CASSINI SPACECRAFT ACOUSTIC FLIGHT AND TEST CRITERIA

Thomas F. Bergen, Harry Himelblau, and Dennis L. Kern, M.S. 125-1'29
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109-8099

ABSTRACT

Acoustic measurements from eight Titan IV flights, and an acoustic test of a Cassini simulator and Titan payload fairing (PLF), were used to derive acoustic flight and test criteria for the Cassini spacecraft. The flight and laboratory data were used or modified to account for the following factors: (a) noise spike contamination of flight data, (b) spatial and flight-to-flight variations of flight data, (c) application of a thicker barr ic]-blanket to the PLF for the Cassini mission after flight data showed an excessive acoustic environment, (d) effects of locating two Cassini assemblies, the Huygens Probe (HP) and the High Gain Antenna (HGA), near the PLF, (e) higher thrust of upgraded Titan solid rocket motors (SRMs) for the Cassini mission, and (f) special considerations for acoustic testing of the Cassini spacecraft without the PLF. An overall sound pressure level of 145 dB was verified for the protoflight acoustic test criteria for the Cassini spacecraft.

INTRODUCTION

The Cassini slmcc.craft, shown in Figure 1, is currently under development at the Jet Prepulsion Laboratory (JPL) and its suppliers for the National Aeronautics and Space Administration (NASA) to explore the planet Saturn, its rings rind its moons. The spacecraft will be launched by a Titan IV vehicle with a Centaur upper stage. As described in three earlier papers [1-3], acoustic data were acquired on prim Titan flights using the same payload failing (1)1 F) to be used on Cassini but, obviously, with different payloads. These data showed that the maximum internal PLF acoustic environment occurred during liftoff and were strongly influenced by the launch pad configuration, e.g., minor differences in acoustic levels were observed between the two similar Titan launch complexes (LC-40 and -41) at Cape Canaveral AFS/Eastern Test Range (ETR), but were substantially exceeded by levels measured at the Vandenberg AFB/Western Test Range (WTR) site (SLC-4E). Since Cassini is scheduled to be launched from LC-41, it was decided to omit WTR data from the database once sufficient ETR data became available.

Like all outer planetary spacecraft, Cassini will require on-board nuclear power bc.cause the great distance from the Sun precludes the use of solar power. Specifically, electric power will be provided by three. radioisotope thermoelectric generators (RTGs) of essentially identical design to those used on Galileo and Ulysses spacecraft. llowc.vet, the Cassini vibration responses to the acoustic environment at the RTG mountings are expected to exceed those of its predecessors, requiring either RTG redesign and requalification or redaction of the Cassini environment. NASA and J]'] , concluded that acoustical attenuation would be the most cost effective solution. Thus a program was initiated to reduce the acoustic environment applied to Cassini [4-8]. However, acoustic reduction was required over only a relatively limited portion of the spectrum, namely, the 1/3 octave band (OB) range of 200-250 Hz.

FLIGHT DATA SUMMARY

Previous summaries included liftoff internal PLF acoustic data from Titan IV Flights K-1,-4, -7, -9, -10, -19, -21, and -23 launched from ETR. A total of 22 internal PLF acoustic measurements have currently been acquired on these eight flights, Of these., 17 microphones were attached [n the PLF, while five were supported off the Centaur forward skirt just below the spacecraft. The 22 measurements include 8 repeal measurements on subsequent flights.

Three additional K-4 microphones were supported on 20 inch standoffs from the PLF. On average, acoustic data from these three standoff microphones were observed to be about 2 dB less than PLF surface data, However, the number of standoff measurements was deemed to be insufficient for the purpose of reducing the acoustic criteria, and the use of the 22 measurements is considered conservative for the derivation of the acoustic flight and test criteria.

As previously described in [l], liftoff acoustic data from ETR were particularly susceptible to electrical noise spikes. A special procedure was developed to remove the effects of this contamination from data for the first six flights [9], while standard editing methods were used on the last two flights prior to spectral analysis [10].

Envelopes over the 17 maximax PLF and the 5 maximax Centaur acoustic spectra were drawn, resulting in the heavy lines of Figures '2-3. Statistical analyses were also performed on all 22 spectra. Figure 4 shows the mean value and 95 percent upper tolerance limit, with 50 percent con fidence, based on statistical analysis of the 22 spectra of Figures 2-3, assuming a normal distribution of sound pressure levels (SPLs) for each 1/3 OB. The usc of P95/50 statistics for deriving vi broacoustic criteria from flight data has been a USAF and NASA tradition for many years.

