0A            BEQ    JF4F
34D2 4A               DEC A
34D3 B7 34C9          STA A  JF4D+1
34D6 FE 2882          LDX    SAVEX
34D9 08               INX
34DA 20 E2            BRA    JF4C1
34DC F7 2854   JF4F   STA B  LOOPCT
34DF 7E 360A          JMP    F4
                      *
                      * AT END OF PASS
                      *
34E2 7A 2854   FLOOPA DEC    LOOPCT
34E5 27 03            BEQ    FLOOP1
34E7 7E 360A          JMP    F4
34EA CE 0100   FLOOP1 LDX    #$100
34ED 5F               CLR B
34EE 7F 2882          CLR    SAVEX
34F1 A6 00     FLOOPB LDA A  0,X
34F3 08               INX
34F4 8C 0200          CPX    #$200
34F7 27 07            BEQ    FLOOP5
34F9 A1 FF            CMP A  255,X
34FB 26 13            BNE    FLOOPD
34FD 5C        FLOOP4 INC B
34FE 20 F1            BRA    FLOOPB
3500 CE 0100   FLOOP5 LDX    #$100
3503 86 FF            LDA A  #255
3505 E6 00     FLOOPC LDA B  0,X
3507 08               INX
3508 E7 FF            STA B  255,X
350A 4A               DEC A
350B 26 F8            BNE    FLOOPC
350D 7E 33D1          JMP    DLOOPB
3510 7D 2882   FLOOPD TST    SAVEX
3513 26 0B            BNE    FLOOPE
3515 FF 2882          STX    SAVEX
3518 CE 2856          LDX    #MES6
351B BD 3559          JSR    PRTR
351E 20 03            BRA    FLOOPF
3520 FF 2882   FLOOPE STX    SAVEX
3523 37        FLOOPF PSH B
3524 C6 20            LDA B  #$20
3526 BD 3575          JSR    PUTC
3529 33               PUL B
352A 37               PSH B
352B 36               PSH A
352C 17               TBA
352D BD 35D6          JSR    PRTDEC
3530 CE 2869          LDX    #MES7
3533 BD 3554          JSR    PRT
```

```
3536 FE 2882          LDX     SAVEX
3539 A6 FF            LDA A   255,X
353B BD 35D6          JSR     PRTDEC
353E CE 2969          LDX     #MES7
3541 BD 3554          JSR     PRT
3544 32               PUL A
3545 BD 35D6          JSR     PRTDEC
3548 CE 2969          LDX     #MES7
354B BD 3559          JSR     PRTR
354E FE 2882          LDX     SAVEX
3551 33               PUL B
3552 20 A9            BRA     FLOOP4
```

```
                   ************************************************
                   ************************************************
                   *  THE FOLLOWING ROUTINES HAVE BEEN INSERTED
                   *   FOR DEBUGGING PURPOSES ONLY AND WILL NOT
                   *   APPEAR IN THE FINAL VERSION OF THE SOFTWARE.
                   ******************************
                   *  PRINT SUBROUTINE
                   *
3554 36            PRT     PSH A
3555 37                    PSH B
3556 4F                    CLR A
3557 20 04                 BRA     PRT3
3559 36            PRTR    PSH A
355A 37                    PSH B
355B 86 AA                 LDA A   #$AA
355D C6 09         PRT3    LDA B   #$09
355F F7 1000               STA B   ACIACS
3562 E6 00         PRT4    LDA B   0,X
3564 27 06                 BEQ     PRTEX
3566 BD 3575               JSR     PUTC
3569 08                    INX
356A 20 F6                 BRA     PRT4
356C 4D            PRTEX   TST A
356D 27 03                 BEQ     PRTX
356F BD 3575               JSR     PUTC
3572 33            PRTX    PUL B
3573 32                    PUL A
3574 39                    RTS
                   *********************************
                   *  PUTC SUBROUTINE
                   *
3575 36            PUTC    PSH A
3576 B6 1000       PUTC1   LDA A   ACIACS
3579 47                    ASR A
357A 47                    ASR A
357B 24 F9                 BCC     PUTC1
357D F7 1001               STA B   ACIAXR
3580 C1 7F                 CMP B   #$7F
3582 27 11                 BEQ     PUTF
3584 BD 35AE               JSR     DLAY
3587 5D                    TST B
3588 26 0B                 BNE     PUTF
358A C6 0D                 LDA B   #$0D
358C BD 3575               JSR     PUTC
358F C6 0A                 LDA B   #$0A
3591 BD 3575               JSR     PUTC
3594 5F                    CLR B
3595 32            PUTF    PUL A
3596 39                    RTS
                   ***********************************
                   *  GETC  SUBROUTINE
                   *
3597 36            GETC    PSH A
3598 B6 1000       GETC1   LDA A   ACIACS
```

