ACOUSTIC TESTING OF THE CASSINI SPACECRAFT AND TITAN IV PAYLOAD FAIRING PART 1—INTRODUCTION AND TEST CONFIGURATION

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SUMMARY

NASA Lewis Research Center recently led a multi-organizational acoustic test program. This testing consisted of acoustically exciting a Cassini spacecraft simulator in a full scale 60 ft high Titan IV payload fairing with various acoustic blanket designs and configurations in a large reverberant acoustic chamber. The primary purpose of this test program was to measure the fairing's internal acoustics and spacecraft vibration, especially the Radioisotope Thermoelectric Generators (RTG) vibration, and to quantify the mitigation efforts in reducing these levels. Key to this reduction effort was the utilization of new acoustic blanket designs. This paper will provide the background and rationale for performing this test program, state the test program's primary and secondary objectives and describe the test matrix, hardware and instrumentation. A second part companion paper will provide the test results and data analysis.

INTRODUCTION

In October 1997, NASA will launch the Cassini spacecraft (fig. 1), to explore Saturn and its moons, with a Titan IV/Centaur launch vehicle (fig. 2). The electric power source for the Cassini mission are three mission critical Radioisotope Thermoelectric Generators (RTGs). The RTG design was previously vibration qualified for the Space Shuttle launch environment and utilized on the Galileo and Ulysses spacecraft missions.

However analysts at the Jet Propulsion Laboratory (JPL), the Cassini spacecraft designer, predicted that the acoustically driven qualification vibration levels for the Cassini RTGs would exceed the RTGs design's previous qualification levels. This exceedence is primarily due to the RTG mounting on the Cassini being significantly different than the mounting used for the RTGs on the Galileo and Ulysses missions.

To avoid an extremely costly ($25 to 30 M) requalification of the RTGs, a major acoustic blanket development and test effort was initiated and funded by NASA Lewis Research Center (NASA Lewis), the launch vehicle integrator for the Cassini mission. Specifically, the goal was to test verify a new acoustic blanket which would reduce the expected acoustic environment for the Cassini RTGs by 3 dB at 200 and 250 Hz, when compared with the baseline Titan IV blanket system environment. Acoustic blankets are typically utilized in the payload fairing (PLF) of expendable launch vehicles (ELVs) to reduce the fairing's interior acoustics and the subsequent vibration response of the spacecraft and its components. Normally these blankets are most effective at 400 Hz and higher, however the predicted RTG vibration qualification exceedances occurred in the 200 to 250 Hz range creating a need for a new blanket design.

Besides NASA Lewis and JPL, other organizations involved in this joint effort included Lockheed Martin Astronautics (LMA, formerly Martin Marietta Technologies Incorporated, MMTI), McDonnell Douglas Aerospace (MDA), Aerospace Corporation, Analex Corporation and Cambridge Collaborative Incorporated. This test program was optimized in scope to go beyond the primary objective and allow an investigation of many secondary areas of technical interest to the aerospace vibroacoustic community.

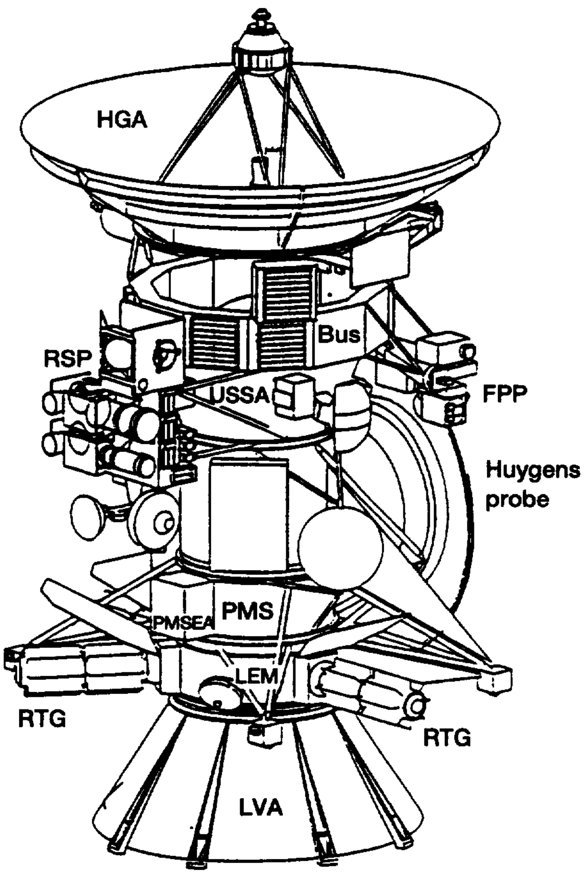


Figure 1.—Cassini Spacecraft [3].

