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TITLE: ___CRITIQUE OF THE INSTRUMENTATION SYSTEM,___

___747 MAJOR FATIGUE TEST___

MODEL _____

ISSUE NO. _____ TO: _WB Harrison_

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REFERENCES

The following documents and drawings will provide useful background information on the 747 Major Fatigue Test Instrumentation System.

D6-20599   Requirements for the 747 Major Fatigue Test Instrumentation System, Revision C, November 18, 1968

D6-20599-1   Requirements for the 747 Major Fatigue Test Instrumentation System - Horizontal Stabilizer Test, December 12, 1968

D6-23977-1   Software Requirements, 747 Major Fatigue Test Instrumentation System, Revision A, June 22, 1970

D6-23977-2   Software Program Design Specification, 747 Major Fatigue System, October 15, 1968

D6-30535-1   Operation and Maintenance Manual - 747 Major Fatigue Test Instrumentation System, General Information, June 9, 1970

D6-30535-2   Operation and Maintenance Manual - 747 Major Fatigue Test Instrumentation System, System Operation, June 9, 1970

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D6-30535-3	Operation and Maintenance Manual - 747 Major Fatigue Instrumentation System, Periodic Maintenance and Troubleshooting, June 10, 1970
D6-30535-4	Operation and Maintenance Manual - 747 Major Fatigue Test Instrumentation System, Miscellaneous Tables and Information, June 10, 1970
64-31099	Functional Block Diagram, 747 Major Fatigue Test Instrumentation System
64-31599	Schematics - 747 Major Fatigue Test Instrumentation System
64-31600	Interconnection Diagram, 747 Fatigue Test System

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PROPRIETARY NOTES

SUMMARY

A critique of the instrumentation system used to support the 747 Major Structural Fatigue Test. The critique was compiled at the conclusion of one life of testing with considerable hindsight available.

RETRIEVAL

Critique

Instrumentation

Major Fatigue Test

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this manual is to document instrumentation type problems and solutions to problems encountered while conducting the 747 Major Fatigue Test. Also included is a list of recommendations for improving future systems. It is hoped this documentation will be an aid to system designers of similar systems in the future.

1.2 SYSTEM DESCRIPTION

The instrumentation system consists of 84 separate analog electro-hydraulic and one electro-pneumatic servo systems used to control loads at each of the load points on the test airplane plus a digital computer for load programming and test control. The system also contains 128 channels of medium speed data acquisition for peak load history and a surveillance interrupt subsystem which monitors the test to ensure test specimen safety. See document series D6-30535-1 thru -4, Operation and Maintenance - 747 Major Fatigue Instrumentation System, for a complete detailed description of the system and its operation.

1.3 GENERAL COMMENTS

The Instrumentation System satisfied the system requirements as set forth in document D6-20599, Requirements for the 747 Major Fatigue Test Instrumentation System. Some of the capabilities provided were not used during the test. These are discussed in Section 2.

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The general consensus among those test operating personnel who had previous major fatigue test experience is:

a.   The 747 system was far superior to previously used major fatigue test instrumentation systems.

b.   Fewer problems were encountered during initial start up.

c.   The system was much easier to operate.

The fact that this test was conducted in an outside environment did not cause significant instrumentation problems. Moisture did occasionally get into a connector or load cell, but the electronics technicians supporting the test became very proficient at solving moisture problems. The aerosol cans of freon worked quite well for drying and cleaning connectors. Load cells were removed and sent to maintenance if internal moisture problems were suspected.

1.4   OUTSTANDING FEATURES

Several features of the 747 major fatigue test system are worth special mention. Probably the two most outstanding features were the automatic programmer rate control and the automatic reset. Two other factors that were essential to the success of the test program were the quality of on-site spares and the soundness of the ramp generator concept.

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1.4.1 AUTOMATIC PROGRAMMER RATE

Programmer rate is a function of the servo error signals when in the automatic rate mode. This provides an almost optimum rate at all times. On condition points calling for a large amount of change, the rate is slow while on those requiring very little change, the rate is maximum. Obtaining a fast average programmer rate was much simpler than would have been the case with a manual rate control.

