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PAYLOAD SPIN ASSEMBLY FOR THE COMMERCIAL TITAN LAUNCH VEHICLE

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ABSTRACT

Honeywell Inc., Satellite Systems Operations has completed a contract to design, build, and test a Payload Spin Assembly (PSA) for installation onto the Martin Marietta Titan III Commercial launch vehicle. This assembly provides launch support for satellite payloads up to 5783 kilograms (6.37 tons) and controls release, spin-up, and final separation of the satellite from the second stage. Once separated, the satellite's Perigee Kick Motor (PKM) boosts the satellite into its transfer orbit. The first successful flight occurred December 31, 1989. This paper discusses requirements, design, test, and problems associated with this unique mechanical assembly.

INTRODUCTION

Integration of satellite payloads onto launch vehicles always presents a challenging set of interface problems, but the challenges multiply when the launch vehicle must also spin the payload at rates up to 70 rpm before release. Spin stabilization of satellites destined for geostationary service (altitude 22,000 miles) is required in low earth orbit (altitude 100 miles) before ignition of the satellite's PKM to improve orbit insertion accuracy and thus extend the satellite's operational life. This is an adaptation of enhancing rifle accuracy with a spinning bullet.

The PSA has been designed and developed to provide structural and electrical interfaces between a satellite payload and the Titan III Expendable Launch Vehicle (ELV) and perform controlled satellite spin-up and release. In this capacity the PSA must allow communications between the satellite and the ELV in all phases of prelaunch and launch operations and support the satellite, while reacting to dynamic loads induced by ELV accelerations and acoustics. It must then perform a precision satellite spin-up and release, while exposed to mission temperature extremes. The PSA structural stiffnesses, weight, mass distribution, spin-up accelerations, interfaces, and self-generated shock loads must also be compatible with both the ELV and the satellite to ensure mission success.

Rigorous development and qualification testing performed on two PSAs contributed to a thorough understanding of system performance, successfully identified design weaknesses, and then verified the associated solutions. The result is a flight-qualified mechanism contained in a single compact package that

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meets all specification requirements. All functions are testable at the component and system levels, and many functions are redundant, providing a fully integrated, flexible, and reliable system.

The location of the PSA in its first launch application is shown in Figure 1. This configuration flew and performed flawlessly on the first Commercial Titan launch, December 31, 1989, when it spun the SKYNET 4A satellite to 60 rpm. The precise injection of this payload has extended the satellite's operational life well beyond the users' expectations.

REQUIREMENTS

1. Provide interface with Titan III aft payload adapter and the upper payload PKM.
2. Provide a system that can support a range of payloads between 1814 kg (4000 lb), I_z = 868 kg-m^2 (640 slug-ft^2) and 5783 kg (12,750 lb), I_z = 5424 kg-m^2 (4000 slug-ft^2).
3. Accelerate selected payload from 0 rpm to desired speed (between 4 and 70 rpm) in 7 minutes while applying less than 13.8 kg-m (100 ft-lb) to Titan vehicle.
4. Separate the 5783-kg (12,750-lb) payload from a 12,247-kg (27,000-lb) mass at minimum velocity of 0.61 m/s (2 ft/s) with a tip-off rate not to exceed 0.10 deg/s.
5. Provide structural stiffnesses of: axial 81.35 x 10^5 N-m (5 x 10^5 lb/in.); torsional 0.45 x 10^8 N-m/rad (4 x 10^8 in.-lb/rad); moment 0.11 x 10^9 N-m/rad (1 x 10^9 in.-lb/rad).
6. PSA mass to be 195 kg (430 lb) maximum.
7. Provide redundant drive motors and electronics with bus current limited to 65 amperes per channel.
8. Environment:
   - Operational temperature of -23 to +60°C (-10 to +140°F)
   - Vacuum level of > 1 x 10^{-5} torr
   - Random vibration at component level
   - Acoustic test at system level

An exploded view of the PSA is shown in Figure 2, and an operational mission time line is shown in Figure 3.

DESIGN DESCRIPTION

The PSA has a basic inverted hollow cone configuration approximately 1.5 m (5 ft) in diameter and 1.22 m (4 ft) high, with flight weight just under 195 kg (430 lb). It comprises a primary and secondary structure, each with a stationary and rotating component. This configuration meets the requirement to provide an upper interface with the PKM and a smaller diameter lower interface with the Titan III aft-payload adapter. Secondary structures are extended below this lower interface to provide internal clearance for the PKM nozzle. The PSA contains a redundant drive motor/electronics combination and a centrally mounted Slip-Ring Assembly (SRA) for signal transmission across the rotating interface. A pyrotechnically released spin V-band clamps the primary rotating structure to the stationary structure for launch. A separation V-band retains the payload to the PSA, clamping it through a Motor Adapter Ring (MAR).

Following release of the spin V-band, the rotating structure is spun for 7 minutes to the desired speed on the single "X" bearing, whose inner race housing is a ring gear to which both drive motor pinions mesh.

At operating speed, the separation V-band is released, freeing the spinning payload, which is injected into its transfer orbit with a velocity of 0.61 m/s (2 ft/s) by the force exerted from four coil springs.

STRUCTURE

The PSA structure consists of two main elements: rotating structure and stationary structure.

The MAR, which rotates, provides the interface with the payload PKM and a 1626-mm (64.0-in.) diameter separation V-band.

The primary rotating structure is a riveted monocoque construction comprising upper and lower rings connected by a four-piece skin.

This structure provides half the clamping interface for both the separation V-band and the spin-release V-band.

The secondary rotating structure (Figure 2) rotates with the spin bearing and provides support for payload harnesses between the rotating element of the SRA and the rotating primary structure.

The primary stationary structure provides half the interface for the spin release V-band and the bolt interface that attaches the complete PSA to the Titan Payload Adapter (PLA).

This structure also provides the outer mounting diameter for the 1181-mm (46.5-in.) diameter thin-section spin bearing.

The secondary stationary support structure (Figure 2) provides attachment for the two-brush DC Drive Motor Assemblies (DMA), the two Spin Electronics Assemblies (SEA), and the SRA.

SPIN SYSTEM

The PSA spin system consists of the following major components: spin bearing, ring gear, two redundant DMAs, two redundant SEAs, off-load spring, and spin-release V-band (Figure 4).

This system provides all functions necessary to apply a controlled torque to the payload, which maintains constant acceleration for nearly 7 minutes, at which time operational spin rate has been achieved and stabilized. The operational sequence starts 1 hour and 4 minutes after launch. The Titan issues the command that pyrotechnically activates the two spin V-band separation bolts, releasing the band. This release allows the off-load spring to assume its natural uncompressed position, thereby elevating the primary rotating structure to provide a 2.54-mm (0.10-in.) clearance from the primary stationary structure. Two seconds after release, both DMAs are energized, allowing rotation of the structure, MAR, and payload. The SEAs control current going to each DMA such that a constant acceleration is maintained for 6 minutes and 55 seconds, at which time the command switches to a speed-control mode to stabilize rotational speed of the payload. At 7 minutes and 3 seconds, all power is removed from the system, and at 7 minutes and 4.5 seconds, the separation sequence is initiated by a command that pyrotechnically releases the separation V-band allowing the payload to be ejected.

The spin bearing is a 1181-mm (46.50-in.) Outside Diameter (OD) by 1143-mm (45.0-in.) Inside Diameter (ID) by 15.9-mm (0.625-in.) thin-section X configuration. It contains 192, 440C balls, which are separated by 16 segmented 6/6 nylon + 6% Teflon separators. Axial capacity of this bearing is 147 kN (33,000 lb). This bearing is lubricated with 3 grams of Bray® 815Z oil, which was selected primarily for its good boundary lubrication characteristics and low outgassing (less than 0.3%). The small quantity of lubricant reduced cold temperature viscous drag torque. This spin system is powered from Titan batteries that limit power to 65 amperes/channel. It was essential, therefore, as part of overall torque budget, to maintain control on bearing drag torque over the complete environmental range. A 40.7-N-m (30-ft-lb) max design goal was established.

The ring gear has a pitch diameter of 1092 mm (43.0 in.) with 215 teeth cut at a 5-Diametral Pitch (DP) and pressure angle of 20°. This gear is cut on the inner diameter of a 7075-T7351 aluminum ring forging whose outer diameter of 1143 mm (45.0 in.) provides the mounting face for the spin-bearing inner diameter. The gear is anodized, nonlubricated, and meshes with both DMA pinions to provide a 10:1 reduction in a lightweight package. No lubrication was required at the gear interface due to low contact stress (<20 ksi) and low number of cycles (<250K). Because the spin system is unidirectional, there was no backlash requirement, though backlash was measured at 0.38 mm (0.015 in.).

