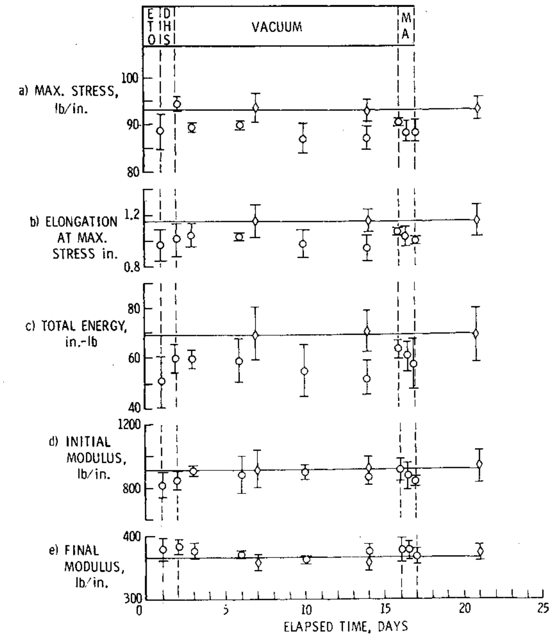

Fig. 4 Variations in mechanical properties with time for the test sequence of Fig. 1.

Figure 4 shows the results, using the same elapsed time scale as in Fig. 1. Each plotted point represents the average for a set of 5 samples, and the standard deviation for the set is indicated by the vertical bar. The effects of mission environments (circles) are compared to the value for the control samples (diamonds and least squares line).

Maximum stress (Fig. 4a) was 5% below the control value of 94 lb/in. after exposure to all of the mission environments. However, the changes varied from +2% after the dry heat sterilization phase (2nd day) to −8% after the vacuum phase (14th day).

Elongation at maximum stress (Fig. 4b) is the product of strain at maximum stress (see Fig. 3) and sample length (3 in.). On completion of all the environmental exposures, elongation was reduced by 13%; however, the changes varied from −18% (14th day) to −7% (16th day) from the 1.16-in. control value.

Total energy (Fig. 4c) is determined by integrating the area beneath the tensile recording. An induced change of −17% occurred after the full sequence, with variations from −24% (1st and 14th days) to −7% (16th day) from the 69-in.-lb control value.

Modulus is the ratio of stress to strain. As shown in Fig. 3, a tangent to the initial loading curve gives the initial modulus (Fig. 4d); a second tangent to the curve in the nearly constant slope region gives the "final" modulus (Fig. 4e). After exposure to all the mission environments, initial modulus was 9% lower than the 915 lb/in. control value, and final modulus was 1% above the 360 lb/in. control value. The initial modulus varied between 905 lb/in. (16th day) and 820 lb/in. (17th day), and the final modulus varied between 382 lb/in. (2nd day) and 363 lb/in. (10th day). The initial modulus had a maximum reduction of 10% after exposure to ETO, whereas the final modulus had its maximum increase of 5% after the dry heat sterilization phase.

Table 1 summarizes control values, the largest changes encountered during the test, and the changes induced by the complete sequence of mission environment phases investigated.

Table 1 Mechanical properties of Dacron on exposure to mission environments

Mechanical property	Control value	Induced change: Maximum	Induced change: End of mission
Maximum stress	94 lb/in.	−8%	−5%
Elongation (max. stress)	1.16 in.	−18%	−13%
Total energy	69 in.-lb	−17%	−17%
Initial modulus	915 lb/in.	−10%	−9%
Final modulus	360 lb/in.	+5%	+1%

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All Digital Guidance and Control System

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Introduction

In the past, a typical booster utilized a digital guidance computer and an analog attitude control computer. Technological advances in the airborne digital computer field have made it practical to convert the attitude control computer to digital and use a single computer to perform both guidance and attitude control. This scheme has been used in recent flights. Further gains can be made by using digital transfer of data between information sources, control devices, and the computer, to save cable weight and eliminate the effects of noise that is induced upon analog signals when transmission lines run through a radiated noise environment. The system discussed here has these advantages; however, the main advantage of this system lies in the centralized approach to the entire airborne logic problem.

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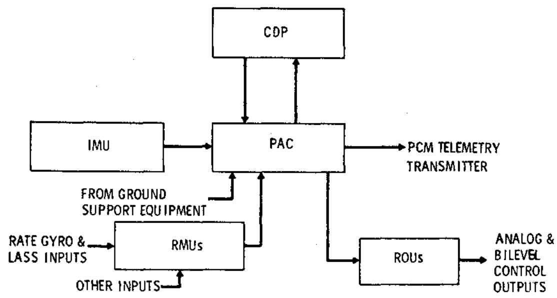


Fig. 1 System configuration.

The system consists of a Central Data Processor (CDP), an interface program and control (PAC) unit, and as many standardized input and output units as necessary. The input and output units are located near groups of input sensors or output control devices. All computations and processing are performed by the CDP, and all communication between the computer and the rest of the vehicle is accomplished by one PAC unit packaged separately. The resulting system can be tailored to meet the specific vehicle requirements by using only the units necessary to meet the actual needs. Growth capability is a built-in factor as is the ability to accommodate any changes in requirements. The system configuration tends to place the computer in the role of a "plug-in" unit and eliminates expensive computer redesign.

