ATTENUATION OF THE CASSINI SPACECRAFT VIBROACOUSTIC ENVIRONMENT

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ABSTRACT

Cassini is a robotic spacecraft currently under development at the Jet Propulsion Laboratory (JPL) whose interplanetary scientific mission is to explore Saturn, its rings, and its moons. Cassini is scheduled to launch on a Titan IV rocket with a Centaur upper stage booster, and will be protected during ascent through the atmosphere by a lightweight aluminum payload fairing (PLF). As a result of the extreme noise levels generated by the powerful Titan IV at liftoff, and the acoustic characteristics of the PLF, Cassini is predicted to experience severe acoustic levels. Furthermore, the high acoustic levels, coupled with the size and configuration of the spacecraft, will induce intense random vibration levels on the structure and critical spacecraft components. A study was performed to identify feasible approaches to attenuating the vibroacoustic environment. Two approaches were selected for development: (1) tuned vibration absorbers (TVAs) installed on the ringframes of the spacecraft shell structure, and (2) improved Titan IV PLF acoustic blankets. An extensive developmental test program was executed which included a series of acoustic tests on (1) a partial developmental test model (DTM) of the Cassini spacecraft (with and without TVAs), (2) the partial DTM enclosed in a full scale Titan IV PLF with standard acoustic blankets and with various blanket modifications, (3) the full-up Cassini DTM (without TVAs), and (4) a follow-up test of the Cassini DTM with flight-like spacecraft components replacing some of the mass mock-ups used on the full-up DTM. This paper will compare the results of the four acoustic test series. The effects of the random vibration reduction approaches and test article configuration differences are discussed.

KEYWORDS: *Cassini spacecraft, Titan IV payload fairing, acoustic blankets, damping, reverberant acoustic test, noise reduction, vibroacoustic environment*

INTRODUCTION

Cassini is a robotic spacecraft currently under development at the Jet Propulsion Laboratory (JPL) whose interplanetary scientific mission is to explore Saturn, its rings, and its moons in the early 21st century. Cassini (Figure 1), the largest robotic spacecraft ever assembled at JPL, is scheduled to launch in October 1997 from Kennedy Space Center (Cape Canaveral, FL) on board a Titan IV launch vehicle with a Centaur upper stage booster which are provided by Lockheed-Martin Astronautics (Denver, CO). The spacecraft is 7.0 m (22.8 ft) high and the diameter of the core shell structure is 1.3 m (4.2 ft). Cassini will be protected during ascent through the atmosphere by a lightweight aluminum 66-foot payload fairing (PLF) which is provided by McDonnell Douglas Space Systems (Huntington Beach, CA). The Cassini/Centaur/Titan IV PLF launch configuration is shown in Figure 2.

As a result of the extreme noise levels generated by the powerful Titan IV at liftoff, and the acoustic transparency of the PLF, Cassini is predicted to experience severe acoustic levels. The Cassini acoustic test criteria levels were derived from Titan IV flight data recorded during launches from Cape Canaveral [1]. The high acoustic levels, combined with the size and configuration of the spacecraft, will induce unusually high random vibration levels at some critical attached hardware components.

Special attention was given to spacecraft hardware mounted to the Lower Equipment Module (LEM). The Radioisotope Thermoelectric Generators (RTGs), which provide electrical power for the spacecraft, were identified as a concern since they ~~flew safely on Galileo and Ulysses,~~ ~~but~~ had not experienced vibration levels quite as high as those expected on Cassini. An investigation of potential noise and vibration reducing modifications was initiated, and included both spacecraft and PLF modifications to mitigate the environment.

Preliminary analyses performed with support provided by Roush Anatrol, Inc., indicated that the use of Tuned Vibration Absorbers (TVAs) would be effective in suppressing ring modes of the LEM. The TVA design involved a rigid mass attached to the base spacecraft structure through a viscoelastic material (VEM) spring/damper element. The TVAs were designed so that the natural frequency of the spring-mass system could be tuned to about 200 Hz. The TVAs then absorb vibrational energy when vibration of the spacecraft structure excites the TVAs into resonance. Additional damping was provided by shearing of the VEM. A typical TVA installation is shown in Figure 3. An early developmental acoustic test on a partial spacecraft was performed to investigate the effectiveness of prototype TVAs [2].

In addition to the Cassini spacecraft modification study at JPL, testing and analyses were performed by the Titan IV launch vehicle community to identify an improved design of acoustic blankets which could be used on the inside of the PLF to reduce liftoff acoustic levels. 'J'he blanket design effort included analytical predictions, flat panel acoustic noise absorption and transmission loss tests of various blanket designs, from which 5 inch (127 mm) and 6 inch (152 mm) thick blankets with limp barriers were identified as the best performing feasible designs. Finally a full scale PLF acoustic test with spacecraft simulator was performed in the Reverberant Acoustic Laboratory (RAL) at Lockheed-Martin Astronautics in Denver, CO with both the baseline 3 inch (76 mm) blankets and the 5 and 6 inch upgrades. Tbe test program was a cooperative effort between NASA Lewis Research Center, Lockheed-Martin Aerospace, McDonnell Douglas Space. Systems, Cambridge Collaborative, and JPL. The blanket design effort and the results of the PLF tests have been meticulously documented [3, 4, 5].

Two additional tests were performed at JPL on development test models of Cassini for the purposes of verifying the vibroacoustic environment. The Full-up DTM acoustic test included all the significant flight spacecraft structure, but employed mass/center of gravity mock-ups for most spacecraft components. The mass mock-ups for some critical components were replaced by engineering models or dynamic simulators for the Follow-up DTM test of the partial spacecraft. 'I'his paper provides a summary of the developmental acoustic test program, and comparison of the test results An assessment of the vibroacoustic environment for Cassini is discussed, including the effects of the random vibration reduction approaches and test article configuration differences.

ACOUSTIC TEST PROGRAM

To date, four acoustic test series using Cassini hardware have been completed with a common objective. of assessing/nlitigating the random vibration environment for the RTGs and other critical hardware. Special emphasis in the analyses, testing, and data evaluations were given to the 2.00 and 250 Hz 1/3rd octave bands. Titan IV flight data shows that the internal PLF acoustic levels peak in these two 1/3rd OBs, which is explained by the measured fairing ring frequency of about 250117. Also, the Cassini core structure has significant shell response modes in this frequency range. Finally, many of the critical spacecraft hardware components have significant resonances in tbc same frequency range.