It was a major system requirement that the PSA contain a redundant spin-up system. Accordingly, two independent motor/electronics combinations were provided.

Each DMA is coupled into the spin system through its pinion, which meshes with the ring gear. Each DMA is independently capable of meeting mission spin requirements by applying a constant 14.37 N-m (10.6 ft-lb) of torque at a rated speed of 720 rpm at the pinion. The DMAs are 85% efficient, power being supplied from the vehicle's batteries and controlled through SEAs in the form of a high-current (up to 80 A) and a low-end voltage of 21 volts. The DMAs were designed, built, and qualified in 6 months.

Each DMA contains the following major components: roller clutch, planetary gear train, brushless dc motor, AC tachometer, and housing (Figure 5). The following paragraphs highlight the key features of each component.

The **roller clutch** is a unidirectional mechanical device capable of transmitting motor torque while decoupling the motor in the absence of torque. This decoupling allows independent operation of the redundant motors without complications and reliability problems associated with retraction/engagement devices. The clutch is a Honeywell-patented device that is designed to ensure that rollers share the load equally without producing a radial force on shaft bearings. It is designed for 827 MPa (120 ksi) Hertzian stress at a 20.3-N-m (15-ft-lb) torque load.

A highly reliable, compact 5:1 **planetary gear train** is employed for speed reduction between motor and pinion gear. The design, based on previous flight heritage, is capable of transmitting 8.12 N-m (6 ft-lb) at 3600 rpm input (sun gear). The gear train has a fixed ring gear and four planet gears connected on bearings to an output carrier. All gears are AGMA 10 quality and lubricated with Bray 601 grease.

The brush-type **DC motor** is a Honeywell-patented design employing an 8-pole, rare-earth, permanent magnet stator and wave-wound armature, commutated by eight brush pairs, connected to provide parallel paths. Winding and brush configurations are dictated by high-current power supply and provide sparkless commutation and a fault-tolerant design. The motor produces 3.5 N-m (2.6 ft-lb) of torque over the 0-3600 rpm speed range with less than 5% ripple. The limited-life application allows the use of simple and compact brush commutation. Carbon graphite brushes with molybdenum disulfide provide good performance and wear characteristics in both air and vacuum environments.

The AC tachometer consists of a 3-phase, 8-pole, calibrated permanent magnet generator. When combined with commutation electronics, a speed-dependent voltage is produced with <1% linearity error and <1% ripple over the -29° to $+65^{\circ}C$ (-20 to $150^{\circ}F$) temperature range and 0 to 3600 rpm speed range.

The two SEAs are identical and capable of meeting the PSA operational requirements independently (Figure 6); each dissipates 153 W, with a maximum input of 65 A at 28 ±3 VDC.

Each SEA provides speed control to its mating DMA, and a motor current in excess of 50 A, in order to meet worst-case mission requirements (largest payload at lowest operational temperature). Drive capability was achieved by paralleling 6 MOSFET transistors whose fast switching times minimized losses. The large voltage transients were controlled by a snubbing circuit and by adding inductance to the source lead of each transistor and referencing the gate drive to the low side of this added inductance. This arrangement provided the feedback needed to control transistor turn-off transient.

A mission profile card is used to select the desired spin rate and to establish overspeed protection as required by each payload. The SEA provides constant acceleration for nearly 7 minutes, up to any selectable speed between 4 and 70 rpm.

The SEA contains four Circuit Card Assemblies (CCA) packaged in an environmentally sealed aluminum chassis, which is 233 mm (9.2 in.) wide by 311 mm (12.25 in.) long by 107 mm (4.2 in.) high and weighs 6.6 kg (14.5 lb). The main chassis is a one-piece ribbed aluminum structure, with a pressure-relief valve activated at a differential of 24 kPa (3.5 psi).

Covers for the SEA are one-piece aluminum construction and ribbed for increased stiffness. The motor driver CCA, containing the power MOSFETs, has high thermal dissipation and is mounted directly to bottom cover for increased thermal conduction to the PSA structure.

The CCAs use multilayer Printed Wiring Boards (PWB) designed to MIL-STD-275E and fabricated from MIL-P-55110 polyimide material. Internal wiring to the MOSFETs is a challenge due to dense packaging and high currents and the use of 14-gauge MIL-W-22759/32 Tefzel®-coated wire.

The SEA operates at -23 to +60°C (-10 to +140°F) in a vacuum less than 1×10^{-5} torr and is packaged to withstand 20g rms random vibration and the shock environment resulting from firing the V-band pyrotechnic bolts.

A unique feature of the PSA is the offload spring. This item is a flat double-element diaphragm spring that, in its natural unclamped position, elevates the spinning portion of the PSA, and hence the payload, away from the stationary structure, providing the clearance necessary for the spin-up phase of the operation (Figures 4 and 7). For launch, this spring is deformed by the clamping action of the spin V-band, which forces primary rotating and stationary structures together. Relative structural stiffness between the offload spring and clamped primary structures also allows a major portion of launch loads to bypass the spin bearing. This offload spring connects to the rotating structure on one side and the ring gear on the other. Shims are used during assembly to set the 2.54-mm (0.1-in.) gap.

Axial stiffness of this 7075-T7351 forged offload spring was sufficient to elevate a 1814-kg (4000-lb) ground test payload without counter balancing and was designed to have moment stiffness and strength to resist payload pitching motions at 70 rpm, V-band clamping and launch loads.

Extensive analysis was completed on this vital component, which showed a worst-case safety margin of 0.02 at stress levels of 0.365 MPa (53 ksi).

The spin release V-band consists of 12 separate aluminum alloy retainers, each loosely clipped to a 2-segment titanium tension strap. It is nominally 1270 mm (50.0 in.) in diameter and weighs 21.3 kg (47.0 lb) (Figure 8).

The inner surface of each retainer is machined to a 30-degree cone angle that mates directly with each half of the spin release interface (Figure 4). The 30-degree cone angle resulted from a trade between stress levels and the need to totally preclude any self locking given the maximum coefficient of friction at this interface. Retainers were fabricated from 7075-T7351 forgings to give the strength necessary to meet the requirement that no gap ever exist at the spin interface, under worst-case combination limit loads, creep, tolerances, and environments.

The two-segment titanium strap holds the retainers in position with a 89-kN (20,000-lb) tension load derived from the two separation bolts acting through titanium trunnions, which are retained loosely in loops at the end of each strap segment. This tension load was derived from the no-gap requirement and was achieved by torquing the separation bolts alternately at increasing levels until the required load was achieved. This load was monitored by an in-series load cell, which also provided a means of monitoring load creep under all ground conditions.

Each separation bolt (Figure 9) is supplied with a screw-in power cartridge complete with electron-beam welded redundant NASA Standard Initiators (NSI). On command, the initiators fire the power cartridge, which drives an internal piston causing the bolt to fracture and the V-band to release. Each separation bolt is fabricated from 4340 steel providing the strength and no-particle generation characteristics. To ensure a smooth release, retainer clamping faces are treated with Tufran H® and the straps with Canadize® Teflon. Following release, the V-band is pulled away from the PSA with six torsion springs to prevent impact with the rotating structure and to retain the released band with the system.

One challenge associated with the sudden release of highly tensioned V-bands is dissipation of the strain energy. This was accomplished by energy absorbers that utilized compression of aluminum honeycomb as the absorbing media. Before-and-after release configurations of these devices are shown in Figures 10 and 11.

SEPARATION SYSTEM

Following the 7-minute spin-up sequence, the PSA is required to separate the spinning payload and simultaneously inject it into its transfer orbit with a velocity of at least 0.61 m/s (2 ft/s).

Seven minutes and 4 seconds after spin-up initiation, the separation V-band is released by pyrotechnically fracturing both separation bolts. This release allows four symmetrically spaced separation springs to push the spinning payload away from the PSA and Titan III second stage. The separation spring configuration and its interface with the MAR are shown in Figures 2 and 12.

During the payload push-off maneuver, the four separation springs must impart the required velocity in a balanced manner to control tip-off rate. The four equally spaced titanium Beta C springs have a wire diameter of 10 mm (0.394 in.) and a mean diameter of 70 mm (2.75 in.). Each spring exerts an installed load of 354 kg (782 lb). To control tip-off rate, the four springs are selected for load at loaded length and then energy matched at the assembly level in a manner shown in Figure 13. All this matching would be useless, however, should one spring fail during its expected storage life. Tests were conducted on a sample set of springs, which established life-cycle margins far in excess of any projected operational use. For further security, all springs were shot-peened and dye-penetrant tested, and the open installation allowed complete visual inspection. The high installed load of these springs raised safety concerns, which were alleviated by use of spring compression tools that were always installed unless separation tests were being conducted.

