

# **AUTOMATED DATA SYSTEM FOR HELICOPTER STRUCTURAL FATIGUE TESTING**

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## **ABSTRACT**

Helicopter structural fatigue testing requires the monitoring and precise control of physical input loads along with the collection and analysis of large quantities of static and dynamic data.

This paper describes an automated, on-line system specifically designed to structurally test a full size helicopter airframe.

Microprocessor controlled shakers apply dynamic loads to the test article and simulate a typical flight profile, e.g., take-off, climb, cruise, descent, hover and landing.

A minicomputer based automated data system acquires up to 128 measurement channels consisting of outputs from accelerometers and strain gages with an overall data system throughput rate of 50,000 samples per second.

The test engineer can select various operational and data processing formats from computer stored menus.

Data tables in engineering units plus graphical displays of time histories or spectral information are also available. The system can be run in a variable data burst mode or in a continuous monitor mode.

## **INTRODUCTION**

Helicopter structural fatigue testing requires the collection and analysis of large quantities of dynamic data. Past tests have been conducted by tape recording the data and performing the detailed processing and analysis off-line. The limitations to such a post processing approach include increased test time and the possibility of changes in the structural

response of the test article occurring before the test engineer can evaluate the data. The automated data system was developed to reduce the time and cost of major structural system testing, improve the accuracy and precision of test data, provide on-line access to data in engineering units and be strongly interactive while retaining simplified operational procedures.

The goal of helicopter structural fatigue testing is to attempt to initiate cracks in the structure and monitor their propagation. Refer to Figure 1. The test airframe is instrumented identically to its flight counterpart and microprocessor controlled shakers apply dynamic loads to the test article. Before beginning the actual fatigue test, the shaker inputs are adjusted until the airframe has a similar response to the flight test aircraft. This response is verified by comparing ground test data to corresponding flight test data. This tuning process is performed for each flight condition or regime. The resulting shaker settings are programmed into the controller which sequentially steps through a typical simulated mission, e.g., take-off, climb, cruise, descent, hover and land. The amplitude levels of the applied loads are cumulatively higher than comparable flight loads in order to accelerate crack initiation time. One hour of test time is equal to some greater number of flight hours. Each flight condition is assigned a regime number which is communicated to the automated data system by the controller. In addition, the data system receives a signal indicating when the loads have been brought up to final level and are stable; the "DATA VALID" signal. The controller receives a shut down command from the data system if conditions warrant. The control loads are then gradually reduced to zero over a programmed period of time to avoid possible structural damage due to an abrupt system halt.

During the fatigue testing the minicomputer based data system acquires the test data and produces required statistics. The test engineer selects the data processing and display type he requires from a computer stored menu. Among the types of displays available are tables of statistical data in engineering units and graphical displays of time or spectral data. A monitor mode is also available in which current results are continuously compared to previously stored stress/load values. If predetermined limits are exceeded, a shutdown command is sent to the controller.

## **SYSTEM DESCRIPTION**

The automated data system has a total data throughput rate of 50,000 samples per second. Refer to Figure 2. It is presently configured to monitor 128 data channels with an information bandwidth of 100 HZ per channel. All channels are sampled simultaneously preserving cross channel phase integrity which is an essential requirement for dynamic processing. The actual sample rate is selectable under computer control via an internal clock or by means of an external scan signal. Analog outputs from all channels are wired

to a system patch panel. Inputs to various recording, display and test equipment are also wired to the system patch panel allowing examination of critical channels and providing a level of backup to the automatic processing. Operator communication is handled through a printing terminal or a vector type graphics display video terminal with a hard copy unit.

The front end signal conditioning and control electronics was supplied by NEFF Instrument Corporation (System 620). Some system modifications were made to acquire data at a carefully controlled rate with samples uniformly spaced, a requirement for performing fast fourier transforms on the time data. The signal conditioning is equipped with relays which the computer operates to select the appropriate calibration mode. "R-Cal" connects a shunt resistor (unique resistance value per channel) across one arm of the Wheatstone bridge offsetting the bridge to a known value. The output of each bridge is connected to a D.C. amplifier and a two pole active filter. The individual channel gains and filter cutoffs may be changed by selection of the appropriate plug-in modules. Signals are multiplexed at the high level then passed to a programmable gain amplifier and a 12 bit analog to digital converter.