Table 1 lists the spacecraft hardware components (and associated mass) which were present for each acoustic test program. In addition, all of the test article configurations, shown in Figures 4-7, differ from the flight spacecraft. The "Partial DTM" acoustic test at JPL (July-Aug. 1994) was performed at the original flight acceptance (FA) levels of 143 dB overall (OA). The "Partial-DTM/PLF" test at LMA (Jan. -Feb. 1995) was controlled to the maximum predicted fairing external acoustic level of 150.4 dB OA. After the improved blankets were baselined for Cassini, the data from the Partial DTM/PLF test was used to adjust the flight acoustic data to account for the presence of the improved blankets and subsequently revise the Cassini acoustic test criteria levels [6]. The "Full-up DTM" (Sept. 1995) and "Follow-up DTM" (Dec. 1995) acoustic tests at JPL were performed at the revised protoflight (PF) test level (with 4 dB margin over flight) of 145 dB OA. The acoustic test levels employed for "each test are compared in Figure 8. All test runs were performed for a duration of about 1 minute. In the following sections, the test objectives, test article configuration, and instrumentation are summarized for each of the four tests.

1. Cassini Partial DTM (JPL)

Test Objectives

The main objectives of the early Partial DTM acoustic test were to 1) evaluate the effectiveness of the prototype TVAs in reducing the LEM vibration around 200 Hz., and 2) assess the acoustically-induced random vibration environment for the RTGs.

Test Configuration

A photograph of the Cassini Partial DTM test article in the JPL acoustic is provided in Figure 4. The hardware present during this test is given in Table 1, and included a dynamically similar Component Evaluation Test (CET) model RTG in addition to two mass/CG models, Both 1.5 lb (0.68 kg) and 3.0 lb (1 .36 kg) TVAs were tested.

Sixteen TVAs were installed on the LEM and LVA forward rings (eight on each). These locations were selected primarily because they did not interfere with adjacent bardware, and provided a somewhat uniform distribution around the rings. To properly assess the performance of the. TVAs, tests were run on various configurations of the test article with and without the TVAS [2].

Instrumentation Summary

The Partial DTM spacecraft was instrumented with accelerometers at 45 locations, twelve triaxial force gages, and two response microphones. Most of' the accelerometers were triaxial, and a total of 96 acceleration measurements were recorded, In addition, eight microphones were utilized in the test chamber of which four provided feedback signal to the closed-loop servo control system, and (he remaining four were used [0 monitor the chamber sound pressure level. All data were recorded either on 14-track FM tape or by digital da(a acquisition system. All vibration data were reduced to narrowband (5 Hz BW) power spectral density values, and acoustic data were reduced to both narrowband PSD and 1/3 octave band (OB) sound pressure level (SPL).

II. Partial DTM/PLF Test (LMA, Denver)

Test Objectives

The primary test objective was to quantify the acoustic environment in the vicinity of the RTGs (PLF Zones 9 and 10 - see Figure 2) for three blanket designs, This was accomplished by the acoustic measurement system provided by Lockheed-Martin which was used to measure the noise reduction of the PLF when exchanging the baseline 3 inch thick acoustic blankets with the two improved barrier blanket designs selected from the flat panel tests, one. of 5 inch thickness and containing a heavy vinyl barrier, and the other 6 inch thick with a lighter barrier. The targeted frequencies were the 200 and 250 Hz 1/3 OBs and the goal was to obtain at least 3 dB improvement in noise reduction from the baseline in these two frequency bands in PLF Zones 9 and 10. This goal was to be achieved by increased blanket coverage and improved blanket design. The improved blankets were installed in Zones 8, 9, 10, and 11, Another primary objective of the test was to quantify the vibration response of the LEM to the PLF acoustic environment with baseline 3 inch and improved blankets. Testing was also performed with and without 3.0 lb (1.36 kg) TVAs. A secondary test objective was to acquire data for the validation of analytical models used to predict the internal acoustics, and the spacecraft anti PLF structure vibration.

Test Configuration

The Partial DTM/Titan IV PLF test article configuration is shown in Figure 5 with the aft cylinder of the PLF installed. This test included the same Cassini Partial DTM which was used in the previous JPL test. Styrofoanl/sheet metal volume simulators were added to the Partial DTM to complete the upper portion of the spacecraft simulator. The Partial DTM was supported by a structure representing the Centaur booster with a high-fidelity forward adapter to interface with the spacecraft. The support structure and Partial DTM were completely enclosed by a 60 foot (18.3 m) Titan IV PLF which included two 20 foot (6.1 m) cylindrical sections and a biconic forward section. Acoustic blankets were mounted to the interior surface of the PLF in a similar manner to flight.

Instrumentation Summary

A total of 27 internal microphones were inside the PLF during the tests to map the internal acoustic field, and 8 microphones were used in the chamber outside the PLF to control/monitor the test levels. The Partial DTM was instrumented with 42 accelerometers, 30 of which were triaxial. In addition, accelerometers were mounted at 27 locations on the PLF and 5 accelerometer measurements were taken on the Centaur structure. A total of 144 data channels were recorded for each test run [3, 4]

III. Cassini Full-up DTM (JPL)

Test Objectives

The primary objectives of the Full-up DTM spacecraft acoustic test were 1) to provide verification of predictions of the acoustically-induced random vibration levels at critical points (in general, the attachment interfaces of RTGs, scicncc instruments, and other assemblies) on the spacecraft, and 2) to serve as a precursor for the flight spacecraft acoustic test. Secondary objectives included that the. test would 1) provide data for comparison with the previous acoustic tests, and 2) provide a database for validation of analytical models.

Test Configuration

The Full-up DTM test article shown in Figure 6 included both flight and non-flight hardware. The spacecraft shell structure consisted of the flight hardware.. The three RTGs were again simulated with the two mass mock-ups and one CET unit. Remaining science instruments and other equipment were simulated using mass mock-ups. High-fidelity engineering models were employed for the High Gain Antenna (HGA) and Huygens Probe (HP).

Instrumentation Summary

The Full-up DTM spacecraft was instrumented with accelerometers at 62 locations, two strain gages, seven triaxial force gages, and one response microphone. Most of the accelerometers were triaxial, and a total of 134 acceleration measurements were recorded. Control/monitor microphones, data acquisition, and data reduc [ion were similar to the Partial DTM test.

IV. Cassini Follow-up DTM (JPL)

Test Objectives

The objectives of the Follow-up DTM spacecraft acoustic test were basically the same as for the Full-up DTM test, except that improved verification of acoustically induced random vibration for some attached assemblies was required. This was accomplished by replacing some of the mass mock-up hardware on the PMS with higher fidelity engineering models.

Test Configuration

The Follow-up DTM test article shown in Figure 7 included both flight and non-flight hardware. Some of the mass mock-up hardware on the PMS was replaced with higher fidelity engineering models (see Table 1) including the PMS Electronics Assembly (PMSEA) and Main Engine Assembly (MEA). The PMSEA is an electronics box which is supported on the outside of the PMS shell (Figure 1), and the MEA includes a large plate which supports the two Cassini main rocket engines, and is suspended horizontally from the PMS aft ringframe by eight struts. The Follow-up DTM did not include the HGA, Huygens Probe, Bus, or Upper Shell Structure Assembly (USSA).

