6/66

International Business Machines Corporation
Federal Systems Division
326 East Montgomery Avenue
Rockville, Maryland 20850

For further information contact:

In Cape Kennedy: J. F. Harroun
305-784-9783

In Houston: A. J. Cella
713-HU 8-3300, ext. 371

In Washington (Bethesda):
E. B. Evans
301-656-2800

SATURN IB - SATURN V INSTRUMENT UNIT

TECHNICAL FACTS

The Saturn family has systems antecedents in early military rocket programs, such as Redstone, Thor, Jupiter, Titan, Atlas and others.

The inertial guidance platform can be traced from the earlier Pershing, Jupiter and Redstone vehicles; the telemetry system evolved from a design first used in Redstone, and a portion of the tracking equipment was developed initially for the Redstone program. Adding the human element required new systems for longer and more varied missions and an overriding concern for safety.

Although the Saturn I series of vehicles tested the Saturn IB concepts, there are only a few identical components in the Saturn IB Instrument Unit (IU). Each of the last five Saturn I vehicles used an inertial guidance platform and control computer similar to those in the Saturn IB. However, the guidance computer is of

-more-

a completely new design incorporating the flexibility and reliability necessary for Saturn IB missions. The design flexibility of the IU is such that the stage will remain nearly identical for both programs after research and development tests are completed.

The IU was designed and developed by NASA's George C. Marshall Space Flight Center (MSFC). In the Saturn IB program, IU responsibility is being transferred gradually to IBM's Federal Systems Division with overall responsibility beginning with the fifth flight IU. Work on the first four flight models is the responsibility of MSFC, with the actual assembly being done in IBM's Huntsville, Alabama, facility. Testing is performed by IBM personnel.

IBM's contract calls for fabrication and assembly, complete system testing, and integration and checkout of the IU with the launch vehicle at the Kennedy Space Center.

Also included in the contract are requirements for the computer programs for simulating mission conditions and predicting vehicle performance, operating automated checkout equipment on the ground, and for reducing and analyzing environment and performance data during and after the flight.

SATURN IB VEHICLE — OVERALL VIEW

The range of capabilities and missions planned for the Saturn IB launch vehicle is reflected in the design of the navigation systems. This flexibility to meet new mission assignments requires a general purpose launch vehicle digital computer

-more-

(LVDC), which generates steering signals under control of an internally-stored program. Different missions can be controlled by different LVDC programs. The vehicle engine actuators are controlled by a separate flight control computer system, including an analog computer, rate gyros, and control accelerometers.

For attitude control, the current attitude of the vehicle is compared with the desired attitude, which is stored in the LVDC's program. Attitude correction signals, or steering commands, are the difference between the existing attitude and the desired attitude.

These steering commands are combined with signals from control sensors in the flight control computer system to generate the control command for the engine actuators. Gimballing the engines changes the direction of the vehicle. During the S-IB burn, pitch and yaw control accelerometers provide lateral acceleration data to the flight control computer so that stable flight is assured.

In guidance and control terms, each Saturn IB vehicle is a separate entity. Long before each flight, NASA plans the mission. From this mission definition, IBM and NASA develop the mathematical equations to be used by the guidance computer and IBM converts these equations into computer programs.

Using a computer complex installed at the IBM facility in Huntsville, the mission is simulated to check out the programs and verify that, for any foreseeable set of conditions, the LVDC will continuously determine vehicle status and determine the optimum path to its destination.

STAGE DESCRIPTION:

The IU consists of six major subsystems: structure, environmental control, guidance, flight control, instrumentation, and electrical.

Mounted on the structural ring inner surface is the electronic equipment used to navigate the vehicle, measure environment and performance, and communicate these data to the ground. Supporting this equipment is an environmental control system for heat dissipation, a supply of nitrogen gas for the guidance platform's gas bearings, and an electrical system.

STRUCTURE:

The structure section is 21.7 feet in diameter and three feet high. Assembled with the launch vehicle, it becomes a load-bearing part which supports both the components within the IU and the weight of the spacecraft.

It is manufactured in three 120-degree segments of thin-wall aluminum alloy face sheets bonded over a core of aluminum honeycomb about an inch thick or as thick as a bar of soap. An aluminum alloy channel ring, bonded to the top and bottom edge of each segment, provides the surface for mating the IU, the S-IVB stage, and the payload. Brackets on the inside of the segments provide attachment points for the cold plates of the environmental control system, and for components not requiring cold plate installation.

-more-

The segments are aligned and joined by means of splice plates bolted to the inner and outer surface of each joint.

