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Using the Saturn V and Titan III Vibroacoustic Databanks for Random Vibration Criteria Development

R.C. Ferebee
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

July 2009

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R.C. Ferebee
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

National Aeronautics and
Space Administration

Marshall Space Flight Center • MSFC, Alabama 35812

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Acknowledgments

This is an update to TN D–7159 "Development and Application of Vibroacoustic Structural Data Banks in Predicting Vibration Design and Test Criteria for Rocket Vehicle Structures," which was originally published in 1973. Errors in the original publication were corrected, and additional data from the Titan program are also included. Some guidelines for calculating vibration criteria were also added. Special thanks to Phillip Harrison, Rajinder Mehta, Andrew Smith, and Lowery Duvall from the Marshall Space Flight Center for their technical review.

TRADEMARKS

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LIST OF ACRONYMNS

BW	bandwidth
dB	decibels
MARL	Mobile Acoustic Research Laboratory
Max Q	maximum dynamic pressure
MEFL	Maximum Expected Flight Level
MSFC	Marshall Space Flight Center
OASPL	overall sound pressure level
P/L	payload
PL	Probability Level
PSD	Power Spectral Density
psi	pounds (force) per square inch
rms	root-mean-square
SRB	Solid Rocket Booster
Sta.	station
TM	Technical Memorandum

NOMENCLATURE

f	frequency of vibration, Hz
f_i	the *i*th center frequency, Hz
g	acceleration due to cyclic motion divided by the acceleration of gravity
g^2/ Hz	acceleration power spectral density of vibration structure (in terms of acceleration)
G_i(97.5% PL)	97.5% probability level of G_i(f) corrected for nonstandard normal distribution
$G_L(f)$	normalized acceleration power spectral density as a function of frequency, g^2/Hz
$G_M(f)$	measured acceleration power spectral density as a function of frequency, g^2/Hz
$G_N(f)$	new vehicle acceleration power spectral density as a function of frequency, g^2/Hz
$G_R(f)$	data bank acceleration power spectral density as a function of frequency, g^2/Hz
K_i(97.5%)	factor for positively skewed function
M_N	mass per unit area of the new vehicle's structure
M_R	mass per unit area of the data bank structure
N	number of g_i(f) or acceleration power spectral density spectra
$P_L(f)$	reference acoustic pressure as a function of frequency, psi_{rms}
$P_M(f)$	measured acoustic pressure as a function of frequency, psi_{rms}
$P_N(f)$	new vehicle measured or predicted acoustic pressure as a function of frequency, psi_{rms}

NOMENCLATURE (Continued)

$P_R(f)$	reference acoustic pressure as a function of frequency, psi_{rms}
S_i	skewness, a measure of how symmetrical a distribution is with respect to the mean
$\bar{X}_i$	the mean or average of all values
X_i	the ith input value, g^2/Hz or g/10 Hz bandwidth
σ_i	standard deviation or measure of dispersion of data points around their mean value
σ_i^2	variance or square of the standard deviation

TECHNICAL MEMORANDUM

USING THE SATURN V AND TITAN III VIBROACOUSTIC DATABANKS FOR RANDOM VIBRATION CRITERIA DEVELOPMENT

1. INTRODUCTION

This is an update to TN D–7159, "Development and Application of Vibroacoustic Structural Data Banks in Predicting Vibration Design and Test Criteria for Rocket Vehicle Structures," which was originally published in 1973.[1] There was an error in the processing of the data in the original report that has been corrected in this version. Originally, the data were normalized before statistics were calculated, which tended to introduce errors into the finished product. The original Saturn data[2,3] were reprocessed and this time the normalization was done after statistics were calculated. The revised process is described in section 2 of this document.

This study presents a comprehensive and accurate semi-empirical method of predicting the acoustically induced broadband random vibration criteria for component installations located on space vehicles. Vibroacoustic structural databanks were developed from the more than 1285 vibration and acoustic measurements taken on static firings and flights of the Saturn and Titan III vehicles and from the Mobile Acoustic Research Laboratory (MARL) testing program.

The MARL was a 12.19 m (40 ft) platform on wheels. Various large flight and development structures, such as instrument units, skirts, and interstages, were installed on the MARL and located in the acoustic near- and mid-fields and subjected to static firings of the various Saturn stages and engines at Marshall Space Flight Center (MSFC) and the Mississippi Test Facility. The MARL test structures were instrumented and vibration and acoustic data were recorded during the static firings.

A vibroacoustic structural databank is a statistical compilation of vibration and acoustic data, which are categorized according to definite structural configurations, such as skin stringer, ring frame, and honeycomb. Simply stated, a vibroacoustic databank indicates the vibration level for a given sound pressure level acting on a particular structural configuration.

An extensive examination of structural drawings for the Saturn vehicles and MARL test structures was made to define the structural parameters for the various databanks. The structural categories studied were ring frames, skin stringer, and honeycomb.

Vibration and acoustic data obtained during static firings and flights of the vehicles, as well as MARL data, were recorded on data summarization sheets. Information, such as data validity, slice time, and other elucidative information necessary for development of the databanks, is contained on these sheets.

For a particular databank, each of the vibration spectra with its associated acoustic spectrum was normalized to the reference acoustic spectrum shown on figure 1. The reference acoustic spectrum has no special meaning other than that it is a typical Saturn V liftoff acoustic spectrum. All vibration spectra were categorized according to structural zone, flight condition, and measurement direction; then, they were statistically analyzed to determine the mean and the 97.5% probability level spectra. The databanks were developed for both the liftoff and transonic environments, which consider the differences in the spatial correlation of the random acoustic pressure fields.

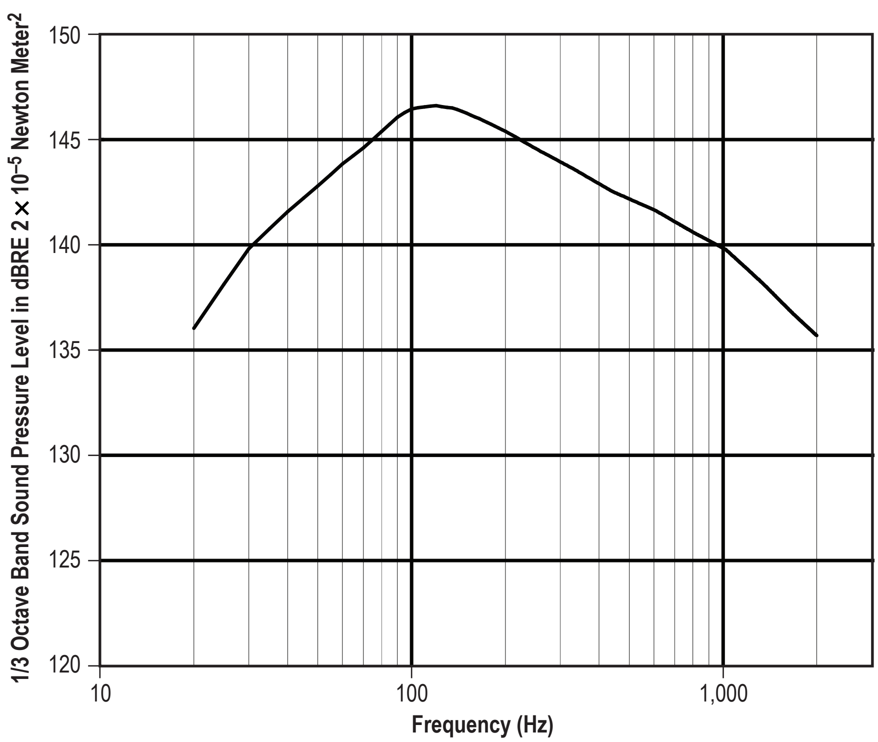

Figure 1. Reference acoustic spectrum.

In utilizing these databanks for determining vibration criteria for a new vehicle structure, the databank that is closest to the new vehicle structural configuration is selected. The proper mass and sound pressure level adjustments are made to determine the vibration criteria for the unloaded new vehicle structure. Component vibration criteria for varying weight ranges are then determined from conventional mass attenuation techniques.

2. VIBROACOUSTIC STRUCTURAL DATABANKS

2.1 Structural Characteristics

The Saturn and Titan launch vehicles have a complex structural definition consisting of ring frames, skin stringers, tanks, structural beams, etc. This Technical Memorandum (TM) is concerned with those structures that respond to acoustic and aerodynamic forcing functions. Therefore, vibroacoustic databanks were developed only for those categories falling under the structural definition of ring frame, skin stringer, and honeycomb panels.

- Ring frame: This type of structure is not directly susceptible to acoustic forcing functions, but receives motion from adjacent panels.

- Skin stringer: This type of structure responds to acoustic forcing functions. The stiffener (stringer) response depends directly on the motion of the skin.

- Honeycomb: This type of structure is directly excited by acoustic forcing functions. The Saturn stages and MARL test structures were structurally defined by reviewing a large number of structural assembly drawings.

Physical dimensions, such as skin thickness, ring frame dimensions, stringer dimensions, honeycomb core density, and other pertinent structural definitions, were assembled into structural configuration books. These books represent an exhaustive accumulation of structural information that was invaluable in defining the vibroacoustic structural databank categories. The structural information along with the locations of the vibration and acoustic measurements were recorded on data summarization sheets. These data sheets were used to develop the vibroacoustic structural databanks.

2.2 Vibration and Acoustic Data

Vibration and acoustic data from static firings and flights of the Saturn and Titan launch vehicles and from MARL were assembled and categorized. Using the measurement location structural description, the data were divided into the three structural categories described in section 2.1. Each measurement number with the measurement direction, measurement location, zone number, data sequence number, slice time, test number, frequency range, data validity, and flight condition (liftoff, Mach 1, and Max Q) were listed on the data summarization sheets. Both valid and invalid data were listed to maintain a permanent record of all the data obtained from static firings and flights of the launch vehicles and MARL tests. All valid vibration and acoustic measurements located on ring frame, skin stringer, or honeycomb structure were utilized in the vibroacoustic databanks with the exception of measurements located on component loaded structures. Component loaded structures were not considered in this study for the simple reason that any small change in the load would change the response of the structure. Measurements located on engines, fuel lines, brackets, loaded panels, and beams were not used to derive the vibroacoustic databanks in this report. However, the vibration measurements in each structural category were evaluated individually to determine if they actually represented a ring frame, skin stringer, or honeycomb response. This close evaluation was necessary since some vibration measurements were located on the skin near a ring and could be more representative of a ring frame response, rather than a skin-stringer response. The acoustic measurements were also summarized according to source variations, such as static firing, liftoff, and transonic flight. Other pertinent information similar to that recorded for the vibration measurement locations was also recorded for each acoustic measurement. The vibration data for numerous flight vehicle and static test locations have varied acoustic forcing functions. Each of the vibration spectra with its associated acoustic spectrum was normalized to a reference acoustic spectrum.

2.3 Statistical Analysis

Vibration and acoustic data from data retention at MSFC were retrieved from the storage tapes and assembled into vibroacoustic databanks for statistical analysis. A mean and 97.5% probability level spectra are derived for each structural category specified by the structural characteristics in section 2.1. The specific structural categories are divided into individual subdivisions depending on dimensional variations of the ring frames, skin stringer, and honeycomb panels. Each group or vibroacoustic databank consists of N spectral density spectra, each composed of 398 input values, covering the range from 20 to 2000 Hz in 5-Hz increments.

These 398 input values of X_i (power spectral density, g^2/Hz) for each spectrum were defined at center frequencies of f_i (Hz). The mean value $\bar{X}_i$ is the average of all values. In equation form, the mean is as follows:

$$\bar{X}_i = \frac{1}{N}\sum_{i=1}^{N} X_i \quad . \tag{1}$$

The mean square value is the average of the squared values. The variance is the mean squared value about the mean. In equation form, the variance is the following:

$$\sigma_i^2 = \frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X}_i)^2 \quad . \tag{2}$$

The standard deviation is the positive square root of the variance. The standard deviation is as follows:

$$\sigma_i = \left[\sum_{i=1}^{N}\frac{(X_i - \bar{X}_i)^2}{N-1}\right]^{\frac{1}{2}} \quad . \tag{3}$$

To determine the probability level, it is necessary to determine the skewness. Most statistical distributions are not symmetrical with respect to their mean and are therefore classified to be skewed. In equation form, the skewness is as follows:

$$S_i = \frac{\left[N\left(N-1\right)\right]^{\frac{1}{2}}}{N-2} \frac{\sum_{i=1}^{N}(X_i - \bar{X}_i)^3}{N\left[\sqrt{\sum_{i=1}^{N}\frac{(X_i - \bar{X}_i)^2}{N}}\right]^3} \quad . \tag{4}$$

For a collection of data samples, the probability level in reference 4 can be used to determine G_i (97.5% PL):

$$G_i\left(97.5\%\text{PL}\right) = \bar{X}_i + K_i\sigma_i \quad , \tag{5}$$

where:

G_i(97.5% PL)	=	97.5 percentile probability level in the i^{th} frequency increment.
$\bar{X}_i$	=	mean of the data samples in the i^{th} frequency increment.
σ_i	=	the standard deviation of the data samples in the i^{th} frequency increment.
K_i	=	the K factor of the i^{th} frequency increment.

The effects on the K_i factor of higher moments are ignored. For a positively skewed function, the factor K_i can be found from

$$K_i(97.5) = 1.96 \exp\left(0.2055\, S_i - 0.0155\, S_i^2\right) \quad , \tag{6}$$

where S_i is the skewness as defined by

$$S_i = \frac{\left[N\left(N-1\right)\right]^{\frac{1}{2}}}{N-2} \frac{\sum_{i=1}^{N}(X_i - \bar{X}_i)^3}{N\left[\sqrt{\sum_{i=1}^{N}\frac{(X_i - \bar{X}_i)^2}{N}}\right]^3} \quad . \tag{7}$$

The vibroacoustic databank normalized vibration data samples were statistically analyzed using the above equations. The results of this analysis are plots of the 97.5% probability level power spectral density (g^2/Hz) versus frequency from 20 to 2000 Hz. The 97.5% probability level composites were also calculated and are presented with the individual vibroacoustic databank parametric listings. The composite values were calculated by the following:

$$g_{\mathrm{rms}} = \frac{1}{\mathrm{BW}} \sum_{i=1}^{398} \frac{g^2}{\mathrm{Hz}} \left(f_i \right) , \tag{8}$$

where BW is equal to 5 Hz.

An alternative to the above procedure is to assume that the measured data is log–normally distributed, which presumes that the logarithms of the data points fit a normal distribution. Equation 5 can be used to calculate the 97.5 % PL using the K_i factors in table 1. For comparison, 95% PL levels are shown. The equation used to derive these numbers is:[5]

$$K\left(p,\gamma\right) = \frac{Z_p\left(1-f\right) + \left\{ Z_p^2\left(1-f\right)^2 - \left[\left(1-f\right)^2 - \frac{Z_\gamma^2}{2\left(n-1\right)}\right]\left(Z_p^2 - \frac{Z_\gamma^2}{n}\right)\right\}^{\frac{1}{2}}}{\left(1-f\right)^2 - \frac{Z_\gamma^2}{2\left(n-1\right)}} \quad . \tag{9}$$

where:

p = desired probability level with γ confidence.

f = $\dfrac{1}{4\left(n-1\right)}$.

Z_p = Prob($Z \le Z_p$) from standard tables, e.g., Z_p = 1.96 for 97.5% PL.
Z_γ = Prob($Z \le Z_\gamma$) from standard tables, e.g., Z_γ = 0 for 50% confidence.
n = number of samples.

Table 1. Tolerance factors for various probability levels.

n	95%PL, 50% Confidence *K*–Factor	97.5%PL, 50% Confidence *K*–Factor
2	2.193	2.613
3	1.880	2.240
4	1.794	2.138
5	1.755	2.091
6	1.731	2.063
7	1.716	2.045
8	1.706	2.033
9	1.698	2.023
10	1.692	2.016
11	1.687	2.010
12	1.683	2.006
13	1.680	2.002
14	1.677	1.998
15	1.675	1.996
20	1.667	1.986
25	1.662	1.981
30	1.659	1.977
40	1.655	1.973
50	1.653	1.970
60	1.652	1.968
70	1.651	1.967
100	1.649	1.965
∞	1.645	1.960

2.4 Normalization Method

To generate the vibroacoustic databanks, it is necessary to make all measured data compatible. Compatibility is achieved by normalizing all the measured vibration spectra and their acoustic spectra to the common acoustic forcing function shown in figure 1. After normalization, the only acoustic spectra needed to scale the acceleration are the reference and new spectra. The reference acoustic spectrum has no special meaning other than that it is a typical Saturn liftoff acoustic spectrum.

The normalization was performed by the following equation:

$$G_L(f) = G_M(f)\left[\frac{P_L(f)}{P_M(f)}\right]^2 , \tag{10}$$

where

$G_L(f)$ = Normalized power spectral density (g^2/Hz) as a function of frequency f.
$P_L(f)$ = Reference acoustic pressure (psi_{rms}) as a function of frequency f.
$G_M(f)$ = Measured power spectral density (g^2/Hz) as a function of frequency f.
$P_M(f)$ = Measured acoustic pressure (psi_{rms}) as a function of frequency f.

Statistics were calculated (mean and 97.5% PL) for all vibration spectra before they were normalized.* The output of the normalization program is power spectral density plots normalized to the reference acoustic spectrum. These individual plots are given a normalized vibration measurement number for identification and assembled into structural categories.

* This is the difference with the original publication. In reference 1, statistics were calculated after normalization, which affected the calculated standard deviation, and, ultimately, the 97.5% PL.

3. SATURN V AND TITAN III FLIGHT DATABANKS

Excel® spreadsheets containing all of these data are available upon request from the author.

3.1 Saturn V Databank

The Saturn V vibroacoustic databanks summarized in appendix A have been arranged into vehicle diameter categories of 6.71 m (22 ft) and 10.06 m (33 ft). Individual ring frame, skin stringer, and honeycomb structural categories are defined under each vehicle diameter. Each structural category is subdivided into longitudinal, radial, and tangential directions and into subdivisions based on structural dimensions. The databanks are further subdivided into conditions of static firing, liftoff, Mach 1, and maximum dynamic pressure. A condition representing combined conditions of liftoff and static firing was developed. Also, a transonic condition representing the combined conditions of Mach 1 and maximum dynamic pressure was developed. Each vibration measurement is presented with the 97.5% probability level acoustic measurement in the measurement zone. All acoustic spectra are shown in 1/3-octave band decibels. Structural characteristics, which came from reference 1, are summarized in table 2.

3.2 Honeycomb Databank

One honeycomb vibroacoustic databank was developed from the available vibration and acoustic data. The honeycomb databank consists of a parametric listing and power spectral density of the 97.5% probability levels. Appendix A, figure 133 shows the honeycomb databank.

3.3 Titan III Databank

The Titan III databanks in appendix B were compiled from data in reference 6 and have been arranged from lightest to heaviest surface density. Adding the weights of the skin, stringer, and ring frames and dividing by an area that includes at least two rings and stringers was used to calculate surface density. These databanks were compiled from data contained in reference 6. Structural characteristics are summarized in table 3 and a list of acoustic spectra is shown in table 4.

Caution should be applied when using the Titan databanks because individual spectra for each flight were often not available. Consequently, 97.5% probability levels were supplied in the reference documentation rather than the individual measurements, so the normalization was not done on each spectrum as in the Saturn V databank. Therefore, it is difficult to show that a vibration spectrum was the result of a particular acoustic spectrum; instead the vibration statistics are a result of acoustic statistics.

Table 2. Saturn V flight accelerometer data.

Page	Source (Ref. 1)	Type	Meas. Dir.	Flight Condition	Skin Thickness (in)	Vehicle Diameter (ft)	Ring Wt. (lb/ft)	Stringer Wt. (lb/ft)	Surface Wt.(lb/ft²)	Composite (g_{rms})	Source Meas.
29	A1	Ring Fr.	Long	Liftoff	0.032	22	0.95	0.47	2.0	3.18	E93–411 E96–411
31	A3	Ring Fr.	Long	Mach 1	0.032	22	0.95	0.47	2.0	13.84	
33	A5	Ring Fr.	Long	Max Q	0.032	22	0.95	0.47	2.0	11.32	
35	A7	Ring Fr.	Long	Mach 1/Max Q	0.032	22	0.95	0.47	2.0	13.41	
37	A9	Ring Fr.	Tangent	Liftoff	0.032	22	0.95	0.47	2.0	3.69	E95–411 E98–411
38	A11	Ring Fr.	Tangent	Mach 1	0.032	22	0.95	0.47	2.0	26.17	
39	A13	Ring Fr.	Tangent	Max Q	0.032	22	0.95	0.47	2.0	22.72	
40	A15	Ring Fr.	Tangent	Mach 1/Max Q	0.032	22	0.95	0.47	2.0	25.80	
41	A17	Ring Fr.	Radial	Liftoff	0.032	22	0.95	0.47	2.0	10.25	E94–411 E97–411
42	A19	Ring Fr.	Radial	Mach 1	0.032	22	0.95	0.47	2.0	34.06	
43	A21	Ring Fr.	Radial	Max Q	0.032	22	0.95	0.47	2.0	45.25	
44	A23	Ring Fr.	Radial	Mach 1/Max Q	0.032	22	0.95	0.47	2.0	34.33	
47	A25–1	Ring Fr.	Long	Liftoff	0.040	33	2.51	0.71	3.3	12.71	E88–219
49	A25–2	Ring Fr.	Long	Mach 1	0.040	33	2.51	0.71	3.3	12.15	
51	A25	Ring Fr.	Radial	Liftoff	0.040	33	2.51	0.71	3.3	15.25	E87–219
52	A27	Ring Fr.	Radial	Mach 1	0.040	33	2.51	0.71	3.3	14.58	
57	A29	Ring Fr.	Radial	Liftoff	0.04–0.07	33	1.09–1.49	0.71–1.0	1.1–1.5	42.13	E79–86–219 E344–200
58	A31	Ring Fr.	Radial	Mach 1	0.04–0.07	33	1.09–1.49	0.71–1.0	1.1–1.5	9.46	
59	A33	Ring Fr.	Radial	Max Q	0.04–0.07	33	1.09–1.49	0.71–1.0	1.1–1.5	13.33	
61	A35	Ring Fr.	Radial	Mach 1/Max Q	0.04–0.07	33	1.09–1.49	0.71–1.0	1.1–1.5	5.81	
64	A37	Ring Fr.	Radial	STATIC	0.100	33	5.53	1.00	9.2	16.37	E19–120
68	A39	Ring Fr.	Parallel	STATIC	0.08–0.13	25.2	4.67–7.95	1.04	4.7–8.0	0.61	WE229–206
70	A41	Ring Fr.	Normal	STATIC	0.130	17.5	11.39	1.04	13.9	2.03	WE181–206
73	A43	Ring Fr.	Long	Liftoff	0.185	33	4.75	N/A	6.2	5.10	E20–118
75	A45	Ring Fr.	Long	Mach 1	0.185	33	4.75	N/A	6.2	17.34	
77	A47	Ring Fr.	Long	Max Q	0.185	33	4.75	N/A	6.2	26.31	
79	A49	Ring Fr.	Long	Mach 1/Max Q	0.185	33	4.75	N/A	6.2	28.39	

Table 2. Saturn V flight accelerometer data (Continued).