Instrumentation Summary.

The Follow-up DTM spacecraft was instrumented with accelerometers at 37 locations, sixteen triaxial force gages, and two response microphones. Most of the accelerometers were triaxial, and a total of 96 acceleration measurements were recorded. Control/monitor microphones, data acquisition, and data reduction were again similar to the Partial DTM and Full-up DTM tests.

TEST DATA SUMMARY

Due to the extremely large volume of data obtained during the test program, only a few measurements of particular interest are presented herein. All acceleration and force data were reduced to constant narrow bandwidth (5 Hz at JPL, 4 Hz at LMA) power spectral density (PSD) levels. Microphone data were also reduced to narrowband pressure spectral densities, as well as 1/3 OB SPL spectra. In addition, the acoustic pressure data and some of the vibration data (on the LEM, primarily) were reduced to 1/6 OB SPLs and PSDS, respectively. Subsequent analyses were performed in 1/6 OBs. The data presented herein include both 1/6 OB and narrowband quantities.

A summary of the vibration reduction achieved on the LEM (measured at the CET mounting interface) by the TVAs, and the 5 and 6 inch blankets (relative to 3 inch blankets) is given in Table 2 for the critical 200250 Hz frequency range. The values in this table are the maximum reduction achieved by each modification in any of the three 1/6 octave bands from 200 to 250 Hz. Other data of interest are plotted in Figures 9-16, and discussed in the following section.

VIBROACOUSTIC ENVIRONMENT ASSESSMENT

The data given in Table 2 compare the effectiveness of each of the noise reduction modifications included in the test program. The comparison shows that the blankets, in general, resulted in greater vibration reduction than the TVAs. Also, the TVAS provided attenuation across a relatively narrow frequency range as shown in Figure 9 [2], whereas the blankets yielded a broadband effect on both the PLF acoustics and spacecraft vibration as shown in Figures 10 and 11, respectively. The attenuation shown in Figures 10 and 11 resulted from the use of 6 inch blankets (the heavier 5 inch blankets provided similar reduction). Table 2 also indicates that the TVAs performed better in the Partial DTM test than in the PLF test, and it was later determined that the discrepancy was due to a mistuning of the TVAs in the PLF test. Also note that the modifications indicated in Table 2 generally provided the greatest reduction in the radial motion of the spacecraft, and had the least effect on the vertical vibration.

Another advantage of the blankets is that they provide global reduction for the spacecraft whereas the TVAs provide only a localized effect. Also, although the total weight of the blanket modifications is significantly greater than the TVAs, the impact on performance for the Saturn mission is nearly the same due to the approximately 22 to 1 launch vehicle to spacecraft effective mass ratio. For these reasons, the blankets were baselined for the Cassini mission, and the TVAs were put in reserve. Subsequently, a revision of the Cassini acoustic test criteria [6] resulted in a 2 dB decrease of the overall test spectrum for the entire spacecraft relative to the level derived prior to the Partial DTM/PLF test [1]. The 4 dB overall SPL reduction provided by the 6 inch blankets (Figure 10) in the PLF Zones 9 and 10 will be used in assessing the environment for the RTGs which will not be tested with the flight spacecraft; however the reverberant chamber test specification cannot be reduced the full 4 dB since it must envelope slightly higher local SPLs expected near the HP and HGA as measured in the Partial DTM/PLF test.

It was expected that the spacecraft shell structure would experience a lower vibration response in the distributed acoustic field inside the PLF as compared to a reverberant chamber acoustic test controlled to an acoustic level derived from [he PLF internal acoustic measurements using standard *P95/50* criteria. To characterize this effect, eight radial acceleration measurements taken on the aft ring of the PMS (Partial DTM) were averaged and compared for the chamber test at JPL and the PLF test at I. MA. The average response of the structure in the chamber was compared to the PLF data by scaling according to: (1) the difference between the chamber test SPL and the *P95/50* SPL in the PLF, and (2) the difference between the chamber test SPL and the *mean* SPL in the PI .F. The two scaled curves are plotted with the PLF measurement in Figure 12. This comparison suggests that, contrary to expectations, the structure in the PLF responds (with a few exceptions) to acoustic levels generally between the mean and P95/50, depending on how the modes are excited.

The fidelity of the test articles was in question since different configurations were employed for each of the four tests. To help characterize these differences (l'able 1), LEM response data (at the CET) from the Partial DTM test were scaled up to the revised PF test level (145 dB) for comparison with the Full-up/Follow-up DTM test data The resulting CET base vibration levels from the three tests performed at JPI. for the spacecraft radial direction are plotted in Figure 13. These data were all normalized to the same acoustic test level, and the variations are due, presumably, to configuration differences between the three tests. Figure 13 shows that the Full-up and Follow-up DTMs exhibited quite similar vibration responses whereas the Partial DTM showed some differences in the low frequencies. In reviewing the configuration differences in Table 1 that could conceivably effect the vibration responses of the LEM, such as presence or absence of 1) the sizable Huygens Probe, 2) the heavy fuel tank mass, 3) the Centaur adapter simulator, or 4) the upper portion of the spacecraft above the PMS, or the presence of the MEA dynamic simulator or TDU versus the MEA mass mock-up, it is concluded that only the fuel tank mass had a significant impact. It is apparent that the mass of the fuel tanks significantly loads the structure below 200 Hz, but decouples above that frequency.

Localized effects of configuration changes were also studied. Differences between the Full- up and Follow-up DTMs were of particular interest since some of the. mass model hardware used on the Full-up were replaced with flight quality hardware on the Follow-up. First, the vibration measured at the base of the three RTG models during the Follow-up DTM test is shown in Figure 14. The mass models clearly exhibit different dynamic behavior from the CET which is a good dynamic simulator of a real RTG. The differences shown in the plot are consistent for all tests. It was important to use only the CET data to assess the vibration environment for the RTGs since they arc sensitive to vi bration in the 200-250 Hz range. In this frequency range as shown in Figure 14, the mass model base vibration peaks at a level nearly 10 dB greater than the CET response.

