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TITAN/CENTAUR D-IT TC-4 VIKING A FLIGHT DATA REPORT

by Staff
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16. Abstract

Titan/Centaur TC-4 was launched from the Eastern Test Range, Complex 41, at 05:22 PM EDT on Wednesday, August 20, 1975. This was the second operational flight of the newest NASA unmanned launch vehicle. The spacecraft was the Viking A, the first of two orbiting and landing missions to Mars planned for the 1975 Martian launch opportunity. The objective of the launch phase of the mission, to inject the Viking spacecraft onto the planned transfer orbit to Mars, was successfully accomplished. This report presents a review of the launch vehicle system flight data.

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TC-4 FLIGHT DATA REPORT

VIKING A

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I SUMMARY

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by R. P. Geye

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II INTRODUCTION

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by R. P. Geye

The Viking Mission to Mars is one of NASA's principal planetary efforts of this decade. Two Viking spacecraft were launched from the AFETR Launch Complex 41, Cape Canaveral, Florida, during the 1975 Mars opportunity and will arrive at the planet in mid-1976. Each spacecraft will be placed into orbit around the planet and the landers will subsequently be separated for entry into the Mars atmosphere and a soft landing on the surface of the planet.

Launch Phase of the Viking Mission

The 1975 Mars launch opportunity extended from August 11 through October 13. The launch windows opened as early as about 1400 GMT (10:00 EDT) and closed as late as about 2230 GMT (18:30 EDT). The earliest windows occurred towards the end of the opportunity and the latest windows occurred near the beginning. On any one launch day, the window was about one hour long. The launch azimuth sector used for the mission was 96° from 108° with trajectories yawing from 108° southward to an equivalent azimuth of 115° during the latter part of some daily windows. Parking orbit coast times varied from about 11 minutes to about 28 minutes. Coast time was longest at daily window opening and shortest at closing.

The launch phase of the Viking A mission was accomplished on August 20.

The flight profile for Titan Stage 0 phase of flight consisted basically of a short vertical rise with roll to the requi ed flight azimuth, followed by an initial pitch/yaw maneuver and subsequent near zero total angle-of-attack. The required steering, referred to as wind biased steering, was determined on launch day and implemented by the Centaur DCU in an open loop mode. Propellant depletion of the Stage 0 engines activated the Titan Step 0 staging timer (1.5 g decreasing axial acceleration) which initiated Titan Stage I engine start, heat shield jettison/Stage I ignition and Titan Step 0 jettison.

During Titan Stages I and II phases of flight, the flight profile was primarily determined by the steering required to achieve a 90 n.mi. parking orbit at the end of the first Centaur burn. The required steering was implemented by combining incremental pitch and yaw rates, derived from the Centaur guidance steering vector, with a rate versus time pitch program that was stored in Titan. Titan Step I jettison/Stage II ignition was initiated by Stage I propellant depletion. The Centaur Standard Shroud was jettisoned 10 seconds after Stage I shutdown, as sensed by the Centaur DCU. Titan Stage II also burned to propellant depletion which then initiated Titan Step 2 jettison, Centaur chilldown and Centaur Main Engine Start.

The Centaur first burn phase was of relatively short duration and terminated at injection into the 90 n.mi. circular parking orbit. The 90 n.mi. orbit is standard for parking orbit ascent missions. Steering commands were provided by the Centaur DCU based on the guidance steering vector. Main engine cutoff was commanded by guidance when the desired orbit was achieved. Continuous Centaur peopellant settling was maintained during the parking orbit coast phase. During most of the coast phase the vehicle was aligned along the inertial velocity vector. Prior to the second burn the vehicle was aligned to the proper attitude for the burn. The second Centaur burn was terminated by guidance when injection conditions satisfied the Viking mission requirements.

Spacecraft separation occurred by Centaur DCU command 220 seconds after Centaur Main Engine Cutoff (MECO-2). Centaur then executed a reorientation and retromaneuver to satisfy planetary quarantine constraints.

Viking Mission Objectives

The goal of the NASA Viking program is to learn more about the planet Mars by direct measurements in the atmosphere and on its surface. Additional scientific data will be acquired from the Orbiter which will circle Mars in a synchronous orbit above the Lander after the latter has descended to the surface. On both the Orbiter and the Lander the primary emphasis will be on biological, chemical and environmental aspects of Mars which are relevant to the existence of life.

The Viking scientific experiments are divided into four groups: Orbiter, entry, Lander and radio. The Lander carries by far the most instruments. It is, in fact, a miniature automated laboratory. The entry experiments involve instruments mounted on a protective shell surrounding the Lander during its high-velocity entry into the Martian atmosphere. The entry experiments will obviously be brief but will give us a unique opportunity to analyze the characteristics of the Martian atmosphere from top to bottom. After the Lander is detached, the Orbiter plays mainly a supporting role, although it may, for selected periods of time, break its radio ties with the Lander and commence independent scientific experiments. The scientific goals and the specific instruments associated with the four groups of experiments are listed in Table 2-1.

TABLE 2-1 - VIKING SCIENTIFIC GOALS AND INSTRUMENTS

Experiment Category	Scientific Goals	Investigations (Instruments)
Orbiter	Perform reconnaissance to verify or search for landing sites. Monitor landing sites. Obtain data from other areas of the planet. Search for future landing sites.	Visual imaging (2 television cameras). Atmospheric water mapping (infrared spectrometer). Surface temperature mapping (infrared radiometer).
Entry	Determine composition and structural profile of the ionosphere and atmosphere.	Ions and electrons (retarding potential analyzer). Neutral gases (mass spectrometer). Pressure and temperature (pressure, acceleration, and temperature sensors).
Lander	Visually examine the landing site. Search for evidence of life. Search for and study organic compounds and determine atmospheric composition and its variations. Study inorganic compounds. Determine temporal variations of pressure, temperature and wind velocity. Determine seismological characteristics. Determine magnetic properties of surface. Determine physical properties of surface.	Visual imaging (2 cameras). Direct biology (3 metabolism and growth detectors). Molecular analysis (gas chromatograph mass spectrometer). Mineral analysis (x-ray spectrometer). Meteorology (pressure, temperature and wind sensors). Seismology (3-axis seismometer). Magnetic properties (2 magnet arrays and magnifying mirror. Physical properties.
Radio	Conduct scientific investigation using the radio and radar systems.	Radioscience (Orbiter and Lander radio equipment).

III SPACE VEHICLE DESCRIPTION

III SPACE VEHICLE DESCRIPTION

Viking Spacecraft

by R. P. Geye

The Viking spacecraft consists of two main elements, the orbiter and the lander, shown in the cruise configuration in Figure 3-1. In this configuration the orbiter is structurally attached to the lander through the truss members of the Viking lander capsule adapter.

Orbiter: The orbiter bus is an unequal-sided octagon structure. The necessary electronics and other subsystems are mounted in 16 bays. Louvers are attached to the bays on the sides of the bus to aid in thermal control o subsystem electronics.

The propulsion subsystem, which consists of two propellant tanks, pressurant tank, engine support structure, and a fixed thrust two-axis-gimbaled rocket engine, is attached to the octagonal bus in a modular fashion. Helium pressure is used to feed the storable propellants, nitrogen tetroxide and hydrazine, to the rocket engine.

The entire propulsion module is enclosed in a multi-layer insulation blanket for thermal control. Four solar energy controllers are used to regulate the quantity of solar energy reflected into the propulsion module through penetrations in the thermal blanket.

Four solar panels are mounted to the bus by means of outriggers in a fan-like array on the coordinate axes. Each panel is composed of two identical subpanels.

Two batteries are used to augment the solar array when the power demand exceeds its capability, and to serve as a secondary power source during off-sun operations. The power system provides 2.4 KHz single-phase, 400 Hz three phase, regulated dc, and unregulated dc power.

Attitude control jets for pitch, roll and yaw coincident with the coordinator axes are mounted at the outboard edge of each of the solar panels.

Celestial sensors, comprised of a Canopus sensor, cruise sun sensors, sun gate, and a stray light sensor are mounted to the appropriate sides of the bus. Acquisition sun sensors are mounted on the solar panel tips.

Orbiter communication requirements are satisfied by low and high gain antennas and a relay antenna. The low gain antenna is used to provide command coverage in any roll attitude throughout the mission while in a sun-acquired attitude,

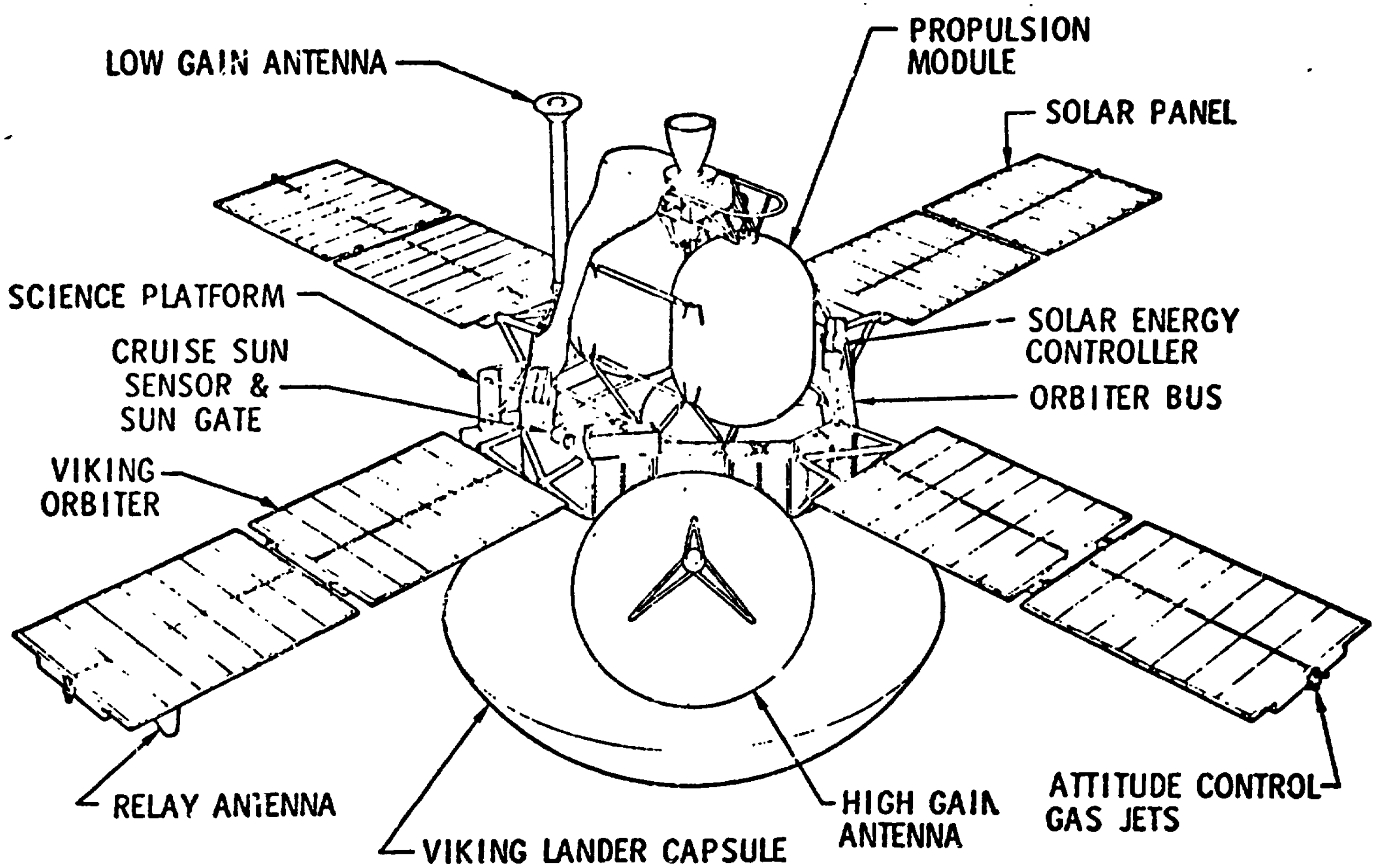

FIGURE 3-1 - VIKING CONFIGURATION IN CRUISE MODE (SUNLIT VIEW)

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and also to transmit S-Band signals during the cruise phase. The high gain antenna is used for transmitting and receiving S-Band signals and transmitting X-Band signals during orbital operations and the latter portions of the cruise phase. The relay antenna is used for receiving UHF signals from the lander.

Lander: The basic elements of the lander capsule are the bioshield cap and base, the base cover and parachute system, the aeroshell and the lander.

The bioshield serves to prevent recontamination of the sterilized lander with Earth organisms by completely encapsulating the lander during and after sterilization which is accomplished prior to launch. The cap is jettisoned soon after the spacecraft leaves Earth orbit and the base is jettisoned in Mars orbit after descent capsule separation.

The base cover permits controlled pressure equilization during launch and entry phases by means of a vent system. It is integral with the mortar support structure which contains the parachute system. The mortar is used for parachute deployment. The parachute is a disk gap band configuration used to slow the lander capsule during descent to the Martian surface.

The aeroshell/heatshield is an aluminum-ring-stiffened 140-degree conical shell structure, with a covering of a lightweight ablator material. It provides a suitable shape for entry and protects the lander from aerodynamic beating and other elements of the entry environment.

Figure 3-2 shows the lander in the landed configuration. The lander body is a hexagonally shaped structure which provides a mounting base for the science and other operational subsystems. It is fabricated primarily from aluminum and titanium structural alloys, and is insulated so as to provide environmental protection to the science and supporting subsystems contained therein.

The lander body is supported by three landing leg assemblies. Each leg consists of a main strut assembly and an A-frame assembly to which is attached a footpad. The landing gear stabilizing struts are attached to the bottom corners of the lander body by load limiters. Borded crushable aluminum honeycomb is used in the main strut for load attenuation at landing.

Three terminal descent engines are attached to the lander sidebeam 120 degrees apart. These engines are the main element of the terminal descent propulsion subsystem which provides roll control, attitude control and a reduction in velocity to the lander after parachute separation. A unique 18-nozzle configuration is used on each engine to minimize soil erosion during lander touchdown.

A reaction control/deorbit propulsion subsystem, utilizing small mono-propellant hydrazine thrusters clustered in four modules mounted near the edge of the aeroshell, provides deorbit thrust and reaction control for lander orientation and rate damping during the lifting entry phase.

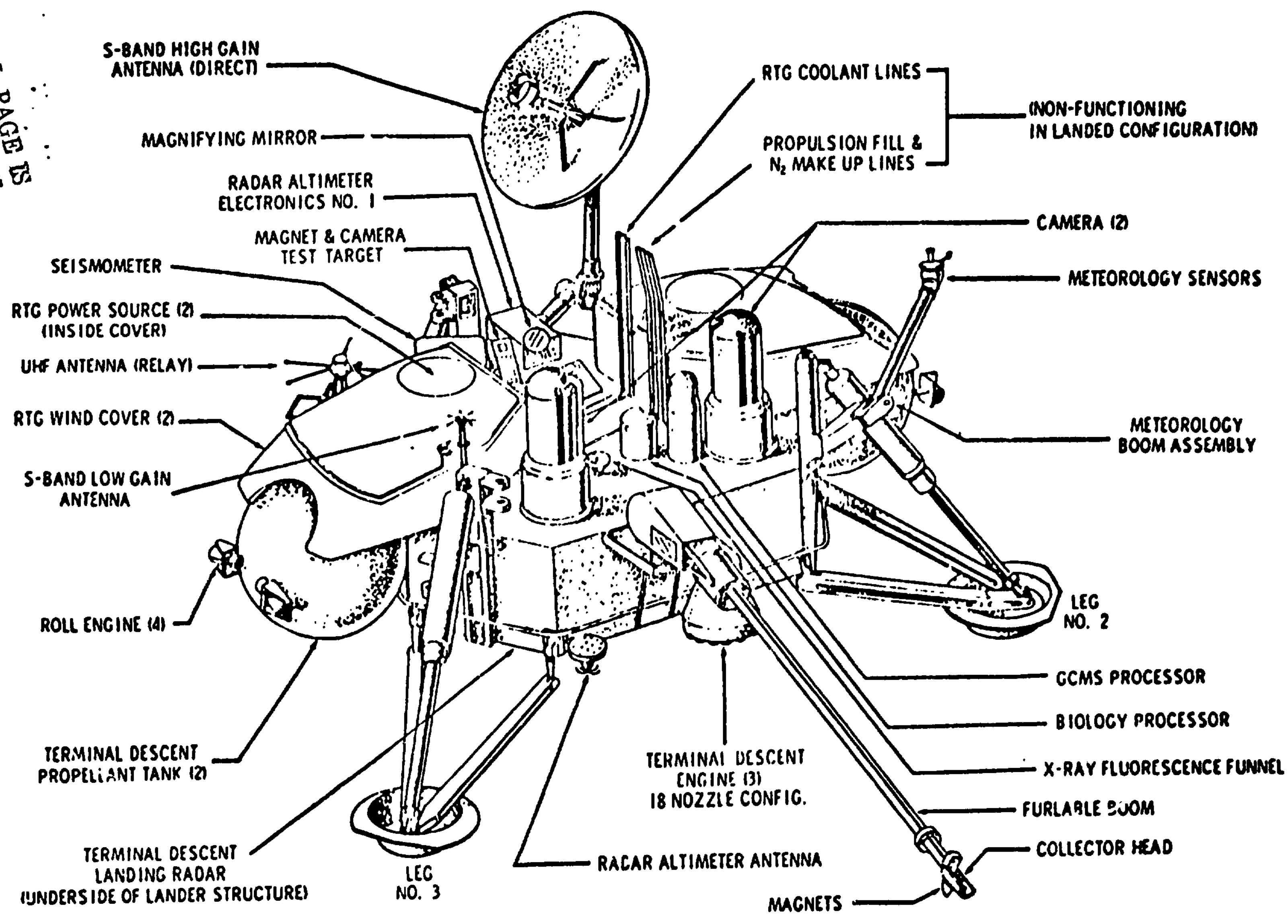

FIGURE 3-2 - VIKING LANDED CONFIGURATION

The lander can transmit data both directly to Earth, using an S-Band communications system, or by way of the orbiter, using a UHF relay system.

The power for the lander is provided by two SNAP 19-style Radioisotope Thermoelectric Generators (RTG's). Lander power requirements in excess of 57 watts are supplied by rechargeable batteries.

The lander has a terminal descent landing radar which is located directly beneath the lander. It consists of four separate CW radars operating at approximately 13 GHz.

The lander has a radar altimeter which is a solid state pulse radar that employs two special design antennas. One antenna is mounted through the aeroshell for high altitude measurements and the other antenna is mounted on the lander for measurements after aeroshell separation.

The lander has a telemetry subsystem which serves to collect and control the flow of scientific and engineering data. It consists of the Data Acquisition and Processor Unit (DAPU), a tape recorder, and a data storage memory.

The Guidance Control and Sequencing Computer (GCSC) is a general purpose digital computer which provides for the flight control system computations and the control and sequencing of the lander components and science instruments. The computer software may be changed or updated through the Earth-to-lander communication system.

Launch Vehicle Configuration

by R. P. Geye

The launch vehicle for Viking A was the four-stage Titan IIIE/Centaur D-1T configuration. This was the second operational flight of this combination of stages.

The overall vehicle configuration is shown in Figure 3-3. The Titan vehicle consists of a two-stage liquid propulsion core vehicle manufactured by the Martin Marietta Corporation and two solid rocket motors (Stage 0) manufactured by United Technology Center. The Titan vehicle integrator is Martin Marietta Corporation. The upper stage is the Centaur D-1T manufactured by General Dynamics Convair Division.

The payload fairing for this configuration is the Centaur Standard Shroud (CSS) manufactured by Lockheed Missiles and Space Company, Inc. Figure 3-4 shows the Centaur/CSS/Viking spacecraft general arrangement.

The following sections of the report give a summary description of the vehicle stage and CSS configurations. Detailed subsystem descriptions can be found in the Flight Data Report for Titan/Centaur TC-1 Proof Flight (NASA TM X-71692). Only configuration differences from TC-1 and/or TC-2 will be addressed in this report.

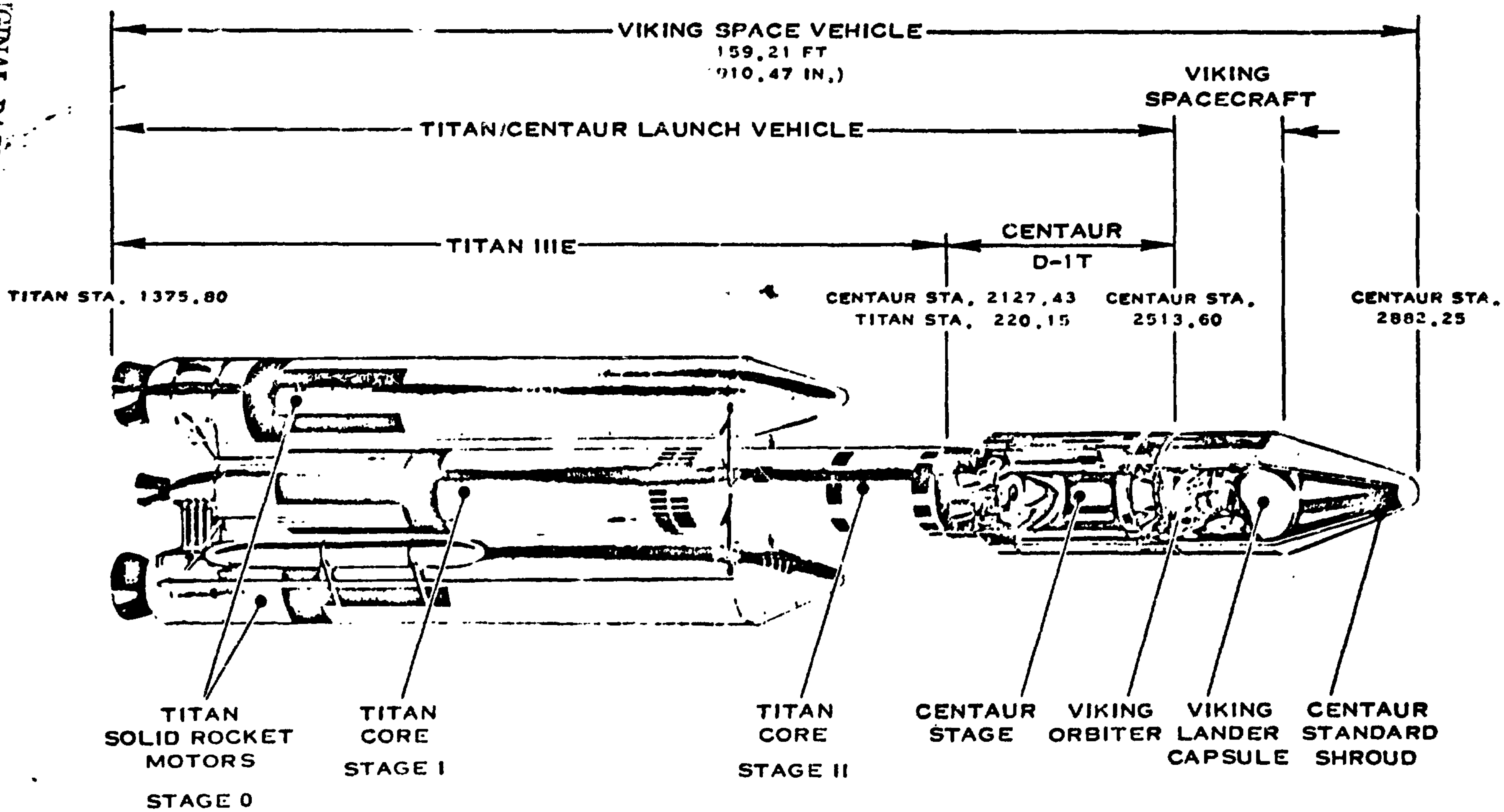

FIGURE 3-3 - OVERALL TC-3, -4 VEHICLE CONFIGURATION

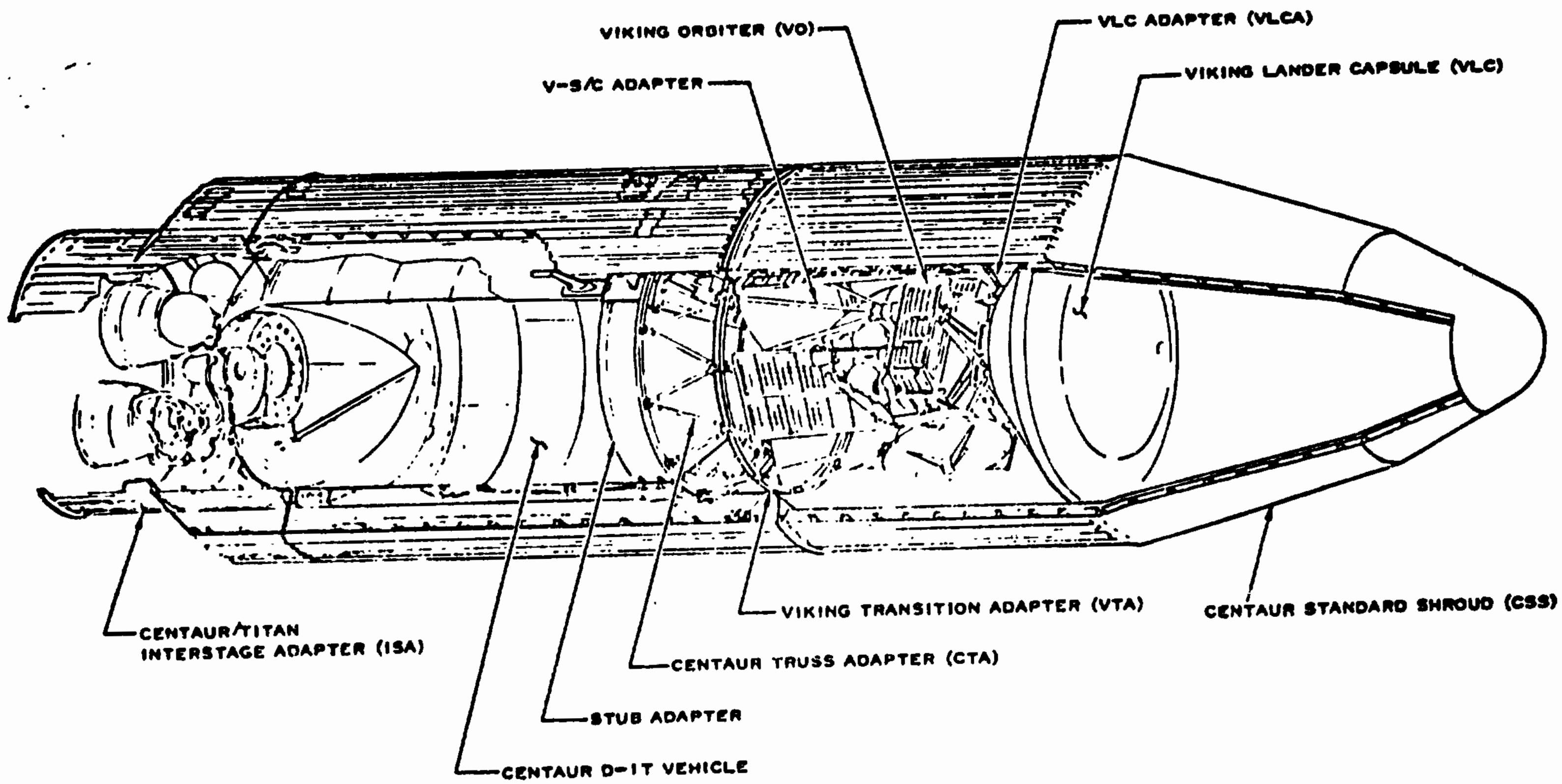

FIGURE 3-4 - CENTAUR VIKING GENERAL ARRANGEMENT

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Titan IIIE

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 (SRM's) provide a thrust of 2.4 million pounds at liftoff. These motors, built by United Technology Center, 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.

To preclude longitudinal oscillations which were encountered during Stage I operation on TC-1 and TC-2, accumulators are installed in the oxidizer feed lines to each of the Stage I thrust chambers on this Titan vehicle. In conjunction with this installation, four pressure measurements are added for ground check of the accumulator bellows pressures.

The Stage I oxidizer autogenous pressurization system consists of two superheaters as flown on TC-1 (only one superheater was flown on TC-2). This pressurization system provides tank ullage pressure during Stage I burn time.

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.

For this Titan vehicle, the following measurements were added beyond the standard Titan IIIE instrumentation: six accelerometers on the Stage I engines, a Stage I oxidizer pump inlet pressure, two narrow band chamber pressure measurements on the two Stage I engines and an orifice and venturi pressure measurement in the Stage I autogenous system.

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-1T

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 fluoride on its outer surface. This Centaur vehicle has no thermal control shielding on components in the thrust section.

The forward equipment module, an aluminum conical structure, attaches to the tank by a short cylindrical stub adapter.

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. This Centaur vehicle has one large helium storage tank.

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 fuel boost pumps. This Centaur vehicle has a boost pump cold gas spinup system used for ground checkout of the 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 6-pound lateral thrust engines manifolded together.

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-1T 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 Measuring Group (IMG).

The Centaur D-1T 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-1T.

This Centaur vehicle has one FM/FM telepac to transmit wideband spacecraft measurements.

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.

This Centaur vehicle uses a basic d-c power system, with power supplied by one 150 ampere-hour battery and distributed via harnessing. The servo-inverter provides a-c power, 26 and 115 volts, single phase, 400 Hz.

Centaur Standard Shroud

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 3-5, 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 bi-conic nose is a semi-monocoque magnesium-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.

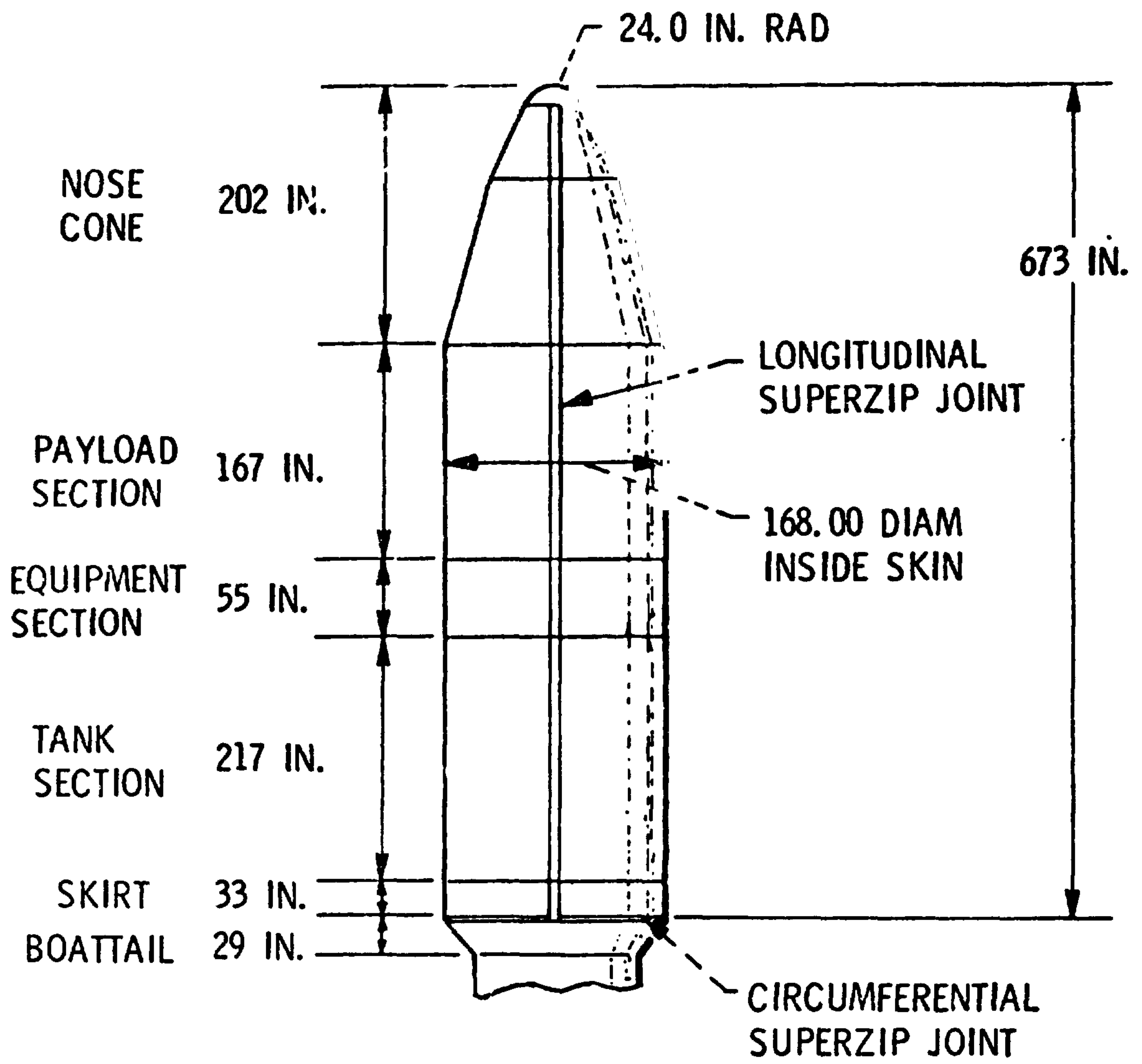


FIGURE 3-5 - CENTAUR STANDARD SHROUD CONFIGURATION

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.

IV TRAJECTORY AND PERFORMANCE SUMMARY

IV TRAJECTORY AND PERFORMANCE SUMMARY

by R. P. Kuivinen

The Titan IIIE/Centaur D-1T launch vehicle (TC-4) was successfully launched on August 20, 1975, at 21:22:00.155 GMT (5:22:00.155 PM EDT) placing the Viking I spacecraft onto the correct MARS transfer orbit. Table 4-1 presents the major flight events.

The Titan Solid Rocket Motors (SRM's) were ignited at 21:22:00.155 GMT (5:22:00.155 PM EDT) with liftoff occurring when the thrust of the SRM's exceeded the total vehicle weight. The launch vehicle was rolled from the pad azimuth of 100.2 degrees from true north to the required flight azimuth of 96.574 degrees from true north. The ADDJUST steering programs, PIA3800*TC04 and YIA3800*TC04, provided the pitch and yaw steering attitude histories for the SRM portion of flight for aerodynamic load relief. These steering programs were designed from wind measurements at launch minus 135 minutes. The trajectory profile through SRM flight was near nominal with Stage I engine ignition occurring at 110.4 seconds into flight and SRM jettison occurring at 121.7 seconds.

The Stage I portion of flight was longer than predicted with Stage I cutoff sensed at 259.4 seconds into flight with Stage I being jettisoned 0.7 seconds later. The velocity at Stage I cutoff was about 22 ft/sec higher than predicted.

The Titan Stage II portion of flight also was longer than predicted with the Stage II cutoff sensed at 467.7 seconds. The vehicle at Stage II cutoff was about 20 ft/sec lower in velocity than predicted. During Stage II portion of flight the Centaur Standard Shroud was jettisoned at 270.3 seconds into flight which was 10.2 seconds after Stage I jettison.

Even though Stages I and II had longer engine firings than predicted, the overall performance of the Titan IIIE vehicle was very good.

The Centaur was separated from the Titan at 473.8 seconds into the flight, with the Centaur first burn main engine start occurring at 484.3 seconds. Centaur Main Engine Cutoff (MECO-1) occurred at 611.3 seconds placing the vehicle into the prescribed parking orbit. Table 4-2 compares selected parking orbit parameters.

After coasting for 15.3 minutes the Centaur second burn occurred to place the Viking I spacecraft onto the correct Mars transfer orbit. MES-2 occurred at 1530.1 seconds into flight and MECO-2 occurred at 1846.1 seconds. Table 4-3 compares the Mars transfer orbit parameters.

TABLE 4-1 -

VIKING I, LAUNCH AUGUST 20, 1975, ARRIVE JUNE 19, 1976

SEQUENCE OF EVENTS FOR TC-4

NO.	FLIGHT EVENTS	TIME (SEC) PREDICTED (1)	TIME (SEC) ACTUAL
1	SRM IGNITION	T = 0	21:22:00:155 (GMT)
2	SEPARATE FWD BEARING REACTORS	100.0	100.0
3	STAGE I IGNITION	110.67	110.4
4	SRM JETTISON	122.0	121.7
5	STAGE I CUTOFF	256.3	259.4
6	STAGE I JETTISON	257.1	260.1
7	STAGE II IGNITION	257.1	260.1
8	CENTAUR SHROUD JETTISON	268.0	270.3
9	STAGE II CUTOFF	459.6	467.7
10	STAGE II JETTISON	465.6	473.8
11	CENTAUR MES 1	476.1	484.3
12	CENTAUR MECO 1	602.8	611.3
13	CENTAUR MES 2	1523.0	1530.1
14	CENTAUR MECO 2	1842.1	1846.1
15	SPACECRAFT SEPARATION	2062.1	2066.1
16	SOLAR PANEL DEPLOY. COMPLETE	2182.1	2201.9
17	BEGIN CENTAUR BLOWDOWN	2917.1	2921.7
18	END CENTAUR BLOWDOWN	3167.1	3171.7

(1) GDC PREFLIGHT ACTUAL LAUNCH TIME TRAJECTORY (PALTT)

TABLE 4-2 - VIKING I (TC-4) PARKING ORBIT

		ACTUALS		
	EXPECTED	CIF	ANTIGUA	GSFC
EPOCH (SEC)	603.3	617.6	612.8	608.0
SEMI MAJOR AXIS (KM)	6541.19	6541.3	6543.1	6540.1
ECCENTRICITY	.0005	.000478	.00078	.000579
INCLINATION (DEG)	29.24645	29.2229	29.185	29.214
PERIGEE (KM)	159.76	160.01	162.98	158.17
APOGEE (KM)	166.31	166.27	172.23	165.47
C_3 (KM^2/SEC^2)	-60.937	-60.936	-60.914	-60.947

TABLE 4-3 - VIKING I (TC-4) SPACECRAFT INJECTION (MECO-2)

		ACTUALS			
	EXPECTED	CIF	GSFC	DSS-42	VANGUARD
EPOCH	1842.6	1849.6	1860.0	1845.0	1845
SEMI MAJOR AXIS (KM)	-18851.5	-18833.1	-18853.4	-18842.25	-18799.23
ECCENTRICITY	1.348133	1.348498	1.348067	1.34843	1.34859
INCLINATION (DEG)	29.19945	29.1612	29.161	29.154	29.1243
PERIGEE (KM)	184.672	184.089	184.079	187.05	175.94
APOGEE (KM) (1)	--	--	--	--	--
C_3 (KM^2/SEC^2)	21.14	21.1683	21.142	21.155	21.2031

(1) HYPERBOLIC

Table 4-4 compares the injection orbit parameters mapped at Mars. The tracking parameters presented are based on several days of tracking of the Viking I spacecraft by the DSN. A 3.9 meter/second midcourse correction would have placed the spacecraft on the original launch vehicle target aim point which was biased for planet quarantine purposes. The guidance solution is based on DCU telemetry data and is presented for comparison.