A spring-loaded umbilical door in the structure provides a means for service connections between the IU and ground support equipment. A larger access door, bolted in place, permits personnel to enter the IU following its mating to the launch vehicle.

Despite its size and the stresses that must be withstood during launch, the complete structure, prior to equipment installation, weighs a little over 500 pounds.

ENVIRONMENTAL CONTROL:

The cold plates of the environmental control system provide a means of mounting and cooling the complex electronic components within the IU and the S-IVB stage, both on the launching pad and during flight.

The long periods of operation in a typical Saturn IB mission, coupled with the vacuum of space, require special provisions for heat transfer and dissipation.
IU + S4B ?
The 32 cold plates (16 in each stage) absorb heat from the electronic components. The heat is conducted through the smooth surface of the cold plates to a coolant mixture much like antifreeze---60% methanol, 40% water. Cooling is a function of the contact area between the component and the cold plate. Since the LVDC, the launch vehicle data adapter (LVDA), flight control computer, and the ST-124M inertial guidance platform generate the most heat, the coolant actually passes through these components instead of extracting the heat via conduction.

-more-

Heat transfer & dissipation

In the vacuum of space, the warmed coolant, after leaving the cold plates, is routed through a device called a sublimator. Water, from a reservoir in the IU is supplied to the sublimator where it is exposed through a porous plate to the low temperature and pressure of outer space. The water freezes, blocking the pores in the plate. The heat from the coolant, transferred to the plate, is absorbed by the ice, converting it directly into water vapor (a process called sublimation).

This system is self-regulating: A sensor constantly monitors the temperature. If the coolant requires chilling, this sensor controls a valve which diverts varying amounts of coolant through the sublimator/heat exchanger. If no cooling is required the sublimator is bypassed.

Other equipment in the environmental control system provides a supply of pressurized gaseous nitrogen to one side of the diaphragm in the coolant and water reservoirs, since in the weightless period of flight, without some form of artificial pressure, these liquids would disperse into droplets. Gaseous nitrogen also is provided to the gas bearings of the ST-124M platform. A pump to circulate the coolant, and the necessary valves and tubing to control its flow, complete the equipment of the environmental control system.

GUIDANCE AND FLIGHT CONTROL

The IU's guidance and flight control systems control the flight of the Saturn IB to meet mission requirements. Completely self-contained, these systems measure acceleration and vehicle attitude, determine velocity and position and their effect on the mission, calculate and issue control commands to the engine actuators to place the vehicle in a desired position. The major components in the system are: an inertial platform, a digital guidance computer, an analog flight control computer, a data adapter, control rate gyros and control accelerometers.

Prior to liftoff, launch parameters are fed into the LVDC. About five seconds before liftoff, the inertial guidance platform and the LVDC are released from ground control. Previously aligned to the launch azimuth, the guidance platform senses and measures the vehicle's acceleration and attitude as the vehicle ascends into the atmosphere, and it sends these measurements to the LVDC via its interface, the LVDA.

The LVDC integrates these measurements with the time since launch to determine vehicle position relative to starting point and destination. The LVDC goes on to compute the desired attitude correction signals in order for the vehicle to arrive at the required velocity and altitude for its mission.

These attitude correction signals, rate gyro outputs, and control accelerometer outputs are sent to the analog flight control computer. Based on the data received from the LVDC and the gyros and accelerometers, the flight control computer issues the actual control commands.

Each mission has at least three phases: atmospheric powered flight; boost period after initial entry into space, and the coasting period.

Loads on the vehicle are greatest during atmospheric boost because of the impact of the atmosphere on the vehicle's surfaces. During this portion of the flight,

(more)

the guidance and flight control systems are concerned primarily with vehicle integrity, and so it is programmed to sustain an attitude to minimize vehicle loading.

After first stage separation the programs are designed to optimize the path the vehicle takes to achieve the desired mission.

During this phase of powered flight, guidance is accomplished by a series of repetitive computations. Approximately once every two seconds during flight, the guidance computer determines vehicle position, vehicle conditions required at the end of powered flight (velocity, attitude, etc.), and generates the attitude correction signals necessary to accomplish the desired end result. This is known as iterative guidance mode, or "closed loop guidance."

Twenty-five times a second, attitude correction signals are generated by the most recent solution of the guidance problem. The LVDC, through the LVDA, sends these signals to the flight control computer where control commands are generated to steer the vehicle along the desired flight path.