Page	Source (Ref. 1)	Type	Meas. Dir.	Flight Condition	Skin Thickness (in)	Vehicle Diameter (ft)	Ring Wt. (lb/ft)	Stringer Wt. (lb/ft)	Surface Wt.(lb/ft²)	Composite (g_{rms})	Source Meas.
81	A51	Ring Fr.	Radial	Liftoff	0.185	33	4.75	N/A	6.2	24.75	E21–118
82	A53	Ring Fr.	Radial	Mach 1	0.185	33	4.75	N/A	6.2	25.07	
83	A55	Ring Fr.	Radial	Max Q	0.185	33	4.75	N/A	6.2	32.27	
84	A57	Ring Fr.	Radial	Mach 1/Max Q	0.185	33	4.75	N/A	6.2	32.28	
88	A73	Ring Fr.	Long	Liftoff	0.375	33	29.06	1.95	25.6	13.87	E23–115
90	A65	Ring Fr.	Long	Mach 1	0.375	33	29.06	1.95	25.6	18.94	
92	A69	Ring Fr.	Long	Mach 1/Max Q	0.375	33	29.06	1.95	25.6	10.60	
94	A75	Ring Fr.	Radial	Liftoff	0.375	33	29.06	1.95	25.6	3.55	E24–115
95	A77	Ring Fr.	Radial	Mach 1	0.375	33	29.06	1.95	25.6	12.10	
96	A79	Ring Fr.	Radial	Max Q	0.375	33	29.06	1.95	25.6	8.45	
98	A81	Ring Fr.	Radial	Mach 1/Max Q	0.375	33	29.06	1.95	25.6	6.75	
100	A87	Skin/Str.	Normal	Liftoff	0.040	33	N/A	1.41	3.3	21.87	
102	A89	Skin/Str.	Long	Liftoff	0.040	33	N/A	0.71	1.5	1.42	E326–219
104	A91	Skin/Str.	Long	Mach 1	0.040	33	N/A	0.71	1.5	2.18	E329–219
106	A93	Skin/Str.	Long	Max Q	0.040	33	N/A	0.71	1.5	1.91	E326–219
108	A95	Skin/Str.	Long	Mach 1/Max Q	0.040	33	N/A	0.71	1.5	4.41	
110	A97	Skin/Str.	Tangent	Liftoff	0.040	33	N/A	0.71	1.5	2.09	E327–219 E329–219
111	A99	Skin/Str.	Tangent	Mach 1	0.040	33	N/A	0.71	1.5	4.63	E327–219
112	A101	Skin/Str.	Tangent	Max Q	0.040	33	N/A	0.71	1.5	4.19	
113	A103	Skin/Str.	Tangent	Mach 1/Max Q	0.040	33	N/A	0.71	1.5	8.11	
114	A105	Skin/Str.	Radial	Liftoff	0.040	33	N/A	0.71	1.5	6.03	E325–219
115	A107	Skin/Str.	Radial	Mach 1	0.040	33	N/A	0.71	1.5	4.25	
121	A109	Skin/Str.	Long	STATIC	0.071	33	N/A	0.86	2.8	9.03	WE146–206
123	A111	Skin/Str.	Radial	Mach 1	0.071	33	N/A	0.86	2.8	56.49	
125	A113	Skin/Str.	Radial	Max Q	0.071	33	N/A	0.86	2.8	90.88	E351–206
127	A115	Skin/Str.	Radial	Mach 1/Max Q	0.071	33	N/A	0.86	2.8	67.06	
129	A117	Skin/Str.	Radial	STATIC	0.071	33	N/A	0.86	2.8	39.77	E75–206 WE240–206 E76–206 WE239–206 WE148–206
130	A119	Honeycomb	Radial	STATIC	0.030	22	N/A	N/A	3.1	67.60	

Table 3. Titan III flight accelerometer data.

Page	Source (Ref. 6)	Type	Meas. Dir.	Flight Condition	Mat'l	Skin Thickness (in)	Ring Wt. (lb/ft)	Stringer Wt. (lb/ft)	Surface Wt. (lb/ft^2)	Composite (g_{rms})	Source Meas.
136	A192	P/L Truss	Long	Mach 1/Max Q	7178 AL	0.028	1.48	2.38	2.28	12.35	2727
137	A193	P/L Truss	Radial	Mach 1/Max Q	7178 AL	0.028	1.48	2.38	2.28	14.04	2728
138	A182	Ring Fr.	Long	Liftoff	7075 AL	0.028	1.48	0.24	2.49	6.94	2718/2721
139	A190	Ring Fr.	Long	Mach 1	7075 AL	0.028	1.48	0.24	2.49	4.96	2718/2721
140	A183	Ring Fr.	Radial	Liftoff	7075 AL	0.028	1.48	0.24	2.49	4.25	2719/2722
141	A191	Ring Fr.	Radial	Mach 1	7075 AL	0.028	1.48	0.24	2.49	4.95	2719/2722
142	A142	Skin/Str.	Long	Liftoff	2014 AL	0.028	0.84	0.38	2.49	4.92	2551/2563/2702
143	A147	Skin/Str.	Long	Mach 1	2014 AL	0.028	0.84	0.38	2.49	11.85	2551/2653/2702
144	A180	Skin/Str.	Radial	Liftoff	2014 AL	0.028	0.84	0.376	2.49	8.79	2552/2703/2654
145	A149	Skin/Str.	Radial	Mach 1	2014 AL	0.028	0.84	0.38	2.49	23.26	2552/2703/2654
151	A127	Skin/Str.	Radial	Liftoff	7075 AL	0.04	0.32–0.77	0.85	2.70	6.83	2519
152	A128	Skin/Str.	Tangent	Liftoff	7075 AL	0.04	0.32–0.77	0.85	2.70	9.32	2530
153	A129	Skin/Str.	Tangent	Mach 1	7075 AL	0.04	0.32–0.77	0.85	2.70	14.88	2530
159	A104	Skin/Str.	Radial	Liftoff	AL	0.04	0.55–0.65	0.86	3.06	9.95	2567/2603
160	A106	Skin/Str.	Radial	Mach 1/Max Q	AL	0.04	0.55–0.65	0.86	3.06	23.16	2566/2602/2603
161	A109	Skin/Str.	Radial	Transonic	AL	0.04	0.55–0.65	0.86	3.06	23.43	2567/2367
162	A107	Skin/Str.	Long	Liftoff	AL	0.04	0.55–0.65	0.86	3.06	3.42	2602/2566
163	A108	Skin/Str.	Tangent	Liftoff	AL	0.04	0.55–0.65	0.86	3.06	3.06	2604
167	A88	Skin/Str.	Radial	Mach 1	7075 AL	0.241	1.8	1.06	4.52	26.40	2723
168	A81	Skin/Str.	Radial	Liftoff	7075 AL	0.04	0.86–1.18	1.06	4.67	18.02	2527
169	A83	Skin/Str.	Radial	Transonic	7075 AL	0.04	0.86–1.18	1.06	4.67	63.94	2527
170	A90	Skin/Str.	Tangent	Liftoff	7075 AL	0.04	1.18	1.06	4.67	7.04	2612
173	A79	Skin/Str.	Long	Liftoff	7075 AL	0.04	0.86–1.18	1.06	4.67	23.09	2610/2526
174	A77	Skin/Str.	Radial	Liftoff	7075 AL	0.04	1.18	1.06	4.67	15.18	2611/2608/2723
181	A40	Skin/Str.	Long	Liftoff	2014 AL	0.25	3.9–4.21	0.73	8.40	8.72	2540
182	A49	Skin/Str.	Radial	Liftoff	2014 AL	0.07	3.9–4.21	0.84	8.40	23.02	2623
183	A51	Skin/Str.	Radial	Liftoff	2014 AL	0.25	3.9–4.21	0.73	12.08	19.20	2541
184	A50	Skin/Str.	Radial	Transonic	2014 AL	0.1	3.9–4.21	0.84	12.08	8.16	2623
185	A51–2	Skin/Str.	Tangent	Liftoff	2014 AL	0.1	3.9–4.21	0.84	12.08	11.50	
186	A47	Skin/Str.	Long	Liftoff	7079 AL	0.07	4.21	0.84	27.9	19.77	2572
187	A38	Skin/Str.	Radial	Liftoff	7079 AL	0.07	4.2	0.84	27.9	8.90	2573
188	A48	Skin/Str.	Radial	Transonic	7079 AL	0.07	4.21	0.84	27.9	5.08	2573

Table 4. Titan III acoustic measurements.

Compartment	Meas. ID	Station	Flight Condition	Page
3A	2574 2628	124 124	Liftoff Mach 1 Max Q	146 147 148
2B	2629 2724	380 380	Liftoff Mach 1/Max Q	154 155
2C	2725	450	Liftoff Mach 1/Max Q	164 165
1A	2630 2575 2726	567 567 559	Liftoff Max Q Mach 1	175 176 177
1C	2576 2631	1219 1219	Liftoff Mach 1	189 190

4. APPLICATION OF VIBROACOUSTIC DATABANKS

4.1 Utilization of Vibroacoustic Databanks

The vibroacoustic databanks presented have been defined for vehicle diameter, flight conditions, static firings, and various parametric categories. The following procedures should be followed to determine vibration criteria for a new vehicle structure:

(1) Select a databank from the appendices that best represents the new vehicle local structural configuration. Tables 2 and 3 provide the databank structural parameters for making this selection. Liftoff and static firing acoustic spectra produce different vibration responses than the ascent spectra because the correlation for ascent is less efficient than the more reverberant field produced at liftoff. Be sure to use the correct conditions. It is prudent to select more than one databank spectrum to scale because that tends to average the structural differences between the reference and new vehicles and leads to a more representative sample.

(2) A 'back–up area' is chosen and the weight is smeared over that area to calculate the surface weight. Using a width of more than three times the ring separation is not advisable because aspect ratio then becomes important. When using the ring-frame data the length and width of the back-up area is usually equal to the ring separation distance.

(3) When the most representative databank is selected, make necessary mass and acoustic pressure adjustments according to equation (11) to determine vibration criteria for unloaded new vehicle structure:

$$G_N(f) = G_R(f)\left[\frac{P_N(f)}{P_R(f)}\right]^2\left[\frac{M_R}{M_N}\right], \quad (11)$$

where:

$G_N(f)$ = New vehicle power spectral density (g^2/Hz) as a function of frequency f.
$G_R(f)$ = Databank power spectral density (g^2/Hz) as a function of frequency f.
$P_N(f)$ = New vehicle measured or predicted acoustic pressure (psi_{rms}) as a function of frequency f.
$P_R(f)$ = Reference acoustic pressure (psi_{rms}) as a function of frequency f.
M_N = Mass per unit area of new structure.
M_R = Mass per unit area of databank structure.

Dimensionally, the mass term should be squared; however, experience has shown that the measured data are better fit by not squaring the term. Alternatively, equation (11) can be re-written as follows:

$$G_N(f) = G_R(f)\left[10\frac{dB_N(f) - dB_R(f)}{10}\right]\left[\frac{M_R}{M_N}\right], \qquad (12)$$

where $dB(f)$ are the reference and new acoustic spectra in decibels.

This technique assumes that structures respond linearly with acoustic amplitude. That assumption can only be carried so far since eventually the structure will hit its elastic limit and become non-linear. Extrapolation upward beyond 6–10 dB should be done with caution and backed up with test data. Scaling downward to lower levels can be done over a greater range, although the results will be conservative.

4.2 Component Weight and Frequency Scaling

If a heavy component is to be mounted to the scaled structure, equation (11) can be modified by the addition of a component mass scaling factor, resulting in the following[7]:

$$G_N(f) = G_R(f)\left[\frac{P_N(f)}{P_R(f)}\right]^2\left[\frac{M_R}{M_N}\right]\left[\frac{W_R}{W_R + W_C}\right], \qquad (13)$$

where

W_R = Weight of the reference structure backup area.
W_C = Weight of the component.

Again, the weight term should be squared for dimensional accuracy, but the data support using the equation as written. When calculating criteria for various component weight ranges, use the lightest component weight in the range in equation 13 for conservatism.

For predictions on cylindrical space vehicle structure, letting f_R and f_N denote the values along the frequency axes for the spectra of the high frequency vibration responses on the reference and new vehicle, respectively, the frequency axis of the spectrum is shifted for diameter from the reference to the new vehicle by

$$f_N \frac{D_R}{D_N} f_R \ , \qquad (14)$$

where D_R and D_N are the diameters for the reference and new vehicle, respectively. Above the fundamental ring frequency, the local structural characteristics predominate, and frequency shifting is not necessary.[8]

4.3 Components Mounted to Rocket Engines

Although this document is concerned with acoustically induced vibration, reference 7 contains some excellent guidelines for developing vibration criteria for engine-mounted components. Scaling is based on relative thrust and exhaust velocity for similar engines.

5. TEST CRITERIA DEVELOPMENT

Test criteria specify how a component is tested in order to qualify it for flight. In general, the amplitudes of the vibration test criteria are the same as the environments, since they also represent the maximum environment. However, for simplicity, the criteria may represent an envelope of the maximum environment for several flight regimes. In presenting the criteria, the space vehicle and payload are divided into major structural zones, such as aft skirt, forward skirt, nose cone, payload rack, etc. Each of these major zones is further divided into subzones based on local structural configuration, such as ring frames, stringers, coldplates, etc. The subzones are further broken down based on component weight ranges and component population. In special cases, random vibration criteria are formulated for specific components. Since the criteria are used for design and testing of space vehicle components and experiments, they also include the time the environment is present.

5.1 Test Duration

Equivalent damage time is the time required to induce an amount of damage at a high test level equivalent to that induced by exposure to a varying stress level. Acoustically induced random vibration on launch vehicles is a non-stationary environment, i.e., its root-mean-square amplitude changes fairly rapidly over its duration. Figure 2 shows a typical acoustic time history for the Space Shuttle Solid Rocket Booster (SRB).

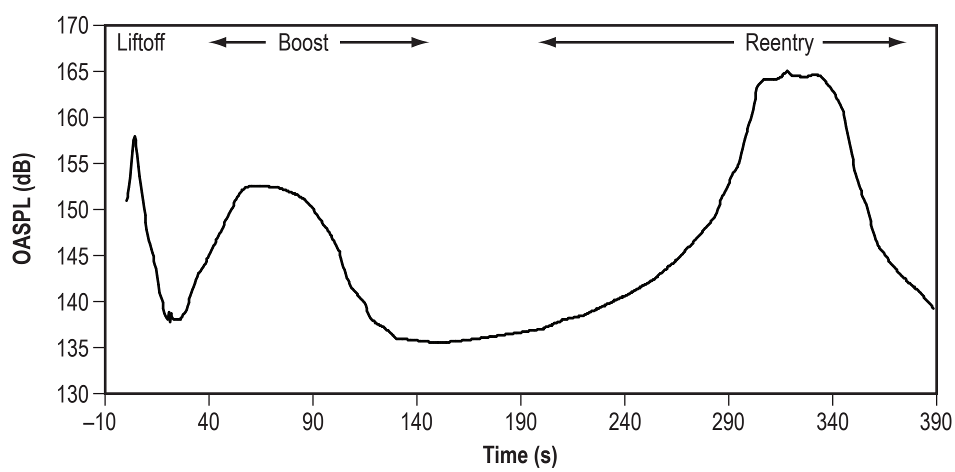

Figure 2. Typical Space Shuttle solid rocket booster mission profile.

Space Shuttle SRB and External Tank random vibration criteria were derived for each flight regime: liftoff, boost, and reentry. The spectra and test durations are specified for each time frame. The spectra are based on the peak acceleration during the particular flight phase, and the test duration is calculated to produce the same amount of fatigue damage as seen during the entire flight phase. The profile shown above can be an aggregate of several flights, or profiles can be normalized to the maximum values and averaged. Another technique is simply to calculate the equivalent fatigue times for several measurements over different flights and use the maximum value.

The equivalent damage time is based on Miner's rule:

$$W_2 = W_1 \left(\frac{T_1}{T_2} \right)^{n/b} , \tag{15}$$

where:

b = measure of slope of stress-cycles-to-failure (S–N) curve (as shown in figure 3). The value of b is in the range 3 to 25. However, a value of 9 is representative of many structural materials.[9]

n = damping-stress exponent. For viscoelastic damping n = 2. For low to intermediate stresses in elastic-plastic materials n = 2.4, and for high stresses n = 8.[9]

T_1, W_1 = duration and overall rms level of random vibration test 1.

T_2, W_2 = duration and overall rms level of random vibration test 2.

Note: When comparing individual PSD values of two spectra, divide n/b by 2.

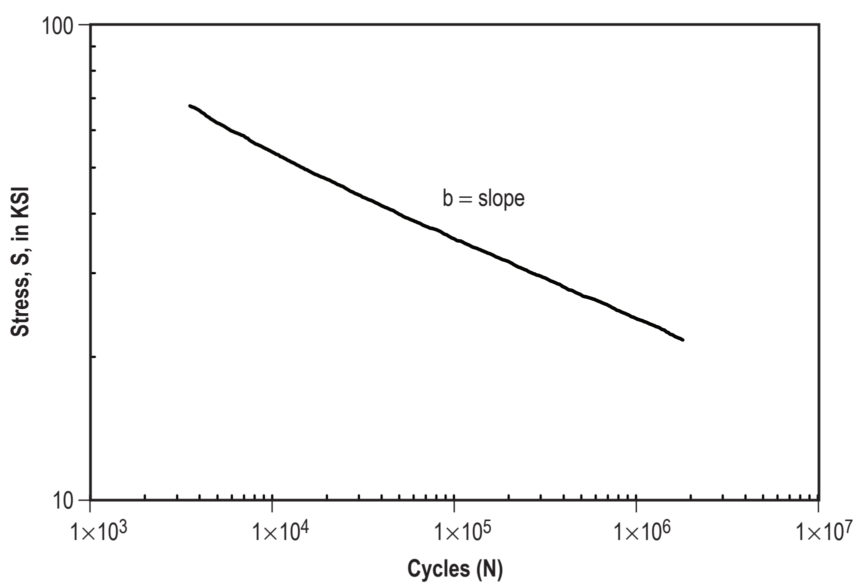

Figure 3. S–N curve for aluminum.

Rearranging terms in equation (15) and summing over N cycles results in the following equation:

$$T_{eq} = \sum_{i=1}^{N} T_i \left(\frac{W_i}{W_{max}} \right)^{b/n} , \quad (16)$$

where

W_{max} = maximum level during time period.
T_{eq} = equivalent damage time at level W_{max}.
T_i = time at level W_i .

Typical values of b/n are from four (for solder joints) to five (for aluminum structures).[9] W can represent any dynamic profile, such as sound pressure level (fig. 2), dynamic pressure, or sinusoidal acceleration. When using equation (15) for test time equivalence, use the minimum difference between the individual PSD values of the two spectra, then calculate the time equivalence using the overall rms values. The equivalent time should be the minimum of the two results.

The Space Shuttle program required that qualification duration should be four times the expected duration, which resulted in the following test durations for SRB hardware. A factor of two times the expected duration is put on the first test so that an article tested for only one flight gets plenty of margin. For liftoff this factor was increased to 50 s so that all items saw at least 60 s of vibration test.

Liftoff: T_{eq} = 2.5 s, flight duration = 10 s/mission. Total test time 50 s, plus 10 s per mission.
Boost: T_{eq} = 10 s, flight duration = 40 s/mission. Total test time 80 s, plus 40 s per mission.
Reentry: T_{eq} = 7.5 s, flight duration = 30 s/mission. Total test time 60 s, plus 30 s per mission.

5.2 Test Amplitude

After the proper scaling techniques have been applied, test criteria are derived by enveloping the scaled data. There is considerable latitude allowed in the enveloping technique; in fact, if five people are given the same data to envelope, they will probably produce six different envelopes.

In this example, Saturn V databank A75 was scaled to the Space Shuttle SRB forward skirt structural characteristics and acoustic environment. The following scale parameters were used:

Table 5. Structural parameters.

	New Structure	Reference Structure
Skin Thickness	0.54 in.	0.375 in.
Vehicle Diameter	12 ft.	33 ft.
Ring weight	9.1 lb/ft	29.1 lb/ft
Surface weight	12.4 lb/ft^2	25.6 lb/ft^2
Total weight (four square ft)	34.1 lb	81.4 lb

The result should look something like figure 4.

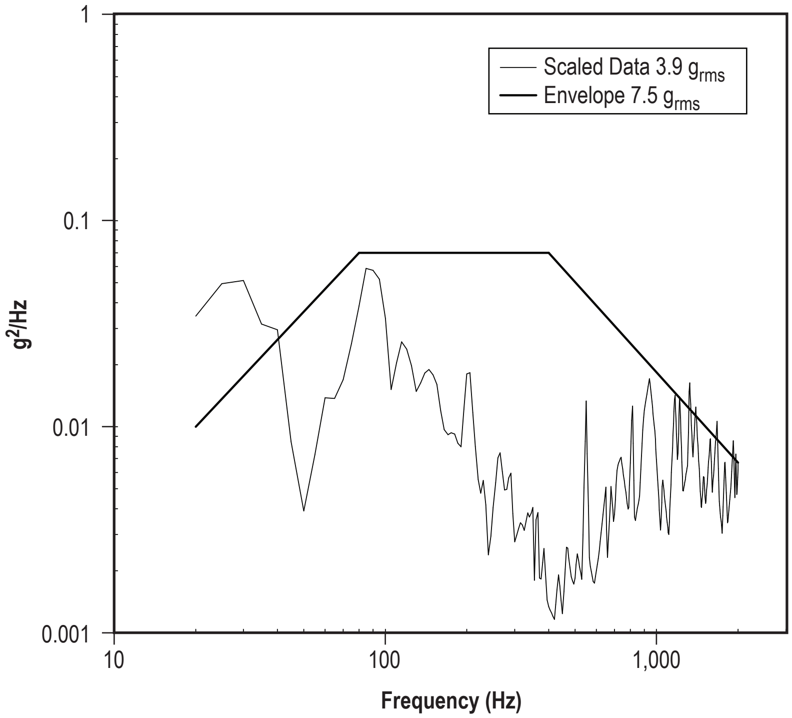

Figure 4. Scaled vibration data enveloped by criteria.