The Centaur completed the launch vehicle mission by performing a deflection maneuver after spacecraft separation to further enhance the Centaur's missing the planet. The orbital parameters resulting from this maneuver are contained in Table 4-5.

TABLE 4-4 - VIKING I (TC-4) MARS B-PLANE MAP OF INJECTION PARAMETERS

		ACTUALS	
	TARGETED [1]	GUIDANCE [2]	TRACKING [3]
B. T. (KM)	152760	157460	164486
B. R. (KM)	-210270	-218465	-277133
TCA (MO/DA/YR HR:MIN)	6/20/76 17:07 GMT	6/20/76 17:56:4 GMT	6/20/76 23:19.3 GMT
MCR M/SEC		0.37	3.9

(1) VIKING '75 PROJECT TARGETING SPECIFICATION, MARCH 1, 1975, JPL DOC: 612-26

(2) GDC COMPUTATION FROM FLIGHT DCU GUIDANCE DATA

(3) JPL COMPUTATION BASED ON SEVERAL DAYS OF DSN TRACKING

TABLE 4-5 - TC-4 CENTAUR DEFLECTION (BLOWDOWN)

	EXPECTED	CIF	ACTUALS GSFC	VANGUARD
EPOCH (SEC)	3167.1	3173.6	4070	3419
SEMI MAJOR AXIS (KM)	-19127.44	-19162.885	-19797.7	-19733.14
ECCENTRICITY	1.342756	1.342045	1.3299	1.32201
INCLINATION (DEG)	29.18745	29.1497	29.124	29.01735
PERIGEE (KM)	177.89	176.42	153.244	--
APOGEE (KM)	--	--	--	--
C_3 (KM^2/SEC^2)	20.84	20.801	20.13	20.199

V VEHICLE DYNAMICS

V VEHICLE DYNAMICS

by T. F. Gerus and J. C. Estes

The Titan/Centaur/Viking received dynamic excitation from wind loads, acoustic excitation, and transient forces from engines starting and stopping, and separation events. The following is an evaluation of those excitation sources.

Wind Loads Evaluation - The ADDJUST system was used to design flight steering programs P1A3800*TC04 and Y1A3800*TC04 for the wind profile measured by a Windsonde balloon released at 1857 Z, August 20, 1975. The pitch and yaw components of this wind are shown in Figure 5-1. During prelaunch verification of the flight steering programs, peak response to the 1857 Z wind was calculated to be 78 percent of the weakest structural allowable. This response was calculated to occur at 22340 feet. It should be noted that this percentage includes a combination of nominal wind responses with allowances for such unmeasured and/or non-nominal quantities as gusts, buffeting, trajectory dispersions and two-hour wind changes.

A post-launch wind sounding was made with a Jimsphere balloon released at 2132 Z, August 20, 1975. The pitch and yaw components of this wind are shown in Figure 5-2. The 2132 Z sounding is the best available measurement of the flight winds, although it reached critical altitude about 40 minutes after launch. Peak calculated response from this sounding was 86 percent of the weakest structural allowable at 24873 feet. This percentage includes all of the same allowances for extreme conditions described above for prelaunch verification. As may be seen in the discussions of measured TVC usage (Section VII) and Titan flight controls (Section VII), all of the measured flight wind responses were well below allowables.

Acoustic Excitation Evaluation - Acoustic levels were measured within the Centaur Standard Shroud near the Centaur equipment module. TC-1 data measured near the equipment module and near the Viking dynamic simulator indicated reasonable comparison so the TC-4 data represent spacecraft acoustic levels. The data was analyzed using standard acoustic analysis techniques by General Dynamics Convair Division and Langley Research Center. Data from both TC-3 and TC-4 are shown for comparison purposes. The data shown on Figures 5-3 and 5-4 indicate reasonable agreement between analyses performed, reasonable repeatability between TC-3 and TC-4, and reasonable margin between measured acoustic levels and the Viking flight acceptance test levels.

Transient Loads Evaluation - Transient loads were evaluated early in the Titan/Centaur program for all transients using Viking dynamic model I and repeated later in the program for the more critical conditions using Viking dynamic model VIII. The evaluation of the predicted loads was made by comparing forces predicted on six lander capsule adapter struts with those measured on TC-3 and TC-4 for comparison purposes. The comparisons are listed on Table 5-1.

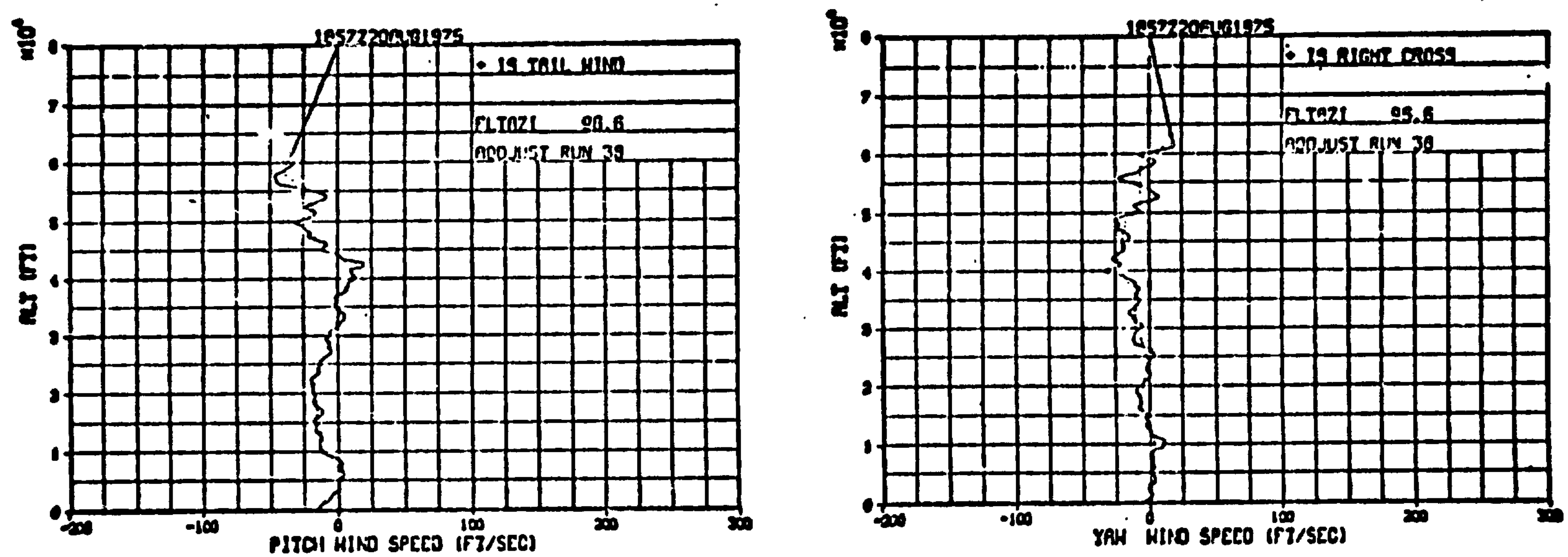


FIGURE 5-1 - WINDSONDE PITCH AND YAW COMPONENTS OF WIND VELOCITY, 1857Z, 8-20-75

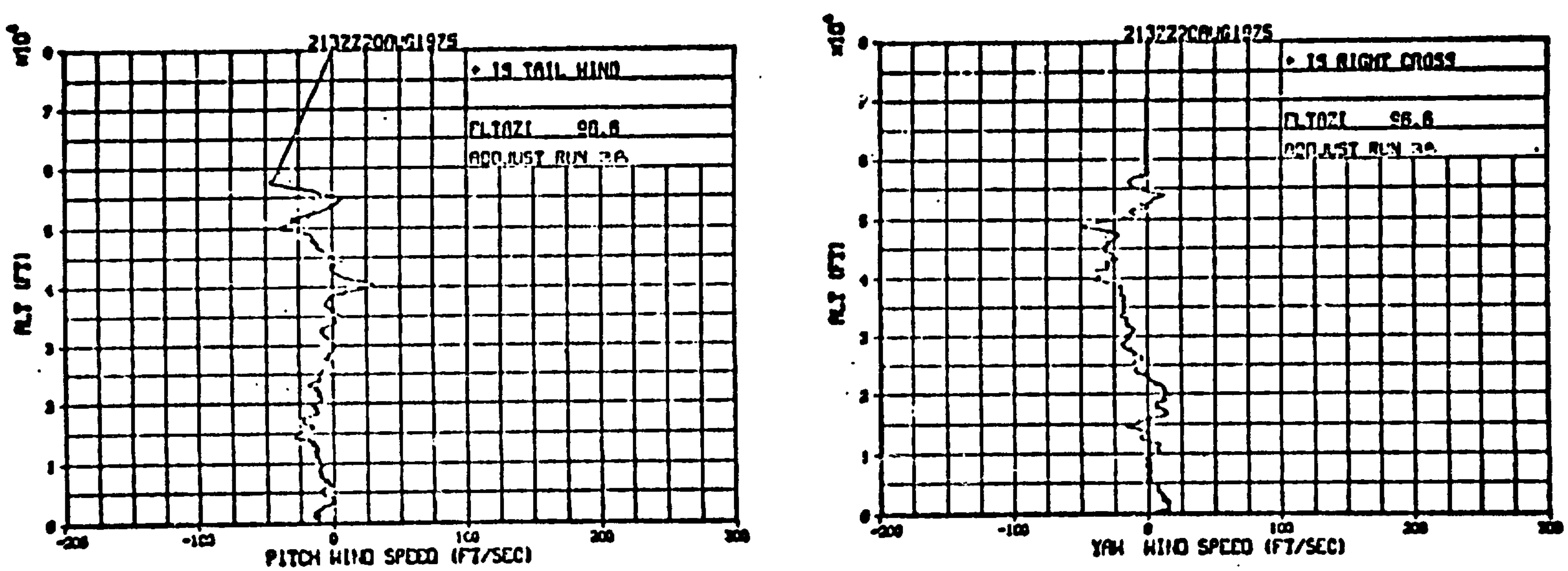
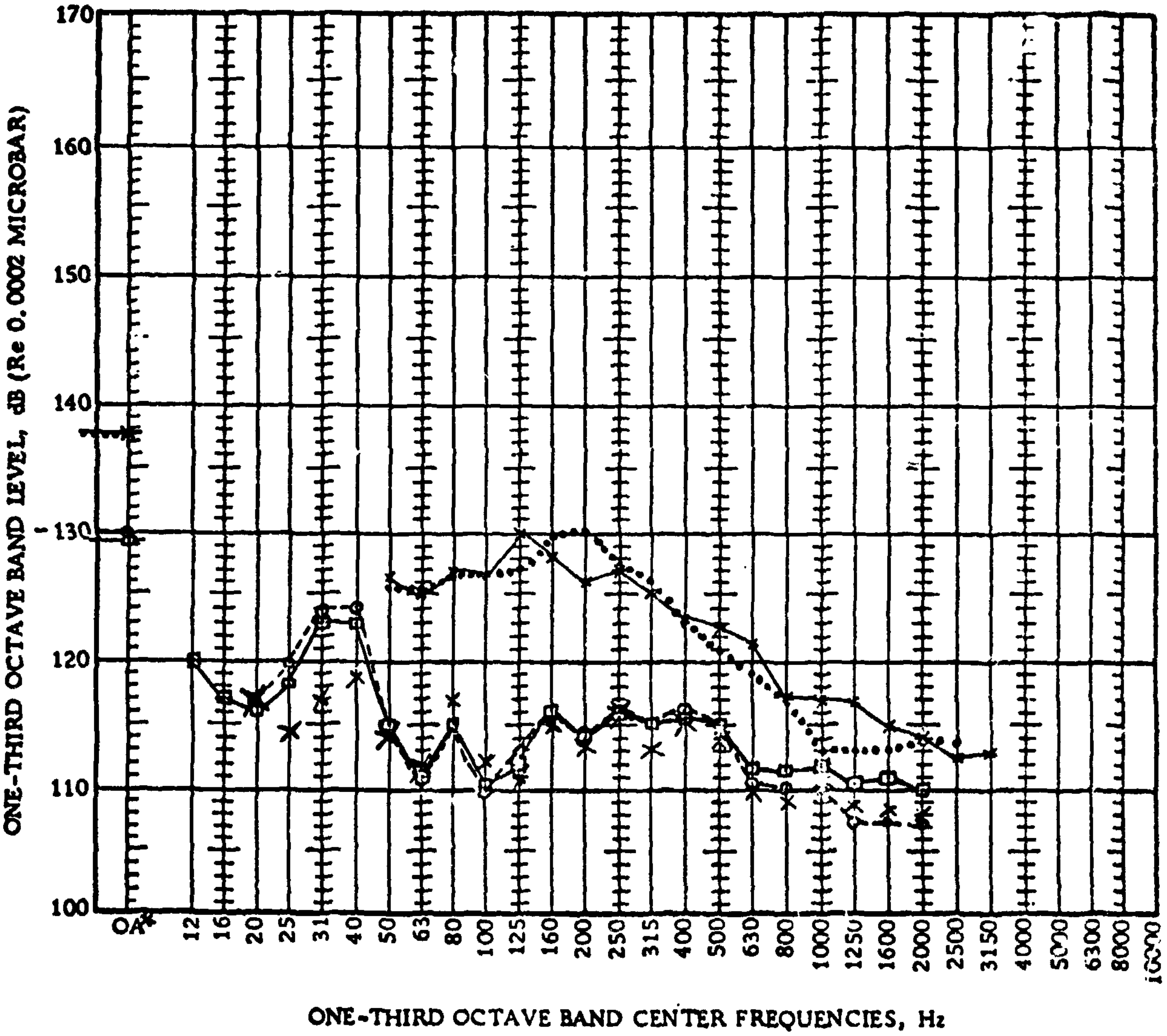


FIGURE 5-2 - JIMSPHERE PITCH AND YAW COMPONENTS OF WIND VELOCITY, 2132Z, 8-20-75

FIGURE 5-3 - TC-4/3 ACOUSTICS, LAUNCH

From CA-886-Y

TC-4	LRC Analysis	——□——	129.4 dB OA (20 to 2KHz)
	GDC Analysis	- - - θ - - -	130.0 dB OA (20 to 2KHz)
TC-3	GDC Analysis	X	127.4 dB OA (20 to 2KHz)
	JPL Flight Acceptance Test	....	137.5 dB*
	MMC Flight Acceptance Test	——+——	137.7 dB*

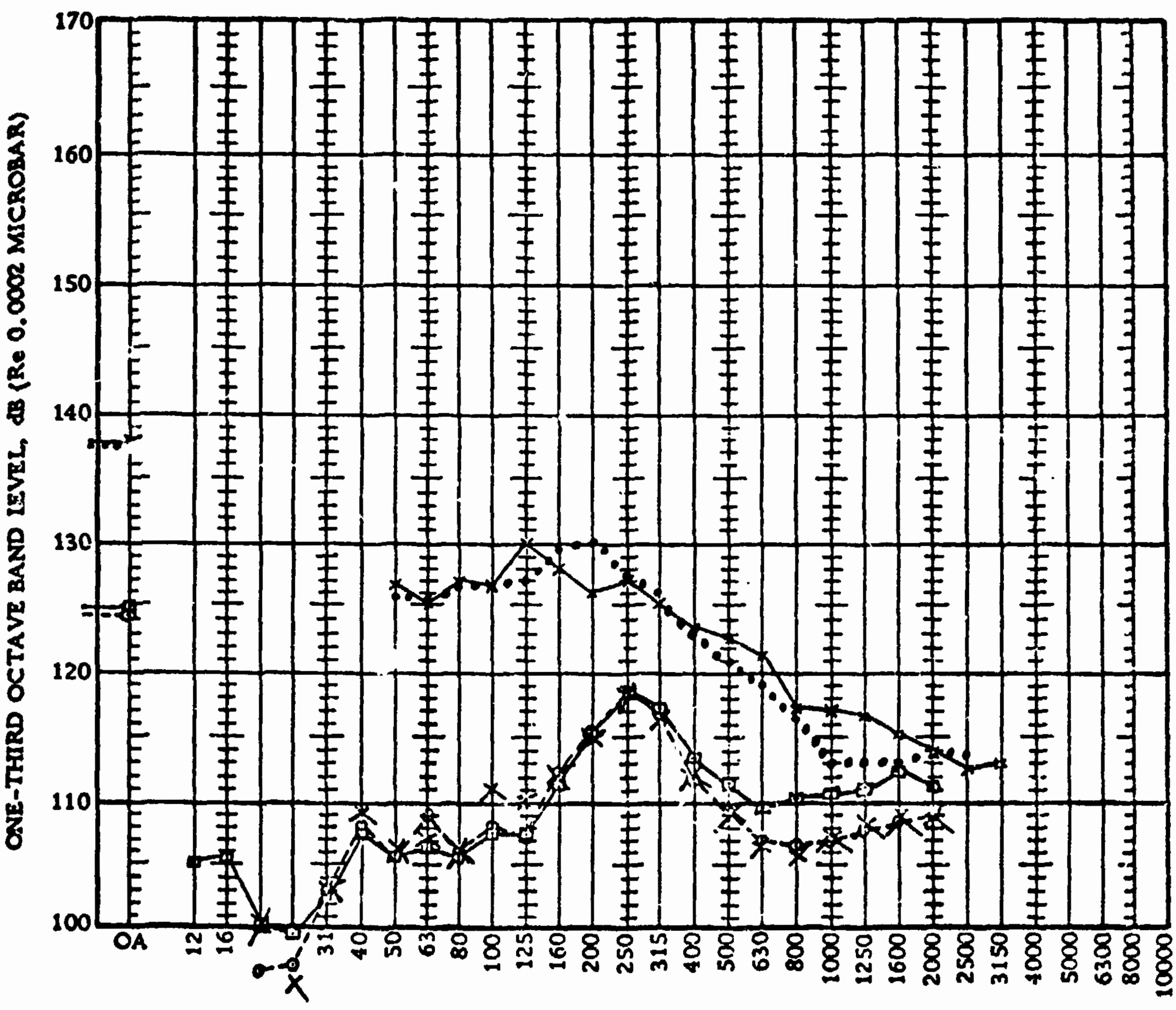


* Over-All (OA) Levels from 20 to 2KHz

FIGURE 5-4 - TC-4/3 ACOUSTICS, TRANSONICS

From CY-886-Y

TC-4	LRC Analysis	—□—	124.9 dB OA*
	GDC Analysis	----θ----	124.2 dB OA*
TC-3	CDC Analysis	XX	124.5 dB OA*
	JPL Flight Acceptance Test	....	137.5 dB*
	MMC Flight Acceptance Test	——*——	137.7 dB*



*Over-All (OA) Levels from 20 to 2KHz

TABLE 5-1 - COMPARISON OF VIKING A AND VIKING B MEASURED VLCA FORCES TO PRE-FLIGHT ANALYTICAL PREDICTIONS

Member/Meas. No.	Minimum (Compression), lb.			Maximum (Tension), lb.		
	Predicted	Viking A	Viking B	Predicted	Viking A	Viking B
			Stage 0 Ignition (Model VIII)			
750/CY 186S	-2900	-2000	-2300	900	800	100
751/CY 187S	-2700	-1600	-1300	1800	800	1000
752/CY 188S	-2300	-2000	-2200	400	100	0
753/CY 189S	-2900	-2500	-2800	900	200	1100
754/CY 190S	-2800	-2200	-1500	1900	600	100
755/CY 191S	-2800	-2200	-2300	800	200	200
			Max αq (Model VIII)			
750/CY 186S	-3200	-2000	-1900	1000	-500	-400
751/CY 187S	-2900	-1500	-1200	1800	300	200
752/CY 188S	-3400	-2100	-2100	1200	-400	-300
753/CY 189S	-3600	-1900	-2000	1400	-300	-300
754/CY 190S	-3000	-1500	-1400	2000	200	400
755/CY 191S	-3400	-1900	-2200	1200	-300	-400
			Stage I Ignition (Model I)			
750/CY 186S	-1600	-1400	-1800	0	-800	-800
751/CY 187S	-1200	-1200	-1200	0	0	0
752/CY 188S	-2000	-2000	-1700	0	-600	-600
753/CY 189S	-2100	-1800	-1800	0	-600	-600
754/CY 190S	-1800	-1200	-1200	0	0	-100
755/CY 191S	-2000	-1900	-1900	0	-500	-700
			SRM Jettison (Model I)			
750/CY 186S	-1200	-1500	-1600	0	-400	-300
751/CY 187S	-700	-1000	-1000	0	200	300
752/CY 188S	-1500	-1700	-1700	0	-500	-200
753/CY 189S	-1200	-1400	-1600	0	-100	0
754/CY 190S	-800	-900	-1100	0	100	200
755/CY 191S	-1400	-1500	-1500	0	-100	-300
			Stage I Burn (Model VIII)			
750/CY 186S	-4900	-2200	-2200	1000	-1600	-1600
751/CY 187S	-2500	-1100	-1000	500	-800	-800
752/CY 188S	-5400	-2200	-2200	1400	-1800	-1600
753/CY 189S	-4500	-2300	-2300	600	-1200	-1500
754/CY 190S	-2900	-1200	-1200	900	-600	-600
755/CY 191S	-4500	-2300	-2400	1300	-1300	-1600

TABLE 5-1 - COMPARISON OF VIKING A AND VIKING B MEASURED VLCA FORCES TO PRE-FLIGHT ANALYTICAL PREDICTIONS

(continued)

Member/Meas. No.	Minimum (Compression), lb.			Maximum (Tension), lb.		
	Predicted	Viking A	Viking B	Predicted	Viking A	Viking B
	Stage I Burnout/Stage II Ignition (Model VIII)					
750/CY 186S	-3100	-2600	-2500	2000	300	300
751/CY 187S	-2000	-1300	-1300	1800	100	300
752/CY 188S	-3100	-2700	-2500	2100	300	600
753/CY 189S	-3100	-2500	-2500	1900	400	700
754/CY 190S	-2200	-1400	-1300	2000	300	300
755/CY 191S	-3000	-2700	-2600	2000	600	400
	Stage II Burnout (Model IV)					
750/CY 186S	-1500	-1400	-1400	400	0	-100
751/CY 187S	-600	-700	-700	400	-100	0
752/CY 188S	-2000	-1400	-1400	400	-100	0
753/CY 189S	-2400	-1300	-1500	400	0	0
754/CY 190S	-1400	-700	-700	900	100	100
755/CY 191S	-2400	-1400	-1600	900	100	200
	Centaur MES II (Model I)					
750/CY 186S	-700	-700	-900	0	0	200
751/CY 187S	-400	-500	-500	100	0	200
752/CY 188S	-800	-900	-900	0	0	200
753/CY 189S	-700	-800	-1000	0	100	200
754/CY 190S	-500	-500	-500	0	0	200
755/CY 191S	-800	-800	-1000	0	100	200
	Centaur MECO II (Model IV)					
750/CY 186S	-1400	-1600	-1500	1300	400	500
751/CY 187S	-800	-800	-800	900	400	500
752/CY 188S	-1900	-1600	-1600	1400	600	700
753/CY 189S	-2100	-1500	-1600	1600	800	1000
754/CY 190S	-700	-800	-900	900	300	600
755/CY 191S	-1500	-1700	-1900	900	700	900

Note: Compression = Negative (-), Tension = Positive (+)

All values in the above table have been rounded off to ± 100 lbs.

Stage 0 ignition is the only condition analyzed using Model VIII where the measured loads approached predicted loads and has been determined to be caused by a lack of adequate longitudinal and torsional forcing functions used in the analysis. The other critical loading conditions analyzed adequately compensated for this event, however. Although significant differences between predicted and measured loads are apparent comparing Model I analyses, none of those conditions were critical. Differences between predicted and measured loads for these conditions are primarily attributed to dynamic model differences between the flight spacecraft and the Model I dynamic model.

The time histories of the Viking Lander Capsule Adapter (VLCA) force data were used in conjunction with the Viking analytical dynamic model in order to evaluate the criticality of all transients to all parts of the spacecraft and launch vehicle. No part of the spacecraft or launch vehicle approached criticality for any transient condition for either TC-3 or TC-4.

VI SOFTWARE PERFORMANCE

VI SOFTWARE PERFORMANCE

Airborne

by J. L. Feagan

All available DCU flight telemetry data for the flight of TC-4 was 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 and the software internal sequencing. The digital data was also 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 (CCLS)

by A. L. Gordan

During the TC-4 launch countdown, the performance of the CCLS was normal. No hardware or software problems were encountered. All CCLS countdown procedure tasks were performed within the allowable time marks. This included the receiving and loading of the Centaur DCU with ADDJUST P/Y data coefficients via the ADDJUST transmission links from GDC, San Diego.

VII TITAN IIIE SYSTEMS ANALYSIS

VII TITAN IIIE SYSTEMS ANALYSIS

Mechanical Systems

Airframe Structures

by R. W. York

Summary

The Titan E4 vehicle airframe configuration remained unchanged from the E1 Proof Flight configuration. The Titan vehicle maintained structural integrity throughout all phases of booster ascent flight. Data from flight instrumentation agreed well with predicted flight values.

Discussion

Response of the vehicle airframe to steady-state loads and transient events was nominal with peaks at expected levels.

The ullage pressures within the oxidizer and fuel tanks of both Stage I and Stage II were within prelaunch limits (Table 7-3) and remained sufficient to maintain structural integrity throughout flight. The pressures did not exceed the design limits of the vehicle.

Compartment IIA internal pressure vented as expected and achieved essentially zero psi at approximately 125 seconds after lift-off (Figure 9-9).

SRM separation and Stage I/Stage II separation occurred within predicted three sigma event times (Table 4-1). Flight data indicates Titan ordnance for these events performed as expected.

Titan Stage 0 Propulsion System

by R. J. Salmi

Summary

The Titan Stage 0 propulsion system for the TC-4 flight consisted of solid rocket motors numbers 43 and 44.

During the initial launch countdown on August 1, 1975, a Stage 0 thrust vector control (TVC) valve failed one of its prelaunch tests, which resulted in the termination of the launch attempt. The valve was removed and replaced. A material flaw was found in the pintle of the failed valve. This flaw allowed nitrogen tetroxide to leak into the critical control areas of the valve and caused the test failure observed.

With the new TVC valve installed all of the SRM systems performed as expected during flight and the performance parameters were within allowable limits.

Discussion

Propulsion Performance - Engine performance data during ignition, steady-state and engine shutdown are summarized in Table 7-1.

SRM ignition transients, as shown in Figure 7-1, were normal and both the thrust and tailoff thrust differentials were small. The measured web action burn times were 103.1 and 103.5 seconds, respectively, for SRM's 43 and 44 for a predicted liftoff temperature of about 80.6°F. Correcting these values to the nominal 60°F temperature, the respective web action times were 105.9 and 106.3 seconds. These corrected thrust levels were slightly on the fast side of the specification class value of 106.9 seconds; but they were well within the three-sigma tolerance limits of ± 2.3 seconds.

The head end chamber pressure data as shown in Figures 7-2 and 7-3 show that, in general, the flight chamber pressures were midway between the specification limits except near ignitions. At ignition the value of P_c max. was just barely below the minimum specification value. The lower values in the first few seconds are normal flight experience and are not indicative of any marginal performance.

Thrust Vector Control - SRM steering requirements were generally low throughout the flight. The EMV's performed as expected and there were no anomalies. The maximum EMV voltage was 2.2 volts during the initial roll maneuver.

The TVC oxidizer loads and tank pressures at liftoff were very close to the nominal values as given in Table 7-1. SRM separation was normal and the

TABLE 7-1 - TC-4 SOLID ROCKET MOTOR PERFORMANCE SUMMARY

Parameter	Rocket Motor Specs		SRM 43			SRM 44		
	Nominal or Maximum Allowable	Allowable Deviation	Measured	Corrected	Deviation	Measured	Corrected	Deviation
Nominal Data Condition, °F	60	—	—	60	—	—	60	—
Firing Condition, °F	—	—	80.6	—	—	80.6	—	—
Web Action Time, seconds	106.9	±2.16%	103.1	105.9	-0.93%	103.5	106.3	-0.56%
Action Time, seconds	116.8	±3.43%	114.4	117.5	+0.60%	113.8	116.8	0
Maximum Forward End Chamber Pressure, psia	791	±3.76%	780	760	-3.92%	780	760	-3.92%
N_2O_4 Loaded, pounds	8424	±42	8419	—	-5	8420	—	-4
Manifold Pressure at Ignition, psia	1041	± 77	1057	—	+16	1051	—	+10
Manifold Pressure at Separation, psia min	450	—	630	—		600	—	
Thrust Differential During Ignition Transient, lbs max	168,000 @ 0.17 sec	19,500						
Thrust Differential During Tail-off, lbs max	290,000	42,3000						
Time of Separation, sec	—	122						
Ignition Delay, msec	150 - 300		250			250		

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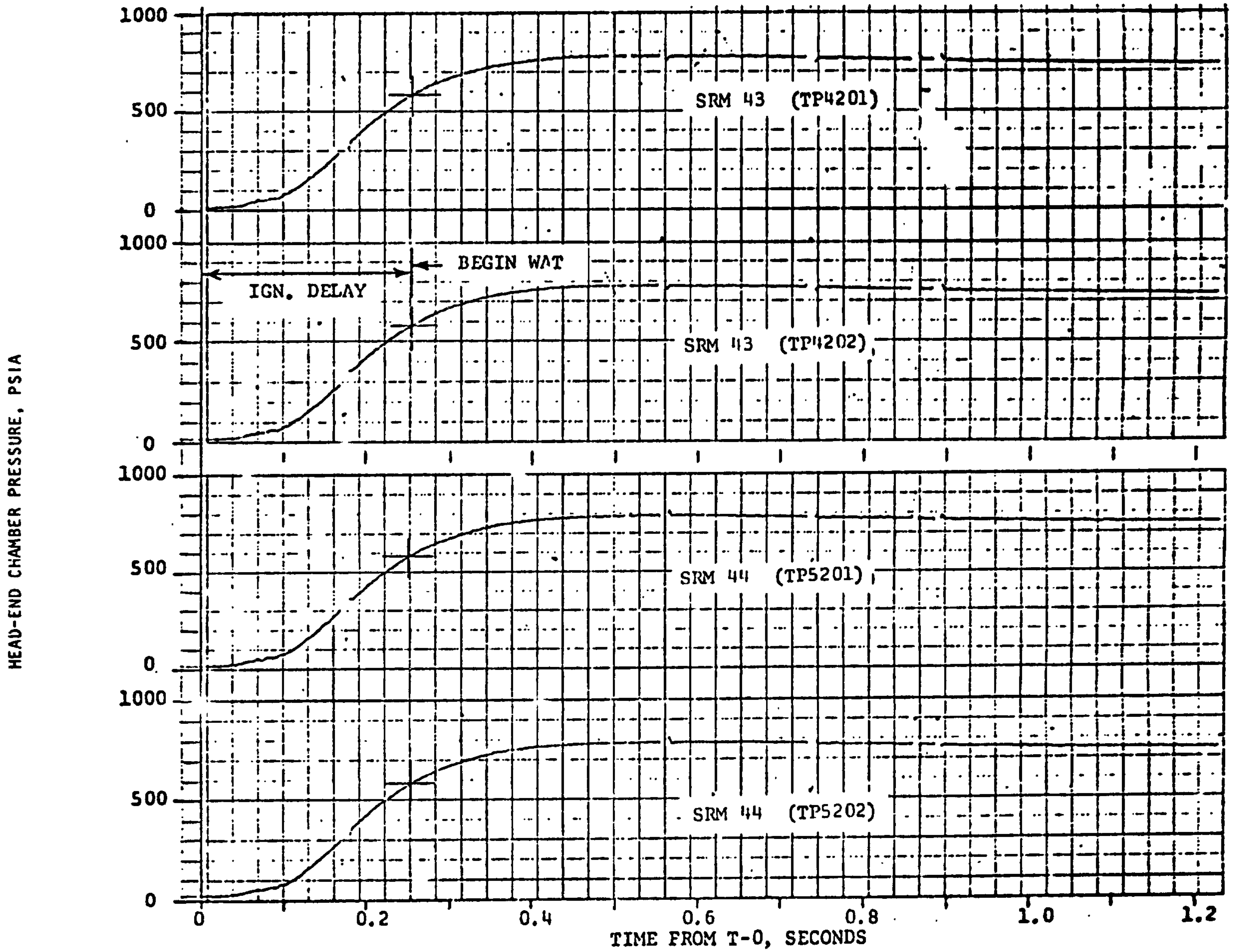


FIGURE 7-1 - SRM HEAD-END CHAMBER PRESSURE IGNITION TRANSIENT

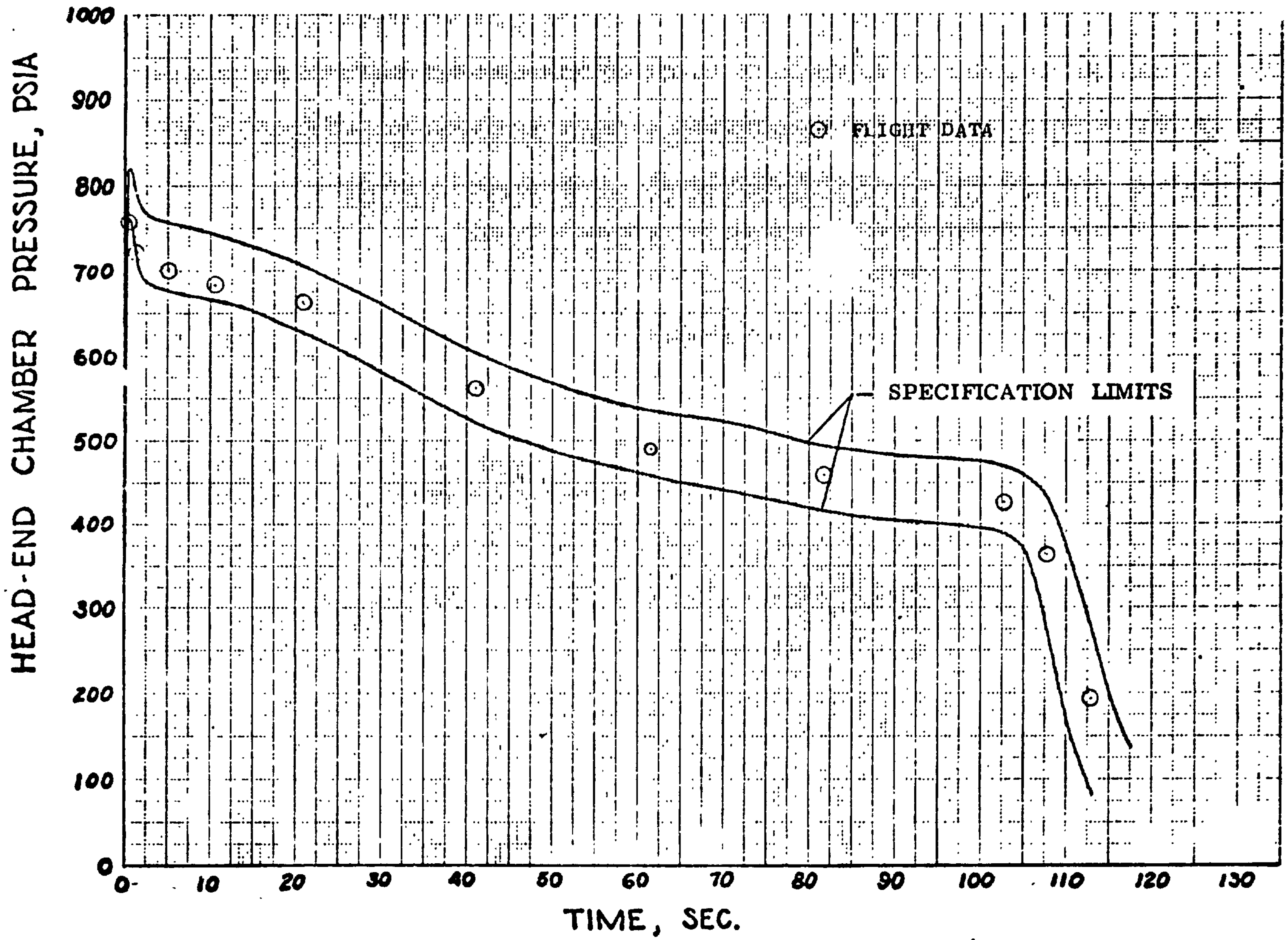


FIGURE 7-2 - COMPARISON OF HEAD-END CHAMBER PRESSURE WITH SPECIFICATION LIMITS. SRM No.43, TITAN IIIE - 4. DATA CORRECTED TO 60° F.