```
359B 47                 ASR A
359C 24 FA              BCC     GETC1
359E 48                 ASL A
359F 36                 PSH A
35A0 85 70              BIT A   #$70
35A2 27 02              BEQ     GETEX
35A4 32                 PUL A
35A5 3F                 SWI
35A6 32         GETEX   PUL A
35A7 F6 1001            LDA B   ACIAXR
35AA C4 7F              AND B   #$7F
35AC 32                 PUL A
35AD 39                 RTS
                ***************************************
                *  DLAY SUBROUTINE
                *
35AE 37         DLAY    PSH B
35AF 86 03              LDA A   #3
35B1 C1 0D              CMP B   #$0D
35B3 26 02              BNE     DLAY1
35B5 86 13              LDA A   #19
35B7 C6 7F      DLAY1   LDA B   #$7F
35B9 BD 3575            JSR     PUTC
35BC 4A                 DEC A
35BD 26 F8              BNE     DLAY1
35BF 33                 PUL B
35C0 39                 RTS
                ***************************************
35C1 CE 286E    INP     LDX     #BUFFR
35C4 BD 3597    INP1    JSR     GETC
35C7 BD 3575            JSR     PUTC
35CA C1 0A              CMP B   #$0A      LF?
35CC 27 F3              BEQ     INP
35CE E7 00              STA B   0,X
35D0 08                 INX
35D1 C1 0D              CMP B   #$0D
35D3 26 EF              BNE     INP1
35D5 39                 RTS
                ****************************************
                *  PRTDEC
35D6 36         PRTDEC  PSH A
35D7 37                 PSH B
35D8 FF 28A4            STX     SAVE+2
35DB CE 2952            LDX     #K10
35DE 5F         CVHTD1  CLR B
35DF A0 00      CVHTD2  SUB A   0,X
35E1 25 03              BCS     CVHTD4
35E3 5C                 INC B
35E4 20 F9              BRA     CVHTD2
35E6 AB 00      CVHTD4  ADD A   0,X
35E8 CA 30              ORA B   #$30
35EA 8C 2953            CPX     #K10+1
35ED 27 06              BEQ     CVHTD5
35EF C1 30              CMP B   #$30
```

```
35F1 26 02                BNE      CVHTD5
35F3 C6 20                LDA B    #$20
35F5 BD 3575 CVHTD5 JSR      PUTC
35F8 08                   INX
35F9 8C 2854              CPX      #K10+2
35FC 26 E0                BNE      CVHTD1
35FE 16                   TAB
35FF CA 30                ORA B    #$30
3601 BD 3575              JSR      PUTC
3604 FE 2884              LDX      SAVEX2
3607 33                   PUL B
3608 32                   PUL A
3609 39                   RTS
```

```
                     ************************************
                     *
                     ****************************************
                     ***  FCC EVENT RECOGNITION ROUTINES  ***
                     ****************************************
                     *
                     **********************************
                     ***  FCC 4 - ROTOR START/STOP  ***
                     **********************************
                     *
3608 CE 0000 F4      LDX    #CVL      SETUP INDEX
360D 6F 3D           CLR    61,X      SET CONE=1
360F 6F 3E           CLR    62,X
3611 86 01           LDA A  #1
3613 A7 3C           STA A  60,X
3615 6D 0B           TST    11,X      ARM?
3617 27 11           BEQ    F4A       NO,BR
3619 6D 05           TST    5,X       RPM<100?
361B 2C 13           BGE    F8        NO,BR
361D 5F              CLR B
361E CE 00F9         LDX    #249      ROTOR CYCLES
3621 86 3C           LDA A  #60       CONSTANT "1"
3623 BD 39A9         JSR    BUMPN     COUNT CYCLE
3626 6F 0B           CLR    11,X      REARM
3628 20 06           BRA    F8
362A 6D 05   F4A     TST    5,X       RPM>200?
362C 2F 02           BLE    F8        NO,CONTINUE
362E 63 0B           COM    11,X      ARM
                     *
                     ********************************************
                     ***  FCC  8-10 - NORMAL LANDINGS         ***
                     ***  FCC 92-94 - AUTOROTATIVE LANDINGS   ***
                     ********************************************
                     *
3630 6D 06   F8      TST    6,X       GROUND?
3632 27 1F           BEQ    F86       NO,BR
3634 6F 3B           CLR    59,X      CLR AIRTIME
3636 6D 0D           TST    13,X      AIR SET?
3638 27 35           BEQ    F1        NO,BR
363A A6 0C           LDA A  12,X
363C 81 64           CMP A  #100      TQ TIMER>=10 SEC?
363E 2D 05           BLT    F8D       NO,BR
3640 CE 0000         LDX    #0        NORMAL LNDGS
3643 20 03           BRA    F8E
3645 CE 0006 F8D     LDX    #6        AUTOROTATIVE LNDGS
3648 86 3C   F8E     LDA A  #60       CONSTANT "1"
364A BD 39A4         JSR    BUMP      COUNT LANDING
364D 6F 0D           CLR    13,X      SET GND
364F 6F 0C   F8F     CLR    12,X      CLR TQ TIMER
3651 20 1C           BRA    F1
3653 A6 3B   F86     LDA A  59,X
3655 81 63           CMP A  #99       AIRBORNE FOR >10 SEC?
3657 2E 05           BGT    F8H       YES,BR
3659 4C              INC A            BUMP AIRTIME
```