ACOUSTIC TEST DATA SUMMARY

Flat Panel Results. A test program was initiated to determine if an increase in acoustic blanket thickness and/or the addition of a sound barrier could achieve the. desired reduction of acoustic loading applied to Cassini and its RTGs. An elaborate series of flat panel tests were first implemented to determine. if either or both of these solutions could produce the needed attenuation of 3 dB 01 more in the 200-250117, bands [6,7,11]. Testing was necessary because the application of acoustic theory to this problem was severely limited duc to an inability to account simultaneously for twin factors of sound absorption and transmission. Flat panel results indicated that only one of the tested configurations could achieve the desired reduction without a substantial increase in payload liftoff weight, namely, a 6 in. blanket having a density of 0.6 lb/ft^3, plus a 0.043 in.nlicl-plane barrier having a surface density of 0.44 lb/ft^2, for an overall surface density of 0.74 lb/ft^2.

The standard Titan IV 3 in. blanket having a density of 0.6 lb/ft^3, for an overall surface density of 0.15 lb/ft^2, was also tested since blankets of this design were installed during flights when acoustic measurements were made.

Cassini Simulator/PLF Reverberant Test Procedure. Unfortunately, the attenuation was needed in the frequency range (200-250 Hz) dominated by the ring frequency of the cylindrical portion of the. PLF. Thus there. was no guarantee that flat panel results would be directly applicable to the Cassini installation. As a result, PLF tests were deemed necessary to demonstrate that adequate reduction was achievable under realistic Cassini conditions. Fortunately, (hc timing of PLF blanket tests coincided with vibroacoustic testing of the Cassini partial development test model (l)"J'M), the simulator shown in Figure 5, which simultaneously permitted the determination of acoustic attenuation effects on the structural response of spacecraft and component simulators [1 1, 12]. Unlike tile. partial-DTM test in its PLF, the forthcoming protoflight acoustic test on the actual Cassini spacecraft in the JPL reverberant chamber will not utilize a PLF. Thus special attention is required to account for acoustic loads expected to cause higher spacecraft vibration response, especially loads applied to the Huygens Probe (HP) and the High Gain Antenna (HGA) as determined from partial-DTM/PLF testing. In addition to determining the acoustic transmission/ absorption of the 3- and 6-in. blanket configurations, (hc other objectives of partial-DTM testing included:

(a) Determination of fill effects of having the. 11P and other Cassini elements in close proximity to the PLF.

(b) Evaluation of the effects of having the HGA separate the biconic section from the cylindrical section of the PLF.

(c) Determination of the effects of percentage blanket coverage on acoustic attenuation.

(d) Evaluation of the effects of tuned vibration absorbers (TVAs) on the structural response of RTGs.

The Cassini partial-DTM was installed in a 60 ft long section of the PLF, along with a Centaur-like support structure, and the blanket con figuration to be tested attached to the PLF interior for the specified acoustic test run, as shown in Figure 5. This assembly was installed in the Reverberant Acoustic Laboratory facility located at Lockheed-Martin Astronautics in Denver, CO, where acoustic noise from air modulators was applied to the PLF exterior. A sketch of the 8 exterior and 27 interior microphone locations appears in Figure 5. A total of 72 accelerometers and 4 triaxial force gages were also installed on or in the Cassini partial-DTM structure. Data from some of these transducers has been reported elsewhere [5-8,1 1,12]. For the Cassini mission, it was intended that the thicker barrier-blanket be installed on the PLF interior in the. vicinity of the major portion of the spacecraft only, rather than complete PLF coverage, in order to save weight while still being locally effective.

Although gene.rally similar, the.rc are important differences between the. acoustic environments applied to the

PLF exterior during flight and during a reverberant acoustic chamber test. Also, there is some variability between reverberant test runs, mainly clue to difficulties in achieving perfeet acoustic test control. To avoid having potential errors influence the evaluation of the 6 in. ban ier-blanket, and the prediction of the flight environment using the thicker configuration, the following procedure was used in processing the measured acoustic data:

(1) For each test run, all microphone data were analyzed twice, first using a constant resolution bandwidth of 4 Hz up to 2 kHz, and then using 1/3 OBs with center frequencies ranging from 31.5 Hz to 4 kHz.
(2) f 'or each run, the average 1/3 OB SPL, plus the ovc.rail (OA) SPL, for the six external control microphones was computed for each 1/3 011, and the. difference taken between this aver age and the external acoustic test specification. This difference is called the external correction.
(3) For each run, the 1/3 OB SPLs from **15** internal micr ophones were averaged and adjusted using the external correction of Step 2. The average 1/3 OB SPLs are cal led the internal adjusted spectrum.
(4) To predict the additional acoustic attenuation of the thicker configurati on, the difference was taken between the internal adjusted acoustic spectra of Step 3 for the applicable pair of test runs, i.e., (a) the original 3 in. flight blanket, and (h) the 6 in. Cassini barrier-blanket.
(5) To establish the revised Cassini flight acoustic criteria using the thicker configur ation, the difference of Step 4 was subtracted from the original P95/50 flight acoustic criteria shown in Figure 4.

Experience has shown that acoustic fill effects can cause a substantial increase in the local acoustic environment applied to structural assemblies which arc c1osc to the PLF [13]. The HP is the close.st of these assemblies, being approximately 34 in. from tile PLF surf ace.. The two methods of determining fill effect arc (a) an analytical formula derived from a recently revised theory [1 3], and/or (b) the direct measurement of the S1'1 .s in the gap.

As seen in Figure 5, the Cassini HGA effectively separates the biconic section of the PLF from the cylindrical section, **i.e.**, separating the PLF cavity into two volumes. Thus **it** would **not** be surprising **to** find two distinct acoustic environments for these volumes, both of which apply fluctuating pressure to opposite sides of the HGA with the structural loading dependent on the pressure cross-spectrum across the I] GA. Coherence data [14-16] fot a microphone pair on opposite sides of the HGA close to the structure, i.e, M4 and M6 in Figure 5, show low coherence (except at 43 Hz), which indicates that the two acoustic fields act independently and the two spectra should be root sum squared. At 43 Hz, the coherence is fairly high and the phase angle is nearly zero, indicating the instantaneous pressures should be subtracted and the loading reduced.

Cassini Simulator/PLF Reverberant Test Results.rl'l)c raw acoustic test data was processed in accordance with Step 1-5 to provide the desired revision to the Cassini flight acoustic criteria. Figure 6 shows the internal adjusted spectra for the tests of the 3 in. flight blanket, and the 6 in. Cassini barrier-blanket (which was installed in the vicinity of the spacecraft) and the 3 in. blanket elsewhere. The additional acoustic attenuation provided by the thicker configuration was obtained by taking the difference and subtracting it from the 1'95/50 flight spectrum of Figure 4 in order to predict the Cassini 1'95/50 internal flight spectrum shown in Figure 7.

To determine the fill effect for the Huygens Probe, Microphone 11 shown in Figure 5 was located in the 28 in. gap between the center of the HP and the PLF. It malfunctio ned during the test o f the 6 in. barrier-blanket, making a direct measurement impossible, but fortunately, the revised analytical fill theory [13] could be substituted.

As observed in Figure S, the HGA effectively divides the 1'1 .F cavity into two volumes, i.e., the biconic section **above** and **[he.** cylindrical section below the HGA. The flight acoustic data were acquired at locations in tile cylindrical section only. Thus it was necessary to obtain acoustic data in both sections during the Partial-DTM/PLF test to ascertain if higher or lower S1'1.s existed in the biconic section. If higher levels were found, then an increase in the Cassini acoustic test criteria would be justified over that determined from previous flight data. For application to Cassini spacecraft acoustic testing, data for the two acoustic fields from the test of the 6 in. blanket were compared. Spectra for the three microphones within the biconic section (M2-4) were averaged anti compared with the spectral average from 15 microphones in tile cylindrical section. Acoustic undertesting of the Cassini spacecraft wiii be avoided by increasing the 1'95/50 flight spectrum of Figure 4 by this difference. The avoidance of HGA under- or over-testing is aiso dependent on the pressure cross- spectrum across opposite sides of the HGA during the forthcoming Cassini spacecraft acoustic test.

