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Vandenberg Ground Support Equipment for the Space Shuttle

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This paper conveys knowledge gained from the Shuttle ground support equipment (GSE) installation at Kennedy Space Center and will also serve as a ready reference for anyone involved with Vandenberg Shuttle GSE. Mechanical and electrical Vandenberg Shuttle GSE systems are discussed, along with ground testing and prelaunch flight simulation.

Introduction

THE emergence of the "reusable" Space Shuttle as the primary U.S. space transportation system brings attention to its complex ground support equipment (GSE). GSE plays a vital role in both NASA and Air Force Space Shuttle operations.

The Shuttle consists of the manned orbiter with payload bay, the external tank (ET), which contains fuel for the orbiter engines, and two solid rocket boosters (SRB's) that, with the orbiter engines, launch the system. Figure 1 depicts the Shuttle configuration and lists major contractors. The Space Shuttle is the U.S. space transportation system of the future, designed to serve both civil and defense users. It will carry a crew of three, plus four experimenters or mission controllers, and will support a wide variety of missions.

Mission Profile

The Shuttle follows basic flight sequences from launch to landing. During a normal ascent, the solid rocket boosters and orbiter main propulsion subsystem fire together until the SRB's are depleted and jettisoned after approximately 2 min. The SRB's parachute into the sea and are refurbished and reused. The fuel in the ET is exhausted after about 8 min. The main engines are shut down, and the external tank is jettisoned. The orbital maneuvering system is then used for orbital insertion and to circularize the orbit. Orbital maneuvering system engine firings vary with the mission profile.

After Earth orbit operations are complete, the orbital maneuvering system is used again for deorbit burn, to begin a normal descent. The orbiter coasts for about 30 min before atmospheric entry. Approximately another 30 min places the orbiter on the runway, having transitioned through several guidance phases and having performed the required landing maneuvers. The orbiter makes a deadstick landing like a glider, and does not have a go-around capability.[1]

Ground Operations and Station Sets

For the most desirable combination of azimuth and orbital inclinations, the Space Shuttle will be launched and recovered from both Kennedy Space Center and Vandenberg Air Force Base. Shuttle ground support equipment (GSE) will perform the same basic functions at both locations and will be similar in design and configuration. Differences are due to mission and geography variations and cost effectiveness requirements.

GSE design at Kennedy Space Center makes maximum use of existing equipment, originally used for the manned spaceflight programs Apollo and Skylab.

GSE design at Vandenberg Air Force Base makes maximum use of existing equipment, some of which was originally intended for the Manned Orbiting Laboratory Program.

Shuttle GSE is the equipment necessary to receive, process, and launch the Shuttle and retrieve reusable elements and components. The Vandenberg GSE must achieve turnaround processing and launch pad turnaround times specified for Vandenberg and, where possible, uses GSE designs and procedures developed at Kennedy Space Center.

Nearly 900 items of GSE will be common to both Kennedy Space Center and Vandenberg. GSE development costs at Vandenberg were reduced by using work already done at Kennedy Space Center. However, there are Vandenberg-unique elements which require development. Original design guidelines will still apply—i.e., that no single failure point should be allowed that will result in loss of life, loss of the Space Shuttle vehicle, or loss of a vehicle system. Also, Kennedy Space Center personnel are maintaining cognizance of the Vandenberg development effort.

GSE at Vandenberg and Kennedy Space Center is separated into station "sets" of equipment. Vandenberg geographic station sets, each of which has a specific purpose and location, are shown in Fig. 2.

In this paper, Vandenberg station sets of equipment are discussed separately in the order in which Shuttle system components are processed. Many GSE systems are common to several station sets and are classified as follows: miscellaneous, mechanical, electromechanical, cryogenic, hypergolic, and electrical.

North Vandenberg Shuttle Operations Functional Flow

Figure 3 displays the ground operations flow of the Shuttle elements through the Vandenberg station sets of GSE.[1] The following discussion summarizes the functions of each station set.