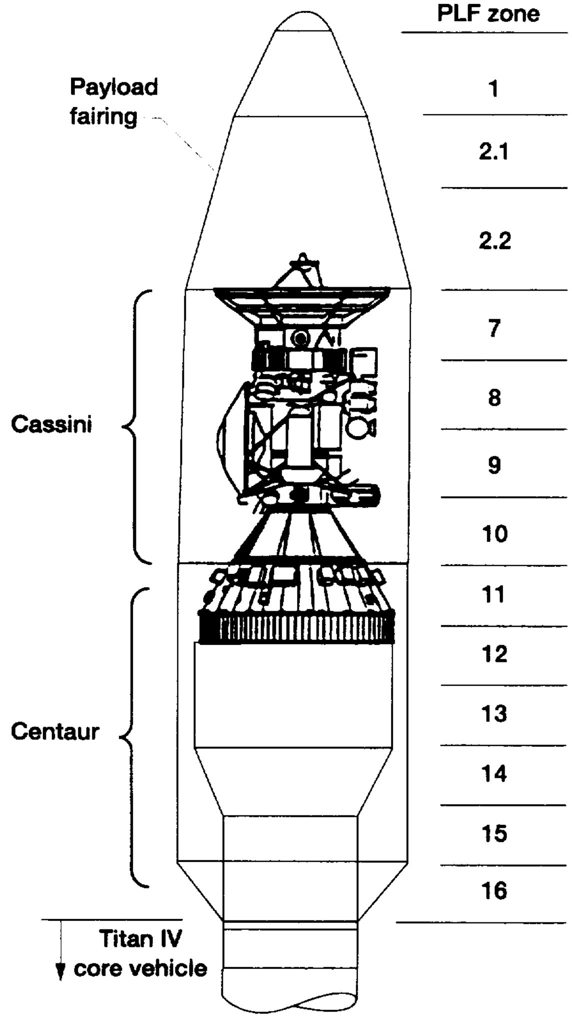


Figure 2.—The Cassini/Centaur/Titan IV launch configuration [3].

ACOUSTIC BLANKETS REVIEW

Previous to the full scale PLF tests, NASA LeRC and MDA led an effort (refs. 1 and 2) to develop a new acoustic blanket which would reduce the acoustic excitation to the Cassini spacecraft. In this effort numerous new blanket designs were quickly evaluated by acoustic testing of flat panel blanket samples. The leading new candidate blanket designs and the baseline Titan IV blanket design were then to be test verified in the full scale cylindrical payload fairing with flight-like boundary conditions and geometry.

The testing of the new blanket designs in a flat panel configuration occurred in March-April 1994 at the Riverbank Acoustical Laboratory (RAL), Geneva, Illinois. Absorption values for the blankets were obtained from reverberation time tests per ASTM C423. Blanket transmission loss (TL) values were obtained from testing per ASTM E90.

A total of 19 different blankets (18 new designs and the Titan IV baseline blanket) were tested for absorption and TL characteristics. Additionally, a isogrid panel sample, from a Titan IV PLF wall, had its TL measured separately and was used for all the blanket TL testing. (The Titan IV PLF is a cylindrical aluminum isogrid structure, consisting of a geometric pattern of machined out triangular pockets.) Each blanket tested was an 8 ft by 9 ft rectangular sample.