The minicomputer used in the system is a Digital Equipment Corporation PDP11/34A with 256 thousand bytes of memory and two RL02 10 megabyte disk drives. RSX-11M was chosen for the operating system due to its performance and driver support despite its somewhat high overhead. The software system was configured to minimize overhead as much as possible. All application programs were written in DEC's FORTRAN IV PLUS.

The front end signal conditioning is connected to a local control assembly which in turn is connected to the DEC computer via a direct memory access interface (DMA). The control assembly contains a four thousand word Random Access Memory (RAM) which is used to store the list of channels to be scanned. The computer writes the scan list out to this RAM using a special software driver. The command to scan from RAM supplies one group of channel samples which is one frame of data to the computer. Early in the software development cycle it became apparent that the minicomputer operating system could not cycle a driver call fast enough to satisfy the system frame rate requirements. It was necessary to by-pass the driver and write an assembly language routine to directly access the DMA interface to achieve the required frame rate (410 frames per second). As stated, it is imperative that all frames be uniformly spaced. A special interface was designed to control the front end to computer communications sequence. The scan rate is provided by a crystal clock and divider. The computer selects the scan rate before taking data by setting the divide factor. The sequence of events necessary to take a group of frames is:

1. The computer writes the scan list to RAM in the front end.
2. The computer selects the frame rate.

3. The computer issues the command to SCAN from RAM.
4. The SCAN command request remains pending until the SCAN rate goes high at which time the SCAN begins.
5. The computer completes its end of SCAN overhead and issues another command to SCAN from RAM, which remains pending until the next rate transitions high.

The process continues until the required number of SCANS (or frames) have been completed.

Once data is taken into memory it must be written out to disk. Two methods are used depending on the required frame rate. When the frame rate is less than 200 frames per second; the data is written to disk during acquisition. This is accomplished by utilizing two 4K buffers, one is loaded while the other is written out to disk after which the buffers are switched - the technique is known as "double buffering". When the frame rate is more than 200 frames per second, the double buffering operation can not be used without losing frames because the initiation of the write to disk command takes approximately 4.75 milliseconds. At higher frame rates, the computer memory is packed with data after which this data is written out to disk.

Performing a fast fourier transform on 1024 time samples requires 5120 complex multiplies and additions. Considering that this operation may be required up to 128 times (once per channel), significant computer processing time could be saved if the FFT's were performed externally to the computer. A Hewlett-Packard Model 3582A digital spectrum analyzer was chosen to perform the operations. This analyzer was selected because access to its time buffer is possible through a built-in IEEE 488 type digital interface. Linking the analyzer to the minicomputer was accomplished by installing a commercially available instrument bus controller and software driver.

For the desired frequency range of 0 to 100 HZ, the required rate is 410 samples per second. Since any channel transferred to the analyzer must be sampled at this rate, the frame rate is set to this value. The spectral data matrix (containing amplitude and phase information) is read back into the computer from the analyzer after the FFT process is completed. The techniques of communicating with the analyzer were developed on a Hewlett-Packard desktop calculator in HPL language then later implemented in FORTRAN for use in the minicomputer.

A standard channel is included in the data system to provide a stable reference for a total system check of dynamic processing performance. The standard channel is a complex wave form of known frequency content, programmed on a read only memory (ROM),

passed through a digital to analog converter, filtered to eliminate quantization noise and then injected into the transducer input of channel 128. The standard channel is optionally included in a data burst and processed along with the other data channels. The computer, recognizing “STANDARD” in the data stream, will compare the processing results to the known values stored and alert the operator to a possible system problem if any discrepancies exceeding a programmed tolerance are discovered. The standard parameter provides high data quality confidence and lends credibility to any unusual test data which may show up in real problem situations.

The software is designed to be highly operator interactive. The operator’s major concern is the data itself, not the particulars of its acquisition and handling. The operator is often a Test Engineer assigned to a particular structural test. A primary system objective was simplicity of operation. All operator interface is through a task called “ICP” for Interburst Command Processor. Refer to Figure 3. ICP is a monitor routine which generates a prompt character (>) expecting the operator to key in one of a number of commands. “HELP” is one such command which results in the listing of all possible commands and how to enter them. Among the complement of commands are: SETUP, AUTOCAL, CALIBRATE, BURST, PSTAT, FFT, SAVE AND MONITOR.

