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THRUST AUGMENTED THOR-AGENA PERFORMANCE FOR THE ORBITING GEOPHYSICAL OBSERVATORY OGO-IV MISSION

Lewis Research Center
Cleveland, Ohio

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16. Abstract

The Thrust Augmented Thor-Agena successfully launched the Orbiting Geophysical Observatory-IV into a low-altitude, near-polar elliptical trajectory. The spacecraft was launched from the Western Test Range in July, 1967, for the purpose of conducting a series of scientific experiments. This report discusses the performance of the Thrust Augmented Thor-Agena launch vehicle from lift-off through spacecraft separation. It does not discuss spacecraft performance or the data obtained from scientific experimentation.

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I. SUMMARY

The Thrust Augmented Thor (TAT)-Agena launch vehicle, with Orbiting Geophysical Observatory-IV (OGO-IV), was successfully launched on the first attempt from the Western Test Range on July 28, 1967, at 0621:07.50 Pacific standard time. The TAT boosted the Agena-spacecraft into the proper suborbital coast ellipse. After separation of the Agena-spacecraft from the Thor, the Agena engine was started and Agena-spacecraft was injected onto the desired near-polar elliptical orbit having an apogee altitude of about 907 kilometers and a perigee altitude of about 415 kilometers at an inclination of 86° to the equator (measured counterclockwise at the ascending mode). Approximately 100 seconds after injection the spacecraft was separated from the Agena; the final spacecraft orbit parameters were within the requirements established for the OGO-IV mission.

The TAT and Agena vehicle systems performed satisfactorily throughout flight. The three solid-propellant rocket motors, used to augment the Thor main engine thrust, performed as expected and provided an additional 713 kilonewtons thrust during the first 42 seconds of flight.

This report contains an evaluation of the TAT-Agena systems in support of the OGO-IV mission.

II. INTRODUCTION

The purpose of the Orbiting Geophysical Observatory-IV (OGO-IV) mission was to perform scientific experimentation using an instrumented Earth-orbiting satellite to obtain data on the magnetic fields, the ionosphere, the composition of the atmosphere, and other related scientific fields. The objectives of the launch vehicle were to inject the OGO-IV spacecraft into a low-altitude, near-polar elliptical Earth orbit and for the Agena to accomplish a 90° yaw maneuver after spacecraft separation.

The launch vehicle and the Agena-spacecraft integration to support the OGO program was under the direction of Lewis Research Center. OGO-IV was the fourth of six planned launches.

OGO-I and OGO-III were launched from the Eastern Test Range in September 1964 and June 1966, and were placed onto planned highly elliptical orbits. OGO-II and OGO-IV were launched from the Western Test Range in October 1965 and July 1967 and were placed onto low-altitude, near-polar elliptical orbits. The polar orbit for the OGO-IV mission was planned to have an apogee altitude of about 925 kilometers (500 n mi), a perigee altitude of about 415 kilometers (225 n mi), and an inclination of 86° to the equator (measured counterclockwise at the ascending node).

A Thrust Augmented Thor (TAT)-Agena launch vehicle was used to place the OGO-IV onto the proper orbit. The TAT stage consisted of a basic Thor vehicle augmented by three solid propellant rocket motors. These solid rockets burned during the initial portion of the flight.

This report evaluates the performance of the TAT-Agena launch vehicle for OGO-IV from lift-off through spacecraft separation and the Agena 90° yaw maneuver.

III. LAUNCH VEHICLE DESCRIPTION

by Rodney M. Knight and Eugene E. Coffey

The TAT-Agena is a two-stage launch vehicle consisting of a TAT first stage and an Agena second stage connected by a booster adapter. The composite vehicle (fig. III-1), including the spacecraft shroud and the booster adapter, is 29 meters (95 ft) long. The total weight at lift-off is approximately 68 950 kilograms (152 000 lbm). Figure III-2 shows the TAT-Agena lifting off with OGO-IV.

The TAT (fig. III-3) stage consists of a Thor and three solid-propellant rockets located 120° apart and attached to the Thor near the aft end. The Thor is 17 meters (56 ft) long and is 2.4 meters (8 ft) in diameter except for the conical forward section, which tapers to a diameter of about 1.7 meters (5.5 ft). The solid rockets are 6 meters (20 ft) long and are 0.8 meter (2.5 ft) in diameter with a cone-shaped forward end. The TAT is powered by a main engine with a thrust of 756 kilonewtons (170 000 lbf), two vernier engines with a total thrust of 8.9 kilonewtons (2000 lbf), and three solid-propellant rockets with a total thrust 713 kilonewtons (160 275 lbf). The propellants for the TAT main engine and the vernier engines are liquid oxygen and high-grade kerosene, and the propellant for the solid rockets is basically a solid grain of polybutadiene acrylic acid and ammonium perchlorate. The vernier engines, the main engine, and the solid rockets are sequentially ignited prior to lift-off. The fixed-nozzle solid rocket motors burn for approximately 42 seconds and are jettisoned about 23 seconds later. The TAT main engine fires until the desired velocity for the planned suborbital coast ellipse is achieved. During powered flight, the TAT main engine is gimbaled for pitch and yaw control, and the vernier engines are gimbaled for roll control. After TAT main engine cutoff, the vernier engines continue to burn for 9 seconds to provide vehicle attitude control and fine trajectory corrections. After vernier engine cutoff, the TAT is severed from the Agena by the firing of a Mild Detonating Fuse system located on the booster adapter. The firing of a retrorocket system, mounted on the booster adapter, then separates the TAT with booster adapter from the Agena.

The Agena stage and the shroud protecting the spacecraft are shown in figure III-4. The diameter of the Agena is 1.52 meters (5 ft), and the length of the Agena and shroud is about 12 meters (40 ft). Agena is powered by a model 8096 Bell Aerosystems engine with a rated vacuum thrust of 71.17 kilonewtons (16 000 lbf). This engine uses unsymmetrical dimethylhydrazine and inhibited red fuming nitric acid as propellants. During powered flight, pitch and yaw control are provided by gimbaling the Agena engine, and roll control is provided by a cold-gas (mixture of nitrogen and tetrafluoromethane) attitude control system. During periods of nonpowered flight, pitch, yaw, and roll control are provided by the cold-gas system. The cold-gas system is also used to perform the Agena 90° yaw maneuver after spacecraft separation. A fiber glass laminate clamshell shroud is used to provide environmental protection for the spacecraft during ascent. This shroud is jettisoned approximately 10 seconds after Agena engine ignition. The OGO-IV is shown in figure III-5.

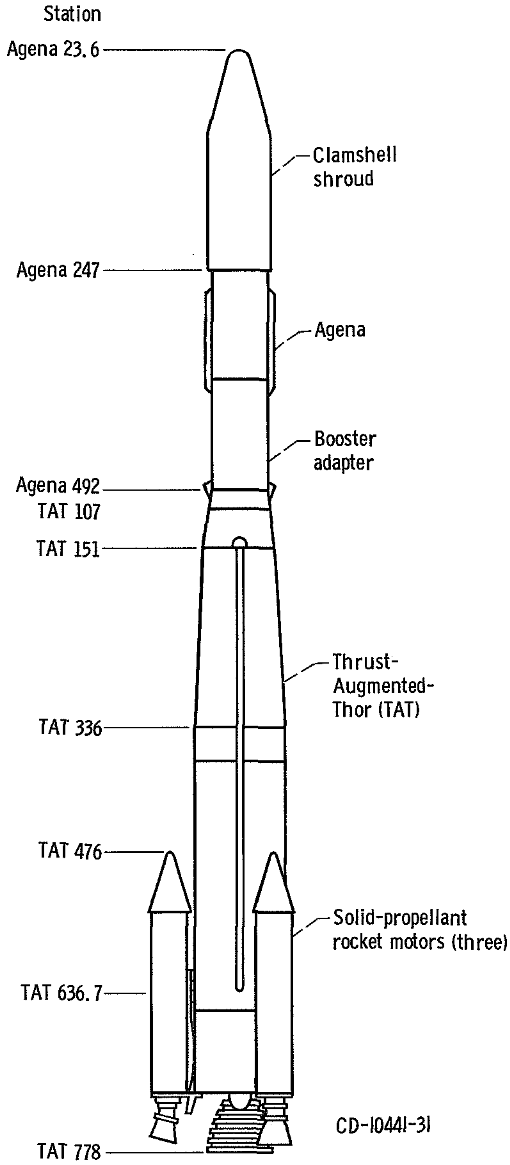


Figure III-1. - Composite space vehicle, OGO-IV.

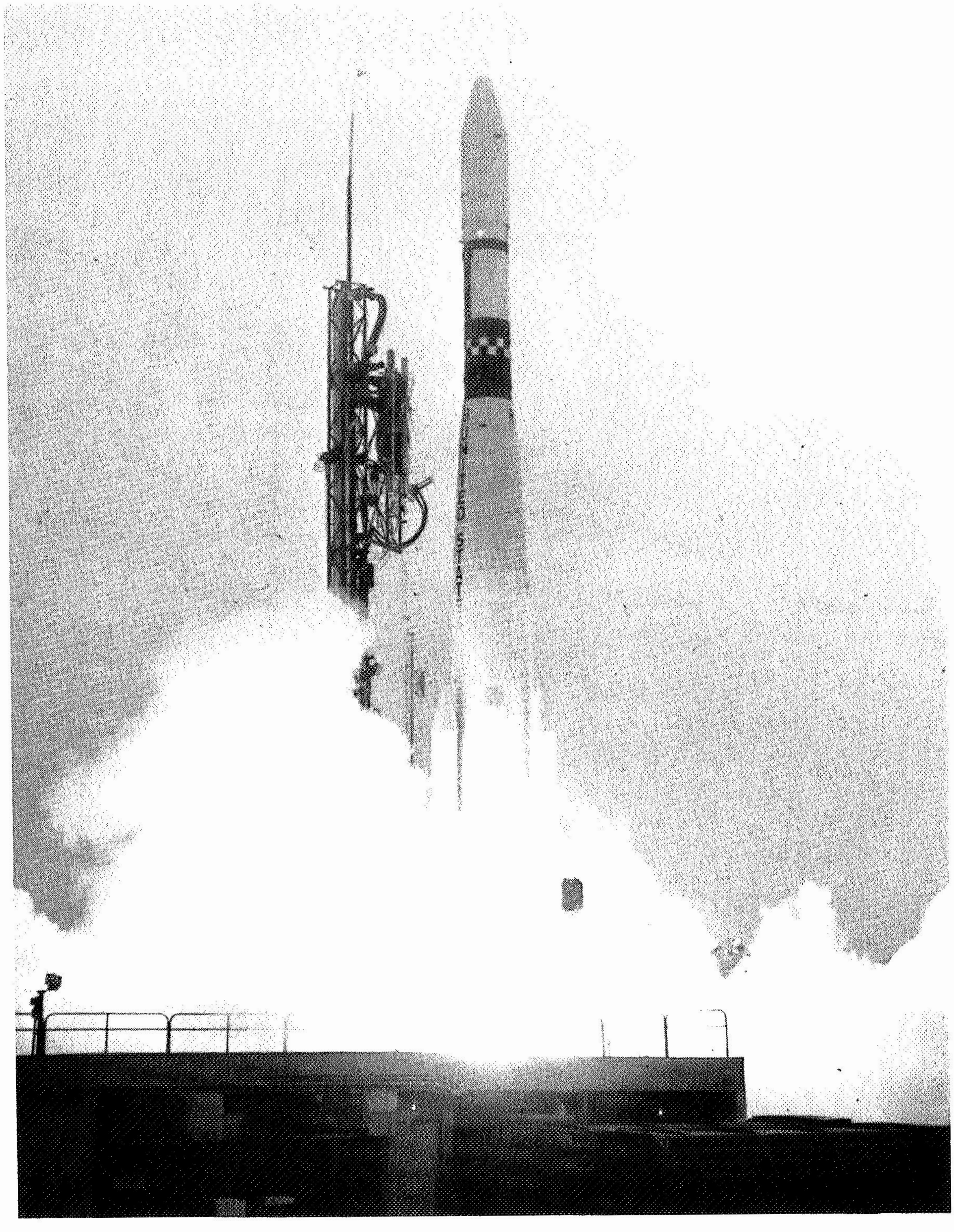


Figure III-2. - TAT-Agena lifting off with OGO-IV.

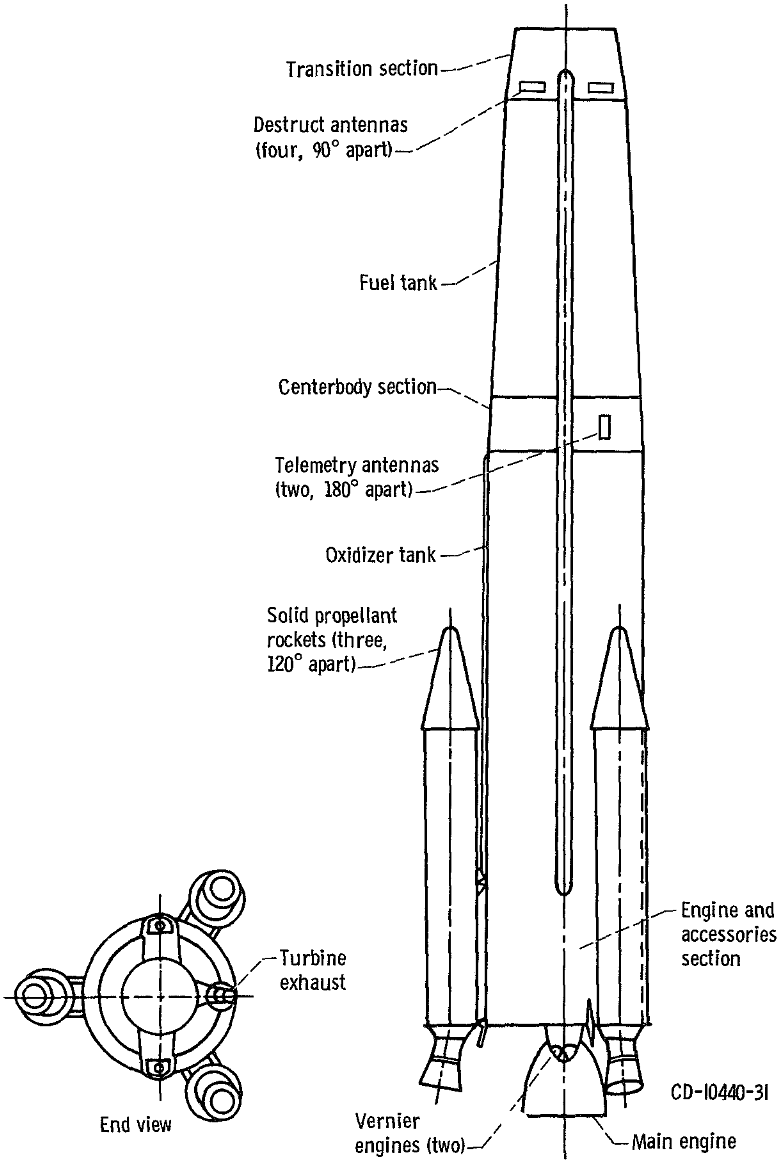


Figure III-3. - TAT configuration, OGO-IV.

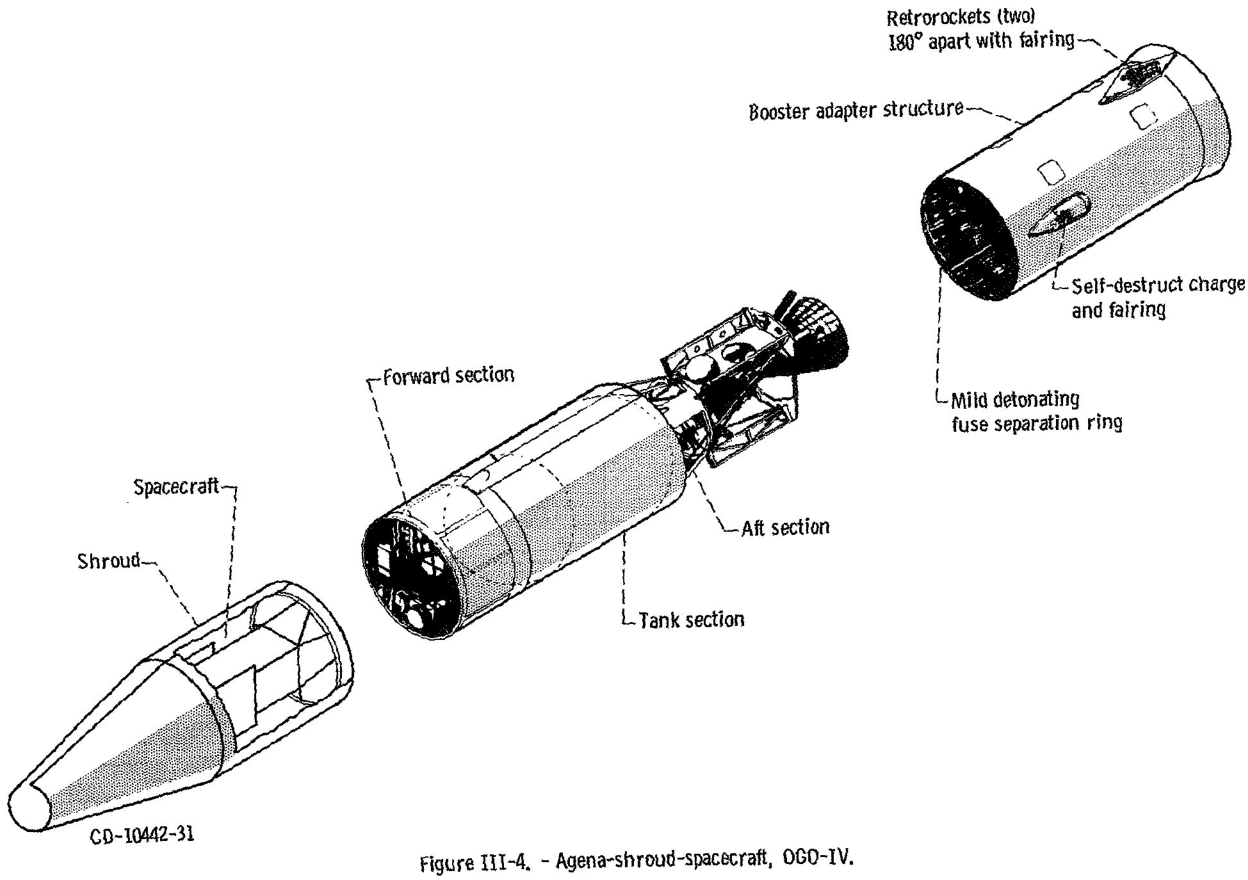


Figure III-4. - Agena-shroud-spacecraft, OGO-IV.

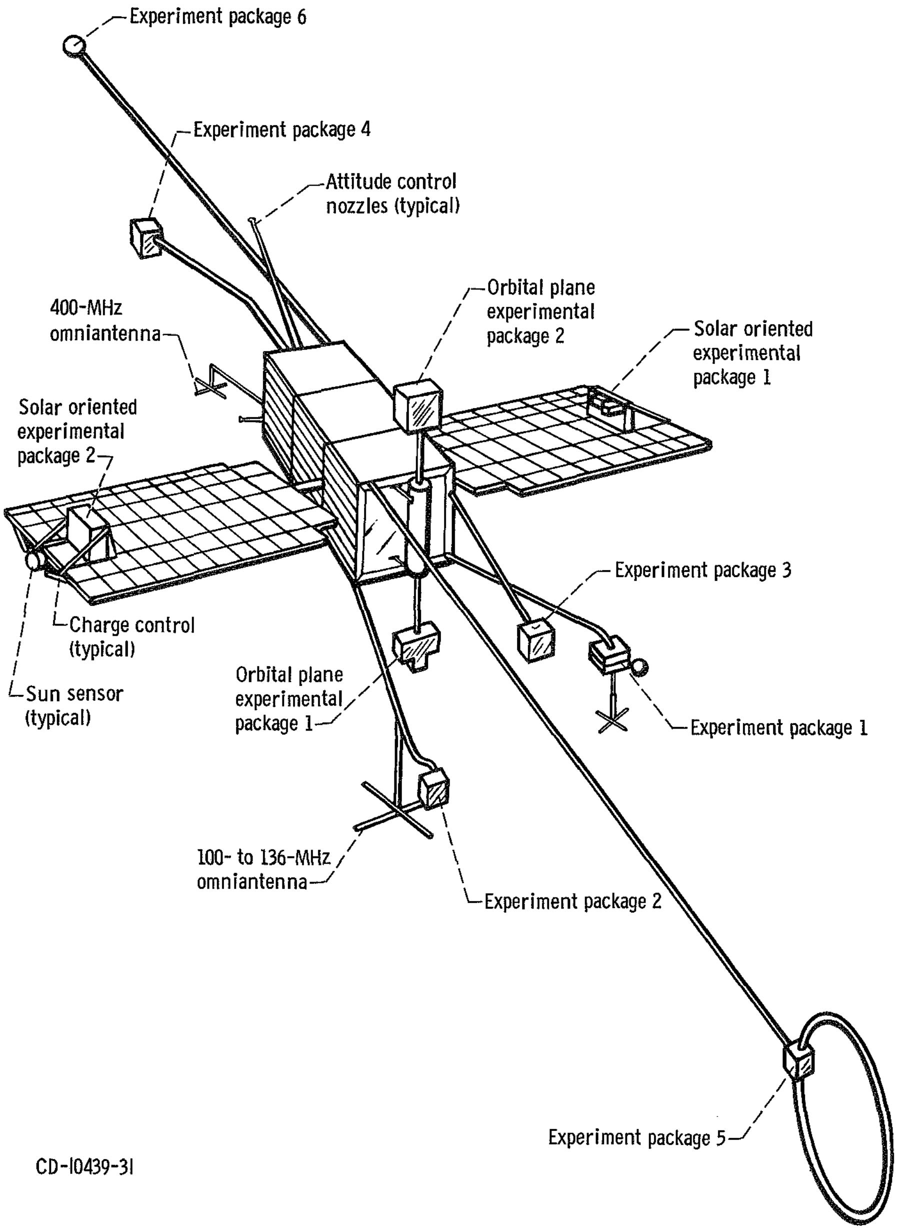


Figure III-5. - Spacecraft shown in deployed configuration, OGO-IV.