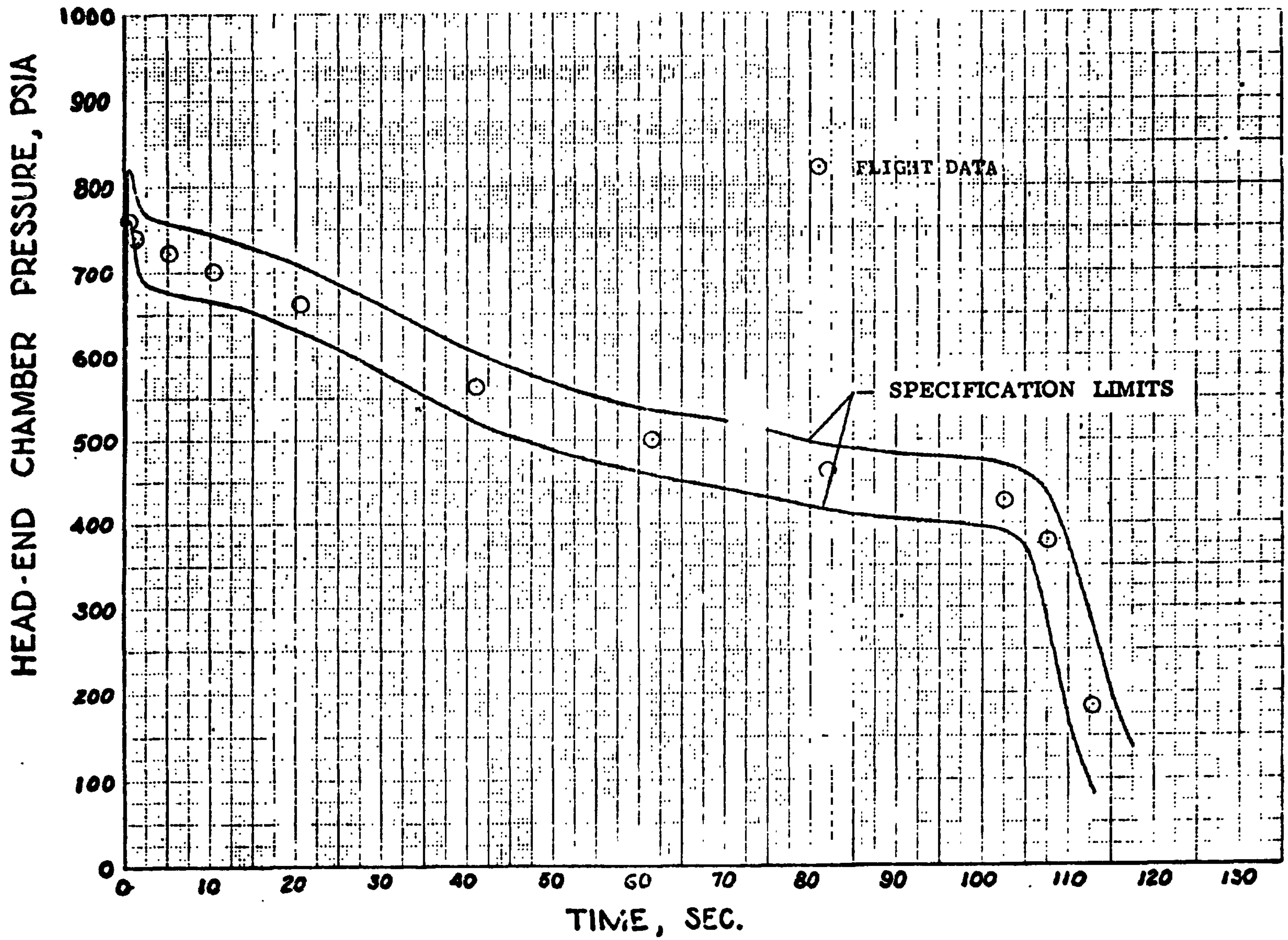


FIGURE 7-3 - COMPARISON OF HEAD-END CHAMBER PRESSURE WITH SPECIFICATION LIMITS. SRM No.44, TITAN IIIE - 4. DATA CORRECTED TO 60° F.

manifold pressures at SRM separation were well above the minimum value. TVC fluid usage as determined by CSD/UT is summarized as follows:

	SRM 43	SRM 44
Nitrogen tetroxide load, lb.	8,418.3	8,419.5
Total expended, lb.	6,542	6,390.5
Total dumped, lb.	4,452	4,395.5
Total TVC steering, lb.	2,090	1,995

Titan Stage I and Stage II Propulsion Systems

by R. J. Schroeder

Summary

The Titan Stage I and Stage II propellant loading, prelaunch pressurization, engine performance and autogenous pressurization were all within acceptable limits for the TC-4 flight. Engine shutdown for both Stage I and Stage II resulted from oxidizer depletion and the shutdown transients were normal. Thrust levels were slightly lower than expected but within allowable dispersions. The lower thrust levels resulted in a slightly longer burn time of 3.2 seconds for Stage I and 4.6 seconds for Stage II.

Discussion

Stage I and Stage II Prelaunch Operations - The required propellant loads for Stage I and Stage II were based on an expected in-flight propellant bulk temperature of 80°F for Stage I oxidizer and fuel, 75°F for Stage II oxidizer and 77.5°F for Stage II fuel.

Stage I propellant load was biased to provide a 2.33 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 $\pm$ 0.3% on the fuel load and $\pm$ 0.4% on the oxidizer load. Comparison of the actual loads with the expected loads is shown in Table 7-2.

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 7-3. All four propellant tank pressures were near the middle of the launch limits. At T-17.5 seconds the propellant prevalves were commanded open and all six valves were fully open within 7.0-7.4 seconds.

Stage I Propulsion System - The Stage I propulsion system was modified from TC-1 and TC-2 by the addition of oxidizer POGO accumulators on the feed lines to each of the two oxidizer pumps. This change was incorporated to eliminate the longitudinal oscillations encountered on TC-1 and TC-2 during Stage I operation.

Flight performance of the Titan Stage I engine was satisfactory. Engine start signal (87FS1) occurred at T + 109.7 seconds when the accelerometer in the Titan flight programmer sensed a reduction in acceleration to 1.5 g's during the tail-off period of the Stage 0 solid rocket motors.

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

TABLE 7-2 - TITAN LOADED PROPELLANT WEIGHTS

STAGE I AND STAGE II - TC-4

	Expected (Lbs.)	Actual (Lbs.)
Stage I		
Oxidizer	168,124	168,242
Fuel	89,534	89,590
Stage II		
Oxidizer	42,941	43,001
Fuel	23,789	23,801

TABLE 7-3 - TITAN PROPELLANT TANK PRELAUNCH PRESSURIZATION

STAGE I AND STAGE II - TC-4

	Prelaunch Limits (psia)		Value at T-30 Sec. (psia)
	Lower	Upper	
Stage I			
Oxidizer Tank	33.6	45.0	42.4
Fuel Tank	24.0	32.0	30.4
Stage II			
Oxidizer Tank	45.0	57.0	52.0
Fuel Tank	50.0	56.0	53.2

Steady-state performance of the Stage I engine was satisfactory. Average engine thrust was 1.82% lower than expected; average specific impulse was the same as expected; and average mixture ratio was 1.03% lower than expected. These performance parameters were within the allowable three-sigma dispersions of ± 3.27% on thrust, ± 2.3 seconds on specific impulse and ± 2.17% on mixture ratio. Performance of the autogenous pressurization system during engine operation was satisfactory. The only noted anomaly was loss of the fuel autogenous temperature measurement (TP3014T) at 11 seconds after Stage I engine start. Comparison of the average expected steady-state performance values for the Stage I engine with the actual steady-state values is shown in Table 7-4.

Stage I engine shutdown occurred at T + 259.4 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 exhaustion as planned. The shutdown transient was normal for an oxidizer exhaustion mode. Propellant outage was 584 pounds of fuel which was less than the expected mean outage of 1,485 pounds of fuel. This was the result of the shift in mixture ratio. Stage I engine operating time (FS1 to FS2) was 3.2 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 + 259.4 seconds (simultaneous with Stage I engine shutdown signal, 87FS2). The Stage II engine start transient was normal. Stage I separation occurred 0.9 seconds after 91FS1.

Engine steady-state performance was satisfactory. Average engine thrust was 2.70% lower than expected, average specific impulse was 2.76 seconds lower than expected and average engine mixture ratio was 0.36% higher than expected. The allowable three-sigma dispersions about the expected values were ± 3.80% on thrust, ± 3.5 seconds on specific impulse and ± 2.66% 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 7-5.

Stage II engine shutdown (91FS2) occurred at T + 467.7 seconds when the sensed vehicle acceleration dropped to 1.0 g's. Engine shutdown was the result of oxidizer exhaustion and the shutdown transient was normal. Propellant outage was only 35 pounds of fuel compared to an expected mean outage of 110 pounds of propellant. Engine operating time (FS1 to FS2) was 4.6 seconds longer than expected due to the lower than expected propellant flow rates.

Stage II/Centaur separation occurred 6.1 seconds after 91FS2 when the vehicle acceleration level reached 0.1 g. Satisfactory operation of the Stage II retrorocket motors was achieved.

TABLE 7-4 - TITAN STAGE I ENGINE STEADY STATE PERFORMANCE - TC-4

Parameter	Units	Average Steady-State Flight Values Expected (2)	Actual
Thrust, total	lbf.	528,652	519,056
Specific impulse	sec.	302.29	302.3
Mixture ratio, O/F	units	1.9163	1.8966
Overboard propellant flow rate, total (1)	lbm/sec.	1748.81	1717.0
Oxidizer flow rate, total	lbm/sec.	1151.76	1126.9
Fuel flow rate, total	lbm/sec.	601.03	594.1
Propellant outage	lbm	1485 mean 3374 max.	584 (fuel)
Oxidizer temperature	°F	80	83.0
Fuel temperature	°F	80	82.7
Oxidizer tank pressure	psi	34.1	34.6
Fuel tank pressure	psi	26.3	25.6
FS_1 to FS_2	sec.	146.5	149.7

NOTES: (1) Excludes autogenous pressurant flow.

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

TABLE 7-5 - TITAN STAGE II ENGINE STEADY-STATE PERFORMANCE - TC-4

Parameter	Units	Average Steady-State Flight Values Expected (3)	Average Steady-State Flight Values Actual
Thrust, total	lbf.	103,867	101,066
Specific impulse (1)	sec.	316.36	313.8
Mixture ratio, O/F	units	1.8135	1.8200
Overboard propellant flowrate, total (2)	lbm/sec.	325.67	319.12
Oxidizer flowrate, total	lbm/sec.	210.68	206.78
Fuel flowrate, total	lbm/sec.	116.17	113.62
Propellant outage	lbm	110 mean 530 max.	35 (fuel)
Oxidizer temperature	°F	75	77.5
Fuel temperature	°F	77.5	81.1
Oxidizer tank pressure	psi	51.6	53.4
Fuel tank pressure	psi	56.5	58.1
FS_1 to FS_2	sec.	203.7	208.3

NOTES: (1) Excludes roll nozzle thrust.

(2) Excludes autogenous pressurant flow.

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

Titan Hydraulic System

by T. W. Godwin

Summary

Performance of the hydraulic systems on Stage I and Stage II was normal during preflight checkout and the boost phases of the TC-4 flight. Stage II actuator loads were considerably below previous maximums. There were no anomalies.

Discussion

Performance data for the Titan hydraulic systems are summarized in Table 7-6a. 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 the countdown and flight.

Stage I actuator peak loads at engine start were nominal and well within the family of Titan data experience. Stage II peak actuator loads at engine start, however, were considerably lower than previous maximums. These loads for Stage II were only about one-third as much as experienced on the TC-1 and TC-2 vehicles. (This indicates that the Stage II thrust chamber loads, which are encountered as Stage II is flown out of the interstage adapter, were lower than on the TC-1 and TC-2 flights.) Table 7-6b shows the maximum actuator loads encountered during the engine start transients. Also shown for comparisons are the TC-1/TC-2 loads and the maximums for all Titan vehicles.

TABLE 7-6 - TITAN HYDRAULICS SYSTEM - TC-4

a) System Pressure and Reservoir Levels

Parameters		Units	Expected Values	Flight Results Stage I	Flight Results Stage II
Hydraulic Supply Pressure	Maximum at pump start	psig	4500 (1)	3400	3825
	Average steady state	psig	2900 - 3000	2930	2900
Reservoir Levels	Prior to pump start	%	47 - 62	50	50.5
	At maximum start pressure	%	22 - 47	36	36
	Average steady state	%	22 - 47	36	39.5
	Shutdown minus 5 seconds	%	22 - 47	38	41.0

(1) proof pressure limit

b) Actuator Loads During Engine Start Transients

	Stage I Actuator Loads, Pounds				Stage II Actuator Loads	
S/A	Subassembly #2		Subassembly #1		Subassembly #3	
Actuator Position	Pitch 1-1	Yaw-Roll 1-1	Yaw-Roll 3-1	Pitch 4-1	Pitch 1-2	Yaw-Roll 1-1
TC-4 (E-4)	+ 8,300 - 8,850	+ 12,070 - 2,760	+ 10,650 - 4,560	+ 4,500 - 6,640	+ 2,830 - 890	+ 3,090 - 4,690
TC-1/-2 max.	+ 8,250 - 9,270	+ 11,000 - 5,530	+ 12,450 - 4,980	9,540 -16,000	+ 9,700 - 510	+ 9,750 - 7,900
Titan Family* (Maximums)	+14,100 -15,400	+ 12,500 - 8,151	+ 15,400 - 6,920	+13,030 -18,782	+ 14,400 - 8,750	+ 9,750 -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

Summary

The flight control system maintained vehicle stability throughout the TC-4 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.

Discussion

Command voltage to each SRM quadrant and the dynamic and static capability limits are shown in Figures 7-4 and 7-5. The stability limits represent the TIIIE-4 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 three-sigma probability of acceptable control authority and vehicle stability. Maximum command during Stage 0 flight was 2.2 volts which is 22 percent of the control system capability and 31.4 percent of the dynamic stability limit. The peak command occurred at T + 7 seconds and was due to Centaur roll to azimuth command.

For Stages I and 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 .88 degrees which is 20 percent of the maximum gimbal angle. The peak angle was required at T + 149 seconds for guidance steering command. During Stage II, .48 degrees or 23.5 percent of peak gimbal angle was the maximum gimbal angle required at T-302 seconds, and was due to the first guidance steering command during Stage II flight.

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 is shown in Table 7-7.

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 7-8.

FIGURE 7-4 -

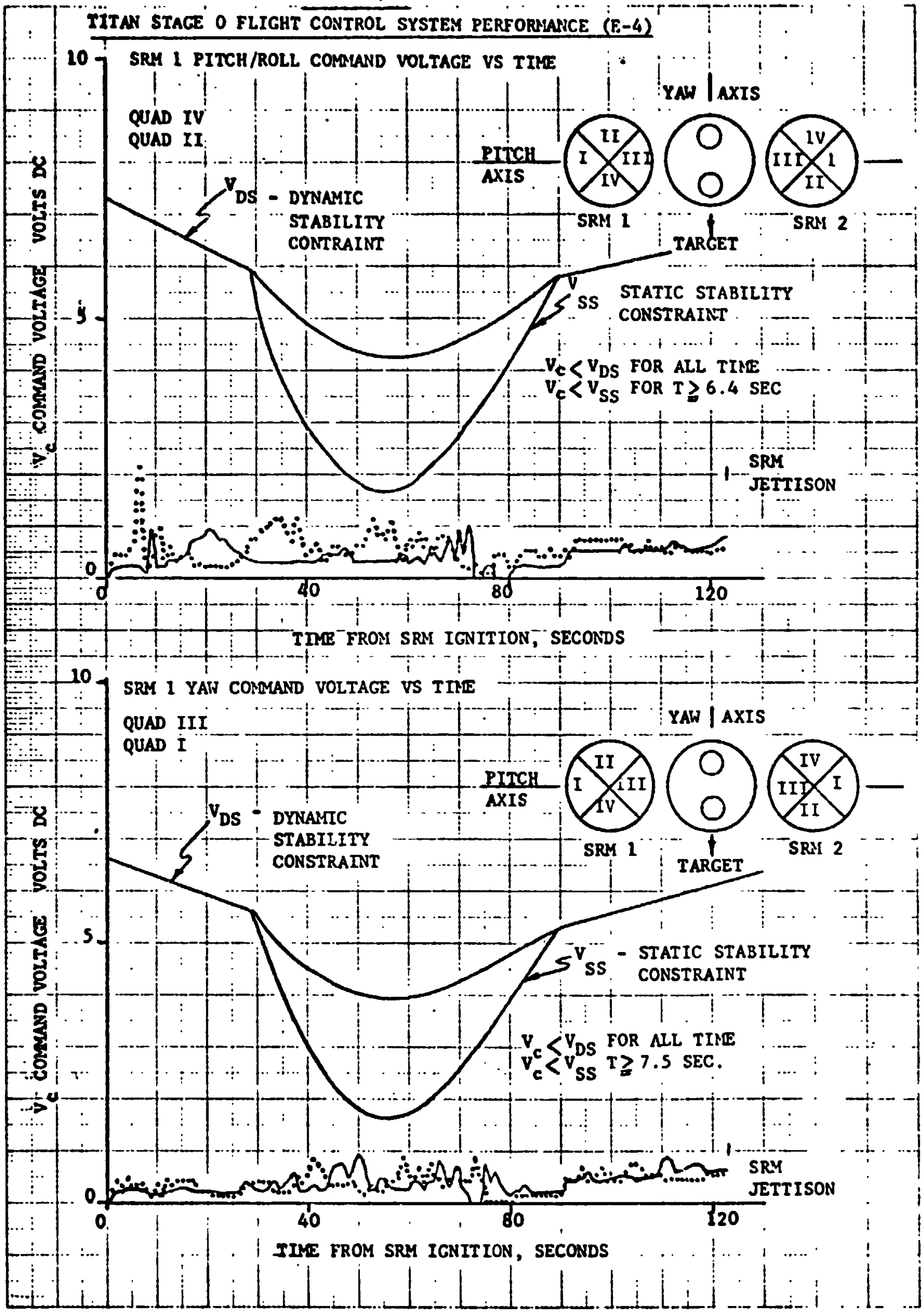

TITAN STAGE 0 FLIGHT CONTROL SYSTEM PERFORMANCE (E-4)
SRM 1 PITCH/ROLL COMMAND VOLTAGE VS TIME
QUAD IV
QUAD II
V_{DS} - DYNAMIC STABILITY CONTRAINT
V_{SS} STATIC STABILITY CONSTRAINT
$V_c < V_{DS}$ FOR ALL TIME
$V_c < V_{SS}$ FOR T ≥ 6.4 SEC
YAW AXIS
PITCH AXIS
SRM 1
SRM 2
TARGET
SRM JETTISON
V_c COMMAND VOLTAGE VOLTS DC
TIME FROM SRM IGNITION, SECONDS
SRM 1 YAW COMMAND VOLTAGE VS TIME
QUAD III
QUAD I
V_{DS} - DYNAMIC STABILITY CONSTRAINT
V_{SS} - STATIC STABILITY CONSTRAINT
$V_c < V_{DS}$ FOR ALL TIME
$V_c < V_{SS}$ T ≥ 7.5 SEC.
YAW AXIS
PITCH AXIS
SRM 1
SRM 2
TARGET
SRM JETTISON
V_c COMMAND VOLTAGE VOLTS DC
TIME FROM SRM IGNITION, SECONDS

FIGURE 7-5 -

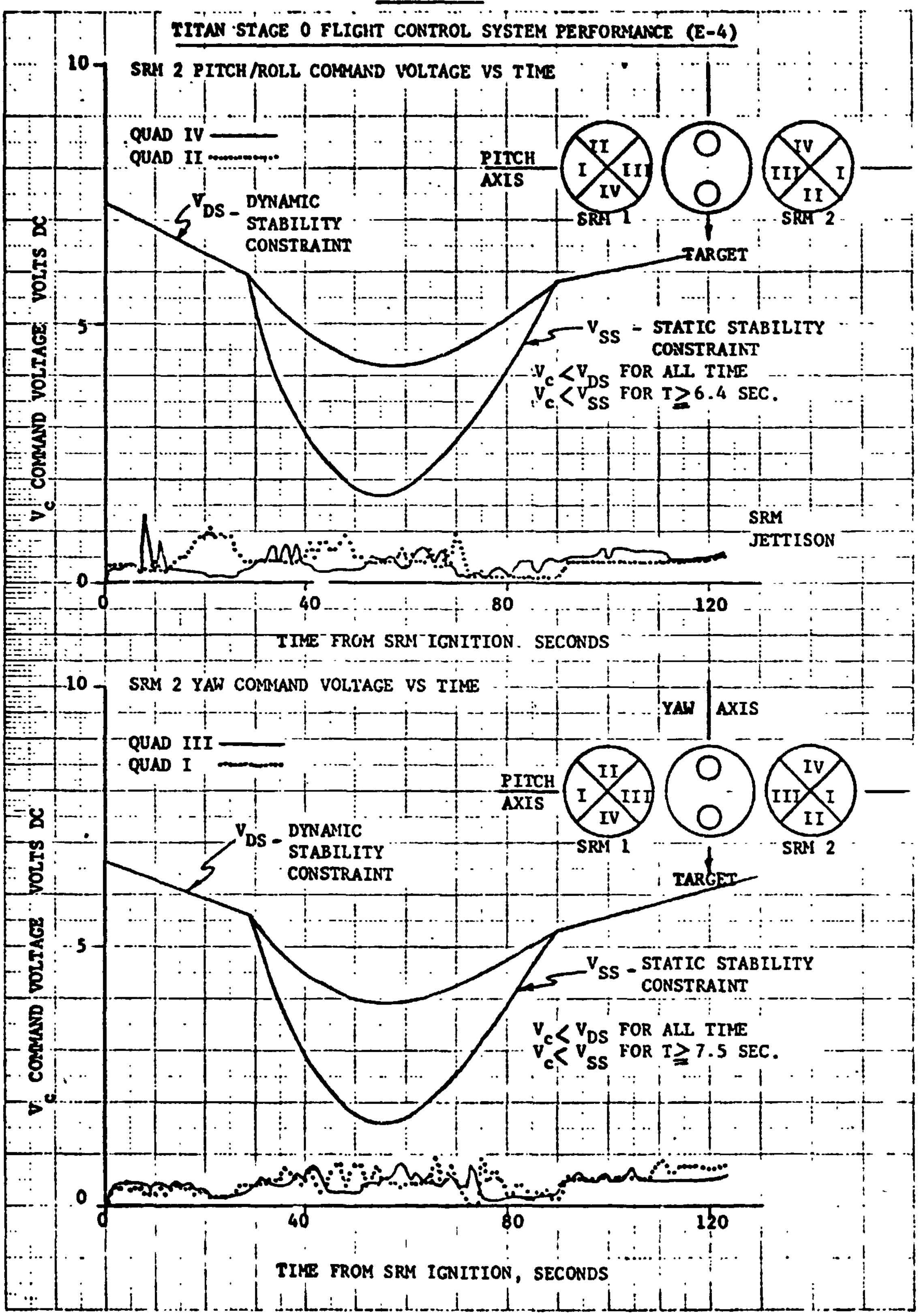

TITAN STAGE 0 FLIGHT CONTROL SYSTEM PERFORMANCE (E-4)
SRM 2 PITCH/ROLL COMMAND VOLTAGE VS TIME
QUAD IV
QUAD II
PITCH AXIS
SRM 1
SRM 2
TARGET
V DS - DYNAMIC STABILITY CONSTRAINT
V SS - STATIC STABILITY CONSTRAINT
V c < V DS FOR ALL TIME
V c < V SS FOR T ≥ 6.4 SEC.
SRM JETTISON
V c COMMAND VOLTAGE VOLTS DC
TIME FROM SRM IGNITION. SECONDS
SRM 2 YAW COMMAND VOLTAGE VS TIME
YAW AXIS
QUAD III
QUAD I
PITCH AXIS
SRM 1
SRM 2
TARGET
V DS - DYNAMIC STABILITY CONSTRAINT
V SS - STATIC STABILITY CONSTRAINT
V c < V DS FOR ALL TIME
V c < V SS FOR T ≥ 7.5 SEC.
V c COMMAND VOLTAGE VOLTS DC
TIME FROM SRM IGNITION, SECONDS

TABLE 7-7 - VEHICLE DYNAMIC RESPONSE

EVENT	TIME SEC.	AXIS	ZERO TO PEAK AMPLITUDE DEG./SEC.	TRANSIENT FREQUENCY HZ.	TRANSIENT DURATION SEC.	REQUIRED CONTROL % OF CAPACITY
Roll Maneuver	7.5	R	2.5	.3	5	22
SRM Jettison (Initial Conditions)	120-122	R	.3	Drift	2	1.5
SRM Jettison Transient	122.2	R	4.8	.37	5.5	7
Start of PR 7 (Pitch Up Program)	131	P	1.2	N/A	N/A	17
Enable Guidance Steering (1.45° PD .35° YR)	149	P	1.32	N/A	N/A	20
	149	Y	.3	N/A	N/A	2
CSS Jettison	271-277	P	.12	.2	5	6
	270	R	2	10	.5	6
	270.5-272.5	R	.6	3-5	2	15
	273	R	.8	N/A	1	15
Enable Guidance Steering (1.8° PU .2° YL)	300	P	.42	.2	5	23.5

TABLE 7-8 - E-4 FLIGHT SEQUENCE OF EVENTS

T-0 = 21:22:00.115 (SRM Ignition Command)

Event	Predicted	F/P A	F/PB	S/T	DCU	Other	Delta
		(Times From T-0) Observed					
Start Roll Program	6.50				6.56		+0.06
Stop Roll Program	-				6.92		-
Pitch Rate 1	10.000	10.003	10.005				+0.003
Pitch Rate 2	20.000	20.008	20.011				+0.008
Gain Change 1	29.000	29.010	29.017				+0.010
Pitch Rate 3	30.000	30.011	30.019				+0.011
Pitch Rate 4	62.C00	62.025	62.037				+0.025
Gain Change 2	70.000	70.030	70.042				+0.030
Pitch Rate 5	75.000	75.030	75.044				+0.030
Enable S/T	75.000		75.045				+0.045
Gain Change 3	90.000	90.038	90.054				+0.038
Pitch Rate 6	95.000	95.040	95.058				+0.040
Enable F/P B	96.000	96.060					+0.060
Stage I Start CMD	109.502		109.697	109.865			+0.195
Stage I Start	110.266					110.460	+0.194
En Stg I ISDS Safe	115.502		115.706				+0.204
O/I Separation CMD	121.502		121.706	122.074			+0.204
O/I Separation	121.587					121.718	+0.131
En Stg I ISDS Safe	121.508	122.074					+0.566
Pitch Rate 7	129.302	130.053	129.511				+0.209
Pitch Rate 9	139.302	140.059	139.518				+0.216
Gain Change 5	191.502	192.080	191.749				+0.247
Gain Change 6	231.502	232.098	231.775				+0.273
Stg I S/D En	244.502	245.107	244.784				+0.282
Stg I S/D/Stg II Start	256.085					259.417	+3.332
I/II Separation	256.781					260.194	+3.413
CSS Sep Prim	266.781				270.244		+3.463
Css Sep Sec	267.281				270.744		+3.463
CSS Sep B/U	285.781			289.217			+3.436
Remove GC7, PR10	309.302	310.134	309.624				+0.322
Gain Change 8	339.502	340.144	339.840				+0.338
Gain Change 9	399.502	400.167	399.876				+0.374

TABLE 7-8 - E-4 FLIGHT SEQUENCE OF EVENTS (CONTINUED)

T-0 = 21:22:00.115 (SRM Ignition Command)

	(Times From T-0) Observed						
Event	Predicted	F/P A	F/P B	S/T	DCU	Other	Delta
Stage II S/D En	446.602	448.191	447.008				+0.406
Stage II S/D	459.974				467.721		+7.747
Stage II S/D	460.497	468.247					+7.750
Stage II/Cen Sep	465.078				473.841		+8.763
Stage II/Cen Sep B/U	467.274	475.657					+8.383

Titan Electrical/Electronic Systems

Solid Rocket Motor Electrical System

by B. L. Beaton

Summary

For TC-4 the solid rocket motor (SRM) electrical system was identical to that flown on TC-1 and TC-2. The SRM electrical system performance was satisfactory with no anomalies. All power requirements of the SRM electrical system were satisfied.

Discussion

The SRM electrical system supplied the requirements of the dependent systems at normal voltage levels. The SRM electrical system performance is summarized in Table 7-9.

The Titan core transfer shunt indicated 9.5 amps for approximately 400 ms at SRM ignition. This condition was experienced on both TC-1 and TC-2. 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.

TABLE 7-9 - SRM ELECTRICAL SYSTEM PERFORMANCE SUMMARY

		POWER ON INTERNAL	LIFTOFF	SRM JETTISON
TVC VOLTAGE	SRM-1	31.4	31.4	31.4
	SRM-2	31.2	31.2	31.2
AIPS VOLTAGE	SRM-1	30.1	30.1	30.1
	SRM-2	30.1	30.1	30.1
INSTRUMENTATION REGULATED BUS VOLTAGE	SRM-1	10.0	10.0	10.0
	SRM-2	10.0	10.0	10.0

Titan Core Electrical System

by B. L Beaton

Summary

For TC-4 the Titan electrical system was identical to that flown on TC-1 and TC-2. 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.

Discussion

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 7-10.

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

The TPS bus voltage was 35.3 volts d-c at TPS bus enable and 34.4 volts d-c at Titan/Centaur staging. This bus voltage was 3 to 4 volts higher than seen on TC-1 and TC-2 due to the topping off charge applied to the TPS battery after activation.

The TPS bus voltage and pyrotechnic firing currents during ordnance events are summarized in Table 7-11.

The transfer current indicated 9.5 amps at T-0 as previously discussed under SRM electrical system performance. The transfer current indicated that during short periods of high current demand on the APS bus, the TPS battery provided load sharing. This occurred at TPS enable, Stage I engine start and Stage I/II separation.

TABLE 7-10 - 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	28.0	28.7	28.0	27.3	28.0	27.3	28.0	28.0	27.65
APS CURRENT	7.5	7.5	8.0	9.5	9.75	12.5	7.6	8.0	9.0
IPS VOLTAGE	28.7	29.05	28.7	28.7	28.7	28.35	28.7	28.7	28.7
IPS CURRENT	9.8	9.8	9.8	10.0	10.0	9.0	9.0	9.0	9.0
TRANSFER CURRENT	0	9.5	0.75	0.5	0	0.7	0	0	0
TPS VOLTAGE	0	0	35.3	35.3	34.4	34.8	35.3	34.4	34.4

TABLE 7-11 - TITAN CORE VEHICLE PYROTECHNIC SYSTEM

	STAGE I START	STG 0/I SEP	STAGING MOTORS	STG I/II SEP	JETTISON	T/C STAG. & RETRO-ROCKETS	T/C STAGING
TPS VOLTAGE	28.9	27.6	27.6	28.1	31.2	30.2	30.2
TPS CURRENT	31.1	182.0	244.3	265.8	28.7	64.6	29.2

Titan Instrumentation and Telemetry System

by R. E. Orzechowski

During the TC-4 flight a total of 197 measurements were telemetered by the Titan Remote Multiplexed Instrumentation System (RMIS). A summary of the type of measurements against the system in which they were monitored is given in Table 7-12. Of these 197 measurements all but seven performed without any anomalies.

The following accelerometer measurements exhibited almost continuous high amplitude, low frequency spikes during Stage I engine operation, as well as a few spikes during transonic flight.

1548	Gimbal Block Accelerometer SA-1
1549	Oxidizer Pump Accel. SA-1
1550	Oxidizer Discharge Line Accel. SA-1
1552	Oxidizer Pump Accel. SA-2
1553	Oxidizer Discharge Line Accel. SA-2

In addition to the above, measurement 2325 (Acceleration, Longitudinal Stage II) was noisy during the high vibration portion of Stage 0 burn. Noise signature was characterized by noise spikes going two to three times more negative than positive.

All the above anomalies were attributed to the accelerometers being sensitive to high frequency inputs which produce low frequency outputs. The data from the first five noisy accelerometers is in most cases not useful. The data from measurement 2325 is readable for its steady state acceleration content.

Measurement 3014, Fuel Pressurant Orifice SA-2 Temperature, failed at approximately T + 120 seconds.

Adequate telemetry coverage of the Titan vehicle was provided from liftoff to beyond Titan/Centaur separation. A summary of the predicted data coverage against actual data coverage of the Titan telemetry link is given in Table 7-13.

TABLE 7-12 - TITAN BOOSTER MEASUREMENT SUMMARY

SYSTEM / TYPE OF MEAS.	ACCELERATION	CURRENT	VOLT	PRESSURE	TEMPERATURE	DISPLACEMENT	RATE	DISCRETES	TOTAL
AIRFRAME	5			1				2	8
RANGE SAFETY									9
ELECTRICAL		10	15						25
HYDRAULIC				8		2			10
PROPULSION	6			34	8			4	52
FLT. CONTROL			33			32	11	10	86
TELEMETRY			6		1				7
TOTAL	11	10	57	43	9	34	11	22	197

TABLE 7-13 - SUMMARY OF PREDICTED DATA COVERAGE VERSUS ACTUAL DATA COVERAGE

TITAN 2287.5 MHZ LINK

STATION	PREDICTED		ACTUAL	
	AOS	LOS		
CIF (MAINLAND)	TURN ON	450	TURN ON	500
GBI (GRAND BAHAMA)	47	506	30	510
GTK (GRAND TURK)	211	585	200	585

Flight Termination System

by R. E. Orzechowski

The Titan flight termination system performance was nominal throughout the flight. Monitoring of 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 safe command was sent by the Range from Antigua at 21:32:24Z. A list of station switching times is given in Table 7-14.

The Range Safety Command battery voltages were 32.5 volts d-c at liftoff and remained steady throughout the flight. The commands from the flight programmer to safe the Stage I and II SRM Inadvertent Separation Destruct Systems (ISDS) 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 7-14 - STATION SWITCHING TIMES

STATION	CARRIER ON	CARRIER OFF
Mainland (Sta. 1)	2049:19Z	2124:52Z
Grand Bahama Is. (Sta. 3)	2124:51.5Z	2129:39Z
Antigua (Sta. 91)	2129:38Z	2133:03.5Z

VIII CENTAUR D-1T SYSTEMS ANALYSIS

VIII CENTAUR D-1T SYSTEMS ANALYSIS

Mechanical Systems

Airframe Structures

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

Summary

The Centaur D-1T structural configuration for the TC-4 vehicle was similar to the TC-1 vehicle.

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

Discussion

Interstage Adapter - Titan/Centaur separation occurred at T + 474.11 seconds. Initial motion was at approximately T + 474.3 seconds. The Interstage Adapter cleared the Centaur vehicle 1.77 seconds after separation. The 15-foot extensometer (yo-yo) between the ISA and the Centaur indicated a smooth normal separation (Figure 8-1).

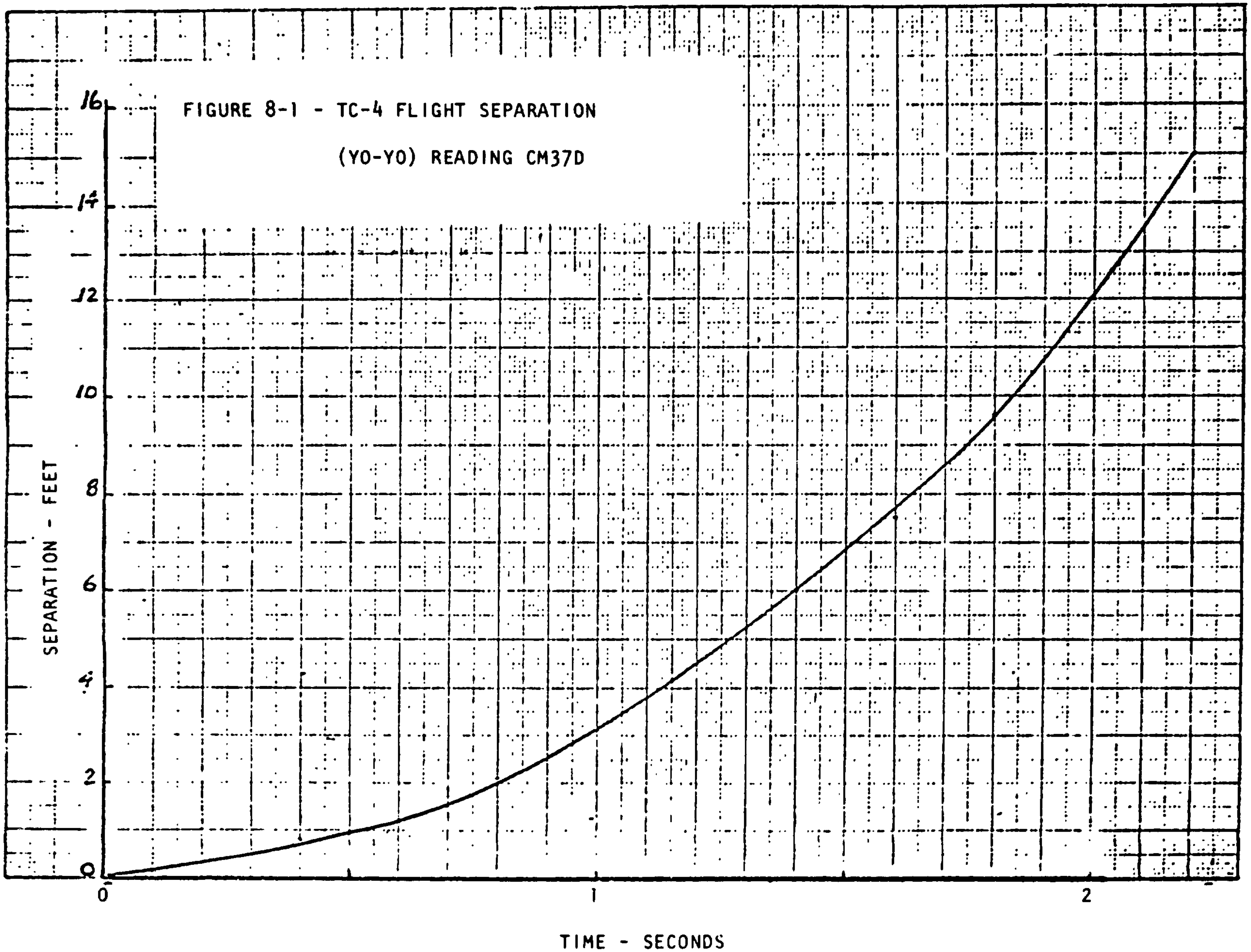
Centaur Tank - The liquid hydrogen tank pressure was always less than the maximum allowable pressure of 29.2 psid.

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 lift-off, the pressure was 24.26 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 anomalous fluctuation of the oxygen tank pressure (discussed in Centaur Pneumatics section) during the second engine start sequence was well within the structural limits of the tank.

FIGURE 8-1 - TC-4 FLIGHT SEPARATION

(YO-YO) READING CM37D



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.