When a command is keyed in, the task of that name is run by ICP and returns to ICP on termination. All tasks are called by ICP and return to ICP.

SETUP prompts the operator to enter all the information required by the system to perform all processing tasks. SETUP would be run prior to the start of testing. Examples of the information entered are calibration equivalent values, engineering units labels (e.g. , psi, lbs, G, etc.), frame rates at which bursts are to be taken, titles for bursts, and scan lists of channels to be taken for various regimes or test conditions.

AUTOCAL (automatic calibrate) causes three bursts of data to be taken. The first of the three is designated as “X-CAL” which is the ambient condition on all channels (transducer mode). The second burst is the “R-CAL” mode during which shunt calibration resistors are relay switched across one arm of each Wheatstone bridge type transducer, or in the case of a voltage input channel, a reference voltage is substituted for the transducer. The third burst is the “Z-CAL” or zero calibrate mode during which all transducers are electrically disconnected from the system and individual channel inputs are shorted allowing their inherent electrical offsets to be determined. After each burst is taken, the data is written out to disk and tagged appropriately. These three bursts can also be taken individually for set-up or checkout purposes.

CALIBRATE takes the information entered during SETUP and combines it with the data acquired during the three calibration bursts and calculates the coefficients for each

channel's engineering units conversion and stores them on disk. CALIBRATE also generates a table which includes all the specific processing information available for all channels. Examples include, plus and minus measurement range in engineering units and the calibration levels in percent of full scale and in engineering units. Error messages are provided on individual channels and are intended to alert the operator to instrumentation problems prior to testing. Among the possible error messages are over full scale either positive or negative, standard deviation exceeds a specified tolerance, and the R-CAL deflection exceeds a specified tolerance. Any one or all of these messages can appear for any channel.

BURST is used to take a data burst on command. After keying in BURST, the system will ask for a regime number, i.e. , the test condition which will have associated with it a list of channels to be scanned (PASS list entered during SETUP). After acquiring data, BURST will write the data to disk then exit to ICP.

The operator will use PSTAT or parameter statistics to view the data in tabular form. Refer to Figure 4. PSTAT will read and decode the raw data stored on disk, calculate statistics using SETUP information, then display the data to the operator. PSTAT will operate on either the most recently taken burst (the default choice), or any of the other data bursts up to the last time CALIBRATE was run and data conversion coefficients calculated. Among the statistics are average value, maximum value, minimum value, standard deviation, the peak spectral elements (frequency, amplitude and phase), and the peak vibratory stress value. The ability to instantly examine past data allows the test engineer to compare results as the testing progresses. PSTAT will print statistics on all channels in a burst (the default choice) or on any particular channel by entering the mnemonic of the desired channel. There is never a need for the operator/test engineer to know the location in the data system of any channel (once entered in SETUP); he need only refer to the mnemonic for the measurement of interest.

FFT allows the operator access to the time data and will perform a fast fourier transform on any channel. Access to the stored data is similar to the PSAT access procedure. FFT will access the most recent burst (the default choice) or any other data burst succeeding the last CALIBRATE run. The task is normally run on a vector graphics terminal (e.g. Tektronics 4006). The plotted data is automatically scaled. The operator has the ability to rescale the data as required. Like all tasks; FFT returns to ICP on its completion. FFT completes when the operator types EXIT, otherwise the task restarts, prompting the next parameter requiring analysis.

The SAVE command is executed when a characteristic test condition is acquired and is to be used as a reference in the monitor mode. After data has been evaluated the operator

types SAVE and the resulting statistics in engineering units are stored on disk in a SAVE file.

