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THE DELTA LAUNCH VEHICLE CAPABILITIES, CONSTRAINTS AND COSTS FOR THE "STRAIGHT 8", MODEL 2914 SERIES

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SEPTEMBER 1971

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

The new Delta launch vehicle, Model 2914, is described for potential users. A functional description of the vehicle, its performance, flight profile, flight environment, spacecraft integration requirements, user organizational interfaces, launch operations and launch costs are provided.

The new three stage Delta offers users greater payload capability, an eight (8) foot diameter spacecraft envelope and greater available volume for attachment of secondary experiments or satellites to the expended orbiting second stage. The first stage Universal Boattail Thor (UBT) liquid propellant capacity is increased to 175,000 pounds from 145,000 pounds and the high performance H-1 engine developed for the Saturn 1B vehicle is adapted to the stage which can be thrust augmented with up to nine strap-on Castor II (TX-354-5) solid propellant motors, depending on mission performance requirements. The Delta second stage, recently uprated with a new propulsion system and a strap-down inertial guidance system, is suspended by an eight foot diameter adapter ring that joins the eight foot diameter UBT and new metal fairing. The third stage is the spin stabilized TE-364-4 solid propellant motor.

The Delta Model 2914 is to be available in mid 1973, cost about $5 1/2 million, and capable of injecting 4,500 pounds into low earth orbit, 1,550 pounds into geosynchronous transfer or escape about 1,000 pounds of payload.

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INTRODUCTION

Delta is a medium class launch vehicle that carries over fifty percent of NASA's unmanned spacecraft each year. This versatile, relatively low cost vehicle that also is used by private industry and foreign governments to launch their scientific and applications satellites has a flight demonstrated reliability record of 93 percent that has been established in 84 launches over an eleven year span while concurrently undergoing nine major upratings to keep pace with the ever increasing requirements of its users. Delta offers mission planners a broad spectrum in performance capability together with unprecedented mission flexibility and a quick response capability to call-up follow-on missions. The vehicle is configured on its new Universal Boattail Thor (UBT) booster in either two or three stages, with thrust augmentation of the booster ranging from three to nine strap-on solid propellant motors. Mission peculiar trajectory and special spacecraft sequencing requirements is programmed by software changes in the new Delta strap-down inertial guidance system computer rather than by hardware adjustments. This provides users broad flexibility and accommodates late changes in mission requirements. Further, on those missions where Delta's performance exceeds the requirements of the primary mission, support and separation systems are qualified and flight proven for carrying secondary experiments or ejectable satellites on the Delta second stage with options for precise on-orbit attitude orientation for long durations.

The newest uprated Delta, Model 2914, that is to be available in early 1973 for launch from both the Eastern Range (ETR) in Florida and the Western Test Range (WTR) in California is described for potential users together with its capabilities constraints, and costs.

DELTA

The Evolution of Delta

The evolution of the Delta launch vehicle, shown in Figure 1, reaches back sixteen years when, in 1955, the United States participated in the International Geophysical Year (IGY) and undertook the development of the Vanguard three-stage launch vehicle; in the same year the Air Force initiated the development of the Thor IRBM. With modifications, the Thor became the first stage of Delta;

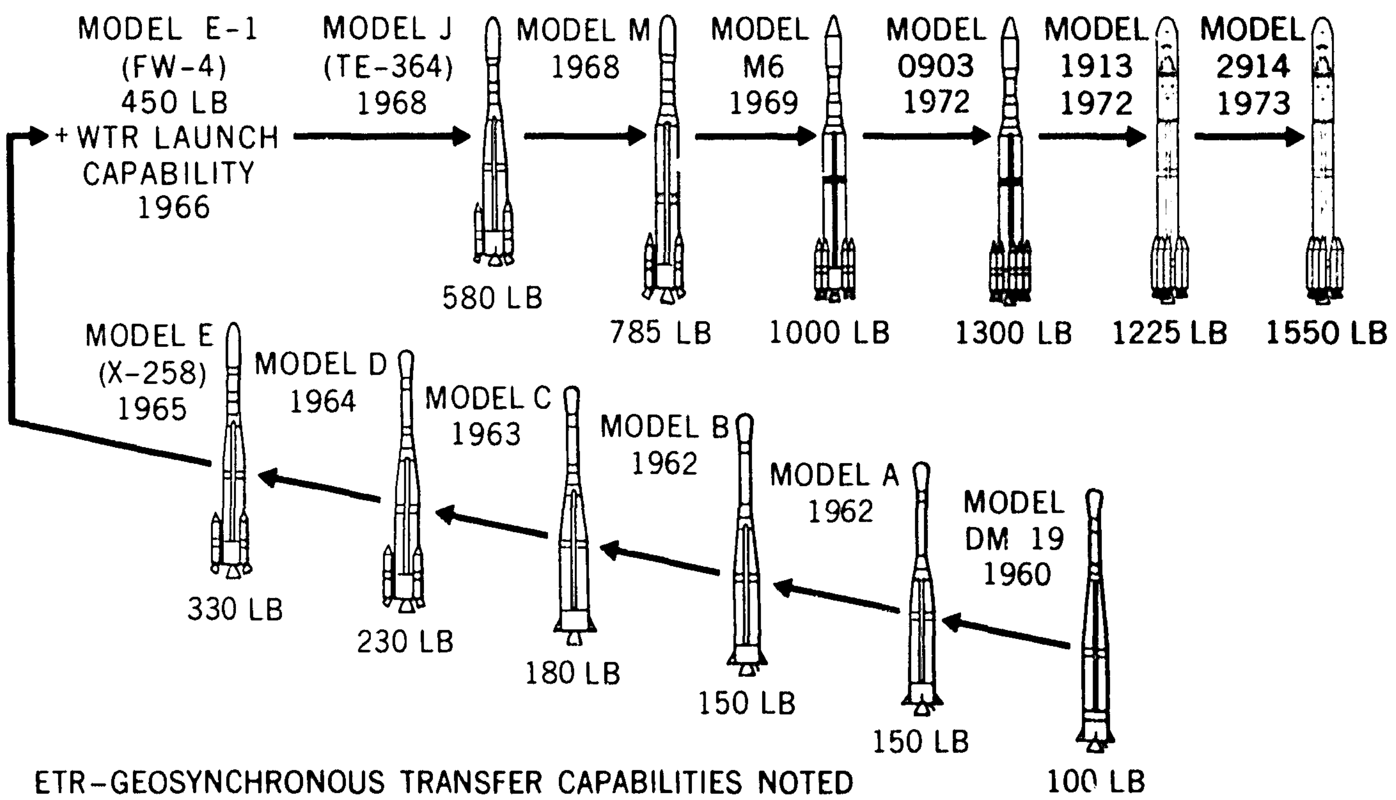


Figure 1. Delta Evolution

the Vanguard second stage propulsion system, evolved through the Able programs, became the Delta second stage propulsion system; and the Vanguard X-248 third stage solid propellant rocket motor was adapted as the third stage for Delta. The development and integration of these systems and the production of twelve (12) vehicles was started in early 1959 under prime contract to the Douglas Aircraft Company, now McDonnell-Douglas Astronautics Corporation (MDAC). The initial objective of the Delta program was to provide an interim space launch vehicle capability for the medium-class payloads until more sophisticated vehicles as Scout and Agena, then under development, could be brought to operational status. The development program spanned 18 months. In a little over two years, following the development period, eleven of the twelve vehicles were launched successfully carrying, among others, the first passive communications satellite, Echo I (August 1960), the cooperative NASA/United Kingdom Ariel I (April 1960), the TIROS II through VI series, the first Orbiting Solar Observatory, and the first private industry satellite, American Telephone and Telegraph Telstar I (July 1962). The total development cost, including the twelve vehicles (Model DM-19) and launch support, was approximately $43,000,000, compared to the $40,000,000 estimated at the outset of the program.

Before the development program was complete the number of missions planned for Delta outstripped the interim buy of twelve vehicles, so an order was placed for fourteen additional vehicles. This follow-on buy of Deltas (Models A and B) incorporated lengthened second stage propellant tanks, a higher energy second stage oxidizer, transistorized guidance electronics, and assiduous application of high-reliability semiconductors in flight critical circuits. This model of Delta carried NASA's first active communications satellite, Relay I (December 1962), and the first synchronous satellites, Syncom I and II (February and July 1963).

The next production order of Deltas (Models C and D) in 1963 brought the adaption of the USAF developed improved Thor booster with thrust augmentation provided by three strap-on solid propellant motors and the adaption of the Scout developed X-258 to replace the X-248 third stage motor. The first thrust augmented Delta (TAD) carried Syncom III (August 1964), the first equatorial synchronous communications satellite. The second TAD vehicle orbited the first commercial communications satellite, The International Communications Consortium's Early Bird Satellite (April 1965).

Another order of Deltas in 1964 brought the development of the Improved Delta (Model E). The Improved Delta model adapted and extended the large diameter propellant tanks from the Able-Star stage, and thereby nearly doubled the propellant capacity of the previous Delta second stage. The larger diameter tanks in addition permitted adaption of the five foot diameter Nimbus fairing developed for the USAF Agena stage. Improved Delta also adapted the USAF developed United Technology Corporation's FW-4 solid propellant motor to replace the X-258 third stage motor (Model E1). The first Improved Delta was launched November 1965 and among the missions carried on this model of Delta are the near polar Geophysical Orbiting Satellites, GEOS A and B; the heliocentric Pioneer series A through D; the low earth orbiting Biological Satellite, BIOS A through C; the synchronous communications satellites, Intelsat F1 through F4; the lunar orbiting Anchored Interplanetary Monitoring Probe, A-IMP A and B; the sun-synchronous ESSA 2 through 6; the High Eccentric Orbiting Satellite, HEOS developed by the European Space Research Organization and the Canadian International Satellite for Ionospheric Studies, ISIS.

In 1966 Delta undertook to adapt the Surveyor spacecraft solid propellant retromotor as a new third stage. The spherical case was modified to mate to a spintable assembly and the motor, designated TE-364-3, was requalified for the Delta spinning environment. The first Delta using this third stage motor, Delta Model J, was launched in July 1968 and carried the Radio Explorer, RAE-A spacecraft.

At about the same time Delta initiated the adaption of the TE-364-3 motor, the USAF undertook the uprating of the Thor booster by lengthening the liquid oxygen and RP-1 fuel tanks and converting the fuel tank to a constant 8 foot diameter. This Long Tank Thor carries about 47 percent more propellants than previous models. In September 1968, Delta launched its first Long Tank Thor with the

Improved Delta second stage and TE-364-3 third stage. The Delta Model M carried, among others, the Intelsat III series and the British Skynet and NATO communications satellites.

In early 1968, Delta started a redesign and retrofit of the Long Tank Thor engine section to permit the addition of a second set of three thrust augmentation solid motors. The first Delta Model M6 with six solid motors was launched from the Western Test Range in January 1970 and carried the NASA TIROS Operational Satellite, TOS-M into a 800n.mi. circular sun-synchronous orbit. The two remaining Delta Model M6 vehicles have been used to carry the Interplanetary Monitoring Probe I and the ITOS-A spacecraft.

