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NASA TECHNICAL MEMORANDUM

NASA TM X-68249

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TITAN/CENTAUR -- NASA'S NEWEST LAUNCH VEHICLE

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TECHNICAL PAPER proposed for presentation at
Space Mission Planning and Executive Meeting for the
Launch Vehicle Issues Section sponsored by the
American Institute of Aeronautics and Astronautics,
American Society of Mechanical Engineers, and the
Society of Automotive Engineers
Denver, Colorado, July 10-11, 1973

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E-7505

Abstract

Titan/Centaur is NASA's last "new-expendable" launch vehicle prior to the advent of the Space Shuttle. Titan/Centaur is an adaptation of the Air Force Titan III booster with an improved version of the Centaur stage and a new 4.2 meters (14 feet) payload fairing. Titan/Centaur is initially being used for high performance escape missions (Helios Solar Probe - 340 kilograms (750 pounds), Viking Mars Orbiter and Lander - 3,629 kilograms (8,000 pounds), and Mariner Jupiter/Saturn Fly-Bys at 771 kilograms (1,700 pounds)) but is also particularly suited for larger spacecraft in synchronous orbits (transfer - 7,031 kilograms (15,500 pounds) and equatorial, with three Centaur burns - 3,175 kilograms (7,000 pounds)). The program which began in 1965 with internal NASA feasibility studies will culminate in a "Proof Flight" launch in early 1974. With the new payload fairing, which also encloses Centaur, payloads of nearly 8.5 meters (28 feet) long and 3.8 meters (12-1/2 feet) in diameter can be accommodated.

Culminating over five years of intensive planning, engineering, development, testing, launch site modifications, and hardware fabrication, NASA's proof flight of the Titan/Centaur launch vehicle is rapidly approaching.

Introduction

A little over a decade ago the Centaur program pioneered the use of high energy vehicles fueled with liquid oxygen and liquid hydrogen. Centaur has flown successfully with the Atlas booster delivering payloads to earth orbit, synchronous transfer orbit, and lunar and planetary trajectories.

The earlier version of Centaur has been improved and integrated with the modified Atlas booster. This Atlas/Improved Centaur launch vehicle system proved itself April 5, 1973, by placing the Pioneer 11 spacecraft on the proper trajectory to the planet Jupiter. The Improved Centaur is currently being integrated with the United States Air Force (USAF) Titan III booster and a new shroud system. The configuration of this new Titan/Centaur launch vehicle is shown in Figure 1. The overall length is 48.8 meters (160 feet) with a total lift-off weight of 6.4×10^5 kilograms (1.4×10^6 pounds). The Titan/Centaur will be used to launch operational payloads such as Helios, a joint undertaking between NASA and the Federal Republic of Germany Space Agency to investigate space near the sun; Viking, a combination Martian orbiter and lander, and Mariner Jupiter/Saturn, a fly-by of these planets.

History

The effort to integrate the Titan with the Centaur began in the mid-sixties. NASA-Lewis Research Center studies were conducted to define an Improved Centaur vehicle and to integrate the Centaur with the USAF Titan III booster. This development was undertaken because NASA recognized the need to fill a performance and cost gap between the Atlas/Centaur and Saturn launch vehicles. The unique capabilities of the Titan/Centaur, which provide a high energy restartable upper stage, fill the need for a launch vehicle capable of delivering larger and heavier payloads to interplanetary trajectories and synchronous orbits.

In the late sixties a contract was awarded to General Dynamics' Convair Aerospace Division to develop an Improved Centaur vehicle that would be adaptable to Atlas and Titan boosters. It would contain such new features as advanced electronics designed into an integrated astrionics system, modularized software, and mechanical modifications to increase reliability and operational flexibility. The Martin Marietta Corporation, Denver Division, during this same period, conducted studies for NASA to integrate the Titan III booster with the Improved Centaur and to investigate what modifications to the Titan launch facility at the Eastern Test Range would be required to checkout and launch the Titan/Centaur.

The next major events occurred rapidly, beginning in 1969, with the NASA decision to proceed with the Viking mission and selection of the Titan/Centaur as the launch vehicle. Thus, the advent of the Viking program gave the impetus to proceed with the Titan/Centaur development program. Overall management responsibility for the Titan/Centaur program was assigned to the NASA-Lewis Research Center. Subsequently, a series of agreements between NASA and the USAF established the ground rules for management of the Titan booster for NASA missions.

In 1970 the Lockheed Missiles and Space Company, Inc. was awarded a contract to develop the Centaur Standard Shroud. The shroud system is being developed to meet both the Centaur and Viking spacecraft requirements during ground and flight operations.

The culmination of the development effort will be the Proof Flight of the Titan/Centaur launch vehicle in the first quarter of 1974. This flight will demonstrate not only the capability to support missions such as Viking, but also demonstrate the capability for three-burn Centaur synchronous orbit missions.

Centaur Stage Description

The Improved Centaur (Figure 2), is being developed by General Dynamics' Convair Aerospace Division. It incorporates design changes necessary to meet new mission requirements and to incorporate certain redundancy and reliability improvements.

The Centaur uses liquid hydrogen and liquid oxygen as the propellants. These are contained in pressure-stabilized thin wall tanks. The propellant tanks are separated by a vacuum-insulated common bulkhead. A newly designed equipment module mounted on the forward end of Centaur provides for the support of the electronic and guidance equipment.