The effects of using the. flight-like MEA anti PMSEA in place of mass models in subsequent tests, arc shown in Figures 15 and 16, respectively. For the MEA, as with the RTG, there was concern about the response of the mass mock-up between 200 anti 250 Hz. As seen in Figure 15, the installation of a more flight-like MEA resulted in dramatically lower (and more realistic) response. This is important since the input acceleration spectrum used in the random vibration qualification test of the MEA was severely notched between 200-2S0 Hz to avoid exceeding engine component random vibration qualification levels. Similarly for the PMSEA, the high response measured on the mass model between 400 Hz and 1 kHz raised concern about the vibration of components inside the PMSEA box. Figure 16 indicates that the use of the f-light-like PMSEA proved that [he more realistic levels were roughly 10 dB lower and enveloped by the random vibration qualification level of 0.1 g^2/Hz in that frequency range. These comparisons demonstrate the advantages of using attached hardware components of high fidelity during dynamics testing of large spacecraft systems. Analogous data will be used in random vibration qualification assessments for other attached hardware when applicable,

CONCLUSIONS

In general, the objectives of this extensive test program were met by showing that significant attenuation of the launch vi broacoustic environment for the Cassini spacecraft was obtained. Furthermore, it was demonstrated that vibration reduction of the spacecraft shell structure was achievable through modification of either the spacecraft or the PLF. On the recommendation of' the vi broacoustics community after the highly successful PLF test at LMA in Denver, NASA anti the Cassini Project agreed to baseline the upgraded 6 inch acoustic blankets for the Cassini mission. The blankets were selected because they provided the desired noise reduction, and added an acceptable amount of weight to the PLF (the 5 inch blankets weighed nearly twice as much). The TVAs arc kept in reserve, but their use is undesirable since they add weight to the spacecraft, and due to potential difficul ties in tuning during spacecraft assembly at Cape Canaveral.

A large volume of vibroacoustic data was provided by the acoustic test program which is useful in assessing [he environment, and characterizing differences between test article configurations as discussed above. In addition [o the vibroacoustic data, valuable interface force measurements were obtained for the RTGs and other equipnlcnt/science instruments. Force measurements from the Cassini spacecraft acoustic tests provide the first direct validation of interface forces specified for equipment force-lin~i\c[i vibration tests which have been employed on numerous spacecraft projects to date [7]. The force information will be used to support future force-limited vibration tests of Cassini hardware. A force-limited low-frequency random vibration test of the flight spacecraft is also planned.

Two other Cassini acoustic tests arc planned to be performed later this year. The first will involve further developmental testing of a partial spacecraft which will include some high-fidelity hardware components not present on the other tests, and recent spacecraft design changes, Finally, an acoustic test of the flight spacecraft will be performed as part of the qualification test program, and only flight or flight-quality hardware (except RTGs) will be present. Although Cassini is still expected to experience an unusually high launch vibroacoustic environment, a reduction in the environment has been achieved, and a safe launch is expected.

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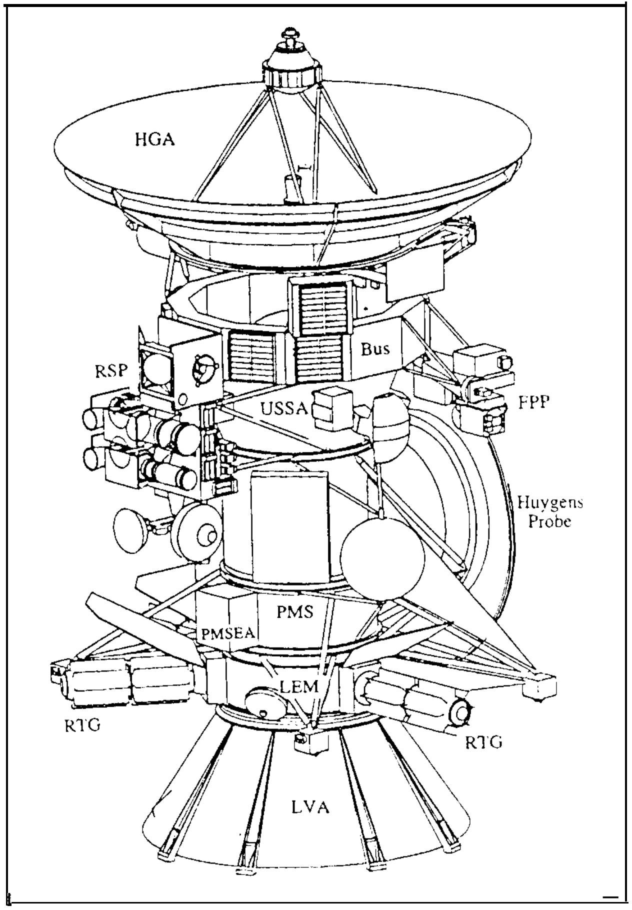

