N87-29873

# PASSIVE ISOLATION/DAMPING SYSTEM FOR THE HUBBLE SPACE TELESCOPE REACTION WHEELS

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## ABSTRACT

NASA's Hubble Space Telescope contains large, diffraction-limited optics with extraordinary resolution and performance far surpassing existing observatories. The need to reduce structural-borne vibration and resultant optical jitter from critical Pointing Control System components - Reaction Wheels - prompted the feasibility investigation and eventual development of a passive isolation system. Alternative design concepts considered were required to meet a host of stringent specifications and pass rigid tests to be successfully verified and integrated into the already-built flight vehicle. The final design employs multiple arrays of fluid-damped springs that attenuate over a wide spectrum, while confining newly-introduced resonances to benign regions of vehicle dynamic response. Overall jitter improvement of roughly a factor of 2 to 3 is attained with this system.

This paper presents the basis, evolution, and performance of the isolation system, specifically discussing design concepts considered, optimization studies, development lessons learned, innovative features, and analytical and ground test verified results. This predictable, readily adaptable mechanism is particularly suitable for application to sources requiring specialized vibration isolation to improve sensor and/or instrumentation pointing stability.

## INTRODUCTION

The Hubble Space Telescope (HST) is a large, unmanned, versatile, free-flying, long-life telescope/spacecraft system developed for NASA (Fig. 1). Planned for Space Shuttle launch from Kennedy Space Center, its performance is centered near the visible portion (4000 to 7000 Å) of the electromagnetic spectrum, although it has a broad uninterrupted spectral range (Fig. 2). It will provide astronomers with data of a quality and quantity that greatly exceeds existing earth-based systems. Placed in a circular low-earth orbit, it will experience at least a 15 year service life, providing enhanced observations that are expected to be some of the most significant in the history of astronomy. The HST spacecraft is characterized by: (1) extremely high stability and pointing accuracy, (2) long-term thermal control and optical system alignment, (3) sophisticated onboard data processing to facilitate flexible multipupose tasks, and (4) very long service life due to Space Shuttle support and capabilities for orbital maintenance and servicing by astronaut crews.

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The diffraction-limited optical system resolution dictates very formidable pointing accuracy and stability requirements; 0.007 arc-sec RMS on single exposure times from 10 seconds (bright sources) to up to 24 hours on faintest targets. Efforts have been continually expended during HST development to control structural-borne vibration caused by operation of electro-mechanical onboard devices that perturb optical elements or sensitive detectors. Onboard systems are largely designed and built near the limits of conventional, proven state-of-the-art technology. Hardware modifications that show potential to achieve significant improvements in pointing performance or prevent eventual degradation are high priority items for further investigations, particularly reductions in Reaction Wheel Assembly (RWA) vibrations.

## Pointing Control System Description

The HST has the most stringent pointing requirements imposed on any spacecraft to date: overall stability during science taking shall not exceed 0.007 arc-seconds RMS. This objective is met by using precision sensors and actuators, all with redundant backup systems. The Pointing Control System (PCS) provides a capability for autonomous maneuvers, target acquisition, and fine pointing based on time-tagged stored program commands, as well as the ability to accept real-time interactive commands from the ground control station. Control for maneuvering and maintaining precise pointing is achieved by onboard digital computer processing of attitude and rate sensor inputs. Gyro assemblies provide angular rate data which is supplemented by attitude data from a user-selectable combination of NASA-standard fixed-head star trackers and Fine Guidance Sensors (FGS's). The FGS's use photomultiplier tubes in an interferometric mode to provide a precise attitude reference on selected guide stars located within the optical system field of view. A momentum management system is used with database and sensor data inputs analyzing orbital magnetic fields to command four magnetic torquers that desaturate and minimize excess RWA momentum. The system also provides control capability for critical orbital phases involving operations close to the Space Shuttle. A diagram of the PCS is shown in Fig. 3.

## Line-of-Sight Jitter

With such tight pointing requirements, reduction of even small amounts of vibration that might interfere with PCS performance is critical for HST objectives. This is especially true for RWA's which operate continuously, and for which no operational workarounds exist to counter debilitating vibrations. The PCS stability error requirement combines all motions of the target star at the optical system focal point with respect to attitude sensor(s). Additional errors are due to internal control system sources, disturbance torques and forces internal to the spacecraft, and external or environmental torques and forces. Jitter error budgets are arranged in categories of error generating sources characterized by frequency of disturbance.

These categories are (1) "Random," consisting of line-of-sight (LOS) jitter contributions due to detector photon noise and gyro electrical noise; (2) "Fast Sine," including electromechanical device vibrations such as those emanating from tape recorders, movable antennas, solar array drives, and Reaction Wheels; (3) "Slow Sine," including longer term cyclic effects with periods from many seconds to minutes; and (4) "Exponential," which are thermal-mechanical deformations in more massive structural elements caused by significant changes in spacecraft thermal conditions during large attitude maneuvers or earth eclipse. Only the Reaction Wheels and the High Gain Antenna (HGA) dishes are planned to operate continuously during science taking, and thus require special attention to limit their induced jitter. Also, infrequent short-term disturbance phenomenon such as Reaction Wheel stimulation of structural-optical resonances have to be fully accounted for rather than averaging them out over long sample times. Figure 4 shows graphical representations of various error producing sources as functions of time. RWA Induced-Vibration (I-V) test results were put into jitter analyses in 1982 (Fig. 5), and indicated that the RWA's could, under certain conditions, individually exceed error budget allocations for all four RWA's together. This, coupled with some uncertainties present in the analyses, prompted exploratory study of alternatives for reducing RWA vibration (Fig. 6). Key study goals for promising alternatives were:

- Significant (target factor of 2) reduction of overall RWA jitter in speed range needed for fine pointing (0 to 1200 RPM), by reducing primarily high-frequency axial direction vibrations;
- Small impact for integration into existing vehicle hardware;
- Capable of full flight certification within limited schedule;
- Noninterference with PCS system configuration and performance.

## HST REACTION WHEEL ASSEMBLIES

### General Description

The four RWA's (Fig. 7) are the constantly operating and torque producing components critical to the PCS. They are sized to encompass both the maximum torque needed for target-to-target maneuvering and the small precise control torques required during fine pointing. An RWA is similar in design and operating principle to Control Moment Gyro's (CMG's) except that RWA's are mounted in distinct orientations, rather than being gimballed. They alter overall vehicle angular momentum by combined variations in their individual rotational speeds produced in response to PCS computed commands. They are basically electrically driven flywheels and nominally slowly sweep their speeds to counteract small vehicle disturbance torques (primarily aerodynamic drag and gravity gradient torques). Their constant operation produces minute structural-borne sinusoidal vibrations which must be controlled with very tight criteria. Key design goals for minimizing RWA mechanical vibration output noise are: (1) extremely precise dynamic balancing of the rotor-bearing assembly, and (2) state-of-the-art mechanical bearing manufacture, quality control and selection process.