To ensure reliability, critical circuits in the LVDC and LVDA are provided in triplicate. Each of 3 identical circuits produces an output which is then "voted" upon. In case of an error in these outputs, the majority rules so that a random failure is ignored. In addition, the computer memory is duplexed, so that if an error is found in one portion of the memory, the output is obtained from the other memory, and then the correct information read back into both memories to correct the error.

To ensure the accuracy of the position data originating in the inertial equipment, gas bearings are provided for the gyros and pendulums of the ST-124M inertial guidance platform to reduce friction in these components to a minimum. The bearings are "floated" on a thin film of dry, pressurized nitrogen supplied at a controlled pressure, temperature, and flow rate from reservoirs in the IU.

In addition to the guidance computations, other functions are performed by the LVDC, and its input/output device, the LVDA. During pre-launch, they conduct test programs; during launch phase they direct the sequencing of events via the IBM-developed switch selector (one in each stage), such as engine ignition and cut-off, stage separations, and check to see that the vehicle is performing normally. During earth orbit, they determine attitude control, conduct tests, and control the transmission of data.

INSTRUMENTATION:

Measuring sensors, or transducers, are located throughout the vehicle to monitor the vehicle environment and systems' performance. Approximately 300 such measurements are made by various sensors. Acoustic transducers monitor sound levels, resistor or thermistor transducers monitor temperature environments; pressures are measured by Bourdon-tube or bellows transducers; force-balance, or piezoelectric accelerometers measure force levels at critical points, and flow meters determine rates of liquid flow.

Signal conditioning modules modify these various transducer outputs to a uniform range of voltage. The different types of data require different modes of

-more-

transmission, and the telemetry portion of the system includes single-sideband frequency modulation, frequency-modulated frequency modulation and pulse-code-modulated frequency modulation.

Each type of information is routed to the appropriate telemetry equipment by the measuring distributors. For maximum utilization of the transmission equipment, multiplexing is employed on most telemetry channels. Measurements from different sensors are transmitted to earth. The information transmitted over any channel is a series of measurements made at different points within the vehicle, so that a large amount of data can be sent with a minimum of communication equipment.

To further increase the amount of data which can be handled, the LVDC sequences the transmission of certain measurements. For instance, during retro-rocket firing, when flame interferes with telemetry transmissions, signals are automatically recorded on tape and transmitted later.

Several tracking systems are used to determine vehicle position and the data are consolidated to provide trajectory information. Transponders in the IU increase the range and accuracy of the ground-based tracking systems. Pulses of radio-frequency energy transmitted by the ground stations interrogate the vehicle in flight. The airborne transponder answers with a pulse, or series of pulses, frequency-or-time-displaced from the incoming pulse to minimize interference. The ground station determines the point of origin of these reply pulses, and "fixes" the location of the vehicle.

One C-band transponder is used to provide tracking independent of vehicle attitude along with a single AZUSA transponder. The C-band tracking system provides orbital tracking data for both real time and post flight trajectory analysis. The AZUSA system provides real time tracking data for range safety impact predictions, and for post-flight trajectory analysis.

A radio command link is used to communicate with the LVDC from the ground. Examples of messages include: updating data from the LVDC; commands to perform the updating, commands to perform tests, special subroutines; a command to telemeter certain sectors of the computer memory; and a command to relay to the ground a particular address in the computer memory. Messages can be added or deleted as necessary.

ELECTRICAL:

Electrical power during pre-launch is furnished from ground sources through the IU umbilical connection. At approximately 20 to 30 seconds prior to lift-off, a signal from the Launch Control Center transfers power to four 28-volt alkaline silver-zinc batteries in the IU. Each battery has a capacity of 350 ampere hours. IU power is designed for 6.8 hours of mission life. Loads are partially distributed over the four batteries to equalize the battery drain, and to provide a redundant power source to the components in the event of battery failure.

Two special power supplies are provided: The 5-volt master measuring voltage supply converts the 28 Vdc main supply to a highly-regulated 5 volts dc to be used as a reference and supply voltage for the components of the measuring system; the 56-volt power supply provides the regulated 56-volt dc required for operation of the guidance and control system's ST-124M inertial guidance platform.

The switch selectors in each vehicle stage provide a means of controlling the sequencing of events taking place in that stage. Each selector can issue up to 112 different 28 volt commands to the various electrical circuits in the Saturn. The guidance system's LVDC and LVDA control these, selecting the appropriate circuits as the mission progresses.

The emergency detection equipment monitors thrust for both powered stages, guidance computer status, angular attack rates, attitude error, and angle of attack. It detects abnormal conditions affecting the safety of the crew. Where time is insufficient for the crew to react, the automatic abort will be used. If the crew can react, the emergency detection system will provide an indication, "manual abort," which the crew can use if deemed necessary.

