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Role of Simulation and Emulation in the Development of Shuttle-Centaur (STS-Centaur)

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SUMMARY

The NASA Lewis Research Center has been given the task of integrating the Centaur liquid-fueled upper-stage space vehicle into the Space Shuttle program in time to support the Galileo and International Solar Polar Interplanetary missions in 1986. To support this integration, a system to simulate and emulate the STS-Centaur avionic flight system and its supporting ground control and checkout equipment has been selected. The system has been designated the "systems integration facility" (SIF) and is located at General Dynamics Convair in San Diego, California. The SIF is composed of integrated simulators that form a composite control system complement to the STS-Centaur airborne and avionic support equipment.

The SIF provides an off-line capability to verify the system design of the Centaur airborne support equipment (CASE) and the Centaur avionic flight system. In addition, it provides a realistic medium for the development and integration of ground checkout and airborne control software programs.

Each simulator is composed of prototype hardware, where feasible, to maximize configuration likeness. Where emulated flight or ground hardware is used, it provides physical characteristics (loads, signals, etc.) equivalent to those of the flight hardware. This report describes the hardware and software implementation of the SIF.

INTRODUCTION

Simulation may be defined as the representation of a device or phenomenon by another device or phenomenon in order to achieve some advantage over using the prime object for the purpose intended. The advantage may be economy, timeliness, or ease of observation or measurement.

Simulation and emulation is used for STS-Centaur, broadly speaking,

(1) To study the performance of the STS-Centaur system of devices by allowing wide manipulation of the device characteristics (i.e., an off-line capability to verify the design of the Centaur integrated support system (CISS) and the Centaur avionic flight system)
(2) To quickly solve theoretical functional problems that may require intensive calculations when solved by analytic means
(3) To provide functional ground support and STS-Centaur hardware systems for the development of the computer-controlled launch set (CCLS), the digital control unit (DCU), and the control unit (CU) ground checkout and flight software programs
(4) To analyze the effects of multiple component failures of mission-critical control functions

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To illustrate the use of this method in one of the most modern fields of technical development, this report describes the application of simulation in developing STS-Centaur automatic checkout systems.

This report elaborates on both the design of the simulator system and some of the more important simulation methods used in the systems integration facility. The discussions center on

(1) The development of the SIF
(2) Software simulators and checkout equipment (the CCLS) and their present and future roles in connection with STS-Centaur
(3) The simulators and the SIF laboratory and their roles in the development of the STS-Centaur systems
(4) The types of simulators used in previous Centaur checkout systems (prototype equipment module (PEM) and Atlas electrical missile simulator (AEMS)) and their shortcomings for current STS-Centaur systems

GENERAL

The requirement of the STS-Centaur project to provide realism in the functional exercising of the STS-Centaur space vehicle necessitated the development of the SIF at General Dynamics Convair in San Diego, California. Furthermore, regardless of the type of implementation (analog or digital), the SIF must behave like the planned STS-Centaur system. It also had to be developed early in the design, and before the fabrication, of the STS-Centaur. In parallel with this operation, the ground support equipment was designed, installed, and checked.

ARCHITECTURE

Figure 1 depicts the overall configuration of the SIF and its supporting ground equipment. The SIF is a programmable checkout system capable of emulating the Centaur airborne systems, the combined STS-Centaur systems, and the integrated vehicle checkout, testing, tanking, and launch of the STS-Centaur. The SIF is so designed that after it is used for integrated laboratory testing of the STS-Centaur at General Dynamics Convair in California, the SIF can be transported to Kennedy Space Center, Florida, to verify the operational readiness of the STS-Centaur prelaunch and launch complexes.

Computer-Controlled Launch Set

Control and data-processing functions for the SIF are provided by the CCLS system (fig. 1). The CCLS includes a general-purpose Harris-800 high-speed digital computer with standard peripheral devices and specialized input and output devices for communication with the STS-Centaur or the SIF and other elements. The Harris-800 computer has three main sections:

(1) The memory section provides fast-access storage for data and instructions.

(2) The arithmetic and control section performs arithmetic logic and shifting operations. The control portion contains the necessary logic for controlling and sequencing the events that occur in the computer.

(3) The input and output section contains the logic for instructing external devices; scanning for external interrupts; and communicating with the operator's console, the telemetry station, the mobile support equipment (MSE), and the airborne digital computer. All data enter and leave the CCLS via the local digital interface equipment (LDIE) and the remote digital interface equipment (RDIE), which interface the CCLS with the outside world. The RDIE is used on Complex 36 for launching Atlas-Centaur vehicles. It plays no role in the STS-Centaur systems. The LDIE is used for both Atlas-Centaur and STS-Centaur. Both DIE's are current-technology equipment, and no major changes are scheduled for them.

The MSE is a mobile interface between the CCLS and the STS-Centaur vehicle and its associated ground support equipment. Housed within the MSE are the hardware extension remote (HER), the terminal distribution system, and the communication electronics. The HER provides the remote interface to the CCLS and thus allows the CCLS to communicate to and monitor Centaur and CISS flight hardware and associated launch ground support equipment (GSE). The HER is composed of two remote interface controllers (RIC), prime and backup; two Harris-100 computers; and an analogic data acquisition system. The RIC controls and monitors the launch and checks out the hardware interfaces. The terminal distribution system provides the electrical and communication links between the Centaur, the CISS, and the tanking skids. The major interfaces of the CCLS are depicted in figure 2.

CCLS Software

The CCLS software consists of a resident (executive) program, tenant programs, and non-time-sharing programs (fig. 1). The tenant programs are of two categories: CCLS system programs and airborne system programs. The CCLS system programs support the operation and maintenance of the CCLS hardware and software independently of any external ground support equipment or airborne system. The airborne system programs initiate and verify the flight readiness of the airborne systems hardware and software. Airborne system programs also control external ground support equipment in support of launch countdown procedures. The CCLS can execute eight tenant programs simultaneously at the operator console stations.

The CCLS that currently supports Atlas-Centaur missions is being phased out. It consists of a Harris/4 computer system with standard peripherals and specialized input/output units. Supporting both Atlas-Centaur and STS-Centaur missions requires the handling of approximately 40 percent more CCLS software tasks. This requirement preempted the use of the current CCLS (Harris/4 - memory restraint) and necessitated its replacement. To conserve time and cost, the Centaur project decided to use the Harris-800 computer because of the ease of moving and translating current software from one Harris system to another.

SIF OVERVIEW

In designing the SIF the combined airborne systems and the operations were first analyzed to identify all of the individual functions necessary to verify STS-Centaur launch readiness. Not only was each item of ground support equipment necessary for the checkout and launch of the STS-Centaur avionic flight systems identified, but each item was also associated with the applicable countdown activity and the functional testing of airborne systems. Then each item was reviewed in detail to determine its purpose (use of prototype flight hardware or emulation), its required input and output, its general operating modes, its components, and its relation to other items. This was accomplished by analyzing functional requirement documents (FRD's), which provided functional descriptions of the equipment. From these sources and engineering analysis, functional and specification requirements were prepared for the SIF and its associated ground support equipment to clarify the relations between the elements of the airborne systems and the launch support equipment and among the components of each element.