RWA's are grouped in pairs, and located in box-like bays in HST's Support Systems Module (Fig. 8). Each RWA outwardly resembles a flying-saucer-shaped oblate spheroid. Spin axes are skewed +/-20 degrees from the plane normal to the HST optical axis and pairs are 90 degrees apart. Underlying mounting structures are at the heart of the HST primary load bearing structure and are hence very stiff.

## Vibration Characteristics and Optical Jitter Impact

When powered and rotating, each RWA emits mechanical vibrations parallel to its spin axis and in directions radially outward in its equatorial rotational plane. The generation of these force and moment disturbances are caused by combinations of: (1) motor ripple/cogging, (2) electronic and resolver imbalance, and (3) rotor-bearing mechanical unbalance/geometry error. These vibrations eminate at the rotor rotational frequency and at other set harmonic ratios of rotational speed (e.g. 2.0, 2.8, 4.0, 5.2). These harmonic ratios are caused by minute bearing alignment and surface irregularities (specifically rotor imbalances, bearing raceway and ball geometric imperfections, and ball-retainer interaction). The precise ratios all have their basis in consistant physical parameters of the bearing-rotor assembly, and have been empirically verified by Induced Vibration (I-V) testing (Fig. 5). Any isolation or attenuation scheme must be capable of addressing the entire range of harmonics as well as the primary unbalance harmonic (1.0). Early RWA induced jitter analyses indicated that key harmonics that create the most deleterious optical system jitter were mid-ratios (primarily 2.8 and 5.2) producing vibratory motion along the RWA spin axes (Fig. 5), so these are the characteristics targeted for reduction.

## Basis for Isolation System Development

As stated, jitter analyses in 1982 were displaying a worrisome increasing trend in RWA induced jitter. Certain concerns were raised about uncertainties in the analyses and applicability of the RWA disturbance level input data (Fig. 6). Additionally, the operational nature of the RWA's - continuous sweeping with no workarounds - caused high priority efforts to be expended to study alternatives (Fig. 6). A list of preliminary requirements (Fig. 9) was created to serve as a starting point for surveying existing damping devices, and assessing basic feasibility/viability. This initial exploration of existing damping device capabilities and manufacturer's experience led to a development program. Some major concerns were: (1) dynamic performance at such low throughput load levels, (2) obtaining target ratios of lateral to axial stiffness, (3) control of large excursions under launch conditions without harming the RWA's, and (4) placement of new isolator resonances.

## ISOLATION SYSTEM DEVELOPMENT

### Development Program and Evolution of Preferred Design

The development program consisted of three phases which combined analysis and test data to adequately resolve areas of concern:

- Phase I- proof-of-concept prototype unit development and tests (to demonstrate that alternative concepts exhibit acceptable stiffness and damping at small force/displacement levels);
- Phase II- flight-like engineering/qualification unit development and testing (to establish confidence in the candidate isolator design's ability to meet or exceed all flight requirements);
- Phase III- flight unit buildup, test, and certification (to verify that final as-built devices meet all requirements and are acceptable for final installation/integration into the HST).

Each phase required sufficient indication that the proposed system could be made to meet the final stringent flight specifications to proceed. Feasibility/optimization analyses were performed at LMSC to help establish specification of key isolator dynamic parameters (Fig. 10). Specifications and qualification/acceptance test plans for procuring and testing prototype units were prepared and requests for proposals were transmitted to manufacturers of commercial damping products. The strong inclination for off-the-shelf or modified commercial designs was driven by the extremely tight timetable then available. After review of the refined specifications and schedule, candidate prototypes were produced for evaluation. Relaxation in schedules prompted Sperry to also propose and test a concept (Fig. 11). After evaluation, the Sperry concept was chosen for further development.

### Subsystem Tests

A thorough series of tests (Fig. 12) was performed, and the Sperry concept was chosen for a flight unit build. I-V tests were conducted using an RWA, and output forces and moments were recorded. Results showed that the device functions as second-order spring-damper system (Fig. 13). As an added benefit, the isolators reduced vibration exposure for RWA's (Fig. 14).

## Isolation System and Device Description

The isolator system was designed to attenuate disturbances while maintaining support stiffness. An important requirement is that the isolation system appear transparent to the PCS. The central element is basically a viscous fluid damped coil spring suspension system shown in Fig. 15. This design configuration provides a dual-acting, multi-directional isolation system for controlling displacements of the RWA's. A three unit set suspends each RWA (Fig. 16). Stiffness is provided by steel springs sandwiched between the central washer-like piston support plate and the retainers. Damping is provided by a low volatility silicone-based fluid (Dow Corning 200 series), confined by metal bellows to internal cavities. Spin axis direction energy dissipation (damping) is provided, and is generated by differential motion. The degree of damping is very deterministic for axial motion, while radial damping has proven to be less deterministic. In both axial and radial cases, damping has been demonstrated to be remarkably independent of the motion amplitude. Fig. 17 shows axial and radial direction transfer function curves for small displacements. The configuration of the design effectively fixes the internal fluid volume as far as dynamic motion is concerned. Volumetric change is also provided to accommodate temperature induced expansion. The outer shell/housing provides protection of inner components and a labyrinth seal. Also, this design provides electrical grounding through the isolators and incorporates features that enhance safety for nearby space-suited astronauts during orbital maintenance activities.

## FULL VEHICLE GROUND TESTS

The four sets (consisting of 3 isolator units each) of flight qualified/accepted isolators were installed with their corresponding complement of RWA's on the assembled HST vehicle (Fig. 18). This was accomplished at the LMSC facilities in Sunnyvale, CA prior to scheduled system jitter performance/modal testing. The HST vehicle was suspended vertically by cables from an array of three air bags. This nearly complete vehicle was instrumented with sensitive accelerometers, and perturbed with shakers and onboard equipment to simulate actual orbital operations and predicted situations.

The performance/modal test consisted of four segments:

- Line-of-Sight (LOS) Transfer Function Test, using shakers to induce sufficient force levels to verify optical system response;
- Jitter Performance Test, measuring small optical component motions to compute overall system jitter;
- Modal Survey, to locate and characterize basic structural mode shapes, frequencies, and damping for finite element models;
- PCS Transfer Function Test, measuring response and thereby check amounts of structural feedback.

Example results from this last test are displayed in Fig. 19, and help confirm the pretest predicted isolator performance in the full vehicle. Measured dynamic responses of isolator related modes agreed well with results from finite element models. However, early LOS Transfer Function Test data produced results showing that some RWA isolators may be "bottomed" in the ground test configuration. Tests were devised to statically check isolation system clearances. The reduced Transfer Function test results showed an isolation mode at 19 Hz, with confirmation data from another transducer device agreeing within 10%. A review of PCS stability analyses found that the presence of the measured isolator dynamics in the PCS loop is acceptably stable (Fig. 20). Perhaps the most dramatic illustration of the isolator system effectiveness at minimizing or eliminating high-frequency vibrations is shown in Fig. 21, which is the axial direction I-V plot of the RWA sweeping from 0 to 3000 RPM with the spectral analyzer set to record the peak response.