The separation V-band is an identical assembly to the spin V-band except it has a larger nominal diameter of 1626 mm (64.0 in.). This separation band is closer to the payload Center of Mass (CM), used smaller retainers, and weighed 11.8 kg (26 lb). This band was tensioned by incrementally torquing its two separation bolts to achieve a measured load of 44.5 kN (10,000 lb). Load measurement, release, energy absorption, and retraction/retention were similar to that used on the spin-release V-band.

TELEMETRY

The PSA provides the means of communication between the satellite and Titan throughout all mission phases: prelaunch to separation. The main items of interest are signals showing satellite status, connections to release the spinning separation V-band, verification of V-band release, and payload status information provided to the Titan Inadvertent Separation Destruct System (ISDS), part of the range safety requirements.

The main hardware item in this system is the SRA, which is mounted centrally in the secondary stationary support structure. Electrical harnesses from the Titan connect directly into six static connectors on the SRA, with the PSA harnesses connecting to the rotating side. These harnesses are supported by the secondary rotating structure, travel across the primary rotating structure, and terminate in two groups of low-separation-force connectors at the PSA side of the structure/MAR interface. Harnesses from the satellite connect to the deployment side of each connector.

The SRA is a 170-channel, gold-on-gold, Bray NPT-4 lubricated unit that weighs 11.8 kg (26.0 lb) and is shown in Figure 14. Each channel has a 5-A capability, using four wipers per channel. This unit was a flight-qualified design with the exception of providing the no-interruption requirement during the launch phase, which was a flow-down requirement from the Titan ISDS system. There was no practical method of verifying such a requirement, so a specification was developed that gave any discontinuity a maximum value of 0.25 ohm with a duration of less than 100 ms and a repetition rate of greater than 1.0 ms.

The two groups of payload separation connectors are spring loaded to cancel the small pin-to-socket drag loads at separation. This was a direct result of the payload tip-off requirement. Two circuits were directly looped in those connectors to provide verification of payload separation. A single break wire was connected across each end of both V-bands to provide telemetry, which verified separation.

The tachometer in each DMA provided angular velocity information directly to each SEA to control the payload spin-up profile.

TEST PROGRAM

Even though the PSA program was schedule driven, an extensive test program was planned from the beginning. The philosophy adopted called for thorough testing at component and subassembly levels, to be followed by a complete qualification and acceptance test program at the system level.

A completely functioning engineering model was designed and built in 8 months. Each component assembled into this model was thoroughly tested in its most extreme environments and then in the complete assembly. The object of this effort was to gain confidence in the design prior to the build of the qualification and flight units, to develop all assembly and test procedures, to design and build all test equipment early in the program, and to develop subcontractor capabilities in preparation for the flight build. After system testing, the engineering model was incorporated by Martin Marietta into the modal test structure.

A flight-worthy qualification model was built and subjected to the extensive test program shown in Table 1, again with each component/subassembly being qualified in its own environment prior to installation. All four flight units and their components were fabricated and tested to the acceptance test flow chart shown in Table 1. A summary of main component tests is shown in Table 2.

Test equipment for this program centered around the PSA safety fixture. All spin-up, separation, load, and (with the addition of side panels) thermal cycle testing was conducted in this fixture. It was designed to support axial loads of up to 453,500 kg (1 million pounds), which is the theoretical buckling load of the PSA structure, as well as contain the largest spinning payload in the event of a major failure. (No such event occurred.) Pneumatic cylinders were used to axially decelerate the off-loaded or counterbalanced simulated payloads during separation testing, and a radial roller system centrally constrained the single-point suspended spinning payload during the deceleration stage. The simulated payloads were configured from a steel Center of Gravity (CG) offset drum, 1.5 m (5 ft.) in diameter and weighing 907 kg (2000 lb), to which was added a series of 2.4-m (8 ft)-diameter steel plates to attain correct mass and inertia.

Load testing used a series of hydraulic cylinders and calibrated load cells to simultaneously apply axial, shear, torsion, and moment loads. Structural stresses were converted directly from 44 strain gages, and deflections were monitored with a series of dial indicators (Figure 15). The PSA performed flawlessly after ultimate load application.

All operational testing of the PSA was performed with an automated test set using an 8088 PC system. All data was recorded on a separate disk for each test, which proved invaluable in performance diagnosis. Speed, time, acceleration, voltages, DMA current, and temperatures were routinely recorded. SRA continuity was measured during every spin-up test. During V-band releases, 500 frames/s high-speed photography was used. This initially showed some surprising motions, which caused redesigns in the energy absorber links (to prevent structural contact) and the addition of cleats to hold trunnions and V-band loops together. Damage to clips holding V-band retainers to the tension strap was a recurring problem because the V-band release dynamics were not fully understood. Replacing the light aluminum alloy clips with heavier steel clips solved the problem. Four equally spaced high-speed cameras were used to monitor separation velocity and tip-off rate.

Component testing was, for the most part, trouble free, except for the failure of the qualification unit DMA to pass insulation testing. This failure was caused by a combination of brush wear debris and wire insulation cracking. The problem was solved by adding a coat of Chemglaze® to motor windings. A failure occurred with the separation bolts when test samples did not fracture after pyrotechnic ignition; a combination of powder charge, its mix, and undercutting of the bolt caused this problem. Problems in establishment of the SRA no-interrupt requirement were extensive, as well as the equipment needed for verification; once resolved, the unit performed well.

The major difficulty during component testing was associated with the spin-bearing drag torque measurement, particularly at -23°C (-10°F). A torque budget of 41 N-m (30 ft-lb) had been established, and drag numbers as high as 136 N-m (100 ft-lb) were initially measured. The problem was due to mismatch in coefficient of thermal expansion of aluminum housings and steel bearing races. To better control these interfaces, steel races were interference fitted into their respective housings, and final grinding of the bearing raceways was completed at this subassembly level. The heavy interference fit was set to cancel any subsequent thermal effects, thus maintaining bearing preload and its internal configuration.

Testing of the Engineering Model (EM) was trouble free, except for problems debugging test equipment and procedures (exactly the role of the EM). When qualification testing started, a major failure occurred during the third spin-up: the SEA totally failed 3 minutes after test start. All six MOSFET transistors failed due to thermal overload, which was a surprise in view of successful testing of the EM. After a lengthy investigation, it was found that during rapid switching, the MOSFETs had become unstable because the designed-in snubber circuit could not control the speed of these S-level components. The EM components were of lesser quality and therefore slower, well within the snubber circuit capabilities. This circuit was changed, and additional inductance was added in the transistor source lead. This cured the problem but showed that building EMs even with small differences can lead to surprises.

During subsequent spin-ups, problems arose with the slow, or in some cases, total lack of engagement of the DMA clutch. An analysis of the clutch geometry indicated that if all possible tolerances occurred in one direction, this problem could happen. It happened that one of the qualification unit DMAs had this combination. All clutches were disassembled, larger diameter engagement rollers were installed, and a limited Acceptance Test Procedure (ATP) was performed to get the motors back on line. The lesson here is: if it can happen, it will.

Analysis of high-speed V-band separation films showed that the energy absorbers were not being activated and were, in fact, going over center and impacting the structure. The links to these absorbers were shortened and a mechanical stop included; lighter-weight honeycomb was also used. All these measures cured this impact problem, which arose through lack of understanding the fine details of V-band dynamics. The PSA failed to attain full 70 rpm during testing in the thermal cycle environment, the problem being that six of the spin-bearing separators displaced from the bearing and wedged together. This displacement occurred because incorrect bearing retainers had been installed, which stemmed from the need to thermal fit the bearing prior to final race grind. Machine access for this grinding had made a reconfiguration of the bearing installation necessary, part of which was redesigned retainers. These were not available at assembly time, so the obsolete configuration was used against the advice of the bearing manufacturer. Schedule pressure is never a reason to ignore sound advice.

In thermal-vacuum testing, the PSA again failed to spin up during the second cold cycle after having shown nominal performance during the first cycle; however, during the first cycle, the PSA had been clamped together with the spin V-band, which, after the 1-hour soak, had been released. The second cycle configuration was, therefore, entirely different thermally and allowed a major thermal mismatch to occur. The problem should never have occurred because the unit, at that time, was in a nonoperational configuration.

The Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) demands on the PSA were extensive, and testing was a lengthy affair. A total of 80 complete spin-ups were required to cover the entire spectrum and stay within the DMA's thermal limits. The test equipment was more of a problem than the unit.