IV. TRAJECTORY AND PERFORMANCE

by Ralph P. Kuivinen

TRAJECTORY PLAN

For the near-polar OGO-IV mission, the TAT-Agena launch vehicle trajectory plan is a direct ascent (Agena single burn) flight launched from the Western Test Range. The TAT boosts the Agena - OGO-IV into a prescribed suborbital coast ellipse. The TAT flight consists of two powered phases; a solid motor main engine phase, and a vernier engine phase. Following TAT-Agena separation, the Agena engine is ignited and burns until it places the Agena - OGO-IV into the desired near-polar orbit of 416.8 by 926.2 kilometers (225 by 500 n mi) at an inclination of 86° to the equator. After Agena engine cutoff, the Agena - OGO-IV coasts for 100 seconds to allow the Agena engine thrust to decay and to aline the Agena - OGO-IV with the local horizontal before the OGO-IV is separated from the Agena. Three seconds after spacecraft separation, the Agena performs a yaw left maneuver of 90°. This is done to insure that any Agena thrust resulting from the expulsion of residual propellants and gases will change the plane of the orbit and thereby reduce the probability of collision between the Agena and the spacecraft. Figure IV-1 shows the ascent profile for the OGO-IV mission. Appendix A shows a sequence of major flight events.

TRAJECTORY RESULTS

Lift-off Through TAT Boost Phase

OGO-IV was successfully launched from the Space Launch Complex 2-EAST (SLC-2E), Western Test Range, on July 28, 1967, at 0621:07.505 Pacific standard time. Table IV-I compares the actual significant flight events with the nominal flight events from the postflight nominal trajectory.

At T + 2.13 seconds the program maneuver (a combined roll-pitch-yaw) to achieve the launch azimuth of 176.7° commenced. At T + 16.38 seconds the launch of azimuth was attained, the roll and yaw rates were terminated, and the vehicle continued to pitch downrange at the programmed pitch rates.

The winds aloft at launch were light and predominently from the southeast with a peak velocity of 26.52 meters per second (87 ft/sec) from the south at an altitude of 13 110 meters (43 000 ft). The maximum wind shear occurred between the altitudes 14 024 and 14 634 meters (46 000 and 48 000 ft) and were not severe.

The maximum vehicle bending response was calculated to be 51.8 percent of the critical value in compression at Agena station 247 and to occur at an altitude of 9563 meters (31 366 ft). The maximum booster gimbal angle was calculated to be 28.9 percent of the available gimbal angle in the yaw plane and to occur at an altitude of 1756 meters (5760.5 ft). The wind data used for these calculations were obtained from the T - 0 (lift-off) weather ballon. (See fig. IV-2).

The three solid motors burned out at T + 42.7 seconds. These motors were jettisoned approximately 23 seconds later.

At T + 65.28 seconds (solid motor jettison), the actual trajectory of the vehicle was 83.8 meters (275 ft) lower, 736.3 meters (2415 ft) uprange, and 113.1 meters (371 ft) to the right compared with the predicted position. The deviations in altitude and range were caused by the headwinds and the lower than predicted TAT thrust. The cross-range deviation to the right of predicted was due to the combination of control system deviations and headwinds.

At T + 149.05 seconds (TAT main engine cutoff) the actual trajectory of the vehicle was 1427.4 meters (4682 ft) lower, 3692.1 meters (12 110 ft) uprange, and 490.9 meters (1610 ft) to the right compared with the predicted position. The velocity of the vehicle at main engine cutoff was 41.07 meters per second (134.7 ft/sec) lower than expected. This lower velocity resulted from a slightly low TAT thrust level; however, the lower TAT thrust level was within the 3 sigma (3σ) tolerance.

The trajectory was designed for TAT main engine cutoff to occur by either radio guidance command or propellant depletion. For OGO-IV, main engine cutoff occurred by propellant depletion. The propellant depletion was primarily attributed to propellant flow rate dispersions. These dispersions, however, were within the 3σ tolerances. The fuel residual was 287.6 kilograms (634 lbm) at main engine cutoff.

The radio guidance system steered the TAT from T + 92.4 seconds to T + 146.1 seconds. Guidance transmitted the discrete command for main engine cutoff and start Agena timer at T + 149.6 seconds. However, cutoff had occurred because of oxidizer depletion 0.55 second before the command was effective.

The TAT vernier engine thrust duration was teminated by the TAT sequence timer 8.91 seconds after main engine cutoff. The insertion parameters at vernier engine cutoff are listed in table IV-II and the resulting coast ellipse parameters are in table IV-III.

Agena Separation and Reorientation Phase

The TAT-Agena separation sequence was commanded at T + 162.36 seconds by the radio guidance system. At T + 212.01 seconds, the Agena timer initiated a fast pitch-down of 60° per minute for 5.96 seconds. The pitch rate was then reduced to 12.1° per minute at T + 217.97 seconds for the remainder of the Agena powered flight.

Agena Powered Phase

The Agena engine ignited at T + 224.05 seconds and achieved 90-percent chamber pressure 1.18 seconds later. At T + 234.07 seconds shroud separation occurred. Agena radio guidance steering was initiated at T + 234.45 seconds with initial pitchup steering of 5.48° to compensate for the low-altitude contribution of the TAT booster energy deficiency. Agena radio guidance steering was terminated at T + 464.75 seconds. Agena engine cutoff was commanded by radio guidance at T + 466.16 seconds. The Agena engine burn time was 1.75 seconds longer than expected but was required to compensate for the low TAT performance and trajectory dispersions. The insertion parameters at Agena engine cutoff are listed in table IV-IV.

The velocity meter provided a backup for Agena engine cutoff and was biased for 69.8 meters per second (229 ft/sec) above the nominal velocity-to-be-gained. Consequently the Agena could gain up to 69.8 meters per second (229 ft/sec) above the nominal velocity-to-be-gained, if required, to compensate for any trajectory and performance dispersions before the velocity meter would command Agena engine cutoff.

At Agena engine cutoff the velocity was 7787.5 meters per second (25 542.9 ft/sec). The reconstructed trajectory data showed that the Agena engine thrust decay provided an additional velocity of 9.6 meters per second (31.6 ft/sec) for a total velocity of 7797.1 meters per second (25 574 ft/sec).

The reconstructed trajectory data also indicated that the Agena gained 63.7 meters per second (209 ft/sec) over the nominal velocity-to-be-gained by the end of thrust decay. The velocity meter telemetry data, sampled 16 seconds after Agena engine cutoff, showed that 8.4 meters per second (28 ft/sec) were available in the velocity meter at the end of thrust decay, which indicated that the Agena gained 61.4 meters per second (201 ft/sec) over the nominal velocity-to-be-gained. It should be noted that the reconstructed values are obtained from radar data and that the accuracy in calculating velocity from Agena engine thrust decay can vary ±1.5 meters per second (±5 ft/sec) because of the quality and duration of the tracking data.

Based on the reconstructed trajectory data, at vernier engine cutoff there was a velocity deficiency of 41.07 meters per second (134.7 ft/sec), and at guidance command for Agena cutoff (not including thrust decay) the Agena had gained an excess velocity of 54.1 meters per second (177.4 ft/sec). Since the Agena velocity meter measures an integrated axial acceleration, which is a vector component of the inertial velocity dependent on the attitude of the vehicle, this difference may be due to the steering commands from the radio guidance for correcting for the TAT energy deficiency and other vehicle dispersions.

An evaluation of the orbit parameters indicates that the launch vehicle successfully inserted OGO-IV into an acceptable orbit within the 3σ low-tolerance limit. The average deviation was approximately $1.6\ \sigma$ from the predicted orbit. Table IV-V shows the Agena orbit and the OGO-IV orbit after Agena-spacecraft separation. The Agena orbit is derived from San Nicholas Island tracking data evaluated approximately 100 seconds after orbit insertion. The OGO-IV spacecraft orbit was determined from early tracking data by the Goddard Space Flight Center.

Agena Post Injection

At T + 567.31 seconds, the Agena sequence timer initiated the separation sequence of the Agena-OGO-IV. At T + 570.0 seconds, the Agena was yawed left 90° at a rate of 3.0° per second for 30 seconds. At T + 636.83 seconds, the Agena sequence timer was shut down to complete the launch vehicle flight events.

TABLE IV-I. - SIGNIFICANT FLIGHT EVENTS, OGO-IV

Event description	Event time, sec after takeoff	
	Actual	Nominal
Lift-off (621:07.505 PST)	0	0
Solid motor burnout	42.7	43.0
Solid motor jettison	65.28	65.0
Start radio guidance steering	92.36	92.19
Stop radio guidance steering	146.12	145.75
Main engine cutoff and start agena timer	149.05	149.55
Vernier engine cutoff	157.96	158.55
TAT-Agena separation (radio guidance)	162.36	162.5
Initiate - 60 deg/min pitch rate	212.01	212.5
Transfer to -12.1 deg/min pitch rate	217.97	218.5
Agena engine ignition	224.05	224.46
Agena engine 90 percent chamber pressure	225.23	225.708
Shroud separation	234.07	234.5
Start radio guidance steering	234.45	234.66
Stop radio guidance steering	464.75	463.13
Agena engine cutoff (radio guidance)	466.16	464.89
Spacecraft separation	567.31	567.5
Start Agena 90° yaw maneuver	570.00	570.5
Stop Agena 90° yaw maneuver	600.1	600.5
Agena timer shutdown	636.83	636.5

TABLE IV-III. - TAT SUBORBITAL COAST ELLIPSE PARAMETERS AT APOGEE, OGO-IV[a]

Parameter	Units	Actual
Radius	m	6705837
	ft	21995150
Altitude	km	330.50
	n mi	178.41
Inertial velocity	m/sec	2943.277
	ft/sec	9653.95
Inclination	deg	81.86
Eccentricity	-----	0.8544

[a]Security classification precludes the comparison of actual with predicted parameters.

TABLE IV-II. - INSERTION PARAMETERS AT VERNIER ENGINE CUTOFF, OGO-IV[a]

Parameter	Units	Actual
Altitude	km	129.08
	n mi	69.68
Range	km	161.05
	n mi	86.94
Inertial velocity	m/sec	3519.27
	ft/sec	11543.2
Inclination	deg	81.857
Inertial azimuth	deg	170.26
Inertial flight path angle	deg	30.396

[a]Security classification precludes the comparison of actual with predicted values.

TABLE IV-IV. - INSERTION AT

AGENA COMMAND CUTOFF,

OGO-IV[a]

Parameter	Units	Actual
Altitude	km	415.47
	n mi	224.28
Range	km	1412.12
	n mi	762.29
Velocity	m/sec	7787.47
	ft/sec	25542.9
Flight path angle	deg	0.125
Azimuth	deg	175.63
Inclination	deg	85.98

[a]Security classification precludes the comparison of actual with predicted values.

TABLE IV-V. - ORBIT PARAMETERS,

OGO-IV[a]

Parameters	Units	Actual	
		Agena[b]	OGO-IV[c]
Apogee altitude	km	907.34	908.45
	n mi	489.80	490.40
Perigee altitude	km	415.99	412.10
	n mi	224.56	222.46
Period	min	97.904	97.88
Inclination	deg	85.985	86.011
Eccentricity	----	0.03493	0.03526

[a]Security classification precludes the comparison of actual with predicted parameters.

[b]Orbit derived from San Nicholos Island tracking data.

[c]Determined from early tracking data from Goddard Space Flight Center.

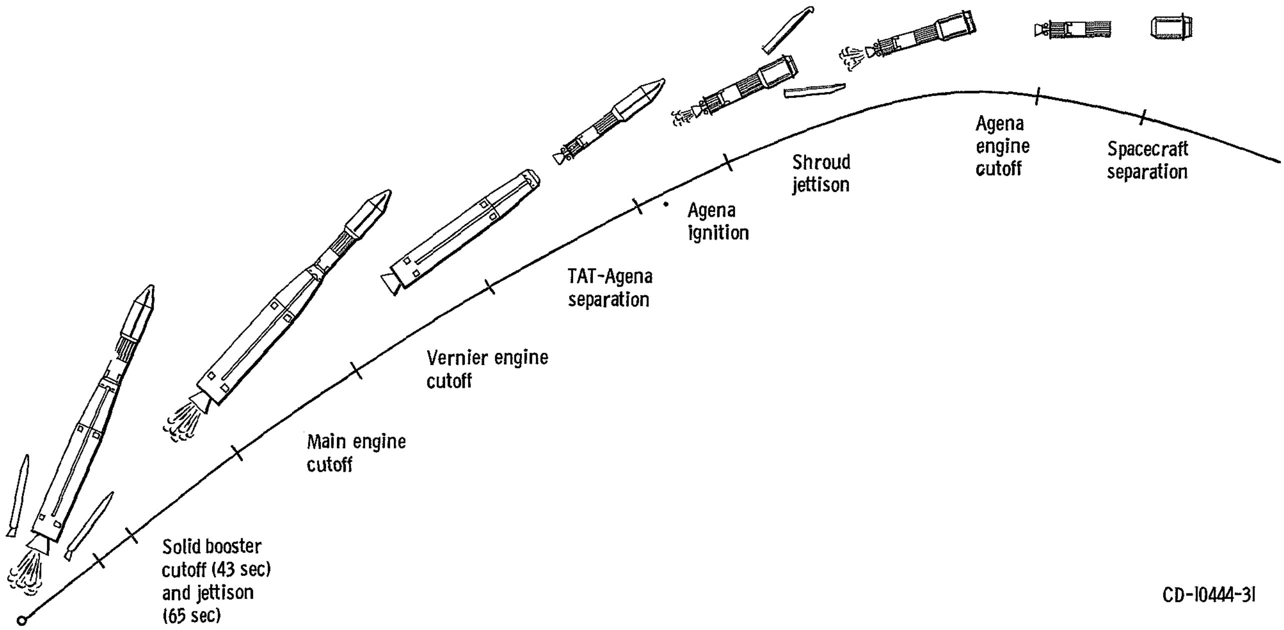
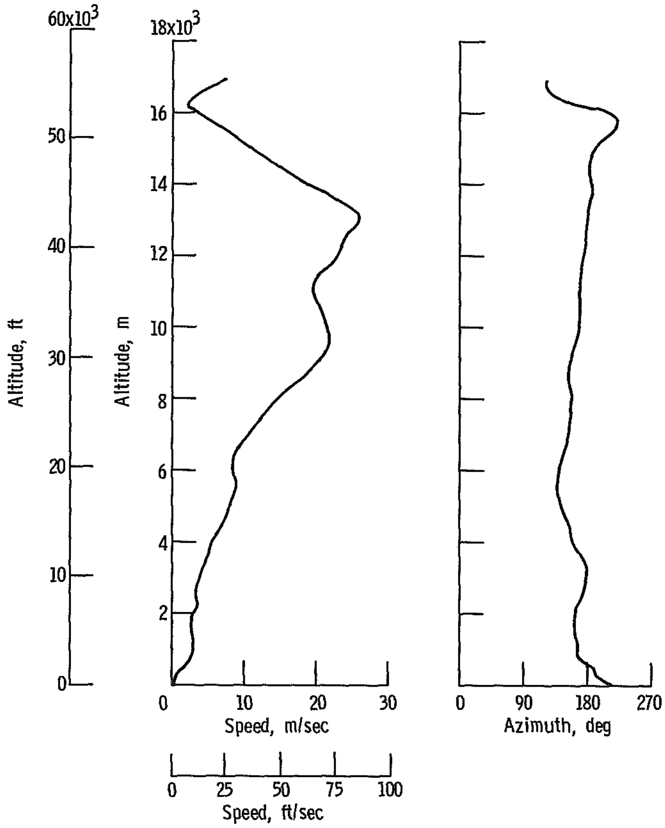


Figure IV-1. - OGO-IV ascent profile.



Figures IV-2. - OGO-IV T - 0 wind data.

V. THRUST AUGMENTED THOR VEHICLE SYSTEM PERFORMANCE

AIRFRAME STRUCTURE SYSTEM

by Robert N. Reinberger

Description

The TAT airframe structure (fig. V-1) consists of five sections: the transition section, the fuel tank, the centerbody section, the oxidizer tank, and the engine and accessories section. The Thor is 17 meters (56 ft) long and is 2.4 meters (8 ft) in diameter except for the conical forward section, which tapers to a diameter of about 1.7 meters (5.5 ft).

The transition section at the forward end of the TAT is 1.1 meters (3.7 ft) long and consists of a truncated cone of semimonocoque construction. The transition section houses the flight control equipment, electrical power components, umbilical connection assembly, and flight termination equipment. Suitable access doors are provided to facilitate inspection and replacement of various equipment.

The fuel tank assembly is 4.7 meters (15.4 ft) long and is longitudinally seam welded in the form of a truncated cone. It has convex domes at either end, internal frames, circumferential and antivortex baffles, and a fuel transfer tube and sump.

The centerbody section, of semimonocoque construction, is 0.8 meter (2.8 ft) long and contains the booster telemetry equipment. Doors are provided for ease of access to all equipment in this section.

The oxidizer tank assembly, 6.8 meters (22.3 ft) long, is similar in construction to the fuel tank assembly, except that it has a constant diameter. The aft end of the oxidizer tank assembly contains the nitrogen pressurization tanks and associated components and the oxidizer fill valve.

The engine and accessories section is of semimonocoque aluminum construction with stringers and formers. The main engine is attached through a gimbal block and tripod structure to three uniformly spaced thrust beams. These beams transmit the engine thrust loads to the booster structure. While the vehicle is on the launcher, the three thrust beams and three launch beams support the vehicle. All the liquid propulsion support items such as the turbopump, lubrication unit, gas generator, hydraulic unit, engine relay boxes and integrated-start airborne system are housed in this section. Three solid motors are attached to the thrust beams.

Performance

The airframe structure system performance was satisfactory and all flight loads were within the design limits. The peak longitudinal load during flight was 8 g's. Maximum engine gimbaling in response to wind shear was calculated to be -0.77° pitch and 1.13° yaw. The actual gimbal angles were -1.29° pitch and 0.94° yaw.

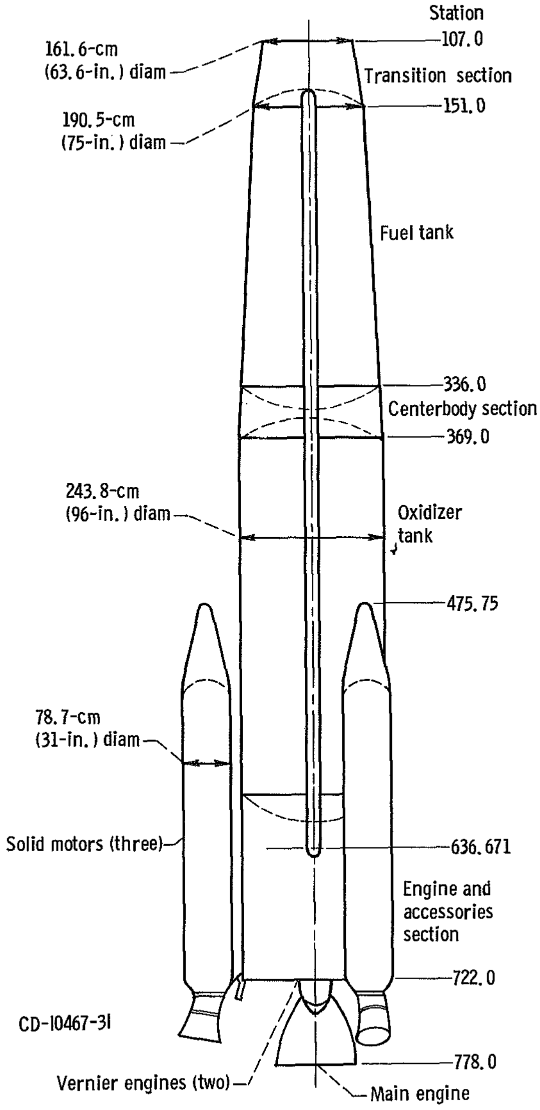


Figure V-1. - TAT vehicle structure system, OGO-IV.

PROPULSION SYSTEM

by Charles H. Kerrigan

Description

The TAT propulsion system (fig. V-2) is composed of a liquid-propellant engine system and three solid motors.

The liquid-propellant engine system consists of a main engine, two vernier engines, an engine start system, and electro-pneumatic controls. These engines are of the single burn type and use liquid oxygen and RJ-1 (kerosene) for propellants. There is no provision for controlling thrust to compensate for change in the turbopump inlet pressures due to longitudinal acceleration.

The TAT main engine, rated at 756 kilonewtons (170×10^3 lbf) thrust at sea level, consists of a gimbaled thrust chamber, propellant valves, one oxidizer and one fuel turbopump driven by a gas generator, lubricating system, and a heat exchanger. Each vernier engine gimbals and is rated at 4.45 kilonewtons (1000 lbf) thrust at sea level when supplied with propellants from the main engine turbopumps during main engine operation. In the vernier phase of flight, each vernier engine is rated at 3.68 kilonewtons (830 lbf) thrust at sea level. For this phase, the vernier engines are supplied with propellants from the engine start tanks because the main engine turbopumps do not operate after main engine cutoff.

During the engine start sequence, electrically initiated pyrotechnic igniters are used to ignite propellants in the gas generator, which drives the turbopump, and hypergolic igniters are used to ignite the propellants in the thrust chambers of the main engine and vernier engines.

The engine start system consists of two small propellant tanks and a pressurization system. These engine start propellant tanks (approximate volume of 1 cu ft (0.028 m^3) each) are filled and pressurized prior to launch; they remain pressurized and are refilled during flight. This system supplies propellants for starting the engines and also for vernier engine operation after main engine cutoff.

The three solid motors are mounted 120° apart on the engine section and have a 11° nozzle cant angle. Each of these motors is sea-level rated at 237.6 kilonewtons (53 425 lbf) thrust. Attainment of approximately 60-percent rated thrust by the main engine actuates a pressure switch that provides an ignition signal to the solid motors. The motors operate at full thrust for approximately 28 seconds and then decay to zero thrust in approximately the next 14 seconds. Jettison of the expended solid motor cases occurs at about T + 65 seconds.

Performance

The performance of the TAT propulsion system for the OGO-IV mission was satisfactory. During the liquid-propellant engine start phase, engine valve opening times and starting sequence events were within tolerances. The flight performance of the liquid-propellant engines and solid motors was evaluated by comparing measured parameters with the expected values. These are tabulated in table V-I. The solid motors burned for 42.7 seconds as expected. Main engine cutoff was initiated by the oxidizer depletion switch. The TAT timer commanded vernier engine cutoff approximately 9 seconds later as expected. Transients were normal at solid motor burnout and during shutdown of the liquid-propellant engines.