## ORBITAL PERFORMANCE PREDICTIONS

Based on ground test results (I-V tests) on the four flight RWA's, output forces and moments are known as a function of RWA rotational speed and can be input to HST structural dynamic math models. Figure 22 shows results of a jitter analysis in which the test-verified RWA outputs are introduced directly into the stiff mounting structure model (i.e. no isolation) with the response computed at the focal plane of the Optical Telescope Assembly (OTA). Figure 23 shows results from the same input, but with the dynamic model altered to duplicate each RWA's isolation system. The performance improvement of this critical HST parameter is evident, with average and peak jitter in the nominal RWA operating speed range of 0 to 10 Hz (0 to 600 RPM) typically decreasing by 55 and 70% respectively. The contingency RWA speed range of 0 to 20 Hz (0 to 1200 RPM) also benefits significantly with typical decreases in average and peak jitter of 60 and 75%. The ability to achieve this high level of improvement in a crucial HST performance parameter in such a short-term, cost-effective development program is the primary success of this effort.

## SUMMARY AND STATUS

A passive isolation system was successfully developed, built, verified, and integrated into the existing HST flight vehicle in a short timespan: 9 months from proof-of-concept proposal to flight hardware delivery for installation. The development program attained a significant improvement in a critical pointing stability performance parameter - RWA jitter - with a cost-effective solution, and the system is awaiting launch. The isolator design met or exceeded the numerous requirements/constraints imposed by the HST application. However, the isolator design is relatively compact and lends itself to readily predictable adaptation. It is suitable for a potentially wide range of situations and applications where the use of off-the-shelf or modified commercial isolators may not be satisfactory.

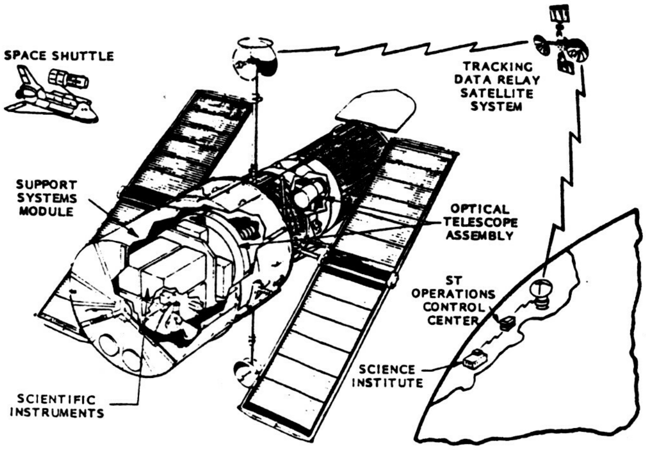
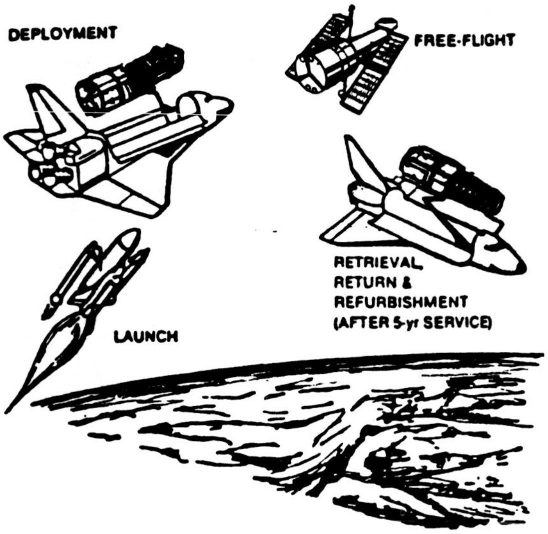


Figure 1. - Hubble Space Telescope - deployed and on station.



SCIENTIFIC CAPABILITIES
- PLANETS, STARS, GALAXIES, DIFFUSE MATTER
- ULTRAVIOLET, VISIBLE AND INFRARED
- DETECT OBJECTS 50 TIMES FAINTER THAN PRESENT
- OBSERVABLE VOLUME OF SPACE MORE THAN 350 TIMES GREATER THAN PRESENT
- 10 TIMES BETTER RESOLUTION THAN GROUND-BASED TELESCOPES
- IMAGING PHOTOMETRIC SPECTROSCOPY

CHARACTERISTICS
- 2.4 METER DIAMETER MIRROR
- RITCHEY-CHRETIEN TELESCOPE
- ACCOMMODATES 5 SCIENTIFIC INSTRUMENTS
- WEIGHT 25,000 LB
- SHUTTLE LAUNCHED
- IN-ORBIT MAINTENANCE AND UPDATE
- RECOVERY FOR REFURBISHMENT AND RELAUNCH
- LIFETIME - GREATER THAN DECADE
- INTERNATIONAL PARTICIPATION

ORBITAL PARAMETERS
- ALTITUDE - 390 TO 590 KILOMETERS
- INCLINATION ANGLE - 28.8°
- ORBITAL PERIOD ~94.5 MINUTES
- KSC LAUNCH SITE

Figure 2. - Hubble Space Telescope System description.

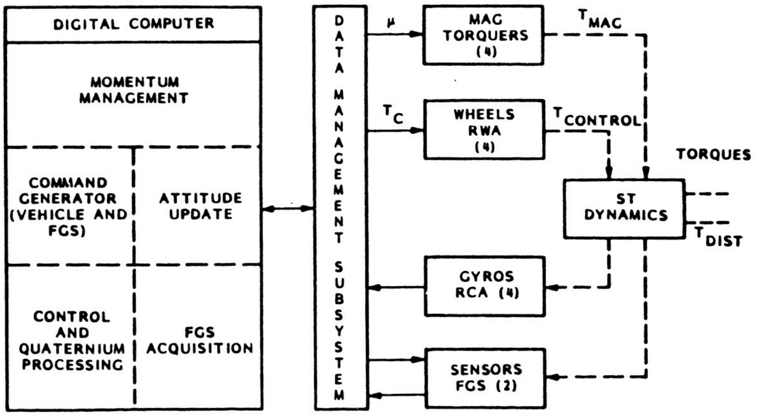


Figure 3. - Pointing Control System functional diagram.