Figure 1: The Cassini Spacecraft Launch configuration

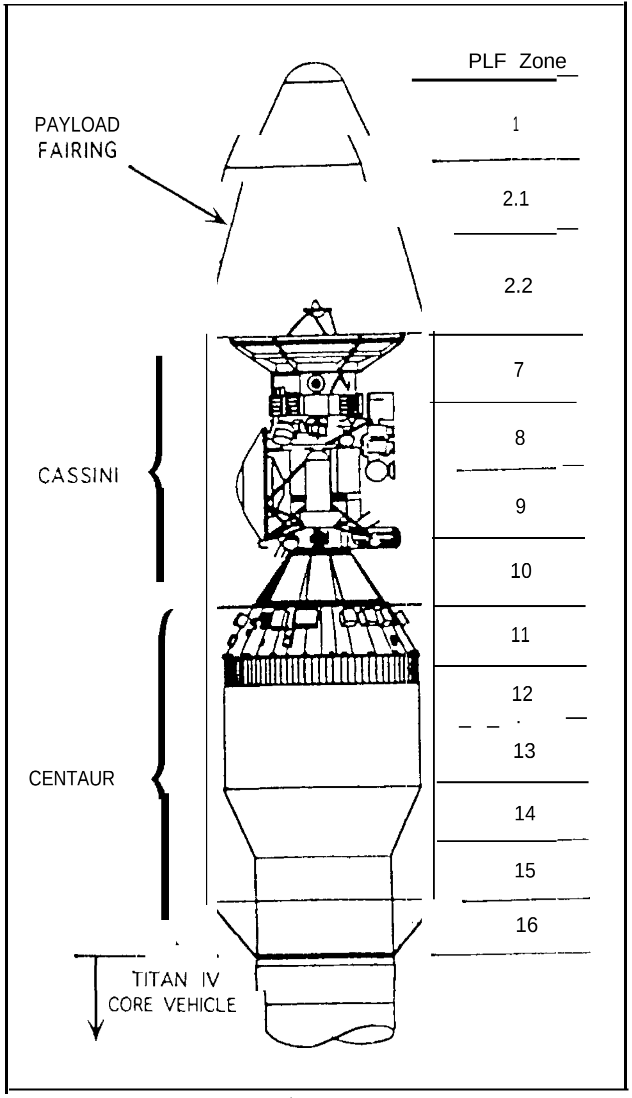

Figure 2: The Cassini/Centau r/Titan I V Launch Configuration

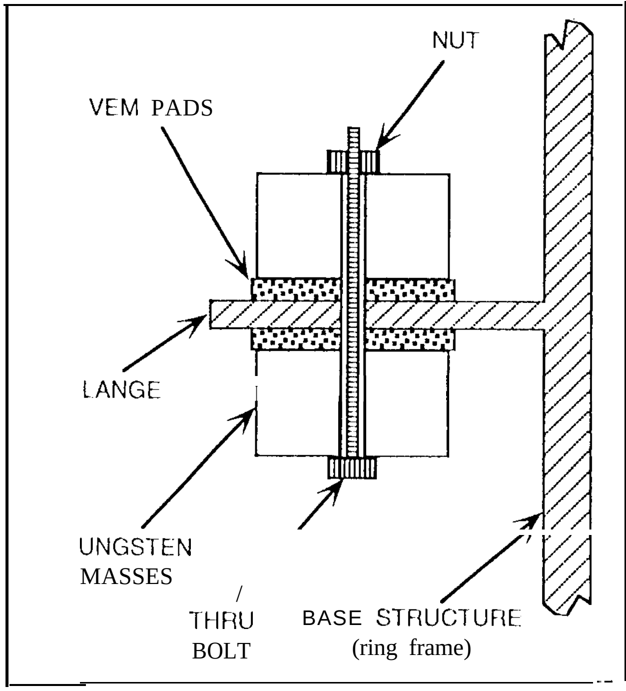

Figure 3: Tuned Vibration Absorber Configuration [2

Table 1: Summary of Cassini DTM Acoustics Test Configurations

TEST DATE	July-Aug. 1994	Jan. -Feb. 1995	Sept. 1995	Dec. 1995
ACOUSTICS TEST LEVEL	FA (143 dB)	T-IV Ext. (150.4 dB)	Revised PF (145 dB)	Revised PF (145 dB
SPACECRAFT STRUCTURE	PARTIAL DTM "	DTM/PLF	FULL-UP DThl	'FOLLOW-UP DTM
Launch Vehicle Adapter (LVA)	Flight	Flight	Flight	Flight
Linear Separation Assembly (LSA)	Flight Identical	Flight Identical	Flight Identical	Flight Identical
Lower Equipment Module (LEM)	Flight	Flight	Flight	Flight
Reaction Wheel Assemblies (RWAS)	Rigid Mass	Rigid Mass	Rigid Mass	Rigid Mass
RTG (3)	CET / Mass (2)	CET / Mass (2)	CET / Mass (2)	CET / Mass (2)
Huygens Prohe (HP)	No	Volume Mock-Up	STPM *	No
Propulsion Module Subsystem (PMS)	Cable Mock-Up	Cable Mock-Up	DTM	DTM
PMS Tanks	No	No	Mass Mock-up	Mass Mock-up
Main Engine Assembly (MEA)	Dynamic Mock-Up	Dynamic Mock-Up	Mass Mock-up	TDU †
PMS Electronics Assembly (PMSEA)	No	No	Mass Mock-up	Flight Equivalent
Other Attached Hardware/Electronics	No	No	Mass Mock-up	Mass or Flight Equiv
Upper Shell Structure Assembly (USSA)	No	Volume Mock-up	Flight	No
USSA Equipment/Science Instruments	No	No	Mass Mock-up	No
Remote Sensing Pallet (RSP)	No	No	Flight	No
RSP Equipment/Science Instruments	No	No	Mass Mock-up	No
Fields and Particles Pallet (FPP)	No	No	Flight	No
FPP Equipment/Science Instruments	No	No	Mass Mock-up	No
Electronics Bus	No	Volume Mock-up	Flight	No
Attached Hardware	No	No	Mass Mock-up	No
High Gain Antenna (HGA)	No	Geometric Mock-up	DTM	No
Total Mass (lb)	= 1304	= 1304	11770	S982
Total Mass (kg)	≈ 593	= 593	5340	4087

* STPM = Structural-Thermal-Pyro Model

† TDU = Thermal Development Unit (dynamically similar)

Note: For reference, the estimated total mass of the flight spacecraft at launch is 12551 lb (5694 kg)

Table 2: Summary of Cassini Lower Equipment Module Vibration Reduction

VIBRATION MEASUREMENT DIRECTION * (spacecraft coordinates)	LEM VIBRATION REDUCTION MEASURED IN 200-250117 RANGE (in dB relative to baseline configuration: no TVAs/ 3-in. blankets)				
	1.5 lb TVAs (JPL)	3,0 lb TVAs (JPL)	3.0 lb TVAs (LMA, Denver)	5-in. blankets (LMA, Denver)	6-in. blankets (LMA, Denver)
RADIAL	2.4	4.8	2.5	6.6	7.2
TANGENTIAL	3.0	3.1	1,7	4.6	4.5
VERTICAL	1.7	1.0	0.0	3.7	2.2

