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A High Temperature Fatigue and Structures Testing Facility

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A HIGH TEMPERATURE FATIGUE AND STRUCTURES TESTING FACILITY

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SUMMARY

As man strives for higher levels of sophistication in air and space transportation (e.g., subsonic, supersonic, hypersonic transatmospheric, etc.), awareness of the need for accurate life and material behavior predictions for advanced propulsion system components is heightened. Such sophistication will require complex operating conditions and advanced materials to meet goals in performance, thrust-to-weight ratio, and fuel efficiency. To accomplish these goals will require that components be designed using a high percentage of the material's ultimate capabilities. This serves only to complicate matters dealing with life and material behavior predictions. An essential component of material behavior model development is the underlying experimentation which must occur to identify phenomena. To support experimentation, the NASA Lewis Research Center's High Temperature Fatigue and Structures Laboratory has been expanded significantly. Several new materials testing systems have been added, as well as an extensive computer system. The intent of this paper is to present an overview of the laboratory, and to discuss specific aspects of the test systems. In this age of computer controlled experimentation, a limited discussion of the computer capabilities will also be presented. Finally, plans for an addition to this laboratory will be briefly described.

INTRODUCTION

An essential component of developing life and material behavior prediction models is the experimentation to support their formulation. This experimentation can be classified into three categories: exploratory, characterization, and verification tests. Exploratory tests are aimed at defining key characteristics or trends that will effect the basic framework of the model. Characterization tests are used to complete the definition of the model by supplying a data base of material parameters. Finally, verification tests assess the precision of the model to predict prototypical component behavior. Each category requires different types of tests depending on the application of the component, its operating environment, and its material type (e.g., superalloy, metal matrix, or ceramic composite, etc.). This testing can be as simple as a monotonic or low cycle fatigue test. It can also be as exotic as thermal ratchetting tests, or probing for surfaces of constant inelastic strain rate (SCISR's). In any case, it can be stated that the accuracy of a life, or material behavior model, depends greatly on its supporting experimentation. This drive toward sophisticated air and space transportation along with its necessity for more precise life and material behavior predictions, has prompted the Structures Division at NASA Lewis Research Center (NASA Lewis) to expand the facilities of the High Temperature Fatigue and Structures Laboratory. Since reference 1 was published, significant changes have occurred and new equipment has been purchased. Centralized hydraulic and distilled water systems were designed and built (table I), some existing test systems were fitted with new heating systems, and most importantly, an extensive computer system was installed. This computer system utilizes a hardware and software architecture that allows a high degree of configurability, enabling the researcher to tailor a solution to the experimental problem at hand.

Figure 1 illustrates the physical organization of the laboratory. The new multiaxial test systems along with the existing uniaxial test systems are located in the larger of the two testing areas. The second testing area houses the new high cycle fatigue/low cycle fatigue (HCF/LCF) test systems, and is located separately to isolate the remaining areas from noise produced by their operation. Centrally located is the control room which houses the control and measurement electronics and the new computer system (fig. 2). Figure 3 details a typical uniaxial test system control console. The control room uses an elevated floor, with all cables routed through a tray system. Both humidity and temperature are controlled, providing an optimum environment for reliable operation and increased longevity of the control electronics and computer system.

The intent of this paper is to present an overview of the laboratory's expansion. Each section will contain a description of a specific aspect of the facility, along with its present and possible future uses. The final section will briefly describe the plans for a future lab addition that is being considered at NASA Lewis.

UNIAXIAL TEST SYSTEMS

The uniaxial capabilities of the High Temperature Fatigue and Structures Laboratory at NASA Lewis have expanded since the publication of reference 1. Presently, there is a total of twelve uniaxial systems including four new systems recently purchased. These new systems are commercially available and will be located in the future lab addition, but for the present, they are temporarily located in the main laboratory area.

The original eight load frames were designed and built at NASA Lewis (fig. 4). They are rated for loads of $\pm$9072 kg ($\pm$20 000 lb), and use a die set to maintain specimen alignment during specimen loading. Commercially available servo controllers are used to control the test systems. The load frame grips can accommodate both button-head and threaded specimens.

Both diametral and axial extensometers are used for uniaxial strain measurement in the laboratory. Diametral extensometry has been used extensively at this facility for over 20 years (ref. 1). The diametral extensometer uses a flex spring pivot system in combination with a LVDT to measure diametral strains.

Axial or longitudinal strains are measured in the laboratory by commercially available axial extensometers (fig. 5). Two axial gauge lengths are used: 25.4 mm (1 in.) and 12.7 mm (0.5 in.). The latter gauge length is more frequently used due to the ease of obtaining and sustaining a relatively uniform thermal gradient over a smaller gauge section. For protection against high test temperatures, these extensometers are water-cooled and are equipped with water-cooled heat shields. Longitudinal displacements are sensed by the extensometer, utilizing either conical point or "V"-chisel probes. Conical point probes require indented dimples on the specimen to ensure positive attachment. This type of probe is not well suited for creep-fatigue testing;

however, when absolute probe placement is necessary, as it is in deformation studies, this type of probe is preferred. On the other hand, for fatigue testing where specimen surface finish is critical, the most suitable probe is the "V" chisel. This type of probe relies on the friction between the probe and the specimen to maintain its placement, and therefore, the surface is not as severely marred and the fatigue life is less affected. The axial extensometer measures strains by using a metallic flexure element in combination with a resistance strain gauge system.

As described in reference 1, solid hourglass and hollow tube specimens for these systems were usually heated by direct resistance and "glow bar" heating, respectively. A number of the original eight systems have been fitted with 5 kW radio frequency induction heaters. This method of heating allows the use of straight section specimens with a minimal thermal gradient over the test section. The induction heaters are controlled in a "closed loop" system, in which a thermocouple or optical pyrometer is used as the temperature feedback sensor.

The computer system has made a major impact on the uniaxial capabilities of the Laboratory. Each uniaxial system has its own minicomputer for experimental control and data acquisition. Preliminary software has been developed by the experimentalists to conduct tests as simple as a low cycle fatigue test, and as complicated as thermomechanical tests.

Current uniaxial testing underway in the laboratory involves different varieties of materials, and various types of experimentation. Materials currently being studied include nickel 201, 304 stainless steel, and Hastelloy-X, along with more exotic materials like single crystal René N4, PWA 1480, and B-1900+Hf. In addition to ordinary low cycle fatigue and deformation tests, other types of experimentation such a bithermal, thermomechanical, cyclic relaxation, and creep ratchetting tests are being conducted. These tests are conducted exclusively using the laboratory's new computer capabilities for test control, data acquisition, and data manipulation.

Recent expansion of the uniaxial testing capability of the laboratory entailed the addition of four new test systems (figs. 6 to 8). The load rating for two of the new systems is $\pm$9072 kg ($\pm$20 000 lb), and the other two at $\pm$22 680 kg ($\pm$50 000 lb). Each system is equipped with a state-of-the-art digital controller. The digital controllers have the ability to complete a smooth control mode transfer, which is accomplished either manually or electronically. This feature will make it possible to conduct some of the more complex tests that have been defined by the constitutive model developers at NASA Lewis. Specimen heating is provided by 5 kW radio frequency induction heaters. Axial strains are measured using an axial extensometer of the type described earlier in this section. To study the effects of the environment on creep-fatigue behavior, the two smaller load capacity test systems are equipped with environmental chambers capable of providing a vacuum and/or an inert environment (fig. 8). The environmental chamber is able to sustain a vacuum of 2.67×10^{-4} Pa (2×10^{-6} torr) with a specimen temperature of 1093 °C (2000 °F). All systems include water-cooled hydraulic grips for simple specimen installation. By the means of exchanging two collets these grips can be adapted to handle either flat bar, smooth shank, or threaded-end specimens. These new systems are an integral part of the planned addition to the lab, which will be described in the final section of this paper.

HIGH CYCLE/LOW CYCLE TESTING SYSTEMS

In response to the technological need for better understanding of the fatigue behavior of materials undergoing cumulative cyclic loadings, an experimental capability is being developed for studying cummulative fatigue damage phenomena.