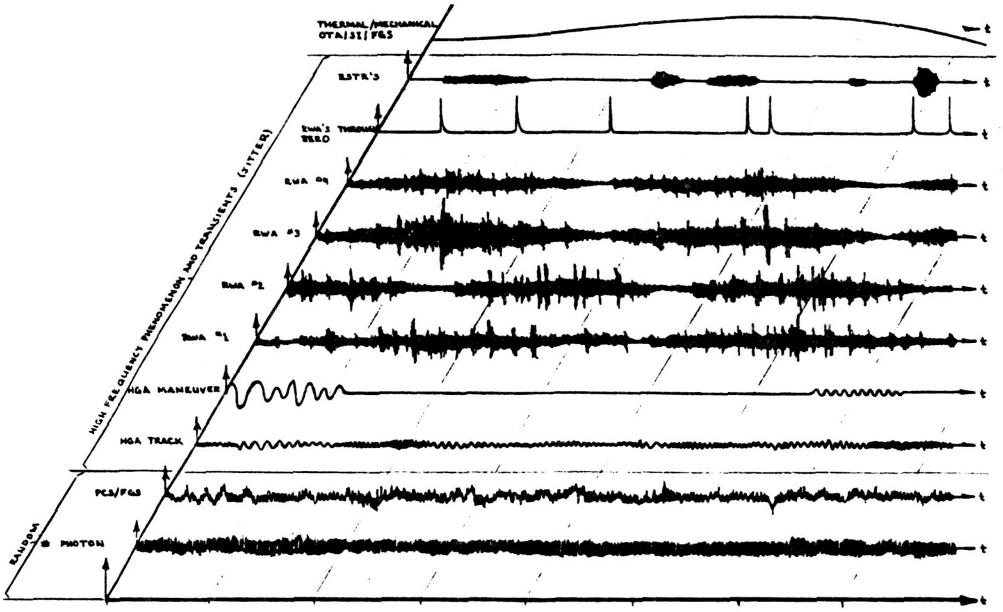


Figure 4. - Jitter categories sources, and characteristics.

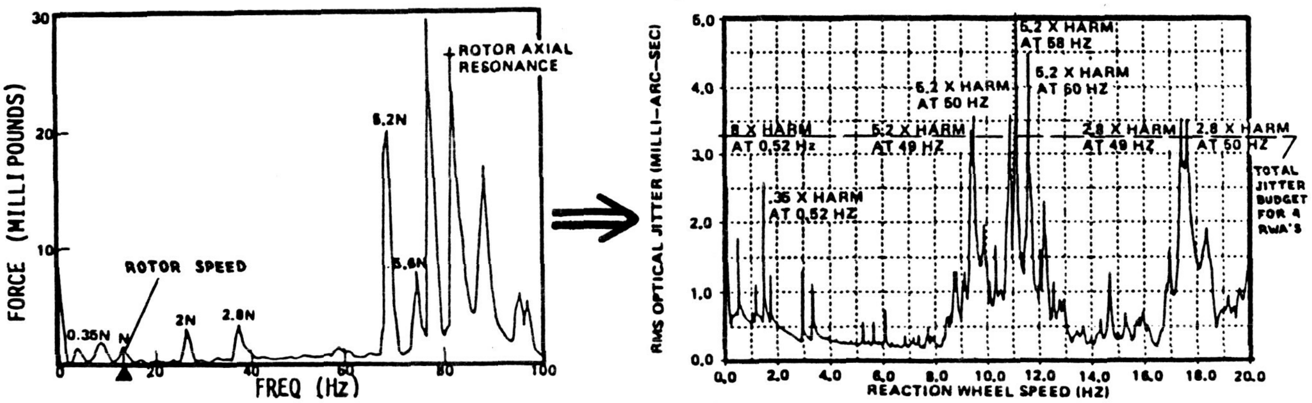
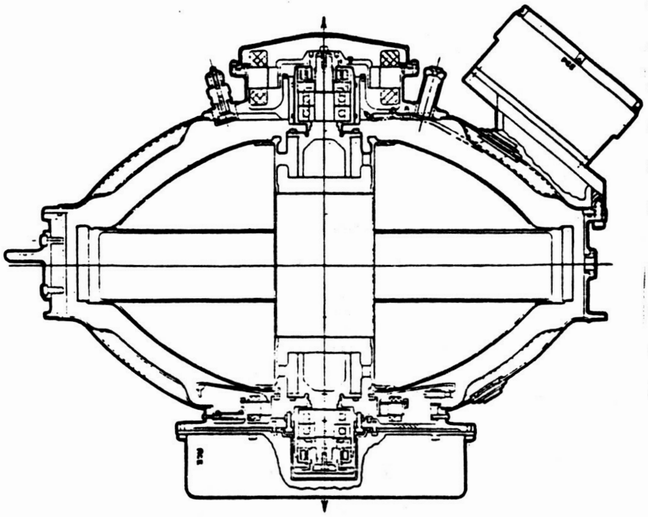


Figure 5. - Reaction Wheel Assembly Induced Vibration Test results and jitter.

| HARDMOUNTED ANALYSIS ISSUES/UNCERTAINTIES | POTENTIAL SOLUTIONS | REMARKS |
|---|---|---|
| ● ANALYSES SHOW SMALL MARGINS: INDIVIDUAL RWA JITTER CAN EXCEED FULL BUDGET UNDER CERTAIN CONDITIONS AND CIRCUMSTANCES<br>● ALTHOUGH FORCING FUNCTIONS ARE WELL KNOWN, DYNAMIC MODEL VERIFICATION PLAN IS NOT IDEAL AND OCCURS LATE IN PROGRAM<br>● UNCERTAINTIES EXIST CONCERNING THE REALISTIC EXTENT OF RWA OPERATING CONDITIONS THAT MAY BE ENCOUNTERED DURING HST ORBITAL LIFETIME<br>● ALTHOUGH RWA BEARING ASSEMBLY ROUGHNESS LIFE TESTS ARE ENCOURAGING, NO FULL "END-TO-END" LIFE-VIBRATION TESTS ARE PLANNED<br>● DYNAMIC MODELS LOSE FIDELITY AND ACCURACY OF JITTER PREDICTION FOR HIGH FREQUENCY JITTER | QUIETER RWA BEARINGS | EFFECTIVE BUT REACHED POINT OF GREAT EXPENSE AND DIMINISHING GAINS IN JITTER PERFORMANCE |
| | STRUCTURAL MODIFICATION OF HST TO ALTER MODAL RESPONSE CHARACTERISTICS | FEASIBILITY STUDIES INDICATE ONLY MINOR IMPROVEMENT FOR GREAT COST, SCHEDULE IMPACT & WEIGHT INCREASE |
| | INCREASE STRUCTURAL DAMPING BY APPLYING DAMPING MATERIAL TO STRUCTURE/EQUIPMENT | SMALL IMPROVEMENT; LARGE AMOUNT OF ELASTOMERIC MATERIAL REQUIRED IS UNACCEPTABLE FOR CONTAMINATION PREVENTION WITH ORBITAL CONDITIONS |
| | LOCALLY ISOLATE ALL RWA'S | PREFERED ALTERNATIVE IF OBSTACLES CAN BE OVERCOME; PROTECTS AGAINST POSSIBLE RWA LONG-TERM DEGRADATION |

Figure 6. - Basis for exploration of isolator alternative.



| | |
|---|---|
| • **TORQUE:** | **0.82 N-M** |
| • **MOMENTUM:** | **+/- 264 N-M-SEC** |
| • **BANDWIDTH:** | **50 Hz** |
| • **SIZE:** | **63 Cm DIA., 51 Cm HEIGHT** |
| • **WEIGHT:** | **467 N (105 Lb)** |
| • **POWER:** | **45 WATTS QUIESCENT, 400 WATTS PEAK (0.0 N-M AND 3000 RPM)** |
| • **DIGITAL INPUT:** | **+/- 0.82 Nm, SIGN + 11 BITS MAG.** |
| • **ANALOG INPUT:** | **-0.82 TO + 0.82 N-M (0-5 VDC)** |
| • **COMMANDS:** | **POWER ON/OFF, ANALOG ENABLE/DISABLE** |

| | | |
|---|---|---|
| **ANALOG:** | • **TORQUE COMMAND:** | **-0.7 TO +0.7 N-M** |
| | • **TEMP:** | **2 SPIN BRG., ELECTRONICS** |
| | • **MOTOR CURRENT:** | **+30 A (Max.)** |

DIGITAL: 16-BIT WHEEL SPEED PULSE TRAIN (640 PPR)

Figure 7. - Reaction Wheel Assembly cutaway and description.