The MONITOR command initiates the automatic monitoring mode of operation. The operator must have performed a SAVE on all possible test conditions (regimes). This will provide the reference for all future data comparison. The system waits for the "DATA VALID" signal from the shaker controller then reads the particular regime number. After taking a burst of data and calculating statistics, comparisons are made against the SAVE file for the same regime. Each channel is assigned an individual fractional weight value. If any measurement exceeds predetermined variation tolerances (entered in SETUP), its corresponding weight value is added to a running total. If the total weight sum value exceeds 1.0, the shaker controller is sent a signal to reduce loading and shut down the test. Out of tolerance parameters are listed individually. If the total weight was insufficient to command shut down, the test continues and the MONITOR restarts with the total weight value reset to zero for the next condition. In the event of a transducer failure, the suspect channel will continuously list out of tolerance. Crack formation and propagation in the structure has been readily identified and monitored by a succession of out of tolerance parameters.

## **CONCLUSION**

An automated data acquisition and control system was successfully developed to satisfy the specific requirements of full scale helicopter airframe structural fatigue testing. The system was initially employed to test the airframe of the Navy's SH-60B SEAHAWK helicopter. Test personnel estimated the total program test time to be half of what it would have been without the level of automation provided by the shaker controller and the data system. The SEAHAWK test engineers were fully competent in system operation with as little as four hours of orientation.

The development of the system consisted of choosing commercially available equipment with appropriate capabilities, interfacing that equipment, writing computer code, and designing some custom hardware to meet specialized requirements. As straightforward as the task at first appeared, there were a surprising number of operating subtleties and special considerations associated with the system design. One should not underestimate the significant effort required to interface so called "standard equipment" and write computer code to access and interface that equipment. However, having made that point, the final operating system proved to be such a significant improvement over previous techniques that its present and future potential value is without question.