TABLE V-I. - TAT PROPULSION SYSTEM PERFORMANCE, OGO-IV

(a) Solid propellant motors

Performance parameter	Units	Expected value	Flight values at T + 10 sec (stabilized operation)		
			Motor 1	Motor 2	Motor 3
Combustion chamber pressure	N/cm^2	334	334	326	328
	psia	445	485	472	475

(b) Liquid propellant engine

Performance parameter	Flight time, sec	Units	Flight values	
			Expected	Measured
Thrust chamber pressure	[a]T + 30	N/cm^2	408	405
		psia	591	587
	[b]T + 149	N/cm^2	371	359
		psia	538	520
Turbopump speed	T + 30	rpm	6304	6013
	T + 149	rpm	6011	5700
Vernier engine number 2[d] thrust chamber pressure when pump supplied	T + 30	N/cm^2	266	266
		psia	385	386
	T + 149	N/cm^2	250	244
		psia	362	354
Vernier engine number 2[d] thrust chamber pressure when tank supplied	[c]T + 158	N/cm^2	213	211
		psia	309	306

[a]Time at which main engine attains stabilized operation.
[b]Main engine cutoff.
[c]Vernier engine cutoff.
[d]Vernier engine number 1 was not instrumented; however, proper vehicle roll control indicated satisfactory engine performance.

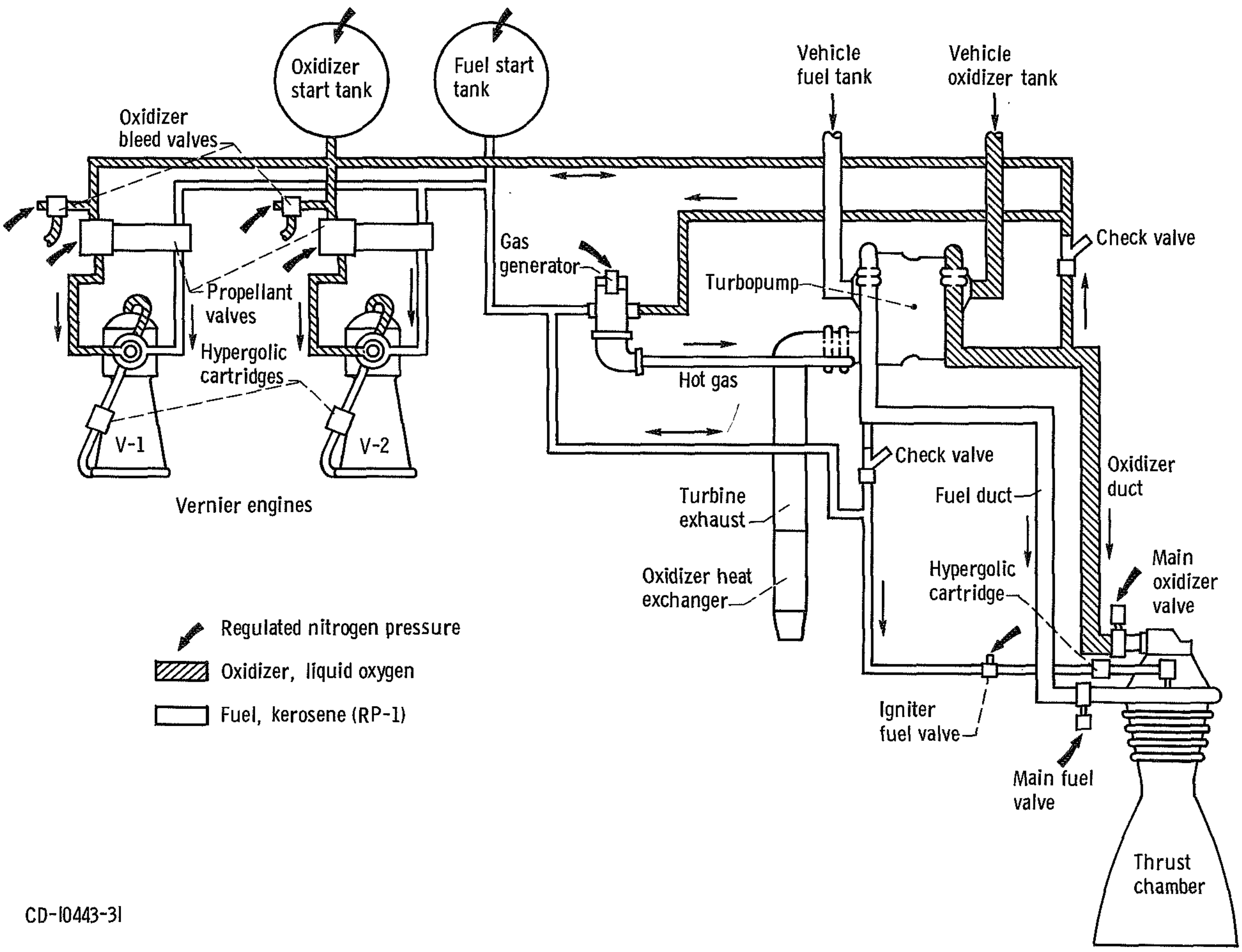


Figure V-2. - TAT liquid propellant engine system, OGO-IV.

HYDRAULIC SYSTEM

by Eugene J. Fourney

Description

The TAT hydraulic system provides hydraulic fluid at the pressures and flows required for gimbaling the main and vernier engines during operation. The system consists of a pump, reservoir, accumulator, filters, pressure relief and check valves, and siz actuator assemblies. The positive displacement pump, mounted on the turbopump accessory unit, provides the required hydraulic fluid flow and pressure during the main engine thrust phase. The accumulator, which is precharged with nitrogen gas during ground operations, provides the required hydraulic fluid flow and pressure for gimbaling the vernier engines during the vernier engine phase. The reservoir provides hydraulic fluid to the pump inlet from the system return lines. Each actuator assembly consist of a servovalve for controlling the flow of hydraulic fluid for engine positioning and a feedback potentiometer for engine position indication. The TAT main engine and vernier engines 1 and 2 each require two acruators.

Performance

The hadraulic system functioned satisfactorily as indicated by vehicle flight behavior and telemetry data. The hydraulic system flight performance is presented in table V-II.

TABLE V-II. - TAT HYDRAULIC SYSTEM PERFORMANCE, OGO-IV

Performance parameter	Supply pressure		Return pressure	
	N/cm^2	psia	N/cm^2	psia
Normal range				
During main engine operation	2065 to 2340	3000 to 3400	31 to 65.5	45 to 90
During vernier engine phase	206 to 345	300 to 500		
Preengine ignition	2040	2980	68.2	99
Flight time, sec				
T + 10	2135	3100	40.7	59
T + 25	2105	3060	37.9	55
T + 40	2135	3100	55.1	80
Main engine cutoff	2080	3020	53.0	77
Vernier engine cutoff	1790	2600	56.5	82

[a]During the vernier phase, the supply pressure normally decays and continues to decay after vernier engine cutoff until supply pressure depletion, as evidenced by a sharp drop to zero.

[b]While the airborne hydraulic system is activated.

PNEUMATIC SYSTEM

by Eugene J. Fourney

Description

The TAT pneumatic system consists of two subsystems: the pneumatic control and the fuel tank pressurization. High-pressure gaseous nitrogen is stored in three airborne spherical tanks to supply pressure to the pneumatic system. A check valve in the system assures that two of these tanks will be restricted to providing nitrogen gas for the pneumatic control subsystem. The remaining tank is used primarily to provide nitrogen gas for pressurizing the fuel tank system. The pneumatic control subsystem consists of a pneumatic control package, a filter, and two four-way solenoid control valves. One of the solenoid control valves regulates the pneumatic pressure to the main oxidizer valve; the other valve regulates the pneumatic pressure to the main fuel valve and the gas generator valve. This subsystem regulates gaseous nitrogen pressure for pressurization of the engine start subsystem, the engine turbopump oil susbystem, and the oxidizer pump seal cavity and for actuation of propellant valves.

The fuel tank pressurization subsystem bleeds high-pressure gaseous nitrogen through a fixed orifice to maintain and absolute pressure between 8.3 and 23.4 newtons per square centimeter (12 to 34 psi) in the fuel tank ullage during flight. The oxidizer tank is not pressurized by the pneumatic system; a heat exchanger in the main engine gas generator exhaust system is used to convert liquid oxygen to gaseous oxygen to pressurize the oxidizer tank during flight.

Performance

All pneumatic system parameters observed were satisfactory during flight. Details of the system's performance are shown in table V-III.

TABLE V-III. - PNEUMATIC SYSTEM PERFORMANCE DATA, OGO-IV

Performance parameter	Fuel tank ullage pressure[b]		Oxidizer tank ullage pressure		Pneumatic control supply pressure	
	N/cm^2	psia	N/cm^2	psia	N/cm^2	psia
Normal range[a]	8.3 to 23.4	12 to 34	22.1 to 31.7	32 to 46	1665 to 2206	2400 to 3200
Lift-off	25.5	37	29.7	43	1924	2790
Flight time, sec						
T + 10	20.7	30	31.0	45	1910	2770
T + 25	17.3	25	29.7	43	1896	2750
T + 40	15.5	22	25.5	37	1889	2740
T + 60	13.1	19	24.2	35	1855	2690
Main engine cutoff	8.9	13	23.2	35	1752	2540
Vernier engine cutoff	8.9	13	23.5	34	[c]993	1440

[a]Values apply only after lift-off.
[b]Shown for reference only.
[c]Pressure change from main engine cutoff to vernier engine cutoff reflects the additional use of nitrogen for pressurization of the start tanks that supply the propellants during vernier engine phase.

GUIDANCE AND FLIGHT CONTROL SYSTEM

by David Schwartz and James L. Swavely

Description

The TAT flight path is controlled by two interrelated systems: the TAT flight control system and the ground radio guidance system. The flight control system directs the vehicle in a programmed mode from lift-off through vernier engine cutoff. During the TAT booster phase, the capability of the flight control system to accept ground radio guidance commands is enabled at T + 90 seconds. However, steering commands were inhibited except for the period between T + 92.4 to T + 146.1 seconds. (T + 146.1 sec is approximately 16 sec prior to TAT-Agena separation.) The radio guidance system also provides discrete commands for TAT main engine cutoff, for TAT-Agena separation, and for Agena engine cutoff.

The major components of the TAT flight control system are the control electronic assembly and three individually mounted rate gyros.

The control electronic assembly contains a programmer, three displacement gyros, and associated electronic circuitry. These displacement gyros have single-degree-of-freedom, are floated, and are hermetically sealed and rate integrating. They are mounted on the vehicle in an orthogonal configuration alining the input axis of each gyro to its respective vehicle axis of pitch, yaw, or roll. Each gyro provides an electrical output signal proportional to the difference in angular position of the measured axis from the gyro input (reference) axis. The programmer supplies sequenced commands to the displacement gyros, to other portions of the control electronic assembly, and to the vehicle. This sequence of commands is accurately controlled by a motor-driven, prepunched tape. Relay circuits in the programmer are activated by prepunched slots in the tape.

The three rate gyros are of the single-degree-of-freedom, spring restrained type. The roll rate gyro is mounted in the centerbody section of the TAT with its input axis alined to the vehicle roll axis. The roll rate gyro provides an electrical output signal proportional to the angular rate of rotation of the vehicle about the gyro input axis. The pitch and yaw rate gyros are mounted in the fuel tank fairing (electric wiring duct) and operate in a manner analogous to the roll rate gyro.

The radio guidance system (fig. V-3) consists of a ground-based X-band pulse-tracking radar, the airborne guidance equipment and a ground-based computer. The airborne guidance equipment is located on the Agena and pitch and yaw commands and discrete commands are routed through the airborne harness from the Agena to the TAT.

The ground-based radio guidance system transmits a composite message train containing an address code and the steering and discrete commands to the launch vehicle. The airborne guidance equipment includes a radar transponder and a command receiver, both located in the Agena forward section. The airborne guidance equipment receives the pulse-coded message train and, if the address code of the received signal is correct, transmits a return pulse to the ground station for use in tracking the vehicle. The ground-based computer processes the tracking data, computes trajectory corrections, and issues the appropriate steering and discrete commands.

Two antennas (dorsal and ventral) are mounted on the Agena and coupled through a directional coupler to the guidance equipment by means of waveguide sections. The dorsal antenna is used primarily for on-pad and early ascent coverage because of the orientation of the vehicle on the launch pad relative to the ground tracking station; the ventral antenna provides in-flight signal coverage when the radio frequency energy is directed near the thrust axis or downrange side of the vehicle. The directional coupler inserts attenuation in the dorsal antenna path to minimize interference effects between the dorsal and ventral antennas during ascent and pitchover of the vehicle. Trajectory information and the launch plan for this specific mission are used to determine the configuration of the antenna, the antenna orientation, and the type of directional coupler to be used for each mission.

Prelaunch acquisition (lock-on) of the vehicle by the radio ground guidance cannot be accomplished because there is no clear line of sight between the ground radar antenna and the vehicle. The procedure for acquiring the launch vehicle antenna is to manually position the ground radar antenna beam centerline to the radar horizon at a point on the programmed trajectory. Solid radar-lock with the airborne system is then obtained as the vehicle passes through the ground radar antenna beam. The ground guidance system is locked onto the vehicle in both range and frequency prior to lift-off. False lock and the resultant antenna slewing from multipath signals are prevented by a threshold-level setting in the ground receiver that inhibits closing of the angle-tracking loops until the signal strength reaches a predetermined value as the vehicle approaches the radar horizon. At lift-off, the receiver threshold signal sensing circuitry is enabled and an angle-loop closure timer is started to provide maximum receiver sensitivity at the time the vehicle is expected to reach the line of sight. As a backup to the threshold sensing level and angle-loop closure timer, the ground radio guidance operator manually switches the ground receiver to maximum sensitivity 4 seconds after lift-off. If the radar has not automatically acquired the launch vehicle by T + 4 seconds, the antenna operator optically acquires the launch vehicle, visibility permitting, or elevates the antenna through a planned sequence of preselected coordinates are required. These coordinates correspond to the expected vehicle positions at T + 20, T + 40, and T + 60 seconds.

Performance

The TAT flight control system performed satisfactorily throughout the flight. Main engine gimbal angles at lift-off (T + 0 sec) were -0.074° in pitch and 0.074° in yaw. Lift-off transients in pitch, yaw, and roll were negligible.

The maximum main engine gimbal angles at the time of greatest wind shear (approx. T + 55 sec) were -1.29° in pitch and $+0.94^{\circ}$ in yaw. Maximum angular displacements from the desired flight path immediately following guidance initiation (T + 92.4 sec) were 1.04° in pitch and 0.38° in yaw; the corresponding rates were -1.06 and -2.07 degrees per second. Gimbal angles at main cutoff (T + 149.05 sec) were 0.27° in pitch and 0.11° in yaw. Angular displacements from the desired flight path at the time the Agena gyros uncaged (T + 158.0 sec) were 0.80° in pitch, 0.16° in yaw, and 0 in roll. The angular displacements noted were well within the allowable booster attitude limits required for proper operation of the Agena guidance system. Angular rates at TAT-Agena separation (T + 162.36 sec) were 0.04 degree per second in pitch, 0.08 degree per second in yaw, and 0 in roll.

An oscillation of 0.32 degree per second peak-to-peak in the roll rate and an oscillation of 3.12 degrees per second peak-to-peak in the pitch-roll vernier engine (both oscillations at a frequency of 1 Hz) were observed after solid motor rocket case jettison (T + 65.28 sec). This motion may have been caused by servovalve nonlinearities and by backlash in the linkage to the vernier engines. The main engine chamber pressure exhibited a 19-hertz, 31.0-newton-per-square-centimeter (45-psi) peak-to-peak oscillation between T + 134 and T + 146 seconds; this was caused by thrust oscillation that excites the first longitudinal mode of the vehicle. None of these oscillations was detrimental to the control system performance.

Evaluation of ground and telemetered data indicates that both the ground radio guidance system and the airborne radio guidance equipment performed satisfactorily.

The range and frequency loops of the ground receiver were locked in with the airborne transponder while on the launch pad. Signal strength of the antenna angle-tracking loops, as measured at the ground receiver and used during vehicle checkout, fluctuated between -50 and -60 dBm (decibels referenced to 1 mW) because of interference. Prior to lift-off the ground receiver was set to an angle-loop closure threshold of -34 dBm based on an expected signal of -24 dBm at the radar horizon and a signal margin of 10 decibels. The angle-loop closure timer was set to switch the threshold-level setting from -34 to -78 dBm at T + 3.5 seconds, and the manual backup angle loop was closed at T + 4 seconds. The signal level at the ground station increased to approximately -23 dBm at T + 5 seconds and gradually decayed to -60 dBm at time of disable pitch and yaw steering by the Agena timer at T + 482.1 seconds. Signal fluctuations were evident as expected during the two-antenna interference region from T + 20 to T + 70 seconds when the received signals from the dorsal and ventral antennas were within 10 decibels of each other. The radio-frequency data link performance indicated angle coast periods of 2.1, 0.3, and 0.2 second during the two-antenna signal-interference region.

The performance of the ground-based computer was satisfactory throughout the countdown and vehicle flight.

Prior to lift-off the airborne guidance equipment automatic gain control monitor indicated a signal strength received by the vehicle of -39 dBm. The maximum received signal strength was -9 dBm at T + 4.5 seconds (when the vehicle rose above the radar horizon) and decreased to -42 dBm by the time of ground guidance power shutdown at T + 509.1 seconds. The airborne magnetron current monitor indicated occasional missing pulses at T + 30.0 and T + 43.7 seconds, and again at T + 432.2 seconds. These periods were not of sufficient duration to cause signal dropout of the airborne transponder. The signal strength received by the vehicle was at an adequate level throughout the radio guidance system operation period.

Radio guidance system steering commands were sent to the TAT booster from T + 92.4 seconds until T + 146.1 seconds as planned. Separation of the Agena from the TAT occurred at T + 162.36 seconds. Approximately 70 seconds later, steering of the Agena by radio guidance began and commands were sent to the Agena from T + 234.5 seconds until T + 464.8 seconds as planned.

The maximum excursions of the integrated steering commands issued by guidance during the flight were 6.29° pitch down and 7.02° yaw left during first stage steering, and 5.48° pitch up and 0.86° yaw left during second stage steering. The times of significant guidance events, except TAT main engine cutoff, are given in table V-IV. TAT main engine cutoff resulted from propellant depletion at T + 149.05 seconds, while the guidance discrete did not occur until T + 149.6 seconds. The airborne guidance power-off occurred at T + 509.1 seconds, 42.9 seconds after the final guidance command, thus allowing the ground guidance station sufficient time to obtain tracking data for the flight evaluation phase.

TABLE V-IV. - TIMES OF SIGNIFICANT

GUIDANCE EVENTS, OGO-IV

Event	Planned time, sec	Actual time from lift-off, sec
Lift-off	0	0
TAT steering		
Commenced	92.19	92.36
Terminated	145.75	146.1
TAT main engine cutoff	149.55	[a]149.0
TAT-Agena separation	162.5	162.36
Transfer guidance to Agena	162.7	162.9
Agena steering		
Commenced	234.66	234.45
Terminated	463.13	464.75
Agena main engine cutoff	464.89	466.16
Disable Agena radio guidance steering (pitch and yaw)	482.7	482.1
Agena radio guidance power off	509.7	509.1

[a]TAT main engine cutoff resulted from propellant depletion.

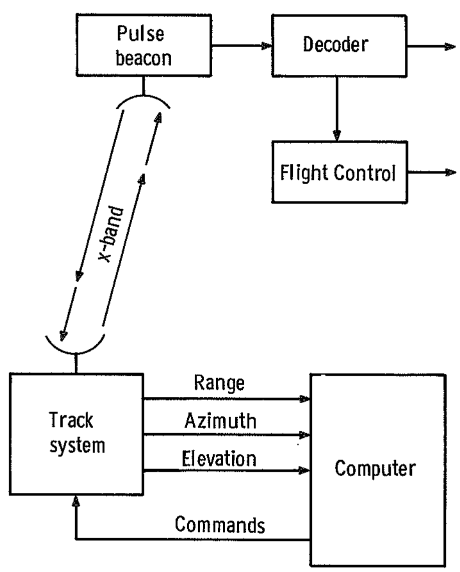


Figure V-3. - Radio guidance system, OGO-IV.

ELECTRICAL SYSTEM

by Edwin R. Procasky

Description

The TAT power requirements are supplied by three 28-volt silver-zinc alkaline batteries and a 400-hertz rotary inverter. (See fig. V-4.) Distribution boxes are located throughout the vehicle to facilitate interconnection and switching of electrical functions. Two tunnels located external to the propellant tanks are used to rout cables between the transition, centerbody, and the engine and accessory sections.

The main battery is rated at 20 ampere hours and supplies all the vehicle power requirements except the telemetry system and the range safety command systems 1 and 2. The power requirements for these systems are supplied by two other batteries. The telemetry battery, which is rated at 3 ampere hours, supplies all telemetry and range safety command system 1 power requirements. The remaining battery is rated at 1 ampere hour and supplies power to range safety command system 2.

The rotary inverter (a dc motor driven ac alternator) provides the 400 hertz, 115/208 volts ac, three-phase power. The voltage output and frequency of the inverter are regulated to ±1.5 percent. The alternator is wye connected with a grounded neutral.

Performance

The main battery supplied the requirements of the dependent systems at near normal voltage levels. The battery voltage at lift-off was 26.4 volts dc, rising to 28.2 volts dc approximately 90 seconds after lift-off and was 28.9 volts dc at TAT main engine cutoff (T + 149.05 sec). The telemetry battery supplied power to the telemetry system and the range safety command system 1 at 27.8 volts dc throughout the TAT flight. The battery that supplies power to the range safety command system 2 is not monitored in flight. The rotary inverter operated with the ±1.5 percent requirements for voltage and frequency throughout the TAT flight. The inverter frequency was 399.7 hertz at lift-off and rose to 400.1 hertz approximately 90 seconds after lift-off and remained at this value throughout the TAT flight. The inverter voltage was 114.0 volts ac throughout the flight.

