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MECHANICAL COMPONENT DIAGNOSTIC SYSTEM

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AVIATION APPLIED TECHNOLOGY DIRECTORATE POSITION STATEMENT

Helicopter vibration is known to cause premature failure of avionic components, structural cracks, aircrew fatigue, and flight envelope restrictions. This report describes a concept for identifying vibration problems and prescribing corrective action needed to lower vibration levels.

The approach taken was to integrate a vibration analyzer, flight data recorder, and cockpit display. Off-the-shelf equipment was selected to demonstrate the concept and reduce technical risk. The program objectives were bench demonstrated only.

Lessons learned from this program will be used in the formulation of future, more comprehensive diagnostic systems. Flight testing is needed to confirm the accuracy of diagnostic algorithms and help answer fundamental questions relating to costs and benefits for this type of an automated and integrated diagnostic concept.

Harvey Young of the RM&MT Technical Area, Aeronautical Systems and Technology Division, served as project engineer for this effort.

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The Mechanical Component Diagnostic System (MCDS) research and development (R&D) program was designed to investigate and demonstrate the benefits of onboard data recording/processing and rotor tuning equipment for monitoring and diagnosis of mechanical subsystems on rotorcraft. The payoffs for such a concept include reduced aircraft vibration levels (with extended MTBF of electronics and mechanical systems as well as reduced crew fatigue), reduced maintenance flights, and early warning of component failures. This program demonstrates an approach to a practical, automated system which monitors certain mechanical subsystems, provides inflight vibration and control system status, and prescribes corrective actions to the maintainer. Various monitoring components were developed and integrated to demonstrate this concept.

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PREFACE

The work reported herein was performed by Sikorsky Aircraft Division of United Technologies Corporation under Contract DAAJ02-87-C-0015 for the Aviation Applied Technology Directorate (AATD), Fort Eustis, Virginia. The work was carried out under the technical cognizance of Jack Tansey and Harvey Young of AATD. Sikorsky Engineering personnel directly involved in the program include Jerome Abbe, Dr. Raymond Carlson, James Cebik, Jerry Harris, Raymond Metro, George Molnar, Joseph Pratt (Program Manager), and Richard Sewersky.

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1. INTRODUCTION

The increasing complexity of the modern helicopter has often resulted in unacceptably high maintenance hours and ground and flight time to isolate mechanical and flight control component faults. Often this is due to a lack of expertise in troubleshooting techniques or simply to inadequate tools and techniques. This lack of expertise often results in a "shotgun" approach to maintenance with removal of good parts and subsequently high "retest OK" rates. Sometimes,inability to bring aircraft vibrations to acceptable levels can even result in restrictions in the operating envelope for the affected aircraft. Sikorsky field experience has borne this out. In visits to military installations, Sikorsky aeromechanics engineers found that aircraft surveyed were often outside specification limits in vibration levels. The application of proper track and balance procedures returned the aircraft to within limits. All of this points to the need for improved equipment and enhanced procedures.

The objective of the Mechanical Component Diagnostic System (MCDS) program was to capitalize on the recent advances and developments in the field of artificial intelligence, onboard data recording/processing, and rotor tuning equipment to develop a system with the capability to perform the following:

1. An on-aircraft pilot or copilot operated rotor vibration diagnostic system that will determine, in flight, the corrections needed to improve main and tail rotor track and balance and reduce one-per-rev vibration of both rotors.

2. An aircraft vibration troubleshooting concept which will monitor, distinguish and process vibrations which are rotor induced, rotating shaft induced, or result from control system feedback or loose mounts.

3. A flight control subsystem troubleshooting concept.

The MCDS design process built upon prior research performed during an earlier Army-contracted R&D program called the UH-60 Advanced Maintenance Demonstration, as well as an Army and Navy sponsored Structural Usage Monitor (SUM) program. The main contribution of these programs was the development of practical rotorcraft regime recognition algorithms which allowed the automation of vibration data gathering without the need for pilot participation. The flight data recorder used in the MCDS was also derived from the SUM program.

The MCDS concept integrates a vibration analyzer, flight data recorder and cockpit display. This concept provides automated background monitoring with minimum pilot interaction required. The system processes the data onboard with little requirement for extensive ground-based postprocessing. The calculated corrections for smoothing one-per-rev rotor induced vibrations are available inflight. In addition, detection and capture of other aircraft vibrations and vibration detectable problems is completed while airborne, and advice is given for further ground-based diagnosis and repair. A concept for detection and capture of certain flight control component problems was also developed.

A bench test of the MCDS configured for the UH-60A was performed and demonstrated the following capabilities: automatic data acquisition and analysis based on aircraft state (regime); pilot initiated capture of vibration and aircraft data (for later analysis); in-flight system status on pilot request; and vibration data trending and archiving. Mechanical subsystems monitored include: main and tail rotor (calculation of smoothing adjustments), engine high speed shafts, oil cooler, tail drive shaft bearing temperature, and general airframe vibration levels.

The following section provides a description of how MCDS capabilities provide technological advances over existing UH-60A field maintenance procedures. Also included is an overview of the MCDS operational modes and a walk-through of a typical flight with MCDS.

2. SYSTEM FUNCTIONAL DESCRIPTION

This section reviews the capabilities of MCDS from a diagnostic viewpoint as well as describes the MCDS user interface through a description of modes of operation and a walk-through of a typical flight with MCDS.

2.1. DIAGNOSTIC CAPABILITIES

This section provides a summary of the diagnostic capabilities for each fault mode covered by MCDS and some potential enhancements that should be considered in any future system updates. (Note that references to "Sikorsky" within this section are to the aeromechanics engineers who support the production line and develop vibration diagnostics.) MCDS capabilities are compared with present UH-60 diagnostic/troubleshooting procedures in Table 1.

TABLE 1. COMPARISON OF MCDS DIAGNOSTICS CAPABILITIES WITH CURRENT CAPABILITIES ON THE UH-60A

Diagnostic Task	Present Operational Capability	MCDS Capability Detection / Isolation
1P Vibrations:		
Main Rotor Track and Balance:		
Flat Pitch Track (PCR Adjustments)	Note 1	Onboard
Ground Balance (Hub Wt. Adjustments)	Note 1	Onboard
Hover Spread (Tip Wt. Distribution)	None	Onboard / Ground
High Speed Vibration:		
PCR Adjustments	Note 1	Onboard
Tab Adjustments	None	Onboard
Blade Resequence	None	Onboard
Dampers	None	Onboard / Ground
Tail Rotor Balance	Note 1	Onboard
4P Vibrations:		
Nose Absorber	Note 1	Onboard
Cabin Absorber	Note 1	Onboard
Shafts:		
Engine Drive	Note 1	Onboard / Ground
Oil Cooler	Note 1	Onboard / Ground
Tail Rotor Drive		
Balance	None	Onboard / Ground
Bearings	None	Onboard / Ground
Disconnect	None	Onboard
General Vibrations	None	Onboard / Ground
Stabilator	Note 2	Onboard / Ground

Note 1. Requires aircraft instrumentation, dedicated flight and use of maintenance manuals.
Note 2. Requires detailed fault tree analysis.

One-per-Revolution (1P) Vibrations

Existing procedures in track and balance are essentially similar for all helicopter models. They require instrumenting the aircraft and making measurements at several locations under various flight conditions and using a hand-held strobe light to measure blade track. Analysis of the data is done by manually plotting the measured data on graphic plots and interpreting these plots to determine an adjustment. Implemented correctly, these adjustments are usually in the correct direction; however, they are not optimum and may require several flights to finally bring the aircraft within specifications. A review of unpublished procedures used at Sikorsky by aeromechanics experts shows that more automated tools are used and additional procedures are available for rotor diagnostics and smoothing. There are several basic tasks pertaining to rotor smoothing which were examined by the MCDS program and are summarized below:

- Flat pitch track - The rotor is initially tracked at flat pitch if one or more new blades are installed or other major rotor hub changes are made. Current practice, using the strobe with mounted blade targets, at best achieves 1/4" accuracy. MCDS and Sikorsky, using an automatic track sensor, achieves an accuracy of only a few millimeters with very good repeatability. In addition, MCDS can tailor its adjustment strategy based on inputs of what rotor maintenance was completed.

- Ground balance - Rotor balance data is acquired using the main rotor contactor and accelerometers. Although data is acquired in the same manner by the field, MCDS and Sikorsky, MCDS has the added capability to output this adjustment as a revised weight configuration (if the existing configuration is maintained by input of all changes to the MCDS).

- Hover spread - This is a change in blade track spread when the aircraft changes from flat pitch ground to hover condition and indicates a possible blade problem (probably due to tip weight distribution problems). There is currently no accurate field procedure to check for this. MCDS will check this and indicate the problem. Further development work in flight testing may allow MCDS to automatically calculate tip weight adjustments in addition to indicating the problem.

- High speed track and balance - This currently involves taking track and vibration data at various test regimes, plotting the data, and manually determining an adjustment to Pitch Control Rods (PCR). MCDS and Sikorsky automatically acquire this data and output optimum adjustments for both vertical and roll vibration while also minimizing track spread. These adjustments include bending the blade tab which is not currently implemented by the Army in the field. MCDS could additionally provide alternate maintenance actions with an indication of the chances of success of each maintenance option to bring the aircraft into specification. Typical maintenance alternatives would include PCR adjustments only, blade resequence with PCR adjustments, and blade tab combined with PCR adjustments. This feature was designed but is not yet incorporated. An additional capability that could be added is to provide feedback if an adjustment was entered incorrectly (i.e., if the vibration response of the aircraft was different or opposite from that expected based on the maintenance that was indicated to the system as completed). This feature would require that MCDS keep track of requested versus actual maintenance performed.

- Dampers - Main rotor dampers can have a significant effect on low frequency vibration comfort levels. Identification of a misbehaving main rotor damper is possible. However, no field procedures exist for the UH-60A. MCDS detects a possible damper fault through examination of roll vibrations. Diagnosis of a particular damper would require further flight test development work to be added to MCDS. However the basic instrumentation is on MCDS.

- Tail rotor balance - This is currently accomplished both in the field and at Sikorsky through use of a strobe (for phase information) and accelerometer with the adjustment calculated manually. MCDS has replaced the strobe with a magnetic contactor and automatically calculates balance adjustments. These adjustments can be provided as specific calculated bolt/washer configurations if the existing configuration is maintained by MCDS (current practice requires the maintainer to carry a scale to the aircraft to weigh the various bolt/washer combinations).

Four-per-Rev (4P) Vibrations

The proper operation of vibration absorbers in the UH-60A aircraft is paramount for any troubleshooting concept. Early UH-60A aircraft were delivered with three mass absorbers; later aircraft with only two. The capability of providing a comfortable, acceptable environment is dependent on the efficiency of those absorbers, particularly the forward cabin absorber. Efficiency of an absorber is a function of proper tuning (resonant frequency) and damping ratio (in this instance, minimum friction in all bearing/bushing locations). Both functions are identifiable and controllable using currently known algorithms. These procedures are currently included in maintenance manuals. MCDS monitors vibrations at two absorber locations but calculates an adjustment for the nose absorber only. Extension of MCDS to calculate cabin absorber tuning adjustments could be made but this would only be allowed in maintenance mode. This procedure is restricted to maintenance test pilots because the vibration data must be acquired at a series of points around 100% Nr, which requires flying the aircraft without automatic engine control.

Engine High Speed Shaft

Engine high speed shaft vibration can be reduced through maintenance actions initiated when vibration levels exceed a predetermined level. Currently this is done after ground runs using procedures contained in field manuals. MCDS monitors vibrations in flight at both engine drive shafts and indicates specification exceedances as well as trending problems. Vibration data is taken on a periodic basis (currently once every 10 minutes).

Oil Cooler

The oil cooler, like the drive shaft, is monitored by exceedance of a vibration level. This is also covered in the maintenance manual. MCDS monitors vibrations at this location and indicates specification or trending exceedances.

Tail Rotor Drive Shaft (TRDS) Bearing Temperature

MCDS monitors the bearing temperature (as it differs from ambient) and will issue a pilot caution if the difference exceeds some predetermined value. Early MCDS plans called for vibration monitoring here as well. However, further investigation found that the accelerometer installation was difficult and that the chosen track and balance instrument was incapable of the type of data analysis that would be required.

TRDS Disconnect Detection

Since MCDS has a permanently mounted tail rotor RPM pickup and accelerometer, MCDS can check to be sure that the tail rotor drive is intact. There have been incidents on the UH-60 where early confirmation that the tail rotor drive has been lost could allow safe autorotative descent. MCDS can only check this periodically due to requirements to share these same channels for other measurements; however, a concept demonstration is possible and a production system could dedicate hardware resources to continuously monitor this.

General Vibration

To discover and capture other possible vibration problems for which specifications may not be available, MCDS periodically acquires asynchronous spectra in the 0-500 Hz range to help identify the onset of vibrations or vibration detectable problems before they become noticeable to the pilot or observer These spectra are compared to a reference spectra, and any vibrations that exceed the reference are displayed as frequency and amplitude pairs.

Stabilator Input Monitoring

The current approach to electronic flight control troubleshooting involves following a detailed fault tree which must be interactively traced on the ground. Sikorsky's flight control troubleshooting experience indicates that often the problems which trip system trouble indicators cannot be duplicated on the ground and only after much effort are traced to intermittent bad inputs from sensors while in flight. MCDS can monitor the dual sensor and stick position inputs to the stabilator system as well as the various stabilator related caution panel discretes. A change of state of either of the key discrete indicators will automatically record a time history of all monitored aircraft parameters which can be examined by the maintainer after the flight. There is a potential that this post-flight analysis could be automated through use of expert systems, and a preliminary set of troubleshooting rules were developed. These basically involve various cross-checks between parameters that indicate inconsistencies pointing to specific sensors.

2.2. SYSTEM FUNCTIONALITY

This section describes the intended functionality of the MCDS from the user's viewpoint with some description of what MCDS is doing in the background. A description of setup and operation of the system is covered in Reference 1.

Architecture Overview

To understand the discussion of operating modes and the flight walk-through below, a basic understanding of the system architecture is required. This section introduces the main system components and their role in MCDS. Section 3 covers the MCDS design in more detail.

There are four major components that comprise MCDS:

- Flight Data Recorder (FDR) serves as the primary interface to the normal aircraft sensors (i.e., airspeed, altitude, attitude, and weight on wheels) and determines aircraft state (or regime) which is used to guide the automatic data acquisition process.

- Maintenance Computer (MC) controls system operation and carries out most of the data acquisition, monitoring and diagnostics. It consists of a modified vibration analysis instrument with two components and a sensor suite. The Control and Display Unit (CADU) executes the system software and controls data acquisition that is carried out by the Data Acquisition Unit (DAU). Sensors include accelerometers for vibration, contactors for rotor timing and a track sensor for rotor position.

- Cockpit Display (CD) is installed in the center console and provides for pilot interaction.

- Ground Processor (GP) is used to support both systems providing software maintenance, calibration, and data download and display.

Each of these components is linked via serial communications lines, the primary one allowing a continuous dialog between the MC and the FDR.

MCDS Operating Modes

The MCDS operates in the following modes which are selectable via the top level menu from the CD:

System Initialization - This mode starts with powerup and ends with the display of the main menu on the CD. As each unit detects presence of power, it initializes its software, completes Built In Test (BIT) and waits for communication to begin. The FDR completes powerup first and automatically enters its monitoring/recording mode waiting for MC commands. If the GP is connected to the FDR, it enters GP mode and responds to GP commands instead. If neither the GP nor the MC is connected and functional, the FDR will still record data normally and complete the stabilator monitoring function. The MC initiates communications with the FDR and if unsuccessful enters a backup mode whereby regimes and other control information can be entered from the CADU screen. Displays intended for the CD are also echoed on the CADU in the FDR backup mode. If initialization is successful, clocks are synchronized and normal MCDS monitoring mode is entered. If there is no display on the CD, the user may manually switch to the backup CD display on the CADU. Hence, failure of any single component does not totally disable the MCDS.

Monitor Mode - In this mode the MCDS continuously watches the incoming data in order to detect faults. Monitoring falls into two categories:

- Regime dependent
- Periodic (or regime independent)

Regime-dependent acquisition is only performed if the aircraft is flying in a diagnostic regime as determined by the FDR. There are currently six regimes of diagnostic interest, and priority is given to data acquisition if one of these is detected by the FDR. For periodic monitoring, the system samples data at close to the given interval (i.e., once per minute or once per 10 minutes), validates it and performs diagnostic routines appropriate to the data. For both regime-dependent and periodic acquisitions, if the data indicates a problem, the pilot is notified as appropriate to the problem urgency in general accordance with the flight manual. The pilot may also request a time history in this mode for any reason. Time history data is continuously buffered on the FDR. A time history request will cause the FDR to record selected parameters and the MC to sequentially record vibration spectra for selected channels. If the system discontinues monitoring for any reason, this will be indicated on the CD. Pending problems will be stored and available upon pilot or maintainer request.

Silent mode - Toggles between ON and OFF. If ON, MCDS holds all advisories until the pilot requests status. Cautions and warnings are displayed regardless of this mode setting.

