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LEWIS' ENHANCED LABORATORY FOR RESEARCH INTO THE FATIGUE AND CONSTITUTIVE BEHAVIOR OF HIGH TEMPERATURE MATERIALS

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Lewis' high temperature fatigue laboratory has undergone significant changes resulting in the addition of several new experimental capabilities. New materials testing systems have been installed enabling research to be conducted in multiaxial fatigue and deformation at high temperature, as well as cumulative creep-fatigue damage wherein the relative failure-life levels are widely separated. A key component of the new high-temperature fatigue and structures laboratory is a local, distributed computer system whose hardware and software architecture emphasizes a high degree of configurability, which in turn, enables the researcher to tailor a solution to the experimental problem at hand.

AN EXPANDED LABORATORY

Significant expansion of the facility has occurred to accommodate the additions in testing systems and computer capabilities. The design convention of locating the load frames in areas separate from the control system electronics, a convention in use at Lewis for over 20 years (ref. 1), was followed, enabling separate environments to be designed for the load frames and their control electronics, as well as the computer system. Figure 1 describes the physical organization of the laboratory. The new multiaxial test systems, together with the existing uniaxial test systems, are located in the larger of the two testing areas. The second testing area houses the new HCF/LCF test systems and is located separately to isolate the remaining areas from noise produced by their operation. The centrally located control room 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 system, with all cables routed through a tray system. Both the humidity and temperature are controlled, providing an optimum environment for the operational longevity of the control electronics and computer system.

NEW EXPERIMENTAL CAPABILITIES

Multiaxial Capability

In response to the need for better descriptions of material behavior under complex states of stress, as seen, for example, in components used in aircraft gas turbines, an experimental capability is being developed for studying material deformation and fatigue behavior under multiaxial states of stress at elevated temperatures.

This capability consists of electromechanical servohydraulic materials test systems possessing both combined and independent axial and torsional loading abilities. Loading capacities are 50 kips axial and 20 inch-kips torsional. Figure 4 is a functional description of a typical (commercially available) system.

The control system electronics consists of two independent channels of servo-control for controlling the axial and torsional hydraulic actuators. Each system can control any axial control variable (load, strain, or stroke) asynchronously or synchronously with any torsional control variable (torque, torsional strain, or angular displacement). Conditioned analog transducer signals appear on an oscilloscope, chart recorders, or digital data displays. The data display units can be programmed to perform a number of signal processing operations and together are able to simultaneously display four channels of data. These units are equipped with RS-232 serial interfaces and can be used as computer-based data acquisition systems. Control system programming is accomplished through digitally based waveform generators. Two of the three systems use a generator able to produce phased sinusoidal and triangular command waveforms. The third system uses two independent generators (different manufacture), each able to produce arbitrary waveforms asynchronously as well as synchronously through programmable phasing. These generators possess IEEE-488 instrumentation interfaces and can be used under computer control. All three test systems are interfaced to individual satellite computer systems through a test machine interface. The test machine interface contains analog-to-digital, digital-to-analog, and discrete input-output devices to enable computer control of the test system control electronics.

High-temperature capability is attained through the use of commercially available audiofrequency furnaces. These furnaces have a power output capability of 50 kW at an operating frequency of 9.6 kHz. A commercially available PID controller is used for closed-loop temperature control. It too, is connected to the test machine interface.

Among the more difficult problems in multiaxial experimental work are specimen gripping and strain measurement. We have chosen to use commercially available hydrocollet grips because of their alignment characteristics and ease of use. Strain measurement will be accomplished through the use of commercial high-temperature extensometry as well as through the extensometry system developed by J.R. Ellis (ref. 2). The latter system is designed for very-high-resolution strain measurement, on the order of a few microstrain required for accurate identification of material behavior at the yield, an ingredient in constitutive model development. It is worth noting that the questions of gripping systems, extensometry, and specimen design are intimately related, and usually cannot be pursued independently.

HCF/LCF Capabilities

In response to the technological need for better understanding of the fatigue behavior of materials undergoing cumulative cyclic loadings, each having a quite different associated life level, a problem typified by gas-turbine blade service cycles, an experimental capability is being developed for studying cumulative fatigue damage accumulation.