This capability consists of being able to produce arbitrary load or deformation histories corresponding to fatigue lives up to 10^7 cycles, in less than 10 hr. This is achieved through the use of state-of-the-art servohydraulic materials test systems designed to NASA specifications for wide frequency response (figs. 9 and 10). NASA Lewis has two such systems, each being able to produce rated capabilities at elevated temperatures typical of turbine blade applications in gas turbine aircraft engines. Figure 11 is a functional description of a typical system. Load ratings are ±9979 kg (±22 000 lb) from static to 20 Hz, corresponding to an actuator piston displacement range of 1.02 mm (0.04 in.) and ±2268 kg (±5 000 lb) from static to 300 Hz, corresponding to an actuator piston displacement range of 0.38 mm (0.015 in.). These were the design goals, with the actual system performance exceeding these goals. During operational checkout, these machines were able to produce significant actuator piston displacements well over 1000 Hz.

To achieve these performance characteristics, a control system consisting of four servo loops driving a unique three servovalve dual-faced actuator was developed. The actuator assembly uses two nozzle-flapper valves ported to the larger of the two actuator faces to control the low frequency portions of the overall control loop. The high frequency portion of the program waveform is produced by a high performance voice-coil, slaved-spool servovalve, ported to the smaller of the two actuator faces. The valve and actuator interface provides feedback signals of valve spool position and pressure difference across the smaller piston faces. These feedback signals are used in two of the three servo loops controlling the high frequency portion of the waveform. The remaining servoloop uses the high frequency program signal as command, and the desired transducer signal for feedback. The net effect of this assemblage is a uniaxial test system which has a very wide frequency range of linear operation.

Data measurement can be accomplished through the use of either analog or digital storage oscilloscopes, a chart recorder, or a digitally based data display. Command waveform programming is accomplished through the use of two digitally based arbitrary waveform generators. One generator provides the low frequency program, and the other, the high frequency program. The units possess ample synchronization, gate and trigger lines, and are connected to make use of these capabilities. Each system is also connected through an appropriate interface to a unique satellite computer system.

High temperature capability is obtained through the use of commercially available radio frequency induction furnaces, driven by conventional PID controllers for closed-loop temperature control. These furnaces possess a 5 kW power output capability at an operating frequency of 450 kHz. The controllers can be computer controlled as well.

Commercially available hydrocollet grips are being used for specimen gripping. Extensometry will be a major development area for these systems, since high temperature extensometry does not currently exist capable of the performance levels required by high frequency testing. Currently, work is going on to develop such a system. In the interim, commercially available room and high temperature extensometry is being used for low frequency strain measurement and control work.

An interesting capability afforded by this system's design is dual mode control. A means of conducting portions of a waveform program in two different control modes exists. Of course, the waveform program must not require a physical behavior which cannot be achieved by the material and suitable transducing systems must exist for making the measurements. Nevertheless, provided that the material physics is compatible, such a control scenario is possible. A typical waveform can be programmed and executed with this arrangement, representative of a turbine blade history, is illustrated in figure 12.

AXIAL TORSIONAL TEST SYSTEMS

The severe operating environments of advanced propulsion system components will induce high thermal and mechanical loads. These loads, in many cases, will produce a stress-strain state that is multiaxial. In many life and material behavior models, multiaxial representations are formulated by modifying uniaxial criteria. Unfortunately, this method does not always achieve the accuracy needed to meet design goals. In response to this need for better life and material behavior predictions under complex states of stress and strain, a multiaxial testing capability is being developed. As an evolutionary step from a uniaxial test capability, a decision was made to begin with biaxial (axial-torsion) test systems (fig. 13) and eventually progress to triaxial systems through the use of internal pressure.

The load frames for each test system are rated for loads of ±22 948 kg (±50 000 lb) axial and ±2824 N-m (±25 000 in.-lb) torsional. Electronics for these systems consist of two servocontrollers, two data display units, function generators, and an oscilloscope. The two servocontrollers allow for both independent and combined control of axial and torsional loading. Each servocontroller can control specimen loading in one of three modes: load, strain or stroke for axial loading and torque, torsional strain or angular displacement for torsional loading. Data display units are used to monitor analog data signals, and provide an important interface between the test system and the computer system. These units can be programmed to perform a variety of signal processing operations. An RS-232 serial interface on the data display unit enables it to act as a computer controlled data acquisition system.

A thin-walled tube was chosen as the basic specimen geometry. This type of geometry has the following advantages: (a) easy decomposition of axial-torsional components of stress and strain, (b) at high temperatures thermal gradients across the diameter are minimal, and (c) for thermomechanical testing, cooling rates are higher. Various configurations of thin-walled tubes are used depending on the type of test being conducted. Presently, the only common denominator of each specimen configuration is the gripping end outside diameter, which must be 5.016 cm (1.975 in.). Gripping of the specimen is achieved by commercially available water-cooled hydrocollet grips. Distinct advantages of this type of grip are its alignment characteristics, ease of specimen installation, and the ability to change collets. The latter gives the test system a simple means of adapting to future specimen designs.

Axial-torsional strain measurements at low temperatures (20° to 230 °C) are usually sensed by foil strain gauge rosettes epoxied onto the specimen. At higher temperatures (230° to 1100 °C), epoxies used for strain gauge applications deteriorate, making this type of strain measurement unsuitable. A more acceptable means of axial-torsional strain measurement at high temperatures can be achieved through the use of extensometry. Presently, three extensometers are being evaluated for high temperature application: a commercially available biaxial extensometer, the Oak Ridge National Lab's (ORNL) biaxial extensometer, and ORNL's multiaxial extensometer.

The commercial axial-torsional extensometer (fig. 14) has an axial gauge length of 2.54 cm (1 in.). It utilizes two probes parallel to each other and perpendicular to the specimen. The probes have conical points, and require dimples in the specimen surface to prevent slipping. As axial displacement occurs, the upper probe moves relative to the lower probe with the upper probe sensing axial displacements (fig. 15). For torsional movement, the probes move relative to one another with the lower probe sensing the torsional rotations (fig. 15). Axial and torsional strains are measured by the use of a metallic flexure element in combination with a resistance strain gauge. The strain sensing devices are mounted to the body of the extensometer transversely from one another. The extensometer is held in position by an complex flexure system located on the heat shield. The flexure system attempts to minimize the crosstalk that can occur in this type of extensometer. Crosstalk is the condition wherein axial displacements can effect torsional measurements or vice versa. The performance of this extensometer is still being evaluated.

The biaxial extensometer designed at ORNL, also utilizes two conical pointed probes (fig. 16). There are two major differences between this extensometer and the previous. First, each probe can sense both axial and torsional movement. This is accomplished through a series of lever arms and "frictionless" pivots (fig. 17). The second difference is the means by which the strains are measured. Both axial and torsional strains are measured by capacitance proximity transducers. These transducers are located at the end of the lever arms. Strains are measured by the capacitance of the air gap between transducer and lever arm. This type of transducer has shown a high degree of insensitivity to signal noise.

The ORNL multiaxial extensometer has the ability to measure axial, torsional, and diametral strains to a high degree of accuracy with minimum crosstalk (fig. 18). This is accomplished by the means of an intricate system of lever arms and "frictionless" pivots. The extensometer utilizes four knife-edge probes to transmit specimen rotations and displacements to the lever arm assemblies. The knife-edge probes rely on the friction between the knife edge and the specimen to prevent slipping.

Figure 19 is a schematic representation that illustrates the basic concepts of the ORNL multiaxial extensometer. In this figure, it is assumed that a suspension system exists which constrains the sensors to planes DEFG and HIJK (these planes are parallel to each other). Axial strain is sensed as the vertical distance BB (fig. 19) changes. Vertical displacements are then measured with the use of a capacitance proximity transducer located at the end of the top sensor which is aimed at a target at the end of the bottom sensor. For diametral strains, change in specimen diameter is transmitted to the mounting arms AA where relative displacement is used for measurement. This measurement is accomplished by utilizing a proximity transducer attached to the end of one mounting arm, with the other mounting arm as the target. Under torsional loading, both the upper and lower sensors rotate different amounts about the Z axis of their own reference planes. Through a system of lever arms and proximity transducers, this difference in angular rotation, θ in figure 19, is then measured and converted to torsional strains. A complete explanation of the inner workings of this extensometer, along with its performance appraisal, can be found in reference 2.

The heating system for each biaxial test system consists of an audio frequency induction generator, an induction coil fixture, and a PID controller for closed-loop temperature control. Each generator has a power output of 50 kW at an operating frequency of 9.6 kHz. Audio frequency generators were chosen because of their ability to operate with minimal electrical interference to instrumentation signals.