```
01232 365A A7 3B           STA A  59,X
01233 365C 20 11           BRA    F1
01234 365E 86 01    F8H    LDA A  #1
01235 3660 A7 0D           STA A  13,X     SET AIR
01236 3662 6D 03           TST    3,X      TQ>5?
01237 3664 27 E9           BEQ    F8F      NO,BR
01238 3666 A6 0C           LDA A  12,X     INC TO TIMER
01239 3668 81 64           CMP A  #100
01240 366A 27 03           BEQ    F1
01241 366C 4C              INC A
01242 366D A7 0C           STA A  12,X
```

```
                *
                *********************************************
                ***  FCC   1-3 - FLIGHT CLOCK TIME          ***
                ***  FCC 77-79 - CLOCK TIME IN AUTOROTATION  ***
                *********************************************
                *
366F 6D 0D      F1     TST     13,X      AIR CONDS?
3671 27 37             BEQ     F1N       NO,BR
3673 CE 0096           LDX     #150      FLIGHT TIME
3676 86 3C             LDA A   #60       CONSTANT "1"
3678 BD 39A4           JSR     BUMP      COUNT FLIGHT TIME
367B 6D 03             TST     3,X       TQ>5?
367D 27 0C             BEQ     F1C       NO,BR
367F 6C 0E             INC     14,X      INC T77 CNTR
3681 6D 02             TST     2,X       ROLL<10?
3683 2C 22             BGE     F1G       NO,BR
3685 6D 07             TST     7,X       NZ<1.3?
3687 2B 2F             BMI     F29       YES,BR
3689 20 68             BRA     F53XX
368B A6 0E      F1C    LDA A   14,X
368D 81 14             CMP A   #20       T77>2 SECS?
368F 2F 02             BLE     F1F       NO,BR
3691 6F 0E             CLR     14,X      CLR T77
3693 6C 0E      F1F    INC     14,X      INC T77
3695 A6 0E             LDA A   14,X      AUTOROTATIVE CLOCK TIME
3697 A7 2C             STA A   44,X
3699 6F 2D             CLR     45,X
369B 6F 2E             CLR     46,X
369D 86 2C             LDA A   #44
369F CE 00CC           LDX     #204
36A2 BD 39A4           JSR     BUMP
36A5 6F 0E             CLR     14,X      CLR T77
36A7 7E 37D4    F1G    JMP     F53Y
36AA 86 2D      F1N    LDA A   #45       CLR MISC FLAGS,CNTRS
36AC CE 000E           LDX     #T77      START AT T77
36AF 6F 00      CLRF   CLR     0,X
36B1 08                INX
36B2 4A                DEC A
36B3 26 FA             BNE     CLRF
36B5 7E 3987           JMP     F95J
```

```
                     *
                     ***********************************
                     ***  FCC 29-40 - GUNNERY RUN DIVES  ***
                     ***********************************
                     *
36B8 6D 04      F29     TST     4,X         RD VALID?
36BA 2B 39              BMI     F5XX        NO,BR
36BC 7D 0096            TST     DVTABL+52   ROLL=0?
36BF 26 5F              BNE     F29X        NO,BR
36C1 7D 0097            TST     DVTABL+53   NZ=0?
36C4 26 5A              BNE     F29X        NO,BR
36C6 7D 0095            TST     DVTABL+51   Q=0?
36C9 27 55              BEQ     F29X        NO,BR
36CB 6D 04              TST     4,X         RD<1650 FPM?
36CD 27 28              BEQ     F29H        NO,BR
36CF 96 94              LDA A   DVTABL+50   GET VL
36D1 81 02              CMP A   #2          A/S>.95VL?
36D3 26 05              BNE     F29B        NO,BR
36D5 CE 001E            LDX     #30
36D8 20 12              BRA     F296
36DA 4D         F29B    TST A
36DB 2D 0C              BLT     F29D        A/S<=.7VL
36DD 27 05              BEQ     F29C        .7VL<A/S<=.85VL
36DF CE 0018            LDX     #24         .85VL<A/S<=.95VL
36E2 20 08              BRA     F296
36E4 CE 0012    F29C    LDX     #18
36E7 20 03              BRA     F296
36E9 CE 000C    F29D    LDX     #12
36EC 86 3C      F296    LDA A   #60         CONSTANT "1"
36EE BD 39A4            JSR     BUMP        INC FCC
36F1 20 2D              BRA     F29X
                *
36F3 20 5D      F53XX   BRA     F53
36F5 20 4F      F5XX    BRA     F5
                *
                *
                *****************************************************
                ***  FCC 11-22 - LOW VELOCITY FLIGHT CONDITIONS  ***
                *****************************************************
                *
36F7 96 93      F29H    LDA A   DVTABL+49   GET VH
36F9 81 03              CMP A   #3          A/S>.95VH?
36FB 26 05              BNE     F29K        NO,BR
36FD CE 00BA            LDX     #186        A/S>=.95VH
3700 20 EA              BRA     F296
3702 81 FE      F29K    CMP A   #$FE        A/S<.5VH
3704 27 1A              BEQ     F29X        YES,BR
3706 4D                 TST A               A/S .65VH?
3707 2C 05              BGE     F29M        YES,BR
3709 CE 00A8            LDX     #168        .5VH<=A/S<.65VH
370C 20 DE              BRA     F296
370E 96 95      F29M    LDA A   DVTABL+51   GET Q
3710 81 01              CMP A   #1
3712 2D 0C              BLT     F29X        TQ<=5?
```