Increased Centaur coast (up to 5-1/4 hours), to provide improved synchronous orbit capability, is obtained by adding an aluminized mylar radiation shield to the hydrogen tank sidewalls. Radiation shielding and insulation have been added to cover the exposed portions of the aft and forward ends of the Centaur tanks.

Vehicle thrust is provided by two Pratt and Whitney Aircraft Corporation engines developing 66,720 newtons (15,000 pounds) thrust each. The Centaur tank pressurization and venting systems were modified to incorporate redundancy features and are controlled by the Centaur computer. Reliability improvements were made to the hydraulic system which provides the necessary force to gimbal the Centaur engines in response to guidance commands. The hydrogen-peroxide system for the propellant boost pumps and attitude control engines has been redesigned to incorporate redundancy features. Attitude control and propellant settling thrust are provided by 26.7 newtons (6 pounds) thrust hydrogen-peroxide engines mounted on the vehicle aft bulkhead. The engine arrangement, in conjunction with the Centaur computer software, can maintain vehicle stability in the event of a single engine failure.

The Centaur updated astrionics system, shown in Figure 3, integrates many former hardware functions into the airborne computer software. Guidance and control are accomplished using a newly developed Centaur Digital Computer Unit (DCU) built by Teledyne Systems Company. This computer is an advanced, high speed digital computer with extensive input and output capabilities. From the DCU, discrete signals are provided to the Sequence Control Unit (SCU). The SCU provides the necessary interface between the DCU and the vehicle systems that require switched and/or timed commands. Engine steering commands go to the Servo Inverter Unit (SIU). The SIU contains four servo-amplifiers. Each amplifier operates in conjunction with the hydraulic system to gimbal the engines. The SIU also contains the electronics for the propellant utilization system and an inverter which supplies vehicle ac power. Electrical power is provided by battery. Up to three batteries can be used to meet expanded mission requirements.

A stable platform and its electronics unit make up the Honeywell, Inc. Inertial Measurement Group (IMG). The IMG measures acceleration and provides a time reference for the DCU to make navigational computations. The IMG consists of two packages: the Systems Electronic Unit (SEU) and the Inertial Reference Unit (IRU). The SEU contains filters, power supplies, and mode control relays for the IRU. The IRU contains a four gimbal all-attitude stable platform. Three gyros stabilize this platform on which are mounted three pulse-rebalanced accelerometers. The IMG, in conjunction with the DCU, performs the navigation and guidance functions for the Titan/Centaur vehicle and also performs the flight control for the Centaur phase of flight. During the Titan boost phase of flight, guidance steering commands are provided by the Centaur guidance system to the Titan flight control system.

The flight software is modularized into several special purpose subroutines that operate under the control of a real time executive program. The executive calls on subroutines to perform various tasks such as guidance and navigation, sequencing telemetry, attitude control, and propellant mixture ratio management. This results in a flexible system readily adaptable to new missions through software rather than hardware changes.

The Centaur pulse code modulation telemetry system is a time division multiplexed system controlled by the DCU. Remote multiplexer units provide a convenient means for handling Centaur instrumentation.

Prelaunch checkout of the Centaur is accomplished using a ground computer called the Computer Controlled Launch Set (CCLS). The CCLS functions include calibration and alignment of the inertial measurement group, loading and verifying storage of Centaur computer programs, and testing of electronic systems.

Titan/Centaur Booster

The Titan/Centaur booster, designated Titan IIIE, is being 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 and sequence system were added. The Titan IIIE, illustrated in Figure 4, 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 10.6 million newtons (2.4 million pounds) at lift-off. 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 2.3 million newtons (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 445,000 newtons (100,000 pounds) thrust at altitude. The thrust chamber gimbals for flight control in pitch and yaw and the turbopump exhaust duct rotates to provide roll control during Stage II flight.

The Titan IIIE flight control system is illustrated in block diagram form in Figure 5. The 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. With the addition of the Centaur inertial guidance system interface, a roll axis interface 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 package, and other circuits were added to provide redundancy. Also, interfaces were added with the Centaur and Centaur Standard Shroud for staging and shroud jettison.

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

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

Many of the modifications to the Titan for Titan/Centaur were made to incorporate redundancy and reliability improvements. In addition to those modifications previously mentioned, a fourth retro-rocket 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. This feature, coupled with the large degree of commonality between the various configurations of the Titan, retains for the Titan IIIE the proven reliability of the Titan family.

Additional details of the Titan III family may be found in Reference 1.

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. It is currently under development by Lockheed Missiles and Space Company, Inc. and NASA-Lewis Research Center. The Centaur Standard Shroud, as shown in Figure 6, consists of three major segments: a payload section, a tank section, and a boattail section. The 4.27 meters (14 feet) diameter of the shroud was selected to accommodate the 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 4.27 meters (14 feet) shroud diameter to the 3.05 meters (10 feet) 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 provides a protective shell around the Centaur and payload and protects them from air loads and temperatures in excess of 505 degrees Kelvin (450 degrees Fahrenheit) as the vehicle rises through the earth's atmosphere. Shroud insulation is as shown in Figure 7.

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 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 (Figure 8).