An induction coil fixture was designed and built to facilitate the process of achieving a proper temperature gradient (fig. 20). This fixture creates the effect of zone heating by being able to use up to three independently movable coils powered by one induction generator. This is accomplished by utilizing three independent "plug in" coil modules that are electrically connected in series. These coil modules are either jumpered out or have a coil section plugged in depending on the required coil configuration. Coil geometry parameters such as coil diameter, number of turns in a coil, reverse coil windings, etc., can be quickly altered by plugging a new coil section into the appropriate module. Changes in the spacing of the individual coils is easily accomplished because each coil module may be independently positioned vertically. This fixture has proven to be quite effective and a smaller version has been built for the 5 kW axial induction heaters (fig. 5).

Each axial-torsional test system is interfaced with its own minicomputer. These minicomputers, along with the data display units, are used for experimental control and data acquisition (fig. 21). Preliminary software is being used to conduct simple tests, while more complicated test programs are still in their developmental stages. Details of the computer system will be presented later.

Currently the axial torsional systems are in the final stages of "check-out." This will include conducting simple relaxation tests in pure torsion on Hastelloy-X specimens, and conducting SCISR's tests using 316 stainless steel, which will then be compared to tests conducted at Oak Ridge National Labs. Once the check-out is successfully completed, a number of experimental projects will start. One such project will study the creep-fatigue behavior of Hastelloy-X and Waspalloy, from a damage mechanics framework. This will entail creating a fatigue and deformation behavior data base for these alloys, and then determining material constants for several continuous damage models. Another project will study the feasibility for representing the behavior of metal-matrix composites within the context of a continuum viscoplastic model. The metal-matrix composite that will be used in this project will be a continuous fiber Kanthol (Fe-Cr-Al alloy) tungsten composite. Each specimen will be made with the fibers throughout all plies, oriented in the same direction. Four different off-axis orientations will be tested. The axial torsional systems are presently supporting a developmental evaluation of high temperature biaxial extensometry. Near-term plans for these systems include supporting the high temperature strain gauge program at NASA Lewis, and the development of a thermomechanical capability, using internal air cooling. The high temperature strain gauge program will involve the purchasing of a three-zone clamshell resistance furnace.

Future considerations for the biaxial systems include supporting the Materials Division at NASA Lewis in evaluating advanced materials (i.e., single crystal metals, metal-matrix and ceramic-matrix composites, etc.). These materials will be evaluated under complex thermomechanical and multiaxial loadings. Another project will be the development and evaluation of optical extensometry for biaxial measurements. Also, there will be a program for the testing of simple structures. Presently the planned structure will be a notched thick-wall cylinder. Eventually, one of the biaxial systems will be fitted with an internal pressure apparatus providing a triaxial test capability.

COMPUTER SYSTEM CAPABILITIES

A significant enhancement to the laboratory's capabilities has been the addition of a locally distributed digital computer system, intended to support all phases of experimental research.

The architectural design goals shaping the hardware elements of the automation effort included:

(1) Automate the operation of each materials testing system so that each would be independent of another; this ensures that only one experiment would be lost if a failure occurred.

(2) Establish an environment for general nonreal-time use; that is, data reduction, plotting, report writing, program development, etc.

(3) Establish a graceful means of allocating additional computing resources as required.

These goals are conflicting: a computing system designed for real-time use will generally not have the scheduling abilities and other resources to adequately support a multiuser development environment. The solution was to dedicate a set of computing resources to each materials test system, optimized for test control. This would require that the hardware must interface to the analog and digital electronics of the materials test system, and the software comprising the operating system must feature interrupt driven, multitasking, capabilities. It should also be highly configurable. Secondly, another set of computing resources would be required for use as a development environment. The hardware in this case should be chosen to support the needs of an operating system featuring multiuser, multiprogramming, multitasking capabilities. Finally, all systems should be interconnected in such a way that sharing of resources is possible under real-time conditions. The solution implementation at NASA Lewis is shown in figure 22. The laboratory computer system hardware architecture is composed of fourteen 16-bit computers, each dedicated to one materials testing system, and one 32-bit superminicomputer. All fifteen processors are connected through a high-speed (direct memory access) multiprocessor communications system, and are also connected through serial lines. Each of the 14 satellite computer systems is equipped with at least 512 kilobytes of main memory, a hardware floating point unit, a battery backup unit, a hard and floppy disc system, an IEEE-488 instrumentation interface, a multiprocessor communications subsystem, and a test machine interface system, containing analog/digital (A/D), digital/analog (D/A) and discrete input/output (I/O) interface devices. This latter system is interfaced to the control and measurement electronics of each materials test system. The 32-bit system, referred to as the host computer system, is equipped with 4 megabytes of main memory, a hardware floating point unit, a battery backup system, a large winchester hard disc, two tape drives, a dual diskette drive (for media compatibility with the satellite systems), a multiprocessor communications subsystem, an IEEE-488 instrumentation interface, and a test machine interface system. CRT terminals can be physically connected to any processor in the system, with the capability to establish logical connections to any processor in the system. All printers and hard copy units are connected to the host computer, as well as a modem and broadband network interface, enabling data communications between the laboratory system and remote personal-computer-based graphics workstations. This last item also provides access to NASA Lewis-wide computing services, including class VI supercomputer resources. The design goals shaping the software elements of the laboratory computer system included:

(1) Provide an efficient real-time operating system for use on the satellite processors; such an operating system should support interrupt driven, multitasking and multiprogramming applications.

(2) Provide an efficient nonreal-time operating system for use on the host processing system to support multiuser, multiprogramming, multitasking applications.

(3) The user interface to both classes of systems should be strongly related; that is, the user should not be unduly burdened with having to learn and efficiently use two completely different operating system environments.

(4) Provide a base for applications developments; this base should include the editors, programming languages, source debuggers, etc., necessary for efficient applications development. This base should be located on the host processing system.

(5) Provide libraries of commonly used utility routines. The libraries available should include mathematical and statistical processing.

(6) A means of performing analyses on data sets, including graphics, should exist.

(7) A means of storing, retrieving, and manipulating the data acquired from an experiment, as well as storing data obtained from the literature, contracts, etc. is essential. This resource should be located on the host processing system.

The solution implementation satisfying 1, 2, and 3 consists of a real-time operating system for use on the satellite processors, having interrupt driven, multiprogramming, multitasking capabilities. The operating system chosen for the host processor has multiuser, multiprogramming, multitasking capabilities. A key feature in the choice of both, is that the system command language processors, and the user interface to each operating system, are essentially identical. That is, file manipulation commands, directory structures, etc., are virtually identical, permitting the user to move between the two classes of computer systems with relative ease.

The solution implementation for element 4 is shown in table II. A comprehensive set of development tools are present on the host processing system to support application development. The choice in application programming language is wide; high level languages include ADA, PASCAL, FORTRAN-77, and BASIC. All compilers produce both 16-bit and 32-bit code for use on either the host or satellite processors. Assemblers are also available for both the 16-bit and 32-bit machine environments. Software facilities are available enabling modules to be developed in any of the above languages (except BASIC) to be called from any language. This is a vendor dependent capability, with ADA being the only language with explicitly defined facilities for including modules written in languages other than ADA. Using this facility, the libraries for statistics, mathematics, etc., are available to a user under any language processor in the system.

Design element 6 was accomplished through the use of a commercially available software system residing on personal computers. The PCs are located both within and out of the laboratory and provide display and plotting capabilities in addition to powerful data analysis capabilities. Key features of this system include:

(1) Data entry and retrieval functions
(2) Data transformation and analysis
(3) Graphics- 2-, 3-dimensional display (CRT, digital plotter)
(4) Curve fitting
(5) Statistical analysis
(6) Analytical modelling
(7) Interactive or program driven

The last design element, 7, consists of a data base management system based on the relational model. The interface is primarily through a structured query language (SQL). The system resides on the host processing system. Key features of this system include:

(1) Multiuser data access, sharing
(2) Relational Data Base Management System (DBMS)
(3) SQL data manipulation/definition language
(4) Interactive or program driven

LABORATORY ADDITION

To address the need for further expansion of the Laboratory's high temperature capabilities, it was proposed to build an addition to the present facility. Figure 23 is an architect's conception of this addition. The addition will double the floor area of the present laboratory, and will be equipped with its own control room. The area will be large enough to locate ten additional test systems, four of these being the uniaxial systems previously described. The control room will house the computer systems necessary for the additional systems along with the computer terminal work stations. The lab addition will include a calibration room. In this room specimens will be inspected and strain gages will be mounted. Other activities that the calibration room will be used for include electronic repairs, and extensometer development and calibration. The completion of this addition will make it possible to increase the high temperature test capabilities of the Laboratory, furthering NASA Lewis's ability to meet the challenge of developing models for life and material behavior necessary for the design of advanced propulsion systems.