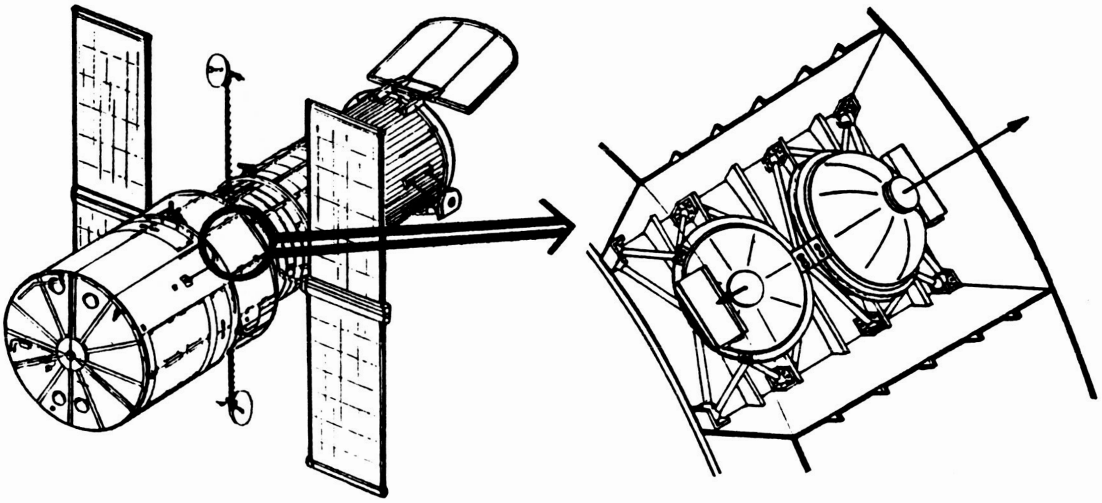


Figure 8. - Reaction Wheel location and mounting.

- ISOLATE AXIAL TRANSLATION: $F < 50$ Hz (ACTUAL
  $Q < 10$ VALUE TBD)
- NO EFFECT ON PCS TORQUE MODE: $F > 50$ Hz
  $Q$ = ANY
- TRANSMITTED FORCES – ON ORBIT 0.001 TO 0.10 LB
  0 TO 280 Hz
  – LIFTOFF 14G's X 102 LB X (8/6 OFFSET)
  = 1904 LB
- OPERATIONAL TEMPERATURE RANGE: 0 TO 100°F
- PHYSICAL SIZE PER UNIT: 2 X 1.5 X 7.5 INCHES
- LIFE: AT LEAST 3 YEARS ON ORBIT
- INTERFACE DEFINED FOR RWA TAB BOLT ON
- "NO" CONTAMINATION
- ORU COMPATIBLE: RECENT ADDED REQUIREMENT

Figure 9. - Preliminary isolation system requirements for development.

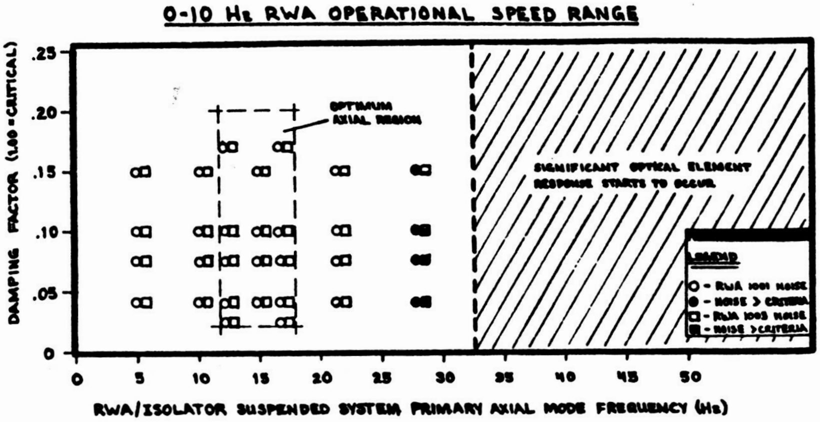


Figure 10. - Isolation system optimization study results.

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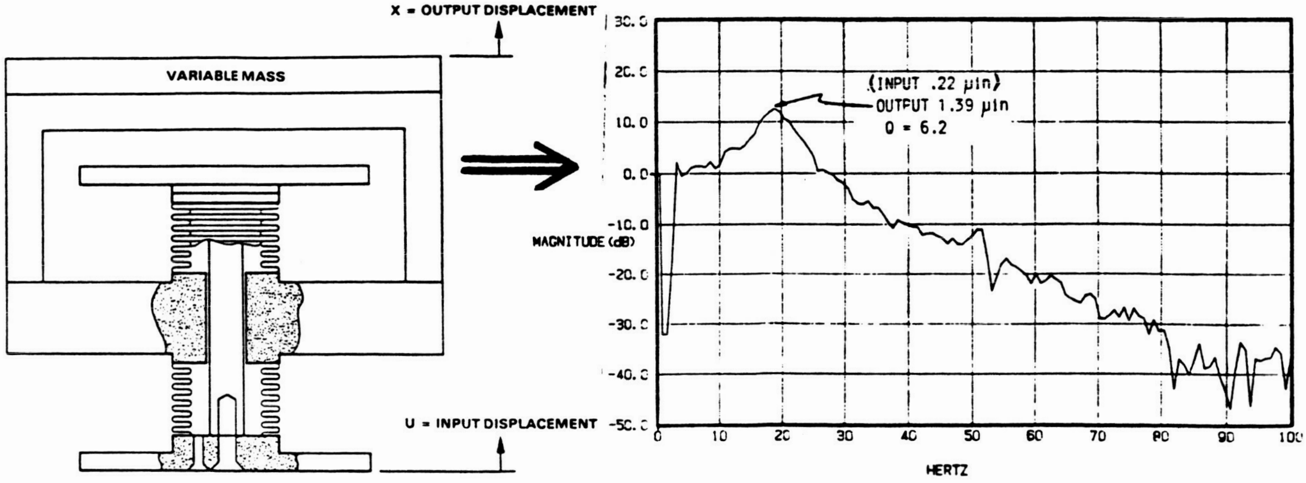


Figure 11. - Sperry's isolator concept and encouraging results.