Since the new structure is about one-third of the diameter of the reference structure, the envelope is shifted higher in frequency to cover the first two peaks in the spectrum, which will occur at about 90 and 270 Hz on the SRB. A plot of the two acoustic spectra shows that they meet the stipulation in section 4.1, except for the area below 40 Hz. Additional margin can be added to the low frequency portion of the criteria to compensate. Figure 5 demonstrates a comparison of reference and new acoustic spectra.

It is quite common for the envelope to clip peaks in the spectrum. Peaks can be clipped by 3 dB if the half-power bandwidth of the peak is less than 10% of the center frequency. The rms value of the envelope is always much higher than that of the spectrum, even in the area where clipping occurs. The results are usually tabulated in a manner similar to that shown below:

Radial Axis, 50 s plus 10 s per mission

20 Hz	@	0.01 g^2/Hz
20 – 80 Hz	@	+4 dB/octave
80 – 400 Hz	@	0.07 g^2/Hz
400 – 2000 Hz	@	–3.5 dB/octave
2000 Hz	@	0.01 g^2/Hz
Composite	=	7.9 g_{rms}

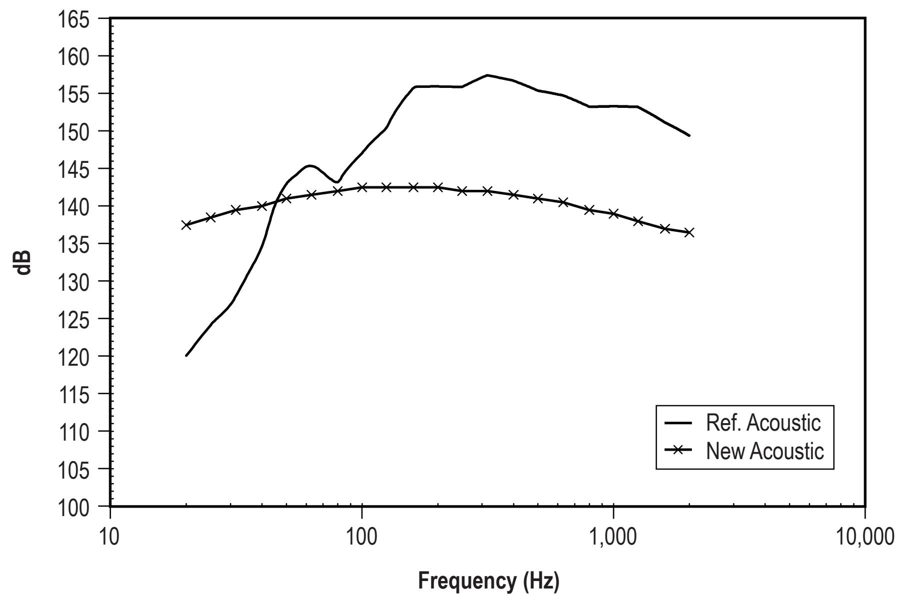

Figure 5. Comparison of reference and new acoustic spectra.

Slopes are calculated as a check for the shaker controller and they should usually be kept below 12–15 dB/octave because the controllers often have a difficult time controlling steep slopes. The slopes can be calculated by

$$m = 10\log_{10}(2)\frac{\log_{10}\left(PSD_2/PSD_1\right)}{\log_{10}\left(f_2/f_1\right)} \quad , \tag{17}$$

where

m = slope in dB/octave.
PSD = PSD values at frequencies f_1 and f_2.

5.3 Acceptance Test Criteria

Acceptance vibration tests can serve various purposes, depending upon the organization's viewpoint. Some acceptance tests are used to verify that the component was assembled correctly, and others are used to certify the component for flight. Some organizations use a minimum level, which often requires a qualification test for the acceptance criteria. Others specify a level below the qualification level for acceptance test with no minimum. Reference 10 contains a very good description of acceptance tests that were conducted during the Apollo program and some of the experiences that they had with the tests. Regardless of the philosophy, a good acceptance test program is essential to ensuring that the hardware is fit to fly.

Some of the methods of calculating acceptance test criteria are as follows:

• Fixed margin between qualification and acceptance – The maximum predicted flight level is used to determine either the acceptance or qualification level. If the MPFL is the acceptance level, then qualification is done at a fixed margin above MPFL. Organizations that use the acceptance test to certify for flight tend to follow this philosophy. Others set the qualification at the MPFL and run acceptance tests at a fixed margin below that level. The qualification test is considered to be the certification test for flight, and the acceptance test is used strictly to screen out manufacturing defects. Defects may include loose electrical connections, loose nuts, cold solder joints, improper crimps, and wire fatigue due to routing. If enough margin exists between acceptance and qualification (usually at least 6 dB), then no qualification for acceptance test will have to be conducted. Duration of the test is usually determined by the amount of functional testing that must be completed during vibration, but is generally between 1 and 3 minutes.

• Minimum acceptance test – If either of the methods above is used to determine acceptance test levels, there is a possibility that the levels may end up being so low that the vibration test may not screen all of the manufacturing defects. Most organizations have set a minimum screening spectrum, usually around 6 g_{rms}, which all acceptance test levels must exceed. The qualification for the acceptance test must be at least as high as the acceptance spectrum plus any tolerance differences. Figure 6 illustrates this concept. In this case, the upper tolerance on the acceptance test is 3 dB and the lower tolerance on the qualification for acceptance test is –1.5 dB, requiring a minimum margin of 4.5 dB. Testing this way ensures that acceptance tests will never exceed the qualification test. Duration of the qualification test should ensure that all possible acceptance tests are covered.

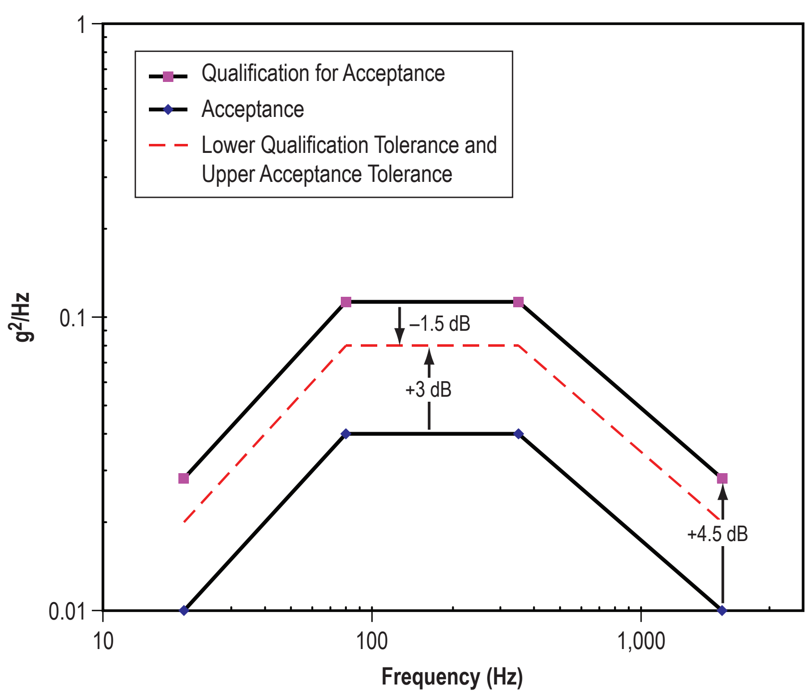

Figure 6. Illustration of tolerance stack-up.

6. CONCLUSIONS AND RECOMMENDATIONS

The vibroacoustic structural databanks that were developed herein represent an advancement in the method of predicting the structural response caused by an acoustic or aerodynamic forcing function. It is recommended that when using these vibroacoustic databanks, engineering judgment should be used in selecting the databank which best represents the new vehicle structure. This is necessary since an exact structural relationship between the databank structure and the new vehicle structure will more than likely not occur.

When implementing the techniques contained in this TM it becomes apparent that random vibration criteria development is not an exact science. Scaling different spectra with the same scaling parameters can give results that vary by a wide margin. The most important aspect of the component qualification process is that every design be given a vibration test with a spectrum that at least approximates the actual flight environment. Exact replication of the flight environment is not necessary, because the test will expose the weak points of the design and allow design fixes before it flies on the launch vehicle. Testing with this method on a shaker is conservative for the following reasons:

- Vibration criteria are broadband envelopes of fluctuating power spectra.
- Zonal vibration criteria are higher than criteria for a specific component.
  - Zonal criteria are based on lightest component weight.
- The applicable vibration test durations are applied in each of three orthogonal axes.
- Components are generally tested on a rigid fixture versus the more flexible vehicle structure.

The Space Shuttle experience showed that a strong ground qualification test program is important. Development flight instrumentation from Space Shuttle flights revealed exceedances to the qualification test criteria; however, no failures occurred during flight, even though the component had a number of failures during qualification testing. This reinforced the point that the component test program is very important to mission success. In addition, using vibration test technology during the component acceptance tests helps to reveal manufacturing flaws that could otherwise have escaped detection.

APPENDIX A—SATURN V VIBRATION AND ACOUSTIC DATA

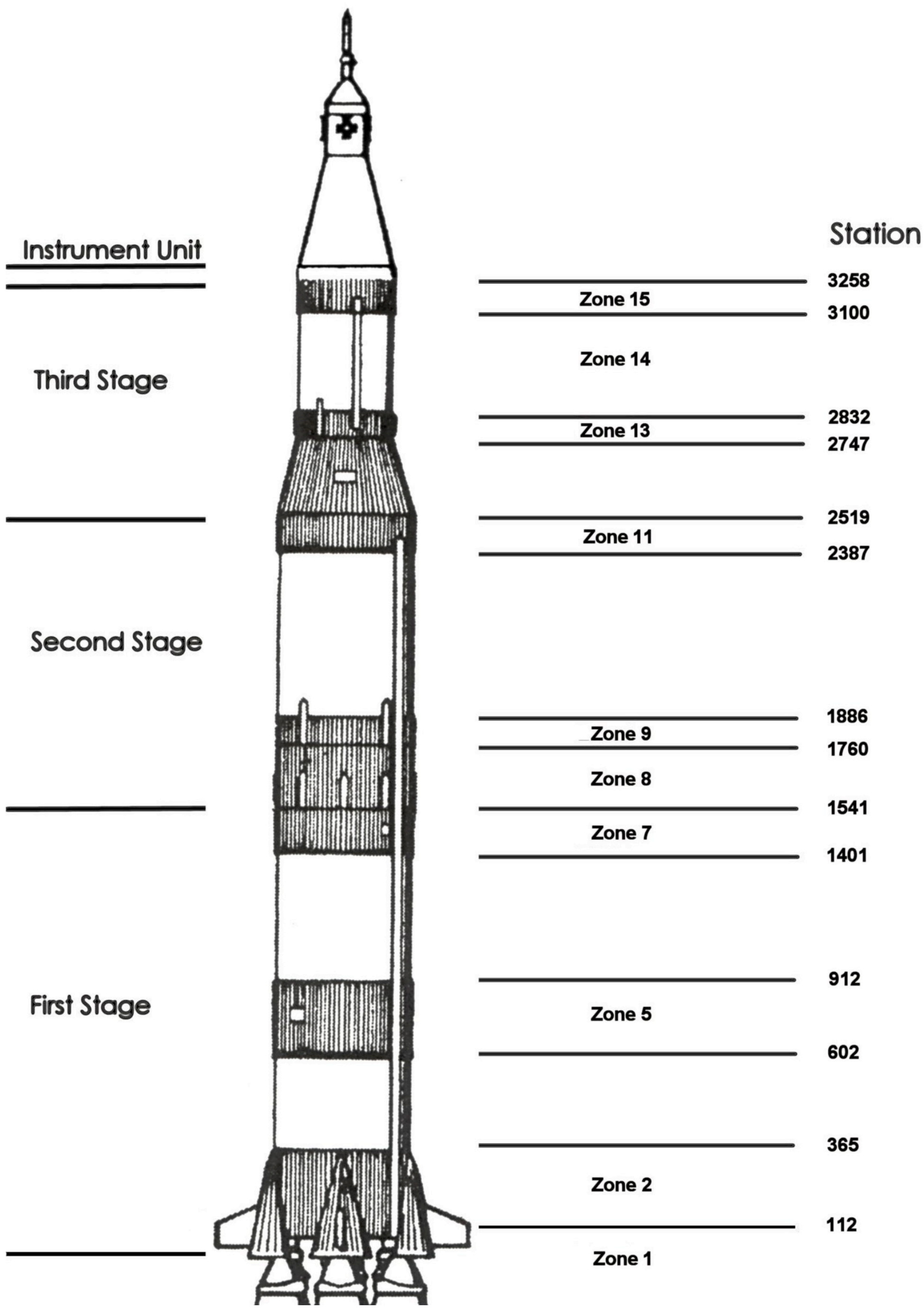

Figure 7. Saturn V zones.

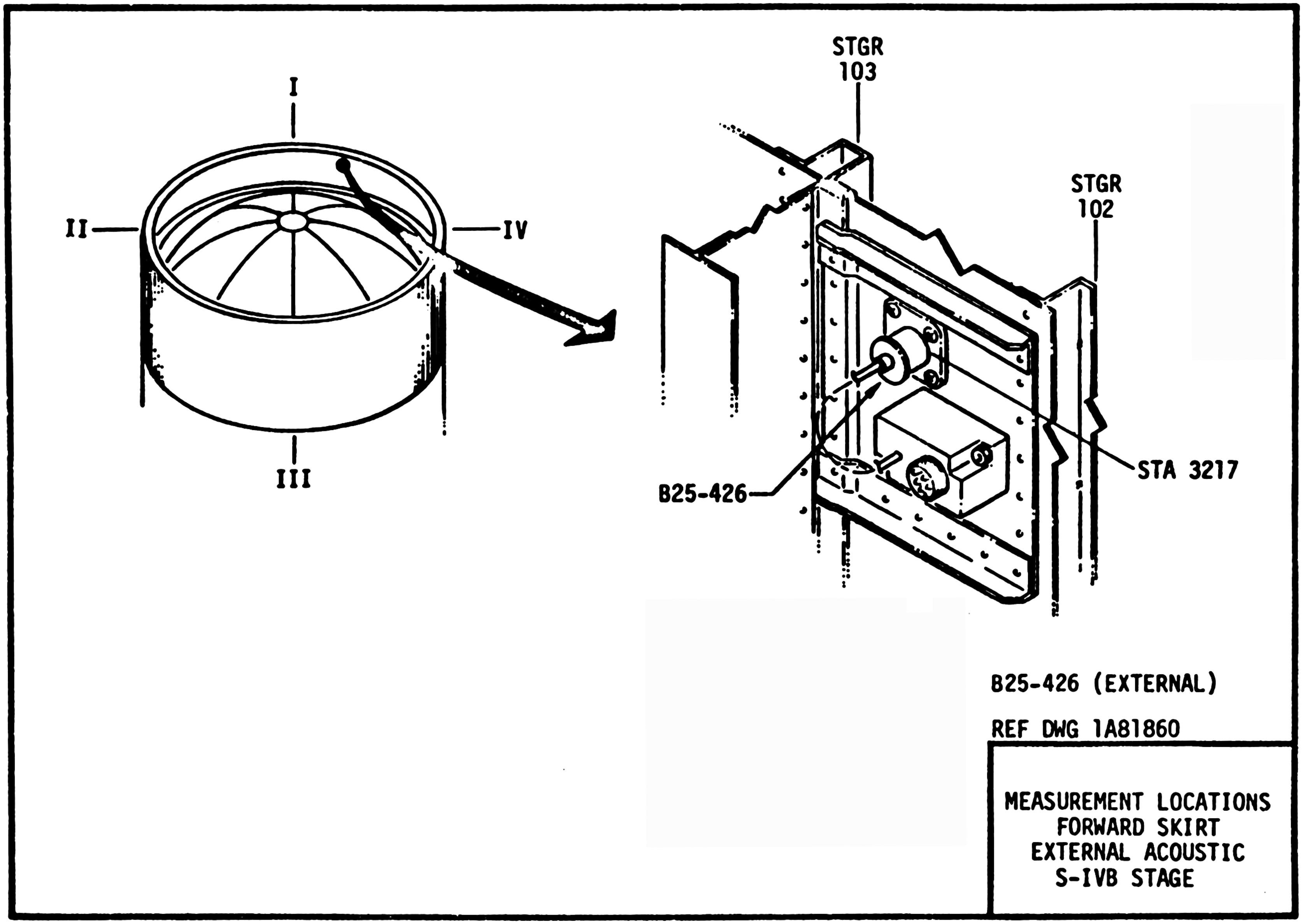

Figure 8. S-IVB stage forward skirt external acoustic measurement location.

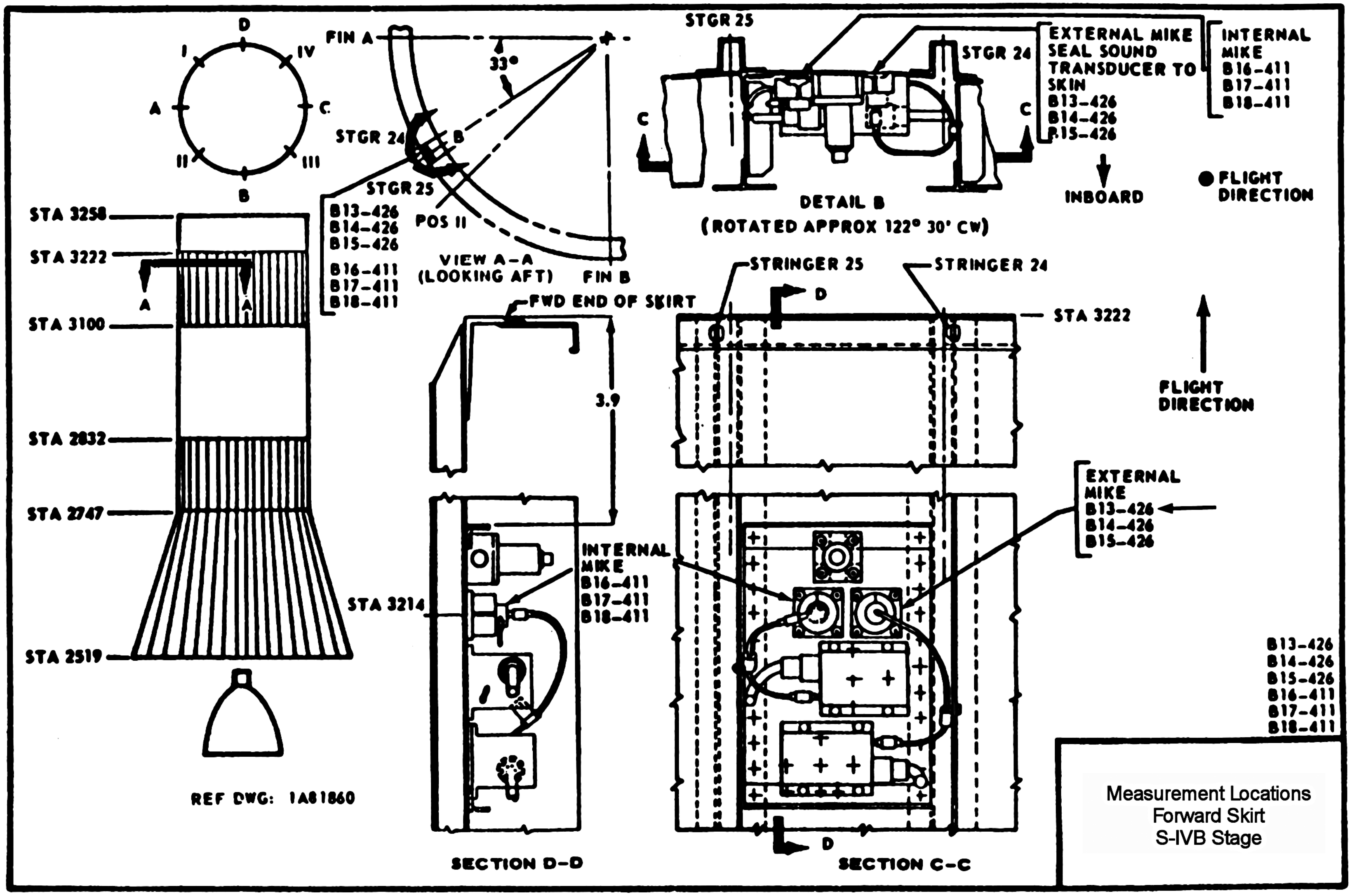

Figure 9. Zone 15: S-IVB stage forward skirt external and internal acoustic measurement location.

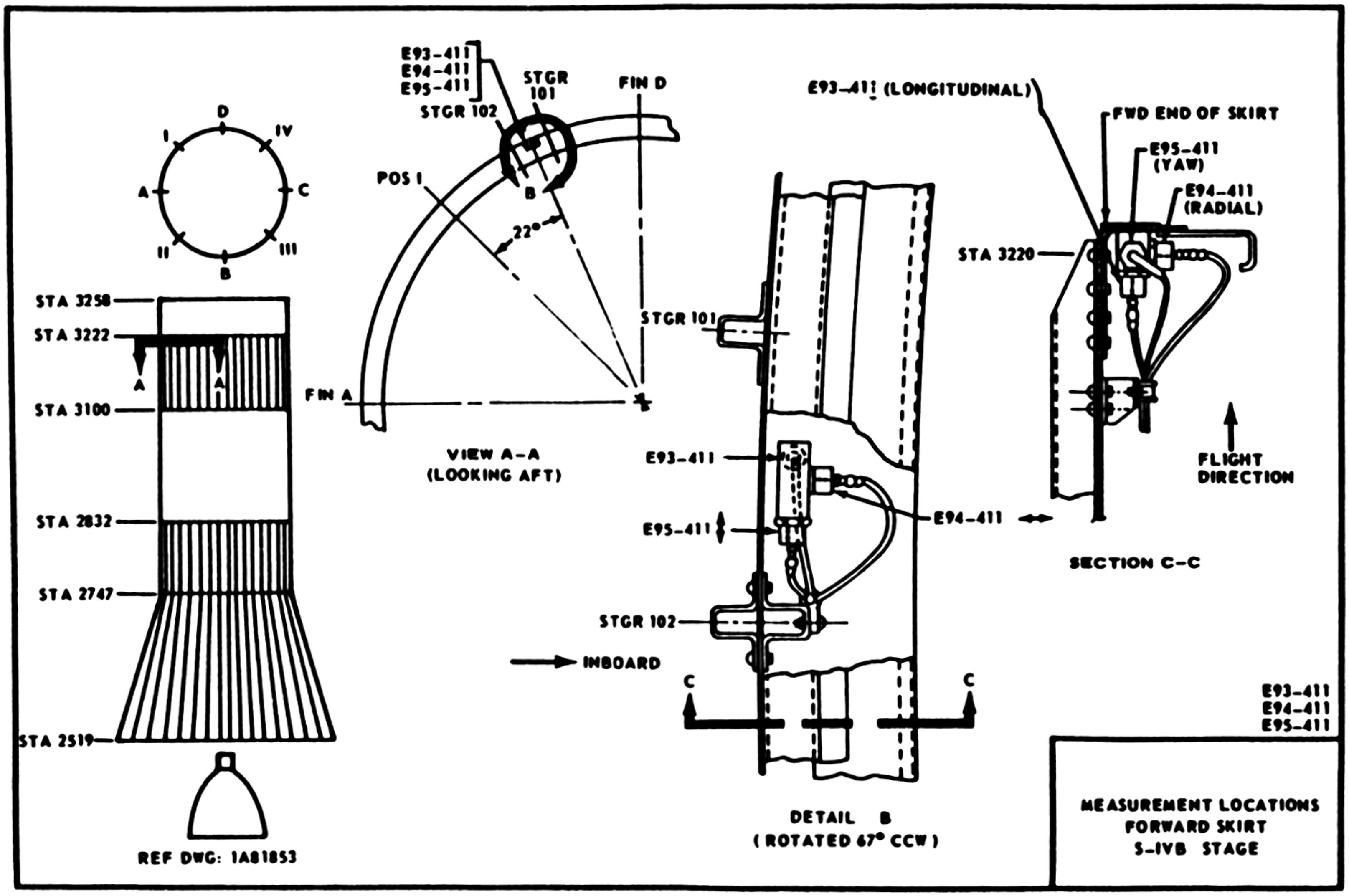

Figure 10. S-IVB stage forward skirt vibration measurement locations.