1.4.2 AUTOMATIC RESET

Automatic reset saved many hours of test operating time. This was made very evident during the latter part of testing when confidence was gained in the ability of the computer to perform an automatic reset (RST) even with slack tension-only load systems. It was not uncommon to spend more than an hour manually unlocking the load systems during the early part of the test when the system was fired up after a long down time such as a weekend shut down. All load systems were unlocked and programmed to bleed point values within minutes when the RST was used for initial unlocking.

1.4.3 ON-SITE SPARES

One of the major factors responsible for the small amount of instrumentation down time during the test was the excellent supply of spare modules stored at the test site. Almost all instrumentation hardware failures were eliminated by on-site operating personnel using spare modules or work around methods. Flight Test maintenance and calibration personnel did a superb job of repairing faulty modules and providing quick turnaround in order to maintain a full set of operable spares on-site.

1.4.4 RAMP GENERATOR CONCEPT

The concept of computer controlled ramp generators for programming a large number of load channels rapidly proved to be very successful.

The Boeing built ramp generators were quite reliable, however they are very sensitive to electro-magnetic noise spikes. Extra care had to be taken when adding or modifying electrical equipment in this part of the system.

2 CAPABILITIES NOT USED

A number of capabilities were specified by the requirements document and were provided for in the system but were not used during the test for various reasons. This section lists these capabilities so they might be scrutinized very carefully before incorporating in other systems.

2.1 ROLL MOMENT CORRECTION

The requirements documents states: " . . . . The system must be capable of correcting for excessive roll moment. . . . . ." By the time the test started, Stress Engineering decided it would be better to absorb any roll moment in the main landing gear reaction load cells rather than use automatic roll moment correction.

The automatic roll moment correction would have measured the roll moment as seen at the main landing gear reaction load cells and would have added roll correction signals to the programmed load on selected wing loading systems. The practicality of this scheme was not proven since it was never used on the test.

2.2 DATA ACQUISITION BRIDGE POWER MONITOR

The data acquisition bridge power failure monitoring capability was no longer required after the software data acquisition tolerance check was added to the computer program. See Paragraph 3.2 for a description of the data acquisition tolerance check. The output relays were removed and short circuits put in their place as these circuits were a nuisance to maintain. The drop-out threshold was difficult to adjust and the monitoring circuitry was not as stable as desired, therefore frequent adjustments were necessary.

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2.3 EXCESS TRAVEL MONITORING

The specified requirement to detect excess travel of the test airplane did not materialize during the test. Hardware was provided to monitor up to eighteen (18) channels of excess travel switches. All eighteen inputs were shorted out during the test as no excess travel switches were needed on the test airplane.

2.4 RECORDER EVENT MARKER

". . . . . Each recorder shall have an event marker to indicate the beginning of a new spectrum. . . . . . .", said the requirements document. These event markers were never used. When permanent recordings were required, test operators wrote the condition point numbers on the pertinent charts with pencil.

2.5 SOUND DETECTION

Twenty-four (24) channels of sound detection equipment were provided as dictated by the requirements document. This equipment was used very little during the test because of the wide range of noise amplitude encountered during the application of a complete spectrum of loads due primarily to the noise generated by the body air system. Paragraph 4.8 describes improvements which would make the noise detection equipment much more usable for this type of testing.

2.6 DISK STORAGE

The system was designed with enough disk storage to handle spectrums containing more than 600 condition points. It was determined after the test had run for a while, that no more than 300 condition points needed to be stored on disk at any one time during the remainder of the test. Therefore, one disk control unit and three disk units were removed from the system by modifying the computer program to store acquired data and load spectrum all in one disk bank. The disk units removed were released for use on other tests.

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3 CAPABILITIES ADDED DURING TEST

Some instrumentation requirements become obvious only after the testing had begun. These vary from one test to another, since each test has its own unique problems which develop after testing begins. This section of the document lists all the changes and additions made to the instrumentation system after test startup and gives the purpose or reason for each.