```
3714 27 05              BEQ     F29P        5<TORQUE<=44?
3716 CE 00C3            LDX     #195        TORQUE>44
3719 20 D1              BRA     F296
371B CE 00B1 F29P       LDX     #177
371E 20 CC              BRA     F296
3720 CE 00A3 F29X       LDX     #DVTABL+65
3723 A6 00   LOOP1      LDA A   0,X
3725 A7 02              STA A   2,X
3727 09                 DEX
3728 8C 0097            CPX     #DVTABL+53
372B 26 F6              BNE     LOOP1
372D CE 0092            LDX     #DVTABL+48
3730 09      LOOP2      DEX
3731 A6 00              LD9 A   0,X
3733 A7 08              STA A   8,X
3735 9C 0062            CPX     #DVTABL
3738 26 F6              BNE     LOOP2
373A CE 0062            LDX     #DVTABL
373D 6F 03              CLR     3,X
373F 6F 04              CLR     4,X
3741 6F 05              CLR     5,X
3743 CE 0000            LDX     #CVL
```

```
                       *
                       ****************************************
                       ***  FCC 5-7 - QUICK STOP DECELERATIONS  ***
                       ****************************************
                       *
3746 6D 09      F5       TST    9,X       PITCH>15?
3748 2F 08               BLE    F53       NO,BR
374A CE 009F             LDX    #159      QUICK STOPS
374D 86 3C               LDA A  #60       CONSTANT "1"
374F BD 39A4             JSR    BUMP
```

```
                    *
                    ***********************************************
                    ***  FCC 53-61 - SYMMETRICAL (GUNNERY RUN) PULLUPS
                    ***********************************************
                    *
3752 6D 04     F53     TST     4,X       CRD VALID?
3754 2B 5A             BMI     F53S      NO,BR
3756 6D 20             TST     32,X      PUFLAG SET?
3758 26 36             BNE     F53N      YES,BR
375A 6D 09             TST     9,X       PITCH<5?
375C 2C 52             BGE     F53S      NO,BR
375E C6 01             LDA B   #1        SET PUFLAG
3760 E7 20             STA B   32,X
3762 6D 04             TST     4,X       PD>1650?
3764 26 02             BNE     F53C      YES,BR
3766 E7 30             STA B   48,X      SET NOPUFG
3768 A6 08     F53C    LDA A   8,X       SAVE GW
376A A7 32             STA A   50,X
376C A6 00             LDA A   0,X       SAVE VL
376E A7 33             STA A   51,X
3770 C6 06             LDA B   #6        START LOOP
3772 86 35             LDA A   #53
3774 B7 377B           STA A   F53E+1
3777 CE 0062           LDX     #DVTABL
377A A6 00     F53E    LDA A   0,X       NZ(-X)>1.3?          15 B
377C 2C 0D             BGE     F53H      YES,BR
377E 5A                DEC B
377F 27 0A             BEQ     F53H
3781 B6 377B           LDA A   F53E+1    SET UP NEXT (-X)
3784 80 08             SUB A   #8
3786 B7 377B           STA A   F53E+1
3789 20 EF             BRA     F53E
378B CE 0000   F53H    LDX     #CVL
378E E7 2F             STA B   47,X      SAVE PUFCTM
3790 C6 01     F53N    LDA B   #1
3792 6D 02             TST     2,X       ROLL<10?
3794 2C 04             BGE     F53P      YES,BR
3796 6D 03             TST     3,X       TORQUE<5?
3798 26 02             BNE     F53Q      NO,BR
379A E7 30     F53P    STA B   48,X      SET NOPUFG
379C 6C 31     F53Q    INC     49,X      INC PU10
379E A6 31             LDA A   49,X
37A0 81 64             CMP A   #100      PU10=10 SECS?
37A2 27 30             BEQ     F53Y      YES,BR
37A4 6D 09             TST     9,X       PITCH<5?
37A6 2C 0A             BGE     F53T      NO,BR
37A8 6C 2F             INC     47,X      INC PUFCTM
37AA 6D 07             TST     7,X       NZ 1.3?
37AC 2B 02             BMI     F53S
37AE E7 36             STA B   54,X      SET YSPUFG
37B0 20 2C     F53S    BRA     F13
37B2 6D 36     F53T    TST     54,X      YSPUFG SET?
37B4 27 1E             BEQ     F53Y      NO,BR
37B6 6D 30             TST     48,X      NOPUFG SET?
```