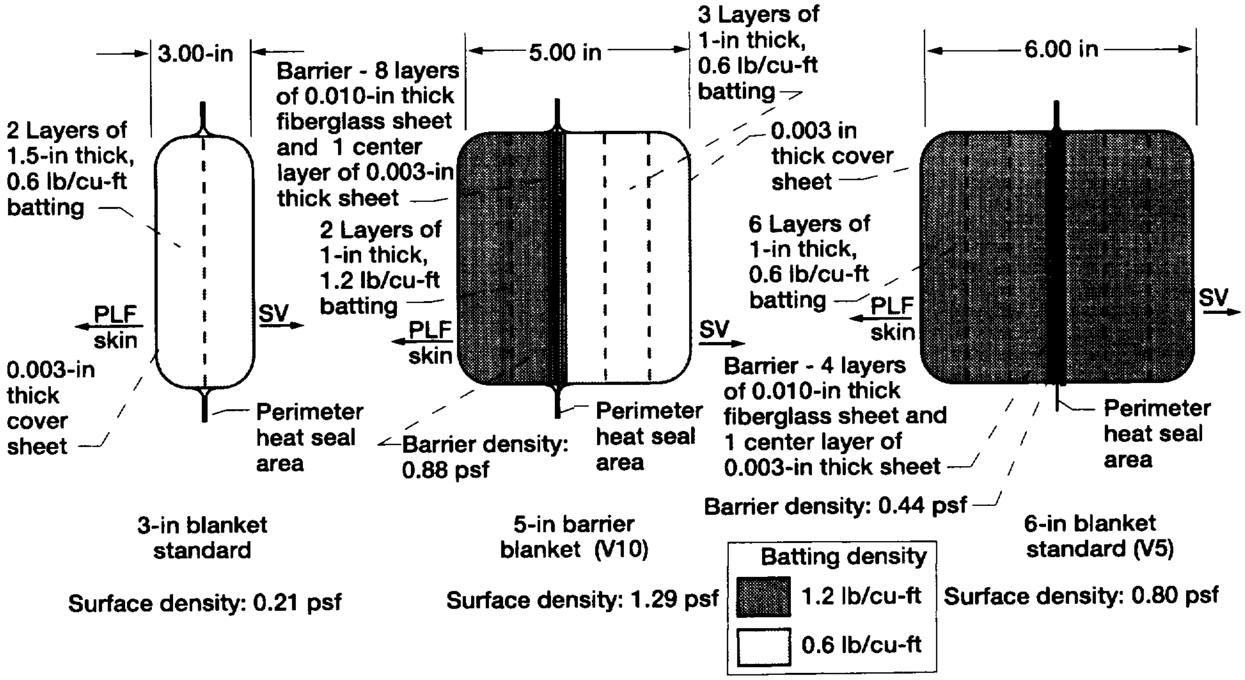


Figure 3.—Blanket designs [4].

Utilizing the absorption and TL test data, analytical predictions were made to calculate the effect of each new blanket design in reducing the PLF's interior acoustics. At the completion of the flat panel testing, two new blanket designs, denoted as V5 and V10, were chosen for the full scale PLF testing.

Figure 3 illustrates the new blanket configurations, in comparison with the Titan IV baseline blanket design. Both the V5 (6 in.) and V10 (5 in.) configurations are thicker than the Titan IV baseline blanket (3 in.). Also, both the V5 (0.44 psf) and V10 (0.88 psf) configurations have heavy internal barriers, whereas the Titan IV baseline blanket has no internal barrier.

TEST CONFIGURATION AND HARDWARE

A series of high intensity acoustic tests were performed on the Cassini spacecraft simulator in a Titan IV PLF in January-February 1995 (fig. 4). The testing occurred at LMA's 76 000 ft^3 Reverberant Acoustic Laboratory (RAL) in Denver, Colorado. This testing was led by LMA, NASA Lewis and JPL.

The Titan IV PLF used in this test was 60 ft high with a 16.8 ft diameter and occupied 15 percent of the reverberant chamber volume. This 60 ft PLF was the forward section of an 86 ft Titan IV PLF test code.

The Cassini spacecraft simulator was a combination of flight, developmental and mockup hardware. The lower portion of the spacecraft, the propulsion module subsystem (PMS) was a high fidelity developmental test model (DTM) supplied by JPL. Included in this was one RTG dynamic simulator (known as the CET, Component Evaluation Test model) and two RTG mass simulators. The Huygens Probe was a volume mockup provided by JPL. The upper portion of the spacecraft, the upper shell structure assembly (USSA) the electronics bus and the high gain antenna (HGA) were styrofoam/sheet metal simulators provided by LMA to represent the proper geometry and volume. The launch vehicle adapter (LVA) and lower equipment module (LEM) was actual flight hardware. Also included was a flight-like linear separation assembly (LSA), mass mockups of the reaction wheel assemblies (RWA), and a dynamic mockup of the main engine assembly (MEA). The total spacecraft mass for this test was ~1304 lb (593 kg). The additional weight of the flight PMS fuel tanks and numerous flight instruments was not included for this test article.