3.1 TEST POINT PANEL

A large number of test points required monitoring periodically by the test operator on a digital voltmeter to ensure proper system operation. To enable him to do this in a more expedient manner the following test points were brought out to a panel mounted in a rack directly over a digital voltmeter that could be read from where adjustments might be made.

3.1.1 SERVO CONTROLLER TEST POINTS

Test points TP1, TP2, TP3, and TP8 on each of the 85 servo controllers were brought out to the test point panel. Of the four test points, TP3 (the servo error signal) was monitored the most often. It was used to check and adjust the output balance which must be set correctly to generate an accurate on-null signal to the computer. TP1 (the program signal), TP2 (the feedback signal), and TP8 (valve current signal) were used for checking and setting up servo system response and for troubleshooting.

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3.1.2 STRIP CHART SELECTOR SWITCH OUTPUT

Provisions were made so the output of any strip chart selector switch could be routed to the test point panel. The operator monitored the signal he desired by connecting the cable from the test point panel into the auxiliary input jacks for a given recorder then selecting the desired signal on the selector switch for that recorder. This provided a means of monitoring the output from each of the feedback signal conditioning cards in the 85 servo controllers. These test points were used by the operator to check and adjust the span and offset settings on the feedback signal conditioning cards.

3.1.3 POWER AND BALANCE UNIT TEST POINTS

The signal monitor output and the excitation voltage monitor from the power and balance rack adapters were brought over to the test point panel. The signal monitor was used by the operator to check and adjust the settings of the feedback balance and the program span on each of the 85 servo controllers. These were periodically checked to make sure the load as read by the data acquisition subsystem agreed with the programmed load. It was necessary for these two to agree for the auto-reset to work properly.

3.1.4 RAMP GENERATOR REFERENCE VOLTAGE

The ramp generator positive and negative reference voltages were brought out to test points on the test point panel so the operator could periodically check these voltages with a minimum of effort.

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3.2 DATA ACQUISITION ERROR CHECK

The system acquired and stored data at condition points during the test spectrum and printed this data on the line printer on manual command as specified in the requirements document. Programming had to be stopped while stored load data was printed. It was a time consuming and tedious job to peruse this data to evaluate system operation. It also became evident that the data acquisition subsystem had a very low reliability, especially the scanning relays, which meant data had to be printed and checked quite often to ensure proper operation.

This problem was alleviated by adding a software check to those channels that could be checked. The 85 programmed load channels could be checked easily since the acquired data on these channels should always be within 2.5 percent of the program value in the ramp generator. A subroutine was added to the computer program which compared the programmed value with the acquired value for the 85 load channels each time data was acquired and stored on disk. Any channel exceeding the tolerance specified by the operator caused a diagnostic message to be printed on the teletype. Reaction channels were still checked by manual printout.

3.3 AUTOMATIC STOP CAPABILITY

Quite often during the test it would be necessary to stop at a specific condition point in a specific spectrum to inspect the test airplane, record some strain gage data or some other such thing. This required extra effort on the part of the operator to wait for the programmer to get to the specific point desired, to stop it.

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This problem was solved by adding an auto-stop panel with thumbwheel switches for spectrum number and condition point number. When the spectrum and condition point numbers on the display panel are the same as those on the thumbwheels a programmer stop signal is generated by an AND gate, thereby stopping the programmer at the desired place.

3.4 ON-NULL BYPASS

Occasionally during the fatigue test, it was desirable to supply the computer program with an on-null signal even though the servo error signals were not all within the on-null threshold. A common example is during an auto-reset when the computer program has programmed loads close enough to the actual loads to allow an unlock, but not close enough to generate an on-null signal.

This problem was eliminated by installing a push button switch on the system operator's panel which generates an on-null signal as long as the switch is pushed.

3.5 RAMP GENERATOR REFERENCE MONITOR

It was decided during the test that the ramp generator positive and negative reference voltages should be monitored continuously by a surveillanece-interrupt type monitor. A failure detector unit was added in the test point monitor rack which would generate a programmer-failure signal when either reference voltage dropped below a threshold level.

3.6 DEAD WEIGHT EXCESS TRAVEL MONITOR

The test airplane was put into a jig position for repair purposes at
times during the test. It was held in jig position by loading certain
hydraulic systems with dead weights. It was necessary to monitor the
position of these weights and sound an alarm if they dropped below a
certain position.