* From accelerometer located at base of CET Model RTG on +Y Support

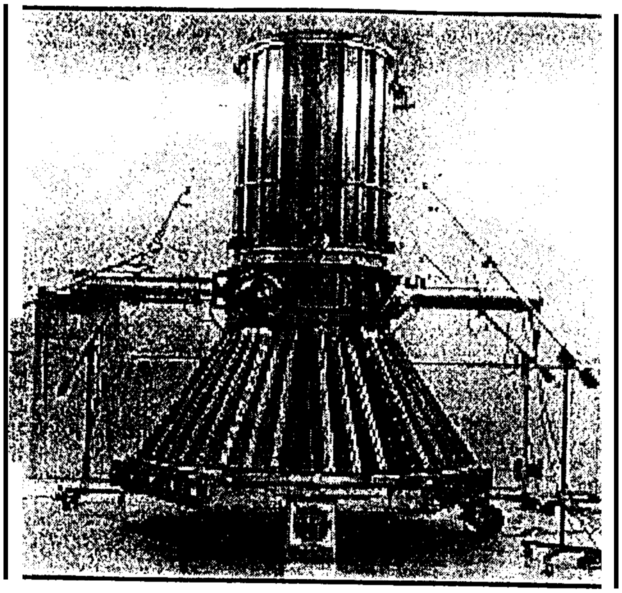

Figure 4: Cassini Partial-DTM Test Configuration

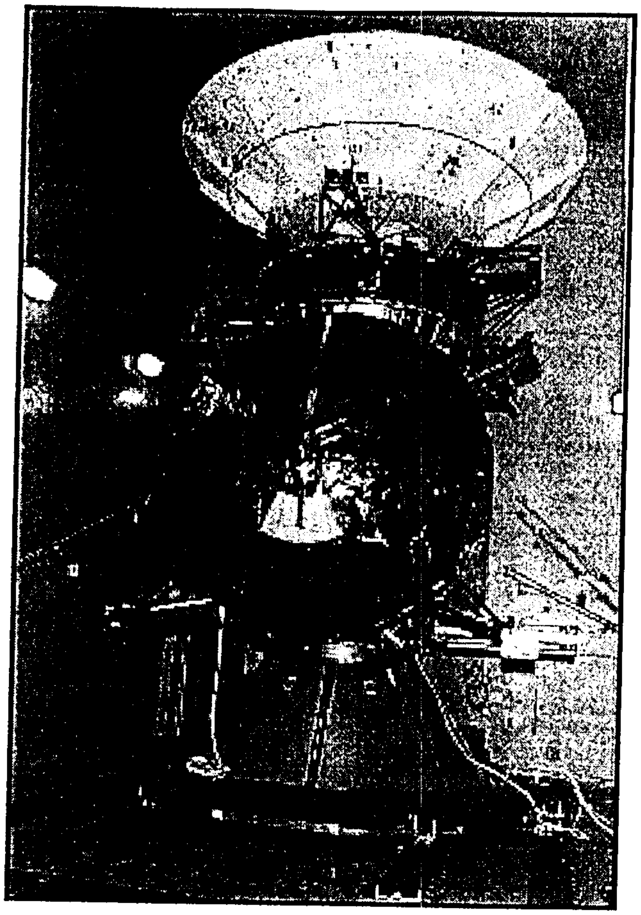

Figure 6: Cassini Full-up DTM Test Configuration

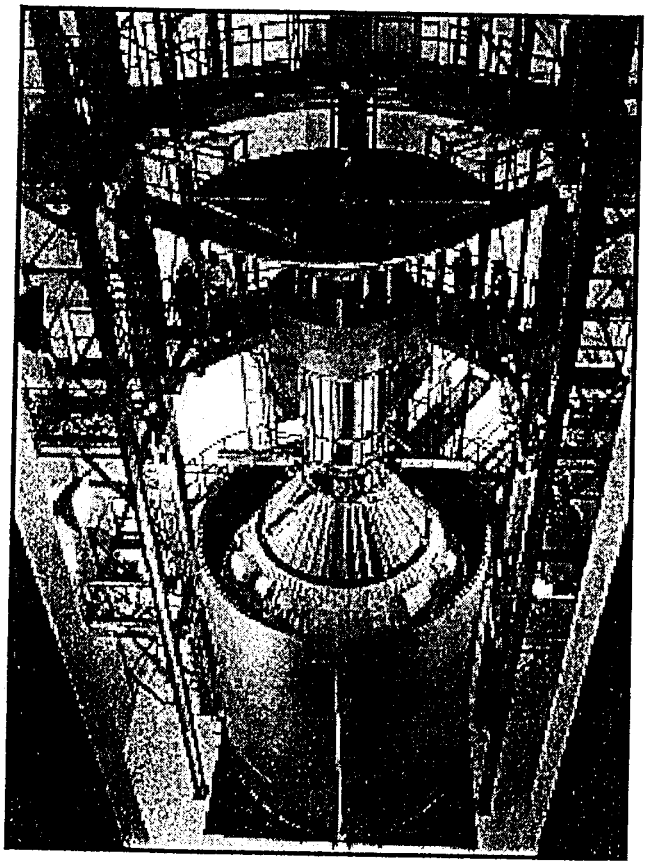

Figure 5: Combined Cassini Partial-DTM/ Titan IV PLF Test Configuration

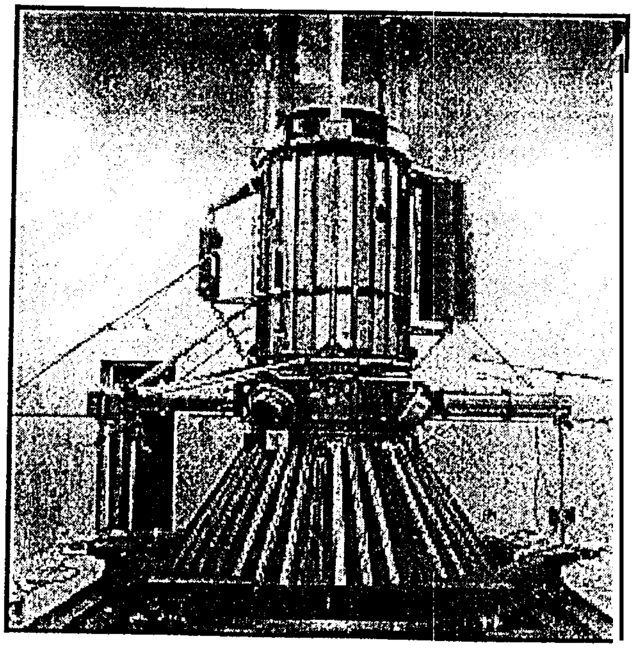

Figure 7: Cassini Follow-up DTM Test Configuration

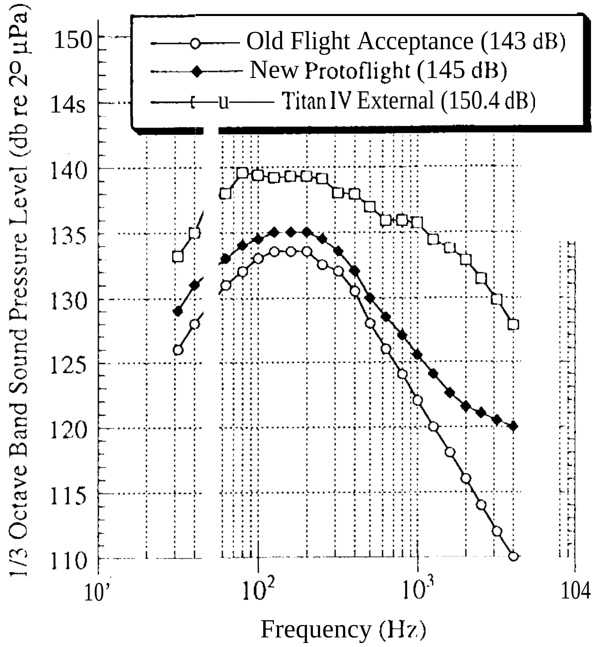

Figure 8: Test Levels Used for Cassini DTM Acoustics Test Program

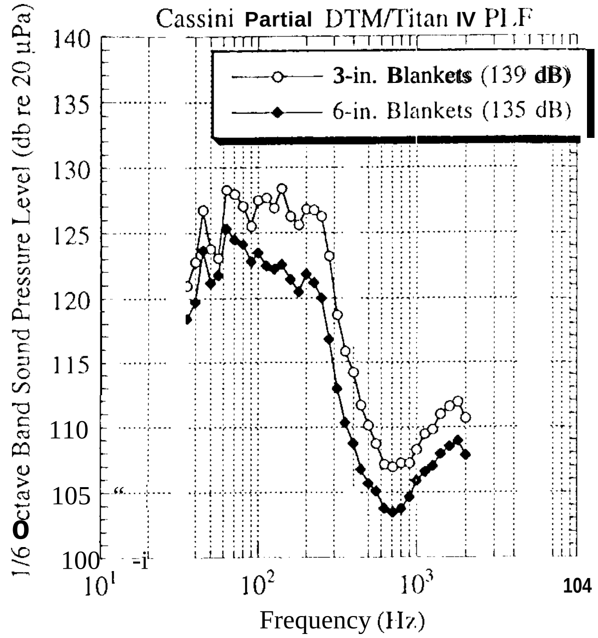

Figure 10: Average PLF Internal SPL Spectra Measured in Spacecraft Zones With Baseline 3-in. and 6-in. Acoustic Blankets