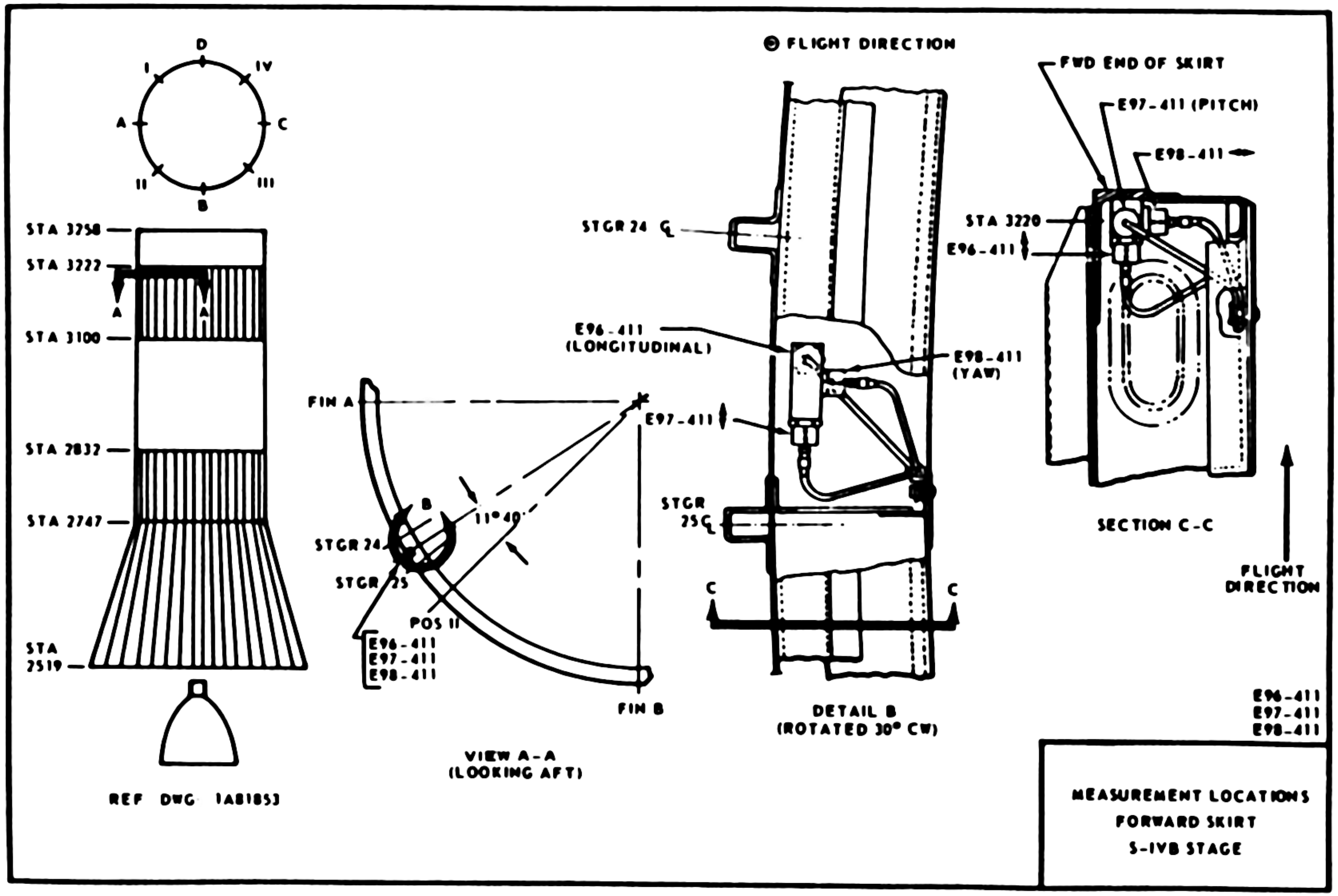

Figure 11. S-IVB stage forward skirt vibration measurement locations.

Document/Page No.: 7159/A1
Flight Condition: Liftoff
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E93-411 E96-411

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 3.18 g_{rms}
Subzone: 15-2-2

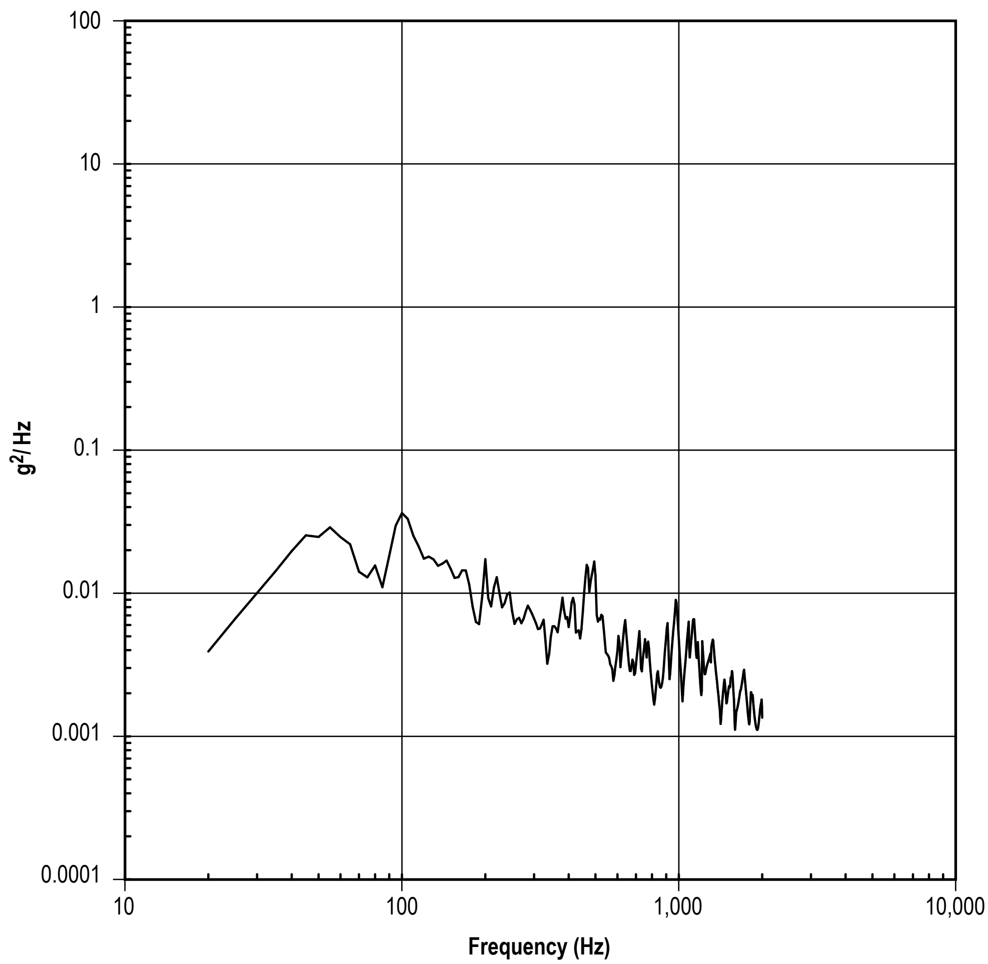

Figure 12. Ring frame PSD, longitudinal, liftoff, 2 lb/ft^2.

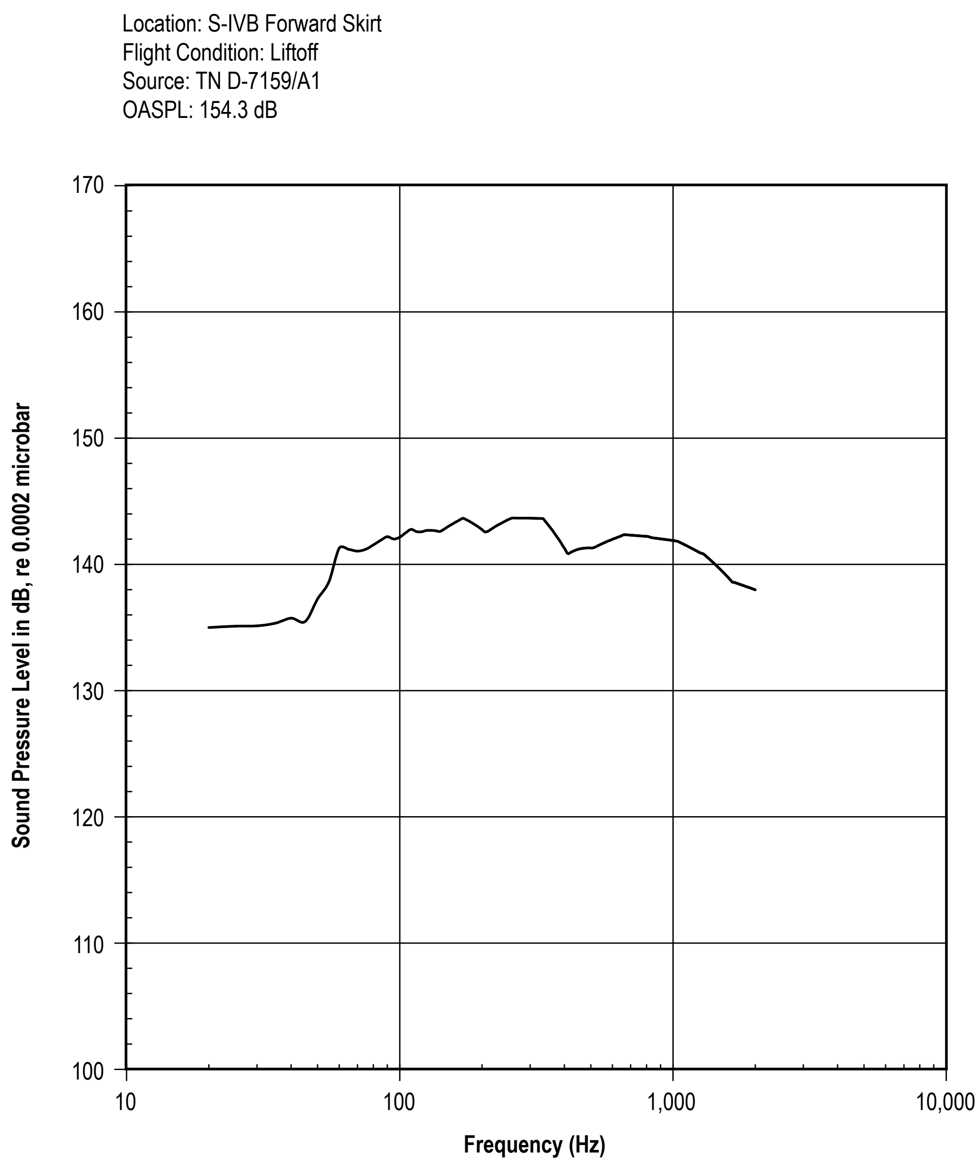

Figure 13. Saturn V acoustic spectrum, S-IVB forward skirt (subzone 15-2-2), liftoff.

Document/Page No.: 7159/A3
Flight Condition: Mach 1
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E93-411 E96-412

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 13.84 g_{rms}
Subzone: 15-2-2

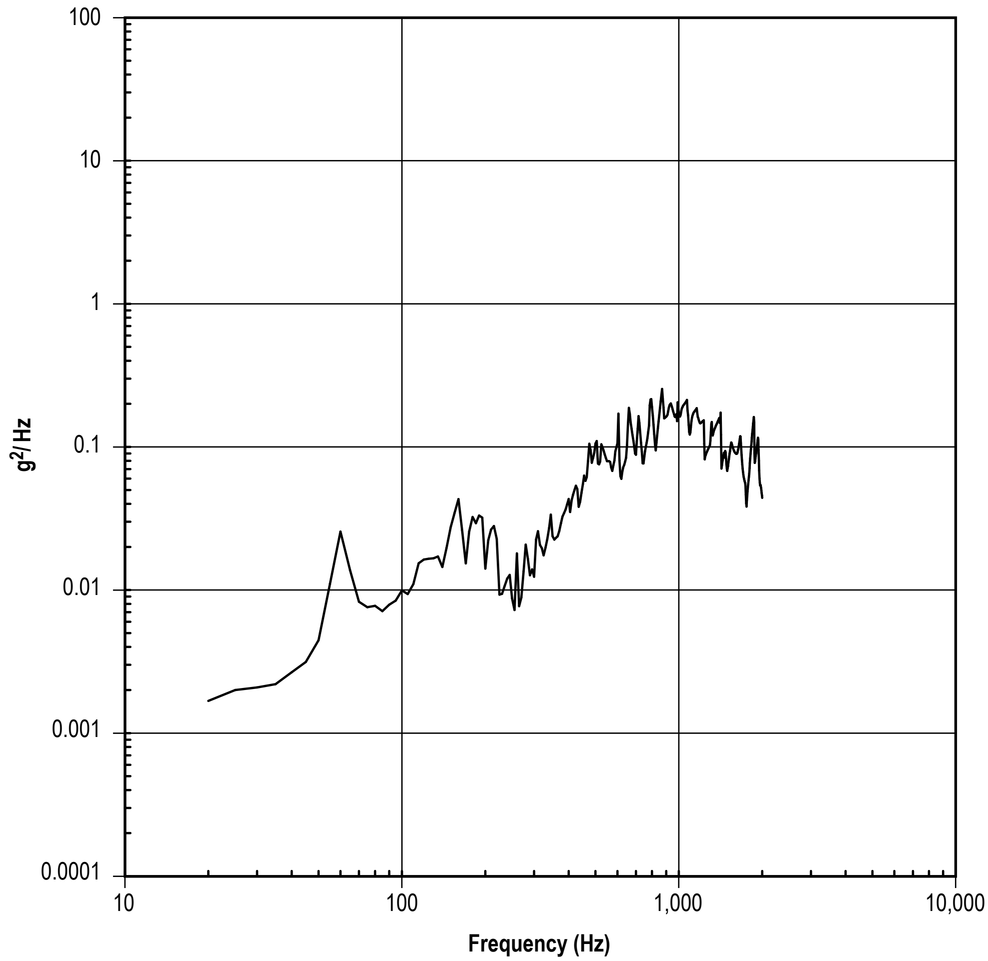

Figure 14. Ring frame PSD, longitudinal, Mach 1, 2 lb/ft^2.

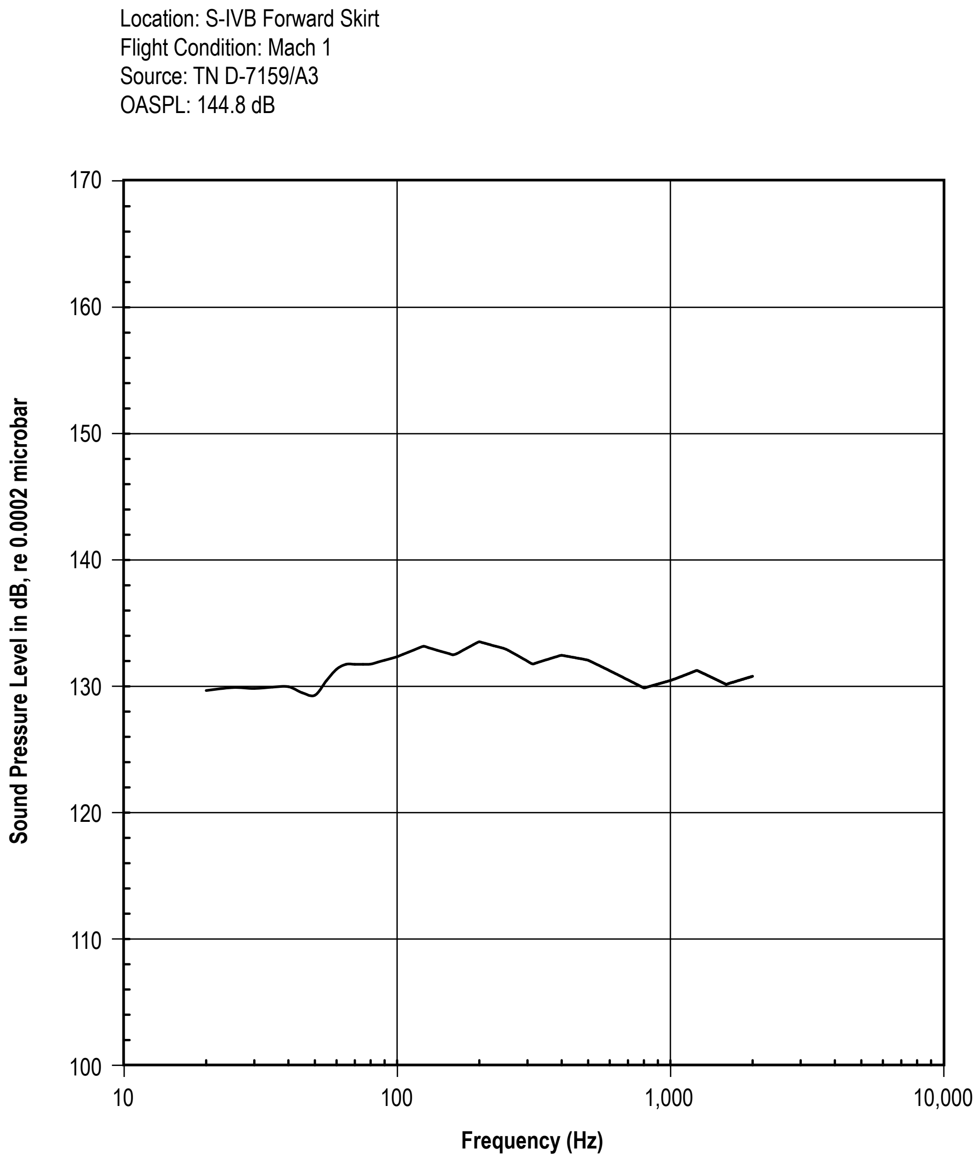

Figure 15. Saturn V acoustic spectrum, S-IVB forward skirt (subzone 15-2-2), Mach 1.

Document/Page No.: 7159/A5
Flight Condition: Max Q
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E93-411 E96-413

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 11.32 g_{rms}
Subzone: 15-2-2

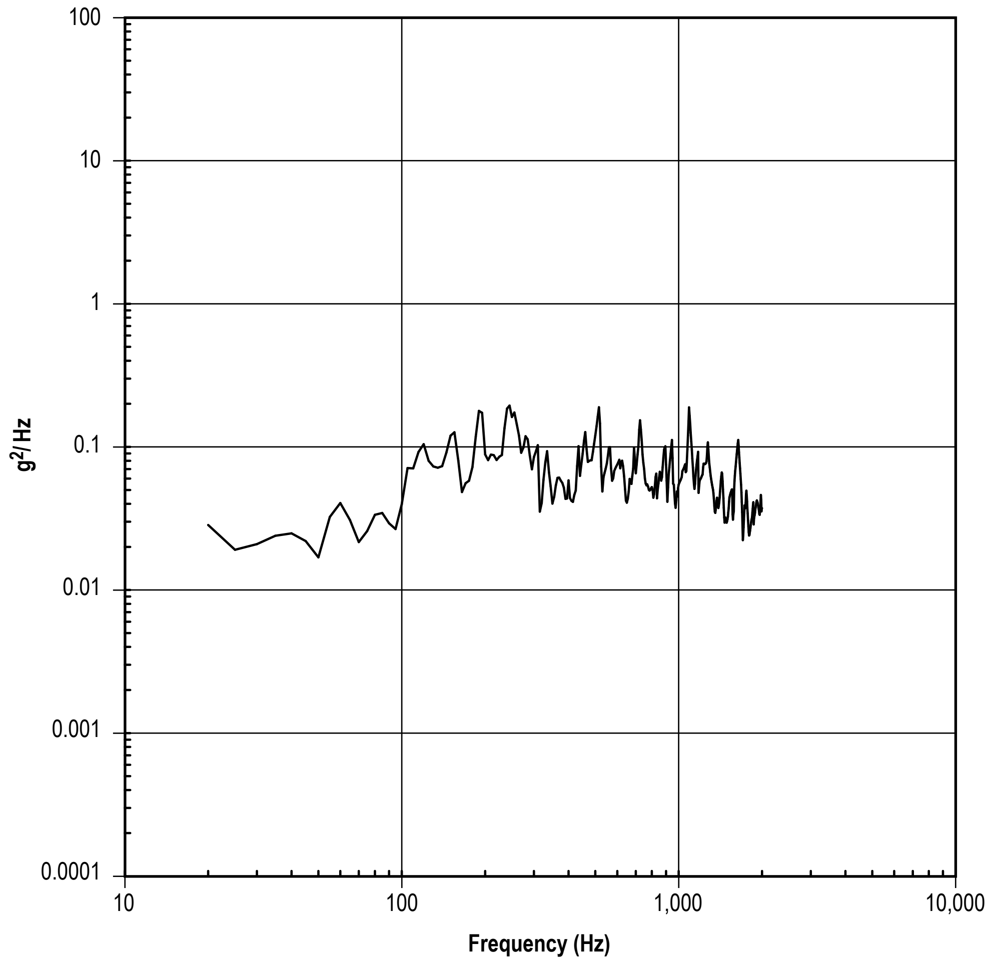

Figure 16. Ring frame PSD, longitudinal, Max Q, 2 lb/ft^2.

