LR 17129

69-5

FATIGUE BEHAVIOR OF MATERIALS FOR THE SUPERSONIC TRANSPORT

FIRST QUARTERLY REPORT

REPORTING PERIOD 1 MAY 1963 TO 31 JULY 1963

LOCKHEED-CALIFORNIA COMPANY

SUPERSONIC TRANSPORT RESEARCH PROGRAM
SPONSORED BY THE
FEDERAL AVIATION AGENCY

CONTRACT NUMBER AF 33(657)-11460
EXHIBIT "B"

The information contained herein is a part of a national undertaking sponsored by the Federal Aviation Agency with administrative and technical support provided by the Department of Defense, Aeronautical Systems Division, Air Force Systems Command with contributing basic research and technical support provided by the National Aeronautics and Space Administration.

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ABSTRACT

The fatigue behavior of candidate sheet materials subjected to supersonic transport load-temperature environments is being evaluated. Three specimen geometries in each of three materials will be used. Constant load amplitude tests will be carried out on specimens without prior exposure and on specimens exposed to load at temperatures of 400 and 650°F for periods of 100, 1,000, and 5,000 hours. The effects of contaminants will be similarly evaluated using exposure at 650°F for 1,000 hours. In addition, realistic wing root loading spectra will be applied on a flight-by-flight basis. In one set of these tests the time at temperature and the sequence of thermal stress cycles will be representative of actual service. In a second set of tests the time at elevated temperature during each "flight" will be minimized. Finally, tests will be carried out to evaluate the effect of the cycle of pressurization and thermal loading which occurs in fuselage skins once every flight.

Because of delayed delivery of material this report does not contain test data, but provides a brief description of the test program and of the design of the test equipment to be employed.

LOCKHEED-CALIFORNIA COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION
BURBANK CALIFORNIA

19 August 1963

To: Addressees on Distribution List

Subject: AF 33(657)-11460, Task F, "Fatigue"

1. At the request of Materials Applications Division of the Air Force Materials Laboratory the first quarterly progress report covering the activity of this organization as of 31 July 1963 is enclosed for your information.

2. The information contained herein is a part of a national undertaking sponsored by the Federal Aviation Agency with administrative and technical support provided by the Department of Defense, Aeronautical Systems Division, Air Force Systems Command, with contributing basic research and technical support provided by the National Aeronautics and Space Administration. Comments on this effort will be appreciated and should be forwarded to:

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LR 17129

Enclosure (a) to LAC/411862

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AF 33(657)-11460
EXHIBIT "B"

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Research Engineer

LOCKHEED-CALIFORNIA COMPANY BURBANK, CALIFORNIA

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LOCKHEED-CALIFORNIA COMPANY BURBANK, CALIFORNIA

FOREWORD

This report was prepared by the Lockheed-California Company, Burbank, California, under Contract Nr. AF 33(657)-11460, Exhibit "B".

The work is administered under the direction of the Materials and Processes Laboratory, Aeronautical Systems Division by Mr. C. L. Harmsworth, Project Engineer.

This Lockheed program is one of a group of three supersonic transport research and development programs under the administrative direction of Mr. R. E. Reedy, Supersonic Transport Program Director; Mr. R. R. Heppe, Chief Advanced Systems Research Engineer, and Mr. J. Hong, Assistant Chief Advanced Systems Research Engineer.

Program Manager for this project is Mr. M. A. Melcon, Department Manager, Structural Methods, assisted by principal investigator, Mr. A. J. McCulloch.

Mr. R. H. Wells, Department Manager, Structures Research, is in charge of the design and operation of the test equipment. He is assisted by Mr. R. J. Cox and Mr. R. L. Lowe. Mr. W. R. Brewer is responsible for the design and installation of the load control and load cycling equipment. Mr. J. A. Knotts, Jr., and Mr. P. S. Starrett are responsible for the design and fabrication of the temperature cycling equipment.

The time period covered by the contract is 1 May 1963 to 31 December 1964.

The time period covered by the report is 1 May 1963 to 31 July 1963.

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INTRODUCTION

To attain the levels of safety, reliability, and economical performance essential in a successful commercial supersonic transport, the design of the airframe must reflect realistic evaluations of the fatigue characteristics of the materials which are proposed for use. These evaluations will be distinguished from those made for subsonic transports by the addition of temperature effects to the list of variables to be considered.

In the design of subsonic transports the selection of materials and the evaluation of processes has been guided by S-N data obtained at normal temperatures. However, in the evaluation of the effects of the wide ranges of loadings acting on structure in service, experience and a growing fund of test data demonstrate the need for more complex tests. This need stems from the basic nonlinearity of fatigue damage growth which markedly reduces the reliability with which the effects of complex time histories of loadings can be predicted. Direct integrations by test specimens of the effects of anticipated service conditions are required. Such tests provide the best guides to the selection of fatigue design parameters which can be obtained through laboratory testing.

In the design of supersonic transports the difficulties and uncertainties in the handling of the fatigue problem are compounded by the introduction of the effects of elevated temperatures. Thermal gradients produce complex additions to the operating stress histories. Prolonged exposure to elevated temperatures may degrade the materials used and increase their susceptibility to the effects of contaminants. Data must therefore be obtained on temperature effects to guide material and process selections. Data must also be obtained to evaluate the effects of the addition of thermal stress cycles, intermittent exposure to elevated temperature, and loadings at elevated temperature to the complex effects of operating conditions at normal temperatures.

To obtain such data unnotched, notched, and fusion welded specimens made from 8-1-1 titanium, 14-8 stainless steel, and Inco 718 sheet will be employed. Fatigue tests will be carried out to define the effects of exposure to stress at elevated temperature for periods up to 5,000 hours. The additional effects of contaminants will be similarly evaluated for an exposure period of 1,000 hours. In addition, realistic loading spectra representing service conditions on a lifting surface of a supersonic transport will be applied on a flight-by-flight basis. In one set of these tests the time at temperature and the sequence of thermal stress cycles will represent actual service. Since the time at temperature during each "flight" will be ninety minutes, a long duration is anticipated for these tests. However, such tests must be run to establish a basis for evaluating the significance of relatively short duration tests. In a second set of tests the same loading and thermal stress cycle magnitudes and sequences will be employed, but the time at elevated temperature during each flight will be minimized. Base line data will be obtained from tests run at room temperature and at constant elevated temperature using the same loading magnitudes and sequences.

By comparisons of test lives, the data obtained in these sets of tests will provide definitions of the additional effect of thermal stress cycling and loading at elevated temperature and the effect of long term intermittent exposure to elevated temperature.

Finally, to provide an evaluation of the quite different loading sequences in fuselage structure, tests will be carried out during which repeated cycles of combined loading and heating will be applied.

In this first quarterly report a brief description of the materials and test specimens to be employed will be presented together with definitions of the scope of the program and descriptions of the design of the test apparatus. Since material has not been available, no test data have been obtained.

MATERIALS

The materials selected for evaluation and the quantities ordered are shown below.

