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TITAN/CENTAUR D-1T TC-5 HELIOS B FLIGHT DATA REPORT

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May 1976

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16. Abstract

Titan/Centaur TC-5 was launched from the Eastern Test Range, Complex 41, at 00:34 EST on Thursday, January 15, 1976. This was the fourth operational flight of the newest NASA unmanned launch vehicle. The spacecraft was the Helios B, the second of two solar probes designed and built by the Federal Republic of Germany. The primary mission objective, to place the Helios spacecraft on a heliocentric orbit in the ecliptic plane with a perihelion distance of 0.29 AU, was successfully accomplished. After successful injection of the Helios spacecraft, a series of experiments were performed with the Centaur stage to demonstrate its operational capabilities. All objectives of the extended mission phase were successfully met. This report presents the analysis of the launch vehicle flight data for the primary mission phase of the TC-5 flight. A detailed analysis of the Centaur extended mission phase will be published in a separate engineering report.

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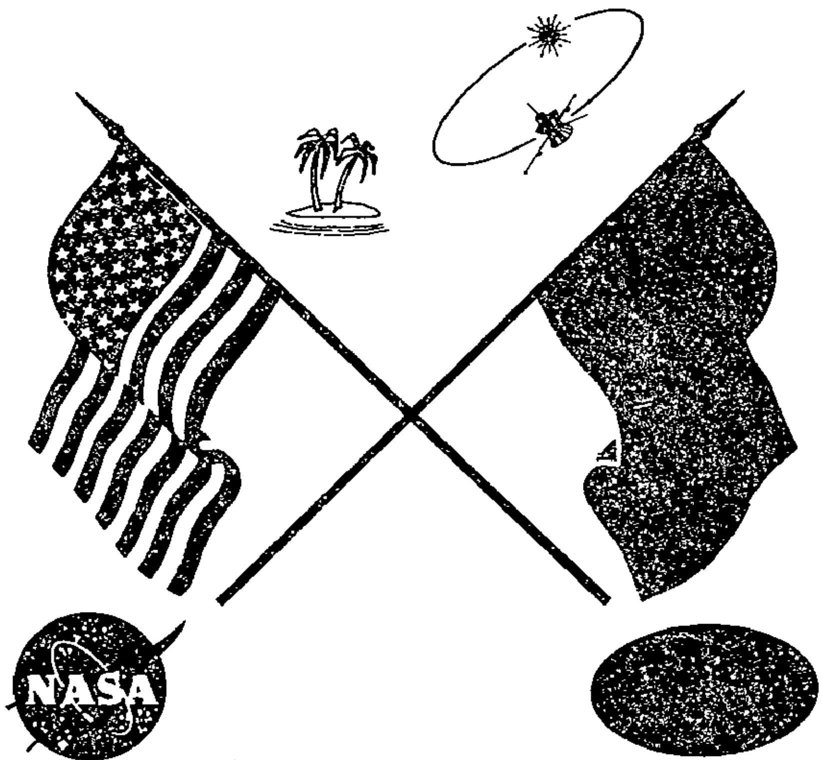
TITAN/CENTAUR D-1T

TC-5
HELIOS B

FLIGHT DATA REPORT



PROJECT HELIOS
UNITED STATES - GERMANY
COOPERATIVE SPACE PROGRAM
KOOPERATIVES RAUMFAHRTPROJEKT

by Lewis Research Staff
Lewis Research Center
Cleveland, Ohio 44135
May 1976

TC-5 FLIGHT DATA REPORT

HELIOS B

Contents

SUMMARY

I SUMMARY

by K. A. Adams

Titan/Centaur TC-5 was launched from the Eastern Test Range, Complex 41, at 00:34 EST on Thursday, January 15, 1976. This was the fourth operational flight of the newest NASA unmanned launch vehicle. The spacecraft was the Helios B, the second of two solar probes designed and built by the Federal Republic of Germany.

The primary mission objective, to place the Helios spacecraft on a heliocentric orbit in the ecliptic plane with a perihelion distance of 0.29 AU, was successfully accomplished.

After successful injection of the Helios spacecraft, a series of experiments was performed with the Centaur stage to demonstrate its operational capabilities. These experiments included a 5.25 hours second coast and subsequent third main engine burn to demonstrate high altitude synchronous orbit injection capability; a demonstration of main engine restart after a minimum (5 minute) settled coast; and a demonstration of multiple coast/restart capability during extended flight. A total of five additional engine restart attempts were programmed during this Centaur extended mission. All objectives of the extended mission phase were successfully met.

II INTRODUCTION

II INTRODUCTION

by K. A. Adams

Helios B Mission Background

In June 1969 the Federal Republic of Germany and the United States of America agreed on the joint cooperative Helios solar probe project. This basic agreement provided for the design, development, test, and launch of two flight spacecraft to within 0.3 AU of the sun. Germany was assigned the responsibility for providing the two spacecraft, seven scientific experiments on each spacecraft, and controlling the spacecraft throughout the mission. The United States was assigned the task of providing three scientific experiments on each spacecraft, two Titan IIIE/Centaur/Delta (TE-M-364-4) launch vehicles and tracking and data reception from the NASA Deep Space Network (DSN). Major contractual effort on the program began in 1970. In March of 1971, the German Government (BMBW) proposed an additional experiment, Celestial Mechanics, for the Helios mission. Late in the program, a Faraday Rotation experiment was also approved.

This joint project is expected to provide new understanding of fundamental solar processes and sun/earth relationships by obtaining information and measurements on the solar wind, magnetic and electric fields, cosmic rays, cosmic dust, and solar disc. It will also test the theory of general relativity. The NASA Lewis Research Center (LeRC) has prime responsibility for the launch vehicle. The NASA Goddard Space Flight Center (GSFC) through its Helios Project is responsible for the activities of the United States agencies which are involved in Helios and for provision of the United States sponsored experiments. The Bereich fur Projektragerschaften (BFP) of the Federal Republic of Germany is responsible for the technical direction of the prime spacecraft contractor, Messerschmidt-Boelkow-Blohm GmBH (MBB-Ottobrun), for the German experiments, and for all other German organizations which contribute to the Helios project.

The Titan IIIE and Centaur D-1TR, fitted with a spin-stabilized solid propellant TE-M-364-4 (Delta) stage, is designed to launch the Helios B unmanned spacecraft into a heliocentric orbit, in the ecliptic plane, with a perihelion of approximately 0.29 AU and an aphelion of approximately 1.0 AU. The launch of Helios B was from the AFETR Launch Complex 41, Cape Canaveral, Florida, utilizing a parking orbit ascent mode. This was the second of two planned Helios spacecraft. Helios A was successfully launched on December 10, 1974.

Flight time of the Helios B primary mission is approximately 120 days, extending through the first solar occultation. The total mission life time, however, is expected to exceed 18 months with primary interest in the region of the orbit between perihelion and solar occultation.

After the spacecraft was placed into its desired heliocentric trajectory, the Centaur vehicle continued into an experimental flight phase. During this post-Helios experiment phase, developmental data were obtained relative to the Centaur capability for extended periods of zero-g coast and multiple engine starts.

Helios B Mission Scientific Objectives

The principal objective of the Helios B mission is the exploration of interplanetary space in the proximity of the sun by:

- Measuring the magnetic field, the density, temperature, velocity, and direction of the solar wind.

- Studying discontinuities and shock phenomena in the interplanetary medium magnetically, electrically, and by observing the behavior of the solar wind particles.

- Studying radio waves and the electron plasma oscillations in their natural state.

- Measuring the propagation and spatial gradient of solar and galactic cosmic rays.

- Studying the spatial gradient and dynamics of the interplanetary dust and chemical composition of dust grains.

- X-ray monitoring the solar disc by means of a Geiger-Muller counter.

- Testing the theory of General Relativity with respect to both orbital and signal propagation effects.

Helios B is programmed to accomplish its mission objectives on April 17, 1976, when it satisfies the agreed scientific measurement criteria during its perihelion passage (0.2903 AU). At present, all instruments are working and good scientific data are being received from each of the 10 active experiments. Data will also be received from the two passive experiments (Celestial Mechanics and Faraday Rotation), but their period of maximum interest is just before first solar occultation (mid-May). All spacecraft systems are operating nominally with temperatures generally falling within a few degrees centigrade of predictions.

Centaur Extended Mission Experiments

Following injection of the Helios into its required trajectory, the Centaur vehicle performed developmental experiments. These post-Helios Centaur extended flight experiments included:

- High altitude synchronous orbit injection capability (5.25 hours second coast and third start).

- Basic Centaur restart capability after minimum coast.

- Multiple coast/restart capability during extended flight.

- The acquisition of systems performance data for the extended flight environments and experiments related to the following new or revised operating modes and special sequences:

  - Coast thermal control maneuvers (revised from Helios A mission).

  - Coast attitude control with wide, narrow, and precision limits.

  - LO_2 tank pressure history with reduced zero-g purge rate.

  - Boost pump deadhead operation (duration revised).

  - Helium consumption monitor (first operational use during extended mission).

  - Restart sequence with simulated settling engine failure.

  - H_2O_2 propellant residual depletion to define actual flight usage requirements.

  - Propulsion restart sequences with reduced:

    - Propellant settling impulse

    - Tank pressurization levels

    - Boost pump deadhead durations

    - Childown durations (with and without prechills)

Extensive special instrumentation was installed on Centaur to provide engineering data which will be used to assess its capability to meet the requirements of future NASA, international, and commercial programs.

During the Centaur extended mission, all experiment objectives were successfully met. A detailed analysis of this mission phase will be published by LeRC in a separate engineering report.

III SPACE VEHICLE DESCRIPTION

III SPACE VEHICLE DESCRIPTION

Helios B Spacecraft

by K. A. Adams

The Helios B spacecraft (Figure 1) has a short 16-sided cylindrical central body with two conical solar arrays attached at its upper and lower end. Above the central body, within and protruding above the upper solar array, is the communications antenna assembly. This antenna assembly consists of a high gain antenna with a despun deflector that orients to face the earth, a medium gain antenna, and an omni antenna.

There are two deployable radial booms attached to the central body on which are mounted the three magnetometer sensors. These two rigid booms are diametrically opposite and when deployed the boom axes are approximately radial. The magnetometer booms are double hinged. Magnetometer Experiment 3 is located at the tip of one boom and Magnetometer Experiment 4 is located at the tip of the other boom. Magnetometer Experiment 2 is located part way along the Magnetometer Experiment 4 boom.

The spacecraft also deploys two radial flexible booms from reel-type storage to provide a 32 meter tip to tip antenna for the Radiowave Experiment 5. The axis of this experiment antenna is normal to the axis of the two rigid booms when they are in the deployed position. In launch configuration, the two rigid booms are folded in against the central body and the experiment antenna booms are stored on their reels. The rigid booms and flexible antenna booms are deployed upon command after initial acquisition of the spacecraft RF signals by the DSN.

The central body has a circular equipment platform at each end with several radial equipment platforms in between. A conical adapter attached to the lower circular equipment platform mates with the Delta stage payload attach fitting to form the spacecraft to launch vehicle mechanical interface.

With the exception of the three magnetometer experiments sensors which are boom mounted, the experiment sensors, their electronic units, and the spacecraft equipment are located on the radial equipment platforms within the central body or within the conical adapter.

The central body is thermally controlled by louver systems which, along with second surface mirrors covering the central body, maintain the temperature inside the central body constant during the mission.

A battery system provides spacecraft power up to the time of sun acquisition and then power is provided by the solar cells.

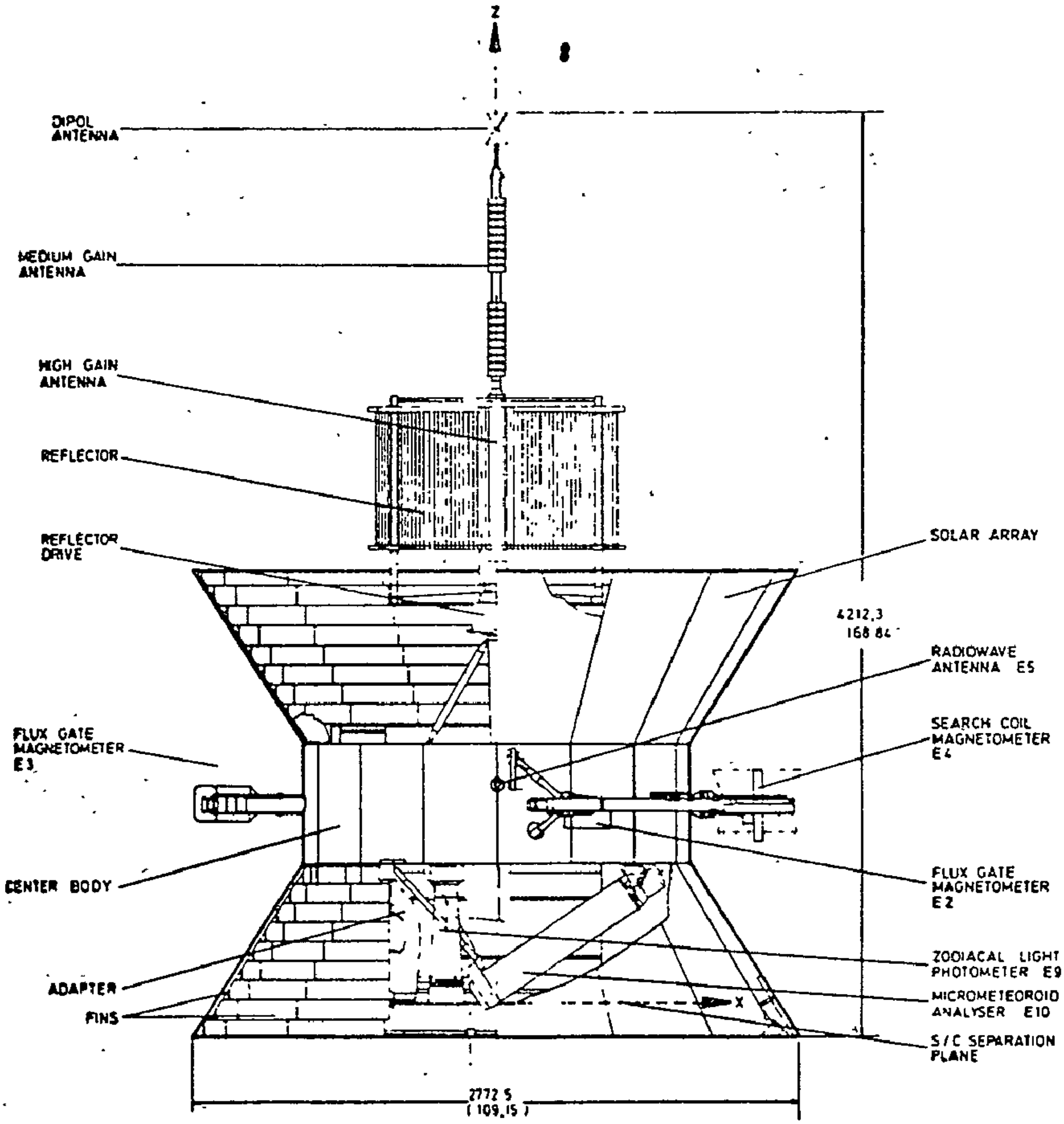


Figure 1 Spacecraft Launch Configuration

The spacecraft attitude control is performed by sun sensors and a cold nitrogen gas jet system. Coarse and fine sensors in the sun sensor assembly will be used to complete the initial acquisition sequence by orientation of the spacecraft spin axes to a position perpendicular to the spacecraft-sun line. Antenna signal strength measurements are used to bring the spin axes of the spacecraft perpendicular to the ecliptic plane. The final spin rate, 60 $\pm$ 1 RPM, will be achieved by the gas jet system, implemented by the ground command based on telemetered spin rate information.

A listing of the Helios B scientific experiments and the principal investigators is presented in Table 1.

TABLE 1 HELIOS SCIENTIFIC EXPERIMENTS

NUMBER	EXPERIMENT	INVESTIGATOR	AFFILIATION	SCIENTIFIC OBJECTIVES
1	Plasma Experiment	Rosenbauer and Pelkoffer Wolfe	Max Planck Institute, Garching Ames Research Center	Solar wind velocity measurement
2	Flux-Gate Magnetometer	Neubauer and Maier	Technical University of Braunschweig	Interplanetary magnetic field measurement
3	Flux-Gate	Ness and Burlaga Mariani and Cantarano	Goddard Space Flight Center University of Rome	Interplanetary magnetic field measurement
4	Search-Coil Magnetometer	Neubauer and Dehmel	Technical University of Braunschweig	Interplanetary magnetic field measurement from 4.7 Hz to 2.2 kHz
5	Plasma and Radio Wave Experiment	Gurnett Kellogg Stone Bauer	University of Iowa University of Minnesota Goddard Space Flight Center	Radio wave measurement from 50 kHz to 2 MHz Plasma measurement from 10 Hz to 100 kHz
6	Cosmic Ray Experiment	Hasler and Kunow	University of Kiel	Energy measurements on solar and galactic particles
7	Cosmic Ray Experiment	McDonald, Trainor Teegarden Roelof McCracken	Goddard Space Flight Center CSIRO Melbourne	Flow and energy measurements on solar and galactic particles Measurement of solar X-ray emission
8	Electron	Keppler and Wilken Williams	Max Planck Institute, Lindau/Harz GSFC	Counting of solar electrons
9	Zodiacal Light Photometer	Leinert and Pitz	Landessternwarte Heidelberg	Wavelength observation and polarization measurement of Zodiacal light
10	Micrometeroid Analyzer	Fechtig and Weihrauch	Max Planck Institute, Heidelberg	Mass and energy measurement of of interplanetary dust particles
11	Celestial Mechanics Experiment	Kundt Melbourne	University of Hamburg JPL	Verify relativity theories
12	Faraday Rotation Experiment	Levy Volland	JPL University of Bonn	Measurement of S-Band polarization due to radio wave passage through solar corona

Launch Vehicle Configuration

by K. A. Adams

The launch vehicle for Helios B was the five stage Titan IIIE/Centaur D-1TR/Delta TE-M-364-4 configuration. This was the second operational flight of this combination of stages.

The overall vehicle configuration is shown in Figure 2. The Titan vehicle consists of a two-stage liquid propulsion core vehicle manufactured by the Martin Marietta Corporation and two solid rocket motors (zero stage) manufactured by United Technology Center. The Titan vehicle integrator is Martin Marietta. The third stage is the Centaur D-1TR manufactured by General Dynamics Convair Division. For the Helios B mission the Delta TE-M-364-4 solid rocket stage, manufactured by McDonnell Douglas Astronautics Company and managed by Goddard Space Flight Center, was integrated into the configuration to provide additional velocity for this high energy mission.

The payload fairing for this configuration is the newly developed Centaur Standard Shroud (CSS) manufactured by Lockheed Missiles and Space Company, Inc. Figure 3 shows the Centaur/CSS/Helios B spacecraft general arrangement for this mission.

The following sections of the report give a summary description of the vehicle stage configurations. Detailed subsystem descriptions can be found in the Flight Data Report for Titan/Centaur TC-1 Proof Flight (NASA TM X-71692). Configuration differences from TC-1 were addressed in the Titan/Centaur TC-2, Helios A, Flight Data Report which was published in September 1975. Configuration differences from TC-2 will be addressed in this report.

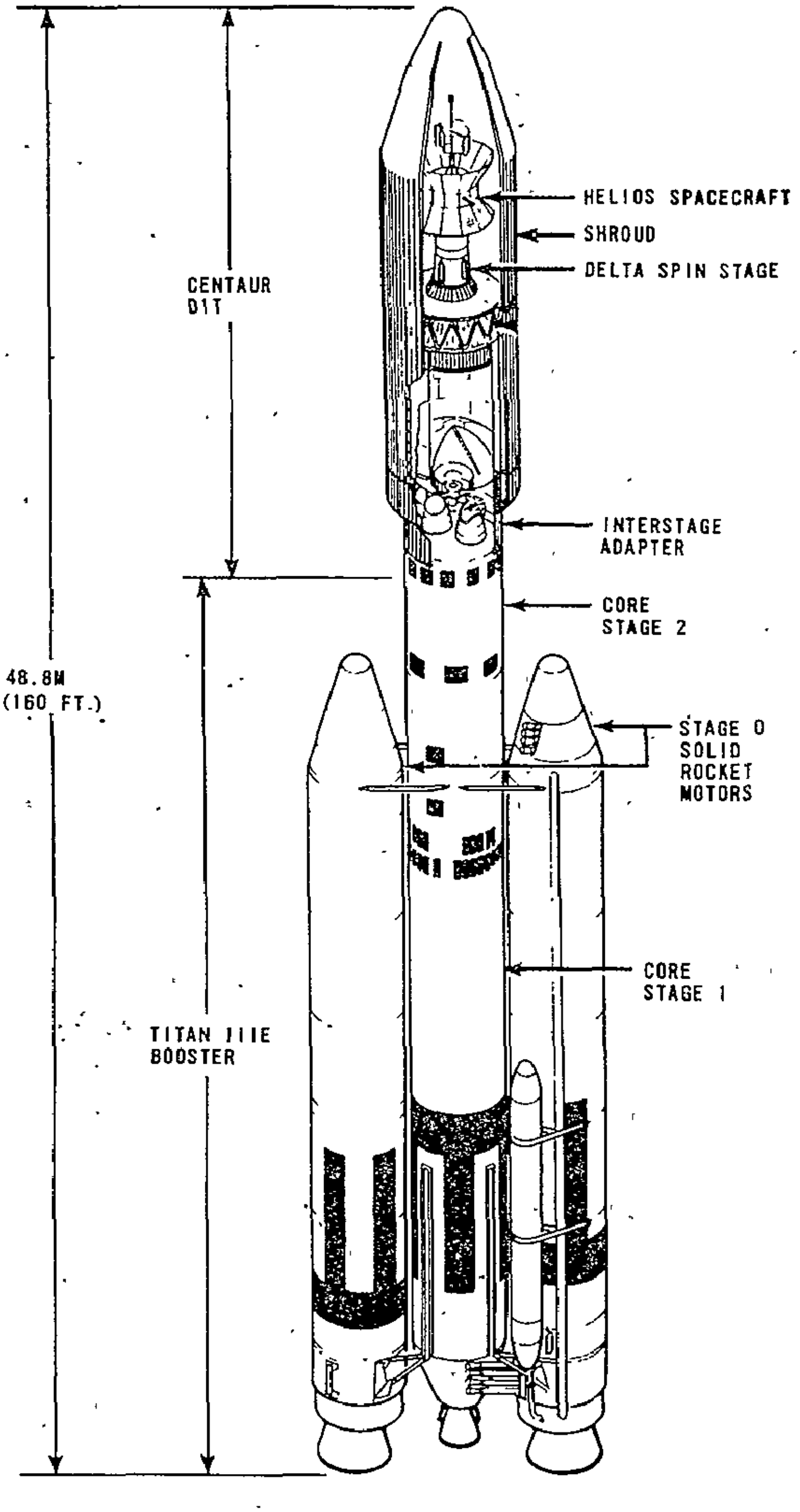


Figure 2 TITAN/CENTAUR Helios Vehicle (TC-5)

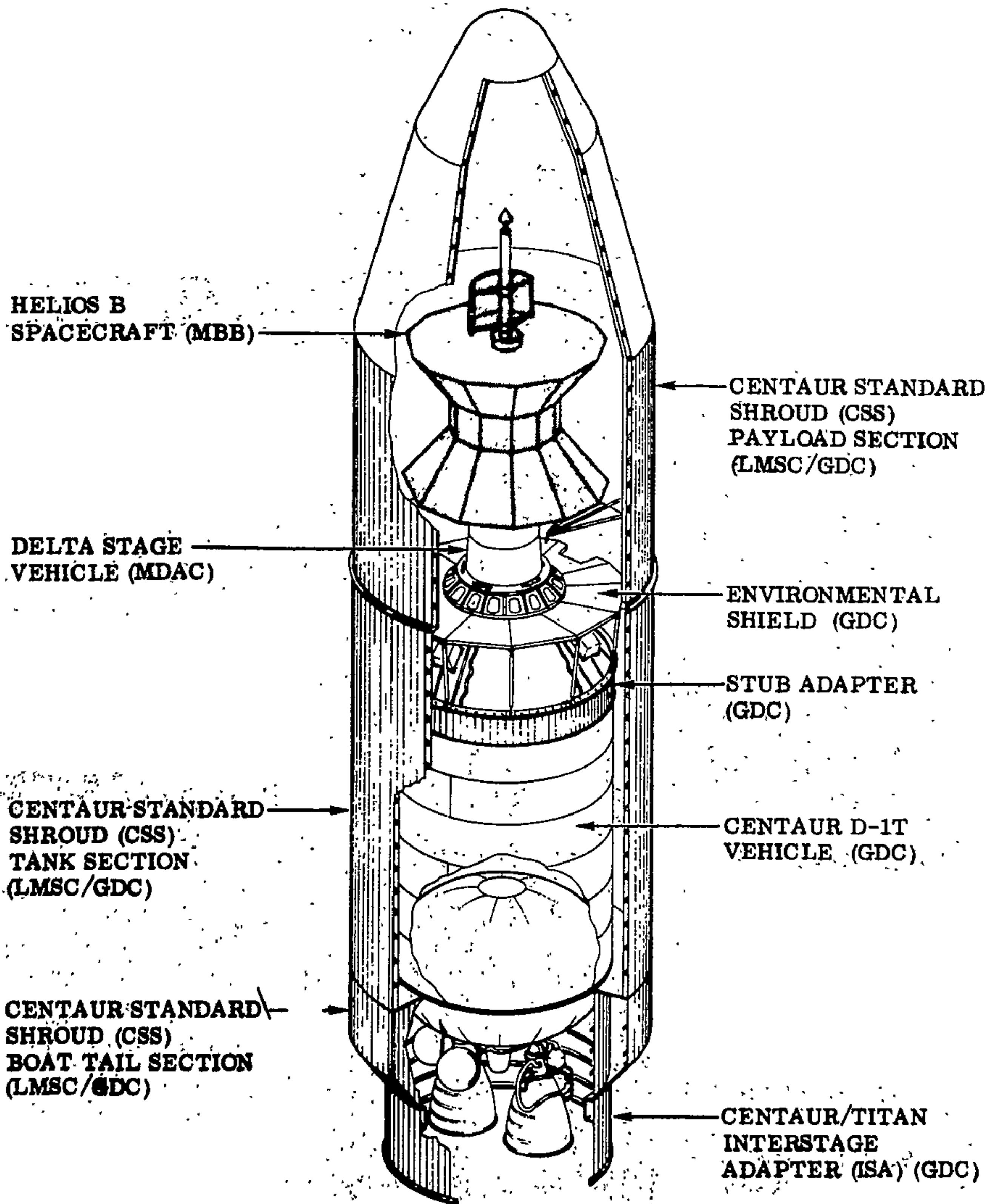


Figure 3
Centaur/CSS/Helios B Spacecraft General Arrangement

Titan IIIE

by J. L. Collins

The Titan/Centaur booster, designated Titan IIIE, was developed from the family of Titan III vehicles in use by the Air Force since 1964. The Titan IIIE is a modified version of the Titan IIID. Modifications were made to the Titan to accept steering commands and discretes from the Centaur inertial guidance system instead of a radio guidance system. In addition, a redundant programmer system was added. The Titan IIIE consists of two solid rocket motors designated Stage 0 and the Titan III core vehicle Stages I and II.

The two Solid Rocket Motors (SRMs) provide a thrust of 2.4 million pounds at liftoff. These motors, built by Chemical Systems Division, United Technologies, Inc., use propellants which are basically aluminum and ammonium perchlorate in a synthetic rubber binder. Flight control during the Stage 0 phase of flight is provided by a Thrust Vector Control (TVC) system in response to commands from the Titan flight control computer. Nitrogen tetroxide injected into the SRM nozzle through TVC valves deflects the thrust vector to provide control. Pressurized tanks attached to each solid rocket motor supply the thrust vector control fluid. Electrical systems on each SRM provide power for the TVC system.

Titan core Stages I and II are built by the Martin Marietta Corporation. The Stages I and II propellant tanks are constructed of welded aluminum panels and domes while interconnecting skirts use conventional aluminum sheet and stringer construction. The Stage II forward skirt provides the attach point for the Centaur stage and also houses a truss structure supporting most of the Titan IIIE electronics. A thermal barrier was added to isolate the Titan IIIE electronics compartment from the Centaur engine compartment.

Stages I and II are both powered by liquid rocket engines made by the Aerojet Liquid Rocket Company. Propellants for both stages are nitrogen tetroxide and a 50/50 combination of hydrazine and unsymmetrical dimethylhydrazine. The Stage I engine consists of dual thrust chambers and turbopumps producing 520,000 pounds thrust at altitude. Independent gimballing of the two thrust chambers, using a conventional hydraulic system, provides control in pitch, yaw, and roll during Stage I flight.

The Stage II engine is a single thrust chamber and turbopump producing 100,000 pounds thrust at altitude. The thrust chamber gimbals for flight control in pitch and yaw and the turbopump exhaust duct rotates to provide roll control during Stage II flight.

The Titan flight control computer provides pitch, yaw, and roll commands to the solid rocket motor's thrust vector control system and the Stages I and II hydraulic actuators. The flight control computer receives attitude signals from the three-axis reference system which contains three displacement gyros.

Vehicle attitude rates in pitch and yaw are provided by the rate gyro system located in Stage I. In addition, the flight control computer generates preprogrammed pitch and yaw signals, provides signal conditioning, filtering and gain changes, and controls the dump of excess thrust vector control fluid. A roll axis control change was added to provide a variable flight azimuth capability for planetary launches. The Centaur computer provides steering programs for Stage 0 wind load relief and guidance steering for Titan Stages I and II.

A flight programmer provides timing for flight control programs, gain changes, and other discrete events. A staging timer provides acceleration-dependent discretes for Stage I ignition and timed discretes for other events keyed to staging events. The flight programmer and staging timer, operating in conjunction with a relay package and enable-disable circuits, comprise the electrical sequencing system. On Titan IIIE a second programmer, relay packages, and other circuits were added to provide redundancy. Also, capability for transmitting backup commands was added to the Titan systems for staging of the Centaur Standard Shroud and the Centaur.

The standard Titan uses three batteries: one for flight control and sequencing, one for telemetry and instrumentation, and one for ordnance. On Titan IIIE additional separate redundant Range Safety Command system batteries were added to satisfy Range requirements.

The Titan telemetry system is an S-band frequency, pulse code modulation/frequency modulation (PCM/FM) system consisting of one control converter and remote multiplexer units. The PCM format is reprogrammable.

Many of the modifications to the Titan for Titan/Centaur were made to incorporate redundancy and reliability improvements. In addition to those modifications previously mentioned, a fourth retrorocket was added to Stage II in order to ensure proper Titan/Centaur separation if one motor does not fire. All redundancy modifications to Titan IIIE utilized Titan flight proven components.

Centaur D-1TR

by R. C. Kalo

The Centaur tank is a pressure-stabilized structure made from stainless steel (0.014 inches thick in cylindrical section). A double-walled, vacuum-insulated intermediate bulkhead separates the liquid oxygen tank from the liquid hydrogen tank.

The entire cylindrical section of the Centaur LH_2 tank is covered by a radiation shield. This shield consists of three separate layers of an aluminized Mylar-dacron net sandwich. The forward tank bulkhead and tank access door are insulated with a multilayer aluminized Mylar. The aft bulkhead is covered with a membrane which is in contact with the tank bulkhead and a rigid radiation shield supported on brackets. The membrane is a layer of dacron-reinforced aluminized Mylar. The radiation shield is made of laminated nylon fabric with aluminized Mylar on its inner surface and white polyvinyl flouride on its outer surface.

The forward equipment module, an aluminum conical structure, attaches to the tank by a short cylindrical stub adapter. Attached to the forward ring of the equipment module is an adapter which forms the mounting structure for the Delta (fourth) stage.

Two modes of tank pressurization are used. Before propellant tanking, a helium system maintains pressure. With propellants in the tank, pressure is maintained by propellant boiloff. During flight, the airborne helium system provides supplementary pressure when required. This system also provides pressure for the H_2O_2 and engine controls system.

Primary thrust is provided by two Pratt & Whitney RL10A3-3 engines, which develop 15,000 pounds total thrust each. The engines are fed by hydrogen peroxide fueled boost pumps. Engine gimballing is provided by a separate hydraulic system on each engine.

During coast flight, attitude control is provided by four H_2O_2 engine cluster manifold assemblies mounted on the tank aft bulkhead on the peripheral center of each quadrant. Each assembly consists of two six pound lateral thrust engines manifolded together.

A retrothrust system consisting of two diametrically opposite nozzles mounted on the tank aft bulkhead and canted 45 degrees from the vehicle longitudinal center line provides the thrust for separating the Centaur from the Delta stage. Actuation of two parallel mounted pyrotechnic valves vent residual helium from the storage bottle through the two retrothrust nozzles.

A propellant utilization system controls the engine mixture ratio to ensure that both propellant tanks will be emptied simultaneously. Quantity measurement probes are mounted within the fuel and oxidizer tanks.

The Centaur D-lT astrionics system's Teledyne Digital Computer Unit (DCU) is an advanced, high-speed computer with a 16,384 word random access memory. From the DCU discretes are provided to the Sequence Control Unit (SCU). Engine commands go to the Servo Inverter Unit (SIU) through six Digital-to-Analog (D/A) channels.

The Honeywell Inertial Reference Unit (IRU) contains a four-gimbal, all-attitude stable platform. Three gyros stabilize this platform on which are mounted three pulse-balanced accelerometers. A prism and window allow for optical azimuth alignment. Resolvers on the platform gimbals transform vector components from inertial to vehicle coordinates. A crystal oscillator, which is the primary timing reference, is also contained in the IRU.

The System Electronic Unit (SEU) provides conditioned power and sequencing for the IRU. Communication from the IRU to the DCU is through three analog-to-digital channels (for attitude and rate signals) and three incremental velocity channels. The SEU and IRU combination forms the Inertial Measurement Group (IMG).

The Centaur D-lTR system also provides guidance for Titan, with the stabilization function performed by the Titan.

The central controller for the Centaur Pulse Code Modulation (PCM) telemetry system is housed in the DCU. System capacity is 267,000 bits per second. The central controller services two Teledyne remote-multiplexer units on the Centaur D-lTR.

The C-band tracking system provides ground tracking of the vehicle during flight. The airborne transponder returns an amplified radio-frequency signal when it detects a tracking radar's interrogation.

The Centaur uses a basic dc power system, provided by batteries and distributed via harnessing. The servo inverter provides ac power, 26 and 115 volts, single phase, 400 Hz.

Delta TE-M-364-4

by R. C. Kalo

The Delta Stage (alternately referred to as Fourth Stage or TE-M-364-4 Stage) major assemblies consist of a spin table, TE-M-364-4 solid propellant rocket motor, batteries, telemetry system, C-band radar transponder, destruct system, motor separation clamp, payload attach fitting, and a spacecraft separation clamp. The Delta Stage-to-Centaur interface is between the Centaur cylindrical adapter and the Delta spin table lower (non-rotating) conical adapter.

The spin table assembly includes a four-segment petal adapter mounted on a bearing attached to the non-rotating conical adapter. During the separation sequence, the eight spin rockets which are mounted on the spin table are ignited, spinning up the stage to provide stability, the two redundant motor separation clamp explosive bolt assemblies are initiated, and centrifugal force swings the adapter segments back on their hinges to free the Delta Stage, the payload attach fitting and the Helios spacecraft.

The TE-M-364-4 rocket motor provides an average thrust of 14,900 pounds over its action time of about 44 seconds.

The MDAC 3731 Payload Attach Fitting (PAF) is a cylindrical aluminum structure 31 inches high and approximately 37 inches in diameter. Fourteen vertical aluminum stiffeners are mounted externally on the attach fitting structure. Four formed stiffeners, mounted internally, serve as spacecraft separation spring supports. The base of the attach fitting is attached to the forward support ring of the TE-M-364-4 motor. The Helios spacecraft is fastened to the attach fitting by means of a V-band clamp. Four separation springs are utilized, each exerting a force of approximately 130 pounds on the spacecraft in the mated configuration. After separation of the Helios spacecraft from the Delta Stage, a yo-weight system is deployed on Delta to tumble the stage to neutralize residual motor thrust and prevent impact with the spacecraft.

Centaur Standard Shroud

by T. P. Cahill

The Centaur Standard Shroud is a jettisonable fairing designed to protect the Centaur vehicle and its payloads for a variety of space missions. The Centaur Standard Shroud, as shown in Figure 4, consists of three major segments: a payload section, a tank section, and a boattail section. The 14-foot diameter of the shroud was selected to accommodate Viking spacecraft requirements. The separation joints sever the shroud into clamshell halves.

The shroud basic structure is a ring stiffened aluminum and magnesium shell. The cylindrical sections are constructed of two light gage aluminum sheets. The outer sheet is longitudinally corrugated for stiffness. The sheets are joined by spot welding through an epoxy adhesive bond. Sheet splices, ring attachments, and field joints employ conventional rivet and bolted construction. The biconic nose is a semi-monocoque mangesium-thorium single skin shell. The nose dome is stainless steel. The boattail section accomplishes the transition from the 14-foot shroud diameter to the 10-foot Centaur interstage adapter. The boattail is constructed of a ring stiffened aluminum sheet conical shell having external riveted hat section stiffeners.

The Centaur Standard Shroud modular concept permits installation of the tank section around the Centaur independent of the payload section. The payload section is installed around the spacecraft in a special clean room, after which the encapsulated spacecraft is transported to the launch pad for installation on the Centaur.

The lower section of the shroud provides insulation for the Centaur liquid hydrogen tank during propellant tanking and prelaunch ground hold operations. This section has seals at each end which close off the volume between the Centaur tanks and the shroud. A helium purge is required to prevent formation of ice in this volume.

The shroud is separated from the Titan/Centaur during Titan Stage II flight. Jettison is accomplished when an electrical command from the Centaur initiates the Super-Zip separation system detonation. Redundant dual explosive cords are confined in a flattened steel tube which lies between two notched plates around the circumference of the shroud near the base and up the sides of the shroud to the nose dome. The pressure produced by the explosive cord detonation expands the flattened tubes, breaking the two notched plates and separating the shroud into two halves.

To ensure reliability, two completely redundant electrical and explosive systems are used. If the first system should fail to function, the second is automatically activated as a backup within one-half second.

The Titan pyrotechnic battery supplies the electrical power to initiate the Centaur Standard Shroud electric pyrotechnic detonators. Primary and backup jettison discrete signals are sent to the Titan squib firing circuitry by the Centaur Sequence Control Unit (SCU). A tertiary jettison signal, for additional redundancy, is derived from the Titan staging timer.

Four base-mounted, coil-spring thrusters force each of the two severed shroud sections to pivot about hinge points at the base of the shroud. After rotating approximately 60 degrees, each shroud half separates from its hinges and continues to fall back and away from the launch vehicle.

Two additional sets of springs are installed laterally across the Centaur Standard Shroud split lines; one set of two springs in the upper nose cone to assist in overcoming nose dome rubbing friction and one set of two springs at the top of the tank section to provide additional impulse during Centaur/shroud jettison disconnect breakaway.