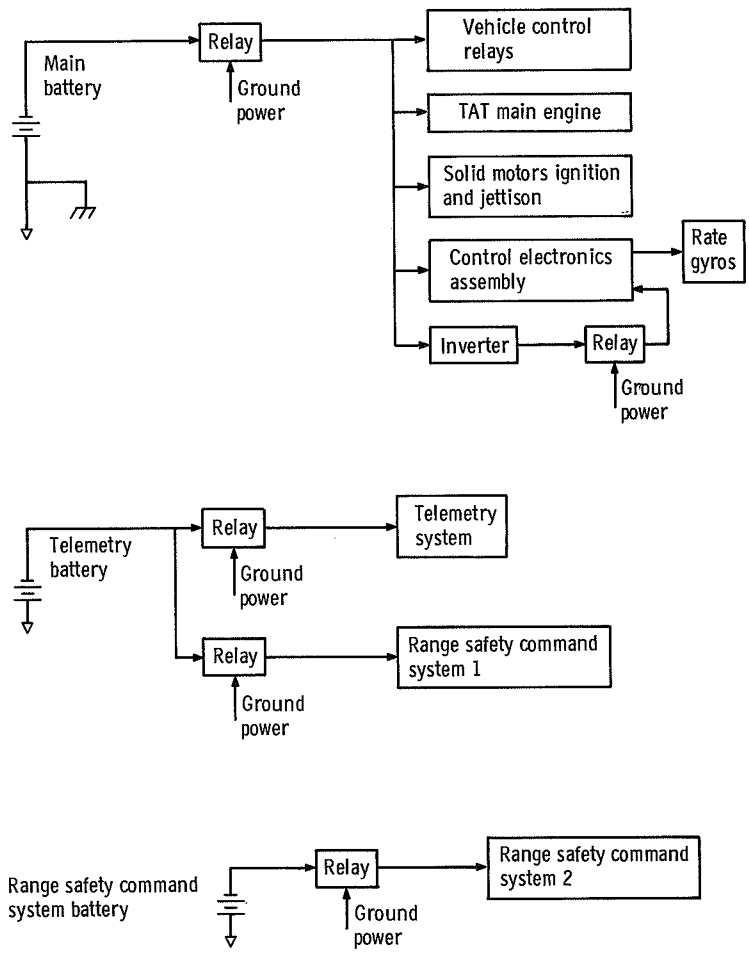


Figure V-4. - TAT power distribution block diagram, OGO-IV.

TELEMETRY SYSTEM

by Edwin S. Jeris

Description

The TAT telemetry system consists of two antenna systems, an FM transmitter, signal conditioning networks, associated transducers, a 28-volt battery, and a multicoder. The telemetry system is located in the centerbody section of the TAT. The telemetry system uses a combination of of two types of transmitter modulation techniques FM/FM and PDM/FM/FM with a common radio frequency link.

The FM/FM section of the PDM/FM/FM telemetry system provides eight channels of continuous data. Voltage controlled subcarrier oscillators are modulated by a single transducer or by a series sequence of signals, to produce an FM output. The FM outputs of the voltage controlled oscillators are combined and applied to the wideband amplifier. The composite FM output of the wideband amplifier modulates the FM transmitter output producing FM/FM.

In the PDM/FM section of the telemetry system transducer data are time multiplexed by a multicoder. The PDM output frequency modulates a single voltage controlled oscillator. The voltage controlled oscillator output is applied to the wideband amplifier and modulates the FM transmitter producing PDM/FM/FM. The multicoder provides 43 channels of commutated data.

Performance

TAT telemetry performance was satisfactory on OGO-IV. Fifty measurements (appendix B) were flown and all yielded usable data. No telemetry problems occurred during the countdown or during the flight. Radio frequency signal strength was adequate during flight as evidenced by the good data. Carrier frequency was stable and no data reduction difficulties were encountered. No direct measurements of telemetry system performance or system environment were made. Appendix C (fig. C-2) shows the specific coverage provided by the supporting telemetry stations.

FLIGHT TERMINATION SYSTEM

by Edwin S. Jeris

Description

The flight termination system for the TAT and the Agena is an interrelated system. The system is designed to function prior to TAT-Agena separation and to destroy both the TAT and the Agena. Also included is an Agena self-destruct feature that will destroy the Agena if a premature TAT-Agena separation occurs. The portion of the flight termination system (fig. V-5) on the TAT side of the TAT-Agena interface is redundant and includes two antenna systems, two command receivers, two safe-arm mechanisms, and detonating cords. Each destruct command receiver uses one antenna system consisting of two cavity antennas (fig. III-3) located on the TAT transition section. The safe-arm mechanisms are armed by lanyards at lift-off. After lift-off, if required, the range safety officer can command destruction of the vehicle by transmitting a coded signal to the destruct command receivers located on the TAT. Either command receiver is capable, when commanded, of energizing the detonator circuits. When the flight termination system is activated, the detonating cords on the TAT, the shaped charge on each of the solid motors, and the shaped charge on the Agena are ignited. The rupture of the liquid-propellant tanks destroys the vehicle, and the rupture of the solid motor cases results in a no-thrust condition.

The Agena portion of the flight termination system is discussed in the COMMUNICATION AND CONTROL section of this report.

Performance

The TAT flight termination system was not monitored during flight; however, because of the system redundancy, it is assumed that the system was capable of destructing the vehicle throughout the TAT boost phase. The telemetry battery, which also supplies power to the range safety command 1 receiver, performed satisfactorily as evidenced by adequate telemetry signal strength. No flight termination commands were required, nor were any commands inadvertently generated by any vehicle system.

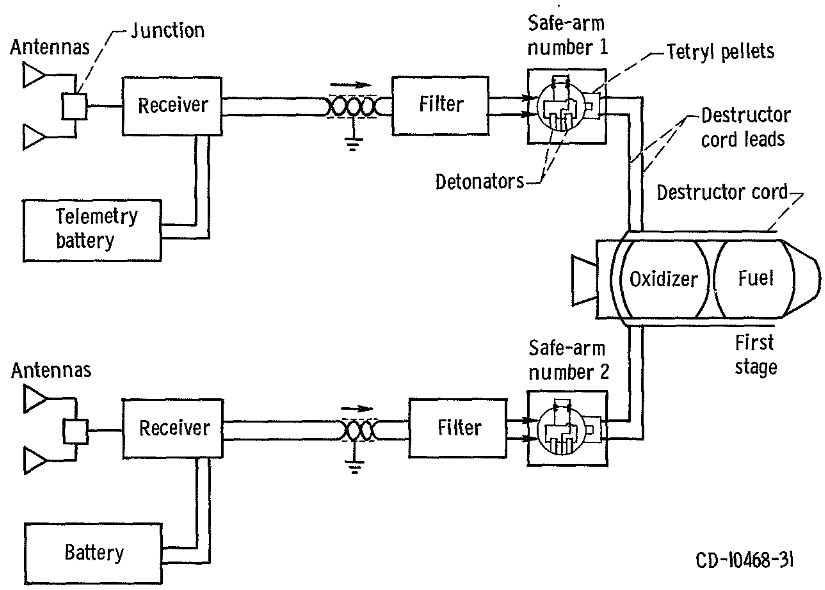


Figure V-5. - Flight termination system, OGO-IV.

VI. AGENA VEHICLE SYSTEM PERFORMANCE

VEHICLE STRUCTURE SYSTEM

by Robert N. Reinberger

Description

The Agena vehicle structure system (fig. VI-1) consists of four major sections: the forward section, the propellant tank section, the aft section, and the booster adapter assembly. Together they provide the aerodynamic shape, structural support, and environmental protection for the vehicle. The forward section is basically an aluminum structure with beryllium and magnesium panels. This section encloses most of the electrical, guidance, and communication equipment and provides the mechanical and electrical interface for the spacecraft adapter and shroud. The propellant tank section consists of two integral aluminum tanks, with a sump below each tank to assure the supply of propellants for engine starts in space. The aft section consists of an engine mounting cone structure and an equipment mounting rack. The magnesium alloy booster adapter section supports the Agena and remains with the TAT after TAT-Agena separation.

Performance

The measured dynamic environment of the structure system was within design limits. The data are presented in appendix D.

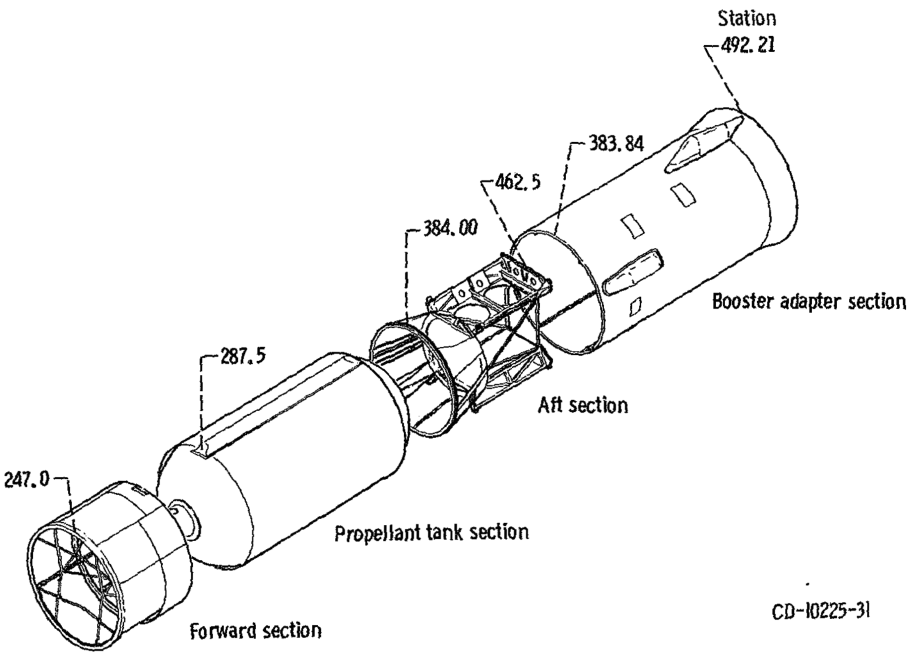


Figure VI-1. - Agena vehicle structure system, OGO-IV.

SHROUD SYSTEM

by C. Robert Finkelstein and Robert N. Reinberger

Description

The shroud system used for the OGO-IV flight was a clamshell type, and it provided environmental protection for the spacecraft prior to and during ascent. This type of shroud was used on the three previous OGO flights. The shroud (fig. VI-2) is 5.67 meters (18.61 ft) long and weighs 282.84 kilograms (623 lbm). It consists of two fairing halves, which form a fairing with a 1.65-meter (5.42-ft) diameter cylindrical section, a 15° half-angle cone, and a 0.61-meter (2 ft) diameter hemispherical nose cap. The shroud halves are constructed of laminated fiberglass strengthened by internal, aluminum longerons, rings, and a tension strap at the aft end of each shroud half. The tension straps prevent the aft edges of the shroud halves from deflecting inward during shroud separation. Microquartz thermal insulation blankets in the cylindrical section of each shroud half and a foil covering in the conical section of each half provide thermal protection for the spacecraft. The shroud halves are held together by two flat bands around the cylindrical section, two explosive bolts, one on each side, at the base of the cylinder on the split line, and two nose latches. The top and bottom bands are tensioned to 22 250 and 11 570 newtons (5000 and 2600 lbf). The two explosive bolts at the base of the cylinder are tensioned to 28 925 newtons (6500 lbf) each.

Shroud jettison is initiated by a radio guidance discrete approximately 10 seconds after the initiation of Agena burn. At this time, Agena electrical power is used to fire two explosive bolts in each of the two bands and two explosive bolts at the base of the shroud. One bolt in each flat band and both bolts at the base of the shroud must be fired to effect shroud separation. The nose latches are released mechanically by first motion of the shroud halves. Then two spring thrusters (in the conical section of the shroud) and two spring actuators (at the base of the shroud) provide the energy to rotate each shroud half about a pivot fitting mounted on the adapter ring. At the time of shroud separation, the Agena has an acceleration of approximately 1 g, and each shroud half rotates through an angle of approximately 75° before it leaves the pivot fitting and falls free.

The shroud system is instrumented with four temperature transducers and two pressure transducers on the inner surface of the shroud fiberglass wall. The temperature transducers are located at stations 23.875 (near the stagnation point) 45.625, 128.125, and 238.625. One pressure transducer located at station 177.125 measures differential pressure across the shroud wall. The other pressure transducer located at station 202.550 measures the absolute pressure in the shroud cavity.

The shroud cylindrical section is clamped around the adapter ring, which is approximately 0.051 meter (0.17 ft) high and is bolted to the forward end of the Agena. The spacecraft adapter is mounted on the adapter ring, and the spacecraft is mounted on the spacecraft adapter. The shroud cavity is isolated from the Agena by a metal diaphragm attached to the Agena forward section.

During ascent the shroud cavity is vented outward through four ports in the cylindrical section and into the Agena through a valve in the diaphragm. Air vented into the Agena passes out in the vicinity of the Agena aft section. A second valve in the diaphragm vents air from the Agena into the shroud cavity if the pressure in the Agena exceeds the pressure in the shroud cavity.

The OGO-IV spacecraft adapter is mated to the adapter ring before being shipped to the launch base. This assembly is mated to the Agena at the launch pad, and the shroud is then installed.

Performance

The history of the shroud internal wall temperatures is shown in figure VI-3. The maximum temperature measured during flight was 354.5 K (178° F). This temperature was measured by the transducer located at station 23.875 (near the stagnation point).

The history of the shroud wall differential pressure ($\Delta P = P_{ambient} - P_{shroud}$) is shown in figure VI-4; the pressure in the shroud cavity exceeded the external pressure at all times during flight. The differential pressure was very nearly zero during the early phase of the flight. During the transonic phase of the flight the differential pressure increased to a maximum value of -0.62 newton per square centimeter (-0.9 psi) at two different times, thereby resulting in a curve with a double peak. The increase in pressure was caused by shock waves on the vehicle during transonic flight. The first peak in the curve might have been caused by shock waves on the shroud; the second peak might have been caused by shock waves on the Agena. After the transonic phase, the differential pressure returned to essentially zero for the remainder of the flight.

The history of the shroud cavity absolute pressure is shown in figure VI-5. The absolute pressure decayed during the flight as predicted and was nearly zero at T + 120 seconds.

Shroud pyrotechnics were fired at T + 234.07 seconds. The Agena was stable at this time, and no measurable Agena roll, pitch, or yaw rates developed as a result of shroud jettison.

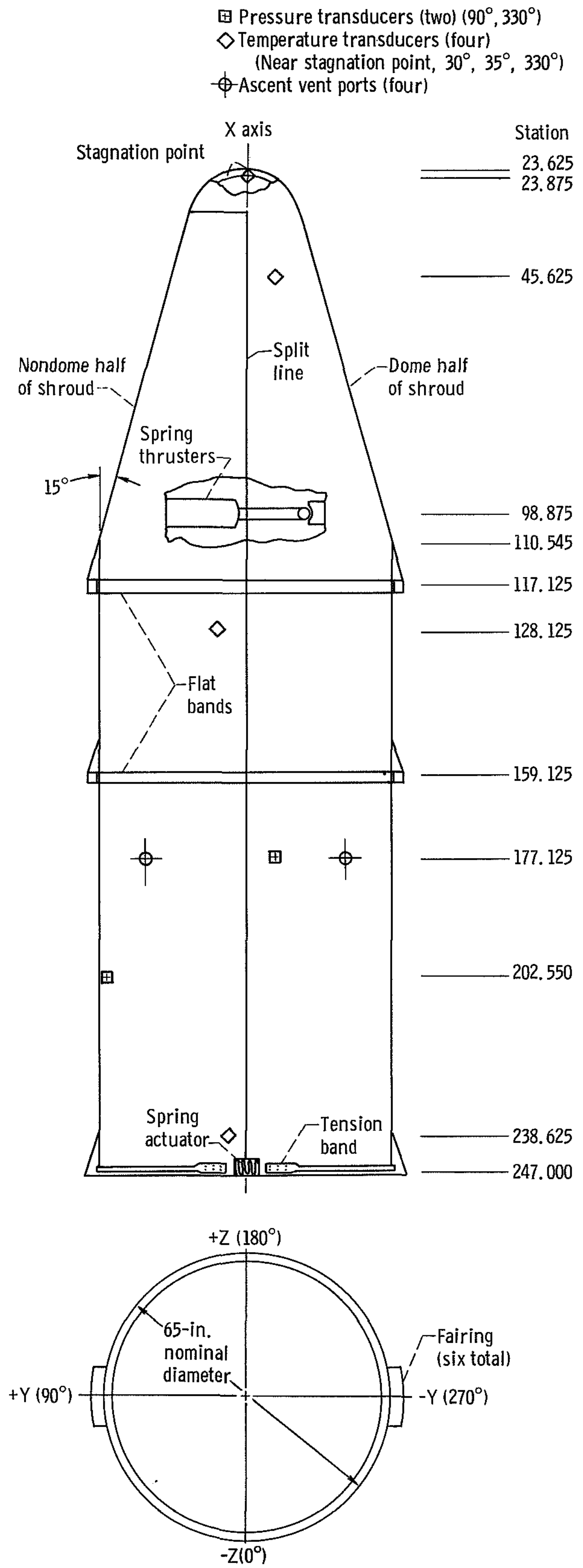


Figure VI-2. - Shroud system, OGO-IV. All insturmentation is located inside the shroud cavity.

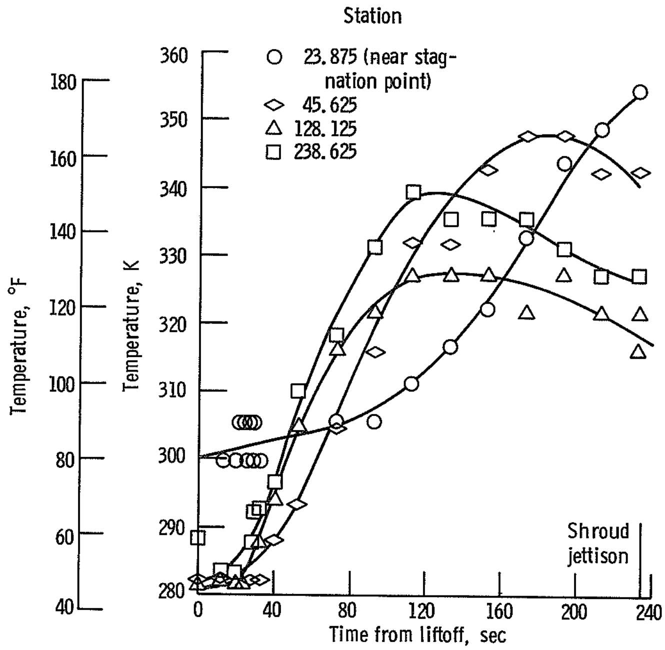


Figure VI-3. - Shroud internal wall temperature history, OGO-IV.

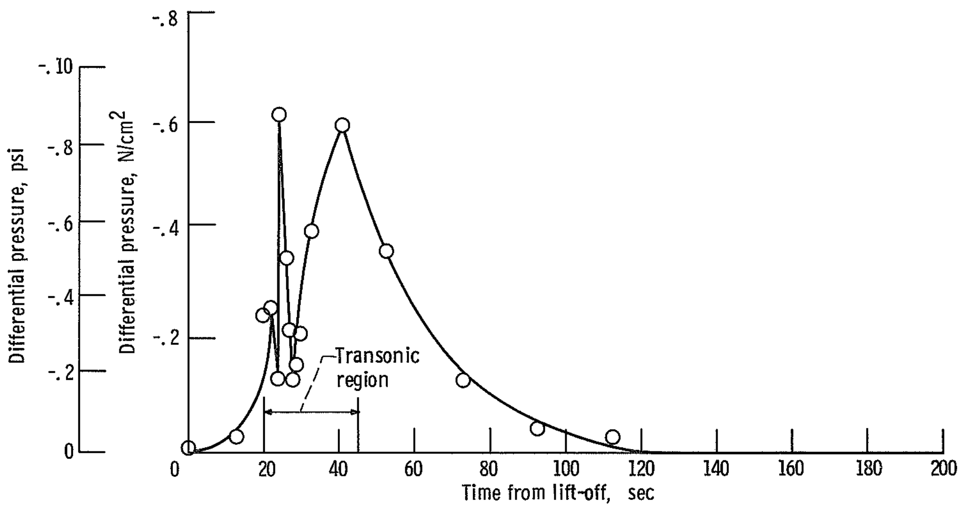


Figure VI-4. - Shroud wall differential pressure history, OGO-IV.

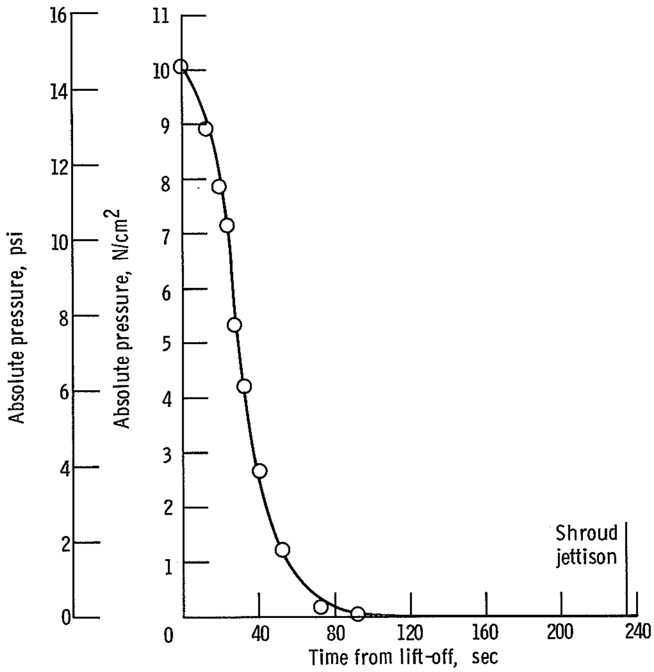


Figure VI-5. - Shroud cavity absolute pressure history, OGO-IV.

PROPULSION SYSTEM

by Robert J. Schroeder

Description

The Agena propulsion system (fig. VI-6) consists of a propellant tank pressurization system, a propellant management system, and an engine system. Also considered part of the propulsion system are the TAT-Agena separation system and Agena vehicle pyrotechnic devices.

The propellant tank pressurization system provides the required propellant tank pressures and consists of a helium supply tank and a pyrotechnic operated helium control valve. Before lift-off, the ullage volume in the propellant tanks is pressurized with helium from a ground supply source. The helium control valve is activated 1.5 seconds after the Agena engine start is initiated to permit helium gas to flow from the supply tank through fixed area flow orifices to each propellant tank. After the Agena engine cutoff, the helium control valve is again activated to isolate the oxidizer tank from the helium supply. This prevents the mixing of oxidizer and fuel vapors that could occur if pressures in the propellant tanks were permitted to reach the same level.

The propellant management system consists of the following major items: propellant fill disconnects to permit the loading of fuel and oxidizer, feed lines from the propellant tanks to the engine pumps, and tank sumps to retain a sufficient amount of propellants for Agena engine start in a near zero gravity environment.

The Agena engine is a Bell Aerosystems Company Model 8096 liquid bipropellant engine that uses unsymmetrical dimethylhydrazine fuel and inhibited red fuming nitric acid oxidizer. Rated thrust in a vacuum is 71 171 newtons (16 000 lbf) with a nozzle expansion area ratio of 45. The engine has a regeneratively cooled thrust chamber and a turbopump-fed propellant flow system. Turbine rotation is initiated by firing a solid-propellant turbine start charge. The turbine is driven during steady-state operation by hot gas produced in a gas generator. Propellants to the gas generator are supplied by the turbopump. Engine thrust vector control is provided by the gimbal mounted thrust chamber. Two hydraulic actuators provide the force for thrust chamber pitch and yaw movement in response to signals produced by the Agena inertial guidance system.