Material	Condition	Sheet Size	No. of Sheets
8-1-1 Titanium	Duplex Anneal	.050 x 36 x 96	10
14-8 Stainless	Solution Anneal	.025 x 44 x 96	8
Inco 718	20% C.R.	.025 x 24 x 72	20

The titanium sheet was received during the latter half of July. Visual inspection of this material shows that adequate control of surface finish and flatness has been provided by the producer. The variation in sheet thickness covers the range +10 to -2% of the nominal value. This range is acceptable for this program. A longitudinal and a transverse static tensile test specimen has been taken from each sheet but these specimens have not been tested.

The 14-8 stainless steel material has not been received. Delivery of this material is now anticipated during the first half of August 1963. Before testing,but after any welding, this material will be subjected to 40 minutes at 1700 ± 25°F, air cooled, 8 hours at -100°F, 1 hour at 1050 ± 10°F then air cooled.

Relatively late delivery of the Inco 718 sheet is anticipated due to a requirement that the supply of this material to be used under this and associated SST research contracts be procured from a single heat. Delivery is now expected about mid September 1963. This cold-rolled material will be aged before testing and before any welding. The aging cycle to be used is 1325 ± 25°F for 8 hours then furnace cool to 1150 ± 25°F and hold until the total aging time is 18 hours followed by air cooling.

SPECIMEN GEOMETRIES

Five specimen designs will be employed. The geometries of these specimens are defined on Figure 1. Note that, with the exception of one longitudinal grained specimen taken from each sheet and tested as a part of the material inspection procedure, all specimens will be taken in the cross grain direction. The first and second designs (A and B) will be used for static tensile tests. Design B includes an aircraft quality butt fusion weld produced by the mechanical tungsten inert gas arc welding method. These designs make provision for the use of stress-strain curve generating equipment. The third design (C) will be extensively used in the test program to obtain fatigue test data for unnotched material. The fourth design (D) will be employed in the fatigue test evaluation of welded specimens. These four designs require machining of contoured edges to produce a test section having substantially smaller cross-sectional area than the ends of the specimens, thus insuring failure in the test area. The fifth design (E) is for a center notched specimen with a quarter-inch diameter hole. For this specimen a simple rectangular shape will be used since experience has shown that the severity of the notch effect provided by the hole ensures fatigue cracking at the hole. Use of the rectangular shape minimizes the cost of specimen preparation and provides the smallest ratio of hole diameter to specimen width and therefore the largest effective stress concentration factor for a given hole diameter and moderate specimen width.

PROGRAM

PHASE I - CONSTANT LOAD AMPLITUDE (S-N) TESTS

To establish base-line data, constant load amplitude tests will be carried out at room temperature, 400°F and 650°F at constant stress ratios R (minimum/maximum stress) of 0.1 and -0.5. These tests will be conducted on machines designed and constructed at Lockheed. Each machine consists basically of a loading column containing the test specimen in series with a calibrated electrical strain gage transducer. The loading column is held stationary at its upper end but is fastened to a hinged beam at its lower end. The hinged beam carries at its free end a motor-driven eccentric disk plus either springs or dead weight for maintaining constant static loads. Dynamic loads of ± 10,000 pounds can be maintained indefinitely within ± 2% accuracy at a normal frequency of operation of 30 cycles per second. A photograph of one of these machines complete with oven and control equipment is shown on Figure 2.

For comparison with the base-line S-N data, large groups of specimens will be statically stressed under axial load before fatigue testing for periods of 100, 1,000, and 5,000 hours at each of the two temperatures, 400°F and 650°F. The nominal gross area stress levels will be 40,000 psi for the 14-8 and Inco 718 specimens and 25,000 psi for the 8-1-1 titanium. For each soak temperature, a 16-column loading rack loaded through a system of dead weights will be used. Each rack with a capacity of 1400 specimens will be provided with an oven utilizing Calrod heating elements mounted on the under side of heavy plates to maintain required test temperatures within ± 10°F. In each loading column the specimens will be connected by close tolerance pins in a combined series - parallel arrangement. The loading distribution will be determined and monitored by the use of strain gages and the specimen temperatures will be recorded and monitored by the use of thermocouples.

The detailed design of the loading racks and ovens is complete and fabrication is scheduled for completion before the first group of test specimens will be available.

To assess the effect of the exposure to constant load and constant stress on static strength, a group of standard tensile and fusion welded specimens having no prior exposure will be employed in tests at room temperature, 400°F and 650°F and a second, exposed group will be similarly tested. These tests are detailed in Table 1. Then to assess the effect of the exposure in terms of constant load amplitude fatigue tests, groups of specimens will be tested at the same three temperatures. These tests and the base-line fatigue tests previously described are detailed in Table 2. Note that one group of specimens will be centrally notched after exposure to obtain data for comparison with specimens so notched before exposure.

The fatigue test data will be presented in the form of S-N curves for constant values of R and will be used on modified Goodman diagrams to derive families of S-N curves at constant values of mean stress. Comparisons of data will be made and a compact presentation in terms of the stress at 10^6 cycles for unexposed specimens tested at room temperature will be prepared.

PHASE II - WING LOADING SPECTRA TESTS - REAL TIME AT TEMPERATURE

In service, the structure of supersonic aircraft will be subjected to sequences of loading at temperature, to thermal stress cycles, and to intermittent exposure to significant periods of time at elevated temperature. In the anticipated service lives of these aircraft, many thousand of hours of such exposure will be accumulated. For this complex picture, evaluations of the effects of individual variables in simple tests are informative. However, knowledge of the nonlinear rate of growth of fatigue damage at normal operating temperatures coupled with a lack of knowledge of the additional effects of thermal stress cycles and of extended exposure times dictates the need for relatively sophisticated testing. In this testing a reasonable representation of the magnitudes and sequences of loadings and thermal cycles anticipated during each flight can be applied to test specimens. However, if the real time of exposure at elevated temperature is used, the time required to conduct such tests effectively prevents their use in evaluations of the range of variables. Nevertheless, until a reasonable number of such long-duration tests have been carried out and the results compared with those obtained in accelerated tests, no basis exists for the acceptance of the results obtained in accelerated tests.

Under this phase of the program, notched and welded specimens will be subjected to realistic, flight-by-flight sequences of loadings and thermal cycles using real time durations at elevated temperature during each flight. A schematic representation of the sequences to be employed is shown on Figure 3. Thermal stress cycles will be generated during each flight. These tests which are detailed in Table 3 will be continued until termination of the contract work.

To carry out the test a machine has been designed and is presently under construction which will incorporate special safety features. These features will guard against cyclic or static overloading during a protracted period of testing.

The test machine will consist of six loading jacks, installed in parallel within a simple reaction frame, together with load measuring transducers. The action of these jacks will be controlled so as to apply the loadings and sequences indicated on Figure 3. Six sets of specimens installed six to a row, will be contained in a single oven as indicated on Figure 4. The control system will make use of partial load feedback to obtain the required test loads and oil flow restriction to the loading jacks to control the cycling rate. Stepping switches will program the loadings as well as the heating and cooling cycle. Load sensing will be obtained by using a Schmitt trigger device in conjunction with each of the load transducers. In operation, the trigger will "fire" each time a desired load level is reached. This will advance the stepping switch, thus presenting the trigger with a new trigger point corresponding to a new load level. After the first group of room temperature loads have been applied, the stepping switch will turn on the furnace and control the load applied during specimen heating. When the desired temperature, measured through thermocouples located near the centers of several specimens, has been reached, and the required soaking time has elapsed, a timer will start the application of the cyclic loads associated with the elevated temperature cruise condition. The furnace will be turned off immediately upon completion of these cruise cycles and the rapid introduction of ambient temperature air will reduce the specimen temperatures before the loadings associated with descent are applied. A schematic representation of the control system is also presented on Figure 4.