Two crack detection alarm boxes were added in a rack adjacent to DA1
to accomplish this monitoring. Switches were mounted at appropriate
positions below the weights and connected to the alarm boxes.

3.7 EXCITATION VOLTAGE POTENTIOMETER PROTECTIVE COVER

The labeling for the feedback balance potentiometer in the servo controller
is to the left of this control and directly below the feedback excitation
potentiometer. As a result of this, test operators would quite often
adjust the feedback excitation when intending to adjust the feedback
balance.

Small plastic caps were installed over the feedback excitation potentiometers
on all servo controllers. No inadvertent misadjustments were reported
after installation of the protective caps.

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3.8 STRAIN GAGE DATA ACQUISITION

The 288-channel B and F recorder was installed on-site at the beginning of the test to acquire and store strain gage data from the test airplane. The B and F recorder was found to be too unreliable for this purpose and was removed for surplus. MST #2 trailer was used to acquire and store data from large batches of gages.

Power and balance units were added to the 747 Major Fatigue Test Instrumentation System which permitted strain gage data acquisition on the unused channels, 86 thru 100 and 114 thru 128. This allowed small special requests to be handled. The data could only be stored for one spectrum however and only one sample was taken at each condition point. The data had to be dumped on the line printer which required the test to be stopped during the dump. Also, any data reduction had to be done off-line from the line printer output which was inconvenient.

3.9 COMPUTER PROGRAM CHANGES

A number of changes were made to the computer program after test startup which improved the test operation. These changes are described in the following paragraphs.

3.9.1 COMPUTER CONTROLLED R_{Cal} (CAR) ROUTINE

The computer controlled R_{Cal} as originally conceived and programmed did not accomplish the desired results. The CAR caused the system to lock-up due to all R_{Cal} relays being pulled in, even those in the analog reaction power and balance units. This problem was alleviated by modifying the program so that a CAR could be performed while the system was locked up.

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It was also determined that the data scanned in by the computer was not reliable enough to use for calculating the slope to be used for data conversion. Therefore, all channels were set up manually for an ideal slope. The slope calculated by the computer was compared with the ideal slope and the difference between the two was printed out for the operator. If a slope was off by more than one-half of one percent, the operator initiated the necessary corrective action.

The program was also modified so the results of the CAR could either be printed on the line printer or the teletype by operator command.

3.9.2 TELETYPE MESSAGE LENGTH

It was found during test operation that most of the messages being printed on the teletype by the computer were far too time consuming. A study was made of all the teletype messages and they were shortened as much as possible without losing their meaning.

3.9.3 LOCK-UP MONITORING

Better load visibility was required to detect leaking lock-up valves when a system lock-up occurred at high load conditions. A lock-up monitoring routine was added to the computer program which printed the channel name and load of any load system everytime it changed by a specified increment after a system lock-up. This routine was tried for a period of test operation, but was not very successful. It was decided that what an operator really needed in a hurry after a system lock-up was to know what load systems were exceeding or near limit loads.

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A new routine was written in place of the lock-up monitoring routine.
This new routine takes a scan of all loads shortly after a system lock-up
and prints the name and load of any channel exceeding its high or low
limit one time automatically. Additional scans and prints are obtained
by commanding LLL on the teletype as often as desired. This routine
has proven to be a very useful aid to the test director during system
lock-up at high loads.

3.9.4 OUT-OF-TOLERANCE LOCK-UP

Test operating experience showed that a programmer failure lock-up was
not required when a ramp generator channel did not reach its correct
program value at condition point. The computer program was modified to
delete the issuing of a programmer failure signal after detecting a ramp
generator out-of-tolerance condition. The programmer still stopped on
an out-of-tolerance, however, and required operator corrective action
to continue cycling.

3.9.5 JMP COMMAND

The original concept of the JMP command was to jump the programmer from
any condition point to any other condition point. The computer program,
therefore, would not accept a JMP command unless the programmer was on
a condition point. During the test it was determined that some method
was required to jump the programmer to a condition point even if it were
not on a condition point to start with. The JMP command routine was
modified to do this.