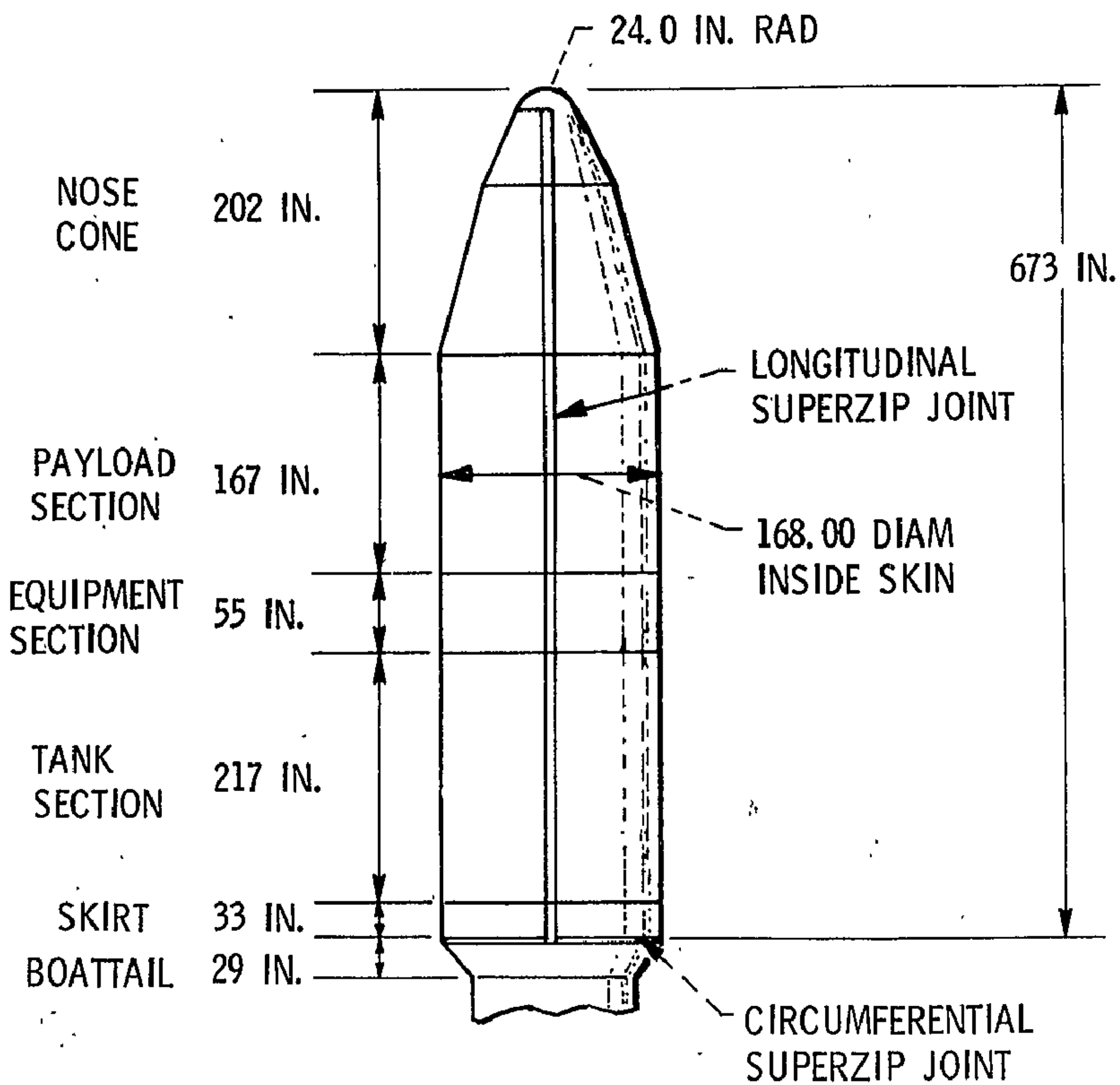


FIGURE 4 - CENTAUR STANDARD SHROUD CONFIGURATION

IV MISSION PROFILE AND PERFORMANCE SUMMARY

IV MISSION PROFILE AND PERFORMANCE SUMMARY

Flight Trajectory and Performance Data

by J. P. Riehl

Stage 0 ignition for the TC-5 launch vehicle occurred at 0534:00:36 GMT (0034:00:36 EST) on Thursday, January 15, 1976, with liftoff occurring approximately 0.47 seconds later. The ADDJUST-designed Titan Stage 0 steering programs for aerodynamic load relief were based on a Jimsphere balloon which was released 2.25 hours prior to the expected launch time.

The flight sequence of events is contained in Table 2. The Helios B portion of the mission extended from Stage 0 ignition through the TE-364-4 burn and spacecraft separation. The Centaur extended mission commenced after the separation of the TE-364-4/Helios B from the Centaur.

The Stage 0 phase of flight was almost nominal. The ignition of the Stage I engines (87FS1) occurred at 114.14 seconds into the flight which was about 1.3 seconds later than predicted. At 12.0 seconds after Stage I ignition, 126.2 seconds into the flight, the Solid Rocket Motors (SRMs) were jettisoned. The comparison of the DCU telemetry data with the preflight predicted trajectory showed the vehicle was about 1700 feet low in position and 65 feet/second low in velocity at SRM jettison.

The duration of Stage I portion of flight was 2.79 seconds longer than predicted. The Stage I/Stage II staging sequence commenced at 265.64 seconds with Stage I shutdown (87FS2) and was completed with separation occurring at 265.68 seconds.

The Stage II ignition signal (91FS1) was sent simultaneously with the Stage I shutdown signal (87FS2). The vehicle was approximately 3100 feet lower in altitude and 63 feet/second lower in velocity than predicted at the time of Stage I shutdown.

During the Titan Stage II portion of flight, the Centaur Sequence Control Unit (SCU) commanded jettison of the Centaur Standard Shroud at 325.64 seconds into flight. This event is commanded by the Centaur SCU 60 seconds after the Centaur flight computer senses Titan Stage I shutdown.

The duration of the Titan Stage II portion of flight was 7.14 seconds longer than predicted, with Stage II shutdown occurring at 478.54 seconds into the flight. The Centaur DCU commanded Stage II separation 4.7 seconds after sensing the shutdown deceleration.

The vehicle was 900 feet high in altitude and 77 feet/second low in velocity at Titan/Centaur separation. These dispersions were well within the expected tolerances.

Centaur main engine start (MES-1) for first burn occurred at 493.74 seconds into flight. The Centaur first burn terminated upon successful insertion into the parking orbit at 595.08 seconds into flight. Table 3.1 shows that a highly accurate parking orbit was achieved.

The Centaur coasted in parking orbit for 28.17 minutes in a propellant settled mode. The Centaur second burn of 289.38 seconds occurred at the end of the coast with main engine start (MES-2) at 2285.42 seconds into the flight and the guidance system commanding MECO-2 at 2574.80 seconds.

Seventy seconds after MECO-2, the TE-M-364-4 and spacecraft were spun up. Separation occurred two seconds later. The second burn orbital data is shown in Table 3.2 at TE-M-364-4 separation from the Centaur. The orbital data indicates a very accurate orbit was achieved by the Centaur second burn.

The TE-M-364-4 burn completed the Helios portion of flight placing the spacecraft into its final heliocentric orbit. The burn appeared to be about one-half second shorter than nominal. The orbital elements at spacecraft separation, which occurred at 2804.03 seconds, are presented in Table 3.3. A slightly lower velocity, approximately 27 feet/second, was achieved by the TE-M-364-4. The free-fall trajectory simulation of the orbital elements to perihelion passage, which is presented in Table 4, shows that a very accurate Helios B heliocentric orbit was obtained.

The Centaur, after the TE-M-364-4 was separated, performed five additional firings of the main engines. The third start was to demonstrate the capability to coast at least five and one-quarter hours in a zero-g mode and fire the engines in simulation of a high altitude geosynchronous mission sequence. Several propellant management experiments were performed in this Centaur extended mission.

The Centaur was aligned along the minus earth radius vector for all of the additional burns. The resultant orbit after each of the additional burns was geocentric hyperbolic.

During the five and one-quarter hour coast, after MECO 2, the Centaur performed a slow roll and four fast rolls. The Centaur third burn occurred at 21474.8 seconds after SRM ignition with a burn duration of 11 seconds. This was followed by a 30-minute zero-g coast in which a fast roll was performed. MES-4 occurred at 23285.8 and lasted 13.04 seconds. After a 20 minute zero-g coast, MES-5 occurred at 24498.84 seconds with MECO-5 occurring 6 seconds later as planned. A five minute settled coast preceded a sixth burn of 6.2 seconds in duration. This was followed by 2 hour zero-g coast, in which three fast rolls occurred, and the seventh and last Centaur main engine start at 32011.2 seconds into the flight. The duration of this burn was 7.1 seconds.

The orbital elements for the extended mission are tabulated in Tables 5.1 and 5.2. The orbit accuracy is considered satisfactory since the last five Centaur burns were not guided. Because of insufficient tracking of the Centaur during the extended mission, confirmation of the orbital parameters was not possible.

TABLE 2

TC-5 HELIOS B SEQUENCE OF EVENTS

EVENT DESCRIPTION	NOMINAL (T+SECS.)	ACTUAL (T+SEC)
GO INERTIAL	T-6	T-6
STAGE 0 (SRM's) IGNITION	T+0.0	T=0
LIFT-OFF	.2117	.47
FORWARD BEARING REACTOR SEPARATION	100.	100.1
STAGE I IGNITION (87.FS1)	112.84	114.135
STAGE 0 (SRM's) JETTISON	124.16	126.2
STAGE I SHUTDOWN (87FS2/91FS1)	261.45	264.88
STEP I JETTISON/STAGE II IGNITION	262.28	265.68
CENTAUR STD SHROUD JETTISON	323.00	325.6
STAGE II SHUTDOWN (91FS1)	468.001	478.54
STAGE II JETTISON (T/C SEP)	474.22	483.24
CENTAUR MES 1	484.72	493.74
CENTAUR MECO 1	582.96	595.08
CENTAUR MES 2	2275.92	2285.42
CENTAUR MECO 2	2569.96	2574.80
TE-364-4 SPINUP	2639.96	2644.80
TE-364-4 SEPARATION	2641.96	2646.80
CENTAUR RETRO		
TE-364-4 IGNITION	2683.96	2692.0
TE-364-4 BURNOUT	2727.76	2735.6

TABLE 2 (CONT'D)

TC-5 HELIOS B SEQUENCE OF EVENTS

SPACECRAFT SEPARATION	2799.96	2804.03
TE-364-4 YO DEPLOY	2801.96	2806.03
CENTAUR MES 3	21469.96	21474.8
CENTAUR MECO 3	21480.96	21485.8
CENTAUR MES 4	23280.96	23285.8
CENTAUR MECO 4	23295.46	23298.84
CENTAUR MES 5	24495.46	24498.84
CENTAUR MECO 5	24501.46	24504.84
CENTAUR MES 6	24801.46	24804.84
CENTAUR MECO 6	24808.30	24811.04
CENTAUR MES 7	32008.3	32011.2
CENTAUR MECO 7	32015.3	32018.3

SRM IGNITION TIME 5:34:00:355 Z JANUARY 15, 1976

TABLE 3.1

HELIOS B ORBITAL DATA

	PARKING ORBIT (MECO-1 + DECAY)		
	NOMINAL	DCU TELEMETRY	ANTIGUA TRACKING
EPOCH (SECS)	583.47	596.02	593.9
PERIGEE ALT (N.MI.)	86.29	86.50	87.20
APOGEE ALT (N.MI.)	89.80	89.78	89.67
SEMI MAJ. AXIS (N.MI.)	3531.98	3530.07	3532.37
ECCENTRICITY (N.D.)	.0004973	.000464	.0003491
INCLINATION (DEG)	30.303	30.315	30.302
ARG. OF PERIGEE (DEG)	312.045	302.74	297.677
$C_3 (KM^2/SEC^2)$	-60.937	-60.936	-60.9301

TABLE 3.2

HELIOS B ORBITAL DATA

	CENTAUR SECOND BURN		
	NOMINAL	DCU TELEMETRY	TRACKING
EPOCH (SECS)	2570.00	2570.00	2570.00
PERIGEE ALT (N.MI.)	106.21	106.64	105.77
APOGEE ALT (N.MI.)			
SEMI MAJ. AXIS (N.MI.)	-12360.92	-12339.61	-12357.21
ECCENTRICITY (N.D.)	1.2870	1.2877	1.2873
INCLINATION (DEG)	30.301	30.305	30.335
ARG. OF PERIGEE (DEG)	260.837	260.868	260.793
C_3 (KM^2/SEC^2)	17.400	17.42	17.44

TABLE 3.3

HELIOS B ORBITAL DATA

	FOURTH STAGE ORBIT AFTER TE-364-4 BURN		
	NOMINAL	DCU TELEMETRY	VANGUARD TRACKING
EPOCH (SECS)	2727.79	2720.75	2728.9
PERIGEE ALT (N.MI.)	148.58	148.588	153.63
APOGEE ALT (N.MI.)			
SEMI MAJ. AXIS (N.MI.)	-2153.02	-2159.27	-2157.70
ECCENTRICITY (N.D.)	2.6686	2.6688	2.6673
INCLINATION (DEG)	30.301	30.3053	30.278
ARG. OF PERIGEE (DEG)	266.435	266.4297	266.667
C_3 (KM^2/SEC^2)	99.965	99.9759	99.7486

TABLE 4

SPACECRAFT HELIOCENTRIC TRAJECTORY

	NOMINAL	ACTUAL (1)	DIFF	3 SIGMA
PERIHELION DISTANCE (A.U.)	0.29	.29038	-.00038	±.000927
INCLINATION (DEG)	0.0	.01935	-.01935	±.201

(1) BASED ON DSS-42 TRACK

TABLE 5.1

CENTAUR EXTENDED MISSION ORBITAL DATA

Parameter	5½ Hour Coast		Post MECO-3		Post MECO-4	
	Nominal	DCU Telemetry	Nominal	DCU Telemetry	Nominal	DCU Telemetry
EPOCH (SEC)	20844.00	20768.02	21481.46	21496.02	23295.97	23310.02
PERIGEE ALT. (N.M.)	107.54	100.64	221.96	227.98	434.60	499.60
SEMI MAJOR AXIS (N.M.)	-12358.23	-12373.92	-15053.20	-15198.63	-21373.42	-20964.85
ECCENTRICITY	1.2874	1.2865	1.2435	1.2416	1.1815	1.1881
INCLINATION (DEG.)	30.3123	*	30.2779	30.9367	30.3951	30.3539
ARG. OF PERIGEE	260.904	*	259.199	258.5	256.361	256.982
C_3 (KM^2/SEC^2)	17.4157	17.3937	14.2978	14.1610	10.0699	10.2662

* DATA NOT AVAILABLE

TABLE 5.2

CENTAUR EXTENDED MISSION ORBITAL DATA

Parameter	Post MECO-5 Nominal	Post MECO-5 DCU Telemetry	Post MECO-6 Nominal	Post MECO-6 DCU Telemetry	Post MECO-7 Nominal	Post MECO-7 DCU Telemetry
EPOCH (SEC)	24501.96	24516.02	24808.8	24822.02	32015.8	32020.03
PERIGEE ALT. (N.M.)	525.00	612.56	642.81	772.36	779.87	801.05
SEMI MAJOR AXIS (N.M)	-25291.22	-24768.52	-32380.67	-30930.49	-44615.92	-45352.21
ECCENTRICITY	1.1569	1.1638	1.1262	1.1363	1.0947	1.100
INCLINATION (DEG)	30.343	29.9471	30.331	29.3285	30.283	28.479
ARG. OF PERIGEE	255.122	256.3	253.464	255.8	251.502	254.451
C_3 (KM^2/SEC^2)	8.5100	8.6896	6.6468	6.9585	4.824	5.082

Titan Phase of Flight

by J. L. Collins

Stage 0 (SRM) ignition and liftoff was nominal followed by a normal pitchover and ascent flight. Performance parameters and steering profiles were near predicted values. SRM web action time was slightly long and a longer than expected tailoff time was noted. There were no adverse effects.

Stage I thrust and specific impulse were slightly less than predicted with a negative mixture ratio shift which resulted in less than predicted outage. Both the oxidizer and fuel tank pressures were approximately 2 psia below predicted throughout the flight but within acceptable operating limits. Overall stage performance was satisfactory.

Following a nominal Stage I/II separation event, Stage II burned to propellant depletion in a normal manner. Thrust and propellant flow rates were low with a burn time over 7 seconds longer than nominal. Depletion was near simultaneous with fuel leading. The shutdown transient was very rough compared to an oxidizer leading shutdown which is characteristic of this type depletion. Stage II/Centaur staging was normal.

The Titan completed its portion of the mission successfully with a velocity at Stage II separation which was 77 fps less than predicted and an altitude of 900 feet greater than predicted, both well within expected dispersions.

Centaur Phase of Flight - Primary and Extended Mission

by F. L. Manning

Centaur (TC-5) successfully placed the Helios spacecraft into a highly accurate heliocentric orbit with the required attitude alignment. Following separation of the TE-M-364-4/Helios payload, the Centaur vehicle proceeded into an 8-1/3 hour experiment phase which successfully accomplished all objectives.

Centaur performance was entirely satisfactory. The Helios mission was performed using a two-burn, settled parking orbit ascent mode. The post-Helios experiment phase consisted of a 5-1/4 hour zero-g coast during which thermal conditioning roll maneuvers were performed. During the final 3-1/4 hours of this coast, attitude control limits were reduced. The third burn was unguided and had a fixed duration of 11 seconds. The second zero-g coast was 30 minutes in duration and included thermal conditioning maneuvers. Prior to the fourth burn, the propellant settling impulse was reduced to below nominal and a settling engine failure was simulated. The fourth burn duration was based on total vehicle mass (as determined by measuring vehicle axial acceleration). This was followed by a 20 minute zero-g coast period. The fifth burn duration was 6 seconds with tank pressures, and prechill and childown times, reduced to below nominal conditions. The fifth coast was 5 minutes long and had continuous settling. The sixth burn was preceded by reduced impulse propellant settling, lower tank pressures, and shorter childown times. The sixth burn length was defined by the total vehicle mass (determined by the vehicle axial acceleration). The sixth coast period was two hours in length and included thermal conditioning roll maneuvers. The seventh Centaur burn was for a fixed duration of 7 seconds and had reduced propellant settling time, lower tank pressures, and shorter prechill and childown times prior to MES. Following the seventh burn, additional engineering investigations were performed, which included an H_2O_2 depletion experiment, a boost pump deadhead experiment, and sequential venting of the LH_2 and LO_2 tanks. All Helios mission objectives, Titan/Centaur operational capability objectives, and the Centaur experiment phase objectives were satisfied. These objectives are listed as follows:

Helios Mission Peculiar

1. The launch vehicle injected the Helios spacecraft into the required heliocentric orbit.

2. Centaur aligned the TE-M-364-4 stage for spacecraft injection burn.

3. Centaur generated the TE-M-364-4 stage spinup and separation commands.

4. Centaur executed a retrothrust maneuver following separation of the TE-M-364-4.

5. Vibration data on the TE-M-364-4 payload adapter was obtained.

6. Centaur Standard Shroud (CSS) payload cavity pressure and temperature data were obtained.

7. Total impulse of the TE-M-364-4 was verified.

Titan/Centaur Operational Capability

1. D-1TR Centaur operational two-burn mission capability was demonstrated.

2. D-1TR Centaur vibration loads data were obtained.

3. Thermal performance of the D-1TR Centaur insulation system (two-burn mission) was demonstrated.

4. Performance of the computer controlled vent and pressurization system was demonstrated.

5. CSS ascent venting and control of cavity differential pressures were demonstrated.

Extended Mission Experiment Phase

1. Data was obtained to evaluate high altitude synchronous orbit injection capability (5-1/4 hours second coast and third start).

2. Data was obtained to evaluate the basic Centaur minimum coast restart capability.

3. Data was obtained which demonstrated an extended flight multiple coast/restart capability (total of five burns, five coasts).

4. Data was obtained to evaluate systems performance from extended flight environments and other experiments as listed below:

- Coast thermal control maneuvers

- Coast attitude control with wide, narrow, and precision limits

- LO_2 tank pressure history with reduced zero-g purge rate

- Boost pump deadhead operation test
- Helium consumption monitor
- Restart sequence with simulated settling engine failure
- H_2O_2 propellant residual/depletion experiment
- Propulsion restart sequences with reduced:
  - Propellant settling impulse
  - Tank pressurization levels
  - Boost pump deadhead durations
  - Chilldown durations (with and without prechills)

V VEHICLE DYNAMICS

V VEHICLE DYNAMICS

by J. C. Estes and R. P. Miller

The dynamic loads on the TC-5 flight were assessed using data from the following flight accelerometers: GA1A (axial -5 to +20 g's), GA2A and GA3A (lateral -6 to +4 g's). The GA accelerometers were located near the base of the Helios spacecraft. Three accelerometers located on the Centaur equipment module were also studied: CA6850 (axial -2 to +8 g's), CA6860 (radial ± 1.5 g's) and CM101A (axial -2 to +8 g's).

Acceleration data from all accelerometers indicated response within expected levels during all dynamic load conditions. The following comments summarize the TC-5 flight data at significant loading conditions and compare TC-5 data to the previous (TC-2) flight and maximum expected levels.

Liftoff - Response at liftoff was similar to that observed on TC-2 but at slightly lower amplitude. The following table summarizes the maximum zero-to-peak payload accelerations.

	Axial GA1A G's	Lateral GA2A G's	Lateral GA3A G's
TC-2	.51	.70	1.00
TC-5	.50	.70	.80
Maximum Expected	.40	.87	1.22

The values in the summary table indicate the maximum measured responses were enveloped by the maximum expected values except for the GA1A, axial acceleration. The present analytical definition of the Titan launch transient is slightly unconservative for response in the axial direction. The design loads for the Helios spacecraft for axial loads were based upon acceleration experienced at the ignition of the TE-364 motor. While the axial acceleration measured on TC-5 (and TC-2) was approximately 25 percent higher than analytically predicted, the loads induced by the response are relatively small in relation to the structural capability. From a total load or equivalent axial load standpoint, the spacecraft loads at liftoff were enveloped by expected values and within the spacecraft structural capability.

Buffet - Response during maximum aerodynamic buffeting was similar to that seen on TC-2 and was well enveloped by maximum expected values. Maximum zero-to-peak values are summarized in the following table.

	Axial GA1A G's	Lateral GA2A G's	Lateral GA3A G's
TC-2	.38	.60	.33
TC-5	.47	.50	.40
Maximum Expected	.56	1.11	1.19

Maximum Air Loads - The post-launch measured wind profiles and the flight steering program (A20) provided vehicle response within the structural allowable as indicated by the 6-D trajectory simulations.

Steering Design	Balloon Release Time	Percent of Allowable: Structural Load	Control Side Force	TVC Usage
J-135	0319Z	80	35	51
W-85	0412Z	82	--	53
W-5	0529Z	86	33	55
J+91	0705Z	88	40	57

The data presented in the above table indicates that the latest load determination prior to liftoff (J-135) indicated loads 80 percent of allowable. Post-launch data (W-85 and W-5) indicate the vehicle actually experienced loads between 82 percent and 86 percent of allowable. The 0319Z (design) and 0529Z pitch and yaw component wind profiles are shown in figure 5.1 and 5.2.

Stage I Flight - Expected FLMN (First Longitudinal Modal Noise) levels were seen on TC-5 during the major portion of flight. The FLMN levels are the response of the structure to the normal random excitation from the Stage I engines. The g levels at the Centaur forward end reach a maximum of ± 0.4 g approximately seven seconds prior to Stage I shutdown with a frequency of 8 Hz. The first closed loop propellant/structural instability longitudinal mode frequency at this time is 15 Hz. TC-2 experienced POGO response five seconds prior to Stage II shutdown which reached levels of ± 1.0 g at 15 Hz, the first longitudinal frequency of the overall

FIG. 5.1 JIMSPHERE BALLOON RELEASED AT 0319Z, 1-15-76

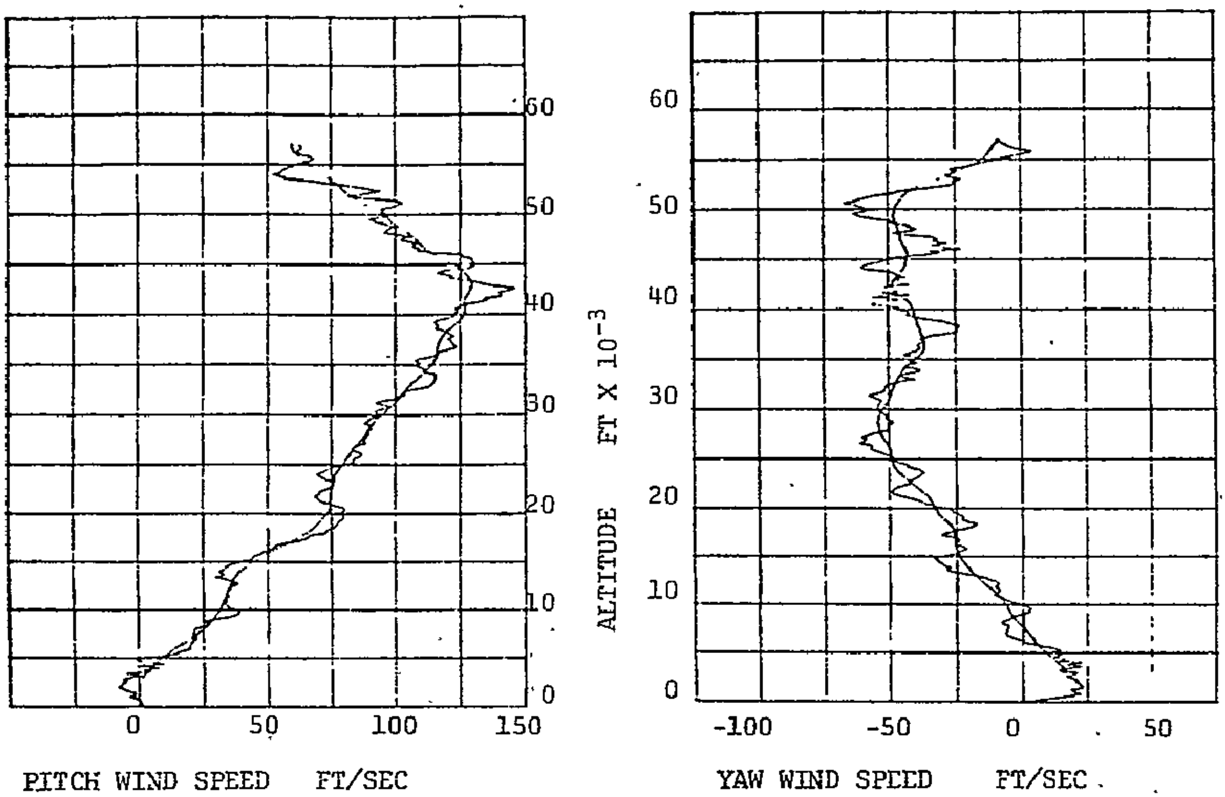
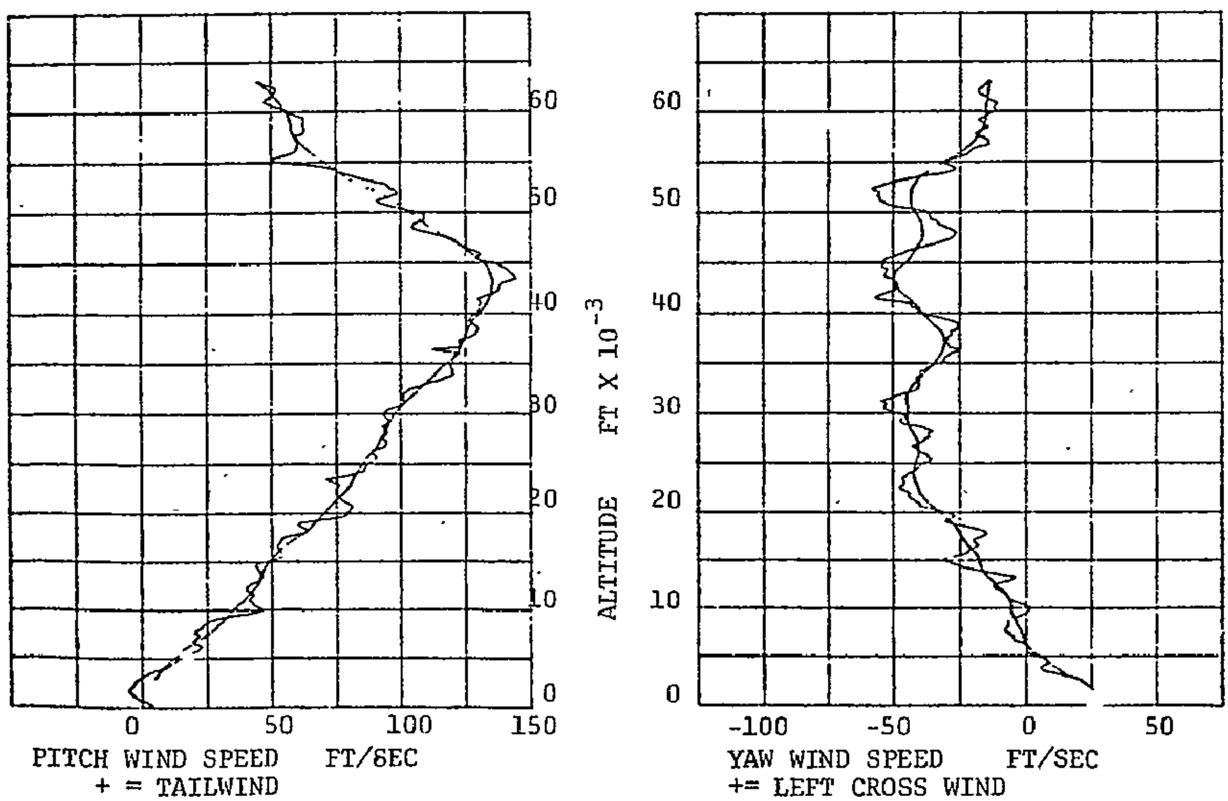


FIG. 5.2 WINDSONDE BALLOON RELEASED AT 0529Z, 1-15-76



vehicle. TC-5 incorporated oxidizer line POGO accumulators, as did TC-3 and 4, and review of its propulsion data indicates no POGO behavior occurred.

Stage I Shutdown - The longitudinal response at Stage I shutdown indicated a very smooth oxidizer depletion shutdown. Response was well below maximum expected levels.

Stage II Shutdown - The maximum spacecraft response during the Stage II shutdown transient on TC-5 is summarized in the following table and compared to TC-2 and expected maximum levels.

	Axial GA1A G's	Lateral GA2A G's	Lateral GA3A G's
TC-2	±1.0	±.10	±.20
TC-5	± .75	±.075	±.10
Maximum Expected	+3.83 -1.18	+.078 -.180	+.349 -.150

The data indicates the spacecraft response was well within the maximum expected levels.

The response of the forward end of Stage II, however, was higher than observed on previous flights. The following table summarizes the TC-5 maximum response and compares it to data from TC-2, TC-3, and TC-4. The Stage II response was monitored with three accelerometers, TA2325A sensing axially with a range of -2.5 to +7.5 g, TA2326A and TA2327A sensing laterally in yaw and pitch respectively with a range of ±2.5 g's.

Flight	Axial TA2325A G's	Lateral TA2326A G's	Lateral TA2327A G's	Type of Shutdown
TC-2	±1.7	± .85	± .95	Started fuel exhaustion and went to oxidizer depletion.
TC-3	±1.2	±1.05	±1.10	Fuel depletion.
TC-4	± .90	± .45	± .40	Oxidizer depletion.
TC-5	±2.3	±1.15	±1.35	Started fuel exhaustion and went to oxidizer depletion.

The major response presented in the preceding table occurred at a frequency near 33 Hz. Response in the 33 Hz range is usually too high to be a significant load condition for primary structures, however, it could be a concern for components.

VI SOFTWARE PERFORMANCE

VI SOFTWARE PERFORMANCE

Airborne

by J. L. Feagan

All available DCU flight telemetry data were thoroughly reviewed to verify that the flight software performed as designed. The data reviewed included analog plots of the DCU inputs (A/D's) and outputs (D/A's), and digital listings of the SCU switch commands used to verify the proper operation of each module of the flight program as well as the transfer of data between the various modules. The details of the software performance are elaborated upon in the descriptions of the various flight systems; e.g., PU, flight control, guidance, CCVAPS, and trajectory.

Computer Controlled Launch Set

by E. R. Procasky

The Computer Controlled Launch Set (CCLS) performed satisfactorily throughout the countdown operation. All countdown tasks were performed as required and no CCLS hardware problems were encountered.

VII TITAN IIIE SYSTEMS ANALYSIS

VII TITAN IIIE SYSTEMS ANALYSIS

Mechanical Systems

Airframe Structures

by R. W. York

The Titan E5 vehicle airframe configuration remained unchanged from the E1 Proof Flight configuration. Response of the vehicle airframe to steady state loads and transient events was nominal with peaks at expected levels.

Compartment IIA internal pressure vented as expected and achieved essentially zero psi at approximately 125 seconds after liftoff (Figure 14, Section VIII).

The ullage pressures within the oxidizer and fuel tanks of both Stage I and Stage II were sufficient to maintain structural integrity throughout flight. The pressures did not exceed the design limits of the vehicle.

SRM separation and Stage I/Stage II separation occurred within predicted three-sigma event times. Flight data indicates Titan ordnance for these events performed as expected.

The Titan vehicle maintained structural integrity throughout all phases of booster ascent flight. Data from flight instrumentation agreed well with predicted flight values.

Propulsion Systems

by R. J. Salmi and R. J. Schroeder

Solid Rocket Motors (SRMs)

The Stage 0 propulsion system was comprised of CSD/UT solid rocket motors numbers 49 and 50. The propulsion performance parameters were within the specification limits or in the expected range from normal flight experience. No system anomalies were detected.

The propulsion performance parameters are summarized in Table 6. The measured Web Action Times (WAT) were 105.6 and 106.6 seconds for SRMs 49 and 50 respectively. The correction for the actual grain temperature of 60.5°F to the nominal temperature of 60°F is negligible. Both SRMs were somewhat faster than the specification WAT value of 106.9 seconds, but well within the 3 sigma limits of ± 2.3 seconds. The head-end chamber pressure (P_c) data are presented in Figures 6 and 7 and the ignition transient phase is shown expanded in Figure 8. The chamber pressures were in general midway between the specification limits except at ignition and tailoff. At ignition, P_c (max.) was below the specification limit. The low P_c (max.) is normal SRM experience and because it is an ignition transient pressure peak, it is of no significance to the overall delivered impulse. At tailoff, the initial pressure decrease was slightly slow and the data points were nearer the upper limit but within bounds. The ignition and tailoff thrust differentials were well below the specification limits.

Thrust Vector Control (TVC)

As listed in Table 6, the TVC system oxidizer loads and pressures were within limits at liftoff, and the TVC tank pressure was well above the minimum value at SRM separation. All electro-mechanical valves (EMVs) in the TVC system operated normally. The maximum steering command was about 1.7 volts out of a 10-volt range.

Table 6 Solid Rocket Motor Performance Summary

Vehicle TC-5

Parameter	Rocket Motor Specs		SRM 49			SRM 50		
	Nominal or Maximum Allowable	Allowable Deviation	Measured	Corrected	Deviation	Measured	Corrected	Deviation
Nominal Data Condition, ^{o}F	60	●	●	60	●	●	60	●
Firing Condition, ^{o}F	●	●	60.5	●	●	60.5	●	●
Web Action Time, seconds	106.9	±2.16%	105.5	105.5	- 1.31%	106.6	106.6	- 0.28%
Action Time, seconds	116.8	±3.43%	119.0	119.0	+ 1.88%	118.6	118.6	+ 1.54%
Maximum Forward End Chamber Pressure, psia	791	±3.76%	740	740	- 6.45%	744	744	- 5.94%
N_2O_4 Loaded, pounds	8424	±42	8420	●	- 4	8422	●	- 2
Manifold Pressure at Ignition, psia	1041	± 77	1012	●	-29	1008	●	-33
Manifold Pressure at Separation, psia min	450	●	570	●		570	●	
Thrust Differential During Ignition Transient, lbs max	168,000 @ 0.17 sec	≈ 50,000						
Thrust Differential During Tail-off, lbs max	290,000	≈ 30,000						
Time of Separation, sec	●	126.2						
Ignition Delay, msec	150 - 300		265			278		

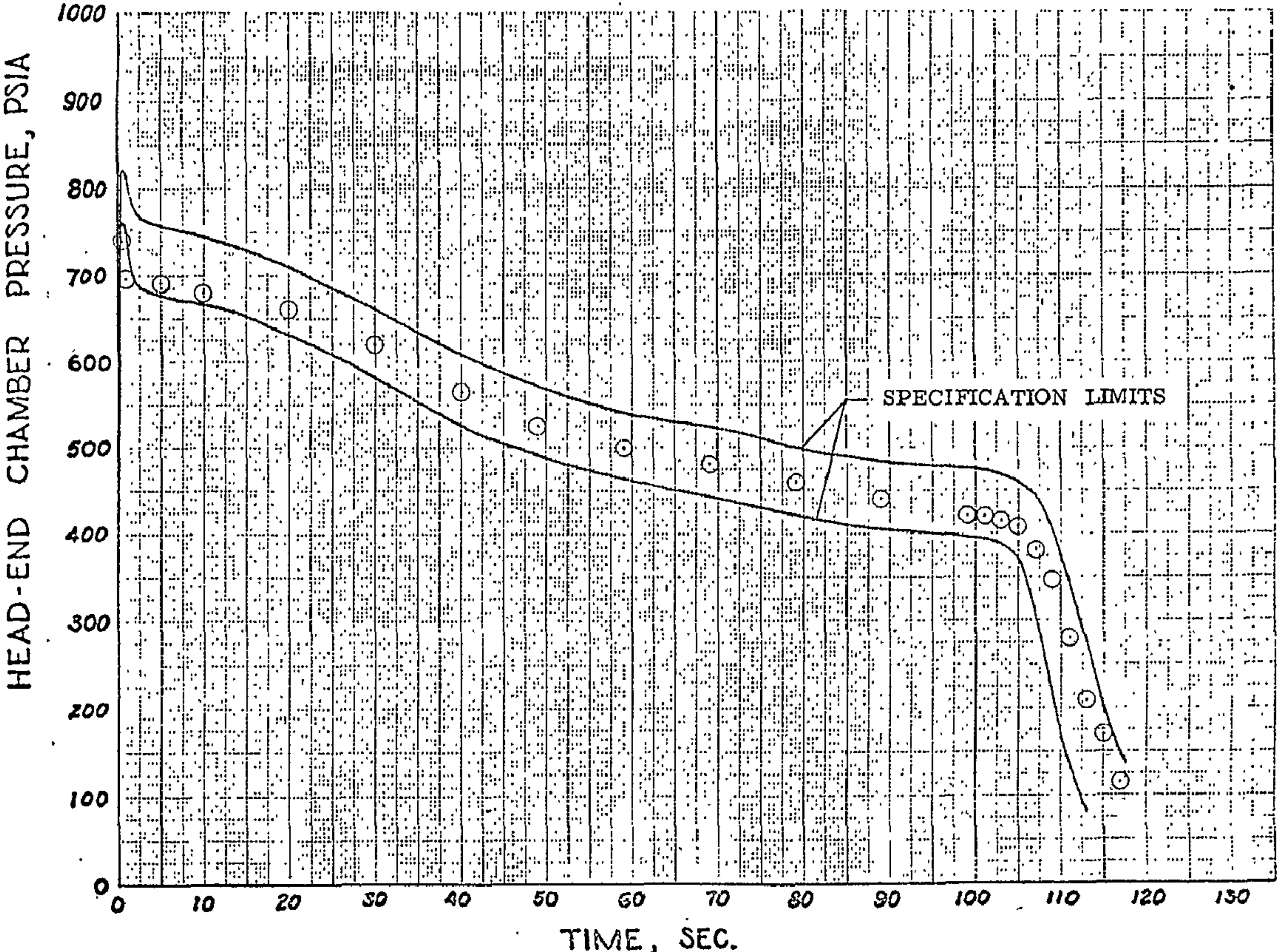


FIGURE 6 COMPARISON OF HEAD-END CHAMBER PRESSURE WITH SPECIFICATION LIMITS. SRM No.49, TITAN IIIE-5. DATA CORRECTED TO 60° F.