The oven to be used will employ a number of quartz lamps mounted on lightweight reflectors. The power required to raise the temperature of the specimens to 550°F will be about 40 kilowatts.

To minimize the possibility of specimen destruction due to transient overloads, the mean loads which must be reached and maintained for varying lengths of time during each 95-minute "flight" will be applied through a combination of dead weight loading and regulated pressure sources. In addition, during the relatively short period of cyclic operation per flight, the hydraulic pressure will be limited to a few percent over that required for the maximum load. As a final precaution, a load-limiter device sensing the output from each of the load transducers will be used to shut down the system if a desired load is exceeded by a given percent. To prevent the individual specimens from buckling during compression loadings, floating stiffeners will be employed on the sides of each specimen. In addition, two flexure plates between each pair of specimens will be employed to keep the columns of specimens from buckling.

PHASE III - WING LOADING SPECTRA TESTS - ACCELERATED TESTS

In the evaluation of the service life potential of supersonic transport structural configurations, spectrum loading tests provide the most directly useful data. Experience has shown that the scatter in test lives is relatively small and that the integration of loading effects obtained in such tests is a requirement. However, for such tests to provide data during the design phase, the time of exposure to elevated temperatures must be minimized. The tests cannot therefore provide data on the effects of long exposure in conjunction with loading sequences. For some materials the effects of long exposure to practical temperature-loading combinations may be shown by long-duration spectrum loading tests to be relatively small. For these materials, adequate data on the effects of thermal stress cycles superimposed on normal loading sequences can be obtained in moderate lengths of time.

To demonstrate the possibilities of such accelerated load spectra tests, groups of notched and welded specimens will be tested. In these tests the flight-by-flight loading and thermal stress sequences indicated on Figure 3 will be employed. However, in these tests, relatively rapid (50°F/sec.) heating and cooling rates will be used and the time at temperature during each flight will be minimized. Approximately two "flights" per minute will be generated. With the exception of the effects of long exposure times, the data obtained will therefore be comparable to that obtained in long-duration tests.

As a preliminary to running these tests, base line flight-by-flight tests conducted at room temperature will be carried out to define the potential test lives of the specimens. Then, before proceeding to the accelerated tests with realistic load and thermal stress cycles, an additional set of specimens will be subjected to the same flight-by-flight loading history but at a constant temperature of 550°F. A comparison of the results obtained in these tests with those obtained at room temperature will provide additional base-line data.

These tests are summarized in Table 3.

The results of these tests will be expressed simply in terms of specimen geometry, design 1g stress, the number of "flights" to failure and the total time at maximum temperature. With the reservation that the effects of long exposure to elevated temperature and load have not been evaluated, the results will provide reasonable assurance that a particular material can or cannot be seriously considered for supersonic transport applications.

The test work will be carried out using dual-jack servo-controlled loading machines. Each machine will consist of a pair of servo jacks installed in parallel within a simple loading rack. Each jack, in turn, will load two specimens in series with a calibrated load transducer.

To illustrate the type of equipment to be used, several single-specimen servo machines and a close up of a specimen installation are shown on Figures 5 and 6. The dual-jack machines presently being built differ from these single specimen machines in the number of specimens which can be tested at one time and in the addition of thermal cycling equipment. On this equipment dynamic loads of ± 10,000 pounds can be controlled with an accuracy of ± 2% at frequencies up to 45 cycles per second.

As in the case of the smaller machines, the loads applied by these dual-jack machines will be programmed by 2-track magnetic tape units such as those shown on Figure 7. The tapes will be prepared using signal generating equipment designed and built at Lockheed. The mean load levels required in a flight sequence will be recorded on one channel of the tape, and the spectra of varying loads will be recorded on the remaining channel.

In operation, the output voltage from either channel of the programmer is fed into the servo loop of one of the servo jacks through a summing junction as shown schematically on Figure 8. This signal programs the action of a servo valve in metering a cyclic flow of oil to the fore and aft ports of the servo jack. Loadings are applied to the specimens and the load transducer by the resulting movement of the jack piston. The servo loop is closed by feeding the signal resulting from the load felt by the load transducer back into the summing junction where the instantaneous summing of these opposing signals at the input side of the servo loop results in the specimen experiencing the same loading history as that represented by the signal on the magnetic tape.

The equipment necessary in obtaining a complete thermal cycle, is indicated schematically on Figure 8. The one-per-flight thermal cycle will be triggered by a peak-follower device operating off the varying signal and will be applied once every 30 seconds by the alternate use of a bank of quartz lamps and normal shop air. As shown on this figure, the pressure and return line to each servo jack will contain a solenoid-operated safety lock-up valve which will immediately stop oil flow to the jack in the event of a loss in servo control due to any interruption of power. In addition the use of a safety device in the form of a load limiter is shown. This device is designed to protect the test specimens against spikes and tape drop-outs simply by limiting the amplitude of any unwanted signals.

Floating stiffeners will be employed to prevent specimens from buckling during compression loadings and two flexure plates between each pair of specimens will be used to keep the columns of specimens from buckling.

This test apparatus and its control have been designed and fabrication is underway.

PHASE IV - FUSELAGE LOADING EVALUATION

In the spectrum loading tests described in previous sections of the proposal, the load magnitudes and sequences are appropriate to lifting surfaces. In other portions of an airframe, quite different conditions apply and require differing test evaluations. One of the most important of these areas is the fuselage skin in the region of windows. For this region, a reasonable approximation to the significant service loadings is obtained by the use of simultaneously applied cycles of loading and heating in which the loading cycle represents the cycle of hoop tension load produced once per flight by fuselage pressurization.

To provide an evaluation of the effect of this loading-heating cycle, notched and welded specimens in each of the three materials under consideration will be mounted in specially constructed apparatus and subjected to repeated load-temperature cycles. Each load cycle will range from zero to a constant maximum, and each temperature cycle will range from room temperature to a constant maximum.

The heating and cooling rates used in this test will be quite similar to those used in the accelerated spectrum loading tests. Approximately three cycles of heating and cooling will be produced each minute of test time. The total time at temperature in the specified test duration will therefore be relatively small. To obtain an indication of the effect of extended exposure to stress at elevated temperature on the test results, an additional set of specimens exposed for 5,000 hours at 650°F will be tested. The tests are summarized in Table 4.

As in the case of the results obtained in the accelerated spectrum loading tests, the most informative report of the results obtained in these tests will be provided in terms of number of flights. In addition, an attempt will be made to correlate the test lives with those described by the S-N curves produced in Phase I of the program.