After these major problems during qualification, all the flight units, particularly Flight No.1, were failure free. With hardware of this size, any problem consumes considerable time, and it is essential to carefully design the test equipment and overlook nothing. Problems erode schedule to a much greater extent than with smaller sized hardware, and safety is always an issue. Observing a 5783-kg (12,750-lb) simulated payload with a spin-axis inertia of 5424 kg-m^2 (4000 slug-ft^2) spinning at 70 rpm demands respect.

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TABLE 1. SYSTEM TEST

Test Requirement	Parameters		
Physical Inspection	Configuration verification		
Mass Properties	Weight and CG in three axes		
Interfaces	Verified by use of master gages		
Functional Test	Spin up to 70 rpm with 4,000-lb payload in 7 minutes; both motors nominal voltage		
Thermal Cycle	8 cycles; 0 to +130^{o}F functional test at each temperature extreme; release of spin V-band at first low and high temperatures	Accept.	
Functional Test	As above		
Performance Test	Simulated flight payload, stalled motor, release spin V-band, spin-up, release separation V-band, measure separation velocity; five additional spin-ups at maximum and minimum voltages, one or two motors		
Alignment & Balance	Measure axial and radial runouts, verify balance is within 100 oz-in.		
Functional Test	As above		
Thermal Cycle	12 cycles -10 to +140^{o}F, otherwise as above		Qual
Functional Test	As above		
Thermal Vacuum Test	3 cycles -10 to +140^{o}F; 10^{-5} torr; spin-up at each extreme; minimum payload; Release spin V-band at first low temperature		
Functional Test	As above		
Acoustic Test	Exposure to 148 OASPL		
Performance Test	As above		
Alignment and Balance	As above		
EMI/EMC	MIL-STD-1541 and MIL-STD-461C radiated/ conducted emissions and radiated/conducted susceptibility		
Limit Load Test	Measure stress and stiffness at combination of axial load (76,500 lb), shear (31,900 lb), moment (1.6M in.-lb) and torsion (382,000 in.-lb.)		
Alignment & Balance	As above		
Service Life	5 spin V-band releases and spin up to 70 rpm; 3 separation releases		
Ultimate Load Test	As limit load, except applied loads were increased by 25%		
Functional Test	As above		

TABLE 2. COMPONENT TEST

Item	Test Summary
V-Bands	Samples of the looped ends were vibrated under tension to verify fatigue characteristics of the design as caused by the overhang of the energy absorbers. Samples were pull tested to destruction to verify design margins and manufacturing processes, particularly riveted joints.
SEA	All flight components were S-level or up-screened and certified. All boards were tested at the assembly level prior to conformal coating. Full-box environmental performance testing with health checks after each environment. The SEAs were tested to 20g rms random vibration, in thermal vac, thermal cycle, and the V-band release shock environment.
SRA	Full environmental testing under vibration, thermal vac, thermal cycle, and shock. Special monitoring to establish the no-interrupt requirement during vibration.
DMA	Insulation, full performance at worst-case voltages after vibration, thermal vac, thermal cycle, and shock as well as operation in explosive atmosphere.
Separation Bolts	Sample tested at lowest load, lowest current and lowest powder charge. All-fire/no-fire current testing.
Spin Bearing	Drag torque measured at low, ambient, and high temperatures at 70 rpm. Externally driven by a motor acting through a calibrated torque transducer.