The TAT-Agena separation is accomplished by firing a Mild Detonating Fuse that severs the booster adapter circumferentially near the forward end. The TAT with booster adapter are then separated from the Agena by firing two solid-propellant retrorockets mounted on the booster adapter. Rated average sea level thrust of each retrorocket is 2180 newtons (490 lbf) with an action time of 0.93 second.

Pyrotechnic devices are used to perform a number of functions on the Agena. These devices include squibs, ignitors, detonators, and explosive bolt cartridges. Squibs are used to open and close the helium control valve and to eject the horizon sensor fairings. Ignitors are used for the solid-propellant turbine start charge and the retrorockets. Detonators are used for the self-destruct charge and the Mild Detonating Fuse separation charge. Explosive bolt cartridges are used to rupture the release devices for shroud jettison.

Performance

The Agena engine burn was initiated by the Agena timer at T + 224.05 seconds. Telemetered data from the engine switch group monitor indicated a normal start sequence of the engine control valves. Ninety-percent combustion chamber pressure was reached 1.18 seconds later at T + 225.23 seconds. The average steady-state thrust generated by the Agena engine was 71 020 newtons (15 966 lbf) compared with an expected value of 71 205 newtons (16 030 lbf). The Agena engine burn was terminated at T + 466.16 seconds by ground radio guidance command. The engine burn duration, measured from 90-percent chamber pressure to cutoff was 240.93 seconds. Burn time was 1.75 seconds longer than the expected value of 239.18 seconds. Approximately 99.6 percent of this increase in burn time resulted from the lower than expected performance of the TAT propulsion system; the remaining 0.4 percent resulted from the lower performance of the Agena propulsion system.

The propellant tank pressurization system supplied the required tank pressures. This was evidenced by the fuel and oxidizer pump inlet pressure values that were within 1.4 newtons per square centimeter (2 psi) of the expected values during the Agena engine burn.

The TAT-Agena separation system performance was normal. Separation was commanded by the ground radio guidance at T + 162.36 seconds. At this time the Mild Detonating Fuse and the two retrorockets were ignited. The Agena cleared the booster adapter 2.3 seconds later.

All the Agena pyrotechnic devices performed their intended functions satisfactorily.

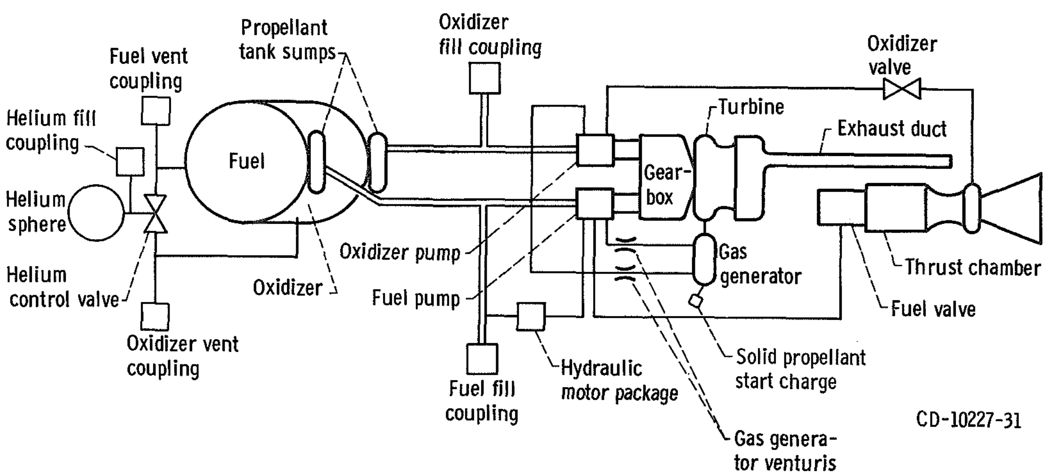


Figure VI-6. - Agena engine propulsion system schematic, OGO-IV.

ELECTRICAL SYSTEM

by Edwin R. Procasky

Description

The Agena electrical system (fig. VI-7) supplies all power, frequency, and voltage requirements for the pyrotechnics, propulsion, flight termination, inertial guidance, radio guidance, and telemetry systems. The electrical system consists of the power source equipment, the power conversion equipment, and the distribution network.

The power source equipment consists of two silver-zinc batteries (type IV-B, minimum design rating of 405 W-hr each) and two nickel-cadmium secondary batteries. The main vehicle battery supplies power to the main vehicle loads, which operates on unregulated power, and to the power conversion equipment. The other silver-zinc battery supplies power to all Agena vehicle pyrotechnics except the destruct charges in the flight termination system. This pyrotechnic battery is connected to the main vehicle battery through a diode so that it can support the load on the main vehicle battery. However, the diode isolates the main battery loads from pyrotechnic transients and from pyrotechnic loads. The two nickel-cadmium batteries are used with the flight termination system.

The power conversion equipment converts unregulated dc power to regulated ac or regulated dc power. The power conversion equipment consists of one inverter and four dc-dc converters. The inverter supplies 115 volts ac (rms) at 400 hertz (±0.02 percent), and one dc-dc converter supplies 28 volts dc to the inertial guidance system. Two dc-dc converters supply 28 volts dc to the telemetry system. The fourth dc-dc converter supplies 28 volts dc to the airborne radio guidance system.

Performance

The Agena electrical system voltages and currents were as expected at lift-off, and the system satisfactorily supplied power to all electrical loads throughout the flight. The battery current load profile was as expected for this mission. The inverter and converter voltages were within specification at lift-off and remained essentially constant throughout flight. Table VI-I summarizes the electrical system performance.

The inverter frequency is not monitored on Agena vehicles; however, performance of the inertial guidance system indicated that the inverter frequency was normal and stable.

TABLE VI-I. - AGENA ELECTRICAL SYSTEM FLIGHT PERFORMANCE SUMMARY, OGO-IV

Measurement	Tolerance	Measurement number	Lift-off	Agena engine ignition	Agena engine shutdown	At spacecraft separation
Main battery voltage	22.5 to 29.5 V	C-1	25.2 V	26.0 V	26.5 V	26.5 V
Pyrotechnic battery voltage	22.5 to 29.5 V	C-141	25.9 V	25.9 V	25.9 V	25.9 V
Main and pyrotechnic battery total current	----------------	C-4	14 A dc	17 A dc	14 A dc	14 A dc
Inertial guidance converter (+28.3 V dc regulated)	27.7 to 28.9 V dc	C-3	28.3 V dc	28.3 V dc	28.3 V dc	28.3 V dc
Inertial guidance converter (-28.3 V dc regulated)	-27.7 to -28.9 V dc	C-5	-28.5 V dc	-28.5 V dc	-28.5 V dc	-28.5 V dc
Guidance inverter phase AB, rms	112.7 to 117.3 V ac	C-31	113.4 V ac	113.4 V ac	113.4 V ac	113.4 V ac
Guidance inverter phase BC, rms	112.7 to 117.3 V ac	C-32	113.4 V ac	113.4 V ac	113.4 V ac	113.4 V ac
Telemetry converter number 1 (+28.3 V dc regulated)	27.7 to 28.9 V dc	H204	28.0 V dc	28.0 V dc	28.0 V dc	28.0 V dc
Telemetry converter number 2 (28.3 V dc regulated)	27.7 to 28.9 V dc	H400	28.5 V dc	28.5 V dc	28.5 V dc	28.5 V dc
Airborne radio guidance converter (+28.3 V dc regulated)	27.7 to 28.9 V dc	BTL-6	28.5 V dc	28.5 V dc	28.5 V dc	28.5 V dc

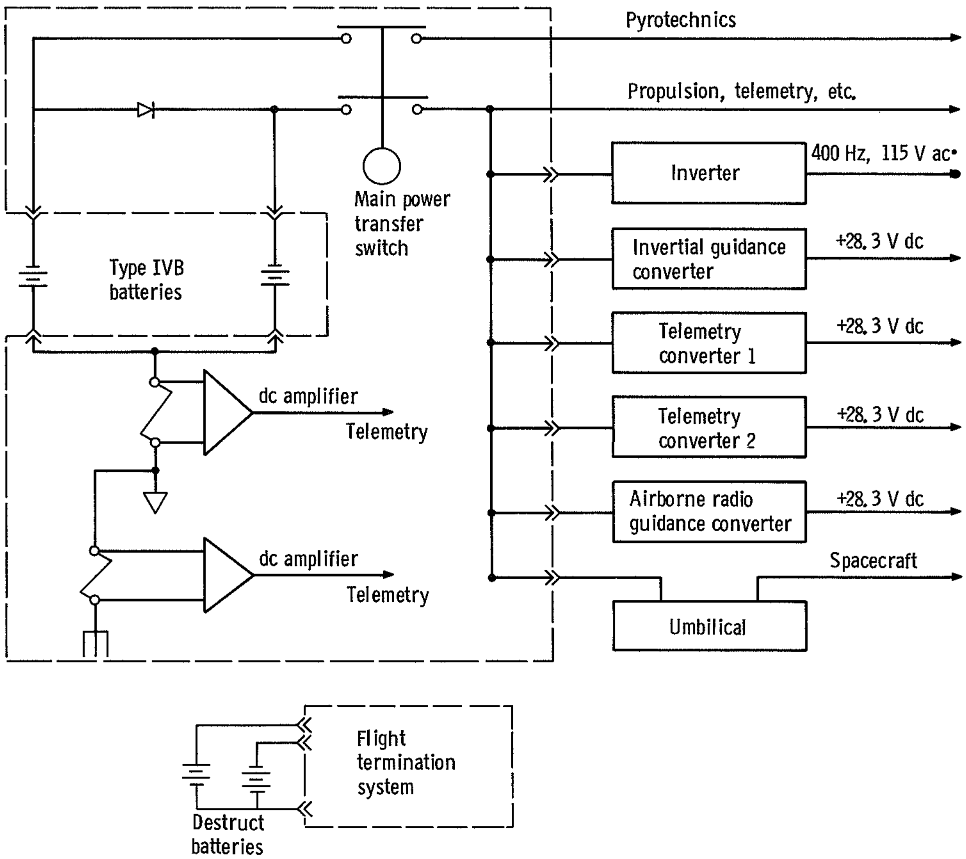


Figure VI-7. - Agena electrical system, OGO-IV.

GUIDANCE AND FLIGHT CONTROL SYSTEM

by Howard D. Jackson

Description

The radio guidance, the Agena inertial guidance and the flight control systems, and the Agena timer perform the vehicle guidance, control, and flight programming functions necessary to accomplish the vehicle mission. A block diagram of the Agena inertial guidance, control, and flight programming functions is shown in figure VI-8.

The airborne radio guidance system is mounted in the Agena. It consists of a radar transponder and a command receiver and provides guidance steering and discrete commands to the TAT during the booster phase of flight. Subsequent to TAT-Agena separation the ground radio guidance system provides guidance steering and descrete commands to the Agena. The radio guidance then controls the vehicle attitude via torquing of the pitch and yaw gyros and also supplies the Agena engine shutdown command on attainment of the required velocity. The ground portion of the radio guidance system is discussed under TAT Guidance and Flight Control System, in section V.

The Agena inertial guidance system consists of an inertial reference package (IRP), horizon sensors, velocity meter, and guidance junction box. Primary attitude reference is provided by three orthogonal rate-integrating gyroscopes in the IRP. The infrared horizon sensors provide continuous corrections in roll attitude to the roll gyro. Pitch horizon sensor corrections are inhibited during the time that the radio guidance system is operational and are activated when radio guidance is disabled. During Agena engine burn, longitudinal acceleration is sensed by the velocity meter accelerometer. The predetermined velocity to-be-gained binary number is counted down in the velocity meter counting register. The burn velocity-to-be-gained number is set slightly greater than the nominal velocity required, which permits the velocity meter to serve as a backup for Agena engine shutdown and also minimizes the possibility of preemptying the radio guidance discrete.

The Agena flight control system, which controls vehicle attitude, consists of a flight control electronics unit, a cold-gas control system, a hydraulic control system, and a flight control junction box. Attitude error signals from the IRP are conditioned and amplified by the flight control electronics to operate the cold-gas and hydraulic systems. During Agena coast periods, the cold-gas system provides roll, pitch, and yaw control by the use of six thrusters operating on a mixture of nitrogen and tetrafluoromethane. During Agena engine burn, the hydraulic system provides pitch and yaw control by means of two hydraulic actuators that gimbal the thrust chamber, and the cold-gas system provides roll control. A patch panel in the flight control junction box provides the means for varying the interconnections of the guidance and flight control system to suit mission requirements.

The Agena timer programs the flight events. This timer provides 22 usable, discrete event times with multiple switch closure capability and has a maximum running time of 6000 seconds. The Agena timer is started by the radio guidance TAT main engine cutoff discrete command or at the time the TAT main engine shutdown occurs if due to propellant depletion. During the coast period between TAT-Agena separation and Agena burn, the radio guidance steering command capability is transferred from the TAT to the Agena by the Agena timer.

Performance

The guidance and flight control system performance was satisfactory throughout flight. All flight events were initiated within tolerance by the Agena timer. A comparison of the expected and actual times of programmed events is given in appendix A. The rates imparted to the Agena at TAT-Agena separation and the attitude errors just following separation were within the range of values experienced on previous flights and are shown as follows:

Rates imparted to Agena at separation, deg/sec			Attitude errors at cold-gas activation (just following separation), deg		
Yaw	Roll	Pitch	Yaw	Roll	Pitch
0.152 left	0.152 CCW	0.228 down	0.2 left	0.2 CCW	1.32 down

Clockwise (CW) and counterclockwise (CCW) roll reference applies when looking forward along the Agena longitudinal axis (see fig. VI-9).

The cold-gas attitude control system reduced these errors to within the dead band limits of $\pm 0.2^{\circ}$ pitch, $\pm 0.18^{\circ}$ yaw and $\pm 0.6^{\circ}$ roll in 1.3 seconds.

The vehicle then completed a programmed pitch down of 12° at a rate of 60 degrees per minute. The pitch rate was then decreased to the geocentric rate of 12 degrees per minute. For the Agena burn radio guidance steering was enabled in pitch and yaw with the horizon sensors controlling only the roll gyro. The vehicle was stable in all axes by the time of engine ignition.

Gas generator turbine spin-up at Agena engine ignition resulted in a roll rate and induced a maximum roll displacement error as follows:

Roll rate, deg/sec	Maximum roll error, deg	Time to reverse initial rate, sec
0.87 CW	2.64 CW	1.6

Clockwise and counterclockwise roll reference is shown in figure VI-9.

Minimal attitude control was required during the Agena engine burn. Vehicle attitude remained very close to gyro null positions throughout the burn period since steering commands were slight in both pitch and yaw. Hydraulic and cold-gas activity were normal throughout the burn period.

Engine shutdown was commanded by radio guidance discrete; the velocity meter, which was a backup for Agena engine shutdown, was biased by 69.80 meters per second (229 ft/sec) in excess of the nominal 4982.56 meters per second (16 346.9 ft/sec) required. Readout of the velocity meter counter after engine thrust decay (about 16 sec after radio guidance cutoff) showed a residual of 53 counts or 8.40 meters per second (27.56 ft/sec) remaining in the counter, indicating that the mission utilized 61.40 meters per second (201.44 ft/sec) of the velocity meter bias.

A normal roll transient, caused by engine shutdown, initiated a pneumatic system overshoot resulting in a 2.2° roll CCW excursion, which was reduced to within the pneumatic control system deadband in 20 seconds.

At T + 482.1 seconds the programmed geocentric pitch rate was decreased to 3.70 degrees per minute and the pitch horizon sensor was connected to the pitch gyro. The Agena had stabilized in all axes by the time of spacecraft separation with the cold-gas control system operating within the deadbands.

Subsequent to spacecraft separation the vehicle performed a 90° yaw maneuver, and the cold-gas control system was switched to orbit mode. Control gas supply temperature was not monitored during this flight; therefore, an accurate assement of gas consumption is not possible.

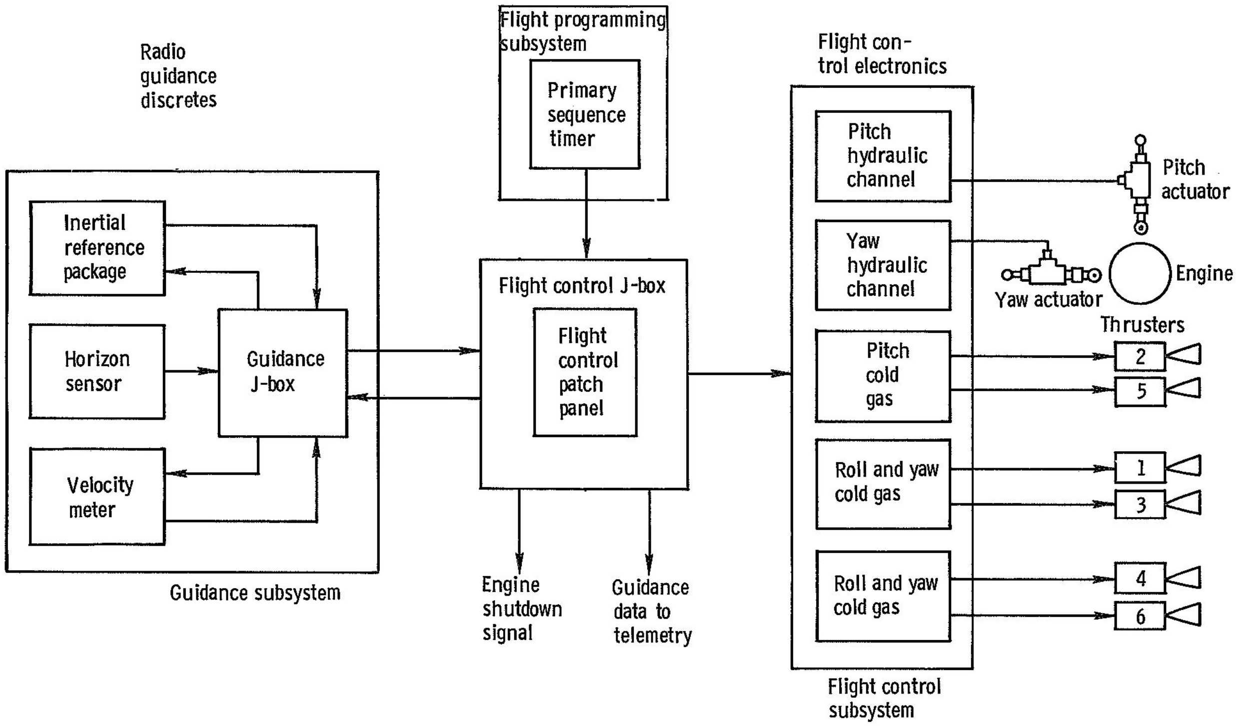


Figure VI-8. - Agena guidance and flight control system block diagram OGO-IV.

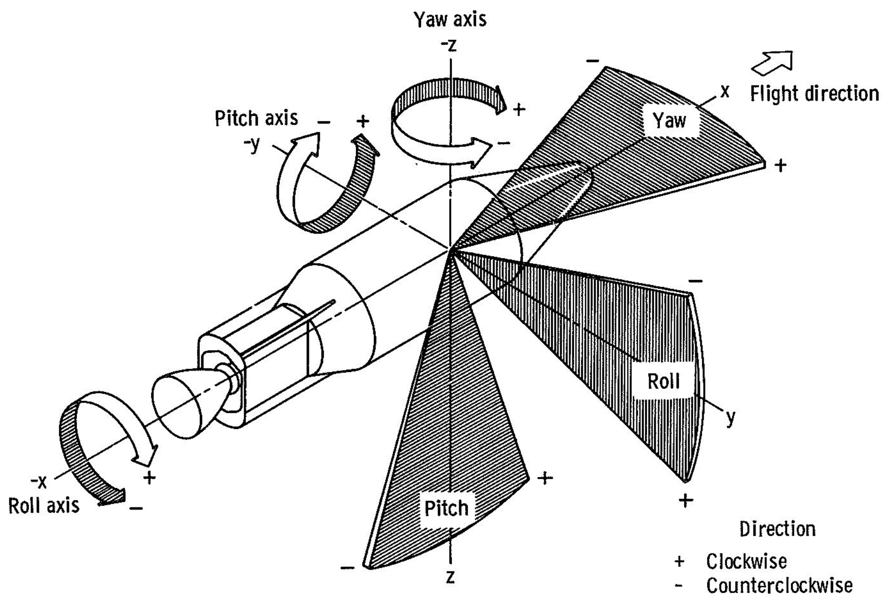


Figure VI-9. - Agena vehicle axes and vehicle movement designations, OGO-IV.

COMMUNICATION AND CONTROL SYSTEM

by Richard L. Greene

Description

The Agena communication and control system consists of telemetry, tracking, and flight termination subsystems and associated power supplies. The telemetry subsystem is mounted in the Agena forward section. It monitors and transmits the Agena functional and environmental measurements during ascent. The FM/FM telemetry unit contains a very high frequency (VHF) transmitter, voltage controlled oscillators, a commutator, a switch and calibrate unit, and dc-dc converters. The transmitter operates on an assigned frequency of 244.3 megahertz at a power output of 2 watts. The telemetry subsystem consists of 14 continuous subcarrier channels and two commutated subcarrier channels.

Seventy-five measurements were telemetered from the Agena vehicle. Appendix B summarizes the launch vehicle instrumentation by measurement description. Eight continuous subcarrier channels were used for accelerometer data; three continuous channels were used for radio guidance measurements; one continuous channel transmitted Agena combustion pressure data; one continuous channel monitored the gas thruster valve current signals; and one continuous channel was shared by the velocity meter accelerometer and the velocity meter counter. The turbine speed signal did not utilize a subcarrier channel but directly modulated the transmitter during engine operation.

The remaining 61 measurements were monitored on the two commutated subcarrier channels. These channels are commutated at 5 revolutions per second with 60 segments on each channel. The transducers are powered by two regulated 28 volts dc power supplies. One power supply is a part of the standard telemetry unit and the second is a self-contained unit added to the vehicle because of the large number of transducers.

The airborne tracking subsystem includes a C-band radar transponder and antenna. The transponder receives coded signals from the tracking radar on a carrier frequency of 5630 megahertz and transmits coded responses on a carrier frequency of 5555 megahertz at a minimum pulsed-power output of 200 watts at the input terminals of the antenna. The coded responses are at pulse rates (pulse repetition frequency) from 0 to 1600 pulses per second. The pulse rate is dependent on the rates transmitted from the ground tracking stations and the number of stations simultaneously interrogating the transponder.