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2. Ellis, J.R.; and Robinson, D.N.: Some Advances in Experimentation Supporting Development of Viscoplastic Constitutive Models. NASA CR-174855, 1985.

TABLE I. - CENTRAL LABORATORY SERVICES

Service	Description
Hydraulic system	350 gal of Mobil DTE-25 oil 3 low pressure pumps (80 gpm at 150 psi per pump) 3 high pressure pumps (70 gpm at 3000 psi per pump) 1 oil to water heat exchanger (400 000 Btu/hr) Oil filters (3 μm) Alarms for reservoir level, oil temperature, oil pressure, and clogged filters
Distilled water system	250 gal of distilled water Flow capacities of 170 gpm at 60 psi 2 backup recirculators (45 gpm at 50 psi)
Shop air system	120 psi pressure Filtered with moisture traps

TABLE II. - PROGRAM DEVELOPMENT TOOLS

Support software/utilities	
Source editor	SLATE SED
Language processors	ADA PASCAL FORTRAN-77 BASIC ASSEMBLER
Miscellaneous tools	Configuration control utility Symbolic debuggers Library editor File editor Etc.
Libraries	Sensor input/output Mathematics Statistics Graphics

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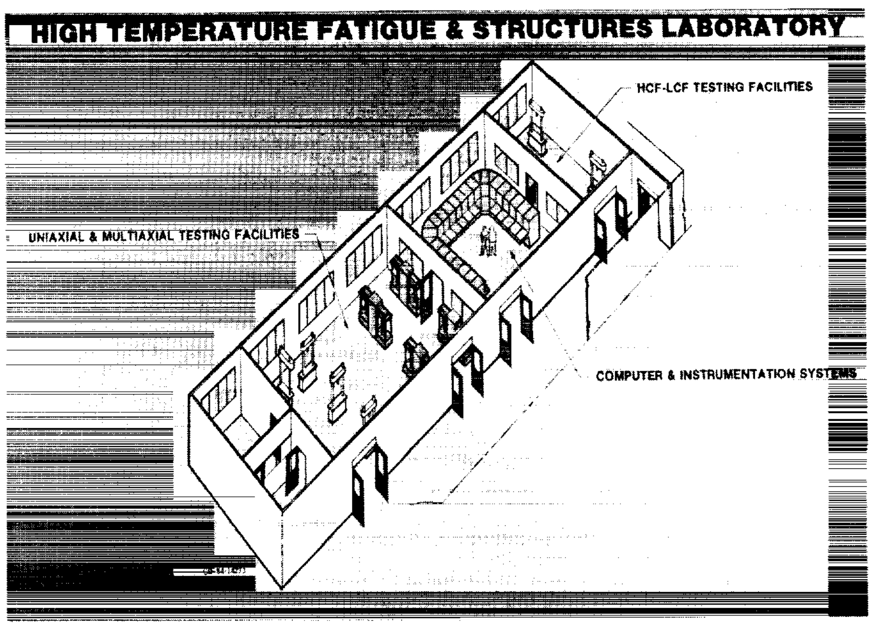

FIGURE 1. - PRESENT LABORATORY LAYOUT.

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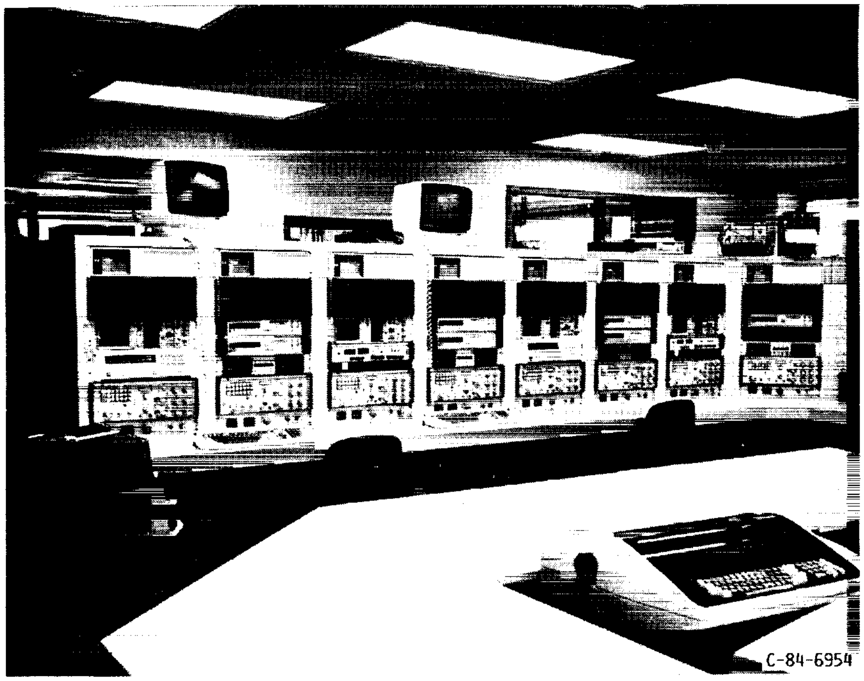

FIGURE 2. - COMPUTER AND INSTRUMENTATION AREA.

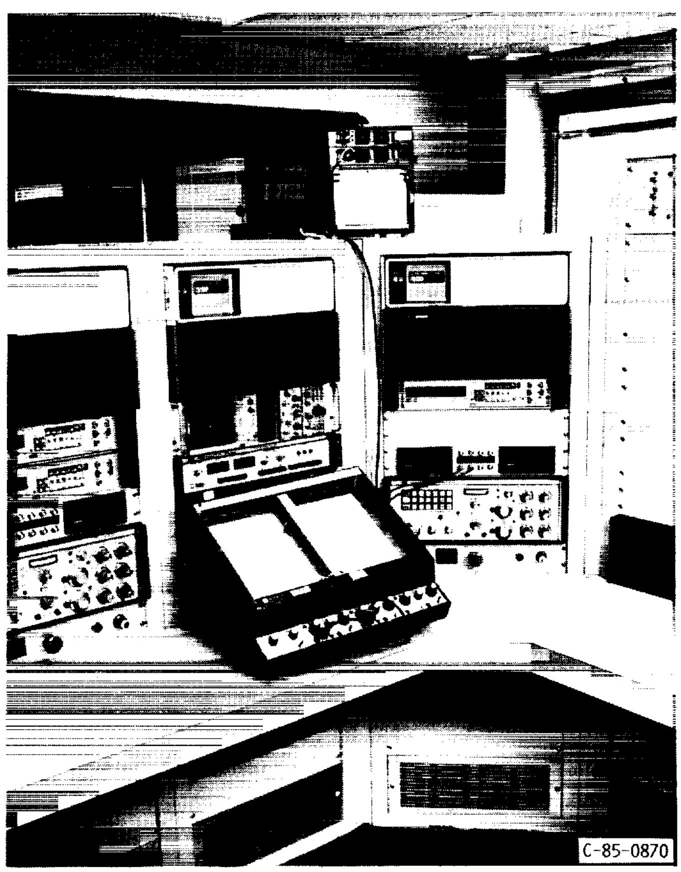

FIGURE 3. - TYPICAL UNIAXIAL TEST SETUP.