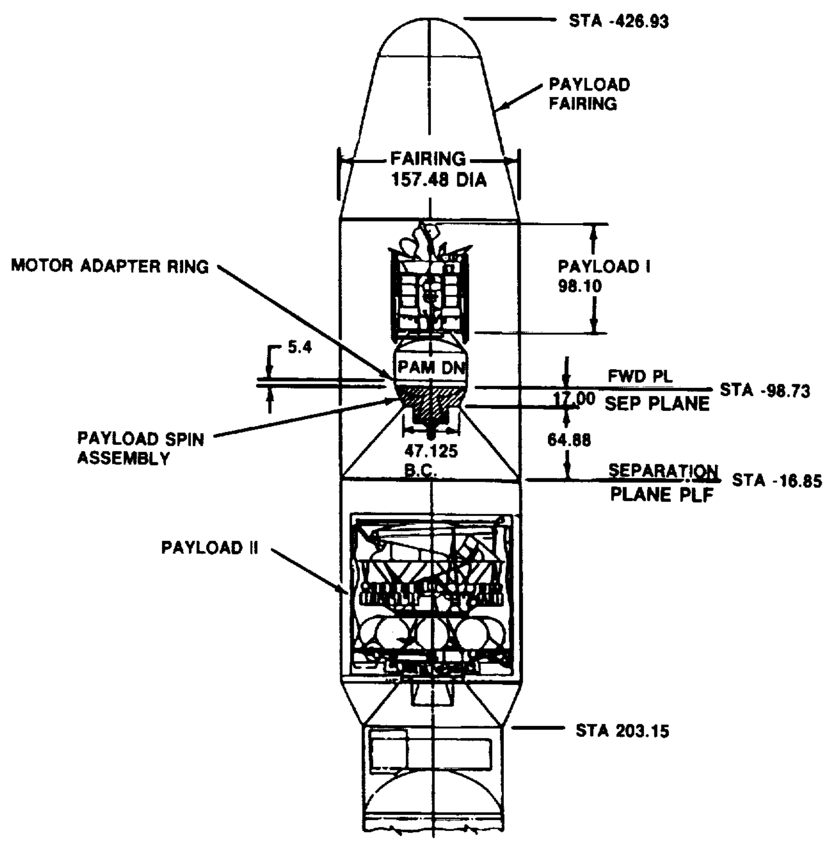


Figure 1. Commercial Titan JC SAT/Skynet Mission

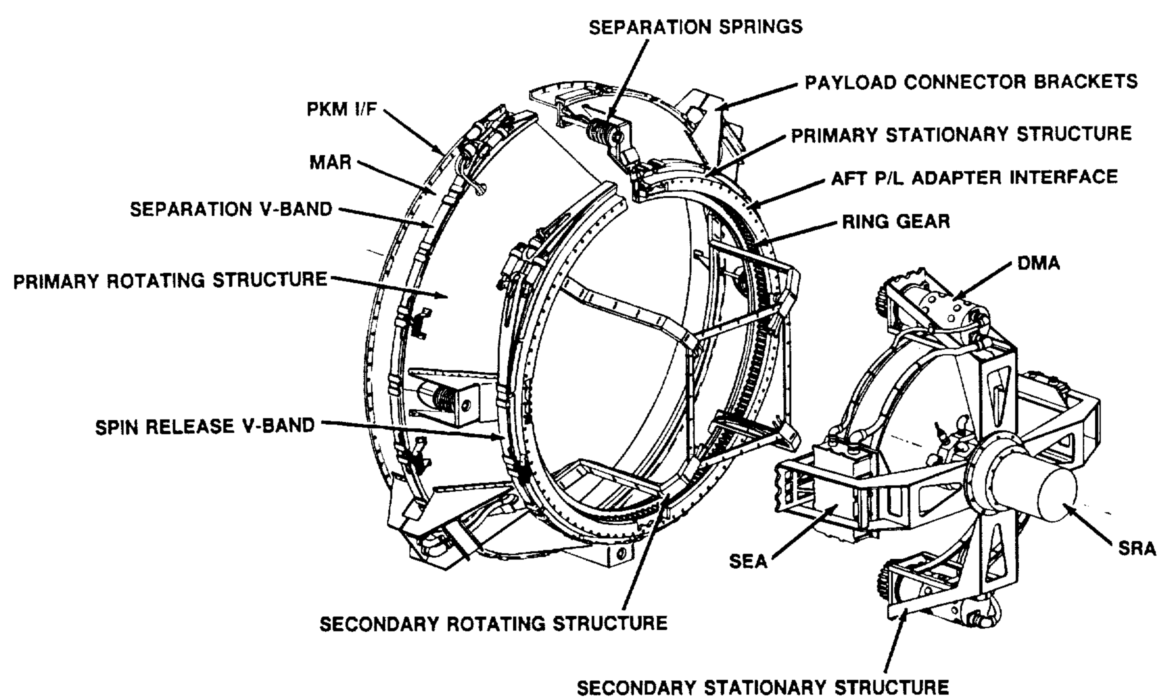


Figure 2. PSA

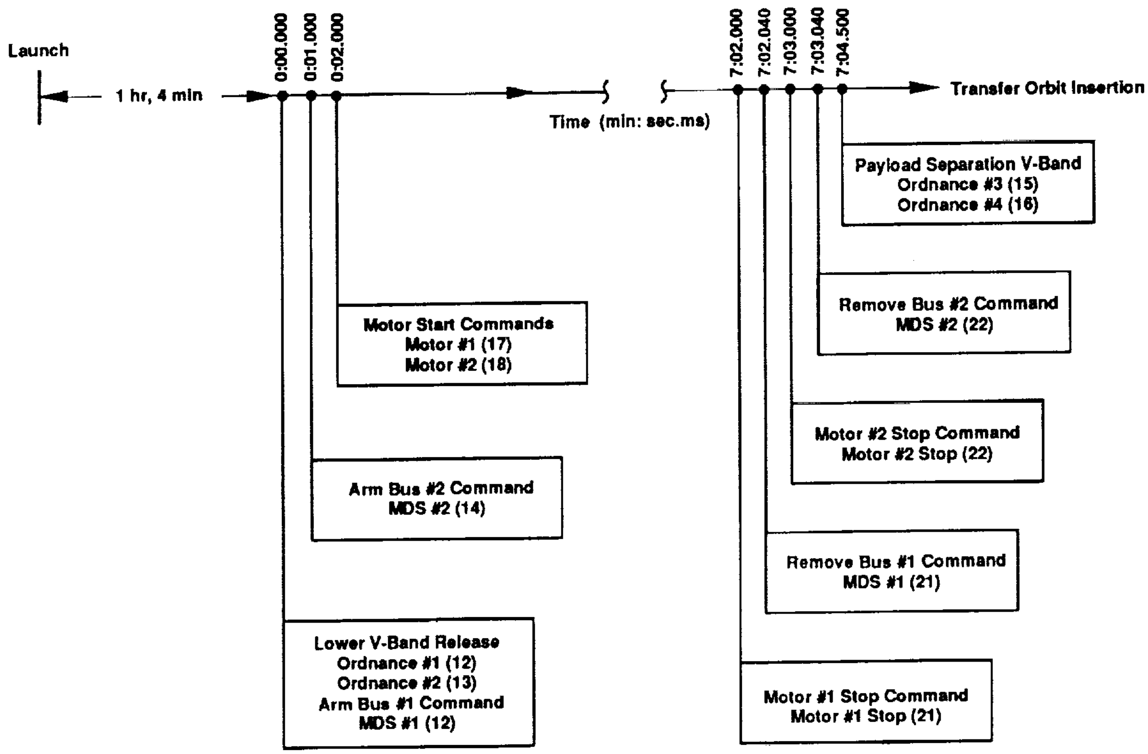


Figure 3. PSA Operation Sequence

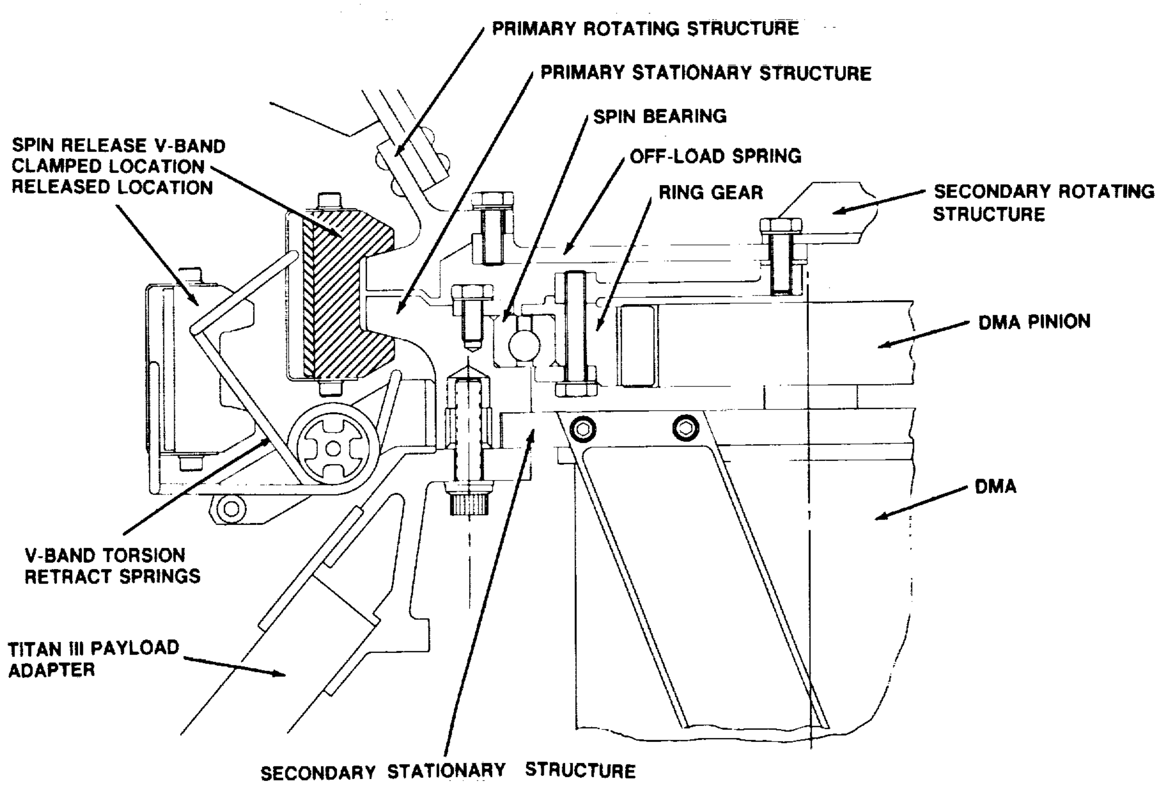
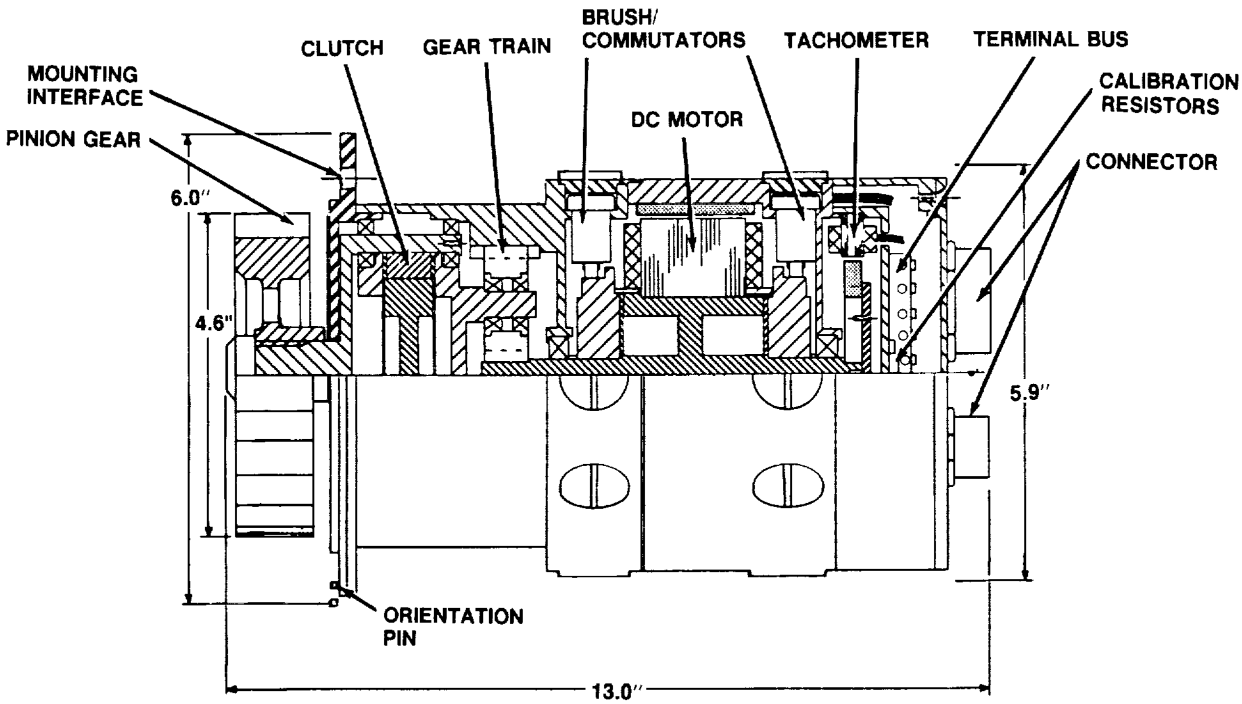


Figure 4. Spin System


BRUSH/
COMMUTATORS
CLUTCH
GEAR TRAIN
TACHOMETER
TERMINAL BUS
MOUNTING
INTERFACE
CALIBRATION
RESISTORS
PINION GEAR
DC MOTOR
CONNECTOR
6.0"
4.6"
5.9"
ORIENTATION
PIN
13.0"