Maintenance Mode - In this mode the maintenance test pilot will use the system to acquire flight data in given regimes for fault isolation and to verify that faults have been removed/corrected and that the aircraft is ready for mission flight. This mode gives the maintenance test pilot access to diagnostic measurements and prompts him through diagnostic regimes with automatic regime verification/data acquisition. The tolerances for regime identification are tighter for maintenance mode since the pilot is specifically flying to gather data for maintenance.

Expert Mode - This mode is similar to the normal testing modes available on current commercial track and balance test equipment. In this mode, the expert has full access to all system measurements and data processing programs as opposed to the preplanned flight plans in the maintenance or monitor mode. It would normally be used by operators thoroughly familiar with the system and vibration diagnostics and will run on the CADU.

Utility Mode - In this mode the system allows the user to view selected data trends, change selected system parameters and unload data for backup. These options are briefly described below:

- Unload data - transfers control to the CADU to enable selective transfer of airborne gathered data to a backup file for later transfer to backup media.

- Alter track or vibration specifications - transfers control to the CADU to allow selection of certain specifications or parameters from a menu on the CADU and, showing what the old value was, allow a new value to be entered. This new value will be used in the execution of the software affected.

- Alter aircraft configuration - transfers control to the CADU to allow update of the configuration of certain components (i.e., hub weights and blade serial numbers). The data structures being updated here are not currently utilized as part of the diagnostics, and use of these would be a potential future enhancement.

Typical Scenario of Operation

The following section walks the reader through a typical flight using the MCDS. (Section 3.6 - Software Development contains flowcharts and more detailed descriptions of the software involved).

After *powerup/initialization* (assuming all components are operational) a screen will appear listing problems from the previous flight. Figure 1 shows an example of a typical initial status screen. The choice of "MENU" will display the main menu as described above and as shown in Figure 2. If nothing is selected and the aircraft begins flight (as described below), the system will default to monitor mode.

On detection of rotor runup (30 to 98%Nr), the FDR issues a STARTFLT regime code indicating the *start of flight*, the system enters monitor mode, and an entry is made to the flight log noting the time. Figure 3 shows an example monitor mode screen.

When the FDR detects that the rotor has reached *100% Nr*, it issues the FPG100 regime code and MCDS acquires main and tail rotor vibration data. Once MCDS has enough data (at least 3 points), each data point is examined in various ways:

- First, it checks for scatter which would indicate an instrument problem.

- Next, it is checked against the historical trend and ignored if it hasn't changed significantly from the previous point (unless it is the first point in the flight which is always kept).

- If it is different but tracking along the trend, it is checked against specifications and if it is over spec limits, MCDS will notify the pilot and attempt to calculate corrections.

- Corrections would include PCR and/or balance weight adjustments for the example flat pitch regime as shown in Figure 4.

- If more data is needed to correctly calculate adjustments (i.e., additional regimes), MCDS will add these to the requested regime list and suspend diagnostics on this problem. This list is available to the pilot at various points whereby the pilot can fly these on return from his mission to avoid a special diagnostics flight.

- Its slope is calculated next and if it is increasing, a linear projection is made to estimate when it will exceed limits (prognosis). If the exceedance is expected shortly, MCDS will also advise the pilot.

- If no problem is indicated, MCDS will save the data point in the historical data base (MCDS keeps up to 30 previous points for about 30 different parameters) or trash it if it is essentially the same as the last sample.

Other regimes (Hover, 80Kts, 120Kts, 145Kts, Vh) are handled similarly as they are recognized by the FDR. MCDS insures data quality by monitoring for regime stability during data acquisition.

The pilot may *request status* at any time. Status is presented in order of problem severity (warnings, cautions, advisories) and chronologically within a category.

The pilot may *request a time history record* at any time. The system will immediately commence data acquisition simultaneously on both FDR (which also buffers the previous 5 seconds of data) and MC subsystems and will request confirmation of storage when the acquisitions are complete as shown in Figure 5.

When *aircraft shutdown* is detected (rotor below 98% and engine torques near zero), the system will log the ending time and bring up the final status screen as shown in Figure 6. Processing of any unprocessed raw data or incomplete diagnoses will continue until power is lost. The FDR indicates if any time history data needs to be downloaded and examined or if memory usage is over 80% full. Download and display of the data is done using the GP. Figures 7 and 8 show example MC spectrum graph and FDR time history printouts respectively. If the system failed during flight or the pilot shut down quickly, queues of both unprocessed raw data and uncompleted diagnostics are maintained and processing of these will continue during the next flight. In the case of a system failure where there was no automatic entry of flight ending time, MCDS will prompt for manual entry of the flight ending time which will be added to the flight log file. This is needed to properly calculate data trends which are based on flight hours.

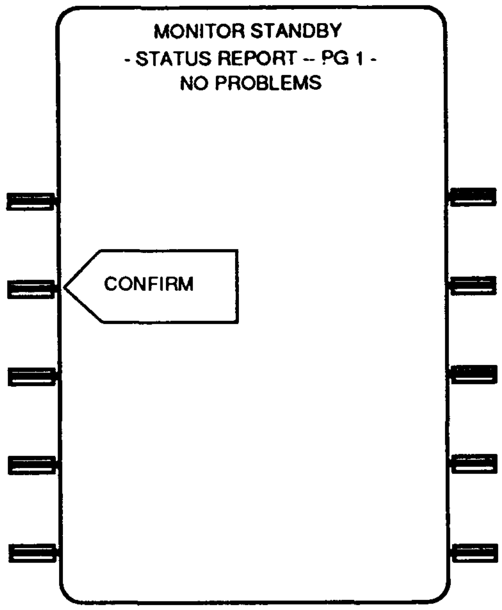

Figure 1. Initial status screen cockpit display.

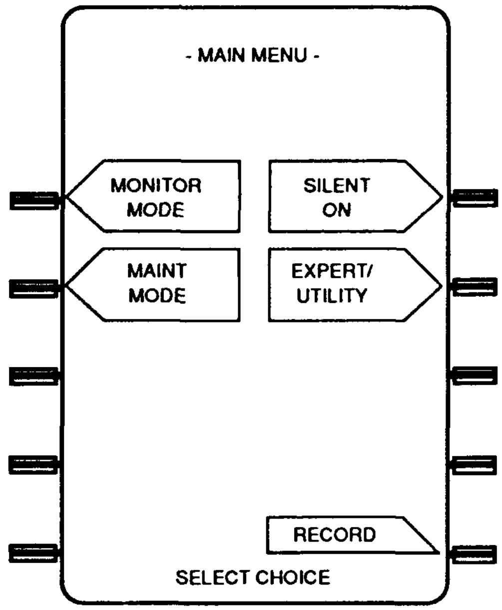

Figure 2. Main menu screen cockpit display.

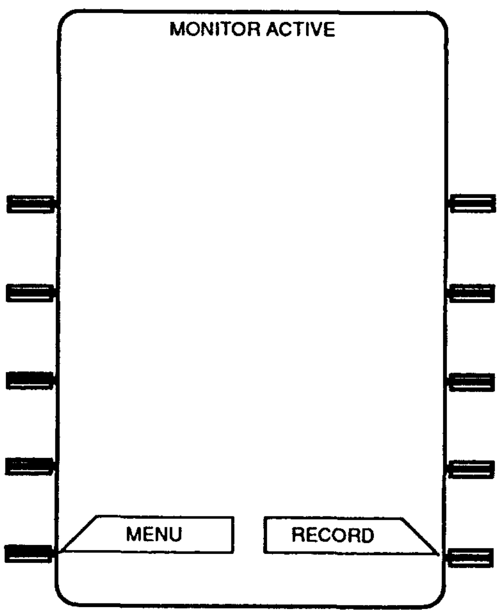

Figure 3. Monitor mode screen cockpit display.

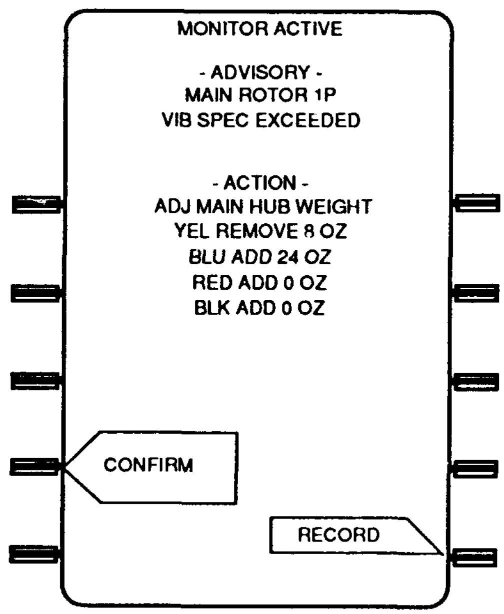

Figure 4. Hub balance advisory screen cockpit display

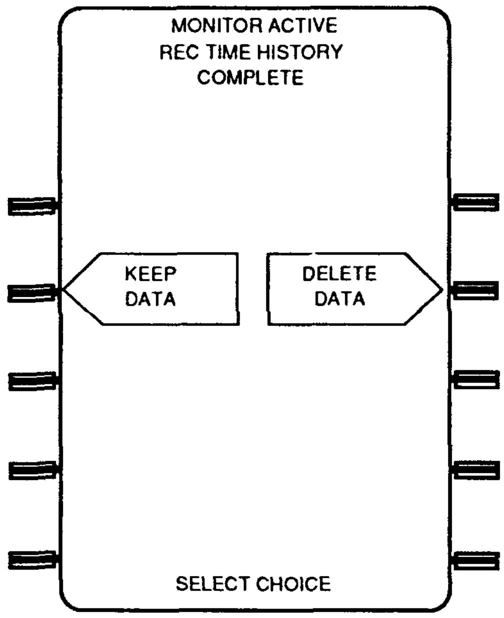

Figure 5. Time history complete screen cockpit display.

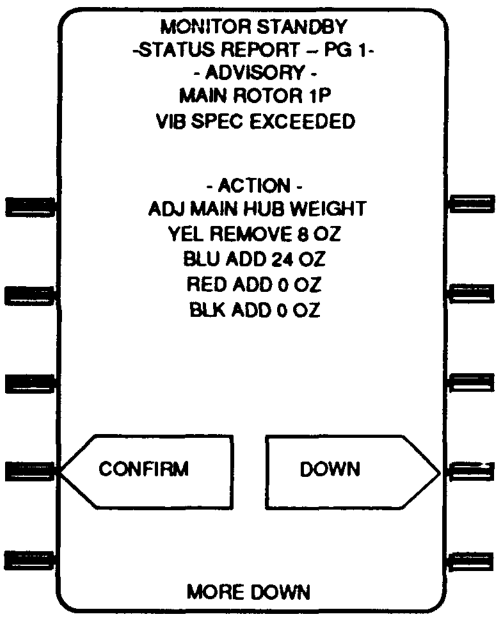

Figure 6. Final status screen cockpit display.

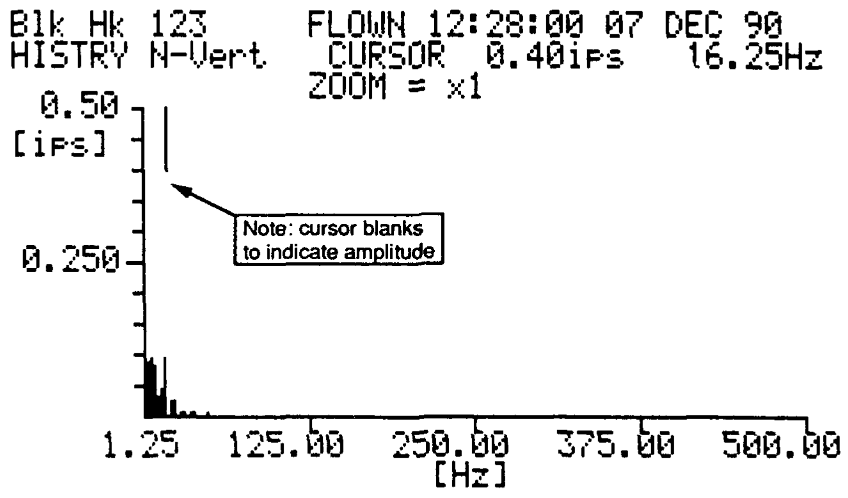

Figure 7. Sample vibration spectrum graph.

Time History Printout - SIKORSKY
90-10-12 17:00:59 exceedences:1 BIT:0 FS:0 ROC:1 IA:0 wraparound:no

Parameter ID	Time	Reading	Condition
BIT results	0.00	00000000	mcds
Rotor Speed (Nr)	0.25	Passing 50%	GAG data
Weight-on-Wheels Detect	0.25	OFF	AIRBORNE
Manual Slew	0.25	OFF	
Stabilator Failed	0.25	OFF	
Stabilator Up Limit	0.25	OFF	
Stabilator Down Limit	0.25	OFF	
Flight Path Stab.	0.25	OFF	
Weight-on-Wheels Detect	80.25	ON	LANDED
Airspeed #1	80.50	regime 0	ROC ON
Radar Altitude	80.50	regime 0	ROC ON
Airspeed #1	81.00	regime 0	ROC OFF
Radar Altitude	81.00	regime 0	ROC OFF
Yaw Rate	387.75	-0.25 deg/sec	before MC req
Pitch Rate #1	387.75	-0.25 deg/sec	before MC req
Pitch Rate #2	387.75	-0.25 deg/sec	before MC req
Load Factor (Nz)	387.75	0.98 G	before MC req
Rotor Speed (Nr)	387.75	79.82 %	before MC req
Engine Torque (Q1)	387.75	79.58 %	before MC req
Engine Torque (Q2)	387.75	80.20 %	before MC req
Barometric Altitude	387.75	-909.73 ft	before MC req
Barometric Rate of Climb	387.75	0.00 fpm	before MC req
Airspeed #1	387.75	30.38 knots	before MC req
Long. Stick Position	387.75	44.71 %	before MC req
Lat. Stick Position	387.75	45.11 %	before MC req
Coll. Stick Position #1	387.75	45.03 %	before MC req
Coll. Stick Position #2	387.75	45.03 %	before MC req
Pedal Position	387.75	44.61 %	before MC req
Radar Altitude	387.75	2.74 ft	before MC req
Temp. TRDS Bearing	387.75	25.98 deg C	before MC req
Stabilator Actuator POSN #1	387.75	56.25 %	before MC req
Stabilator Actuator POSN #2	387.75	30.28 %	before MC req
Lateral Acceleration #1	387.75	0.00 G	before MC req
Lateral Acceleration #2	387.75	0.00 G	before MC req
Temp. Tail Drive Amb	387.75	24.00 deg C	before MC req
Roll Attitude	387.75	1.41 deg	before MC req
Stabilator Position	387.75	-23.85 deg	before MC req
Weight-on-Wheels Detect	392.75	ON	LANDED
Manual Slew	392.75	OFF	
Stabilator Failed	392.75	OFF	
Stabilator Up Limit	392.75	OFF	
Stabilator Down Limit	392.75	OFF	
Flight Path Stab.	392.75	OFF	
REGIME CODE	387.75	regime 1	before exc/req
REGIME CODE	388.75	regime 1	before exc/req
REGIME CODE	389.75	regime 1	before exc/req
REGIME CODE	390.75	regime 1	before exc/req
REGIME CODE	391.75	regime 1	before exc/req
REVERSAL	387.75	reversal 0	before exc/req
REVERSAL	388.75	reversal 0	before exc/req
REVERSAL	389.75	reversal 0	before exc/req
REVERSAL	390.75	reversal 0	before exc/req
REVERSAL	391.75	reversal 0	before exc/req
END OF FLIGHT			

Figure 8. Sample time history printout.

3. SYSTEM DESIGN

Since the MCDS was designed primarily as a demonstration of the application of existing technologies to the goal of onboard monitoring, a conscious effort was made to minimize the development of new hardware and software and to use as much "off-the-shelf" components as possible. The following paragraphs briefly outline the development process.

First, competing rotor diagnostics and flight data recorder systems were evaluated and one of each was selected. This selection process is described in detail in Reference 2 and was based on application of qualitative rating criteria to the various systems under consideration. The rating criteria that were used to select the chosen configuration included the following:

- Technological Maturity
- Cost of New Software
- System Reliability
- Integration Difficulty
- Availability of Hardware
- Subsystem Capability
- High Level Diagnostic Language
- Standard Operating/Development Environment
- Unique Features

Second, a plan was developed to modify the chosen equipment into the required MCDS configuration. After several technical exchanges and an in-depth review of the technical documentation of each selected system, the "surgical process" to convert both systems from manual operation to automatic background monitoring was defined. Since the existing rotor track and balance systems are designed as support equipment, they require manual operation to select and initiate data acquisition and analysis. The diagnostic capabilities are also limited to basic track and balance calculations. Modifications to the track and balance system required addition of software to handle the other types of problems as well as to convert from manual to automatic data acquisition.

Existing FDR's are primarily stand-alone and thus operate as passive recording devices only. In order to fulfill its intended role in MCDS, the FDR modifications involved addition of communications interfaces and changes to the time history function already available in the structural usage monitoring configuration.

Based on this modification plan, a top level structured design was completed which is documented in Reference 2. This included the definition of appropriate data structures needed, design of top level flow and control, and determination of which modifications could best be implemented by each subcontractor.