SIF - GENERAL DESCRIPTION

The STS-Centaur presents an entirely different picture of the role of simulation. With the advent of automatic checkout systems and the use of digital computers, telemetry data can be used as an integral part of the checkout. This is particularly true of the STS-Centaur, where multiple interfaces (spacecraft, Centaur, Orbiter, etc.) are involved. The use of pulse code modulation (PCM) data interleavers has radically reduced the number of signals (particularly analog signals) that must be hard-wired out of the stages. Thus the checkout of the digital acquisition system has become an integral part of the overall checkout and is a prerequisite for the operation of the CCLS-SIF system. Any simulator that is to verify the functional integrity of the flight systems and their checkout procedures and programs must supply a telemetry (digital data acquisition system) link to the checkout system. Furthermore parameter values transmitted over this link must be responsive to hard-line commands from the checkout system.

The most difficult tests to develop for the STS-Centaur stages are the propulsion subsystem tests and the overall simulated tanking functions - not only in the factory checkout, but also in verifying launch complex readiness. In these tests and simulations there is a direct interaction between the facility supplies and the vehicles. The control and regulation of the facility supplies require considerable development. The operation of the facility supplies presents a higher degree of danger to equipment and personnel than pure electrical tests. The danger is magnified when cryogenic loading is required. Therefore, for STS-Centaur, development effort (simulation/emulation) and analysis has been concentrated on controlling these systems and providing the appropriate safety functions (CASE). This area is one of the main deficiencies in the current Atlas-Centaur (PEM-AEMS) simulators; that is, they are deficient in simulating the interaction of the launch complex facilities and the vehicles for checkout at the factory, except for manual inputs at the test set to simulate certain vehicle responses. Because of the large number of unknowns the Centaur project has required the facility and the vehicles to be simulated in such a way that prelaunch, launch, and flight checkout programs are developed before the actual operations.

SIMULATORS

The major interfaces of the SIF are illustrated in figure 3. The major hardware elements are the prototype Centaur vehicle, the Shuttle-peculiar stage portions, and the ground support equipment. Because the STS-Centaur simulators are rack-mounted prototype avionic hardware modules and electrical simulation assemblies, they are easily transportable.

Flight article connectors and harness assemblies are used for interfacing the modules. A simulated hardware module is designed to provide equivalent physical characteristics of a specific item of flight or ground support hardware. For example, simulation of fluid, mechanical, and electromechanical systems is designed to provide equivalent source and loading characteristics of the monitor and control signals (i.e., true signal delay times). In automatic checkout systems involving simulated and emulated hardware the timing of responses to commands takes on additional significance. For example, if relays are employed to simulate vehicle valves, the response characteristics are considerably different from the actual valve operation. In a computer-controlled system such a difference is not allowable if valid (realistic) procedures and programs are to be developed. Experience has shown that a major area of test programming requiring modification is timing between commands and their responses or between commands and other commands. In the SIF each simulator contains the necessary timing and control logic to monitor the status of all inputs. The control circuitry uses these input statuses to generate functionally equivalent digital and analog-timed response signals.

Sandwich boxes are provided at the avionic module interface connectors for fault insertion. Fault insertion for fluid system simulation (i.e., tanking and tanking skid operations) is done by the microprocessor controller software, which provides erratic transducer responses to simulate the results of failed valves or transducers.

Simulation is used to analyze the effects of multiple component failures and worst-case time-phase asynchrony for mission-critical control functions. Simulation provides a tool whereby the integrity of the control safety design is demonstrated. This aspect of simulation is required to meet the dual-failure-tolerant redundancy imposed by the Space Shuttle program (i.e., verification of the control concept for both flight hardware and imbedded software). Dual-failure tolerance refers to avionic controls that, after two control units are lost, leave <u>at least</u> one subsystem branch still in control. (The control units are five autonomous Z-80 microprocessors located in the CISS.) All safety-related vehicle functions are under the control of the Centaur airborne support equipment (CASE)[1] during prelaunch, ascent, on-orbit, and abort operations until separation. The simulation of CASE includes a detailed operation of its safety-related control subsystem.

The Centaur liquid-oxygen and liquid-hydrogen tanks are also simulated systems. The tanking simulators are the electrical equivalent of the Centaur tanking functions and associated monitor element responses. They are controlled by accepting tank fill, pressurization, vent, drain, and dump commands from the CCLS, the Orbiter, or the Centaur and CISS simulators. The tanking skid simulator, an electrical equivalent of the helium, liquid-oxygen, and liquid-hydrogen tanking skids, provides equivalent valve load

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[1] CASE is composed of the CISS avionic systems (i.e., those electronic and electrical items associated with the control of all safety functions related to the Centaur vehicle as long as it resides in the Shuttle cargo bay). CASE avionics are located on the CISS equipment shelf in the Shuttle cargo bay.

characteristics and analog equivalents of transducers and sensors. The simulator software is used to simulate the active environmental control of the Centaur and the tanking skids. The Z-80 microprocessor simulation assembly receives conditioned valve status discretes from the Centaur and CISS simulators and outputs simulated pressure transducer responses based on the incoming valve status information under CCLS control.

SIMULATOR DESCRIPTIONS

The following discussions highlight some of the system functions and, where appropriate, emphasize the driving requirements.

Centaur Simulator

The Centaur simulator provides the fluid, mechnical, electromechanical, and pneumatic monitor and control functions. Prototype hardware is used and consists of the digital computer unit (DCU), the inertial reference unit (IRU), the systems electronics unit (SEU), the servo inverter unit (SIU), the remote multiplexer unit (RMU), the signal-conditioning unit, telemetry, the tracking and command subsystem, the star scanner, the dual-failure-tolerant arming sequencer (DUFTAS), the engine actuators, and the servopositioners.

Simulation electronic assemblies are provided for the star scanner, the battery system, the solenoid and pyrotechnic valves, the hydraulic system, and the propellant tank and level-indicating systems. Figure 4 is a block diagram of the Centaur simulator interfaces. The star scanner simulator (fig. 5) provides the Centaur simulator with digital star coincidence signals and analog star magnitude and video threshold outputs. The Centaur simulator in turn transmits digital video threshold commands and self-test commands to the star scanner simulator. These signals are used to update the guidance system on the Centaur simulator.