To carry out these tests a single machine has been designed for in-phase applications of tension loading cycles and room-to-elevated temperature thermal cycles. In this machine a group of four test specimens will be installed in series with a load transducer and a pneumatic loading jack. The maximum jack force will be controlled by a regulated pressure source. Elevated temperature, measured at the center of the test specimens, will be reached in about 6 seconds through the use of radiant heat lamps. Cooling by a large centrifugal blower fitted with a solenoid-operated diverter, will take approximately 14 seconds. In operation, the load will be applied by metering air, at a given pressure, to the loading jack. Phased with this load increase will be the heating cycle which will be controlled through a regulated power supply to peak out at 475°F ± 10°F. When this temperature has been reached, the power to the lamps will automatically shut off, the ambient air from the blower will be directed to the four specimens and the load will be reduced to zero by exhausting the air contained in the jack. When the temperature of the test specimens reaches the lower limit, the blower output will be directed away from the specimens, the lamps and the air to the jack will be switched on, and the cycle will be repeated.

Safety devices include the regulated pressure source together with a load limiter device which, working off the load transducer, will shut down the system if the desired load is exceeded. A schematic representation of this apparatus is presented on Figure 9. This apparatus and its controls have been designed and fabrication is under way.

PHASE V - EVALUATION OF CONTAMINANT AND CORROSIVE EFFECTS

In the test work previously described for this program, no provision was made for evaluating the effect of contaminating or corrosive agents. To guard against the possibility that the effect of these agents is markedly accelerated by elevated temperature exposure, a series of screening tests will be carried out.

In the first set of tests, unnotched, notched, and welded specimens will be tested at 650°F at one amplitude of varying load at a stress ratio R of 0.10. The amplitude will be chosen by referring to the S-N curves defined under Phase I of the program so that unduly long test times will be avoided. Before the start of the tests a contaminating or corrosive material will be applied to the specimen test section. At intervals during the tests corresponding to approximately one-tenth of the anticipated test duration, the loading will be removed, the specimens will be cooled to approximately room temperature and the contaminant or corrosive agent will be reapplied. Two of these contaminating materials will be used. One will be a concentrated saline solution and the second will be a super-refined mineral oil now considered suitable for use both as an engine lubricant and as a hydraulic system fluid on supersonic transports.

In the second set of tests, three specimens for each geometry and material will be loaded by dead weight and heated to 650°F intermittently for a total exposure time of approximately 1,000 hours. At intervals of approximately 1-1/2 hours during this test the loading will be removed, the temperature will be returned to approximately room temperature, one of the contaminating or corrosive materials previously described will be painted on the specimen test section, load will be reapplied and the temperature returned to 650°F.

At the end of the exposure described above the effect of the exposure on static strengths and stress-strain curves will be obtained using the standard tensile strength specimens, and selected specimens will be sectioned and microscopically examined. In addition, the fatigue test specimens will be tested at 650°F at the same amplitude of varying load and at the same stress ratio as was used in the first set of screening tests. Again the test lives obtained will be compared with those for specimens without the intermittent exposure history to assess its effect.

As a minimum additional effort, provision has been made for carrying out accelerated spectrum loading tests. In these tests the specimens will be subjected to the flight-by-flight loading sequence containing thermal stress cycles which was described under Phase III. Two specimens of one geometry subjected to the most severe contaminant as indicated by the previous test work are considered to be adequate for these additional screening tests. In these tests, since the "flights" are applied at the rate of approximately two per minute, interruption of the test sequence for applications of contaminant or corrosive material will be restricted to once per hour.

The static loading tests for this Phase are detailed in Table 1, the constant amplitude load tests in Table 2, and the spectrum loading tests in Table 3.

The test apparatus required for the 1,000-hour exposure portion of the test work will be a simple loading rack in which the specimens will be loaded simultaneously by dead weight through a system of links and whiffletrees. A bank of radiant heat lamps will be employed in heating the specimens to the required 650°F and an exhaust system will be used to remove explosive and contaminating vapors from the immediate area. The dead weight loading will be applied in a simple on-off manner. All controls will be manually operated. This apparatus has been designed but fabrication has not begun.

FUTURE WORK

During the next three-month period, it is anticipated that all specimen material will be received and substantially all of the test specimens will be prepared. One-half of the specimens to be subjected to constant load at elevated temperature will have been placed in the loading racks. All test equipment will be built and checked out with the possible exception of the check-out of the loading and temperature sequencing programmer for the real time tests. Approximately 6 percent of the constant load amplitude tests of specimens without contaminant and approximately 60 percent of the exploratory tests of this type on specimens with contaminant will be completed. In the spectrum loading tests with minimum time at temperature, it is anticipated that approximately 25 percent of the exploratory tests at room temperature will be completed. In the evaluation of fuselage loadings approximately 10 percent of the tests will be completed.

TABLE 1 - SUMMARY OF STATIC TENSILE TESTS

PROGRAM PHASE →	PHASE I		PHASE V - EVALUATION OF CONTAMINANT & CORROSIVE EFFECTS
SPECIMEN CONDITION →	SPECIMENS WITH NO PRIOR EXPOSURE	SPECIMENS SUBJECTED TO PRIOR EXPOSURE TO STRESS (1) AT ELEVATED TEMPERATURE	SPECIMENS SUBJECTED TO PRIOR EXPOSURE TO STRESS (1) AND CONTAMINANT AT ELEVATED TEMPERATURES
Materials	Titanium, Statinless Steel, and Inconel 718	→	→
Specimen Configurations	Standard Tensile and Fusion Welded	→	→
Exposure Temperatures	—	400°F. and 650°F.	650°F.
Exposure Times	—	100 hours, 1000 hours, 5000 hours.	1000 hours
Test Temperatures	RT, 400°F., and 650°F.	RT, 400°F., and 650°F.	RT & 650°F.
Contaminants	—	—	Saline solution and super-refined mineral oil.
Number of Specimens Each	3	3	3
Total Number of Specimens	54	324	108

(1) Gross area stress for stainless steel and Inconel 718 = 40,000 psi and for titanium = 25,000 psi.

TABLE 2 - SUMMARY OF CONSTANT LOAD AMPLITUDE FATIGUE TESTS TO DEFINE S-N CURVES

PROGRAM PHASE →	PHASE I			PHASE V EVALUATION OF CONTAMINANTS AND CORROSIVE EFFECTS	
SPECIMENS CONDITIONS →	SPECIMENS WITH NO PRIOR EXPOSURE	SPECIMENS SUBJECTED TO PRIOR EXPOSURE TO STRESS (2) AT ELEVATED TEMPERATURE		SPECIMENS WITH NO PRIOR EXPOSURE	SPECIMENS SUBJECTED TO PRIOR EXPOSURE TO STRESS(2) & CONTAMINANT AT ELEVATED TEMPERATURE
Materials	Titanium, Stainless Steel, and Inconel 718	→	→	→	→
Specimen	Unnotched, center notched, & fusion welded	Unnotched, center notched, prior to exposure & fusion welded	Center notched after exposure	Unnotched, Center notched, & fusion welded	Unnotched, center notched, and fusion welded
Exposure Temperatures	—	400°F. & 650°F.	400°F. & 650°F.	—	650°F.
Exposure Times	—	100 hrs, 1000 hrs 5000 hrs	5000 hrs	—	1000 hrs
Test Temperature	RT, 400°F. & 650°F.	RT, 400°F. & 650°F.	RT, 400°F & 650°F.	650°F.	650°F.
Contaminants	—	—		Saline solution & super-refined mineral oil	Saline solution & super-refined mineral oil
Constant Stress Ratios (R)	0.1 and -0.5	0.1 and -0.5	0.1(1)	0.1(1)	0.1(1)
Number of S-N Curves	54	324	18	27	27
Specimens per S-N Curve	12	12	3	3	3
Total Number of Specimens	648	3888	54	81	81