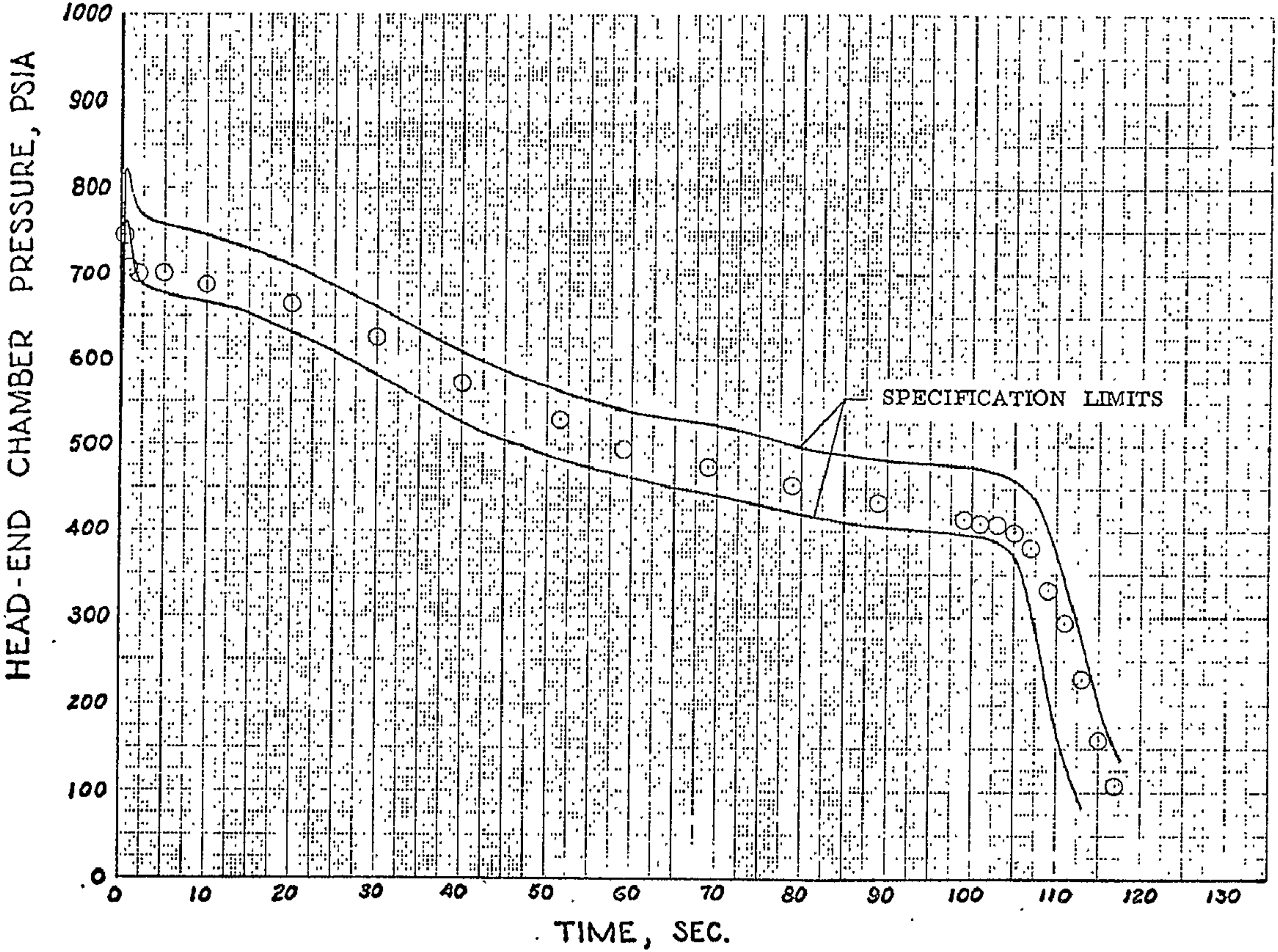


FIGURE 7 COMPARISON OF HEAD-END CHAMBER PRESSURE WITH SPECIFICATION LIMITS. SRM No.50, TITAN IIIE -5. DATA CORRECTED TO 60° F.

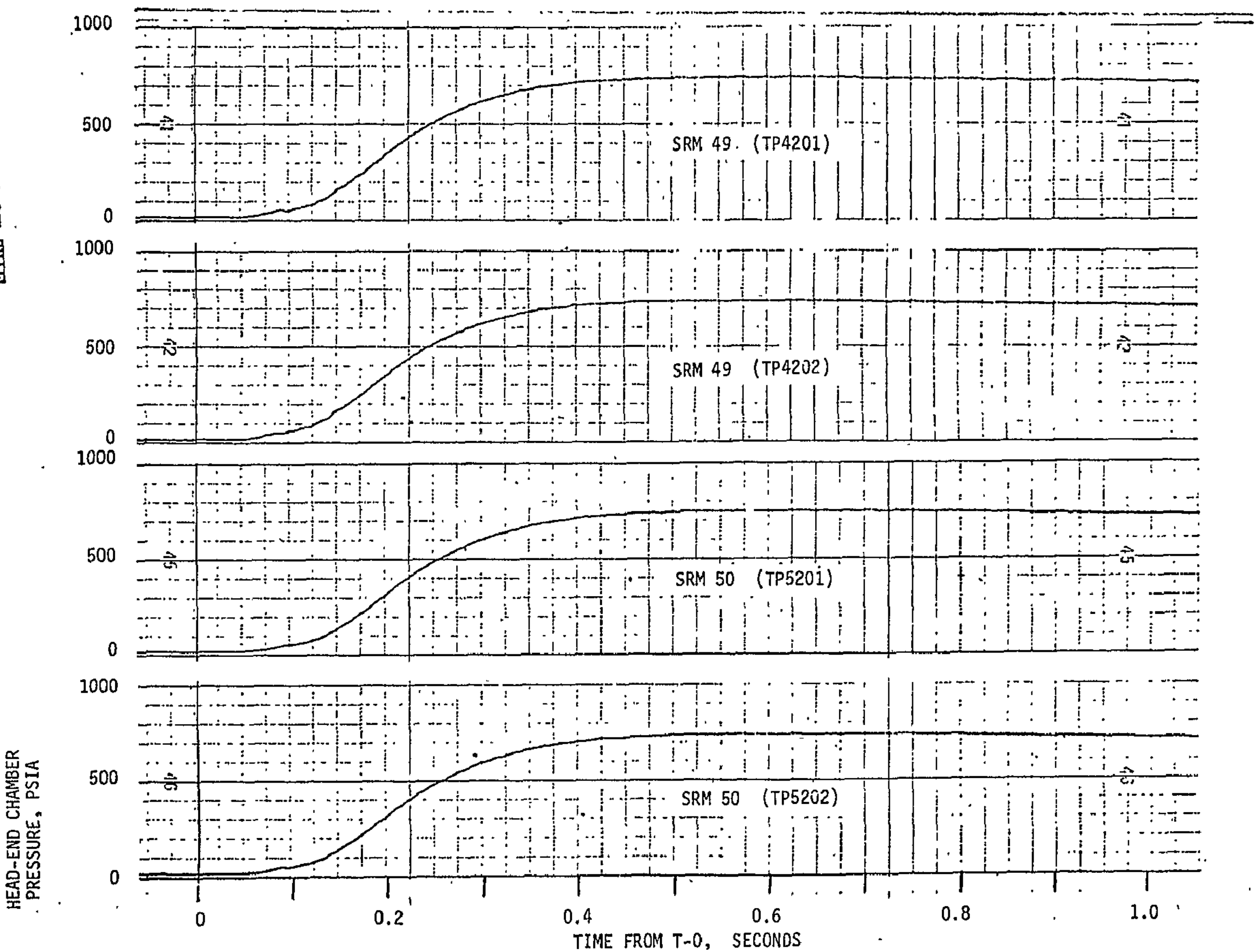


FIGURE 8 SRM HEAD-END CHAMBER PRESSURE IGNITION TRANSIENTS.

Stage I and Stage II Propulsion Systems

The Titan Stage I and Stage II propellant loading, prelaunch pressurization, engine performance, and autogenous pressurization were all within acceptable limits. Stage I engine shutdown resulted from oxidizer depletion and Stage II shutdown resulted from fuel depletion. Shutdown transients for each stage were characteristic of the shutdown mode experienced. Thrust levels were lower than expected but within allowable dispersions. The lower thrust levels resulted in a longer burn time of 2.1 seconds for Stage I and 7.2 seconds for Stage II.

Stage I and Stage II Propellant Feed Systems

The required propellant loads for Stage I and Stage II were based on an expected inflight propellant bulk temperature of 65°F for the fuel and oxidizer on both stages.

Stage I propellant load was biased to provide a 2.0 sigma probability of having an oxidizer depletion shutdown. This was done to minimize the risk of encountering high Stage II actuator loads during the Stage II engine start transient. Stage I and Stage II propellant tanks were loaded within the allowable limit of ± 0.3 percent on the fuel load and ± 0.4 percent on the oxidizer load. Comparison of the actual loads with the expected loads is shown in Table 7.

Prelaunch tank pressurization was satisfactory. Comparison of the actual oxidizer and fuel tank pressures with the allowable prelaunch limits at T-30 seconds is shown in Table 8. At T-17.5 seconds, the propellant prevalves were commanded open and all six valves were fully open within 6.9 - 7.3 seconds.

Stage I Propulsion System

Flight performance of the Titan Stage I engine was satisfactory. Engine start signal (87FS1) occurred at T+114.1 seconds when the accelerometer in the Titan flight programmer sensed a reduction in acceleration to 1.5 g's during the tailoff period of the Stage 0 solid rocket motors.

Engine start transients on both subassemblies were normal, indicating satisfactory jettison of the nozzle exit closures.

Steady-state performance of the Stage I engine was satisfactory. Average engine thrust was 0.79 percent lower than expected; average specific impulse was 0.18 seconds lower than expected; and average mixture ratio was 0.24 percent lower than expected. These performance parameters were within the allowable 3 sigma dispersions of ± 3.27 percent on thrust, ± 2.3 seconds on specific impulse, and ± 2.17 percent on mixture ratio. Performance of the autogenous pressurization system during engine operation was satisfactory. Comparison of

TABLE 7 TITAN LOADED PROPELLANT WEIGHTS STAGE I AND STAGE II - TC-5

	Expected (Lbs.)	Actual (Lbs.)
Stage I		
Oxidizer	168,885	169,005
Fuel	90,213	90,230
Stage II		
Oxidizer	43,366	43,427
Fuel	23,942	23,951

TABLE 8 TITAN PROPELLANT TANK PRELAUNCH PRESSURIZATION, STAGE I AND STAGE II - TC-5

	Prelaunch Limits (psia)		Value at T-30 Sec. (psia)
	Lower	Upper	
Stage I			
Oxidizer Tank	33.6	45.0	38.0
Fuel Tank	24.0	32.0	30.0
Stage II			
Oxidizer Tank	45.0	57.0	52.8
Fuel Tank	50.0	56.0	52.8

the average expected steady-state performance values for the Stage I engine with the actual steady-state values is shown in Table 9.

Stage I engine shutdown occurred at T+264.9 seconds when the thrust chamber pressure switches sensed a reduction in chamber pressure and issued the engine shutdown signal (87FS2). Engine shutdown was the result of oxidizer depletion as planned. The shutdown transient was normal for an oxidizer depletion mode.

Propellant outage was 1041 pounds of fuel which was less than the expected mean outage of 1292 pounds of fuel. This was the result of the shift in mixture ratio. Stage I engine operating time (FS1 to FS2) was 2.1 seconds longer than expected due to the lower than expected propellant flow rates.

Stage II Propulsion System

Flight performance of the Titan Stage II engine was satisfactory. Engine start signal (91FS1) occurred at T+264.9 seconds (simultaneous with Stage I engine shutdown signal, 87FS2). The Stage II engine start transient was normal. Stage I separation occurred 0.80 seconds after 91FS1.

Engine steady-state performance was satisfactory. Average engine thrust was 3.4 percent lower than expected, average specific impulse was 2.66 seconds lower than expected and average engine mixture ratio was 0.14 percent lower than expected. The allowable 3 sigma dispersions about the expected values were ± 3.80 percent on thrust, ± 3.5 seconds on specific impulse, and ± 2.66 percent on mixture ratio. Performance of the autogenous pressurization system during engine operation was satisfactory. Comparison of the average expected steady-state performance values for the Stage II engine with the actual steady-state values is shown in Table 10.

Stage II engine shutdown (91FS2) occurred at T+478.6 seconds when the sensed vehicle acceleration dropped to 1.0 g's. Engine shutdown was the result of fuel depletion. The shutdown transient was normal for a fuel depletion mode. Propellant outage was zero pounds compared to an expected mean outage of 111 pounds. Engine operating time (FS1 to FS2) was 7.2 seconds longer than expected due to the lower than expected propellant flow rates.

Stage II/Centaur separation occurred 5.7 seconds after 91FS2 when the vehicle acceleration level reached 0.1 g. Satisfactory operation of the Stage II retrorocket motors was achieved.

TABLE 9 TITAN STAGE I ENGINE STEADY-STATE PERFORMANCE - TC-5

Parameter	Units	Average Steady-State Flight Values Expected (2)	Average Steady-State Flight Values Actual
Thrust, total	lbf.	519,431	515,347
Specific impulse	sec.	301.25	301.07
Mixture ratio, O/F	units	1.9058	1.9012
Overboard propellant flow rate, total (1)	lbm/sec.	1724.27	1711.73
Oxidizer flow rate, total	lbm/sec.	1133.49	1124.33
Fuel flow rate, total	lbm/sec.	594.76	591.38
Propellant outage	lbm	1292 mean 3172 max.	1041 (fuel)
Oxidizer temperature	^{o}F	65	68.1
Fuel temperature	^{o}F	65	67.3
Oxidizer tank pressure	psi	33.9	31.8
Fuel tank pressure	psi	25.6	23.6
FS_1 to FS_2	sec.	149.7	150.8

NOTES: (1) Excludes autogenous pressurant flow.

(2) Expected values are those used in the final preflight targeted trajectory.

TABLE 10 TITAN STAGE II ENGINE STEADY-STATE PERFORMANCE - TC-5

Parameter	Units	Average Steady-State Flight Values	
		Expected (3)	Actual
Thrust, total	lbf.	102,965	99,459
Specific impulse (1)	sec.	315.71	313.05
Mixture ratio, O/F	units	1.8197	1.8172
Overboard propellant flowrate, total (2)	lbm/sec.	323.42	314.67
Oxidizer flowrate, total	lbm/sec.	209.55	203.80
Fuel flowrate, total	lbm/sec.	115.15	112.15
Propellant outage	lbm	111 mean 534 max.	Zero
Oxidizer temperature	^oF	65	68.4
Fuel temperature	^oF	65	67.6
Oxidizer tank pressure	psi	50.3	52.7
Fuel tank pressure	psi	55.2	55.1
FS_1 to FS_2	sec.	207.1	213.7

NOTES: (1) Excludes roll nozzle thrust.

(2) Excludes autogenous pressurant flow.

(3) Expected values are those used in the final preflight targeted trajectory.

Hydraulic Systems

by E. J. Fourney

Performance of the hydraulic systems on Stage I and Stage II was normal during preflight checkout and the boost phases of flight. Actuator loads were well within the Titan family maximums. There were no anomalies.

Performance data for the Titan hydraulic system are summarized in Table 11.1. All system parameters were nominal and within specification limits. The electric motor pump in each stage supplied normal hydraulic pressure for the flight control system tests performed during countdown. Hydraulic pressures supplied by the turbine driven pumps were normal. Hydraulic reservoir levels were within limits throughout countdown and flight.

Stage I actuator peak loads at engine start were nominal and within the family of Titan data experience. Stage II peak actuator loads at engine start were considerably lower than previous maximums. Table 11.2 shows the maximum actuator loads encountered during the engine start transient period. Also shown for comparison are the TC-1 through TC-4 loads and maximum loads for all Titan vehicles.

Table 11 TITAN HYDRAULICS SYSTEM - TC-5

Table 11.1 System Pressure and Reservoir Levels

Parameters		Units	Expected Values	Flight Results	
				Stage I	Stage II
Hydraulic Supply Pressure	Maximum at pump start	PSIG	4500 (1)	3240	3690
	Average steady state	PSIG	2900 - 3000	2925	2925
Reservoir Levels	Prior to pump start	%	47 - 62	48	48
	At maximum start pressure	%	22 - 47	33	35
	Average steady state	%	22 - 47	32	37
	Shutdown minus 5 seconds	%	22 - 47	35	39

(1) Proof Pressure Limit.

Table 11.2 Actuator Loads During Engine Start Transients

S/A	Stage I Actuator Loads, Pounds				Stage II Actuator Loads	
	Subassembly #2		Subassembly #1		Subassembly #3	
Actuator Position	Pitch 1-1	Yaw-Roll 2-1	Yaw-Roll 3-1	Pitch 4-1	Pitch 1-2	Yaw-Roll 2-2
TC-5 (E-5)	+ 5,533	+ 12,449	+ 12,449	+ 6,916	+ 6,120	+ 3,060
	- 6,916	- 6,916	- 6,916	- 6,916	- 1,530	- 4,590
TC-1 thru -4 (max.)	+10,600	+ 12,070	+ 12,450	+12,800	+ 9,700	+ 9,750
	- 9,270	- 5,530	- 5,120	-18,780	- 890	- 7,900
Titan Family* (max.)	+14,100	+ 12,500	+ 15,400	+13,030	+14,400	+ 9,750
	-15,400	- 8,151	- 6,920	-18,782	- 8,750	-11,184

* TIII C/D/E - Only for Stage I
\+ Indicates Compression Load
\- Indicates Tension Load

Flight Controls and Sequencing System

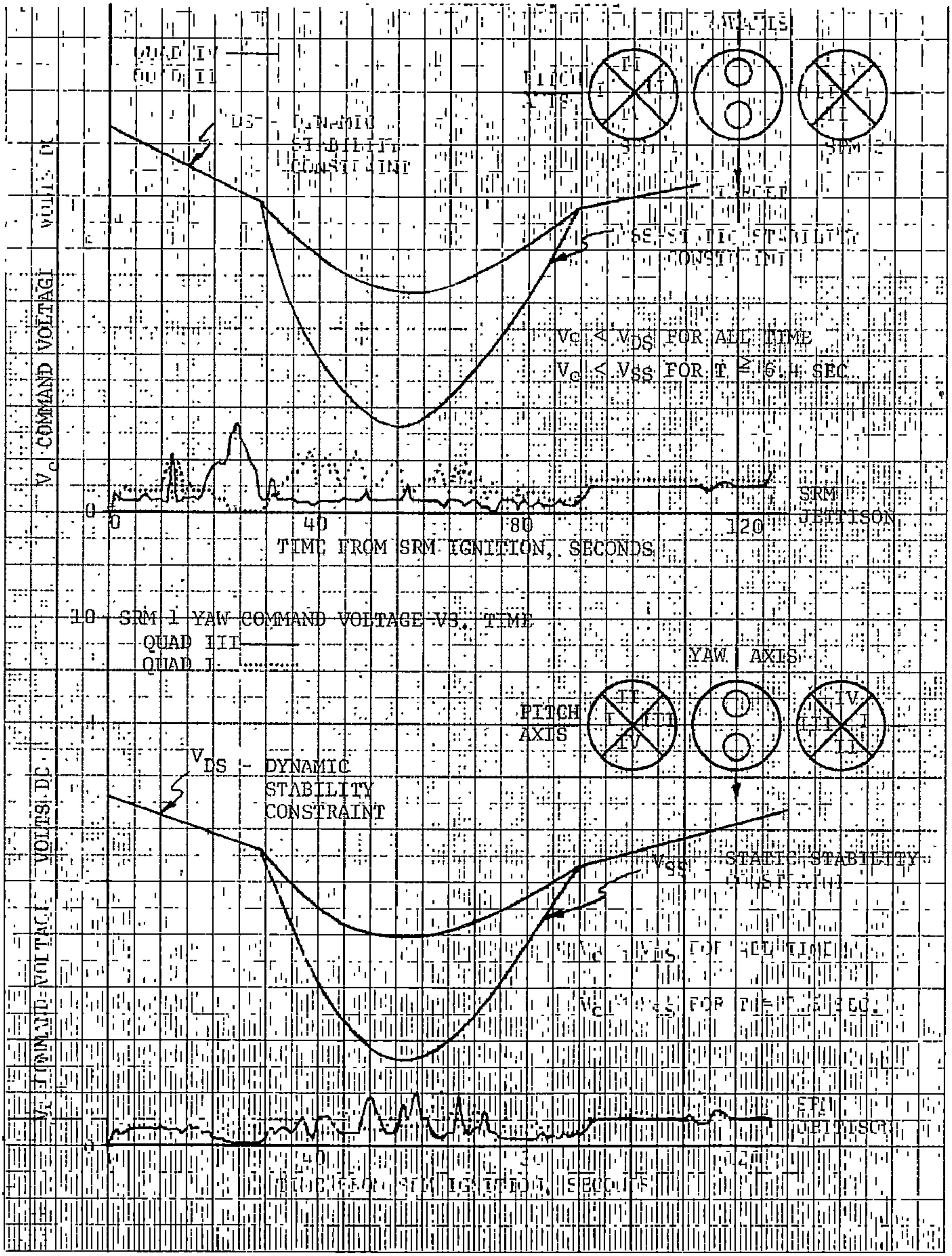
by E. S. Jeris and T. W. Porada

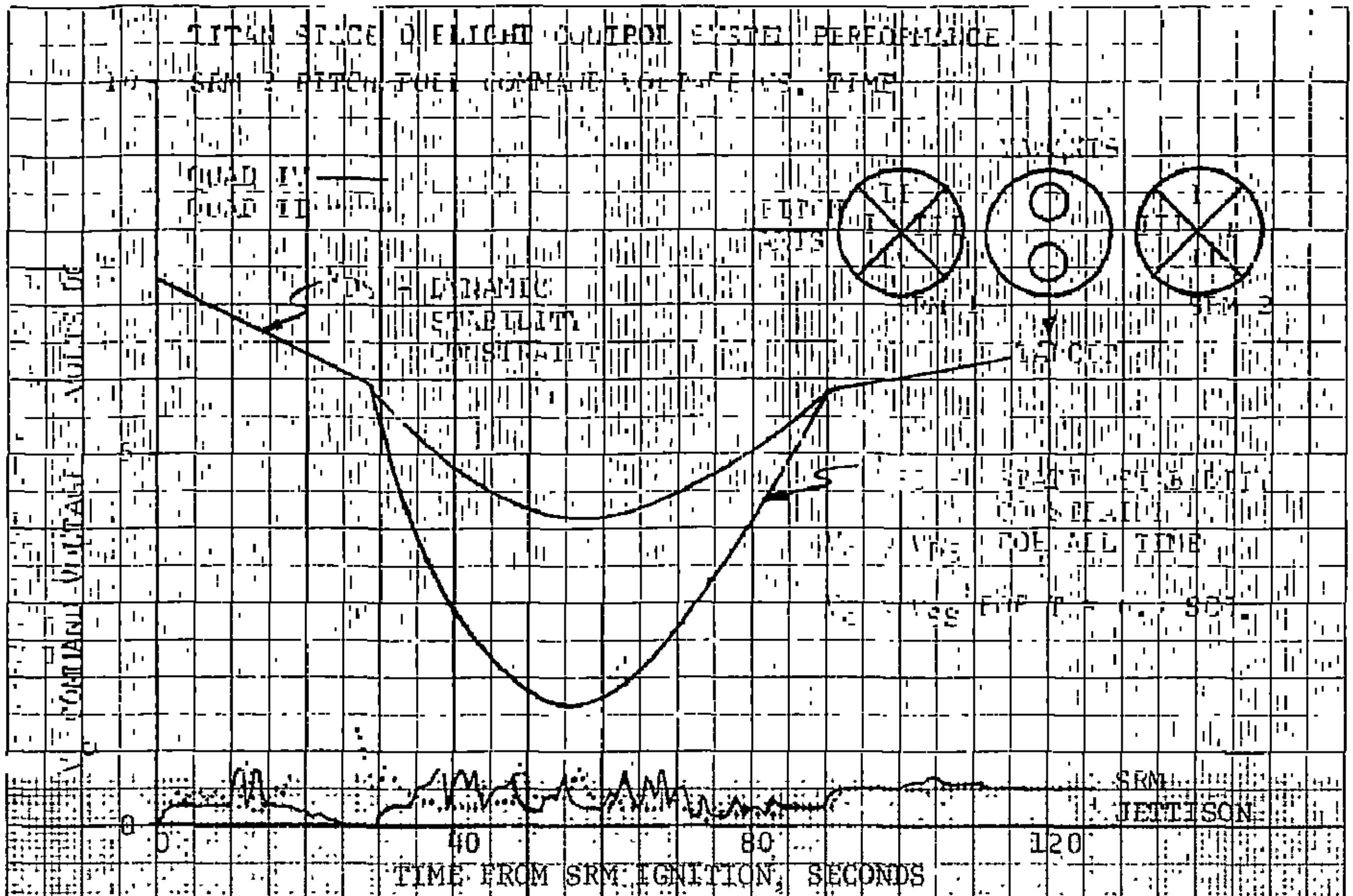
The flight control system maintained vehicle stability throughout powered flight. All open loop pitch rates and preprogrammed events were issued as planned. No system or component anomalies occurred. Dump programming of TVC injectant fluid was satisfactory. During Stage I flight, after SRM jettison, a 1 Hz oscillation was noted on the pitch and yaw rate gyros. Peak displacement was less than $.1^{\circ}$ at a $.2^{\circ}$/second peak rate. The oscillation is attributed to propellant slosh which has been noted on other Air Force vehicles and was not seen on other TIIIE flights. No adverse effects resulted from the oscillations and less than one percent of total steering capability was used as a result of the oscillation. Also observed during Stage I flight, after SRM jettison, were 25 Hz and 45 Hz mixed oscillations in yaw at a peak rate of $.7^{\circ}$/second. No steering resulted from the oscillations and there were no adverse effects on vehicle performance. Similar oscillations were observed on TIIIE-3. The source of the oscillations is not known.

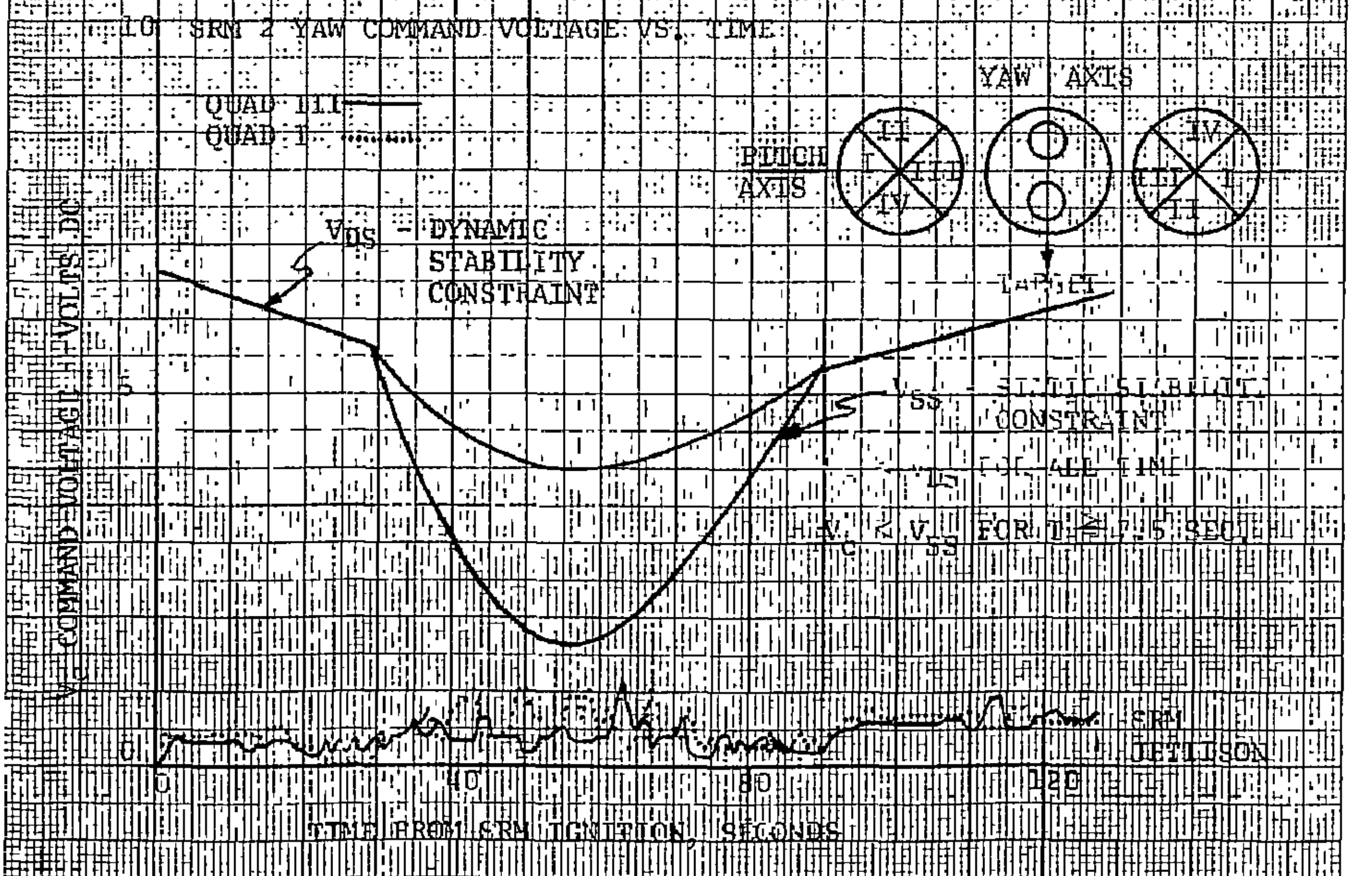
Command voltage to each SRM quadrant and the dynamic and static stability limits are shown in Figures 9 and 10. The stability limits represent the TIIIE-5 side force constraint in terms of TVC system quadrant voltage. This constraint is used in conjunction with launch day wind synthetic vehicle simulations as a go/no-go criterion with respect to vehicle stability and control authority. Simulation responses satisfying the constraint assures a 3 sigma probability of acceptable control authority and vehicle stability. Maximum command during Stage 0 flight was 1.7 volts which is 17 percent of the control system capability and 33.3 percent of the dynamic stability limit. The peak command occurred at T+24 seconds and was due to Centaur ADDJUST steering and the Titan pitch program.

For Stage I and Stage II, the control system limit is the maximum gimbal angle associated with the actuator stop. During Stage I flight, the peak gimbal angle required for control was $.8^{\circ}$ which is 17.8 percent of the maximum gimbal angle. The peak angle was required at T+131 seconds for pitch rate seven command. During Stage II, 2.3° or 6.8 percent of peak gimbal angle was the maximum gimbal angle required and was due to CSS jettison.

The control system response to vehicle dynamics was evaluated for each significant flight event. The amplitude, frequency, and duration of vehicle transients, and the control system command capability required are shown in Table 12.


QUAD IV
VDS - DYNAMIC STABILITY CONSTRAINT
VC COMMAND VOLTAGE
Vc < VDS FOR ALL TIME
Vc < VSS FOR T ≥ 64 SEC
SRM JETTISON
0
40
80
120
TIME FROM SRM IGNITION, SECONDS
10
SRM 1 YAW COMMAND VOLTAGE VS. TIME
QUAD III
QUAD I
YAW AXIS
PITCH AXIS
II
I
III
IV
VDS - DYNAMIC STABILITY CONSTRAINT
VSS - STATIC STABILITY
VOLTS DC
0
40


QUAD IV
QUAD II
DYNAMIC
CONSTRAINT
FOR ALL TIME
SRM
JETTISON
0
40
80
120
TIME FROM SRM IGNITION, SECONDS


10
SRM 2 YAW COMMAND VOLTAGE VS. TIME
YAW AXIS
QUAD III
QUAD I
PITCH
AXIS
II
III
IV
I
V_{DS} - DYNAMIC
STABILITY
CONSTRAINT
5
CONSTRAINT
FOR ALL TIME
V_C - COMMAND VOLTAGE, VOLTS DC
SRM
JETTISON
0
40
80
120
TIME FROM SRM IGNITION, SECONDS

VEHICLE DYNAMIC RESPONSE

EVENT	TIME SEC.	AXIS	ZERO TO PEAK AMPLITUDE Deg./Sec.	TRANSIENT FREQUENCY Hz.	TRANSIENT DURATION Sec.	REQUIRED CONTROL % of Capacity
SRM Jettison (Initial Conditions)	124-126	R	.24	Drift	2	4.3
SRM Jettison Transient	127	R	5.3	.375	4	4.3
Start of PR 7 (Only Pitch Up Program)	133	P	1.14	N/A	N/A	19
Enable Guidance Steering (2.05° PD .5° Yr.)	156.5	P	1.44	N/A	N/A	16.8
	156.5	Y	.48	N/A	N/A	8.5
CSS Jettison	327	P	.12	1.5	5	4
	326	R	.24	10	.5	6.3
	328	R	.96	3-4	2	16.7
	329	R	.7	N/A	1.5	12.6

Table 12

Both flight programmers and the staging timer issued all preprogrammed discretes at the proper times. The Centaur sent four discretes to the Titan at the proper times. The complete sequence of events with actual and nominal times from SRM ignition is shown in Table 13.

Table 13

E-5 FLIGHT SEQUENCE OF EVENTS

T-0 = 05:34.00.355 (SRM Ignition Command) (Times from T-0) Observed

Event	Predicted	F/P A	F/P B	S/T	DCU	Other	Delta
Start Roll Program	6.50				6.562		+0.062
Stop Roll Program					6.579		
Pitch Rate 1	10.000	10.002	10.004				+0.002
Pitch Rate 2	20.000	20.005	20.007				+0.005
Gain Change 1	29.000	29.009	29.011				+0.009
Pitch Rate 3	30.000	30.010	30.013				+0.010
Pitch Rate 4	62.000	62.022	62.024				+0.022
Gain Change 2	70.000	70.024	70.027				+0.024
Pitch Rate 5	75.000	75.024	75.029				+0.024
Enable S/T	75.000		75.027				+0.027
Gain Change 3	90.000	90.031	90.033				+0.031
Pitch Rate 6	95.000	95.033	95.036				+0.033
Enable F/P B	96.000	96.039					+0.039
Stage I Start CMD	111.572		114.124	114.164			+2.809
En Stg I ISDS Safe	117.572		120.432				+3.117
O/I Separation CMD	123.572		126.130	126.132			
En Stg I ISDS Safe	123.578	126.129					+2.551
O/I Separation	123.657					126.137	+2.737
Pitch Rate 7	130.000	130.046	133.289				+0.046
Pitch Rate 9	140.000	140.051	143.938				+0.051
Gain Change 5	192.000	192.069	196.160				+0.069
Gain Change 6	232.000	232.083	236.174				+0.083
Stg I S/D En	245.000	245.091	249.182				+0.091
Stg I S/D/Stg II Start	261.083					264.880	+3.141
I/II Separation	261.786					265.656	+3.810
Remove GC7, PRIO	310.000	310.116	314.007				+0.116
CSS Sep Prim	321.835				325.649		+3.814
CSS Sep Sec	322.335				326.149		+3.814
CSS Sep B/U	331.572		334.214				+2.642
Gain Change 8	340.000	340.125	344.218				+0.125
Gain Change 9	400.000	400.146	404.238				+0.146
Stage II S/D En	448.000	448.165	451.359				+0.165
Stage II S/D	467.307				478.545		+11.238
Stage II S/D	467.930	478.948					+11.018
Stg II/Cen Sep	473.162				483.245		+10.083
Stg II/Cen Sep B/U	475.330	486.359					+11.029

Electrical/Electronic Systems

Airborne Electrical System

by B. L. Beaton

Solid Rocket Motor Electrical System

The Solid Rocket Motor (SRM) electrical system performance was satisfactory with no anomalies. All power requirements of the SRM electrical system were satisfied.

The SRM electrical system was identical to that flown on TC-1 through TC-4.

The SRM electrical system supplied the requirements of the dependent systems at normal voltage levels. The SRM electrical system performance is summarized in Table 14.

The Titan core transfer shunt indicated 5.8 amps for approximately 400 ms at SRM ignition. This condition was experienced on TC-1 through TC-4. It is caused by a short from an SRM igniter bridgewire positive to structure and simultaneous shorting from the transient return to readiness return within the igniter safe and arm device. The transfer current dropped to zero simultaneous with the removal of the current path when the SRM umbilicals were ejected. This condition had no adverse effect on any airborne system.

Titan Core Electrical System

The core electrical system performance was satisfactory with no anomalies. All power requirements of the core electrical system were satisfied. All voltage and current measurements indicated expected values. Some bridgewire shorting (after initiation) was observed at every ordnance event.

The Titan electrical system with the exception of one cordage modification, was identical to that flown on TC-1 through TC-4. The brackets, through which the Stage I harnessing is routed aft of the Stage I/II staging disconnects, were modified to ensure a straight pull on the staging disconnects at Stage I/II separation.

The Titan core electrical system supplied the requirements of the dependent systems at normal voltage and current levels. The Titan core electrical system performance is summarized in Table 15.

The 800 Hz squarewave output of the static inverter was 38.0 volts during the entire flight.

TABLE 14 SRM ELECTRICAL SYSTEM PERFORMANCE SUMMARY

		POWER ON INTERNAL	LIFTOFF	SRM JETTISON
TVC VOLTAGE	SRM-1	30.3	31.5	31.2
	SRM-2	30.7	31.5	31.5
AIPS VOLTAGE	SRM-1	30.0	30.0	29.6
	SRM-2	29.6	29.6	29.2
INSTRUMENTATION REGULATED BUS VOLTAGE	SRM-1	10.1	10.1	10.1
	SRM-2	10.0	10.0	10.0

TABLE 15 TITAN CORE VEHICLE ELECTRICAL SYSTEM PERFORMANCE SUMMARY

	POWER ON INTERNAL	LIFTOFF	ENABLE TPS	STAGE I START	STG 0/I SEP	STG I/II SEP	CSS JETTISON	STAGE II S/D	T/C STAGING
APS Voltage	28.5	28.85	28.5	27.8	28.2	27.6	28.5	28.4	27.8
APS Current	7.5	7.7	8.0	9.5	10.2	12.8	7.2	8.0	9.1
IPS Voltage	29.3	29.3	29.3	29.2	29.1	28.9	28.9	28.9	28.9
IPS Current	9.8	9.7	9.8	9.9	9.9	9.8	9.1	9.2	9.2
Transfer Current	0	5.8	0.5	0.2	0.1	0.5	0	0.3	0
TPS Voltage	0	0	36.1	36.1	36.1	36.1	36.1	36.1	36.1

The TPS steady-state bus voltage was 36.1 volts dc throughout the flight. The TPS battery received a topping off charge after activation. This technique was first used on TC-3 and TC-4.

The TPS bus voltage and pyrotechnic firing currents during ordnance events are summarized in Table 16.

The transfer current indicated 5.8 amps at T-0 as previously discussed under SRM electrical system performance. The transfer current indicated that during short periods of high current demands on the APS bus, the TPS battery provided load sharing. This occurred at TPS enable, Stage I engine start, Stage 0/I separation, Stage I/II separation, and Stage II shutdown.

TABLE 16 TITAN CORE VEHICLE PYROTECHNIC SYSTEM

	STG I START	STG 0/I SEP	STAGING MOTORS	STG I/II SEP	CSS JETTISON	T/C STG & RETRO ROCKETS	T/C STAGING
TPS Voltage	30.2	23.8	23.8	27.3	29.9	29.9	29.9
TPS Current	31.3	184.4	239.5	282.6	30.2	67.0	26.5

Flight Termination System

by R. E. Orzechowski

The Titan flight termination system performance was nominal throughout the flight. Monitoring the receiver AGC voltages by telemetry indicated that sufficient signal was present throughout the powered flight to assure that any destruct or engine shutdown commands would have been properly executed. A list of station switching times is given in Table 17. Receiver safing command was issued at 05:44:01 GMT.

The Range Safety command battery voltages were 32.5 VDC at liftoff and remained steady throughout the flight. The commands from the flight programmer to safe the Stage I and the two SRM Inadvertent Separation Destruct Systems (ISDC) were issued at their expected times. The flight programmer also issued the command to safe the Destruct Initiator on Stage II prior to the Titan/Centaur separation.