In 1969, Delta was again uprated in performance capability and also in guidance accuracy. The Delta Model 0903 introduced the Universal Boattail Thor (UBT), with a new engine section on the first stage that is designed to accommodate attachment of up to nine (9) thrust augmentation solid motors; an uprated second stage propulsion system that incorporates the Titan Transtage engine (AJ10-118F), operating on N_2O_4 and Aerozene 50 propellants; and a strapdown inertial guidance system that replaces both the first and second stage autopilot systems and the Western Electric Co. (WECO) radio guidance system. The first flights of the Model 0903 series are scheduled for early 1972 and will carry the IMP-H, ITOS-D, Earth Resources Satellites A&B and Nimbus E&F.

To keep pace with the growing launch capability and spacecraft envelope requirements of scientific and applications satellites, both domestic and foreign, the Delta launch vehicle is being again uprated. Early this year, the development of a new and larger spacecraft fairing was initiated together with the incorporation of a higher performance engine into the Delta booster. These changes are being phased into Delta in two configuration steps. First, an eight foot diameter spacecraft fairing is being integrated with the Model 0913 vehicle by adding a new, constant eight foot diameter interstage and suspending the current five foot diameter second stage within the interstage by an adapter that also interfaces with the new fairing. To help offset the performance loss due to the eight foot fairing, the UBT booster propellant tanks are extended ten feet thereby increasing the propellant load 30,000 pounds. This configuration, designated Delta Model 1913 and known as the "Straight 8" because of its streamlined appearance, is to be launched in mid 1972. The Model 1913 series are assigned to carry the Canadian Telesat Satellites 1 and 2, the Synchronous Meteorological Satellite (SMS) A and the Radio Astronomy Explorer (RAE) B.

The second and most recent step in uprating Delta ushers in the Model 2914, that is now under development and is shown in Figure 2. The Model 2914 booster and second stage are the same as the "Straight 8", except the booster incorporates the more powerful Saturn 1B H-1 engine as a replacement for the current UBT

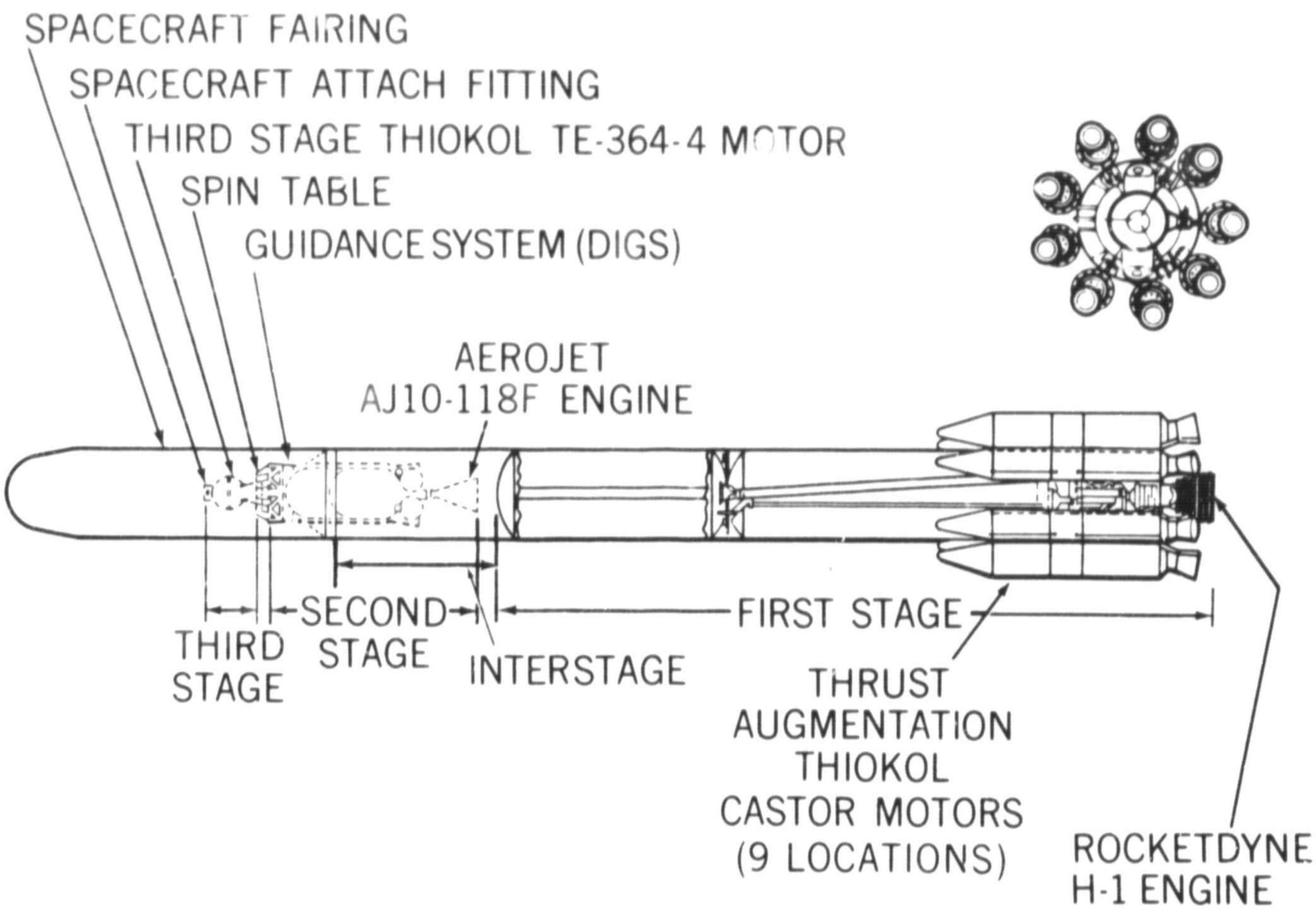


Figure 2. Delta Model 2914

booster engine. The third stage is now the Thiokol TE-364-4 solid propellant motor that is an uprated version of the TE-364-3 currently in use. The Delta "Straight 8", Model 2914 series is to be available for launch in early 1973 and is now scheduled to carry the British Skynet II series, the Interplanetary Monitoring Probes J&K, the Canadian Technology Satellite and the follow-on missions of the Synchronous Meteorological Satellites, the Orbiting Solar Observatories (OSO), the Improved TIROS Operational Systems (ITOS) and the Atmospheric Explorer series.

The reliability and cost effective history of Delta is, in a large part, attributable to the technical approach taken at the outset of the program and still adhered to today. This approach is to use current technology and flight proven components wherever possible from other space programs. The resultant vehicle is normally heavy, but relatively inexpensive and has a high probability of performing repeatedly and reliably from the outset. Delta has never considered it necessary to have a pre-operational or development flight test launch for any of the ten major changes made to the vehicle. And with the exception of the first Delta launch in 1960, there has never been a failure of the first flight article on its maiden launch. The criteria for evaluating improvements to Delta is that they must meet the mission requirements at the lowest possible cost and risk without compromise of Delta reliability record — currently 78 successes out of 84 launches for a cumulative success rate of 93%. For this reason Delta has wherever possible, adapted flight proven components from other programs. The current evolutionary uprating of Delta to the Model 2914 configuration is consistent with this past pattern of change.

Vehicle Description

The three stage Delta vehicle, Model 2914, shown in Figure 2 stands 116 feet and weighs 291,000 pounds at lift-off. The vehicle is designed for ascent through 95% ETR and WTR upper atmosphere annual wind profiles, lift-off in 40 knot ground winds, and hold on the launch pad for several hours in readiness for launch windows only seconds wide.

The first stage is composed of a liquid propellant core that is thrust augmented by solid propellant motors. The eight foot diameter core is the UBT booster now elongated to 70 feet from 60 feet in order to increase the liquid propellant load to 177,000 pounds from 147,000 pounds of RP-1 and liquid oxygen. The core is powered by the North American Rockwell Rocketdyne H-1 engine used on the Saturn 1B vehicle and is now adapted to the Thor. The turbopump fed H-1 develops 205,000 pounds thrust at lift-off compared to the 170,000 pounds thrust of the standard MB-3 Thor engine. The core burns to propellant depletion about 224 seconds after lift-off (T + 224) at an altitude of 60 to 70 nautical miles (n. mi.). Thrust augmentation solid propellant motors attach at the base of the core on the UBT engine section structure. The UBT is structurally designed and thermally insulated to carry up to 9 Thiokol Castor II solid motors (TX-354-5) or 3 Algol class of solid motors with six Castor II's. Use of the Algol class of solid motors is not approved at this time.

Normally, the thrust augmentation motors are build-up in sets of three. Up to six motors can be ignited on the pad and the remainder no sooner than 38 seconds after lift-off in order to hold the vehicle acceleration induced loads on the propellant tank bottoms within allowable limits. The Castor II motors each develop 33,000 pounds thrust at ignition, burn for 40 seconds and are jettisoned from the core at about T + 90. This time is dictated by considerations of combined dynamic pressure angle-of-attack loadings on the jettison mechanism and a Range safety requirement for an offshore impact of the expended motors. Jettison is effected by firing an explosive bolt holding a clamped ball-socket joint. Acceleration of the core plus aerodynamic drag on the motors eject the empty cases away from the vehicle as shown in Figure 3.

During powered flight pitch and yaw steering is exerted by gimballing the core main engine. Roll control is effected by differentially gimballing a pair of small outboard vernier engines. Subsequent to main engine shut-down the verniers continue to operate for about 6 seconds, damping shut-down transients and stabilizing the vehicle for staging of the second stage.