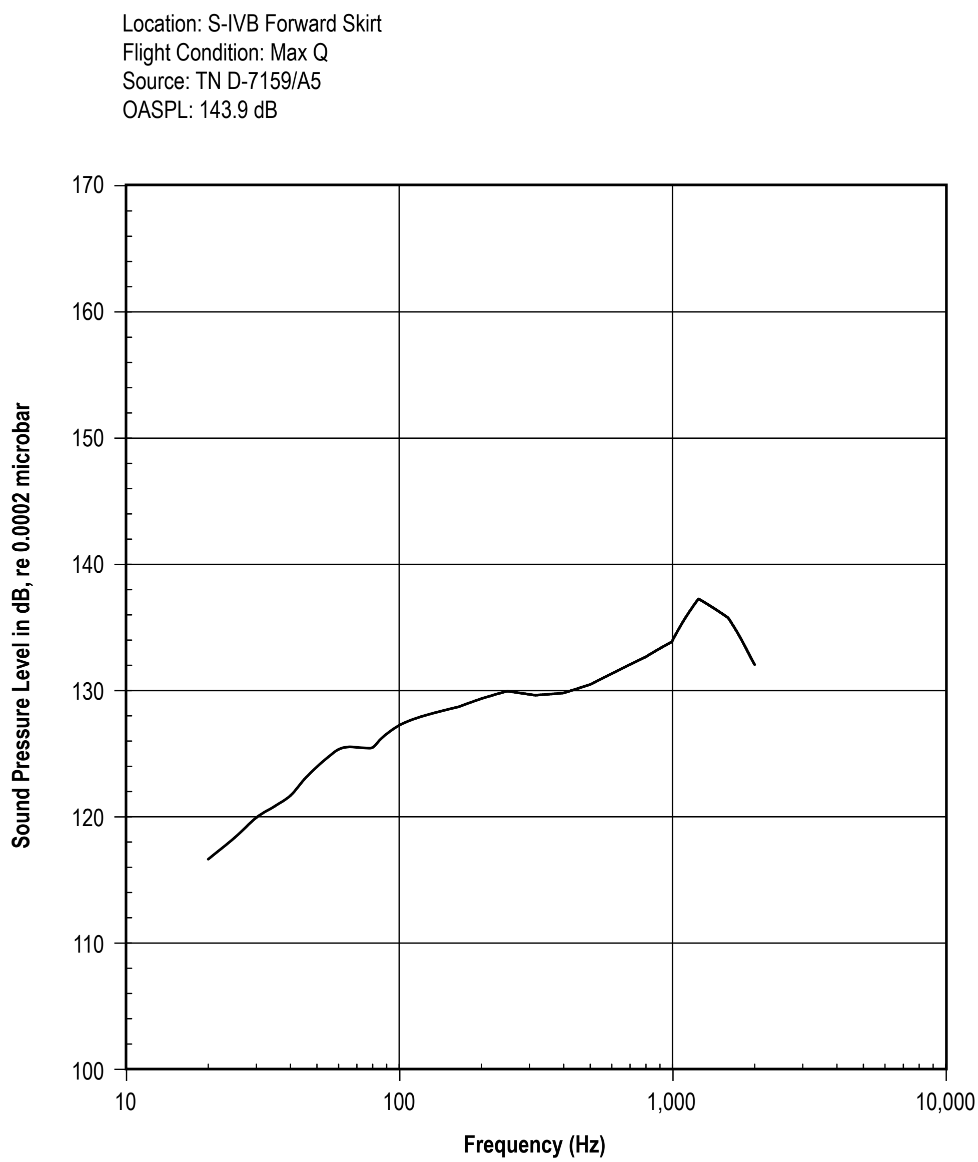

Figure 17. Saturn V acoustic spectrum, S-IVB forward skirt (subzone 15-2-2), Max Q.

Document/Page No.: 7159/A7
Flight Condition: Mach 1/Max Q
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E93-411 E96-414

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 13.41 g_{rms}
Subzone: 15-2-2

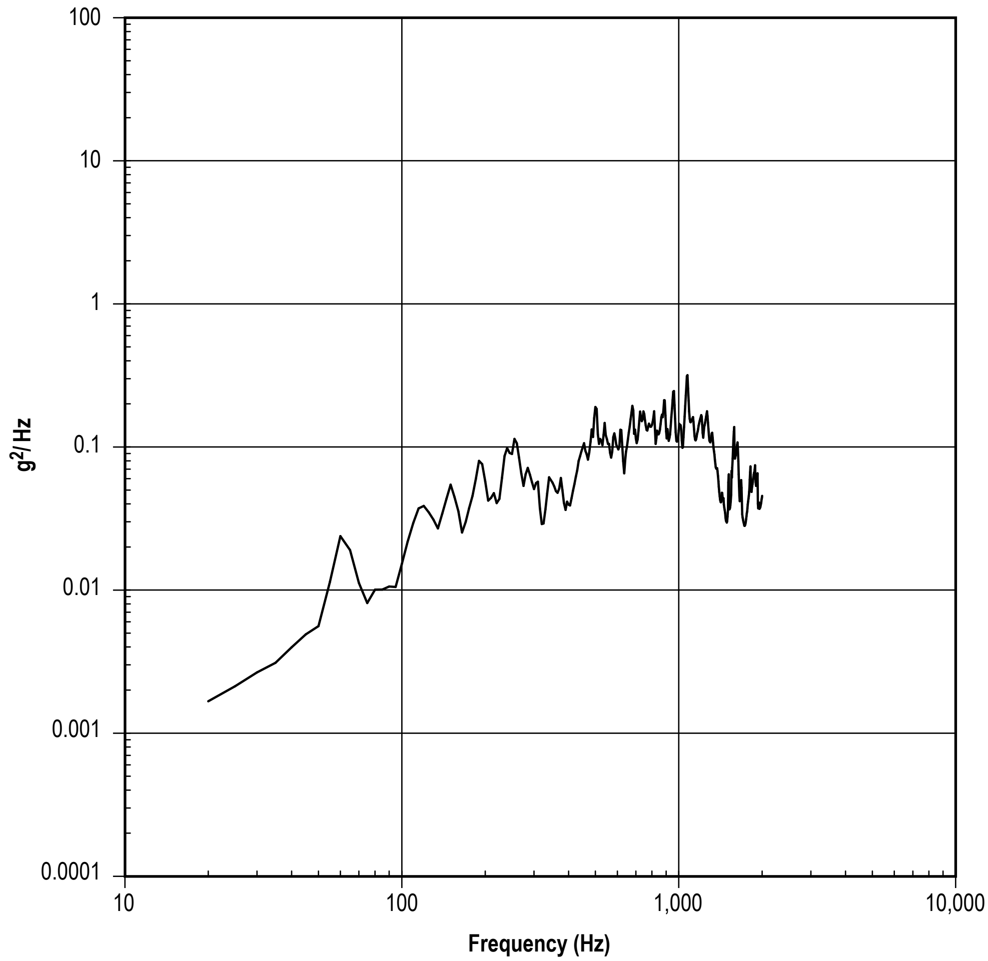

Figure 18. Ring frame PSD, longitudinal, Mach 1/Max Q, 2 lb/ft^2.

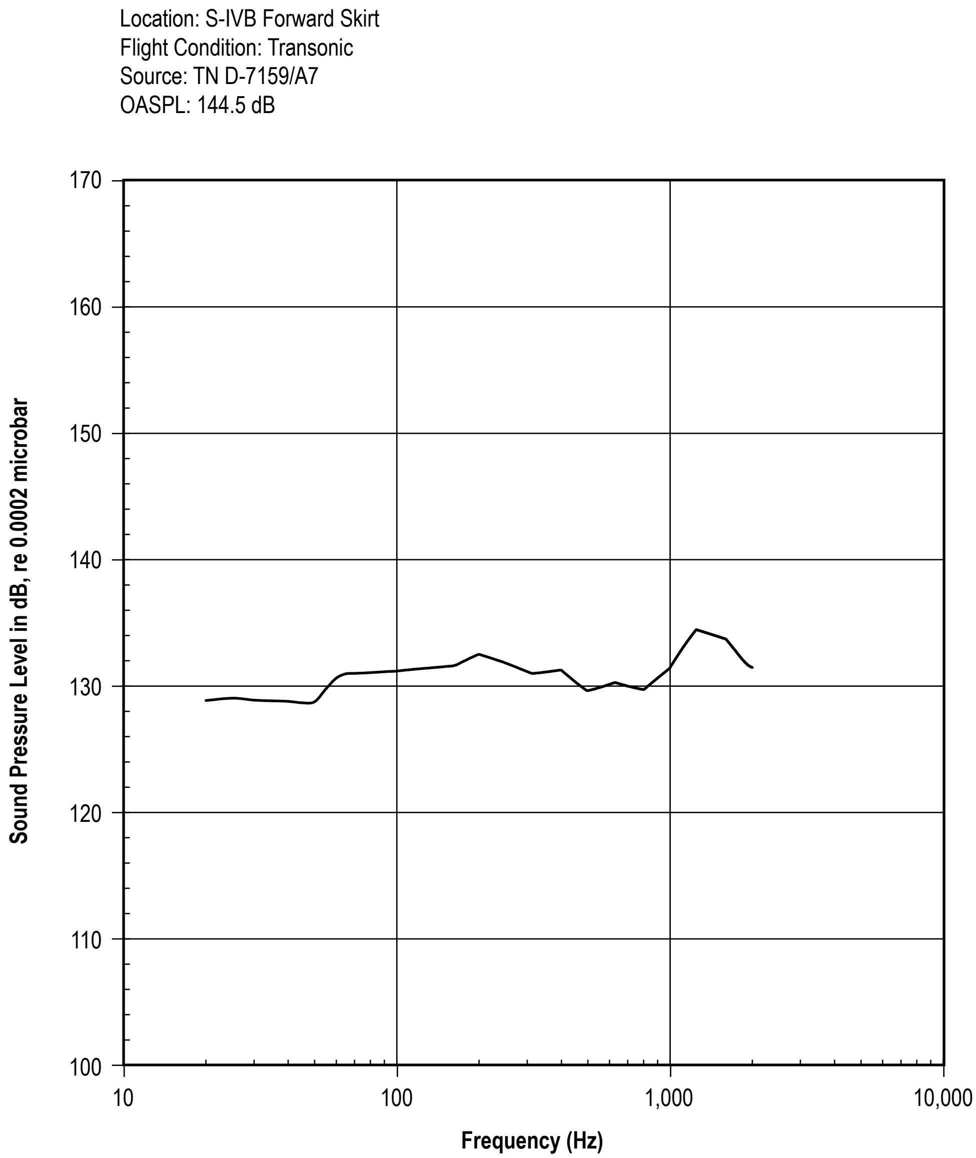

Figure 19. Saturn V acoustic spectrum, S-IVB forward skirt (subzone 15-2-2), transonic.

Document/Page No.: 7159/A9
Flight Condition: Liftoff
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E95-411 E98-411

Meas. Direction: Tangential
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 3.69 g_{rms}
Subzone: 15-2-2

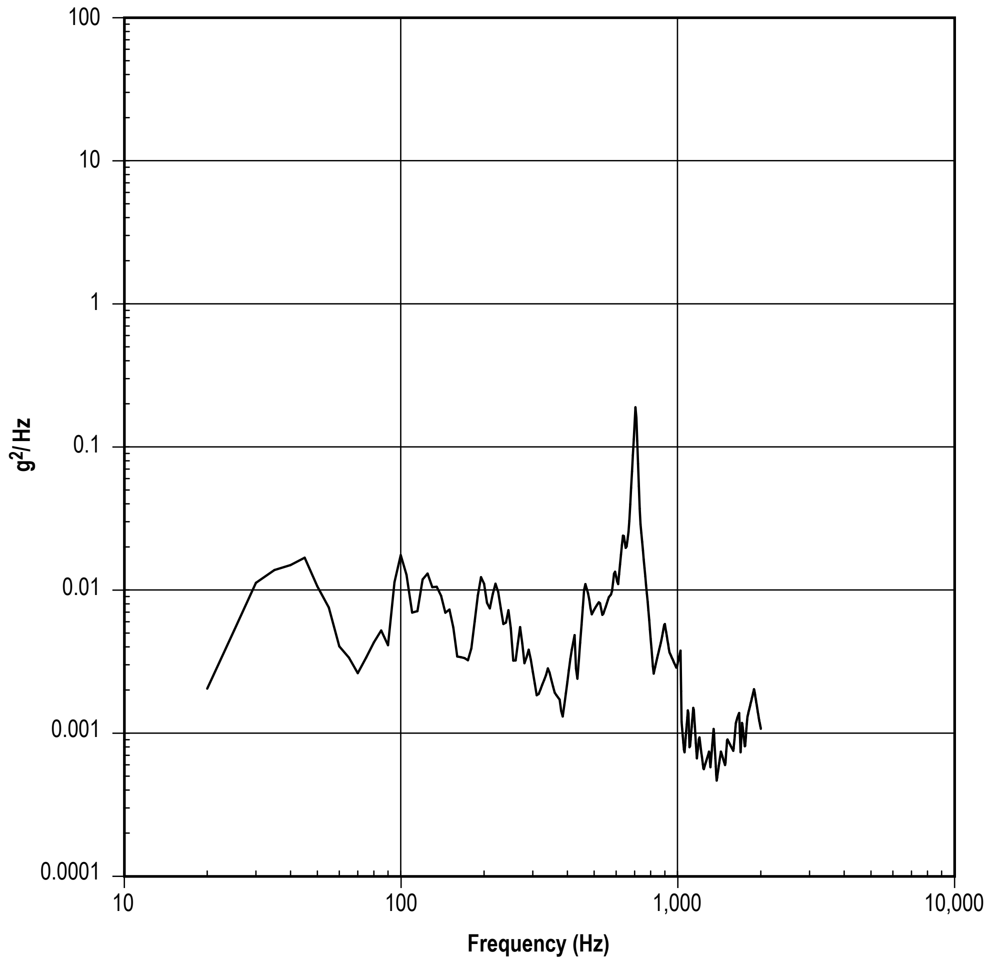

Figure 20. Skin-stringer PSD, tangential, liftoff, 2 lb/ft^2.

Document/Page No.: 7159/A11
Flight Condition: Mach 1
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E95-411 E98-411

Meas. Direction: Tangential
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 26.17 g_{rms}
Subzone: 15-2-2

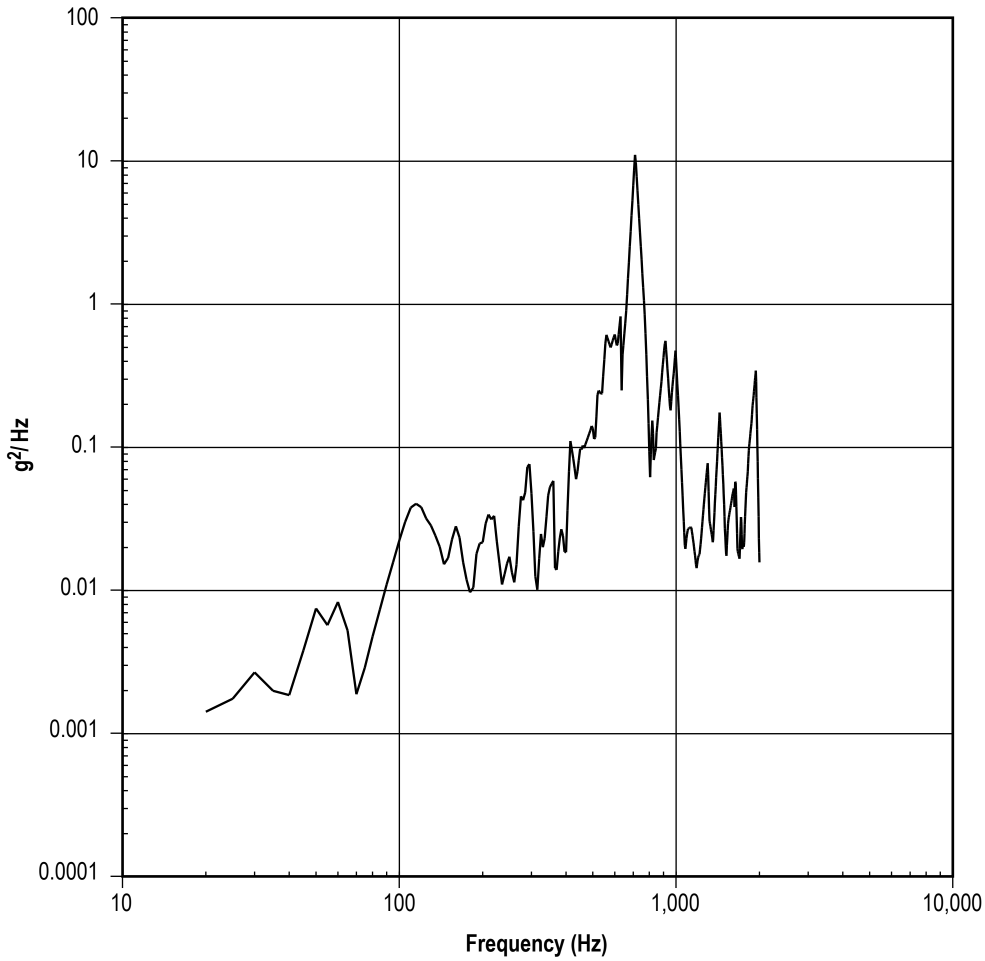

Figure 21. Skin-stringer PSD, tangential, Mach 1, 2 lb/ft^2.

Document/Page No.: 7159/A13	Meas. Direction: Tangential
Flight Condition: Max Q	Material: AL
Vehicle Diameter: 22 ft	Skin Thickness: 0.032 in
Ring Sep.: N/A	Ring Wt.: 0.95 lb/ft
Stringer Sep.: 7.55 in	Stringer Wt.: 0.47 lb/ft
Surface Wt.: 2 lb/ft^2	Composite: 22.72 g_{rms}
Measurements: E95-411 E98-411	Subzone: 15-2-2

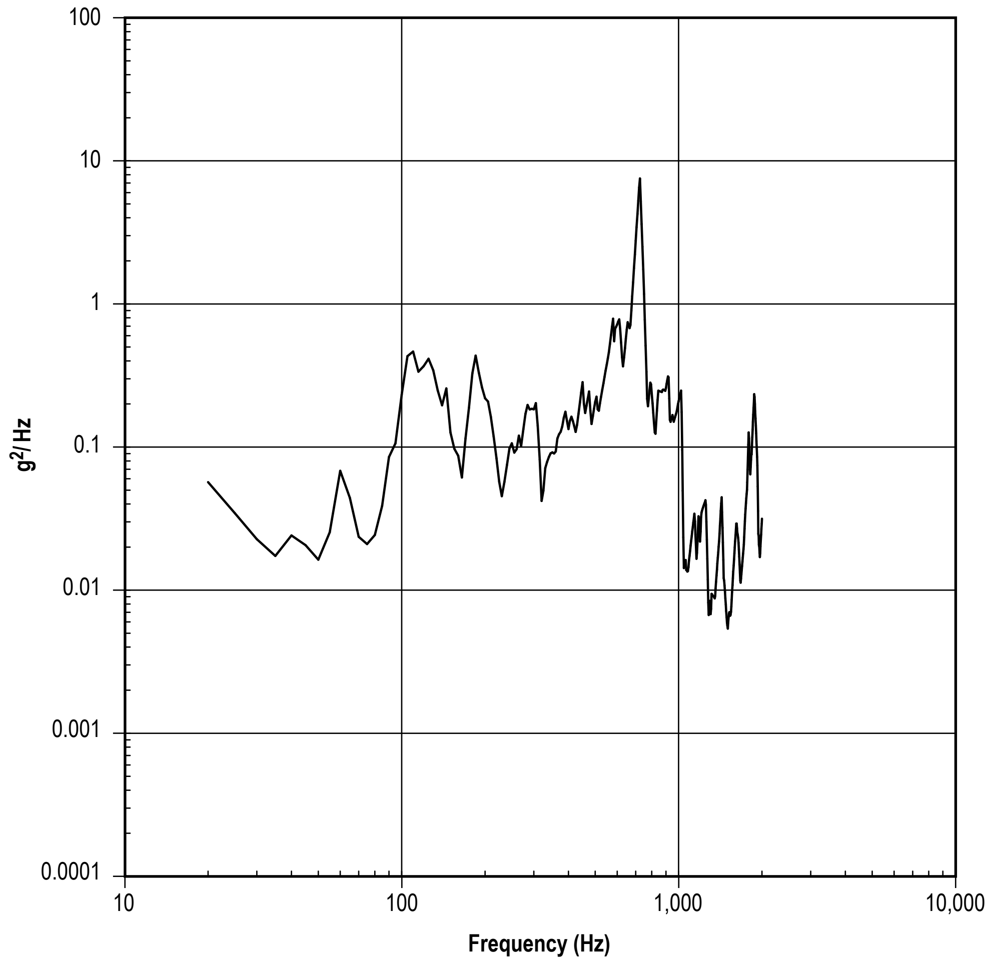

Figure 22. Ring frame PSD, tangential, Max Q, 2 lb/ft^2.