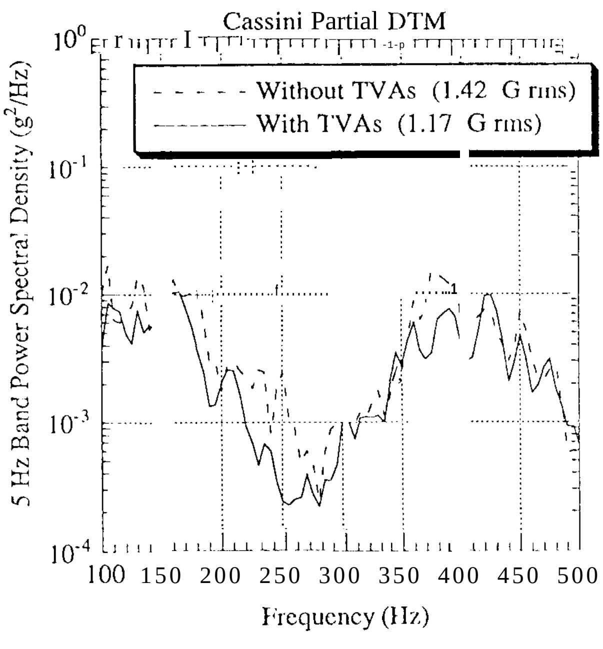

Figure 9: Radial Vibration Response of Structure at Base of CET With and Without TVAs

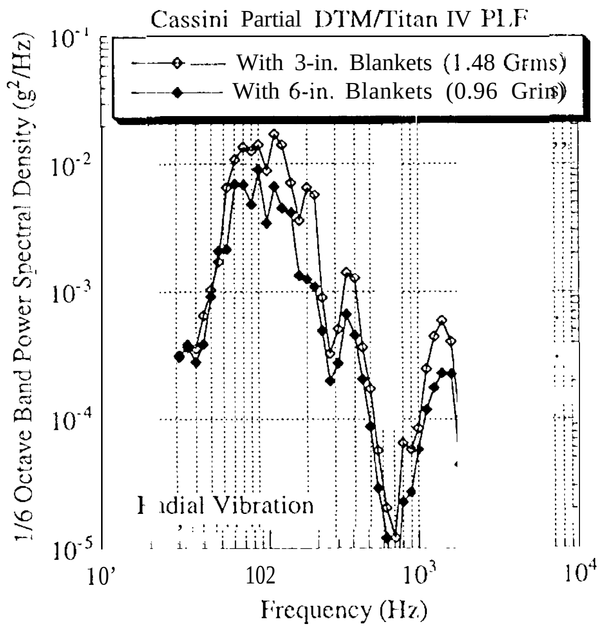

Figure 11: Radial Vibration Response of LEM (at CET) Measured in PLF With Baseline 3-in. and 6-in. Acoustic Blankets (no TVAs)

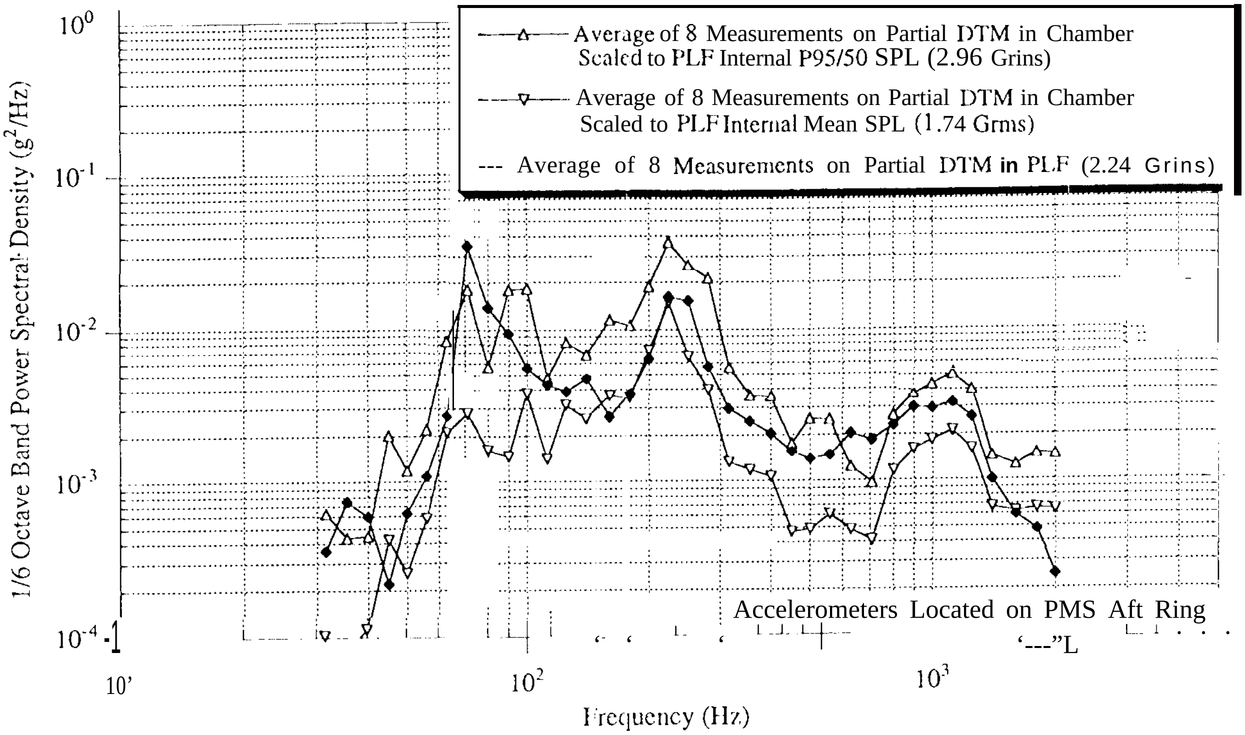

Figure 12: Comparison of Spacecraft Radial Vibration Response in PLF versus Reverberant Test Chamber