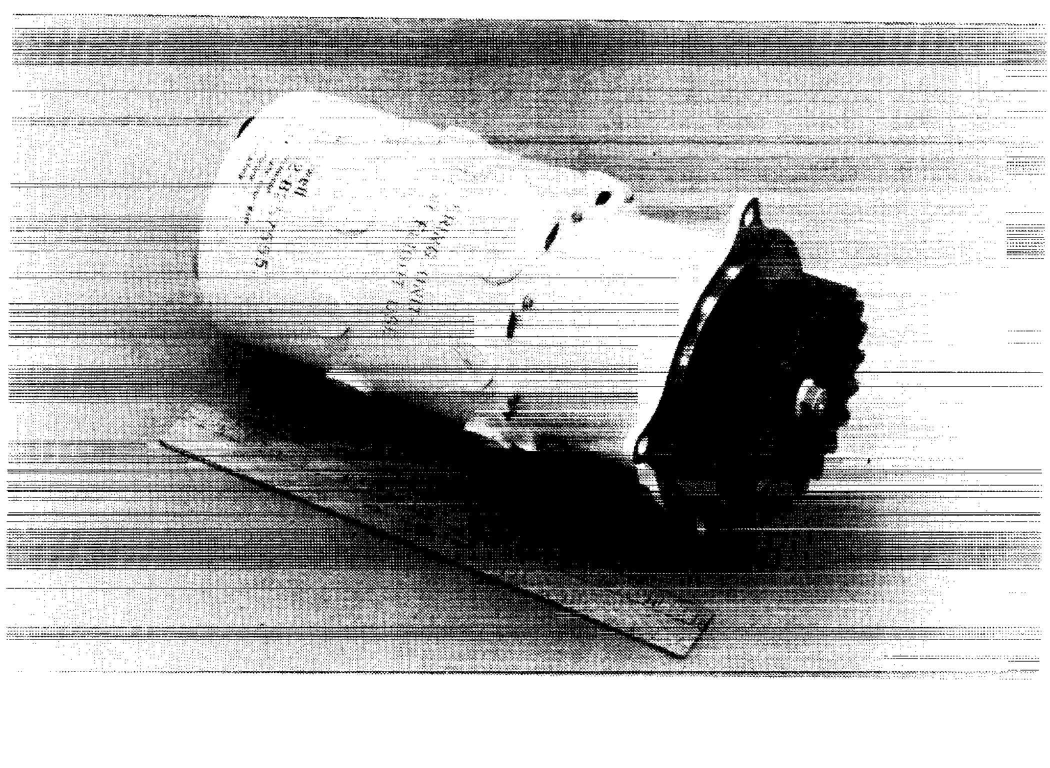


Figure 5. DMA

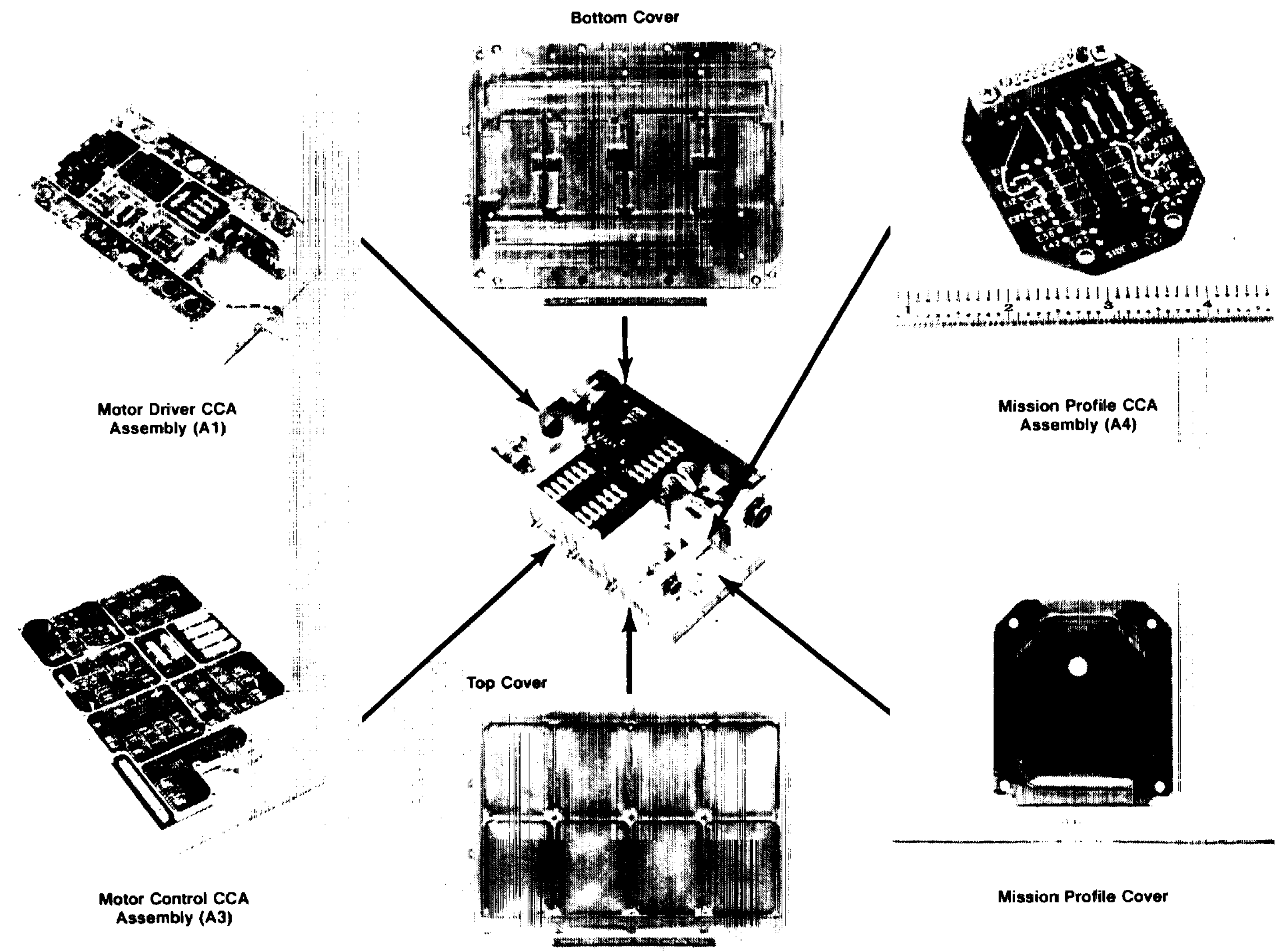

Bottom Cover
Motor Driver CCA
Assembly (A1)
Mission Profile CCA
Assembly (A4)
Motor Control CCA
Assembly (A3)
Top Cover
Mission Profile Cover