The liquid hydrogen and oxygen tank ullage pressure time histories are listed in the Centaur D-1T pneumatics section of this report. See Figures 8-4.1, 8-4.2 and 8-4.3.

Centaur Main Propulsion

by W. K. Tabata

Summary

Centaur main propulsion prelaunch operations were normal for TC-4. Engine performance in flight was normal and steady-state performance agreed well with engine acceptance test values. No anomalies outside of previous Centaur flight experience were encountered.

Discussion

Liquid Helium Prechill - Liquid helium prechill of the main engine fuel pumps (Table 8-1) was satisfactory. The C-1 and C-2 engine fuel pump housing temperatures CP60T and CP62T were below the 100°R redline from T-20 minutes until liftoff on both engines. At liftoff, CP60T and CP62T were 62°R and 70°R respectively.

First-Burn - First-burn prestart, start transient, steady-state, and shutdown transients were normal. C-1 and C-2 fuel and oxidizer pump housing temperatures at the beginning of first-burn prestart were as expected (Table 8-2). The pump housing temperature probes were slow in responding to pump cooldown during prestart, but this is a characteristic of the temperature probe previously experienced in flight.

The first-burn start transient is shown in Figure 8-2 and agrees well with TC-2 first-burn. Acceleration time (MES to 90% steady-state chamber pressure) was 1.38 and 1.46 seconds for the C-1 and C-2 engines respectively.

Steady-state engine parameters measured at MES #1 +110 seconds are compared to acceptance test values in Tables 8-3 and 8-4. The comparison is excellent. Actual first-burn time was 126.9 seconds. (Predicted burn time was 126.6 seconds.) First-burn shutdown transients were normal.

Second-Burn - The second-burn prestart was normal. Engine pump housing temperatures (Table 8-2) were as expected at the beginning of prestart. All pump housing temperature probes again exhibited slow response.

Second-burn start transients were normal (Figure 8-3). The engine acceleration times for C-1 and C-2 engines were 1.51 seconds and 1.56 seconds respectively.

Steady-state performance is listed in Tables 8-3 and 8-4 and comparison to acceptance test is excellent. Actual second-burn time was 316.0 seconds. (Predicted burn time was 319 seconds). Second-burn shutdown transients were normal.

Table 3-1 - TC-4 Prelaunch Thermal Conditioning of RL-10 Engines

a. Time to liquid indication at pump inlets

Meas. Number	Description	Units	Time from Start of Tanking til Liquid Indication at Engine Pump Inlets	
			TCD	Launch
Oxidizer Pumps				
CP 59T	C-1 Pump LOX Inlet	Mins.	7.9	8.0
CP 61T	C-2 Pump LOX Inlet	Mins.	8.8	8.5
Fuel Pumps				
CP 60T	C-1 Pump LH_2 Inlet	Mins.	7.8	9.9
CP 62T	C-2 Pump LH_2 Inlet	Mins.	7.3	10.6

b. Liquid helium chilldown of engine fuel pumps

Meas. Number	Description	Units	Time from Start of LHe Chilldown til Fuel Pump Inlet Temperature = 360°F	
			TCD	Launch
CP 122T	C-1 Engine Fuel Pump	Mins.	11.6	10.0
CP 123T	C-2 Engine Fuel Pump	Mins.	10.0	10.0

TABLE 8-2 - TC-4 ENGINE AND OXIDIZER PUMP HOUSING TEMPERATURES AT PRESTART

Meas. Number	Description	Units	First Burn		Second Burn	
			Expected Values	Actual	Expected Values	Actual
Engine Fuel Pump						
CP122T	C-1 Engine Fuel Pump	DGF	190-200	196	190-220	212
CP123T	C-2 Engine Fuel Pump	DGF	190-200	192	190-220	209
Engine Oxidizer Pump						
CP124T	C-1 Engine Lox Pump	DGF	370-430	382	300-400	328
CP125T	C-2 Engine LOX Pump	DGF	370-430	382	300-400	357

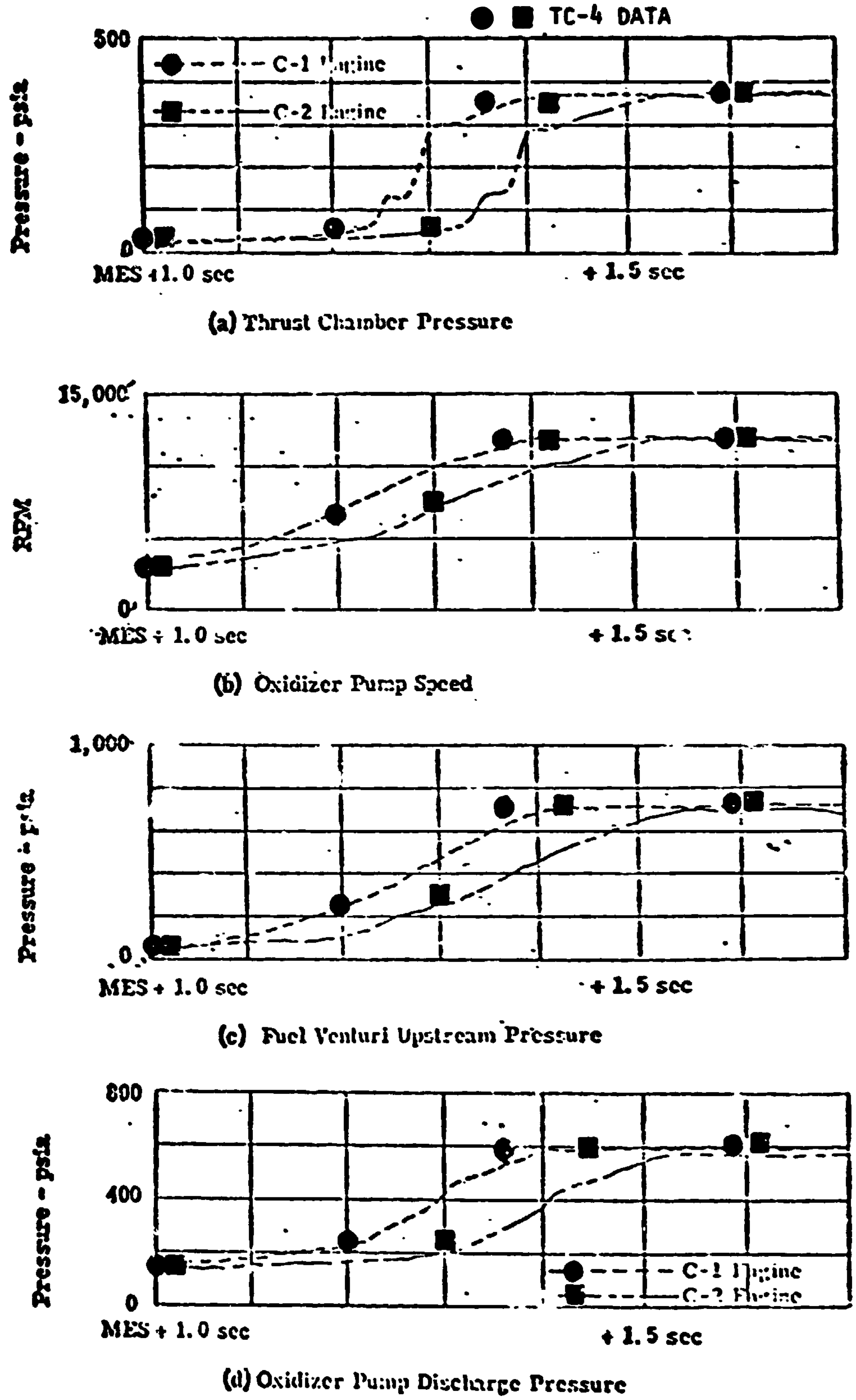


FIGURE 8-2 - TC-4 FIRST-ENGINE START TRANSIENT

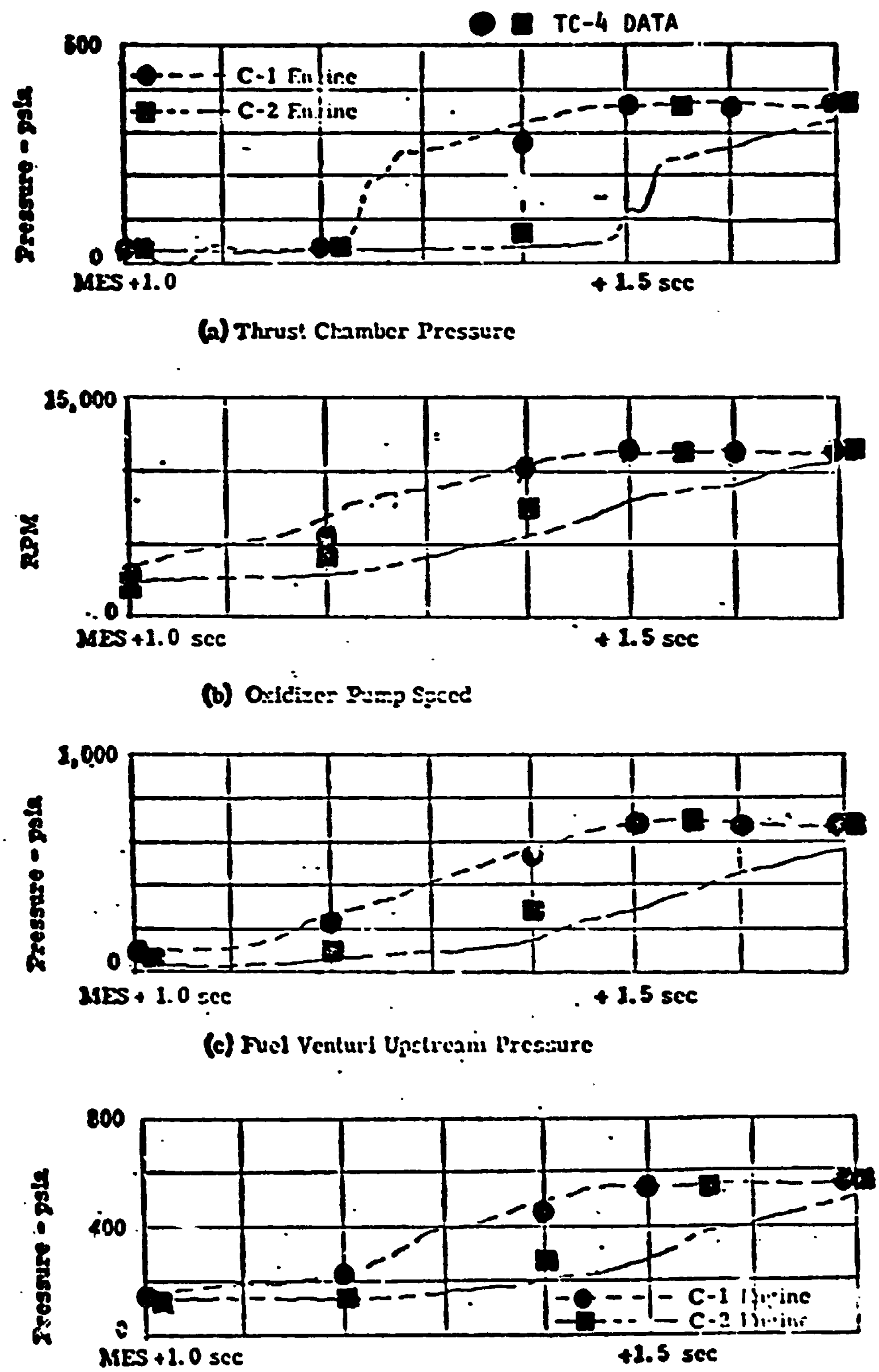
TABLE 8-3 - TC-4 RL10 ENGINE STEADY STATE PERFORMANCE PARAMETERS

Meas. Number	Description	Units	Accuracy	Expected Value at O/F=5.0	Actual Values	
					1st Burn @ MES + 110 Sec.	2nd Burn @ MECO
CP1B	C-1 Pump Speed	rpm	±600	12,340	12,356	12,338
CP2B	C-2 Pump Speed	rpm	±600	12,477	12,554	13,460
CP7P	C-1 Fuel Venturi Inlet	psia	± 30	737	736	742
CP8P	C-2 Fuel Venturi Inlet	psia	± 30	748	756	757
CP46P	C-1 Thrust Chamber	psia	± 10	391	387	388
CP47P	C-2 Thrust Chamber	psia	± 10	391	393	392
CP107P	C-1 Pump LOX Disch.	psia	± 16	604	608	605
CP108P	C-2 Pump LOX Disch.	psia	± 16	620	623	616
CP5T	C-1 Turbine Inlet	DGR	± 16	379	367	378
CP6T	C-2 Turbine Inlet	DGR	± 16	327	378	389

TABLE 8-4 - TC-4 CENTAUR MAIN PROPULSION PERFORMANCE

Parameter	P&WA Accept. Test	First Burn MES #1 + 100 Sec.	Second Burn MECO #2
C-1 Thrust, pounds	14,974	14,851	14,826
C-2 Thrust, pounds	14,984	15,061	14,963
C-1 Mixture Ratio, O/F	5.05	4.98	4.92
C-2 Mixture Ratio, O/F	5.02	4.96	4.91
C-1 Specific Impulse, seconds	442.0	442.3	442.4
C-2 Specific Impulse, seconds	442.6	443.2	443.3

NOTE: Flight performance calculated by P&WA C* iteration computer program



(a) Thrust Chamber Pressure

(b) Oxidizer Pump Speed

(c) Fuel Venturi Upstream Pressure

(d) Oxidizer Pump Discharge Pressure

FIGURE 8-3 - TC-4 SECOND-ENGINE START TRANSIENT

Centaur Hydraulic System

by T. W. Godwin

Summary

Centaur hydraulic system performance was normal throughout the TC-4 flight. The recirculation pumps functioned properly prior to engine starts and during the blowdown maneuver. There were no anomalies, but an unusual amount of steering corrections were noted following guidance enable after MES #1.

Discussion

System pressures and temperatures are presented in Table 8-5. All parameters were normal throughout the countdown and flight. A maximum temperature of 171°F was noted on the C-2 manifold just prior to MECO #2. The recirculation pumps functioned normally when commanded on prior to MES #1, MES #2 and during the blowdown maneuver. There were no system anomalies.

Following guidance enable after Titan/Centaur separation and MES #1, 11 maximum velocity cycles were observed on the yaw/roll actuators, and 10 cycles were seen on the pitch actuators. Four or five cycles are typical. During these short periods of maximum demand, the hydraulic pressure dropped to 300 psia, followed by an immediate recovery to normal system pressure. This characteristic is normal. These unusually severe steering commands are attributed to a 23 degree tilt of the Centaur vehicle after separation and a software limitation of the maximum gimbal angle +2°. Actuator response, however, was normal.

TABLE 8-5 - CENTAUR HYDRAULICS SYSTEM TC-4 FLIGHT PERFORMANCE

Flight Sequence	Parameters	Hydraulic Pressure, psia			Manifold Temp., °F		
		Expected Values (approx.)	CH 1P C-1 Engine	CH 3P C-2 Engine	Expected Values	CH 5T C-1 Engine	CH 6T C-6 Engine
Count	Max. during count				180 max.	113	111
First Burn	Prior to recirc. on				180 max.	65	52
	Recirc. motors on	120 - 140	127.5	126	"	65	54
	MES - 1	1110 -1150	1140	1132	"	65	54
	MECO - 1	1110 -1150	1132	1140	"	111	111
Second Burn	Prior to recirc. on				180 max.	87	89
	Recirc. motors on	120 - 140	124	122	"	85	87
	MES - 2	1110 -1150	1140	1140	"	87	89
	MECO - 2	1110 -1150	1140	1130	"	162	171
	Recirc. motors on	120 - 140	139	128	180 max.	124	129
Blowdown	Recirc. motors off	120 - 140	137	132	"	115	116

Centaur Pneumatics

by R. A. Corso and R. F. Lacovic

Summary

Centaur pneumatics system for controlling vehicle purges, propulsion system valves and propellant tank pressurization performed normally through all phases of the TC-4 flight. One anomalous condition was noted during LOX tank pressurization for second MES due to an unusual oscillation in the indicated tank pressure. The control system, however, responded properly under the circumstances and the required pressures were maintained for engine start.

Discussion

Purge System - Purge operations were normal throughout prelaunch operations. The tank shroud annulus pressure (TSAP) was maintained above the required 0.045 psid for winds less than 3? knots. The minimum pressure during prelaunch activity was 0.125 psid. And at liftoff the TSAP was steady at 0.31 psid.

Propulsion Pneumatics - Engine control and attitude control regulator outlet pressure were nominal throughout the flight. At liftoff the engine control and attitude control regulator outlet pressures were 454.1 and 310.1 psig. Required control limits for these outlet pressures were 445 to 475 and 297 to 320 psig respectively. The regulator pressures at various times during the flight are summarized in Table 3-6.

Tank Pressurization Pneumatics - LO_2 and LH_2 tank pressures, see Figures 8-4.1, 8-4.2 and 8-4.3, were within predicted values at liftoff. The hydrogen tank vent valve was locked at T-28.1 seconds. And the pressure increased from 21.12 to 24.26 psia at liftoff. The minimum predicted pressure at liftoff was 23.1 psia, and the maximum was 24.9 psia

The secondary vent valve did not vent during flight. At T + 90 seconds the primary vent valve was unlocked, and the tank pressure vented to the normal regulating pressure of 19 to 21.5 psia. LH_2 tank pressures during the remainder of the flight, during both engine start sequences and during the low gravity coast, were as expected.

LOX tank pressures during the boost phase and Centaur first-burn were as expected. The initial ramp pressurization for second MES was also normal but then exhibited an anomalous pressure oscillation. Pressure levels were satisfactory for engine start and steady state engine operation, however. Following MECO #2 the pressures were again as expected.

TABLE 8-6 - PNEUMATIC SYSTEM DATA SUMMARY FOR TC-4

Meas. Number	Description	Units	Control Range	Start Auto Count	T-0	T+90 Sec.	Start Przn. #1	Pre-start #1	MES #1	MECO #1	Start Przn. #2	MES #2	MECO #2
CF1P	LO2 Tank Ullage Press.	psia	29-32	31	31	30	30	392	38.5	30.5	32	36*	29*
CF6T	LO2 Tank Ullage Temp.	°F	ref. data	-285.2	-284.7	-284.7	-286.1	-283.7	-2842	-286.1	-284.2	-280.7	-286.1
CF3P	LH2 Tank Ullage Press.	psia	19-21.5	21.0	23.8	24.7	200	26.6	26.6	18.2	19.6	23.4	12.6
CF100T	LH2 Tank Ullage Temp.	°F	ref. data	056	-409	-374	-348	-341	-288	-338	-413	-241	-352
CFT8P	Eng. Ctl. Reg. Outlet Press.	psig	440-475	468.8	468.8	458.4	456.6	453.5	456.6	456.6	458.1	461.1	464.1
CFT10P	Att. Ctl. Reg. Outlet Press.	psig	297-315	324.8	324.8	320.8	310.8	310.8	310.8	310.8	305.3	312.6	318.8
CF2P	Helium Bottle Press.	psia	3180-3325 (1)	3325	3290	3290	3290	2975	2800	2844	2695	1942	2030
CF4T	Helium Bottle Temp.	°F	50-90 (1)	79.3	79.3	77.5	73.0	61.7	45.9	50.4	54.7	43.6	27.9
CF134T	Aft Pneu. Panel #2	°F	ref. data	63.6	63.6	56.8	55.5	55.5	55.5	55.5	62.2	55.5	46.0

*Questionable Data

Boost Pump Spin System Test			Control Range	Actual
CFS113P	GN2 Spin Reg. Out.	psig	540 ± 10	530
CFS114P	GN2 Spin Accum. Out.	psig	ref. data	238

(1) Limit range at liftoff

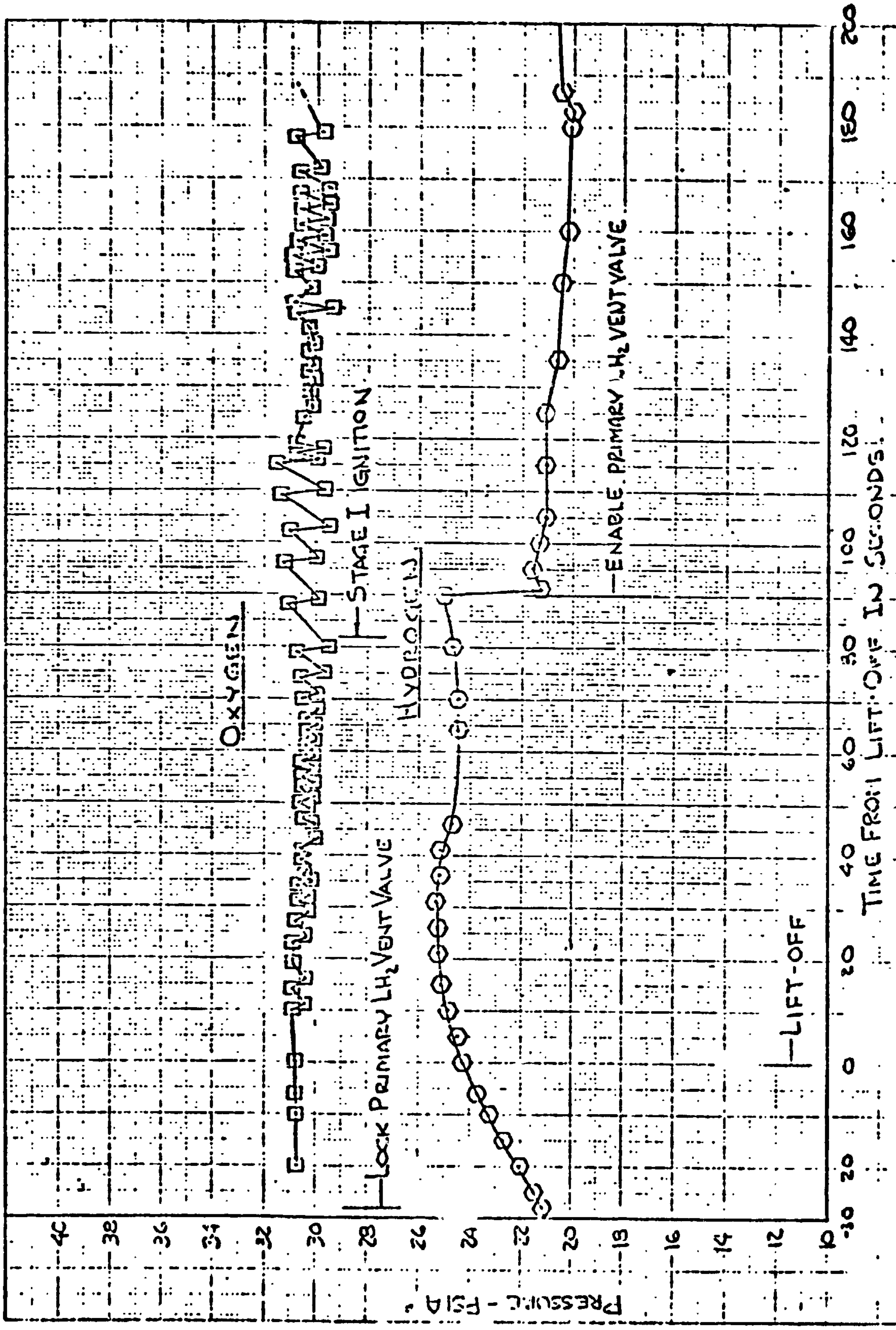


FIGURE 8-4.1 - CENTAUR TANK ULLAGE PRESSURE TIME HISTORY

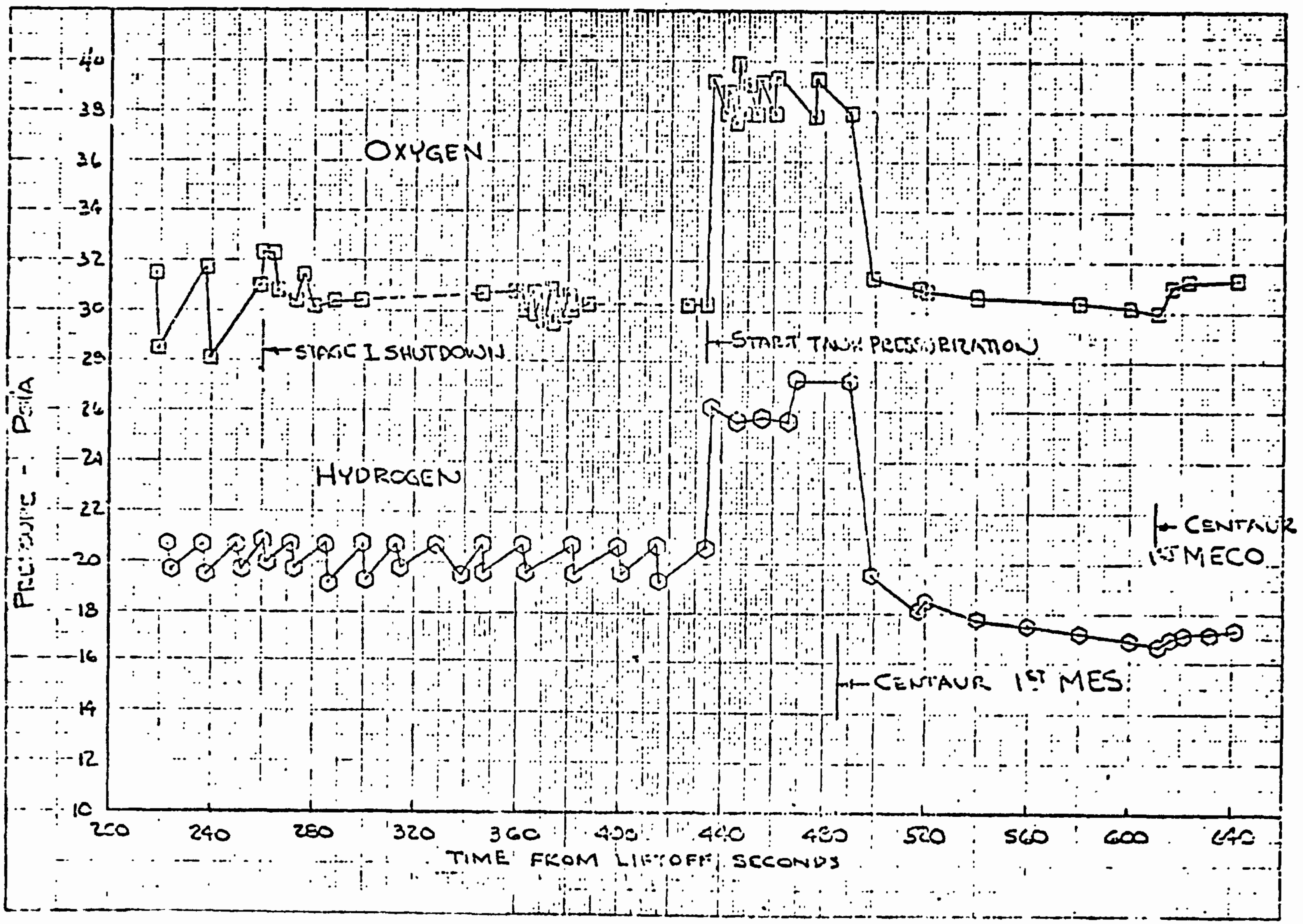


FIGURE 8-4.2 - CENTAUR TANK ULLAGE PRESSURE TIME HISTORY (CONTINUED)

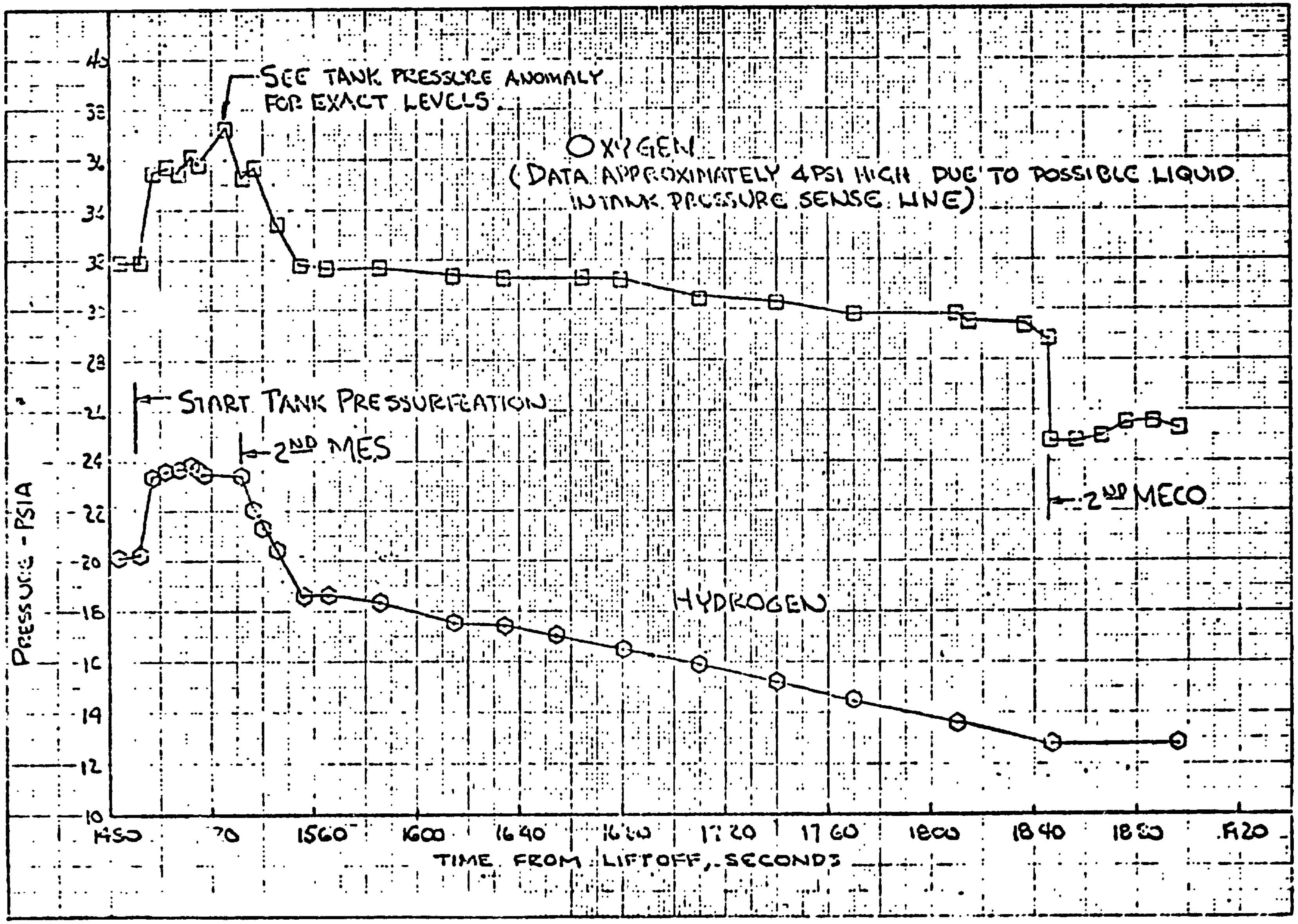


FIGURE 8-4.3 - CENTAUR TANK ULLAGE PRESSURE TIME HISTORY (CONTINUED)

Helium Usage - The helium usage for the TC-4 flight was nominal and well within the predicted usage range. The helium required for pre-MES 1 pressurization was 0.79 pounds as compared to a predicted range of 0.58 to 0.85 pounds. The helium required for pre-MES 2 pressurization was 1.33 pounds as compared to a predicted range of 1.19 to 1.49 pounds. The helium required for the post-MECO 2 pressurization was 0.58 pounds as compared to a predicted range of 0 to 1.5 pounds.

The final helium bottle residual was 5.56 pounds as compared to an initial bottle loading of 8.81 pounds. This residual indicates that an extensive helium usage margin exists for the Viking missions. Consequently, this extensive margin can easily accommodate the additional helium usage that will be required to operate the zero-g purges added for TC-3.

Computer Controlled Vent and Pressurization System (CCVAPS) - For the LH_2 tank liftoff pressure check CCVAPS predicted a tank pressure at T-0 of 24.35 psia as compared with the actual value of 24.26 psia. This pressure was well within the liftoff pressure gate of 23.1 to 24.9 psia and well above the predicted minimum LH_2 tank pressure of 23.3 psia. The LH_2 tank pressure history during the entire vent valve lockup period is shown in Figure 8-5 where comparison is made with the TC-2 pressure history and the predicted TC-4 minimum pressure history. The TC-4 pressure was significantly greater due to the greater primary vent valve initial lock[illegible]sure.

During the pre-MES 1 pressurization CCVAPS controlled the [illegible] pressures to within the expected operating range. For the LH_2 tank pre[illegible]zati[illegible] CCVAPS properly controlled the tank pressure by the P_{max} criteria to ens[illegible] the LH_2 tank pressure allowables were not exceeded. The pre [illegible] pressure histories are shown in Figure 8-6. The CCVAPS pressuriz[illegible]trol parameters are shown in Table 8-7.

The pre-MES 2 tank pressure histories are shown in Figure 8-7. At LO_2 tank pressurization for MES 2 CCVAPS initiated and controlled a normal ramp pressure increase in LO_2 ullage pressure to the required range for engine start. After the pressurization valve closed, however, the indicated tank pressure continued to rise slowly and began to exhibit oscillations with increasing amplitude as shown in Figure 8-8. Oscillations were indicated by all three CCVAPS transducers and the one instrument transducer CF1P. At an indicated pressure of 36.01 psia (upper maximum control limit) the CCVAPS logic triggered a failed pressurization valve sequence and commanded the main pressurization control valve closed at MES 2 - 24.5 seconds. Thereafter, all pressurization control commands were switched over to the backup pressurization valves.

Pressure oscillations continued with increasing amplitude through termination of the pressurization sequence at engine start. After engine start pressure oscillations of a lesser amplitude and at intermittent intervals were noted throughout the period of main engine firing. Then at engine shutdown the indicated ullage pressure showed an abrupt drop of 4.0 psia, after which the pressure again appeared normal.