Landing Field Station Set

The orbiter will arrive at the landing field station set either via a modified Boeing 747 (Shuttle carrier aircraft) or returning from orbit. The landing facility will consist of a 15,000-ft runway and a high intensity approach lighting system with edge, threshold, and centerline lights. The microwave scanning beam landing system will transmit accurate directional information to the orbiter. As soon as the hot orbiter returns from a mission and rolls to a stop, emergency equipment is positioned around the vehicle and two cooling convoys are connected.

Early Missions

During early Shuttle missions, the orbiter with cooling

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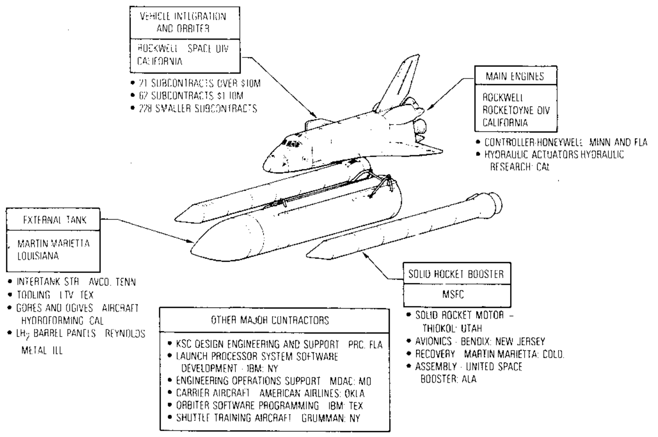

Fig. 1 Shuttle configuration and major contractors.

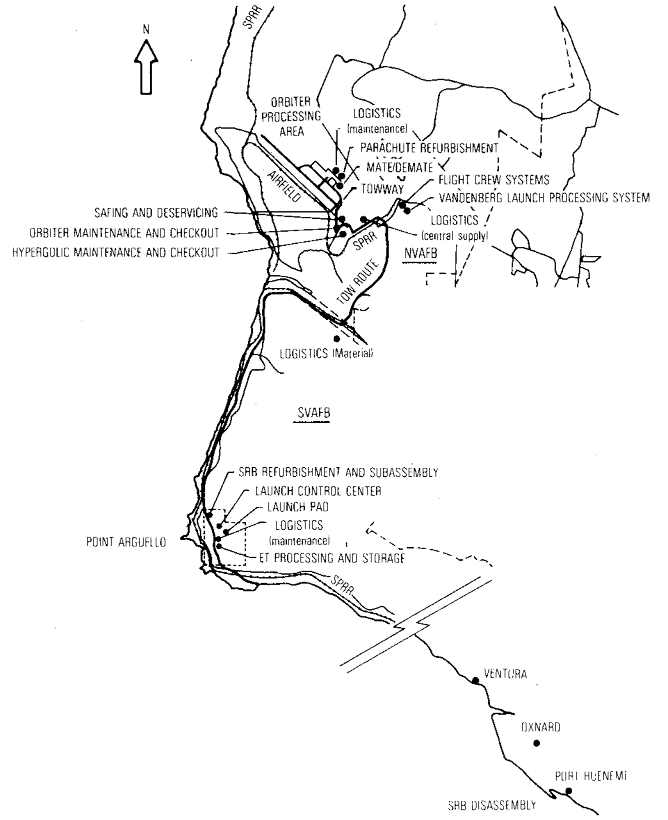

Fig. 2 Vandenberg station set geographic locations.

convoys will be towed directly from Vandenberg's runway to the orbiter maintenance and checkout station set. If Shuttle launch rates in the later 1980s reach the forecast 20 missions per year from Vandenberg, a safing and deservicing station set will be built between the runway and the orbiter maintenance and checkout station set. This would facilitate a two-orbiter checkout flow at Vandenberg. For early Shuttle operations only one orbiter can be handled at a time, since the orbiter maintenance and checkout station set has only one bay for orbiter support.

Mate/Demate Station Set

If the orbiter arrives via Shuttle carrier aircraft, it will be towed to the mate/demate station set where a Vandenberg unique structure, the orbiter lifting frame, Fig. 4, will lift the orbiter off and place it on its landing gear. Then the orbiter will be towed to the orbiter maintenance and checkout station set.