The flight termination subsystem provides a range safety flight termination capability for the Agena from lift-off until TAT-Agena separation. This subsystem is composed of two batteries, interconnecting wiring assemblies, two separation switches, a destruct initiator, and a destruct charge. Flight termination can be initiated by a signal from either the TAT command destruct system prior to booster separation or automatically by premature TAT-Agena separation. The destruct charge, which is located on the booster adapter, ruptures both Agena propellant tanks and affects dispersion of the hypergolic propellants.

Performance

The telemetry subsystem performance was satisfactory throughout the flight. Signal strength data from all participating ground stations indicated an adequate and continuous signal level from the vehicle telemetry transmitter from lift-off through the Agena yaw maneuver. Analysis of the telemetry data indicated that the performances of the voltage controlled oscillators, the switch and calibrate unit, the dc-dc converters, and the commutator were satisfactory. (A description of the tracking and data acquisition network used in support of the OGO-IV flight is given in appendix C.)

The tracking subsystem performance was satisfactory throughout the flight. The C-band transponder transmitted a continuous response to received interrogations for the required tracking periods.

The flight termination subsystem maintained the capability to destruct the Agena during TAT boost phase and was disarmed just prior to TAT-Agena separation as planned.

VII. LAUNCH OPERATIONS

by Frank E. Gue and Howard Schwartzberg

PRELAUNCH ACTIVITIES

The TAT, the Agena, and the OGO-IV spacecraft arrived at Western Test Range on June 17, 1966, May 15, 1967; and July 10, 1967, respectively. A calendar of the major activities at the launch base is shown in table VII-I.

All prelaunch tests were completed satisfactorily. The significant problems that occurred during the prelaunch period were as follows:

(1) The connector on the TAT main engine pitch acutator was replaced after inspection showed that it was bent.

(2) The TAT control electronics assembly was reworked because of mechanical interference discovered during the laboratory checkout.

(3) The TAT hydraulic power package was replaced after a leak was noted in the reservoir.

(4) An Agena fuel valve frangible disk was replaced after receiving inspection disclosed a leak.

(5) The Agena velocity meter electronics package was reworked to preclude a chopper failure that had recently occurred on an Air Force program.

(6) The Agena engine was replaced with an engine having a reworked turbine pump assembly. Parts in the drive section of the original turbine pump assembly were the same as those suspected of causing a momentary drop in chamber pressure experienced on previous Agena flights.

(7) An Agena telemetry transmitter was replaced after the compatibilities test showed that its frequency was 12 kilohertz below the specified frequency.

(8) The Agena velocity meter was returned to the contractor's plant for recalibration because discrepancies were found in the scale factor calculations.

(9) The power distribution panel in the radio ground guidance equipment at the complex was replaced after the mock countdown because of a short in the 400-hertz power wiring. Mice had mutilated a large amount of wiring.

(10) During removal of the gantry for the radio frequency interference test, an aerospace ground equipment test cable between the umbilical mast and the Agena was damaged. The cable was replaced.

COUNTDOWN AND LAUNCH

The TAT-Agena - OGO-IV was successfully launched on the first attempt. The launch vehicle countdown was initiated at T - 660 minutes (approx. 1821 hr Pacific Standard time, July 27, 1967). The countdown was completed without any unscheduled holds. Liftoff occurred at 0621:07.50 Pacific standard time on July 28, 1967. All aerospace ground equipment operated satisfactorily during the countdown and launch.

TABLE VII-I. - CALENDAR OF MAJOR ACTIVITIES

AT LAUNCH BASE, OGO-IV

Date	Event
6/15/67	TAT on launch pad (SLC-2E)
6/21/67	Agena on launch pad
6/21-22/67	Compatibilities test
6/23/67	All systems run (TAT stage)
6/27/67	Agena returned to Missile Assembly Building
7/01/67	Agena returned to pad with replacement engine
7/05/67	TAT engine functional and leak checks
7/08/67	All systems run
7/11/67	Booster adapter mate
7/11/67	Agena mate
7/12/67	Spacecraft mate
7/12/67	All systems run
7/17/67	Mock countdown (dual flow)
7/17/67	Radio frequency interference test
7/17/67	Solid motors installed
7/22/67	All systems run
7/26/67	All systems run
7/28/67	Launch

VIII. CONCLUDING REMARKS

The Thrust Augmented Thor TAT/Agena placed the OGO-IV spacecraft in a near-polar elliptical orbit. The parameters of the final orbit were within the mission requirements for apogee, perigee, and inclination. This mission was accomplished with a single burn of the Agena and the ground radio guidance had line of sight with the launch vehicle throughout the powered flight.

The TAT thrust termination occurred from propellant depletion. The TAT velocity deficiency at the time of vernier engine cutoff was compensated for by a 1.75-second longer burn of the Agena. The additional burn time was well within the Agena performance reserve planned for this mission.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 4, 1969,

APPENDIX A

SEQUENCE OF MAJOR FLIGHT EVENTS, OGO-IV

by Richard L. Greene

Nominal time, sec	Actual time, sec	Event description	Source	Event monitor (a)
0	0	Lift-off (0621:07.505 PST)	---------------	Lift-off switch
43	42.70	Solid motor burnout	---------------	Solid motor chamber pressure[b]
65	65.28	Solid motors jettison	TAT timer	Sequence 3[b]
149.55	149.05	TAT main engine cutoff, disarm Agena premature destruct, start Agena timer	Propellant depletion	Longitudinal acceleration (PL-30)
158.55	157.96	Vernier engine cutoff	TAT engine	
		Arm TAT-Agena separation	TAT engine	
162.5	162.36	TAT-Agena separation	Radio guidance	
162.7	162.9	Transfer radio guidance steering to Agena	Pullaway plug	
165.5	164.70	Activate cold-gas attitude control	Separation switch	Guidance and control monitor (D-14)
212.5	212.01	Initiate -60 deg/min pitch rate	Agena timer	Pitch torque rate (D-73)
218.5	217.97	Transfer to -12.1 deg/min pitch rate		Pitch torque rate (D-73)
		Enable radio guidance pitch and yaw Agena steering		Estimated[c]
		Connect velocity meter accelerometer output to telemetry		Velocity meter accelerometer (D-83)
224.46	224.05	Arm engine control and enable velocity meter		Switch group Z (B-13)
		Fire Agena ignition squibs		Velocity meter accelerometer (D-83)
		Deactivate pitch and yaw cold-gas thrustors		Estimated[c]
225.708	225.23	Agena engine at 90 percent chamber pressure		Chamber pressure (B-91)
234.5	234.07	Fire shroud separation squibs		Longitudinal vibration (PL-20)
452.7	452.6	Arm velocity meter cutoff		Estimated[c]
		Arm radio guidance for engine cutoff		Estimated[c]
464.89	466.16	Agena engine cutoff	Radio guidance	Chamber pressure (B-91)
		Activate pitch and yaw cold-gas thrustors	Radio guidance	Estimated[c]

[a]All events except those noted were monitored on Agena telemetry. The designation in parenthesis is the Monitor Measurement designation. See appendix B for the measurement range and channel assignment.

[b]This event was obtained from the TAT telemetry data.

[c]No direct measurement to identify the event.

Nominal time, sec	Actual time, sec	Event description	Source	Event monitor (a)
482.7	482.1	Disable velocity meter and connect counter output to telemetry	Agena timer	Velocity meter counter (D-88)
		Transfer to -3.70 deg/min pitch rate		Pitch torque rate (D-73)
		Connect pitch horizon sensor to inertial reference package pitch gyro		Estimated[c]
		Disable radio guidance pitch and yaw Agena steering		Estimated[c]
487.7	487.1	Start telemetry calibrate		All continuous channels
		Connect velocity meter accelerometer output to telemetry		Velocity meter accelerometer (D-83)
509.7	509.1	Radio guidance power off		Magnetron current monitor (BTL-1)
567.5	567.31	Fire spacecraft separation squibs		Longitudinal vibration (PL-20)
570.5	570.0	Initiate +180 deg/min yaw rate		Yaw torque rate (D-51)
		Transfer to 0 deg/min pitch rate		Pitch torque rate (D-73)
600.5	600.1	Transfer to 0 deg/min yaw rate		Yaw torque rate (D-51)
615.7	615.1	Fire helium pressure control squibs (close)		Estimated[c]
634.7	634.1	Flight control, horizon sensor gains, and gyro telemetry to orbit mode		Estimated[c]
		Switch roll horizon sensor to roll inertial reference package, gain to coarse		Estimated[c]
636.5	636.83	Shutdown Agena timer		Estimated[c]

[a]All events except those noted were monitored on Agena telemetry. The designation in parenthesis is the Monitor Measurement designation. See appendix B for the measurement range and channel assignment.

[c]No direct measurement to identify the event.

APPENDIX B

LAUNCH VEHICLE INSTRUMENTATION SUMMARY, OGO-IV

by Richard L. Greene and Edwin S. Jeris

THRUST AUGMENTED THOR TELEMETRY

Channel	Measurement title	Measurement range	
		SI	U.S. Customary
FM-1-01	Inverter frequency	370.0 to 430.0 Hz	
FM-1-09	Vernier engine number 2 chamber pressure	0 to 344.5 N/cm^2	0 to 500 psia
FM-1-10	Sequence 2 Ignition switch number 1 pickup Ignition switch number 2 pickup Separation signal, timer relay Separation signal, backup relay	0 to 5 V	
FM-1-11	Main engine chamber pressure	0 to 551.5 N/cm^2	0 to 800 psia
FM-1-12	Sequence 1 Fuel tank float switch Oxidizer tank float switch Main engine cutoff Vernier engine cutoff	0 to 5 V	
FM-1-13	Solid motor number 1 chamber pressure	0 to 551.5 N/cm^2	0 to 800 psia
FM-1-A	Solid motor number 3 chamber pressure	0 to 551.5 N/cm^2	0 to 800 psia
FM-1-C	Solid motor number 2 chamber pressure	0 to 551.5 N/cm^2	0 to 800 psia
PDM-1-01	5-Volt transducer calibration	0 to 5 V	
PDM-1-02	Instrumentation ground	0 to 5 V	
PDM-1-03	Main engine pitch position	-2° to 2°	
PDM-1-04	Main engine yaw position	-2° to 2°	
PDM-1-05	Vernier engine number 1 pitch-roll position	-45° to 45°	
PDM-1-06	Vernier engine number 1 yaw position	-28° to -8°	
PDM-1-07	Vernier engine number 2 pitch-roll position	-45° to 45°	
PDM-1-08	Vernier engine number 2 yaw position	8° to 28°	
PDM-1-09	Pitch attitude error	-4° to 4°	
PDM-1-10	Yaw attitude error	-4° to 4°	
PDM-1-11	Roll attitude error	-6° to 6°	
PDM-1-12	Pitch rate (also on PDM-1-34)	-4 to 4 deg/sec	
PDM-1-13	Yaw rate	-3.50 to 3.50 deg/sec	
PDM-1-14	Roll rate	-17 to 17 deg/sec	
PDM-1-15	Pitch command	-4° to 4°	

Channel	Measurement title	Measurement range	
		SI	U. S. Customary
PDM-1-16	Yaw command	-3.5^{o} to 3.5^{o}	
PDM-1-17	Actuator potentiometer positive voltage	0 to 30 V	
PDM-1-18	Actuator potentiometer negative voltage	-30 to -10 V	
PDM-1-19	400-Hz volt control inverter	110 to 120 V	
PDM-1-20	5-Volt potentiometer excitation	0 to 5 V	
PDM-1-21	5-Volt potentiometer excitation (internal-external)	0 to 5 V	
PDM-1-22	Main engine chamber pressure	0 to 551.5 N/cm^2	0 to 800 psia
PDM-1-23	Main battery voltage	0 to 30 V	
PDM-1-24	Telemetry battery voltage	0 to 32 V	
PDM-1-25	Hydraulic supply pressure	0 to 2756 N/cm^2	0 to 4000 psia
PDM-1-26	Hydraulic return pressure	0 to 137.8 N/cm^2	0 to 200 psia
PDM-1-27	Turbopump speed	0 to 8000 rpm	
PDM-1-28	Turbine inlet temperature	225 to 1255.4 K	-200^{o} to 1800^{o} F
PDM-1-29	Fuel pump inlet pressure	0 to 137.8 N/cm^2	0 to 200 psia
PDM-1-30	Sequence 3 All solid motors attached Solid motor number 1 jettisoned Solid motor number 2 jettisoned Solid motor number 3 jettisoned All solid motors jettisoned	0 to 5 V	
PDM-1-31	Vernier engine number 1 housing temperature (left)	255 to 810.9 K	0^{o} to 1000^{o} F
PDM-1-32	Vernier engine number 2 housing temperature (right)	255 to 810.9 K	0^{o} to 1000^{o} F
PDM-1-33	Engine pneumatic bottle pressure	0 to 3447 N/cm^2	0 to 5000 psia
PDM-1-34	Pitch rate (also PDM-1-12)	-4 to 4 deg/sec	
PDM-1-35	Main engine pitch-yaw actuator temperature station 652	255 to 810.9 K	0^{o} to 1000^{o} F
PDM-1-36	Air temperature left side main engine station 670	255 to 810.9 K	0^{o} to 1000^{o} F
PDM-1-37	Air conditioning duct inlet temperature station 705	255 to 810.9 K	0^{o} to 1000^{o} F
PDM-1-38	Oxidizer tank section temperature station 613	255 to 810.9 K	0^{o} to 1000^{o} F
PDM-1-39	Oxidizer pump inlet pressure	0 to 68.9 N/cm^2	0 to 100 psia
PDM-1-40	Fuel tank ullage pressure	0 to 68.9 N/cm^2	0 to 100 psia
PDM-1-41	Gas generator injector pressure	0 to 551.5 N/cm^2	0 to 800 psia
PDM-1-42	Oxidizer tank ullage pressure	0 to 68.9 N/cm^2	0 to 100 psia
PDM-1-43	Oxidizer pump inlet temperature	88 to 102.6 K	-300^{o} to -275^{o} F

Measurement	Measurement title	Channel (a)	Measurement range	
			SI	U.S. Customary
AD 032	Shroud separation monitor 1 and 2	16-12	(b)	
AD 040	Inside shroud temperature, stagnation point	16-19	294 to 561 K	70^{o} to 550^{o} F
AD 042	Inside shroud temperature, near base	16-20	294 to 561 K	70^{o} to 550^{o} F
AD 044	Inside shroud temperature, midpoint number 1	16-23	294 to 561 K	70^{o} to 550^{o} F
AD 045	Inside shroud temperature, midpoint number 2	16-25	294 to 561 K	70^{o} to 550^{o} F
AT 106	Agena spacecraft diaphragm temperature	15-48	255 to 367 K	0^{o} to 200^{o} F
B1	Fuel pump inlet pressure	15-15	0 to 68.9 N/cm^2	0 to 100 psig
B2	Oxidizer pump inlet pressure	15-17	0 to 68.9 N/cm^2	0 to 100 psig
B6	Combustion chamber pressure	4	0 to 472 N/cm^2	0 to 700 psia
B7	Helium supply pressure	15-32	0 to 2758 N/cm^2	0 to 4000 psia
B8	Oxidizer tank pressure	15-51	0 to 41.4 N/cm^2	0 to 60 psig
B9	Fuel tank pressure	15-13	0 to 41.4 N/cm^2	0 to 60 psig
B11	Oxidizer venturi inlet pressure	15-23/53	0 to 827 N/cm^2	0 to 1200 psid
B12	Fuel venturi inlet pressure	15-11/41	0 to 827 N/cm^2	0 to 1200 psid
B13	Switch group Z (propulsion system monitor)	15-7/22/37/52	(b)	
B31	Fuel pump inlet temperature	15-6	255 to 367 K	0^{o} to 200^{o} F
B32	Oxidizer pump inlet temperature	15-8	255 to 367 K	0^{o} to 200^{o} F
B35	Turbine speed	(c)		
B71	Oxidizer pump lip seal	15-19	0 to 17 N/cm^2	0 to 25 psig
B91	Combustion chamber pressure number 3	15-4/34	328 to 379 N/cm^2	475 to 550 psig
BTL1	Magnetron monitor	6	(b)	
BTL2	Combined events monitor	F	(b)	
BTL4	Automatic gain control monitor	5	-70 to 0 dbm	
BTL5	Relay transfer	16-34	(b)	
BTL6	Radio guidance power	16-24/56	22 to 30 V dc	
C1	28-V dc unregulated supply	16-40	22 to 30 V dc	
C3	28-V dc regulator (guidance and control) number 1	15-12	22 to 30 V dc	
C4	28-V dc unregulated current	16-13/44	0 to 100 A	
C5	-28-V dc regulator (guidance and control)	15-30	-30 to -22 V dc	
C11	Battery case temperature	15-2	272 to 324 K	30^{o} to 125^{o} F
C21	400 Hz, 3 phase; inverter temperature	15-14	255 to 367 K	0 to 200^{o} F
C31	400 Hz, 3 phase; bus phase AB	15-18	90 to 130 V ac	
C32	400 Hz, 3 phase; bus phase BC	15-20	90 to 130 V ac	
C38	Structure current monitor	15-10/25/40/55	0 to 50 A	

[a]The first number indicates the Interrange Instrumentation Group (IRIG) subcarrier channel used. The second number indicates the commutated position for the measurement. If no second number is indicated, the channel was used continuously for the designated transducer.

[b]Events are determined by a step change in voltage.

[c]The turbine speed signal does not utilize a subcarrier channel, but directly modulates the transmitter during engine operation.

Measurement	Measurement title	Channel (a)	Measurement range	
			SI	U.S. Customary
C141	Pyrotechnic bus voltage	15-5/35	22 to 30 V dc	
C14	Guidance and control monitor	16-27	(b)	
D41	Horizon sensor pitch	16-45	-5° to 5°	
D42	Horizon sensor roll	16-46	-5° to 5°	
D46	Gas valve cluster 1 temperature	15-39	228 to 339 K	-50° to 150° F
D47	Gas valve cluster 2 temperature	15-36	228 to 339 K	-50° to 150° F
D51	Yaw torque rate (ascent mode)	16-38	200 to 200 deg/min	
D51	Yaw torque rate (orbital mode)	16-38	-10 to 10 deg/min	
D54	Horizon sensor head temperature (right)	15-47	228 to 367 K	-50° to 200° F
D55	Horizon sensor head temperature (left)	15-46	228 to 367 K	-50° to 200° F
D59	Control gas supply pressure (high)	16-47	0 to 2758 N/cm^2	0 to 4000 psia
D60	Hydraulic oil pressure	15-21	0 to 2758 N/cm^2	0 to 4000 psia
D66	Roll torque rate (ascent mode)	16-41	-50 to 50 deg/min	
D66	Roll torque rate (orbital mode)	16-41	-4 to 4 deg/min	
D68	Pitch actuator position	15-3	-2.5° to 2.5°	
D69	Yaw actuator position	15-24	-2.5° to 2.5°	
D72	Pitch gyro output	16-36	-10° to 10° -5° to 5°	
D73	Pitch torque rate (ascent mode)	16-35	-200 to 200 deg/min	
D73	Pitch torque rate (orbital mode)	16-35	-10 to 10 deg/min	
D74	Yaw gyro output	16-39	-10° to 10° -5° to 5°	
D75	Roll gyro output	16-42	-10° to 10° -5° to 5°	
D83	Velocity meter acceleration	14	0 to 2000 pulses/sec	
D86	Velocity meter cutoff switch	16-28		
D88	Velocity meter counter	14	Binary code (50 bits/sec)	
D129	Inertial reference package internal case temperature	15-54	255 to 341 K	0° to 155° F
D149	Gas valves 1 to 6 current	7	(d)	
H47	Beacon receiver pulse repetition rate	16-17	0 to 1600 pulses/sec	
H48	Beacon transmitter pulse repetition rate	16-21	0 to 1600 pulses/sec	
H204	DC-DC converter number 2	15-50	22 to 30 V dc	
H400	Secondary DC/DC converter	15-16	22 to 30 V dc	
PL2	Shroud differential pressure	16-18-1/1	-0.7 to 0.7 N/cm^2	-0.98 to 0.98 psi

[a]The first number indicates the Interrange Instrumentation Group (IRIG) subcarrier channel used. The second number indicates the commutated position for the measurement. If no second number is indicated, the channel was used continuously for the designated transducer.
[b]Events are determined by a step change in voltage.
[d]A unique voltage level is associated with any one or a combination of several gas valve firings.

Measurement	Measurement title	Channel (a)	Measurement range	
			SI	U.S. Customary
PL3	Shroud pressure	16-16	0 to 10.3 N/cm^2	0 to 15 psi
PL20	Longitudinal vibration	18	-20 to 20 g	
PL22	Pitch axis vibration	17	-20 to 20 g	
PL30	Longitudinal acceleration	10	-4 to 12 g	
PL31	Torsional acceleration	11	-10 to 10 g	
PL32	Spacecraft y-axis acceleration	13	-4 to 12 g	
PL33	Radial acceleration	12	-10 to 10 g	
PL34	Spacecraft z-axis acceleration	9	-5 to 5 g	
PL36	Spacecraft x-axis acceleration	8	-5 to 5 g	
PL50	Explosive bolt actuation monitor	16-32	(b)	
PL60	Payload separation monitor	15-44	(b)	

[a]The first number indicates the Interrange Instrumentation Group (IRIG) subcarrier channel used. The second number indicates the commutated position for the measurement. If no second number is indicated, the channel was used continuously for the designated transducer.

[b]Events are determined by a step change in voltage.

APPENDIX C

TRACKING AND DATA ACQUISITION

by Richard L. Greene

The launch vehicle trajectory as projected on a world map is presented in figure C-1. The land based tracking and telemetry stations that provided data coverage for the launch phase of this mission were Vanderberg Air Force Base, Point Mugu, and San Nicholas Island. In addition to these land stations, two Range Instrumentation Ships (RIS) located in the Pacific Ocean extended the data coverage through the Agena post spacecraft-separation yaw maneuver. The Manned Space Flight Network (MSFN) station at Hawaii supported this mission with tracking and telemetry data coverage of the Agena during its first orbital pass over Hawaii.

TELEMETRY DATA

Telemetry signals from the TAT-Agena launch vehicle were recorded on magnetic tape at tracking stations from lift-off through the post spacecraft separation Agena yaw maneuver. The data recorded on magnetic tape at each supporting station were used for postflight analysis of the launch vehicle performance. Real-time monitoring of specific TAT and Agena parameters was required for verification of the occurrence of significant flight events and evaluation of the launch vehicle performance. The telemetry sites at Vandenberg permitted real-time readout of all telemetered signals through the Agena engine cutoff. Subsequent flight events were monitored by the downrange stations. The time of occurrence of these events were reported back to Vandenberg in "near" real time by single side-band radio links. Figure C-2 shows the specific telemetry coverage provided by the supporting telemetry stations.