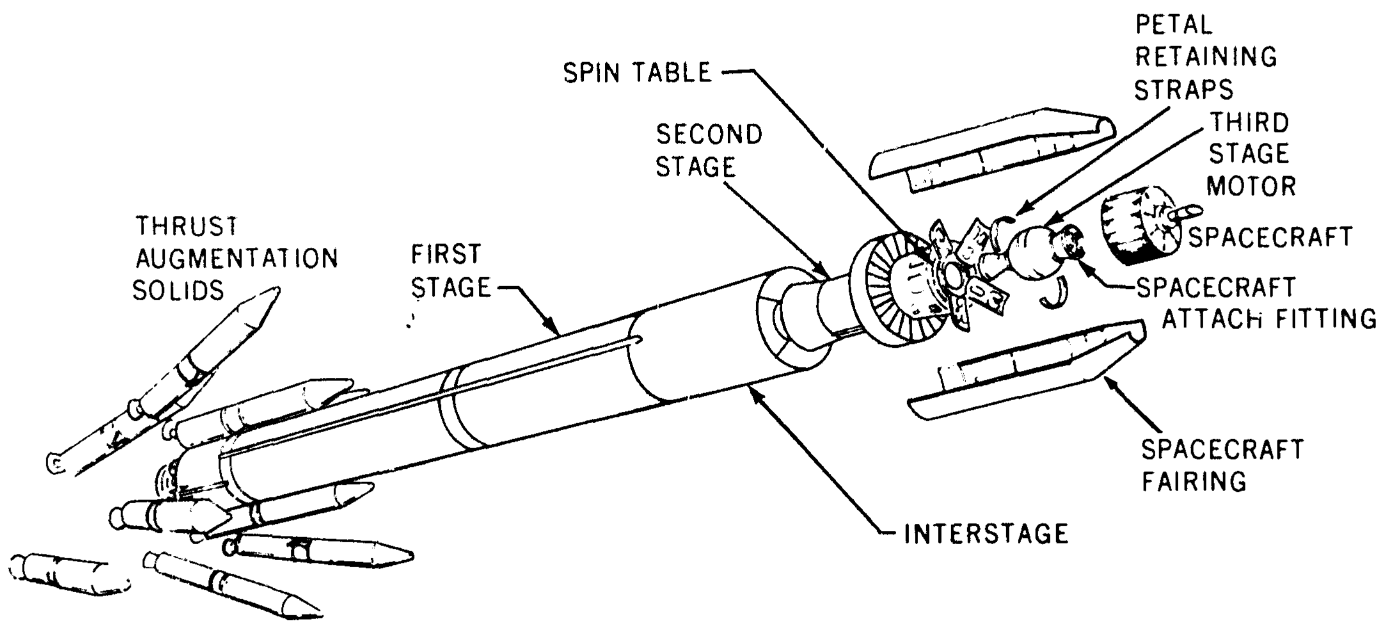


Figure 3. Delta Staging Schematic

The guidance and control for the booster originates from the second stage. A strap-down inertial guidance system provides guidance and control for the total vehicle from lift-off through attitude orientation and ignition of the spin stabilized third stage solid propellant motor. This strap-down system is composed of a digital computer developed by Teledyne for the Advance Centaur vehicle and an inertial measurement unit (IMU) developed by Hamilton Standard for the Apollo Lunar Excursion Module Abort Sensing Assembly. The 4096 word memory computer performs the navigation, guidance, steering, controls systems stability and shaping, and initiates discretes for both first and second stages. It directs the vehicle through a pre-programmed trajectory navigating on IMU velocity data to determine present position and velocity, which it then predicts forward along a nominal trajectory to determine the final position and velocity at injection. The predicted final terminal state is compared to the desired terminal state to derive the required vehicle steering commands and engine shut-down time to reach the desired terminal injection state. All guidance functions are programmed into the vehicle computer with launch pad computer software rather than hardware adjustments. This permits maximum mission flexibility for the user.

The eight foot diameter interstage section between the first and second stages is provided with a spring separation assembly. Eight seconds after that first stage main engine shutdown explosive bolts that attach the two stages are fired and the second stage is spring separated from the first stage. Three seconds later the second stage engine is started.

The Delta second stage is 17 feet long and approximately 5 feet in diameter, except at the eight foot diameter adapter ring that interfaces with interstage and fairing and carries the second stage umbilicals and antennas. At ignition the second stage weighs 12,000 pounds. The Aerojet engine originally developed for the Titan III Transtage vehicle and now adapted by Delta, is a pressure fed, ablative and radiation cooled engine that develops 9460 pounds thrust at an uprated 125 pounds per square inch chamber pressure and operates for about 345 seconds on Aerozine-50 and N_2O_4 storable propellants. The propellant tanks are cylindrical with a hemispherical internal common bulkhead between the fuel and oxidizer tank. The system is pressurized from lift-off to strengthen the structure and suppress oxidizer boiling. The engine, designated AJ 10-118F, is capable of multiple restarts and is started by actuation of a single bi-propellant valve.

During the second stage powered flight, pitch and yaw steering is provided by gimballing the engine and roll is controlled by cold nitrogen gas jets. Cold nitrogen gas jets control the vehicle in all axes during coast and provides propellant settling ullage thrust for restarting the engine. The control system electrical power and nitrogen gas supply is capable of maintaining second stage attitude for a little over two hours. For long second stage coast periods before third stage spin-up and separation, the second stage may be reoriented with respect to the sun or the vehicle placed in a slow yawing or pitching tumble to alleviate assymetric solar heating of the spacecraft.

Peripheral second stage systems include a "C" band tracking beacon, a PDM/PCM/FM/FM 45 × 20 "S" band telemetry system, dual command destruct receivers and associated power supplies.

On several Delta missions where the second stage was orbited and the vehicle performance exceeded the requirements of the primary mission, the second stage was used as a platform for placing secondary satellites into orbit. Table 1 summarizes the secondary satellites that have been carried on the Delta second stage and ejected into orbit after either the primary spacecraft or the third stage with the primary spacecraft had been separated from the second stage. Included also in Table 1 are the secondary experiments and satellites currently under active consideration for piggyback flights on Delta. With the introduction of the new eight foot diameter fairing and attendant structural modifications to the second stage to interface with the fairing and interstage, a substantially greater volume is now available to accommodate secondary spacecraft or experiments as shown in Figure 4.

Secondary experiments or satellites can either remain on-board the second stage or be ejected. Support and separation systems have been qualified and flight proven for ejecting satellites. For experiments that remain on-board, an orbiting Delta second stage secondary experiment recently demonstrated the feasibility of providing on-board experiments with power, data and command RF links, passive thermal control and earth-oriented attitude pointing for long duration.

Table 1

Delta Secondary Experiments/Satellites

SECONDARY EXPERIMENT/ SATELLITE	PRIMARY MISSION	DATE	EXPERIMENT/ SATELLITE WT. (lbs.)	ORBIT
PAST MISSIONS				
TETR-A	PIONEER-C	12/67	55	160 x 260 n.mi. x 28.5°
TETR-B	PIONEER-D	11/68	55	240 x 500 n.mi. x 28.5°
PAC	OSO-G	8/69	265	300 n.mi CIRC x 33°
OSCAR V	TIROS M	1/70	40	790 n.mi. CIRC. x 101.6°
CEP	ITOS A	12/70	11	790 n.mi. CIRC x 101.6°
MISSIONS UNDER CONSIDERATION				
TETR-D	OSO-H	1971	66	300 n.mi. CIRC x 33°
OSCAR VI	—	1972	53	—
INTASAT	NEAR POLAR	1973-74	77	

In August 1969, Delta launched a Packaged Attitude Control (PAC) system experiment, utilizing the orbiting expended Delta second stage which was used to inject the Orbiting Solar Observatory (OSO-G) into orbit. PAC demonstrated the feasibility of making platforms for earth-oriented experiments out of an otherwise expended stage by use of a new low-cost attitude control system. Using gravity gradient torqueing of the stage, the Delta PAC is a three-axis attitude control system that aligns the second stage roll axis to the earth geocenter and the pitch axis normal to the orbit plane. The PAC system includes a power supply (batteries, solar panels and electronics package), a telemetry subsystem, a command subsystem, a magnetic moment assembly, solar aspect indicators, a passive thermal system utilizing heat pipes, and the PAC attitude control system.

Active pitch control is provided by a reaction wheel driven in response to pitch information provided by a horizon scanner. The gyroscopic action of the same reaction wheel in conjunction with gravity gradient torques provide the mechanism for roll/yaw control. Damping of roll/yaw motion is provided by gimballing the wheel and coupling it to the stage through an eddy current damper and a very weak spring suspension. The motor in the reaction wheel scanner provides

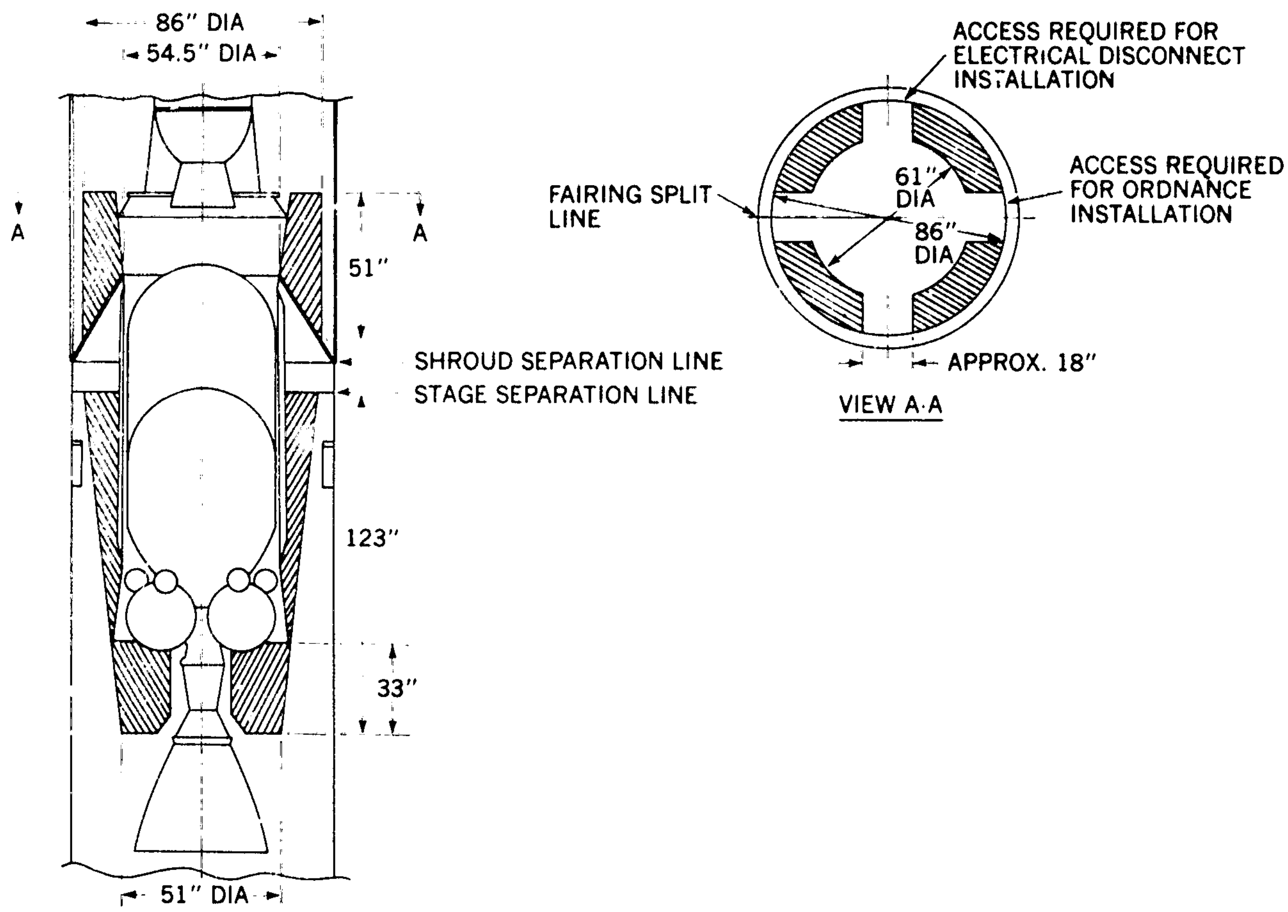


Figure 4. Potential Secondary Experiment Envelope

gyroscopic action, provides a reaction torque by accelerating or decelerating when a pitch error is sensed, and rotates the optics in an infra-red optical system, producing a cone scanning action, which locates the earth's horizons, with respect to PAC. In addition, this motor has magnetic pickoffs which are used to furnish both speed information and vertical reference data. The motor provides all this capability with the use of only a few watts of power.

Although the system is designed to require no attention from the ground, a number of options are available by ground command which modify the control laws. The stage can be flown right-side-up, upside-down, frontwards, or backwards. The nominal speed of the wheel is adjustable, as is the amount of tachometer feedback. In addition, the scanner null can be electronically adjusted to correspond with the gravity gradient null. All of these control law modifications, which are available by ground command, have been verified in orbit. Performance of the control system in orbit, to date, has been satisfactory. Attitude pointing of sensors of experiments has been maintained within a ±2 degree accuracy.