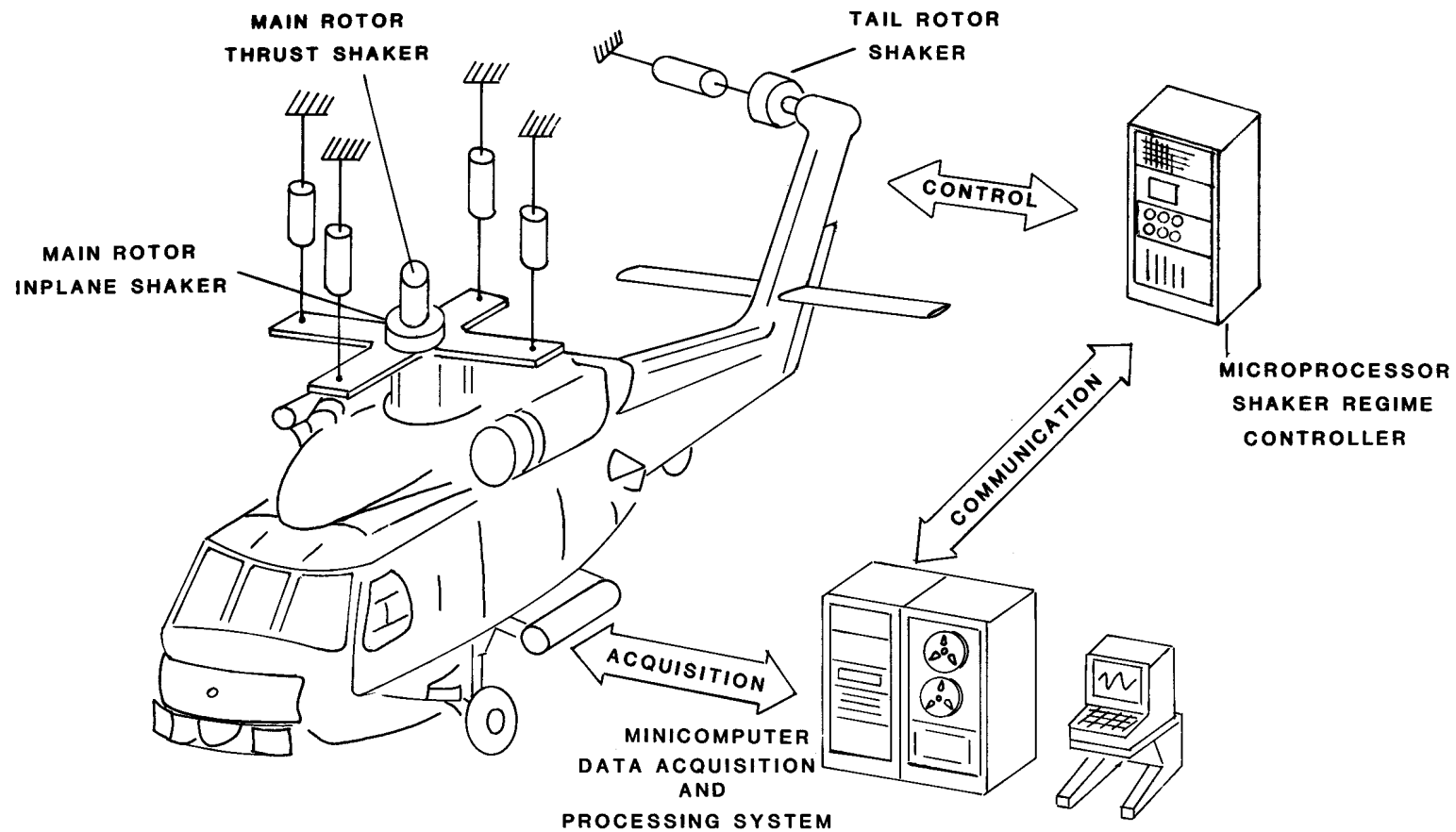
## ACKNOWLEDGEMENTS

The successful development of the helicopter dynamic test system described in this paper is a result of the collective endeavors of many individuals. The author would particularly like to cite the work of K. C. Lewis of Sikorsky Aircraft, J. Krodel of United Technologies Research Center and J. Vance and R. Chambers of Neff Instrument Corporation.