CASSINI SPACECRAFT ACOUSTIC FLIGHT ANI) TEST CRITERIA

In order to provide more thrust to the Titan I V vehicle, which is required to permit tile launch of the heaviest possible spacecraft propellant mass, the previously-used standard steel case solid rocket motors (SRMs) will be replaced by recently-developed mot-powerful (7 percent) composite case SRM upgrades (SRMUs). This change is predicted to result in a small increase in acoustic levels, less than 1 dB, which must be taken into account before the re.vise.d Cassini flight criteria and the Cassini spacecraft acoustic test criteria are dc.rived. In summary, the acoustic flight criteria, and the acoustic test criteria for the upcoming spacecraft test without the PLF, were derived using:

(1) the P95/50 internal PLF flight spectrum of Figure 4,

(2) minus the difference between the internal adjusted spectra of Figure 6 to account for the thicker barrier-blanket attenuation,

(3) plus a 1 dB increase for using the SRMUs for the Cassini mission, lc.suiting in the revised Cassini acoustic flight criteria of Figure 8,

(4) plus the maximum of (a) the HP analytical fill effect, and (b) the difference between the two average acoustic spectra across the HGA,

(5) plus minor "adjustments" needed to provide a smooth test spectrum required by air modulators, resulting in the revised acoustic test criteria for the Cassini spacecraft, also shown in Figure 8.

The test spectrum to be used for the reverberant acoustic test of the Cassini spacecraft without the PLF has a protoflight margin of 4 dB over the FA test spectrum of Figure 8.

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REFERENCES

1. Himelblau, H., Kern, D. L., and Davis, G. L., "Development of Cassini Acoustic Criteria Using Titan IV Flight Data", *Proc. 38th ATM, Inst. Envir. Sc.*, v.2, pp 307-331, May 1992.
2. Himelblau, H., Kern, D. L., and Davis, G. L., "Summary of Cassini Acoustic Criteria Development Using Titan IV Flight Data", *J. Inst. Envir. Sc.*, v. XXXVI, n. 5, c.over and pp 19-27, Sept./Oct. 1993.
3. Bergen, T. F., Himelblau, H., and Kern, D. L., "Development of Acoustic Test Criteria for the Cassini Spacecraft", *Proc. 42nd ATM, Inst. Envir. SC,, v.* PR/DTE, pp 266-285, May 1996.
4. Bergen, T. F., "Vibration Damping of the Cassini Spacecraft Structure", *Proc. 41st ATM, Inst. Envir. SC.*, v. PR/DTE, pp 189-195, Apr./May 1995.
5. Bergen, T. F., and Kern, D. L., "Attenuation of Cassini Spacecraft Vibroacoustic Environment", *Proc. 42nd ATM, Inst. Envir. SC., v.* PR/DTE, pp 254-265, May 1996.
6. Hughes, W. O., and McNelis, A. M., "Cassini/Titan IV Acoustic Blanket Development and Testing", *Proc. 42nd ATM, Inst. Envir. Se., v.* PR/DTE, pp 205-221, May 1996.
7. Bradford, L., and Manning, J. E., "Acoustic Blanket Effect on Payload Acoustic Environment", *Proc. 42nd ATM, Inst. Envir. SC., v.* PR/DTE, pp 244-253, May 1996.
8. Long, M, B., Carne, D. A., and Fuller, C. M., "Acoustic Blanket Effect on Payload Fairing Vibration", *Proc. 42nd ATM, Inst. Envir. Sc., v. PWIY1'11*, pp 22?-? 33, May 1996.
9. Himelblau, H., "A Procedure for Editing Flight Dynamic Data Using a Combination of Digital Processing and Manual Removal of Electrical Noise Spikes", *Proc. 65th Shock and Vib. Symp., v.]*, pp 132-138, Nov. 1994.
10. Himelblau, H., Piersol, A. G., Wise, J. H., and Grundvig, M.R., "Handbook for Dynamic Data Acquisition and Analysis", *Inst. Envir. Sc. Recommended Practice DTE 012,1*, Sec.4, May 1994.
11. Hebert, B. F., and Manning, J. E., "Cassini Acoustic Blanket Test Program", Cambridge Collaborative Rept 95-2-12485-2, Feb. 1996.
12. Bradford, L... "Cassini Payoad Fairing (PLF) Acoustic Blanket Test", *Lockheed-Martin/Denve - Rept NAS3-00014*, Oct. *1995.*
13. Hughes, W. O., McNelis, M. E., and Manning, J. E., "NASA LeRC's Acoustic Fill Effect Test Program and Results", *Proc. 15th Aerospace Test Seminar*, Inst. Envir. Sc, Oct. 1994. Also *Proc. 65th Shock and Vib. Symp.*, *v.* 1, pp 459-474, Oct./Nov. 1994 and *NASA TM-106688*, Oct. 1994.
14. Ref. 10, Sec. 5.
15. Bendat, J. S., and Piersol, A .G., *Random Data: Analysis and Measurement Procedures, 2* nd cd., Wiley, NY, 1986.
16. Bendat, J. S., and Piersol, A. G., *Engineering Application of Correlation and Spectral Analysis, 2nd cd.*, Wiley, NY, 1993.