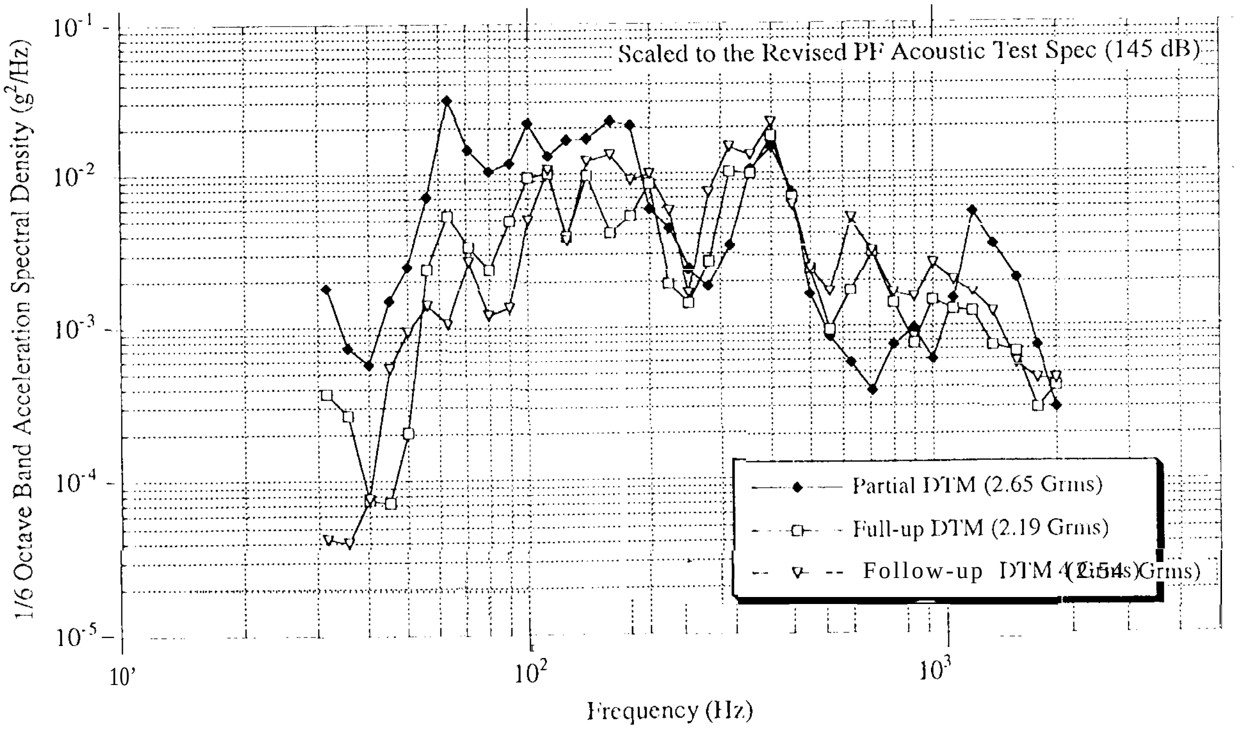

Figure 13: Comparison of Spacecraft Radial Vibration Response (measured at base of CET) for Three Different DTM Configurations Tested Without PLF in the Reverberant Acoustic Chamber

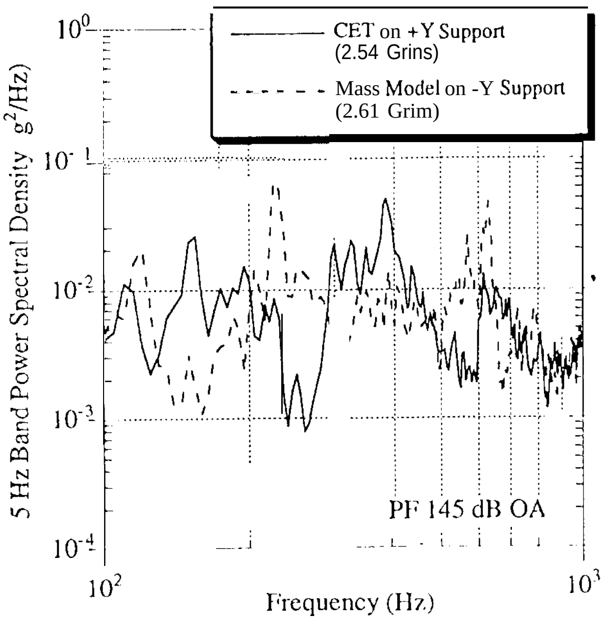

Figure 14: Radial Vibration Response at Base of RTG Models Measured During Follow-up DTM Acoustics Test

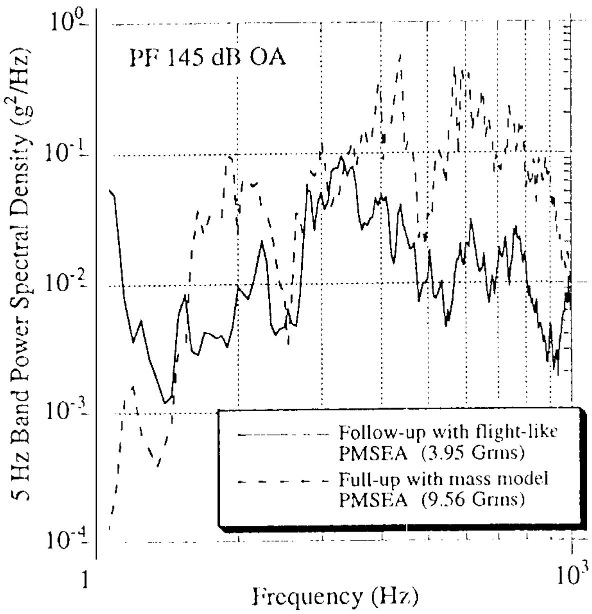

Figure 16: Comparison of Radial Vibration Response of PMSEA Measured During Full-up and Follow-up DTM Acoustics Tests

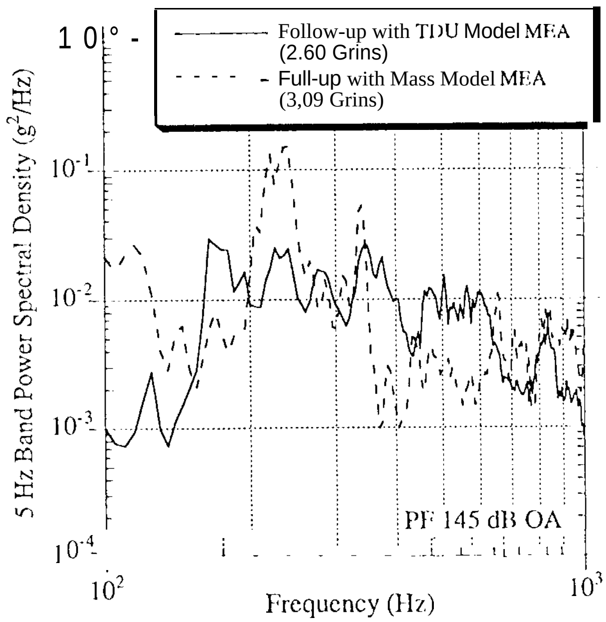

Figure 15: Comparison of Vertical Vibration Response of MEA Plate Measured During Full-up and Follow-up DTM Acoustics Tests