System Configuration

Figure 1 illustrates the system. The PAC is the primary component in the system. The other units may be considered as plug-ins. The PAC is not a part of the processor nor is it packaged as such. The interface between the PAC and processor is totally digital and the PAC itself, is strictly a digital device. All analog signals are converted to digital at their source and are transmitted digitally. This is accomplished by means of Remote Multiplexer Units (RMUs), each of which contains an analog-to-digital (A/D) converter. A number of analog inputs can be accommodated by each RMU, and the PAC can use as many as 16 RMUs.

The PAC can also communicate and accept data from those devices that normally have digital outputs, such as certain IMUs. This is done directly without multiplexing. The PAC unit also transmits digital data. Remote Output Units (ROUs) are controlled by the PAC to drive actuators, attitude control system valves, etc. Any digital-to-analog conversion is done by the ROU physically located in the area of the device to be driven.

A party-line philosophy is used in communication and data transmission between the PAC and RMUs or ROUs. One single address line, a clock line, and a data line connect between the PAC and all the RMUs. The same is true of the ROUs. Each RMU contains logic specifying its particular address and examines the information transmitted on the address line common to all RMUs. The transmitted address information consists of two segments RMU-address and channel number. When the transmitted address segment agrees with the internal code, that RMU specified becomes active and examines the information contained in the channel number segment. A number of sensors (up to 27) may be connected into each RMU and each sensor is referred to by a specific channel number.

The RMU, in addition to handling analog inputs, may also accommodate discrete type of data. All RMU data is transmitted to the PAC via the common data line. The ROU relationship to the PAC is similar to that described for the RMU with the addition of output data to the ROU address and channel number.

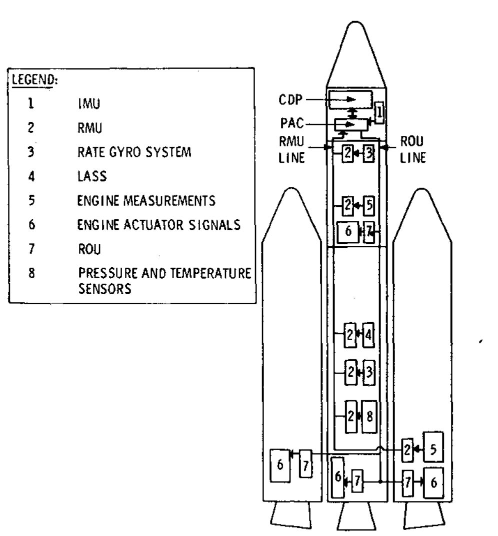
Each RMU can be used to gather the outputs from several sensors and each ROU may drive several devices as long as they are physically close together. Changes in the system requirements with regard to number of sensors, actuators, etc., do not result in expensive and extensive modifications, but are accommodated instead, in the worse case, by additions of standard units to the basic system.

System Operation

The operational aspects of the system can best be understood by reference to its mechanization in a typical vehicle. This is illustrated by Fig. 2 for a current vehicle. The CDP, PAC unit, and the IMU are shown physically located in Stage III. Stage II contains sensors such as rate gyros and lateral accelerometers, and also control devices (e.g., engine actuators). The other two stages also contain various sensor devices and engine control elements.

All input into and output from the CDP is accomplished digitally through the PAC. The PAC connects to RMUs located throughout the vehicle in its different stages. Three common lines are involved; an address, data, and clock line. Similarly, the PAC connects to remotely located ROUs through three common lines. The PAC also calls in digital data from an Inertial Measurement Unit.

The telemetry requirements have been integrated into the system. The telemetry format is contained in the computer memory and consists of a sequence of addresses referring to the source of telemetry data. The PAC sequences through the format on a memory cycle stealing basis, and calls in data according to the contents therein. This data may be



NOTE: 1. EACH RMU WILL HANDLE 27 SEPARATE ANALOG SENSOR INPUTS AND 40 DISCRETES.
2. CAPABILITY EXISTS FOR 16 SEPARATE RMUs AND 16 ROUs.
3. DIGITAL SIGNALS INTERFACE DIRECTLY TO THE PAC.

Fig. 2 Typical installation.

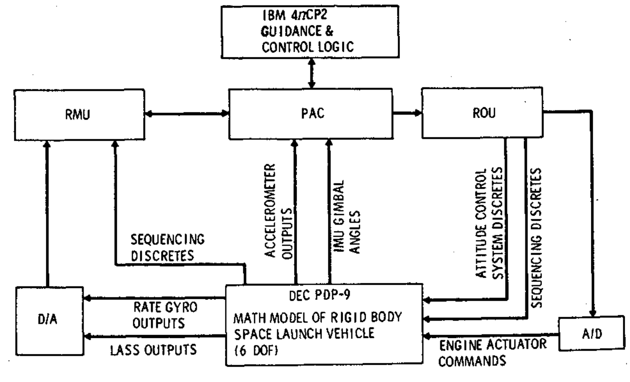


Fig. 3 System simulation.

brought in from an RMU or may be found within the computer. In the latter event, PAC accesses the processor memory and pulls out the desired data for transmission. The format is flexible and permits desired sampling frequencies to be attained.