Planned Delta missions with trajectories that place the second stage into orbit are given in Table 2 together with the current excess performance capability that can be used to carry secondary experiments or satellites. Some missions show no excess capability; however, on these missions, an excess capability can be made available by additional thrust augmentation solid motors on the first stage. The excess performance shown are, of course, subject to changes as the primary mission spacecraft weight or orbital parameters change.

Table 2

Future Delta Missions Through 1975 With Orbiting Second Stage

YEAR	MISSION	SECOND STAGE ORBIT	CURRENT EXCESS CAPABILITY
1971	OSO-H	300 NM. CIRCULAR $i = 33^{\circ}$	50 lb
1971	ITOS-D	790 NM. CIRCULAR $i = 101.56^{\circ}$	50 lb*
1972	HEOS-A2	216 NM. CIRCULAR $i = 190^{\circ}$	–
1972	TD-1	300 NM. CIRCULAR $i = 97.4^{\circ}$	–
1972	ERTS-A	500 NM. CIRCULAR $i = 99.16^{\circ}$	75 lb
1972	NIMBUS-E	600 NM. CIRCULAR $i = 110^{\circ}$	<25 lb*
1973	ITOS-E	790 NM. CIRCULAR $i = 101.56^{\circ}$	50 lb*
1972	SMS-A	100 NM. CIRCULAR $i = 28.5^{\circ}$	—
1973	RAE-B	100 NM. CIRCULAR $i = 28.5^{\circ}$	90 lb*
1973	ERTS-B	500 NM. CIRCULAR $i = 99.16^{\circ}$	75 lb
1974	NIMBUS-F	600 NM. CIRCULAR $i = 100^{\circ}$	<25 lb*
1973	OSO-I	300 NM. CIRCULAR $i = 33^{\circ}$	200 lb*
1973	SMS-B	100 NM. CIRCULAR $i = 28.5^{\circ}$	—
1973	AE-C	81 NM. x 2160 NM. $i = 63^{\circ}$	250 lb*
1975	OSO-J	300 NM. CIRCULAR $i = 33^{\circ}$	200 lb*
1974	AE-D	81 NM. x 2160 NM. $i = 98^{\circ}$	250 lb*
1976	OSO-K	300 NM. CIRCULAR $i = 33^{\circ}$	200 lb*
1974	ITOS F	SAME AS ITOS E	
1975	ITOS G	SAME AS ITOS E	

*Can be increased with additional first stage thrust augmentation

For this reason, experimenters who desire to utilize the Delta piggyback capabilities must work closely with the Delta Project Office to ensure mission compatibility and performance availability.

Possible orbits for secondary experiments and satellites are not necessarily constrained to those shown for the primary spacecraft in Table 2 since the second stage can be restarted and injected into a new orbit after the primary spacecraft is deployed.

The third stage assembly consists of a spin table, the Thiokol TE-364-4 solid propellant motor, spacecraft attach fitting, spacecraft and the spacecraft fairing. The spin table shown in Figure 5 consists of a bearing support structure and a conical third stage motor pedestal truss that is divided into four petals hinged at

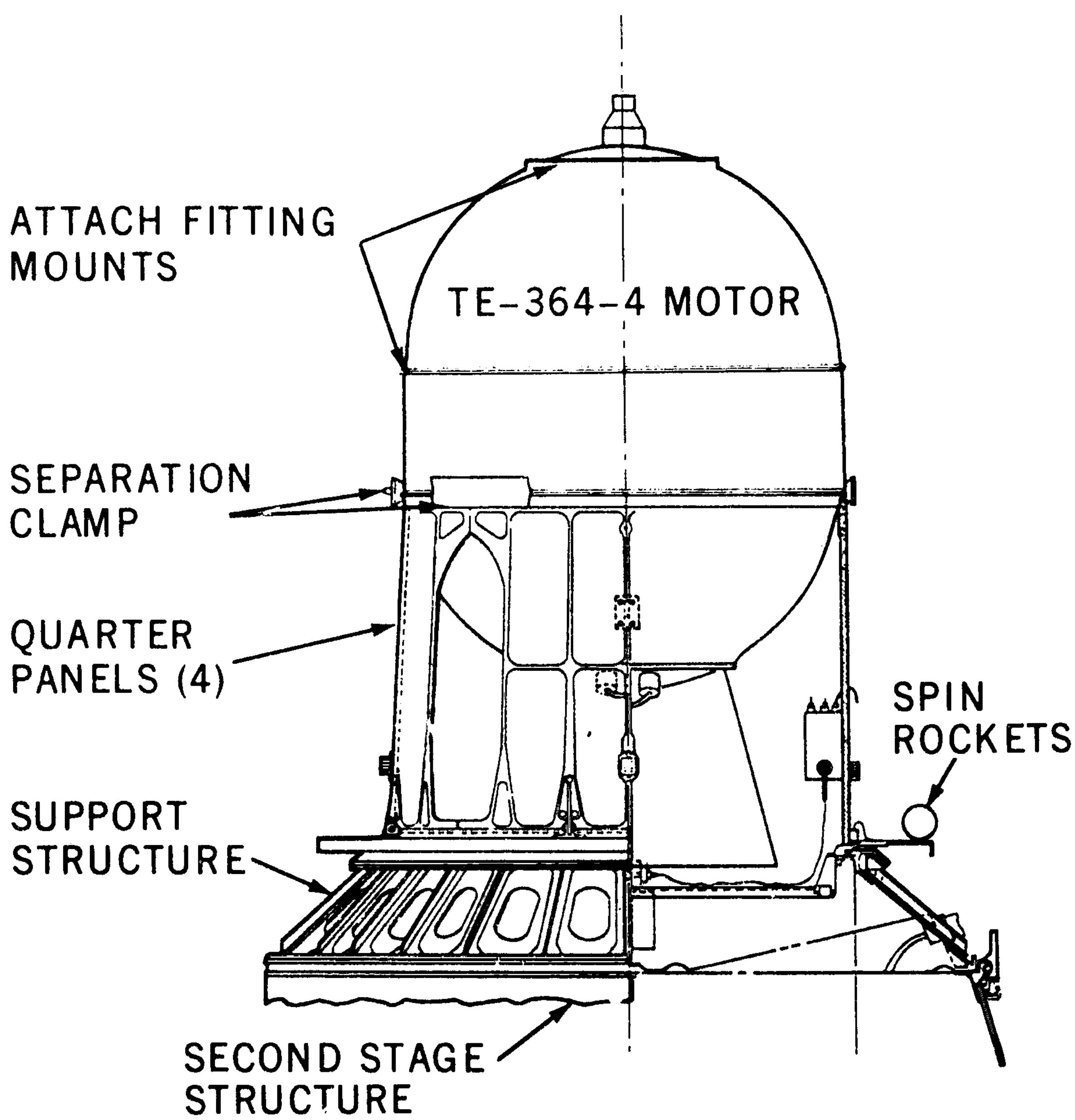


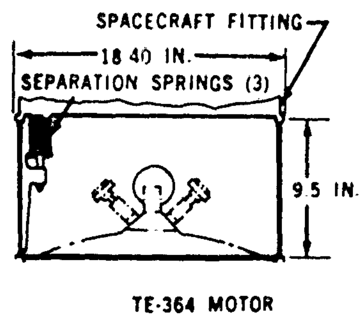
Figure 5. TE-364-4 Third Stage and Spin Table

the base and clamped to the equator of the third stage motor by a retaining strap. The retaining strap is held in tension by two explosive bolts that are fired two seconds after the motor and spacecraft are spun up and the 15 second time delay squib that ignites the TE-364-4 motor is started. The released petals fly outward under centrifugal force, releasing the third stage from the spin table (Figure 3). At the same instant the second stage is backed away from the free spinning third stage by venting residual pressurant (helium) overboard through two retrojets. Approximately thirteen seconds later the third stage motor is ignited by the time delay squib. The TE-364-4 motor is essentially identical to the -3 model that is in current use except that a 14 inch cylindrical section is added between the two hemispherical halves of the case. The propellant weight is increased to 2300 pounds from 1440 pounds, it burns for 44 seconds and develops an average thrust of 15,000 pounds.

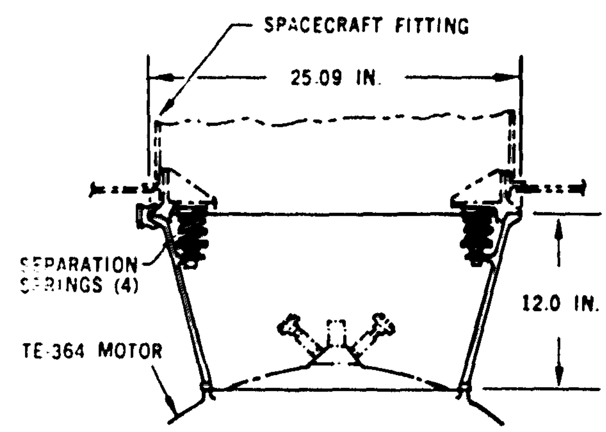
Torque to the spin table is imparted by combinations of small solid propellant rocket motors, which provide spin rates from 30 to 100 revolutions per minute (±10 percent) for spacecraft roll moments of inertia ranging from 20 to 170 slug-feet squared. A lower limit of approximation 30 rpm is dictated by minimum dynamic stability of the third stage/spacecraft during third stage motor burning. If less than 30 rpm is desired the effect upon orbit injection errors must be carefully assessed. The anticipated maximum spin rate users would desire was 100 rpm, consequently the third stage motor is qualified only up to this spin rate.

For those spacecraft that require spin stabilization but mission performance does not require use of a third stage, a spacecraft can be spun either by use of the spin table or by placing the combined second stage/spacecraft in a controlled spin with the second stage roll attitude control jets. This technique, which was used to spin up the TOS-M spacecraft (Delta Mission: 76) eliminates the spin table for missions requiring spacecraft spin rates up to 20 rpm.