RADAR DATA

C-band radar data (time, elevation, azimuth, and range) were provided for both real-time operations and postflight analysis. Real-time radar data were provided for monitoring the launch vehicle flight performance for range safety purposes and for assisting the downrange stations in acquiring tracking of the vehicle. These data were also used for computation of orbital elements and insertion conditions at Agena engine cutoff. The MSFN tracking station at Hawaii also provided data for the determination of Agena orbital elements. The specific radar coverage provided by the supporting tracking stations is presented in figure C-3.

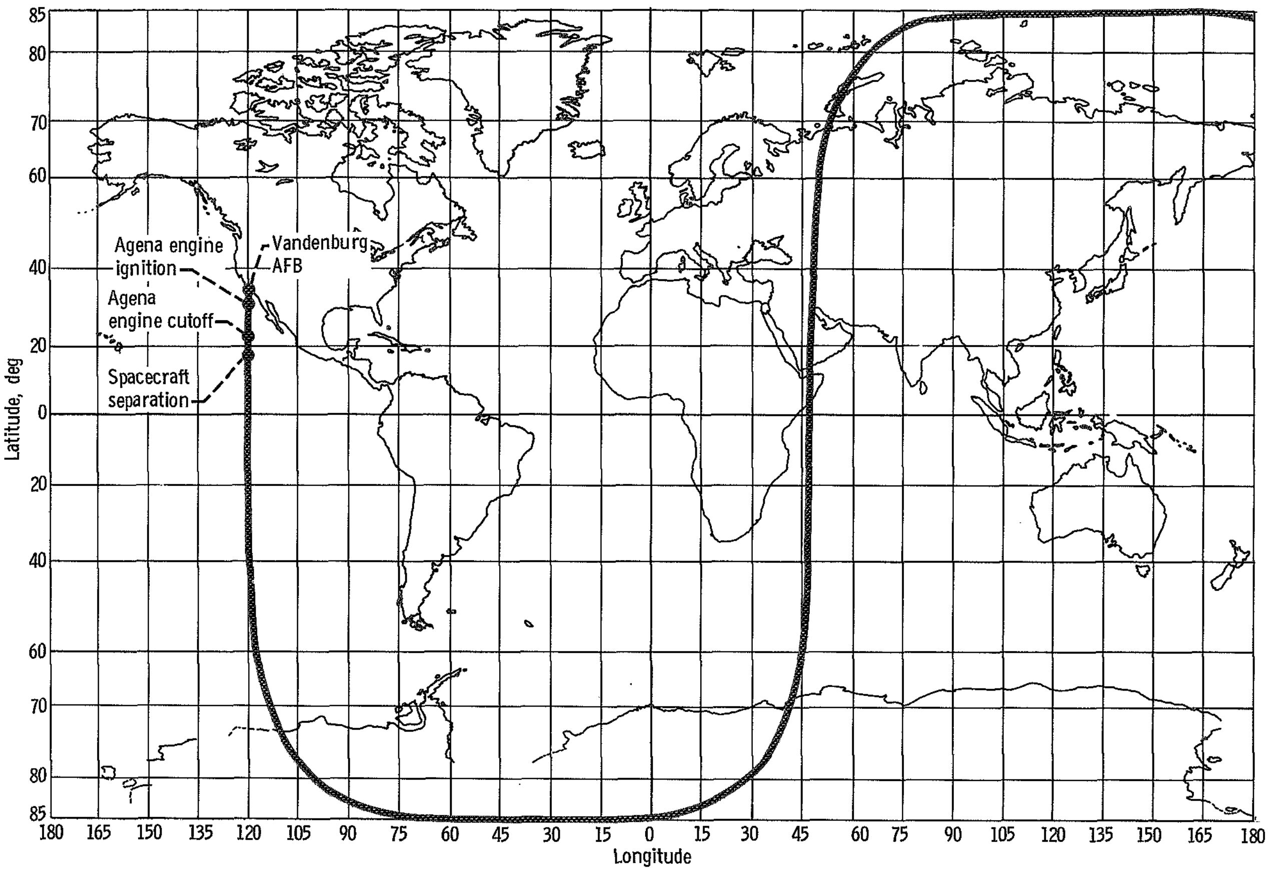


Figure C-1. - Launch vehicle trajectory, OGO-IV.

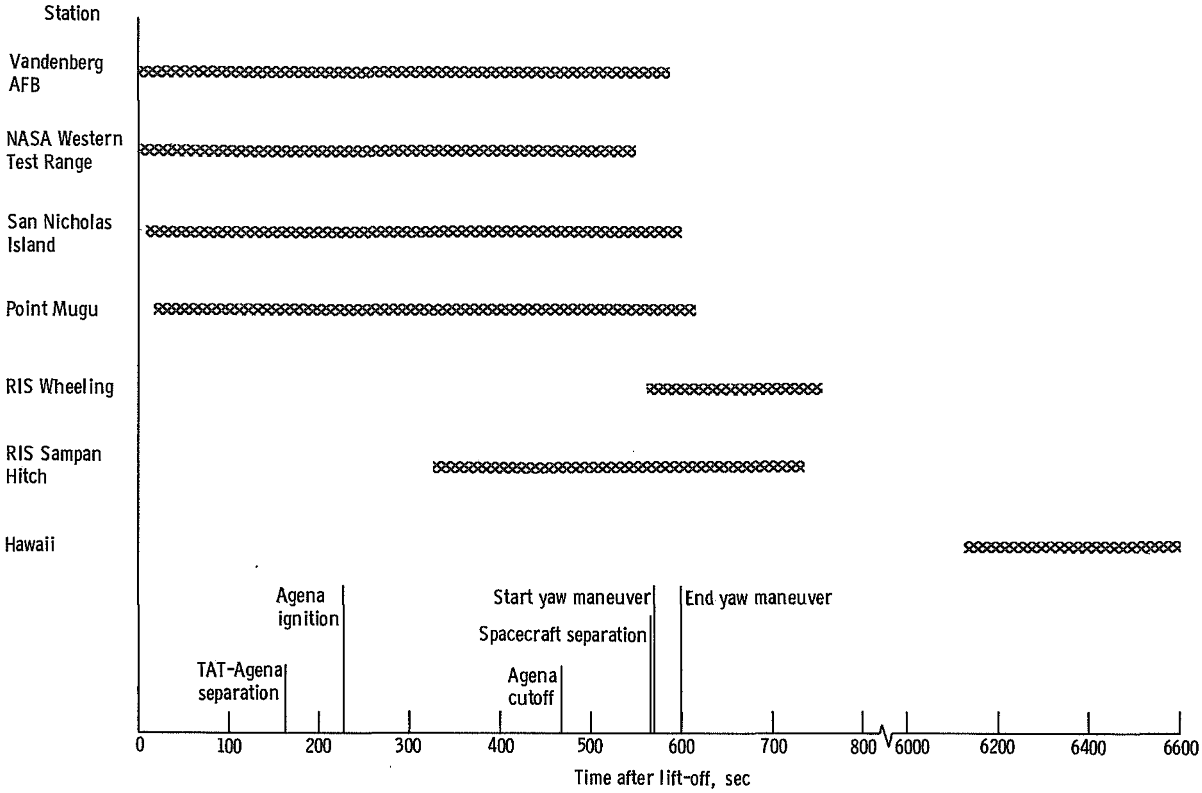


Figure C-2. - Launch vehicle telemetry coverage, OGO-IV. (RIS denotes range instrumentation ship.)

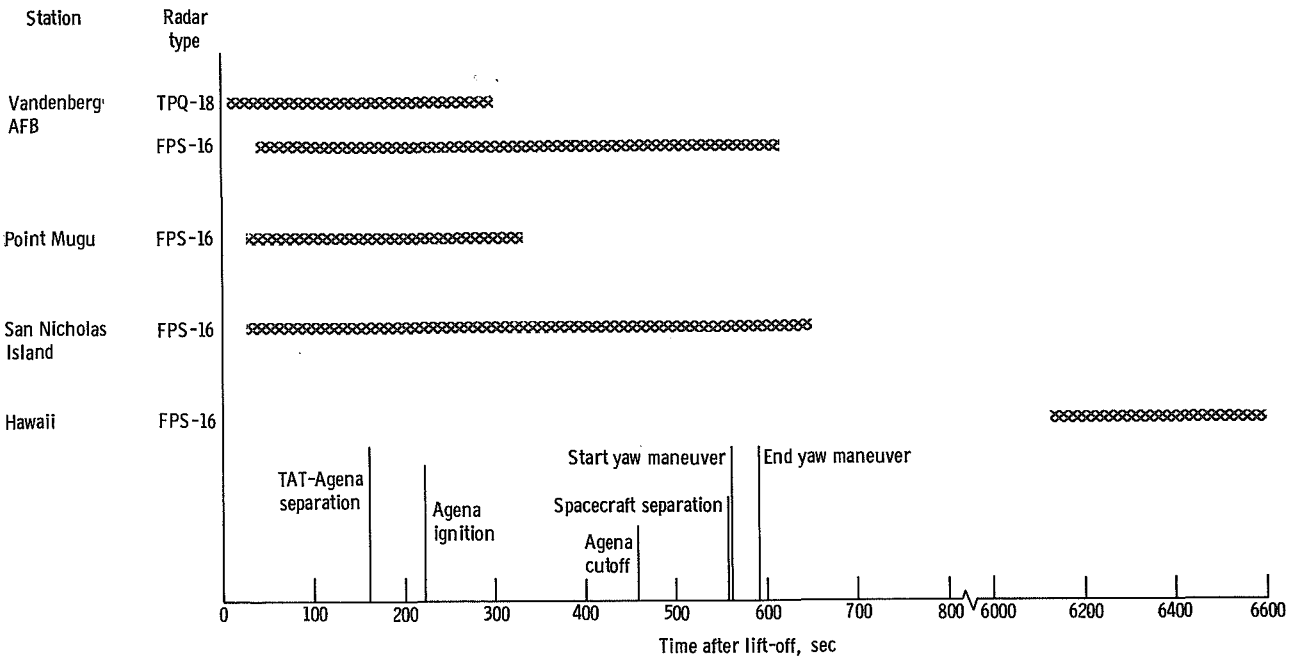


Figure C-3. - Launch vehicle radar coverage, OGO-IV.

APPENDIX D

VEHICLE FLIGHT DYNAMICS

by Robert W. York

Flight dynamic data from the OGO-IV mission were obtained by three accelerometers and two vibration transducers installed in the Agena forward section and three accelerometers mounted on the spacecraft. A summary of dynamic instrumentation locations and characteristics is presented in figure D-1.

The table D-I presents the actual flight times during which significant dynamic disturbances were recorded. Data traces of the dynamic environment recorded by all eight instruments for these events are presented in figures D-2 to D-12.

Table D-II is a summary of the largest acceleration levels and corresponding frequencies experienced during significant flight events.

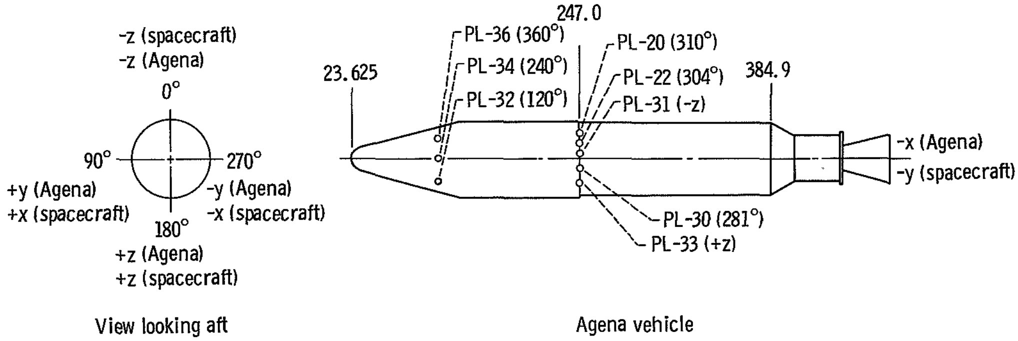
TABLE D-I. - FLIGHT TIMES DURING WHICH DYNAMIC DISTURBANCES WERE RECORDED

Event causing disturbance	Time, sec after lift-off
Lift-off	0
Transonic region	20 to 45
Solid motor jettison	65.31
Approximately 8 sec prior to TAT main engine cutoff	140.49
Main engine cutoff	148.98
Horizon sensor fairing jettison	157.97
TAT-Agena separation	162.35
Agena engine ignition	225.23
Nose shroud separation	234.07
Agena engine cutoff	466.23

TABLE D-II. - SUMMARY OF DYNAMIC ENVIRONMENT, OGO-IV

Event causing disturbance	Time of dynamic disturbance (sec after lift-off)	Accelerometers												Vibrometers			
		Channel 8		Channel 9		Channel 10		Channel 13		Channel 11		Channel 12		Channel 17		Channel 18	
		Measurement PL-36 (spacecraft x-axis)		Measurement PL-34 (spacecraft z-axis)		Measurement PL-30 (longitudinal)		Measurement PL-32 (spacecraft y-axis)		Measurement PL-31 (torsional)		Measurement PL-33 (radial)		Measurement PL-22 (pitch axis)		Measurement PL-30 (longitudinal)	
		Frequency, Hz	g [a](0-P)	Frequency, Hz	g [a](0-P)	Frequency, Hz	g [a](0-P)	Frequency, Hz	g [a](0-P)	Frequency, Hz	g [a](0-P)	Frequency, Hz	g [a](0-P)	Frequency, Hz	g [a](0-P)	Frequency, Hz	g [a](0-P)
Lift-off	0	50	0.4	32	0.6	14	1.2	14	1.5	170	0.8	110	1.5	30	0.5	16	1.5
Transonic region	22.00	75	0.2	70	0.1	(b)	(b)	(b)	(b)	150	0.7	150	2.0	700	0.4	High	4.0
	32.00	45	0.1	33	0.2	High	0.7	(b)	(b)	200	0.2	400	0.6	High	8.0	High	4.0
Solid motor jettison	65.31	48	0.3	48	0.4	(b)	(b)	(b)	(b)	74	0.5	(b)	(b)	(b)	(b)	(b)	(b)
Approximately 8 sec prior to TAT main engine cutoff	140.49	19	0.5	56	0.2	19	2.0	19	2.4	(b)	(b)	38	0.3	38	0.5	20	2.5
Main engine cutoff	148.98	(b)	(b)	30	0.2	24	0.4	24	0.3	110	0.4	(b)	(b)	(b)	(b)	24	0.4
Horizon sensor fairing jettison	157.97	(b)	(b)	48	0.1	Pulse	5.0	400	0.2	160	1.0	600	3.7	640	15	480	10
TAT-Agena separation	162.35	50	0.1	86	0.1	Pulse[c] 60	[c]5.0 8	96	0.2	160	0.4	90	0.4	High	>20	High	>20
Agena engine ignition	225.23	60	0.3	32	0.3	76	0.2	64	0.2	120	0.4	80	0.4	(b)	0.2	(b)	0.2
Shroud separation	234.07	55	0.2	55	0.2	70	4.2	(b)	0.3	120	4.2	260	5.2	High	>20	High	>20
Agena engine cutoff	466.23	68	0.7	72	0.4	120	2.0	48	1.6	100	2.5	220	1.5	50	1	High	2

[a]Zero to peak.
[b]Instrument output negligible during these events.
[c]Double entries indicates the frequencies and acceleration levels of two superimposed vibrations.



Measurement number	Telemetry channel	Measurement	Agena station	Frequency response, Hz	Range, g
PL-36	8	x-axis accelerometer, spacecraft	90.0	0 - 100	±5
PL-34	9	z-axis accelerometer, spacecraft	90.0	0 - 100	±5
PL-30	10	Longitudinal accelerometer	247.0	0 - 130	-4, +12
PL-31	11	Torsional accelerometer	247.0	0 - 130	±10
PL-33	12	Radial accelerometer	247.0	0 - 130	±10
PL-32	13	y-axis accelerometer, spacecraft	90.0	0 - 100	-4, +12
PL-22	17	Pitch axis vibration	247.0	20 - 1500	±20
PL-20	18	Longitudinal vibration	247.0	20 - 2000	±20

Figure D-1. - Flight instrumentation, OGO-IV.

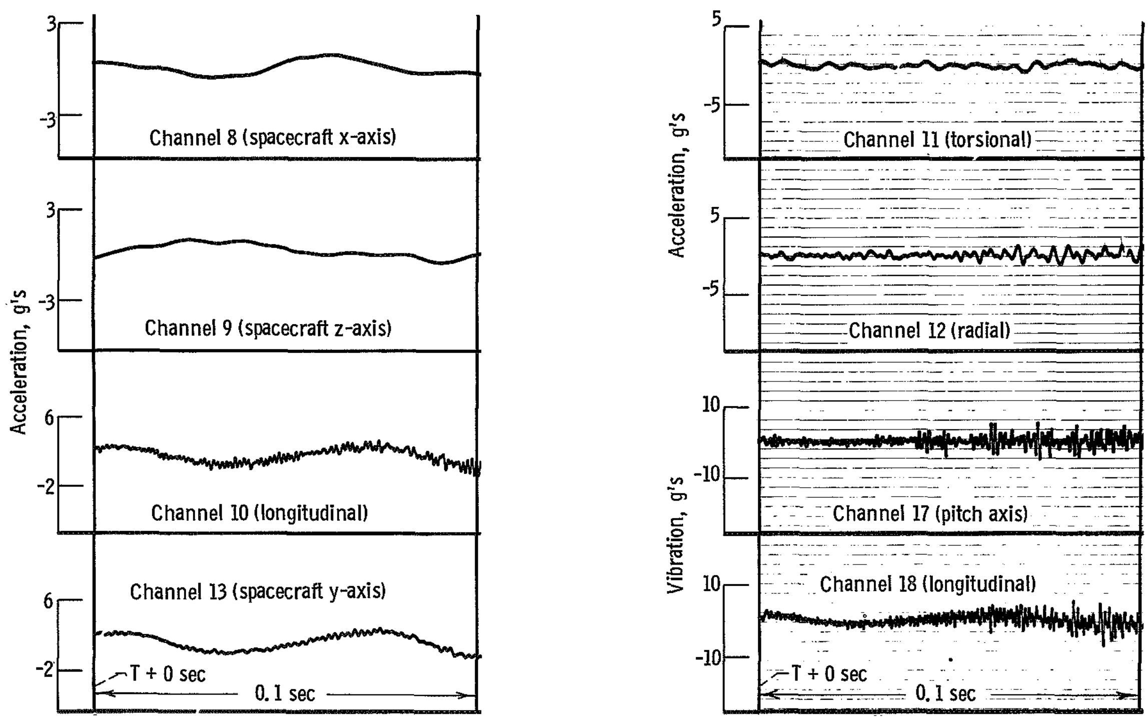


Figure D-2. - Accelerations at lift-off, OGO-IV.

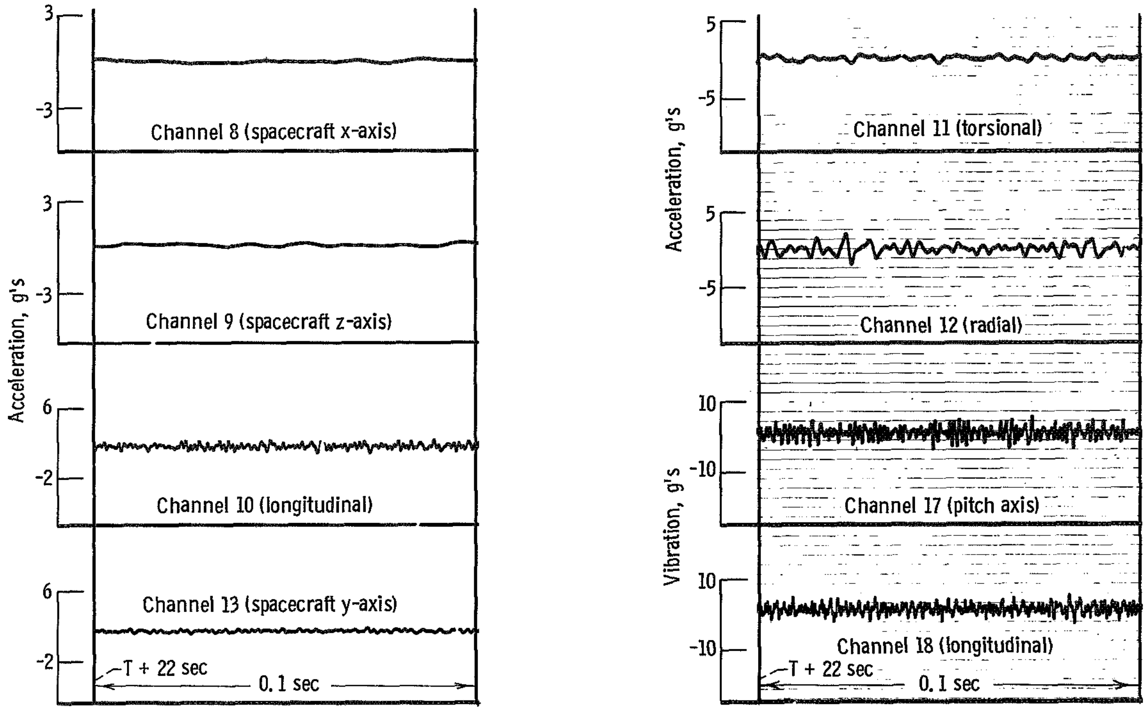


Figure D-3. - Accelerations during transonic region at T + 22 seconds, OGO-IV.