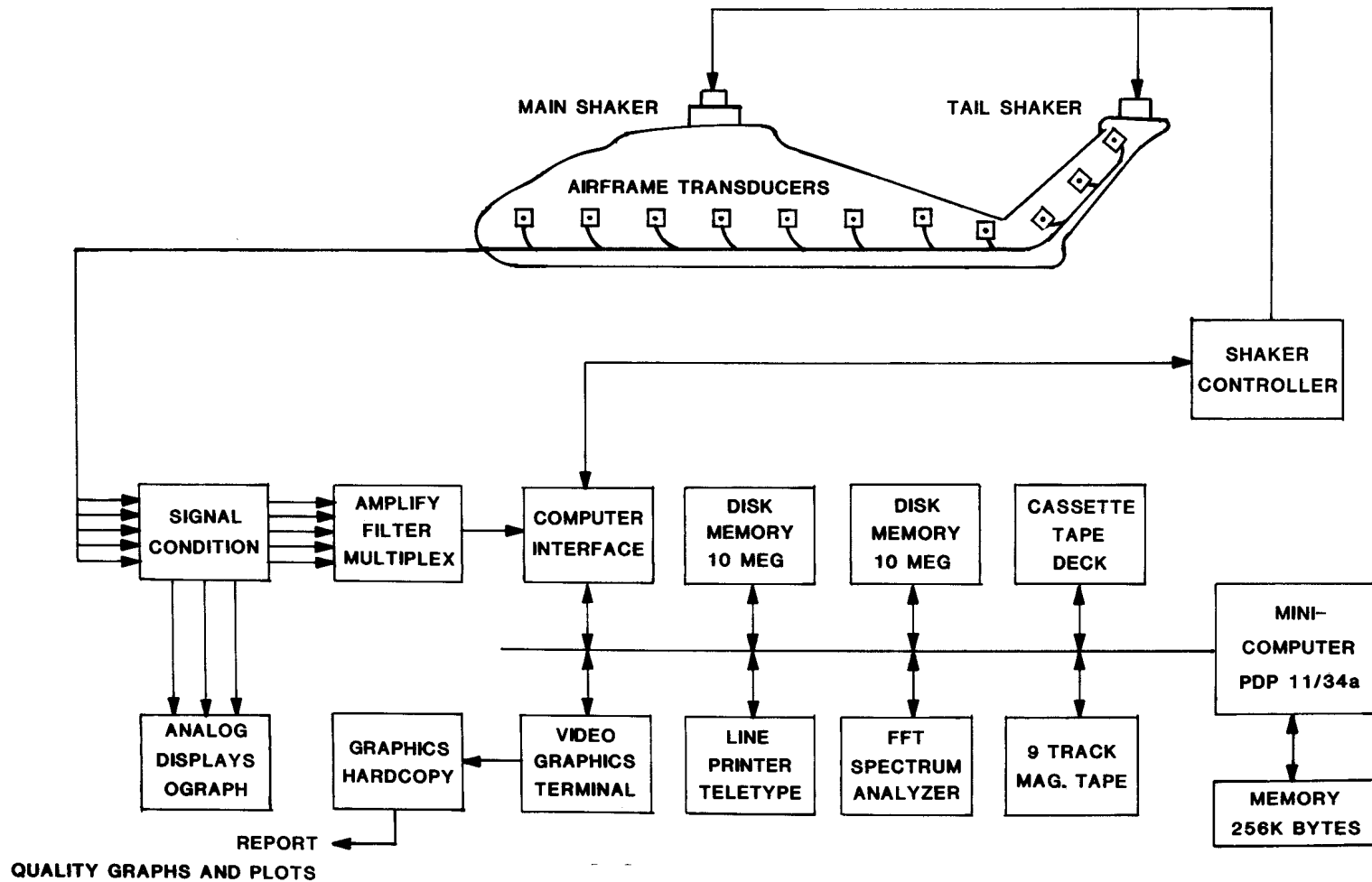
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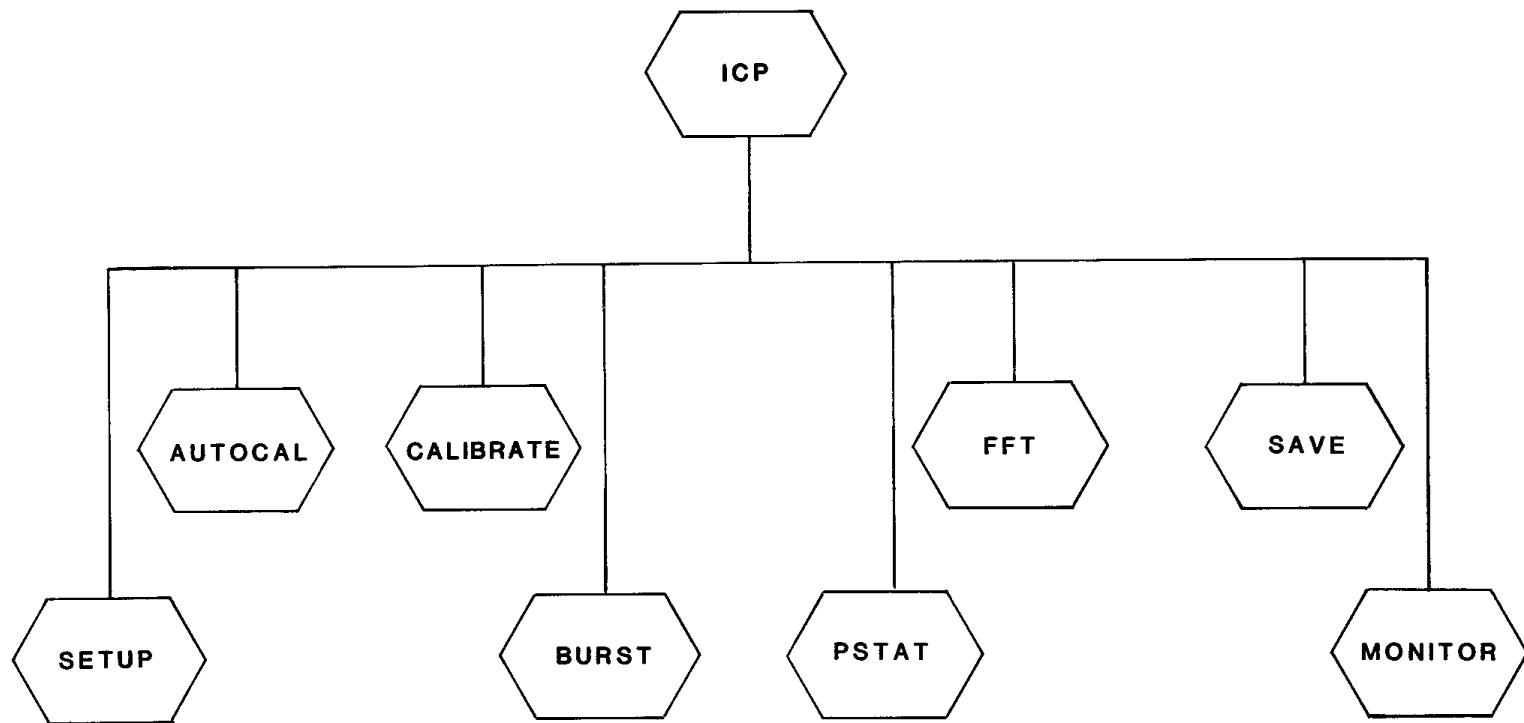