```
37B8 26 1A              BNE     F53Y      YES,BR
37BA 6D 33              TST     51,X      CLASSIFY BY VL
37BC 2B 07              BMI     F53TE
37BE 27 0A              BEQ     F53TF
37C0 CE 0030            LDX     #48       A/S>.85VL
37C3 20 08              BRA     F53TG
37C5 CE 0024 F53TE      LDX     #36       A/S<.7VL
37C8 20 03              BRA     F53TG
37CA CE 002A F53TF      LDX     #42       .7VL<A/S<=.85VL
37CD D6 32      F53TG   LDA B   GSV53     GET GW
37CF 86 2F              LDA A   #47
37D1 BD 39A9            JSR     BUMPN
37D4 6F 2F      F53Y    CLR     47,X      CLR PUFCTM
37D6 6F 30              CLR     48,X      NOPUFG
37D8 6F 31              CLR     49,X      PU10
37DA 6F 20              CLR     32,X      PUFLAG
37DC 6F 36              CLR     54,X      YSPUFG
```

```
                        *
                        ***********************************************
                        ***  FCC 23-28 - NORMAL (HIGH SPEED) TURNS        ***
                        ***  FCC 41-52 - ASYMMETRICAL PULLUPS             ***
                        ***  FCC 62-70 - GUNNERY TURNS                    ***
                        ***  FCC 71-76 - GUNNERY S-TURNS                  ***
                        ***  FCC 86-91 - HIGH SPEED AUTOROTATION TURNS    ***
                        ***********************************************
                        *
37DE C6 01      F13     LDA B   #1
37E0 6D 02              TST     2,X       ROLL>=10?
37E2 2B 74              BMI     F13N      NO,BR
37E4 86 34              LDA A   #52
37E6 BD 398E            JSR     BUMPT
37E9 6D 11              TST     17,X      MODE=X? (0)
37EB 26 14              BNE     F13D      NO,BR
37ED 6D 07              TST     7,X       NZ>=1.3?
37EF 2C 0E              BGE     F13C      YES,BR
37F1 A6 00              LDA A   0,X       SAVE CVH,CVL,CGW
37F3 A7 1A              STA A   26,X
37F5 A6 01              LDA A   1,X
37F7 A7 19              STA A   25,X
37F9 A6 08              LDA A   8,X
37FB A7 1B              STA A   27,X
37FD 20 02              BRA     F13D
37FF E7 15      F13C    STA B   21,X      SET NZE FLAG
3801 6F 11      F13D    CLR     17,X      SET MODE=Y (-1)
3803 6A 11              DEC     17,X
3805 6D 03      F13E    TST     3,X       TQ<5?
3807 27 0F              BEQ     F13F      YES,BR
3809 86 1C              LDA A   #28       INC T86
380B BD 398E            JSR     BUMPT
380E A6 1C              LDA A   28,X
3810 81 14              CMP A   #20       =2 SECS?
3812 26 0A              BNE     F13G      NO,BR
3814 E7 12              STA B   18,X      SET HITQ FLAG
3816 20 06              BRA     F13G
3818 E7 13      F13F    STA B   19,X      SET LOTQ FLAG
381A 6F 1C              CLR     28,X      CLEAR T86
381C 6F 1D              CLR     29,X
381E 6D 14      F13G    TST     20,X      M SET?
3820 26 14              BNE     F13J      YES,BR
3822 A6 02              LDA A   2,X       ROLL>=35?
3824 81 02              CMP A   #2
3826 26 02              BNE     F13H      NO,BR
3828 E7 18              STA B   24,X      SET HI ROLL FLAG
382A 6D 07      F13H    TST     7,X
382C 27 04              BEQ     F13I2     1.3<=NZ<1.5
382E 2B 0C              BMI     F13J1     NZ<1.3,BR
3830 E7 16      F13I    STA B   22,X      SET HI NZ FLAG
3832 E7 17      F13I2   STA B   23,X      SET LO NZ FLAG
3834 20 06              BRA     F13J1
3836 6D 02      F13J    TST     2,X       ROLL>25?
3838 2F 02              BLE     F13J1     NO,BR
```