Table 17 Station Switching Times

Station	Carrier On	Carrier Off
Mainland (Station 1)	04:57:11 Z	05:36:51 Z
Grand Bahama Island (Station 3)	05:36:50 Z	05:41:42 Z
Antigua (Station 91)	05:41:40.5 Z	05:44:13 Z

Instrumentation and Telemetry System

by R. E. Orzechowski

A total of 185 measurements were telemetered by the Titan Remote Multiplexed Instrumentation System (RMIS). A summary of the types of measurements versus the systems in which they were monitored is given in Table 18. Review of the flight data indicated that all measurements yielded satisfactory data.

Adequate telemetry coverage of the Titan vehicle was provided from liftoff to beyond Titan/Centaur separation. A summary of the predicted data coverage versus actual data coverage of the Titan telemetry link is given in Table 19.

TABLE 18 TITAN BOOSTER MEASUREMENTS SUMMARY

SYSTEM \ TYPE OF MEASUREMENT	ACCELERATION	VOLTAGE	CURRENT	PRESSURE	TEMPERATURE	DISPLACEMENT	RATES	DISCRETES	TOTAL
AIRFRAME	4			1				2	7
RANGE SAFETY		3						6	9
ELECTRICAL		15	10						25
HYDRAULICS				8		2			10
PROPULSION				29	8			4	41
FLIGHT CONTROL		33				32	11	10	86
TELEMETRY		6			1				7
TOTAL	4	57	10	38	9	34	11	22	185

TABLE 19

Summary of Predicted Data Coverage

Versus Actual Data Coverage

Titan 2287.5 MHZ Link

STATION	PREDICTED		ACTUAL	
	AOS	LOS	AOS	LOS
CIF (Mainland)	Turn On	450 sec	Turn On	490 sec
GBI (Grand Bahama)	48 sec	474 sec	35 sec	525 sec
GTK (Grand Turk)	230 sec	474 sec	187 sec	528 sec

VIII CENTAUR STANDARD SHROUD

VIII CENTAUR STANDARD SHROUD

Preflight/Liftoff Functions and Ascent Venting

by T. L. Seeholzer and W. K. Tabata

CSS Disconnects and Door Closures

The CSS disconnects and door closures located as shown in Figure 11 functioned normally on the TC-5 flight. The CSS disconnects and door closures were equivalent to the systems used on the TC-2 flight.

Movie and television coverage verified proper disconnect of the umbilicals and the closing of the T-0 and T-4 CSS doors on the primary latches.

Micro-switches mounted on the T-4 aft door verified that the door closed on the primary latches following umbilical disconnect.

Centaur Standard Shroud Ascent Vent System

The Centaur Standard Shroud ascent vent system controls the venting of seven separate compartments. The venting rates are controlled to minimize vehicle and spacecraft structural differential pressures during ascent through the atmosphere. The seven vented compartments, the gas media and volumes, the vent areas and the number of vents for the TC-5 vehicle are shown in Figure 12. The TC-5 CSS ascent vent system was identical to that of TC-2. Detailed description of the vent system and the various compartments are contained in the TC-2 Flight Report (Reference 1).

The TC-5 measured internal compartment pressures as a function of flight time for Compartment 2/3 and 6 are shown in Figures 13 and 14, respectively. Shown with the TC-5 flight data are the preflight estimates and the TC-1 and TC-2 flight data. Both compartment pressures show good agreement with previous flight data. There is a time bias between flights due to actual trajectory flown. No differential pressure measurements between compartments were flown on this flight.

The CSS ascent vent system also had a constraint to minimize the maximum rate of pressure decay in the spacecraft compartment during the transonic portion of flight. The maximum decay rate was approximately -0.65 psi/second on TC-5. The maximum rate on TC-2 was approximately -0.75.

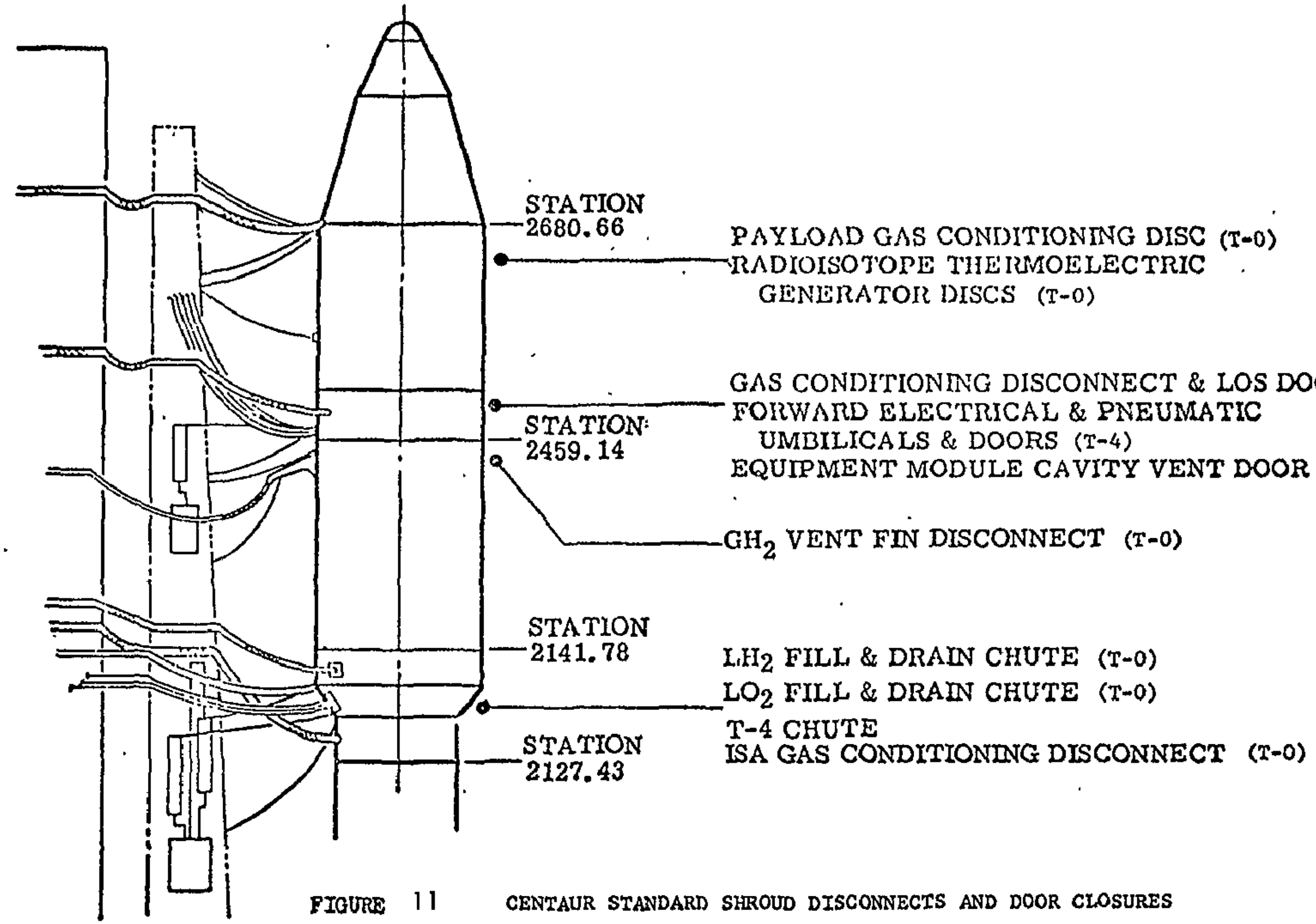
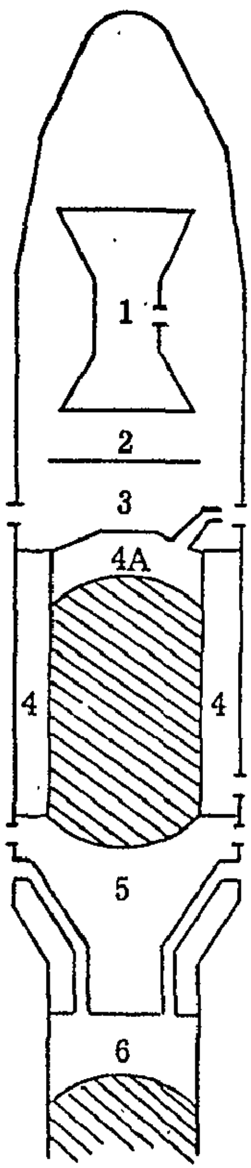


FIGURE 11 CENTAUR STANDARD SHROUD DISCONNECTS AND DOOR CLOSURES

TC-5 CENTAUR STANDARD SHROUD ASCENT VENT SYSTEM



	Compartment	Gas Media	Vol. (ft^3)	Vent Area (in^2)	No. Vents
1	Helios Spacecraft	GN_2	66		
2	Payload Compartment	GN_2	3225	125	11
3	Centaur Electronics	GN_2	562		
4A	Equipment Module	GHe	78		
4	LH_2 Tank Compartment	GHe	1370	24	1
5	Centaur Interstage	GN_2	839	90	9
6	Titan Forward Skirt	Air	338	40	4

Figure 12 Centaur Standard Shroud Ascent Vent System Schematic

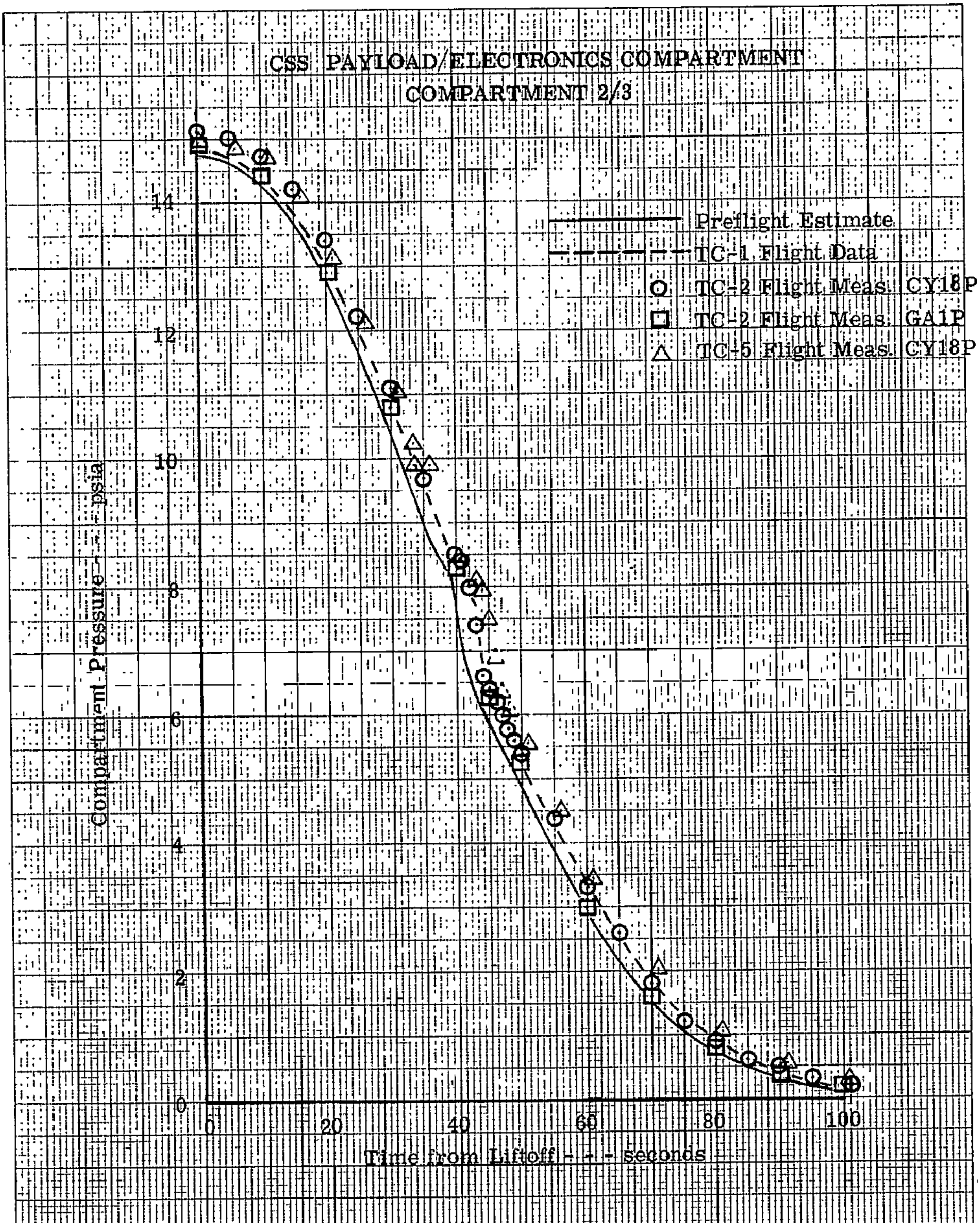


Figure 13 CSS Payload/Electronics Compartment Pressure History

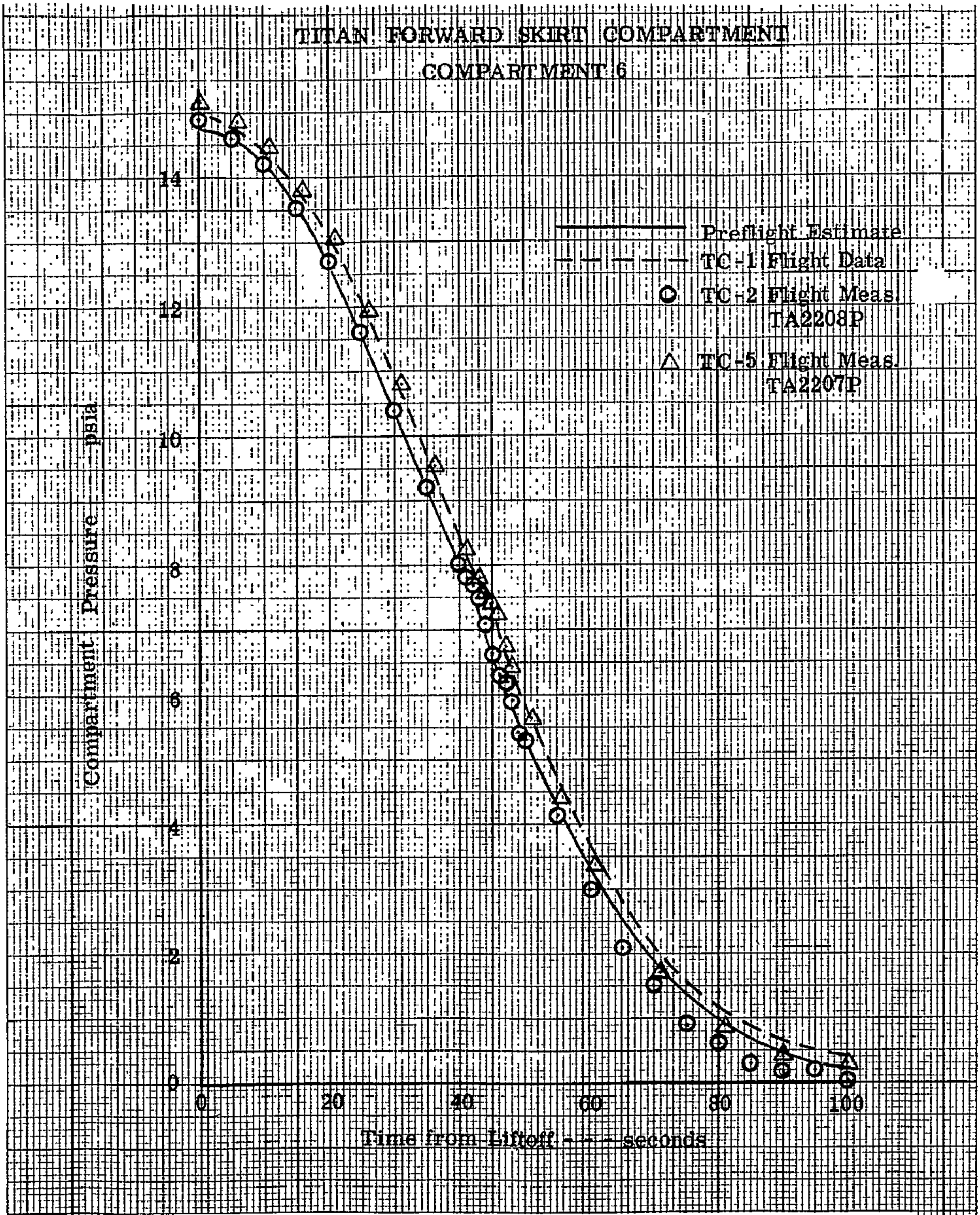


Figure 14 Titan Forward Skirt Compartment Pressure History

The TC-5 Centaur Standard Shroud ascent vent system performed satisfactorily:

1. Compartment pressure time histories agreed well with previous flight data.

2. The spacecraft compartment maximum pressure decay rate during the transonic portion of flight agreed well with previous flight data.

[1]Titan/Centaur D-1T TC-2 Helios A Flight Data Report, Lewis Research Center, September 1975

CSS Inflight Events and Jettison

by T. L. Seeholzer

All CSS inflight events and jettison were normal on the TC-5 flight. These events included forward bearing reaction separation, forward seal release, shroud separation, and jettison. These systems, as shown in Figures 15 through 19, were equivalent to those on the TC-2 flight.

All six forward bearing reaction struts were separated at T+100.1 seconds as verified by breakwires on the explosive bolts. Nominal separation time was T+100 seconds.

Forward seal release occurred at T+241.29 seconds as verified by breakwires on the explosive bolts.

The CSS Super*Zip primary system separated the shroud at T+325.65 seconds. Separation by the primary system was verified by the fact that the CSS rotated over 3 degrees prior to secondary system command. Secondary command was issued .50 seconds after primary system command. The secondary system is deactivated by electrical disconnect after 1 degree rotation.

Shroud rotation times comparing TC-1, TC-2, TC-3, TC-4, and TC-5 are given in Table 20.

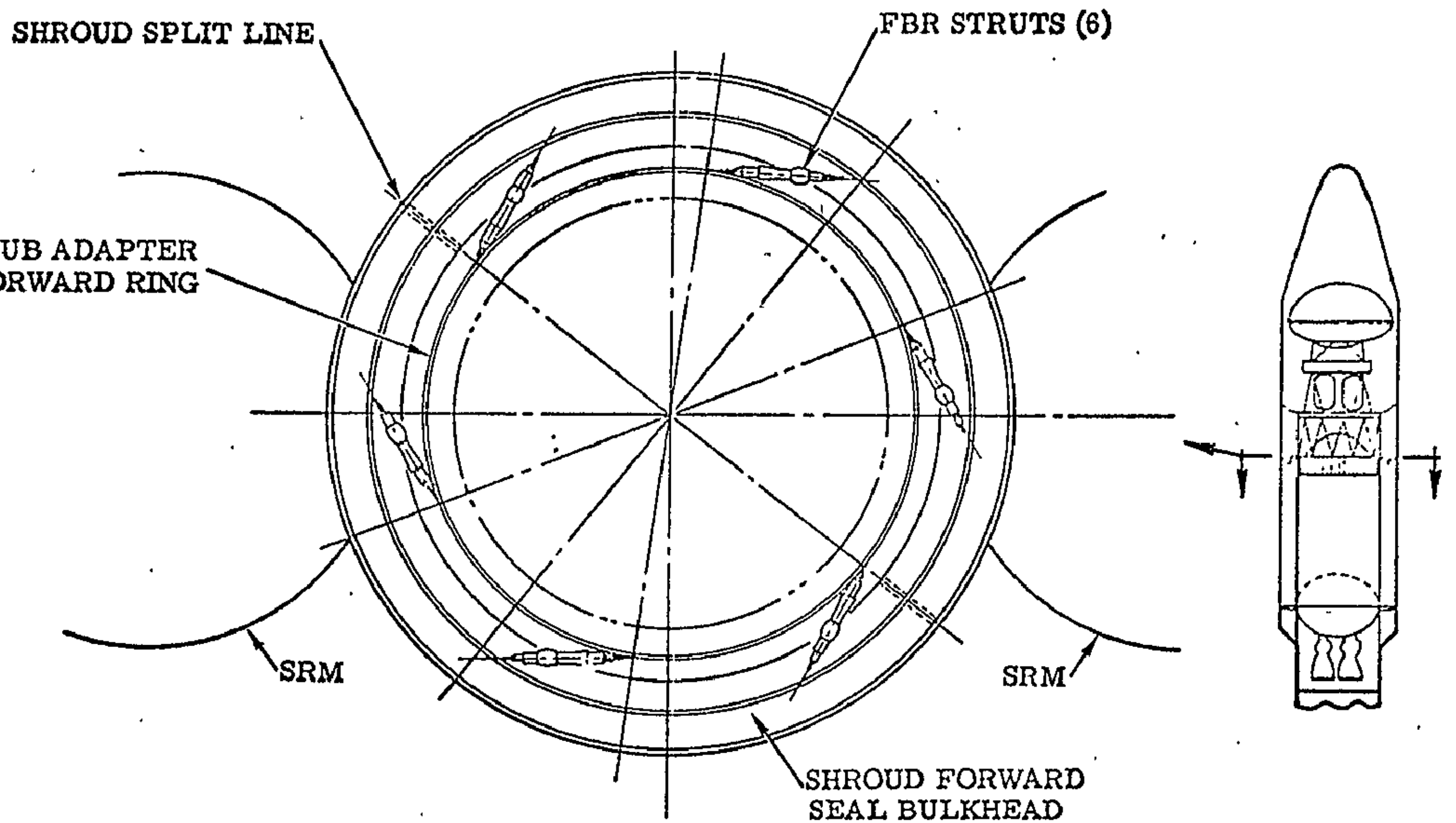


FIGURE 15 FORWARD BEARING REACTION SYSTEM

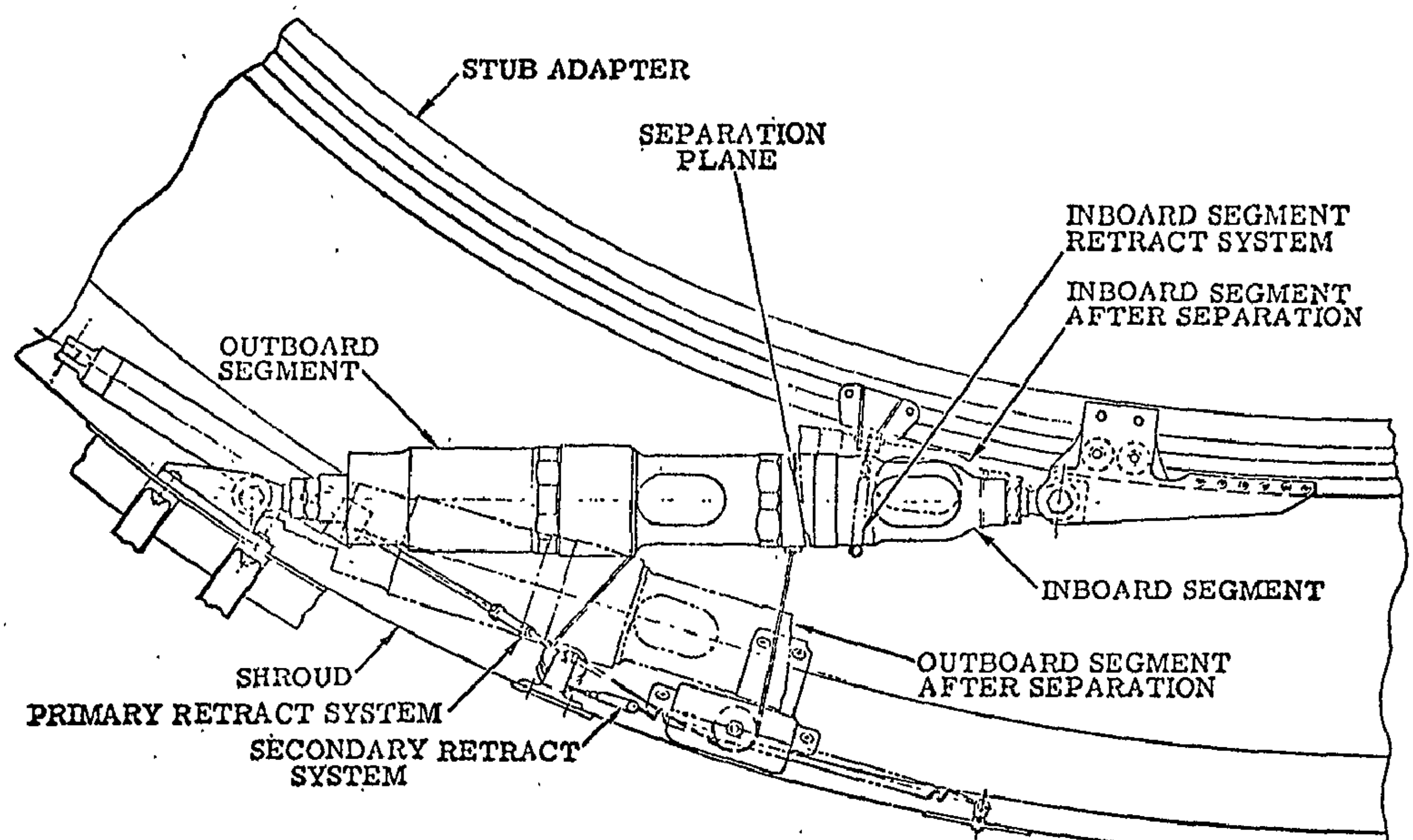


FIGURE 16 FORWARD BEARING REACTION STRUT INSTALLATION

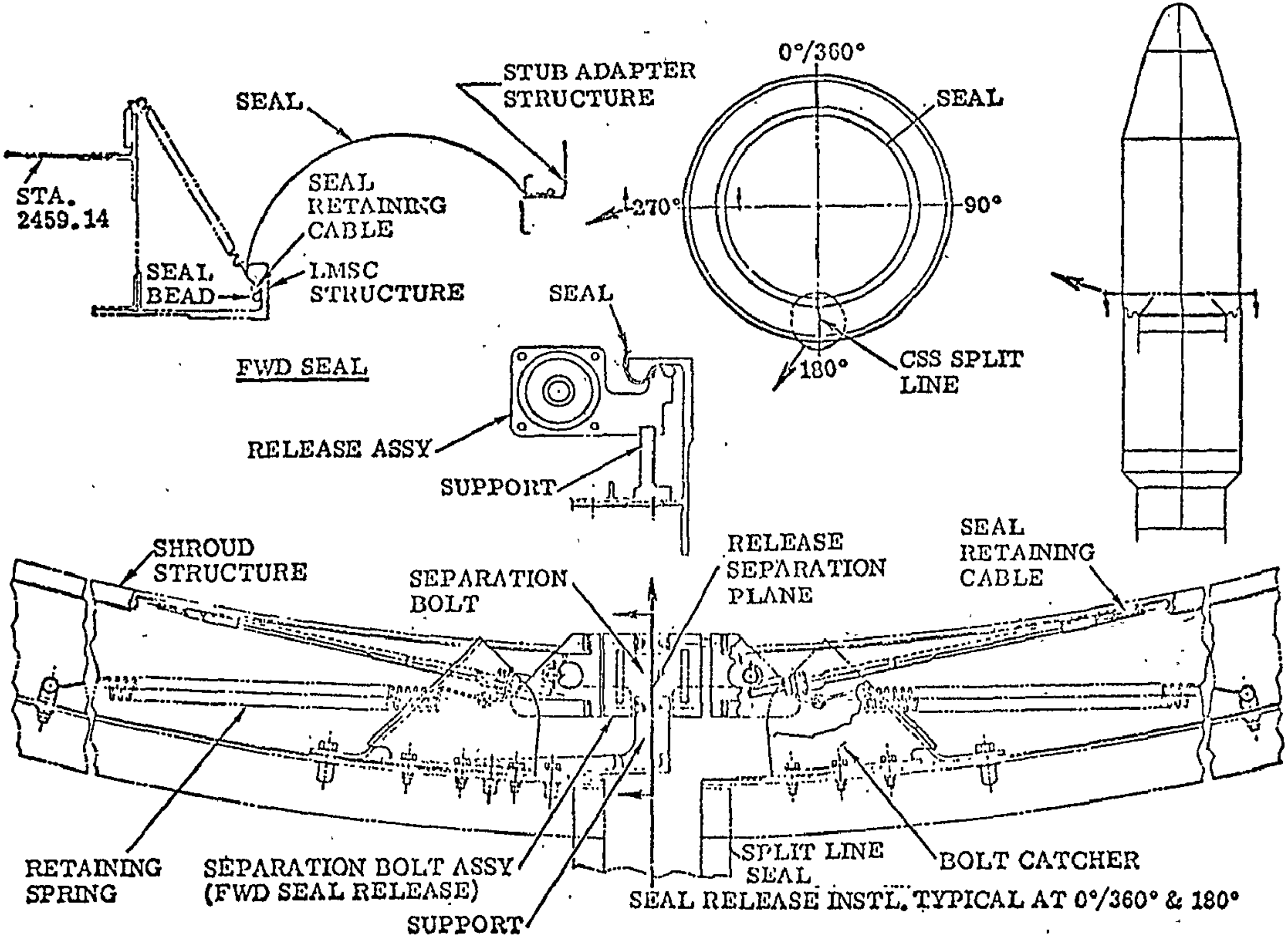


FIGURE 17 FORWARD SEAL

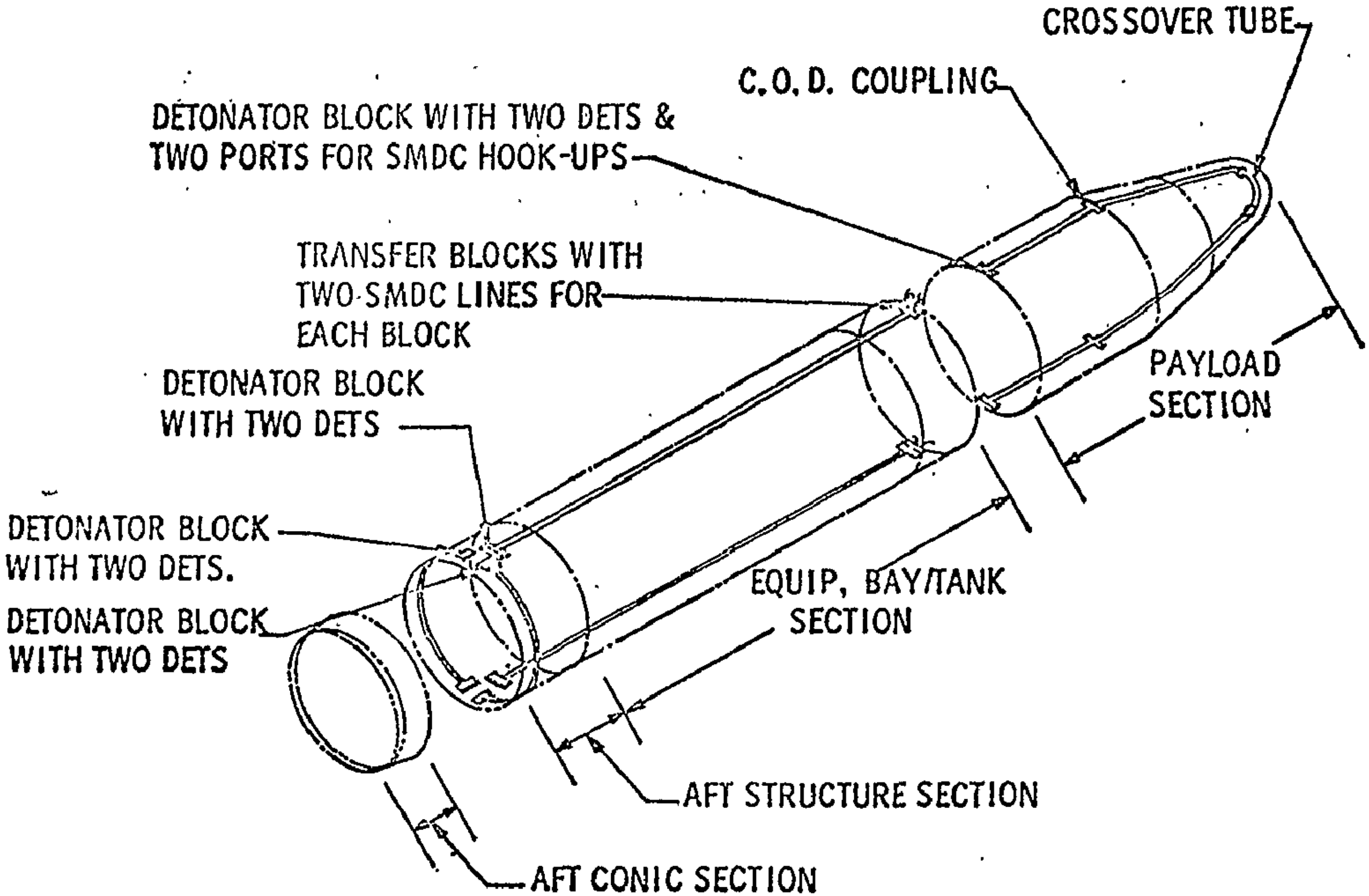
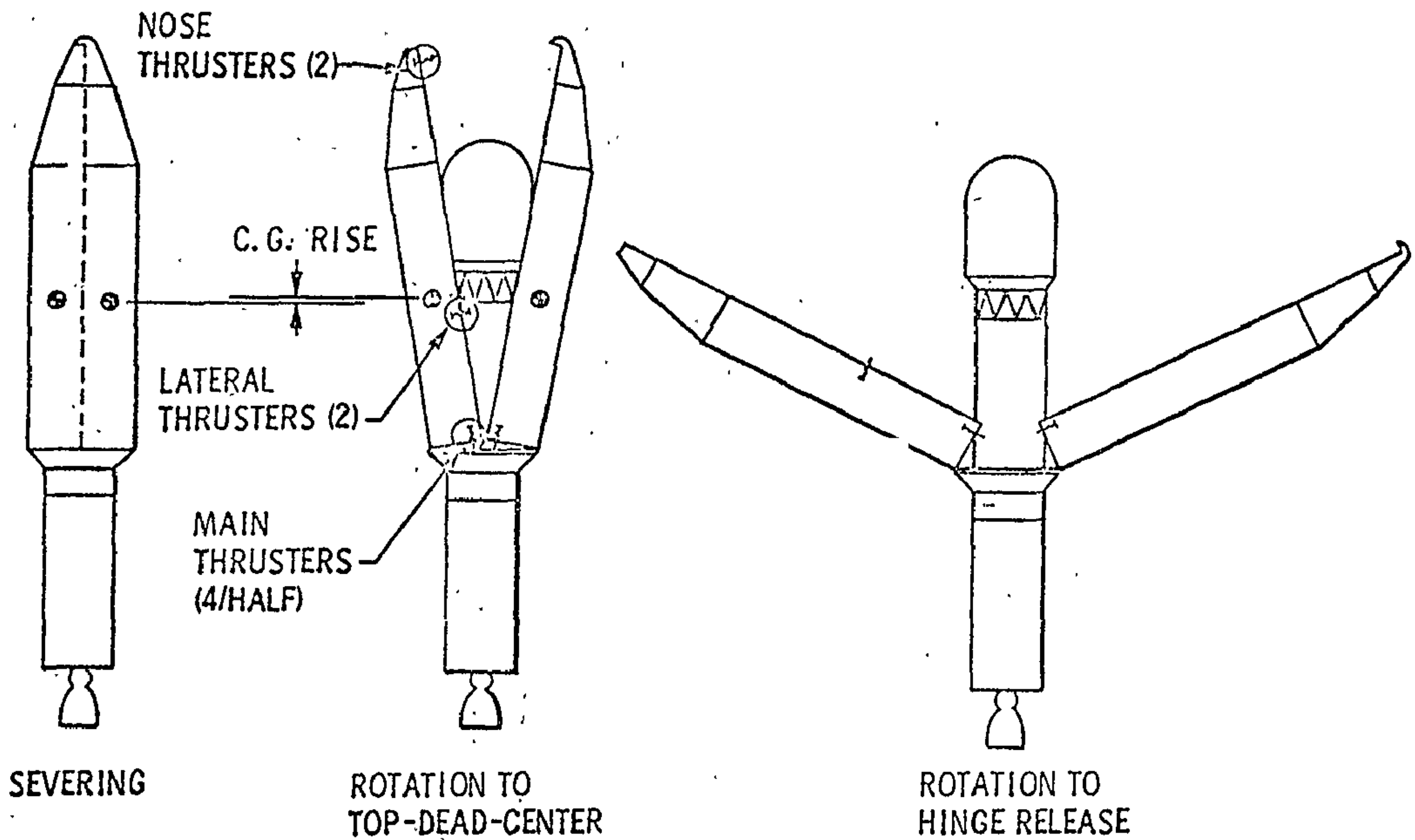


FIGURE 18 SUPER * ZIP SEPARATION SYSTEM



JETTISON SEQUENCE AND SPRING LOCATION

FIGURE 19

TABLE 20

CSS BREAKWIRE SUMMARY

BREAKWIRE (ROTATION AND LOCATION)		TIME FROM PRIMARY COMMAND (SECONDS)				
		TC-1	TC-2	TC-3	TC-4	TC-5
3^0 QUAD I	CAPPED	.40	.39	.39	.36	.41
3^0 QUAD II	CAPPED	.42	.41	.41	.36	.41
3^0 QUAD III	UNCAPPED	.39	.41	.39	.36	.41
3^0 QUAD IV	UNCAPPED	.40	.40	.39	.36	.41
8^0 QUAD I - II	CAPPED	.65	.76	.71	.69	.75
8^0 QUAD III - IV	UNCAPPED	.72	.76	.69	.70	.75
32^0 QUAD I - II	CAPPED	2.02	1.86	1.86	1.89	1.91
32^0 QUAD III - IV	UNCAPPED	1.84	1.56	1.77	1.75	1.86

IX CENTAUR D-1TR SYSTEMS ANALYSIS

IX CENTAUR D-IT SYSTEMS ANALYSIS

Mechanical Systems

Structures

by R. T. Barrett and R. C. Edwards

The Centaur D-IT structural configuration had no significant difference from the TC-2 configuration.

The Interstage Adapter (ISA) satisfactorily transferred all Centaur and CSS loadings onto the Titan skirt structure. The ISA forward ring was completely severed at Titan/Centaur staging and the vehicles separated at a constant acceleration.

The ullage pressures in the Centaur propellant comparts were within prescribed limits. Sufficient pressure was maintained to prevent buckling and maximum pressures did not exceed burst limits of the tank structure.

Interstage Adapter

Titan/Centaur separation occurred at T+483.3 seconds. Initial motion was at approximately T+484.0 seconds. The ISA cleared the Centaur vehicle 1.79 seconds after separation. The 15 foot extensometer (yo-yo) between the ISA and the Centaur indicated a smooth normal separation (Figure 20).

Centaur Tank

The liquid hydrogen tank pressure was always less than the maximum allowable pressure of 29.2 psid.

Sufficient pressure was maintained in the liquid hydrogen tank to prevent compressive buckling of the pressure stabilized tank skin for all periods of flight. During the critical compressive loading at liftoff, the pressure was 24.2 psia. The hydrogen tank pressure during the aerodynamic phase of flight (T+10 to T+90 seconds) was similar to previous Titan/Centaur flights and provided sufficient compressive strength.

The liquid oxygen tank pressure was within the structural limits for all periods of flight.

The differential pressure across the intermediate bulkhead did not exceed the structural limit of 23.0 psi. As required, the oxygen tank pressure was always greater than the hydrogen tank pressure.