ASSEMBLY OPERATIONS:

Assembly of an IU begins with the arrival of three curved structural segments at IBM's Huntsville, Alabama, facility.

The three segments---each weighing approximately 175 pounds---are placed on a circular assembly fixture and arranged for alignment and splicing. Following this, protective rings are bolted to the top and bottom of the assembly to stiffen the structure so that it can be moved about without disturbing the alignment. Holes are cut through the structure to mount vehicle antennas.

Transducers to measure temperatures and thermal conditioning panels are mounted to the IU's inner skin, and a frame-like, cable tray to carry the electrical cables is installed around the top of the structure. Components are mounted on the thermal conditioning panels, and the thermal conditioning system's pumps, accumulators (storage tanks), heat exchangers, and plumbing are installed. A gaseous nitrogen supply system for the gas bearings of the inertial guidance platform is attached. Finally, ducts, tubing, and electrical cables complete the assembly of the IU. The assembled IU weighs approximately 4000 pounds.

CHECKOUT FACILITIES:

The Huntsville checkout facility includes manufacturing, component, and systems test equipment. When received, components are checked against drawings, sent to the component acceptance test area and tested as a unit.

After acceptance tests, the components are assembled into the IU, where functional tests are performed on each system. From assembly stations, the IU is moved to the systems checkout stand where all systems are checked individually, and finally as an integral unit. The systems test complex is divided into six areas; power, sequence and control, telemetry, instrumentation, navigational systems, and radio frequency. Each area is self-contained and separated from the others.

Test sequencing, monitoring, and evaluation are performed by a ground control computer complex similar to that used at the Launch Control Center for pre-launch testing. The test conductor calls for a specific test by keying an input console, the

-more-

computer conducts the test in accordance with a test procedure provided on a magnetic "library" tape, and test results are displayed on the operator's console and recorded on magnetic tape or on-line printers. Pre-launch, launch and flight operations are tested, using computer simulated inputs to represent signals which are present during flight.

Electro-magnetic compatibility (EMC) tests are conducted upon completion of systems checkout.

After EMC tests are completed, the water and water/methanol coolant solution of the environmental control system is drained, and the gaseous nitrogen is removed from the air bearing supply. Certain equipment (the ST-124M inertial guidance platform, the LVDC and the LVDA) is removed and packaged separately for shipment to the launch site. The assembled IU, with other components attached, is placed on a shipping carrier. Accelerometers are mounted at sensitive points within the IU to measure stresses experienced during shipment. The unit is flown to the Kennedy Space Center.

VEHICLE INTEGRATION AT CAPE KENNEDY:

Upon arrival at the Kennedy Space Center, the IU is checked to verify that no damage has occurred during shipment. Mechanical alignment of the IU and platform mounting surfaces is verified in the receiving area.

-more-

S-IB LAUNCH COMPLEX

The IU is moved to the launch pad and raised to its position on the forward skirt of the S-IVB and fastened into place. Components removed before shipment are reinstalled at this time. Water and water/methanol are supplied to the environmental control system from service equipment on the launch tower, and gaseous nitrogen is supplied to the high pressure storage spheres of the air bearing supply. At this time, the IU systems are functionally-tested to verify operational status. Tests include "flight readiness," "plug-in" (umbilicals connected), "plug-drop" (umbilical dropped during test to verify satisfactory transfer from ground to vehicle power), and, finally "countdown demonstration" (dress-rehearsal of terminal countdown terminated in simulated abort just prior to lift-off).

As the terminal launch countdown nears T-10 hours, the pre-launch test batteries are removed, and the flight batteries installed and connected. The service platforms and components' handling equipment are removed from the interior of the IU, and, after a final check to ensure that the area is clear, the access door is bolted in place and the IU service arm is retracted into the gantry.

✓ As the launch countdown progresses, a beam of light from a precisely-located theodolite hut on the ground passes through a small hole in the IU and into a window in the guidance platform. The light beam is reflected back to the theodolite from a pair of platform prisms. Each prism reflects a different portion of the frequency spectrum, and this "color code" is used to align the platform to its launch azimuth

The "color code" of the prisms...

prior to the flight. An acquisition light goes "on" in the control center when the platform is properly aligned. Computer-derived launch azimuth signals are then used to refine the position of the platform with respect to a fixed ground reference.

With the launch azimuth established, and the required mission parameters stored in the LVDC memory, the IU is ready for flight.

###

FSD-22