Meetings were held with the subcontractors to define detailed interface specifications. Since Sikorsky was also making modifications to subcontractor's software, there were three primary interfaces that needed to be defined:

- the communications between the MC and the FDR

- module interfaces between Sikorsky applications code running on the MC and the controlling MC executive program

• module interfaces between Sikorsky applications code running on the FDR and the controlling FDR executive program.

The final step required negotiation of contracts for the defined subcontractor modifications. All equipment and subcontracted modifications of this equipment used in this program were purchased by Sikorsky.

3.1 MCDS ARCHITECTURE

MCDS equipment configuration is shown schematically in Figure 9.

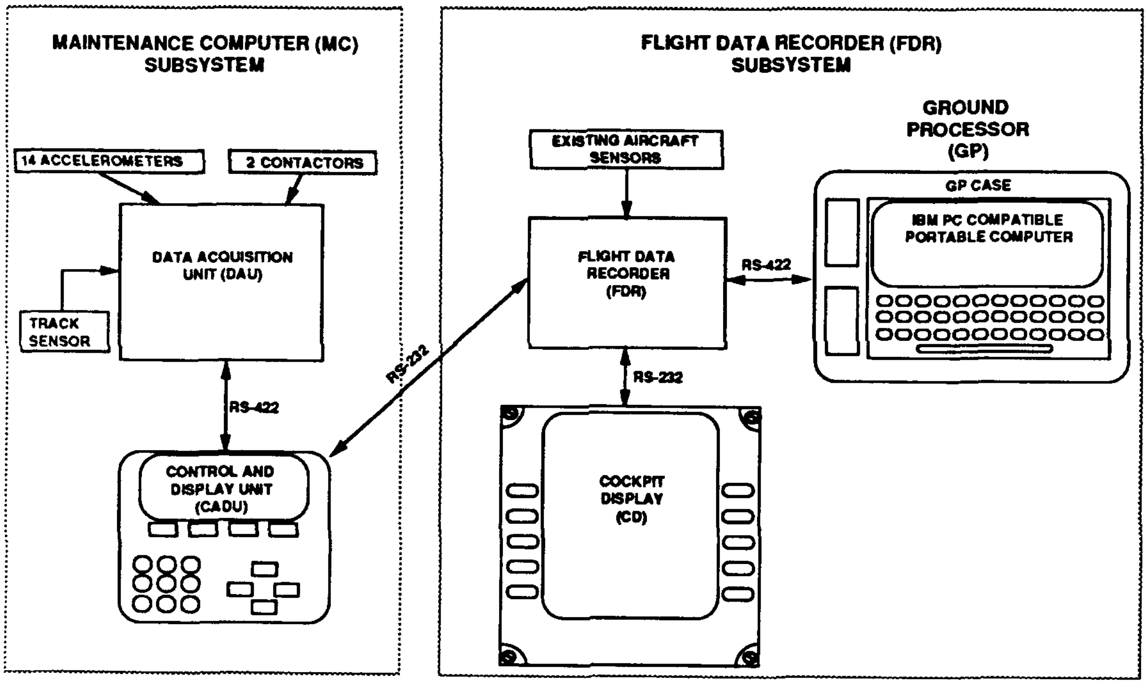

Figure 9. MCDS configuration diagram.

The MCDS is composed of two major subsystems, the MC and the FDR. There is also a GP which supports the major airborne subsystems. The following section briefly describes each major subsystem and how the subsystems tie together to form the MCDS (details of the components of each subsystem follow in section 3.2):

3.1.1. Maintenance Computer Subsystem

This subsystem acquires all vibration, blade track, and rotating shaft position data. The MC also acquires certain data from the FDR. The unit analyzes the data according to resident diagnostic programs and provides temporary storage of data. The MC also contains the executive program which controls the monitoring and diagnostic processing as well as the overall user interfaces. The

MC has a separate control unit capable of setting up and executing certain data acquisition and processing functions.

The MC is capable of stand-alone operation using the control unit or in conjunction with the ground processor. The control unit has a self-contained battery for temporary power so that data can be permanently stored prior to system shutdown.

3.1.2. Flight Data Recorder Subsystem

This subsystem acquires data from aircraft state sensors. The FDR analyzes the data in order to recognize when a stabilized regime of diagnostic value is being flown. The unit provides this information to the MC so that regime dependant data acquisition can be performed. The unit drives the CD and transmits information to and from the MC. The FDR, either upon command from the MC or upon detection of certain parameter value changes, stores a parameter time history.

The FDR subsystem is capable of stand-alone operation as a usage monitoring device and in conjunction with the GP. The FDR has battery-backed memory so that data can be permanently stored. The case that contains the GP can also supply power to the FDR during data download operations and contains specialized hardware to speed up download data transfer. The system has self-test capability.

The CD allows the entire MCDS to communicate with the pilot or maintainer. The CD also allows the pilot to activate certain MCDS functions.

3.2. AIRBORNE SYSTEM DESCRIPTION

All MCDS components are used in the airborne configuration with the exception of the ground processor. The tasks that are performed by each subsystem are described below.

3.2.1. Maintenance Computer Subsystem

Vibration Measurements - The system monitors vibration levels for 14 locations (up to 4 simultaneously). All the vibration data is evaluated by Fourier analysis. Vibration measurements are of two types: synchronous (contactor related orders of main and tail rotor such as 1P main rotor, 4P main rotor, 1P tail rotor, etc.) or asynchronous for non-rotor (non-contactor) related frequencies.

Track Measurements - The system measures blade track from one or two track sensors (two track sensors are necessary to make this system extensible to the CH-47). For the UH-60A only one track sensor is used. The system is capable of taking both relative and absolute flap and lead/lag track measurements for as many as seven blades. The track sensor is hard-mounted on the aircraft.

Timing Measurement - The purpose of this measurement is to allow identification of individual blades for the rotor system adjustments and to provide a reference for synchronous vibration analyses. Two magnetic contactors (one for the main rotor and one for the tail rotor) are used as a part of the permanently mounted instrumentation.

Data Processing - The MC provides signal and data processing for directly accessed sensor data as well as information acquired from the FDR. The operating system is real-time and multi-tasking.

Communications - The MC will control the entire MCDS during ground and flight operations. Communication from the MC is provided through RS232 ports to the FDR and to the GP when it is connected.

The MC subsystem is a modified version of the Rotor Analysis and Diagnostics System - Advanced Technology (RADS-AT) produced by Scientific Atlanta of San Diego, CA. It is composed of several components as described below:

Control and Display Unit (CADU) - This is a hand-held computer based on the 68000 microprocessor with access to 2 megabytes (MB) of battery backed memory and programs stored in read-only memory. It contains most of the MCDS diagnostic and executive software which is written in a specialized interpretive language running under the OS/9 operating system. The CADU maintains communications with the FDR and through it with the CD. It can be used as a flight engineer's station to monitor the internal functioning of the MCDS system. There are also removable "Credit Card" memory devices which are used for supplemental storage and data archival. Figure 10 is a photo of the CADU.

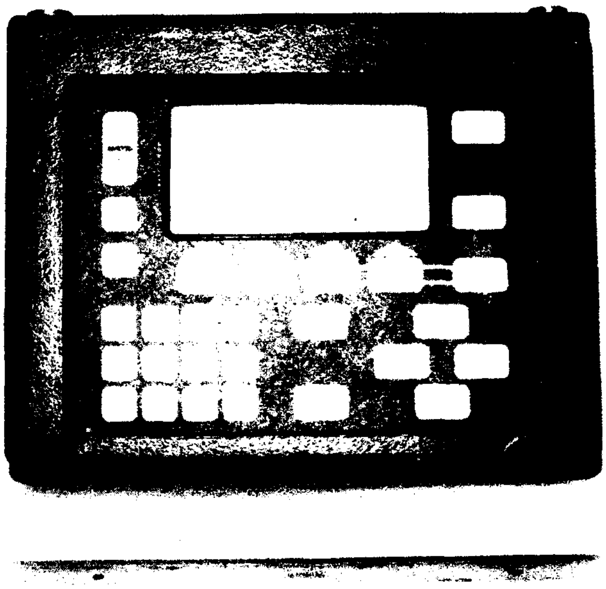

Figure 10. Control and display unit.

Data Acquisition Unit (DAU) - This is also a 68000 based system with specialized signal processing hardware which interfaces with accelerometers, contactors and the track sensors. It acquires and processes vibration and track data under command from the CADU and relays this data to the CADU for storage and analysis. Figure 11 is a photo of the DAU.

Accelerometers - MCDS uses standard 100 milivolt/G accelerometers.

Track Sensor - This is a fixed mounted unit that converts measured blade position into a digital pulse train which is interpreted by the DAU and processed into flap and lag track information.

Contactors - Standard magnetic contactors are used for acquiring main and tail rotor timing data.

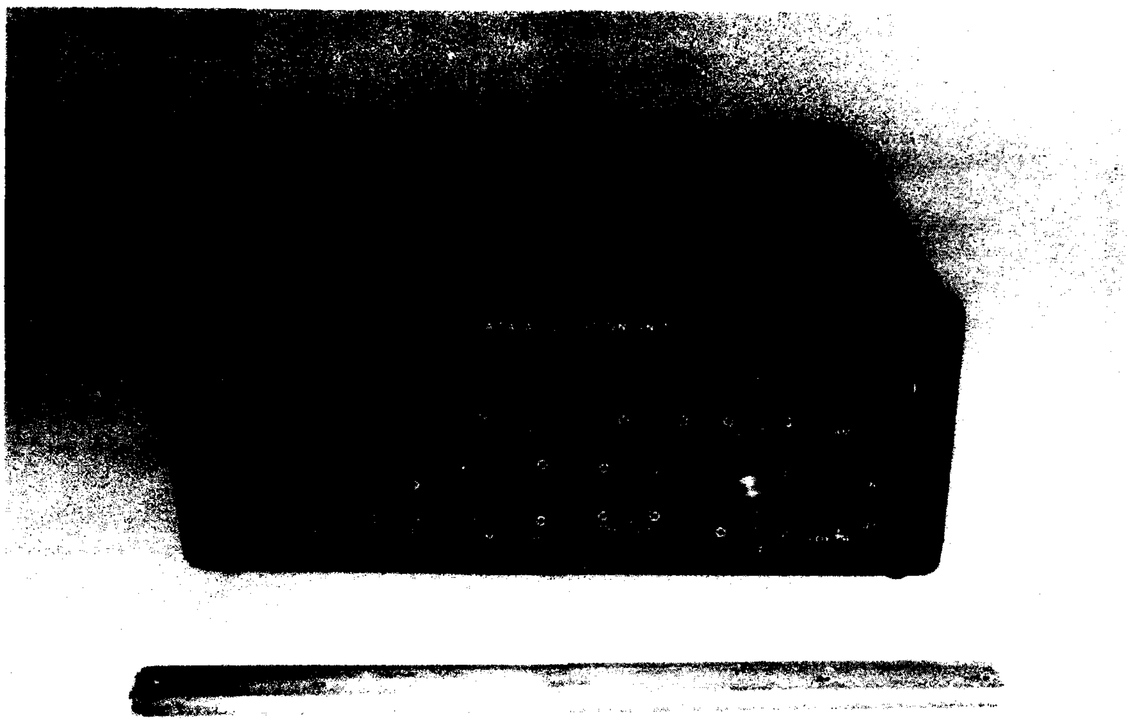

Figure 11. Data acquisition unit.

3.2.2. Flight Data Recorder Subsystem

Data Acquisition and Processing - The FDR provides signal conditioning for all FDR connected sensors. The FDR acquires data from these sensors and processes it to determine aircraft regime, builds certain parameter and regime histograms, buffers it for capture of time histories, and passes requested parameter values to the MC. Each analog channel is tested on powerup and is tested periodically during operation. Each channel also has a differential input in series with isolation resistors to prevent degradation of ship systems.

Communications - The FDR maintains communications with other systems through serial ports. Its I/O ports are used as follows:

Mating System	Type	Role
MC	RS232	Responds to MC requests for regimes and data
CD	RS232	Passes MC display commands and CD keystrokes
GP	RS422	Used for data download, calibration, and program maintenance

The FDR subsystem includes a modified version of the Structural Usage Monitor (SUM) produced by Canadian Marconi of Kanata, Canada. It is composed of several components as described below.

Flight Data Recorder - The FDR uses a 1750A microprocessor with its own memory and access to an auxiliary memory unit composed of battery-backed memory for data and program storage. It is programmed in ADA and runs under a proprietary operating program. Figure 12 is a photo of the FDR.

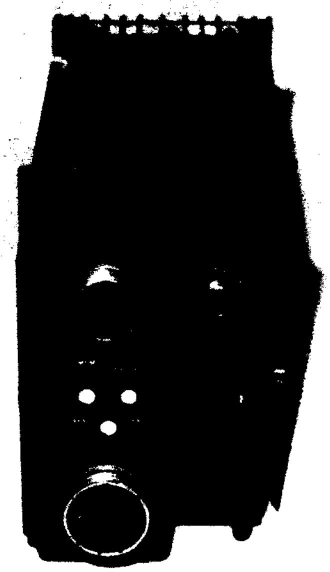

Figure 12. Flight data recorder.

Cockpit Display - This is a Canadian Marconi self-contained display unit. It is a smart terminal, microprocessor-controlled (Intel 80186/8087) system with 256 Kbytes EPROM, 16 Kbytes RAM, and 8 Kbytes EEPROM. The unit has been qualified for MIL-E-5400 Class 1A environmental conditions and is currently in production. The unit has a display capacity of 20 lines at 21 characters per line which will be sufficient to provide MCDS messages. The CD is 5.75 inches wide, 6 inches in depth, and 9.375 inches long. It will be located in the pilot's side, lower control console to enable visible, convenient and accessible operation for the MCDS demonstration. Figure 13 is a photo of the CD.

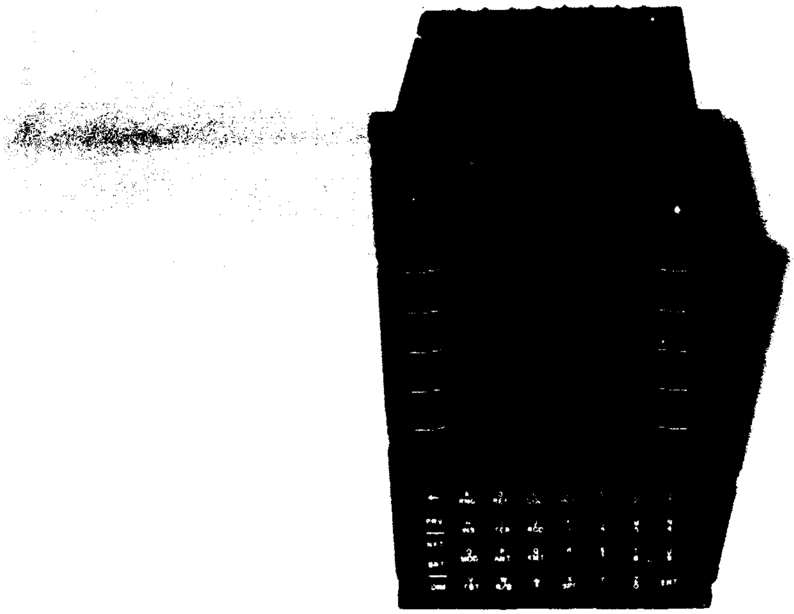

Figure 13. Cockpit display.

Ground Processor - This is a portable GRID 386 IBM PC compatible computer with a 80386 processor running MS DOS. It is used for downloading and analysis of airborne acquired data, system software maintenance, and potentially extended diagnostics. It is interfaced to the FDR using a custom board which converts RS422 serial signals from the FDR to bidirectional parallel signals on the GRID computer. Figure 14 is a photo of the GP in its case.

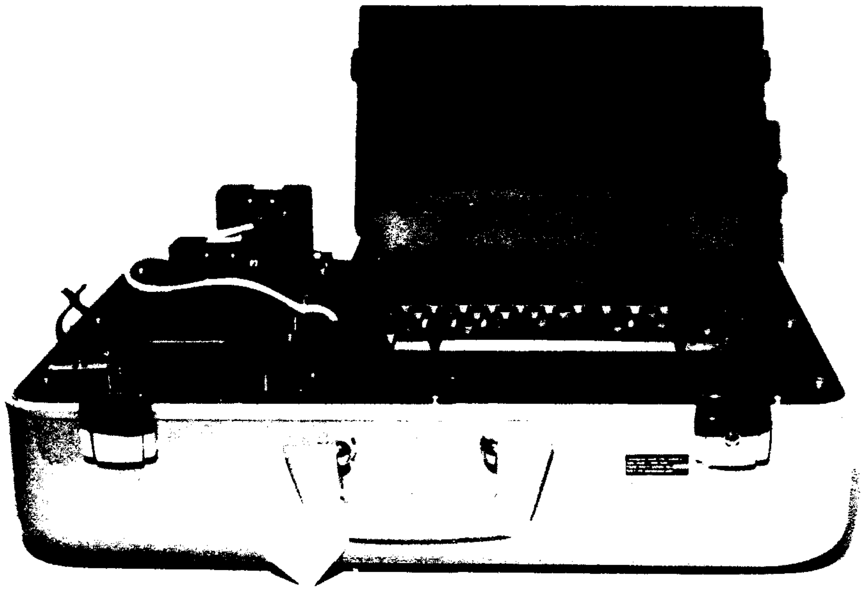

Figure 14. Ground processor.