The tanking simulator (fig. 6) receives from the Centaur simulator valve assembly conditioned valve discretes that represent the active and inactive states of the valves. The Centaur simulator, in turn, receives simulated transducer outputs from the tanking simulator. The fluid systems (CISS and Centaur) are simulated by a Z-80 microprocessor assembly that receives the conditioned valve status discretes from the Centaur and CISS simulators. The Z-80 outputs simulated pressure transducer responses based on the incoming valve status information. The microprocessor reads the input status words and performs the necessary software tasks (table lookup, matrix manipulation, etc.) to define the associated pressure transducer responses. These digital words (representing the transducer's response to the input conditions) are then sent to the appropriate digital-to-analog converter which outputs a dc analog signal to its particular monitor and control element (e.g., Centaur DCU or CISS control units). The tanking simulator is controlled by accepting tank fill, pressurization, vent, drain, and dump commands from the CCLS, the Orbiter, the launch processing station (LPS), the Centaur sequence control unit (SCU), or the CISS control distribution unit (CDU). One-hundred and twenty simulated valve loads can be driven from the CISS and Centaur valve simulation assemblies, and 48 individual simuated transducer outputs can be monitored by the CISS CU's, the RMU's, the Centaur DCU, and the Orbiter multiplexer-demultiplexer (MDM).

Auxiliary tanking simulation programs (tanking scenarios) and real-time control commands can be received from the CCLS HER by the uplink (serial data uplink and downlink (PCM)) interface from the mobile support equipment.

The pyrotechnics on the Centaur are also simulated, and their actuation states are displayed. The command discretes to the tanking simulator's emulated solenoids and pyrotechnics provide a closed-loop simulation. Excitation state feedback is also provided to the tanking simulator microprocessor's interface input and output unit. Figure 7 is a typical diagram of an emulated solenoid valve used for simulation.

The tanking skid simulator (fig. 8) is a single bay of rack-mounted prototype and simulation chassis assemblies. This simulator is controlled by the commands from the mobile support equipment. It electrically simulates the tanking skid's pneumatic and solenoid valves, pressure and temperature transducers, current-to-pressure converters, and valve-positioning signals. It contains three prototype skid control panels for liquid oxygen, liquid hydrogen, and helium that interface to the skid simulator. The skid simulator receives analog and conditioned discrete valve command signals from the three skid control panels. The skid simulator then synthesizes the feedback responses of the transducers, the sensors, and the valve status signals. These output responses are retransmitted back to the CCLS hardware extension remote through the skid control panels. Through the uplink-downlink interface the skid simulator can receive auxiliary simulation scenarios or real-time control capability from the CCLS hardware extension remote.

The simulations of the propellant level indication system (PLIS) probes and the overfill sensors for the liquid-oxygen and liquid-hydrogen tanks are independent of the probes during the tanking simulation scenarios. A sandwich box at the interface between the propellant level indication unit (PLIU) and the RMU and CU in the CISS simulator provides jumper access for the simulated analog and discrete quantity status signals originating from the tanking simulator - simulating the PLIU outputs respective to tank quantity status. The analog status signals and overfill discretes are controlled by the tanking simulator's microprocessor. The capacitive fill probes and resistive overfill probes that interface with the PLIU are simulated systems. A sandwich box at the Centaur simulator's SIU-RMU interconnect provides analog signals for the liquid-oxygen and liquid-hydrogen quantity status during simulated tanking. These analog signals simulate the propellant utilization system (PU) probes from the tanking simulator and are jumpered to provide the analog status to Centaur's RMU. The signals are controlled by the tanking simulator microprocessor.

The deployment simulator (fig. 9) electrically emulates the deployment adapter mechanism's monitor and control signals. It is electrically equivalent to the motor and clutch loads of the deployment adapter flight hardware. It samples the three phases of ac power, determines the direction of rotation, and generates discrete signals representing fully deployed or fully stowed and an analog signal for midrotation positioning information. Upon activation of the deployment power switching system, all control and monitor signals are emulated in real time and transmitted to the respective control units in the CISS simulator. The entire deployment procedure is a sequenced event begun by redundant command discretes to the CISS simulator control units from a switch panel in the Orbiter interface emulator panel. Full deployment is achieved in 600 seconds. Rotation direction is determined by attenuating and shaping the input ac phases into transistor-transistor logic (TTL) level pulses. The three-phase pulses are inputs to a control circuitry that determines rotation direction and outputs these numbered redundant position discretes to the control units in the CISS simulator. The position discretes verify the control interface between the deployment control and the control units. When the control units receive the full deploy position discretes, they begin to cut off the rotation mechanism (simulated) motor.

The Orbiter simulator (fig. 10) simulates the avionic interface from the Centaur cargo element to the Orbiter. Flight service functions provided by the Orbiter are simulated as follows:

(1) Telemetry and data services to monitor the status of the Centaur cargo element in the attached and detached modes
(2) Command interface for controlling on-orbit deployment functions
(3) Displays and controls for crew status monitoring and safety functions
(4) Power and cable interfaces

The Orbiter simulator (interface emulator) also provides the necessary command and control signals as well as measuring and monitoring capability to perform parametric testing of selected interface signals with auxiliary laboratory equipment.

The remainder of this section focuses on the role of the control units in the CISS simulator in order to highlight the Centaur airborne support equipment (CASE), which controls all Centaur and CASE safety-critical systems. The CISS simulator (fig. 11) is a rack-mounted prototype and preflight simulation of the actual flight article. The functional prototype modules that make up the CISS are the signal-conditioning unit, the digital control unit (DCU), the control units (CU), the remote multiplexer units (RMU), the electrical distribution unit (EDU), the propellant level indicating unit (PLIU), the pryo initiator controller (PIC), and the control distribution units (CDU). Simulation assemblies are provided for the Centaur development system and for the fluid and electrical systems.

Data uplink and PCM downlink lines between the CCLS mobile support equipment and the Centaur DCU, the CISS, the control units, and the CISS DCU pass through the CISS simulator's EDU for isolation and lightning protection. The CISS has a separate PCM downlink to the PCM interface rack in the mobile support equipment. The control units shift the CISS data into the DCU, which encodes them into a PCM signal for transmission over the PCM link. The hardware extension remote (HER), resident in the mobile support equipment, transmits (uplink) five redundant sets of serial data to each of the five control units and an independent serial uplink to the CISS simulator's DCU. In addition, the CISS simulator has another PCM data link from its DCU to the payload data interleaver in the Orbiter simulator.

The CISS simulator contains five independently operating control units (Z-80 microprocessors). Their interconnecting harness forms the voting plane to control the loads, the pneumatic and fluid control systems, and the Centaur tanks. Operation includes all normal and backup control strings and covers all modes of preflight and flight. (Fig. 12 is a block diagram of the safety control functions.) The CISS simulator actively controls Centaur while it is in the Shuttle cargo bay and provides a dual-fault-tolerant control of all safety-critical functions.

Control Unit Methodology

The CU control system, in general, bases its control response on the "end function" result. The end function is a significant subsystem measurement that is supplied to the five independent control units as a basis for determining further control action. To begin a control action requires that the five control units vote, thus affecting the end function result. For example, the venting and pressurization subsystems of the Centaur propellant tanks are based on tank pressures and not on downstream individual component measurements. This reduces feedback while maintaining high reliability. Each control unit executes and outputs a majority rate that forms a plane of control for the load. This enables compliance with the requirement to maintain control after sustaining two component failures. Relay networks are used to produce a three-out-of-five vote to supply power to activate the loads. To complement the electronics, the fluid systems are structured by using series and parallel combinations to complete the double-fault-tolerant systems (DUFTAS).