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.

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. The entire separation sequence occurs in a period of about four seconds.

The Centaur Standard Shroud provides a large, environmentally protected volume for the spacecraft. An envelope of the volume available to the spacecraft is illustrated in Figure 9.

The Centaur Standard Shroud is undergoing development and qualification testing at the NASA-Lewis Research Center's Plum Brook Station. Three series of tests are being run on the shroud to demonstrate its ability to protect the Centaur and payload during ground hold operations and during ascent through the atmosphere. The first series of tests is complete and has verified that the shroud will (1) thermally protect the Centaur when it is tanked with cryogenic propellants and (2) unlatch or jettison from the Centaur under cryogenic conditions. The second series of tests will verify the structural design of the shroud. The third series of tests will prove that the shroud will jettison successfully at simulated altitude after it is subjected to heating that simulates the aerodynamic heating during ascent.

Launch Facility

The Titan/Centaur vehicles will be launched from Complex 41 at the Cape Kennedy Air Force Station under the direction of the NASA-John F. Kennedy Space Center's Unmanned Launch Operations organization. Launch Complex 41 is a part of the Air Force's East Coast Titan launch center, the Integrate-Transfer-Launch (ITL) facility.

The ITL facility is shown in Figure 10. It consists of solid rocket motor servicing and storage areas; a Vertical Integration Building (VIB); a Solid Motor Assembly Building (SMAB); Launch Complexes 40 and 41, and a double-track locomotive system which transports the mated Titan core and Centaur vehicle from the VIB through the SMAB to Launch Complex 41.

The Titan, Centaur, and Centaur portion of the shroud are erected and mated in the VIB on a mobile transporter/umbilical mast structure. Attached to the transporter are three vans housing launch control and monitoring equipment which remain connected to the transporter and vehicle throughout the receipt-to-launch sequence. Upon completion of integrated tests in the VIB, the assembled Titan and Centaur are moved on the transporter to the SMAB. After the SRM's and core stages are structurally mated, the vehicle is moved to the launch complex. A mobile service structure provides access to all vehicle stages. An environmental enclosure provides protection for the Centaur and the spacecraft. The spacecraft prelaunch operations include checkout and encapsulation in the payload section of the shroud and mating of the encapsulated spacecraft to Centaur at the launch complex. The processing of the elements of the launch vehicle from receipt to launch is shown in Figure 11.

Modifications at the ITL to support the Titan/Centaur and spacecrafts included addition of Centaur propellant and gas services, expansion of electrical power and air conditioning, and addition of launch control monitoring equipment. Modifications were made to handle and to give access to the Titan/Centaur vehicle and the spacecraft. The Computer Controlled Launch Set (CCLS), discussed previously, is physically located at Launch Complex 36. The CCLS supports both the Atlas/Centaur and Titan/Centaur programs.

Titan/Centaur Proof Flight

The first flight of the Titan/Centaur launch vehicle, scheduled for the first quarter of 1974, is a "Proof Flight" designed to demonstrate the capability of the launch vehicle and its associated ground systems to support operational missions. In addition, a series of propellant management experiments will be conducted to demonstrate the capability of the Centaur vehicle to coast for 5-1/4 hours in a zero gravity environment, to support two-burn missions with extended parking orbit coast phases, and to support three-burn synchronous orbit missions.

The payload will consist of a mass model of the Viking spacecraft and a secondary spacecraft called the SPHINX (Space Plasma High Voltage Interaction Experiment). The Viking mass model, which weighs approximately 3,545 kilograms (7,800 pounds), is a dynamic representation of the Viking spacecraft. The SPHINX spacecraft weighs approximately 91 kilograms (200 pounds). The project is managed by NASA-Lewis Research Center and is designed to obtain scientific data. These data will assist in establishing the design and test criteria of high voltage systems for future spacecraft. The Proof Flight trajectory profile is shown in Figure 12. The initial phase of flight through the second Centaur main engine cutoff will simulate the Viking trajectory. The Centaur vehicle will then be programmed to coast in zero gravity in a relatively low earth orbit for about 80 minutes. Following a third Centaur burn, the SPHINX spacecraft will be separated. The Centaur vehicle and the mass model will continue to coast in zero gravity for about 5-1/4 hours. The fourth Centaur burn will occur near synchronous altitude.

Titan/Centaur Performance Capability

As was noted previously, the Titan/Centaur was added to the NASA family of launch vehicles to fill a performance gap between the Atlas/Centaur and Saturn V launch vehicles. The performance data presented in Figure 13 for the Atlas/Centaur, Titan/Centaur, and the Saturn V vehicles clearly illustrate that Titan/Centaur has accomplished this goal. Performance data are also presented for the Titan/Centaur vehicle with a spin-stabilized TE-364-4 solid rocket motor stage required for high energy missions such as Jupiter fly-bys.