3.9.6 DATA ACQUISITION AVERAGING

Test control data acquisition was designed around a one sample per channel scheme due to the time critical nature of the test control load programming. This provided satisfactory data for load history, but was not completely satisfactory for non-time critical operations such as a computer controlled R_{Cal} (CAR) or a print of current loads while not cycling. A study was made to determine what could be done to improve data acquisition that was not time critical. The most desirable would have been a software change to a multisample method with bad sample rejection. This method requires a considerable amount of memory space, so was not used.

The data acquisition routines for the CAR and PRT (current loads) were modified to averaged multisample acquisition with operator control of the number of samples to be acquired. This was accomplished using existing storage space in core.

3.9.7 SPECTRUM MODIFICATION

The system was designed with the concept that load spectrum paper tapes would be punched on the Boeing large scale central computer using punched card input. Late in the fatigue test program when special tests were run with the system it became desirable to punch small spectrum tapes on-site. An off-line program called SPEC was assembled which provides the capability to modify existing spectrums or punch out new ones using the teletype as an input.

3.9.8 MAXIMUM ANALOG-TO-DIGITAL CONVERTER (ADC) COUNT

At times the load cycling slowed down for no apparent reason. Investigation revealed that when the octal number 4000 was strobed in from the ADC, the time required to perform the data acquisition error check increased significantly. This number represents a maximum negative output from the ADC, but an illegal negative number to the floating point package, and would frequently occur on an open channel. The channels used for strain gage data acquisition were quite often left open when not being used and therefore caused a problem.

The computer program was modified so that any time an octal 4000 was strobed in from the ADC it was changed to a 4001 before being converted to percent load.

3.9.9 INHIBIT CYCLING FROM BLEEDPOINT

The original design did not prevent the programmer from cycling into non-existent condition points if the programmer run button was actuated while at bleedpoint. The computer program was modified so it would not accept a programmer run signal if at the bleedpoint.

3.9.10 TITLE ON CURRENT LOADS PRINT

It became evident during the test that a title on current loads printouts would be advantageous. The current loads routine was therefore modified to print a heading which contained the time, spectrum number, indicated condition point, and a fifteen (15) character title.

3.9.11 HISTORICAL DATA PRINTS

Historical data was printed for all load channels at a variety of condition points (CP) peridically for the purpose of checking the accuracy of servo controller spans. Fifteen to twenty individual PRT commands were required to accomplish the total print in a minimum of time. The PRT command routine was changed to incorporate a new argument called CHECK SPANS. This permits the entire print to be accomplished in a minimum of time with only a single PRT command.

3.10 FEED FORWARD NETWORK

It was found that several of the load systems were unable to maintain their programmed loads within an acceptable tolerance when the load cycling rate was increased to meet the desired spectrum time. The problem was solved on some of the channels by increasing the size of their hydraulic servo valves. Six of the system required special feed forward networks from adjacent load channels in addition to larger servo valves. The servo valves for the load systems were originally sized on average flow rate requirements. This problem illustrates the necessity of considering peak flow rates when determining valve size.

3.11 RAMP ROUNDING

One of the limitations on programmer or cycling rate was excessive overshoot of loads if the rate was increased too much. This overshoot was reduced by adding ramp rounding circuitry to the interface buffer and the rate unit. The interface buffer generated signals at 70 and 90 percent of ramp complete which were used by the rate unit to decrease the rate before reaching the end of a ramp. This allowed a higher average programmer rate to be used thereby reducing the overall spectrum time.

3.12 LOAD CELL CABLE MODIFICATION

The load cell end of cable 61-11677 has a splice joint where multiple wires are connected together to enter single pins on the connector. This splice was located very close to the load cell connector and all cable bending due to load cycling was absorbed right at the edge of the potting on the splice. This caused excessive breakage of the conductors.

The load cell nine wire measure cables were modified to move the splice back at least twelve inches from the connector which solved the problem.