G-2

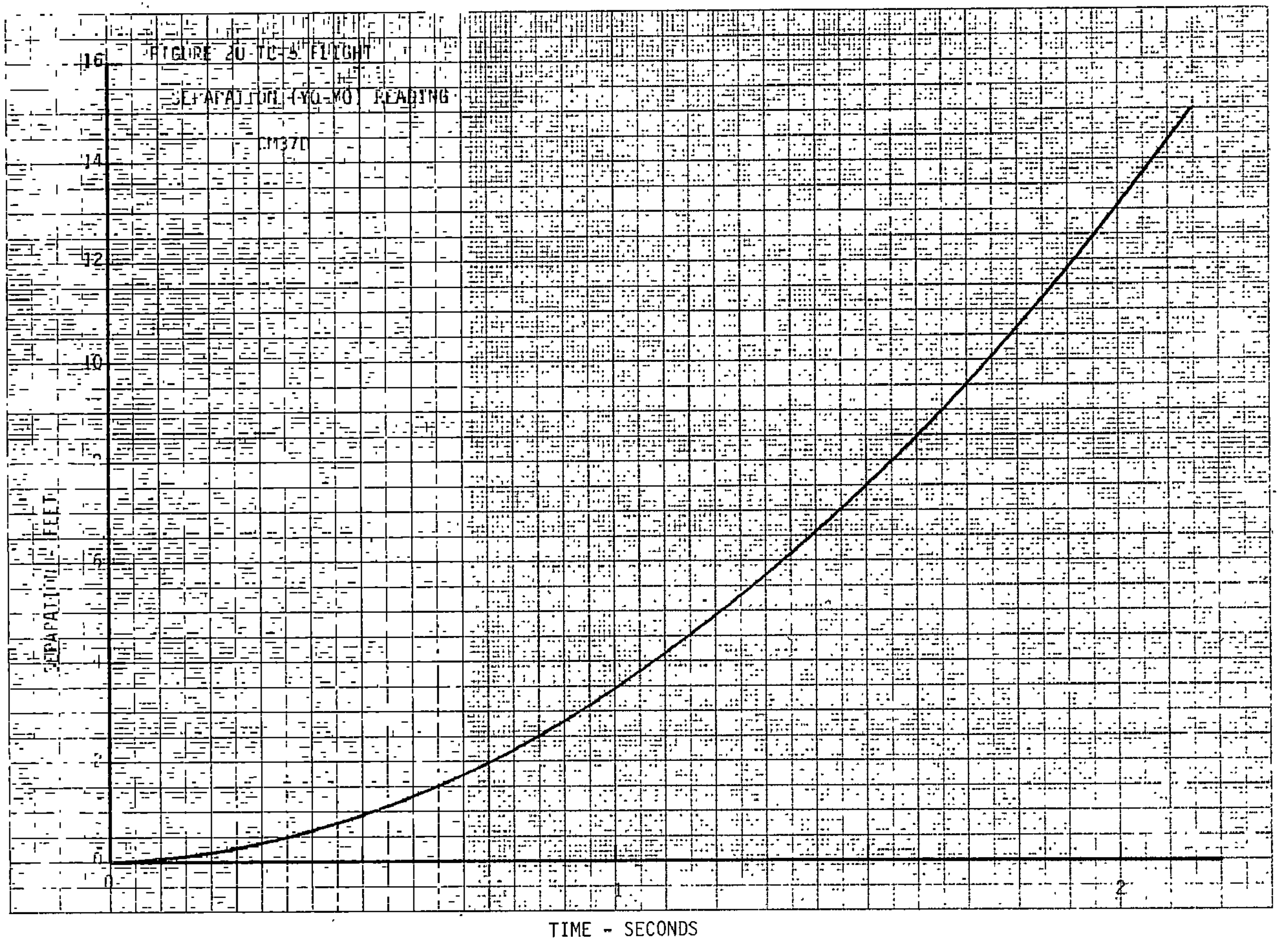


FIGURE 20 TC-5 FLIGHT
SEPARATION (YO-MO) READING
CM370
16
14
12
10
8
6
4
2
0
0
1
2
SEPARATION - FEET
TIME - SECONDS

The liquid hydrogen and oxygen tank ullage pressure selected time histories are listed in the Centaur D-1T pneumatics section of this report.

Propulsion/Propellant Feed System

by W. K. Tabata and D. B. Zelten

RL10 Engine System

Ground Prechill - Liquid helium prechill of the engine fuel pumps on the ground was satisfactory. Listed in Table 21 are the C-1 and C-2 engine fuel and oxidizer pump housing temperatures and the fuel turbine inlet temperatures at liftoff. All temperatures were within the experience of previous Centaur launches, except for the C-1 fuel pump housing and the C-2 fuel turbine inlet temperatures which were slightly colder. These colder temperatures were due to the extended prechill during the launch hold and did not create any engine problems.

Prestart - The C-1 and C-2 engine fuel and oxidizer pump housing temperatures and the fuel turbine inlet temperatures at the beginning of the first burn and second burn prestarts are listed in Table 21. For both prestarts, all temperatures were as expected and within the range of previous Centaur flights.

Start - The first and second burn start transients were normal and no unusual characteristics were noted. The start transient performance for both engines is given in Table 22.

Steady State - The C-1 and C-2 engine steady-state performance was as expected. In Table 23, the measured engine parameters at first main engine start (MES No. 1) plus 100 seconds and second main engine cutoff (MECO No. 2) are compared to engine acceptance test values. All parameters are within the flight instrumentation accuracy.

The C-1 and C-2 engine thrust, specific impulse and mixture ratio for the first and second burn, as calculated by Pratt & Whitney Aircraft, are presented in Table 24.

Shutdown - The shutdown transients of both engines on the first and second burn were normal with no unusual characteristics noted.

Extended Mission Experiments - After spacecraft separation, a Centaur extended coast experiment was performed. During the experiment, the RL10 engines were started five more times and operated satisfactorily.

In summary, the RL10 engines operated satisfactorily on the TC-5 mission:

1. The ground prechill was satisfactory.

Table 21 RL10 Engine Temperatures

	At Liftoff		At Prestart # 1		At Prestart #2	
	Measured	Expected	Measured	Expected	Measured	Expected
C-1 Fuel Pump Housing, °R	58	60 - 100	192	160 - 210	237	190 - 240
C-2 Fuel Pump Housing, °R	60	60 - 100	194	160 - 210	241	190 - 240
C-1 Oxidizer Pump Housing, °R	396	390 - 430	381	360 - 430	350	280 - 420
C-2 Oxidizer Pump Housing, °R	405	390 - 430	371	360 - 430	414	280 - 420
C-1 Fuel Turbine Inlet, °R	398	370 - 410	391	350 - 420	308	290 - 350
C-2 Fuel Turbine Inlet, °R	355	370 - 410	366	350 - 420	312	290 - 350

Table 22 RL10 Engine Start Transient Performance (a)

	Flight Value		Expected Range
	C-1	C-2	
First-Burn:			
Acceleration time to 90% thrust, sec.	1.322	1.377	1.318 - 1.620
Start Impulse to 2.0 seconds, lb-sec	12,261	11,065	7,465 - 12,584
Second-Burn:			
Acceleration time to 90% thrust, sec.	1.468	1.605	1.336 - 1.878
Start Impulse to 2.0 seconds, lb-sec	10,796	8,959	6,951 - 12,254

(a) Values are from Pratt & Whitney Aircraft analyses.

Table 23 RL10 Engine Steady-State Performance

	MES #1 + 100 sec	MECO #2	Acceptance Test	Meas. Accuracy
C-1 Thrust Chamber Pressure, psia	388	390	390	± 10
C-2 Thrust Chamber Pressure, psia	385	385	392	± 10
C-1 Oxidizer Pump Speed, rpm	12, 220	12, 290	12, 300	± 600
C-2 Oxidizer Pump Speed, rpm	12, 390	12, 390	12, 390	± 600
C-1 Venturi Upstream Press., psia	724	740	743	± 30
C-2 Venturi Upstream Press., psia	746	753	766	± 30
C-1 Turbine Inlet Temp., °R	383	375	379	± 16
C-2 Turbine Inlet Temp., °R	382	386	380	± 16
C-1 Ox Pump Discharge Press, psia	593	595	599	± 16
C-2 Ox Pump Discharge Press, psia	593	600	604	± 16
C-1 Fuel Pump Disch. Press., psia	970	974	976	±30
C-2 Fuel Pump Disch. Press., psia	982	1002	992	± 30

Table 24 RL10 Engine Steady-State Performance (a)

	MES #1 + 100 seconds	MECO #2	Acceptance Test
C-1 Engine:			
Thrust, lbs.	14, 965	14, 951	14, 957
Specific Impulse, sec.	441. 2	441. 8	441. 6
Mixture Ratio	5. 19	4. 96	5. 02
C-2 Engine:			
Thrust, lbs.	14, 837	14, 919	15, 019
Specific Impulse, sec	441. 4	441. 5	441. 7
Mixture Ratio	5. 12	5. 08	5. 02

(a) Values are from Pratt & Whitney Aircraft analyses (C^* Iteration).

2. Engine cooldown (prestart) prior to each engine start was satisfactory.

3. Engine ignition and start transients were normal on all burns.

4. Engine steady-state performance was normal and agreed well with engine acceptance test values.

5. Engine shutdown transients were normal on all burns.

Propellant Feed System

The Centaur propellant feed system performed satisfactorily during ground operations and in flight.

Operation of the liquid helium system, propellant supply ducts and their recirculation lines, and the tank fill and drain valves was satisfactory. The C-1 and C-2 LO_2 inlet temperature sensors indicated liquid approximately 7 and 8 minutes respectively after start of LO_2 tanking. The C-1 and C-2 engine inlet temperature sensors indicated liquid approximately 7 and 6 minutes respectively after start of LH_2 tanking. These times compare favorably with TC-5 tanking test data and data from prior launches. A summary of the propellant feed system temperature data is shown in Table 25. One instrumentation problem was observed. The backup LH_2 duct temperature patch (CP56T) on the C-1 engine inlet went off scale high before the first boost pump start and was abnormal for the remainder of the flight. This problem is discussed further in the Instrumentation Section.

Boost pump performance during the prelaunch spin-up test and during both Centaur burns was satisfactory. Performance data at selected times during boost pump operating periods are presented in Tables 26 and 27. The boost pumps were first started 35.6 seconds prior to Titan Stage II cutoff. This was 7.2 seconds earlier than the nominal start time and is attributed to the late Stage II cutoff time. The turbine inlet pressure delay times (time from boost pump start signal to time of first indication of turbine inlet pressure rise) were less than one second for both boost pumps on both starts. Steady-state performance was normal.

Table 25 Centaur Propellant Feed System Temperature Data

Parameter	Meas. No.	Units	Event and Event Time							
			T-0	BPS-1	MES-1	MECO-1	BPS-2	MES-2	MECO-2	P/L Sep.
Propellant Feed System										
LH2 boost pump inlet	CP 32T	DGF	-420.1	-420.8	-420.8	-421.2	-419.9	-421.2	-423.6	-423.4
LO2 boost pump inlet	CP 33T	"	-282.1	-282.1	-281.8	-282.7	-282.4	-282.1	-285.3	-285.6
C-1 LO2 duct surface	CP 55T	"	-275.2	-270.6	-271.5	-273.6	-274.2	-274.7	-277.9	-277.0
C-1 LH2 duct surface	CP 56T	"	-400.8	>-378	-389.0	>-378	>-378	>-378	-387.3	>-378
C-2 LO2 duct surface	CP 57T	"	-275.1	-263.1	-265.9	-263.2	-270.5	-271.4	-267.8	-273.2
C-2 LH2 duct surface	CP 58T	"	-401.3	-402.9	-405.8	-405.1	>-378	-396.3	-413.2	-411.1
C-1 LO2 pump inlet	CP 59T	"	-281.3	-279.6	281.0	-282.8	>-275	-281.2	-285.3	-285.0
C-1 LH2 pump inlet	CP 60T	"	-419.2	-420.1	-419.8	-420.6	>-413.8	-420.1	-422.5	-422.7
C-2 LO2 pump inlet	CP 61T	"	-281.1	-279.6	-280.8	-282.8	-280.3	-281.2	-285.3	-285.0
C-2 LH2 pump inlet	CP 62T	"	-419.3	-420.1	-419.8	-420.6	>-413.6	-420.0	-422.6	-422.6
C-1 LO2 duct surface	CP 750T	"	-274	-275	-277	-280	-264	-275	-281	-281
C-1 LH2 duct surface	CP 751T	"	<-400	<400	<400	<400	-260	-389	<-400	<400
LO2 Boost Pump Turbine										
Rotor lower bearing	CPT 36T	DGF	71	71	91	118	208	216	314	338
Gearcase surface (output)	CP 176T	"	65	63	69	91	172	173	>206	>206
Catalyst bed surface	CP 186T	"	101	136	>597	>597	548	>597	>597	>597
LH2 Boost Pump Turbine										
Rotor lower bearing	CPT 127T	DGF	71	71	91	124	196	202	308	332
Gearcase surface (output)	CP 177T	"	64	59	67	100	168	171	>217	>217
Catalyst bed surface	CP 187T	"	97	127	>597	>597	464	>597	>597	>597

Table 26 Centaur Boost Pump Spin Up Test Data

Parameter	LO_2 Boost Pump Vehicle TC-2	LO_2 Boost Pump Vehicle TC-4	LO_2 Boost Pump Vehicle TC-5	LH_2 Boost Pump Vehicle TC-2	LH_2 Boost Pump Vehicle TC-4	LH_2 Boost Pump Vehicle TC-5
Run Duration, seconds	223	211	221	223	211	221
Rotation Delay, seconds	13	19	20	24	25	22
Turbine Inlet Pressure at First Rotation, psia	54	63	63	81	78	78
Turbine Inlet Pressure at Shutdown, psia	155	156	153	152	156	153
Turbine Speed at Shutdown, rpm	16,440	15,730	14,000	20,460	20,475	18,200
Pump Headrise at Shutdown, psid	14.4	13.5	13.5	3.9	3.5	3.5
Rotation Coastdown Time, seconds	38	25	30	34	27	27

Table 27 Centaur Boost Pump Performance Data Summary

Parameter	Meas. No.	Units	First Burn Prestart	First Burn MES	First Burn MECO	Second Burn Prestart	Second Burn MES	Second Burn MECO
LO2 Boost Pump								
Pump headrise △ P	CPT 120P	psid	84.0	81.0	33.5	63.0	81.0	33.9
Turbine speed	CPT 15B	rpm	38,350	37,960	33,800	33,800	39,000	33,800
Turbine inlet pressure	CPT 26P	psia	92.4	93.0	93.0	92.1	93.0	94.5
LH2 Boost Pump								
Pump headrise △ P	CPT 121P	psid	23.0	21.0	11.0	14.5	20.8	12.0
Turbine speed	CPT 16B	rpm	42,900	40,625	39,650	33,800	40,950	39,940
Turbine inlet pressure	CPT 28P	psia	96.9	97.2	97.2	94.8	96.9	99.0

Hydrogen Peroxide Supply and Reaction Control System

by D. B. Zelten

The hydrogen peroxide supply and engine system performed satisfactorily for the Helios mission. The two supply bottles were tanked with a total of 484.5 pounds of hydrogen peroxide. Bottle pressure at liftoff was 319 psia and system temperatures were normal. During the Titan boost phase of flight, four engines were fired for 20 seconds each to remove any large accumulation of gas in the hydrogen peroxide bottles. All eight lateral thrust engines were simulaneously fired for 10 seconds starting at 20 seconds prior to first main engine cutoff. The purpose of these firings was to warm the engines prior to the long coast period.

The data showed that the attitude control and propellant settling engines operated as programmed and properly maintained vehicle attitude control during the settled coast period and also after MECO No. 2 out through payload separation. System temperature data were as expected during the flight. Measurement CP159T; LH_2 boost pump H_2O_2 feed line in quadrant 4, went off scale high (178°F) about 10 minutes before second boost pump start and remained there until shortly after boost pump start. This high temperature is attributed to solar radiation. The measurement is located on a section of line near the H_2O_2 bottles which are covered with aluminized mylar. Therefore, the line, which was empty at the time, not only received direct solar radiation but also reflected radiation from the surface of the bottles. The line cooled rapidly with the flow of hydrogen peroxide at second boost pump start. Similar data were observed on TC-2 flight. Temperature data at selected times are presented in Table 28.

Table 28 Centaur H_2O_2 Supply and Engine System Temperatures, D-1T

Parameter	Meas. No.	Units	Events T-0	BPS #1	MES #1	MECO #1	BPS #2	MES #2	MECO #2	P/L Sep
Engine Chamber Surfaces:										
S2A	CP 691T	dgf	68	671	576	497	1246	1246	619	585
S2B	CP 837T	"	68	892	705	559	1246	1246	637	602
S4A	CP 693T	"	68	68	68	68	1330	1330	671	637
S4B	CP 836T	"	68	68	68	68	1279	1279	671	637
Y1	CP 148T	"	68	740	619	1077	1010	1026	619	1094
Y4	CP 149T	"	68	68	68	909	1077	1110	637	1128
P3	CP 375T	"	68	68	68	757	1144	1144	602	1060
P4	CP 376T	"	68	68	68	723	909	942	637	1060
H2O2 Lines to Engines:										
Quad 1	CP 150T	dgf	74	91	92	87	92	90	88	86
Quad 2	CP 151T	"	76	88	88	88	101	100	111	117
Quad 3	CP 153T	"	80	96	97	94	93	92	93	94
Quad 4	CP 154T	"	80	94	95	93	94	94	98	94
Quad 1-4	CP 155T	"	74	93	93	92	94	94	95	98
Quad 2-3	CP 152T	"	83	93	93	91	92	92	96	93
H2O2 Lines to Boost Pumps:										
LH2 orifice inlet	CP 361T	dgf	79	65	98	112	101	100	127	156
LO2 orifice inlet	CP 714T	"	68	76	101	144	107	114	160	132
LH2 inlet, near tee	CP 833T	"	86	70	87	94	88	93	117	123
LH2 Quad 1 fitting	CP 156T	"	76	72	82	88	82	91	104	99
LH2 Quad 2 line	CP 157T	"	69	84	88	88	107	97	98	105
LH2 Quad 3 line	CP 158T	"	67	67	87	89	89	87	91	91
LH2 Quad 4 line	CP 159T	"	67	83	91	92	OSH	121	95	104
Between Feed Valves	CP 831T	"	83	100	88	90	129	92	92	94
Boost Pump Orifice Holder:										
LH2	CP 710T	dgf	75	71	87	93	90	94	104	108
LO2	CP 711T	"	68	66	88	94	109	104	102	105
LH2 B/P Electrical Connector	CP 712T	dgf	75	70	71	76	120	116	148	155
Boost Pump Feed Valve #2 Body	CP 834T	"	76	78	87	91	92	92	94	98
H2O2 Crossover Line	CP 756T	"	92	95	93	95	94	92	92	92
H2O2 Bottle, Boost Pump	CP 659T	"	86	86	88	88	90	90	91	91
H2O2 Bottle, Reaction Ctl.Sys.	CP 93T	"	87	84	88	88	89	89	89	89
H2O2 Vent Line No. 1	CP 832T	"	80	81	82	82	92	92	89	90

Hydraulic System

by E. J. Fourney

The Centaur hydraulic system flight performance was satisfactory. The recirculation system responded properly when commanded "ON" by the PCU prior to main engine starts (MES-1 and MES-2).

At MES-1 and MES-2, the hydraulic system pressure increased to the expected values and operated normally throughout both main engine burns. At main engine cutoff (MECO-1 and MECO-2) system pressure decay was normal.

No anomalies were noted.

System pressures and temperatures are presented in Table 29.

CENTAUR HYDRAULIC SYSTEM FLIGHT PERFORMANCE

Parameter	Measurement No.	Units	Centaur First Burn			Centaur Second Burn		
			Recirc. ON	MES-1	MECO-1	Recirc. ON	MES-2	MECO-2
C-1 Hydraulic Power Package Pressure	CHT1P	psia	150	1170	1170	150	1170	1140
C-1 Hydraulic Manifold Temperature	CHT5T	°F	69°	69°	113°	72	76°	164°
C-2 Hydraulic Power Package Pressure	CHT3P	psia	128	1140	1140	128	1140	1125
C-2 Hydraulic Manifold Temperature	CHT6T	°F	62	62	117	78	80	175

TABLE 29

Pneumatics and Tank Vent Systems

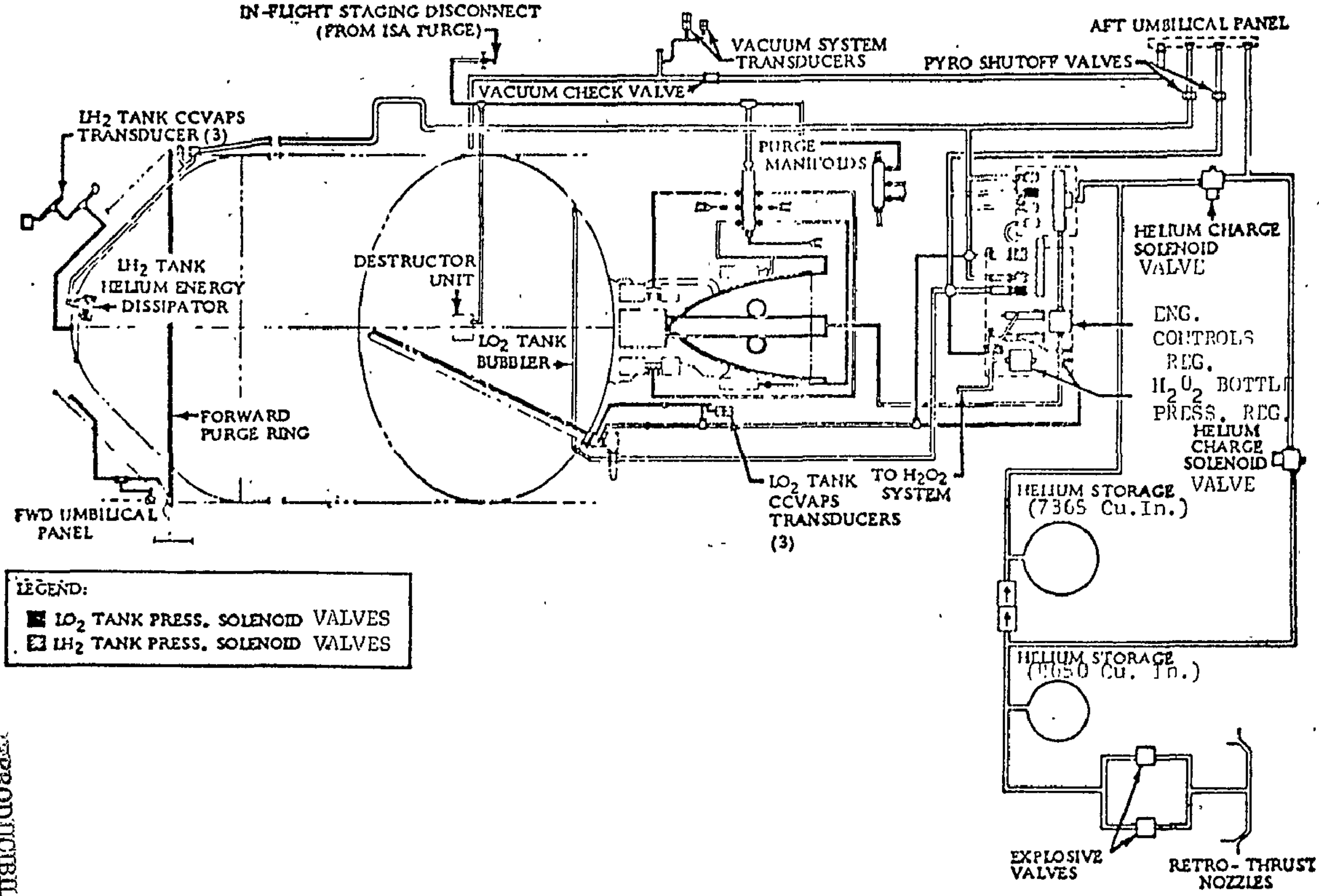
by M. L. Jones and R. F. Lacovic

The Centaur pneumatic and vent system, which is shown schematically in Figures 21.1 and 21.2, was the same as that on TC-2. All systems performed normally during the flight.

Tank Pressurization and Venting. - A time history of the tank ullage pressures for selected portions of the mission is shown in Figures 22.1 through 22.6. Prior to T-27.8 seconds, the primary hydrogen vent valve, which has a specification operating range from 19.0 to 21.5 psia, regulated the tank pressure at 21.2 psia. At T-27.8 seconds, the primary hydrogen vent valve was commanded to the locked mode and the tank pressure was allowed to rise in order to satisfy the tank structural strength requirements during liftoff and during the subsonic portion of the flight. A minimum requirement of 23.5 psia at liftoff had been established before the flight. A maximum limit of 25.0 psia had also been established in order to preclude the possibility of venting hydrogen gas overboard before 8 seconds into the flight.

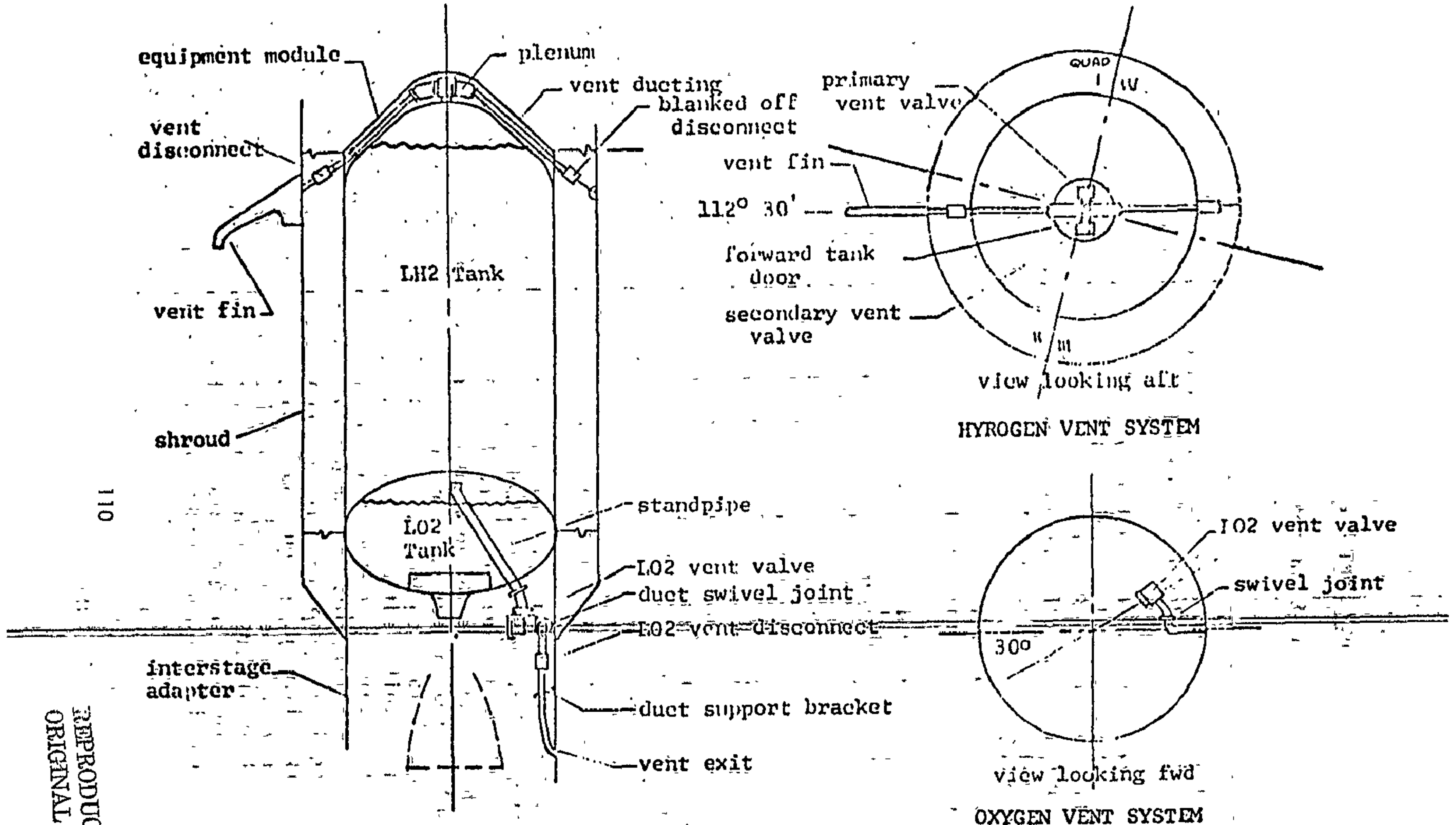
From T-30.1 until T-8.1 seconds, the tank pressure was monitored by the Computer Controlled Vent and Pressurization System (CCVAPS) which calculated the pressure rise rate and predicted the tank pressure at liftoff. If the CCVAPS prediction had not fallen within the established limits, an automatic launch abort would have been initiated. At T-8.1 seconds the CCVAPS predicted pressure at liftoff was 24.25 psia. The actual liftoff pressure was 24.32 psia. At T-8.1 seconds the CCVAPS was deactivated until the start of tank pressurization for the first main engine start sequence.

After liftoff, the tank pressure continued to rise, but at a decreasing rate, until it reached a peak value of 25.1 psia at approximately T+25 seconds, after which the pressure gradually decreased until T+90 seconds, when the primary vent valve was commanded to the relief mode. The decreasing rate of pressure rise and the eventual decrease in pressure can be attributed to a combination of factors: decreased convective heat input to the tank from the helium purge gas as it vented overboard during atmosphere ascent; suppressed boiling of the liquid hydrogen as the vehicle acceleration increased; and the increased ullage volume by virtue of the tank changing shape as the tank differential pressure increased. During the period when the primary vent valve was in the locked mode, the secondary vent valve, which has a specification operating range from 24.8 to 26.8 psia, was in the relief mode in order to protect against overpressurization of the tank. Venting through the secondary vent valve did not occur, however.



Pneumatics System

Figure 21.1 Centaur Pneumatics & Vent Systems



Vent System

Figure 21.2

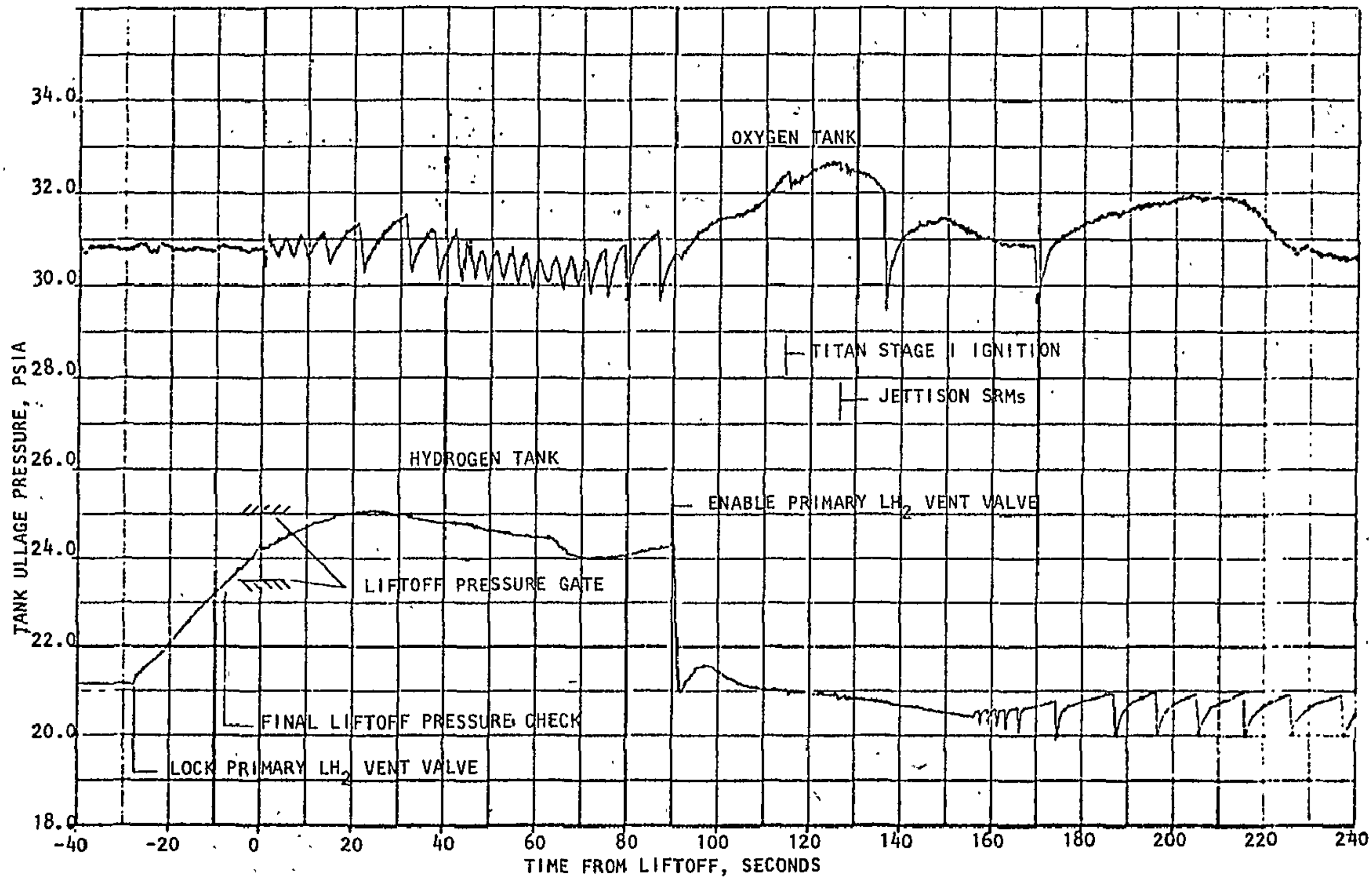
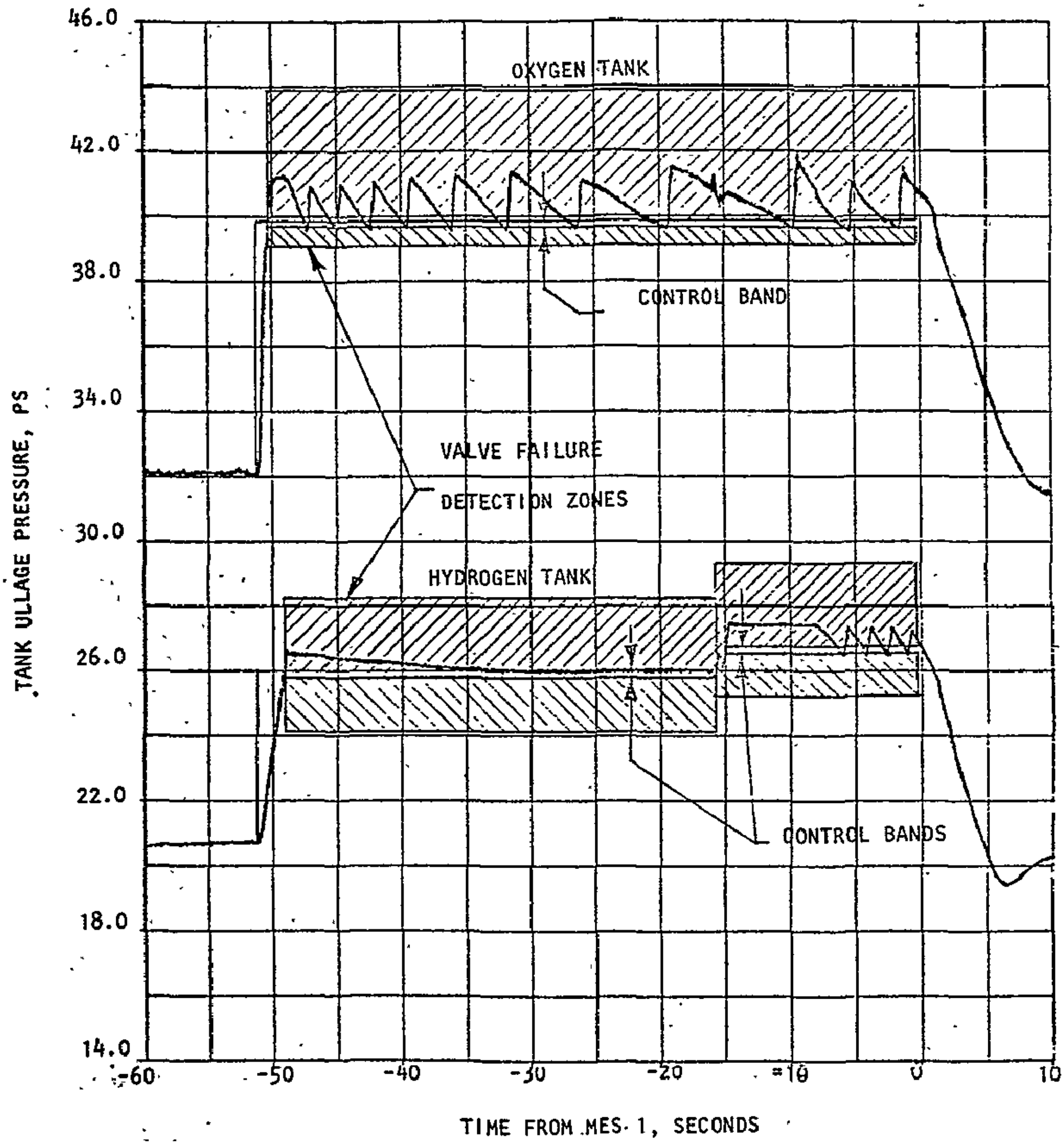
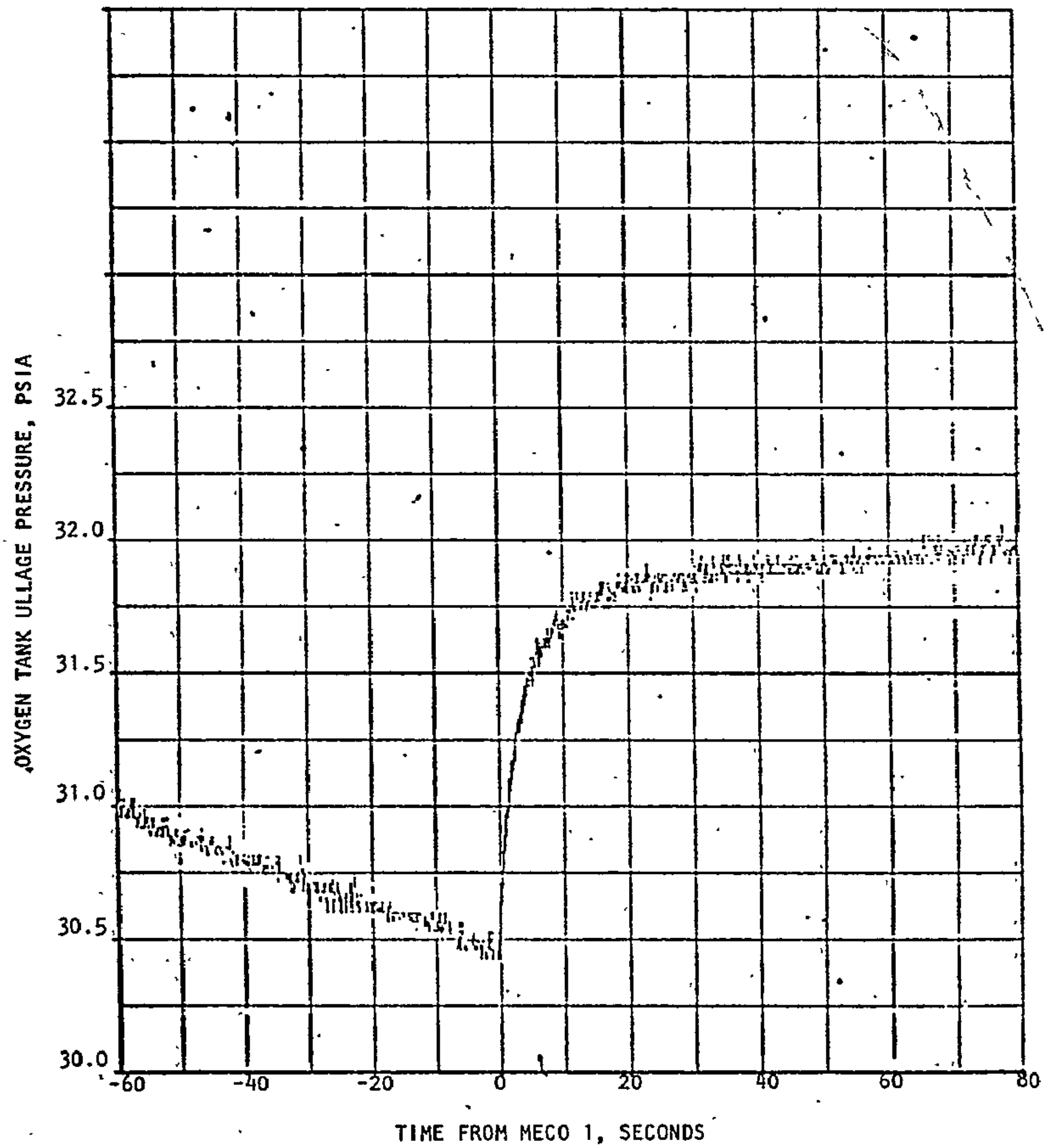