This capability consists of being able to produce arbitrary load (or, alternatively, deformation) histories corresponding to (separation) fatigue lives over the range of 1/4 cycle to approximately 10^7 cycle, in wall clock times of 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-bandwidth (with respect to frequency and amplitude), load (deformation) history programming. Lewis has two such systems, each able to produce rated capabilities at elevated temperatures typical of turbine blade applications in gas-turbine aircraft engines. Figure 5 is a functional description of a typical system. Load ratings are 22 kips over the frequency range of dc to 20 Hz, with a corresponding actuator piston displacement range of 0.04 in., and a load rating of 5 kips over the range of dc to 300 Hz, with a corresponding actuator piston displacement range of 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 displacement to well over 1000 Hz.

To achieve these performance characteristics, a control system consisting of five servoloops 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 a typical history program, driven by one 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. This valve and its actuator interface provides feedback signals of valve spool position and pressure difference across the smaller piston faces, used in two of the four servoloops controlling the high-frequency portion of the waveform. The remaining two servoloops use 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 linear response over a very wide frequency range of operation.

Data measurement can be accomplished through the use of a storage oscilloscope, a chart recorder, or the digitally based data display. This latter item is of the same type as used in the multiaxial testing systems. Command waveform programming is accomplished through the use of two digitally based arbitrary waveform generators, of the type referred to earlier, in use for one of the multiaxial testing systems. They are used in a somewhat different manner here, however, in that 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 to a machine interface unit and to a unique satellite computer system.

High-temperature capability is obtained through the use of commercially available radiofrequency 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 are connected to the test machine interface and can be compute controlled as well.

Commercially available hydrocollet grips are being used for same reasons stated earlier: alignment characteristics and ease of use. Extensometry is a major problem: No known extensometer system exists that is capable of being used at high temperatures (to 2000 °F), with very wide frequency response. Currently, work is going on to develop such a system, and in the interim commercially available high-temperature extensometry is being used for the low-frequency work.

An interesting capability afforded by this system's design is the ability to control, say, the low-frequency portion of a waveform program in load control, and the high-frequency portion of the waveform program in strain control. Of course, the waveform program must not require a physical behavior which cannot be achieved by the material being tested; nonetheless, provided that the material physics is compatible, such a control scenario is possible. A typical waveform which can be programmed and executed with this arrangement is a low-frequency program consisting of a ramp from zero to tension, in load control, holding for a specified period of time, then ramping back to zero, and a high-frequency program consisting of a simple sinusoid with a mean level, in strain control. In this case, the low-frequency generator is programmed to issue either a trigger or gate signal upon reaching the hold, and the high-frequency generator is programmed either for a fixed number of output cycles or to output continuously only when gated. Such a program captures salient characteristics of histories often seen by turbine blades.

COMPUTER CAPABILITIES

A significant enhancement to the laboratory's capabilities has been the addition of a local, 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) Automating the operation of each materials testing system such that each would be independent of another. This ensures that only one experiment would be lost if a failure of any sort occurred.
(2) Establishing an environment for general non-real-time user; that is, data reduction, plotting, report writing, program development, etc.
(3) Establishing 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 architectural solution chosen was to dedicate a set of computing resources to each materials test system, optimized for test control: the hardware must interface with the analog and digital electronics of the materials test system, and the software, comprising the operating system, must feature interrupt-driven multitasking and multiprogramming capabilities. 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 Lewis is shown in figure 6. The laboratory computer system hardware architecture is composed of fourteen 16-bit computers, each dedicated, one system per materials testing system, and one 32-bit superminicomputer. All 15 processors are connected through a high-speed (direct memory access) multiprocessor communications system and will soon be connected through serial RS-232 lines as well. Each of the 14 satellite computer systems is equipped with 256 Kbytes of main memory, a hardware floating-point unit, a battery backup unit, a disk system consisting of a 1.26-Mbyte diskette and a 5 Mbyte winchester hard disk unit, an IEEE-488 instrumentation interface, a multiprocessor communications subsystem, and a test machine interface system containing analog-to-digital, digital-to-analog, and discrete input-output 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 Mbytes of main memory, a hardware floating-point unit, a battery backup system, a 354-Mbyte winchester hard disk, a 800 or 1600-bit per-inch tape drive, an 800-bpi streaming tape drive, a dual 1.26-Mbyte 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-based terminals can be physically connected to any processor in the system, but soon will all be connected to the host computer, with the capability of being able 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 Lewis-wide computing services, including class VI supercomputer resources.