To implement the DUFTAS concept, two basic relay networks are used to command the intended function when a component or system fails. These networks positively control the load to be on when commanded "on" and "off" when commanded off. One type of network allows one failure to occur (single-fault tolerant). The second type of network allows two failures to occur (dual-fault tolerant). These networks are wired between control units and are terminated in the CDU for load isolation.

Command decision measurements are spread across all CU's to maintain the fault tolerance of the system. Certain critical measurements (e.g., analog pressure transducer readings) are cross-strapped among the control units. There are several discrete control signals into the control units: Orbiter can command abort functions or self-test functions, and ground control (i.e., CCLS) can command abort or checkout functions.

The functional operations of all control units are identical. Each operates on a timed update cycle. At the beginning of each cycle the control units read their respective sensor input measurements and discrete command inputs. Each determines its independent course of action by calculating end function trigger points or function sequences with respect to the current mode of flight (or simulated flight). The desired state of each function is correlated to the state of the necessary switching relays. The relays are updated in banks, with the priority function relays in the first banks. The control unit then performs housekeeping tasks until the top of the next cycle.

CISS Centaur Airborne Support Equipment

During ground checkout tests CISS CASE is responsible for safe control of Centaur. All test functions are begun and controlled by the CCLS. The test objective of the systems integration facility, in a sense, is to exercise the primary and secondary subsystem functions necessary for developing control unit software operational modes and the CCLS test programs. The simulations in normal operation will exercise all of their checkout functions. The simulated tests include the CCLS interface and those ground checkout functions necessary for the performance of all of the interrelated systems and subsystems.

Current Atlas-Centaur Simulators

The PEM-AEMS simulators that are used to verify the CCLS operating programs for current Atlas-Centaur launches are in many ways similar to the SIF. These simulators are designed such that the flight avionic systems would respond to inputs in much the same manner as the Atlas-Centaur under test (i.e., the PEM and AEMS both use prototype flight avionic hardware). Manual operations, however, are provided for where the output is a direct result of a nonelectrical input (e.g., pneumatic, hydraulic, or tanking systems). These simulators are designed chiefly to verify and check out the combined Atlas and Centaur avionic systems using CCLS operational programs. In certain cases, time-delay circuits are used within the PEM-AEMS configuration to allow checkout of interlocking or sequencing circuitry between the combined vehicles and the spacecraft interface.

With the advent of STS-Centaur, this type of simulation became invalid because of the following shortcomings:

(1) Lack of simulation of facility-vehicle interaction
(2) Lack of timing response characteristics
(3) Lack of exercising safety-related functions
(4) Lack of simulating fault conditions or scenarios
(5) Lack of providing Centaur liquid-oxygen and liquid-hydrogen tanking characteristics

CONCLUSIONS

A more realistic simulator-emulator system was needed for STS-Centaur than was available at the outset of the STS-Centaur program. This need was satisfied by the development of the computer-controlled launch set (CCLS) and the system integration facility (SIF) described in this report. The CCLS-SIF costs less than the simulators presently used to support the Atlas-Centaur missions. It can realistically simulate the type of operations (preflight and flight) required of the STS-Centaur and enhances the readiness of combined vehicle operation before actual flight.

Past experience with the prototype equipment module - Atlas electrical missile simulator - computer-controlled launch set (PEM-AEMS-CCLS) simulation approach and its shortcomings led to consideration of a more sophisticated type of simulation. The simulation considered for the SIF provides a high degree of verification as a hardware simulator and eliminates the additional burden on the design of software simulation and modeling language programmers. The emulators were designed from test design information and specifications independently of the test requirements or test programs. They were designed to run in real time much the same as the actual hardware would. This was accomplished by designing the CCLS-SIF computer program such that it actually emulates the systems and subsystems within the missile stages. In its most complete form the SIF simulates all of the interactions between the various subsystems and responds not only to correct inputs but also to incorrect inputs in the same way the missile stages would. To provide this capability, the representation of the subsystem, or parts thereof, must do more than merely provide an overall transfer function for expected sequences of input. For example, if the missile's bus voltage is low (by design or error), the subsystems should react to this low voltage and provide appropriate deviations in its output.

Advantages

Past experience has indicated that using simulated and emulated hardware in developing missile airborne hardware, ground checkout systems, and their associated operating procedures is cheaper than a computer modeling-simulating system. It is also more timely since the simulation can be developed before manufacturing of the stages is completed. Measurement and observation is easier since special capabilities can be built into the simulation equipment for those purposes. The advantages of simulated and emulated hardware and of software modeling techniques are compared in the following table:

Simulation or emulation method	Software modeling method
No simplifying assumptions are necesary if tests are run on an actual system. The true behavior of the system is revealed. Accurate measurements are necessary to give a true picture. Test and launch procedures and associated computer programs are debugged at the factory before usage at the launch site. The time required for design, construction, and debugging of hardware is reduced.	Results usually are of general use rather than for restricted application. Simplifying assumptions are required. Thus, not the actual physical system but a simplified "mathematical model" of the system is studied. Theoretically predicted behavior could be different from actual behavior. This method is used for experimental studies since adequate theories or knowledge may not be available. This method can lead to complicated software problems. Long time delays may be engendered in building modules and in assembling, checking, debugging, and gathering data.

To date, few simulated and emulated systems are in use and the "prime systems" being studied are less complex than space systems. However, as these systems become more complex (e.g., to simulate nuclear powerplants, NASA's future space station, and new energy technology), they will take on many characteristics of the SIF system described in this report. Clearly the degree of automation used is directly proportional to the degree of similarity required between prime and simulator equipment. As automatic systems become more sophisticated, so must the simulation used.