3.2.3. Summary of System Performance

In general, each component of the system performed reasonably well as configured for MCDS. Opportunities for performance enhancement are described below.

Maintenance Computer:

- Onboard memory is limited to 2MB which must store program code, raw data awaiting processing, and historical data. The final code size required offload of code to PROM and Credit Card Memory which creates software development and data reliability problems respectively. Enhancements would involve adding memory capacity and/or reducing code size by recoding into a more efficient language. This code translation could result in general speed improvement as well, since compiled languages are generally more efficient than interpreters.

- The requirement to maintain background processing for FDR communications and DAU monitoring slows overall system operations. This could be minimized by tuning DAU monitoring periods and FDR polling rates to optimize system performance.

Flight Data Recorder:

• The overhead of filtering display commands through the communications protocol slowed down the CD to the point where it took minutes to update screens. This was improved to about 10 seconds by preloading display data that can be called with single commands, but further display efficiency improvements are possible.

• FDR memory limitations required that a maximum of 20 seconds (5 prior and 15 after), of time history data be kept when a pilot requests a time history record. Additional memory on the FDR would allow this period to be extended to 60 seconds (15 prior and 45 after), allowing a more complete vibration survey to be done simultaneously.

3.3. PARAMETER LIST

Sensor requirements for the MCDS system are shown in Tables 2 and 3. Table 2 describes the sensor requirements for the FDR. Table 3 describes the sensor requirements for the MC.

In addition to the data usage requirements described below, the system provides the following sensor interface functions:

Sensor Conditioning - The MCDS provides sensor excitation and conditioning for sensors that are not part of the normal aircraft suite.

Data Validation - The MCDS automatically and continuously checks all incoming data from sensors for validity. This includes checking for sensor circuit shorts, sensor circuit opens, over-full scale (saturation), gain accuracy, and abnormal quiescent channels. The system flags invalid data to allow potential system operation with partial sensor failures in a degraded mode.

Sensor Calibration and Setup - The system is self-calibrating. System calibrations will consist of V-cals, R-cals, sensitivities or range checks (i.e., accelerometer turnovers) for proper phasing.

There are basically three categories for data usage:

Regime Recognition - The values from these sensors are periodically fed to the regime recognition software which outputs a regime code (currently once per second).

Vibration and Track Measurements - These are monitored during flight, compared against specifications and trended against previous history. Exceedances or near exceedances are reported and additional data may be requested to allow calculation of corrective adjustments.

Special Diagnostic Sensors (temperature, TRDS RPM, stabilator inputs) - These are processed in similar manner to the vibration data except for the stabilator inputs. The inputs to the stabilator amplifiers are normally used to calculate and adjust instantaneous stabilator position by the aircraft system. These inputs are buffered along with remaining aircraft state data (for 5 seconds). MCDS monitors the discretes that indicate a stabilator problem to the Caution Warning Advisory (CWA) panel and captures a buffered time history if they change state. This history can later be examined to determine the possible cause of failure (especially if it is intermittent).

TABLE 2. MCDS FLIGHT DATA RECORDER PARAMETER LIST

ITEM NO.	PARAMETER	TYPE	SENSOR TYPE	SIGNAL RANGE	DATA RANGE	DATA CHARACTER	NOMINAL SAMPLE RATE (HZ)
1	Yaw Rate	3	Ship's Rate Gyro I/F	+/- 5.5 V	+/- 44 deg/sec	QUASI-STATIC	4
2	Pitch Rate #1	3	STAB Amplifier	+/- 5.5 V	+/- 44 deg/sec	QUASI-STATIC	32
3	Pitch Rate #2	3	STAB Amplifier	+/- 5.5 V	+/- 44 deg/sec	QUASI-STATIC	32
4	Load Factor (Nz)	3	Servo. Accel (Dedicated)	+/- 5.36 V	-1.5 to +3.5 G's	QUASI-STATIC	4
5	Rotor Speed (Nr)	3	Ship's Contactor	-0.2204 to 16.5279 KHz	-2 to 150.0 %	QUASI-STATIC	4
6	Engine Torque (Q1)	3	Ship's ECU	-0.35 to 5 V	-10 to 142.0 %	QUASI-STATIC	4
7	Engine Torque (Q2)	3	Ship's ECU	-0.35 to 5 V	-10 to 142.0 %	QUASI-STATIC	4
8	Barometric Altitude	3	Ship's XDCR	-0.53 to 10.5 V	-2K to 20K ft	QUASI-STATIC	4
9	Barometric Rate of Climb	3	Ship's XDCR	+/- 10 V	+/- 6K fpm	QUASI-STATIC	4
10	Roll Attitude	3	Ship's Gyro	0 to 11.8 VAC 400Hz	+/- 190 deg.	QUASI-STATIC	4
11	Airspeed #1	3	Ship's XDCR	1.5 to 15 V	20 to 200 knots	QUASI-STATIC	4
12	Airspeed #2	3	Ship's XDCR	1.5 to 15 V	20 to 200 knots	QUASI-STATIC	4
13	Long. Stick Posit.	3	Ship's	-/+ 8.4 V	-10 to 110 %	QUASI-STATIC	16
14	Lat. Stick Posit.	3	RVDT (Dedicated)	-/+ 0.6 V	-10 to 110 %	QUASI-STATIC	16
15	Coll. Stick Posit. #1	3	Ship's	-/+ 8.04 V	-10 to 110 %	QUASI-STATIC	16
16	Coll. Stick Posit. #2	3	Ship's	-/+ 8.04 V	-10 to 110 %	QUASI-STATIC	16
17	Pedal Posit.	3	RVDT (Dedicated)	-/+ 1.2 V	-10 to 110 %	QUASI-STATIC	16
18	Radar Altitude	3	Ship's Sys. (APN 209)	+.14 to -19.6 V	-20 to 2800 ft	QUASI-STATIC	4
19	Weight-on-Wheels Detect.	1	Ship's Sys.	Open/Gnd	Landed/Airborne	DISCRETE	4
20	Temperature TRDS Bearing	3	Thermocouple Type "K"	-2.2mV to 6.1mV	-60 to +150 deg C	QUASI-STATIC	4
21	Stabilator Position	3	Ship's XDCR	0 to11.8 VAC 400Hz	-45 to +12 deg	QUASI-STATIC	4
22	26 VAC 400 Hz Ref.		Ship's "B" Phase	26 VAC	N/A	N/A	-
23	Manual Slew	1	Ship's Sys.	28VDC/Open	Discrete	DISCRETE	1
24	Stabilator Failed	2	Ship's Sys.	28VDC/Open	Discrete	DISCRETE	1
25	Stabilator Up Limit	1	Ship's Sys.	28VDC/Open	Discrete	DISCRETE	1
26	Stabilator Down Limit	1	Ship's Sys.	28VDC/Open	Discrete	DISCRETE	1
27	Stabilator Actuator POSN #1	3	Ship's Sys.	-11.6 to 7.6V	-10 to110% Travel	QUASI-STATIC	32
28	Stabilator Actuator POSN #2	3	Ship's Sys.	-11.6 to 7.6V	-10 to110% Travel	QUASI-STATIC	32
29	Lateral Acceleration #1	3	Ship's Sys.	+/- 8.2V	+/- 2.1g	QUASI-STATIC	32
30	Lateral Acceleration #2	3	Ship's Sys.	+/- 8.2V	+/- 2.1g	QUASI-STATIC	32
31	Flight Path Stab.	2	Ship's Sys.	28VDC/Open	Discrete	DISCRETE	1
32	Temperature TRDS Ambient	3	Thermocouple Type "K"	-2.2mV to 6.1mV	-60 to +150 deg C	QUASI-STATIC	4

TABLE 3. MCDS MAINTENANCE COMPUTER PARAMETER LIST

Item No.	Parameter	Sensor Type	Primary Use	Secondary Use
1	Copilot Vertical (A)	Accelerometer	1P Main Rotor	3P & 4P Main Rotor
2	Pilot Vertical (B)	Accelerometer	1P Main Rotor	3P & 4P Main Rotor
3	Copilot Lateral	Accelerometer	1P Main Rotor	Damper
4	Nose Vertical	Accelerometer	4P Main Rotor	3P Main Rotor
5	Cabin Absorber Frame Vertical	Accelerometer	4P Main Rotor	
6	Tail Rotor Gearbox	Accelerometer	1P Tail Rotor	Pylon Drive Shaft
7	#1 Engine Drive Shaft	Accelerometer	1/Shaft	
8	#2 Engine Drive Shaft	Accelerometer	1/Shaft	
9	Oil Cooler Longitudinal	Accelerometer	1/Oil Cooler	
10	Copilot Vertical (A) Backup	Accelerometer	1P Main Rotor	
11	Pilot Vertical (B) Backup	Accelerometer	1P Main Rotor	
12	Copilot Lateral Backup	Accelerometer	1P Main Rotor	
13	Nose Vertical Backup	Accelerometer	4P Main Rotor	
14	Spare	Accelerometer		
15	Main Rotor Track	Optical Track	Track	
16	Main Rotor Timing	Mag. Contactor	Reference	
17	Tail Rotor Timing	Mag. Contactor	Reference	

3.4. INSTALLATION HARDWARE

A complete set of brackets and fixtures were designed and fabricated to allow the MCDS to be installed in the test helicopter. They included items such as accelerometer mounting brackets, equipment mounts, connector patch panel, etc. Wherever possible, existing designs were used or slightly modified. However, two installations required some development. Both of these were fabricated and flight tested on UH-60 aircraft at Sikorsky and worked satisfactorily. These included:

Track Sensor Enclosure - This was needed to protect the sensor from the weather during the planned extended flight evaluation and due to changing the mounting location to improve viewing angle and prevent blockage of the E-Bay vent. Figure 15 is a photograph of the completed unit.

Tail Rotor Contactor - This was needed to provide a reliable permanent location (a tail rotor contactor is not normally used on the UH-60A - tail balance timing data is generally acquired with a strobe). The bracket accepts both magnetic and optical sensors and both were tested on aircraft.

All installation locations are summarized in Figure 16 and some significant points are described below:

> The cockpit display is located in the center console between pilot and copilot to allow viewing and interaction with the system. The display is sunlight readable and all interaction is through ten "soft-function" keys, some of which change meaning based on the active screen.

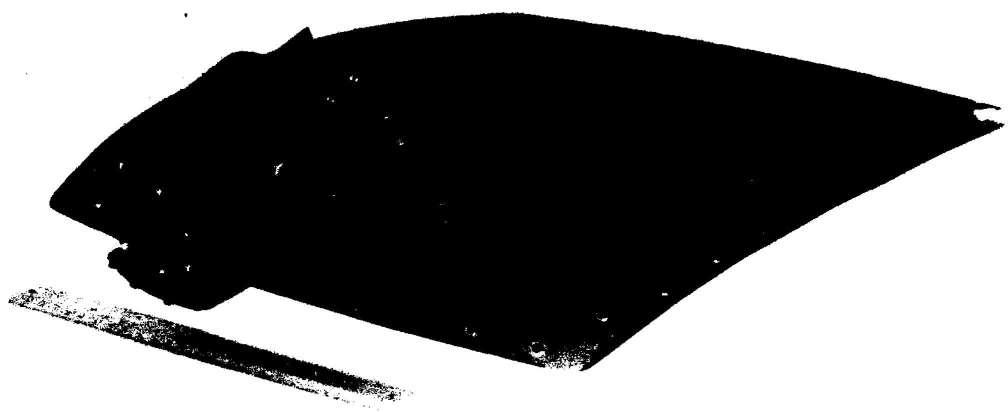

Figure 15. MCDS track sensor enclosure.

The CADU enclosure is located aft of the center console and allows the CADU to be stowed (and protected) when it is not used or removed for use as a flight engineer station.

The remote panel was designed for the SUM program and a copy was fabricated for MCDS. It is located in the center console and allows connection of the GP to the FDR for data download, software update or calibration. FDR BIT and status indicators are remotely displayed here also (in case the FDR is mounted in an inaccessible location).

The estimated installed weight of the MCDS is 98 lbs., of which the major components include: FDR 16 lbs., DAU 10.8 lbs., CADU 4.4 lbs., CD 10 lbs., track sensor 4.4 lbs. and wiring harness 22 lbs. The remaining 30 lbs includes other sensors and mounting hardware.

3.5. AIRCRAFT WIRING

Since a wiring diagram must be customized to the specific tail number aircraft that it will be used on, programmatic changes resulted in several versions of wiring harness designs before the final version was fabricated:

- For the original planned Ft. Rucker aircraft with a Sundstrand interim tape recorder as a replacement (i.e., the Sundstrand was planned to be removed during the testing).

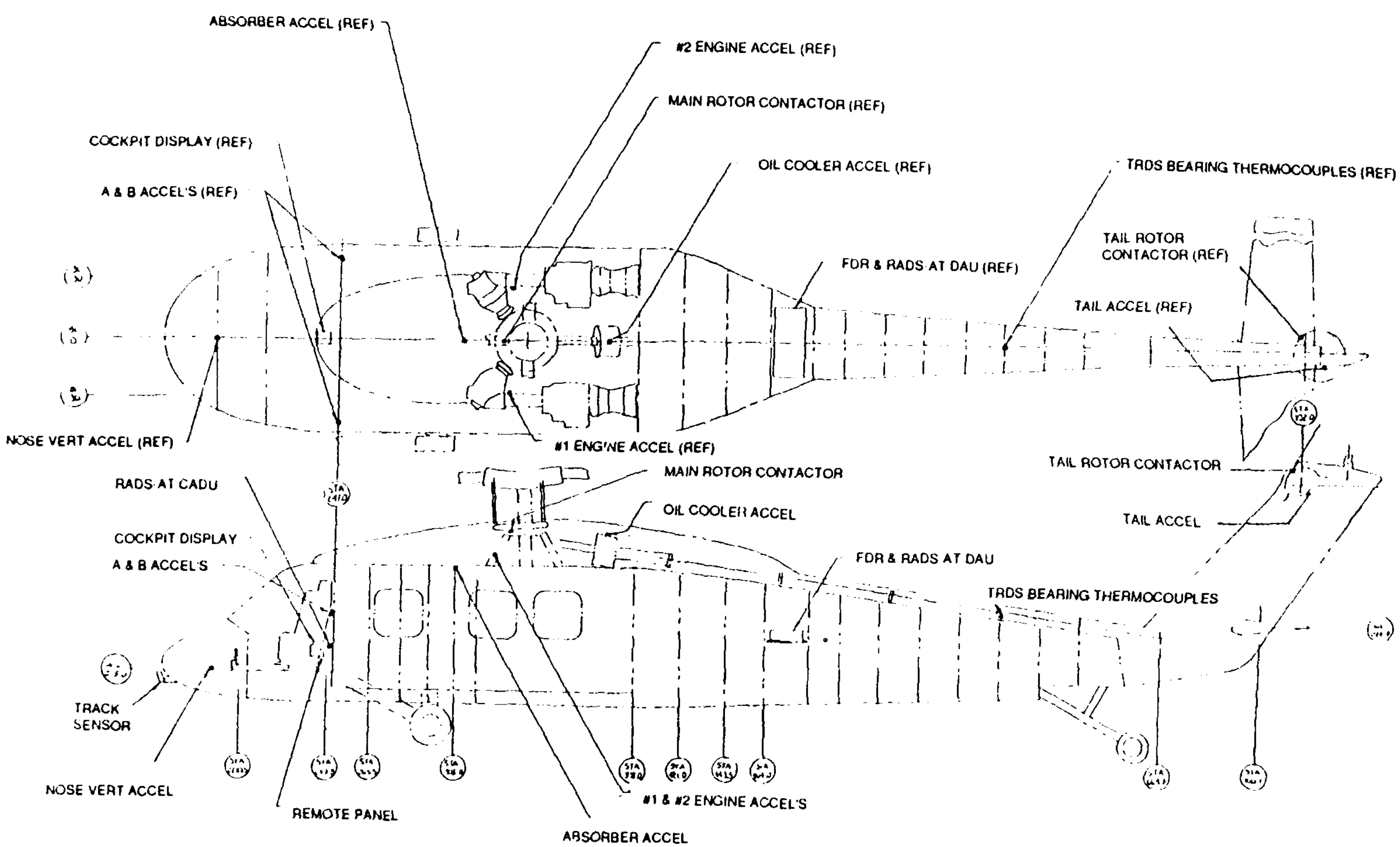

Figure 16. MCDS aircraft installation location diagram.

- For the original planned Ft. Rucker aircraft with a Sundstrand interim tape recorder as a tap-in (permission was not secured to remove the Sundstrand unit and hence both recorders needed access to some overlapping sensors).

- For the Army bailed aircraft to be used at Sikorsky's WPB facility with no other FDR and equipment relocated to cabin instead of aft of the fuel cell. This version was fabricated.

Figure 17 depicts the top level harness design which is detailed on drawing T7055-01113. The "Task Number" designations match to related installation drawings for each installed item.