4 RECOMMENDATIONS FOR FUTURE SYSTEMS

This section lists improvements which might be included in future major fatigue test instrumentation systems. The list is confined to improvements in system concept since it is taken for granted that the best state-of-the-art hardware and techniques would be used in any future instrumentation design. These recommendations for the most part were the result of difficulty or inconvenience experienced by the operators during the operation of the test. These improvements have not been evaluated in terms of cost and may in some cases cost more to incorporate than is practical. Also, some of these recommendations may be impractical during the design phase of a new system due to the lack of pertinent information at that time.

As many of the recommended improvements to the system as possible have been categorized by subsystem in this section.

4.1 POWER DISTRIBUTION SUBSYSTEM

The 747 Major Fatigue Test Instrumentation System did not have a power distribution subsystem. Power supplies were scattered throughout the system and prime power came from several power distribution panels in widely dispersed locations. Power was not applied or removed from the system in any specific sequence and difficulty was encountered when trying to isolate power supply malfunctions.

It is recommended that future systems have a power distribution subsystem with a central control panel and indicators or switchable meter for monitoring all power supply outputs.

4.2 MASTER CONTROL CONSOLE

The test director needs to know the overall load status as quickly as possible when a system lock-up occurs. The system was designed with this in mind as were all previous systems; and each succeeding fatigue system has had improved quick-look load status. On this system the operator could command a print of current loads on the computer line printer and receive a complete list of all loads in about 15 seconds. The test director also could display any programmed or actual load on a strip chart recorder by selecting it on one of the four switch panels. Even though this would appear to be sufficient visibility of overall load status, there were times when loads were changing fast enough to cause the test director to have anxiety.

It is recommended that a better means of quick-look visibility be devised for large systems. One method that might be considered would consist of a bank of small inexpensive meters scaled to some common value and marked with red lines to show critical tension and compression loads. The meters would provide a coarse indication of loads only.

Another method might be a red lamp that comes on steady when a critical load is approached and starts flashing when the load becomes critical. One indicator would be needed for each channel.

A third possibility would be a CRT display which displayed all loads that exceeded a selectable threshold. The update rate on the CRT would need to be relatively high and preferably controlled by the test director or operator.

4.3 TEST CONTROL SUBSYSTEM

4.3.1 CONTROLLER GROUP HARDWARE LAYOUT

The servo controllers were not located in their racks in the alphanumeric sequence. For example, the B systems followed the P, W, N, T, L, and G systems. This would frequently cause operator frustration when trying to spot a specific servo controller in a hurry. Operating efficiency would improve if the servo controllers were located in alphanumeric order or any other easily remembered sequence.

4.3.2 TWO LEVEL LIMIT DETECTION

Common procedure for reducing loads that had exceeded their limits was to bleed them down using the hydraulic bleed valves. This can be a very intricate operation if the system is locked up with high wing loads. The operation could be made much simpler and safer for the test specimen if a two-level load limit were employed similar to that now used for excess reactions.

The operator would be able to switch to a higher limit level, command an auto-reset, and let the programmer bring the loads safely down with a two-level limit detection system.

4.3.3 HIGHER PROGRAMMER LIMIT

The system was designed with the concept that the programmer would never program a load higher than 100 percent. A safety feature called programmer overtravel was incorporated which caused a programmer failure lock-up any time any channel was programmed to 102.4 percent or more. This limited the auto-reset capability in that all loads had to be less than 102.4 percent before an RST command could be used.

It is recommended that future systems have the capability to program at least 20 percent higher loads. It is also recommended that the existing system be modified so that overtravel does not occur until a load of 115.2% is reached.

4.3.4 PROGRAMMER POSITION INDICATOR

At times during the test it was necessary to stop the programmer at some specific place between condition points. It is recommended that future systems have some type of easy to read indicator for determining programmer position between condition points. It would be desirable if this indicator could be read by the computer so that it could be printed on current load prints, etc.

4.3.5 SERVO ERROR SIGNAL MONITORING

Periodically it is necessary to measure the servo error signal from each servo controller while the system is unlocked and in a static condition. This is required to ensure all valve balance adjustments are correct for proper on-null windows. It was a tedious and time consuming task on the existing system. The problem was somewhat alleviated by the addition of the test point panel (see Paragraph 3.1.1).