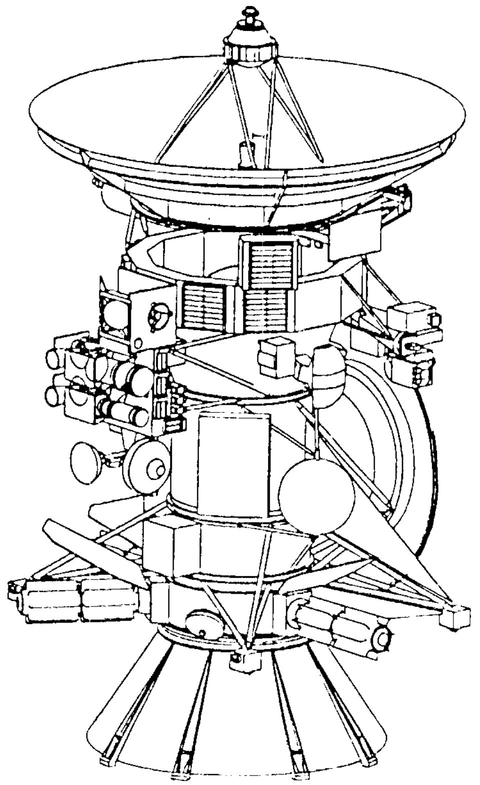

Figure 1: Trimetric View of the Cassini Spacecraft Launch Configuration

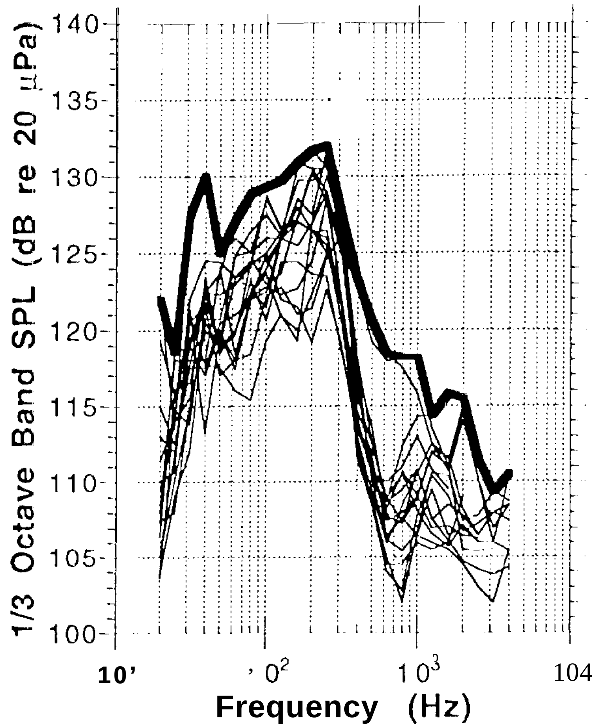

Figure 2: Spectral Envelope of Maximax Acoustic Spectra for 17 Internal Payload Fairing Measurements During Liftoff of Six Flights