- **PROTOTYPE PARAMETRIC INVESTIGATION**
  - **- DIMENSIONAL PARAMETER EFFECT ON DAMPING**
  - **- FLUID VISCOSITY EFFECT ON DAMPING**
  - **- LOW AND HIGH LEVEL STIFFNESS CHARACTERIZATION**
- **COMMAND TORQUE CHARACTERIZATION**
- **FATIQUE LIFE INVESTIGATION**
- **I-V TRANSFER FUNCTION AND PEAK ENVELOPE RWA SWEEP RUNUP**
- **THERMAL-VACUUM EXPOSURE**
- **I-V TRANSFER FUNCTION AND PEAK ENVELOPE RWA SWEEP RUNUP REPEAT**
- **HIGH LEVEL VIBRATION**
- **FINAL I-V TRANSFER FUNCTION AND PEAK ENVELOPE RWA SWEEP RUNUP**

Figure 12. - Engineering development and qualification tests.

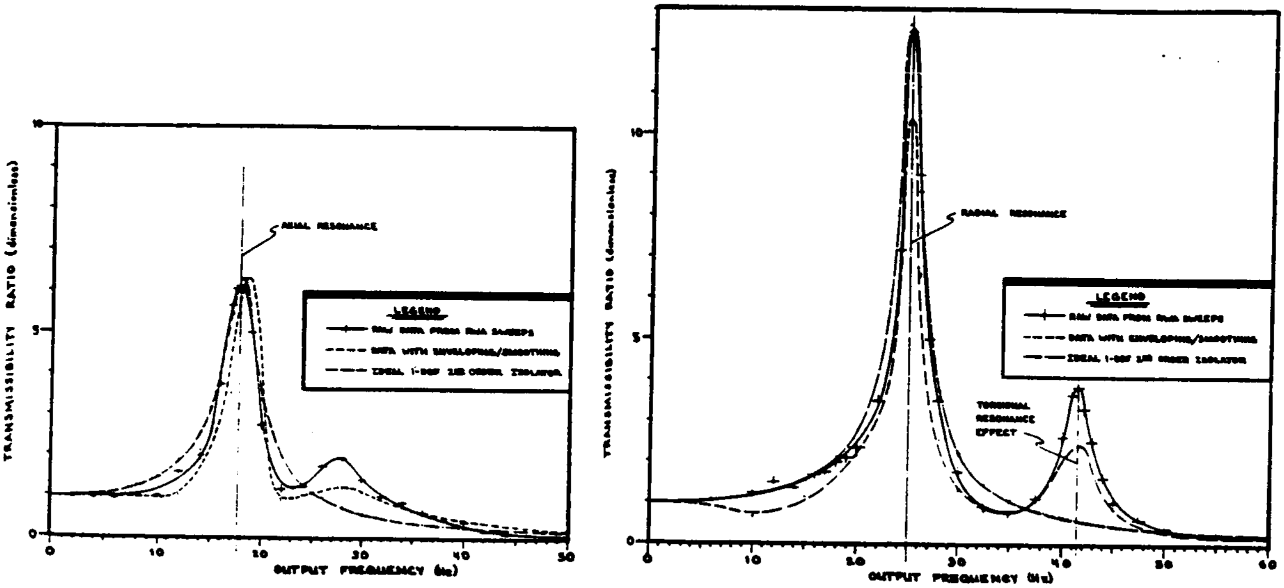


Figure 13. - Isolation system measured axial and radial response characteristics.

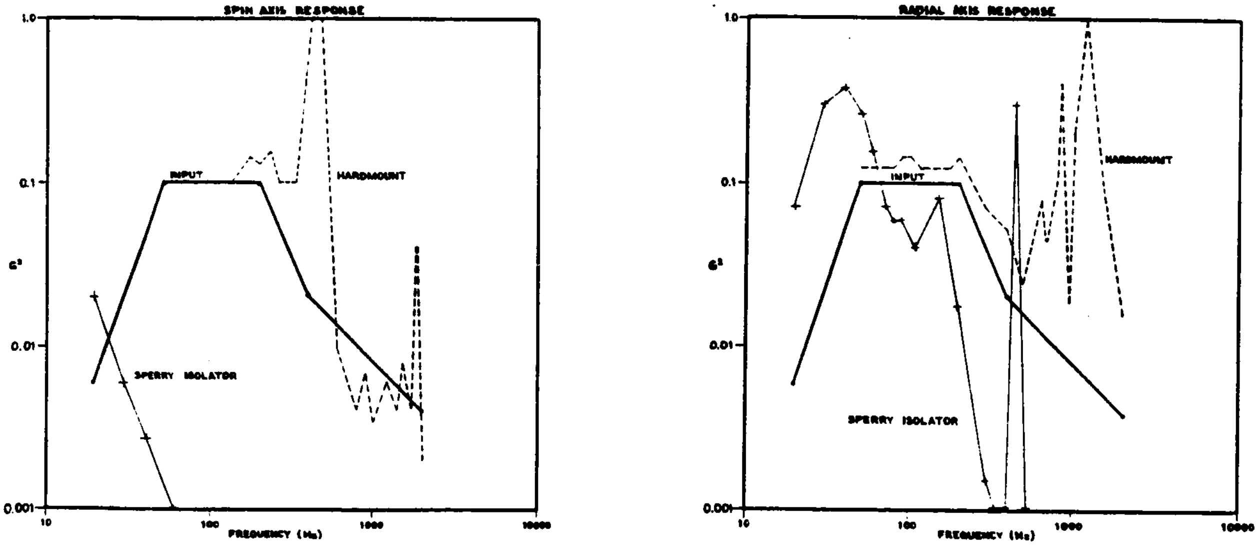


Figure 14. - Isolation attenuation of high-level axial and radial random vibration.

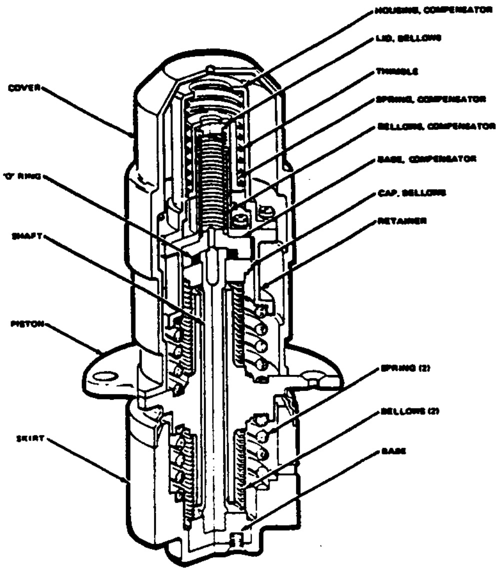
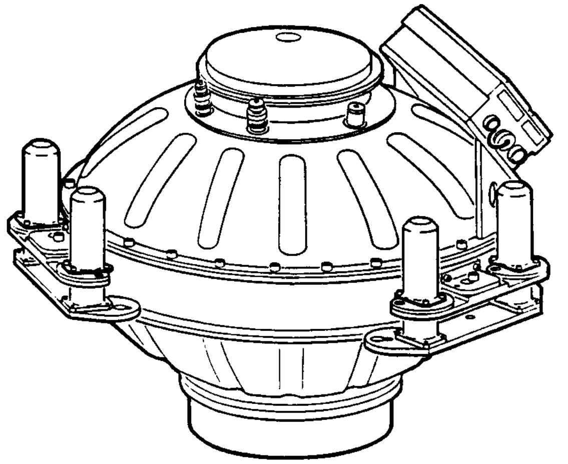