These data are based on the following ground rules:

1. Parking orbit ascent.

2. Launch azimuth - 90 degrees.

3. Parking orbit altitude - 167 kilometers (90 nautical miles).

4. Three sigma flight performance reserves.

5. Launch vehicle contingency - 68 kilograms (150 pounds).

6. Payload capability includes separated spacecraft, spacecraft adapter, and any other mission peculiar equipment.

The representative Titan/Centaur payload capability for specific missions includes:

1.	Circular low earth orbit	- 15,422 kilograms (34,000 pounds)
2.	Synchronous transfer	- 7,031 kilograms (15,500 pounds)
3.	Planetary ($C_3 = 20\ km^2/sec^2$)	- 3,629 kilograms (8,000 pounds)
4.	..ynchronous orbit (three-burn Centaur)	- 3,175 kilograms (7,000 pounds)

A Titan/Centaur ascent profile and major flight event times are presented in Figure 14 for an operational two-burn mission with a 30 minute parking orbit coast phase.

A more detailed discussion on Titan/Centaur performance capability is contained in Reference 2.

Launch Schedule

The introduction of the Titan/Centaur launch vehicle in 1974 will usher in a new era of planetary and solar exploration. Figure 15 presents the current NASA planning for missions using the Titan/Centaur launch vehicle. The missions include solar probes, Mars landers, Jupiter/Saturn fly-bys, Jupiter/Uranus fly-bys, direct flights to Saturn, and a Comet Encke fly-by.

References

1. Driggers, G. W., "Short Guide to Titan III Launch Vehicles," Astronautics and Aeronautics, Volume 11, No. 2. Feb. 1973, pp. 68-73.

2. Anon.: "Centaur Mission Planner's Guide," Rev. A, Oct. 11, 1973, General Dynamics' Convair, San Diego, Calif.

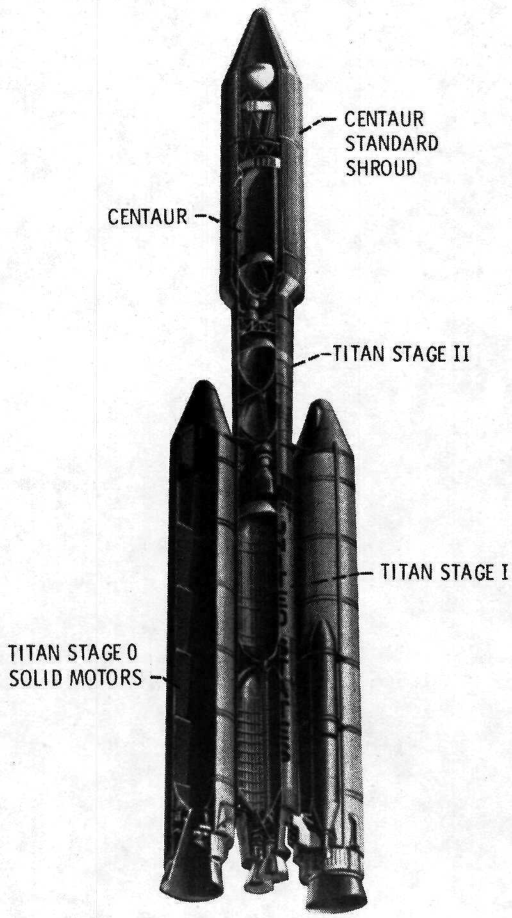

Figure 1. - Titan/Centaur launch vehicle.

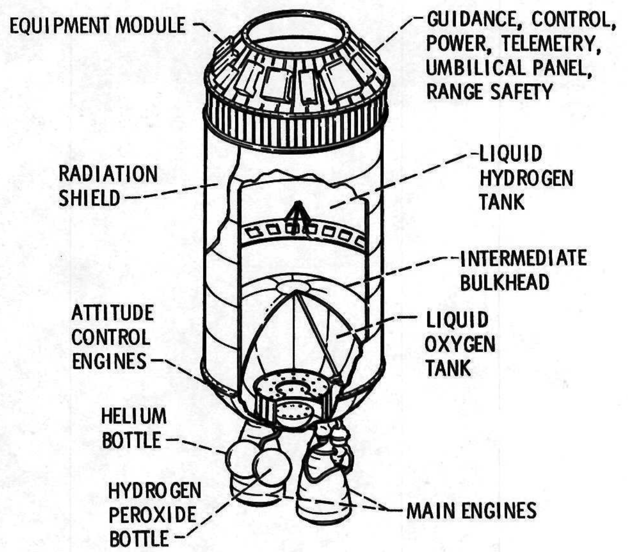

Figure 2. - Improved Centaur.

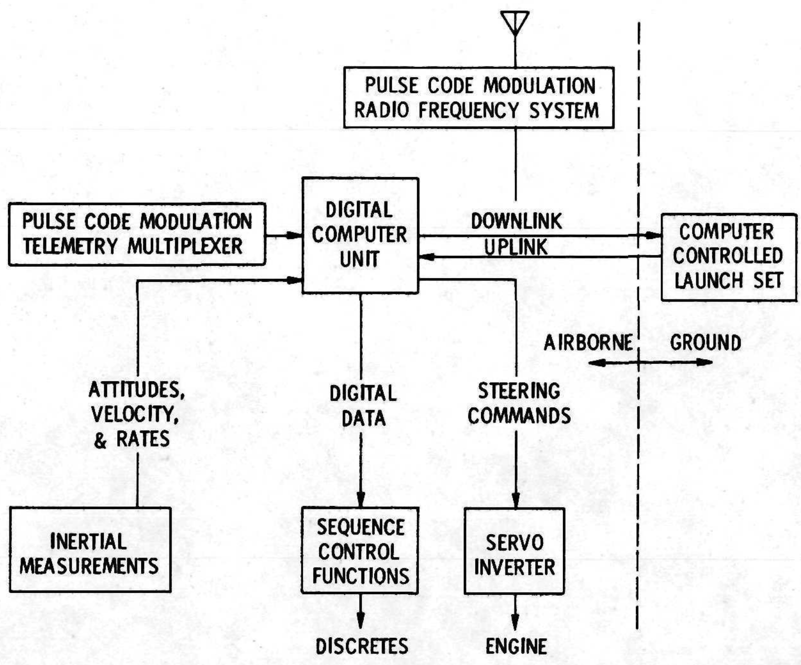

Figure 3. - Centaur astrionics block diagram.