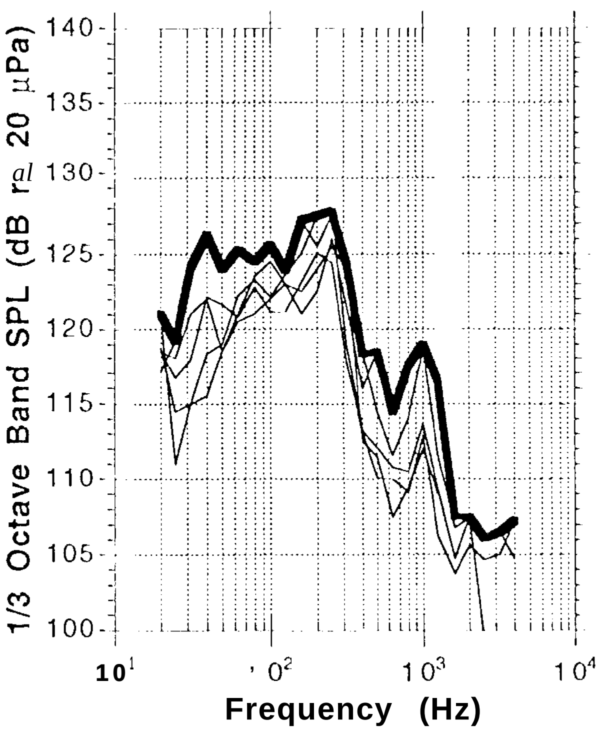

Figure 3: Spectral Envelope of Maximax Acoustic Spectra for Five Internal Centaur Measurements During Liftoff of Five ["lights

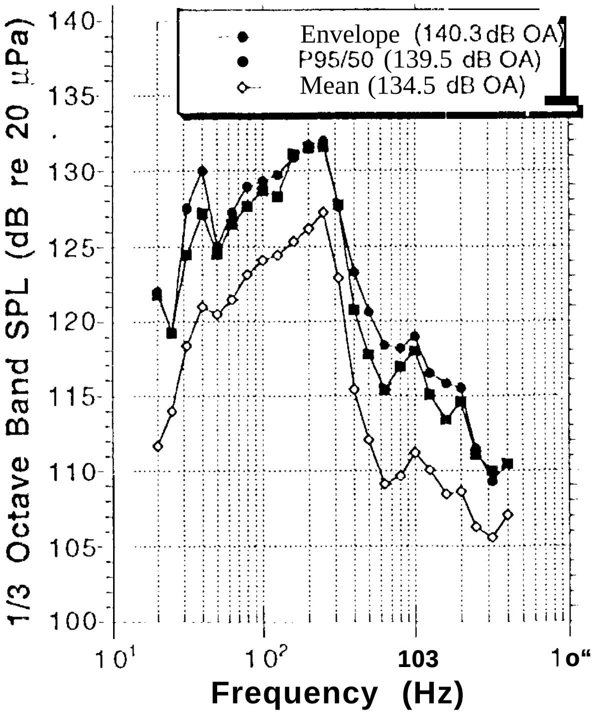

Figure 4: Comparison of Mean, P95/50%, and Spectral Envelope of Maximax Acoustic spectra for 22 Internal PLF/Centaur Measurements from 8 Titan IV Flights

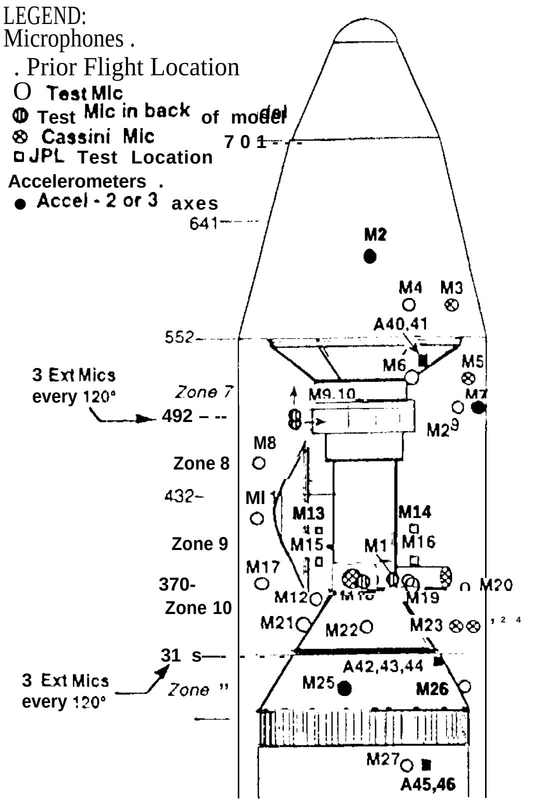

Figure 5: Configuration and Instrumentation Locations for the Partial DTM/PLF Acoustic Tests