The spacecraft simulator was mounted on a Centaur Forward Adapter simulator known as the MIVE (Mechanical Interface Verification Equipment). The MIVE itself was mounted on a mockup of a Centaur upper stage vehicle.

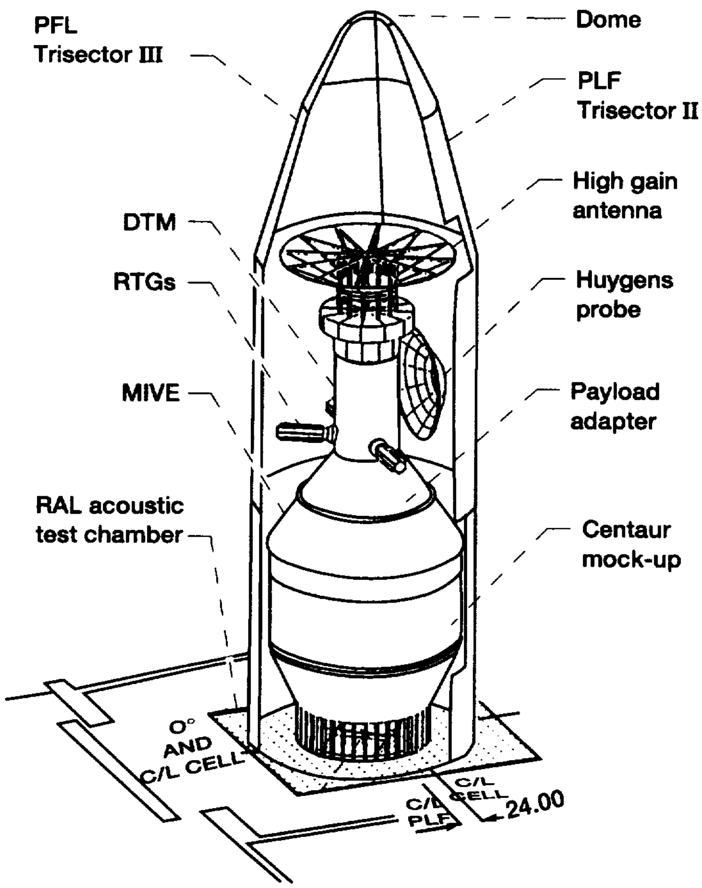


Figure 4.—Overall test hardware setup [4].

TEST MATRIX

The testing consisted of a series of seven acoustic tests to determine the acoustic environment and the RTG vibration environment for three different blanket configurations (3 in. baseline, 5 in. V10 and 6 in. V5). The test matrix is given in figure 5. (Two additional tests were performed at the end of the test series and funded by LMA. These tests measured the PLF's noise reduction and absorption characteristics for the unblanketed PLF without a spacecraft simulator.)

As illustrated in figure 5, the PLF's blanket coverage was varied during the testing. For all seven tests the Titan IV baseline (3 in.) blankets were in place in PLF zones 2.1, 2.2 and 7. The blankets in PLF zones 8 to 11 were varied in each test in both the type of blanket used (baseline, V5 or V10) and the percentage of the blanket coverage (full or partial). In the test matrix, the term "full coverage" does not imply 100 percent blanket coverage but is meant to convey that the tested configuration had similar blanket coverage to that expected for the actual Cassini flight. Partial coverage was a test condition equal to 75 percent of the "full" coverage. Two partial coverage tests (tests numbers 3 and 6) were performed. Figure 6 illustrates the percentage of blanket coverage for the tests and the locations of the blankets which were removed in the partial coverage tests.

The test matrix (fig. 5) also shows testing with and without TVAs or tuned vibration absorbers. The TVAs are designed to absorb energy at the natural frequency of the TVA spring/mass system (fig. 7). The TVAs were tuned to about 200 Hz and thereby reduce the amount of energy transferring from the spacecraft to the RTGs (ref. 3) at that frequency. A total of sixteen TVAs were installed on the LEM and LVA forward rings (eight on each). Each TVA has a mass of 3.0 lb (1.36 kg).