It is recommended that the servo error signals be connected into the Data Acquisition Subsystem so they can be read and printed by the computer on operator command.

4.3.6 SERVO SYSTEM RESPONSE

System lock-up quite often occurred as a result of trying various servo controller compensation settings in a search for the ideal setting. It is recommended that future systems have the capability to make on-line Bode plots of the individual servo systems. The frequency response of each individual system could then be checked periodically and corrections made as necessary to maintain the response within predetermined parameters.

4.3.7 PROGRAMMED REACTIONS

Reaction load cell outputs were only checked periodically on the 747 Major Fatigue Test System. If an anticipated value for each reaction channel had been included in the load spectrum, the computer could have checked them at each condition point as part of the digital acquisition error check (see Paragraph 3.2). It is recommended that the capability to program the reaction channels be included in future systems.

4.3.8 OFF-NULL DETECTOR

The off-null indicators were very useful for determining which channels were the pacing ones when making adjustments to optimize the cycling rate. Even though some operators said the ability to spot pacing load systems on this test was better than any previous major fatigue test, it could be improved considerably. It is recommended that this ability be considered as a requirement in future systems. The 747 Major Fatigue Test System could be improved by adding a detector which would identify the last off-null indicator to extinguish after each ramp complete.

4.4 DATA ACQUISITION SUBSYSTEM

4.4.1 ADDRESSABLE R_{Cal}

The computer controlled R_{Cal} (CAR) would cause the 747 system to lock-up if performed while unlocked. This was the result of all R_{Cal} relays pulling in, even those in the analog channels, when the R_{Cal} function word was issued from the computer. An addressable R_{Cal} would be very desirable since it would provide a means of performing a CAR on any number of channels requested.

A less expensive solution on the 747 Major Fatigue Test System would have been to use non-standard power and balance units for the analog channels. By disabling the remote R_{Cal} in the power and balance units in these channels, the unwanted lock-up could have been avoided.

4.4.2 STRAIN GAGE CHANNELS

Quite often during the major fatigue test, data was required from special sensors such as strain gages, displacement transducers, flowmeters, pressure transducers, etc.

It is highly recommended that this type of data acquisition be recognized as a normal part of any major fatigue test and that at least 100 channels of data acquisition capability of this type be supplied as part of the basic system. Hardware and software should be provided which would allow this special data to be calibrated and printed out in document format or at least dumped on a high speed device for off-line processing.

4.4.3 HARDWARE LAYOUT

The power and balance units were not arranged in alphanumeric (channel identification) sequence on this system. This resulted in much loss of time and frustration when an operator could not readily spot a particular power and balance unit. It is recommended that more human engineering be applied to the man-machine interface on future systems containing multi-unit hardware. This hardware should be layed out so that the equipment for a specific channel can easily be found.

4.4.4 INCREASED DATA RANGE

The ideal slope chosen for this system allowed a maximum digital data value of 111.1 percent (see Paragraph 3.9.1). Occasionally loads would reach values higher than 111.1 percent, but could not be read by the computer. It is recommended that the capability to read a higher value than 111.1 percent be considered for future tests and that whatever maximum is chosen be compatible with the programmer maximum for an improved auto-reset as mentioned in Paragraph 4.3.3.

4.4.5 PEAK LOAD RECORDING

The concept of using an on-null window to determine when all loads are on condition point as a means of determining peak loads is acceptable if servo frequency response and programmer rate are controlled to prevent excessive overshoot.

It is felt that the ability to judge the quality of the fatigue testing would be improved if a high speed data system could be used to record data from 95% of ramp complete to a point past peak load. If the peak load were then derived from this data and saved on disk it would provide the testing personnel with the data they actually need.

4.5 SURVEILLANCE-INTERRUPT SUBSYSTEM

4.5.1 FAILSAFE INTERLOOP INDICATORS

It was very time consuming and difficult to determine the location of a discontinuity in the failsafe interloop in this system. It is recommended that an indicator be installed on each unit the interloop passes through in future systems. This indicator should be used to give an indication if the interloop has continuity through to that particular unit.