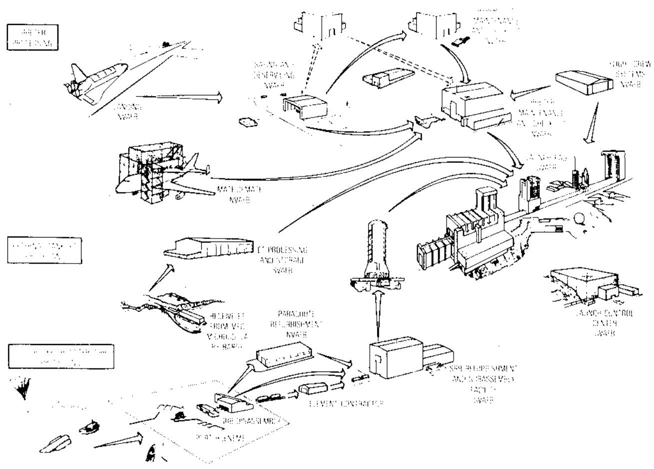

Fig. 3 Shuttle ground operations functional flow at Vandenberg.

Safing and Deservicing, and Orbiter Maintenance and Checkout Station Sets

As noted previously, for the first few years of Shuttle operations at Vandenberg, the orbiter maintenance and checkout station set will also perform the functions of the safing and deservicing station set. This includes ordnance safing, main engine purge and drying, venting of high pressure gases, draining of the hypergolic manifolds and cryogenic systems, deservicing the ammonia in the environmental control system, and data dump to ground recorders.

In addition, the hypergolic modules (forward reaction control system) can be moved and sent to the hypergolic maintenance and checkout station set. When the safing and deservicing station set is built, the above functions will be performed there before the orbiter is sent on to the orbiter maintenance and checkout facility. At either location, all functions will be performed with the vehicle jacked up off its landing gear and leveled.

Additional operations that are performed at the orbiter maintenance and checkout station set include complete internal and external inspection, checkout of the fluid and electrical systems, repair of thermal protection system tiles, and reinstallation of flight crew equipment and hypergolic modules. After all inspection, testing, maintenance, and repairs are finished, the payload bay doors are closed, access panels and ports are closed out, and the orbiter is lowered off its jacks onto a special transporter for towing to the launch pad, 17 miles distant.

Payloads

Vandenberg's orbiter maintenance and checkout station set has a second major work area separated from the orbiter bay by a blast wall, and payload safing and deservicing will be performed in this area.

Retrieval of digital imaging reconnaissance spacecraft for their refurbishment and reuse is a prime goal of Vandenberg defense Shuttle operations. Such spacecraft will be left in the orbiter until it reaches the orbiter maintenance and checkout station set at the end of a retrieval mission. The spacecraft will be lifted from the orbiter and transferred to the spacecraft safing bay, where it will be prepared for shipment back to its prime contractor.[2]

The only payload that will be placed in the Shuttle orbiter payload bay while the orbiter is horizontal in this facility will be NASA Spacelab hardware. All other civil and military payloads will be loaded into the Shuttle in its vertical position on the launch pad.

Hypergolic Maintenance and Checkout Station Set

The hypergolic maintenance and checkout station set, referenced above, is a depot-level maintenance and repair facility for the hypergolic propulsion units. The fuel and oxidizer subsystems, the pneumatic pressurant subsystems, and the electrical components can be completely checked out and refurbished and any necessary tile repairs can be made before the modules are returned to the orbiter maintenance and checkout station set.

All the above facilities are located at North Vandenberg, and owing to the presence of toxic and explosive materials, hazardous operations are performed in all but the mate/demate station set.

Parachute Refurbishment, Flight Crew Systems, and Logistics Station Sets

North Vandenberg contains some other station sets which are less complex. These include the parachute refurbishment station set, where the retrieved SRB parachutes are washed, dried, repaired, and repacked; the flight crew systems station set, where existing facilities will be modified to provide sleeping and medical facilities, and where the flight crew equipment is checked out. Also included is the logistics central supply, which is part of the logistics station set, where material management and line replaceable unit (LRU) maintenance activities will be performed.