(1) One Stress level only

(2) Gross Area stress for stainless steel and Inconel 718 = 40,000 psi and for titanium = 25,000 psi

TABLE 3 - SUMMARY OF REALISTIC WING LOAD SPECTRA FATIGUE TESTS

PROGRAM PHASE	PHASE II REAL TIME TESTS	PHASE III ACCELERATED TESTS			PHASE V EVALUATION OF CONTAMINANT AND CORROSIVE EFFECTS
SPECIMEN CONDITION →	SPECIMENS TESTED WITH THERMAL CYCLE	SPECIMENS TESTED AT ROOM TEMPERATURE	SPECIMENS TESTED AT ELEVATED TEMPERATURE	SPECIMENS TESTED WITH THERMAL CYCLES	SPECIMENS TESTED WITH CONTAMINANT AND THERMAL CYCLE
Materials	Titanium, Stainless Steel, and Inconel 718	→	→	→	→
Specimen Configurations	Center Notched & Fusion Welded	→	→	→	$1^{(2)}$
Contaminant	——	——	——	——	$1^{(2)}$
Test Temperature	RT to 550°F.	RT	550°F.	RT to 550°F.	RT to 550°F.
Time at Elevated Temperature	90 min/flight	None	All	1 sec/flight	1 sec/flight
Number of Specimens Each	5	$8^{(1)}$	4	4	2
Total Number of Specimens	30	$48^{(1)}$	24	24	6

(1) Includes Specimens for exploratory tests

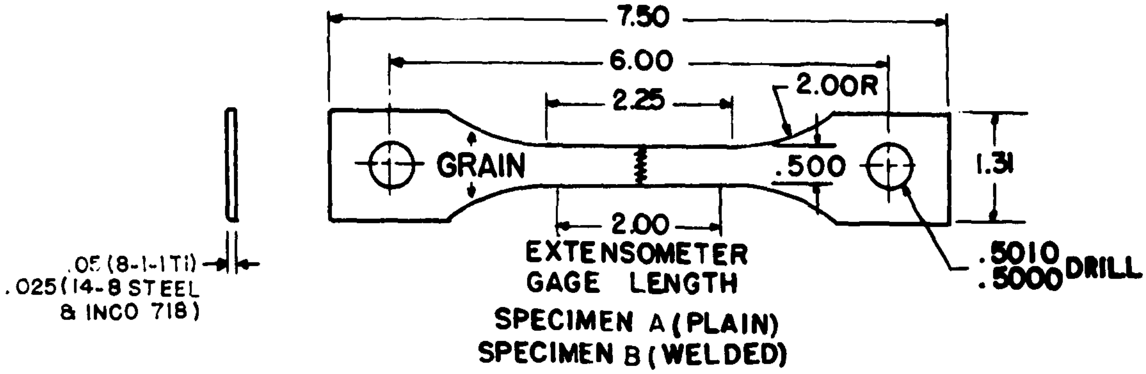
(2) Selection of contaminant and specimen configuration will be based on results of S-N data.

TABLE 4 - FUSELAGE LOADING FATIGUE TESTS

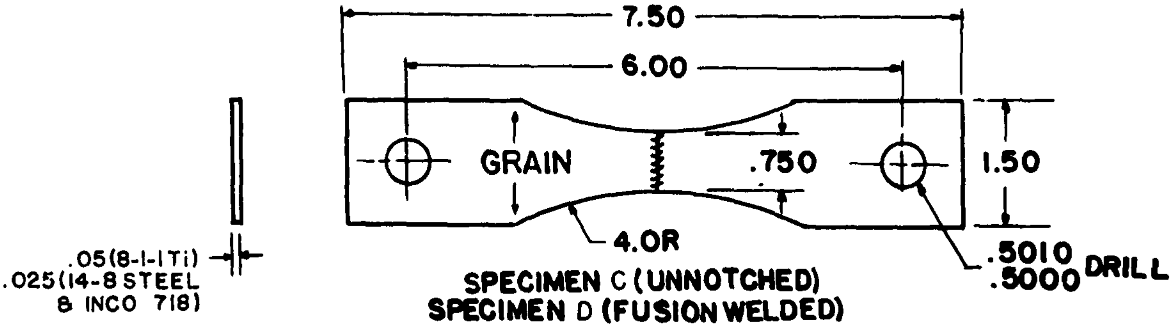
PROGRAM PHASE	PHASE IV - FUSELAGE LOADING EVALUATION	
SPECIMEN CONDITION →	SPECIMENS WITH NO PRIOR EXPOSURE	SPECIMENS SUBJECTED TO PRIOR EXPOSURE TO STRESS(2) AT ELEVATED TEMPERATURE
Materials	Titanium Stainless Steel, and Inconel 718	→
Specimen Configurations	Center Notched and Fusion Welded	→
Exposure Temperatures	—	650°F.
Exposure Time	—	5000 Hours
Test Temperature	RT to 475°F.	RT to 475°F.
Number of Specimens Each	4(1)	2
Total Number of Specimens	24(1)	12

(1) Includes specimens for exploratory tests.

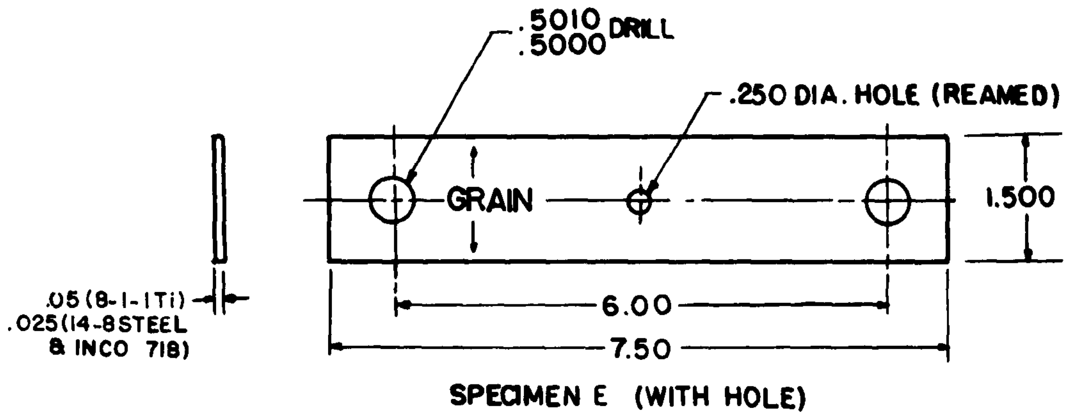
(2) Gross area stress for stainless steel and Inconel 718 = 40,000 psi and for titanium = 25,000 psi