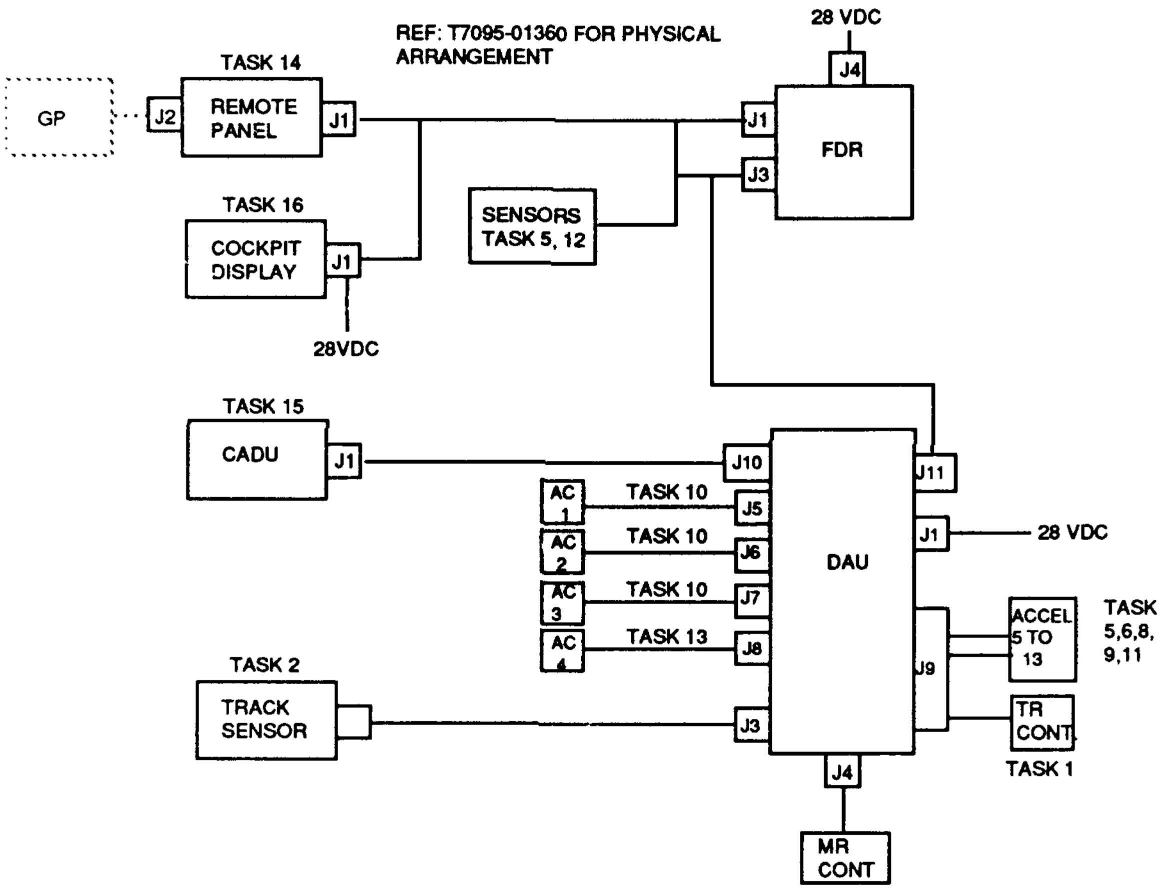

Figure 17. MCDS top level schematic diagram.

3.6. SOFTWARE DEVELOPMENT

This section documents the design and development process for the major MCDS software components. There were two subcontractors involved in both hardware and software modifications of their equipment in support of the MCDS contract. Their efforts were considered part of the cost of the equipment that Sikorsky purchased and are so noted. Their efforts are described here for reference only.

Regime Recognition

The regime recognition function was developed by Sikorsky under a previous Navy program (see Reference 3) and was slightly modified for MCDS. It was written in Ada on an IBM PC compatible and compiled into the FDR onboard software by Canadian Marconi. The FDR provides the current value of all regime recognition parameters to the regime recognition application once per second. The module examines each parameter and classifies it into one of a defined subset of levels per the applicable regime threshold table (maintenance or monitor mode version). These levels are then mathematically combined to a coded value which is then matched (via a second table) to a regime code which uniquely identifies the regime to the rest of the system. Table 4 summarizes the criteria used by the regime recognition algorithm to determine which regime the aircraft is currently within.

TABLE 4. MCDS REGIME RECOGNITION SUMMARY

MONITOR MODE

REGIME CODE	AIRCRAFT REGIME CONDITION	AIRCRAFT REGIME ROTOR SPEED (PER CENT)	AIRCRAFT SYSTEM PARAMETER: WEIGHT ON WHEELS ON/OFF	ROTOR SPEED PER CENT	ENGINE TORQUE PERCENT	AIRSPEED KNOTS	RATE OF CLIMB FEET/MIN	ANGLE OF BANK DEGREES	YAW RATE DEG/SEC	RADAR ALTITUDE FEET
1	START FLIGHT		ON	30/98	10/142	25/35	N/A	< +/- 15.0	< +/- 10.0	N/A
2	FLAT PITCH	100	ON	98/102	10/142	25/35	N/A	< +/- 15.0	< +/- 10.0	N/A
3	HOVER	100	OFF	98/102	10/142	25/35	< +/- 500	< +/- 15.0	< +/- 10.0	10/1500
4	80 KIAS	100	OFF	98/102	10/142	70/90	< +/- 500	< +/- 15.0	< +/- 10.0	N/A
5	120 KIAS	100	OFF	98/102	10/142	110/135	< +/- 500	< +/- 15.0	< +/- 10.0	N/A
6	145 KIAS	100	OFF	98/102	10/142	135/150	< +/- 500	< +/- 15.0	< +/- 10.0	N/A
7	Vh	100	OFF	98/102	10/142	150/200	< +/- 500	< +/- 15.0	< +/- 10.0	N/A
8	END FLIGHT		ON	30/98	0	25/35	N/A	< +/- 15.0	< +/- 10.0	N/A

MAINTENANCE MODE

REGIME NUMBER	AIRCRAFT REGIME CONDITION	AIRCRAFT REGIME ROTOR SPEED (PER CENT)	AIRCRAFT SYSTEM PARAMETER: WEIGHT ON WHEELS ON/OFF	ROTOR SPEED PER CENT	ENGINE TORQUE PERCENT	AIRSPEED KNOTS	RATE OF CLIMB FEET/MIN	ANGLE OF BANK DEGREES	YAW RATE DEG/SEC	RADAR ALTITUDE FEET
1	START FLIGHT		ON	30/99	10/142	25/35	N/A	< +/- 10.0	< +/- 5.0	N/A
2	FLAT PITCH	100	ON	99/101	10/142	25/35	N/A	< +/- 10.0	< +/- 5.0	N/A
3	HOVER	100	OFF	99/101	10/142	25/35	< +/- 200	< +/- 10.0	< +/- 5.0	10/1500
4	80 KIAS	100	OFF	99/101	10/142	75/85	< +/- 200	< +/- 10.0	< +/- 5.0	N/A
5	120 KIAS	100	OFF	99/101	10/142	115/125	< +/- 200	< +/- 10.0	< +/- 5.0	N/A
6	145 KIAS	100	OFF	99/101	10/142	140/150	< +/- 200	< +/- 10.0	< +/- 5.0	N/A
7	Vh	100	OFF	99/101	10/142	150/200	< +/- 200	< +/- 10.0	< +/- 5.0	N/A
8	END FLIGHT		ON	30/99	0	25/35	N/A	< +/- 10.0	< +/- 5.0	N/A

Monitoring Mode/System Executive

This function is composed of a number of modules coded by Sikorsky in a Scientific Atlanta proprietary Diagnostic Programming Language (DPL). DPL is an interpretive language which was designed to allow simple access to the data base, graphics and measurement functions of the RADS-AT. DPL code is developed on a SUN workstation using a development environment which simulates the display screen of the RADS-AT CADU, allowing testing of screen and data base related functions. The DPL code is then partially compiled into modules which run on the target CADU. Figure 18 shows the software development setup including the SUN workstation and the target RADS-AT system where the code is tested. Figure 19 illustrates the basic flow of monitor mode. The measurement data processing function involves taking the data returned by the RADS-AT DAU (which contains much more information than MCDS requires) and queuing them for the data filtering process which extracts the pertinent values. These are then stored in a buffer which holds them until they are passed to problem diagnosis (described below) which actually determines what is to be done based on the data value.

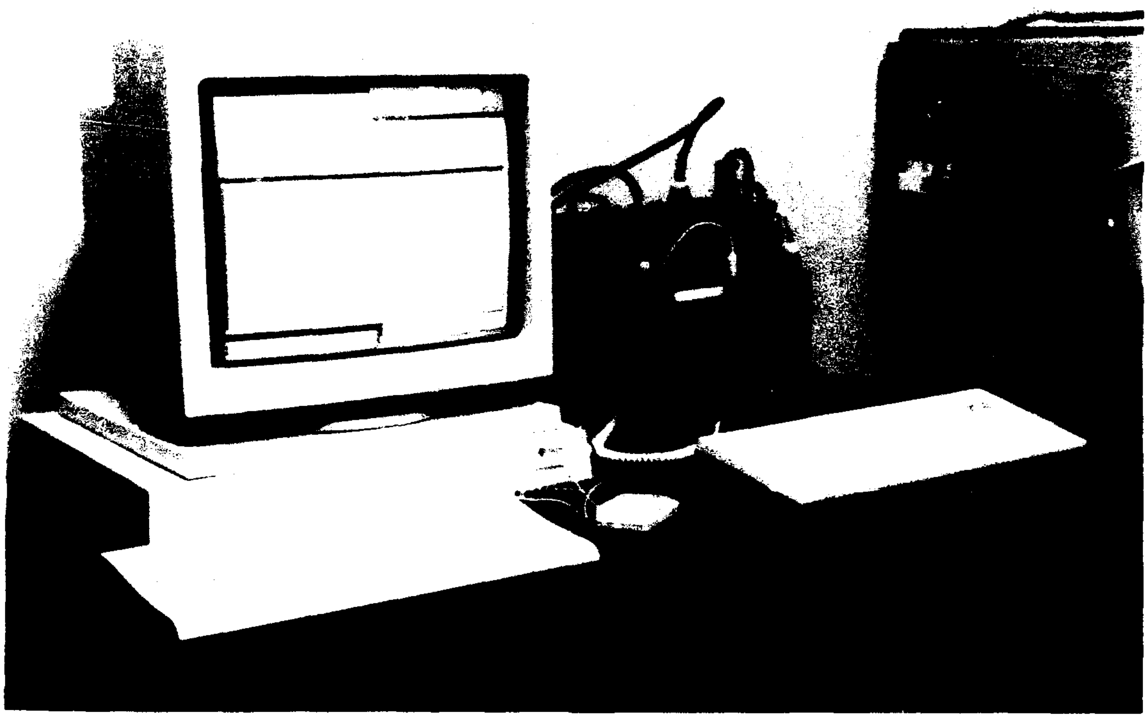

Figure 18. MCDS maintenance computer software development environment.

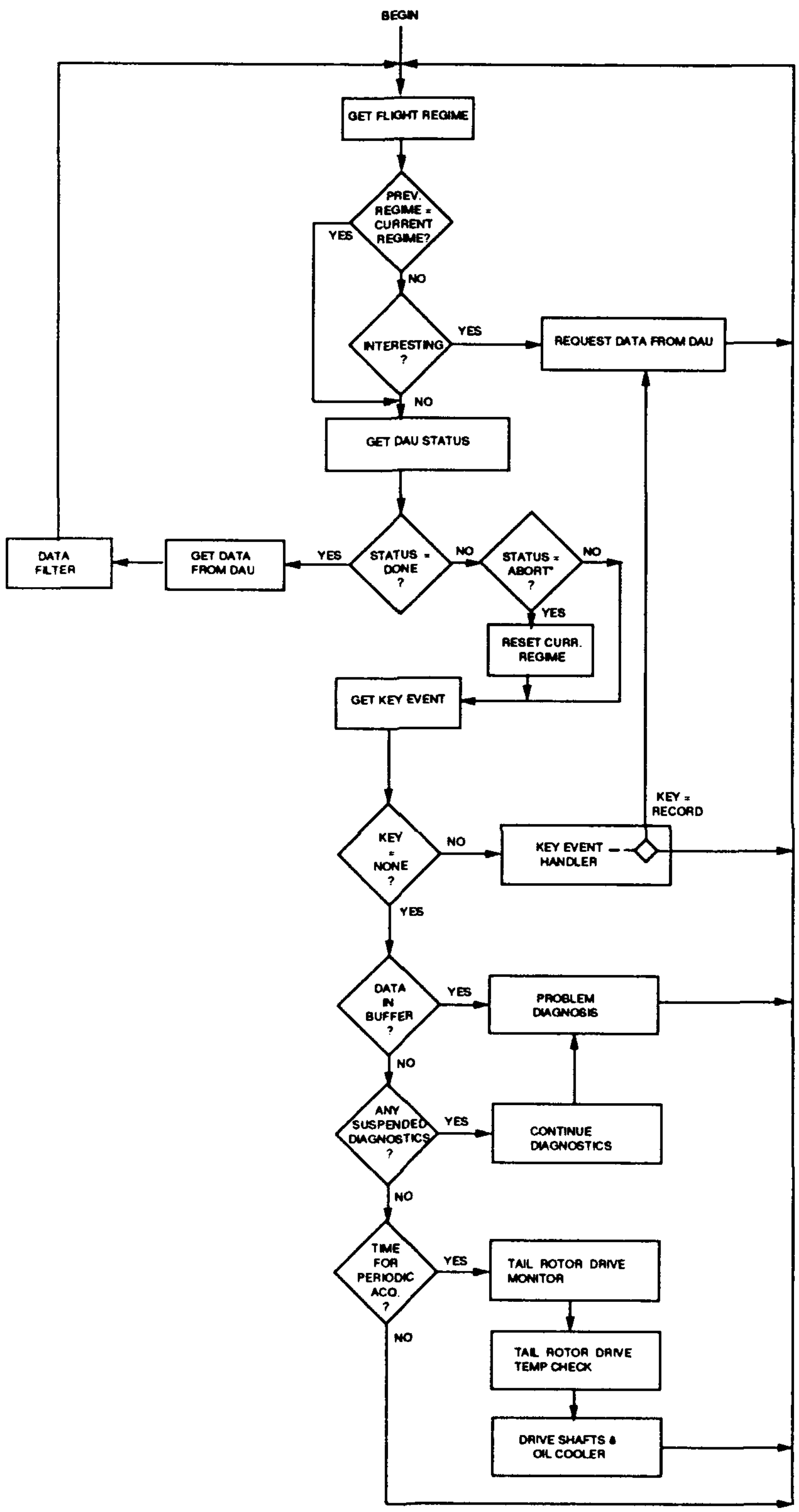

Figure 19. Monitor mode flowchart.

Cockpit Display Drivers

These functions are responsible for maintaining the screens and handling keystrokes received from the CD. They were coded by Sikorsky in DPL to send line by line screen updates which were passed through the FDR to the CD in its native language. This approach worked well during early testing (while directly driving the CD from the SUN workstation) but slowed down unacceptably when MC/FDR communications link was finally used. This problem necessitated conversion to a method of preloading many display commands to be called using the CD "macro" facility. Records of the screens are also stored on the CADU data base for log purposes, and a backup mode allows the same displays to be viewed on the CADU in a slightly different format (due to display shape differences).

Data Screening Algorithms

These modules were also developed in DPL by Sikorsky. Figure 20 depicts a model flowchart from which all specific problem diagnosis scripts are derived. The screened data is finally stored in the vibration history file by vibration parameter number classification which matches the specifications shown in Table 5.

TABLE 5. MCDS VIBRATION PARAMETER SUMMARY

VIB. PARM. NO.	DESCRIPTION			SIMULATOR OUTPUT	LIMITS				
	REGIME	CHANNEL	FREQ.	(IPS)	GOAL (IPS)	SPEC (IPS)	DNE (IPS)	SLOPE	SLOPE ROC
1	HOVER	A + B	1/M	0.22	0.10	0.20	0.50	0.01	0.10
2	80 KIAS	A + B	1/M	0.24	0.10	0.20	0.50	0.01	0.10
3	120 KIAS	A + B	1/M	0.27	0.10	0.20	0.50	0.01	0.10
4	145 KIAS	A + B	1/M	0.35	0.10	0.20	0.50	0.01	0.10
5	Vh	A + B	1/M	0.48	0.10	0.20	0.50	0.01	0.10
6	FLAT PITCH	A - B	1/M	0.31	0.10	0.20	0.50	0.01	0.10
7	HOVER	A - B	1/M	0.01	0.10	0.20	0.50	0.01	0.10
8	80 KIAS	A - B	1/M	0.02	0.10	0.20	0.50	0.01	0.10
9	120 KIAS	A - B	1/M	0.05	0.10	0.20	0.50	0.01	0.10
10	145 KIAS	A - B	1/M	0.02	0.10	0.20	0.50	0.01	0.10
11	Vh	A - B	1/M	0.04	0.10	0.25	0.50	0.01	0.10
12	120 KIAS	COCKPIT LAT	1/M	0.21	0.10	0.20	0.50	0.01	0.10
13	145 KIAS	COCKPIT LAT	1/M	0.23	0.10	0.20	0.50	0.01	0.10
14	Vh	COCKPIT LAT	1/M	0.26	0.10	0.20	0.50	0.01	0.10
15	145 KIAS	A + B	3/M	N/A	0.15	0.20	0.30	0.01	0.10
16	Vh	A + B	3/M	N/A	0.15	0.20	0.40	0.01	0.10
19	145 KIAS	NOSE VERT	3/M	N/A	0.30	0.40	0.60	0.01	0.10
20	Vh	NOSE VERT	3/M	N/A	0.30	0.40	0.80	0.01	0.10
21	145 KIAS	A + B	4/M	0.57	0.30	0.40	1.00	0.01	0.10
22	120 KIAS	NOSE VERT	4/M	0.40	0.40	0.60	1.00	0.01	0.10
23	FLAT PITCH	TAIL	1/T	0.35	0.10	0.20	1.50	0.01	0.10
24	PERIODIC	#1 ENGINE	350 Hz	0.58 (Note 1)	0.50	1.30	2.00	0.01	0.10
25	PERIODIC	#2 ENGINE	350 Hz	0.58 (Note 1)	0.50	1.30	2.00	0.01	0.10
27	PERIODIC	OIL COOLER	70 Hz	0.37 (Note 2)	0.50	1.00	2.00	0.01	0.10
28	145 KIAS	ABSORBER	4/M	0.24					

Note 1 - Varies by regime from 0.75 to 4 at 352.5 Hz.
Note 2 - Varies from 0.5 to 3.0 in regime "pilot record" at 72 Hz.
Note 3 - A = copilot vertical vibration.
B = pilot vertical vibration.
A+B = one half vector sum of A and B.
A-B = one half vector difference of A and B.