APPENDIX - ABBREVIATIONS AND ACRONYMS

AEMS	Atlas electrical missile simulator
CASE	Centaur airborne support equipment
CCLS	computer-controlled launch set
CDU	control distribution unit
CISS	Centaur integrated support system
CPU	central processing unit
CRT	cathode ray tube
CU	control unit
CWEA	caution and warning electronics assembly
DCU	digital control unit
DMA	direct memory access
DUFTAS	dual-failure-tolerant arming sequencer
EDU	electrical distribution unit
FRD	functional requirement document
GSE	gound support equipment
HER	hardware extension remote
IRU	inertial reference unit
LCC	launch control center
LDIE	local digital interface equipment
LPS	launch processing station
MDM	multiplexer-demultiplexer
MDS	microprocessor development station
MSE	mobile support equipment
OTC	out-of-tolerance condition
PCM	pulse code modulation
PDI	payload data interleaver
PEM	prototype equipment module
PI	payload interrogator
PIC	pyro initiator controller
PLIS	propellant loading indicating system
PLIU	propellant level indicating unit
PSP	propellant signal processor
PU	propellant utilization system
RDIE	remote digital interface equipment
RIC	remote interface controller
RMU	remote multiplexer unit
SCU	sequence control unit
SEU	system electronics unit
SIF	systems integration facility
SIU	servo inverter unit
TTL	transistor-transistor logic
VPF	vertical processing facility
XDCR	transducer

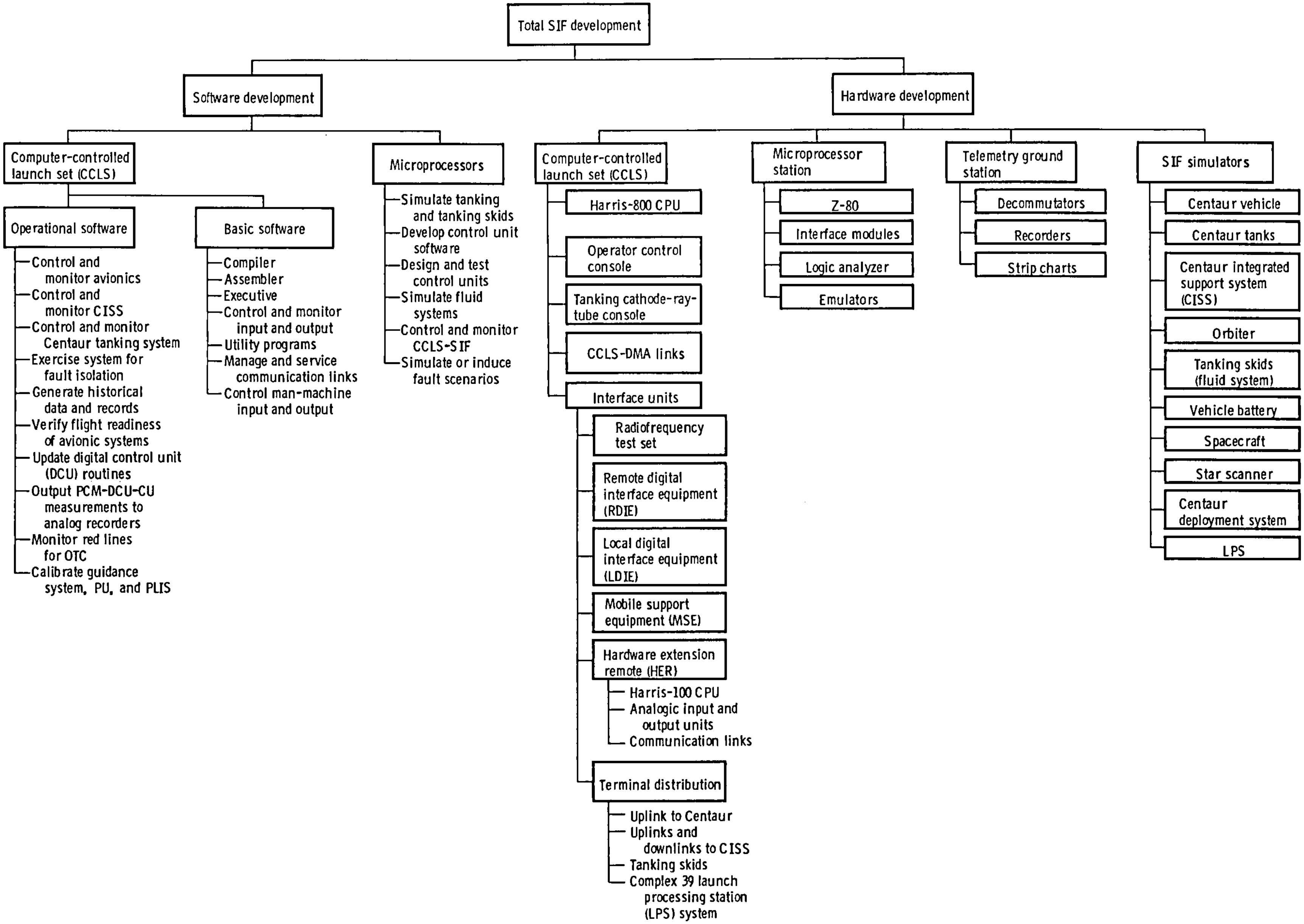

Figure 1. - Overall configuration of systems integration facility and ground equipment.

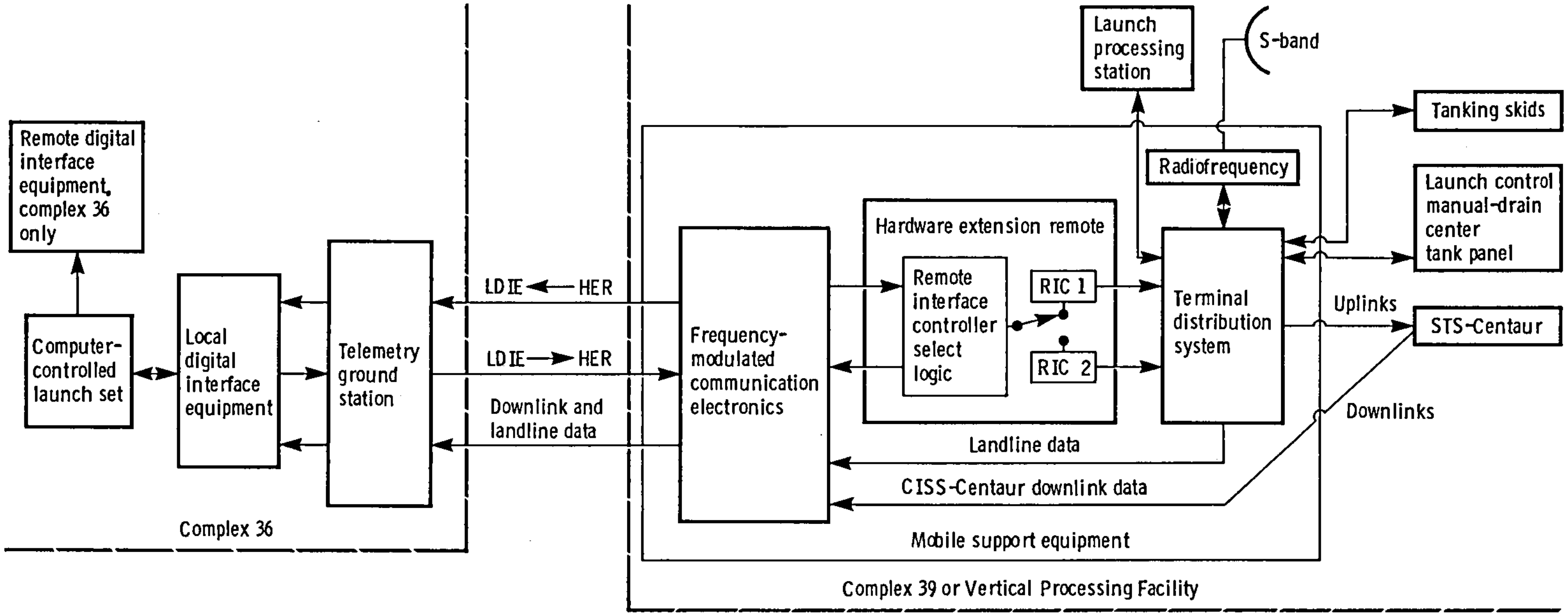

Figure 2. - Computer-controlled launch set interfaces.