Figure 6. SEA

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BLACK AND WHITE PHOTOGRAPH

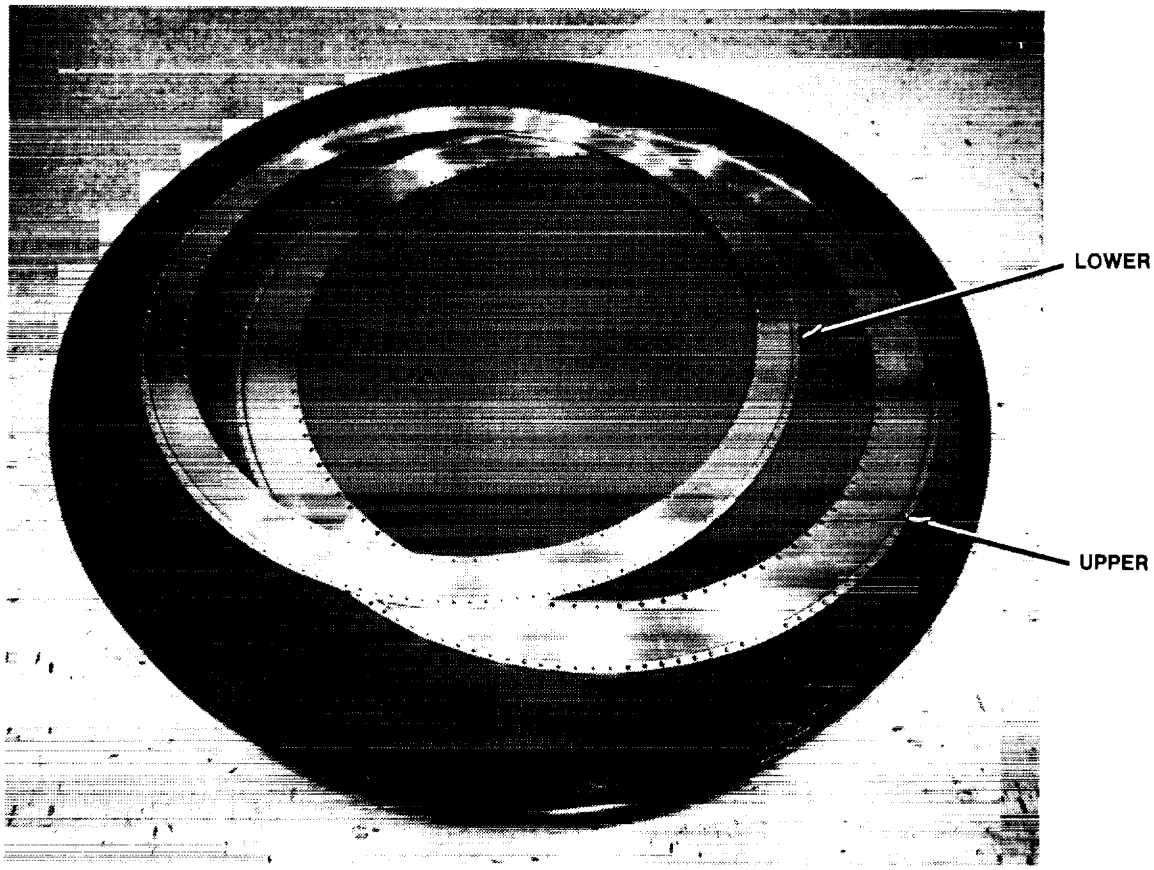

Figure 7. Off-Load Spring

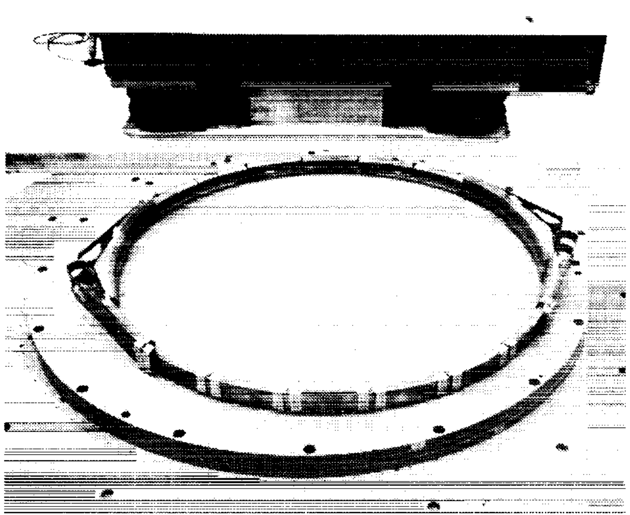

Figure 8. Spin Release V-Band

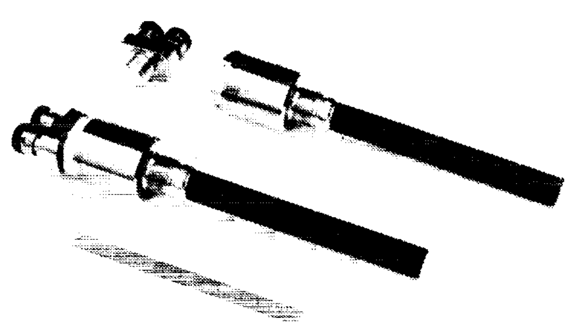

Figure 9. Separation Bolt and Pressure Cartridge

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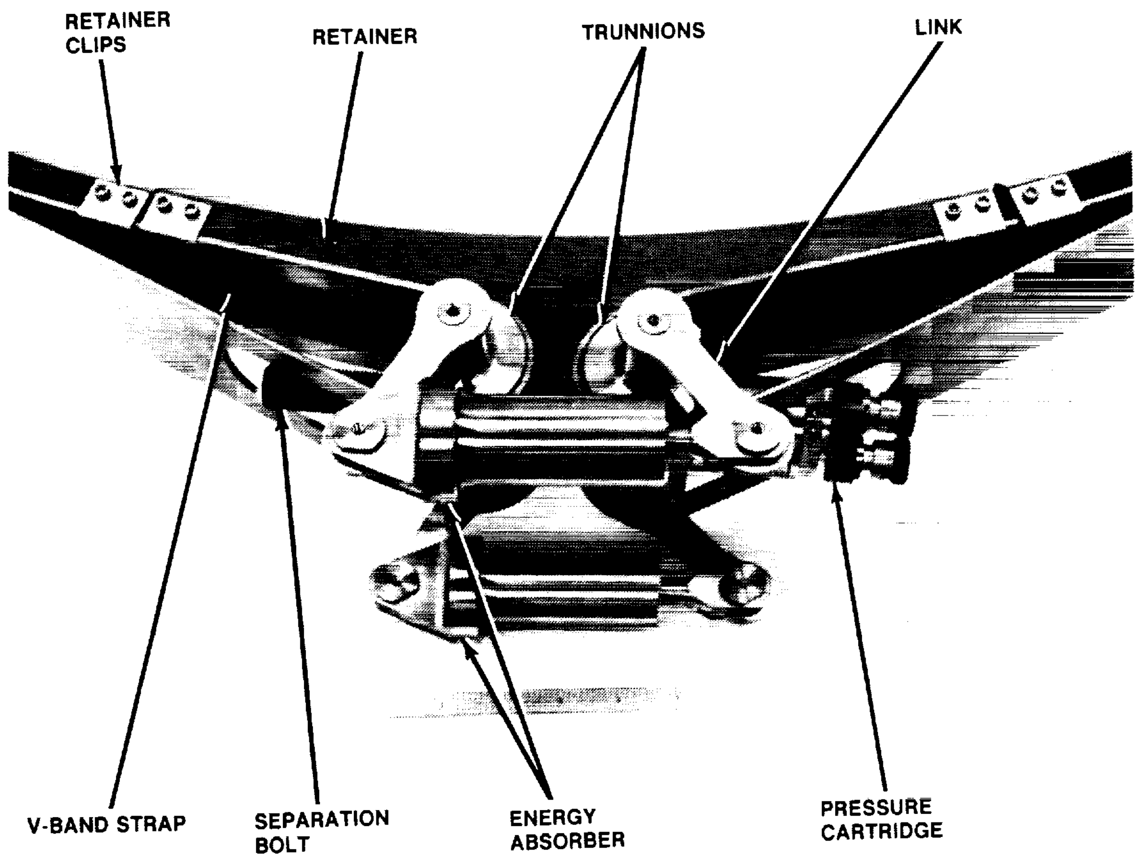