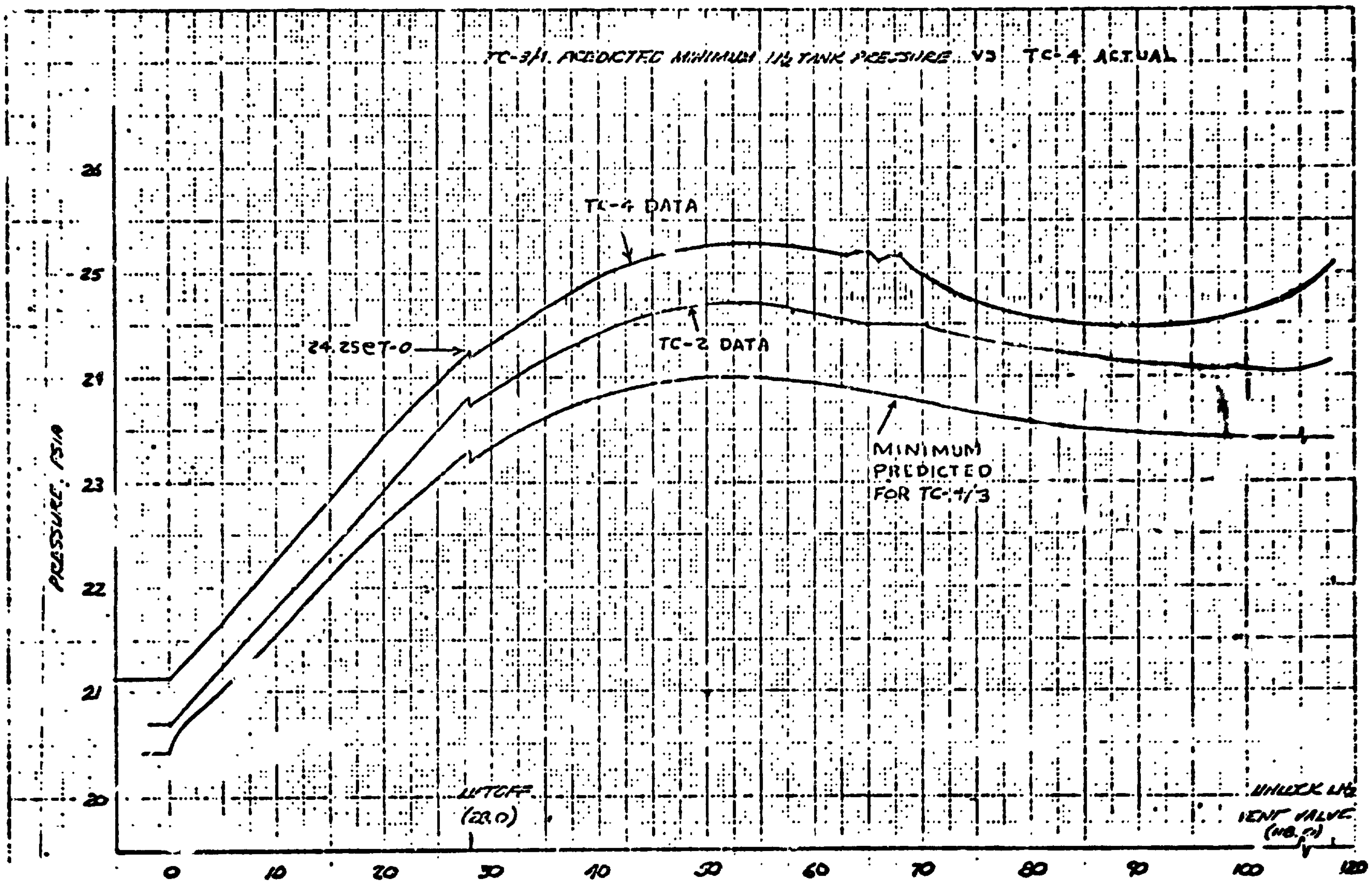


FIGURE 8-5 - LH_2 TANK PRESSURE PROFILE AT LIFTOFF

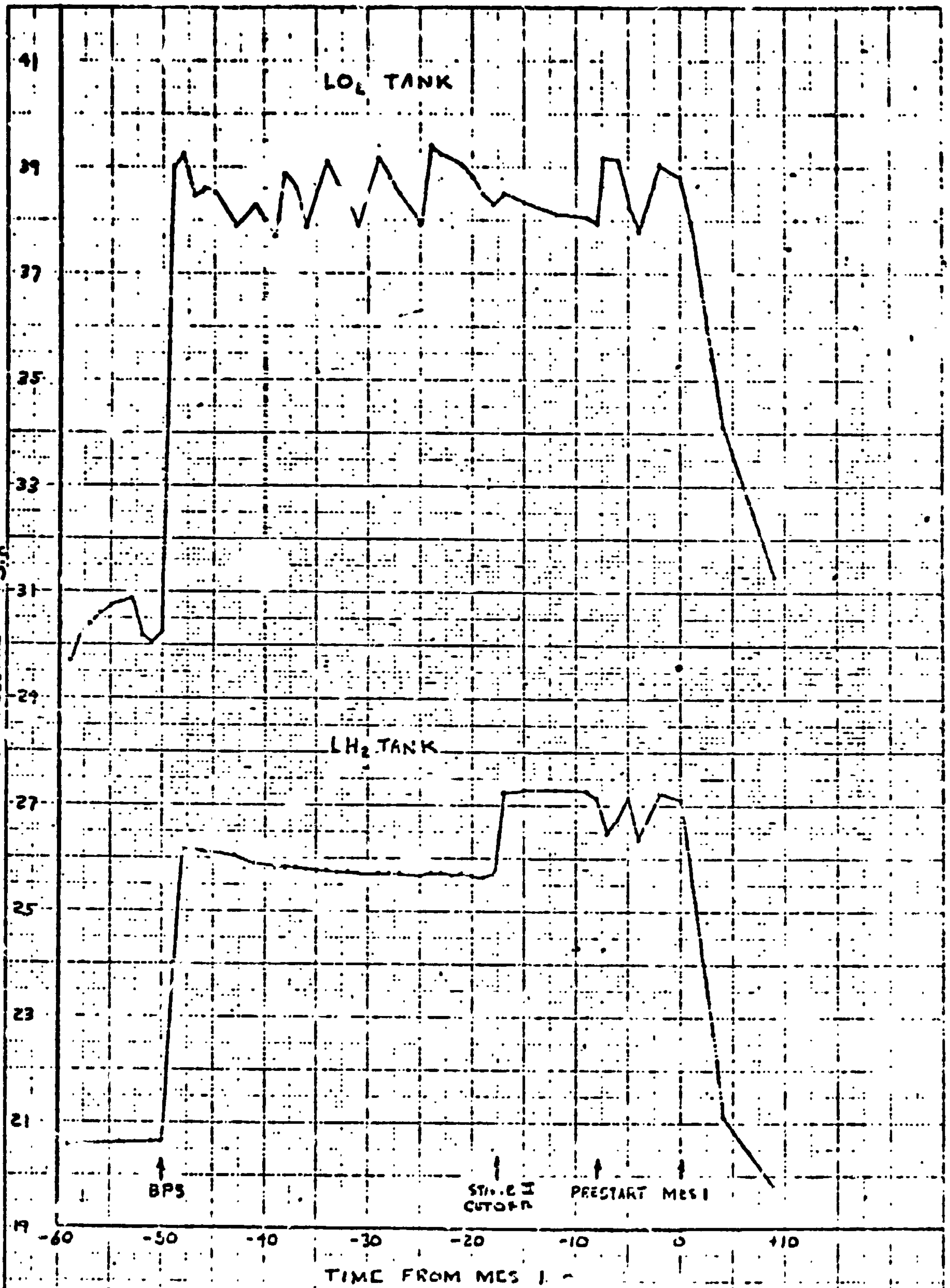


FIGURE 8-6 - TANK PRESSURE HISTORIES DURING F... PRESSURIZATION

TABLE 8-7 - CCVAPS TANK PRESSURIZATION CONTROL PARAMETERS

Parameters		LO2 Tank Pressures, psia			LH2 Tank Pressures, psia		
		TC-2	TC-3/4 Expected Values	TC-4	TC-2	TC-3/4 Expected Values	TC-4
Tank Pressurization Sequence for First MES							
Prior to Stage II Cutoff	initial pressure @ start of prztn.	32.15	29.0-32.7	30.26	19.92	19.0-21.5	20.65
	closing pressure	39.12	38.2-[illegible].5	38.02	25.92	25.0-[illegible].5	25.50
	closing pressure criteria	Δp max	---	Δp close	Δp close	---	Δp max
	minimum undershoot pressure	38.2	37.40 min	37.68	25.66	23.10 min	25.65
	maximum overshoot pressure	40.75	44.27 max	39.40	26.63	27.82 max	26.18
	initial pressure rise in 1 5 sec.	3.81	≥1.33	8.80	2.73	≥0.66	2.15
After Stage II Cutoff	closing pressure	39.91	38.2-40.5	38.02	25.92	25.0-26.6	26.60
	closing pressure criteria	Δp close	---	Δp close	Δp close	---	Δp max
	minimum undershoot pressure	39.87	37.4 min	37.8	26.05	23.1 min	26.30
	maximum overshoot pressure	41.6	44.27 max	39.2	26.60	28.92 max	27.29
Tank Pressurization Sequence for Second MES							
initial pressure at start of prztn.		32.61	29.0-39.0	31.90	20.13	19.0-23.5	20.14
closing pressure		36.11	32.5-44.5	35.41	23.53	22.4-28.1	23.54
closing pressure criteria		Δp close	---	Δp close	Δp close	---	Δp close
minimum undershoot pressure		39.49	31.7 min	35.13	23.37	21.9 min	23.33
maximum undershoot pressure		40.30	48.27 max	37.63	23.65	28.4 max	23.82
initial pressure rise in 2.0 seconds		1.21	≥0.75	1.80	0.35	≥0.18	1.20
Post-MECO-2 Tank Pressurization							
initial pressure at start of prztn.		31.5	29.0-39.0	24.75			
closing pressure		26.8	26.8	26.80			
closing pressure criteria		p max	p max	p max			
minimum undershoot pressure		none	none	---			
maximum overshoot pressure		none	none	---			
initial pressure rise in 25 seconds		none	0.04	---			

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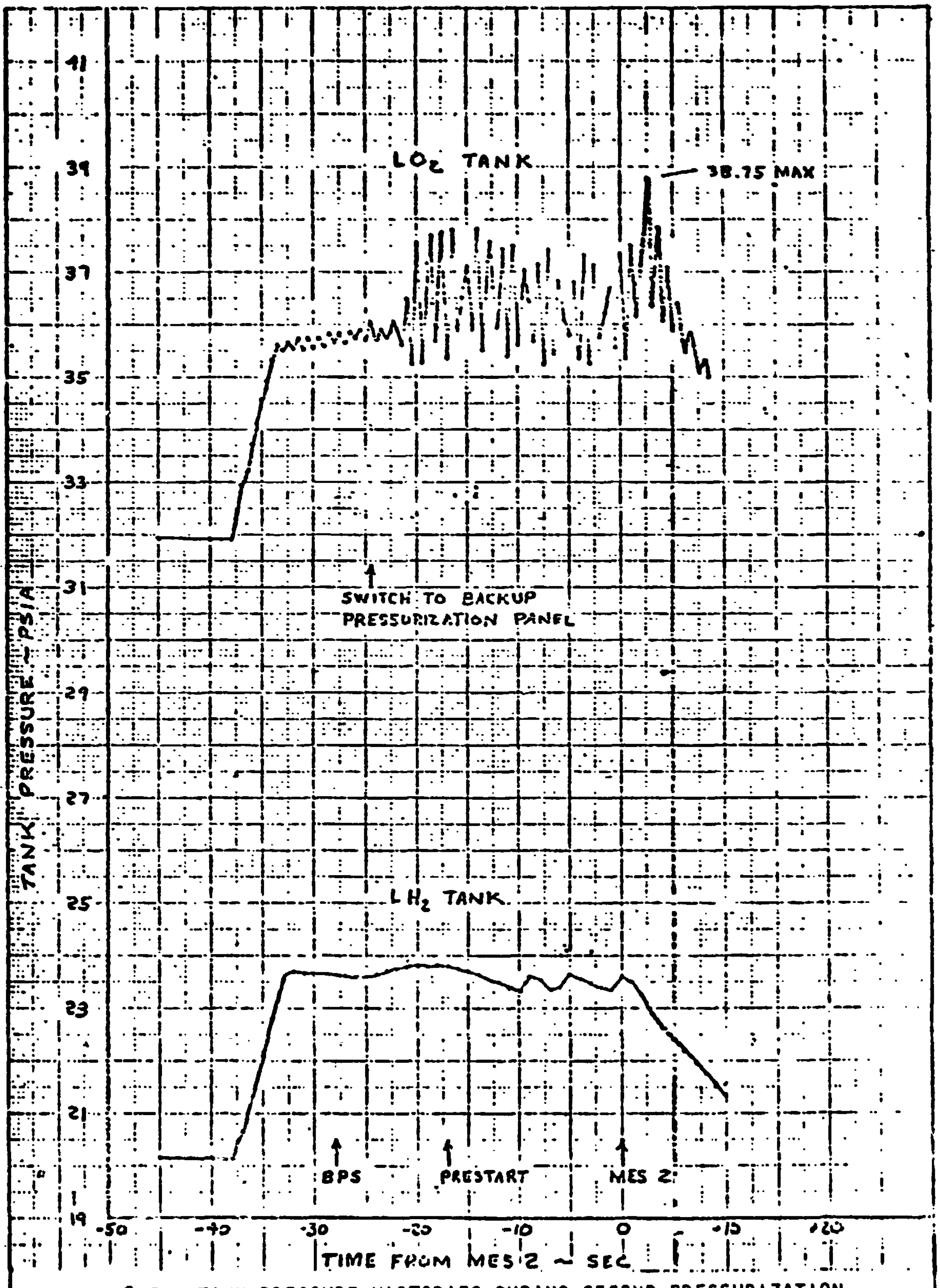

FIGURE 8-7 - TANK PRESSURE HISTORIES DURING SECOND PRESSURIZATION

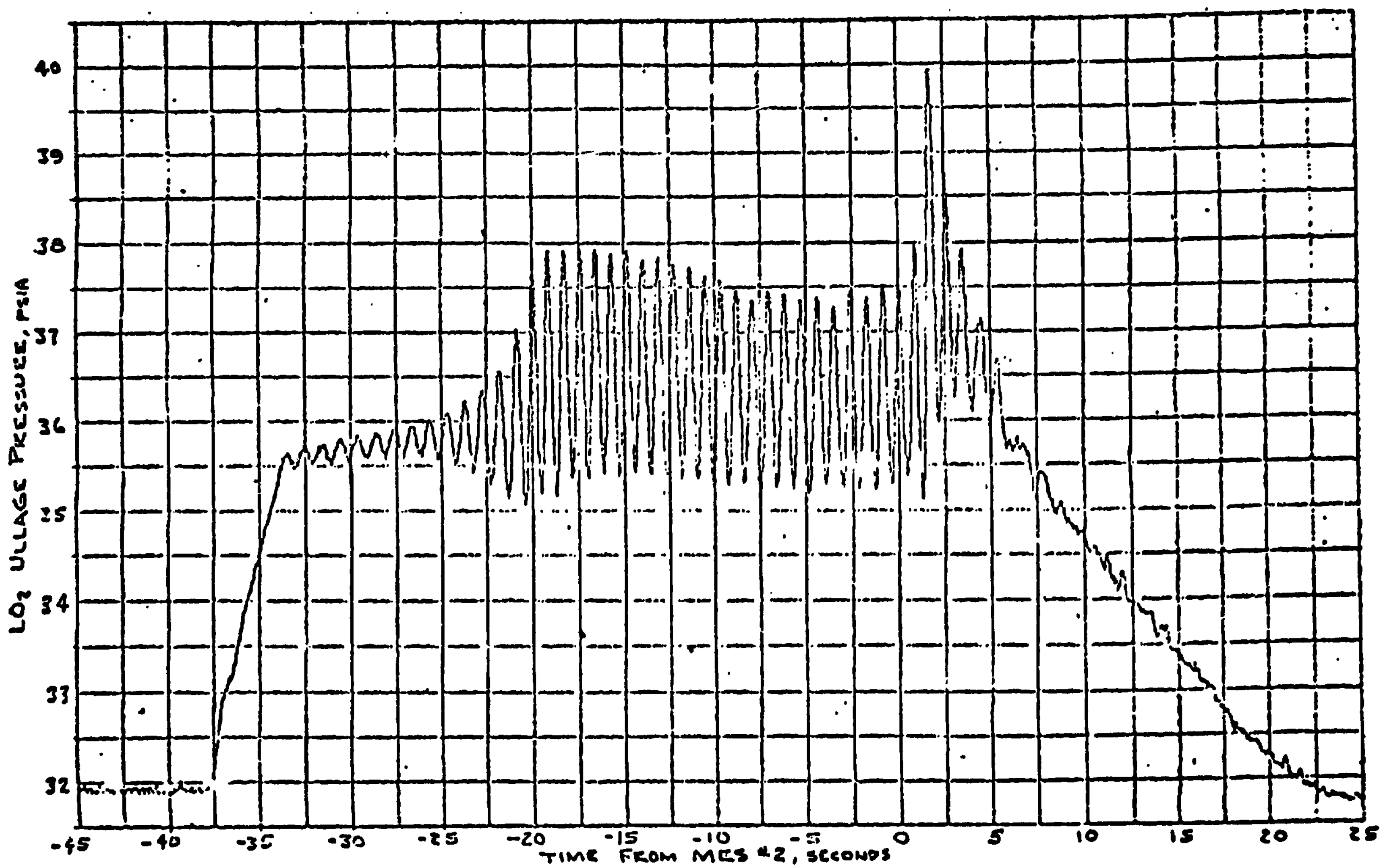

Figure 8-8 - LO2 Tank Pressure Profile at MES #2 (CCVAPS transducer #1)

The indicated pressure oscillations, and the tank pressure drop at MECO 2, were both explained by a common hypotheses; that a column of LO_2 existed in the pressure sense line. The line is common to all four transducers. With LO_2 in the line a pressure drop at MECO 2 would result when the head effect of the liquid column was lost as the vehicle acceleration dropped from 2.15 g to 0.

In order to prevent LO_2 from entering the sense line on TC-3, a zero-g purge kit identical to the ones flown on TC-1 and TC-2 was installed. This kit provided a continuous helium purge of 32 SCIM to the LO_2 tank pressure sense line.

CCVAPS did not enable a venting of either propellant tank throughout the entire flight since the tank pressures were well below the tank vent initiation criteria as given in Table 8-8.

TABLE 8-8 - TANK VENTING PARAMETERS, SETTLED COAST PHASE

Parameters		Vent Control Pressures*, psia		
		TC-2	TC-3/4** Expected Values	TC-4
LO2 Tank - Did not vent during coast				
Before	Vent control pressure range, start	47.0	----	47.0
MES-Tv	Vent control pressure range, stop	38.0	----	38.0
seconds	Maximum tank pressure	32.6	<47.0	31.91
After	Vent control pressure range, start	40.0	----	40.0
MES-Tv	Vent control pressure range, stop	39.0	----	39.0
seconds	Maximum tank pressure	32.61	<40	31.91
LH2 Tank - Did not vent during coast				
Before	Vent control pressure range, start	28.8	----	28.8
MES-Tv	Vent control pressure range, stop	27.1	----	27.1
seconds	Maximum tank pressure	20.0	<28.8	20.14
After	Vent control pressure range, start	24.5	----	24.5
MES-Tv	Vent control pressure range, stop	23.5	----	23.5
seconds	Maximum tank pressure	20.1	<24.5	20.14

*Venting enable from MECO #1 + 260 seconds to MES #2 - 97 seconds

**Venting not expected during TC-4 settled coast phase
(No venting occurred during TC-2 settled coast phase)

Centaur Propellant Feed and Reaction Control Systems

by K. W. Baud

Summary

Performance of the TC-4 Centaur Propellant Feed and Reaction Control Systems was satisfactory. No anomalies were detected during either the countdown or subsequent launch. Usable peroxide residual at start of the depletion experiment was 142 pounds. Actual time required to deplete the residual peroxide was 894 seconds versus a predicted time of 866 seconds. The depletion time difference (28 seconds) was equivalent to 4.6 pounds of peroxide.

Discussion

Propellant Feed System - The ability of the b ost pumps to rotate under cryogenic conditions was demonstrated during the countdown by successful completion of the GN_2 spin test at T-45 minutes. A sudden 9 psi increase in turbine inlet pressures was noted approximately 2 minutes after start of the test. This increase was attributed to a partially closed GSE shutoff valve during the first 2 minutes of the test. Results of the test are presented in Table 8-9 and also compared with previous vehicle testing.

The boost pumps operated normally during both burns. A summary of the performance is presented in Table 8-10. Turbine inlet pressure rise occurred within 2 seconds of the peroxide feed valve opening for both burns. The turbines accelerated smoothly and operated within the expected speed range; corresponding pump headrise was also normal.

Following MECO #2, the LO_2 boost pump accelerated to 59,475 RPM and the LH_2 boost pump accelerated to 62,400 RPM due to the combined effect of pumping cessation and purging of residual peroxide through the turbine catalyst beds. This phenomena was expected based on previous flight data. The maximum possible turbine speed predicted by analysis and tests was 68,000 RPM.

A summary of propellant feed system temperature data is presented in Table 8-11. All temperatures were within expected values.

Reaction Control System - Component temperatures were maintained within expected ranges during the prelaunch countdown and flight. A summary of temperatures at selected times is presented in Table 2.

TABLE 8-9 - CENTAUR BOOST PUMP SPIN-UP TEST DATA

VEHICLE AND TEST		Run Duration	LO2 BOOST PUMP						LH2 BOOST PUMP					
			Rotation Delay	Turbine Inlet Pressure at First Rotation	Turbine Inlet Pressure at Shutdown	Turbine Speed at Shutdown	Pump Headrise at Shutdown	Rotation Coast-down Time	Rotation Delay	Turbine Inlet Pressure at First Rotation	Turbine Inlet Pressure at Shutdown	Turbine Speed at Shutdown	Pump Headrise at Shutdown	Rotation Coast-down Time
Vehicle	units	sec.	sec.	psia	psia	rpm	psid	sec.	sec.	psia	psia	rpm	psid	sec.
AC-32	TCD Spin #1	236	11	57	157	15,900	15.0	35	23	90	156	20,500	4.0	33
	TCD Spin #2	245	14	60	156	15,900	15.0	30	19	69	155	20,500	4.0	35
	Launch	194	14	60	155	16,250	15.0	36	22	78	155	20,600	4.0	29
AC-33	TCD Spin #1	166	17	--	163	14,300	15.1	32	20	--	159	21,450	4.3	31
	TCD Spin #2	160	14	--	162	14,300	15.1	32	25	--	158	21,130	4.3	32
	Launch	190	15	66	156	15,600	15.0	29	20	78	156	20,500	4.3	41
AC-35	TCD	210	17	--	148	14,300	15.0	19	26	--	150	19,625	4.0	32
	Launch	211	16	--	165	16,900	12.0	--	20	--	165	22,100	4.0	--
TC-2	TCD Spin #1	140	14	60	155	15,650	12.6	32	23	87	158	19,800	3.5	31
	TCD Spin #2	204	17	60	160	16,250	13.5	35	20	69	161	20,345	3.4	33
	Abort Spin #1	223	14	54	152	16,575	14.5	38	20	71	148	20,325	4.0	34
	Abort Spin #2	208	16	60	158	16,825	15.7	36	20	70	154	20,450	4.3	31
	Launch	223	13	54	155	16,440	14.4	38	24	81	152	[illegible],460	3.9	34
TC-3	TCD Spin #1	219	24	78	151	14,040	9.3	22	18	63	154	20,020	3.5	39
	TCD Spin #2	212	19	72	161	15,340	12.0	24	13	54	163	21,060	4.0	36
	Launch													
TC-4	TCD Spin #1	217	15	66	155	15,600	invalid	26	23	75	155	20,475	3.7	31
	Retanking Spin #2	213	17	64	152	15,470	13.2	28	22	77	156	20,670	3.7	28
	Launch	211	19	63	156	15,730	13.5	25	25	78	156	20,475	3.5	27

TABLE 8-10 - TC-4 CENTAUR BOOST PUMP PERFORMANCE DATA SUMMARY

Parameter	Meas. Number	Units	First Burn			Second Burn		
			Prestart	MES	MECO	Prestart	MES	MECO
LO2 Boost Pump								
Pump headrise ΔP	CPT120P	psid	82.5	81.0	30.0	64.5	81.8	33.0
Turbine speed	CP15B	rpm	39,650	39,390	34,580	34,775	40,300	34,255
Turbine inlet pressure	CPT26P	psid	93.0	93.9	96.9	93.9	96.0	100.5
LH2 Boost Pump								
Pump headrise ΔP	CPT121P	psid	23.3	20.0	12.0	14.8	21.3	12.0
Turbine speed	CPT16B	rpm	44,200	41,925	41,080	34,450	41,600	40,950
Turbine inlet pressure	CPT28P	psid	93.0	93.9	94.5	90.0	91.5	95.7

TABLE 8-11 - TC-4 CENTAUR PROPELLANT FEED SYSTEM TEMPERATURE DATA

Parameter	Meas. Number	Units	Event and Event Times							
			T-0	BPS-1	MES-1	MECO-1	BPS-2	MES-2	MECO-2	P/L SEP.
Propellant Feed System										
LH2 boost pump inlet	CP32T	DGF	-420.8	-421.6	-421.5	-422.3	-421.7	-422.0	-424.7	-424.7
LO2 boost pump inlet	CP33T	DGF	-282.8	-283.0	-282.2	-283.5	-281.2	-282.8	-286.7	-286.7
C-1 LO2 duct surface	CP55T	DGF	-276.1	-276.1	-276.1	-278.8	-277.0	-277.9	-283.0	-281.6
C-1 LH2 duct surface	CP56T	DGF	-400.5	-408.0	-407.5	-410.5	>-378	-388.0	-413.2	-414.6
C-2 LO2 duct surface	CP57T	DGF	-276.9	-276.0	-275.1	-277.8	-278.5	-277.4	-283.8	-282.9
C-2 LH2 duct surface	CP58T	DGF	-394.0	-411.1	-410.5	-413.9	>-378	-404.4	-417.1	-419.6
C-1 LO2 pump inlet	CP59T	DGF	-280.2	-280.0	-280.5	-283.0	>-275	-281.5	-286.5	-286.0
C-1 LH2 pump inlet	CP60T	DGF	-419.2	-420.1	-419.7	-420.6	>-413.7	-420.3	-423.0	-423.1
C-2 LO2 pump inlet	CP61T	DGF	-280.5	-280.0	-280.5	-283.0	-280.5	-281.5	-286.5	-286.0
C-2 LH2 pump inlet	CP62T	DGF	-419.1	-420.0	-419.9	-420.6	>-413.6	-404.4	-417.1	-419.0
LO2 Boost Pump Turbine										
Rotor lower bearing	CPT36T	DGF	77	77	103	136	205	213	308	359
Gearcase surface (output)	CP176T	DGF	64	61	72	101	165	168	>206	>206
Catalyst bed surface	CP186T	DGF	110	127	>597	>597	> 597	>597	>597	>597
LH2 Boost Pump Turbine										
Rotor lower bearing	CPT127T	DGF	77	77	94	142	203	210	317	362
Gearcase surface (output)	CP177T	DGF	70	63	74	109	173	174	>217	>217
Catalyst bed surface	CP187T	DGF	101	110	>597	>597	555	>597	>597	>597

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TABLE 8-12 - TC-4 CENTAUR H202 SUPPLY AND REACTION CONTROL SYSTEM TEMPERATURES

Parameters	Meas. Number	Units	Event and Event Times							
			T-0	BPS-1	MES-1	MECO-1	BPS-2	MES-2	MECO-2	P/L-SEP
H202 Bulk										
RCS bottle	CP93T	DGF	86	89	89	88	90	90	90	90
B/P bottle	CP659T	DGF	83	83	83	84	88	88	88	86
Thrust Chamber Surfaces										
Y1	CP148T	DGF	68	637	567	1060	1110	1110	585	909
Y4	CP149T	DGF	68	45	45	959	1043	1144	611	1326
P3	CP375T	DGF	45	45	45	942	1043	959	546	807
P4	CP376T	DGF	57	45	45	942	1144	1161	637	1026
S2A	CP691T	DGF	68	567	514	443	1110	1110	559	470
S4A	CP693T	DGF	57	45	45	45	1212	1212	559	470
S4B	CP836T	DGF	57	45	57	68	1103	1103	550	470
S2B	CP837T	DGF	57	884	714	532	1178	1178	573	443
H202 Lines to Thruster										
Quad 2/3	CP152T	DGF	82	95	95	96	96	94	88	92
Quad 1/4	CP155T	DGF	74	93	92	94	96	96	95	96
Quad 1/2	CP160T	DGF	72	87	85	84	94	92	81	84
H202 Lines to Boost Pumps										
LH2 orifice inlet	CP361T	DGF	66	61	101	111	127	103	112	171
LO2 orifice inlet	CP714T	DGF	66	73	96	120	131	99	135	105
Between feed valves	CP831T	DGF	30	94	84	94	123	96	95	103
LH2 inlet (near tee)	CP833T	DGF	88	64	92	96	100	98	101	112
Other										
Bottle manifold line	CP756T	DGF	78	95	94	96	99	96	97	97
H202 vent line	CP832T	DGF	80	84	84	84	84	84	80	80
BPFV #2 body	CP834T	DGF	79	80	89	92	103	100	97	107

Programmed 20 second firings of the S2A, Y1, Y2 and S2B thrusters to prime the peroxide supply lines during the boost phase was verified by the response of thermocouples located on the thrusters. Similarly, the thermocouple response verified the programmed 10 second warming firing of all P and Y thrusters prior to MECO #2 and all settling engine operating modes except for the 2 S-on mode during the settled coast. Switching from the 4 S-on mode to the 2 S-on mode at MECO #1 plus 250 seconds was not confirmed due to the lack of telemetry coverage.

The DCU computed hydrogen peroxide consumption at the start of the peroxide experiment was 177.9 pounds. The preflight predicted value was 177.4 pounds. A total of 323.9 pounds was loaded for flight of which 4.4 pounds were unusable. Thus, the predicted usable peroxide at start of the depletion experiment was 142.1 pounds. The predicted time to deplete the residual peroxide was 866 seconds. Based on the settling engine temperature data, actual depletion time was 894 seconds. The 28 seconds difference was equivalent to 4.6 pounds of peroxide.

Environmental Control and Thermodynamics

by R. F. Lacovic and R. A. Corso

Summary

The environmental control system maintained proper thermal conditioning in all compartments and all component temperatures were maintained within specifications limits during prelaunch and during flight. The TC-4 vehicle flew a hotter trajectory than previous Titan/Centaur vehicles resulting in warmer external temperatures, otherwise all temperature data are in good agreement with previous TC-1 and TC-2 flight experiences.

Discussion

Temperature survey data for the prelaunch and flight periods are summarized in Table 8-13 through 8-17 for the Centaur airframe and mechanical systems.

The CSS and ISA flight temperature data, as shown in Figures 8-9 through 8-11 are identical in profile to the TC-1 flight data except for the peak external temperatures. They are significantly greater, as much as 62°F, on TC-4 as the result of a hotter trajectory. The temperatures, however, are still well below the design allowables.

The shroud internal temperature data, as shown in Figures 8-12 and 8-13, show only a slight increase in temperature as a result of the higher external temperatures. Also, the internal temperature data show good agreement with the TC-1 flight data.

A composite summary of all other vehicle temperature data, Tables 8-14 through 8-17, for significant flight event times shows a detailed comparison with corresponding TC-1 and TC-2 data. There is good agreement in all of the temperature data and no significant deviations or anomalous behavior was observed. All equipment and component temperatures remained well within the given operational limits.

An examination of the more responsive temperature data shows that the vehicle was in the earth's shadow from MECO #1 + 5 minutes to MECO #2 + 13 minutes.

Table 8-13 - Prelaunch Environmenta Control Data Summary

Meas. Number	Description	Units	Prelaunch Events: Amb. Cond.	Start LOX Chill	Start LH_2 Chill	Start LH_2 Tank	Start LH_2 Chill	T-10 Min.	Auto Seq. Start	T-0
	GMT Hour		1910	1924	1938	2000	2052	2102	21223	2122
Payload Compartment										
COS 14P	Payload Duct Pressure	INW	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2
COS 24R	Payload Flow Rate	LBM				NOT RECORDED				
COS 5T	Payload Inlet Temp.	DGF	55	55	55	54.8	54.9	55	54.9	54.9
COS 34T	Payload Supply Temp.	DGF				NOT RECORDED				
COS 38T	Payload Inlet Temp. UT	DGF				NOT RECORDED				
Centaur Equipment Module										
COS 7P	CEM Duct Pressure	INW	17.5	17.4	17.4	17.4	17.3	17.3	17.3	17.3
COS 22R	CEM Flow Rate	LBM				NOT RECORDED				
COS 8T	CEM Inlet Temp.	DGF	73	72.8	72.8	72.8	72.8	72.8	72.5	72
COS 35T	CEM Supply Temp.	DGF				NOT RECORDED				
COS 37T	CEM Inlet Temp. UT	DGF				NOT RECORDED				
Interstage Adapter										
COS 6P	ISA Duct Pressure	INW	26.8	29.4	29.2	29.4	29.2	29.2	29.2	29.2
COS 23R	ISA Flow Rate	LBM				NOT RECORDED				
COS 9T	ISA Inlet Temp.	DGF	130	130	130	130	129	129	129	129
COS 36T	ISA Supply Temp.	DGF				NOT RECORDED				
COS 39T	ISA Inlet Temp. UT	DGF				NOT RECORDED				
Centaur Tank Shroud Annulus										
CAT880P	Tank Shroud Annulus (TS AP)	psid	.45	.45	.45	.35	.25	.25	.25	.35
CAS893P	" " " "	psid	.48	.48	.44	.33	.31	.32	.32	.33
CFS565R	He Purge Flow Rate	LBH	139	139	139	139	173	173	173	173

TABLE 8-14 - SUMMARY COMPARISON OF TEMPERATURE DATA

System	Meas Number	Description	Vehicle	Temperature, °F at Discrete Event Times: Liftoff	Shroud Jettison	MES-1	T+730 Seconds	T+1000 Seconds	T+1500 Seconds	MES-2	S-C Separate
Airframe & Insulation	CA900T	Viking Transition Adapter	TC-1	54	44	43	43	—	—	—	—
Airframe & Insulation	CA900T	Viking Transition Adapter	-2	NA	NA	NA	NA	NA	NA	NA	NA
Airframe & Insulation	CA900T	Viking Transition Adapter	-3	63	55	53	50		26	31	23
Airframe & Insulation	CA900T	Viking Transition Adapter	-4	63	53	53	47	40	30	29	21
Airframe & Insulation	CA914T	Equip. Module Skin, +Z	TC-1	48	35	33	35	—	—	—	—
Airframe & Insulation	CA914T	Equip. Module Skin, +Z	-2	52	41	36	35	32	27	26	30
Airframe & Insulation	CA914T	Equip. Module Skin, +Z	-3	47	38	38	85	—	85	85	85
Airframe & Insulation	CA914T	Equip. Module Skin, +Z	-4	51	45	43	40	39	34	34	27
Airframe & Insulation	CA963T	LH_2 Tank Radiation Shield 2279/03	TC-1	-361	-410	-91	38	—	—	—	—
Airframe & Insulation	CA963T	LH_2 Tank Radiation Shield 2279/03	-2	-352	-403	-279	-175	-149	-120	-78	-59
Airframe & Insulation	CA963T	LH_2 Tank Radiation Shield 2279/03	-3	-367	-403	-64	29	—	40	-41	-116
Airframe & Insulation	CA963T	LH_2 Tank Radiation Shield 2279/03	-4	-354	-408	-165	-100	-85	-100	-100	-120
Component and Payload Compartment	CY112T	Spacecraft Comp. Ambient	TC-1	53	36	75	130	—	—	—	—
Component and Payload Compartment	CY112T	Spacecraft Comp. Ambient	-2	NA	NA	NA	NA	NA	NA	NA	NA
Component and Payload Compartment	CY112T	Spacecraft Comp. Ambient	-3	62	50	62	63	—	43	39	25
Component and Payload Compartment	CY112T	Spacecraft Comp. Ambient	-4	53	46	51	47	32	21	20	10
Component and Payload Compartment	CET56T	RSC Battery #1 Internal	TC-1	83	80	76	76	—	—	—	—
Component and Payload Compartment	CET56T	RSC Battery #1 Internal	-2	108	79	78	76	74	70	67	66
Component and Payload Compartment	CET56T	RSC Battery #1 Internal	-3	106	94	94	89	—	83	82	78
Component and Payload Compartment	CET56T	RSC Battery #1 Internal	-4	92	87	84	83	81	79	78	70
Component and Payload Compartment	CET57T	RSC Battery #2 Internal	TC-1	97	90	87	87	—	—	—	—
Component and Payload Compartment	CET57T	RSC Battery #2 Internal	-2	79	88	97	90	97	93	95	96
Component and Payload Compartment	CET57T	RSC Battery #2 Internal	-3	82	79	75	76	—	69	71	73
Component and Payload Compartment	CET57T	RSC Battery #2 Internal	-4	84	[illegible]	77	77	76	73	73	68
Component and Payload Compartment	CI300T	IRU Skin Internal	TC-1	80	80	86	86	—	—	—	—
Component and Payload Compartment	CI300T	IRU Skin Internal	-2	77	84	85	85	86	85	85	85
Component and Payload Compartment	CI300T	IRU Skin Internal	-3	76	78	78	87	—	91	91	93
Component and Payload Compartment	CI300T	IRU Skin Internal	-4	77	78	78	80	82	83	83	81
Component and Payload Compartment	CK 30T	DCU Skin	TC-1	77	80	87	87	—	—	—	—
Component and Payload Compartment	CK 30T	DCU Skin	-2	87	92	90	94	96	97	102	106
Component and Payload Compartment	CK 30T	DCU Skin	-3	80	92	80	87	—	93	95	97
Component and Payload Compartment	CK 30T	DCU Skin	-4	82	85	86	88	90	95	96	97
Centaur Hydraulics	CH 5T	C-1 Hydraulic Manifold	TC-1	68	65	60	56	—	—	—	—
Centaur Hydraulics	CH 5T	C-1 Hydraulic Manifold	-2	70	63	65	71	73	76	76	79
Centaur Hydraulics	CH 5T	C-1 Hydraulic Manifold	-3	77	69	69	98	—	90	87	145
Centaur Hydraulics	CH 5T	C-1 Hydraulic Manifold	-4	66	62	62	96	—	86	82	152
Centaur Hydraulics	CH 6T	C-2 Hydraulic Manifold	TC-1	70	63	60	56	—	—	—	—
Centaur Hydraulics	CH 6T	C-2 Hydraulic Manifold	-2	49	60	45	59	61	67	71	73
Centaur Hydraulics	CH 6T	C-2 Hydraulic Manifold	-3	60	60	71	94	-	87	87	145
Centaur Hydraulics	CH 6T	C-2 Hydraulic Manifold	-4	47	47	47	94	—	86	82	145
Centaur Pneumatics	CF 4T	Helium Storage Bottle	TC-1	81	79	67	64	—	—	—	—
Centaur Pneumatics	CF 4T	Helium Storage Bottle	-2	78	77	64	66	65	65	32	49
Centaur Pneumatics	CF 4T	Helium Storage Bottle	-3	82	82	60	66	-	66	21	30
Centaur Pneumatics	CF 4T	Helium Storage Bottle	-4	83	82	52	64	66	55	4	20
Centaur Pneumatics	CF134T	Aft Pneumatic Panel #2	TC-1	66	61	56	43	—	—	—	—
Centaur Pneumatics	CF134T	Aft Pneumatic Panel #2	-2	61	48	47	54	43	36	33	31
Centaur Pneumatics	CF134T	Aft Pneumatic Panel #2	-3	69	56	56	66	—	115	96	69
Centaur Pneumatics	CF134T	Aft Pneumatic Panel #2	-4	63	54	53	71	76	35	54	41

TABLE 8-15 - SUMMARY COMPARISON OF TEMPERATURE DATA

System	Meas Number	Description	Vehicle	Temperature, °F at Discrete Event Times: Liftoff	Shroud Jettison	MES-1	T+740 Seconds	T+1000 Seconds	T+1500 Seconds	MES-2	S/C Separate
H_2O_2 Supply System (continued)	CP832T	H_2O_2 Vent Line No. 1	TC-1	85	86	84	84	—	—	—	—
			-2	82	87	87	87	88	90	91	88
			-3	82	82	82	74		82	92	78
			-4	20	80	84	84	—	84	84	80
	CP833T	LH_2 BP Inlet Line	TC-1	91	70	82	131	—	—	—	—
			-2	74	68	73	121	123	101	98	151
			-3	76	57	137	OSH		OSH	135	OSH
			-4	88	66	92	117	—	100	98	112
	CP834T	BP Feed Valve #2 Body	TC-1	73	75	84	87	—	—	—	—
			-2	72	77	81	90	93	93	92	98
			-3	78	78	87	95		101	99	109
			-4	79	77	90	94	—	103	100	107
Centaur Main Propulsion System	CP118T	C-1 Engine Fuel Pump BU	TC-1	-380	-295	-380	-409	—	—	—	—
			-2	-384	-285	-350	-335	-295	-257	-442	-363
			-3	-386	-293	-267					-322
			-4	-392	-290	-350	-325	—	-252	-362	-350
	CP119T	C-2 Engine Fuel Pump BU	TC-1	-380	-290	-380	-407	—	—	—	—
			-2	-382	-290	-362	-338	-317	-275	-443	-320
			-3	-288	-300	-274					-325
			-4	-379	-290	-357	-325	—	-250	-358	-350
	CP122T	C-1 Engine Fuel Pump	TC-1	-380	-295	-380	-414	—	—	—	—
			-2	-388	-285	-350	-339	-296	-258	-414	-409
			-3	-396	-293	-272				—	-322
			-4	-402	-290	-350	-325	—	-252	-360	-350
	CP123T	C-2 Engine Fuel Pump	TC-1	-380	-290	-380	-407	—	—	—	—
			-2	-383	-225	-350	-338	-300	-264	-409	-407
			-3	-386	-298	-277				-279	-322
			-4	-385	-290	-358	-325	—	-250	-360	-352
	CP124T	C-1 Engine LO_2 Pump	TC-1	-57	-77	-94	-127	—	—	—	—
			-2	-66	-93	-175	-220	-202	-173	-144	-272
			-3	-51	-71	-94				-190	-252
			-4	-60	-74	-100	-240	—	-144	-138	-270
	CP125T	C-2 Engine LO_2 Pump	TC-1	-48	-69	-90	-123	—	—	—	—
			-2	-51	-80	-170	-222	-204	-134	-99	-258
			-3	-40	-58	-84				-115	-190
			-4	-60	-72	-208	-212	—	-108	-100	-224
	CP144T	C-2 Engine Compartment Amb.	TC-1	68	68	-135	-275	—	—	—	—
			-2	60	40	-11	-11	-11	-22	-199	-33
			-3	69	40	-66	22		[illegible]	-165	-2
			-4	70	46	46	22	17	-27	-199	-44
	CP828T	C-2 Engine Turbopump Surf.	TC-1	-393	-300	-288	—	—	—	—	—
			-2	-371	-299	-310	-318	-304	-263	-231	-347
			-3	-381	-309	-331	-347		-238	-361	-322
			-4	-388	-305	-267	-340	—	-248	-246	-340
	CP829T	C-2 Engine Pump Shield	TC-1	-27	-250	-27	—	—	—	—	—
			-2	9	-215	-44	-125	-156	-113	-78	-113
			-3	-9	-188	-101	-165		-106	-135	OSL
			-4	-20	-200	-80	-200	—	-135	-130	OSL