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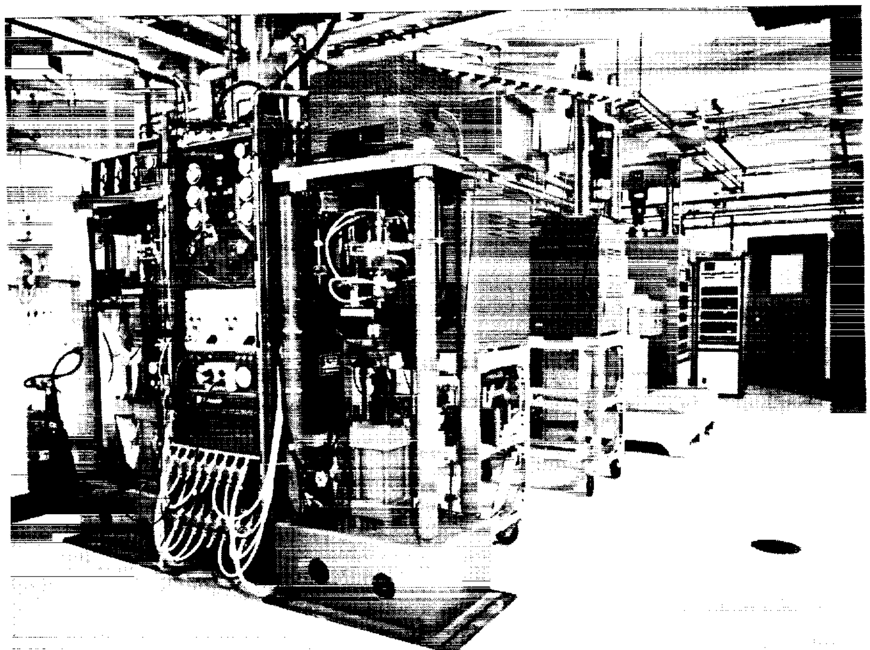

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FIGURE 4. - UNIAXIAL AND BIAXIAL TESTING AREA.

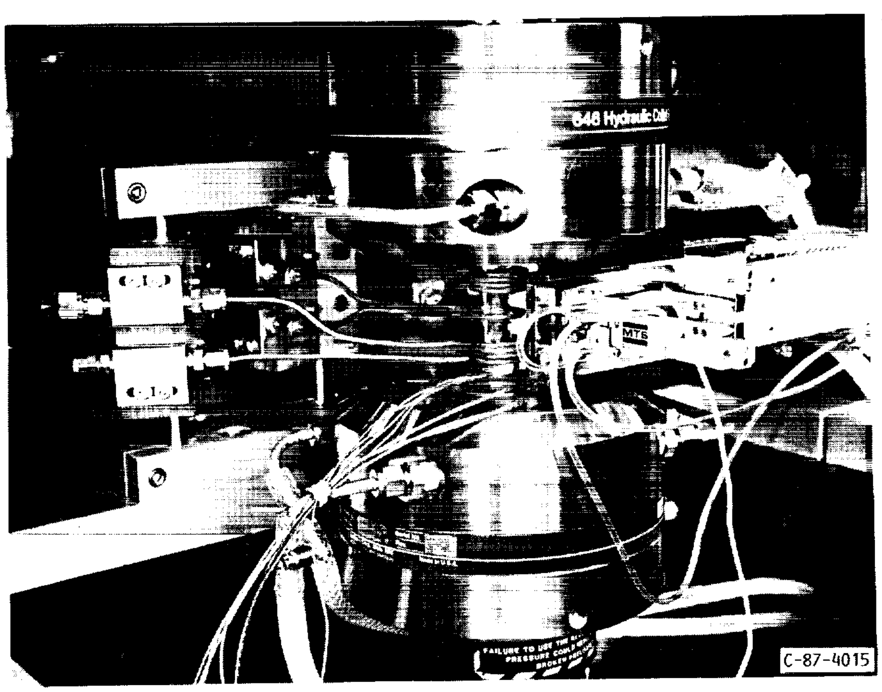

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FIGURE 5. - UNIAXIAL LONGITUDINAL EXTENSOMETER IN TEST SETUP.

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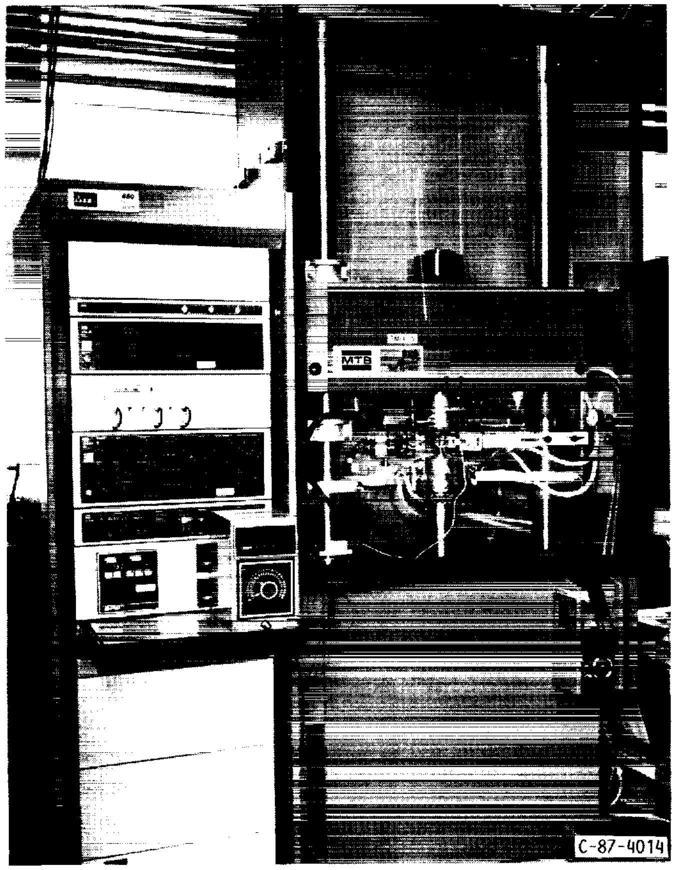

FIGURE 6. - NEW UNIAXIAL TEST SYSTEM.

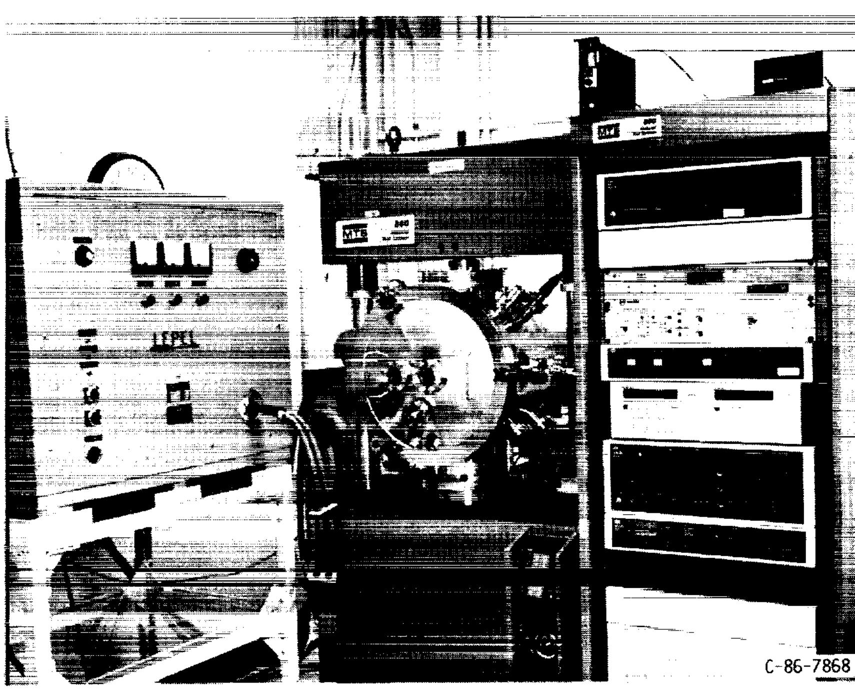

FIGURE 7. - NEW UNIAXIAL TEST SYSTEM WITH VACUUM CHAMBER.

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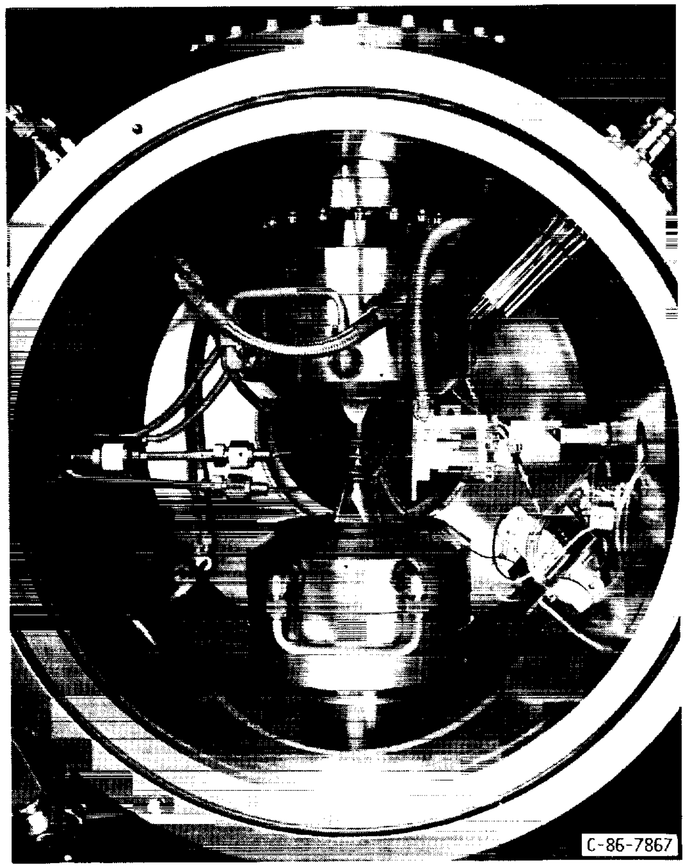

FIGURE 8. - INSIDE OF VACUUM CHAMBER OF NEW UNIAXIAL TEST SYSTEM.