```
383A E7 2B             STA B  43,X      SET GTS
383C 6D 06      F13J1  TST    6,X       GND COND?
383E 26 04             BNE    F13K      YES,BR
3840 6D 05             TST    5,X       RPM<100?
3842 2C 11             BGE    F13L      NO,EXIT
3844 86 0F      F13K   LDA A  #15       CLR FLAGS
3846 6F 0F      F13K1  CLR    15,X      AND SET MODE=X
3848 08                INX
3849 4A                DEC A
384A 26 FA             BNE    F13K1
384C CE 0000           LDX    #CVL
384F 6F 2B             CLR    43,X
3851 6F 34             CLR    52,X
3853 6F 35             CLR    53,X
3855 7E 390D    F13L   JMP    F80
3858 6D 11      F13N   TST    17,X      MODE=X?
385A 27 F9             BEQ    F13L      YES,EXIT
385C 2B 0F             BMI    F13R      MODE=Y? YES,BR
385E A6 34             LDA A  52,X
3860 81 64             CMP A  #100      10 SECS UP?
3862 27 2E             BEQ    F13RZ     YES,BR .
3864 86 34      F13P   LDA A  #52       INC T23
3866 BD 398E           JSR    BUMPT
3869 A7 11             STA A  17,X      SET MODE=Z (1)
386B 20 98             BRA    F13E
386D 6D 17      F13R   TST    23,X      NZLO SET?
386F 27 D3             BEQ    F13K      NO,BR
3871 E7 14             STA B  20,X      SET M
3873 6D 15             TST    21,X      NZE SET?
3875 26 15             BNE    F13RC     YES,BR
3877 6D 13             TST    19,X      TQLO SET?
3879 27 04             BEQ    F13RA     NO,BR
387B 6D 12             TST    18,X      TQHI SET?
387D 26 0D             BNE    F13RC     YES,BR
387F A6 34      F13RA  LDA A  52,X
3881 A7 2C             STA A  44,X
3883 A6 35             LDA A  53,X
3885 A7 2D             STA A  45,X
3887 86 0F             LDA A  #15
3889 BD 3998           JSR    BUMPT2    ADD T23 TO T23A
388C 6F 34      F13RC  CLR    52,X
388E 6F 35             CLR    53,X
3890 20 D2             BRA    F13P
                *
                ** MISC MANEUVERS  GROUP 5   (FCC 86-91)
                *
3892 6F 11      F13RZ  CLR    17,X      CLR MODE BYTE
3894 6D 13             TST    19,X      TQ LO SET?
3896 27 0E             BEQ    F13T      NO,BR
3898 6D 16             TST    22,X      NZHI SET?
389A 27 05             BEQ    F13S      NO,BR
389C CE 0072           LDX    #114
389F 20 62             BRA    F13ZA
38A1 CE 006C    F13S   LDX    #108
```

```
38A4 20 5D               BRA     F13ZA
                   *
                   ** MISC MANEUVERS  GROUP 1   (FCC 23-28)
                   *
38A6 6D 16         F13T  TST     22,X      NZHI SET?
38A8 26 0E               BNE     F13V      YES,BR
38AA 6D 19               TST     25,X      A/S>=.8VH?
38AC 2F 05               BLE     F13U      NO,BR
38AE CE 00DE             LDX     #222
38B1 20 50               BRA     F13ZA
38B3 CE 00D5 F13U        LDX     #213
38B6 20 4B               BRA     F13ZA
                   *
                   ** MISC MANEUVERS  GROUP 2   (FCC 41-52)
                   *
38B8 6D 18         F13V  TST     24,X      HIGH ROLL SET?
38BA 26 20               BNE     F13Y      YES,BR
38BC A6 1A               LDA A   26,X
38BE 81 01               CMP A   #1        CHK A/S:VL
38C0 2E 15               BGT     F13W2     BR IF A/S>.95VL
38C2 27 0E               BEQ     F13W1     BR IF .85VL<A/S<=.95VL
38C4 6D 1A               TST     26,X
38C6 27 05               BEQ     F13W0
38C8 CE 0036             LDX     #54       A/S<.7VL
38CB 20 36               BRA     F13ZA
38CD CE 003C F13W0       LDX     #60       .7VL<A/S<=.85VL
38D0 20 31               BRA     F13ZA
38D2 CE 0042 F13W1       LDX     #66
38D5 20 2C               BRA     F13ZA
38D7 CE 0048 F13W2       LDX     #72
38DA 20 27               BRA     F13ZA
                   *
                   ** MISC MANEUVERS  GROUP 3   (FCC 62-70)
                   *
38DC 6D 2B         F13Y  TST     43,X      GUN S-TURN?
38DE 26 15               BNE     F13YA     YES,BR
38E0 6D 19               TST     25,X
38E2 2E 0C               BGT     F13Y2     BR IF A/S>=.8VH
38E4 27 05               BEQ     F13Y1     BR IF .65VH<=A/S<.8VH
38E6 CE 004E             LDX     #78       A/S<.65VH
38E9 20 18               BRA     F13ZA
38EB CE 0054 F13Y1       LDX     #84
38EE 20 13               BRA     F13ZA
38F0 CE 005A F13Y2       LDX     #90
38F3 20 0E               BRA     F13ZA
                   *
                   ** MISC MANEUVERS  GROUP 4   (FCC 71-76)
                   *
38F5 A6 19         F13YA LDA A   25,X
38F7 81 02               CMP A   #2
38F9 2D 05               BLT     F13YB     BR IF A/S<.9VH
38FB CE 0066             LDX     #102      A/S>=.9VH
38FE 20 03               BRA     F13ZA
3900 CE 0060 F13YB       LDX     #96
```