TABLE 8-16 - SUMMARY COMPARISON OF TEMPERATURE DATA

System	Meas Number	Description	Vehicle	Temperature, °F at Discrete Event Times: Liftoff	Shroud Jettison	MES-1	T+740 Seconds	T+1000 Seconds	T+1700 Seconds	MES-2	S-C Separate
Centaur Propellant Feed System	CP127T	LH_2 BP Turbine Bearing	TC-1	75	72	70	145	—	—	—	—
			-2	72	70	97	153	169	186	202	298
			-3	76	76	93	165		207	205	343
			-4	77	73	94	170	—	203	210	362
	CP185T	LO_2 BP Decomp. Chamber	TC-1	NA	NA	NA	NA	NA	NA	NA	NA
			-2	110	120	>597	>597	>597	>597	>597	>597
			-3	113	123	>597	>597		>597	>597	>597
			-4	110	120	>597	>597	—	>597	>597	>597
	CP187T	LH_2 BP Decomp. Chamber	TC-1	NA	NA	NA	NA	NA	NA	NA	NA
			-2	100	110	>597	>597	>597	>597	>597	>592
			-3	102	102	>597	>597		579	>597	>597
			-4	101	107	>597	>597	>597	>597	>597	>597
	CP361T	LH_2 BP Supply Line Near Orifice	TC-1	79	60	105	136	—	—	—	—
			-2	77	63	100	134	134	116	116	183
			-3	82	56	102	164		149	119	175
			-4	76	57	101	158	—	127	103	171
	CP714T	LO_2 BP Inlet Line	TC-1	66	40	95	102	—	—	—	—
			-2	66	40	96	99	117	111	111	106
			-3	71	46	99	105		130	97	108
			-4	66	47	96	110	—	131	99	105
Centaur H_2O_2 Supply System	CP 93T	Attitude Control H_2O_2 Bottle	TC-1	84	83	83	83	—	—	—	—
			-2	85	84	85	87	87	87	87	88
			-3	86	84	86	86		68	91	88
			-4	86	86	89	89	—	90	90	90
	CP152T	Quad 2/3 A/C Line	TC-1	80	80	92	94	—	—	—	—
			-2	72	70	92	91	90	89	90	94
			-3	62	78	92	95		95	95	93
			-4	82	76	95	96	—	96	94	88
	CP155T	Quad 1/4 A/C Line	TC-1	77	78	92	96	—	—	—	—
			-2	70	71	95	94	95	95	95	96
			-3	75	75	94	97		99	98	99
			-4	74	72	92	96	—	96	96	96
	CP160T	Quad 1/2 A/C Line	TC-1	NA	NA	NA	NA	NA	NA	NA	NA
			-2	NA	NA	NA	NA	NA	NA	NA	NA
			-3	69	59	84	95		97	98	99
			-4	72	[illegible]	85	94	—	94	92	84
	CP659T	Boost Pump H_2O_2 Bottle	TC-1	82	82	82	82	—	—	—	—
			-2	80	80	82	83	84	86	87	88
			-3	85	85	85	85		86	88	86
			-4	83	83	83	85	—	88	88	86
	CP756T	H_2O_2 Crossover Line	TC-1	83	83	92	92	—	—	—	—
			-2	88	90	88	93	93	93	93	94
			-3	78	87	91	99		99	100	93
			-4	78	83	94	96	—	99	96	97
	CP831T	Line Btwn. [illegible]P Feed Valves	TC-1	82	92	84	95	—	—	—	—
			-2	83	96	91	93	107	119	111	97
			-3	82	84	93	97		129	71	99
			-4	80	86	95	101	—	123	96	103

TABLE 8-17 - SUMMARY COMPARISON OF TEMPERATURE DATA

System	Meas Number	Description	Vehicle	Temperature, °F at Discrete Event Times: Liftoff	Shroud Jettison	MES-1	T+740 Seconds	T+1000 Seconds	T+1500 Seconds	MES-2	S C Separate
Centaur H_2O_2 Propulsion System	CP148T	Y1 Chamber Surface	TC-1	80	70		—	—	—	—	—
			-2	89	69	600	991	942	963	1070	1105
			-3	89	89	620	1160		[illegible]	1211	959
			-4	68	68	567	1128	—	1110	1110	969
	CP149T	Y4 Chamber Surface	TC-1	75	60	75	—	—	—	—	—
			-2	79	50	60	[illegible]	1112	863	1140	1182
			-3	69	50	69	991		1009	1245	1076
			-4	69	45	45	941	—	1043	1144	1026
	CP375T	P3 Chamber Surface	TC-1	70	60	70	—	—	—	—	—
			-2	79	60	64	1133	1119	663	1006	635
			-3	79	79	79	1009		1076	1043	942
			-4	45	45	45	976	—	1043	959	807
	CP376T	P4 Chamber Surface	TC-1	70	60	75	—	—	—	—	—
			-2	79	60	69	820	800	742	1384	1072
			-3	79	79	79	1128		1143	1194	1009
			-4	57	34	45	1110	—	1144	1161	1026
	CP691T	S2A Chamber Surface	TC-1	75	65		—	—	—	—	—
			-2	75	68		1250	1260	580	1260	570
			-3	69	69	505	1228		636	1262	496
			-4	69	57	514	1086	—	1110	1110	470
	CP693T	S4A Chamber Surface	TC-1	70	65	72	—	—	—	—	—
			-2	79	69	69	1252	1270	600	1259	620
			-3	69	69	69	1245		514	1279	671
			-4	57	45	45	1211	—	1212	1212	470
	CP836T	S4B Chamber Surface	TC-1	65	60	70	—	—	—	—	—
			-2	75	65	75	1295	580	1290	1290	650
			-3	69	50	69	1279		1279	1277	514
			-4	57	45	57	1077	—	1103	1103	470
	CP837T	S2B Chamber Surface	TC-1	70	60		—	—	—	—	—
			-2	70	60		1230	550	1220	1220	630
			-3	69	50	734	1245		1245	1262	514
			-4	57	45	714	1178	—	1178	1178	443
	CPT36T	LO_2 BP Turbine Bearing	TC-1	66	64	68	—	—	—	—	—
			-2	72	71	97	152	173	197	216	320
			-3	73	73	105	165		207	225	361
			-4	77	74	103	162	180	205	213	259
	CP176T	LO_2 BP Gearcase	TC-1	NA	NA	NA	NA	NA	NA	NA	NA
			-2	66	63	72	115	134	160	177	—
			-3	77	66	75	110		162	170	>206
			-4	65	64	72	119	—	165	168	>206
	CP177T	LH_2 BP Gearcase	TC-1	NA	NA	NA	NA	NA	NA	NA	NA
			-2	61	58	61	114	130	148	157	217
			-3	72	66	77	128		170	178	>217
			-4	70	64	74	134	—	173	174	>217

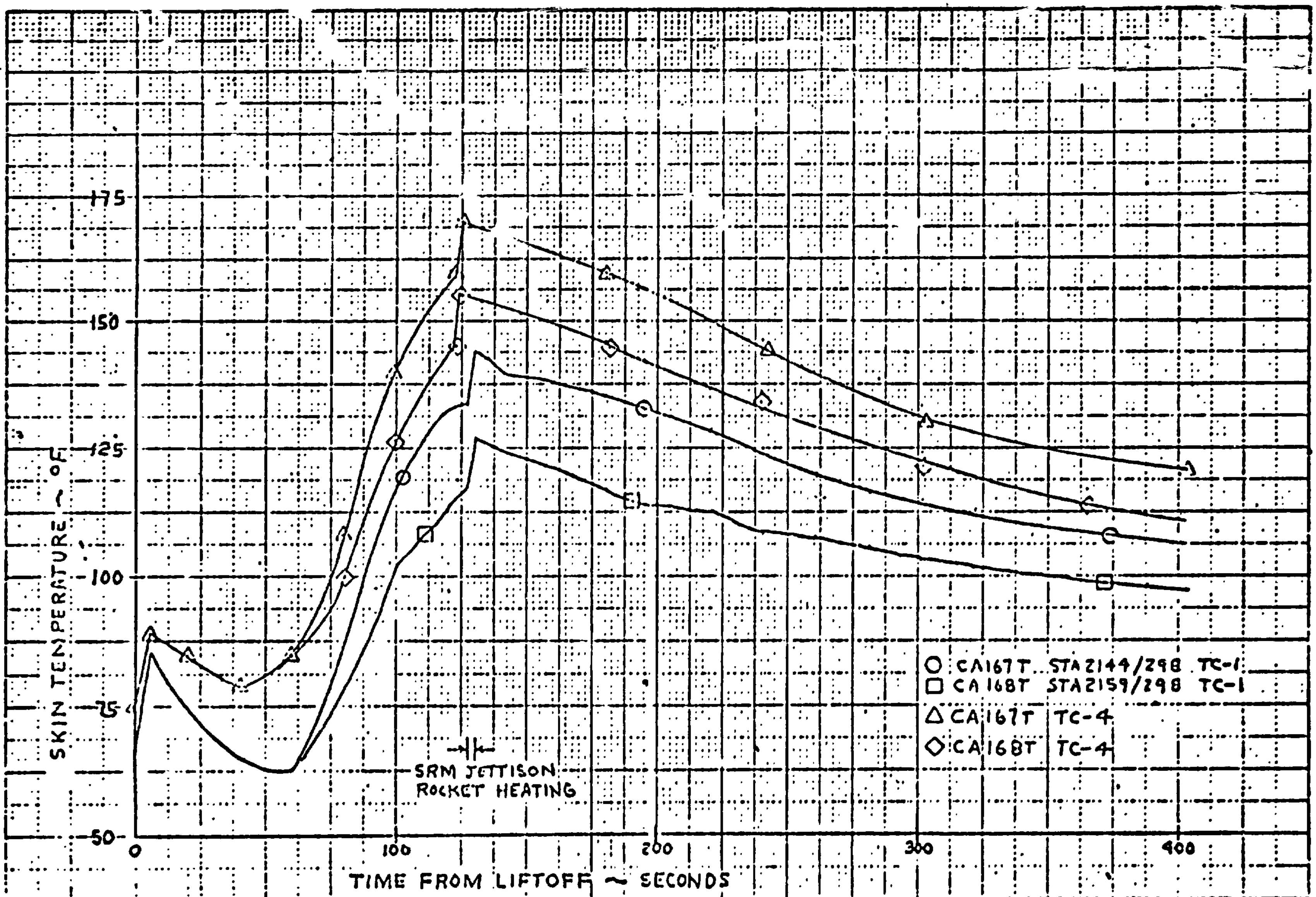


FIGURE 8-9 - INTERSTAGE ADAPTER HEATING

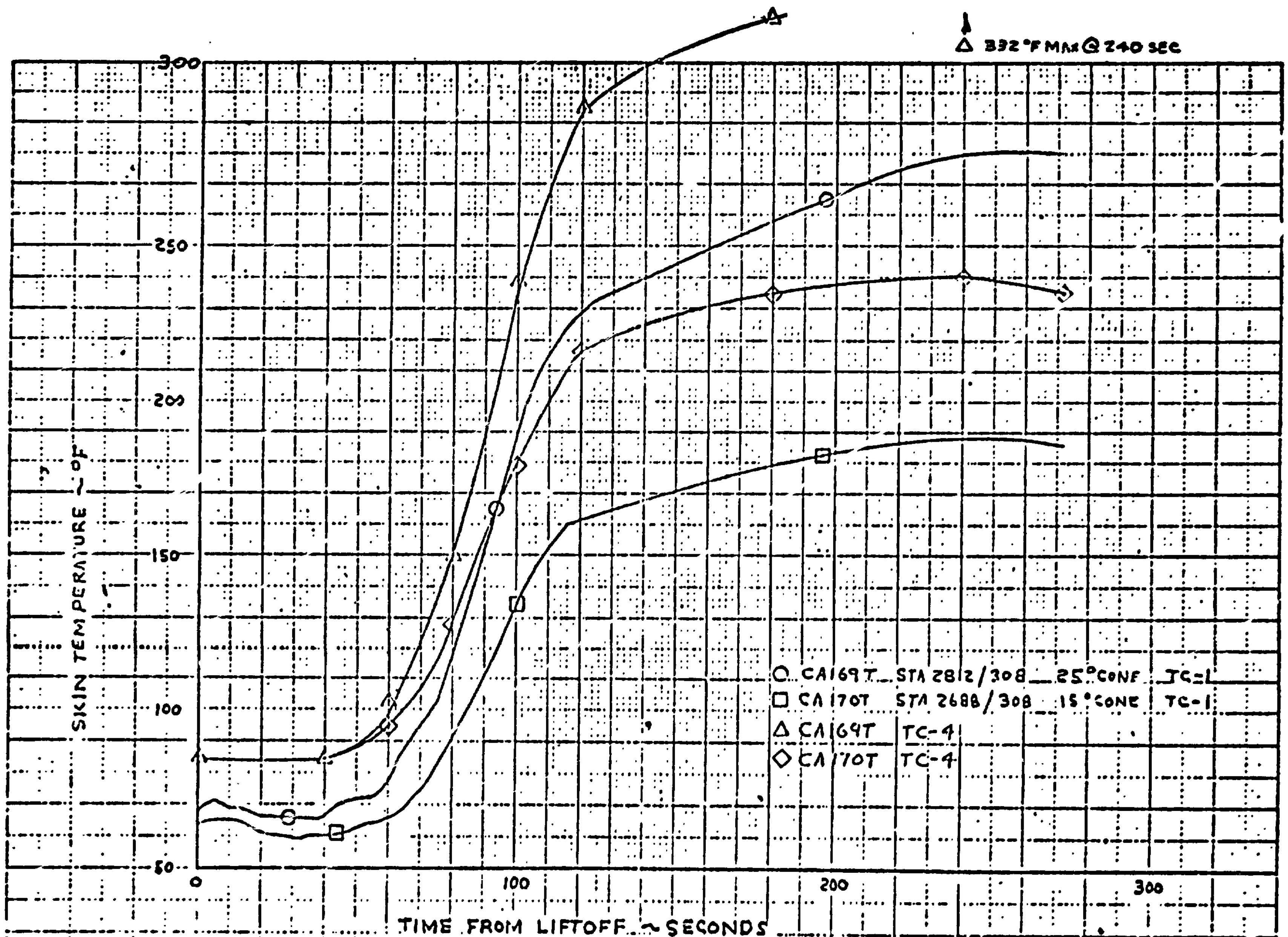


FIGURE 8-10 - CENTAUR STANDARD SHROUD HEATING

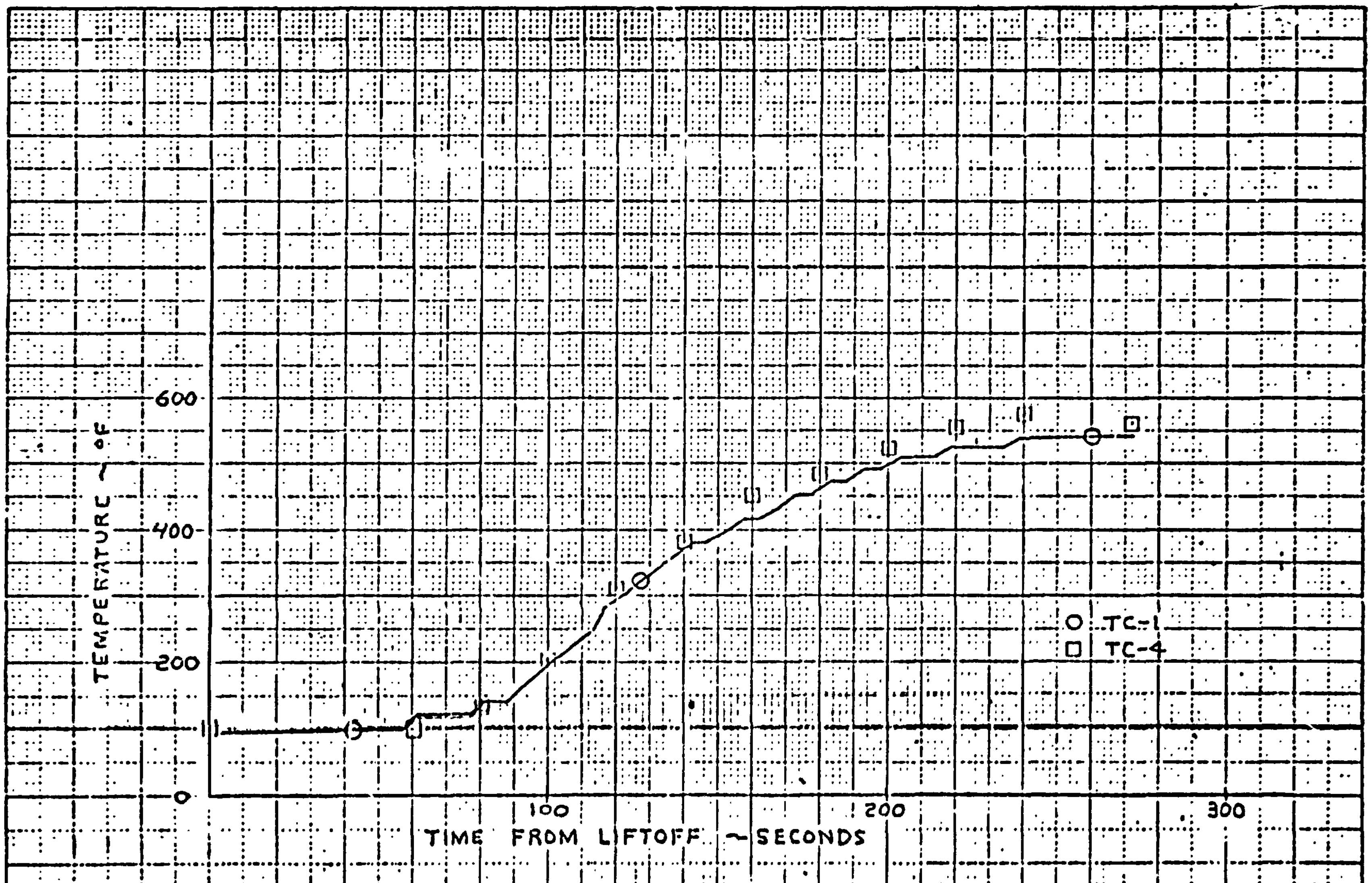


FIGURE 8-11 - SHROUD STAGNATION POINT TEMPERATURE

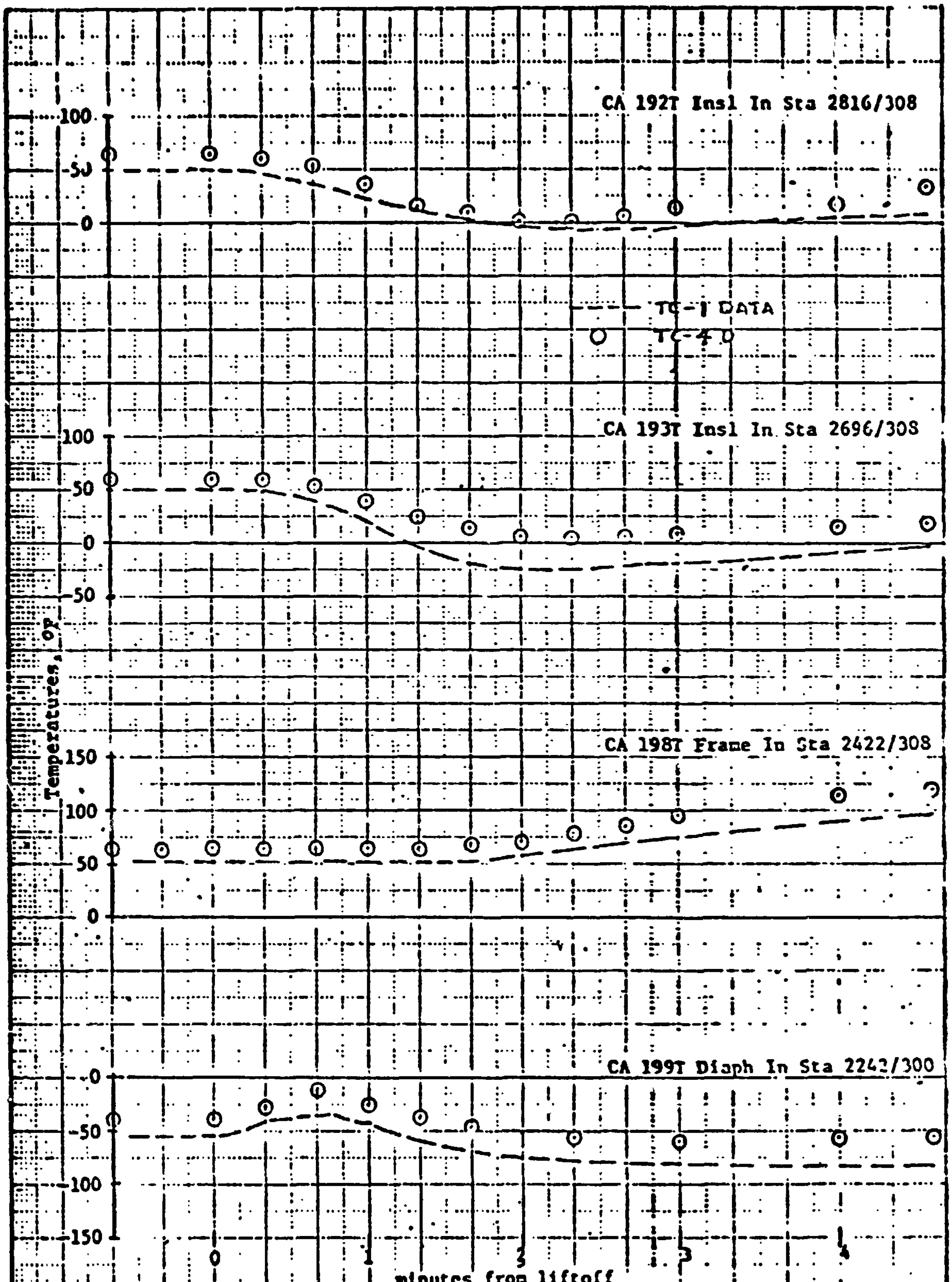


FIGURE 8-12 - AIRFRAME & INSULATION TEMPERATURE COMPARISON WITH TC-1

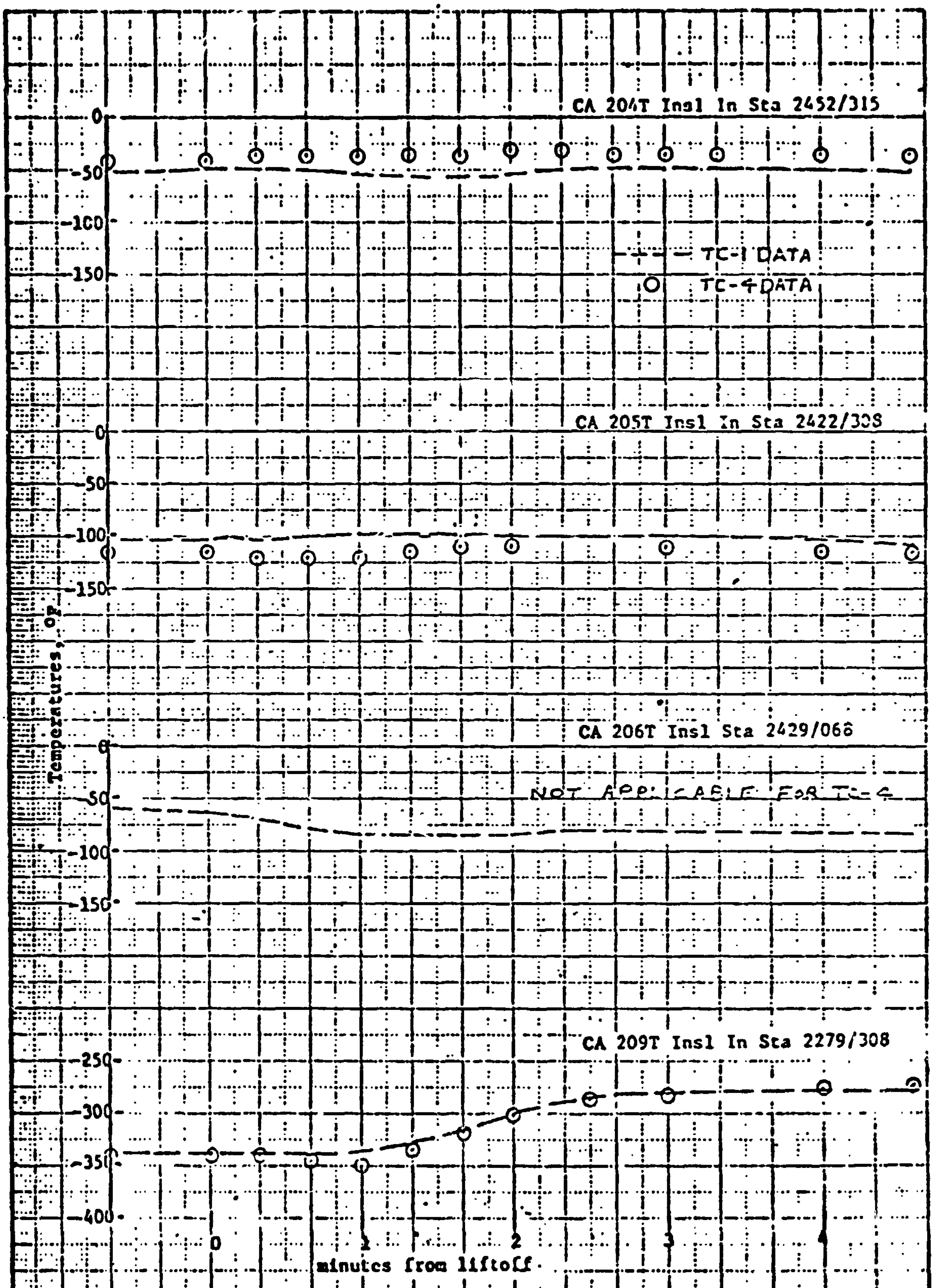


Figure 8-13-Shroud Insulation Temperature Comparison with TC-1

Electrical/Electronic Systems

Electrical Power System

by J. B. Nechvatal

Summary

Performance of the Centaur electrical system on TC-4 was satisfactory throughout the countdown and flight until loss of telemetered data at 14100 seconds. An unexpected main battery current demand of 2 amperes was observed following acquisition of data from Ascension at 1260 seconds and disappeared at MES-2 during igniter firing. The load reappeared after completion of the programmed flight, reaching a maximum of 10 amperes above normal during this period, and remained until loss of signal at 14100 seconds.

There were no detrimental effects noted to user system operation due to this added load.

Post-flight tests and analysis indicate the cause of the anomaly was leaking current in the battery, caused by electrolyte being vented from a battery cell or cells and making contact with the metallic case. (See details in discussion.)

Discussion

Configuration: The electrical power system, Figure 8-14, consists of a power changeover switch (integral part of the Sequence Control Unit), a main battery, two independent Range safety command (vehicle destruct) batteries and a single phase, 400 Hertz inverter. (Inverter is an integral part of the Servo-Inverter Unit.)

System Performance: Transfer of the Centaur electrical loads from external power to the internal battery was accomplished at minus 112.4 seconds by the changeover switch.

The main battery voltage was 27.5 volts at liftoff (Table 8-18). A low of 26.3 volts was recorded during main engine first start sequence and 26.8 volts at main engine second start sequence. The voltage recovered to 28.0 volts after spacecraft separation, reaching a peak of 28.5 volts at 13000 seconds (Table 8-19).

Main battery current was 38.5 amperes at liftoff. It peaked at 58.5 amperes at main engine first start and 60.0 amperes at main engine second start. The flight current profile was consistent with values recorded during preflight tests. The individual bus and package currents also indicated normal operating profile. Battery current values with respect to flight programmed events are shown in Table 8-20.

FIGURE 8-14

TC-3/4

SINGLE BATTERY CONFIGURATION

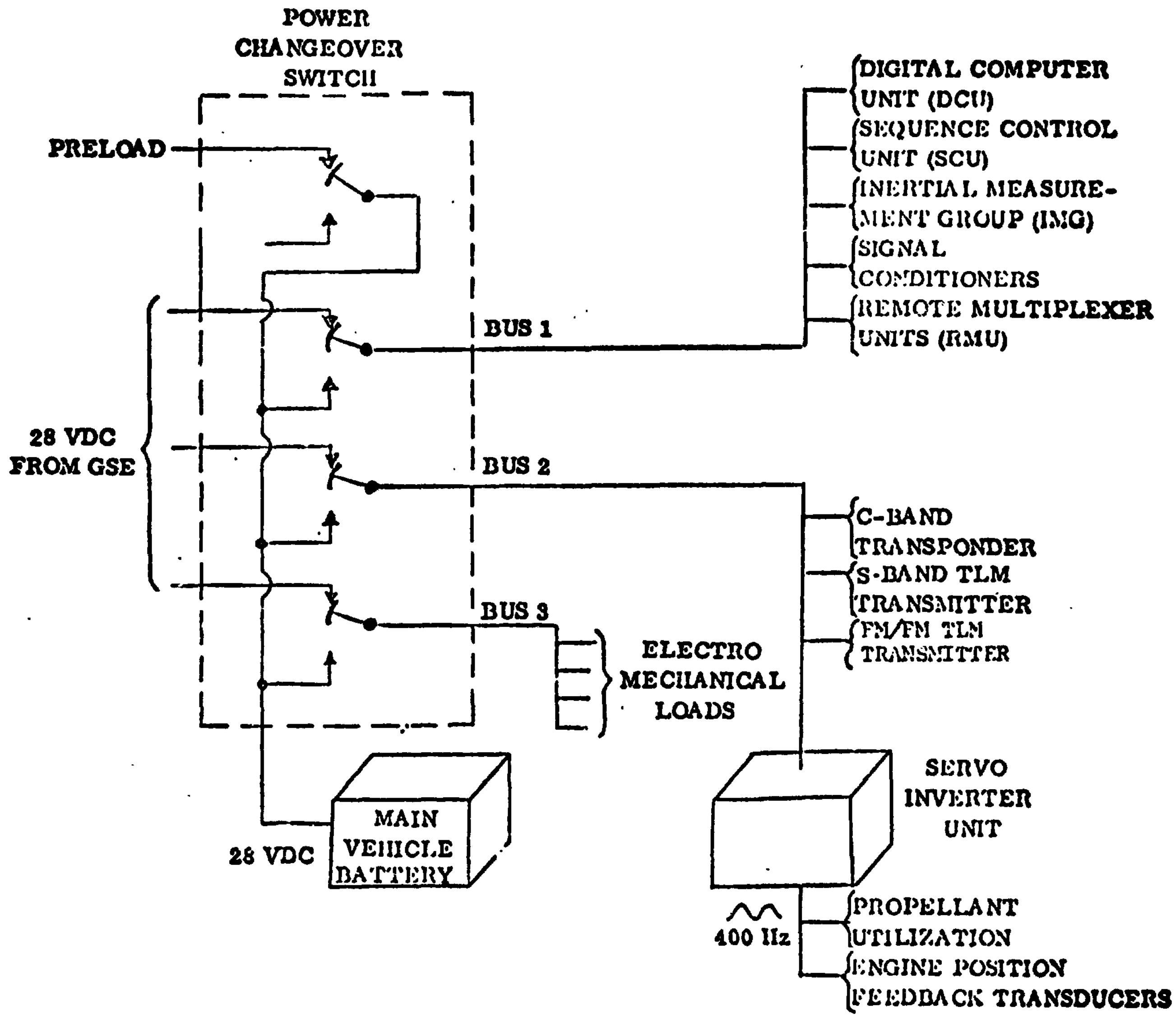


TABLE 8-18 - TC-4 CENTAUR BATTERY DATA

	OPEN CIRCUIT	T-0 LIFT-OFF	LOAD TEST
Main Battery Voltage	35.1	27.5	26.8 @ 65A
RSC No. 1 Battery Voltage	34.5	32.5	28.90 @ 10A
RSC No. 2 Battery Voltage	34.0	33.0	29.19 @ 10A

TABLE 8-19 - TC-4 CENTAUR ELECTRICAL SYSTEM PARAMETERS

MEAS No.	DESCRIPTION	UNITS	T-0	SHROUD SEP.	T/C SEP.	MES No. 1	MECO No. 1	MES No. 2	MECO No. 2	S/C SEP.	BLOW DOWN
CEIC	Main Battery Current	Amps	38.5	35.8	49.8	58.5	42.0	60.0	39.8	40.0	46.3
CE600V	Main Battery Voltage	VDC	27.5	27.4	26.8	26.3	27.3	26.8	27.7	27.9	28.0
CE28V	BUS No. 1 Voltage	VDC	27.3	27.2	26.7	26.25	27.2	26.8	27.7	27.9	27.9
CE142C	BUS No. 1 Current	Amps	10.1	10.0	10.0	10.1	10.0	9.9	9.9	9.6	9.9
CE143C	BUS No. 2 Current	Amps	8.5	8.5	8.5	8.5	7.8	8.5	8.5	8.3	8.3
CE144C	BUS No. 3 Current	Amps	12.2	10.4	16.8	22.0	14.5	21.0	14.5	14.4	17
CE97C	BUS No. 3 Partial Current	Amps	1.0	0	1.9	1.1	0	1.0	0	0.30	0
CS844V	Inverter Output Volts	VAC	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9

TABLE 8-20 - TC-4 CENTAUR BATTERY CURRENT PROFILE

EVENT	EXPECTED NOMINAL	EXPECTED MAXIMUM	ACTUAL	TIME SECONDS
Centaur to Internal	39.0	58.3	36.5	-112.4
Lock LH_2 Vent valve	40.2	62.3	38.3	- 28.2
Lift-Off (T-0)	40.5	62.6	38.5	0.0
Unlock LH_2 Vent Valve	38.3	58.1	37.3	89.9
Fwd. Bearing Reaction Sep.	39.0	58.5	37.6	99.9
Fwd. Bearing Reaction Reset	38.8	58.1	37.3	101.9
Fwd. Seal Release	39.0	58.5	37.3	209.7
Fwd. Seal Release Reset	38.8	58.1	37.0	212.7
Shroud Coax Switches	37.8	56.1	35.8	270.3
H_2O_2 Engines - S2A On	38.3	56.7	36.3	275.1
H_2O_2 Engines - S2A Off; Y1 On	38.3	56.7	36.3	295.1
H_2O_2 Engines - Y1 Off; Y2 On	38.3	56.7	36.3	315.1
H_2O_2 Engines - Y2 Off	37.8	56.1	35.8	335.1
H_2O_2 Engines - S2B On	38.3	56.7	36.3	378.1
H_2O_2 Engines - S2B Off	37.8	56.1	35.8	398.1
Lock All Vent Valves	41.2	66.3	41.2	432.2
LO_2 & LH_2 Tank Pressurization; Control Valve On	43.6	75.3	43.8	434.2
Boost Pumps - Primary & Back-Up On; H_2O_2 Purge Valve On	46.7	79.2	47.0	434.3
End LO_2 Tank Pressurization	45.9	76.2	46.2	435.1
End LH_2 Tank Pressurization	45.1	73.2	45.5	435.6
Hydraulic Circ. Pumps On	52.0	92.2	49.8	467.7
Open Prestart Valves	54.9	95.6	52.5	476.2
Igniters On; Open Start Valves Control Valve Off	60.3	96.7	58.5	484.2
Igniters Off	56.8	91.7	54.3	488.2
Hydraulic Circ. Pumps Off	51.4	78.7	49.3	496.2
H_2O_2 Engines - Y & P's On	55.4	83.1	51.5	591.3
H_2O_2 Engines - Y & P's Off	51.4	78.7	47.5	601.2
MECO: Boost Pumps, Primary & Backup Off; H_2O_2 Purge Valve Off; Close Prestart & Start Valves & H_2O_2 Engines On	42.7	63.0	42.0	611.2
H_2O_2 Engines "S 1/2 On" Mode	44.7	70.2	43.3	861.2
H_2O_2 Engines All "S" On Mode	43.7	69.1	42.5	1410.0
Hydraulic Circ. Pumps On	50.1	83.2	49.0	1470.0
LO_2 & LH_2 Tank Pressurization & Control Valve On	52.5	92.2	50.6	1492.0
End LO_2 Tank Pressurization	51.7	89.2	49.8	1497.0
End LH_2 Tank Pressurization	50.9	86.2	49.0	1497.8
Boost Pumps - Primary & Back-Up On; H_2O_2 Purge Valve On	54.6	90.1	52.0	1502.1
Control Valve Off; Backup Pressurization On	53.2	87.1	51.3	1505.3

TABLE 8-20 - TC-4 CENTAUR BATTERY CURRENT PROFILE (CONTINUED)

EVENT	EXPECTED NOMINAL	EXPECTED MAXIMUM	ACTUAL	TIME SECONDS
Open Prestart Valve	56	90.5	55.8	1513.0
MES No. 2: Igniters On; Open Start Valve S; Y & P H_2O_2 Engines Off	62.3	99	60.0	1530.0
Igniters Off	58.8	94.0	54.5	1534.0
H_2O_2 Engines 4S Off	56.8	91.7	52.0	1535.0
Hydraulic Circ. Pumps Off	51.4	78.7	47.0	1542.0
MECO No. 2: Boost Pumps - Primary & Back-Up Off; H_2O_2 Purge Valve Off; Close Pre-Start & Start Valves	42.6	68.0	39.8	1846.1
Control Valve On	45.0	77.0	40.5	1856.1
Control Valve Off	42.6	68.0	39.8	1870.1
Separate Viking Command	42.9	68.4	40.0	2066.1
Separate Viking Command Reset	42.6	68.0	39.8	2071.1
H_2O_2 Engines - 4S On Mode	44.7	70.2	41.0	2671.1
H_2O_2 Engines Off	42.6	68.0	39.3	2746.1
Hydraulic Circ. Pumps On	48.0	81.0	44.0	2896.1
Open Prestart Valves	50.9	84.4	46.3	2921.1
Hydraulic Circ. Pumps Off: Close Prestart Valve	42.7	68.0	39.1	3171.1
H_2O_2 Engines 4S On Mode	44.7	70.7	40.5	3176.1
Unlock All Vent Valves	41.3	60.0	37.5	3246.1
H_2O_2 Engines 4S Off	39.3	57.8	36.0	5176.1

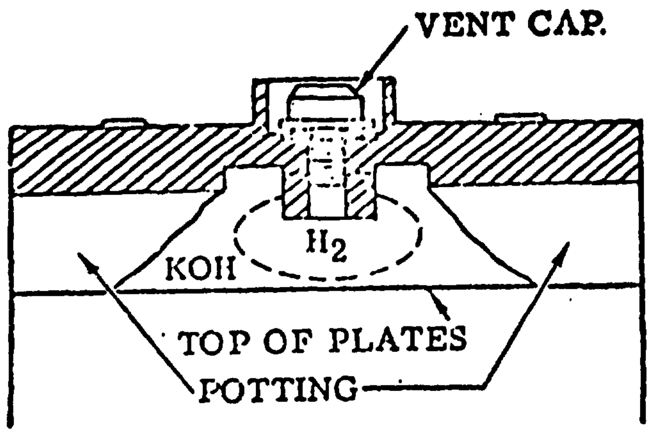
Unexpected current demands were noted on the main battery current (measurement CEIC) during the first coast phase and again after completion of programmed events. The unexpected 2 ampere load during the coast phase was initially observed at acquisition of Ascension data (1260 seconds). The load was maintained until second main engine start. The unprogrammed load was again observed at 4287 seconds (MECO 2 and 2441 seconds), and continued until loss of data at 14100 seconds. The random, low frequency fluctuating current demand average 5 amperes with peaks of 10 ampere. above normal expected level. The demand was observed on the main battery voltage as a slight decrease (less than 0.3 volts DC), but was not seen on any of the individual busses or component currents.