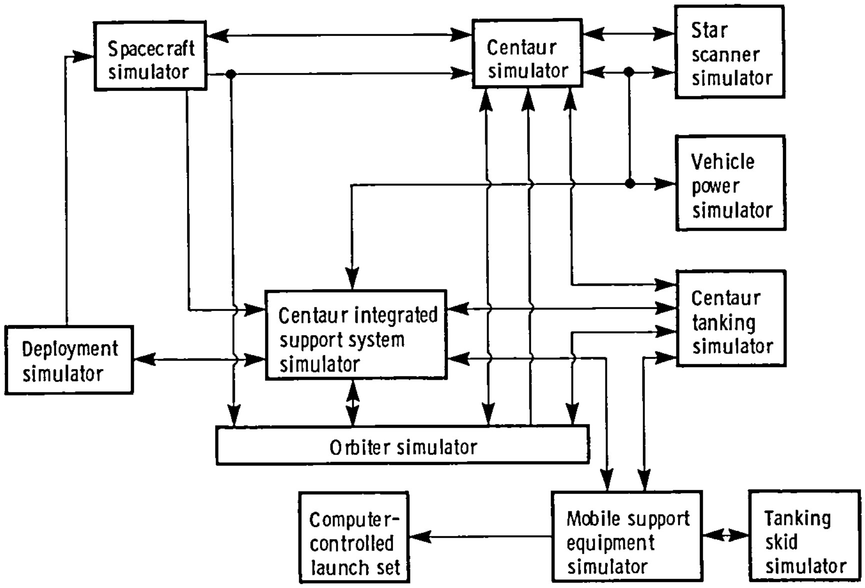

Figure 3. - Systems integration facility major interfaces.

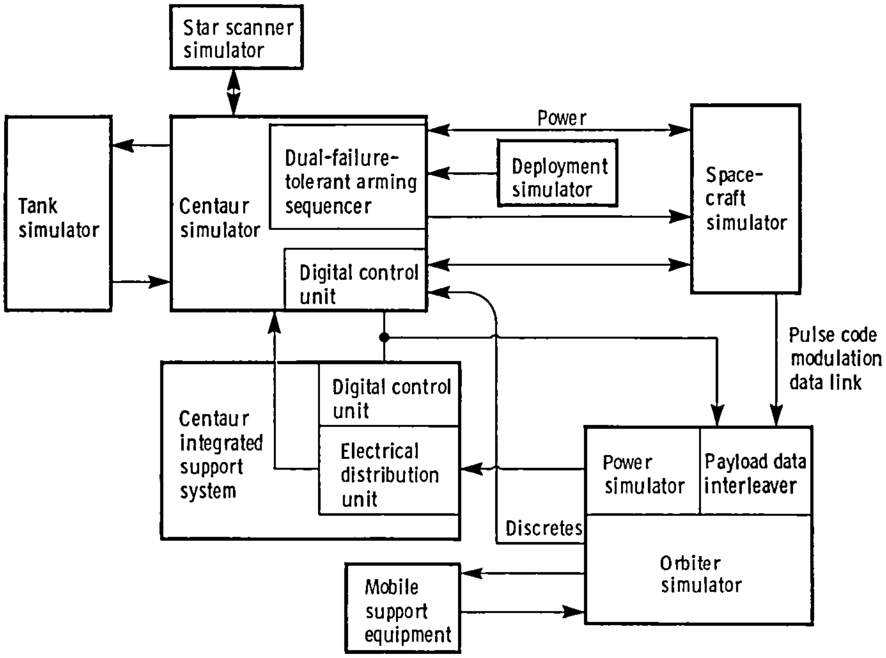

Figure 4. - Centaur simulator interfaces.

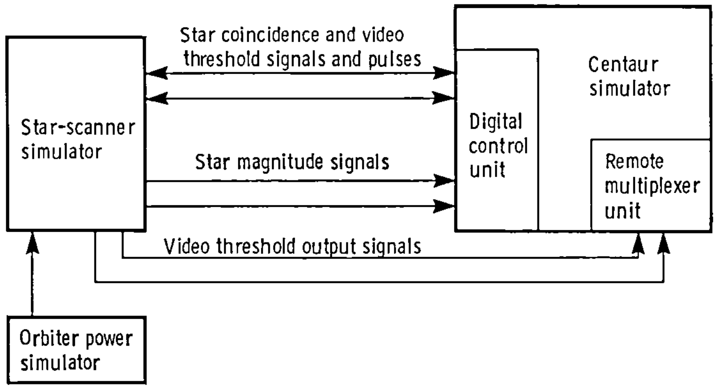

Figure 5. - Star scanner simulator interfaces.

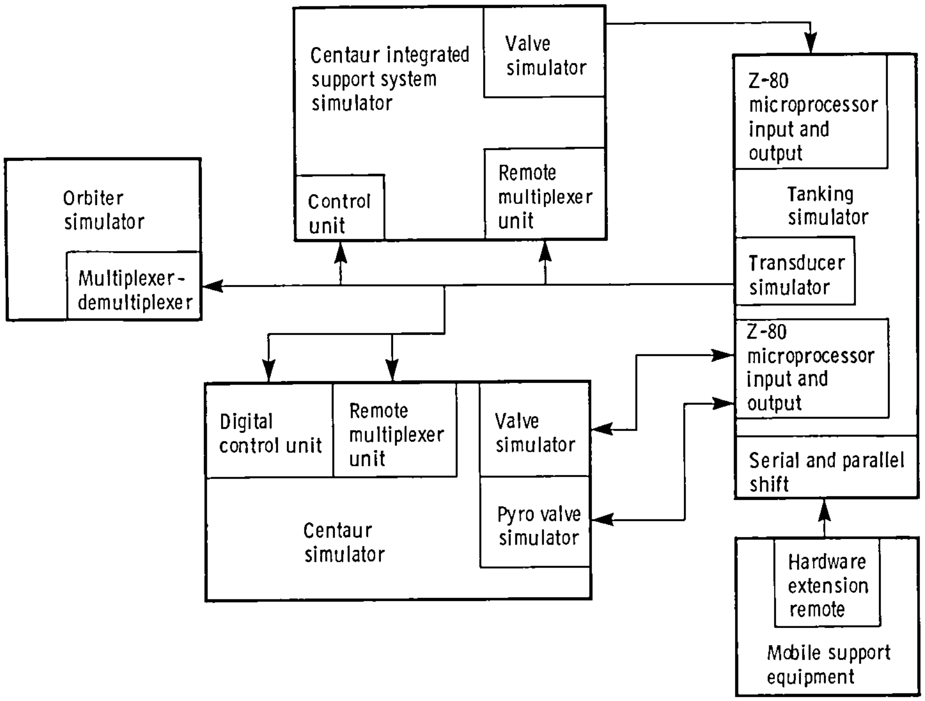

Figure 6. - Tanking simulator interfaces.