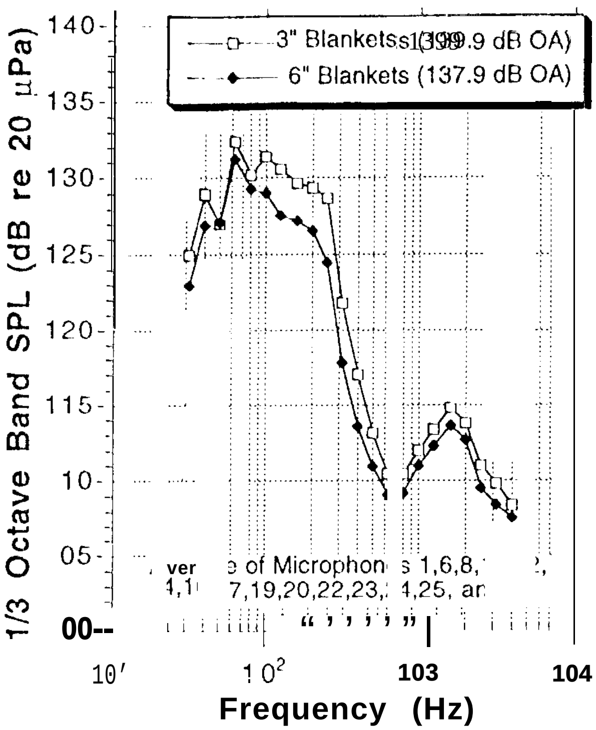

Figure 6: Comparison of Average Acoustic Levels Around the Spacecraft Measured During Testing of the Original 3" Flight Blanket and the 6" Cassini Blanket

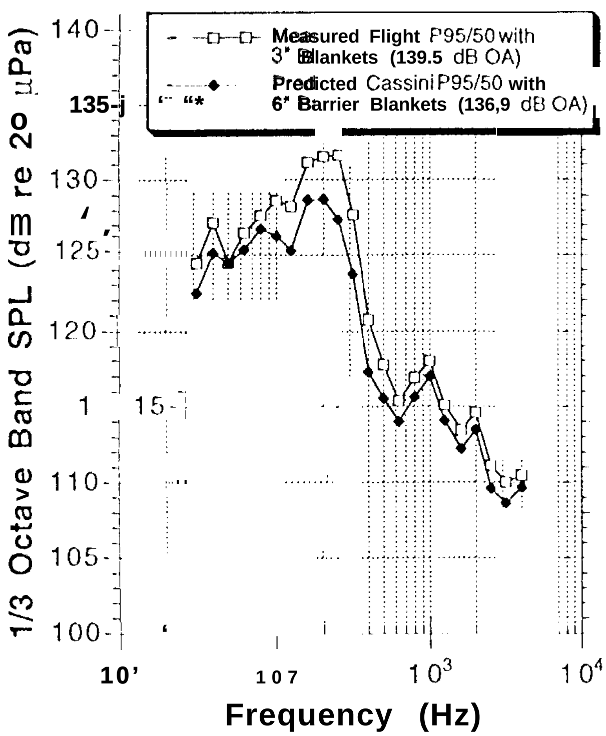

Figure 7: P95/50 Flight Spectrum Adjusted to Account for Cassini 6" Barrier Blankets

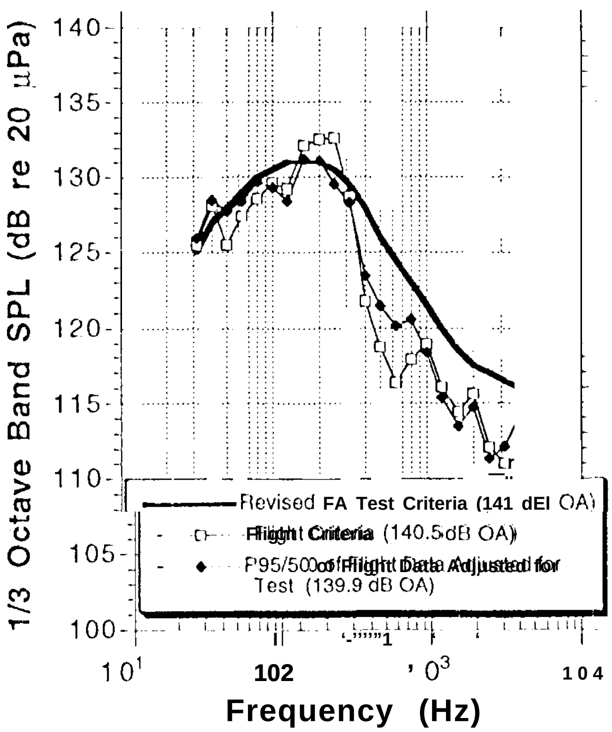

Figure 8: The Cassini Acoustic Flight Criteria and Flight Acceptance (FA) Test Criteria