Figure 15. - Isolator spring-damper element cutaway.



| PARAMETER | REQUIREMENT |
|---|---|
| • AXIAL STIFFNESS | 670-910 LB/IN |
| • LATERAL STIFFNESS | 1380-1870 LB/IN |
| • AXIAL DAMPING | .170-.025<br>(Q - 3 TO 20) |
| • LATERAL DAMPING | .170 - .025<br>(Q - 3 TO 20) |
| • MEET DYNAMIC PROPERTIES WITH STATIC LOAD ON 3 UNITS -1G | 37.0 LB AXIAL<br>102.0 LB RADIAL |
| • ENVIRONMENT | TEMP: -20°F TO +120°F<br>PRESSURE: 810 to $10^{-13}$ TORR<br>ACCEL.: 9.2 g's FOR 1.5 min.<br>RANDOM VIB: 6.18 g (rms) OVERALL |
| • LIFE | UNIT: 2 YEARS GROUND<br>5 YEARS ORBITAL<br>DAMPING ELEMENT: 7 YEARS |
| • WEIGHT | 5.0 LBS MAX PER ISOLATOR |

Figure 16. - Full isolation system with Reaction Wheel and description.

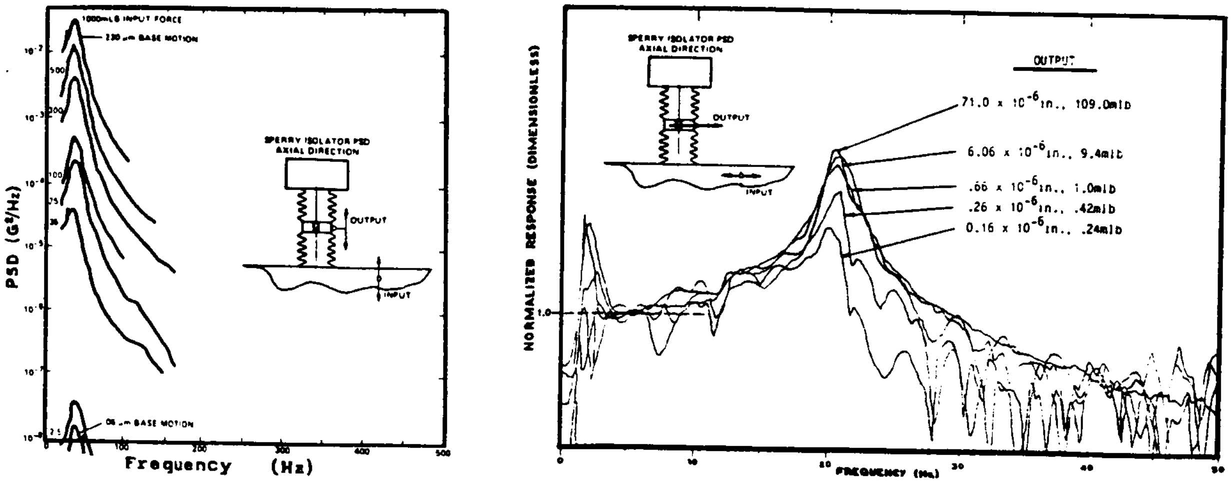


Figure 17. - Measured system axial and radial response at different levels.

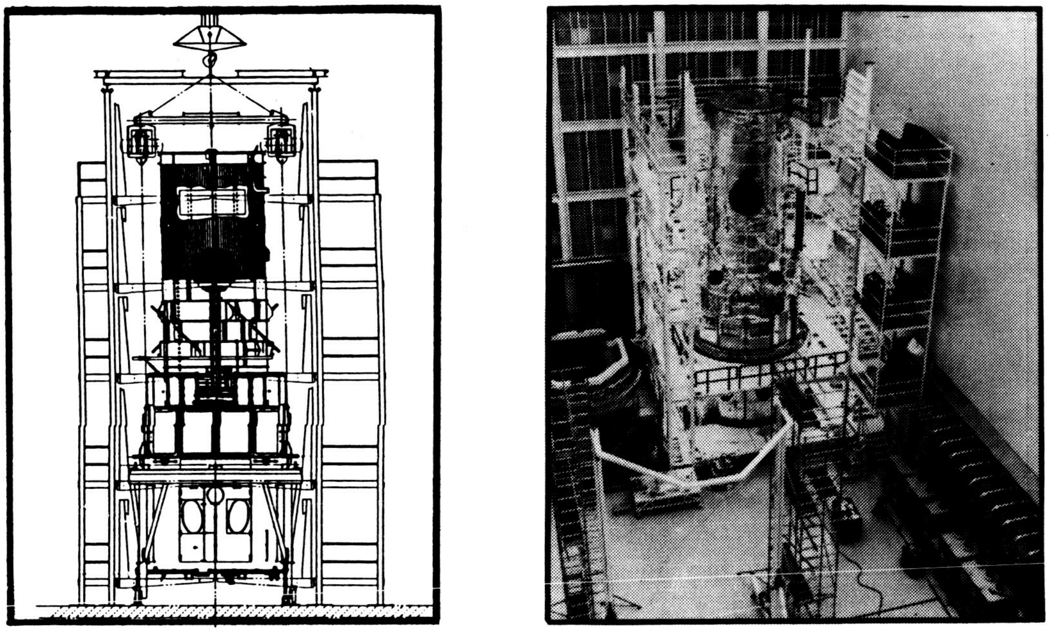


Figure 18. - Hubble Space Telescope in stand for ground vehicle tests.

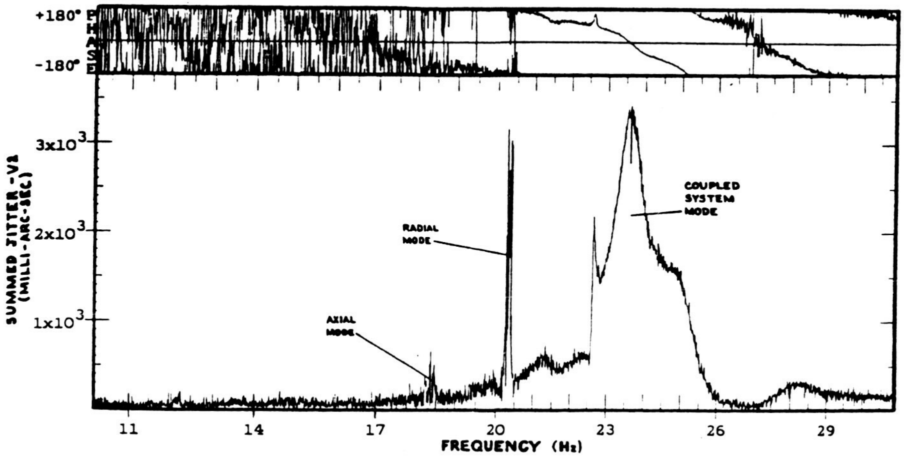


Figure 19. - Results from PCS Transfer Function test measuring LOS jitter.