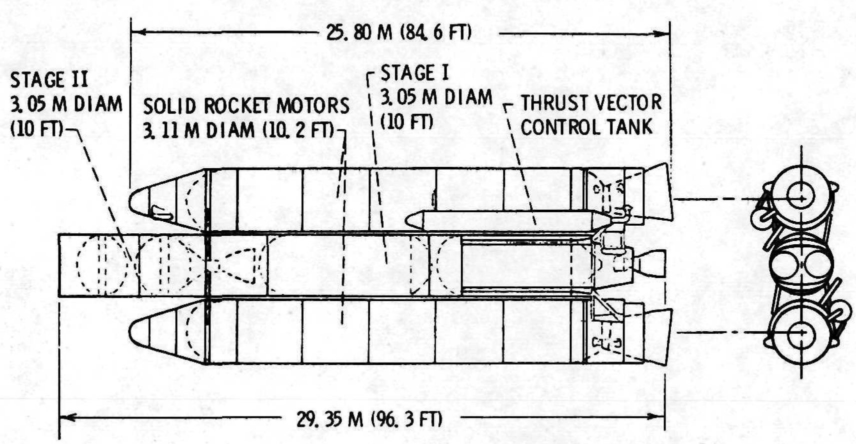

Figure 4. - Titan IIIE booster.

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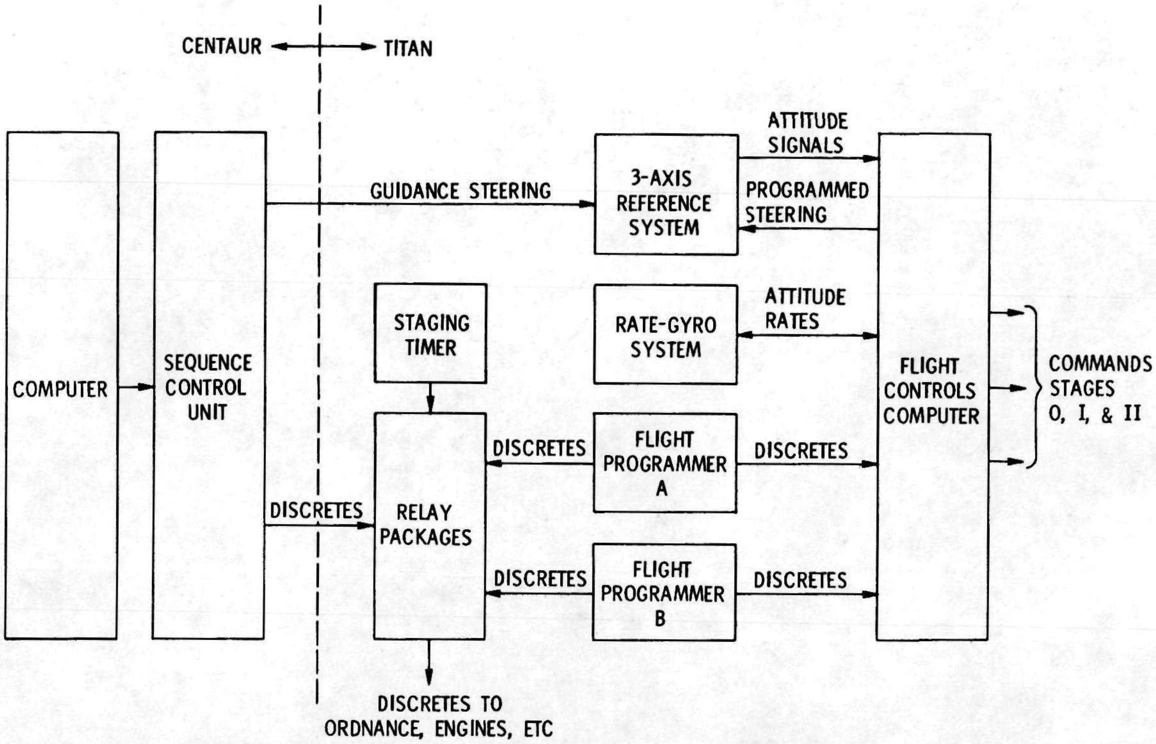

Figure 5. - Titan IIIE flight control system.