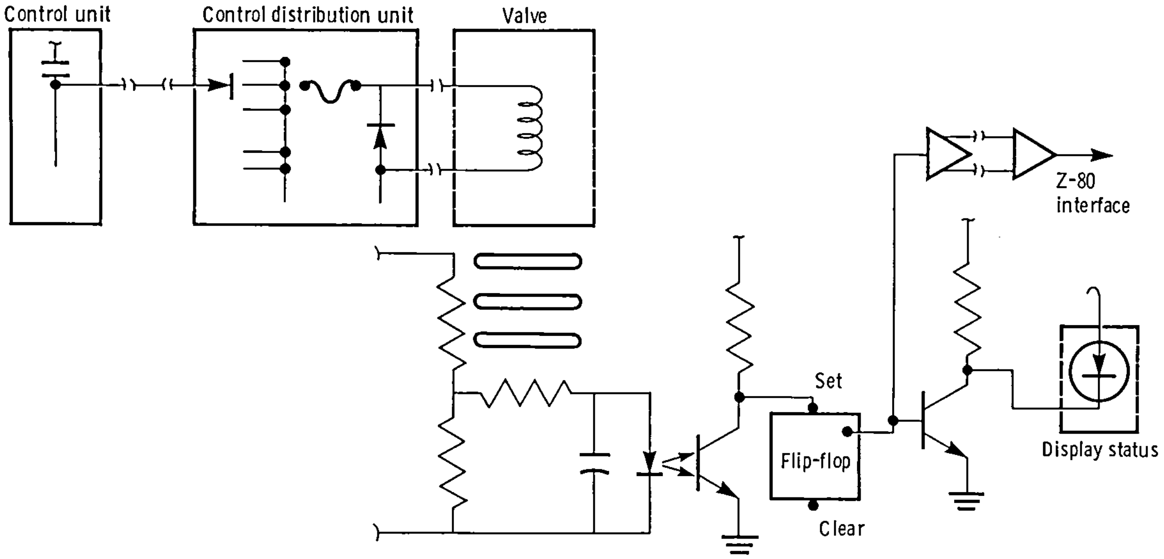

Figure 7. - Load emulation solenoid valve.

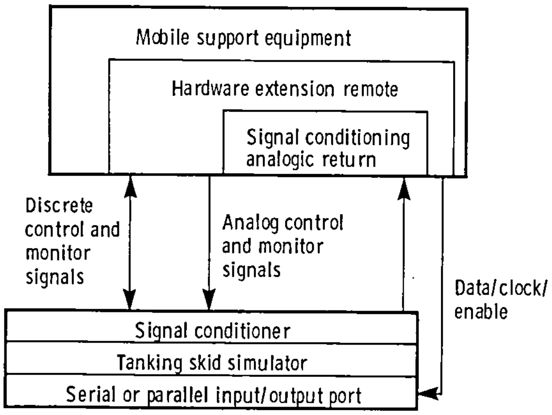

Figure 8. - Tanking skid simulator interface.

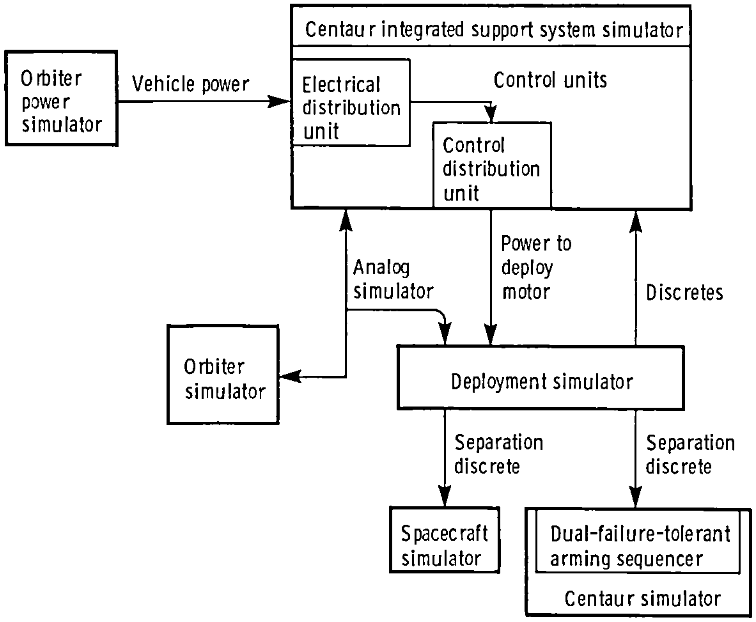

Figure 9. - Deployment simulator interfaces.

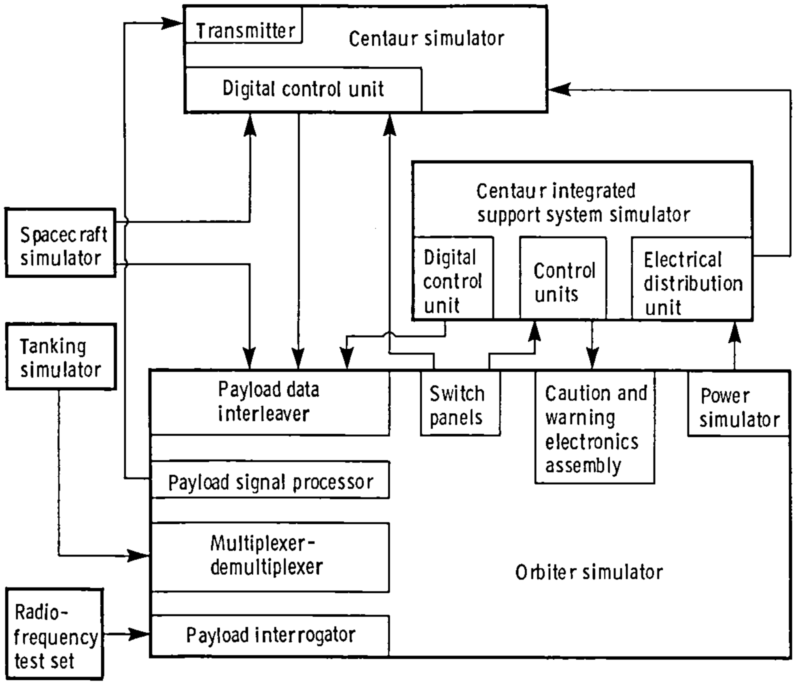

Figure 10. - Orbiter simulator interfaces.