STATIC SPECIMENS - ASTM E8-61T



FATIGUE SPECIMENS



FATIGUE SPECIMEN

FIGURE 1 - FATIGUE AND STATIC TEST SPECIMENS

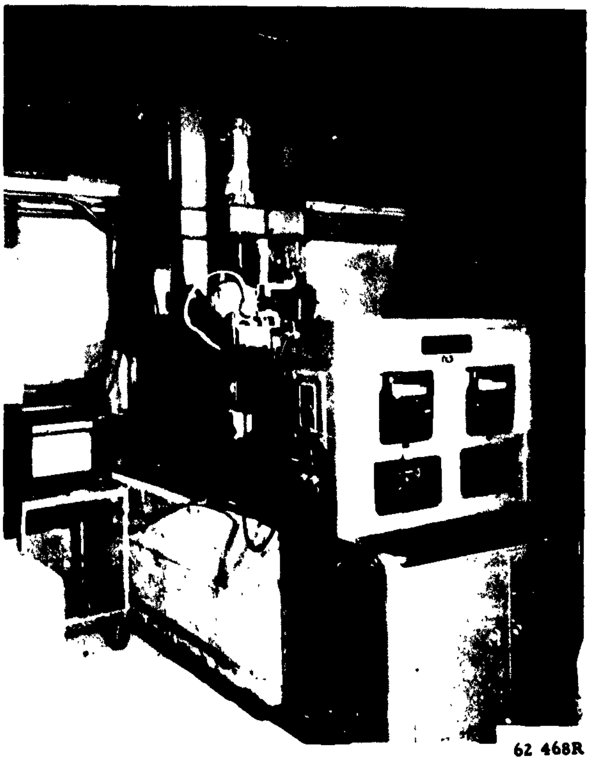


FIGURE 2-ELEVATED TEMPERATURE OVEN (WITH CONTROL EQUIPMENT) INSTALLED IN CONSTANT LOAD AMPLITUDE FATIGUE MACHINE

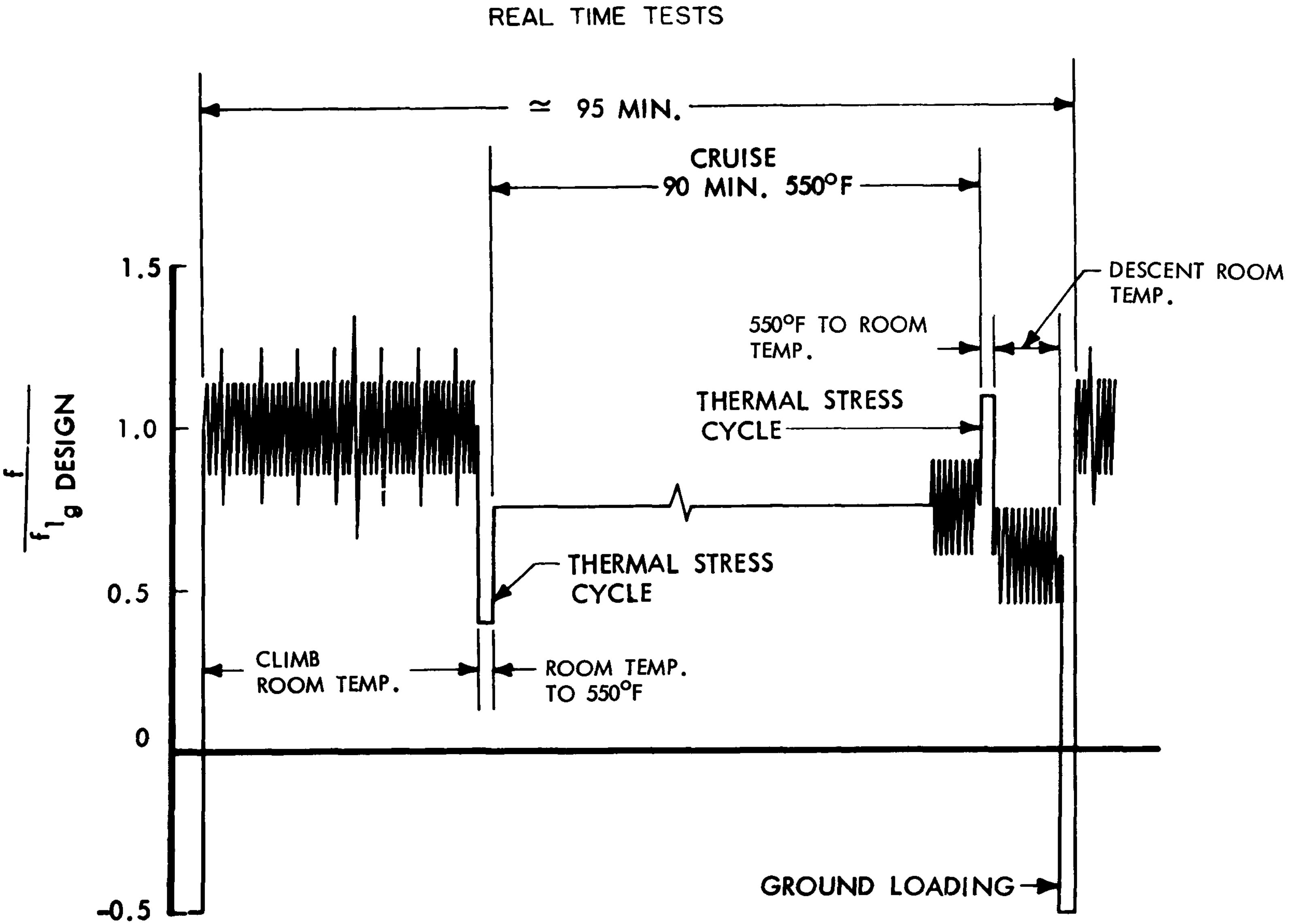


FIGURE 3 - SCHEMATIC REPRESENTATION OF FLIGHT-BY-FLIGHT SEQUENCE OF LOADING AND THERMAL CYCLES TO BE APPLIED TO TEST SPECIMEN FOR 140 MINUTE FLIGHT