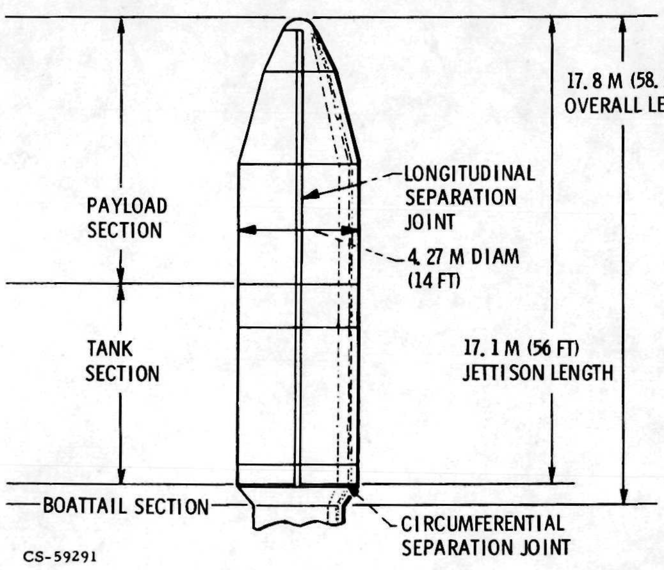

Figure 6. - Centaur standard shroud.

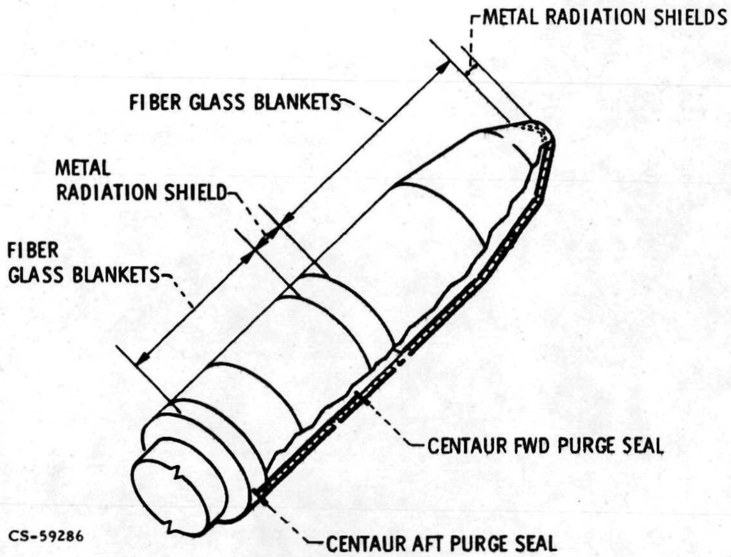

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Figure 7. - Shroud insulation.

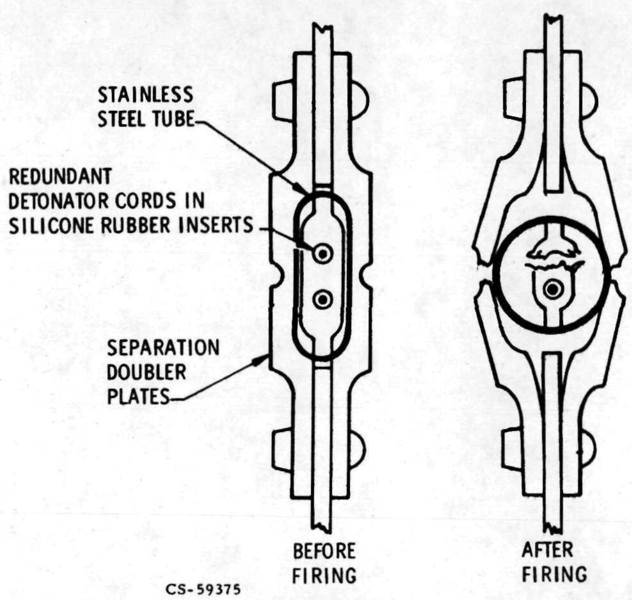

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Figure 8. - Centaur standard shroud separation joint.

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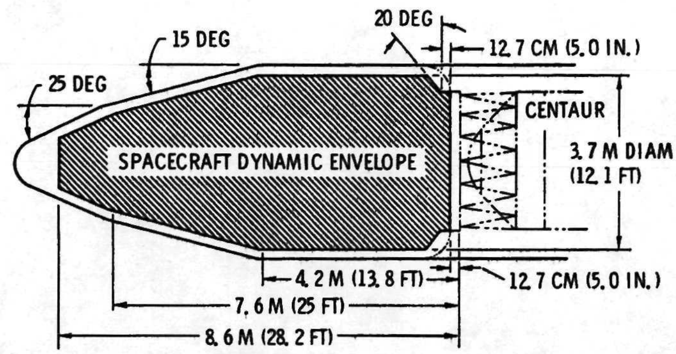

Figure 9. - Spacecraft envelope with Centaur standard shroud.