```
01608 3903 86 0F    F132A  LDA A  #15
01609 3905 D6 1B           LDA B  SGW      GET GROSS WT
01610 3907 BD 39A9         JSR    BUMPN
01611 390A 7E 3644         JMP    F13K
```

```
                        *
                        ****************************************************
                        ***  FCC 80-85 - AUTOROTATION TO POWER TRANSITION  *
                        ****************************************************
                        *
390D C6  01     F80     LDA B  #1
390F 6D  03             TST    3,X        TQ<5?
3911 27  18             BEQ    F80H       YES,BR
3913 6D  1E             TST    30,X       LOTQ MODE?
3915 26  08             BNE    F80G       NO,BR
3917 E7  1E             STA B  30,X       SET HITQ
3919 6D  01             TST    1,X        A/S>.65VH
391B 2B  02             BMI    F80G       NO,BR
391D E7  1F             STA B  31,X       SET A/S FLAG
391F 6C  21     F80G    INC    33,X       BUMP T80 CNTR
3921 6D  07             TST    7,X
3923 2B  10             BMI    F80K       BR IF NZ<1.3
3925 27  08             BEQ    F80J       BR IF NZ<1.5
3927 E7  22             STA B  34,X       SET NZ FLAG
3929 20  0A             BRA    F80K
392B 6F  1E     F80H    CLR    30,X       CLR LO TQ MODE
392D 20  22             BRA    F80R
392F 6D  22     F80J    TST    34,X       NZ>1.5 FOUND?
3931 2E  02             BGT    F80K       YES,BR
3933 6F  22             CLR    34,X       NO,CLR NZ FLAG
3935 A6  21     F80K    LDA A  33,X
3937 81  32             CMP A  #50        5 SECS ELAPSED?
3939 26  1E             BNE    F95        NO,BR
393B 6D  1F             TST    31,X       REQ'D A/S OK?
393D 27  12             BEQ    F80R       NO,BR
393F 6D  22             TST    34,X
3941 2B  0E             BMI    F80R       BR IF NO NZ FOUND
3943 27  05             BEQ    F80L
3945 CE  007E           LDX    #126
3948 20  03             BRA    F80M
394A CE  0078   F80L    LDX    #120
394D 86  3C     F80M    LDA A  #60
394F 8D  53             BSR    BUMP       INC CNTR
3951 6F  1F     F80R    CLR    31,X       CLR FLAGS
3953 6F  21             CLR    33,X
3955 6F  22             CLR    34,X       SET NZF TO -1
3957 6A  22             DEC    34,X
```

```
                    *
                    ****************************************
                    ***  FCC 95 - MISC. HIGH-G MANEUVERS  ***
                    ****************************************
                    *
3959 C6 01          F95    LDA B  #1
395B 6D 23                 TST    35,X      ARM?
395D 27 18                 BEQ    F95F      NO,BR
395F 6D 07                 TST    7,X       NZ<1.3?
3961 2C 1A                 BGE    F95G      NO,BR
3963 6D 24                 TST    36,X      LO A/S SET?
3965 26 0A                 BNE    F95C      YES,BR
3967 86 3C                 LDA A  #60
3969 5F                    CLR B
396A CE 00FB               LDX    #251
396D 8D 3A                 BSR    BUMPN     INCR FCC
396F 20 02                 BRA    F95E
3971 6F 24          F95C   CLR    36,X      CLR LO A/S FLAG
3973 6F 23          F95E   CLR    35,X      REARM
3975 20 10                 BRA    F95J
3977 A6 07          F95F   LDA A  7,X
3979 81 02                 CMP A  #2        NZ>1.7?
397B 26 0A                 BNE    F95J      NO,BR
397D A6 01          F95G   LDA A  1,X
397F 81 FE                 CMP A  #$FE      A/S<.5VH
3981 26 02                 BNE    F95H      NO,BR
3983 E7 24                 STA B  36,X      SET LO A/S FLAG
3985 E7 23          F95H   STA B  35,X      ARM
                    **
                    **
3987 73 000A        F95J   COM    IFLAG     SET DONE
398A 01             WAIT   NOP              WAIT FOR NEXT TIME INTRUPT
398B 7E 34E2               JMP    FLOOPA    (WAI,JMP F4)
```