Vandenberg Launch Processing Station Set

Other facilities at North Vandenberg include the Shuttle operations headquarters and major elements of the Vandenberg launch processing system station set, Fig. 5.

The launch processing system used at Vandenberg is functionally identical to that at Kennedy Space Center. At Vandenberg, the system's central data subsystem and one set of the checkout control and monitor subsystem hardware is located at North Vandenberg.

The central data subsystem at North Vandenberg will support both the Shuttle checkout at North Vandenberg and Shuttle launch activities on South Vandenberg. The checkout control and monitor hardware on north base will be devoted exclusively to Shuttle checkout. Another set of the hardware located in the blockhouse adjacent to the launch pad at south base will handle launch operations functions discussed later.

South Vandenberg Shuttle Operations Functional Flow

While the orbiter is being processed at North Vandenberg, the external tank (ET) and solid rocket boosters (SRB's) are being checked out at South Vandenberg.

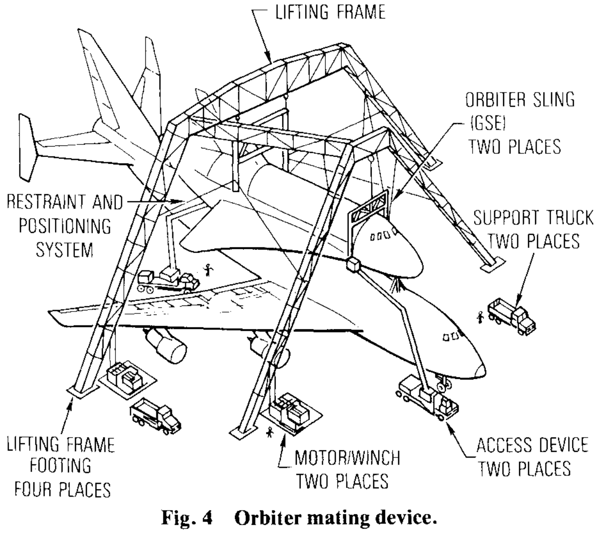

Fig. 4 Orbiter mating device.

ET Processing and Storage Station Set

The ET's are delivered by NASA barge via the Panama Canal to a modified harbor at South Vandenberg. They will be removed from the barge and towed over a newly constructed tow route to the ET processing and storage facility. In addition to storing up to four of these large tanks and maintaining an internal blanket pressure, the facility has a checkout cell where inspection, cleaning, leak, humidity, and electrical checks will be conducted, and spray-on foam insulation will be applied at the closeout ports. The harbor, tow route, and processing facility are all considered part of the ET processing and storage station set.

SRB Refurbishment and Subassembly Station Set

There is also a station set for refurbishment and subassembly of the SRB components. The propellant segments are received by rail and transferred to the storage area of the station set. The SRB forward and aft skirts are also delivered by rail from Port Hueneme for refurbishment, subassembly, and checkout. Since the skirts contain complex electronic and hydraulic subsystems which will have been exposed to seawater, thorough checkout will be performed. Rate gyros and range safety components will be tested and reinstalled in the forward skirt while the parachute pack and separation ordnance are installed in the frustum. Insulation is applied to the segments, and the forward skirt, frustum, and nose cap are mated to form the forward assembly of the SRB.

Meanwhile, paint and insulation are being applied to the aft skirt, hydraulic and electrical lines are fabricated for replacement as required, and installation of the various components, including the thrust vector control system and