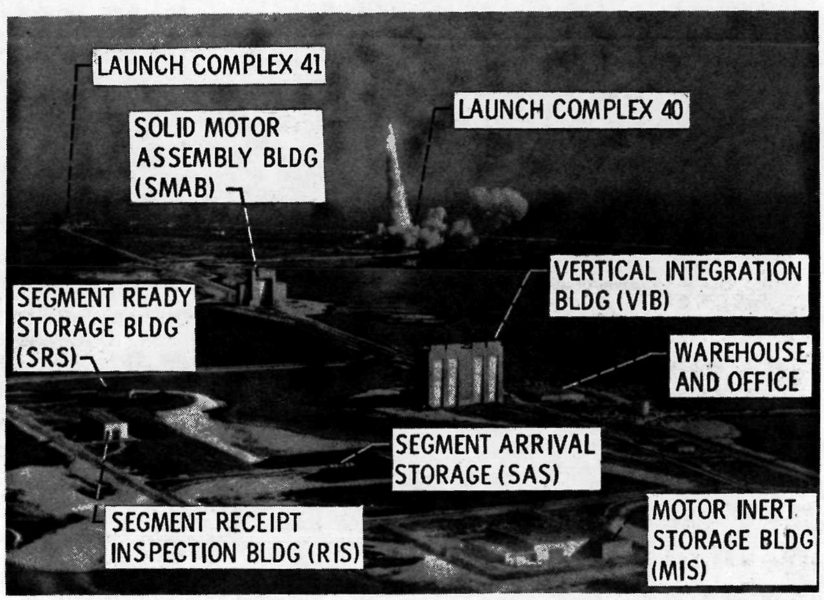

Figure 10. - CKAFS integrate-transfer-launch facilities.

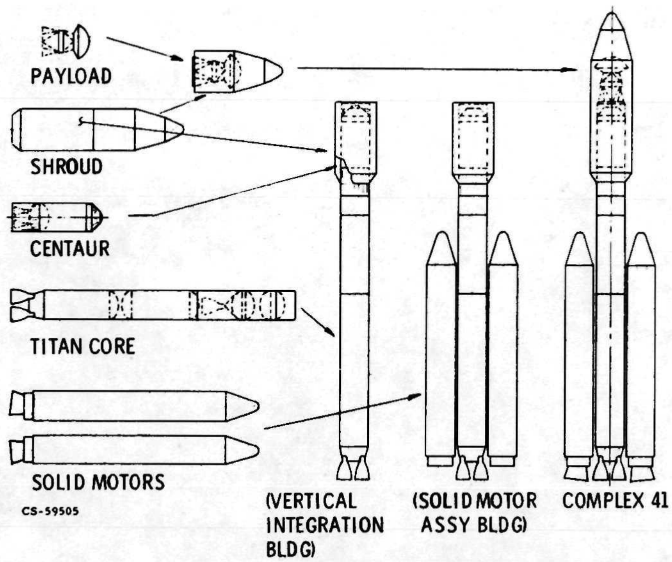

Figure 11. - Prelaunch hardware assembly at the integrate-transfer-launch facility.

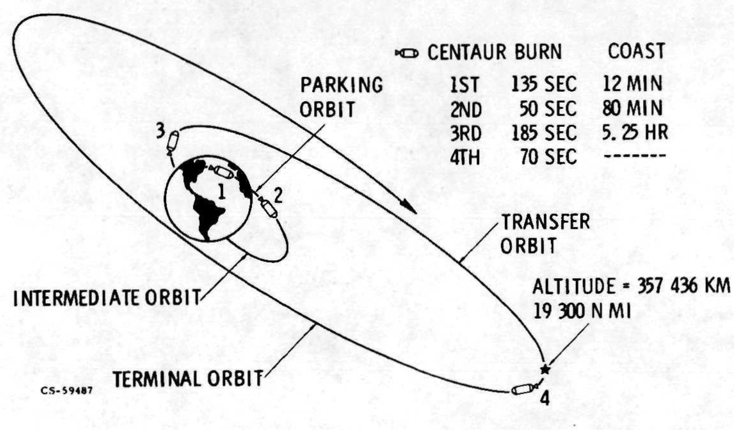

Figure 12. - Titan/Centaur proof flight trajectory.