The architectural design goals shaping the software elements of the laboratory computer system included:

(1) Providing an efficient real-time operating system for use on the satellite processors; such an operating system should support interrupt-driven multiprogramming, multitasking applications.
(2) Providing an efficient non-real-time operating system for use on the host processing system to support multiuser, multiprogramming, multitasking applications.
(3) Providing a strongly related user interface to both classes of systems; that is, the user should not be unduly burdened with having to learn and efficiently use two completely different operating system environments.
(4) Providing a base for applications development: This base should include the editors, programming languages, source debuggers, etc., necessary for efficient applications development, and it should be located on the host processing system.
(5) Providing libraries of commonly used utility routines. The libraries available should include mathematical and statistical processing, as well as graphing routines.
(6) Providing a means of storing, retrieving and manipulating the data acquired from an experiment, as well as storing data obtained from the literature, contracts, etc. 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, the user interfaces to the 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 d is shown in figure 7. 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. Pascal and Fortran-77 compilers producing both 16-bit and 32-bit code are available. The Ada compiler currently generates 32-bit code for use on the host processor only; a target generator for the 16-bit satellites will be available in the very near future. Assemblers are available for both the 16-bit and 32-bit machine environments. 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, Ada being the only language with explicitly defined facilities for including modules written in languages other than Ada. Using this facility, the libraries for statistical, mathematical, etc., use are available to a user under any language processor in the system. Graphing routines and appropriate display devices will be available shortly.

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The last design element f will be implemented shortly and consists of a data-base management system based on the relational model. The interface will be a structured query language (SQL). The system will reside on the host processing system.

Figure 8 describes the development cycle in use at NASA to build applications. The user develops the sources with an editor and compiles with the appropriate compiler. The choice of which implementation of the language to use, 16- or 32-bit native-code generation, is made here as well; faster execution of the compilation and resultant application in the host environment will result if the native 32-bit version is used. However, when the application is ready to be exported to the target satellite system for execution, the sources must be recompiled with the 16-bit version. Generally, the 16-bit implementation will be used for application development. Once compiled, the resulting objects are linked for execution on the host to begin initial testing. When the testing phase is completed, the user, if the 16-bit version of the language processor was used, simply relinks the objects for execution on the target satellite and exports the image. Otherwise, the sources are recompiled with the 16-bit version of the language processor and linked for execution on the target satellite and exported. The user then tests the application on the satellite system for subsequent usage. This last step is necessary since timing differences can't be easily modeled in the host processing environment.

REFERENCES

1. Hirschberg, M.H.: A Low-Cycle Fatigue Testing Facility. Manual on Low Cycle Fatigue Testing, ASTM-STP-465, ASTM, 1969, pp. 67-86.