Document/Page No.: 7159/A15	Meas. Direction: Tangential
Flight Condition: Mach 1/Max Q	Material: AL
Vehicle Diameter: 22 ft	Skin Thickness: 0.032 in
Ring Sep.: N/A	Ring Wt.: 0.95 lb/ft
Stringer Sep.: 7.55 in	Stringer Wt.: 0.47 lb/ft
Surface Wt.: 2 lb/ft^2	Composite: 25.80 g_{rms}
Measurements: E95-411 E98-411	Subzone: 15-2-2

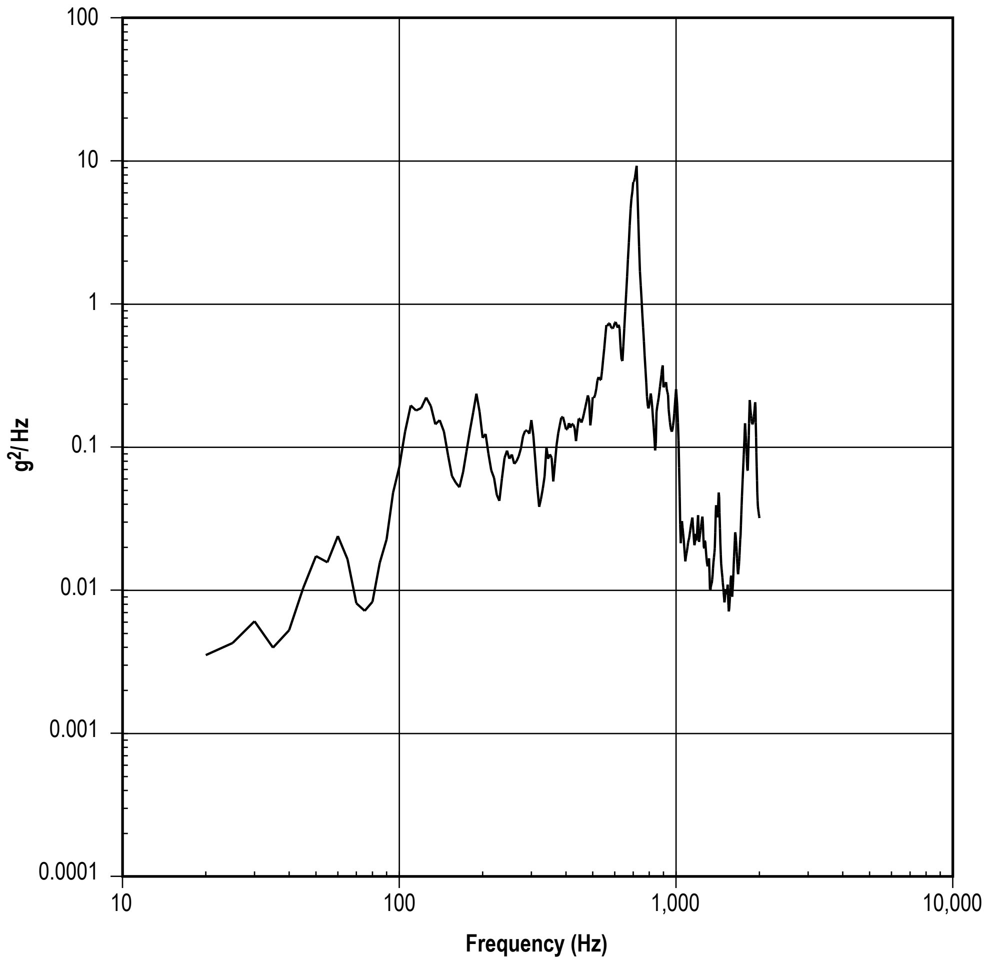

Figure 23. Ring frame PSD, tangential, Mach 1/Max Q, 2 lb/ft^2.

Document/Page No.: 7159/A17
Flight Condition: Liftoff
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E94-411 E97-411

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 10.25 g_{rms}
Subzone: 15-2-2

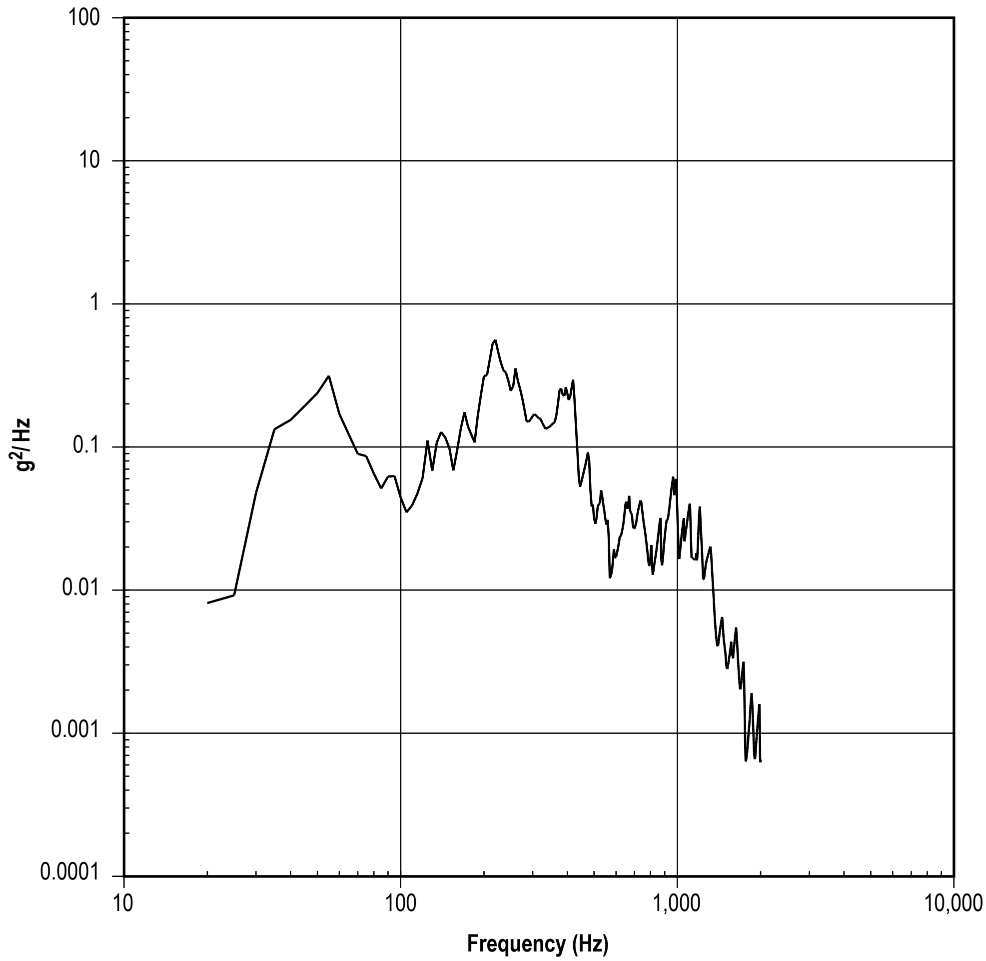

Figure 24. Ring frame PSD, radial, liftoff, 2 lb/ft^2.

Document/Page No.: 7159/A19
Flight Condition: Mach 1
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E94-411 E97-411

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 34.06 g_{rms}
Subzone: 15-2-2

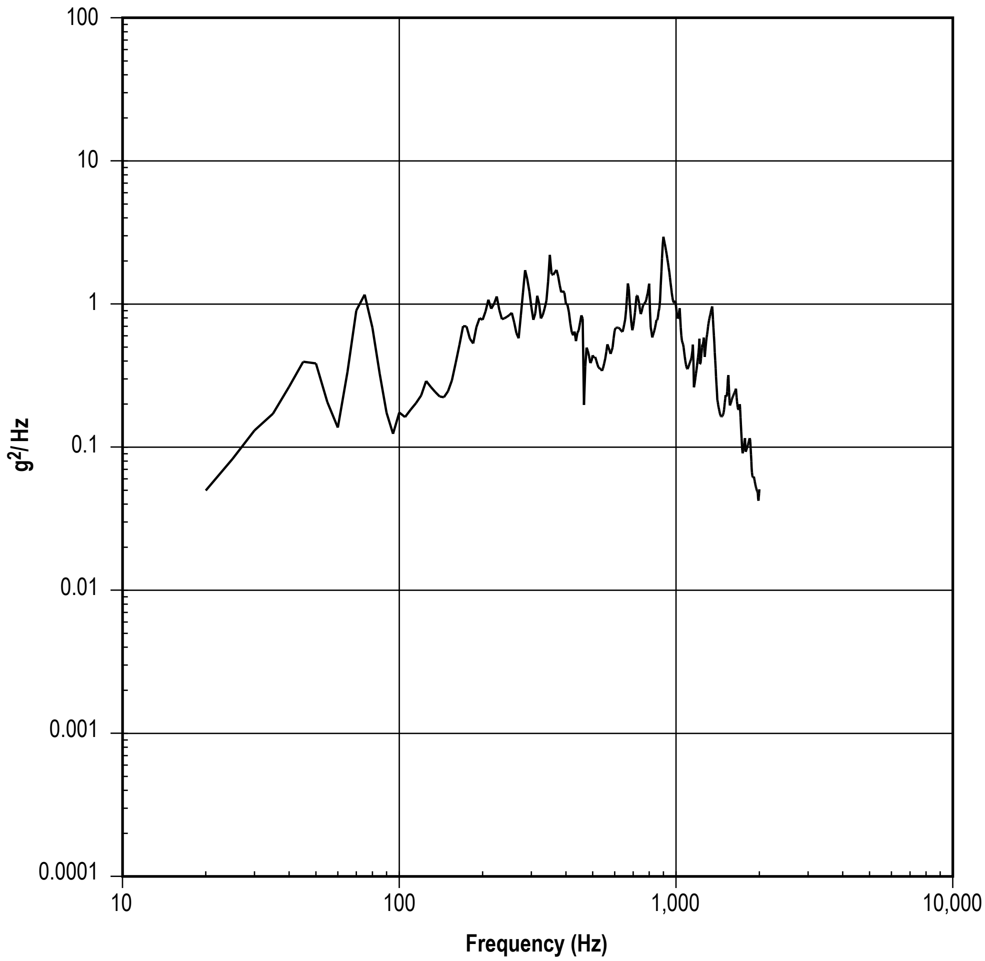

Figure 25. Ring frame PSD, radial, Mach 1, 2 lb/ft^2.

Document/Page No.: 7159/A21
Flight Condition: Max Q
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E94-411 E97-411

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 45.25 g_{rms}
Subzone: 15-2-2

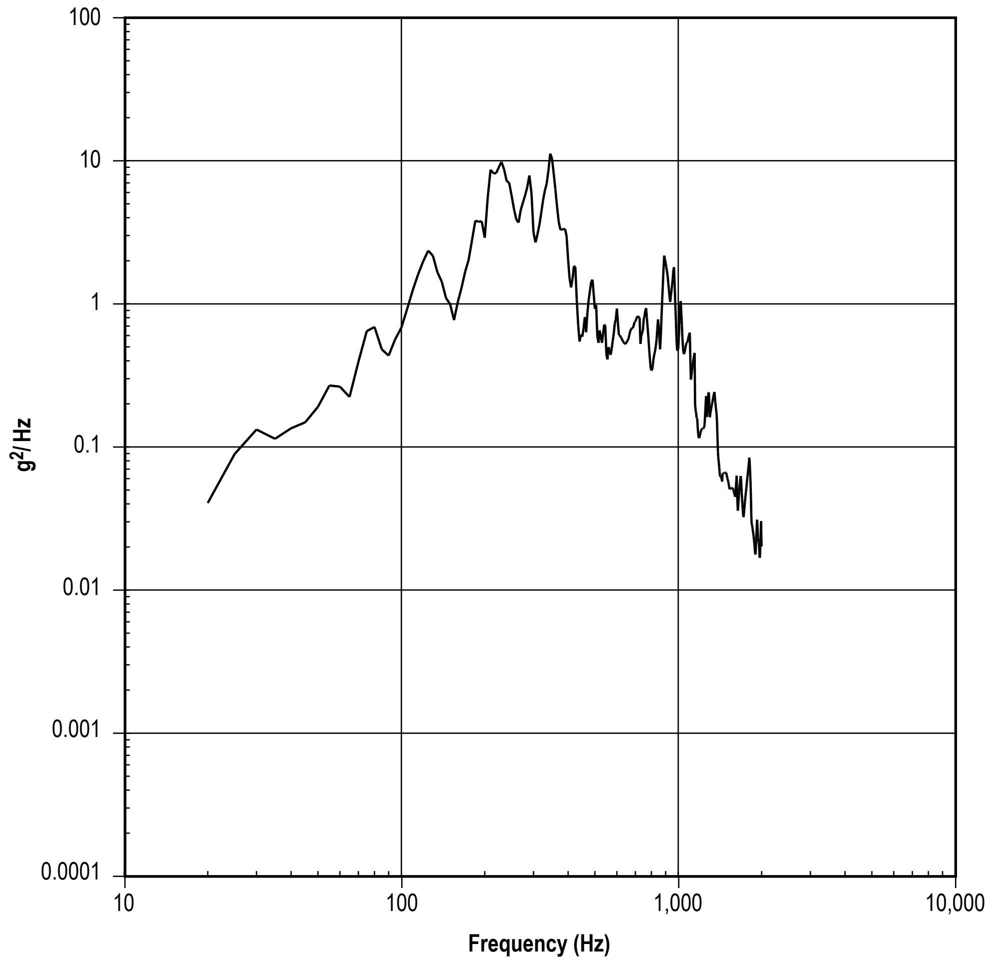

Figure 26. Ring frame PSD, radial, Max Q, 2 lb/ft^2.

Document/Page No.: 7159/A23
Flight Condition: Mach 1/Max Q
Vehicle Diameter: 22 ft
Ring Sep.: N/A
Stringer Sep.: 7.55 in
Surface Wt.: 2 lb/ft^2
Measurements: E94-411 E97-411

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.032 in
Ring Wt.: 0.95 lb/ft
Stringer Wt.: 0.47 lb/ft
Composite: 34.33 g_{rms}
Subzone: 15-2-2

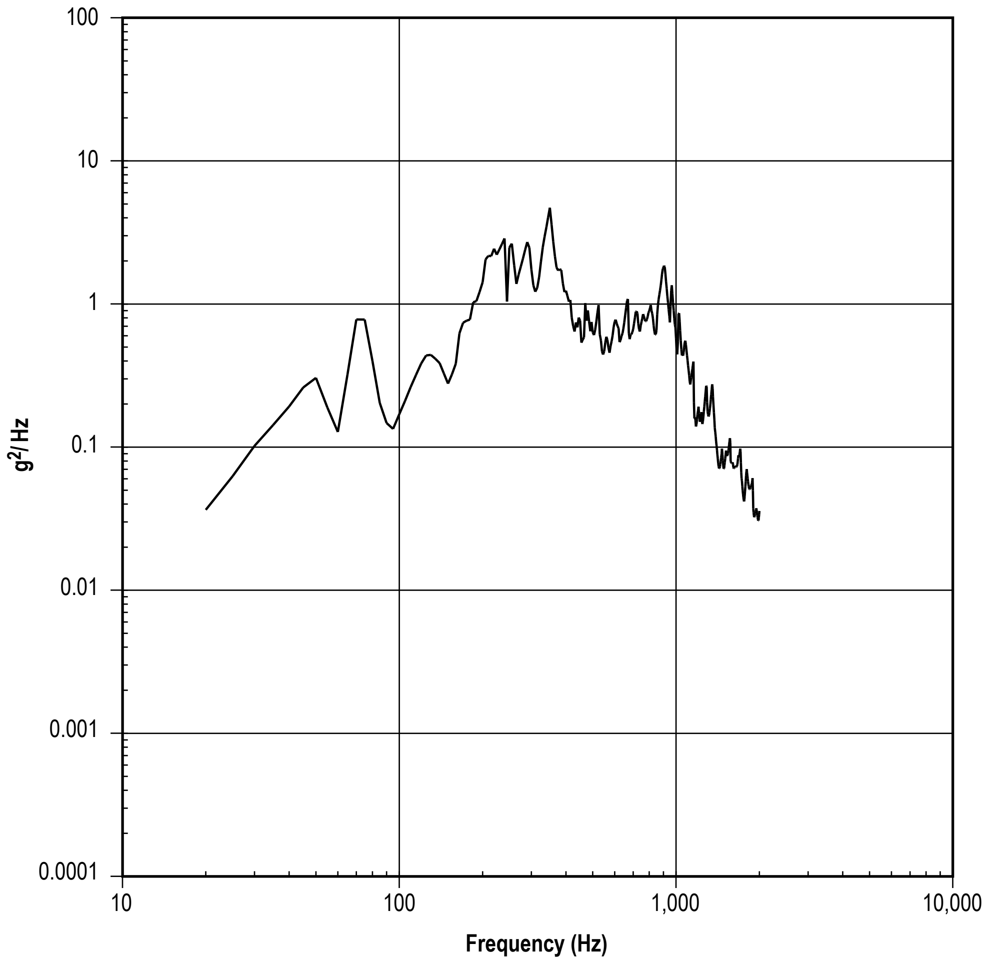

Figure 27. Ring frame PSD, radial, Mach 1/Max Q, 2 lb/ft^2.

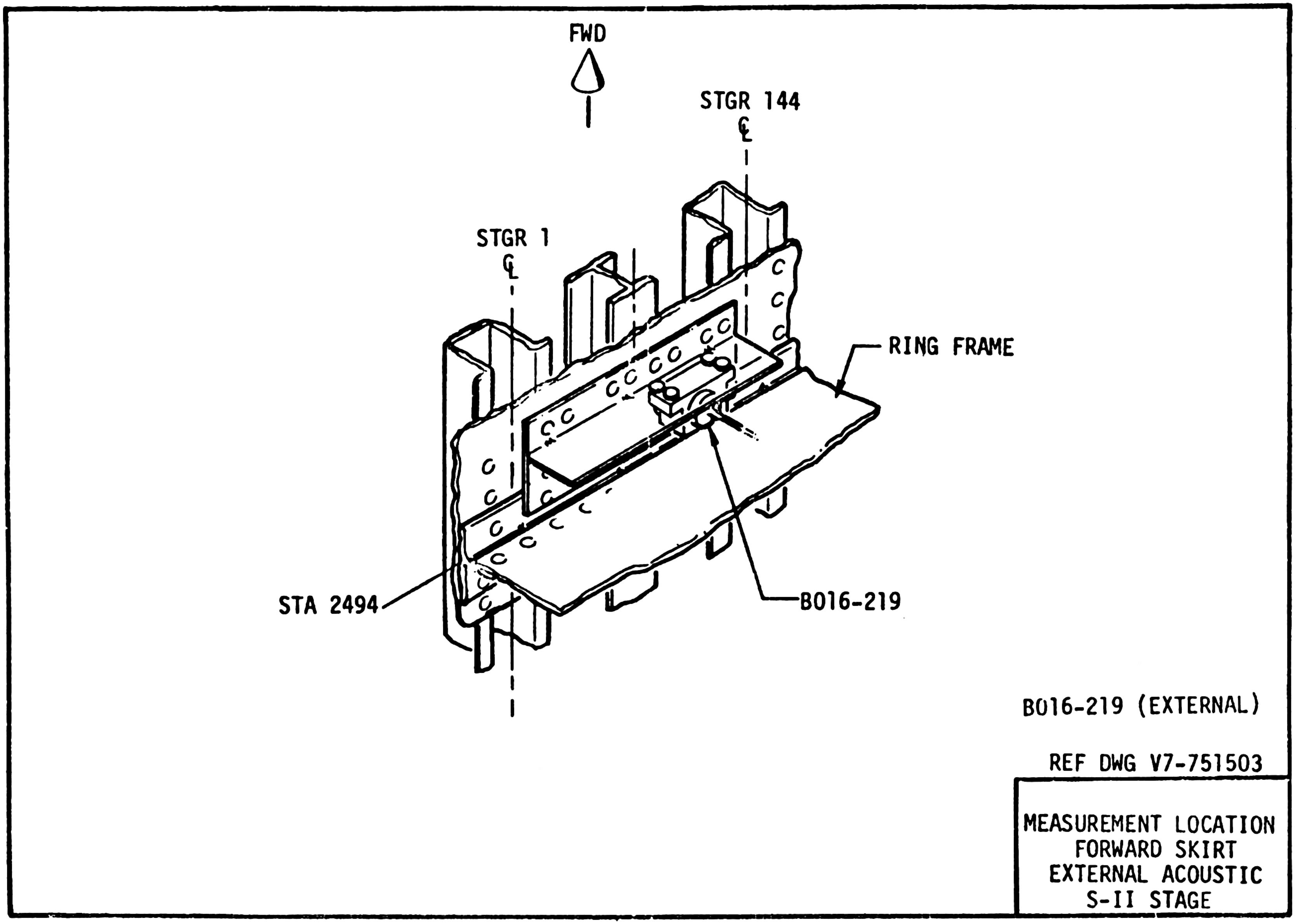

Figure 28. Zone 11: S-II stage forward skirt external acoustic measurement location.

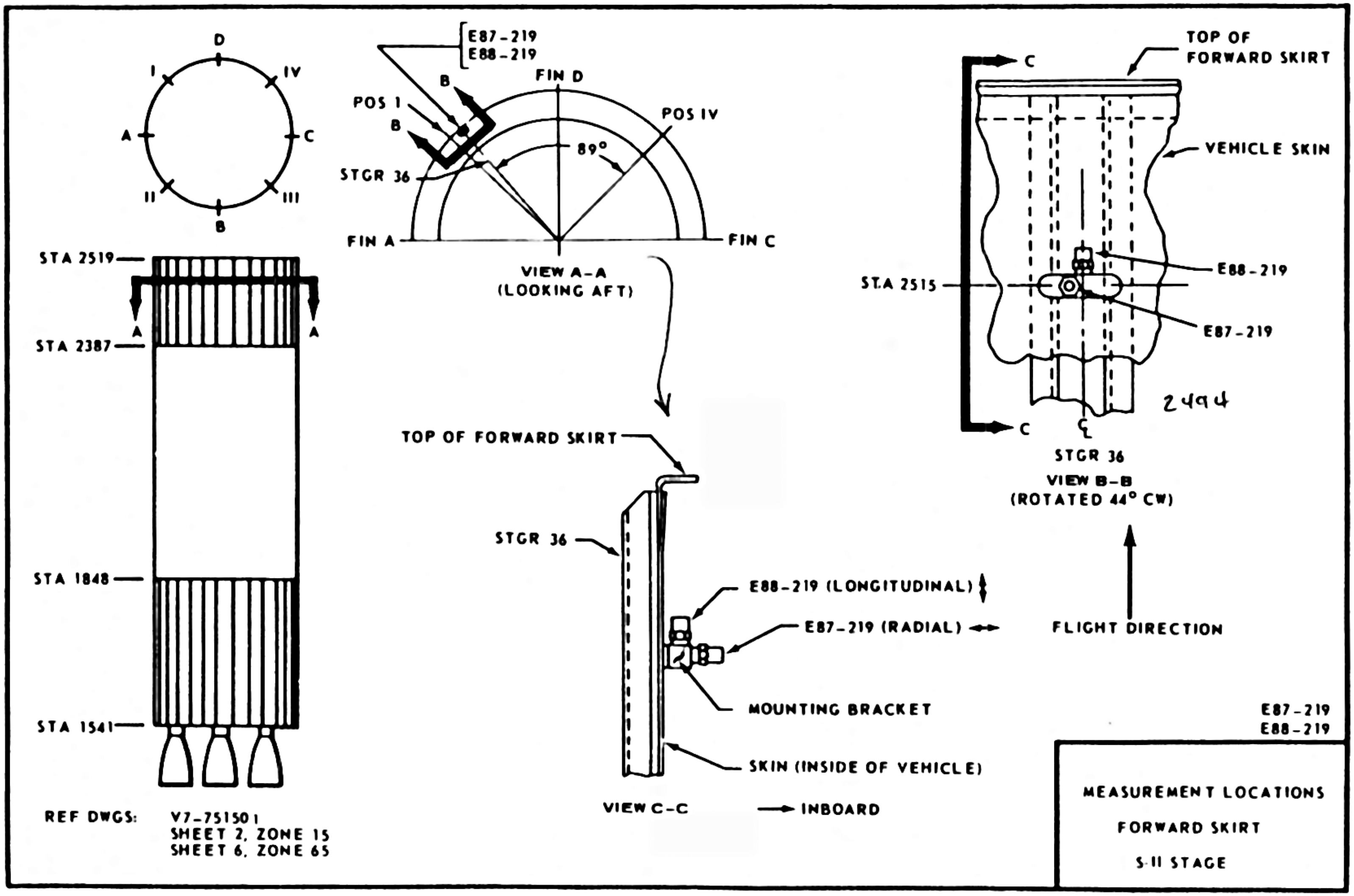

Figure 29. S-II stage forward skirt vibration measurement locations.