FIGURE 22.1 . CENTAUR TANK ULLAGE PRESSURE HISTORY



OXYGEN TANK
CONTROL BAND
VALVE FAILURE
DETECTION ZONES
HYDROGEN TANK
CONTROL BANDS
TANK ULLAGE PRESSURE, PS
46.0
42.0
38.0
34.0
30.0
26.0
22.0
18.0
14.0
-60
-50
-40
-30
-20
-10
0
10
TIME FROM MES 1, SECONDS

FIGURE 22.2



OXYGEN TANK ULLAGE PRESSURE, PSIA
32.5
32.0
31.5
31.0
30.5
30.0
-60
-40
-20
0
20
40
60
80
TIME FROM MECO 1, SECONDS

FIGURE 22.3

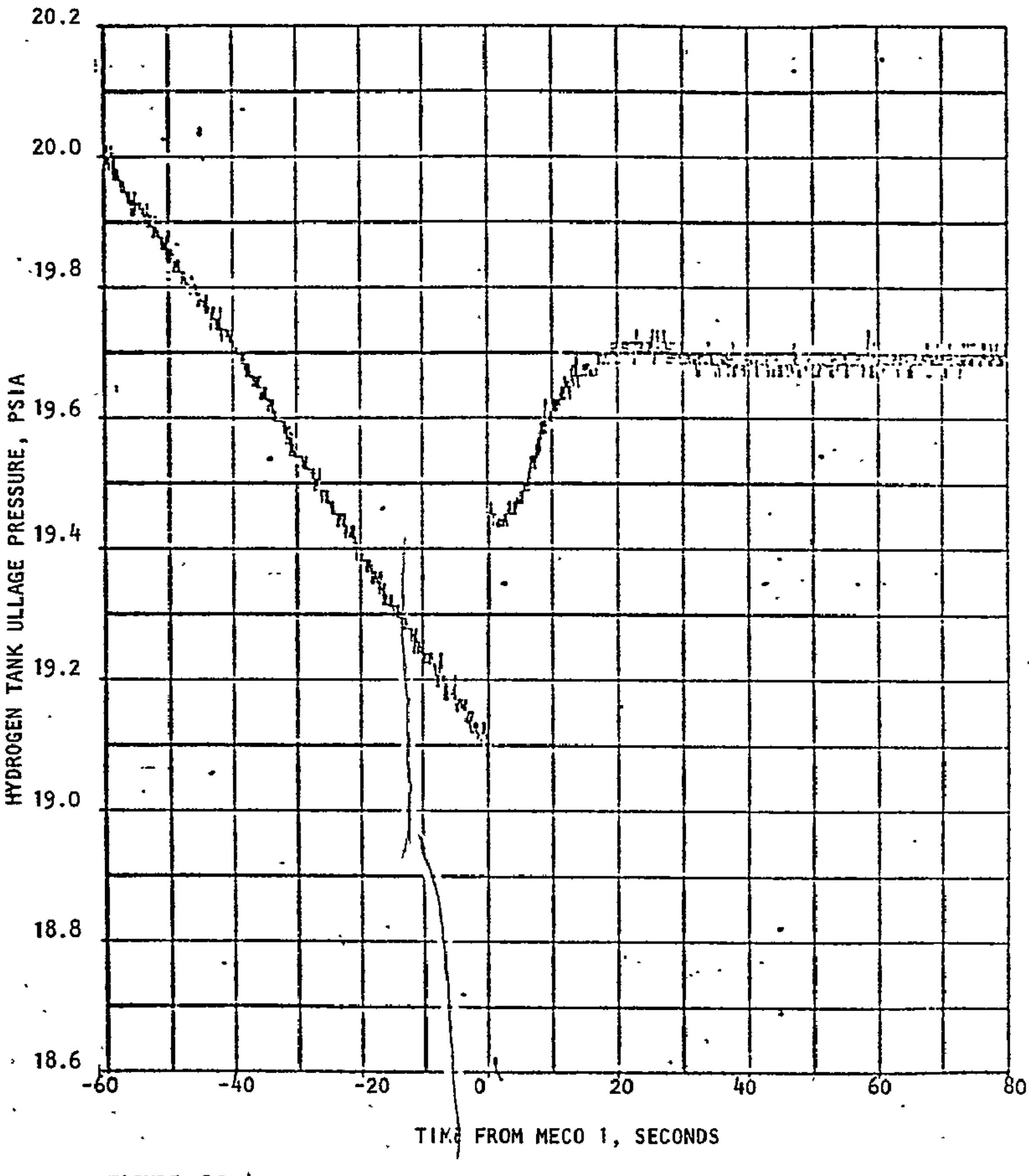

20.2
20.0
19.8
19.6
19.4
19.2
19.0
18.8
18.6
HYDROGEN TANK ULLAGE PRESSURE, PSIA
-60
-40
-20
0
20
40
60
80
TIME FROM MECO 1, SECONDS

FIGURE 22.4

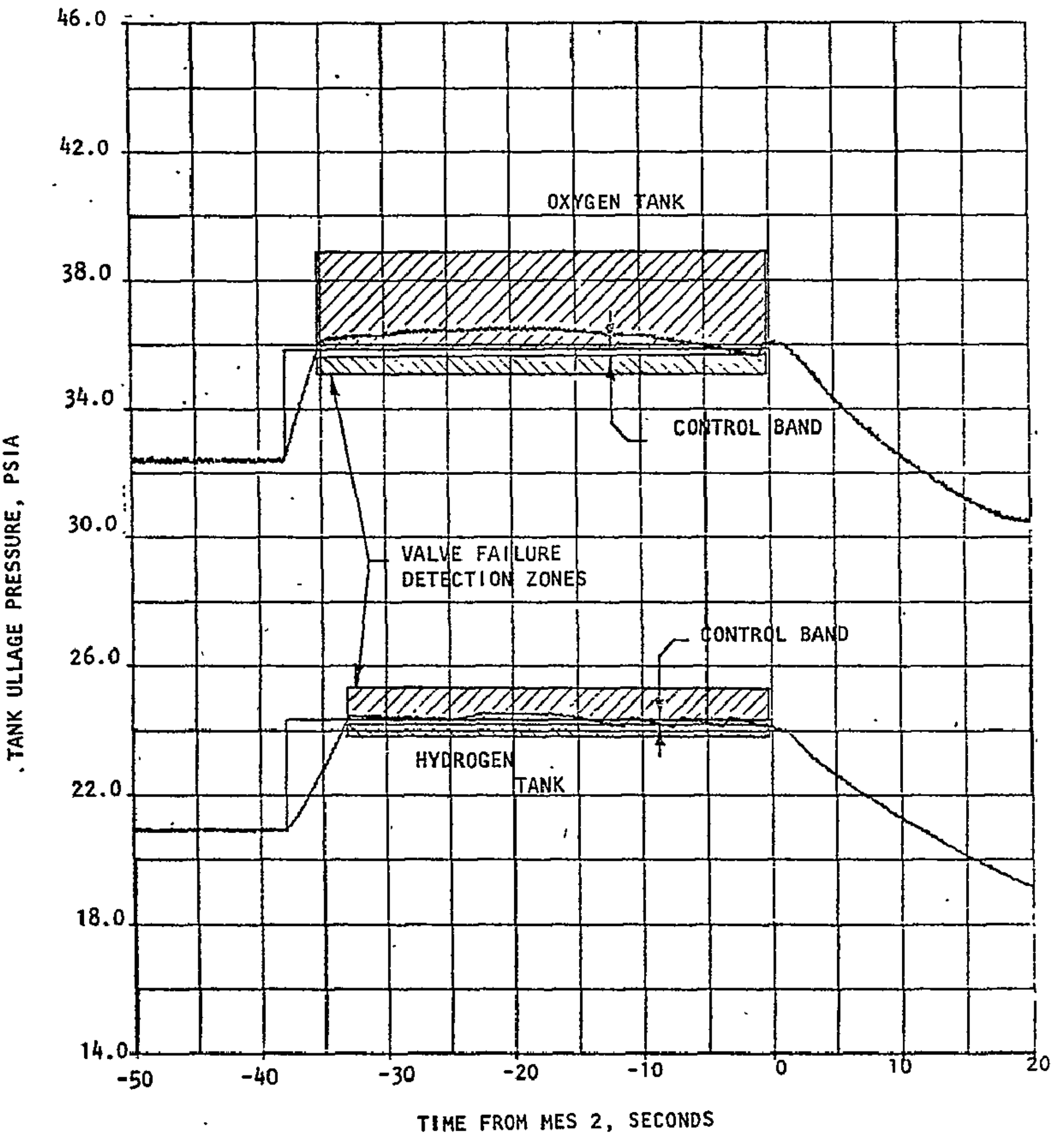

46.0
42.0
38.0
34.0
30.0
26.0
22.0
18.0
14.0
OXYGEN TANK
CONTROL BAND
VALVE FAILURE
DETECTION ZONES
CONTROL BAND
HYDROGEN
TANK
TANK ULLAGE PRESSURE, PSIA
-50
-40
-30
-20
-10
0
10
20
TIME FROM MES 2, SECONDS

FIGURE 22.5

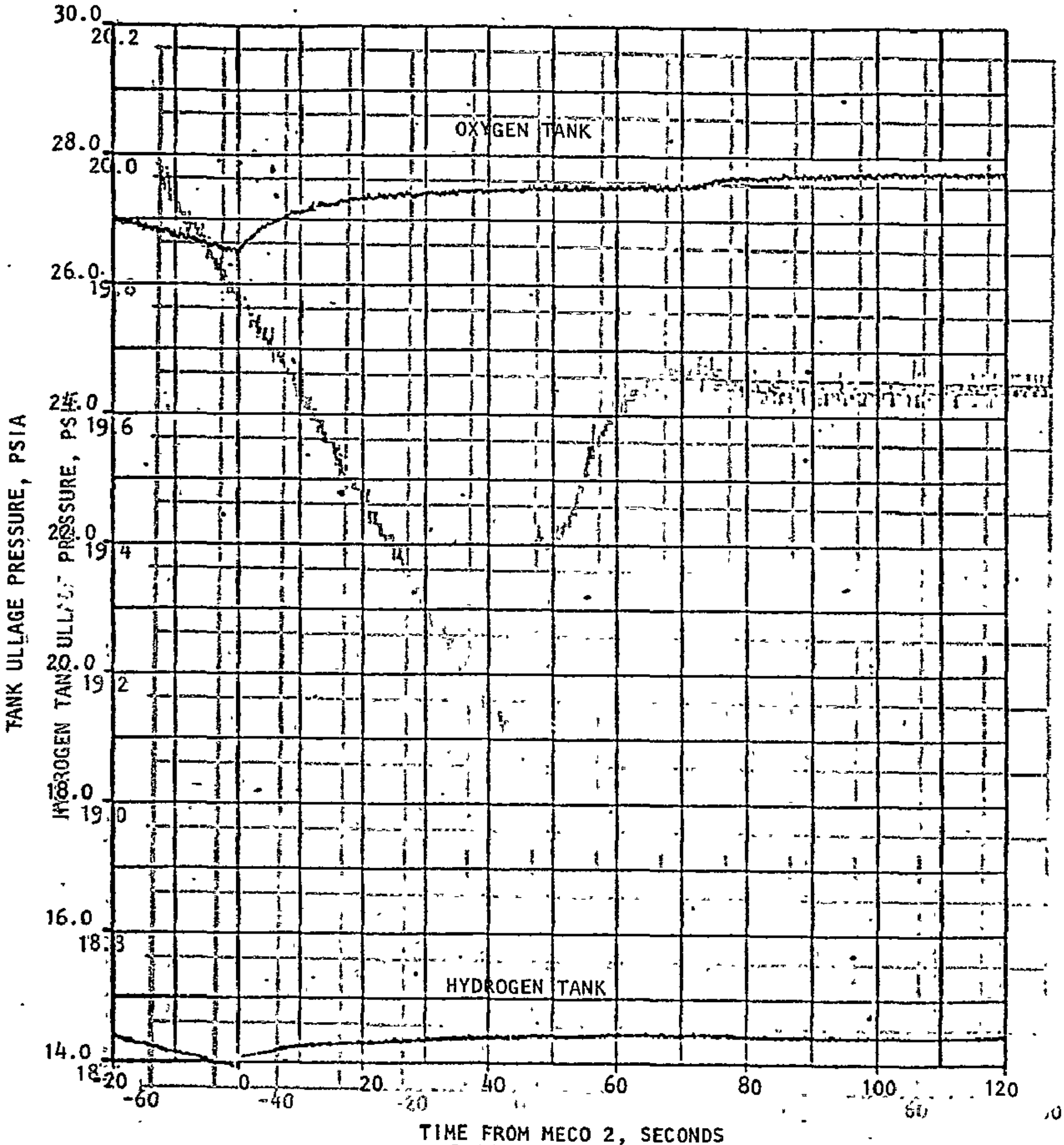


FIGURE 22.6
FIGURE 22.4

At T+90 seconds, with the primary hydrogen vent valve commanded to the relief mode, the hydrogen tank pressure vented down to the control range of the primary vent valve. The valve then began to cycle between its operating limits and continued to cycle until commanded to the locked mode for the start of tank pressurization for first main engine start.

The ullage pressure in the oxygen tank was 30.74 psia at liftoff. The vent valve, which has a specification operating range from 29.0 to 32.0 psia, was in the relief mode. Immediately after liftoff, the vent valve began to cycle between its operating limits and continued to cycle until the beginning of tank pressurization for first main engine start. At T+25 seconds, the reseat pressure decreased about 0.5 psia. Later in the flight during atmospheric ascent, the reseat pressure decreased an additional 0.5 psi. These same operating characteristics were observed on earlier Titan/Centaur vehicles and can be attributed, in part, to the diminishing back pressure on the vent system as the vehicle ascended through the atmosphere. During the Titan Stage 0 shutdown/Stage I startup, the abrupt reaction in vehicle acceleration resulted in increased boiling and possibly some liquid entrainment causing the ullage pressure to increase to 32.6 psia. After the staging transient, the pressure decreased and again was controlled within the vent valve operating limits.

At T+440.7 seconds the oxygen vent valve and both hydrogen vent valves were commanded to the locked mode. Two seconds later tank pressurization for the first main engine start was initiated. The ullage pressures in both tanks increased, under CCVAPS control, by predetermined incremental amounts and were then maintained by CCVAPS within the predetermined control band until MES 1. The CCVAPS control parameters are summarized in Table 30. At MES 1 the hydrogen tank ullage pressure was 26.8 psia while that in the oxygen tank was 40.7 psia. At MECO 1 the hydrogen and oxygen tank ullage pressures were 19.1 psia and 30.4 psia, respectively. During the settled coast, which followed MECO 1, CCVAPS did not initiate a tank venting sequence, since both tank pressures remained well below the vent initiation criteria. These criteria are summarized in Table 30.

At T+2247.4 seconds tank pressurization for the second main engine start was initiated. Tank pressures were controlled until MES 2 by CCVAPS to predetermined levels which are summarized in Table 30. At MES 2 the hydrogen tank ullage pressure was 24.2 psia, while that in the oxygen tank was 36.0 psia.

At MECO 2 the hydrogen and oxygen tank ullage pressures were down to 13.8 psia and 26.5 psia respectively. After MECO 2 the oxygen tank ullage pressure increased slightly until Centaur retromaneuver while the hydrogen tank ullage pressure remained constant.

Table 30 CCVAPS Tank Pressurization and Vent Control Parameters

Parameters		LO_2 Tank Pressures, psia			LH_2 Tank Pressures, psia		
		TC-2	TC-5 Expected Values	TC-5	TC-2	TC-5 Expected Values	TC-5
Tank Pressurization Sequence for First MES:							
Prior to Stage II Cutoff	Initial pressure at start of prztn.	32.15	29.0-32.7	32.1	19.92	19.0-20.0	20.7
	Closing pressure	39.12	36.76-40.5	39.9	25.92	25.0-26.0	26.0
	Closing pressure criteria	ΔP_i Max.	--	ΔP Close	ΔP Close	--	ΔP Max.
	Minimum undershoot pressure	38.2	35.96	39.5	25.66	23.10	26.0
	Maximum overshoot pressure	40.75	44.27	41.5	26.63	27.53	26.6
	Initial pressure rise in 1.5 sec.	8.81	$\geq$ 1.33	9.1	2.73	$\geq$ 0.66	4.1
After Stage II Cutoff	Closing pressure	39.91	36.76-40.5	39.9	25.92	25.0-27.1	26.7
	Closing pressure criteria	ΔP Close	--	ΔP Close	ΔP Close	--	ΔP Close
	Minimum undershoot pressure	39.87	35.96	39.6	26.05	23.1	26.4
	Maximum overshoot pressure	41.6	44.27	42.0	26.60	28.63	27.5
Tank Pressurization Sequence for Second MES:							
	Initial pressure at start of pressurization	32.61	29.0-41.0	32.3	20.13	19.0-24.7	20.9
	Closing pressure	36.11	32.5-44.5	35.8	23.53	22.4-28.1	24.3
	Closing pressure criteria	ΔP Close	--	ΔP Close	ΔP Close	--	ΔP Close
	Minimum undershoot pressure	36.11	31.7	35.6	23.37	21.9	24.1
	Maximum overshoot pressure	36.80	45.1	36.6	23.65	28.46	24.6
	Initial pressure rise in 2.0 seconds	2.42	$\geq$ 0.75	2.5	1.35	$\geq$ 0.18	1.35
Tank Venting Control Parameters, Settled Coast Phase:							
Before MES-TV Seconds	Vent control pressure range, start	47.0	No Vent	47	28.8	No Vent	28.8
	Vent control pressure range, stop	38.0	No Vent	38	27.1	No Vent	27.1
	Maximum tank pressure	32.6	$<$47.0	32.4	20.0	$<$ 28.8	20.9
After MES-TV Seconds	Vent control pressure, start	40.0	No Vent	40.0	24.5	No Vent	24.5
	Vent control pressure, stop	39.0	No Vent	39.0	23.5	No Vent	23.5
	Maximum tank pressure	32.61	$<$ 39.0	32.4	20.1	$<$ 24.5	20.9

venting for TC-5 enabled at MECO 1 + 260 seconds until MES 2 - 96 seconds.

Helium Storage and Consumption - The helium, which was stored in one 7365 cu. in. bottle and one 4650 cu. in. bottle, was used to pressurize the propellant tanks during engine start sequences, to operate the engine control valves, to pressurize the H_2O_2 bottles, and to provide purges to various parts of the Centaur. The amount of helium stored at liftoff was 15.28 pounds. The amount consumed during the flight through Centaur retromaneuver was 7.38 pounds.

Propulsion Pneumatics - The engine control regulator and the H_2O_2 bottle pressure regulator maintained proper system pressure levels from pressurization of the helium bottles through retromaneuver. The engine controls regulator output pressure at liftoff was 469.6 psia (allowable limits are 440 to 479 psig), while that of the H_2O_2 bottle pressure regulator was 318.1 psia (allowable limits are 297-316 psig). Both regulators are referenced to ambient pressure, so after liftoff both output pressures decreased, corresponding to the decrease in ambient pressure, and remained relatively constant after the ambient pressure had decreased to zero.

Helium Retro-thrust - At T+2646.8 seconds, the two normally closed pyrotechnic valves in the helium retro-thrust system were fired, allowing the remainder of the helium in the smaller bottle to discharge through two forward canted nozzles. The discharge of the helium through the nozzles created a reverse thrust on the Centaur, providing a separation distance between the Centaur and the spacecraft. The pressure in the smaller bottle went from 2740 to 0 psia. The pressure in the large bottle remained constant, indicating that the check valves did not leak.

Helium Purge - Throughout the launch countdown, the ground system supplied a helium gas purge to the forward and aft ends of the vehicle. The gas was used to purge the hydrogen tank/shroud annulus, the destruct package, and several propulsion system components. The purge was required to maintain enough pressure differential across the shroud after cryogenic tanking to prevent ground winds inflow. For the launch day wind conditions of approximately 10 MPH, a minimum differential pressure of 0.045 psid was required. At the beginning of hydrogen tanking the pressure dropped momentarily to 0.121 psid but then recovered to 0.442 psid and remained essentially constant until hydrogen vent valve lockup. The pressure then began to rise until it reached a value of 0.499 psid at liftoff.

Centaur D-1TR Thermal Environment

by R. F. Lacovic

The Centaur environmental and component temperatures were nominal and well within operational limits. These temperatures were also in good agreement with the temperatures observed during the TC-2 flight.

The Centaur component and environmental temperatures at significant flight event times are listed in Tables 31 through 36. These temperatures are compared with TC-2 flight temperatures in order to indicate the repeatability of the thermal control and insulation system performance. There is good agreement in all of the temperature data and no anomalies behavior was observed. All component temperatures remained well within their operational limits. The only significant temperature deviation occurred at CA969T (LH_2 sump outer radiation shield) which was 140°F colder than measured on TC-2. This cold temperature is attributed to a localized helium leak from the tank-shroud annulus. No other measurements were affected. The H_2O_2 line temperature CP159T increased to over 178°F during the coast as a result of H_2O_2 engine exhaust impingement. This behavior was expected and does not present a problem since the line rapidly cools with the resumption of H_2O_2 flow at second boost pump start.

The aero-heating of the ISA and CSS skin and insulation during the ascent was normal and very similar to TC-2. The maximum temperatures were well below the design limits.

TABLE 31 PACKAGE TEMPERATURES

Measurement No.	Description	TEMPERATURE °F													
		Liftoff		CSS Jett		MES 1		1000 Sec.		1500 Sec.		MES 2		S/C Sep.	
		TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2
CB 1T	C-Band Transponder	78	70	82	73	83	73	84	76	84	77	84	78	85	80
CC 202T	SCU Housing Web	77	73	77	72	77	72	74	70	74	70	77	70	77	72
CE 56T	RSC Batt. 1 Internal	101	108	91	99	89	96	71	91	80	85	73	82	73	80
CE 57T	RSC Batt. 2 Internal	84	79	80	79	80	78	82	74	71	70	65	67	65	66
CE 108T	Main Batt. 1 Internal	86	87	86	88	88	97	90	97	92	93	94	95	96	96
CE 109T	Main Batt. 2 Internal	82	91	86	91	88	91	88	92	90	92	90	92	90	92
CE 110T	Main Batt. 3 Internal	88	77	92	82	94	82	100	86	100	88	102	91	104	93
CS 811T	SIU Skin	75	74	75	75	77	77	77	78	77	80	81	82	83	84
CI 300T	IRU Skin Internal	83	77	85	84	87	85	87	86	87	85	87	85	87	85
CI 316T	SEU Internal	75	72	75	73	75	73	73	73	73	73	73	74	73	76
CK 30T	DCU Skin	90	87	94	92	96	90	100	96	102	97	106	102	110	106
CT 56T	Sig. Conditioner No. 1	72	71	72	70	72	69	70	69	67	68	64	68	64	68
CT 57T	Sig. Conditional No. 2	82	80	80	79	82	79	80	79	80	78	80	79	80	77
CT 58T	Equipment Mod. MUX 1	71	71	71	70	71	69	67	69	65	69	55	65	67	68
CT 59T	Thrust Section MUX 2	77	70	77	69	77	69	73	68	73	67	73	66	73	66
CT 61T	S-Band XMIR PCM	78	87	80	98	82	102	86	109	83	116	92	121	94	124
CT 75T	Equip. Mod. Instr. Box	77	73	77	73	77	72	77	72	77	72	74	72	74	71
CT 76T	Aft Bulk. Instr. Box	76	74	74	72	74	73	71	71	69	71	69	72	69	72
CT 77T	C-2 Instr. Box	71	69	69	66	69	67	65	63	65	62	64	58	64	53
CU 240T	C-1 Servo PSN Hsg.	67	64	70	63	73	66	59	58	52	52	52	48	47	39
CU 241T	C-2 Servo PSN Hsg.	59	54	63	57	63	57	73	69	70	67	70	75	67	61
CF 133T	Aft Pneu. Panel No. 1	66	60	55	52	55	53	50	46	44	40	37	37	33	34
CF 134T	Aft Pneu. Panel No. 2	66	61	55	48	53	47	47	43	42	36	33	33	33	31
CF 20T	LO_2 Vent Valve Sol.	-135	-120	-204	-207	-129	-127	-135	-154	-124	-142	-111	-135	-125	-142
CF 31T	LH_2 Prim Vnt Vlv Sol.	-144	-211	-237	-211	-278	-264	-115	-165	-140	-126	-104	-111	- 98	- 94

TABLE 32 STRUCTURAL TEMPERATURES

Measurement No.	Description	Liftoff		CSS Jett		MES 1		1000 Sec.		1500 Sec.		MES 2		S/C Sep.	
		TEMPERATURE °F													
		TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2
CA 901T	Payload Adapter	71	69	66	57	65	55	50	49	47	47	44	49	49	54
CY 19T	S/C Comp. Amb.	70	67	60	56	36	-		-		-		-		-
CA 903T	Eq. Mod. Skin Q4	50	43	36	30	36	30	36	30	36	32	36	33	36	36
CA 904T	Eq. Mod. Skin Q1	46	41	36	29	32	29	32	29	32	27	32	29	32	33
CA 905T	IRU Out Mount	80	82	77	77	73	77	69	73	66	72	66	80	-	106
CA 914T	Eq. Mod. +Z	58	52	43	41	40	36	36	32	32	27	32	26	32	30
CA 972T	Stub Adapt. Shld. 180	-87	-61	-121	-115	-121	-123	-144	-137	-156	-142	-144	-132	-64	-56
CA 973T	Stub Adapt. Shld. 100	-93	-71	-144	-71	-144	-144	-178	-168	-169	-177	-87	-71	17	7
CA 974T	Stub Adapt. Shld. 0	-35	-37	-110	-115	-104	-93	-47	-56	-35	-83	-12	-83	-12	-9
CA 975T	Stub Adapt. Shld. 270	-52	-51	-93	-123	-93	-86	-23	-44	-17	-29	0	0	6	12
CA 976T	Stub Adapt. Skin 2437	-240	-255	-310	-306	-316	-326	-350	-352	-354	-358	-350	-358	-354	-361
CA 977T	Stub Adapt. Skin 2439	-156	-170	-195	-207	-201	-213	-234	-233	-256	-253	-261	-262	-267	-266
CA 978T	Stub Adapt. Skin 2441	-133	-147	-144	-156	-144	-159	-161	-168	-178	-189	-195	-195	-198	-202
CA 979T	Stub Adapt. Skin 2454	-70	-54	-81	-79	-81	-73	-58	-61	-52	-56	-47	-51	-47	-46
CA 980T	Wire TNL LH_2 Sump	-195	-211	-267	-275	-87	-213	-172	-189	-184	-200	-195	-211	-189	-209
CA 981T	Wire TNL LO_2 Tank	0	41	-110	-64	-81	-59	-122	-88	-122	-96	-110	-101	-105	-103
CA 983T	Wire TNL Fairlead 2346	-354	-367	-380	-389	-380	-386	-366	-382	-360	-352	-354	-370	-350	-364
CA 987T	Recirc. Line 2296	-395	-410	-395	-410	-395	-410	-387	-410	-379	-403	-373	-406	-366	-410
CA 988T	Destruct Mount PLT	23	12	-64	-81	-76	-111	-99	-135	-104	-144	-93	-149	-104	-151
CA 989T	Destructor Pod	17	12	-190	-168	-223	-200	-184	-177	-139	-113	-139	-96	-133	-81

TABLE 33 PROPULSION SYSTEM TEMPERATURES

Measurement No.	Description	TEMPERATURE °F															
		Liftoff		CSS Jett		MES 1		1000 Sec.		1500 Sec.		MES 2		S/C Sep.	
		TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2	TC-5	TC-2
CP 148T	Y-1 Chamber Surf	68	89	68	69	620	600	1110	942	1010	963	1026	1070	1043	1105
CP 149T	Y-4 Chamber Surf	68	79	68	50	68	60	722	1112	807	863	807	1140	942	1182
CP 375T	P-3 Chamber Surf	68	79	68	60	68	69	925	1119	1110	663	1110	1006	1128	635
CP 376T	P-4 Chamber Surf	68	79	68	60	68	69	824	800	908	742	874	1384	OSH	1077
CP 691T	S2A Chamber Surf	68	75	68	68	567	680	1076	1260	925	580	975	1260	824	570
CP 693T	S4A Chamber Surf	68	79	68	69	68	69	1128	1273	942	600	1009	1259	406	620
CP 836T	S4B Chamber Surf	68	75	68	65	68	75	688	580	1228	1290	1245	1290	OSH	650
CP 837T	S2B Chamber Surf	68	70	68	60	705	700	654	550	1194	1220	1194	1220	1211	630
CP 741T	C1 Eng. Bell	71	67	54	53	54	67	- 97	- 87	- 97	- 76	- 97	- 76	-207	-1[illegible]2
CP 742T	C2 Eng. Bell	71	67	54	49	62	67	- 55	- 73	- 47	- 59	- 53	- 41	- 97	-283
CP 743T	C1 Eng. Bell	71	63	54	49	71	63	- 80	- 62	- 72	- 94	- 47	- 52	-173	-171
CP 744T	C2 Eng. Bell	71	63	62	49	80	63	- 97	- 97	- 97	-104	- 64	-101	-165	-175
CP 745T	C1 Eng. Bell	71	63	62	53	62	56	- 97	- 59	- 97	- 45	- 97	- 46	-215	-227
CP 746T	C2 Eng. Bell	71	63	54	53	54	56	- 81	- 62	- 81	- 69	- 30	- 38	-148	-161
CP 750T	C-1 LO_2 Duct Surf	-273	-270	-277	-276	-277	-276	-273	-296	-273	-274	-277	-263	-277	-279
CP 751T	C-1 LH_2 Duct Surf	<-400	-403	<-400	-400	<-400	-400	-355	-383	-324	-354	-386	-416	-400	-403
CP 752T	C-1 LH_2 Pmp Dsch.	-342	-344	-214	-235	-250	-252	- 80	-143	- 86	- 78	-120	-317	-293	-269
CP 753T	C-1 LH_2 Pmp Hsg.	-338	-342	-254	-244	-236	-296	-240	-241	-210	-191	-290	-185	-329	-309
CP 754T	C-1 LH_2 Jckt. Line	- 47	-101	- 55	-108	-131	- 90	-200	-273	-173	-210	-131	-168	-258	-283
CP 828T	C-2 Eng. TBPMP	-370	-371	-305	-299	-347	-310	-215	-304	-140	-263	-215	-231	-342	-347
CP 829T	C-2 Pump Shield	- 2	9	-198	-215	-106	- 44	-135	-150	-135	-113	-135	- 78	-165	-113
CP 127T	LH_2 B/P Bearing	71	72	71	70	88	97		169		186		202		298
CPT 36T	LO_2 B/P Bearing	71	72	71	71	88	97		173		197		216		320

TABLE 34 H_2O_2 SYSTEM TEMPERATURES

Measurement No.	Description	TEMPERATURE °F Liftoff TC-5	Liftoff TC-2	CSS Jett TC-5	CSS Jett TC-2	MES 1 TC-5	MES 1 TC-2	1000 Sec. TC-5	1000 Sec. TC-2	1500 Sec. TC-5	1500 Sec. TC-2	MES 2 TC-5	MES 2 TC-2	S/C Sep. TC-5	S/C Sep. TC-2
CP 93T	Att.Cntrl.H_2O_2 Btl.	82	85	82	84	82	85	82	87	82	87	82	87	84	88
CP 659T	B/P H_2O_2 Btl.	81	80	81	80	81	82	81	84	82	86	82	87	86	88
CP 756T	H_2O_2 Crossover Line	89	88	91	90	94	88	93	93	90	93	91	93	91	94
CP 361T	LH_2 B/P Sup. Ln Orf.	79	77	64	63	97	100	123	134	116	116	101	116	156	184
CP 150T	QD 1 A/C Line	79	76	76	73	89	92	91	93	91	95	89	90	85	85
CP 151T	QD 2 A/C Line	76	72	82	70	87	88	91	95	91	96	99	102	117	112
CP 152T	QD 2/3 A/C Line	82	72	82	70	92	92	91	90	91	89	91	90	93	94
CP 153T	QD 3 A/C Line	80	81	89	87	95	98	93	95	91	95	91	95	93	91
CP 154T	QD 4 A/C Line	80	87	87	87	93	99	93	96	93	96	93	96	93	97
CP 155T	QD 1 A/C Line	74	70	76	71	92	95	93	95	93	95	93	95	97	96
CP 156T	QD 1 LH_2 B/P Ftg.	76	73	70	73	84	73	88	87	88	87	91	95	99	97
CP 157T	QD 2 LH_2 B/P Ln	68	69	62	65	88	90	94	87	84	87	95	96	103	97
CP 158T	QD 3 LH_2 B/P Ln	66	67	60	59	86	86	88	89	86	88	86	89	90	91
CP 159T	QD 4 LH_2 B/P Ln	66	70	74	75	90	90	141	119	>178	>178	118	109	102	102
CP 710T	LH_2 B/P Orf. Holder	75	77	71	71	86	86	105	103	97	97	94	96	108	108
CP 711T	LO_2 B/P Orf. Holder	86	66	68	63	68	65	116	99	109	111	105	106	105	105
CP 712T	LH_2 B/P Elect.	75	74	60	53	71	62	94	77	105	89	116	103	153	146
CP 831T	Ln Btwn. B/P FD Vlvs.	88	83	94	96	84	91	107	107	119	119	92	127	94	97
CP 832T	H_2O_2 Vent Ln No. 1	82	82	80	87	80	87	86	88	88	90	92	91	90	88
CP 833T	LH_2 B/P Inlet Ln	88	84	68	68	87	73	102	123	94	101	91	98	123	151
CP 834T	B/P FD Vlv. 2 Bdy.	86	77	78	77	78	81	96	93	94	93	91	92	97	98
CPT714T	LO_2 B/P Inlet	68	66	53	40	101	96	105	99	116	117	116	111	134	106

TABLE 35 RADIATION SHIELD TEMPERATURES

Measurement No.	Description	Liftoff TC-5	Liftoff TC-2	CSS Jett TC-5	CSS Jett TC-2	MES 1 TC-5	MES 1 TC-2	1000 Sec. TC-5	1000 Sec. TC-2	1500 Sec. TC-5	1500 Sec. TC-2	MES 2 TC-5	MES 2 TC-2	S/C Sep. TC-5	S/C Sep. TC-2
	TEMPERATURE °F														
	LH_2 TANK SIDEWALL														
CA 954T	Rad. Shld. Inn 2422 Q4	-326	-304	-380	-396	-305	-326	-260	-277	-250	-262	-234	-246	-234	-240
CA 953T	Rad. Shld. Mid 2422 Q4	-256	-270	-345	-370	-278	-297	-190	-235	-160	-182	-127	-135	-110	-103
CA 952T	Rad. Shld. Out 2422 Q4	-144	-118	-289	-321	-150	-142	0	- 26	11	2	40	41	40	48
CA 962T	Rad. Shld. Inn 2422 Q1	-349	-295	-395	-396	-360	-358	-326	-314	-326	-302	-321	-297	-310	-288
CA 961T	Rad. Shld. Mid 2422 Q1	-267	-195	-380	-394	-343	-311	-299	-286	-294	-268	-234	-235	-172	-186
CA 966T	Rad. Shld. Out 2422 Q1	-127	-130	-354	-293	-289	-242	-195	-200	-184	-177	11	- 4	- 6	48
CA 957T	Rad. Shld. Inn 2279 Q4	-400	-396	-425	-410	-400	-367	-343	-341	-330	-326	-300	-304	-290	-288
CA 956T	Rad. Shld. Mid 2279 Q4	-380	-382	-406	-403	-332	-311	-245	-262	-195	-163	-144	-120	-122	- 96
CA 955T	Rad. Shld. Out 2279 Q4	-350	-344	-350	-389	-173	-144	17	- 26	11	5	40	43	40	45
CA 965T	Rad. Shld. Inn 2279 Q3	-380	-396	-406	-410	-380	-389	-343	-355	-332	-344	-337	-341	-337	-336
CA 964T	Rad. Shld. Mid 2279 Q3	-380	-382	-406	-406	-366	-352	-316	-306	-300	-275	-278	-256	-261	-227
CA 963T	Rad. Shld. Out 2279 Q3	-349	-352	-395	-403	-250	-279	-139	-175	-116	-120	- 81	- 78	- 64	- 59
	LH_2 SUMP														
CA 966T	Rad. Shld. Out 2247	-383	-358	-371	-336	-347	-277	-293	-238	-281	-115	118	12	172	62
CA 967T	Rad. Shld. Mid 2247	-395	-367	-395	-367	-377	-336	-353	-314	-353	-311	-281	-284	-186	-242
CA 968T	Rad. Shld. Inn 2247	-400	-389	-413	-392	-390	-361	-395	-358	-395	-396	-383	-389	-360	-376
CA 969T	Rad. Shld. Out 2235	-126	14	- 66	- 19	-114	- 66	-138	-177	-150	-	+ 16	-211	- 42	-

TABLE 36 BULKHEAD TEMPERATURES

Measurement No.	Description	TEMPERATURE °F Liftoff TC-5	Liftoff TC-2	CSS Jett TC-5	CSS Jett TC-2	MES 1 TC-5	MES 1 TC-2	1000 Sec. TC-5	1000 Sec. TC-2	1500 Sec. TC-5	1500 Sec. TC-2	MES 2 TC-5	MES 2 TC-2	S/C Sep. TC-5	S/C Sep. TC-2
	FORWARD BULKHEAD														
CA 906T	Bulk Skin Q1	-416	-417	-418	-417	-404	-418	-402	-417	-400	-416	-394	-416	-399	-422
CA 912T	Bulk Ins. Mid Q1	-204	-215	-254	-265	-254	-265	OSL	-265	OSL	-265	OSL	-267	OSL	-265
CA 913T	Bulk Ins. Ext. Q1	- 84	- 78	-108	-112	- 62	- 88	- 27	- 43	- 9	- 15	1	1	4	3
CA 908T	Bulk Skin Q4	-416	-416	-416	-417	-406	-412	-404	-418	-402	-417	-400	-417	-395	-422
CA 911T	Bulk Ins. Mid Q4	-190	-217	-254	-265	-254	-267	OSL	-267	OSL	-265	OSL	-267	OSL	-265
CA 910T	Bulk Ins. Ext. Q4	- 38	- 54	-126	- 54	- 73	- 54	- 20	- 44	- 2	- 23	8	- 15	11	- 9
CA 907T	Bulk Skin +Z	-413	-418	-416	-418	-400	-413	-393	-417	-390	-416	-386	-416	-387	-422
CA 909T	Bulk Ins. Ext. +Z	- 41	- 63	- 98	-137	- 73	- 79	- 27	- 40	- 13	- 20	- 2	- 13	1	- 7
	AFT BULKHEAD														
CA 302T	LO_2 Duct Rad.Shld.Out	55	55	- 30	- 28	- 3	- 59	- 58	- 85	- 80	-121	- 76	-108	-107	-129
CA 303T	LH_2 Duct Rad.Shld.Inn	23	44	- 58	- 28	- 44	- 51	-135	-110	-171	-164	-166	-174	-171	-174
CA 304T	LO_2 Duct Rad.Shld.Out	50	42	10	16	28	37	193	182	186	182	186	182	72	72
CA 305T	Periph.Rad.Shld.Out	23	- 51	- 90	- 98	- 44	- 85	- 26	- 72	- 8	- 28	- 3	20	19	29
CA 306T	Periph.Rad.Shld.Inn	- 98	-202	-162	-198	-121	-189	-148	-187	-144	-168	-144	-157	-166	-168
CA 307T	LO_2 Sump Rad.Shld.Out	46	50	5	3	10	- 6	- 76	- 70	- 98	- 96	- 98	- 91	-103	-106
CA 308T	LO_2 Sump Rad.Shld.Inn	- 12	- 8	- 48	- 53	- 58	- 62	- 94	- 96	-126	-127	-126	-161	-166	-172
CA 309T	Aft Bulk Rad.Shld.Out	28	37	- 3	- 13	5	- 17	- 35	- 47	- 26	- 70	- 62	- 85	- 62	- 89
CA 310T	Aft Bulk Rad.Shld.Inn	-148	NA	- 85	NA	- 76	NA	-157	NA	-171	NA	-180	NA	-198	NA

Electrical/Electronic Systems

Electrical Power Systems

by W. W. Hultzman

The electrical system consists of a power changeover switch (integral part of the Sequence Control Unit), three main batteries (interconnected by a diode assembly), two independent range safety command (vehicle destruct) batteries, and a single 400 Hz inverter (the inverter is an integral part of the Servo Inverter Unit).