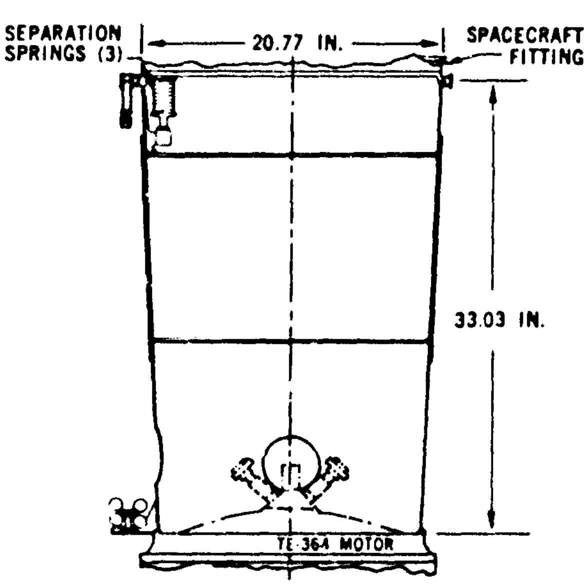
The spacecraft is clamped to the attach fitting by a circular retaining strap assembly that releases by firing two explosive bolt cutters subsequent to third stage motor burn-out. Separation from the expended third stage is then effected by a separation spring, or springs, which provides the spacecraft with a relative separation velocity of 6 to 8 fps with respect to the expended third stage motor. Although peculiar spacecraft requirements may dictate the design of a special spacecraft attach fitting, a number of standard Delta fittings are available. These are shown in Figure 6. These fittings use either a small rocket or yo weight system to tumble the expended third stage motor after spacecraft separation to preclude possible motor outgassing from accelerating it into the spacecraft. Also available is a yo-yo weight despin system which can despin the third stage and spacecraft combination prior to spacecraft separation. Attach fittings include timer assemblies, battery and delay squib switches. The timers are



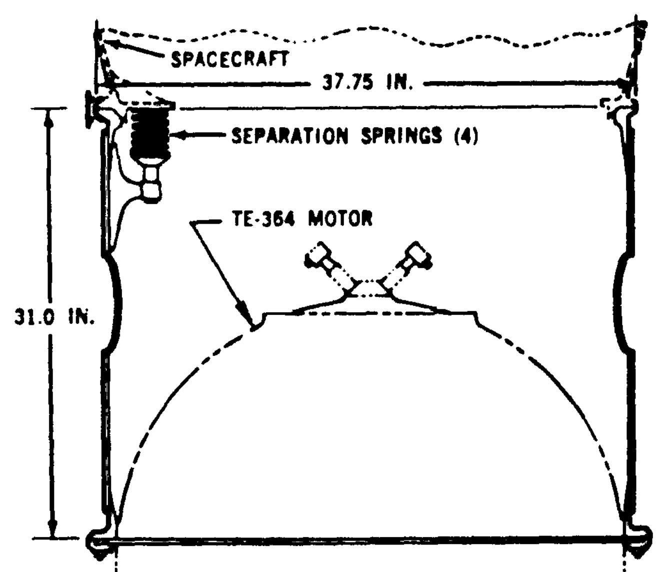
18 × 9 INCH CYLINDRICAL ATTACH FITTING
WT: 24 LB



25 × 12 INCH CONICAL ATTACH FITTING
WT: 30 LB



20 × 30 CONICAL ATTACH FITTING
WT: 24–30 LB



37 × 31 INCH CYLINDRICAL ATTACH FITTING
WT: 54 LB

Figure 6. TE-364 Motor/Payload Attach Fittings

initiated by the second stage computer and run on mechanical energy until reaching a predetermined time to fire the spacecraft separation clampband bolt cutters and a pair of squib switches. Two seconds later the squib switches initiate a small rocket or yo weight to tumble the expended third stage motor.

For users requiring real time third stage motor performance, environmental or velocity increment information an "S" band telemetry system and a "C" band tracking beacon are developed and flight proven. These are carried on either the spacecraft attach fitting or on the third stage motor.

The new eight foot diameter spacecraft fairing is aluminum and constructed in two half-shells that are brought up around the spacecraft laterally. A contamination-free thrusting joint between the fairing halves is used to thrust the two shells laterally and clear of the spacecraft and vehicle (Figure 3). Normally, the fairing is jettisoned within 5 to 20 seconds after second stage engine start. Fairing jettison time is dictated by the free molecular heating rate that can be tolerated by the spacecraft. Normally, the heating rate is held below 0.1 BTU/Ft^2-sec. or about equivalent to the solar heating rate to the spacecraft. Aerodymanic heating of the fairing is controlled, if required for the spacecraft, by application of ablative materials to the external surface of the fairing.

Access ports through the fairing and R.F. transparent windows are provided at the locations that meet the needs of the vehicle user. The available fairing internal envelope is shown in Figure 7.

Flight Sequence and Performance

The Delta flight profile and sequence of events for a three stage geosynchronous transfer mission having a perigee altitude of 100 n. mi., an apogee altitude of

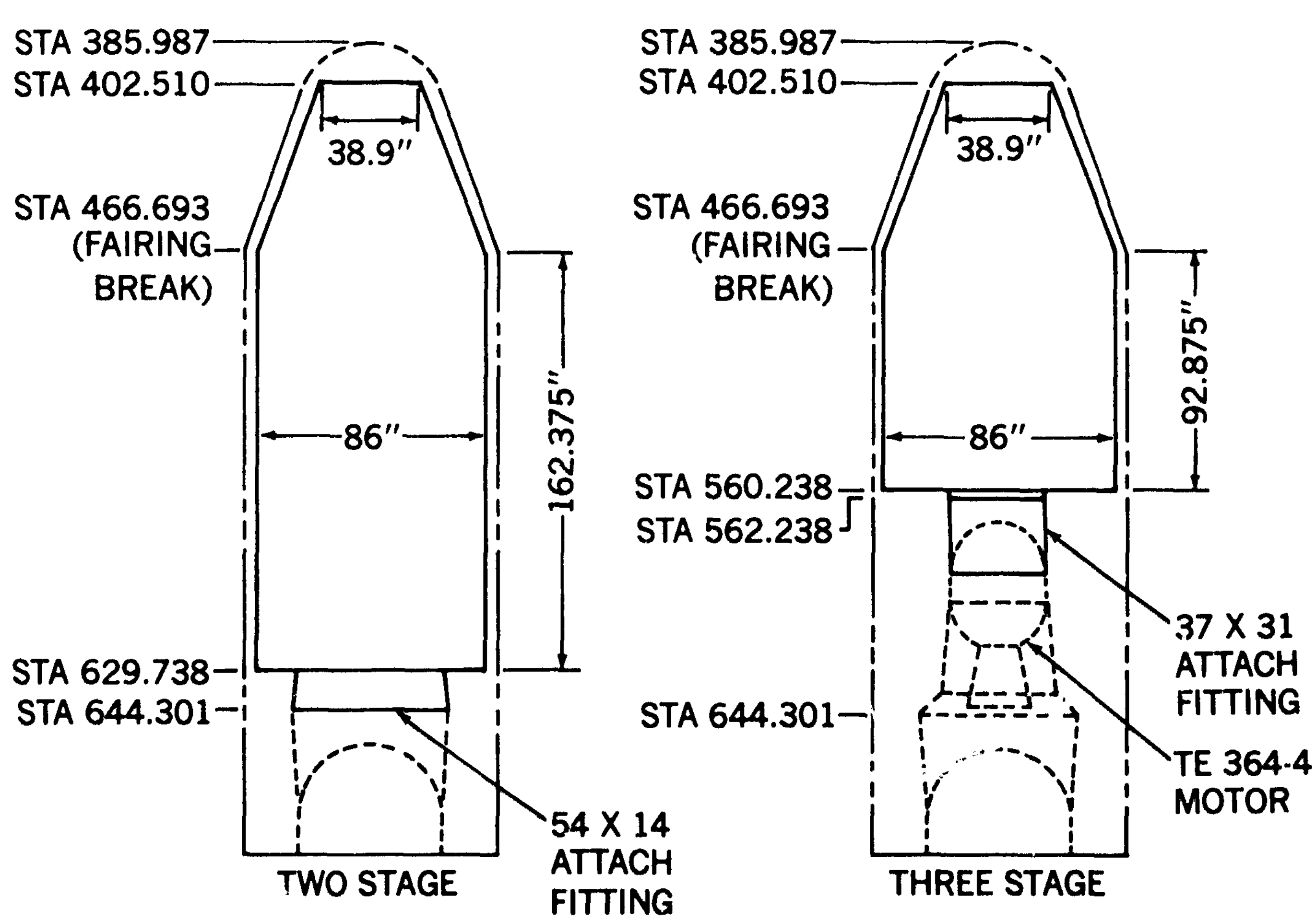


Figure 7. Delta Payload Envelope

19,400 n. mi. and an inclination of 28.5 degrees is shown in Figure 8. The vehicle is launched from ETR on an azimuth of 95 degrees. The third stage assembly is placed into a 100 n. mi. parking orbit with the booster and first burn of the second stage. The second stage and third stage assembly then coast to a point just short of the Equator where the second stage is reburned and then the third stage is spun-up, separated, and ignited. The third stage burns out directly over the Equator at an altitude of 100 n. mi., an inertial flight path angle of zero degrees, and with sufficient velocity to coast the spacecraft to an altitude of 19,400 n. mi. on the opposite side of the Earth so that the line of apsides lies in the equatorial plane to permit the spacecraft apogee motor to rotate the transfer orbital plane into the equatorial plane as part of the circularization maneuver.

Payload weight versus characteristic inertial velocity for Delta from the Eastern Test Range in Florida and the Western Test Range in California is shown in Figures 9 and 10. The performance capability for a number of scientific and applications missions carried on Delta is summarized in Table 3. These Delta performance capabilities are the useful load that can be carried above the last powered stage and thus includes the spacecraft weight, its attach fitting, and the third stage telemetry and tracking system weight, if one is provided. Definition of Delta model number nomenclature noted on Figures 9 and 10 is presented in Table 4. For the Delta Model 2914 described here, the first digit (2) designates the extended UBT with the new H-1 engine; the second digit (9) means that nine Castor II thrust augmentation solid motors are used; the third digit (1) that the second stage incorporates the AJ10-118F engine, N_2O_4/Aerozine 50 propellants, DIGS, and the new eight foot diameter metal fairing; and the fourth digit (4) that the TE-364-4 third stage solid motor is used.

The injection accuracy of Delta is strongly dependent on whether the vehicle is two or three stages and on the trajectory profile. The three sigma (3σ) injection accuracy for several typical Delta missions is provided in Table 5. The two stage missions are inertially guided and controlled up through injection. For three stage missions, inertial guidance and control is maintained up until the unguided, spin-stabilized third stage is separated from the second stage. Nearly two thirds of the errors in injection velocity and attitude on a three stage mission are caused by dispersions in the motor total impulse and lateral tip-off impulses applied during separation from the second stage and at motor ignition.

Though the three stage dispersions are moderately large, it should be remembered that typically this class of missions, for example, the synchronous communications satellites, carry a propulsion system for velocity adjustment or station keeping and hence the penalty paid in additional propellant to trim out injection errors is quite small.