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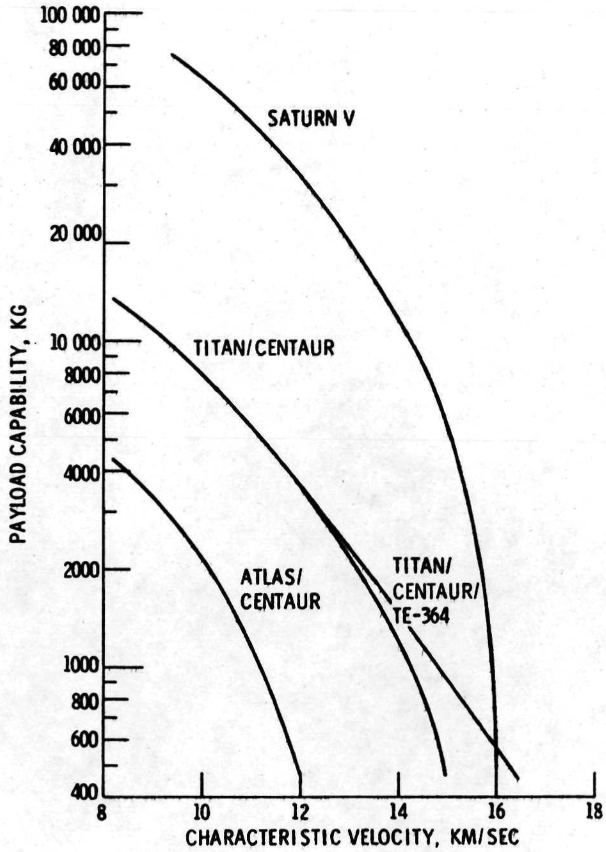
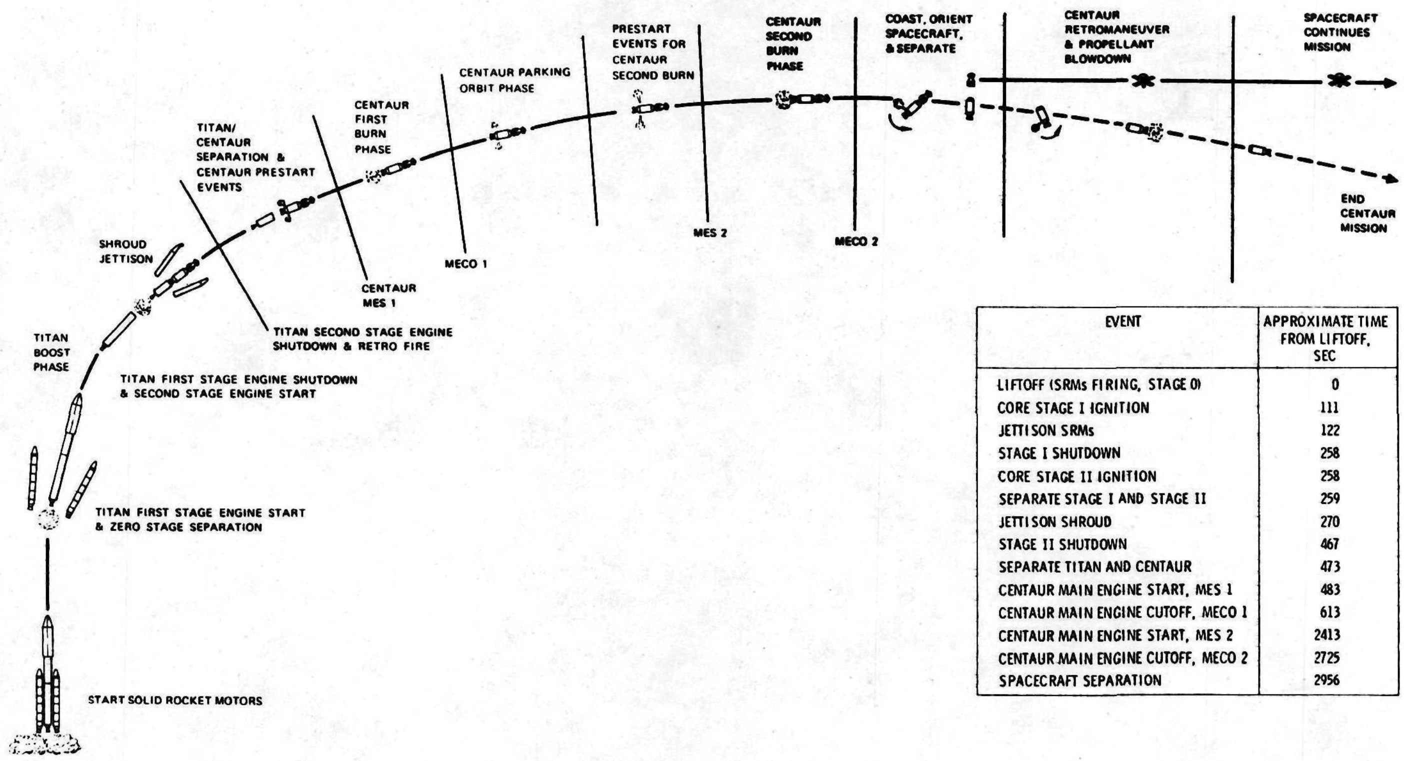


Figure 13. - Titan/Centaur performance capability.



EVENT	APPROXIMATE TIME FROM LIFTOFF, SEC
LIFTOFF (SRMs FIRING, STAGE 0)	0
CORE STAGE I IGNITION	111
JETTISON SRMs	122
STAGE I SHUTDOWN	258
CORE STAGE II IGNITION	258
SEPARATE STAGE I AND STAGE II	259
JETTISON SHROUD	270
STAGE II SHUTDOWN	467
SEPARATE TITAN AND CENTAUR	473
CENTAUR MAIN ENGINE START, MES 1	483
CENTAUR MAIN ENGINE CUTOFF, MECO 1	613
CENTAUR MAIN ENGINE START, MES 2	2413
CENTAUR MAIN ENGINE CUTOFF, MECO 2	2725
SPACECRAFT SEPARATION	2956

Figure 14. - Typical Titan/Centaur flight profile for a two-burn mission.

MISSION	1974	1975	1976	1977	1978	1979	1980
PROOF FLIGHT	▼						
*HELIOS (SOLAR PROBE)	▼		▼				
VIKING (MARS LANDER)		▼▼				▽	
MARINER 77 (JUPITER/SAT)				▼▼			
MARINER 79 (JUPITER/URANUS)						▽▽	
*PIONEER SATURN						▽	
*COMET ENCKE FLYBY							▽

*REQUIRES SPIN-STABILIZED TE-364-4 STAGE

▼ APPROVED
▽ PROPOSED

Figure 15. - Titan/Centaur launch schedule.

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