The three Centaur busses were supplied by separate 150 ampere-hour batteries, interconnected by a diode assembly (as shown in Figure 23). The diode assembly permitted Bus No. 2 battery to supply Bus No. 1 and Bus No. 3 power during surge loads and at possible deletion of capacity of Bus No. 1 and/or Bus No. 3 battery during a long/extended flight sequence. (Bus No. 2 battery has the lowest programmed power drain.)

The performance of the Centaur three battery electrical system was satisfactory and no unexpected system current demands were noted during the programmed flight period. Transfer of the electrical load from external power to the internal batteries was accomplished at minus 108.0 seconds by the changeover switch and normal transfer characteristics were observed.

The battery current anomalies of the TC-3 and TC-4 flights which occurred during the first coast phase and also subsequent to the propellant tank blowdown sequence were not observed during the TC-5 flight. Random and unexpected current demands ranging from 2 to a maximum 8.5 amperes were observed during these periods for TC-3 and TC-4. The fill/vent valves for the 150 ampere-hour batteries for TC-5 and on were lengthened and changed to nylon to minimize electrolyte leakage in the zero-g flight environment.

At liftoff, the three main battery bus voltages were 28.4, 29.1, and 28.7 volts for Bus No. 1, No. 2, and No. 3 batteries respectively. Battery data are shown in Table 37.

Bus No. 1 battery voltage was relatively constant during the prime mission (through TE-364 separation), reflecting only the Bus No. 2 battery variations. Bus No. 2 battery voltage reflected the effects of the Bus No. 3 flight current demands, especially during the burn sequences, but remained fairly constant through fourth stage separation. Bus No. 3 battery voltage responded normally to level changes resulting from the application and removal of electro-mechanical loads per the programmed flight sequence. A low of 27.7 volts was

TC-5
THREE BATTERY CONFIGURATION

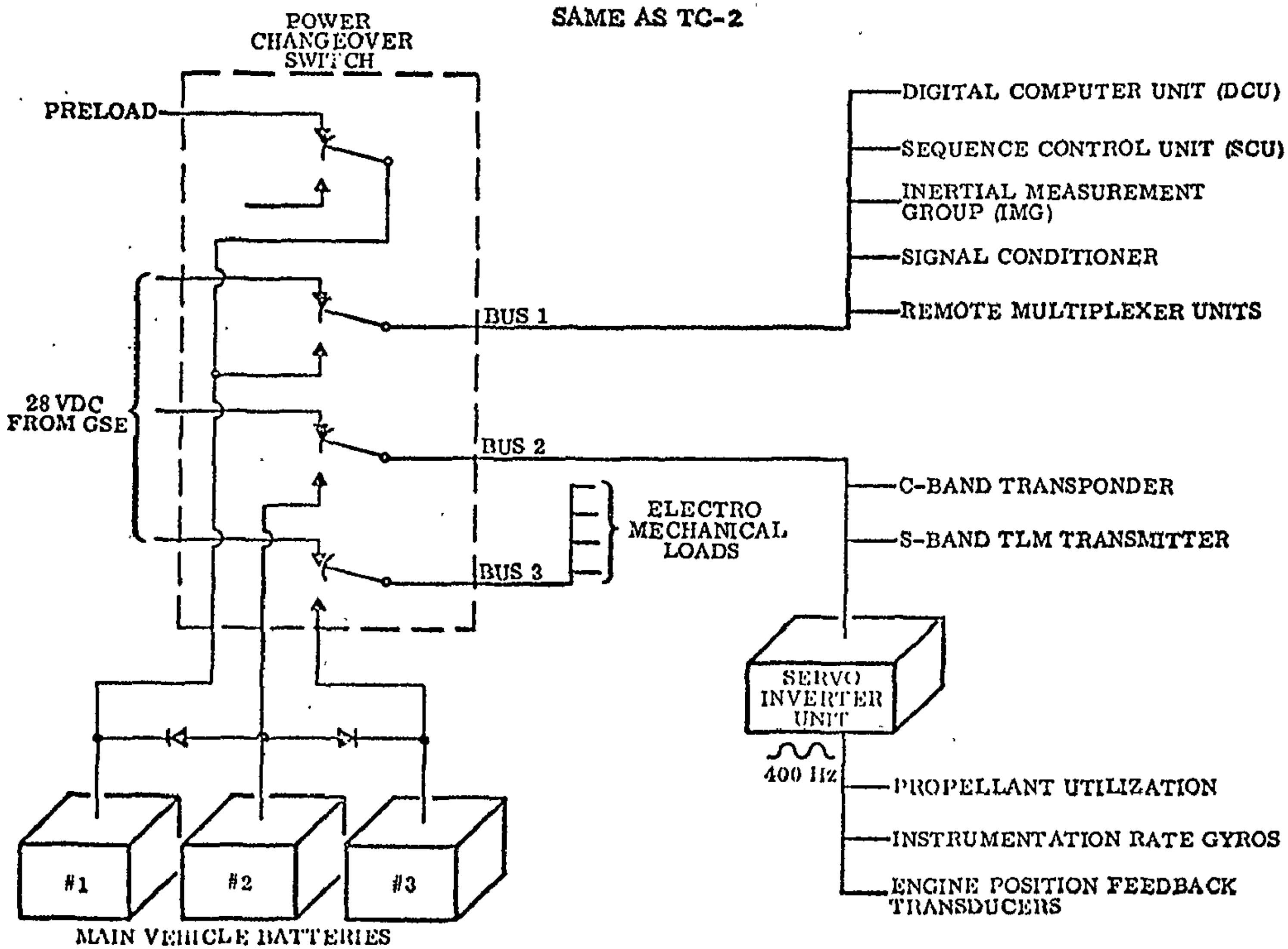


FIGURE 23

TABLE 37

CENTAUR BATTERY DATA

	OPEN CIRCUITS VOLTS	T-0 LIFT-OFF VOLTS	LOAD TEST AMPS VS VOLTS
Main Battery-BUS No. 1	35.15	28.4	65A at 27.18
Main Battery-BUS No. 2	35.17	29.1	65A at 27.56
Main Battery-BUS No. 3	35.14	28.7	65A at 27.52
RSC Battery - No. 1	34.41	32.7	10A at 29.30
RSC Battery - No. 2	34.40	32.8	10A at 29.82

observed during Main Engine Start Sequence No. 1 and 27.6 volts at MES 2 (periods of maximum loads). Bus No. 3 battery voltage gradually recovered to 28.2 volts at Centaur/TE-M-364-4 separation.

However, at about T plus 4 hours, 30 minutes, main vehicle battery No. 1 voltage began to decay, dropping from 28.7 volts to a value of 27.3 volts at about T plus 6 hours, 6 minutes. Approximately 70 ampere-hours of the battery nominal 150 ampere-hour capacity had been used up at this time.

Main vehicle battery no. 2 also began to decay at about T plus 4 hours, 45 minutes (about 15 minutes after battery no. 1), dropping from 29.1 volts to a final value of 28.3 volts at about the same time as battery No. 1. Both batteries remained at or slightly above their stabilized values (with a delta V of 0.9 volts) until loss of telemetry data.

Battery No. 2 temperature rate-of-rise increased significantly during the period of load sharing. Battery No. 1 temperature peaked at 135°F at the start of load sharing and slowly decreased during the remainder of the flight. Battery No. 3 temperature increased at a relatively uniform rate during the flight.

All battery currents were normal throughout the flight as indicated by total current CEIC and individual bus shunts.

Investigation of this anomaly is continuing at this time.

The total Centaur current (as measured by CETIC) was 40.0 amperes at liftoff. Peak currents were recorded during the Main Engine Start Sequences, with a maximum peak of 59.5 amperes at Main Engine Start No. 1. The periods of maximum and minimum current levels relative to Mark Events are shown in Table 38. The flight current profile was consistent with values recorded during preflight tests and no anomalies were observed.

Battery current values with respect to flight programmed events are shown in Table 39.

The individual bus currents exhibited normal profiles through third stage separation. Bus No. 1 remained steady between 9.7 to 10.0 amperes, reflecting only the expected variations due to the DCU duty cycle and real time interrupts.

Bus No. 2 current was relatively constant, with the exception of the period of PU control which caused variations of 4.8 to 5.9 amperes during this time interval. This activity was nominal and as expected. Bus No. 3 current exhibited changes throughout the flight in response to vehicle demands. The maximum current observed was 17.5 amperes at Main Engine first start sequence.

TABLE 38 TC-5 CENTAUR BATTERY CURRENT PROFILE

EVENT	CALCULATED NOMINAL	CALCULATED MAXIMUM	ACTUAL	TIME SECONDS
Centaur to Internal	38.8	56.5	37.0	-108.0
Lock LH_2 Vent Valve	39.8	57.8	39.5	- 27.8
Lift-Off (T-0)	39.6	57.6	40.0	0
Unlock LH_2 Vent Valve	38.6	56.3	38.0	90.0
Separate Fwd. Bearing Reactor	38.8	56.6	38.3	100.0
Reset Fwd. Bearing Reactor	38.6	56.3	38.0	102.0
Forward Seal Release	38.8	56.6	38.3	214.3
Reset Fwd. Seal Release	38.6	56.3	38.0	217.3
Shroud Coax Switches	37.4	53.9	37.0	325.9
H_2O_2 Engines - S2A On	37.9	54.4	37.5	326.6
H_2O_2 Engines - S2A Off; Y1 On	37.9	54.4	37.3	346.6
H_2O_2 Engines - Y1 Off; Y2 On	37.9	54.4	37.3	366.6
H_2O_2 Engines - Y2 Off; S2B On	37.9	54.4	37.3	386.6
H_2O_2 Engines - S2B Off	37.4	53.9	36.8	406.6
Lock All Vent Valves	40.5	57.9	42.5	440.7
LO_2 & LH_2 Tank Pressurization; Control Valve On	42.9	66.9	45.3	442.8
Boost Pumps-Primary and Backup On: H_2O_2 Purge Valve On	46.0	70.8	48.5	442.9
End LO_2 & LH_2 Pressurization	44.4	64.8	46.5	443.6
Hydraulic Circ. Pumps On	49.8	77.8	50.5	478.6
Open Prestart Valves	52.5	81.2	53.5	485.7
Control Valve Off	51.7	78.2	52.8	493.5
MES 1: Igniters On: Open Start Valves	58.1	86.6	59.5	493.8
Igniters Off	54.6	81.6	55.5	497.8
Hydraulic Circ. Pumps Off	49.2	68.6	50.0	505.8
H_2O_2 Engines - Y's & P's On	53.2	73.0	53.5	575.0
H_2O_2 Engines - Y's & P's Off	49.2	68.6	49.5	585.0
MECO 1: Boost Pumps Primary & Back-Up Off: H_2O_2 Purge Valve Off; Close Start & Prestart Valves	40.5	57.9	41.0	595.0
H_2O_2 Engines - All "S On" Mode	42.4	60.1	43.0	595.1
H_2O_2 Engines - "S-1/2 On" Mode	41.5	59.0	41.0	845.1
H_2O_2 Engines - Change "S" Engine Pairs	41.5	59.0	41.0	1507.4

TABLE 38 TC-5 CENTAUR BATTERY CURRENT PROFILE (Cont.)

EVENT	CALCULATED NOMINAL	CALCULATED MAXIMUM	ACTUAL	TIME SECONDS
H_2O_2 Engines - All "S" On Mode	42.4	60.1	42.0	2165.5
Hydraulic Circ. Pumps On	47.9	73.1	46.5	2225.4
LO_2 & LH_2 Tank Pressurization & Control Valve On	50.3	82.1	48.5	2246.4
End LO_2 & LH_2 Pressurization	48.7	76.1	46.8	2252.4
Boost Pumps - Primary & Back-Up On: H_2O_2 Purge Valve On	51.8	80.0	50.0	2257.4
Open Prestart Valves	54.5	83.4	53.0	2268.4
Control Valve Off	53.8	80.4	52.2	2285.2
MES 2: Igniters On; Open Start Valves; Y & P H_2O_2 Engines Off	60.1	88.8	58.7	2285.4
Igniters Off	56.6	83.8	54.8	2289.4
H_2O_2 4S Engines Off	54.6	81.6	52.8	2290.4
Hydraulic Circ. Pumps Off	49.2	68.6	47.5	2297.4
MECO 2: Boost Pumps Primary & Back-Up Off; H_2O_2 Purge Valve Off; Close Start & Prestart Valves	40.5	57.9	40.0	2574.8
Fire Spin Rockets	40.7	58.2	40.3	2644.8
Spin Rockets Off	40.5	57.9	40.0	2645.7
Fire Wire Cutters	40.7	58.2	40.3	2645.8
Separate TE-364 Stage; Fire Retros	40.9	58.5	40.6	2646.8
Reset S/C Sep and Fire Retro Commands	40.7	58.2	40.3	2651.8
Reset Wire Cutters	40.5	57.9	40.0	2652.0

TABLE 39 TC-5 CENTAUR ELECTRICAL SYSTEM PARAMETERS

MEAS NO.	DESCRIPTION	UNITS	T-0	T/C SEP.	MES NO. 1	MECO NO. 1	MES NO. 2	MECO NO. 2	3rd STG SEP.
CEIC	Main Battery Current	AMPS	40.0	50.5	59.5	41.0	58.7	40.0	40.6
*CE28V	BUS No. 1 Voltage	VDC	28.4	28.2	28.2	28.2	28.2	28.3	28.3
CE142C	BUS No. 1 Current	AMPS	10.0	10.0	10.0	9.9	9.9	9.7	9.7
CE143C	BUS No. 2 Current	AMPS	5.9	5.9	5.8	5.8	5.7	5.7	5.7
CE144C	BUS No. 3 Current	AMPS	6.6	11.7	17.5	9.3	16.0	8.3	8.5
CE97C	BUS No. 3 Partial Current	AMPS	10.2	10.9	10.1	9.2	10.0	9.1	9.4
*CE600V	Battery No. 1 Voltage	VDC	28.4	28.2	28.3	28.4	28.4	28.4	28.4
*CE609V	Battery No. 2 Voltage	VDC	29.1	28.8	28.6	29.1	28.7	29.1	29.1
*CE610V	Battery No. 3 Voltage	VDC	28.7	28.2	27.7	28.5	27.6	28.5	28.2
*CE21V	RSC. Battery No. 1 Voltage	VDC	32.7	32.6	32.6	32.8	33.6	33.7	33.7
*CE22V	RSC. Battery No. 2 Voltage	VDC	32.8	32.8	32.8	32.8	33.4	33.5	33.5
CE844V	Inverter Voltage	VAC	26.0	26.0	26.0	26.0	26.0	26.0	26.0

* Corrected to panel mater reading at T-10 seconds.

Two individual electronic package currents (IMG and SCU) were monitored via telemetry. The Inertial Measurement Group (IMG) current exhibited normal low level oscillations following platform stabilization (prelaunch function). The load current varied between 6.3 and 6.8 amperes. The Sequence Control Unit (SCU) current also exhibited normal output with a steady-state load of 0.17 amperes, and a strobe current of 0.71 amperes. The IMG and SCU are supplied by the Bus No. 1 battery and are part of the total Bus No. 1 load.

The actual pyrotechnic bridgewire firing currents are not observable as they bypass the CEIC main current shunt and return directly to the battery supply. However, operation of the forward bearing reactor and forward seal release functions were observed by momentary decrease of the Bus No. 3 battery voltage. Also, current transients were present on current measurement CEIC due to low-level ionization currents generated at squib firing. Similar transients have been observed on the previous Titan/Centaur flights.

Performance of the two range safety command batteries was satisfactory. The voltages at liftoff were 32.7 volts for range safety command No. 1 and 32.8 volts for range safety command No. 2. Voltages remained steady throughout the flight until Main Engine Cutoff No. 1, when the range safety command receivers are turned off and the destruct system is deactivated.

Vehicle AC power was supplied by the Servo Inverter Unit. The voltage output of the inverter remained constant at 26.0 volts AC throughout the programmed flight.

Digital Computer Unit

by R. S. Palmer

All DCU inputs and outputs were analyzed. The DCU performed satisfactorily as evidenced by proper functioning of flight events and operation of associated systems. The data indicating DCU performance are presented with the flight performance analysis of the associated systems.

Inertial Measurement Group

by D. E. Pope

Inertial Measurement Group (IMG) No. 24 consisting of Inertial Reference Unit (IRU) 24 and Systems Electronics Unit (SEU) 20 was calibrated prior to final alignment and all parameters were well within specification. The IRU platform was then final aligned to the Complex 41 heading resulting in the U and V accelerometer input axis being aligned to 181.7 and 91.7 degrees respectively. GO-inertial was commanded by resetting sequence control switches 84, 85, and 86 at approximately T-6 seconds.

Telemetered data indicated satisfactory performance of the group. Maintenance of the inertial reference block to within its specified maximum gimbal error of ± 60 arc seconds was accomplished. Maximum displacement of gimbals one, two, and three was ± 11, ± 5, and ± 5 arc seconds respectively. Gimbal one exhibited four unusual bursts of alignment activity of approximately 200 seconds duration during non-burn periods. A common denominator of vehicle activity and/or gimbal alignment has not been found and this activity remains under investigation.

IRU temperature varied from a liftoff temperature of 83°F to a maximum of 111°F. Variations are cyclic corresponding to the thermal roll intervals and corresponding to a spread of approximately 12°F in the later thermally stable portion of the flight events. The maximum qualification temperature of the IRU is 120°F.

IMG current varied from 5.5 to 7.0 amperes. However, the overall mission average was low ($\cong 5.7$) due to the lower heater demand reflecting a high package temperature.

Transformation of the F1 and F2 steering vectors from the U, V, and W inertial coordinates to the Centaur vehicle pitch, yaw, and roll axis coordinates was performed satisfactorily by the resolver chain. Attitude errors were nominal throughout the flight, with the expected roll error increase seen during roll maneuvers.

This flight was the first to contain accelerometers which had matched magnets. Matching was done to minimize the coast phase accelerometer bias shift as seen from the one "g" calibration point. The following table summarizes coast bias data:

Table 40 Coast Phase Accelerometer Bias

FLIGHT	POSITION	"0"-g BIAS FLIGHT	PREFLIGHT PREDICTION	DELTA
TC-5	U	-33 μg	-33 μg	--
	V	6 μg	-22 μg	28
	W	-10 μg	-36 μg	26
TC-4	U	37 μg	4 μg	33
	V	55 μg	33 μg	22
	W	0 μg	-2 μg	2
TC-3	U	56 μg	135 μg	79
	V	48 μg	26 μg	22
	W	-109 μg	-77 μg	32
TC-2	U	42 μg	14 μg	28
	V	72 μg	32 μg	40
	W	-30 μg	-32 μg	2

The one sigma of the expected error is 53 μg and TC-5 is the first system to be well within this value in performance. Previous zero "g" coasts have always included at least one accelerometer per system that has exceeded this value. While there has been an apparent improvement in actual zero "g" bias, the prediction of the value appears to be no better now than in the past.

Flight Control System

by R. C. Kalo and T. W. Porada

Flight Control Commands

The Digital Computer Unit (DCU) and the Sequence Control Unit (SCU) performed satisfactorily in issuing the flight control system commands to other vehicle systems. The SCU receives its input from the DCU and converts this input into switch commands usable by other vehicle systems.

Table 41 lists the SCU switching sequence and flight events. The column headed "Sequence" shows the time of the event from the start of each phase of flight. The column headed "Planned Time" shows the time after liftoff for each event based upon the preflight actual launch time trajectory with launch day winds. The "Actual Time" column shows the time after liftoff that each command was issued by the SCU during flight. Other functions programmed by the DCU software are shown in the table to help in clarifying the flight sequence.

Flight Control Dynamics

Vehicle dynamic behavior indicated proper control system performance. The dynamic response of the vehicle was evaluated in terms of amplitude, frequency or duration of attitude error, steering commands, and accelerometer data. These data indicated no anomalous behavior of vehicle motion. Responses to commands and transients were compared to postflight data of past Centaur vehicles and were determined to be normal. A description of the observed data follows at selected event times where vehicle motions were of interest.

Titan/Centaur Staging - Milli-g accelerometer data indicated that the separation shaped charge was fired at T+483.3 seconds at a positive acceleration level of approximately 5 milli-g's. Immediately following the command, the g level dropped to near zero, then 2.5 seconds later increased to a level of approximately 4 milli-g's. This coincides with opening the prestart valves, confirming the initiation of that event. All data indicated a clean separation.

Centaur Powered Flight 1 - The ignition transient was small requiring less than 0.7 degree engine commands in each axis. Sustained lateral oscillations were observed to occur immediately following the engine start event. Lateral accelerometer data showed oscillations at a frequency of 7.1 Hz and amplitudes as high as 0.3 g's peak to peak. Blossoming occurred throughout the powered phase of the flight decreasing in amplitude as the burn progressed, but maintaining the 7.1 Hz frequency. This has been observed on other Centaur

TABLE 41

TC-5 FLIGHT SEQUENCE OF EVENTS

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
84	Reset	Go Inertial(1)	T-6	T-6	T-6
85	Reset				
86	Reset				
-	-	SRM Ignition(05:34:00.36Z)	T=0	T+0	0.0
-	-	Liftoff(2)	T+0.23	0.23	0.47
59, 60	Set	Begin Roll Program	T+6.5	6.5	6.56
59, 60	Reset	End Roll Program	T+6.64	6.64	6.58
-	-	Begin DCU Pitch, Yaw Program	T+10.0	10.0	11.08
28	Reset	Unlock LH_2 Vent Valve 1	T+90.0	90.0	90.0
34	Set	Sep Fwd Brg Reactor	T+100.0	100.0	100.0
34	Reset	Reset Fwd Brg Reactor	T+102.0	102.0	102.0
-	-	Stg 0 Shutdown(3)	Stg 0	112.8	114.2
39	Set	Release Fwd Seal	Stg0+100	212.8	214.24
39	Reset	Reset Fwd Seal	Stg0+103	215.8	217.24
-	-	Stg 1 Shutdown(4)	Stg 1	261.45	265.65
61	Set	Unlatch Shroud Cmd 1	Stg1+60	321.45	325.65
62	Set	Unlatch Shroud Cmd 2	Stg1+60.5	321.95	326.15
8	Set	S2A On	Stg1+61	322.45	326.65

(1) Go Inertial occurs 25 seconds after the control monitor group sends a command to start the DCU count.
(2) Liftoff - noted by DCU when computed acceleration is greater than 1.4g.
(3) Stg 0 Shutdown - noted by DCU when computed acceleration is less than 1.5g.
(4) Stage 1 Shutdown - noted by DCU when computed acceleration is less than 1.5g.

TABLE 41 (Cont'd.)

TC-5 FLIGHT SEQUENCE OF EVENTS

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
61	Reset	Reset Shroud Cmd 1	Stg1+61.5	322.95	327.15
62	Reset	Reset Shroud Cmd 2			
8	Reset	S2A Off	Stg1+81	342.45	346.65
1	Set	Y1 On			
1	Reset	Y1 Off	Stg1+101	362.45	366.65
2	Set	Y2 On			
2	Reset	Y2 Off	Stg1+121	382.45	386.65
12	Set	S2B On			
12	Reset	S2B Off	Stg1+141	402.45	406.65
24	Set	Lock LO_2 Vent Valve	Stg2-30.5	437.5	440.70
28	Set	Lock LH_2 Vent Valve #1			
31	Set	Lock LH_2 Vent Valve #2			
27	Set	Open Control Valve	Stg2-28.56	439.44	442.68
29	Set	Press LO_2 Tank			
32	Set	Press LH_2 Tank			
23	Set	Primary Boost Pumps On	Stg2-28.4	439.6	442.80
18	Set	B/U Boost Pumps On			
-	-	Stg 2 Shutdown (5)			
65	Set	Stg 2 S/D B/U	Stg 2	468.0	478.54
17	Set	C1 Circ Pump On	Stg2+0.1	468.1	478.64
21	Set	C2 Circ Pump On			
63	Set	T/C Separation (6)	Sep	473.8	483.24
64	Set				

(5) Stg 2 Shutdown - Noted by DCU when observed accelration is less than 1g.

(6) T/C Separation - Commanded by DCU when computed acceleration is less than 0.01g.

TABLE 41 (Cont'd.)

TC-5 FLIGHT SEQUENCE OF EVENTS

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
19	Set	Open Prestart Valves	Sep+2.5	476.3	485.74
27	Reset	Close Control Valve	Sep+10.22	484.02	493.46
-	-	MES 1 (7)			
22	Set	Igniters On	MES 1	484.7	493.74
20	Set	Open Start Valves			
22	Reset	Igniters Off	MES1+4	488.7	497.74
17	Reset	C1 Circ Pump Off	MES1+12	496.7	505.74
21	Reset	C2 Circ Pump Off			
-	-	MECO 1 (8)			
23	Reset	Primary Boost Pump Off	MECO 1	582.96	595.08
18	Reset	B/U Boost Pump Off			
20	Reset	Close Start Valves			
19	Reset	Close Prestart Valves			
8	Set	S2A On	MECO+0.1	583.06	595.18
10	Set	S4A On			
12	Set	S2B On			
14	Set	S4B On			
17	Set	C1 Circ Pump On	MES2-60	2215.92	2225.42
21	Set	C2 Circ Pump On			
24	Set	Lock LO_2 Vent Valve			
31	Set	Lock LH_2 Vent Valve #2			

(7) MES 1 - Commanded by DCU 10.5 seconds after T/C separation.

(8) MECO 1 - Commanded by DCU based on guidance computed time.

TABLE 41 (Cont'd.)

TC-5 FLIGHT SEQUENCE OF EVENTS

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
27	Set	Open Control Valve	MES2-38.06	2237.86	2247.40
29	Set	Press LO_2 Tank			
32	Set	Press LH_2 Tank			
23	Set	Boost Pumps On	MES 2-28	2247.92	2257.42
18	Set	B/U Boost Pumps On			
19	Set	Open Prestart Valves	MES 2-17	2258.92	2268.42
27	Reset	Close Control Valve	MES 2-0.28	2275.64	2285.16
-	-	MES 2 (9)			
20	Set	Open Start Valves	MES 2	2275.92	2285.42
22	Set	Igniters On			
22	Reset	Igniters Off	MES2+4	2279.92	2289.42
8	Reset	S2A Off	MES2+5	2280.92	2290.42
10	Reset	S4A Off			
12	Reset	S2B Off			
14	Reset	S4B Off			
17	Reset	C1 Circ Pump Off	MES 2+12	2287.92	2297.42
21	Reset	C2 Circ Pump Off			
-	-	MECO 2 (10)			
18	Reset	Boost Pump B/U Off	MECO 2	2569.96	2574.80
19	Reset	Close Prestart Valves			
20	Reset	Close Start Valves			
23	Reset	Boost Pumps Off			

(9) MES 2 - Commanded by the DCU based upon guidance computed time.

(10) MECO 2 - Commanded by the DCU based upon guidance computed time.

TABLE 41 (Cont'd.)

TC-5 FLIGHT SEQUENCE OF EVENTS

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
95	Reset	Enable TE 364 Ignition	MECO2+60	2629.96	2634.80
73 74	Set Set	Fire Spin Rockets	MECO2+70	2639.96	2644.80
73 74	Reset Reset	Reset Fire Spin Rockets	MECO2+70.8	2640.76	2645.60
35	Set	Fire Wire Cutters	MECO2+71	2640.96	2645.80
69 70	Set Set	Sep TE 364/Fire Retros	MECO2+72	2641.96	2646.80
69 70	Reset Reset	Reset S/C Commands	MECO2+77	2646.96	2651.80
35	Reset	Reset Fire Wire Cutters	MECO2+77.1	2647.06	2651.90
-	-	TE 364 Ignition	MECO2+114	2683.96	2692.0
-	-	TE 364 Burnout	MECO2+157.8	2727.76	2735.6
-	-	Helios Separation	MECO2+230	2799.96	2804.03

flights at lower levels and is under further study. The vehicle was also observed to respond to sustained steering commands. A maneuver of approximately 33 degrees nose down was required. This was averaged over eight steering cycles. Analysis of the trajectory and associated software indicated that the longer than nominal Titan burn time would account for the large maneuver observed.

Centaur Coast 1 - Attitude error data indicated complete control of the vehicle during the first coast. At the MECO-1 event, all four axial H_2O_2 motors were commanded on. Accelerometer data indicated approximately 0.92 milli-g's of sustained axial acceleration for the programmed time of 250 seconds. Following this time, two axial H_2O_2 motors are programmed on which was verified by a drop in the acceleration level to 0.56 milli-g's. This acceleration level was sustained until MES-2 -120 seconds when four axial H_2O_2 motors are programmed on as part of the main engine start sequence. Acceleration level was again observed to increase to the 0.92 milli-g level. At MES-2 -17 seconds the prestart valves were commanded open and a corresponding increase in the axial acceleration was observed at an average level of 4.8 milli-g's.

Centaur Powered Flight 2 - The ignition transient was small requiring less than 0.7 degrees engine commands in each axis. Steering activity was normal. Lateral oscillations were observed to occur similarly as described during the first powered phase of flight.

Spacecraft Separation - Accelerometer data verified that the proper sequence of events was initiated and that the proper spin rate of 86.5 RPM was achieved. The spin table was observed to decay to zero rate in approximately 18 seconds.

Propellant Loading/Propellant Utilization

by K. Semenchuk

Propellant Level Indicating System (PLIS)

The Propellant Level Indicating System (PLIS) consists of an LH_2 probe, LO_2 probe, and LO_2 overfill sensor. LH_2 and LO_2 probes contain three hot wire sensors. The LO_2 overfill sensor contains one hot wire sensor. Each sensor has two redundant sensing elements.

The PLIS is used to indicate the tanking of the propellants to the desired levels. Each sensor gives an indication that a certain level has been reached by the liquid propellant by changing its operaing characteristics. This change is detected by the GSE which gives a "wet" or "dry" light indication on the Blockhouse Auxiliary Fuel Tanking Panel.

The LO_2 and LH_2 probe sensors operate at 95 percent, 99.8 percent, and 100.2 percent levels in their respective tanks. The LO_2 overfill sensor is located at approximately 1.75 inches above the 100.2 percent sensor.

The Centaur Propellant Level Indicating System operated satisfactorily during countdown. Propellant tank loading at liftoff was 25,484 pounds of LO_2 and 5,289 pounds of LH_2.

Propellant Utilization (PU) System

The Propellant Utilization (PU) System consists of LH_2 and LO_2 sensors, electrical harnesses, a servo positioner mounted on each engine mixture ratio control valve, and electronics circuitry housed within the Servo Inverter Unit (SIU). The SIU provides error detection and valve servo positioner feedback excitation.

The signal generated by this circuitry is processed by the Digital Computer Unit (DCU) for creation of valve position commands. The DCU operates switches in the Sequence Control Unit (SCU) to drive the engine valves to the required position.

The PU system reduces residual mass of one propellant at depletion of the other propellant and reduces errors caused by dispersion due to tanking, boiloff, propellant uncertainties, and engine performance uncertainties.

The PU system controls mixture ratio as a continuous function of the mass ratio of propellants in the tanks.

The Propellant Utilization System operated satisfactorily during the entire flight. PU valve angle measurements for C-1 and C-2 engines responded properly. PU valves were properly locked in a null position until five seconds after MES-1, when they were properly commanded to the fixed angle positions of 2.0 degrees for C-1 and 1.1 degrees for C-2 engines. PU valves remain in their fixed position for 110 seconds after MES-1, before they are brought into control.

The DCU disabled the valves to begin controlling at MES-1 +110 seconds. At MES-2 +5 seconds, the PU valves went into control and remained in control throughout the second burn. The propellant residuals at the end of the second burn are shown in the following table.

Table 42 Residuals at MECO 2

	Actual	Predicted
LO_2	3300 pounds	3377 pounds
LH_2	760 pounds	722 pounds

The temperature of the servo positioners remained constant from liftoff through the second burn.

Instrumentation and Telemetry Systems

by J. M. Bulloch and T. J. Hill

Instrumentation

A total of 477 measurements were instrumented; 454 PCM measurements and 23 twenty-four bit DCU words via the PCM system.

The following measurements exhibited data anomalies during the flight.

1. Measurement CA6850 (Payload Adapter Longitudinal) exhibited a +2 percent Information Bandwidth (IBW) shift at forward bearing reactor separation. Measurement CA6860 (Payload Adapter Radial) exhibited a -8 percent IBW shift at this time. Both measurements remained shifted for the remainder of the acquisition period. The signature of the bias shifted data appeared normal. The cause is unknown. Similar shifts have been observed on previous flights and were attributed to a sensitivity of the transducer to ambient pressure changes. A capacitor was added to the TC-5 transducer feedback loop to correct this condition. Previously noted oscillations following the shifts were not apparent on TC-5. Investigation is continuing.

2. Measurements CA290T (tank skin station 2370/000 -425° to -352°F) and CA293T (tank skin station 2334/000 -425° to -352°F) exhibited abnormal fluctuations with levels 5 to 10 percent higher than expected during the TCD countdown.

   The anomalous data is believed to be caused by the transducers becoming unbonded from the tank skin. A change in adhesive used for temperature patch installations, from 0-73024-3 to 0-73024-2, was required when the -3 adhesive was found to be carcinogenic. The -2 adhesive is inferior in strength and thermal conductivity but was determined to be the best available for this application.

3. Measurement CP56T (C-1 LH_2 pump backup temperature -425° to -378°F) which should roughly track the pump temperature CP60T did not display the expected profile during flight.

   This backup measurement is a resistance patch cemented to the surface of the pump inlet duct. Its primary purpose is to function as a backup redline measurement to CP60T which uses a resistance probe in the duct. The measurement satisfied its primary purpose during the countdown, but displayed unexpected trends during the flight.

The anomalous data is believed to be caused by the transducer becoming unbonded from the duct. A change in adhesive used for temperature patch installation, from 0-73024-3 to 0-73024-2, was required when the -3 adhesive was found to be carcinogenic. The -2 adhesive is inferior in strength and thermal conductivity, but was determined to be the best available for this application.

4. Measurements CA288T (tank skin station 2426/000), CA289T (tank skin station 2426/90), and CA292T (tank skin station 2370/180) exhibited erratic outputs during the first two minutes of the Titan phase. CA289T then drifted slowly to 100 percent IBW by 1000 seconds while CA288T and CA292T yielded satisfactory data.

The anomalous data is believed to be caused by the transducers becoming partially or completely unbonded from the tank skin. A change in adhesive used for temperature patch installations, from 0-73024-3 to 0-73024-2, was required when the -3 adhesive was found to be carcinogenic. The -2 adhesive is inferior in strength and thermal conductivity but was determined to be the best available for this application.

5. Measurement CY18P (spacecraft compartment ambient at adapter) displayed a flat spot in the otherwise normal pressure decay curve for approximately three seconds between 32 and 35 seconds of flight. Cause is unknown and is under investigation.

6. Measurement CP742T (C-2 engine bell station 518 outboard), and CP745T (C-1 engine bell station 500 outboard) exhibited slow response to changes in engine bell temperatures during engine firing.

The most probable cause is considered to be excessive adhesive under the resistance patch which caused poor thermal bonding to the engine bell. Numerous problems of this nature have been experienced since the change from 0-73024-3 to 0-73024-2 adhesive. That change was made when it was found that the -3 adhesive was carcinogenic. The -2 adhesive is inferior in strength and thermal conductivity, but has been considered to be the best available for this application.