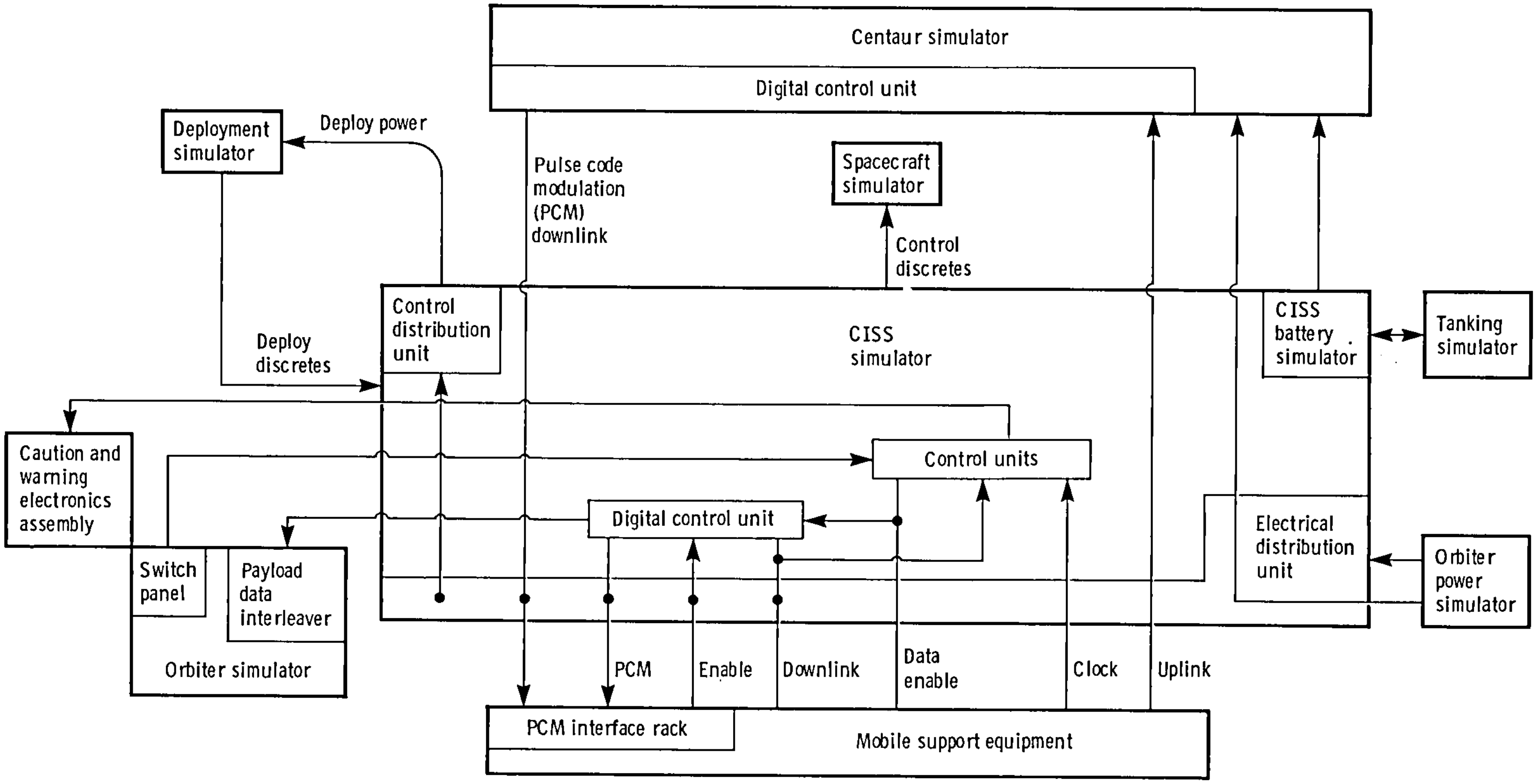

Figure 11. - Centaur integrated support system (CISS) simulator interfaces.

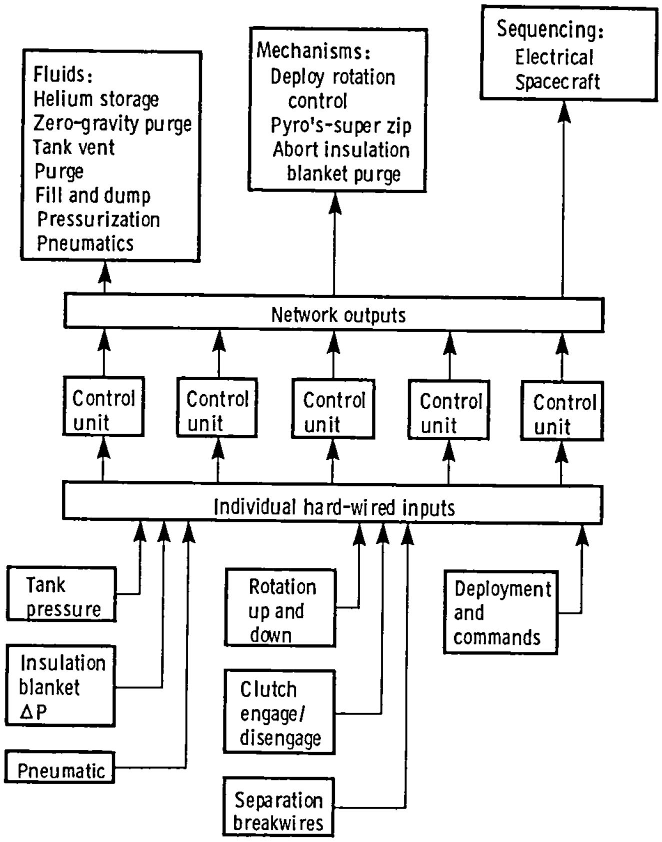

Figure 12. - Control unit flight safety control functions.

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16. Abstract

The NASA Lewis Research Center has been given the task of integrating the Centaur liquid-fueled upper-stage space vehicle into the Space Shuttle program in time to support the Galileo and International Solar Polar Interplanetary missions in 1986. To support this integration, a system to simulate and emulate the STS-Centaur avionic flight system and its supporting ground control and checkout equipment has been selected. The system has been designated the "systems integration facility" (SIF) and is located at General Dynamics Convair in San Diego, California. The SIF is composed of integrated simulators that form a composite control system complement to the STS-Centaur airborne and avionic support equipment. The SIF provides an off-line capability to verify the system design of the Centaur airborne support equipment (CASE) and the Centaur avionic flight system. In addition, it provides a realistic medium for the development and integration of ground checkout and airborne control software programs. Each simulator is composed of prototype hardware, where feasible, to maximize configuration likeness. Where emulated flight or ground hardware is used, it provides physical characteristics (loads, signals, etc.) equivalent to those of the flight hardware. This report describes the hardware and software implementation of the SIF.

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