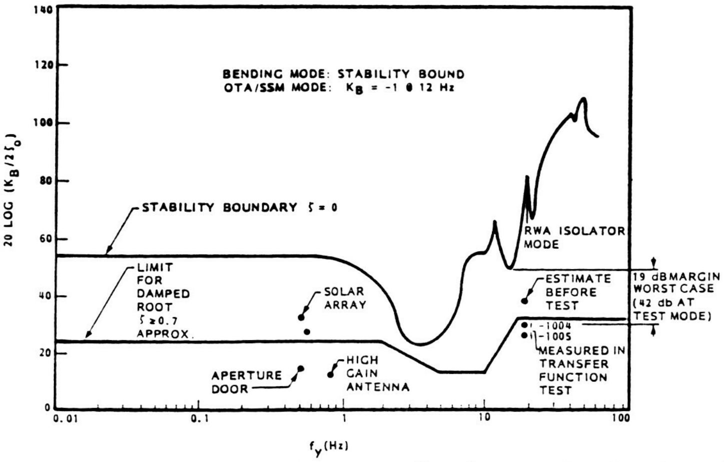


Figure 20. - Results from PCS stability analysis of isolation in PCS loop.

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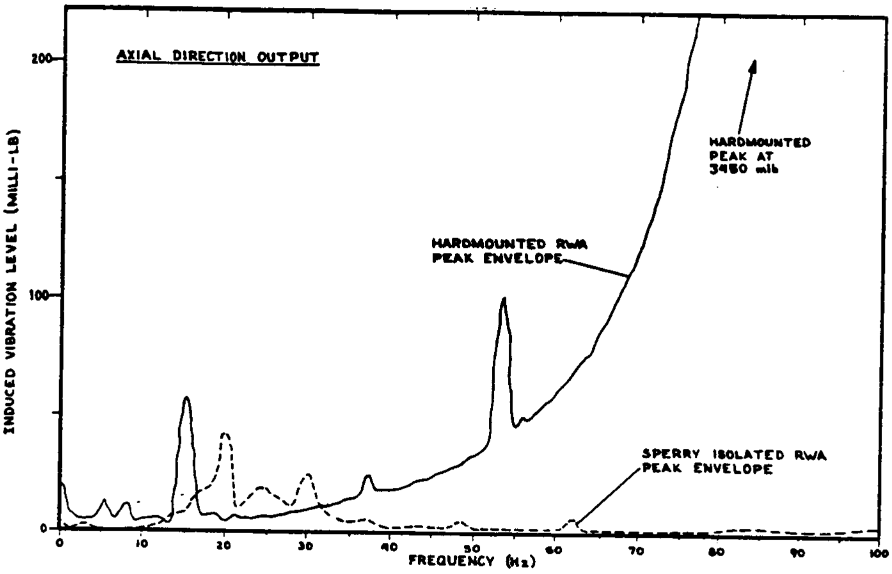

Figure 21. - Comparative peak envelope axial I-V: hardmounted and isolated RWA.

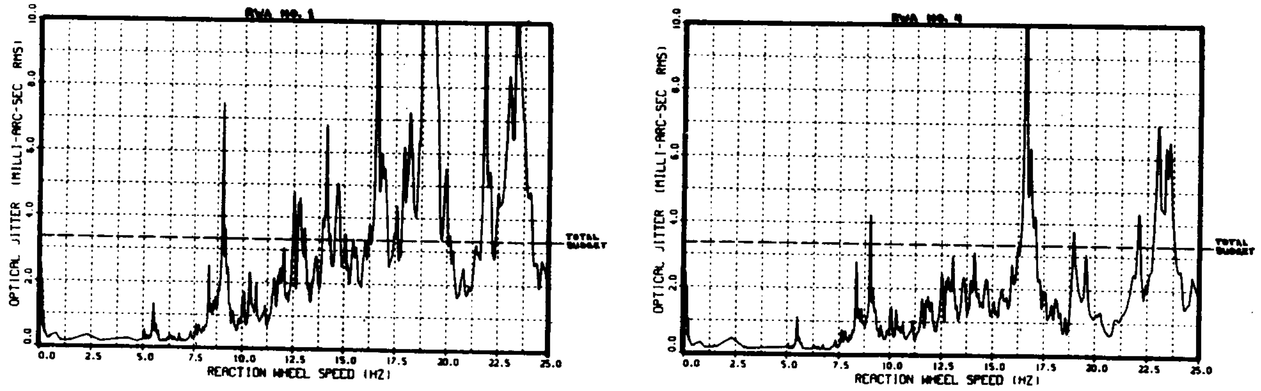

Figure 22. - Orbital LOS jitter analysis results for hardmounted RWA's.

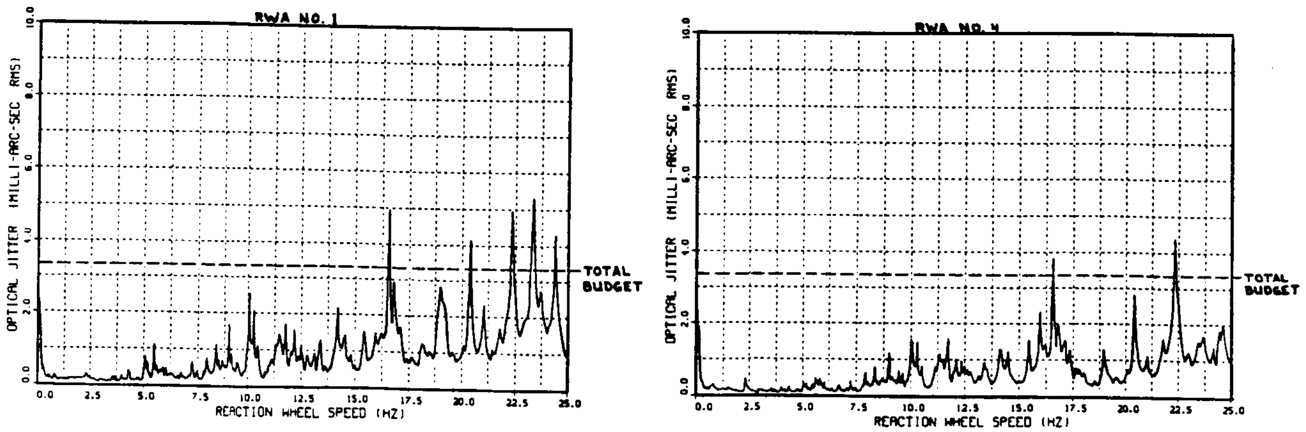

Figure 23. - Orbital LOS jitter analysis results for isolated RWA's.