The purpose of the seven tests shown in figure 5 follows. Test 1 was to establish the baseline PLF interior acoustic levels, without a spacecraft simulator. Test 2, in comparison with Test 1, measures the effects of the

Test number	Blankets	Coverage	P/L simulator
1	3-in. Std	Full	No
2	3-in. Std	Full	Yes, w/TVAs
3	3-in. Std	Partial	Yes, w/TVAs
4	5-in. V-10	Full	Yes, w/TVAs
5	5-in. V-10	Full	Yes, w/o TVAs
6	5-in. V-10	Partial	Yes, w/o TVAs
7	6-in. V-5	Full	Yes, w/o TVAs

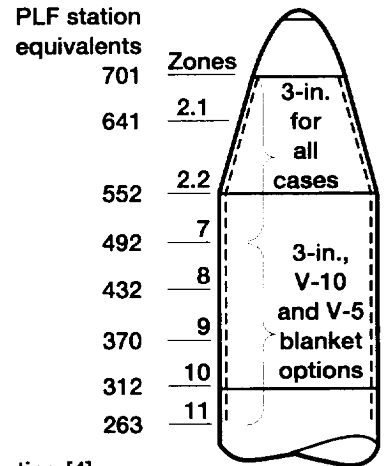


Figure 5.—Test matrix for PLF testing [4].

spacecraft simulator on the acoustics and also serve as the baseline blanket test levels for all blanket type comparisons. Test 3, in comparison with Test 2, allows an evaluation of the partial blanket coverage effect for the standard Titan IV blanket. Test 4, in comparison with Test 2, measures the effect of the V10 blanket as compared to the standard blanket. Test 5, in comparison with Test 4, measures the test to test acoustic repeatability and also measures the effect of the TVAs. Test 6, in comparison with Test 5, measures the effect of partial blanket coverage for a barrier blanket (V10). Test 7, in comparison with Test 2, measures the effect of the V5 blanket.

PRIMARY TEST OBJECTIVES

The primary objectives of this test program was to:

(1) Quantify the acoustic environment within the PLF, specifically in the vicinity of the RTGs, and
(2) Quantify the vibration response of the RTGs,

by measuring the delta effect of these environments when using the two new barrier blankets (V5 and V10) compared to using the Titan IV baseline blankets.

The test program was designed to measure the delta effect of the environments since the reverberant acoustic field of the test chamber is different than the traveling acoustic wave at a launch pad. It was therefore felt that delta measurements would be most meaningful as opposed to the absolute measurements.

SECONDARY TEST OBJECTIVES

Because a test program of this magnitude and potential value occurs so infrequently, this testing was optimized in scope to investigate many secondary areas of technical interest. Among the secondary objectives were:

(1) Measure the effect of the TVAs on the RTG vibration response,
(2) Measure the effect of reduced blanket coverage on the PLF interior acoustics,
(3) Measure the effect of blankets on PLF vibration,
(4) Obtain data to support the Cassini PLF acoustic and vibration prediction models and to develop test chamber to flight correlations, including investigating the following items:

(a) Fill factor effects of the Huygens Probe
(b) Effect of HGA on PLF interior acoustics
(c) Comparisons of ground test measurements to past and future flight measurements
(d) Effect of distance from PLF wall on measurements