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

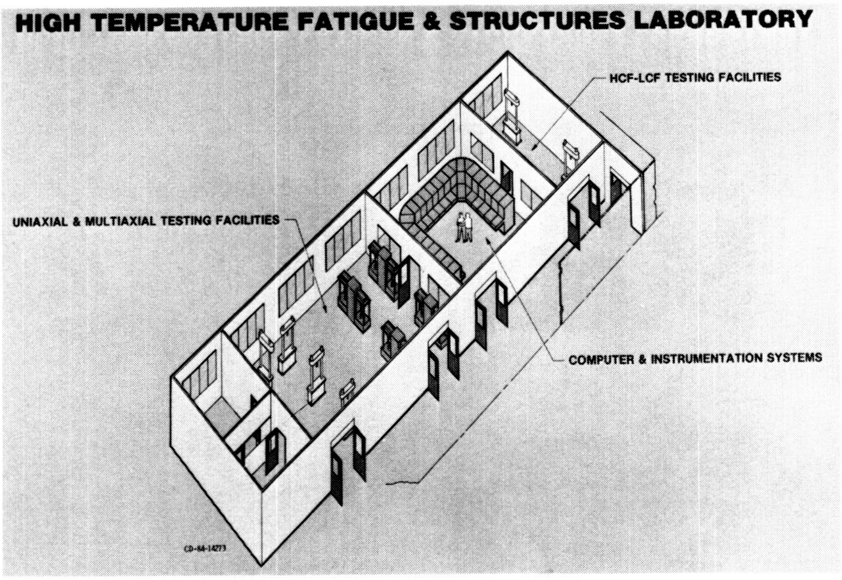

Figure 1

CONTROL ROOM

Figure 2

ORIGINAL PAGE IS
OF POOR QUALITY

TEST SYSTEM CONTROL CONSOLE

Figure 3

AXIAL-TORSION MATERIALS TEST SYSTEM

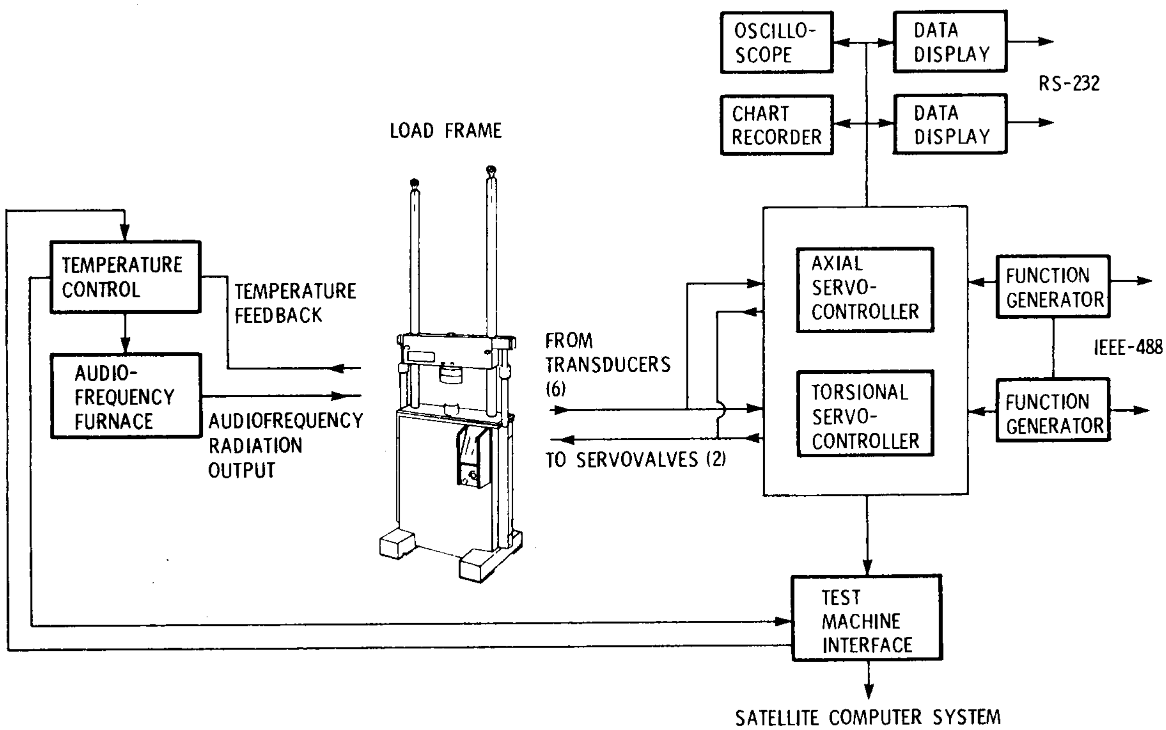

Figure 4

HCF/LCF MATERIALS TEST SYSTEM

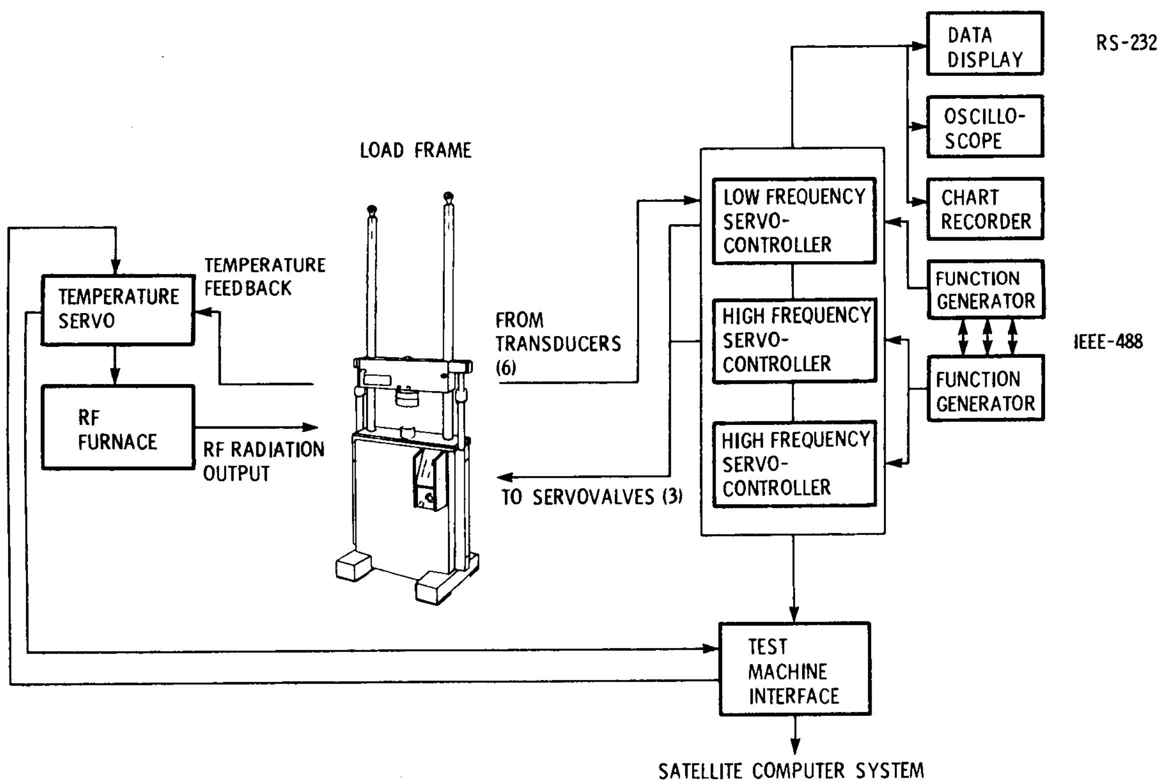

Figure 5

PROGRAM DEVELOPMENT TOOLS

- SOURCE EDITORS
- LANGUAGE PROCESSORS
  - ADA
  - PASCAL
  - FORTRAN-77
  - BASIC
  - ASSEMBLER
- LINKER
- MISCELLANEOUS TOOLS
  - CONFIGURATION CONTROL UTILITY
  - SYMBOLIC DEBUGGERS
  - LIBRARY EDITOR
  - FILE EDITOR
  - ETC.
- LIBRARIES
  - SENSOR INPUT/OUTPUT
  - MATHEMATICS
  - STATISTICS
  - GRAPHICS