The cause of the above normal current is attributed to an electrolyte leakage path from inside a battery cell or cells, through the metallic cell vent valve to the battery case. The battery case is electrically bonded to the vehicle ground plane, and provides a leakage path from the battery/vehicle ground plane to the battery negative through the measurement CEIC current shunt. The leakage path occurs when electrolyte is vented from the cell/cells and bridges the gap between the fill/vent valve and the battery case. On venting, the path is of electrolyte instead of gas when in a zero G flight environment. The free electrolyte in the cell tends to wet the entire cavity surface with the gas bubble in the geometric center of the cell cavity. See Figure 8-15.

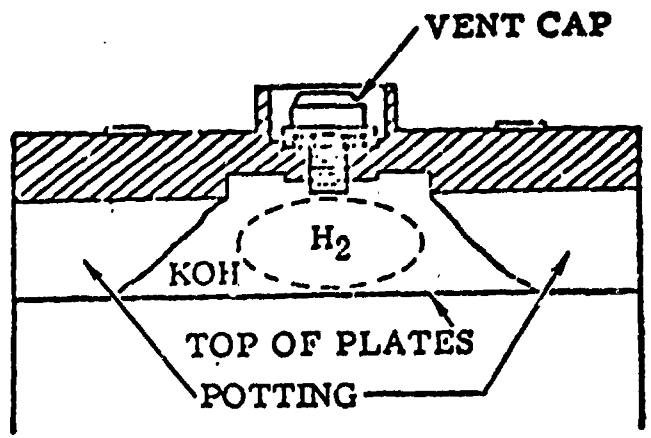
TC-4 and TC-3 are the only two flights which have flown a short fill port configuration and are the only two flights to exhibit the current anomaly. In order to prevent a recurrence of the current anomaly, the vent valves will be lengthened to extend further into the cell cavity and the material will be changed from the present metal vent valve to a nylon vent cap. This will allow for gas instead of electrolyte venting and eliminate the continuous electrical path from inside to the outside of the cell.

Performance of the two range safety command system batteries was satisfactory. At liftoff, the battery voltages were 32.5 and 33.0 volts (Table 8-18) and remain steady to first main engine cutoff, when the RF disable was initiated.

Vehicle AC power was supplied by the Servo Inverter Unit. The voltage output of the inverter remained steady at 25.9 volts AC throughout the programmed flight.



TC-1/2 CONFIGURATION



TC-3/4 CONFIGURATION

FIGURE 8-15 - FILL PORT CONFIGURATION

Digital Computer Unit

by D. S. Repas

Performance of the DCU throughout the flight for TC-4 was satisfactory as evidenced by proper functioning of flight events and operation of associated systems. The data indicating DCU performance are presented with the flight performance analyses of the associated systems.

Inertial Measurement Group

by P. W. Kuebeler

The Inertial Measurement Group (IMG) performance during the flight of TC-4 was satisfactory as evidenced by the accuracy of the trajectory, which is described in the Trajectory and Performance Section, and the telemetered data which is considered below.

The IMG consisted of IRU S/N 15, P/N GG8065B2, and SEU S/N 16, P/N EG8076B1. Gimbal loop performance was satisfactory. The maximum gimbal error observed was approximately 6 arcseconds as compared to a specification of 60 arcseconds. The IMG current was normal throughout the flight. The IRU temperature was 76°F at liftoff and rose to 83°F by the end of the flight. These temperatures were well within the operating range of the IRU.

Flight Control System

by D. W. Bitler

The Digital Computer Unit (DCU) and the Sequence Control Unit (SCU) performed satisfactorily in issuing the flight control system commands to other vehicle systems during the flight of TC-4. The SCU receives its input from the DCU and converts this input into switch commands usable by other vehicle systems. The DCU commands were issued at the expected times and for the expected duration of time.

Table 8-21 lists the planned switching sequence and actual 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 preflight actual launch time trajectory with launch day winds. The "Actual Time" column shows the time after liftoff that the DCU command was issued to the SCU. Other functions programmed by the DCU software are shown in the table to help in clarifying the flight sequence.

TABLE 8-21 - TC-4 FLIGHT SEQUENCE OF EVENTS

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
84	Reset	Go Inertial (1)	T-6.0	T-6.0	T-6.0
85	Reset				
86	Reset				
-	-	Liftoff (2)	SRM+0.0	0.0	0.0
57, 58	Set	Begin Roll Program	SRM + 6.5	6.5	6.5
57, 58	Reset	End Roll Program	(3)	6.9	6.9
-	-	(4) Begin DCU Pitch, Yaw Program	SRM + 10.0	10.0	10.1
28	Reset	Unlock LH_2 Vent Valve 1	SRM + 90.0	90.0	90.0
34	Set	Sep Fwd Brg Reactor	SRM + 100.0	100.0	100.0
34	Reset	Reset Fwd Brg Reactor	SRM + 102.0	102.0	102.0
-	-	(5) Stg 0 Shutdown Detected by DCU	STG 0 + 0	(6) 110.0	109.8
-	-	End Pitch, Yaw Program	STG 0 + 0	(6) 110.0	109.8
-	-	Enable Titan Steering	STG 0 + 32	142.0	141.8
39	Set	Release Fwd Seal	STG 0 + 100	210.0	209.8
39	Reset	Reset Fwd Seal	STG 0 + 103	213.0	212.8
-	-	Inhibit Titan Steering	STG 0 + 122	232.0	231.8
-	-	(7) STG 1 Shutdown Detected by DCU	STG 1 + 0	(6) 257.0	260.2
61	Set	Unlatch Shroud CMD 1	STG 1 + 10	267.0	270.2
62	Set	Unlatch Shroud CMD 2	STG 1 + 10.5	267.5	270.7

(1) Go Inertial occurs 25 seconds after the control monitor group sends a command to start the DCU count.
(2) Liftoff - Defined as start of Rocket Motor Ignition (DRS 496) 17:22:00.115 EDT.
(3) End Roll Program - Time is launch azimuth dependent.
(4) Pitch Yaw Steering - Enabled when altitude exceeds 1050 feet and time exceeds 10 seconds from SRM ignition.
(5) STG 0 Shutdown - Noted by DCU when computing a decreasing acceleration of less than 1.5 g's.
(6) Expected time from preflight actual launch time trajectory dtd 8/21/75.
(7) STG 1 shutdown - noted by DCU when computing a decreasing acceleration of less than 1.5 g's.

TABLE 8-21 - TC-4 FLIGHT SEQUENCE OF EVENTS (CONT.)

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
61	Reset	Reset Shroud CMD 1	STG 1 + 11.5	268.5	271.7
62	Reset	Reset Shroud CMD 2	STG 1 + 11.5	268.5	271.7
8	Set	S2A On	STG 1 + 15.0	272.0	275.2
8	Reset	S2A Off	STG 1 + 35.0	292.0	295.2
1	Set	Y1 On	STG 1 + 35.0	292.0	295.2
-	-	Enable Titan Steering	STG 1 + 35.0	292.0	295.2
1	Reset	Y1 Off	STG 1 + 55.0	312.0	315.2
2	Set	Y2 On	STG 1 + 55.0	312.0	315.2
2	Reset	Y2 Off	STG 1 + 75.0	332.0	335.2
12	Set	S2B On	STG 1 + 118.0	375.0	378.2
12	Reset	S2B Off	STG 1 + 138.0	395.0	398.2
24	Set	Lock LO_2 Vent Valve	STG 2 - 30.5	429.1	432.3
28	Set	Lock LH_2 Vent Valve 1	STG 2 - 30.5	429.1	432.3
31	Set	Lock LH_2 Vent Valve 2	STG 2 - 30.5	429.1	432.3
-	-	Inhibit Titan Steering	STG 2 - 30.0	429.6	432.8
27	Set	Open Control Valve	STG 2 - 28.56	431.0	434.3
29	Set	Press LO_2 Tank	STG 2 - 28.56	431.0	434.3
32	Set	Press LH_2 Tank	STG 2 - 28.56	431.0	434.3
23	Set	Primary-Boost Pumps On	STG 2 - 28.4	431.2	434.4
18	Set	B/U Boost Pumps On	STG 2 - 28.4	431.2	434.4
-	-	(8) STG 2 Shutdown Detected by DCU	STG 2 + 0	(6) 459.6	467.7
65	Set	Stg 2 S/D B/U	STG 2 + 0	(6) 459.6	467.7
17	Set	C1 Circ Pump On	STG 2 + .1	459.7	467.8
21	Set	C2 Circ Pump On	STG 2 + .1	459.7	467.8
63	Set	(9) T/C Separation	Sep + 0	(6) 465.6	473.8
64	Set				
19	Set	Open Prestart Valves	Sep + 2.5	468.1	476.3
27	Reset	Close Control Valve	Sep + 10.22	475.8	484.1

(8) Stage II shutdown-noted by DCU when observed acceleration is less than 1g
(9) T/C separation-commanded by DCU when computed acc. is less than 0.01g.
(6) Expected time from preflight actual launch trajectory, dtd 9/12/75.

TABLE 8-21 - TC-4 FLIGHT SEQUENCE OF EVENTS (CONT.)

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
-	-	MES 1 (10)	SEP+10.5	(6) 476.1	484.3
22	Set	Igniters On	SEP+10.5	(6) 476.1	484.3
20	Set	Open Start Valves	SEP+10.5	(6) 476.1	484.3
22	Reset	Igniters Off	MESI+4	480.1	488.3
-	-	Start Guidance Steering	MESI+7	483.1	492.0
17	Reset	C1 Circ Pump Off	MESI+12	488.1	496.3
21	Reset	C2 Circ Pump Off	MESI+12	488.1	496.3
1-4	Set	Yaw Engines On	(13)MECOI-20	582.8	591.5
5,6 15,16	Set Set	Pitch Engines On	MECOI-20	582.8	591.5
1-4	Reset	Yaw Engines Off	MECOI-10	592.8	601.3
5,6 15,16	Reset	Pitch Engines Off	MECOI-10	592.8	601.3
-	-	MECO 1 (11)	MECOI+0	(6)602.8	611.3
23	Reset	Primary Boost Pumps Off	"	"	"
18	Reset	B/U Boost Pumps Off	"	"	"
20	Reset	Close Start Valves	"	"	"
19	Reset	Close Prestart Valves	"	"	"
8	Set	Settling Engines On	MECOI+.1	602.9	611.4
10	Set	"	"	"	"
12	Set	"	"	"	"
14	Set	"	"	"	"
68,72	Reset	Reset PU Switches	MECOI+1.0	603.8	612.2
76,80	"	"	"	"	"
- 12,14	- Reset	Reduce to 2S Engines On S2B, S4B Off	MECOI+250	852.8	(12)
- 8,10 12,14	- Reset Set	Change S Engines Pairs S2A, S4A Off S2B, S4B On	Halfway thru 2S On Mode	1135.7	(12)

(10) MES 1 - commanded by the DCU 10.5 seconds after T/C separation.
(11) MECO 1 - commanded by the DCU based on guidance computed time.
(12) No telemetry recovered.
(13) MECO 1-20-MECO time used here is the guidance predicted time at that particular instant.
(6) Expected time from preflight actual launch time trajectory, dated 9/12/75.

TABLE 8-21 - TC-4 FLIGHT SEQUENCE OF EVENTS (CONT.)

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
-	-	Increase to 4S Engines On	MESII-120	1403.0	1410.2
8,10	Set	S2A, S4A On			
17	Set	C1 Circ Pump On	MESII-60	1463.0	1470.1
21	Set	C2 Circ Pump On	MESII-60	1463.0	1470.1
27	Set	Open Control Valve	MESII-38.06	1484.9	1492.1
29	Set	Press LO_2 Tank	MESII-38.06	"	"
32	Set	Press LH_2 Tank	MESII-38.06	"	"
23	Set	Primary Boost Pumps On	MESII-28.0	1495.0	1502.1
18	Set	B/U Boost Pumps On	"	"	"
27	Reset	Switched to B/U Pressurization	(14)	(14)	1505.4
19	Set	Open Prestart Valves	MESII-17	1506.0	1513.1
-	-	End Pressurization Enabled	MESII-0.28	1522.7	1529.8
-	-	MES 2 (15)	MESII+0	(6)1523.0	1530.1
20	Set	Open Start Valves	MESII+0	(6)1523.0	1530.1
22	Set	Igniters On	MESII+0	(6)1523.0	1530.1
1-4	Reset	Yaw Engines Off	MESII+.2	1523.2	1530.3
5,6 15,16	Reset	Pitch Engines Off	MESII+.2	1523.2	1530.3
22	Reset	Igniters Off	MESII+4	1527.0	1534.1
8	Reset	End 4S Settled Thrust	MESII+5	1528.0	1535.1
10	Reset	"	"	"	"
12	Reset	"	"	"	"
14	Reset	"	"	"	"
-	-	Start Guidance Steering	MESII+7	1530.0	1537.1
17	Reset	C1 Circ Pump Off	MESII+12	1535.0	1542.1
21	Reset	C2 Circ Pump Off	MESII+12	1535.0	1542.1

(14) Pressurization backup mode was commanded in place of primary mode. This was not expected.

(15) MES 2 - Command by the DCU based on guidance computed time.

(6) Expected time from preflight actual launch time trajectory, dated 9/12/75

TABLE 8-21 - TC-4 FLIGHT SEQUENCE OF EVENTS (CONT.)

SCU	SWITCH	EVENT	SEQUENCE	PLANNED TIME-SEC	ACTUAL TIME-SEC
-	-	(16) MECO 2	MECOII+0	(6) 1842.1	1846.1
23	Reset	Primary Boost Pumps Off	"	"	"
19	Reset	Close Prestart Valves	"	"	"
20	Reset	Close Start Valves	"	"	"
18	Reset	B/U Boost Pumps Off	"	"	"
68,72	Reset	Reset PU Switches	MECOII+1.0	1843.1	1847.1
-	-	Start Tank Pressurization	MECOII+10.0	1852.1	1856.1
-	-	End Pressurization Enable	MECOII+110.0	1952.1	1956.1
69,70	Set	Viking S/C Separation	MECOII+220.0	2062.1	2066.1
8,10 12,14	Set	S2A, S4B, S2B, S4B On	MECOII+825	2667.1	2671.1
8,10 12,14	Reset	S2A, S4B, S2B, S4B Off	MECOII+900	2742.1	2746.1
17,21	Set	C1&C2 Circ Pumps On	MECOII+1050	2892.1	2896.1
19	Set	Open Prestart Valve (Blow Down)	MECOII+1075	2917.1	2921.1
17,21	Reset	C1&C2 Circ Pumps Off	MECOII+1325	3167.1	3171.1
19	Reset	Close Pre-Start Valve (Blow Down)	MECOII+1325	3167.1	3171.1
8,10 12,14	Set	S2A, S4A, S2B, S4B On	MECOII+1330	3172.1	3176.1
24,28 31	Reset	Unlock LO_2 Vent Valve Unlock LH_2 Vent Vlv 1&2	MECOII+1400	3242.1	3246.1
8,10 12,14	Reset	S2A, S4A, S2B, S4B Off	MECOII+3330	5172.1	5176.1

(16) MECO 2 - Commanded by the DCU based on guidance computed time.

(6) Expected time from preflight actual launch time trajectory, dated 9/12/75.

Propellant Utilization/Propellant Loading Systems

by K. Semenchuk

Propellant Utilization (PU) - At about 200 seconds into the flight of TC-4, three transients occurred on each of the LO_2 quantity, LH_2 quantity and PU error signals, lasting approximately 12 seconds. These transients disappeared and did not reappear during the remainder of the flight. Subsequent analysis and testing at San Diego (GDC) attributed the anomalous transients to a high resistance (1/2 to 1 megohm) in series with the PU LO_2 probe. A review of the associated hardware provided no positive clues to the cause of the transient conditions; however, the likely source of the problem was considered to be the Servo Inverter Unit (SIU) LO_2 probe coaxial connector B305U2P/J3.

The Propellant Utilization system operated satisfactorily during the remainder of the flight. PU valve angle measurements for C1 and C2 engines responded properly. PU valves were properly locked in a null position until 5 seconds after MES-1, when they were properly commanded to the fixed angle positions of 5.3 degrees for C1 and 3.4 degrees for C2 engines. PU valves are to remain in their fixed position for 110 seconds after MES-1, before they are brought into control.

The LO_2 level passed the probe top at MES-1 + 96 seconds, and the LH_2 level passed the probe top at MES-1 + 108 seconds.

DCU enabled the valves to begin controlling at MES-1 + 110 seconds. The valves then moved to the LO_2 rich stop and remained there until 27 seconds before MES-2. At MES-2 + 5 seconds, PU valves went into control again.

The propellant residuals remaining at the Centaur Main Engine Cutoff were calculated by using the times when the propellant levels passed the bottom of the probes as reference points.

Liquid propellant residuals are shown below:

	Actual	Predicted
LO_2	430 lbs.	443 lbs.
LH_2	90 lbs.	104 lbs.

The burning time remaining to depletion was calculated to be approximately 7.5 seconds. at which time the liquid propellant outage was determined to be 6 pounds of LH_2.

Propellant Loading Indicating Systems (PLIS) - Centaur Level Indicating System operated satisfactorily during countdown. Propellants tanked at liftoff were 25,480 pounds of LO_2 and 5,287 pounds of LH_2.

Instrumentation and Telemetry Systems

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

Instrumentation - For the TC-4 flight a total of 324 measurements were instrumented, 288 PCM measurements and 23 twenty-four bit DCU words via the PCM System and 13 FM/FM analog measurements. The following measurements exhibited data anomalies during the flight.

1. CA8950 (SCU Normal ± 10g's) from start of ascension AOS to end of flight (T + 3180 seconds) exhibited an approximate 12 percent peak-to-peak frequency oscillation and +5 percent bias shift. The problem has been isolated to a servo loop instability due to the loss of atmospheric damping pressure at altitude. AC-31, AC-34 and TC-2 exhibited similar anomalies. The problem has been corrected for AC-37 and on, TC-5 and on for the 27-01922 accelerometers by the addition of a damping capacitor.

2. CT 70T (Thermocouple reference junction on LO_2 sump -330°F to +108°F) showed a gradual drift from liftoff (-273°F) to end of flight (-248°F at T + 3180 seconds). CT 70T monitors the thermocouple reference junction and does not control it. It is not known at this time whether it is data.

3. CP118T (C-1 engine fuel pump backup temperature -430°F to -57°F), CP119T (C-2 engine fuel pump backup temperature -430°F to -57°F), CP122T (C-1 engine fuel pump temperature -425°F to -124°F), CP123T (C-2 engine fuel pump temperature -425°F to -124°F), CP124T (C-1 engine LO_2 pump temperature -310°F to +104°F), and CP125T (C-2 engine LO_2 pump temperature -310°F to +104°F). All exhibited slow response during the flight. This condition may arise because of the Pratt and Whitney transducer installation. The slow response problem has occurred on previous flights.

Telemetry Systems - There were no RF problems in either the PCM or FM/FM systems. All ground stations providing Centaur telemetry data and their coverage intervals are shown on Figure 8-16. Guam is not shown since it provides spacecraft data only.

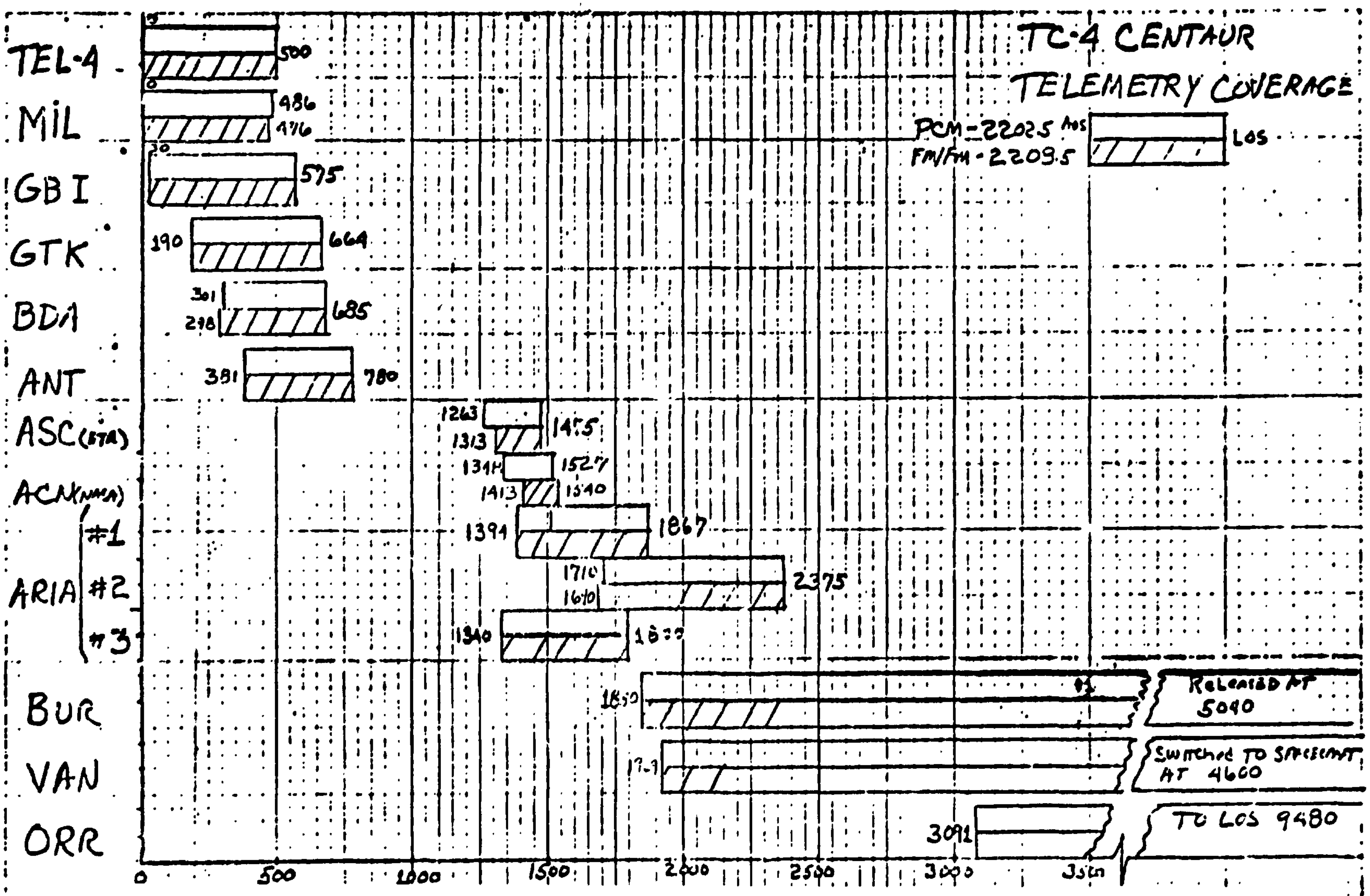


FIGURE 8-16 - FLIGHT TIME - SECONDS

Tracking and Range Safety Systems

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

C-Band Tracking - The Centaur C-Band tracking system on TC-4 performed satisfactorily. The ground radar tracking intervals are shown Figure 8-17. No significant problems were encountered. Grand Bahama radar (3.13) lost track for 36 seconds due to X-polarization disturbance but reacquired with no problem.

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

Station	Carrier On (Sec.)	Carrier Off (Sec.)
Cape Canaveral	-1961	+170
Grand Bahama Island	+170	+458
Antigua	+458	+663

The Antigua transmitter sent Range Safety Command RF Disable at T + 624 resulting in shutdown of the airborne RSC receivers.

The following anomalies occurred with the Range Safety power supply located in MTR #2.

1. At approximately T-300 minutes to T-100 minutes, CES181V (RSC Power Supply #1) was observed fluctuating between 30.75 VDC and 30.5 VDC. The RSC panel meter indications were reported normal. After T-100, the voltage was consistent. The power supply was removed from MTR #2 and sent to the ETR Calibration Lab prior to TC-5 erection. No problem could be found -- power supply voltage regulation was within parameters. The power supply was reinstalled in MTR #2 and system exercised with no malfunction.

2. CES221C (RSC Ground Power Current) had a series of ringing and noise bursts at T + 21 and T + 55 seconds.

Post TC-4 launch inspection of the umbilical cables found that the umbilical connector pins were coated with a "green" and "white" chemical substance.

A chemical analysis was conducted at San Diego with the results indicating that the substance contained large amounts of chlorine, gold oxidation, copper oxidation, traces of many chemicals commonly found in water.

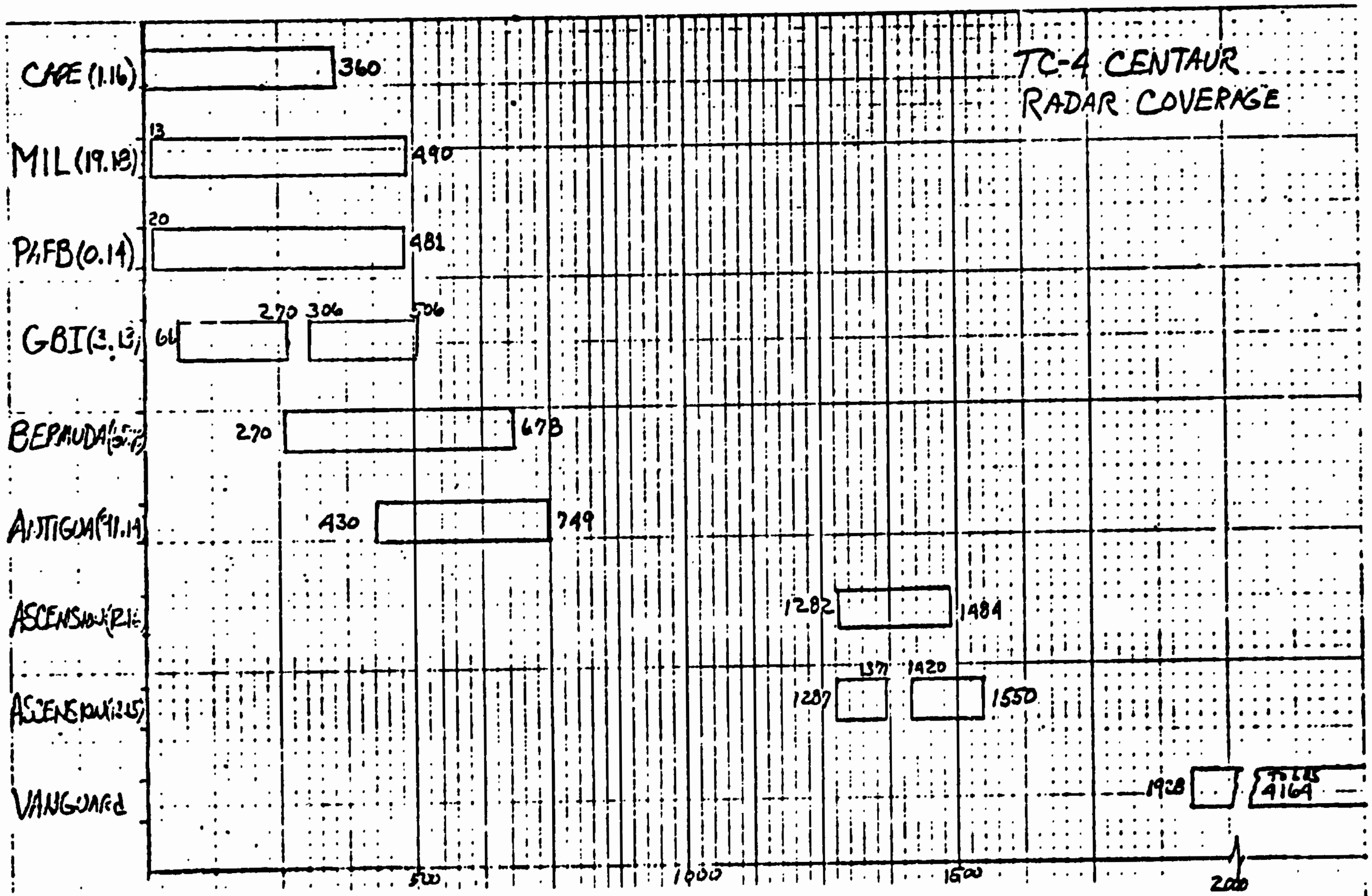


FIGURE 8-17 - FLIGHT TIME - SECONDS

Removal of the chemicals from the umbilical connector pins revealed that the pins had deteriorated. Cause of the problem is attributed to the fact that the umbilical connectors were subjected to water deluge and solid rocket exhaust. This condition would provide an electrical path (B600P1-3, 6 and 42 to ground) thus resulting in noise bursts or oscillations on CE221C. The connectors will be replaced before the next launch.

IX CENTAUR STANDARD SHROUD (CSS)

IX CENTAUR STANDARD SHROUD (CSS)

Liftoff/In-flight Functions

by T. L. Seeholzer

CSS Disconnects and Door Closures - The CSS disconnects and door closures, located as shown in Figure 9-1, functioned normally on the TC-4 flight. The CSS disconnects and door closures were equivalent to the systems used on the TC-2 flight with the exception of the encapsulation seal and RTG doors which were Viking peculiar and incorporated on the TC-1 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.

CSS In-flight Events and Jettison - All CSS in-flight events and jettison were normal on the TC-4 flight. These events included forward bearing reaction separation, forward seal release, shroud separation and jettison, as shown in Figures 9-2 through 9-6. These systems were equivalent to those on the TC-1 and TC-2 flights.

Discussion

All six forward bearing reaction struts were separated at T + 100.07 seconds as verified by breakwires on the explosive bolts. Nominal separation time was T + 100 seconds.

Forward seal release occurred at T + 209.9 seconds as verified by breakwires on the explosive bolts. Nominal separation time was T + 210 seconds.

The CSS Super*Zip primary system separated the shroud at T + 270.27 seconds. Separation by the primary system was verified by the fact that the CSS rotated over 3 degrees prior to secondary system command. The secondary system is deactivated by electrical disconnect after 1 degree rotation.

Shroud rotation times comparing TC-1, TC-2, TC-3 and TC-4 are given in Table 9-1.