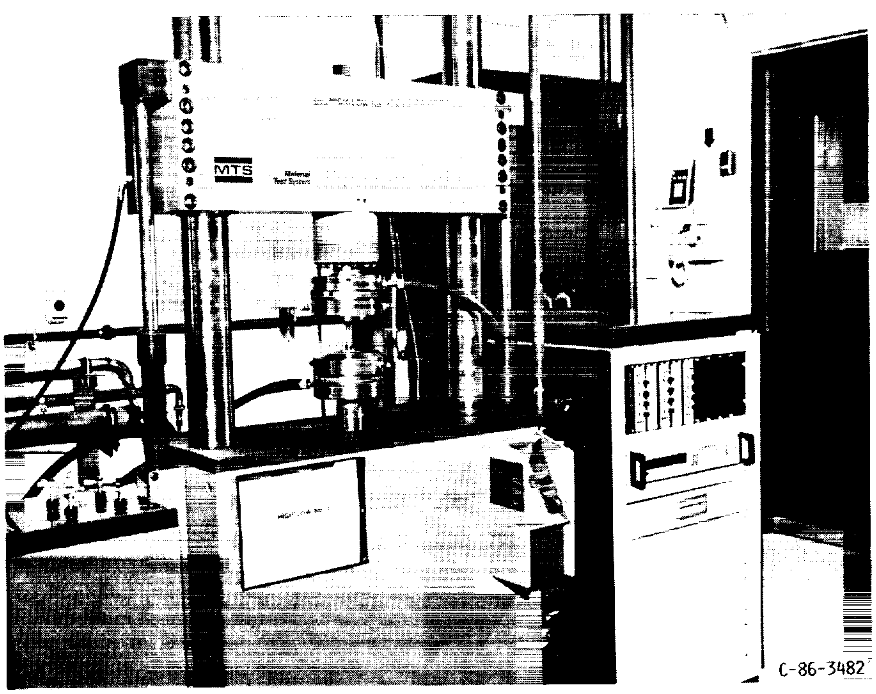

FIGURE 9. - HIGH CYCLE/LOW CYCLE TEST SYSTEM.

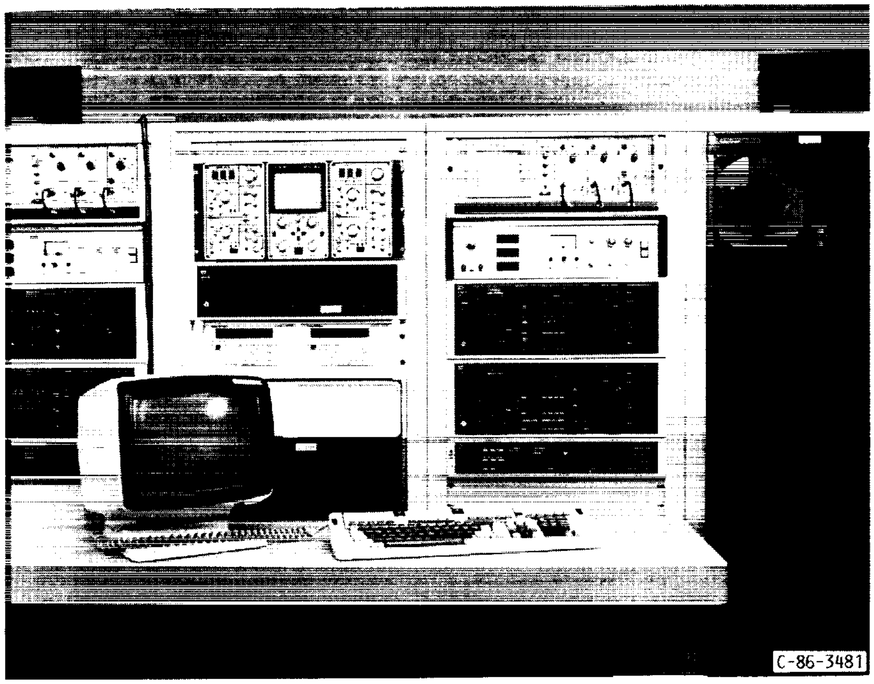

FIGURE 10. - COMPUTER SETUP FOR HIGH CYCLE/LOW CYCLE TEST SYSTEMS.

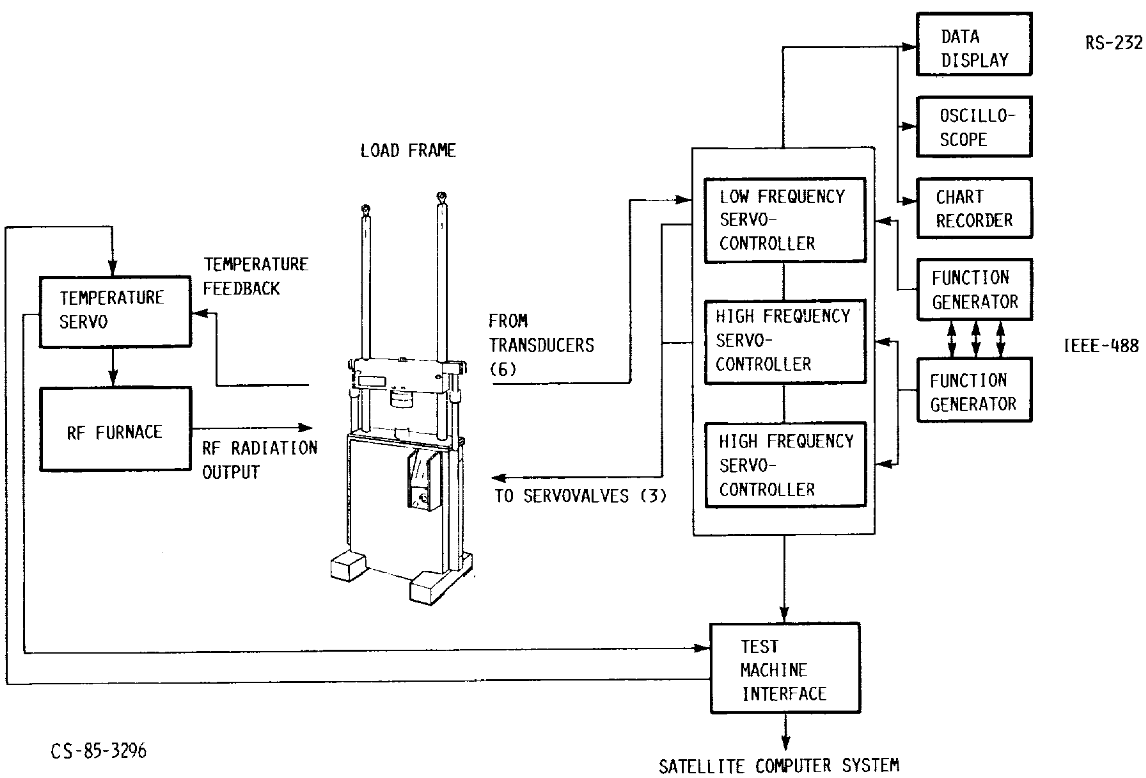

FIGURE 11. - SCHEMATIC OF THE HIGH CYCLE/LOW CYCLE TEST SYSTEMS.