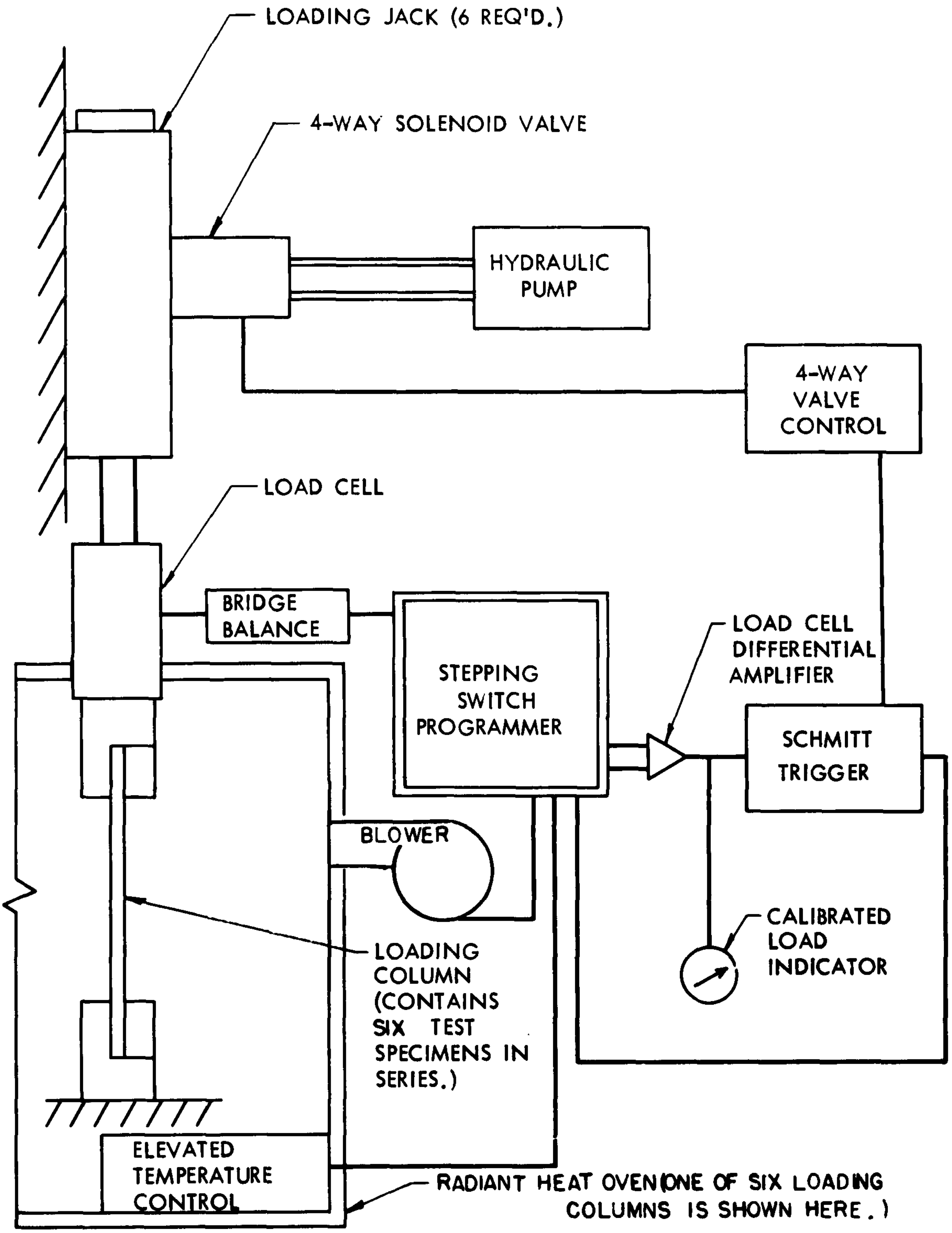


FIGURE 4 - BLOCK DIAGRAM OF TIME, TEMPERATURE, AND LOAD CYCLING SYSTEM FOR USE IN REAL TIME SPECTRUM LOADING TESTS

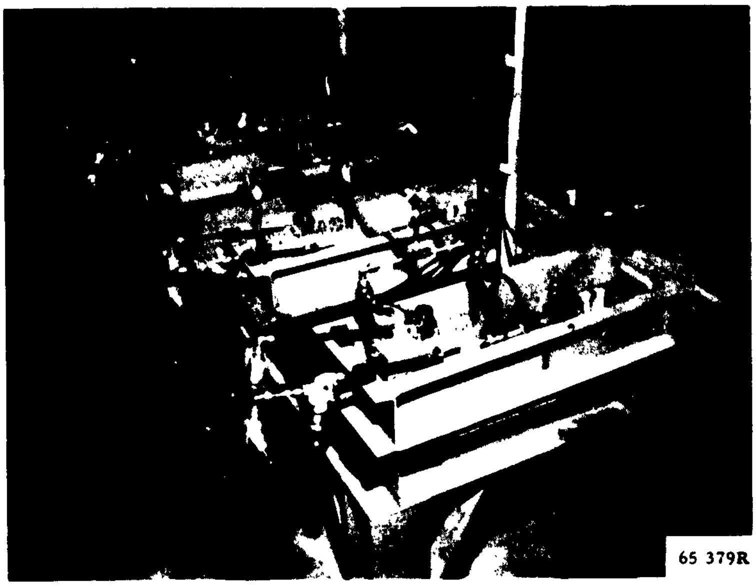


FIGURE 5 - GENERAL VIEW OF SERVO CONTROLLED FATIGUE MACHINES

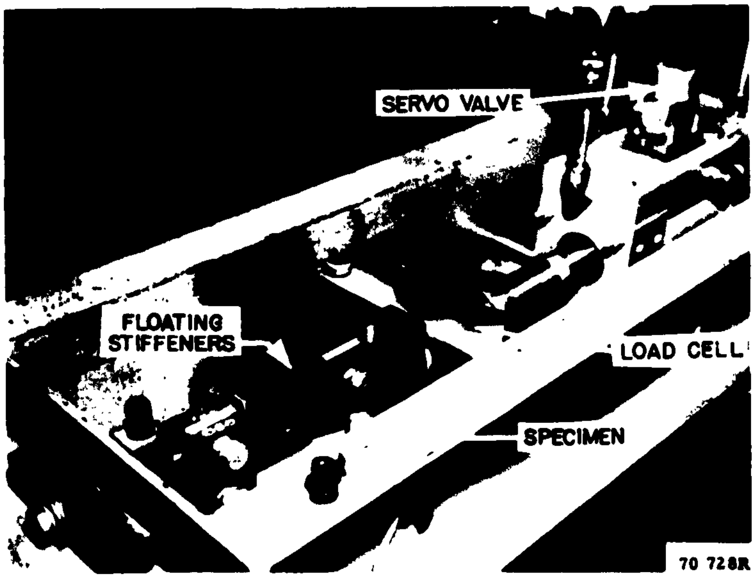


FIGURE 6 - CLOSE-UP OF SPECIMEN INSTALLATION IN SERVO CONTROLLED FATIGUE MACHINE