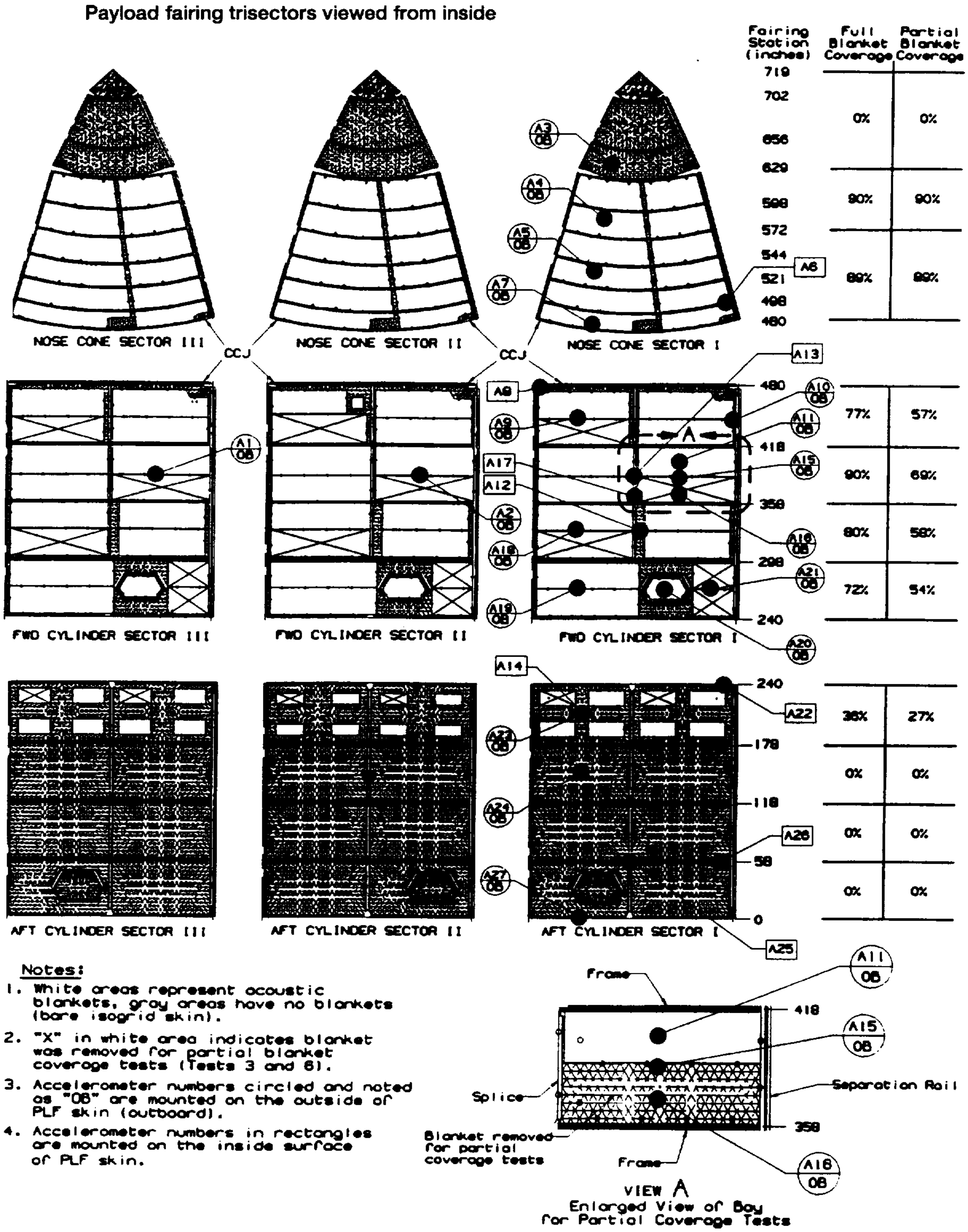


Figure 6.—Blanket configuration and PLF accelerometer locations [5].

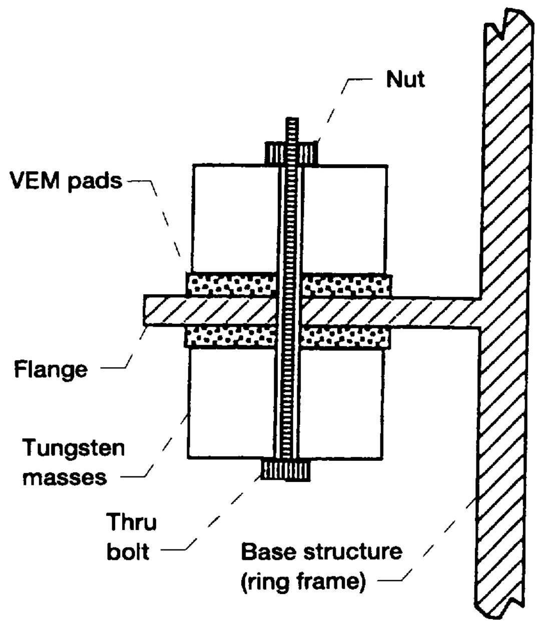


Figure 7.—Tuned vibration absorber configuration [3].

(5) Measure the Cassini spacecraft simulator vibration response at numerous locations of interest, including similarly located measurements from previous JPL testing.

As stated earlier, LMA also utilized the availability of the test setup to perform two additional tests to measure the unblanketed PLF noise reduction and absorption characteristics.

TEST INSTRUMENTATION

To achieve both the primary and secondary objectives a large amount of instrumentation was carefully selected for the tests (ref. 4).