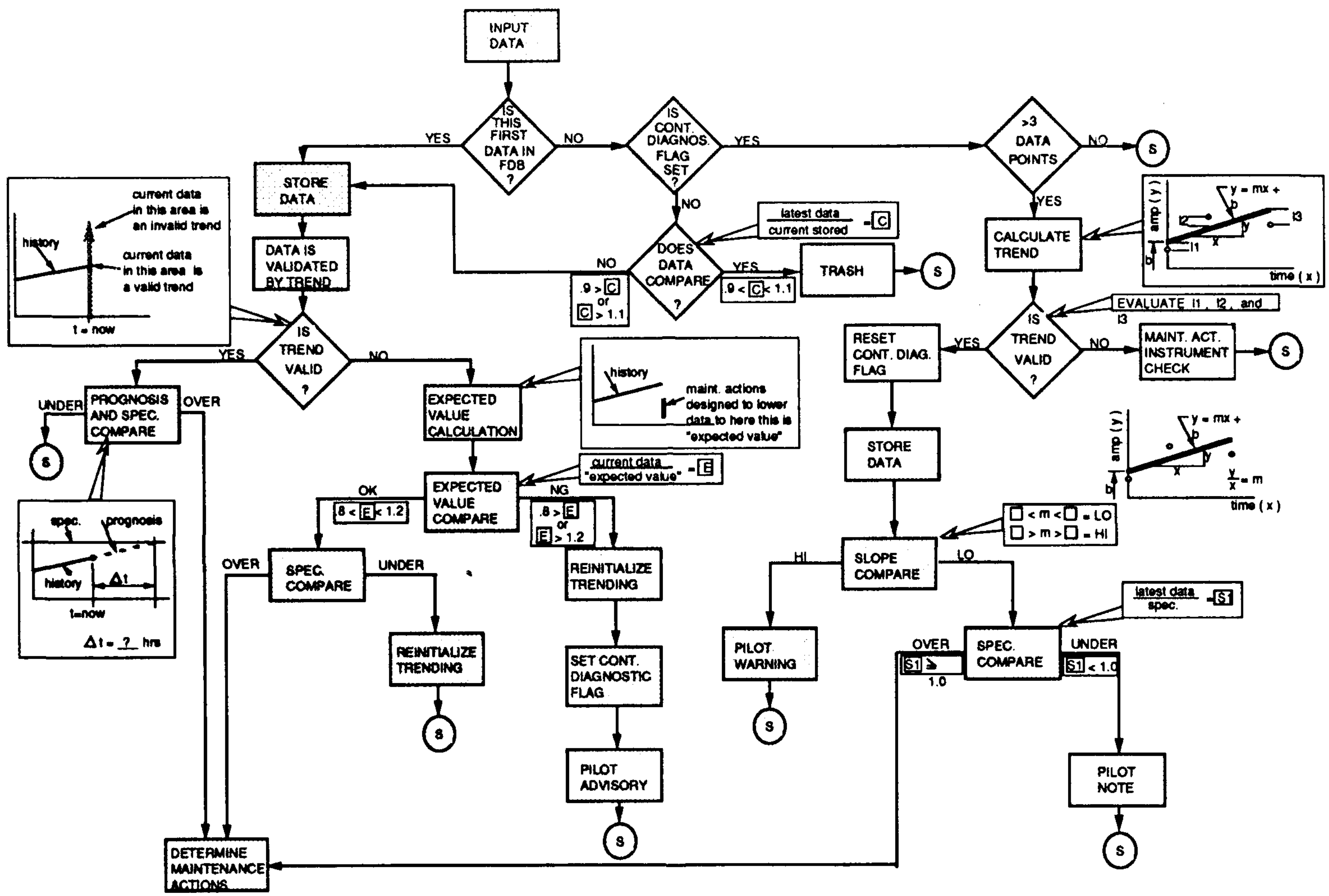

Figure 20. Model problem diagnosis flowchart.

Determination of Maintenance Actions

These modules were coded in DPL by Sikorsky and are called by the appropriate problem diagnosis script to generate the maintenance action recommendation. The basic rotor correction calculations use a proprietary Scientific Atlanta routine which optimizes the adjustments to data presented via predefined sensitivity factors and constraints. Incorporation of these Scientific Atlanta modules included both generation of new (MCDS specific) DPL code by Sikorsky and Sikorsky modifications of proprietary Scientific Atlanta modules to allow their use in MCDS. The use of these algorithms (as opposed to development of new ones) was done to reduce development time and maintain compatibility with Expert Mode.

FDR Operational Program

All of the systems and applications software on the FDR were coded by Canadian Marconi under Sikorsky subcontract (except the regime recognition module described above). Figure 21 documents the basic flow of parameter processing on the FDR. Processing is data type dependant and there are three basic types as indicated in the FDR parameter table (Table 2 in section 3.3). In summary, type 1 and 2 discrete parameters are recorded into a time history only when they change state (where type 2 parameters are related to problems with the stabilator system and cause a time history sample to be stored as well). Type 3 parameters are quasi-static and their values are stored when they change by more than a defined amount. The presence of a time history which was either requested by the MC or due to a type 2 discrete change is indicated by the "exceedance" indicator on the FDR chassis and the remote panel. A subset of the parameters are periodically fed to the regime recognition algorithm.

MC/FDR Communications Protocol

This consists of a number of modules coded under Sikorsky subcontract by both Scientific Atlanta and Canadian Marconi (both under Sikorsky subcontract) to implement the MC/FDR communications protocol. Table 6 includes a summary of these commands and their use in MCDS. They include commands to synchronize clocks, request regime codes and parameter values from the FDR, control the time history storage process, and relay various types of status between the two systems.

TABLE 6. MCDS MC/FDR COMMUNICATIONS PROTOCOL COMMAND SUMMARY

COMMAND	DESCRIPTION / USE
FDR Time Request	Requests time from FDR to synchronize clocks
FDR Parameter Value Request	Requests current value of any parameter on FDR
Regime Code Request	Requests latest regime code as determined by FDR
Regime Table Change Request	Requests FDR to change to Mission or Maintenance mode
Time History Request	Requests FDR to immediately capture a time history
FDR Time History Status Request	Requests status of last time history requested
FDR Time History Store Request	Requests FDR to store or delete the latest time history
Cockpit Display Test Request	Requests FDR to display test pattern on CD
Cockpit Display Command Request	Requests FDR to pass command data to CD
Cockpit Display Key Event Request	Requests latest keypress from CD
FDR Status Request	Requests latest FDR BIT status

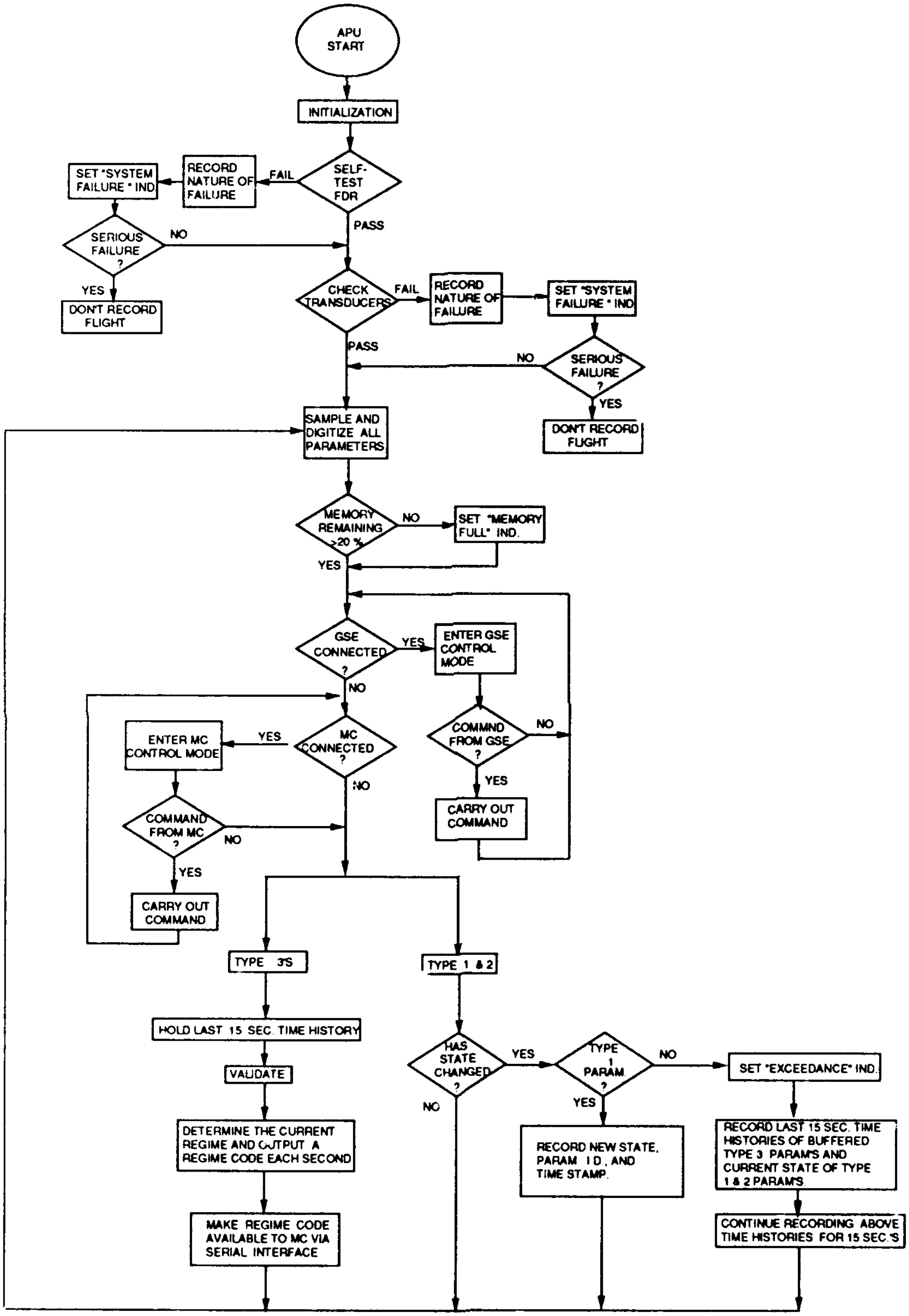

Figure 21. FDR flowchart.

GP Software

The primary role of the GP is to support the FDR and to download and display data stored on the FDR. The code was modified from the SUM version by Canadian Marconi under Sikorsky subcontract. Figure 22 outlines the main menu options available on the GP. These include software update, display and calibration of each sensor channel, regime recognition table maintenance, data download/display, and checks of FDR and CD functionality.

FDR Program Load and Identification Setup
FDR Sensor Parameter and System Constant Load
FDR AMU Flight Data Download
FDR System BIT
FDR Maintenance Datadump
FDR Sensor Parameter Static Test
FDR Sensor Parameter Calibration
Data Transfer Between Selected Media
- **FDR Data Download Selection**
  - **FDR Flight Selection**
  - **FDR Flight Histogram Display**
  - **Regime Recognition Parameter Histogram Display**
  - **Regime Recognition Histogram Display**
  - **Sensor Validity Check Data Display**
- **FDR System Constant Update**
- **FDR Sensor Parameter Data Update**
- **Regime Recognition Threshold Update (Monitor)**
- **Regime Recognition Threshold Update (Maintenance)**
- **Regime Recognition Multi-Radix Update**

Figure 22. Ground processor main menu.

3.7. SYSTEM INTEGRATION

Since the MCDS is tied together using serial communications links, the major task in design of the system involved defining protocols and related command software. A communications protocol for use between FDR/CD and FDR/MC was designed based on an existing protocol used between FDR and GP in the previous SUM program. This was designed as a master/slave scheme with MC acting as master and FDR as slave. A major advantage of this approach is that the complexity of a fully bi-directional protocol was avoided and that modification cost (and risk) of the FDR software was minimized. This required definition of interface specifications between three companies. Each component of the interface was separately coded and tested by each subcontractor, then tested together at a low level (basic message passing/traffic control protocol) at the facility of one of the subcontractors.

As a final step, the high level commands were tested at Sikorsky during system integration bench testing (with both subcontractors present and setup to correct problems.) This co-location approach to system integration significantly reduced debug/repair time over remote efforts at separate locations. Difficult-to-find problems included those which involved the interface between the background communications monitoring processes (which were written in "C") and the DPL language itself. These modules were initially tested by calls from a "C" test program and worked correctly yet would not function when called from within the DPL interpreter (where they are called by MCDS diagnostic software).

4. TEST/DEMONSTRATION

The primary focus of the MCDS testing effort was to verify basic system operation and prepare the MCDS for a demonstration of these capabilities using the bench test setup. The detailed test procedures are described in Reference 4. The testing was carried out over a 5-month period from January through May of 1990, culminating in a demonstration of the system for an Army audience in May. This testing and demonstration was completed using simulated inputs from a computer driven data simulator which provided both normal and fault data values for various typical flight conditions.

4.1. TEST SETUP

Figure 23 schematically shows the MCDS bench test setup. Each of the major testing components in this diagram is briefly described below and depicted photographically in Figure 24.

Dynamic Data Simulator (DDS)

The DDS is designed to directly substitute for aircraft installed transducers and signal sources and consists of three components: the host computer which defines 20-30 channels of input signal profiles, the digital/analog hardware which converts profile definitions to 0-10V analog signals, and the sensor conversion hardware which changes the 0-10V signals to simulated sensor signals. Prestored flight profiles can be individually played out or strung together into simulated complete flights. Note that certain static channels are simulated with signal generators rather than the DDS and that rotor RPM is varied manually to indicate start and end of flights (STRTFLT and ENDFLT regimes).

Interface Panel

The interface panel simply provides an exposed interface to the MCDS bench test harness for debug purposes.

Serial Protocol Analyzer

The analyzer allows continuous monitoring/capture of serial bus traffic between either the MC/FDR or FDR/CD ports. The model used here was a software package that converts an IBM PC compatible to handle this task.

SUN Workstation

Besides software development for the RADS-AT, a display window was opened as a terminal to monitor DAU activity during requested vibration measurements.

RADS-AT Test Set

This test set provides simulated (and calibrated) sensor inputs for checkout of accelerometer, track and timing inputs to the DAU.

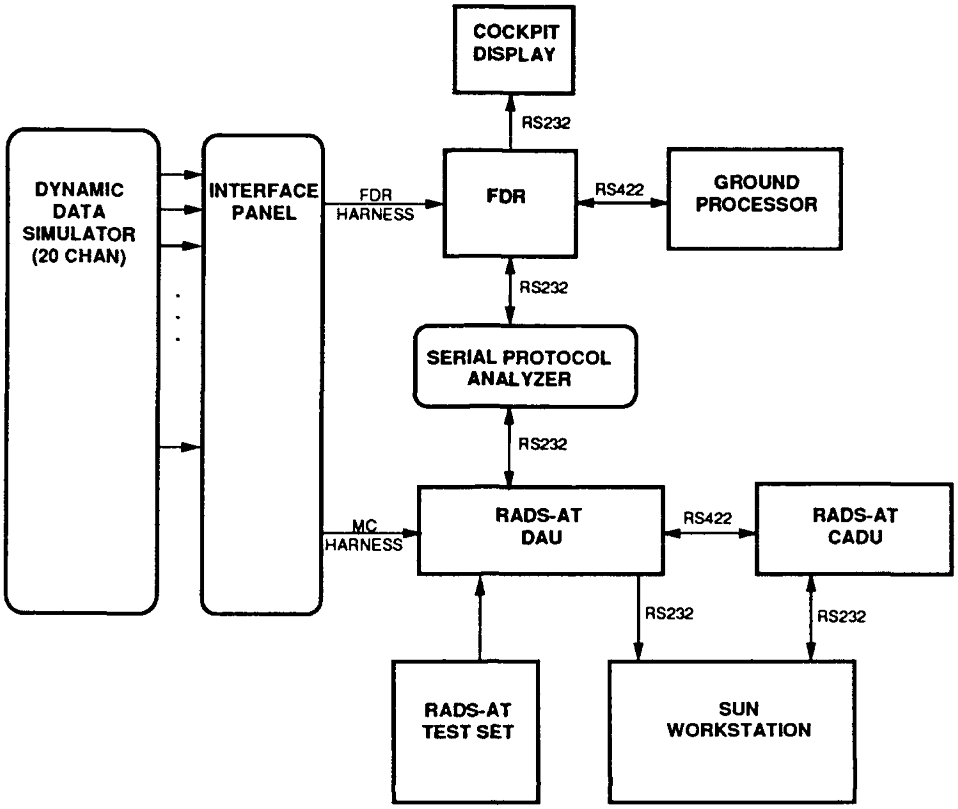

Figure 23. MCDS bench test block diagram.