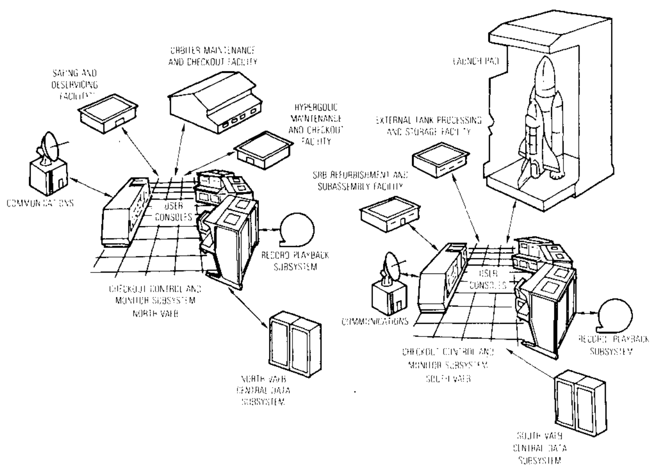

Fig. 5 Vandenberg launch processing system (VLPS).

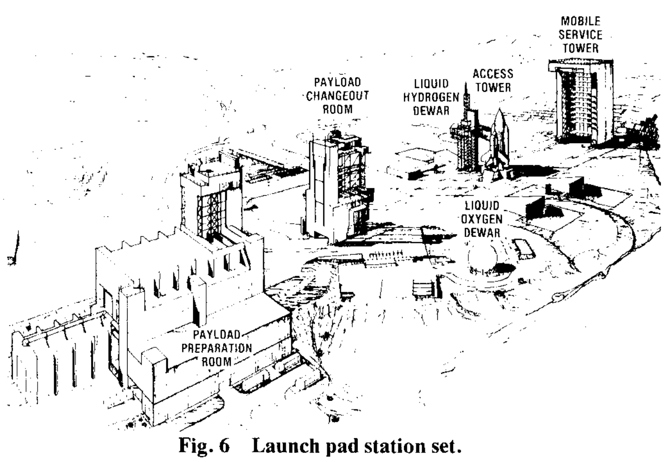

Fig. 6 Launch pad station set.

actuators is performed. A spin-up and hot fire test will be performed on the monopropellant turbine auxiliary power unit that provides hydraulic power. Finally, the aft skirt is mated to the aft solid propellant segment to form the aft assembly, and the aft and forward assemblies are connected together with electrical cable for an end-to-end electrical checkout.

Launch Pad Station Set

At the launch pad station set, Fig. 6, payload satellites will be receiving final assembly and checkout in the payload preparation room. When the SRB aft segments are ready, they will be delivered to the launch pad on a rubber-tired transporter and lifted onto the launch mount by a crane on the existing mobile service tower. When both the SRB's are completely stacked and checked for alignment, the interconnecting cables, tunnel covers, and ordnance are installed and safed. Next, the external tank is delivered to the launch pad on a special transporter, and mated to the SRB's. Finally, the orbiter is delivered to the launch pad on a transporter, and mated to the ET.[3]

Note that all these Shuttle assembly operations are conducted at Vandenberg at the launch pad, whereas at Kennedy Space Center, they are conducted inside the 30-story Apollo vehicle assembly building and then the assembled Space Shuttle vehicle is delivered in the erect position to the launch pad by the huge crawler.

All electrical and mechanical subsystems on the stacked vehicle at Vandenberg are then subjected to final integrated verification tests, including a dynamic flight simulation test (discussed later). Then the payload is transferred from the payload preparation room up into the payload changeout room, and over into the payload bay of the orbiter using a payload ground handling mechanism. Before the countdown begins, the vehicle is serviced by pressurizing the various nitrogen and helium tanks, loading the environmental control and life support system with water, ammonia, and freon, and loading the hypergolic propellants. The payload bay doors are closed, the mobile service tower and payload changeout room rolled to their far-back positions and secured, and loading of the cryogenic propellants begins the countdown.

The crew and experimenters/mission controllers then enter the orbiter and prepare for terminal countdown; the ordnance circuits are armed; the guidance, navigation, and control systems alignment is verified; all major subsystems statused; the monopropellant hydraulic auxiliary power units started up; and finally the main engines are started. When the desired thrust level is achieved, the SRB's are ignited, the holddown bolts pyrotechnically released, and liftoff occurs.

Launch Control Center Station Set

Just like the control center at North Vandenberg, the launch control center station set provides for remote monitor, control, and automated sequencing of operations at all station sets at South Vandenberg.