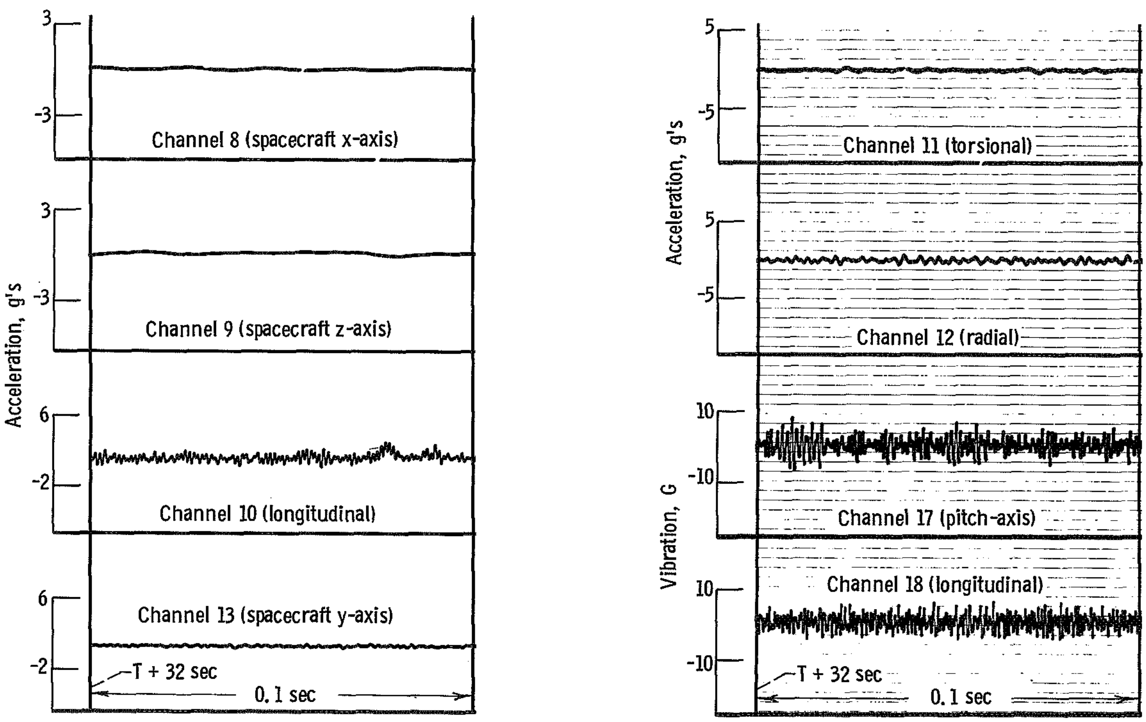


Figure D-4. - Accelerations during transonic region at T + 32 seconds, OGO-IV.

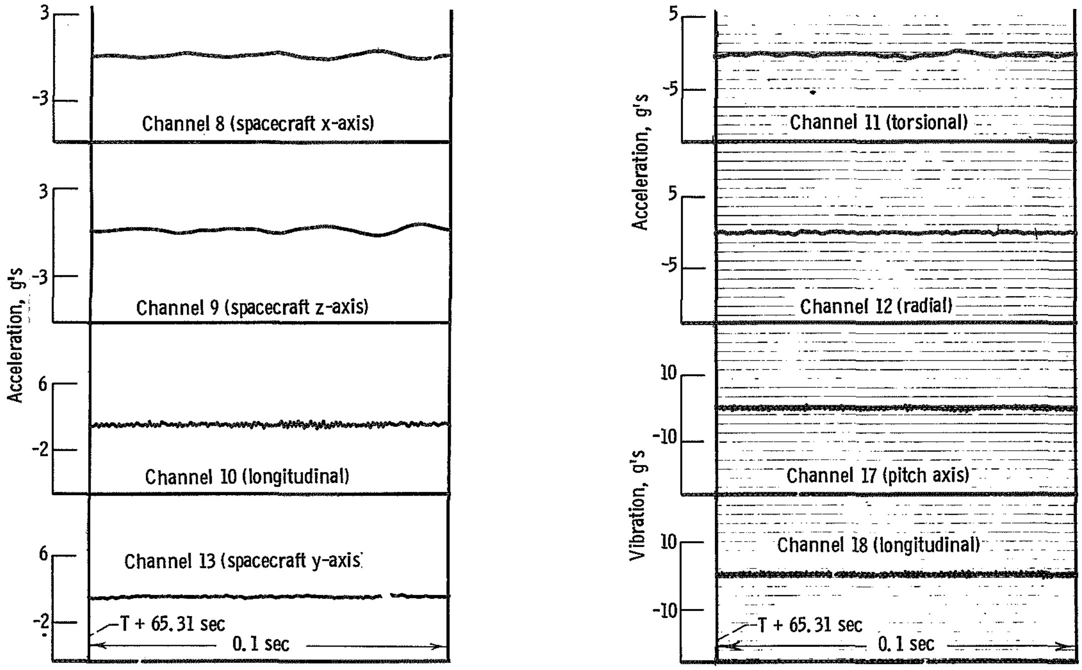


Figure D-5. - Accelerations at solid motor jettison, OGO-IV.

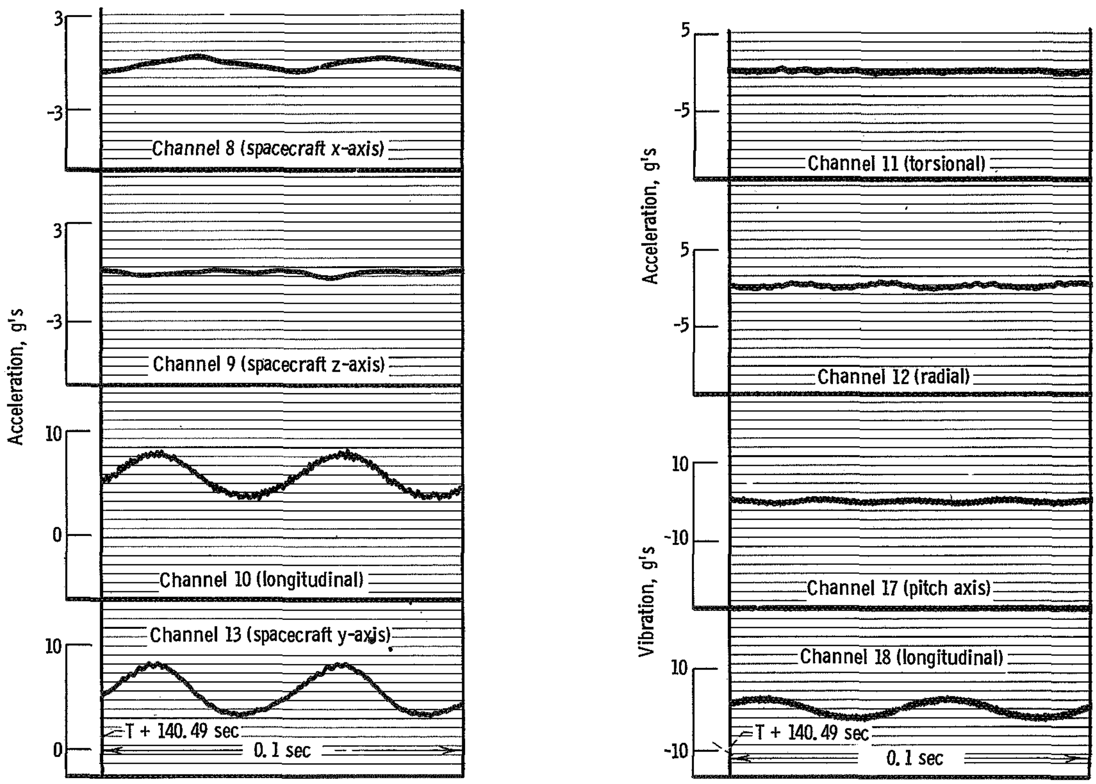


Figure D-6. - Accelerations at approximately 8 seconds prior to TAT main engine cutoff, OGO-IV.

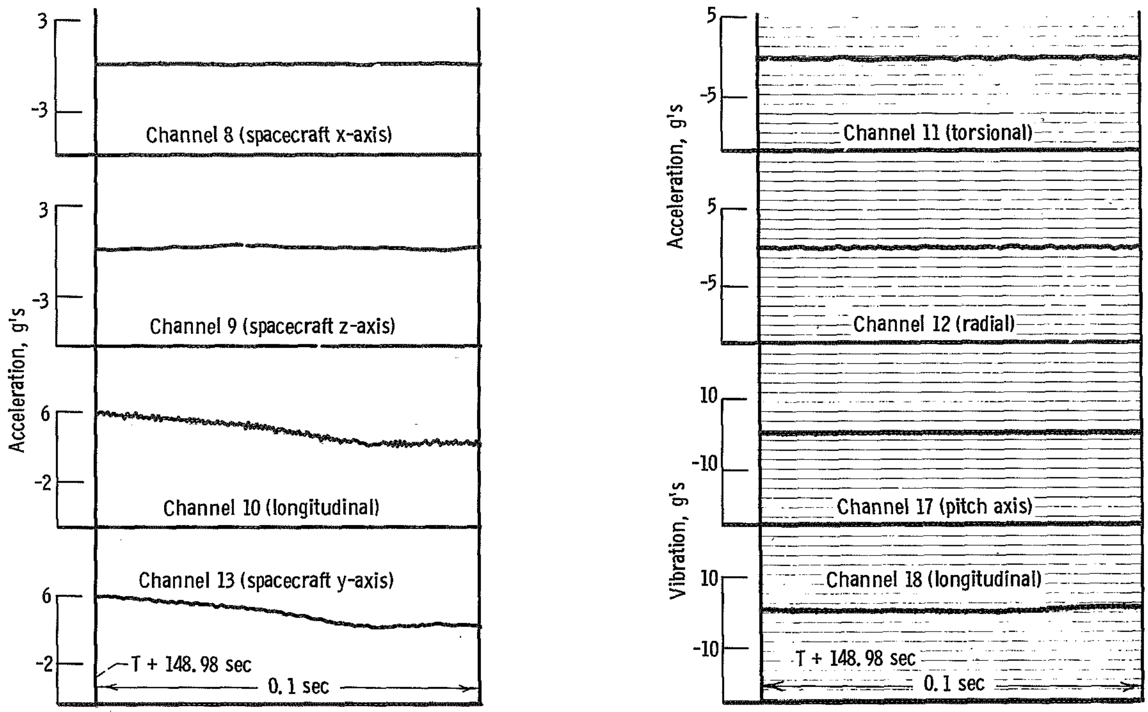


Figure D-7. - Accelerations at main engine cutoff, OGO-IV.

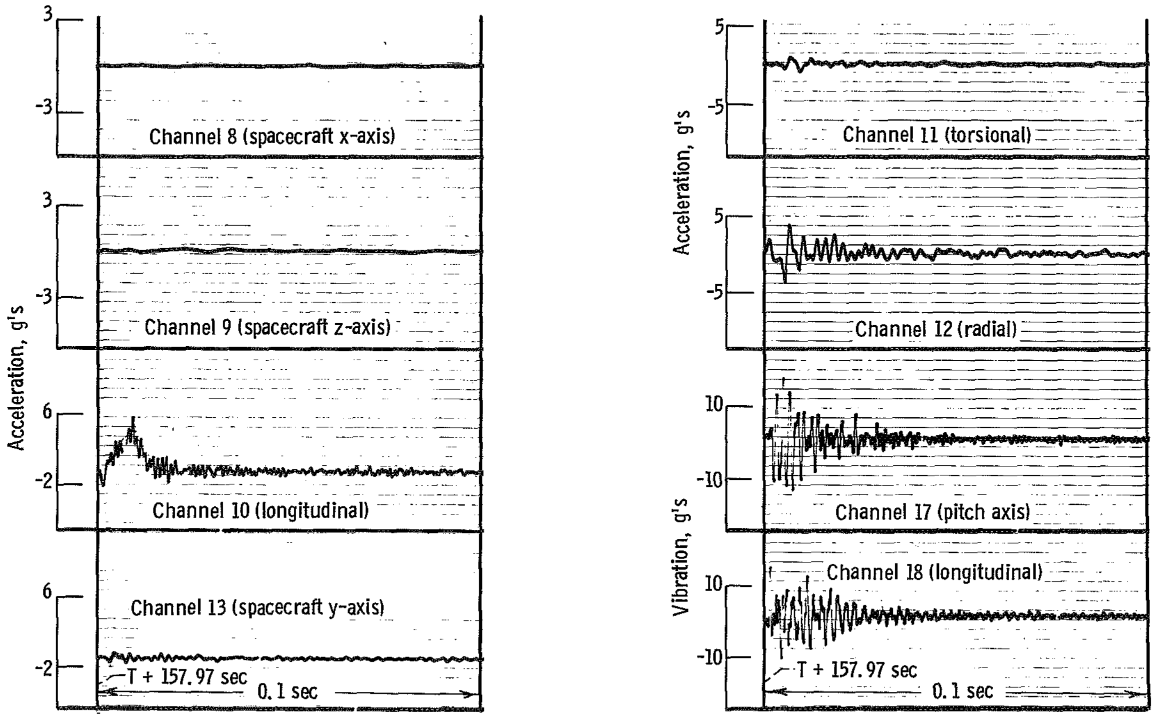


Figure D-8. - Accelerations at horizon sensor fairing jettison, OGO-IV.

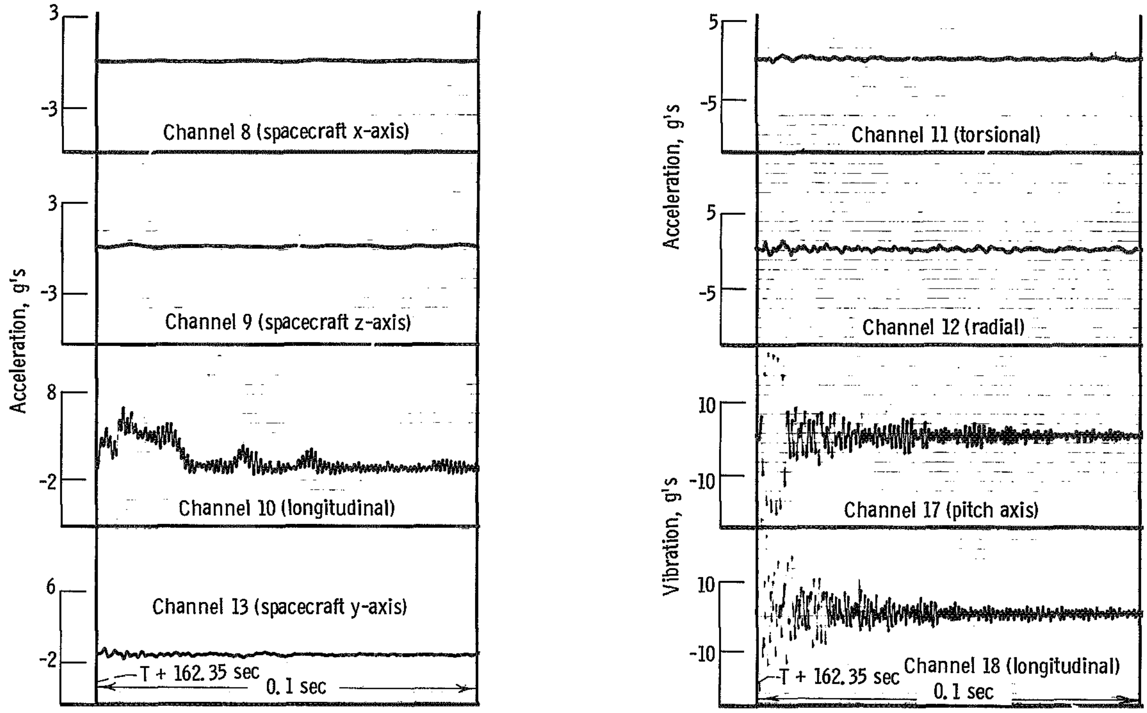


Figure D-9. - Accelerations at TAT-Agena separation, OGO-IV.

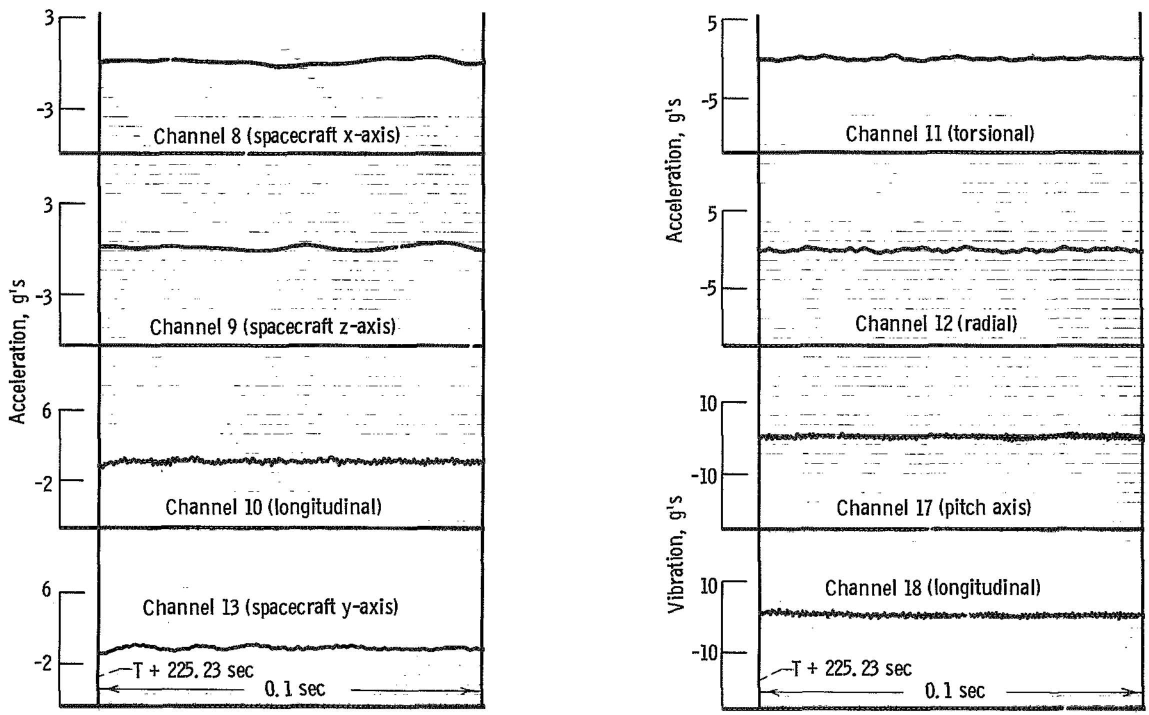


Figure D-10. - Accelerations at Agena ignition, OGO-IV.

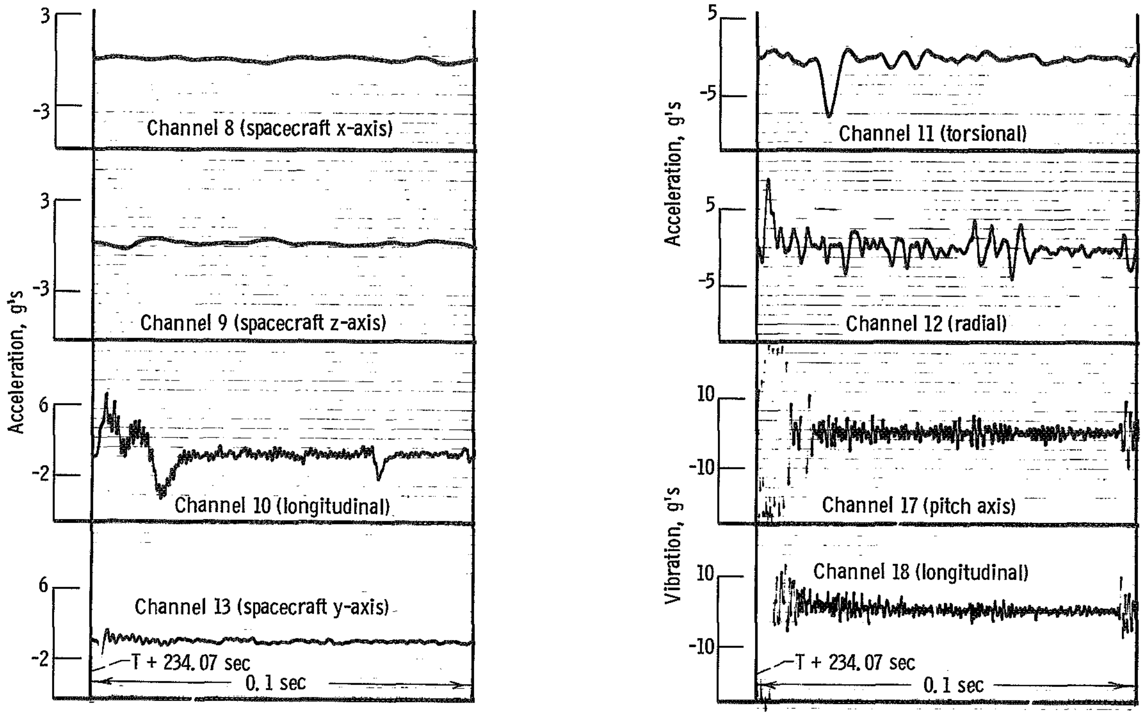


Figure D-11. - Accelerations at shroud separation, OGO-IV.

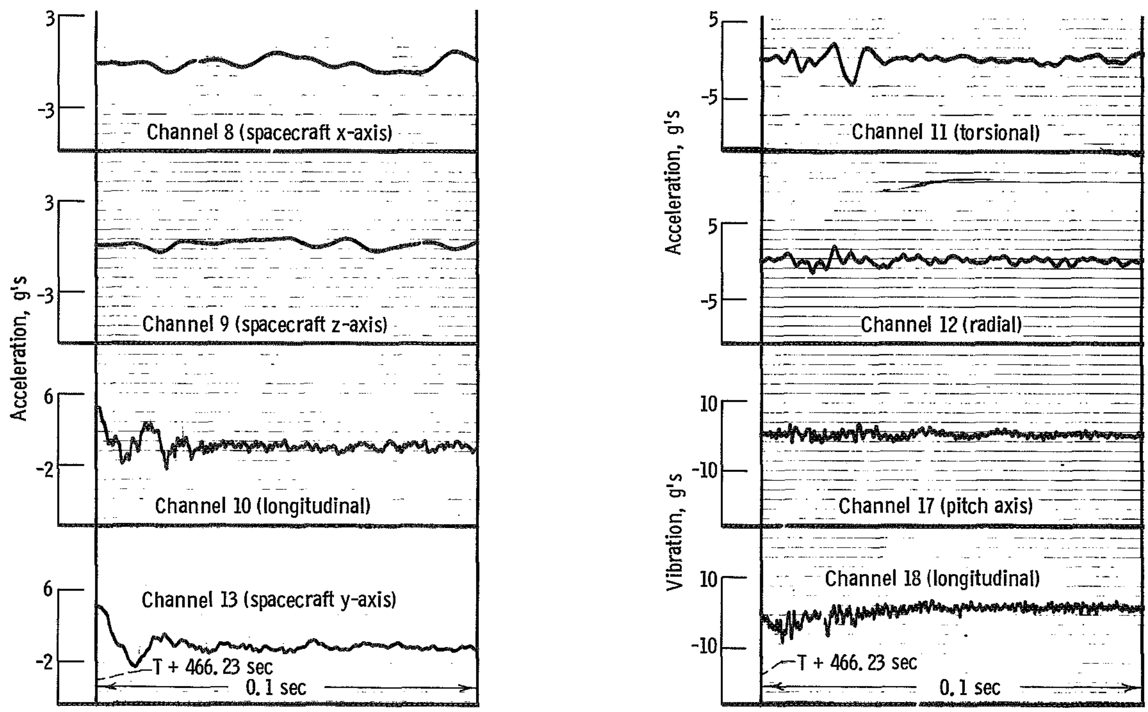


Figure D-12. - Accelerations at Agena cutoff, OGO-IV.

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