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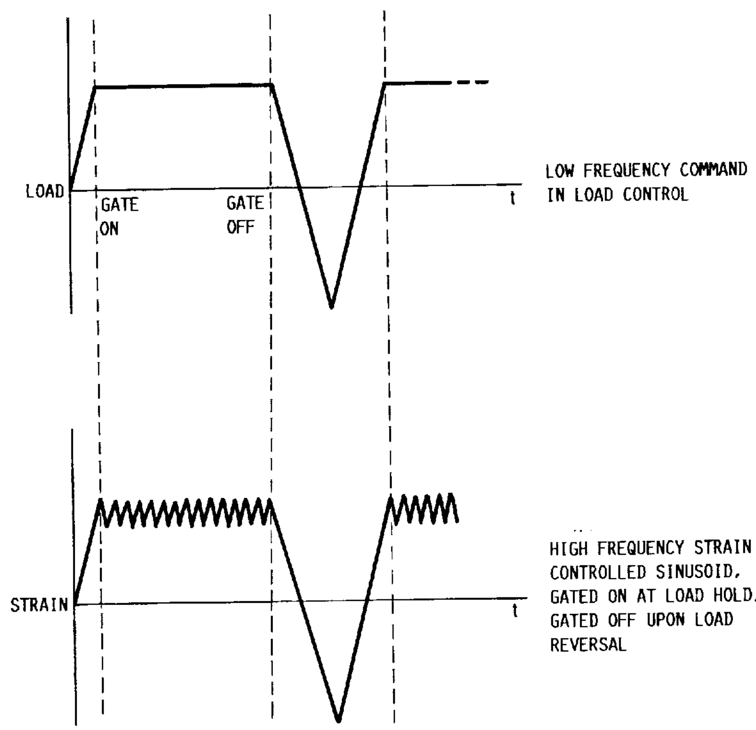

FIGURE 12. - A TEST COMMAND TYPIFYING TURBINE BLADE HISTORIES.

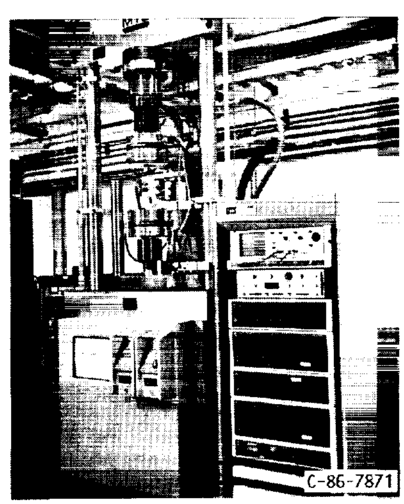

FIGURE 13. - BIAXIAL MATERIAL TEST SYSTEM.

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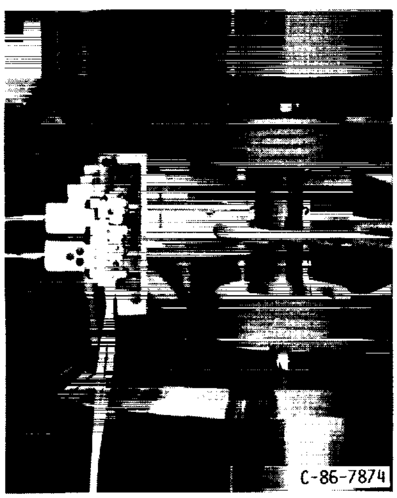

FIGURE 14. - COMMERCIALLY AVAILABLE BIAXIAL EXTENSOMETER.

FIGURE 16. - ORNL BIAXIAL EXTENSOMETER.

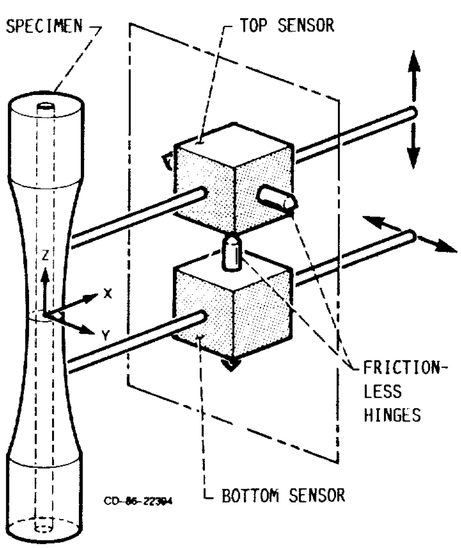

FIGURE 15. - A SCHEMATIC OF COMMERCIAL EXTENSOMETER SHOWING BASIC CONCEPTS.

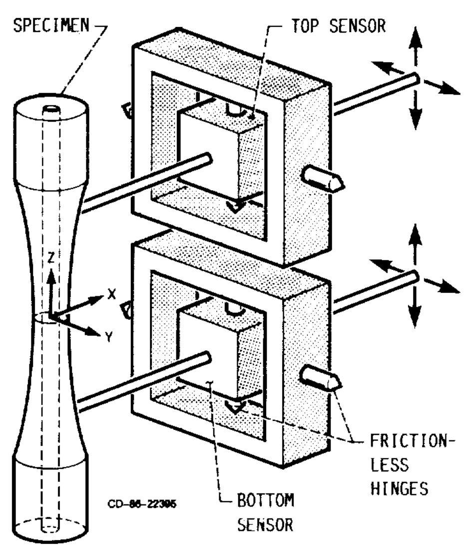

FIGURE 17. - A SCHEMATIC OF THE ORNL BIAXIAL EXTENSOMETER SHOWING BASIC CONCEPTS.

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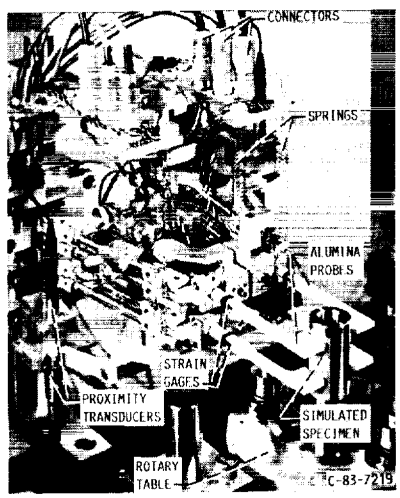

FIGURE 18. - ORNL MULTIAXIAL EXTENSOMETER.

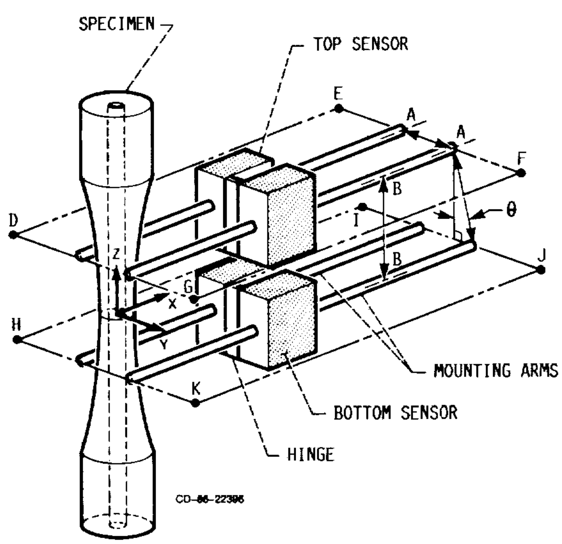

FIGURE 19. - A SCHEMATIC OF THE ORNL MULTIAXIAL EXTENSOMETER SHOWING BASIC CONCEPTS.

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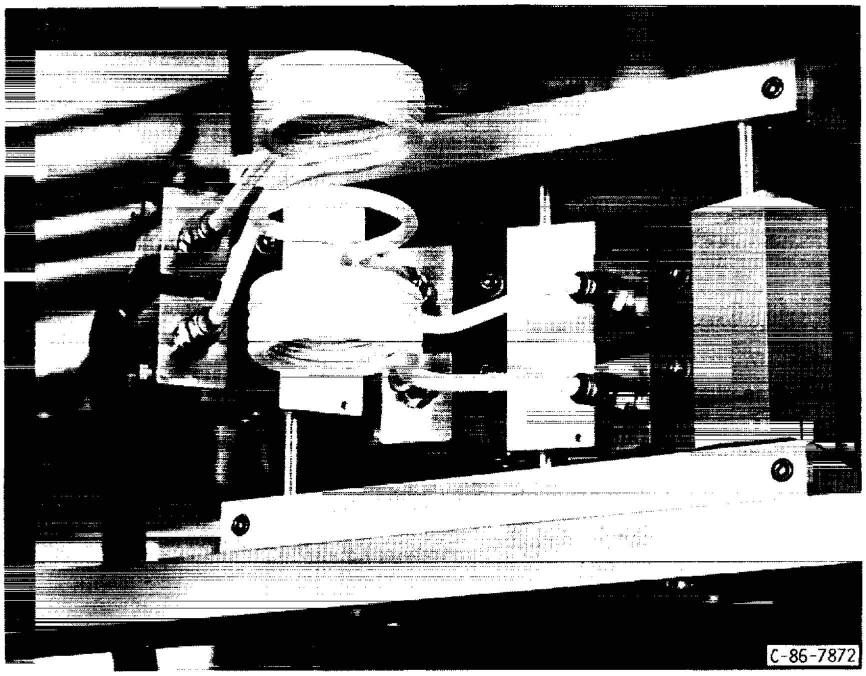

FIGURE 20. - INDUCTION HEATING COIL FIXTURE FOR BIAXIAL TEST SYSTEMS.