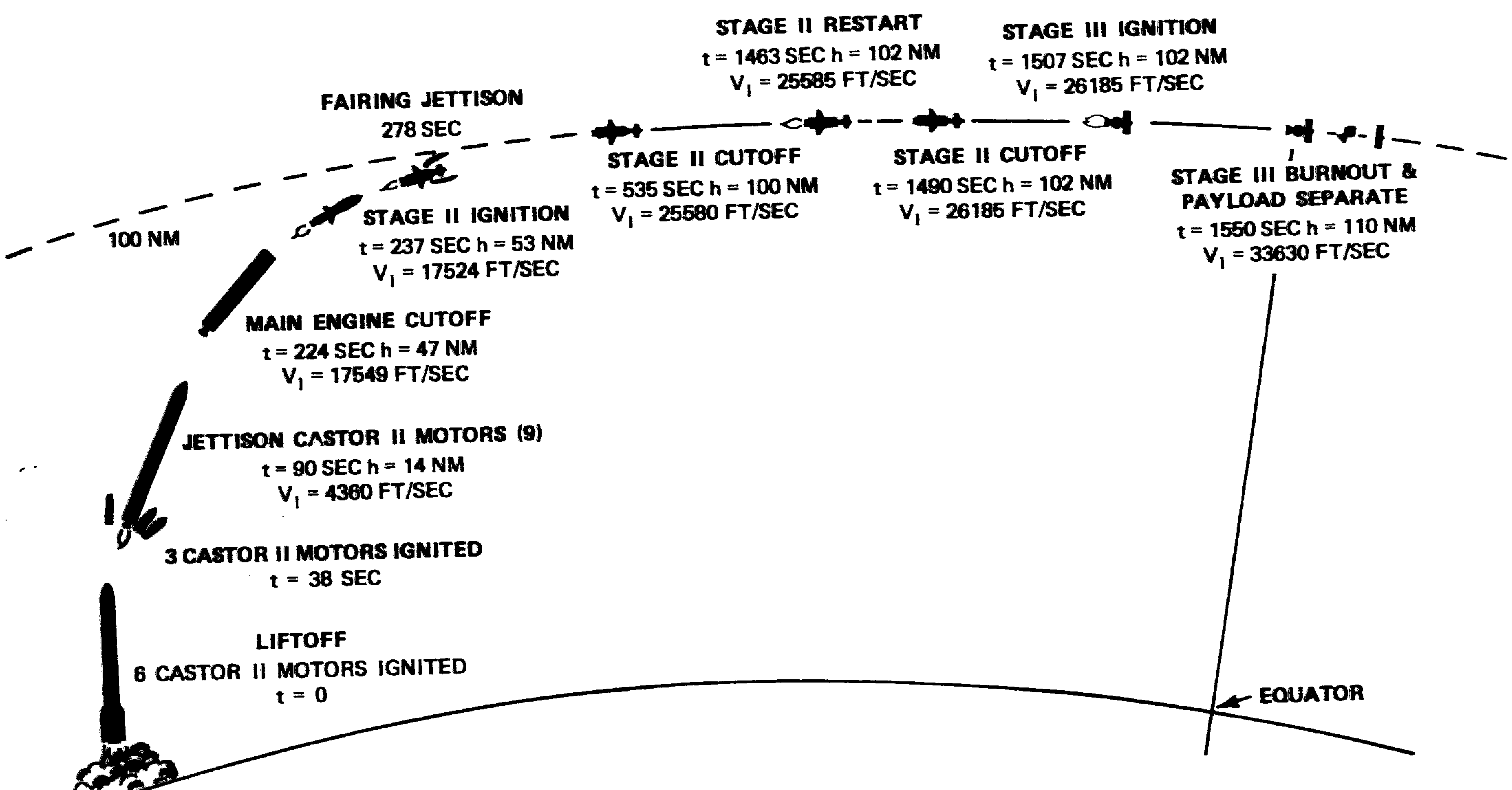


Figure 8. Typical Three Stage Geosynchronous Mission Profile

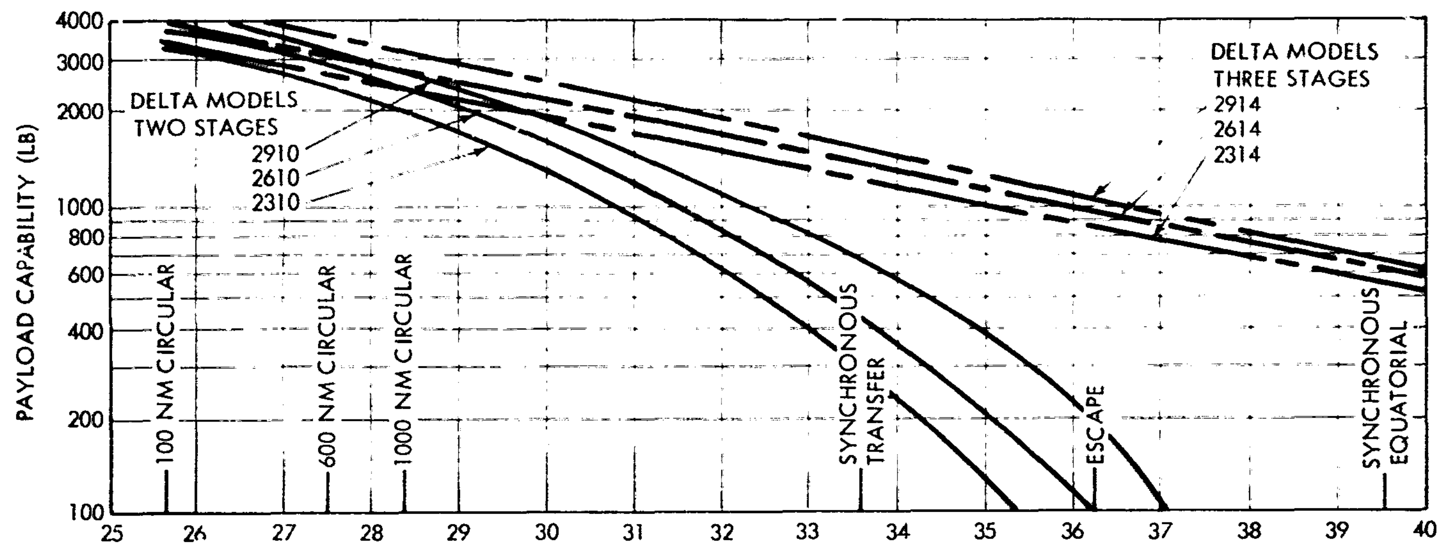


Figure 9. Delta Payload Capability — Eastern Test Range

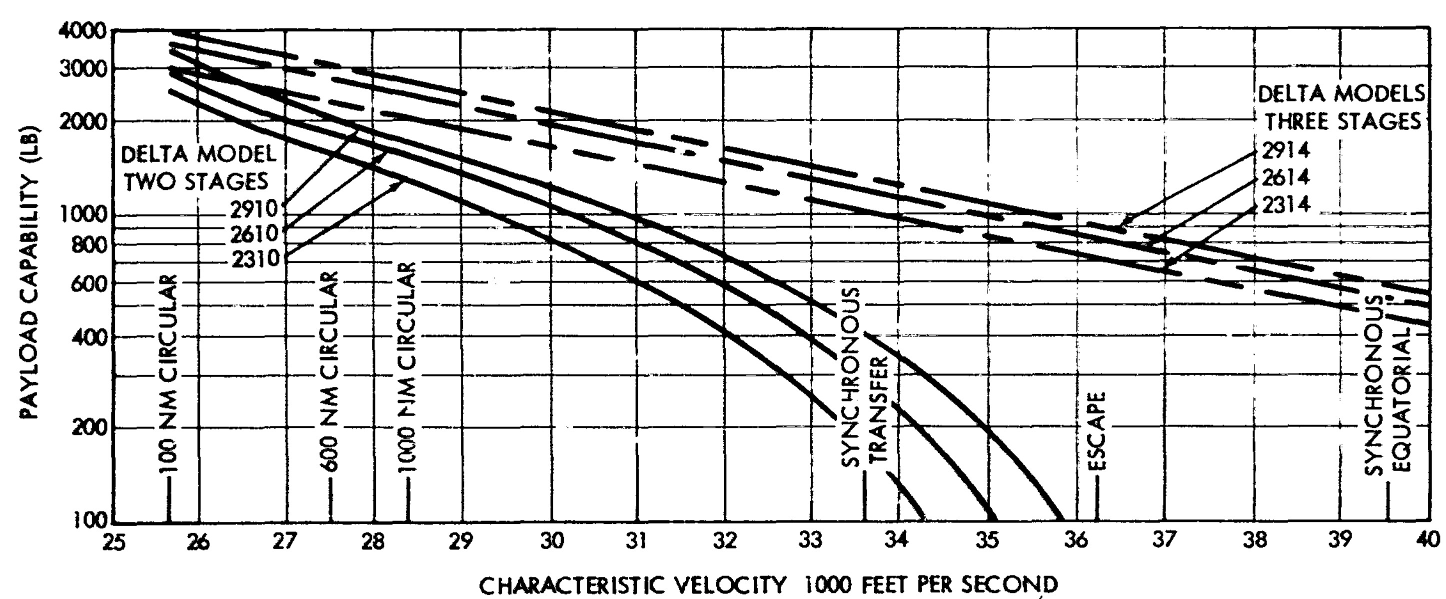


Figure 10. Delta Payload Capability — Western Test Range

Table 3

Delta Performance Capabilities

MISSIONS	FLIGHT MODE	DELTA PERFORMANCE CAPABILITY-POUNDS MODEL NUMBER		
		2314	2614	2914
BIOSATELLITE 200 N.M. CIRCULAR INCL. = 28 DEGREES	TWO STAGE, RESTART 100 × 200 N.M. HOHMANN TRANSFER.	3400	4000	4300
EARTH RESOURCES 500 N.M. CIRCULAR SUN-SYNCHRONOUS INCL. = 99 DEGREES	TWO STAGE, RESTART 100 × 500 N.M. HOHMANN TRANSFER.	1950	2350	2600
IMPROVED TIROS OPERATIONAL SATELLITE (ITOS) 800 N.M. CIRCULAR SUN-SYNCHRONOUS INCL. = 102 DEGREES	TWO STAGE, RESTART 100 × 800 N.M. HOHMANN TRANSFER.	1550	1850	2100
SKYNET II SYNCH. TRANSFER 100 × 19,400 N.M. INCL. = 28.5 DEGREES	THREE STAGE, DIRECT ASCENT. SECOND STAGE PLACED IN 100 N.M. PARKING ORBIT.	1225	1400	1550
PLANETARY EXPLORER VENUS-TYPE II $C_3 = 8.231\ KM^2/SEC.^2$	THREE STAGE DIRECT ASCENT. SECOND STAGE PLACED IN 100 N.M. PARKING ORBIT.	800	900	975

Flight Environment

The environment imposed on the spacecraft by the vehicle is estimated from previous flight measurements. A summary of the expected environment for both the two and three stage Delta vehicle is provided in Table 6 for use in preliminary studies by spacecraft mission planners.