Document/Page No.: A25-1	Meas. Direction: Longitudinal
Flight Condition: Liftoff	Material: AL
Vehicle Diameter: 33 ft	Skin Thickness: 0.040 in
Ring Sep.: N/A	Ring Wt.: 2.51 lb/ft
Stringer Sep.: 8.63 in	Stringer Wt.: 0.71 lb/ft
Surface Wt.: 3.3 lb/ft^2	Composite: 12.71 g_{rms}
Measurements: E87-219 E88-219	Subzone: 11-2-2

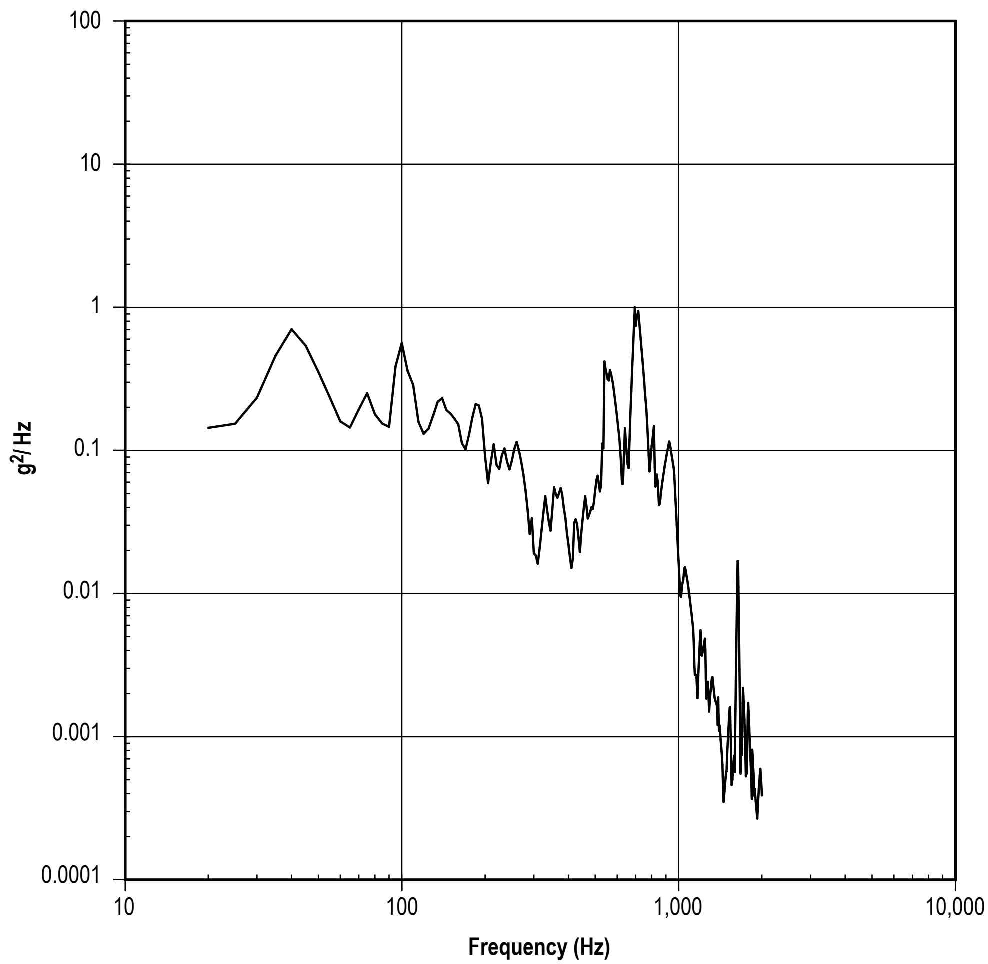

Figure 30. Ring frame PSD, longitudinal, liftoff, 3.3 lb/ft^2.

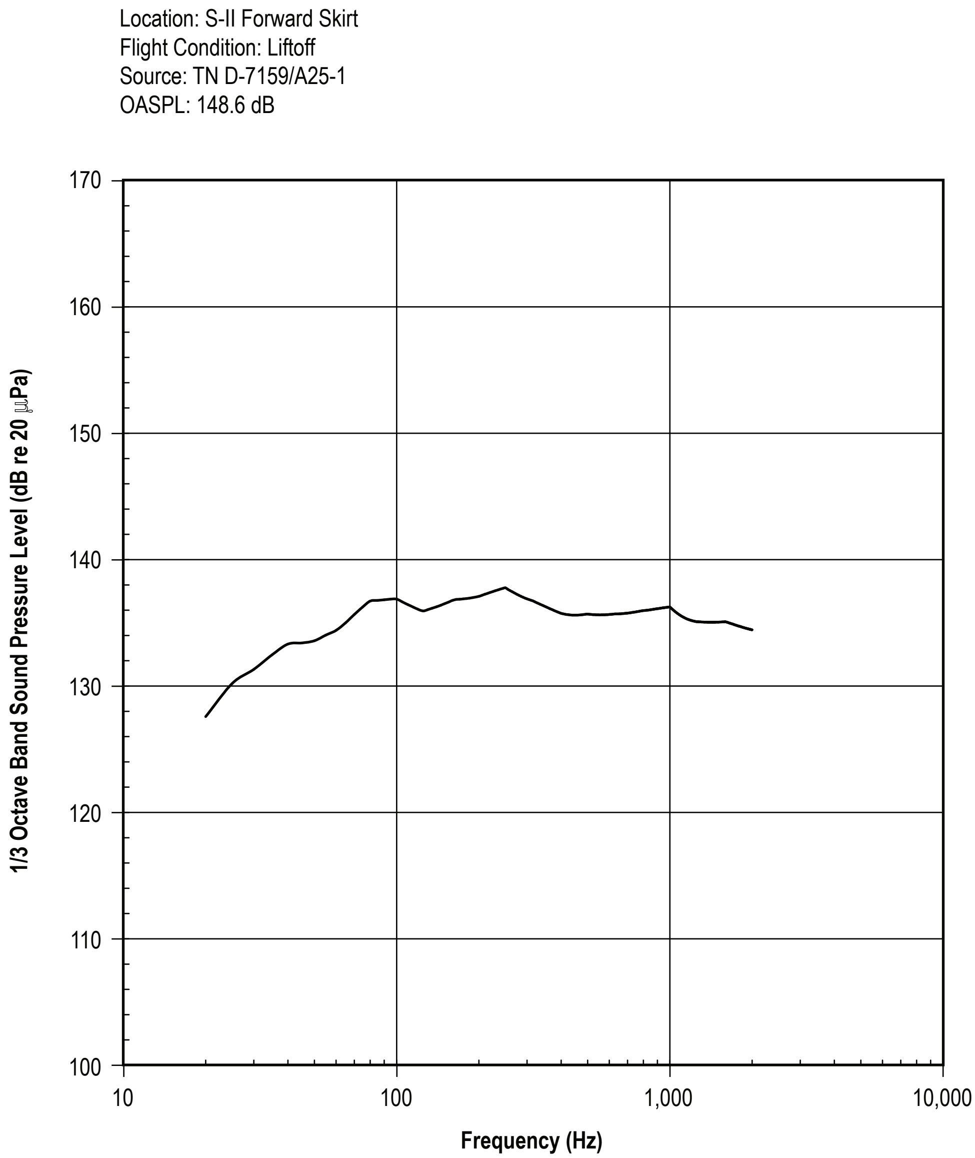

Figure 31. Saturn V acoustic spectrum, S-II forward skirt (subzone 11-2-2), liftoff.

Document/Page No.: A25-2
Flight Condition: Mach 1
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 8.63 in
Surface Wt.: 3.3 lb/ft^2
Measurements: E87-219 E88-219

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: 2.51 lb/ft
Stringer Wt.: 0.71 lb/ft
Composite: 12.15 g_{rms}
Subzone: 11-2-2

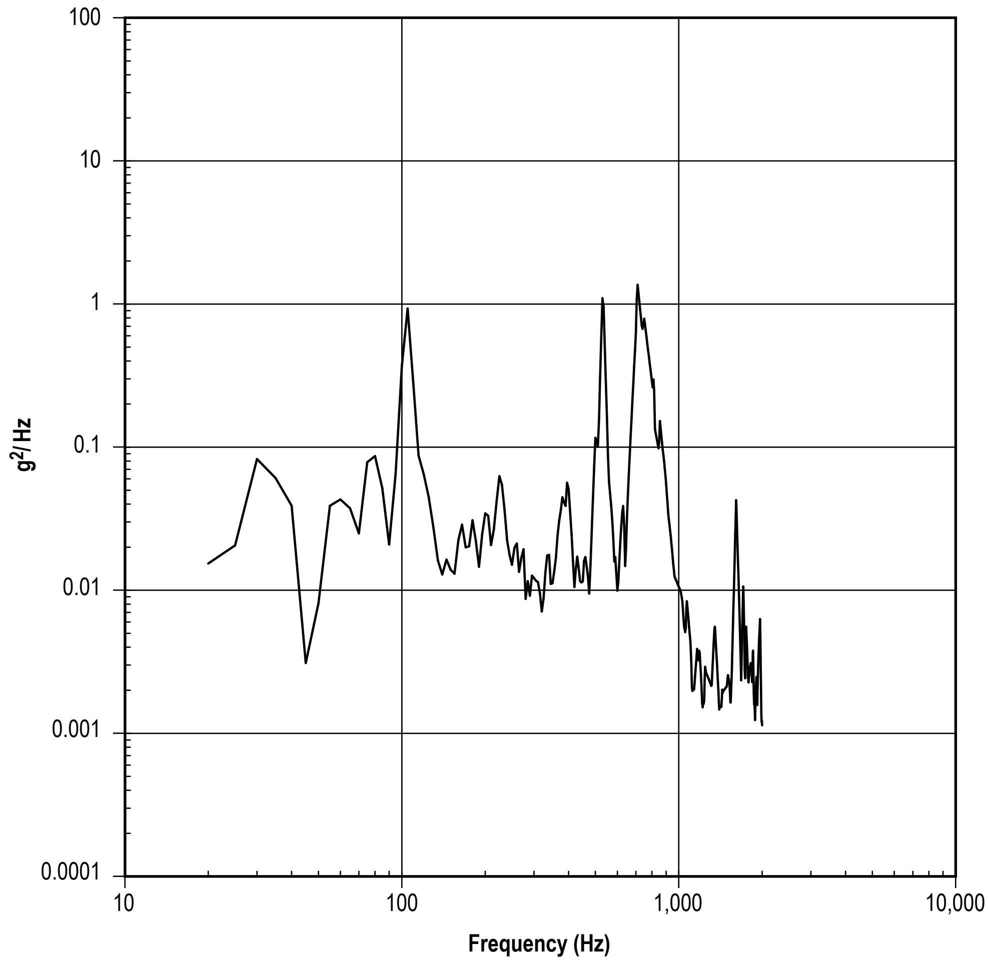

Figure 32. Ring frame PSD, longitudinal, Mach 1, 3.3 lb/ft^2.

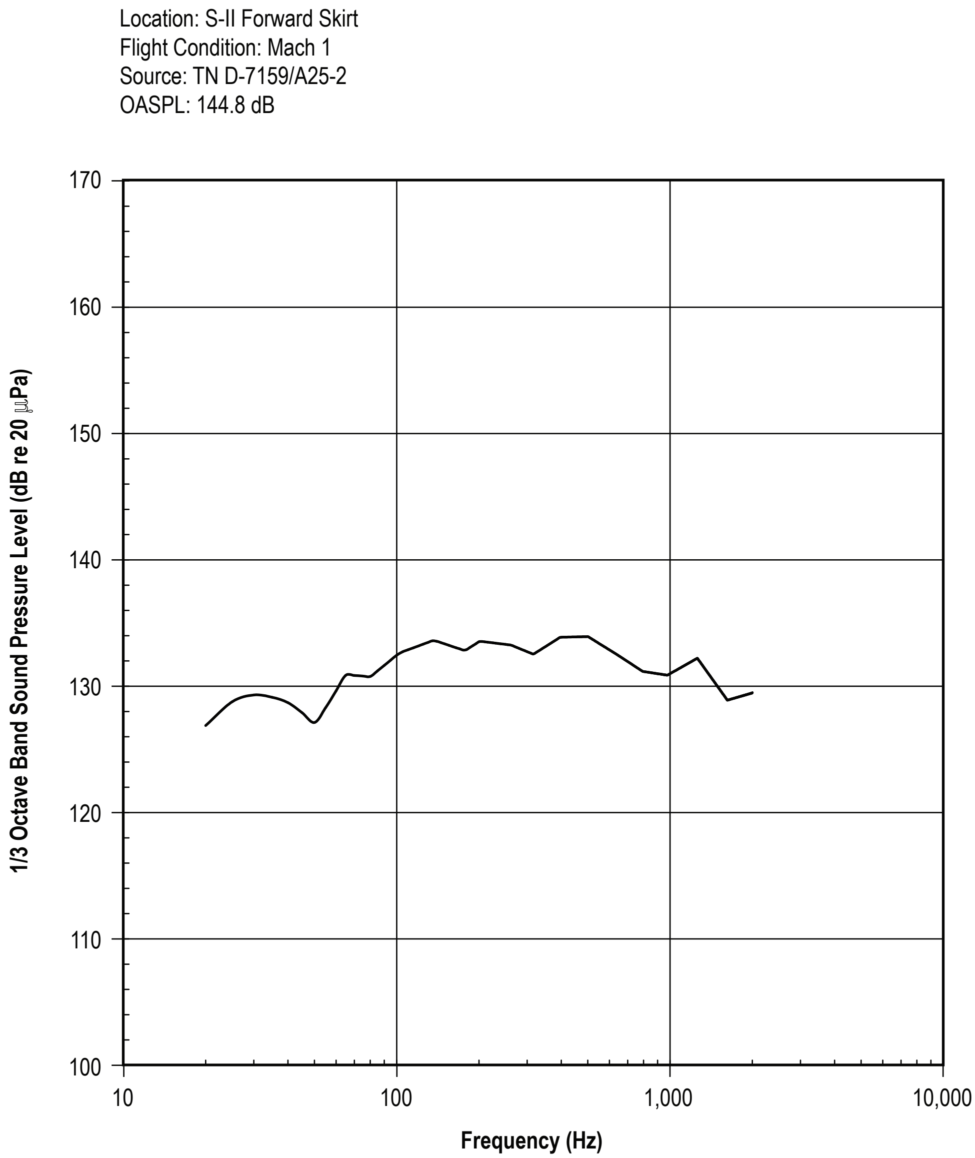

Figure 33. Saturn V acoustic spectrum, S-II forward skirt (subzone 11-2-2), Mach 1.

Document/Page No.: 7159/A25
Flight Condition: Liftoff
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 8.63 in
Surface Wt.: 3.3 lb/ft^2
Measurements: E87-219 E88-219

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: 2.51 lb/ft
Stringer Wt.: 0.71 lb/ft
Composite: 15.25 g_{rms}
Subzone: 11-2-2

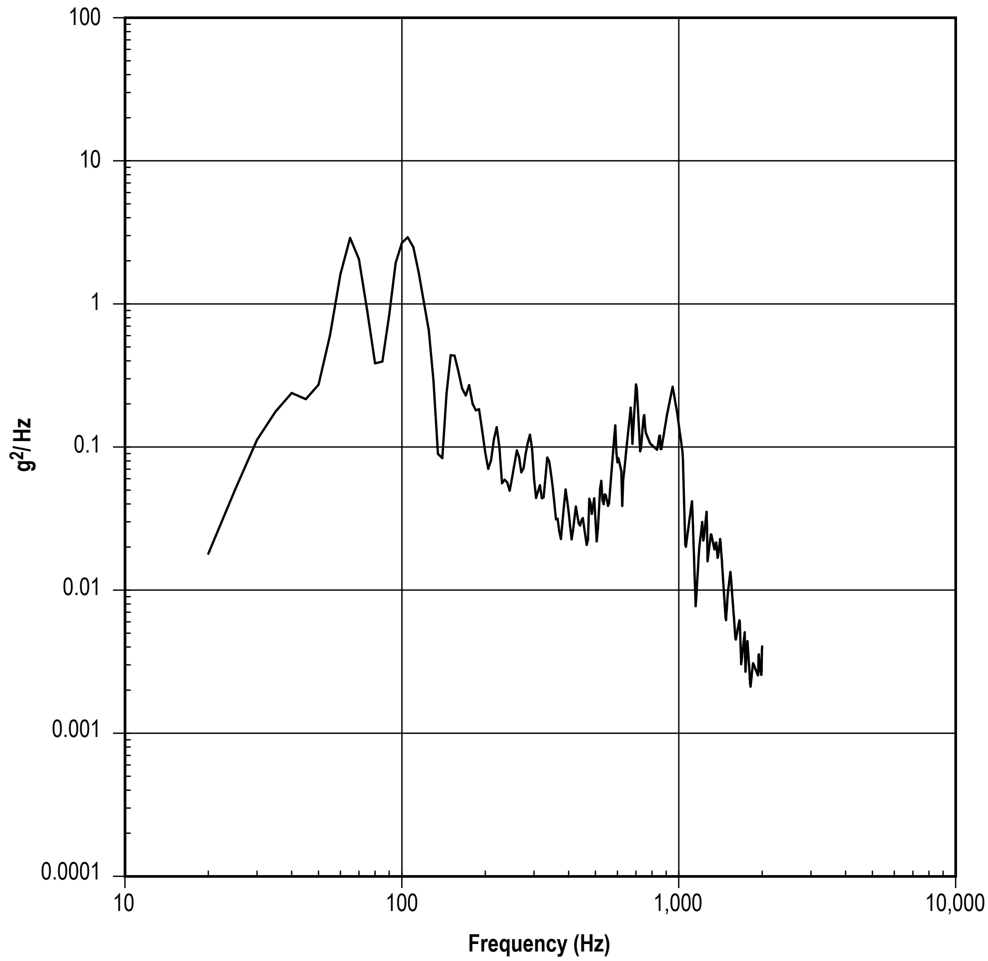

Figure 34. Ring frame PSD, radial, liftoff, 3.3 lb/ft^2.

Document/Page No.: 7159/A27
Flight Condition: Mach 1
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 8.63 in
Surface Wt.: 3.3 lb/ft^2
Measurements: E87-219 E88-219

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: 2.51 lb/ft
Stringer Wt.: 0.71 lb/ft
Composite: 14.58 g_{rms}
Subzone: 11-2-2

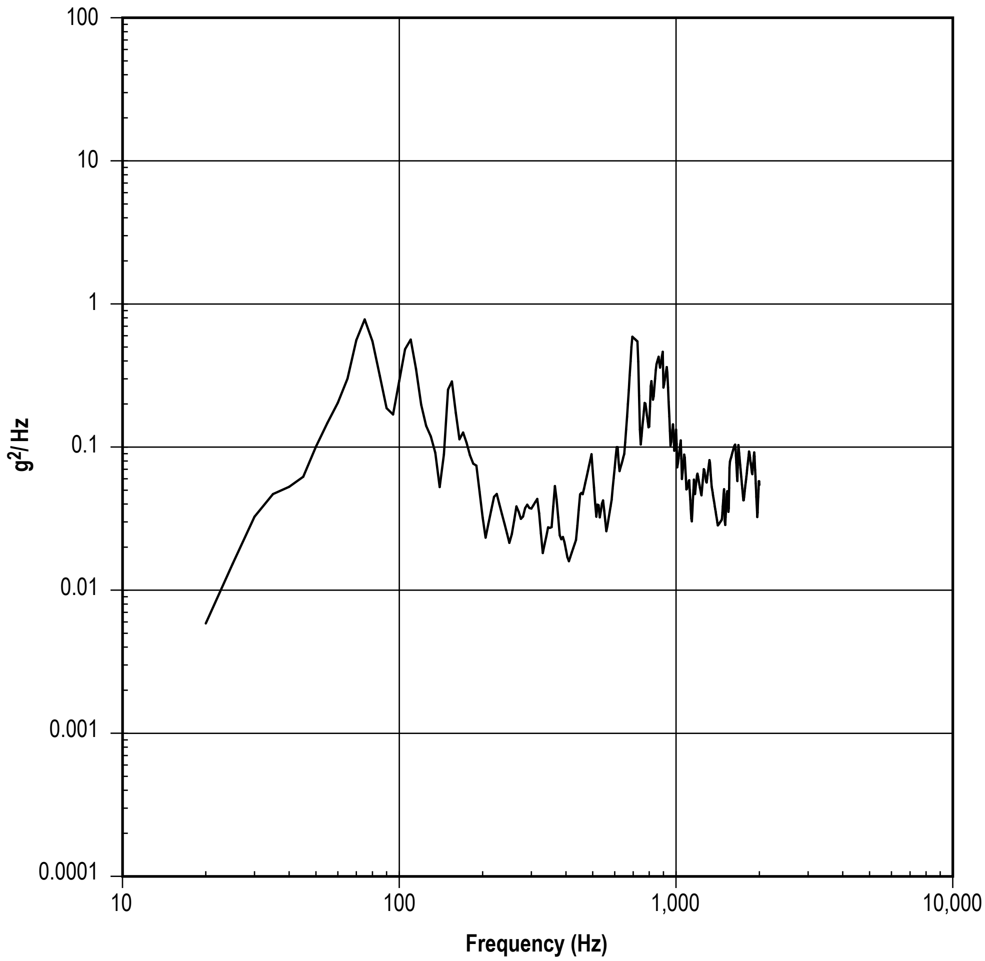

Figure 35. Ring frame PSD, radial, Mach 1, 3.3 lb/ft^2.