To properly measure the interior acoustics levels, LMA made acoustic microphone measurements at 31 locations within the PLF (fig. 8). Over one-half (16) of these microphones were located in Zones 9 and 10 of the PLF, which was the region of high interest for the RTGs. Four of these sixteen microphones were placed at locations similarly to previous JPL DTM test positions. Other microphones were located to measure the acoustic field in various PLF zones. Microphones were also placed in locations similar to previous flown Titan IV flight measurement locations, and in locations planned for the upcoming Cassini flight measurements.

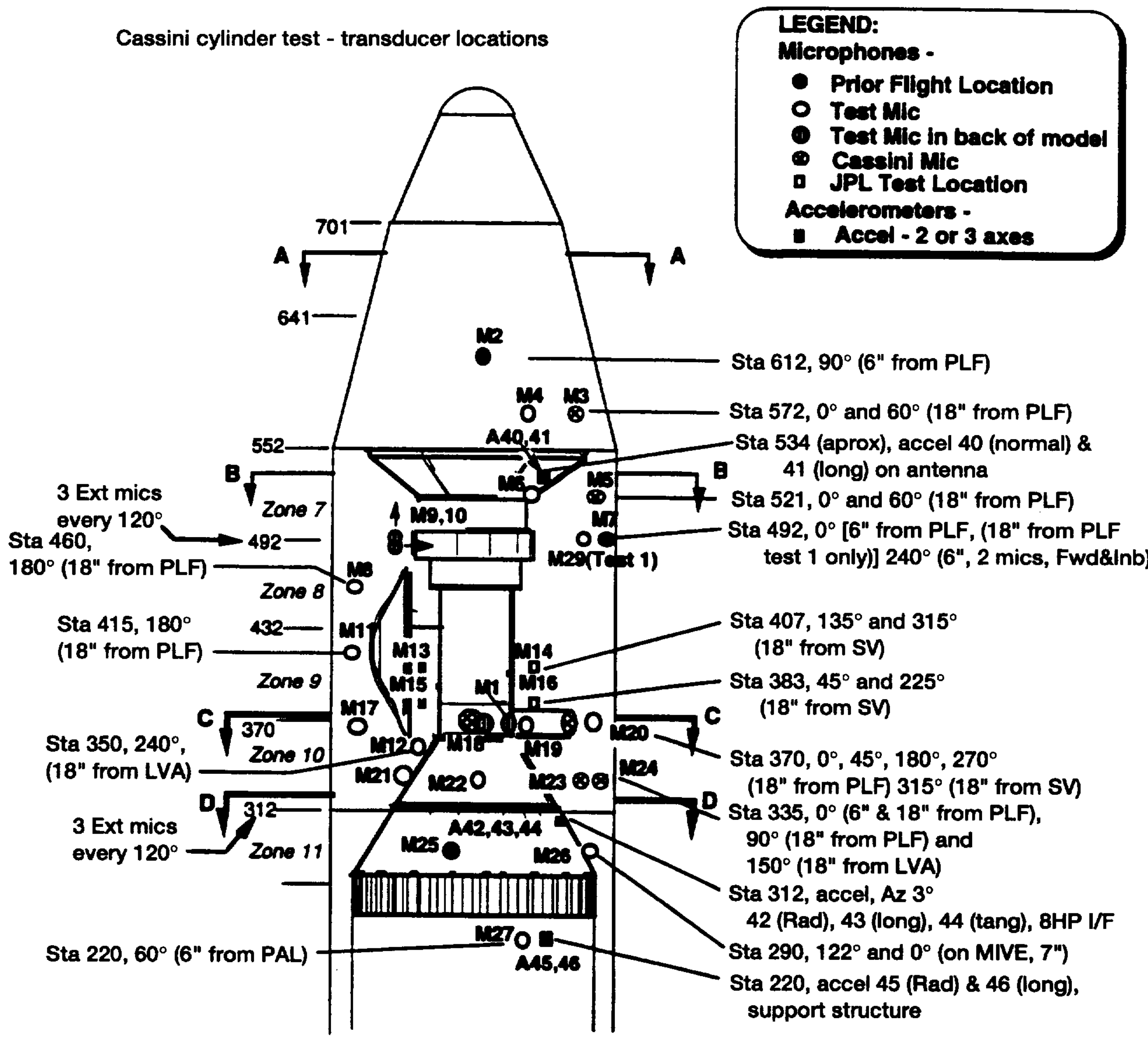
Measurements of the PLF external acoustics were measured at 8 locations. Six of these eight were used to control the acoustic excitation level.