4.2. CHECKOUT OF DDS OUTPUTS

The first step in the bench test sequence was to verify the test equipment outputs, the bench test harness, and the interface to the target equipment. This was completed by exhaustively checking each simulator (or signal generator) output in each programmed test state using the target FDR and MC. The FDR testing was carried out using the static display and calibration mode which displays continuously updated parameter readings one channel at a time on the GP. The MC was initially checked out for calibration purposes against it's test set. The MC inputs were then checked by using Expert Mode measurements during each simulator test state. Any discrepancies that were found were tracked down and corrected or work-arounds implemented. Table 7 summarizes the static and dynamic inputs to the MCDS under each test state.

There were a few problems which were never resolved and were demonstrated as work-arounds:

- Tracker output simulation was attempted on the DDS but was ultimately unsuccessful. The problem was never successfully duplicated by Scientific Atlanta at their facility. The work-around was to remove track acquisitions from the demonstration pending a separate checkout of the track data processing capability from the RADS-AT test set.

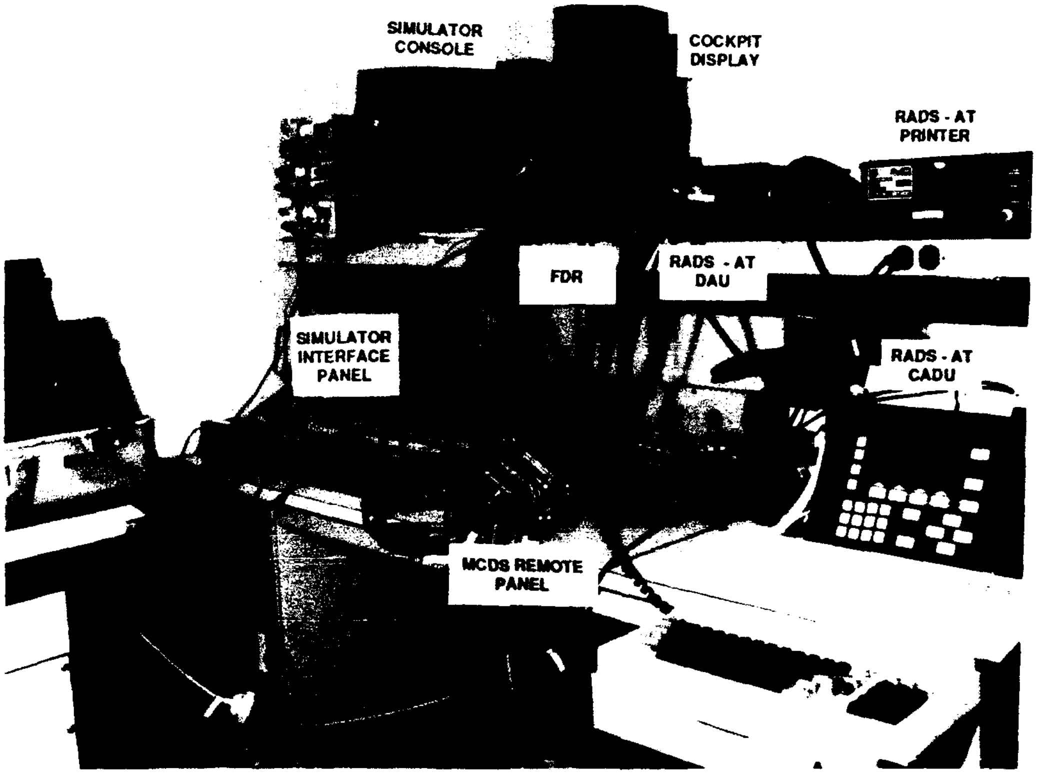

Figure 24. MCDS bench test setup.

- Thermocouple simulation by the DDS introduced excessive noise and was thus replaced by actual thermocouples for ambient and elevated temperatures. The elevated temperature was introduced via a hot water bath.

4.3. CHECKOUT OF COMMUNICATIONS PROTOCOL - LOW LEVEL

Low level aspects of the MC/FDR communications protocol such as message traffic, flow control and communications error handling were tested by the subcontractors in December 1989. This was done at Canadian Marconi using a serial protocol analyzer to monitor traffic and simulate fault conditions.

4.4. CHECKOUT OF COMMUNICATIONS - COMMAND PROCESSING

Once a command has passed between components, the receiving unit must interpret the command and carry it out. Also, the sending unit must properly initiate the command in the correct format. These functions were tested at Sikorsky by calling individual commands from DPL interactive mode while monitoring and recording message traffic using the "Breakout" serial protocol analysis program on an IBM PC compatible as described in 4.1 above. The first check was made with the MC communicating with a PC running an emulation of the FDR. The second check was with the actual FDR.

TABLE 7. MCDS SIMULATOR REGIME CONTENT

PARAMETER SIMULATION	PARAMETER NAME	USED FOR	START FLIGHT	FLAT PITCH	HOVER	80 KIAS	120 KIAS	145 KIAS	Vh KIAS	PILOT RECORD	TRDS DISCONNECT	#1 HI-SPEED OVER SPEC.	HOVER	END FLIGHT
NOT APPLICABLE	TIME IN MINUTES	REFERENCE FOR INFO.	1	3	3	1	1	1	1	3	1	1	1	1
SIGNAL GENERATOR	YAW RATE	R/R	0 DEG./SEC.	0 DEG./SEC.	0 DEG./SEC.	0 DEG./SEC.	0 DEG./SEC.	0 DEG./SEC.	0 DEG./SEC.	0 DEG./SEC	0 DEG./SEC.	0 DEG./SEC.	0 DEG./SEC.	0 DEG./SEC.
SIGNAL GENERATOR	ROTOR SPEED	R/R	0 TO 80 PER CENT	100 PER CENT	100 PER CENT	100 PER CENT	100 PER CENT	100 PER CENT	100 PER CENT	100 PER CENT	100 PER CENT	100 PER CENT	100 PER CENT	100 TO 0 PER CENT
SIGNAL GENERATOR	BAROM RATE OF CLIMB	R/R	10 FPM	10 FPM	10 FPM	10 FPM	10 FPM	10 FPM	10 FPM	10 FPM	10 FPM	10 FPM	10 FPM	10 FPM
SIGNAL GENERATOR	ROLL ATTITUDE	R/R	2 DEG.	2 DEG.	2 DEG.	2 DEG.	2 DEG.	2 DEG.	2 DEG.	2 DEG.	2 DEG.	2 DEG.	2 DEG.	2 DEG.
1 SIMULATOR	AIRSPEED #1	R/R STAB	30 KIAS	30 KIAS	30 KIAS	80 KIAS	120 KIAS	145 KIAS	160 KIAS	145 KIAS	145 KIAS	145 KIAS	30 KIAS	30 KIAS
2 & 3 SIMULATOR	ENGINE TORQUES	R/R	0 PERCENT	80 PERCENT	100 PERCENT	100 PERCENT	100 PERCENT	100 PERCENT	106 PERCENT	100 PERCENT	100 PERCENT	100 PERCENT	100 PERCENT	0 PERCENT
4 SIMULATOR	WEIGHT ON WHEELS	R/R	ON GROUND	ON GROUND	AIR-BOURNE	AIR-BOURNE	AIR-BOURNE	AIR-BOURNE	AIR-BOURNE	AIR-BOURNE	AIR-BOURNE	AIR-BOURNE	AIR-BOURNE	ON GROUND
5 SIMULATOR	RADAR ALTITUDE	R/R	0 FEET	0 FEET	100 FEET	1000 FEET	1000 FEET	1000 FEET	1000 FEET	1000 FEET	1000 FEET	1000 FEET	100 FEET	0 FEET
6 SIMULATOR	TRDS BRG. TEMPERATURE	DIAG	25 DEG. C	25 DEG. C	25 DEG. C	25 DEG. C	25 DEG. C	25 DEG. C	25 DEG. C	25 DEG. C	25 C SLOW TO 150 DEG. C	25 DEG. C	25 DEG. C	25 DEG. C
SIGNAL GENERATOR	TRDS BRG AMB. TEMP.	DIAG	20 DEG. C	20 DEG. C	20 DEG. C	20 DEG. C	20 DEG. C	20 DEG. C	20 DEG. C	20 DEG. C	20 DEG. C	20 DEG. C	20 DEG. C	20 DEG. C
7 SIMULATOR	TAIL ROTOR CONTACTOR	T & B	0 HZ CONTACTOR	20 HZ CONTACTOR	20 HZ CONTACTOR	20 HZ CONTACTOR	20 HZ CONTACTOR	20 HZ CONTACTOR	20 HZ CONTACTOR	20 HZ CONTACTOR	20 HZ SLOW TO 0 HZ	0 HZ CONTACTOR	0 HZ CONTACTOR	0 HZ CONTACTOR
8 SIMULATOR	MAIN ROTOR CONTACTOR	T & B	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR	4 HZ CONTACTOR
STEWART HUGHES	BLADE TRACKER	T & B												
9 SIMULATOR	TAIL ACCEL	T & B	0 IPS	0.35 IPS @20 HZ	0.35 IPS @20 HZ	0.35 IPS @20 HZ	0.35 IPS @20 HZ	0.35 IPS @20 HZ	0.35 IPS @20 HZ	0.35 IPS @20 HZ	0.35 IPS @20 HZ	0 IPS	0 IPS	0 IPS
10 SIMULATOR	PILOT VERT ACCEL (B)	T & B	0.60/4 0.30/16	0.30/4 0.30/16	0.22/4 0.30/16	0.20/4 0.40/16	0.20/4 0.45/16	0.30/4 0.60/16	0.40/4 0.65/16	0.30/4 0.60/16	0.30/4 0.60/16	0.30/4 0.60/16	0.22/4 0.30/16	0.60/4 0.30/16
11 SIMULATOR	COPILOT VERT ACCEL (A)	T & B	0.0/4 0.25/16	0.35/4 0.25/16	0.20/4 0.25/16	0.25/4 0.35/16	0.30/4 0.40/16	0.35/4 0.55/16	0.50/4 0.60/16	0.35/4 0.55/16	0.35/4 0.55/16	0.35/4 0.55/16	0.20/4 0.25/16	0.0/4 0.25/16
12 SIMULATOR	NOSE C.L. ACCEL	DIAG	0.25 IPS @ 16 HZ	0.25 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16HZ	0.40 IPS @ 16 HZ	0.25 IPS @ 16 HZ
13 SIMULATOR	ABS FRAME ACCEL	DIAG	0.25 IPS @ 16 HZ	0.25 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.40 IPS @ 16 HZ	0.25 IPS @ 16 HZ
14 SIMULATOR	#1 HI-SPD ACCEL	DIA	0.75 IPS @ 350 HZ	0.75 IPS @ 350 HZ	0.80 IPS @350 HZ	0.85 IPS @ 350 HZ	0.85 IPS @ 350 HZ	0.85 IPS @ 350 HZ	0.85 IPS @ 350 HZ	0.85 IPS @ 350 HZ	0.85 IPS @ 350 HZ	0.85 SLOWLY INCR. TO 4.00	0.80 IPS @350 HZ	0.75 IPS @ 350 HZ
15 SIMULATOR	COPILOT LAT ACCEL	T & B	0.20 IPS @ 4 HZ	0.20 IPS @ 4 HZ	0.10 IPS @ 4 HZ	0.15 IPS @ 4 HZ	0.20 IPS @ 4 HZ	0.23 IPS @ 4 HZ	0.25 IPS @ 4 HZ	0.23 IPS @ 4 HZ	0.23 IPS @ 4 HZ	0.23 IPS @ 4 HZ	0.10 IPS @ 4 HZ	0.20 IPS @ 4 HZ
16 SIMULATOR	OIL COOLER ACCEL	DIAG	.5 IPS @ 70 HZ	0.5 IPS @ 70 HZ	0.5 IPS @ 70 HZ	0.5 IPS @ 70 HZ	0.5 IPS @ 70 HZ	0.5 IPS @ 70 HZ	0.5 IPS @ 70 HZ	3.0 IPS @ 70 HZ	.5IPS @ 70 HZ	.5 IPS @ 70 HZ	0.5 IPS @ 70 HZ	.5 IPS @ 70 HZ
17 SIMULATOR	P.V. REDUND ACCEL	DIAG	1.0 IPS @ 50 HZ	1 IPS @ 50 HZ	1.1 IPS @ 50 HZ	1.1 IPS @ 50 HZ	1.2 IPS @ 50 HZ	1.2 IPS @ 50 HZ	1.2 IPS @ 50 HZ	1.5 IPS @ 50 HZ	1.2IPS @ 50 HZ	1.2 IPS @ 50 HZ	1.1 IPS @ 50 HZ	1.0 IPS @ 50 HZ
18 SIMULATOR	COP REDUND ACCEL	DIAG	2.0 IPS @ 100 HZ	2 IPS @ 100 HZ	2.1 IPS @ 100 HZ	2.1 IPS @ 100 HZ	2.2 IPS @ 100 HZ	2.2 IPS @ 100 HZ	2.2 IPS @ 100 HZ	2.5 IPS @ 100 HZ	2.2 IPS @ 100 HZ	2.2 IPS @ 100 HZ	2.1 IPS @ 100 HZ	2.0 IPS @ 100 HZ
19 SIMULATOR	COP LAT RED. ACCEL	DIAG	3.0 IPS @150 HZ	3 IPS @150 HZ	3.1 IPS @150 HZ	3.1 IPS @150 HZ	3.2 IPS @150 HZ	3.2 IPS @150 HZ	3.2 IPS @150 HZ	3.5 IPS @150 HZ	3.2 IPS @150 HZ	3.2 IPS @150 HZ	3.1 IPS @150 HZ	3.0 IPS @150 HZ
	NOSE C.L. RED ACCEL	NOT FOR GROUND TEST	XXX XXX	(WITH NO SIGNAL COMING IN, AN IN-OPERATIVE TRANSDUCER WILL BE SIMULATED....) XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX XXX	XXX XXX	XXX XXX	XXX XXX

NOTE: CONSISTENT PHASE RELATIONSHIPS MUST BE MAINTAINED BETWEEN CONTACTORS AND VIBRATION SIGNALS, IE:

1) TAIL ROTOR CONTACTOR AND TAIL ACCELEROMETER PHASES MUST BE CONSISTENT FROM THE BEGINNING OF THE FIRST CONDITION TO THE END OF THE LAST CONDITION.

2) MAIN ROTOR CONTACTOR AND PILOT VERT.,COPILOT VERT., COPILOT LAT., NOSE VERT., AND ABSORBER FRAME ACCELEROMETER PHASE RELATIONSHIPS MUST ALSO BE MAINTAINED FOR BOTH THE 4 AND 16 HZ FREQUENCIES, THE SAME AS 1) ABOVE

4.5. CHECKOUT OF SYSTEM INTEGRATION

Once the basic communications functions had been verified, the next step was to test/debug the Sikorsky generated application programs which provide the overall system operation. This testing was carried out in the following order:

- CD drivers were first tested by direct serial interface to the SUN workstation, then by sending individual display commands from interactive DPL and finally driven by the full MCDS.

- Regime recognition was tested by placing the FDR in time history mode (which also captures regime codes and the intermediate codes which can be parsed to verify the FDR interpreted value of each input parameter) with each of the available simulated regimes. A final check was done to verify that the regime codes were correctly received by the MC. These checks were carried out with both maintenance and monitor mode tables, and key parameters were varied outside their normal range to prove that the tables were correctly interpreted.

- Regime driven data acquisition and DAU background monitoring was checked next. This was done by taking the MCDS through sample flights with each regime and monitoring activity on the DAU using the SUN workstation. After a series of successful data acquisitions, the vibration history file was examined to verify the values and quantity of data points stored. In addition, the function which monitors DAU progress was checked by installation of diagnostic code that continuously displayed the DAU status on a CADU screen and comparing this with the actual DAU status as displayed on the SUN workstation.

- Invalidation of data should occur if the regime changes during an acquisition. This was checked by changing simulator regimes at various points during acquisitions. This worked well except that a problem was discovered with one of the work-arounds. Internal system limitations require that only one data pipe be open between the CADU and the DAU at a given moment. Contention for this pipe forced shortening of the DAU background monitoring period until after data acquisition was underway by using a time-out period before launching the monitoring process. This left a brief time period where a change in regime could be missed by the system and the data incorrectly associated with the wrong regime. This was fixed by verifying that the regime at the conclusion of data acquisition is the same as when the measurement was initiated.