The CDP performs the tasks of navigation, guidance, flight control, attitude control, self check, and system malfunction detection. It operates as a sampled data system using inputs brought in as a result of its own periodically made request, and also those periodic inputs automatically brought in by the PAC. After processing, outputs are sent via the PAC to the ROUs to control the engine action.

Advantages

The system offers three distinct advantages; growth capability, noise immunity, and high efficiency in terms of size, weight, and power.

Growth or modification capability is provided by the modular design of the system. The central exchange electronics package (PAC) is the primary component while the central processor and the remainder of the system elements are merely plug-in units. The interface between the PAC and the central processor is quite standard so that central processors may be changed without a major PAC redesign.

The PAC unit acquires data by addressing the remote multiplexer units and sends digital data to the remote output units. The digital-to analog conversion is made at the device to be driven. Figure 2, a sketch of the system operating in a typical booster, illustrates the location of the RMU and ROU units. They are placed relatively near the source or destination of the information. The resulting digital transmission of the input and output data has several advantages. The radiated noise environment through which the cables run has little or no effect upon a digital signal. Hence, cleaner signals are obtained from the sensors used to gather data. Another important advantage is provided by party-line communication, i.e., each RMU can be used to gather ininformation from several sources as long as they are physically close together. The sensor outputs are converted to digital at the source and sequentially sent down the same line to the PAC unit. Therefore, each sensor does not require its own communication line. This same party line philosophy is used by the ROUs.

System Simulation

The flight system has been breadboarded and is in operation at the Martin Marietta Denver Inertial Laboratory as illustrated by Fig. 3. An IBM 4π CP2 computer acts as the CDP.

A six-degree-of-freedom, real-time trajectory and an IMU model are simulated in a laboratory computer (DEC PDP-9) and used to provide closed loop verification of the airborne electronics guidance and control system. The simulation is designed to exercise all flight functions of the airborne system.

As shown in Fig. 3, the engine actuator commands, vehicle sequencing discretes, and the commands to the attitude control system engines are input to the PDP-9 simulation. The A/D and D/A converters shown are within the PDP-9 simulation. The A/D and D/A converters shown are within the PDP-9. The PDP-9 calculates the vehicle motion due to the forces acting on it and generates analog signals to simulate roll, pitch, and yaw rate gyros, inertial measurement unit gimbal angles and accelerometer outputs. In addition, the PDP-9 calculates the vehicle state variables in an inertial reference frame.

Since the accelerometer and gimbal angle information is in digital form, it goes directly into the PAC unit that has been constructed as a breadboard model. The PAC stores this information in the 4π CP2 memory on a cycle-stealing basis. The PAC unit also commands an RMU to convert the analog sensor information (i.e., rate gyro signals) to digital words and causes this information to be stored in the 4π CP2 memory.

The 4π CP2 has been programed to perform the guidance and flight control functions and thereby provide control of the vehicle in all phases of flight. This is accomplished by vectoring the engine thrust during powered flight and on-off control of the attitude control engines during coast flight in response to attitude error steering commands.

The required engine actuator displacement or attitude control system status is achieved via the PAC and an ROU. For example, during powered flight, engine actuator displacements are calculated by the 4π CP2. The 4π CP2 then sends an address and the displacement information to the PAC. The PAC decodes the address and causes the proper channel of the proper ROU to convert the digital displacement command to an analog signal to drive the actuator.

The airborne electronics guidance and control system is programed to pilot the booster on a satellite injection mission. The satellite injection mission places multiple payloads into synchronous equatorial orbit. The entire boost mission requires $\sim$6.5 hr. The demonstration of the satellite injection mission consists of simulation of four stages of powered flight, the associated staging sequences, and all phases of attitude control system operation.

Conclusions

The system described exploits the advantages of an all-digital system and permits the tailoring of the electronics to the unique and multifarious problems of a large flexible booster. The system performs the logical computation, data acquisition, and data distribution efficiently and in an optimum mode. Requirement changes can be accomplished in a straightforward, logical, inexpensive manner. This is accomplished by use of the building block concept.

A single hardware system performs a variety of functions through efficient time-sharing of hardware and eliminates equipment duplication. Small changes in requirements can be accommodated by redesign of a small part of the system and not by redesign of major system elements. The concept allows major reconfiguration with little or no redesign or requalification of system elements. This is accomplished without the significant penalty of excess hardware for even the smallest set of requirements.

Galerkin Stress Functions

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STRESS analysis techniques that utilize closed-form solutions of the governing equations, but only approximately satisfy the boundary conditions, are coming into their own in engineering applications as one alternative to the more established finite element and finite-difference techniques. For example, a least-squares point matching method has been applied recently[1] to axisymmetric problems of incompressible solid-propellant rocket charges; a system of two biharmonic Galerkin stress functions was suggested for the extension of the method to star-centered charges, which possess n-fold

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