**FIGURE 1**  
**AIRFRAME STRUCTURAL FATIGUE TEST**  
**SYSTEM CONFIGURATION**



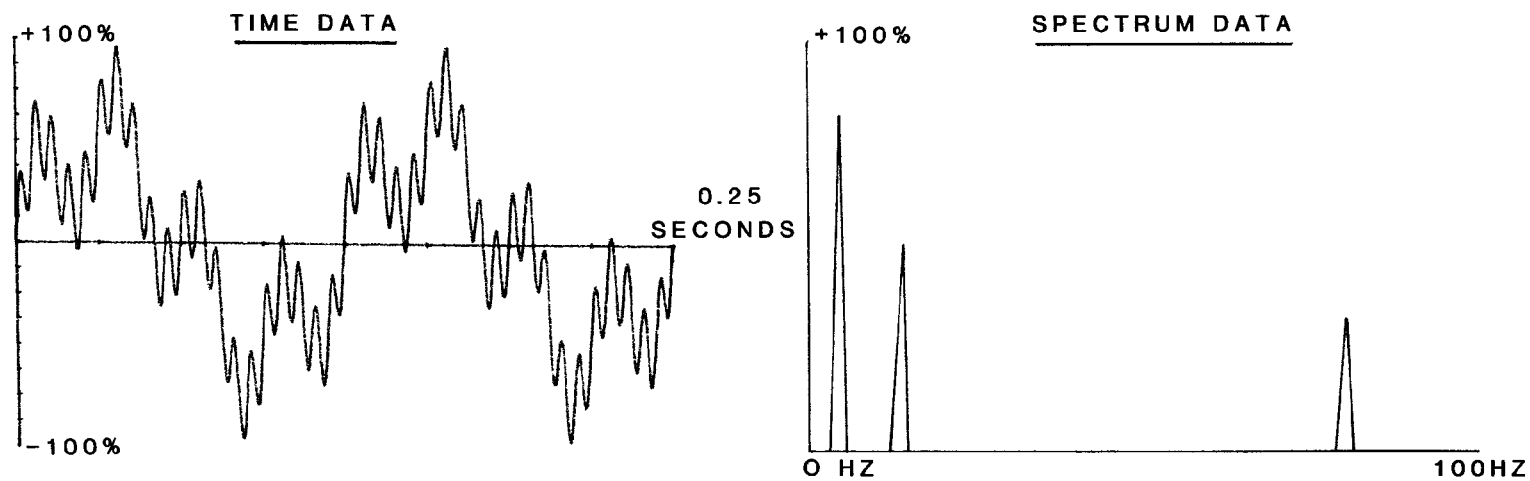
**FIGURE 2**  
**SIGNAL FLOW BLOCK DIAGRAM**



**FIGURE 3**  
**SOFTWARE-GENERAL CONFIGURATION**

# OPERATOR/COMPUTER DIALOG

ICP > FFT  
ENTER REGIME NUMBER: 1  
PARAMETER NAME: STANDARD  
ENTER UNITS--(E)NG OR (R)AW E  
PLOT TIME DATA? Y  
REGIME #1 HOVER 18JAN82 13:53:32PASS#4  
EXIT  
PLOT SPECTRUM? Y



**FIGURE 4**  
**REPRESENTATIVE DATE**  
**(THE STANDARD CHANNEL REFERRED TO IN THE TEXT IS PRESENTED)**