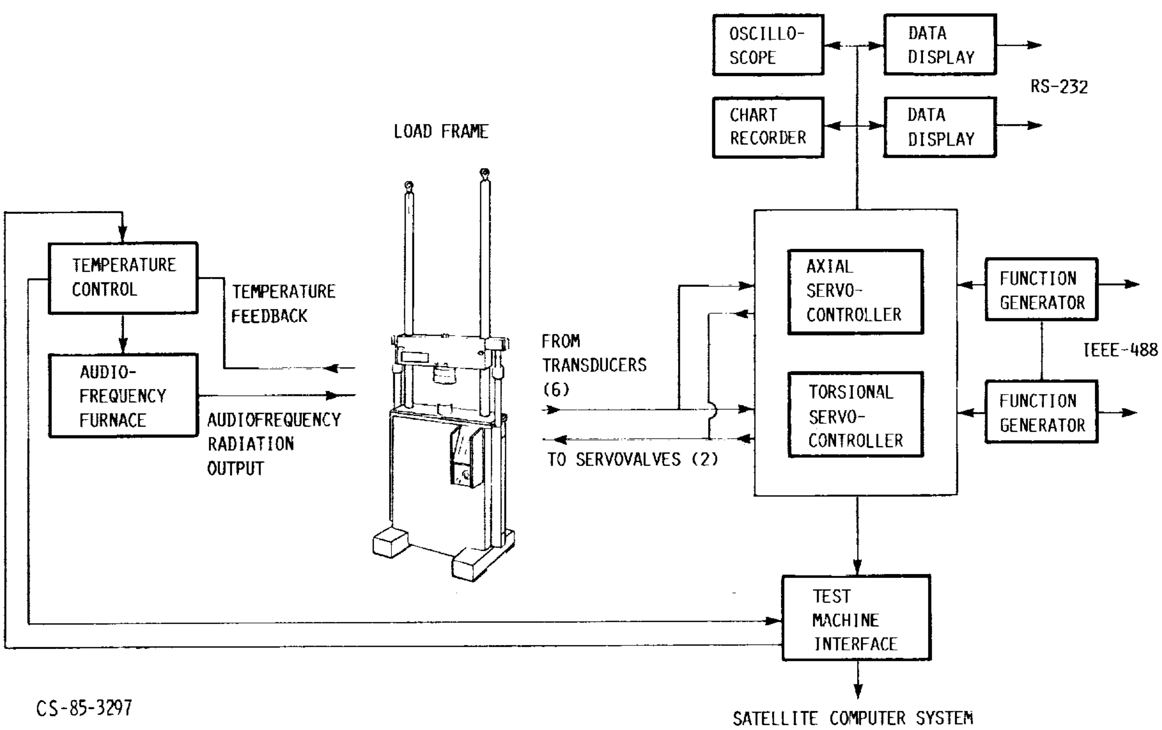

FIGURE 21. - SYSTEM SCHEMATIC OF THE BIAXIAL TEST SYSTEMS.

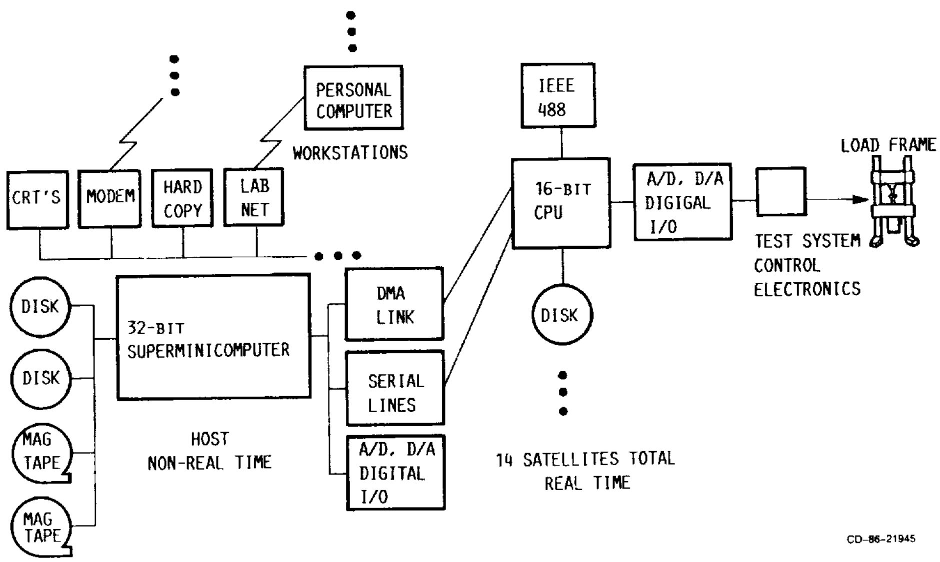

FIGURE 22. - THE LABORATORY'S COMPUTER SYSTEM HARDWARE ARCHITECTURE.

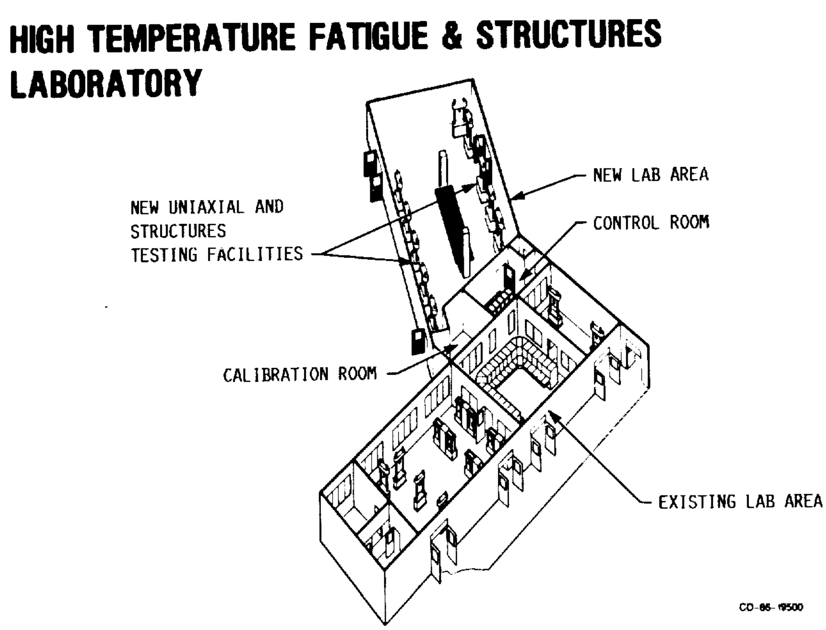

FIGURE 23. - EXISTING LABORATORY AREA WITH FUTURE LABORATORY ADDITION.

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15. Supplementary Notes

16. Abstract

As man strives for higher levels of sophistication in air and space transportation (e.g., subsonic, supersonic, hypersonic transatmospheric, etc.), awareness of the need for accurate life and material behavior predictions for advanced propulsion system components is heightened. Such sophistication will require complex operating conditions and advanced materials to meet goals in performance, thrust-to-weight ratio, and fuel efficiency. To accomplish these goals will require that components be designed using a high percentage of the material's ultimate capabilities. This serves only to complicate matters dealing with life and material behavior predictions. An essential component of material behavior model development is the underlying experimentation which must occur to identify phenomena. To support experimentation, the NASA Lewis Research Center's High Temperature Fatigue and Structures Laboratory has been expanded significantly. Several new materials testing systems have been added, as well as an extensive computer system. The intent of this paper is to present an overview of the laboratory, and to discuss specific aspects of the test systems. In this age of computer controlled experimentation, a limited discussion of the computer capabilities will also be presented. Finally, plans for an addition to this laboratory will be briefly described.

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