Considerable system troubleshooting time could have been saved on the existing system, since the interloop had to be complete to unlock and sometimes the only indication of this, was the inability to unlock the system.

4.5.2 SPECIAL TEST BOXES

Special test boxes were supplied with the system for checkout and calibration of the level detectors and the load differential detectors. The test boxes were connected to the system by disconnecting normal system cables and then connecting the test box into the vacated connectors. As a result of the inconvience of using these test boxes, they were not used very often during the test.

It is recommended that special test boxes of this type be designed as an integral part of the system so that checkout and calibration can be accomplished by actuating a switch.

4.6 SOFTWARE

4.6.1 BUFFERED OUTPUT

The 747 Major Fatigue Test Instrumentation System did not contain a buffered output. As a result of this, the computer would always completely print a message or punch a tape before starting another task or function. This caused considerable anxiety on the part of the operator when he was waiting to initiate an operation, but had to wait for a teletype or line printer message before he could act.

It is recommended for future systems that the output and input be buffered so that these operations take place in sequence but only when the computer is not busy with other operations.

4.6.2 SOFTWARE NOISE REJECTION

An unacceptable data value would occasionally be strobed in by the Data Acquisition Subsystem during the test. This was tolerable for the historical load data saved on disk as this operation had to be accomplished in a minimum of time. However for the non-time critical operations such as current loads, RST, CAR, and CAV it is recommended that the software be designed for multiple samples. The computer program should employ techniques commonly used in data acquisition systems to integrate the acquired data and discard undesirable samples or noise for these non-time critical functions.

4.6.3 COMPUTER TABLE INPUTS

Load cell calibration data was reduced off-line to get a channel slope and R_{Cal} percent load value. These values were then put into the computer table by teletype using the on-line table editor. It is recommended that the on-line program be designed to receive data directly from the load cell calibration sheet, calculate required values, and input these directly into the Major Fatigue Test computer table without operator intervention.

It is also recommended that the table be expanded to contain other data pertinent to individual channels. This would include a tolerance value to be used by the Data Acquisition Error Check routine and the high-low limits for each channel for the loads exceeding limits (LEL) routine.

4.6.4 CURRENT LOADS PRINTOUT

Current loads were always printed for all channels when requested on this system. Very often the operator was only interested in the current loads for a few channels. It is recommended that the software be designed so the current loads can be requested for an individual channel or a block of channels.

4.6.5 CONFIGURATION CONTROL

A considerable amount of time was required to manually maintain the configuration records for the 747 Major Fatigue Test System. This system would have lent itself very nicely to a software configuration control scheme having plenty of disk storage available. It would be desirable

to have a larger line printer however, if configuration control was to be maintained with the computer. An optical keyboard/display would be exceptionally useful for this purpose.

If such a system is designed, consideration should be given to incorporating a section for maintaining Fatigue Damage Reports which presently are very time consuming and tedious for Structures personnel to maintain.

4.7 AUTOMATIC BLEED SYSTEM

It is recommended that consideration be given to incorporation of an automatic system of hydraulic bleeding of the loads in future systems. The manual system was quite awkward to operate and depended on good communications between the bleed trailer and the control room.

Installation of computer controlled on-off bleed valves would allow automatic bleeding by the computer which has good rapid visibility of all loads. The computer program could be designed to provide an automatic bleed to any loads exceeding their limits as an initial part of the RST command or commands could be added that would allow the operator to request any or all channels to be bled to any specified load condition.

4.8 VARIABLE SENSITIVITY SOUND DETECTORS

The sound detectors were used very little during the fatigue test as explained in Paragraph 2.5. It is recommended that a calibration method be designed for the sound detectors and an interface which will allow computer control of the sensitivity. This would provide the capability to have low sensitivity during the noisy part of the load spectrum and thereby make the sound detectors useful throughout the test.

4.9 FUNCTIONAL FLOW DIAGRAMS

Functional flow diagrams would have been very helpful for isolating troubles in the system when troubleshooting. It is recommended that functional flow diagrams be provided with future systems since troubles are usually isolated by tracing a given signal through the system rather than by working on a single unit.