SRB Retrieval and Disassembly Station Set

After liftoff, when the SRB's have expended all their propellant, they separate from the ET and fall back to the ocean suspended from parachutes. Beacons on the SRB's provide guidance to a naval retrieval vessel. A nozzle plug is lowered into the water and remotely guided into the SRB nozzle. Air is pumped into the SRB to displace water and cause the SRB to float horizontally on the surface. The parachutes are wound onto reels on the retrieval vessel and a tugboat tows the first SRB to the Naval Station at Port Hueneme. The same operation is performed on the second SRB, except the retrieval vessel itself tows the SRB to Port Hueneme.

A large straddle-lift carrier removes each SRB from the water and places it on special rail cars riding on a leveled, continuously welded track. The ordnance is safed and any remaining turbine monopropellant drained. The rail cars are towed into an initial wash facility and then the cars are rolled into the main building for complete disassembly. The forward and aft assemblies are sent back to the wash facility for insulation removal by a high pressure water spray and subsequent drying. The empty propellant segments are shipped back to the manufacturer for installation of new propellant and the forward skirts, aft skirt, parachutes, and remaining components are sent to Vandenberg for refurbishment. The above operations are all included in the SRB retrieval and disassembly station set, Fig. 7.[4]

Transportation and Communication Station Sets

There are additional station sets for auxiliary services; these include the transportation station set, which consists of the roads and special transportation equipment to move the Space Shuttle vehicle elements around Vandenberg and the communications station set, which provides voice and data transmission within and among the station sets and control centers.

Testing and Prelaunch Flight Simulation

Digital Interface Required

The Shuttle is a digitally controlled spacecraft, with no direct mechanical linkages by which the crew can manipulate control surfaces or cause the propulsion systems to fire. The orbiter requires continuous computer control to maintain stability. In certain flight modes the crew can select either the automatic mode for guidance, navigation, and control of the vehicle (which allows the onboard computers to do all the flying), or select the manual mode of flight (which allows the crew to fly the orbiter by hands-on control). However, if manual flight is selected, crew commands to the control surfaces and engines still pass through and are issued by the computers. Therefore there is complete dependence on the onboard computers.

The five orbiter onboard computers consist of a redundant set of four which forms the primary flight system, plus a single computer used as backup. The software for the primary flight system is loaded identically into each of the four redundant computers. During flight operations, intercomputer communication insures self-consistency and synchronization within the primary flight system.

To provide for additional cross-check and redundancy, a fifth computer operates independently, executing separately developed backup software. The crew manually engages the backup flight computer if critical failures are detected in the primary flight system. The first Shuttle launch at Kennedy Space Center was delayed two days because this fifth computer detected an improper internal clock timing skew within the four primary computers during the final countdown.

The primary and backup flight software are both written in HAL/S, a high-order structured programming language.

Figure 8 depicts avionics onboard the orbiter. The central computers interface with subsystems through serial data

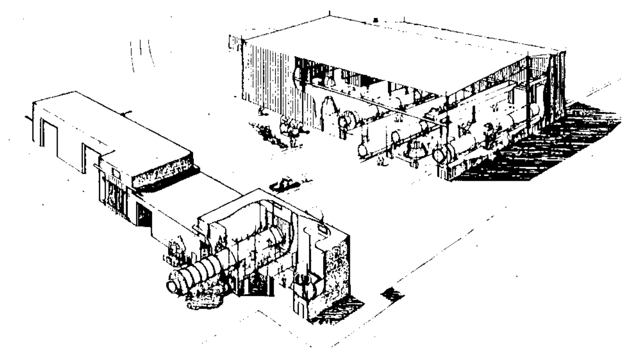

Fig. 7 SRB retrieval and disassembly station set.

buses. The master timing unit provides an accurate time source for the computers. Sensors such as the inertial measurement unit, accelerometer assembly, and rate gyro assembly provide velocity and attitude information. The tactical air navigation system, microwave landing system, radar altimeter, air data system, and star tracker are external navigation aids. The reaction control system, orbital maneuvering system, and main engines are all propulsion systems. Vehicle control surfaces include elevons, rudder, speedbrake, and body flap; and the cockpit switches and controls and dedicated display units provide information to the crew on Shuttle velocity, altitude, attitude, and other flight critical parameters.