LMA also instrumented the HGA mockup, the MIVE and the Centaur mockup with a total of 7 accelerometers to ensure that the simulators were behaving normally.

The vibration response of the Cassini DTM spacecraft hardware was measured by JPL instrumentation. A total of 70 accelerometers and 5 force measurements were measured. Critical to the RTG vibration measurements were triaxial accelerations measured at the base of the RTG dynamic simulator (fig. 9).

The vibration response of the PLF was measured by 27 radial accelerometers provided by MDA (fig. 6). Nine of these were mounted inboard on the PLF and the remaining 18 were mounted on the outside of the PLF.

To guarantee that the primary objectives would be met certain instrumentation was denoted as critical prior to the start of testing. This critical instrumentation was composed of: (1) a minimum of 10 microphones in the RTG vicinity, (2) a minimum of 5 external microphones, and (3) a minimum of one acceleration measurement in each direction at the base of the dynamic RTG simulator. The success criteria for each test was to obtain valid data from this defined list of critical instrumentation.



Note 1: On test no. 1, M28 will be positioned on the centerline above the MIVE at approximately PLF Sta 370.
Note 2: M29 will be used on test no. 1 only
Note 3: Station numbers are referenced to Cassini PLF Station numbers.

Figure 8.—Instrumentation locations [4].

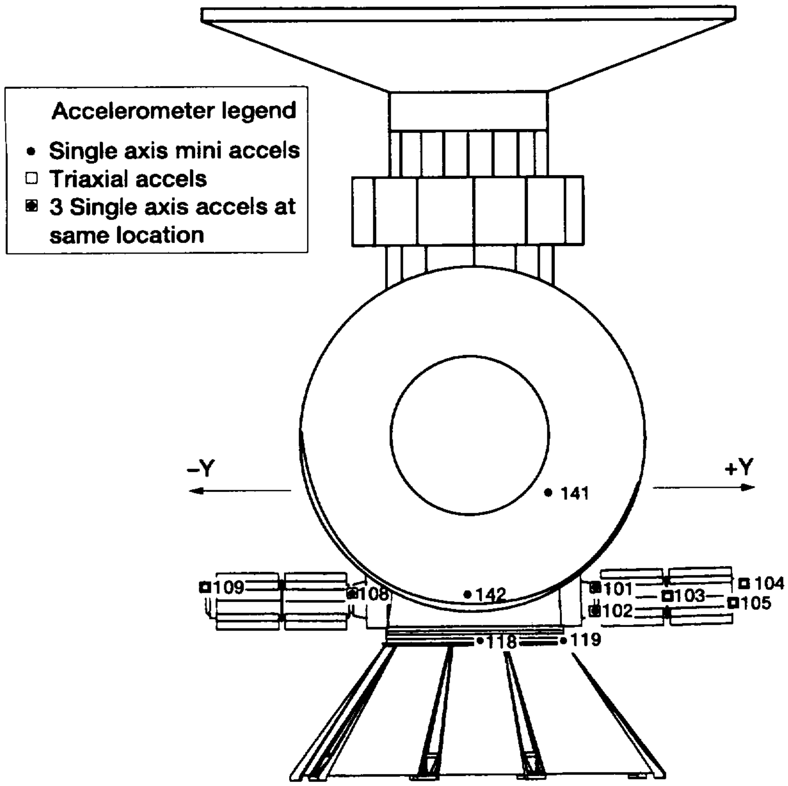


Figure 9.—RTG instrumentation locations [4].

ACOUSTIC EXCITATION

The acoustic level in the reverberant chamber (PLF's external level) was the P95/50 prediction of the external liftoff level at the Eastern Test Range, for the Titan IV with SRMU (Solid Rocket Motor Upgrade) configuration and corrected to an 18 in. distance from the PLF. This full level spectrum, defined by LMA, has an overall SPL (sound pressure level) of 150.4 dB.

CONCLUSIONS

A multi-organizational effort, led by NASA Lewis Research Center, to test verify new acoustic blankets has been successfully completed. The test planning involved with this full scale acoustic test program, consisting of a Cassini spacecraft simulator in a Titan IV payload fairing with various blanketing conditions, is provided in this paper. The test results and data analysis are provided in the second part companion paper.

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