Figure 6

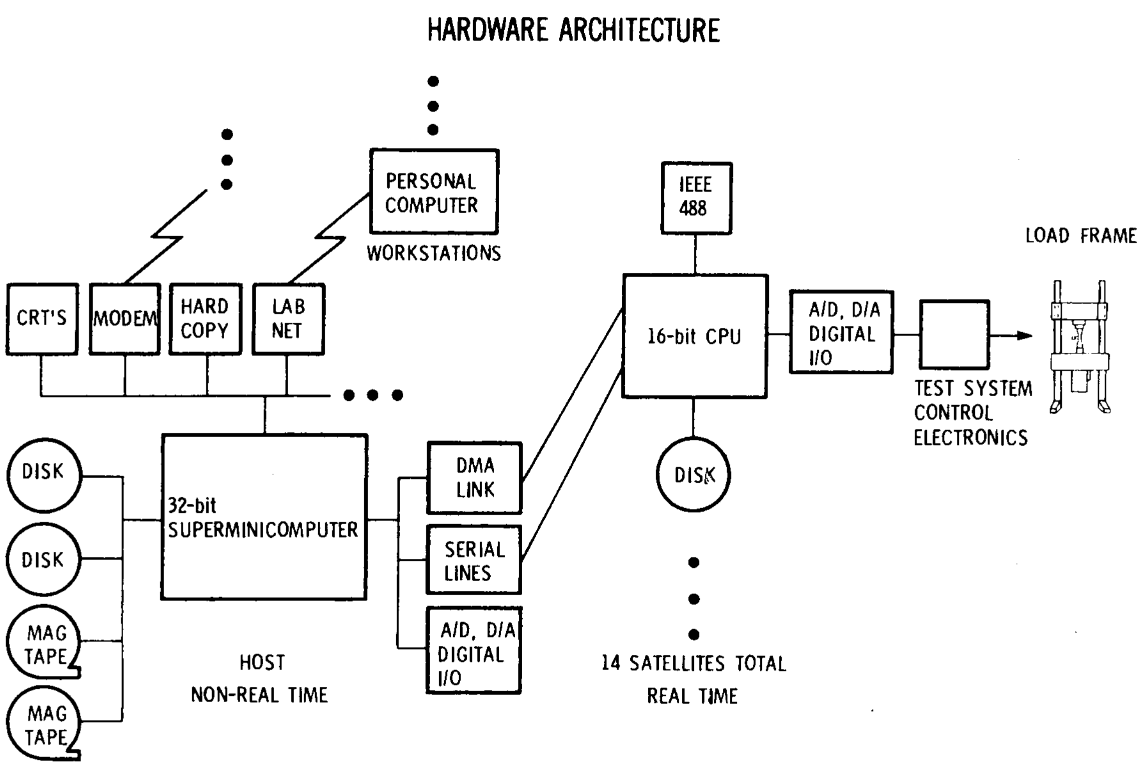

Figure 7

PROGRAM DEVELOPMENT CYCLE

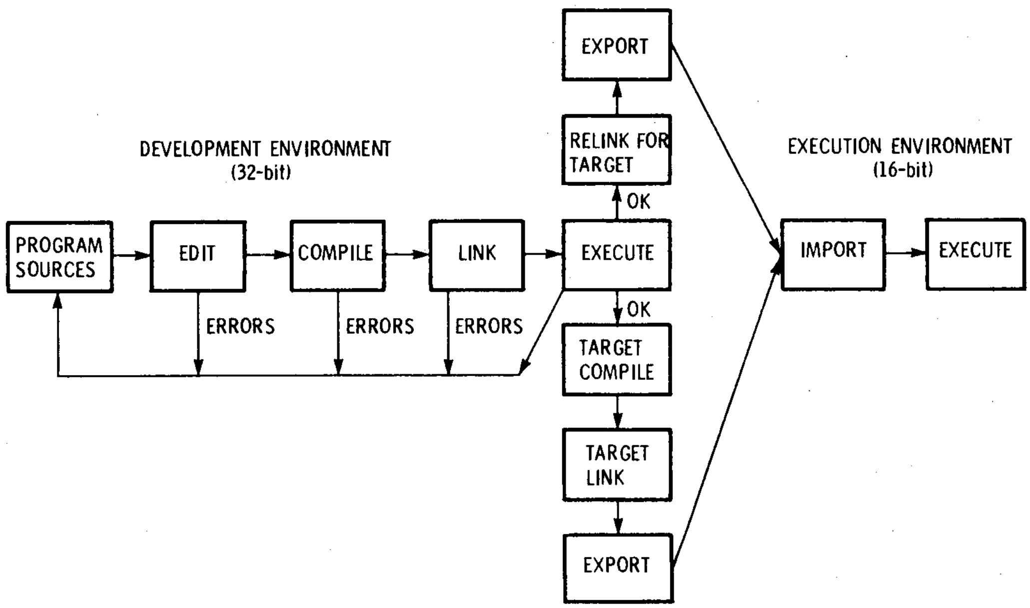

Figure 8