FIGURE 7- MAGNETIC TAPE LOADING CONTROL UNITS FOR SERVO CONTROLLED FATIGUE MACHINES

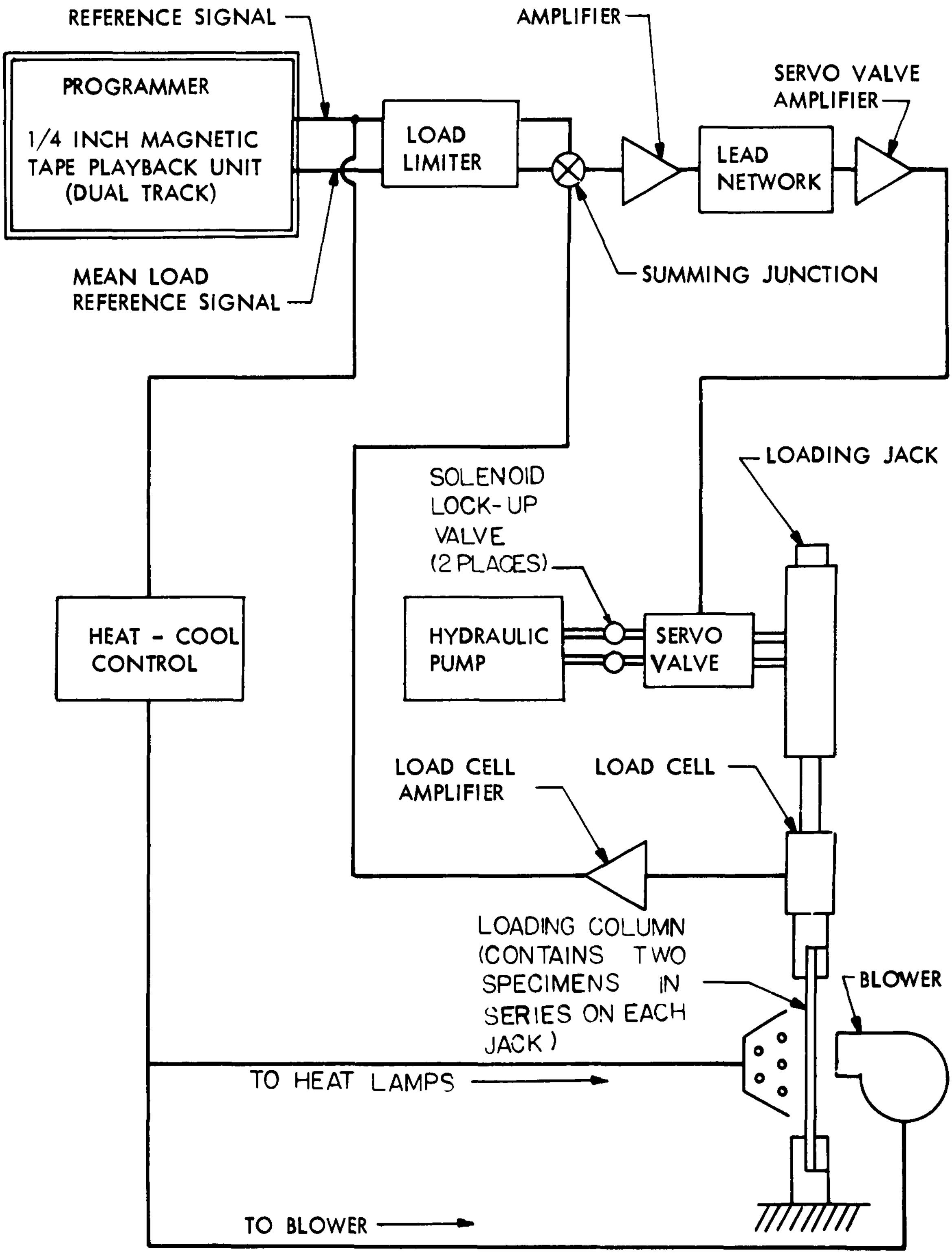


FIGURE 8 - BLOCK DIAGRAM OF ELECTRO-HYDRAULIC SERVO SYSTEM FOR ACCELERATED SPECTRUM LOADING TESTS

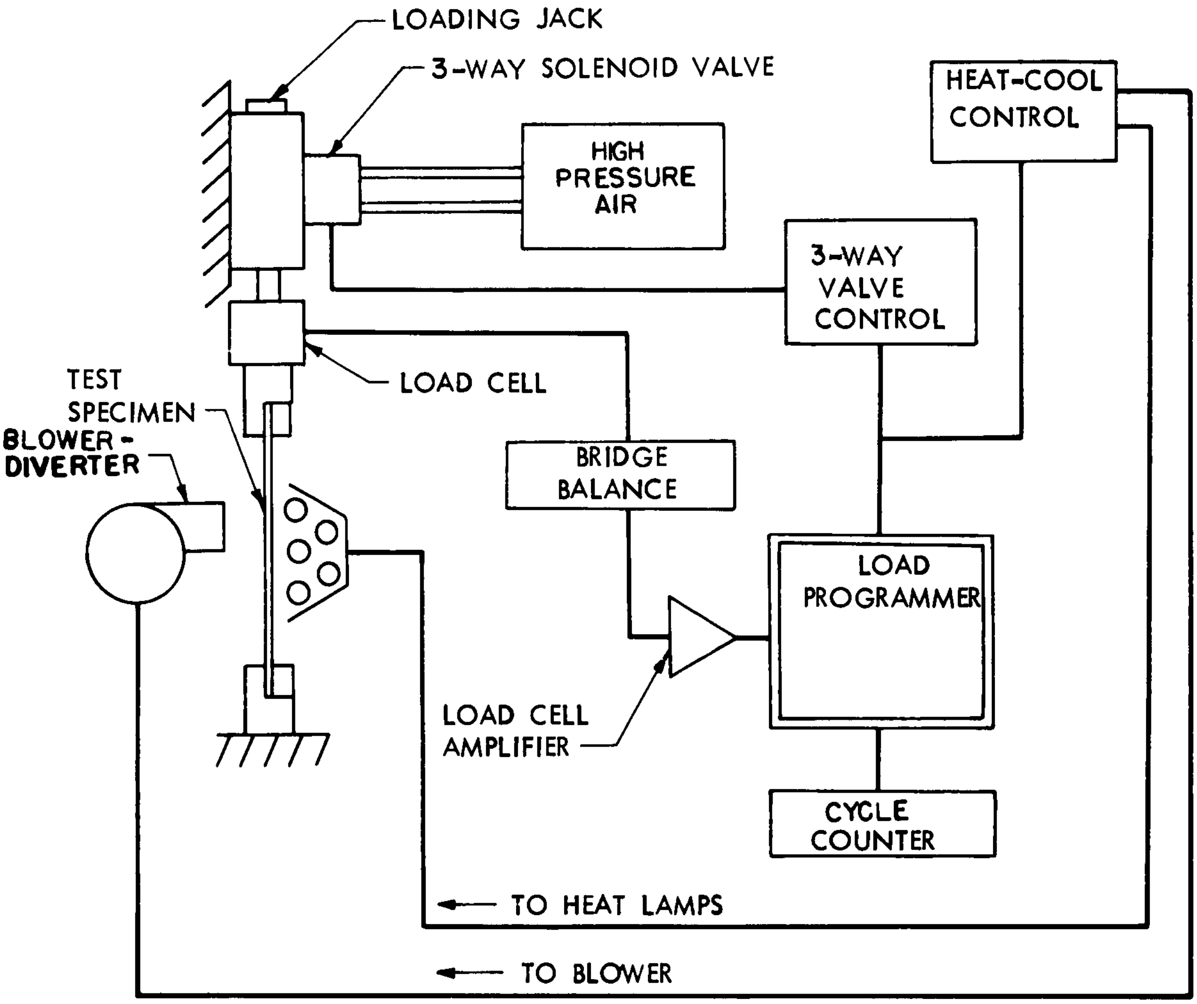


FIGURE 9 - BLOCK DIAGRAM FOR SIMPLE TEMPERATURE AND LOAD CYCLING SYSTEM

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