```
                    *
                    ************************************
                    ***  BUMP SELECTED TIMER (BY 1)  ***
                    ************************************
                    *
398E 36             BUMPT   PSH A
398F 6F 2D                  CLR     45,X        SET BAA = 1
3991 6F 2E                  CLR     46,X
3993 86 01                  LDA A   #1
3995 A7 2C                  STA A   44,X
3997 32                     PUL A
3998 A7 28          BUMPT2  STA A   40,X
399A 6F 27                  CLR     39,X
399C DE 27                  LDX     NDX         GET ADDR OF TIMER
399E 8D 48                  BSR     MPBA2       BUMP TIMER
39A0 CE 0000                LDX     #CVL
39A3 39                     RTS                 EXIT
                    *
                    ********************************
                    ***  FCC TABULATION ROUTINE  ***
                    ********************************
                    *
39A4 37             BUMP    PSH B
39A5 D6 08                  LDA B   CGW         GET GROSS WEIGHT
39A7 20 01                  BRA     BUMP3
39A9 37             BUMPN   PSH B
39AA DF 27          BUMP3   STX     NDX         SAVE ADDEND ADDR
39AC 7F 0025                CLR     ASV
39AF 97 26                  STA A   ASV+1
39B1 DE 25                  LDX     ASV
39B3 A6 00                  LDA A   0,X         MOVE 2ND ADDEND TO BAA
39B5 97 2C                  STA A   BAA
39B7 A6 01                  LDA A   1,X
39B9 97 2D                  STA A   BAA+1
39BB A6 02                  LDA A   2,X
39BD 97 2E                  STA A   BAA+2
39BF 17                     TBA
39C0 97 29                  STA A   SNDX        SAVE GW
39C2 48                     ASL A               CVT TO NDX
39C3 D6 28                  LDA B   NDX+1
39C5 C1 96                  CMP B   #150        WHICH PREC?
39C7 25 02                  BCS     BUMP4       BR IF 2
39C9 9B 29                  ADD A   SNDX        MUST BE 3
39CB 9B 28          BUMP4   ADD A   NDX+1
39CD 97 28                  STA A   NDX+1
39CF C6 01                  LDA B   #1
39D1 D7 27                  STA B   NDX
39D3 DE 27                  LDX     NDX
39D5 0F                     SEI                 DISABLE INTERRUPTS TEMPORARIL
39D6 96 28                  LDA A   NDX+1       WHICH PRECISION?
39D8 81 96                  CMP A   #150
39DA 24 04                  BCC     BUMP5       IF TRIPLE,BR
39DC 8D 0A                  BSR     MPBA2       DOUBLE
39DE 20 02                  BRA     BUMPX
```

```
01744 39E0 8D 0A    BUMP5  BSR     MPBA3
01745 39E2 0E       BUMPX  CLI             REENABLE INTERRUPTS
01746 39E3 33              PUL B
01747 39E4 CE 0000         LDX     #CVL
01749 39E7 39              RTS             EXIT
```

```
                *
                ****************************************************
                ***  MULTIPLE PRECISION BINARY ADDITION ROUTINE  ***
                ****************************************************
                *
39E8 37         MPBA2  PSH B           DOUBLE PRECISION
39E9 5F                CLR B
39EA 20 03             BRA   MPBAA
39EC 37         MPBA3  PSH B           TRIPLE PRECISION
39ED C6 01             LDA B #1
39EF 36         MPBAA  PSH A
39F0 96 2C             LDA A BAA       BYTE 1
39F2 AB 00             ADD A 0,X
39F4 A7 00             STA A 0,X
39F6 96 2D             LDA A BAA+1     BYTE 2
39F8 A9 01             ADC A 1,X
39FA A7 01             STA A 1,X
39FC 5D                TST B           TRIPLE PRECISION?
39FD 27 06             BEQ   MPBAX     NO,BR
39FF 96 2E             LDA A BAA+2     BYTE 3
3A01 A9 02             ADC A 2,X
3A03 A7 02             STA A 2,X
3A05 32         MPBAX  PUL A
3A06 33                PUL B
3A07 39                RTS             EXIT
                *************************************************
                *************************************************
                *************************************************
```

```
2800                   ORG    $2800
2800 41       MES2     FCC    /ALTER PARAMETER? (0-9,N,L) /
281B 00                FCB    0
281C 49       MES3     FCC    /ILLEGAL PARAMETER!/
282E 00                FCB    0
282F 20       MES4     FCC    /    #/
2834 00                FCB    0
2835 45       MES5     FCC    /ENTER PASS COUNT (1-255) /
284E 00                FCB    0
284F 01       K1       FCB    1,10,100
2852 64       K10      FCB    100,10
2854 0001     LOOPCT   RMB    1
2855 0001     COUNT    RMB    1
2856 42       MES6     FCC    /BYTE    WAS     IS/
2868 00                FCB    0
2869 20       MES7     FCC    /    /
286D 00                FCB    0
286E 0014     BUFFER   RMB    20
2882 0002     SAVEX    RMB    2
2884 0002     SAVEX2   RMB    2

                       END

TOTAL ERRORS 00000
```


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