The computers are also connected with the multifunction CRT display system in the cockpit, which provides and allows crew access to the computers via keyboard commands. Mass memory units contain the primary and backup flight software to be loaded into the computers as needed, and also communicate directly with the computers. The computers also transmit pulse code modulation telemetry data used on the ground to monitor internal state of the computers and flight progress, either in real time or after the mission.

Use of the Vandenberg Launch Processing System

The launch processing system interfaces with the vehicle prior to launch via the umbilical launch data bus. This allows direct access to onboard computer memory. In addition to performing vital ground launch sequencing tasks, the launch processing system uses a general memory read/write capability to monitor and modify computer core, if needed. For example, it can be used to update launch pad initial conditions. This launch processing system capability is also used to perform the prelaunch flight simulation test on the Shuttle.

Testing the Integrated System

Shuttle components and subsystems will be bench tested to the fullest extent possible, then shipped to Vandenberg for final integration into the Shuttle vehicle, during which additional subassembly testing is performed.

After assembly, the final integrated Shuttle configuration will have to be verified, since the complete hardware/software data paths which are utilized in flight do not exist until the vehicle is assembled. The integrated flight simulation test—controlled via the launch processing system—will verify that proper connections have been made, correct polarity is maintained, and no unexpected interference is generated.

The integrated test is complicated, since the software and hardware configurations change during the course of a mission as the software is sequenced through various modes. A valid integrated test must therefore be a dynamic test which checks out hardware/software data paths in the vehicle, sequenced through the events of a typical flight profile.

A simulated flight sensor profile is transmitted from the launch processing system over the umbilical launch data bus on the launch pad, and injected into the flight software so that the grounded vehicle believes it is flying. Therefore, on the launch pad, the vehicle is sequenced through normal flight phases and deceived to react to the environment, position, velocity, and attitude it would experience on a mission.

The hardware sensors actually continue to detect their Earthbound environment, or in some cases the output of test sets, so the Shuttle navigation software injects simulated sensor data. The flight simulation exercises the complete hardware/software data paths from sensors to actuators insofar as possible.

Either of two data injection modes, called substitution and combining, illustrated in Figs. 9b and 9c, are used. In the substitution mode, the real sensor data are processed but do not influence the applications, calculations, or commands sent to the actuators. In the combining mode, real sensor data are added to the simulated sensor data, and the combined values drive the applications, routines, and actuators. The combining mode gives a more complete verification of the data paths during a flight simulation test, but is more complex.

Only selected flight profiles are used to exercise the software and verify hardware/software interfaces and interactions. The control surfaces, engine gimbals, and other actuators on the vehicle are physically moved, as they would be during a real flight, except where prohibited for safety reasons.

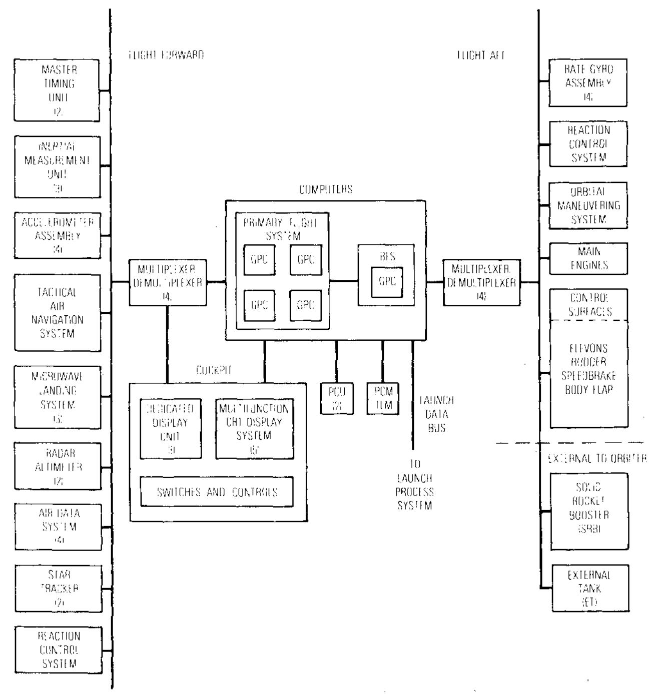

Fig. 8 Orbiter on-board avionics.