Table 4

Delta Model Nomenclature

1ST DIGIT	0 — — —	UNIVERSAL BOATTAIL THOR (UBT)
	1 — — —	EXTENDED TANK UBT
	2 — — —	EXTENDED TANK UBT WITH THE H-1 ENGINE
2ND DIGIT	— 3 — —	NUMBER OF CASTOR II THRUST AUGMENTATION SOLID MOTORS
	— 6 — —	
	— 9 — —	
3RD DIGIT	— — 0 —	SECOND STAGE (N_2O_4/A50, DIGS, 5 FOOT DIA FAIRING)
	— — 1 —	SECOND STAGE (N_2O_4/A-50, DIGS, 8 FOOT DIA FAIRING)
4TH DIGIT	— — — 0	NO THIRD STAGE
	— — — 2	FW-4 MOTOR THIRD STAGE
	— — — 3	TE 364-3 MOTOR THIRD STAGE
	— — — 4	TE 364-4 MOTOR THIRD STAGE

Table 5

Typical Delta Orbit Accuracy

MISSION	ORBIT DEFINITION	ACCURACY
GEOSYNCHRONOUS TRANSFER (3 STAGE)	100 x 19400 NM i = 28.5 DEG	$3\sigma \triangle$ hp = ± 10 NM $3\sigma \triangle$ ha = ± 600 NM $3\sigma \triangle$ i = ±0.50 DEG
HIGH CIRCULAR (2 STAGE)	800 NM CIRCULAR i = 102 DEG	$3\sigma \triangle h_C$ = ± 16 NM $3\sigma \triangle$ i = ±0.04 DEG
LOW CIRCULAR (2 STAGE)	100 NM CIRCULAR i = 90 DEG	$3\sigma \triangle h_C$ = ± 12 NM $3\sigma \triangle$ i = ± 0.04 DEG
ESCAPE (3 STAGE)	$C_3 = 16\ KM^2/SEC$	$3\sigma \triangle$ V = ±75 FPS (TOTAL ENERGY ERROR) $3\sigma \triangle \gamma_1$ = ±0.75 DEG $3\sigma \triangle \gamma_2$ = ±0.75 DEG

Table 6

Delta Critical Flight Environment

EXCITATION	FLIGHT EVENT	DURATION SECONDS	TWO STAGE (MODEL 2910)		THREE STAGE (MODEL 2914)	
			FREQUENCY, Hz	LEVEL	FREQUENCY, Hz	LEVEL
SINUSOIDAL VIBRATION THRUST AXIS	LIFT OFF T + 210 SEC.	2 TO 5 5 TO 7	5-15 15-21 21-100	1.5g (O-P) [1] 4.0 1.5	5-15 15-21 21-100	1.5g (O-P) [1] 4.5 1.5
LATERAL AXIS	LIFT OFF	2 TO 5	5-14 14-100	1.3 [1] 1.0	5-14 14-100	1.5 [1,2] 1.0
RANDOM VIBRATION THREE AXES	TRANSONIC & MAX. Q.	10 TO 15	20-300 300-1000 1000-2000	+4db/ OCTAVE $0.06g^2$/Hz -6db/ OCTAVE	20-300 300-2000	+3db/OCTAVE $0.02g^2$/ Hz
SHOCK	SPACECRAFT SEPARATION	0.001	1600g AT 0.8 MILLISECONDS TERMINAL PEAK SAW TOOTH		1400g AT 0.3 MILLISECONDS TERMINAL PEAK SAW TOOTH	
STEADY STATE ACCELERATION	FIRST STAGE BURNOUT THIRD STAGE BURNOUT			8.5g	7.7g 23.5g FOR 500 LBS. SPACECRAFT 10g FOR 1500 LBS. SPACECRAFT	
ACOUSTIC	LIFT OFF AND TRANSONIC	10 TO 15	142db 37 TO 9600 Hz (PEAK LEVEL 800 TO 1000 Hz)			

[1]Because of shaker limitations acceleration can be limited to 0.5" D.A. displacement of the armature.

[2]For spacecraft weight of 1000 pounds. For lighter spacecrafts, levels are higher.

At liftoff the spacecraft is subjected to both lateral and longitudinal sinusoidal vibration that load the spacecraft structure dynamically. At the time the three stage Delta lifts off the launch pins and the umbilicals are simultaneously retracted, a 1000 pound spacecraft can experience a maximum of ±1.5g, zero-to-peak (O-P), in the vehicle lateral modal frequencies, which range from 5 to 14 Hz. Superimposed at this time is a ±1.5g (O-P) longitudinal 13 Hz oscillation. These combined liftoff oscillations typically last for two to five seconds with the peak acceleration lasting one to two cycles. During the last twenty seconds of first stage flight, the Thor exhibits a 20 Hz "pogo" longitudinal oscillation that builds up to ±4.5g (O-P). For conservatism it is assumed here that the Delta booster with the new H-1 engine will exhibit the same phenomenon and oscillatory acceleration levels. However, a "pogo" suppression device for the current booster engine is to be flight tested on the next Delta launch. This device is placed at the inlet to the LOX pump and is essentially the same pneumatic accumulator that is being used successfully on the Saturn II center J-2 engine. If successfully applied on Delta, this device or a derivative of the device will be incorporated on the H-1 engine and the thrust axis sinusoidal vibration levels shown in Table 6 for the 15 to 21 Hertz frequence range will be reduced to 1.5g (O-P). The maximum first stage steady state acceleration of 8.5g's is the highest imposed by the two stage Delta. For three stage Delta, the maximum steady state acceleration is dictated by the TE-364-4 third stage and reaches 23.5g's for a 500 pound spacecraft; or 10g's for a 1500 pound spacecraft.

Random vibration measured at the third stage attach fitting and spacecraft show power spectrum densities between 0.0001 and $0.06g^2$/Hz from 20 Hz to 2000 Hz in both lateral and longitudinal axes. The principal source of random vibration is boundary layer turbulence over the fairing and the second stage that excites the structure and feeds up through the third stage assembly to the base of the spacecraft. Acoustical excitation also contributes to the random levels experienced.

At liftoff and transonic the overall accoustical level inside the fairing is approximately 142 db (referenced to 0.0002 dynes/cm^2) from 37.5 to 9600 Hz. These levels are present for about 10 seconds at lift-off and again for about 15 seconds at transonic.

Shocks occur at main engine start, thrust augmentation solid motors ignition and jettison, staging, fairing jettison, and spacecraft separation from the expended third stage. For three stage Delta, cutting the bolts to separate the spacecraft from the expended third stage imposes the most severe shock spectrum on the spacecraft. The third stage motor and spin table assembly act to absorb the high frequency excitation from other sources. Cutting the separation bolts results in an estimated shock spectrum equivalent to one-third millisecond, 1400g terminal peak sawtooth input.

Cost

The projected cost of Delta Model 2914 reimbursable launches in 1973 from ETR is about $5 1/2 million dollars. This includes hardware, the launch services, trajectory software, spacecraft integration, launch support services, and NASA administrative charges. This cost does not include charges made by the U.S. Air Force for Range use that would include tracking, data acquisition, technical operations, and U.S. Air Force support charges, as these costs are highly dependent on mission requirements. The breakdown of costs shown in Table 7 are based on actual or estimated expenses billed to outside agency users such as ESSA, Comsat, and ESRO for reimbursement to NASA and a projection of these costs into the 1973 time frame when the Delta, Model 2914 shall be operational. Actual charges for any given mission will, of course, vary to reflect the specific mission requirements.

For launches conducted for outside government agencies and private industry, identifiable launch service charges are segregated and charged directly against the mission. Indirect or cost not identifiable to a peculiar mission are prorated normally over the duration of a launch services contract or a number of Delta launches and allocated accordingly.

ORGANIZATION AND INTERFACES

Delta users interface organizationally with three elements within NASA. This is best illustrated by the relationship that existed between the European Space Research Organization's, Project HEOS, and the NASA Delta Project on the Delta 61 launch as is shown in Figure 11.

Agreement between NASA and a foreign space organization for a launch and associated services is established at NASA Headquarters level. This is normally done with a Memorandum of Understanding outlining the principles under which such arrangements are to be made, followed by a specific contract for each mission. The agreed-to policies and fiscal arrangements are then passed through the NASA Office of Space Sciences and Applications (OSSA) Delta Programs Office to the Goddard Space Flight Center (GSFC) Delta Project Office for implementation. The Delta Project Office is vested with the authority and responsibility for carrying out all aspects of a Delta vehicle mission. The Delta Project works directly with the Spacecraft Project to develop and define the spacecraft/vehicle mission requirements, integrate the spacecraft to the vehicle, establish schedules, and determine the final flight readiness of the vehicle. The Delta Project contracts with and directs a single industrial contractor, MDAC, for vehicle hardware, mission analysis, and launch support services. Direction of the launch support services furnished by MDAC at the

Table 7

Delta Launch Costs (1973)

MODEL 2914	COSTS (THOUSAND DOLLARS)	
	INITIAL LAUNCH	FOLLOW-ON LAUNCH
HARDWARE		
FIRST STAGE CORE	$1,300	$1,300
THRUST AUGMENTATION SOLID MOTORS (9)	675	675
SECOND STAGE AND FAIRING	1,600	1,600
THIRD STAGE	130	130
ATTACH FITTING	35	35
LAUNCH SERVICES		
SOFTWARE/ANALYSIS/SUSTAINING SUPPORT	750	500
VEHICLE CHECKOUT		
PRODUCTION AREA	200	200
LAUNCH SITE	750	750
TRANSPORTATION	15	15
PROPELLANT	15	15
SUBTOTAL	$5,470	$5,220
RANGE LAUNCH SUPPORT	*	*
GOVERNMENTAL ADMINISTRATION CHARGES	170	170
TOTAL	$5,640	$5,390

*RANGE TRACKING, DATA ACQUISITION, TECHNICAL OPERATION AND U.S. AIR FORCE SUPPORT CHANGES DEPENDENT ON MISSION REQUIREMENTS.

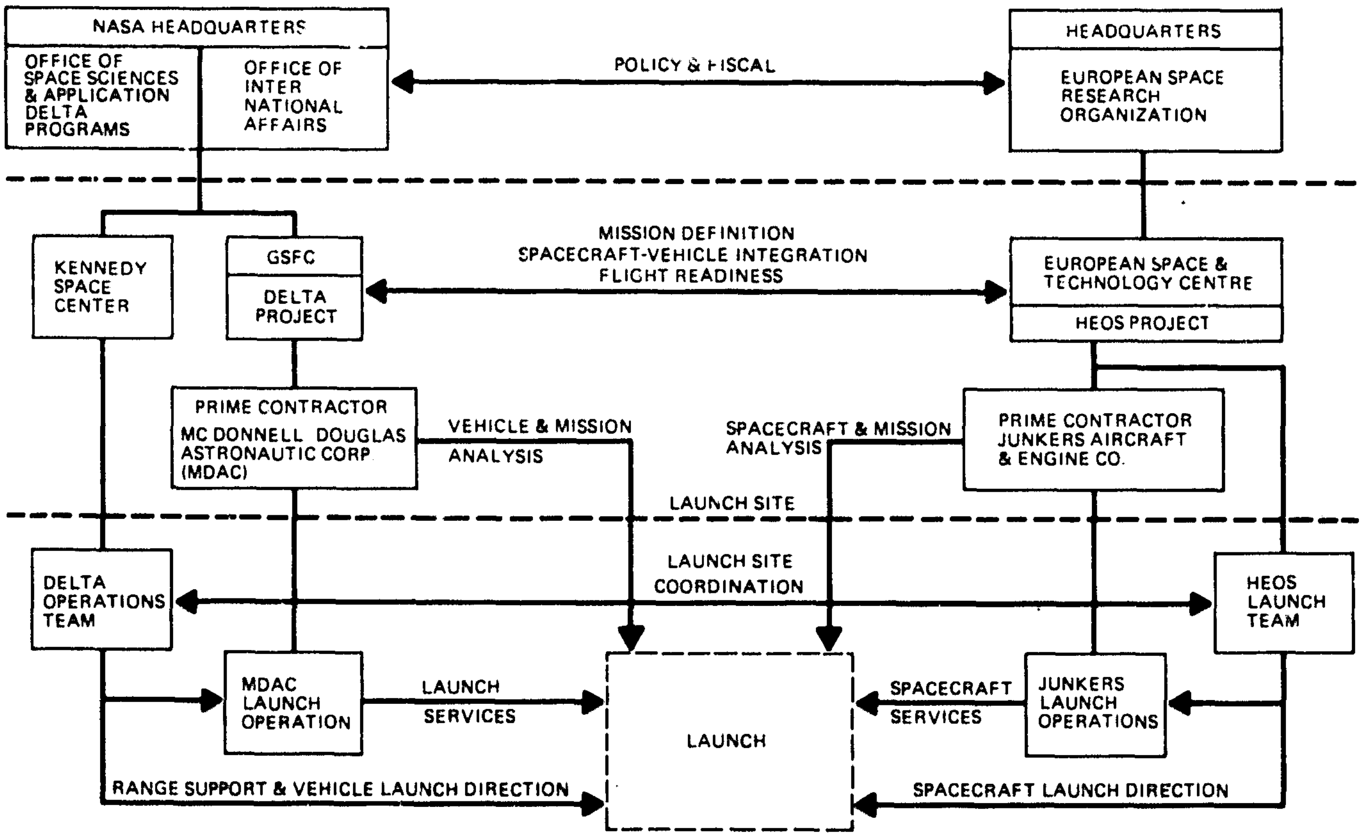


Figure 11. Delta Organization and Interfaces

launch site is delegated to the NASA Kennedy Space Center (KSC). The KSC Delta Operations Team works directly with the Spacecraft Project at the launch site to insure required Range and contractor services are provided and to coordinate the launch site vehicle and spacecraft activities.