Figure 10. V-Band Energy Absorber Before Release

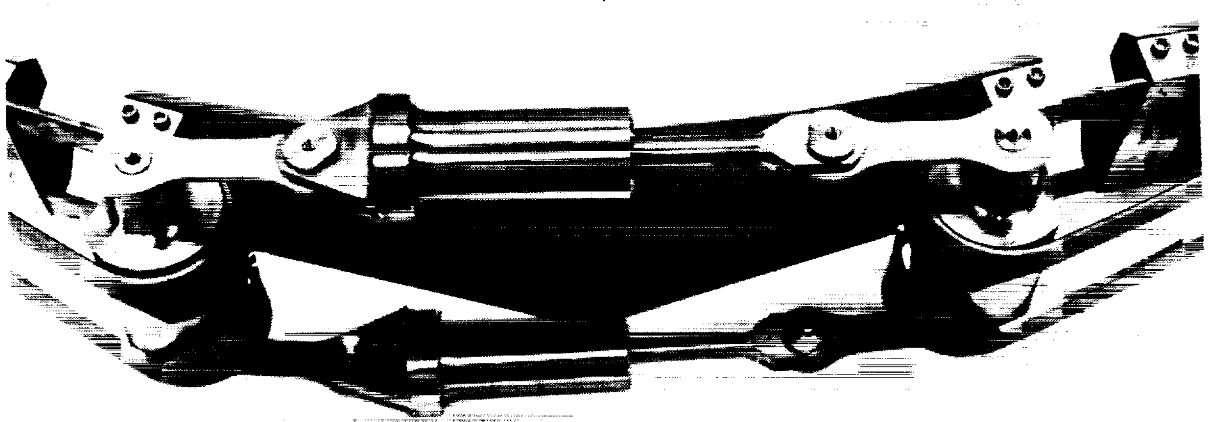

Figure 11. V-Band Energy Absorber After Release

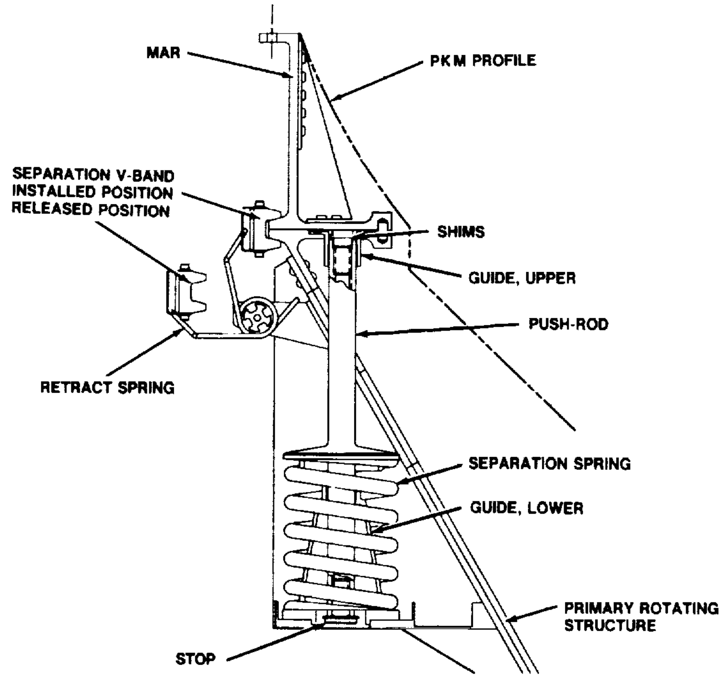

Figure 12. Separation Spring

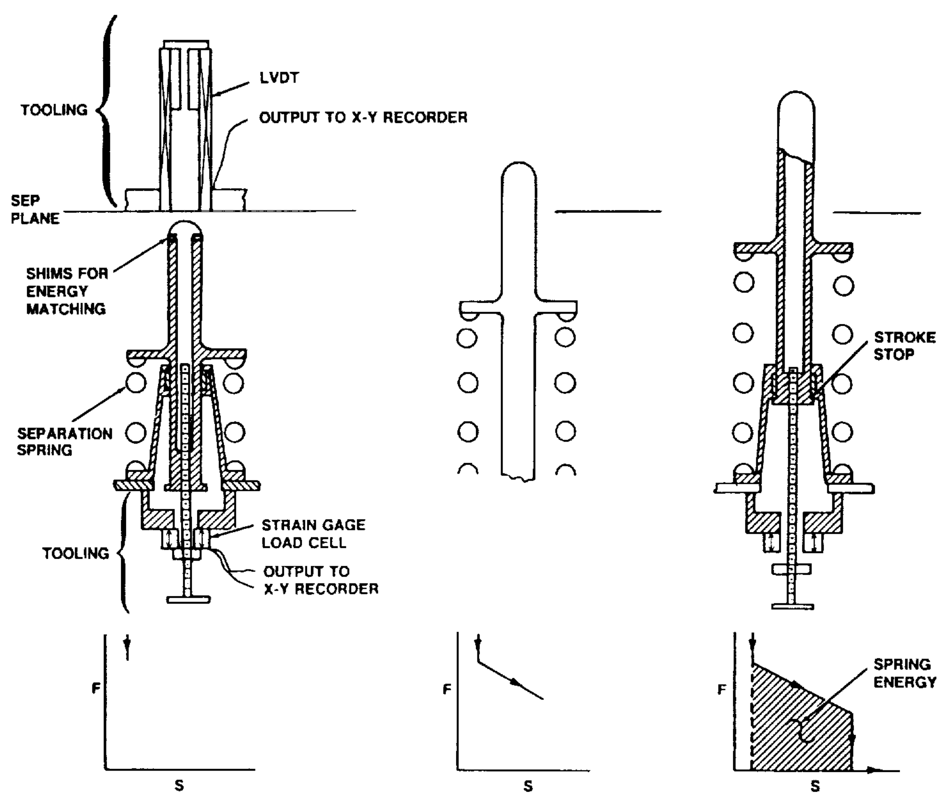

Figure 13. Separation Spring Energy Measurement

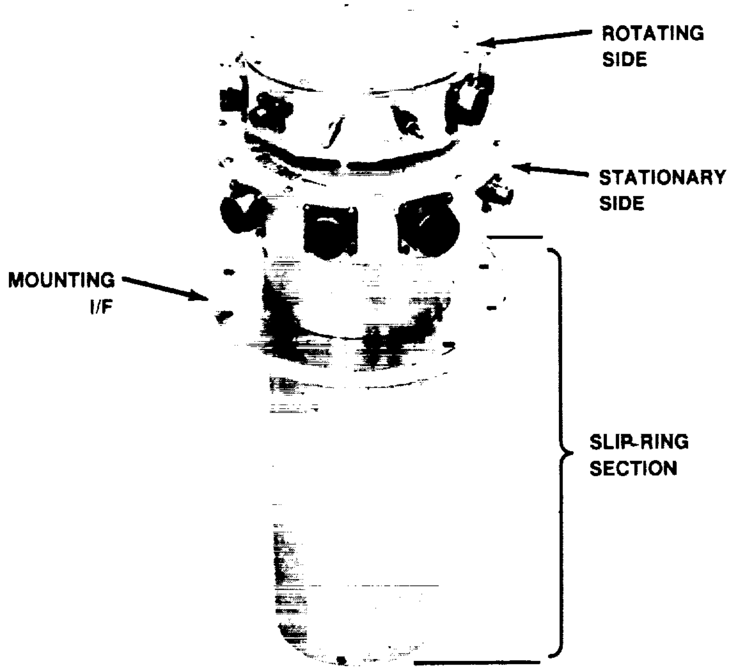

Figure 14. Slip-Ring Assembly

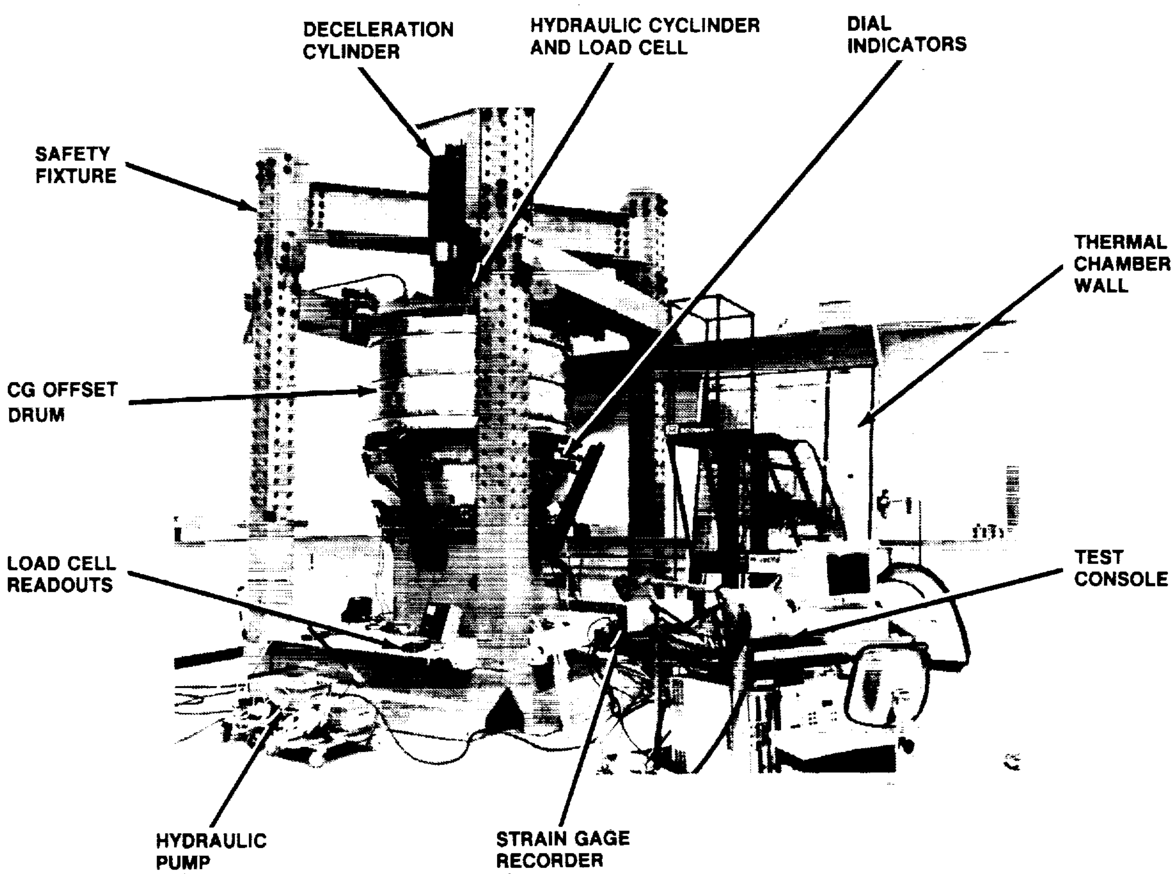

Figure 15. Test Equipment