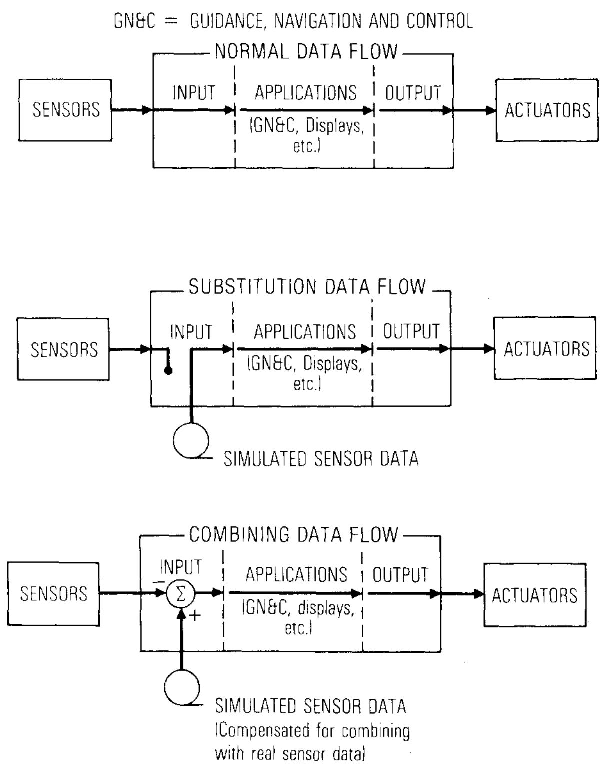

Fig. 9 Orbiter avionics data flow.

Tape Generation

To generate a flight simulation data tape, data are taken from the general purpose computer during a closed loop digital simulation in an avionics laboratory, just as a motion picture is made by taking a series of still snapshots of the real world with a movie camera.

The capacity to transmit a 128-word data packet to the onboard computer every 120 ms is a standard Vandenberg launch process system capability, and is used for transmitting flight simulation data from the tape to the vehicle.

Use of the Vandenberg Launch Processing System to Evaluate Test Results

A flight simulation test is evaluated the same as for an actual flight: by analyzing the standard telemetry, monitoring cockpit displays, and observing movement of the vehicle hardware. The Vandenberg launch processing system is the monitoring station where flight simulation test engineers can follow the progress and evaluate the test. During a successful flight simulation test, the vehicle will sequence correctly through the events associated with the mission being simulated.

Future Applications

The Shuttle is the first manned spacecraft with complete digital control and therefore introduces a new level of avionics complexity. All flight control occurs via serial data buses with no direct mechanical connections to control surfaces. As vehicle and system complexities continue to increase, fully integrated systems tests which are as close to real flight as possible will be performed.[5]

Conclusion

GSE for the Space Shuttle at Vandenberg is an integral part of the overall U.S. space transportation system concept. Although much of the Vandenberg equipment is common to Kennedy Space Center, there are sufficient unique requirements and problems to merit close attention to detail in GSE design, integration, activation, and application at Vandenberg.

Use of the experiences at Kennedy Space Center will help to ensure successful GSE installation at Vandenberg owing to the high degree of commonality at the two locations.

Successful application of the Shuttle GSE concepts and installation at Vandenberg will ensure that Shuttle defense missions will have high probability of success.

Flight simulation testing is now a necessary element of Shuttle flight readiness verification, but had to be retrofitted to the vehicle. As even more complex space transportation evolves, it follows that this capability will be built-in from the start. The flight simulation test software and hardware and the support facilities and equipment will be designed for flight simulation.

Acknowledgments

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