This simple organizational structure with short and direct authority and communications lines is a significant factor in the flexibility and responsiveness Delta can provide its users.

SPACECRAFT INTEGRATION AND LAUNCH OPERATION

Delta vehicle interface constraints together with performance and accuracy estimates are provided to potential vehicle users as soon as the concept of the mission is outlined to the NASA, Goddard Space Flight Center Delta Project Office. The Delta Project welcomes and encourages early definition of prospective missions by potential users. In some instances, mission definition and integration planning has preceded actual mission commitment by two and three years. Experience has demonstrated that this advance and continuous coordination between the user and the Delta Project during the period of developing mission requirements, enhances the visibility of both parties and reveals problem areas before final definition of the spacecraft/vehicle interface and trajectory parameters. In general, spacecraft/vehicle planning for new missions follow the pattern and time frame outlined in Figure 12 and starts about one year (T-52 weeks) before launch when the Spacecraft Project provides the Preliminary Mission Definition and Requirements to the Delta Project Office. This definition encompasses the preliminary spacecraft configuration, mass properties, trajectory, and orbital requirements necessary for preliminary vehicle performance evaluation and analysis. A preliminary trajectory with attendant injection error studies and thermal studies is completed within ten weeks. With this visibility, the Delta Project and the Spacecraft Project jointly develop a Final Mission Requirement specification (T - 40 to T - 26 weeks) that includes such constraints as spacecraft orbital lifetime, apogee and perigee altitude and geocentric location, permissible injection errors, injection attitude orientation, launch window criteria, tracking and data retrieval requirements, spacecraft mass properties, and all other data necessary for the preparation of the Final Mission Analysis.

The Spacecraft Project reviews the final mission trajectory about T - 35 weeks and the final injection and orbital error analysis about T - 23 weeks. The trajectory includes all technical data defining the flight mode, sequence of flight events, vehicle weights and propulsion system characteristics, tabulations of trajectory parameters, weight history, radar look angles, and instantaneous impact loci. Final definition of the maximum and minimum allowable spin rate, spacecraft RF systems, and permissible inflight thermal inputs are provided to the Delta Project by T - 26 weeks. A full scale compatibility drawing based on the Spacecraft Project's final configuration drawings is prepared normally at T - 16 weeks. This drawing is primarily to show all clearances between the spacecraft and fairing, attach fitting, and third stage motor and locate the orientation of such features as umbilical connectors, access ports through the fairing, and any special interface wiring between the attach fitting and spacecraft. A Spacecraft Handling Plan is jointly developed and finalized about T - 8 weeks and describes all hazardous systems, spacecraft test procedures, and details prelaunch work schedules. Typically the spacecraft arrives to the launch-site two weeks before launch (T - 2) and is built up on the third stage motor assembly the following week and mated to the vehicle on the pad one week before launch for RFI testing with the vehicle and Range RF systems. Final weights are inputed to trim the final trajectory parameters in the inertial guidance computer the week of launch.

For three stage missions the spacecraft must be statically and dynamically balanced prior to receipt at the launch site. The allowable spacecraft center-of-gravity offset and principle axis misalignment is 0.050 inches and 0.003 radians, respectively. For missions where injection attitude is extremely critical for mission success, a third stage assembly composite spin balance can be conducted.

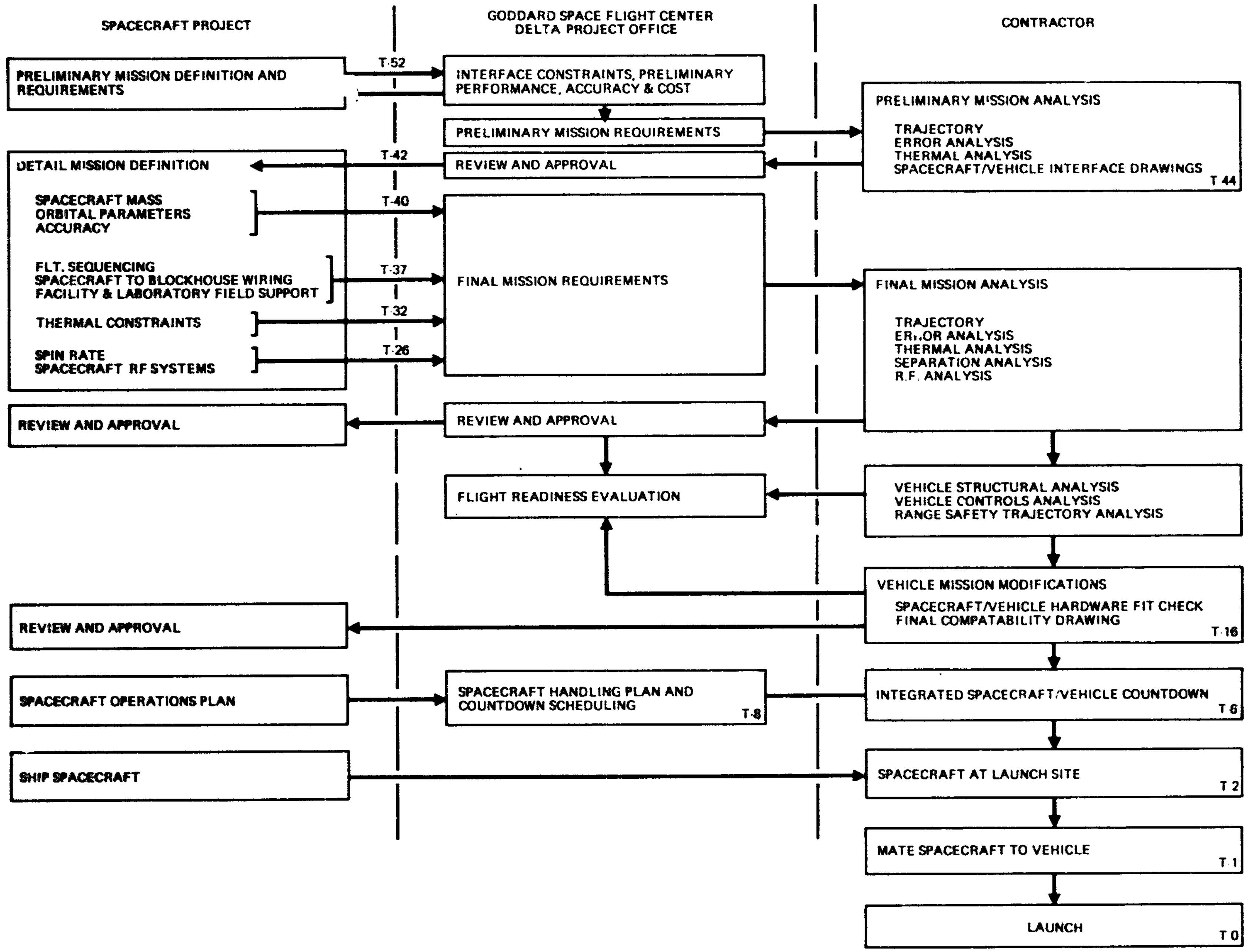


Figure 12. Delta Mission Analysis and Integration

The Delta Project conducts launches from both ETR and WTR. Prograde missions with orbital inclinations of 30 degrees or less are normally launched from ETR and near-polar or retro-grade missions from WTR, though near polar missions have been launched from ETR.

Facilities for the Spacecraft Project use at the launch site include spacecraft assembly and checkout laboratories, telemetry, fabrication and cryogenic laboratories, clean rooms, shops, storage, and offices.

The first and second stage mission modifications to the vehicle are made in the contractor production area. The first and second stages are delivered directly to the launch pad, erected, and again undergo systems testing. The thrust augmentation solid motors and third stage solid motors are stored and prepared at the launch site. The thrust augmentation solid motors are mated to the first stage on the launch pad about two weeks before launch. The third stage motor is built up on the spin table and the spacecraft mated with the assembly at about the same time. The spacecraft/third stage assembly is transported in an environmentally controlled canister to an environmental room on top of the mobile service tower around the vehicle and there the assembly is mated to the vehicle. While the spacecraft is mated to the vehicle, spacecraft and vehicle checkout and testing is interspersed and whenever possible to accommodate the spacecraft requirements.

On pad checkout of the vehicle culminates in a pre-countdown simulated flight without propellant on-board, wherein all systems of the vehicle are exercised as they are during the mission. The simulated flight test takes place one week before launch and is followed by final preparation of the vehicle for launch and then a three day countdown to lift-off. If necessary, complete access to the spacecraft can be provided up to four hours prior to liftoff, though normally the fairing is installed about 12 to 16 hours prior to launch. Provisions to continuously power and monitor the spacecraft from the blockhouse is provided through the vehicle wiring. While the spacecraft is on the vehicle, thermally and hermetically conditioned, filtered air is provided to the spacecraft right up to lift-off.

Launches off the same pad at ETR have been conducted at two week intervals, though six weeks is a normal one-shift per day operation. For follow-on spacecraft in a mission series a called-up launch can be made on 90 days notice at no increase in launch costs provided it is an identical mission, the mission peculiar hardware (attach fitting, etc.) have been provisioned and the launch does not impact another scheduled mission. Call-up time may be reduced to 60 days at a cost of about $100,000 for factory and launch checkout overtime or to 30 days, provided the vehicle has been previously configured for the mission and completed factory checkout in anticipation of call-up. The 30 day option however, requires commitment of about $200,000 of non-recoverable funds if call-up is not exercised.

Based on 10 years of experience at ETR, the probability of launching in a window 15 seconds wide on a given day is about 70 percent. The probability for a thirty minute launch window, typical for most missions, is about 90 percent. Recently, when spacecraft development delays impacted a number of Delta launches of lower priority and a call-up launch option was suddenly exercised, the Delta Project launched three spacecraft at one-week intervals to relieve a congestion of six spacecraft awaiting launch. Normally, however, the scheduled launch date desired by the Spacecraft Project can be met.