- TRDS bearing temperature acquisition was checked, placing each thermocouple in water and viewing the GP static test mode display for both channels.

- Time history mode initiation was checked both by request from the CD and by manually tripping one of the stabilator discretes. The resulting FDR time history file was downloaded to the GP and examined for initiation time and parameter value content. The MC vibration time history spectra was also checked. CD save and delete options were also tested in a similar fashion.

- Transition to expert mode was checked by requesting a time history be taken and choosing expert mode from the CD menu. The vibration spectra was then examined using expert mode graphics capabilities.

- MCDS is able to recover from a loss of MC/FDR communications. This was checked by disconnecting the serial cable temporarily and monitoring system activity on the CADU. The system noted the error and automatically entered backup mode (accepting regime codes from the backup selection menu) and took data accordingly. When the cable was replaced, the serial traffic resumed and the system was successfully restored to fully automatic mode.

4.6. CHECKOUT OF FAULT DETECTION - SIMULATED INPUTS

The basic method of checking MCDS abilities to diagnose faults involved acquisition of data during simulated failure regimes and verification that an appropriate CD advisory was issued. Limitations in MCDS bench simulation capabilities prevented all implemented functions from being verified as noted below.

1P Vibration Problems

This fault is simulated by overspec vibrations at all of the available test states on the pilot and copilot accelerometer channels. This verifies the ability to complete tail rotor balance, main rotor balance, and high speed adjustments to PCR's and blade tab. Flat pitch track, high speed track and hover spread algorithms could not be verified since track simulation was not available. Track inputs to ground and high speed adjustments are routinely conducted by Sikorsky factory personnel using identical equipment and algorithms and thus should function properly on an aircraft. Hover spread algorithms will require verification in flight.

Vibration Absorber Problems

A specification exceedance is simulated at high speed regimes, and MCDS will detect this and issue an advisory.

Damper Problems

Damper problems are not simulated but should be detected by MCDS.

Engine High Speed Shaft Vibrations

Engine high speed shaft vibrations are simulated to increase from 0.85 to 4 ips in a special regime and are detected by MCDS which will generate an advisory (or caution if the level is over 3 ips), indicating the existence of the problem.

Tail Rotor Drive Shaft Bearing Temperature

This bearing temperature is simulated with a hot water bath and MCDS generates a caution which displays the actual temperatures.

Oil Cooler Vibration

The oil cooler vibration is simulated to exceed specifications during a special regime and MCDS will generate an advisory.

General Vibration

Vibration is checked by manually adjusting the reference spectrum for a set of frequencies to cause it to trip and generate an advisory. This will require further adjustment and testing under actual flight conditions.

Tail Rotor Drive Shaft Disconnect

This is simulated through a special regime that drops RPM from 20 to 16 Hz and causes a coincident drop in tail rotor vibration. MCDS will generate a warning message with advice on safe descent procedures from the flight manual.

Stabilator Input Monitoring

Specific problems are not simulated and no automated diagnostic code is available; however, the triggering discretes are switch controlled and MCDS does capture the correct time history if they are manually switched.

4.7. SUMMARY OF RESULTS/PROBLEMS

A bench demo was shown to the invited Army audience in May 1990 to demonstrate the basic capabilities of the MCDS. The following is an outline of the steps that were executed to complete this demo:

Review of individual bench test components - The following components in the lab were described and their role in the bench demo was reviewed:

- Dynamic data simulator
- RADS-AT subsystem (it was noted that the keyboard attached to the CADU was for convenience only and is not a required part of the system)
- FDR subsystem
- Serial protocol analyzer
- SUN workstation

Demo of the FDR in GP mode - The FDR was pre-booted with the GP connected and the MC disconnected:

- A BIT check of the FDR was requested and displayed.
- The static test mode was shown while varying rotor RPM (RPM was left at 80%).
- The static test mode monitored airspeed as the simulator was changed from Vh to FPG100 (160 Kts to 30 Kts).
- The CD test mode was requested and the CD function keys were pressed to show their effect on the display.

- The regime threshold and multiradix tables were displayed and explained (including differences between maintenance and monitor mode).

- The auxiliary memory pointer was reset (to clear any previously stored data on the FDR).

- Power was removed and the unit repowered with GP connected switch to OFF.

MCDS was then demonstrated as a system by walking through a typical flight (initial conditions included the simulator in the STRTFLT regime with Nr at 80%, serial traffic monitoring was on, the DAU was monitored by the SUN workstation, and the data base had been preloaded with at least 4 points already taken at each test state):

- The harness was reconnected to the CADU, causing communications to resume.

- The main menu was reviewed and utility mode was demonstrated (by changing a vibration specification and restoring it).

- MCDS was returned to monitor mode by increasing Nr to 100% which changed the regime to FPG100.

- The system took 2 data points while the data acquisition process was followed on the SUN window and the CADU screen.

- The DDS was switched to the HOVER regime with Nr at 80% (no regime) which allowed the system to analyze the data. The specification exceedance (0.305 vs. 0.2 ips for the main rotor hub) on the first point caused MCDS to generate an advisory and calculate a hub balance correction. The second point was deleted as it was nearly the same as the first.

- While in the maintenance mode loop, the RECORD button was pressed to capture a time history (the time was noted and the Nr was varied to show some activity in the FDR time history).

- The vibration time history was followed on the SUN and when the CD menu came up, the KEEP DATA option was chosen.

- To demonstrate communications fault tolerance, the MC harness connector was removed, causing the CADU to note the FDR error and display the REGIME SELECTION screen.

- The MC harness was reconnected, the RETRY FDR option was selected to resume FDR communications, and the DISPLAY ON CD option was used to resume CD communications.

- The bearing temperature monitor was demonstrated by placing the thermocouple in a cup of hot water (near 100 °C). A caution message was displayed on the CD, overwriting the earlier hub balance advisory.

- Maintenance mode was chosen and explained. The HOVER regime was entered by increasing Nr to 100% and following data acquisition on the SUN. Upon completion, the

Vh regime was entered and the HOVER state dropped from the regime list and Vh data was taken.

- Maintenance mode was exited by changing Nr to 80% then changing the DDS regime to ENDFLT.
- The EXPERT MODE option on CD was selected and the expert mode credit card memory was inserted. The vibration time history graph was displayed (which was taken earlier when the RECORD button was pressed).

To examine the FDR time history, the FDR needed to be rebooted in GP mode and the data downloaded and displayed:

- The FDR was powered down and the MC was disconnected.
- The GP connected switch was changed to ON and the FDR repowered.
- A FDR BIT check was completed and examined.
- The data download option was chosen and the data was downloaded.
- The time history report was examined and matched the parameter values at the time it was taken.

In summary, the MCDS demonstration showed that the basic system is operational, can take and analyze the data based on flight regime, and can display the results to the pilot and maintainer. In preparation for further testing, the diagnostic capabilities should be more thoroughly checked and some modifications need to be made to speed up CD screen updates and data acquisition.

5. ASSESSMENT

The following ideas are offered as potential extensions to the MCDS research efforts.

5.1. FLIGHT TEST NEEDED TO EVALUATE/DEBUG DIAGNOSTIC ALGORITHMS

The use of simulated fault and regime data during the bench testing showed that the basic system can work. However, true verification of the diagnostic algorithms must be done through flight testing on a real aircraft. Due to the limitations with simulating various track patterns, some algorithms (which use blade track) cannot be properly checked. In addition, the variation in real aircraft vibration levels during various flight conditions are not precisely known, and thus the trending and prognostic functions may need some refinement based on flight experience. Monitor mode flow should also be verified during real flight (especially the effects of regime stability or lack thereof) to verify that enough data will be acquired using the opportunistic sampling scheme. Communications and data acquisition need to be checked in real aircraft noise environment (which may or may not be worse than the lab environment).

5.2. POTENTIAL PRODUCTION CONFIGURATION AND DEVELOPMENT ROUTE

Since MCDS was designed as a concept demonstration using "off-the-shelf" components, a production implementation would be significantly different. This section describes some ideas of how a production version could be developed and produced.

Assuming that the Army continues with plans to install digital FDR's in the fleet, to reduce system weight and size, the vibration functions should be reduced to a boardset that could end up in the flight data recorder using some of the spare capacity planned for maintenance purposes. The regime recognition function could either be imbedded into the FDR software or the necessary parameters passed from the FDR to this boardset where the regime determination would have to be done. This would entail a hardware development and qualification process and recoding the diagnostic and measurement software to a faster compiled language suitable for airborne deployment. CD functions should be reimplemented onto an existing onboard display subsystem (if available), or a special simple controller could be added to provide minimal onboard control and pilot interaction (a full CD is really not justified for this application alone).

5.3. USE OF MCDS AS A DIAGNOSTIC TEST BED

Prior to decisions on productionizing MCDS or a similar system, further research is needed to explore other diagnostic technologies and concepts to synthesize the optimum mix of mechanical diagnostics to be added to each aircraft type and to develop the necessary background data to justify the cost and weight penalties of onboard diagnostics.

Key to this justification would be the definition and evaluation of several Measures Of Effectiveness (MOE) for an integrated diagnostics system. These might include: (a) incremental improvements in the accuracy of fault detection and fault isolation (including intermittent failures) demonstrated by an integrated diagnostics system compared to the current system, (b) reductions in training time and costs, (c) savings in projected spares, (d) offloading of test/support equipment, and (e) improved availability of helicopters. Evaluation of these MOE's should continue into a field evaluation phase where the integrated diagnostics system could be tested under realistic conditions.

The MCDS is designed with an open architecture, has the basics of monitoring and data handling in it's current configuration, and thus could be used as a flying testbed of new diagnostic technologies. This would be done by expansion of the existing MCDS FDR chassis to add additional hardware functionality. There are additional serial ports currently available for communications from these new functions to the rest of the MCDS. The primary effort would be to repackage the new hardware to fit inside the FDR (or simply connected to the FDR harness) and to integrate the software functions. The diagnostic processing could be handled by the MC (where the communications protocol already has a generic information passing command which could be reconfigured to other data types). A possible expanded architecture is summarized in Figure 25.

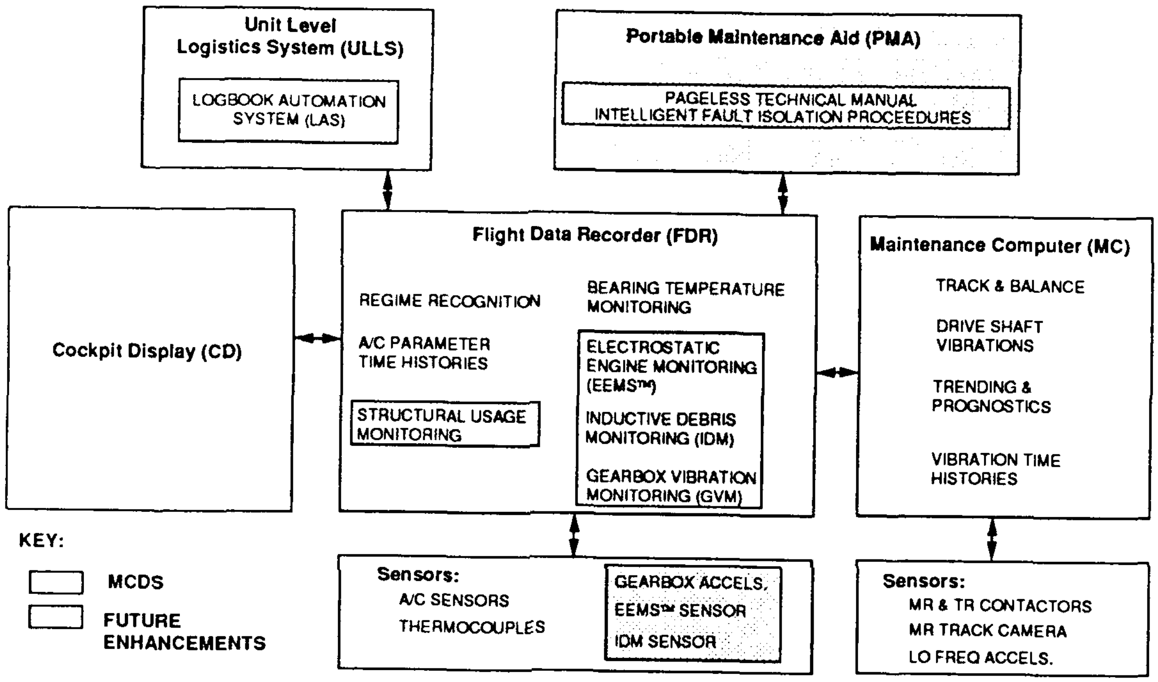

Figure 25. MCDS expanded architecture.

Some potentially interesting technologies include:

Electrostatic Engine Monitoring System (EEMS), which monitors the jet engine exhaust for evidence of wear degradation or damage.

Inductive Debris Monitoring (IDM), which is a potential substitute for chip detectors that monitors ferrous and nonferrous debris passing through the oil path.

High frequency vibration diagnostics, which typically look at internally induced vibration signatures of mechanical systems such as the gearbox to monitor changes that might indicate developing problems.

Structural usage monitoring uses regime statistics to monitor the actual usage of the aircraft with the potential to eventually affect component retirement times. This would primarily consist of FDR software changes to add these functions back in (since the MCDS FDR was derived from a usage monitor).

Interface to a portable maintenance computer to allow more detailed data analysis, logistics system interface, maintenance procedure prompting, and interaction between maintenance actions and airborne diagnostics.

6. CONCLUSIONS

The MCDS program has met its basic objective of demonstrating a mechanical diagnostic system, to be located onboard, which calculates 1P rotor smoothing adjustments and demonstrates general vibration and flight control troubleshooting concepts. The following features contribute to its utility in meeting mission goals:

- The system can be operated to gather data with minimal pilot intervention, thus having little impact on pilot workload.
- It provides the pilot with status information when desired and the ability to capture data helpful in diagnosing intermittent problems.
- Since most of the vibration data gathering is accomplished during mission flights, there would be a reduction in the requirement for dedicated maintenance flights to tune the aircraft (potentially zero if the next mission flight is used to confirm maintenance success).
- The maintainer is presented with specific repair instructions which minimize his required depth of understanding of the vibration dynamics of the helicopter. If these instructions are followed, the MCDS allows the aircraft vibration level to be kept at an optimum level with increased component MTBF and reduced crew fatigue.

These MCDS benefits can reduce aircraft operating costs by reducing maintenance time and required skill levels needed to maintain mechanical systems, reduction in costly maintenance test flights, extended MTBF of many electronic components by lower vibration, and reduction in "retest OK" parts in the supply pipeline. Aircraft availability would correspondingly increase since the time spent for ground maintenance and test flights directly reduces availability.

7. RECOMMENDATIONS

Based on the results of this effort it is recommended that:

1. MCDS be carried through flight evaluation (see Reference 5). This would include flight testing of MCDS using inserted faults as well as a potential longer evaluation period where an instrumented aircraft could be used for normal mission work to measure the usefulness of the MCDS.

2. The system be expanded to include other capabilities and be used as a diagnostic testbed to evaluate other potential diagnostic technologies. This experience would be used to define an optimum mechanical diagnostic system within fiscal and weight constraints.

3. The results of this testing/refinement be developed into a specification for inclusion into an upgraded UH-60 avionics system for future aircraft models. In addition, since MCDS was designed with enough added capacity for other rotorcraft models (see Reference 2), it could be reconfigured and tested on other models.

8. REFERENCES

1. Sewersky, R. A., Mechanical Component Diagnostic System (MCDS) Software Operator's Manual, Sikorsky Aircraft Division, United Technologies Corp., SER-701641, August 1990.

2. Pratt, J., Mechanical Component Diagnostic System Preliminary Design Report, Sikorsky Aircraft Division, United Technologies Corp., SER-701315, June 1988.

3. Molnar, G., SH-60B Structural Usage Monitor Final Report, Sikorsky Aircraft Division, United Technologies Corp., SER-520859, July 1990.

4. Metro, R., Experimental Test Plan for UH-60A Mechanical Component Diagnostic System, Sikorsky Aircraft Division, United Technologies Corp., SER-701392, March 1989.

5. Sheets, F., Ground and Flight Evaluation of the Mechanical Component Diagnostic System, Sikorsky Aircraft Division, United Technologies Corp., SER-701382, March 1989.

9. GLOSSARY

1P	One-per-revolution Frequency
4P	Four-per-revolution Frequency
BIT	Built In Test
CADU	Control And Display Unit
CD	Cockpit Display
CWA	Caution Warning Advisory
DAU	Data Acquisition Unit
DPL	Diagnostic Programming Language
EEMS	Electrostatic Engine Monitoring System
FDR	Flight Data Recorder
GP	Ground Processor
IDM	Inductive Debris Monitoring
MC	Maintenance Computer
MCDS	Mechanical Component Diagnostic System
MOE	Measures Of Effectiveness
PCR	Pitch Control Rod
PDR	Preliminary Design Review
RADS-AT	Rotor Analysis and Diagnostics System - Advanced Technology
SUM	Structural Usage Monitor
TRDS	Tail Rotor Drive Shaft