Telemetry Systems

TC-5 S-band telemetry coverage for TC-5 and TE-M-364-4 stage involved a total of 18 ground, sea, and air telemetry stations. Good data was obtained from T-0 through the end of the extended mission except for the planned gap of approximately 400 seconds during coast phase. A second planned gap earlier in the coast was unexpectedly filled by ARIA 4 which was on a training flight in preparation for CTS launch support. Station coverage intervals for the three RF downlinks are shown in Figures 24.1, 24.2, and 24.3. The Centaur

Figure 24.1

TELEMETRY COVERAGE TC-5

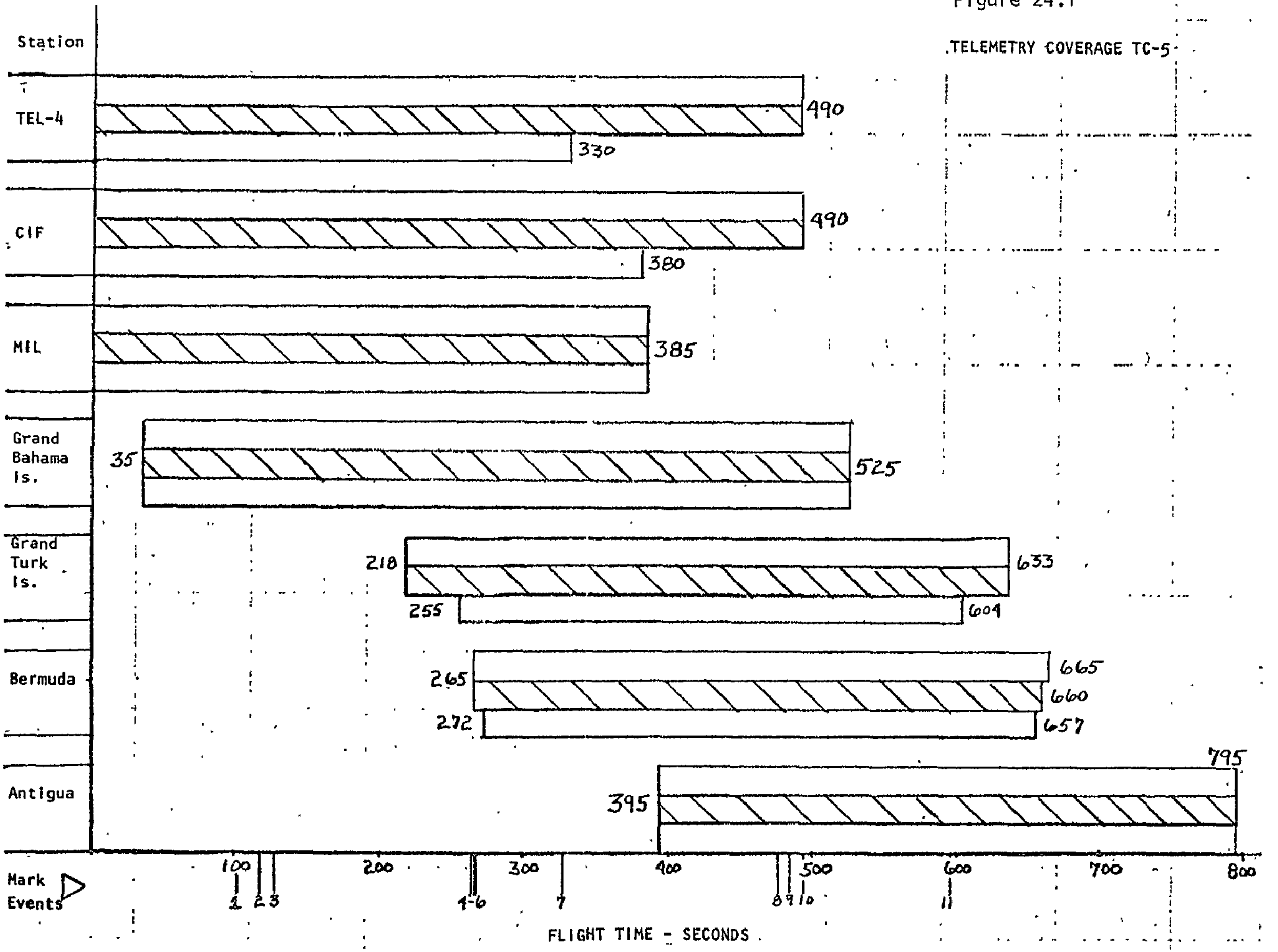


Figure 24.2

TELEMETRY COVERAGE TC-5

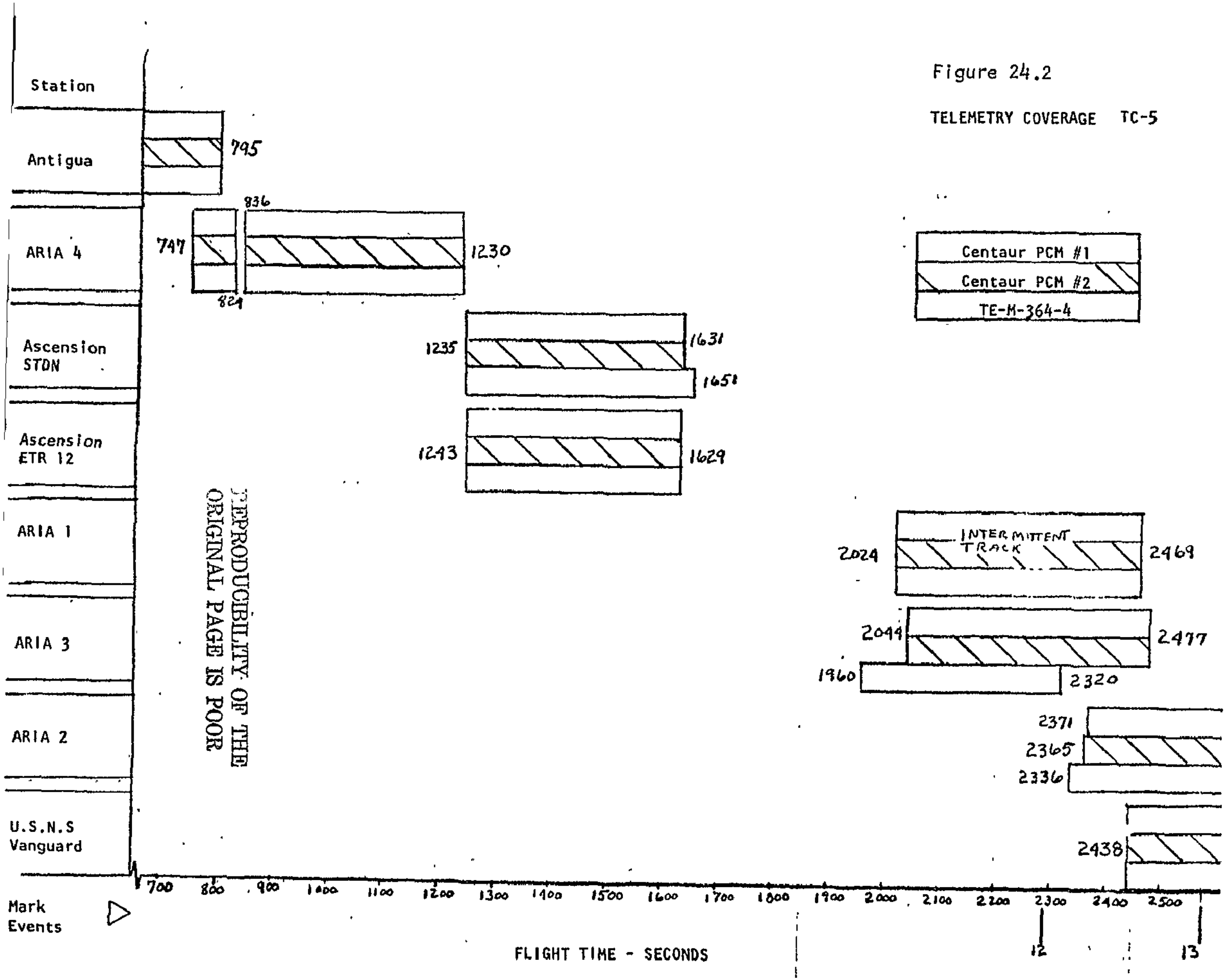
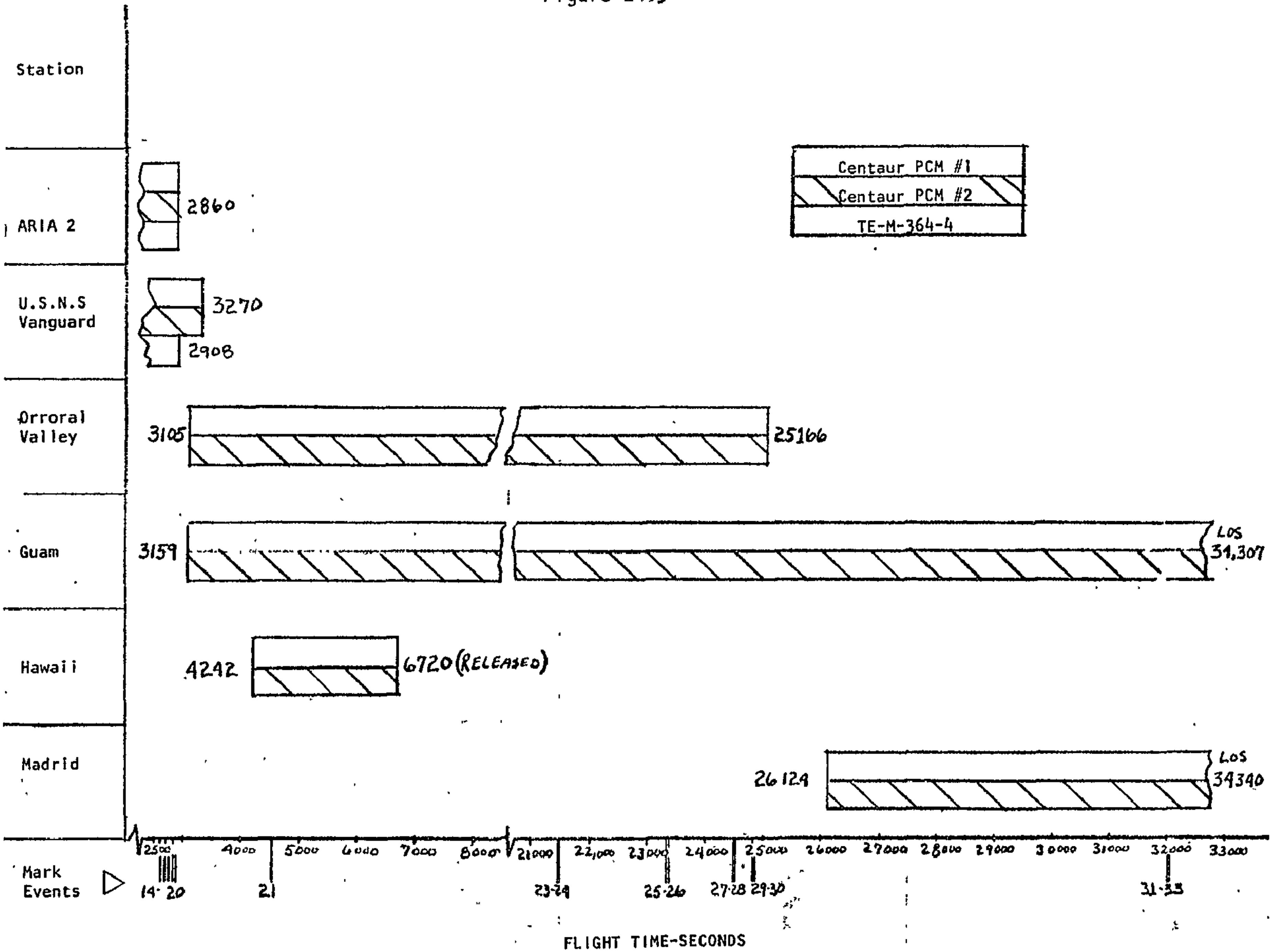


Figure 24.3


Station
ARIA 2
2860
U.S.N.S
Vanguard
3270
2908
Orroral
Valley
3105
25166
Guam
3159
LOS
31,307
Hawaii
4242
6720 (RELEASED)
Madrid
26124
LOS
34340
Centaur PCM #1
Centaur PCM #2
TE-M-364-4
Mark
Events
14-20
21
23-24
25-26
27-28
29-30
31-33
FLIGHT TIME-SECONDS

PCM data was transmitted simultaneously on two RF links, 2202.5 and 2208.5 MHz, to provide redundancy for the extended mission.

ARIA 1 had only 55 seconds of Decom Lock during its pass, but ARIA 3 provided good data for nearly the same interval. The ARIA 1 problem is under investigation. During the extended mission, Madrid was called up but signal strengths were close to threshold from AOS to LOS.

Tracking and Range Safety Systems

by T. J. Hill

C-Band Tracking

The Centaur and TE-364-4 tracking systems performed satisfactorily. The ten ground radar stations and their tracking intervals are shown in Figure 25. Antigua, 91.14, had intermittent track in the T+544 to 600 second period due to operator error. However, this period was adequately covered by Bermuda radar. After the Vanguard met their commitment of 240 seconds of valid track on TE-364, they switched to the Centaur beacon. Only 40 seconds of track was possible before Centaur went over the horizon.

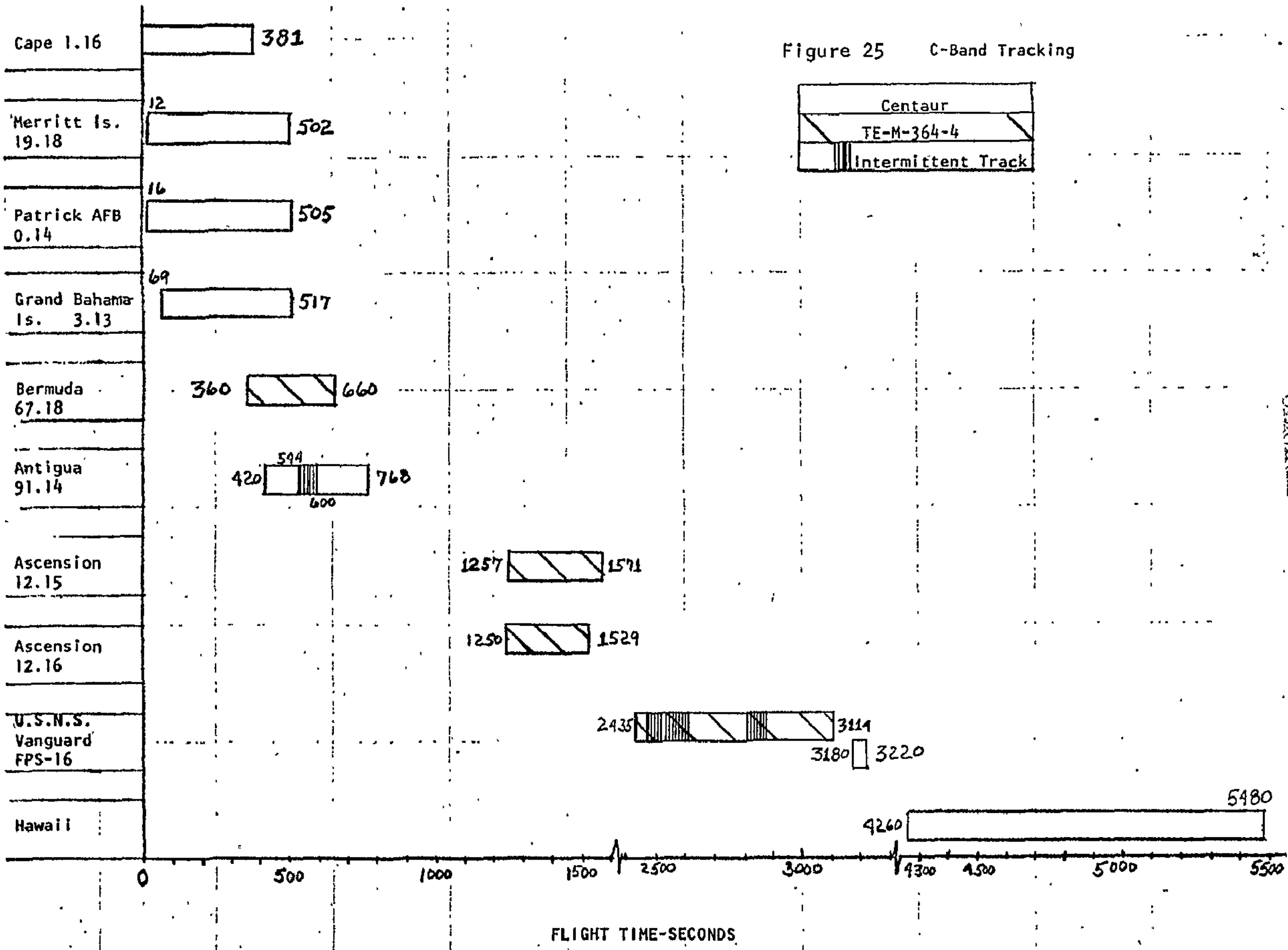
Range Safety Command System

Operation of the Range Safety Command (RSC) System was satisfactory. Signal strength (AGC) data indicated a satisfactory received signal level throughout the flight. System control was maintained as the vehicle flew downrange by switching of RSC transmitter control. Station switching times are presented in the following table:

Table 43

Station	Carrier On (Sec.)	Carrier Off (Sec.)
Cape Canaveral	T-2210	T+170.17
Grand Bahama Island	T+169.17	T+461.17
Antigua	T+459.73	T+612.17

The Antigua transmitter sent RSC RF Disable at T+610.77 seconds resulting in shutdown of the airborne RSC receivers.



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X DELTA TE-M-364-4 SYSTEMS ANALYSIS

X DELTA TE-M-364-4 SYSTEMS ANALYSIS

Mechanical System

by R. C. Edwards

During the TC-5 flight, the Delta structure performed satisfactorily. The payload attach fitting, TE-364-4 motor, and spin table safety withstood the structural loadings imposed during the booster and TE-364-4 thrust period of flight.

The mechanical events occurred on time and no anomalies were noted. The tension cord that secures the spin table in place functioned satisfactorily. The spin rockets were fired on time, breaking the tension cord. A spin rate of 86.5 RPM was imparted to the TE-364-4 motor and spacecraft. The motor attaching clamp was severed on time and was jettisoned due to its own stored energy. Following clamp band separation, the four spin table petals rotated about hinges at their base to free the TE-364-4 motor from the spin table. The wire cutter device severed the wiring harness between the spin table and the timer mounted on the payload attach fitting. The payload clamp band and the "yo" weight were released on schedule and without any discrepancies noted.

The maximum pressure decrease in the payload compartment was .65 psi per second. Due to noise on the accelerometer traces, the maximum axial acceleration at TE-364-4 burnout could not be determined.

Propulsion System

by W. K. Tabata

The performance of the TE-M-364-4 solid propellant motor was normal. The ignition delay was 46.7 seconds. The action time of the motor was 42.2 seconds. The action time is defined as the time interval from when the chamber pressure reaches 300 psia on the ascending portion of the chamber pressure time history curve to when it reaches 100 psia on the descending portion of the curve. Combustion was smooth and stable. The maximum chamber pressure was 590 psia.

Electrical System

by C. H. Arth

The telemetry battery was satisfactorily above the redline value (26.0 VDC) at liftoff reading 28.8 VDC. The flight history of the telemetry battery voltage and current indicated normal performance. The ordnance battery satisfied the redline value of 11.0 VDC reading 11.05 VDC at liftoff and performed normally.

Telemetry and Tracking Systems

by T. J. Hill

The TE-364-4 tracking by the U.S.N.S Vanguard was intermittent in the period between T+2420 and T+2876 but the required 240 seconds of valid track was obtained.

Station coverage data are included in Section IX in the discussion of the Centaur C-band tracking.

XI FACILITIES AND AGE

XI FACILITIES AND AGE

Complex 41 Facilities

by M. Crnobrnja

AGE Building Modifications

The launch of TC-3 resulted in considerable damage to the AGE Building due to a post-launch fire within the AGE Building. A joint NASA-USAF Launch Damage Committee was chartered to determine the cause of the fire and recommend corrective measures. The following major modifications were implemented prior to TC-5 in response to the Launch Damage Committee's recommendations.

1. The transporter cable support boom/blast door interface was redesigned.

2. All possible SRM exhaust entry points were sealed.

3. All combustible construction materials were eliminated from the AGE Building rebuild.

4. An automatic water sprinkler system was installed in the upper and lower levels of the AGE Building.

5. A Halon 1301 fire protection system was installed in the equipment rooms and the Mobile Transfer Room.

6. A personnel door was installed in the east wall of the AGE Building.

7. The north AGE Building blast doors were redesigned to allow rapid opening from the exterior.

8. Fire hose reels were installed in the AGE Building.

9. The fire detection system was expanded to all areas within the AGE Building.

All fire modifications performed satisfactorily during launch and post-launch. No flame entry was evident on TV monitors during launch or during film examination after launch.

Facility Operation

All facility systems on the Mobile Service Tower and Umbilical Tower required for TC-5 performed satisfactorily during prelaunch and countdown operations. The configuration of all platforms and lanyard anchors was identical to the launch of TC-2. Launch damage was minimal.

Fluid Systems Operations

by M. Crnobrnja

Titan Propellant Loading

Titan propellant loading was accomplished on F-5 and F-4 days. Quantities loaded and propellant temperatures were within specified limits. Titan fuel loading was accomplished utilizing only one Ready Storage Vessel. Procedures were revised for this loading operation and all operations were performed satisfactorily.

Centaur Propellant Loading

Centaur propellants were tanked during launch countdown. The Centaur LOX and LH_2 systems were identical to TC-2. The system operation was satisfactory.

Liquid Helium System

Liquid helium flow for chilldown of Centaur turbopumps was initiated during launch countdown. System operation was satisfactory.

Mechanical Ground Systems

by A. C. Hahn

The Titan and Centaur mechanical ground system configuration was essentially the same for the launch of TC-5 (Helios B) as it was for TC-2 (Helios A). Several modifications had been made to the Centaur air conditioning system between TC-2 and TC-3 to improve operational reliability. TC-3 and TC-4 both had demonstrated satisfactory performance of the improvement modifications.

All Titan and Centaur mechanical ground systems operated satisfactorily during prelaunch and launch operations.

The 500KW diesel generator which supplies critical Centaur air conditioning loads developed electrical control and coolant overheating problems at F-6 days. Two 300KW diesel generators operating in parallel replaced the 500KW unit and operated satisfactorily from F-6 days through the launch.

All Titan and Centaur mechanical ground system data were within parameters during launch countdown. The payload air conditioning flow rate was increased from 80 ± 5 lbs/min. to 120 ± 5 lbs/min. at the start of UES opening. The payload inlet temperature was increased from $72^{+9^{\circ}}_{-13}$ °F to 74 ± 3 °F at T-12 hours. Both changes were specified in the parameters.

Electrical Ground Systems

by H. E. Timmons

Titan Electrical

The Titan electrical ground systems configuration was essentially the same for the launch of TC-5 as it was for TC-2 -- the first Helios launch. The launch countdown is initiated and monitored from the Launch Control Console (LCC) in the Launch Control Center. The actual processing of critical readiness and hold functions is performed by the Control Monitor Group (CMG), a time-based automatic countdown controller. The CMG works in conjunction with peripheral equipment such as the Vehicle Checkout Set (VECOS), Tracking and Flight Safety Monitor Group (TFSMG), and Flight Safety Checkout Control Monitor Group (FSCCMG).

The data received during the countdown are transmitted to various recording devices over hardline transmission systems, both from the vehicle and from the ground PCM system. Capability also exists to strip data out of the open loop RF telemetry signal.

Prior to this launch, the Pad Safety Officer's Console was modified to provide additional launch critical information. These changes included adding indications of the status of the six facility water deluge system pumps, an indication of which command control receiver issued engine shutdown and the safe and arm status of the inadvertent separation destruct system. Also, the indicating lights which the PSOC previously had relating to Titan tank overpressures were replaced with analog meters showing the tank pressure values. This change was the result of a decision to remove the tank top pressure switches from all Titan vehicles.

Additional instrumentation was added on and in the AGE Building to attempt to determine the environment to which the ground equipment is subjected at launch. These data, which were played back through a 100Hz filter, are shown in Figures 26 and 27. A sketch of the transducer locations is shown in Figure 28.

The countdown and launch of TC-5 was accomplished with no major launch control or ground instrumentation system problems. The final count was started at T-625 minutes at 1259 PM EST (1759 GMT) on January 14, 1976.

Prior to the start of the countdown, a calibrator in the landline instrumentation system failed. This calibrator is used to calibrate the Voltage Controlled Oscillators (VCO) which provide the carrier frequency for the hardline telemetry and landline PCM signals for

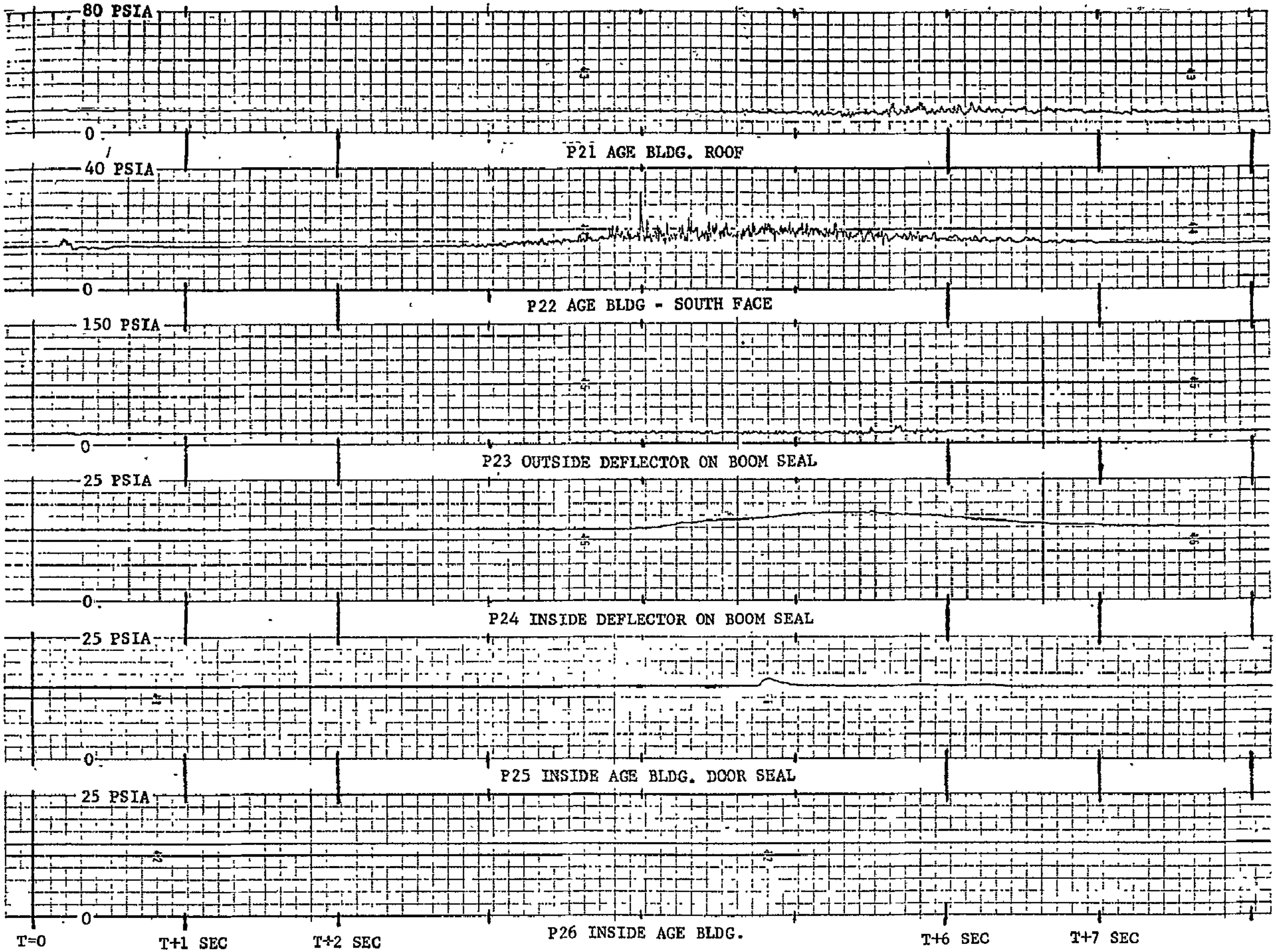

FIGURE 26 - LAUNCH ENVIRONMENT PRESSURE DATA

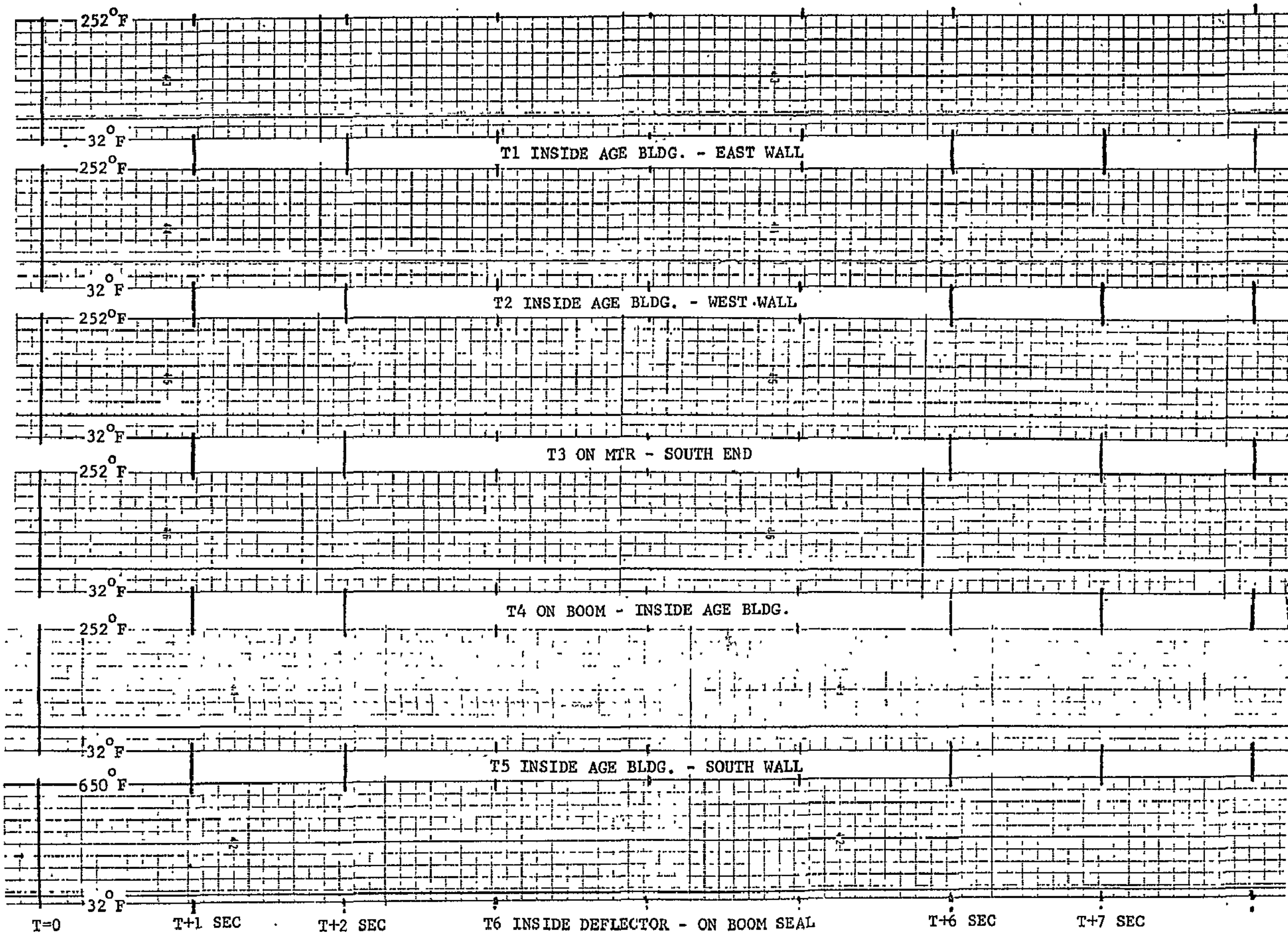

FIGURE 27 - LAUNCH ENVIRONMENT TEMPERATURE DATA

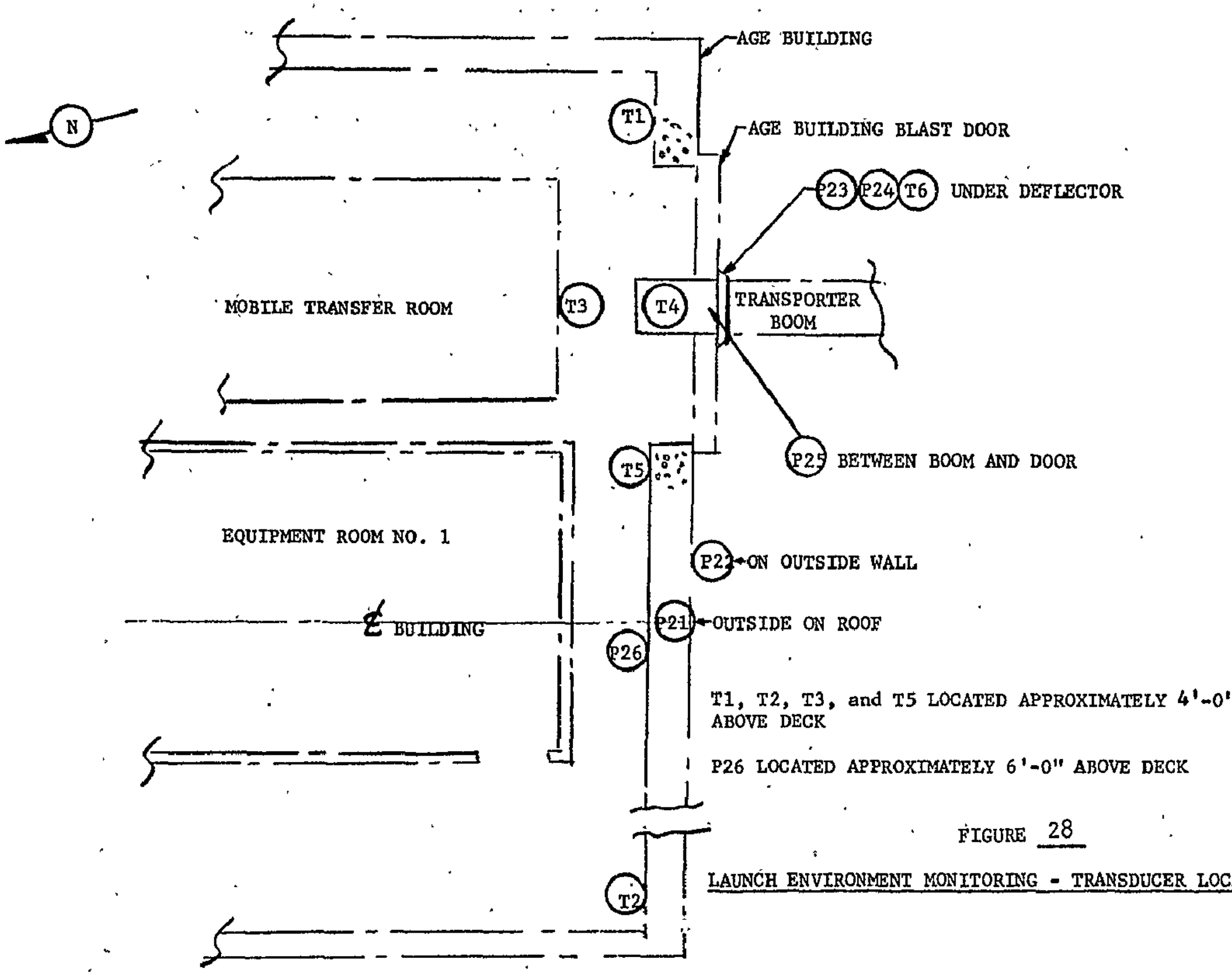

FIGURE 28

LAUNCH ENVIRONMENT MONITORING - TRANSDUCER LOCATIONS transmission to the VIB. Since the calibrator would have been required only in the event of a VCO replacement, no attempt was made to repair the problem. A spare was available if it had been needed.

At approximately T-380 minutes, landline measurement TE-8069V, transient power supply no. 2 voltage, went out of limits low. The measurement was reading 157 to 163 bits instead of the nominal value of 214 bits (34.4 volts). The calibration relay in the signal conditioning system was suspected as these relays have been a continuing source of this type of problem on this program. The calibrator was cycled into the calibrate mode and back to the data mode. The measurement immediately returned to the proper value and remained there for the remainder of the countdown. The calibrate relay was replaced post-launch.

The umbilical disconnect sequence for the Titan umbilicals was not as planned. The no. 2 electrical umbilical in compartment 2A (2A2E) came out ahead of the no. 1 umbilical (2A1E). Although this sequence was not like any previous sequence seen on the Titan/Centaur program, it has been determined by analysis that no adverse effects will be experienced regardless of the disconnect sequence. Complete umbilical disconnect data are shown in Table 44.

At umbilical disconnect, two channels on the Data Recording and Quick Line Set (DRQLS) indicated a change of state. The first of these was channel 093, CCLS Ready, which went off at 0534:00.736 GMT and went back on 3 milliseconds later. This is a signal from the Centaur ground computer at Complex 36 to the Control Monitor Group (CMG) located in the Titan launch control van. The second signal to pulse was channel 570, Dump Disable, which came on at 0534:00.793 and went off 3 milliseconds later. Dump disable is a signal from the Vehicle Checkout Set (VECOS) to the Titan airborne flight controls computer. Since the VECOS is turned off for launch, the signal seen was obviously not a real command. Both of these pulses are similar to those seen on all Titan launches from ETR since the new Data Recording and Quick Look Set (DRQLS) was installed. It is theorized that the new equipment with its faster time resolution records spurious signals generated due to the loss of ground reference on some DRS channels. This loss of reference occurs between the time an umbilical connection is broken and the time the grounding contactor in the power supply reconnects the negative bus to facility ground. During the "fly-time" of the contactor, no ground reference is available. No adverse effect has ever been experienced from the type of pulses seen here.

During the process of shutting down the pad deluge water systems after the launch, the Launch Control Console (LCC) operator was unable to shut off the water flow from the launch deck sprays. The pad safety team was directed to turn the water off manually with a hand valve in the system. The problem was determined to be a mechanical failure in the speed control needle valve mounted on the main water valve. The needle valve was replaced post launch.

TABLE 44 - TITAN UMBILICAL DISCONNECT DATA

Umbilical Designation	Time of Disconnection	
	GMT	Time from Official T-0
LB1E	0534:00.718	T+0.363
RB1E	0534:00.727	T+0.372
1C1E	0534:00.787	T+0.432
2A2E	0534:00.793	T+0.438
2A1E	0534:00.796	T+0.441
2C1E	0534:00.883	T+0.528

CMG T-0 = 0534:00.319 GMT

Ignite SRM Command from CMG = 0534:00.337 GMT

Ignition Signal from VPDC to SRM = 0534:00.355 GMT (Official T-0)

Centaur Electrical

All systems performed satisfactorily throughout the countdown and launch operations. No problems or significant anomalies were observed. All Centaur electrical umbilical systems also performed properly and as expected. Table 45 provides data on the Centaur umbilical sequence.

The only change made to the Centaur electrical ground equipment since the last usage involved the addition of a circuit breaker in the battery circuit which backs up the GSE 28 volt DC power supply. This circuit breaker was added to provide a disconnect means for safety purposes and to provide overload protection in the event of a hardware failure elsewhere in the system. This change was the result of the investigations which took place after the AGE Building fire on the previous launch.

TABLE 45 - CENTAUR UMBILICAL DATA

(Official T-0 = 0534:00.355 GMT)

Event	Time of Occurrence	
	GMT	Time from official T-0
CMG T-4 second command to MTR	0533:56.338	T-4.017
MTR relay actuation - eject aft plate and eject upper umbilicals	0533:56.356	T-3.999
Umbilical B600P2 ejected	0533:57.193	T-3.162
Umbilical B600P1 ejected	0533:57.412	T-2.943
Aft door closed signal	0533:58.288	T-2.067
Vent door open signal	0533:58.342	T-2.013
Aft plate ejected signal from MTR to CMG	0533:58.345	T-2.010
CMG T-0.5 second command to MTR -	0533:59.839	T-0.516
MTR relay actuation - eject Fill and drain valves -		
LH_2	0533:59.857	T-0.498
LO_2	0533:59.860	T-0.495
LO_2 F/D valve ejected	0534:00.226	T-0.129
LH_2 F/D valve ejected	0534:00.544	T+0.189
CMG T-0 signal to MTR	0534:00.337	T-0.018
MTR relay actuation - air conditioning duct disconnect	0534:00.358	T+0.003
Umbilical B600P4 disconnect (rise-off)	0534:00.958	T+0.603
Umbilical B600P5 disconnect (rise-off)	0534:01.084	T+0.729

Delta Stage Support Systems

by A. Lieberman

All AGE and facility installations in support of the fourth stage Delta vehicle and its associated GSE operated satisfactorily during prelaunch and launch operations.

Delta GSE for monitor and control of Delta functions were located in the Launch Control Center No. 1 in the VIB, in Equipment Room No. 2 of the AGE Building and on Level 11 of the MST. Interconnecting cabling was provided between the VIB Delta GSE, PSOC, DTS and Landline PCM systems, the AGE Building Delta GSE, spacecraft umbilical, MST, and MTR.

The Delta safe and arm and recorder control panel in the LCC provided remote S&A arming and monitoring as well as remote control of the Delta recorder on Level 11 of the MST. The PSOC provided an arm permission signal to the S&A panel. The Delta TLM and instrumentation control panel in the LCC controlled and monitored Delta stage power.

The GSFC power supply rack in the AGE Building provided ground power for the S&A circuits, local monitor and control of various Delta stage functions and local control of the Delta recorder on the MST. Space and facility power were provided to miscellaneous Delta GSE on Level 11 of the MST for Delta checkout. The recorder monitored the Delta pyrotechnic system during prelaunch operations. In addition, the installation provided simultaneous transmittal of these signals via the MTR to Complex 36 and CIF.

The Delta portable ground station located in the LCC was cabled to an existing VIB receiving antenna to permit ground checkout of the RF systems with the vehicle at the pad.

Helios B Spacecraft Support Systems

by A. Lieberman

All AGE and facility installations in support of the Helios spacecraft and its peculiar GSE operated satisfactorily during prelaunch and launch operations.

Helios GSE for monitor and control of the spacecraft during prelaunch and launch operations were located in the AGE Building and on Level 12 of the MST. Interconnecting cabling was provided between the AGE Building Helios GSE and Level 12 of the MST, the spacecraft umbilical cable and the Range interface to Hangar AO. Ground power and adapter cables to mate with German type connectors were also provided.

Ground checkout of the Helios RF systems was accomplished using a system of reradiating antennas on Level 12 of the MST coupled to a CSS antenna.

For TC-5, one modification was made to the TC-2 configuration with respect to Helios GSE. Provisions were made to allow a second adaption unit to be installed in the AGE Building, adjacent to the original adaption unit. This second adaption unit, normally located on the Mobile Service Tower during prelaunch checkout activities, was moved to the AGE Building late in the countdown to provide a redundant data handling capability for the spacecraft system during the pad-clear operations. A data display CRT was also installed in the AGE Building for local data access by the Helios operations personnel.