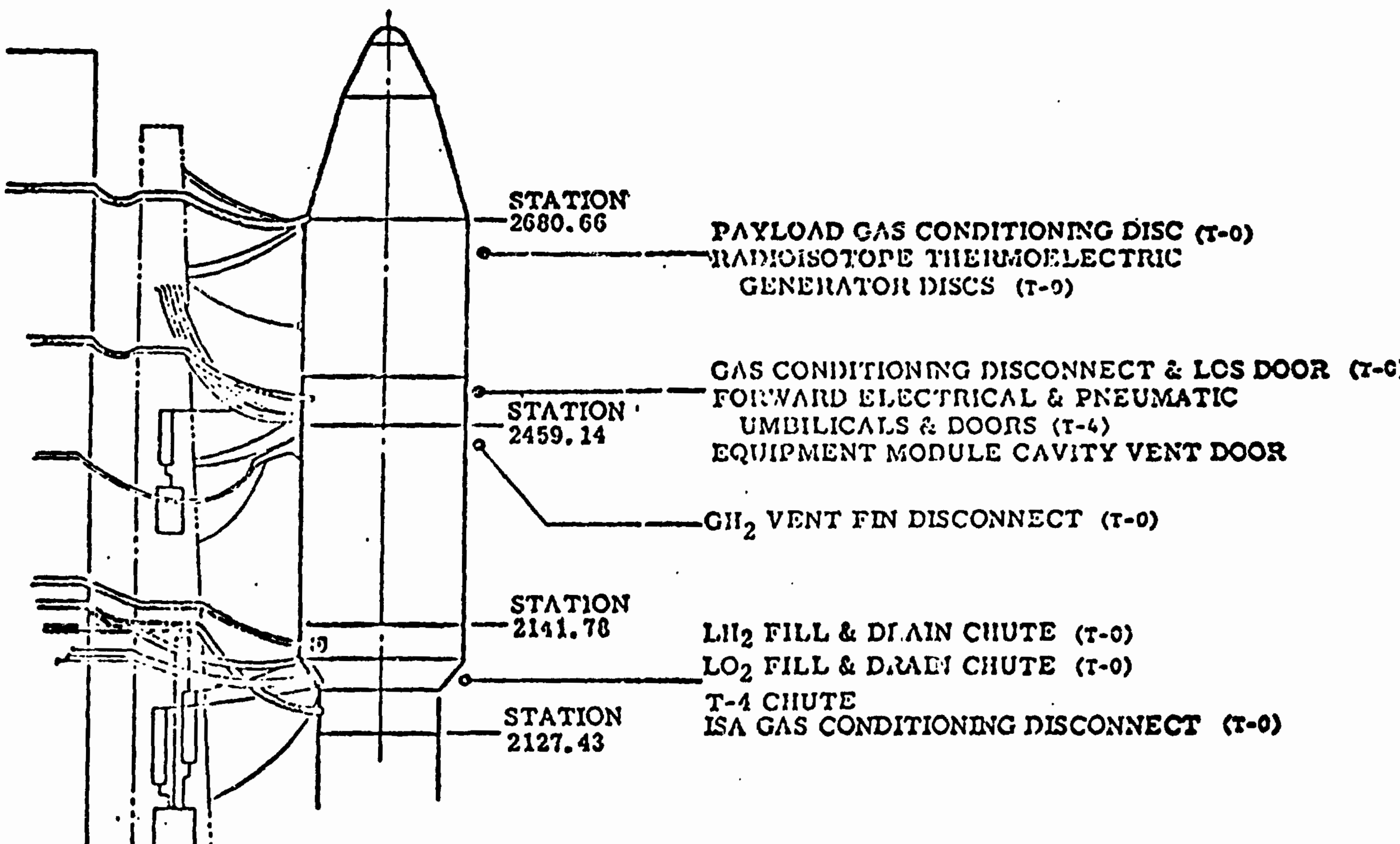


FIGURE 9-1 - CENTAUR STANDARD SHROUD DISCONNECTS AND DOOR CLOSURES

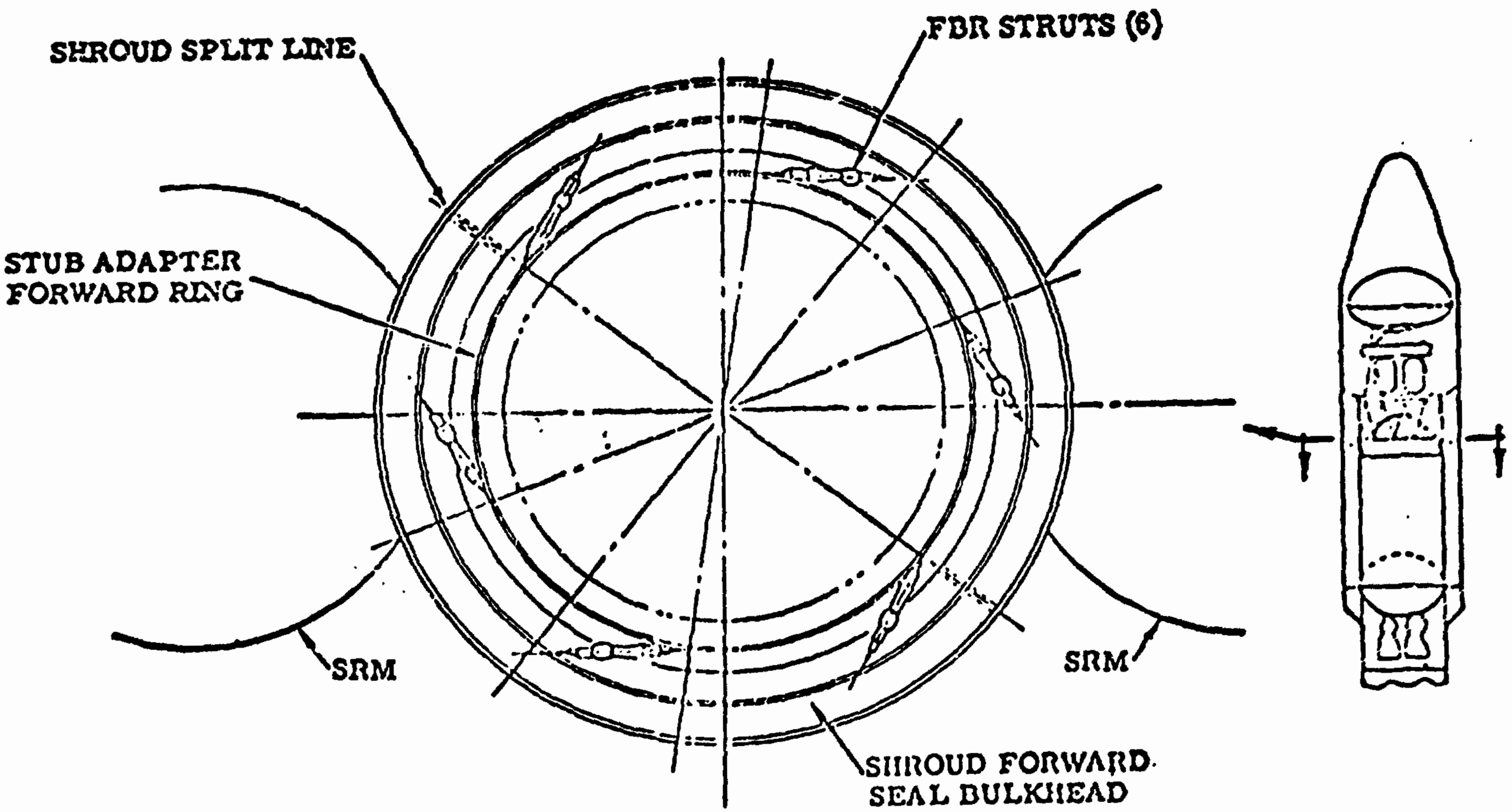


FIGURE 9-2 - FORWARD BEARING REACTION SYSTEM

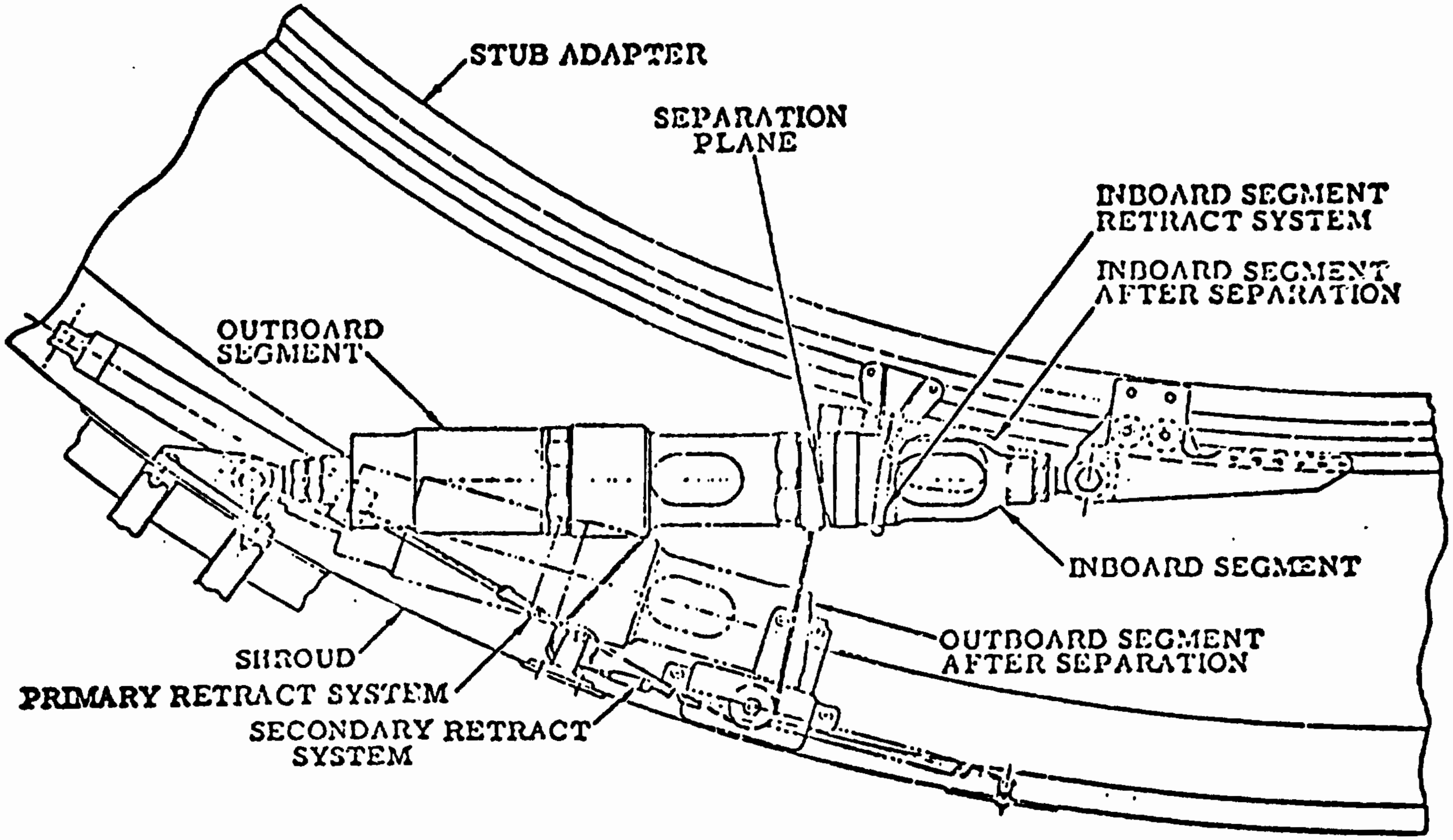


FIGURE 9-3 - FORWARD BEARING REACTION STRUT INSTALLATION

ORIGINAL PAGE IS OF POOR QUALITY

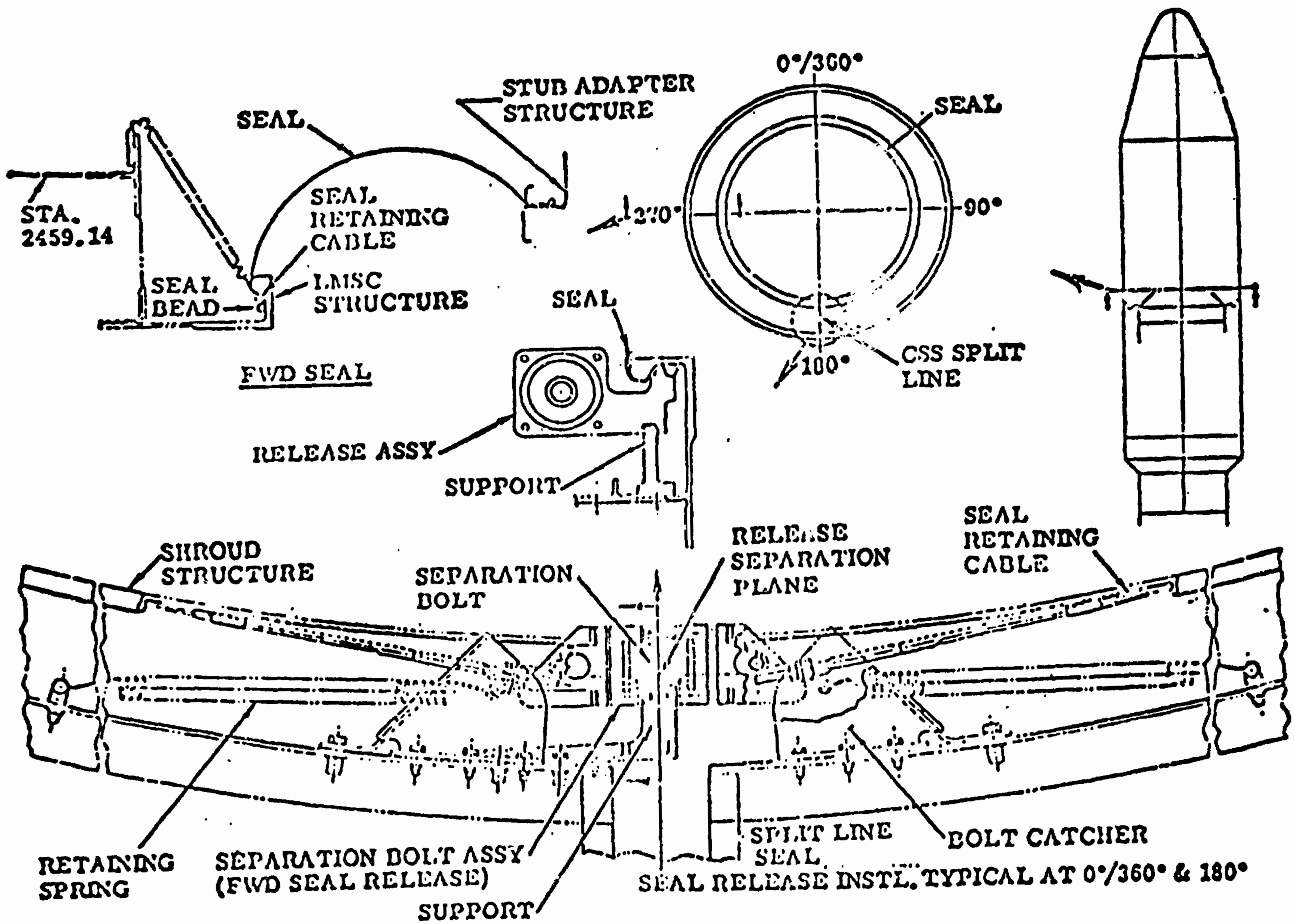


FIGURE 9-4 - FORWARD SEAL

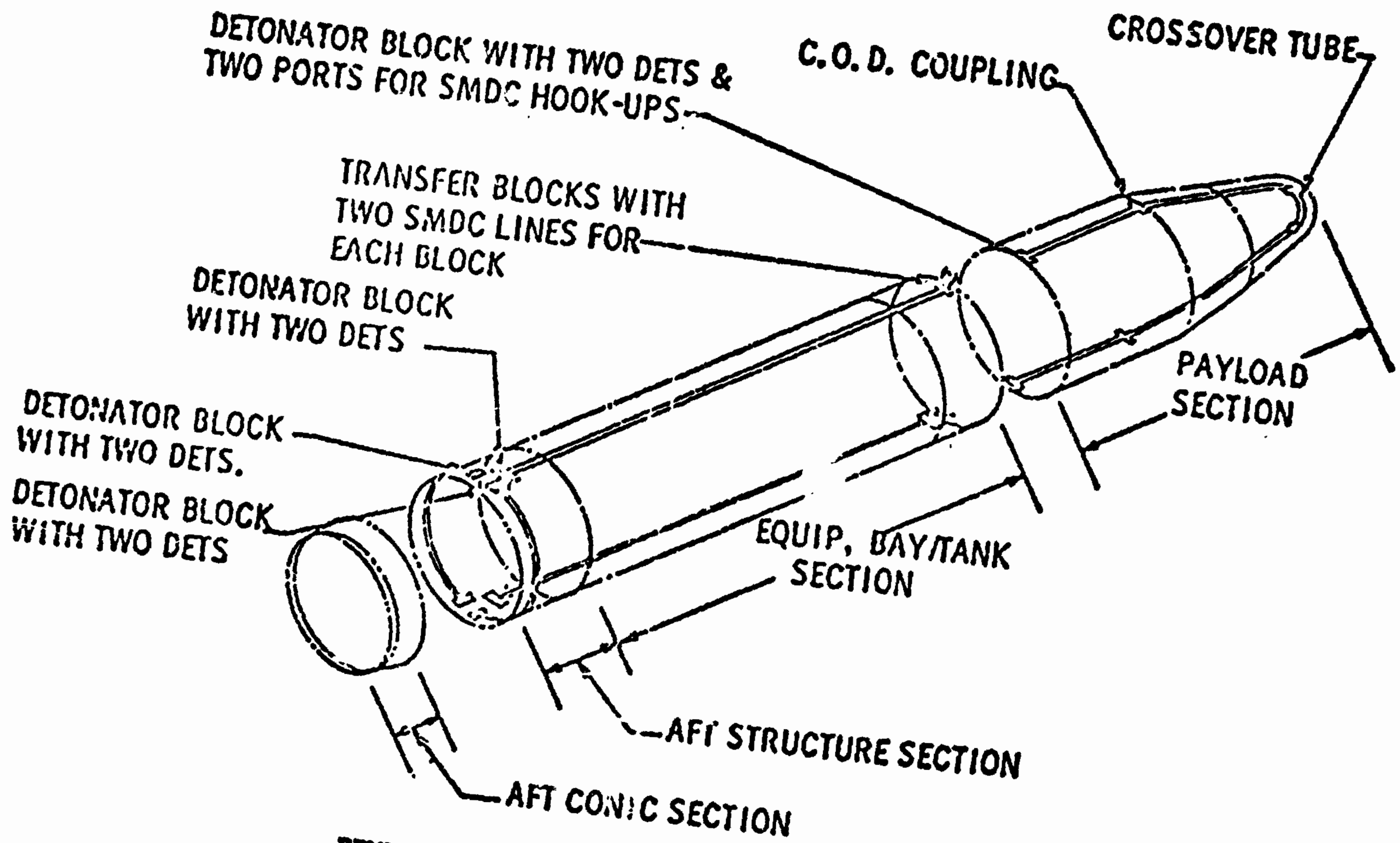


FIGURE 9-5 - SUPER * ZIP SEPARATION SYSTEM

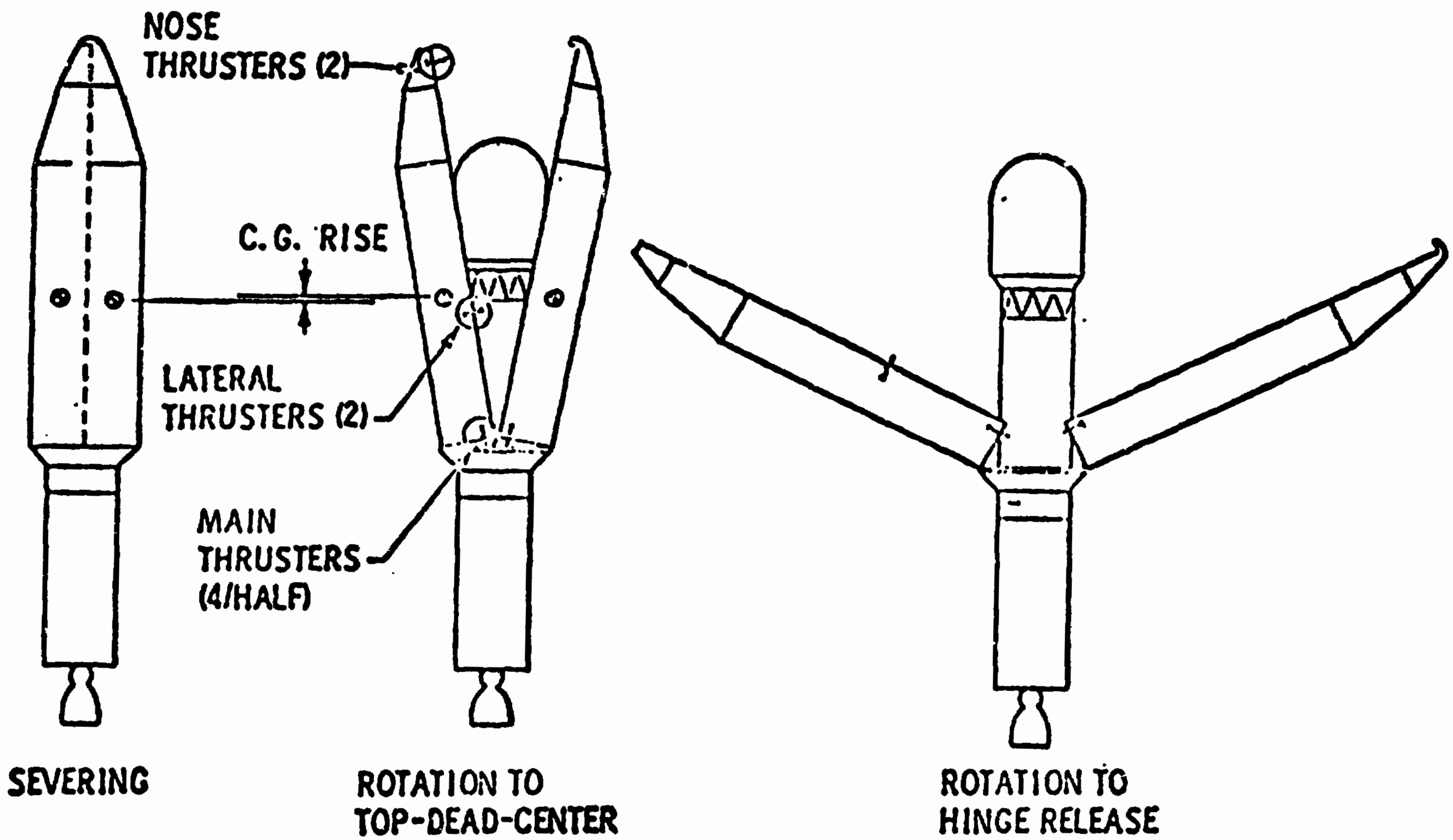


FIGURE 9-6 - JETTISON SEQUENCE AND SPRING LOCATION

TABLE 9-1 -
CSS BREAKWIRE SUMMARY

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

CSS Ascent Vent System

by W. K. Tabata

Summary

The CSS Ascent Vent System performed satisfactorily in-flight. The reduction in spacecraft compartment maximum dp/dt during transonic, expected by blocking two of the 11 vents was realized.

Discussion

Spacecraft Compartment - Time-pressure history of the spacecraft compartment is shown in Figure 9-7. The data agree well with TC-1 and TC-2. Blocking two of the 11 vents effected the compartment internal absolute pressure only insignificantly as predicted by preflight analysis. The maximum dp/dt during transonic was -0.67 psi/sec (Figure 9-8). The spacecraft bioshield experienced a maximum ΔP of 0.34 psi as predicted in the normal spacecraft venting case.

Titan 2A Compartment - Venting of the Titan 2A compartment was normal. Pressure-time history of the 2A compartment is shown in Figure 9-9 compared to TC-1 and TC-2.

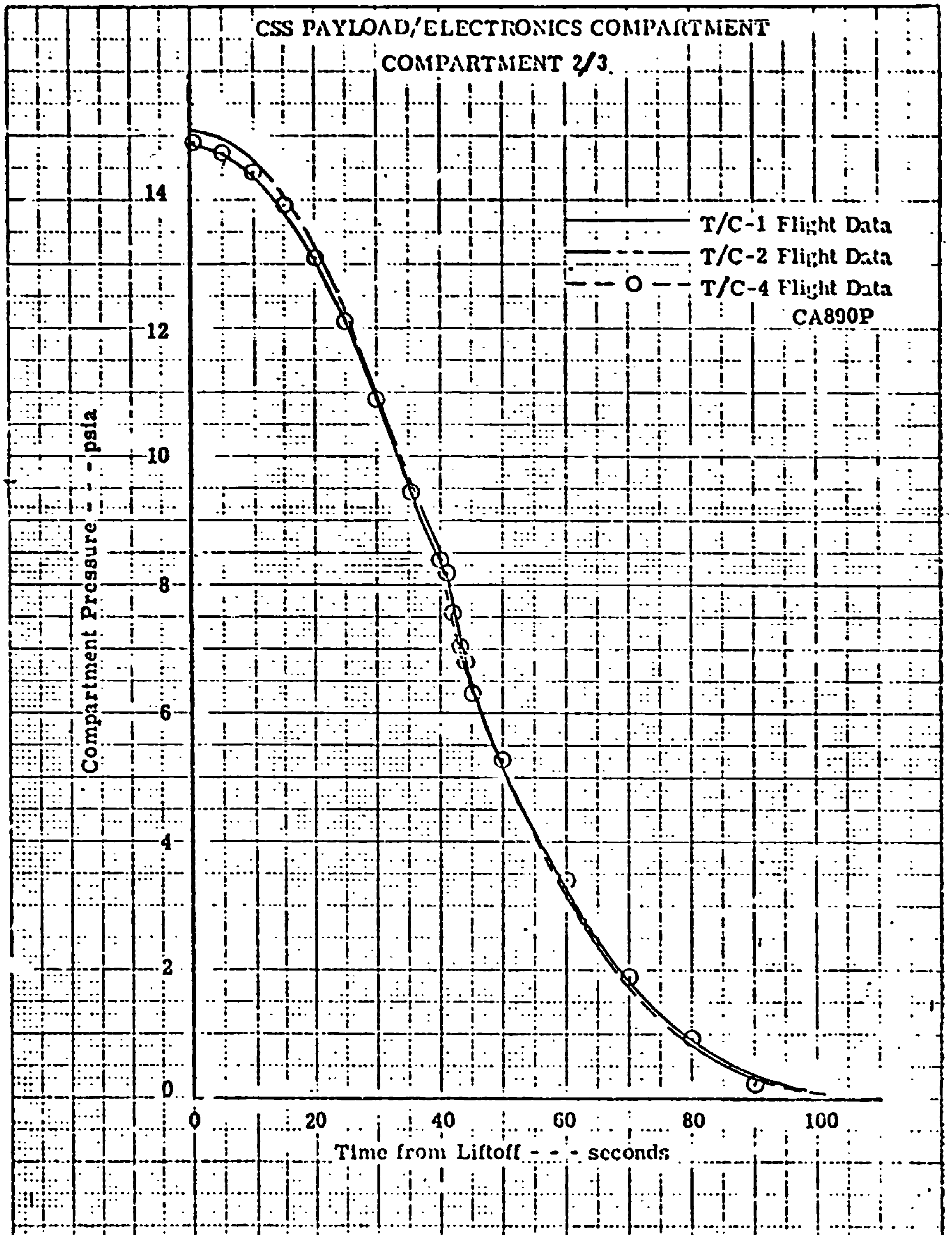


Figure 9-7 - CSS Payload/Electronics Compartment Pressure History

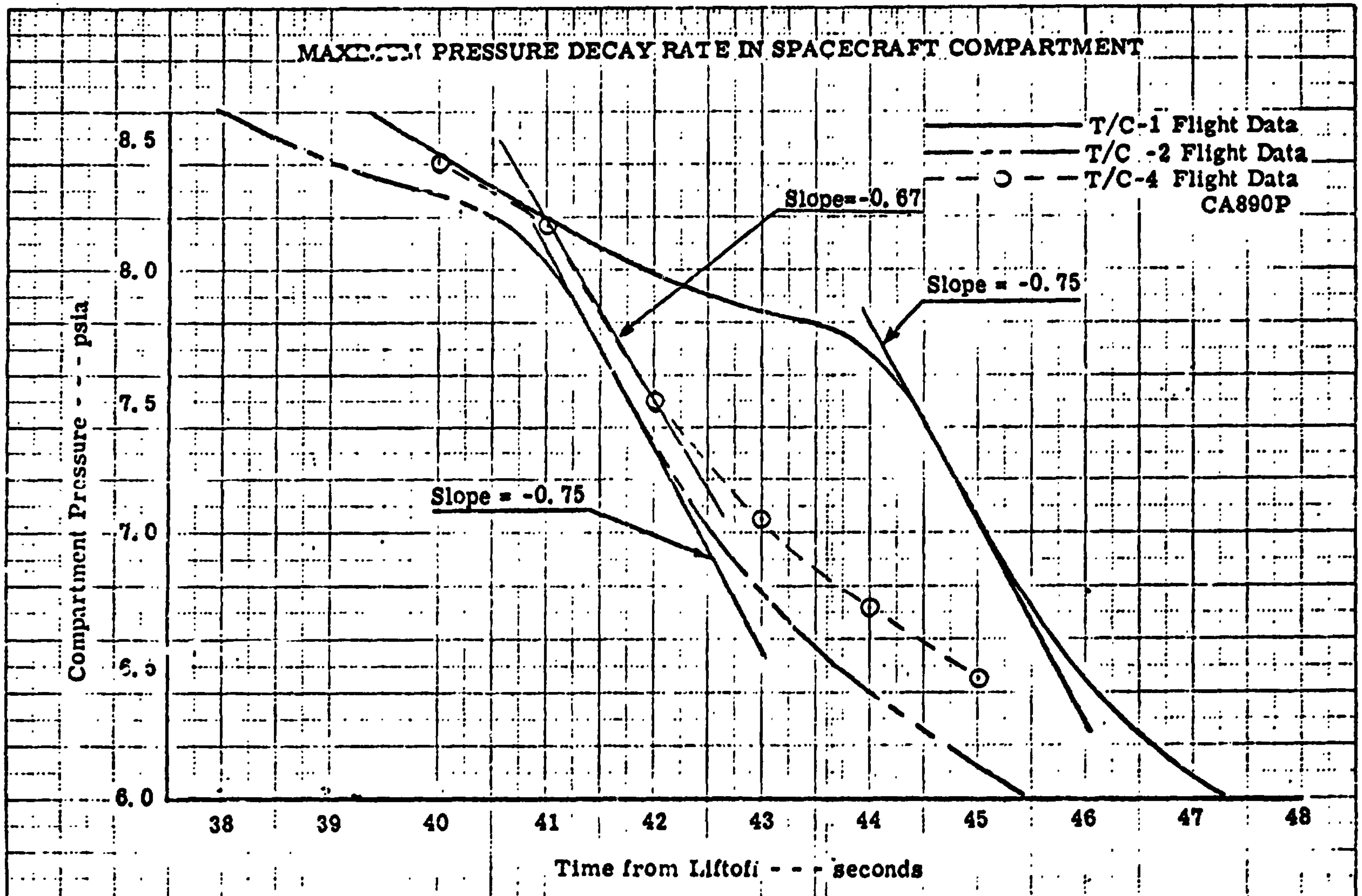


Figure 9-8 -Maximum Pressure Decay Rate in Spacecraft Compartment During Transonic

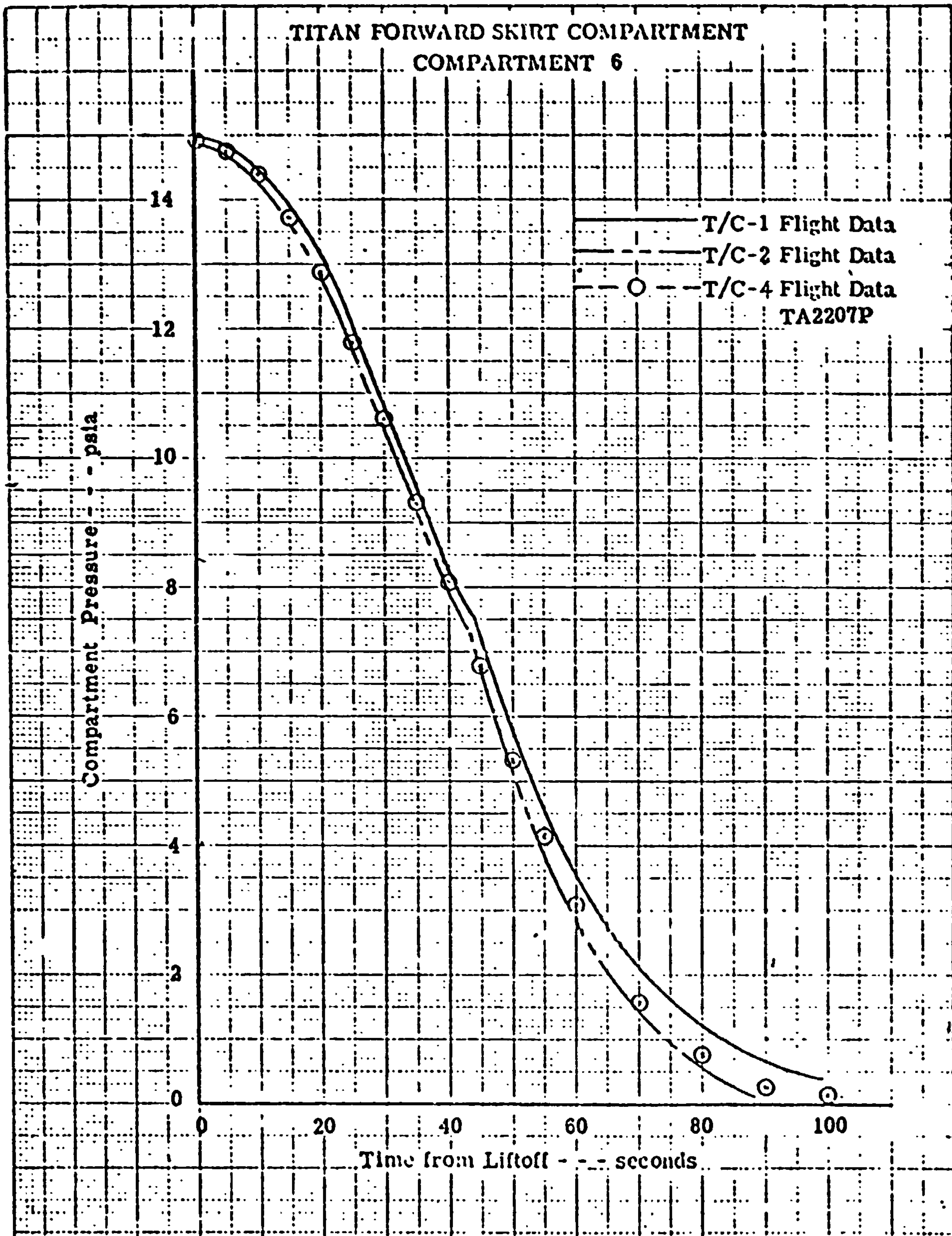


Figure 9-9 - Titan Forward Skirt Compartment Pressure History

X TITAN/CENTAUR GROUND SYSTEMS

X TITAN/CENTAUR GROUND SYSTEMS

by H. E. Timmons and A. C. Hahn

August 11, 1975, Launch Attempt - During the countdown for the first launch attempt on August 11, 1975, there were several minor instrumentation problems.

Between T-625 minutes and T-500 minutes, three landline measurements became noisy. Measurements CLS 452P and CFS 565R, both GDC measurements, required changing the calibrate relay in the Titan landline signal conditioner. Measurement 8703, which is the TVC tank pressure on SRM No. 2, required replacement of an amplifier card in the landline signal conditioner.

At T-350 minutes, measurement 8703 became inoperative. Troubleshooting could not immediately solve the problem. After the launch was scrubbed, it was determined that the measurement did not have the proper ground reference and was floating higher above ground than the PCM encoder could accept. The input to the signal conditioner from the transducer was connected to ground through a 1 megohm resistor, which cleared the problem. The associated SRM No. 1 measurement was likewise modified.

This launch was scrubbed at T-115 minutes when one of the TVC valves on SRM No. 2 did not respond to the VECOS flight controls test properly as noted elsewhere in this report.

August 20, 1975, Launch - The second countdown for the launch of TC-4 began at 5:47 a.m. on August 20, 1975, at T-625 minutes. During the entire countdown, the ground system functioned normally with the following reported anomalies:

One of two air-conditioning compressors on the MTR became noisy and was shut down. The compressor will be replaced/repaired prior to need date for TC-5.

The payload evaporator discharge temperature cycled after switch to GN_2. The cycling was between 32°F and less than 30°F and the maximum allowable of 40°F was not exceeded. The back pressure regulator was replaced after launch.

At liftoff, the 500 kw generator supplying the backup payload air-conditioner shut down. The suspected reason was lack of oxygen at the diesel air intake. When shutdown occurred, an automatic transfer switch operated to connect the air-conditioner to commercial power per design. The inrush current from the transfer action caused the motor control center circuit breakers which protect the blower and compressor of the unit to trip. The breaker protecting the GN_2 heater motor also tripped at this time. Post-launch, it was determined that the instantaneous trip setting of these breakers was set relatively close to the expected inrush current value. In anticipation of the launch of TC-3, the trip settings were increased by 25 to 30 percent by an adjustment on the breakers.

Several minor problems occurred after launch associated with the water deluge system. The Launch Control Console (LCC) operator failed to turn on the spacecraft area deluge water at T + 4.0 seconds per procedure. He later turned it on at T + 12 minutes for a short time to prove the system was operable. No ill effects were seen as a result of this oversight.

At T + 10 minutes, the LCC operator attempted unsuccessfully to turn off the water flow from the 4 nozzles at the base of the umbilical tower which spray the base of the transporter. After several attempts had failed, the safing crew was directed to manually shut the system off with a hand valve. The problem was isolated to an open solenoid valve in the system which was replaced and checked out during the post-launch water system tests.

Two other water deluge circuits failed to give the proper "on" indication on the LCC. This was the result of faulty limit switch contacts on the water valves. This problem was also corrected post-launch. The water flow was initiated properly in these two cases as it was verified by television.

A bend was discovered in the emergency helium line near the storage area after launch. The line was pressure tested at 125 percent of operating pressure and put back into service. Subsequent to the TC-3 launch, this section of piping was replaced and retested.

The post-launch data review produced 10 anomaly reports in the ground systems area:

Report GSE001 concerned a shift in current shunt trace CES33C, GSE/MTR bus current. This occurred during the plus count and is attributed to premature removal of the guard voltage.

Report GSE002 noted a series of noise bursts in current shunt trace CES221C, RSC Power Supply current. This also occurred post-launch at approximately T + 21 seconds. Subsequent investigation revealed corrosion buildup on some umbilical pins which, combined with the water deluge after liftoff, could have caused this anomaly.

Report GSE003 concerned the umbilical pull sequence on the Titan. Umbilical 2A1E came out first instead of fourth as had been predicted. All other umbilicals pulled properly. The lanyard system was investigated thoroughly and no out-of-tolerance rigging could be found. Investigation of launch films also shows nothing to explain the sequence. Since no adverse effects were experienced from this sequence, no changes are anticipated in the umbilical system.

Report GSE004 covered a problem which occurred during the boost pump spin test at T-45 minutes. After the initial spin startup, the nozzle box pressure increased 9 psi as measured by the airborne transducers. The transducers in the ground system did not show a corresponding increase. It was concluded that the shutoff valve in the system did not initially open completely. The valve was replaced and retested post-launch.

Report GSE005 was written with respect to the tripping of circuit breakers on the backup payload air-conditioner at liftoff. The breaker trip settings were increased as previously noted.

Report GSE006 covered a problem which occurred during spacecraft de-erection after the first launch attempt. During the demate activity, the chilled water disconnect on the pressure side was accidentally disengaged. Reconnection was accomplished in 5 1/2 minutes. The resultant rate and total temperature rise within the spacecraft was considered acceptable. To prevent a recurrence of this problem, a retaining collar was designed, fabricated and installed prior to the erection of the second Viking spacecraft.

Reports GSE007 and GSE008 were written to cover an anomaly in the data at liftoff. DRS channels 78, "Titan Tracking and Flight Safety Power Switch Internal," and channel 93, "CCLS Ready," both pulsed off for 3 milliseconds and back on. These pulses do not cause any undesirable effects on the system. A review of data from past launches indicates this occurs regularly and affects random channels.

Report GSE009 dealt with loss of data at the VIB ground station from approximately T + 2 minutes to T + 4 minutes. This was a problem with transmission of data from the Central Instrumentation Facility to the VIB. The data was available at other sites for evaluation.

Report GSE010 concerns a discrepancy between the analog pressure data and the Data Recording Set (DRS) data relative to the disconnect time of the Centaur LH_2 fill and drain valve. The analog data indicated a disconnect time of approximately 540 milliseconds. DRS data showed loss of the closed indication occurred 798 milliseconds after the command to disconnect was sent. The analog data corresponds favorably with both TC-1 and TC-2 data. The controller for the transducer was suspected. It was removed for failure analysis after TC-3 and replaced with another unit for TC-5 operations.

During the launch sequence the electrical umbilical and mechanical umbilical disconnect times were as shown in Table 10-1 and Table 10-2 respectively.

TABLE 10-1 - TC-4 ELECTRICAL UMBILICAL DATA

CMG T-0 (DRS channel 295 off) - 2122:00.116

Ignite SRM command (DRS 739) - 2122:00.137

SRM ignition relay closed (DRS 496) - 2122:00.155 (official T-0)

Titan Umbilicals	Time Disconnected	Time from Official T-0
2A1E	2122:00.503	T + 0.348
LB1E	2122:00.509	T + 0.354
RB1E	2122:00.527	T + 0.372
1C1E	2122:00.563	T + 0.408
2A2E	2122:00.602	T + 0.447
2C1E	2122:00.635	T + 0.480
Centaur Umbilicals		
B600P3	2121:56.975	T - 3.180
B600P2	2121:57.230	T - 2.925
B600P1	2121:57.503	T - 2.652
B600P4	2122:00.758	T + 0.603
B600P5	2122:00.878	T + 0.723

TABLE 10-2 - TC-4 MECHANICAL UMBILICAL DATA

Centaur

Event	Time	Time from CMG T-0
Aft Plate Eject Command	2121:56.156	T - 3.960
Aft Door Closed	2121:58.424	T - 1.692
Aft Plate Ejected	2121:58.427	T - 1.689
LH_2 Fill & Drain Valve Eject Command	2121:59.657	T - 0.459
LO_2 Fill & Drain Valve Eject Command	2121:59.660	T - 0.456
LO_2 Fill & Drain Valve Disconnected	2122:00.026	T - 0.090
LH_2 Fill & Drain Valve Disconnected	2122:00.20	T + 0.08*
Air-Conditioning Duct Disconnect Command	2122:00.137	T + 0.021

*Disconnect time for LH_2 fill and drain valve established from analog data on retract cylinder. Signal from valve controller to DRS indicated a total disconnect time of 0.798 seconds. Post-launch analysis proved DRS time anomaly was caused by a faulty controller.