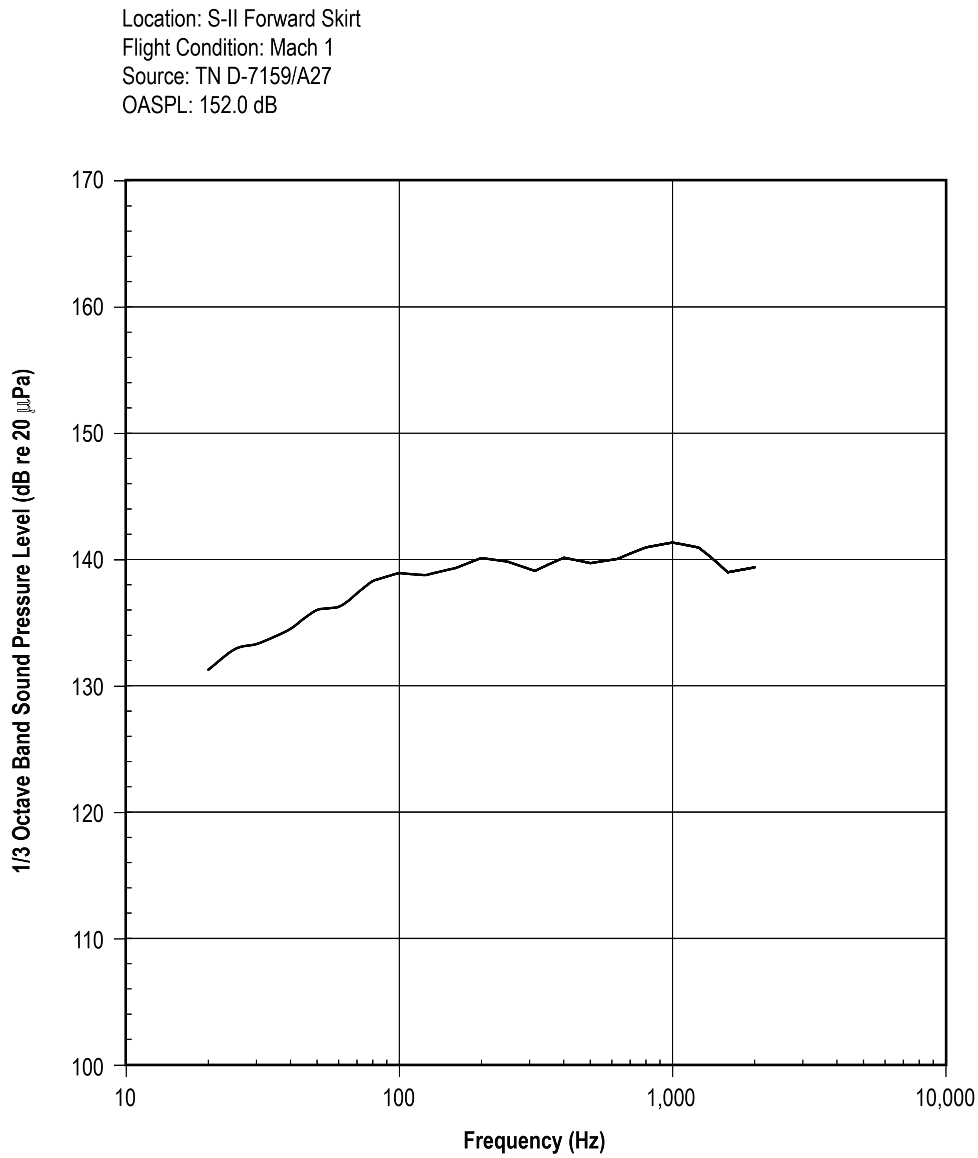

Figure 36. Saturn V acoustic spectrum, S-II forward skirt (subzone 11-2-2), Mach 1.

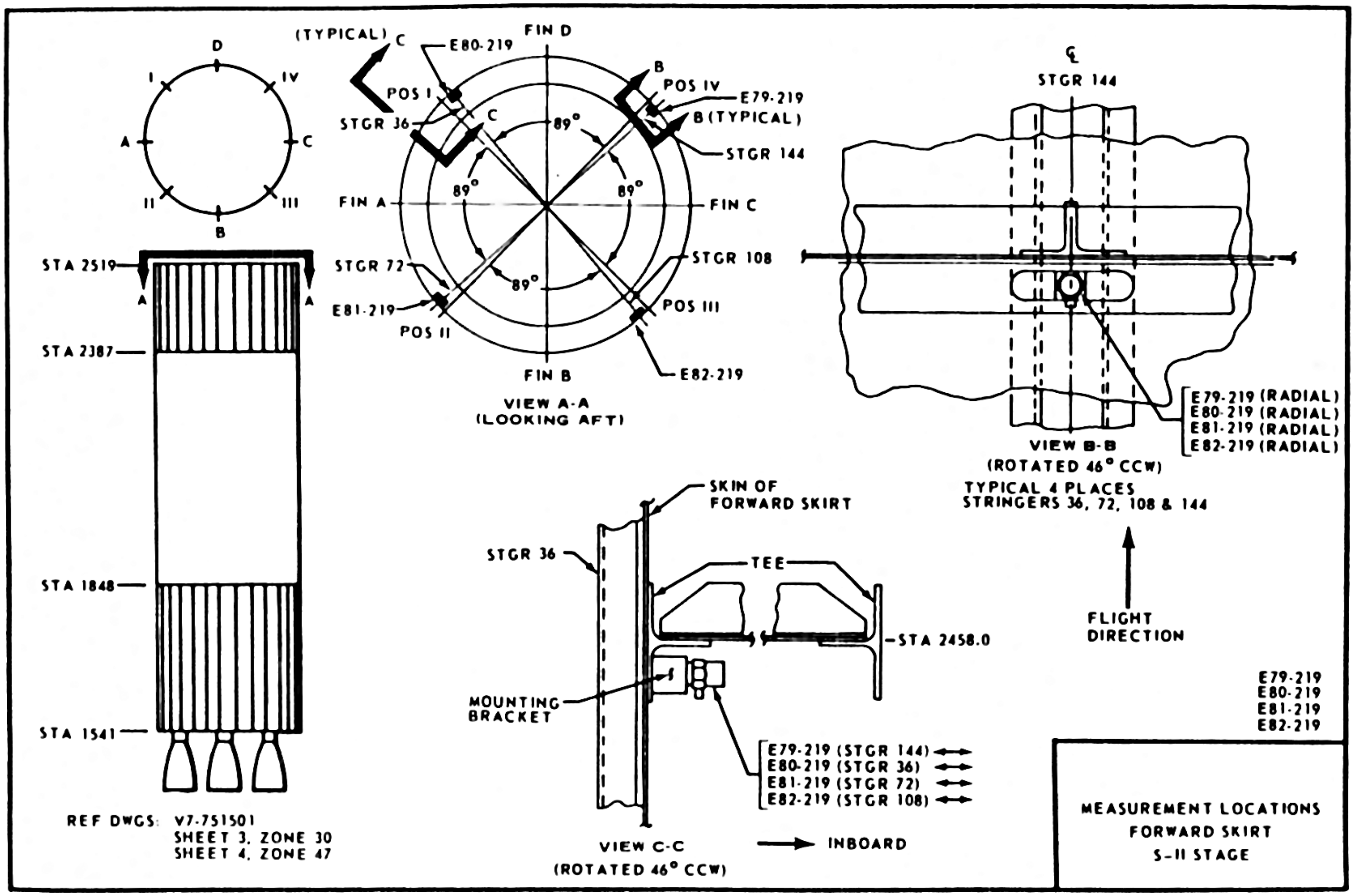

Figure 37. S-II stage forward skirt vibration measurement location.

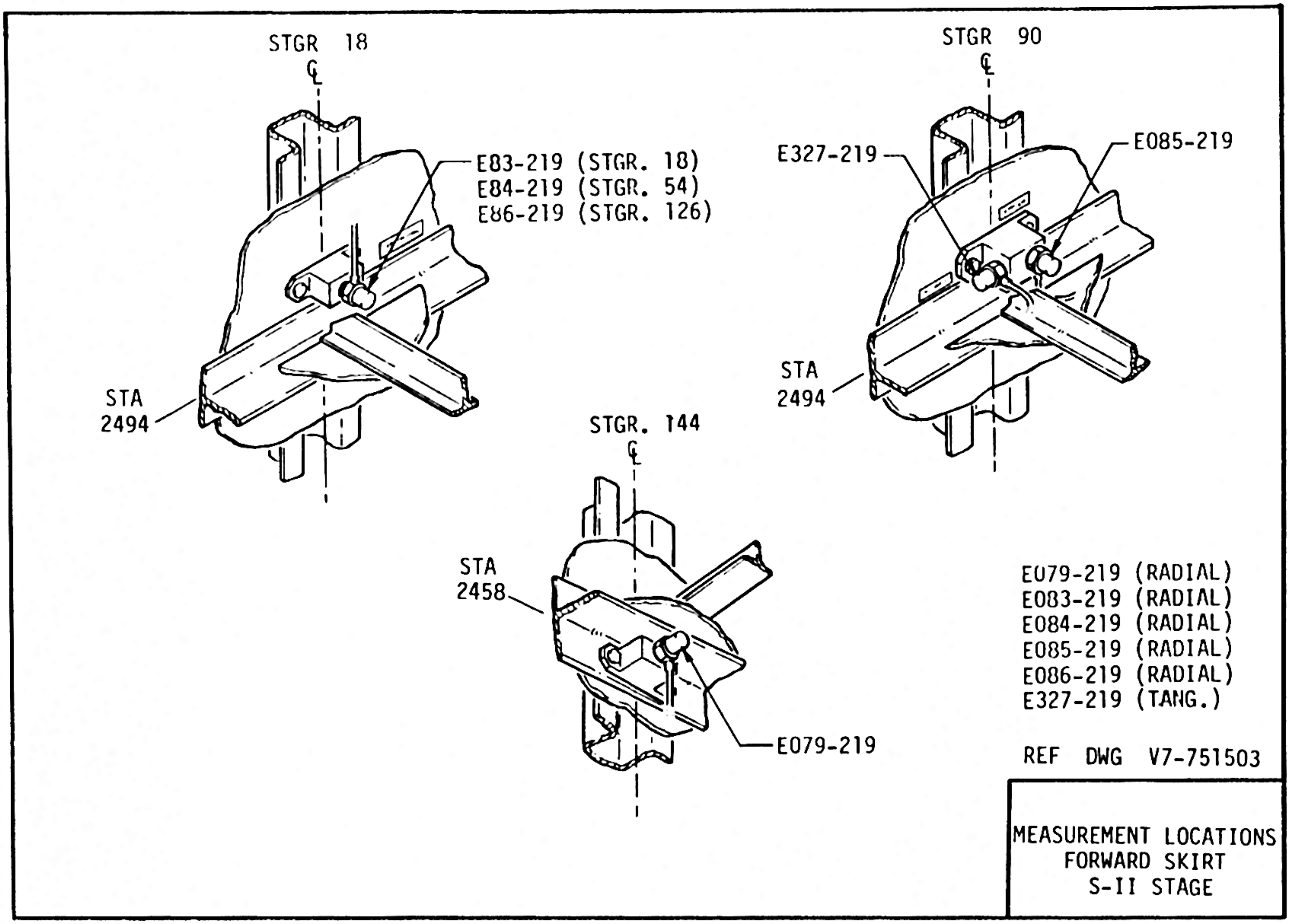

Figure 38. S-II stage forward skirt vibration measurement locations.

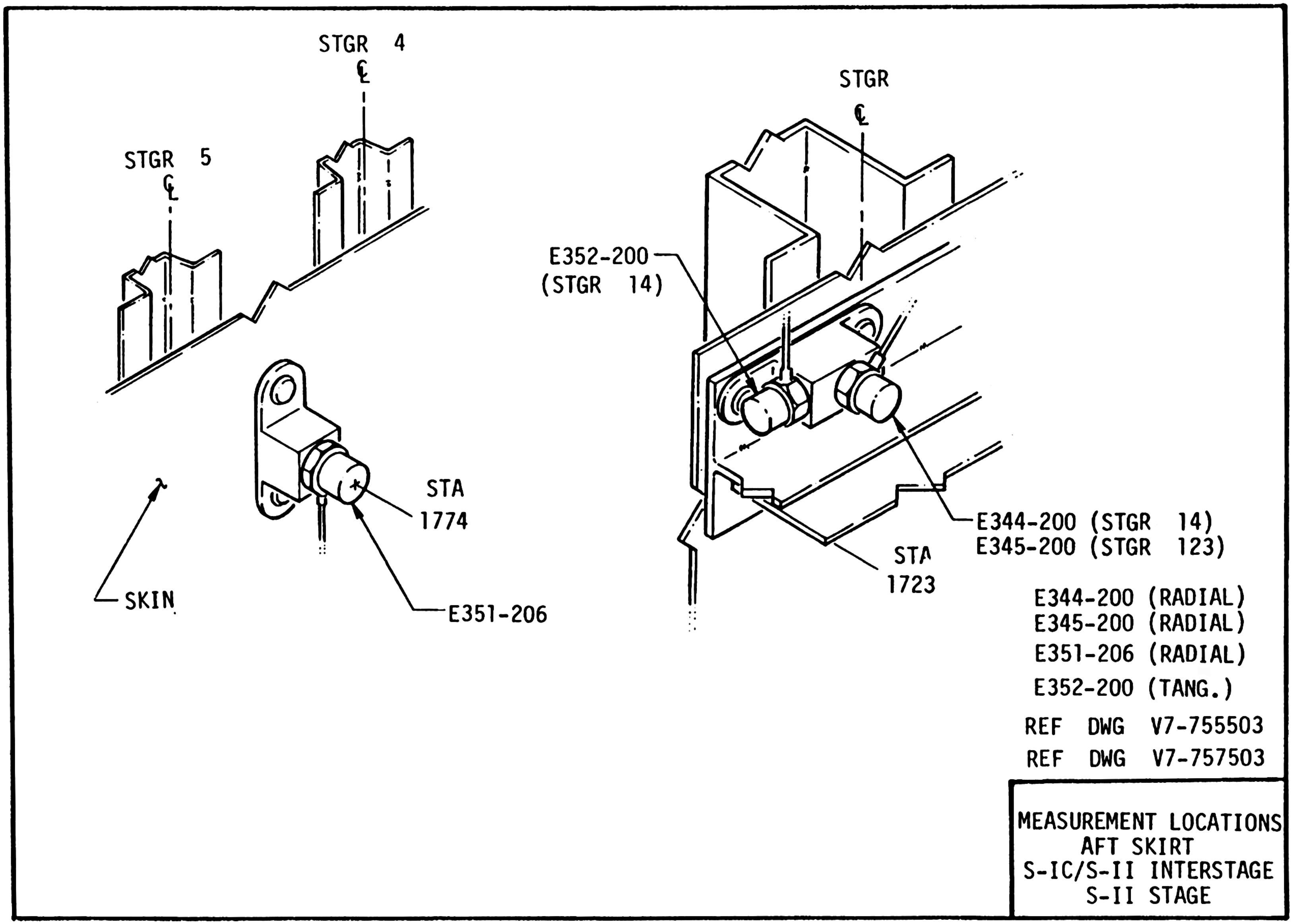

Figure 39. S-II stage S-IC/S–II interstage, and S-II aft skirt vibration measurement locations.

Document/Page No.: 7159/A29
Flight Condition: Liftoff
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 5.76-8.63 in
Surface Wt.: 1.1–1.5 lb/ft^2
Measurements: E79-86-219 E344-200

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.04–0.071 in
Ring Wt.: 1.09–1.49 lb/ft
Stringer Wt.: 0.71–1.0 lb/ft
Composite: 42.13 g_{rms}
Subzone: 11-2-2

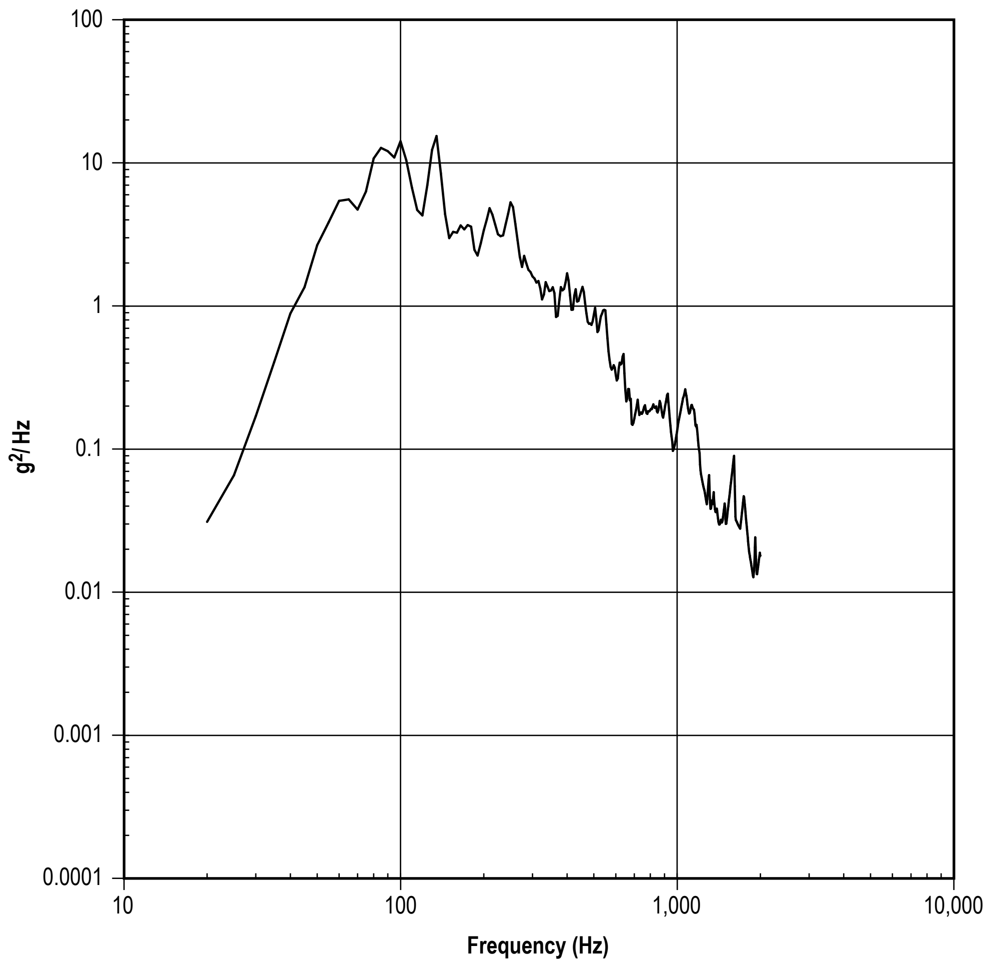

Figure 40. Ring frame PSD, radial, liftoff, 1.1–1.5 lb/ft^2.

Document/Page No.: 7159/A31
Flight Condition: Mach 1
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 5.76–8.63 in
Surface Wt.: 1.1–1.5 lb/ft^2
Measurements: E79-86-219 E344-200

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.04–0.071 in
Ring Wt.: 1.09–1.49 lb/ft
Stringer Wt.: 0.71–1.0 lb/ft
Composite: 9.46 g_{rms}
Subzone: 11-2-2

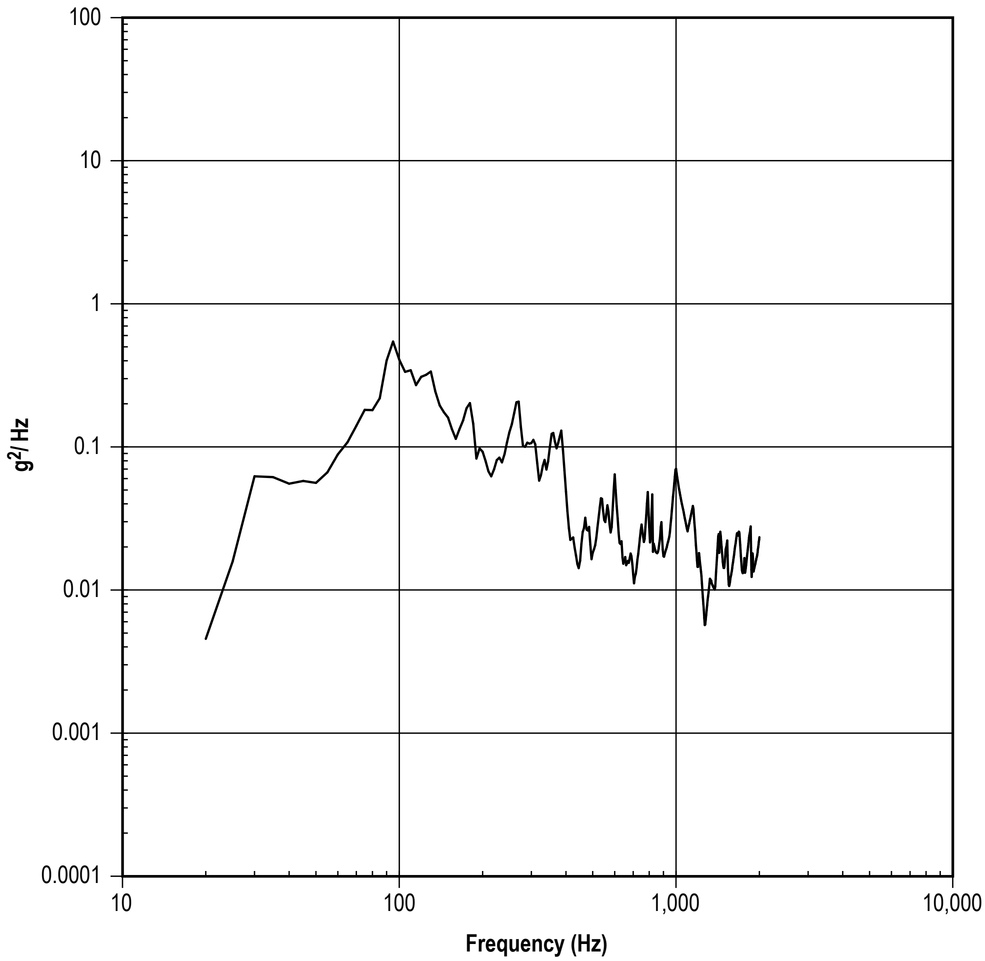

Figure 41. Ring frame PSD, radial, Mach 1, 1.1–1.5 lb/ft^2.

Document/Page No.: 7159/A33	Meas. Direction: Radial
Flight Condition: Max Q	Material: AL
Vehicle Diameter: 33 ft	Skin Thickness: 0.04–0.07in
Ring Sep.: N/A	Ring Wt.: 1.09–1.49 lb/ft
Stringer Sep.: 5.76–8.63 in	Stringer Wt.: 0.71–1.0 lb/ft
Surface Wt.: 1.1–1.5 lb/ft^2	Composite: 13.33 g_{rms}
Measurements: E79-86-219 E344-200	Subzone: 11-2-2

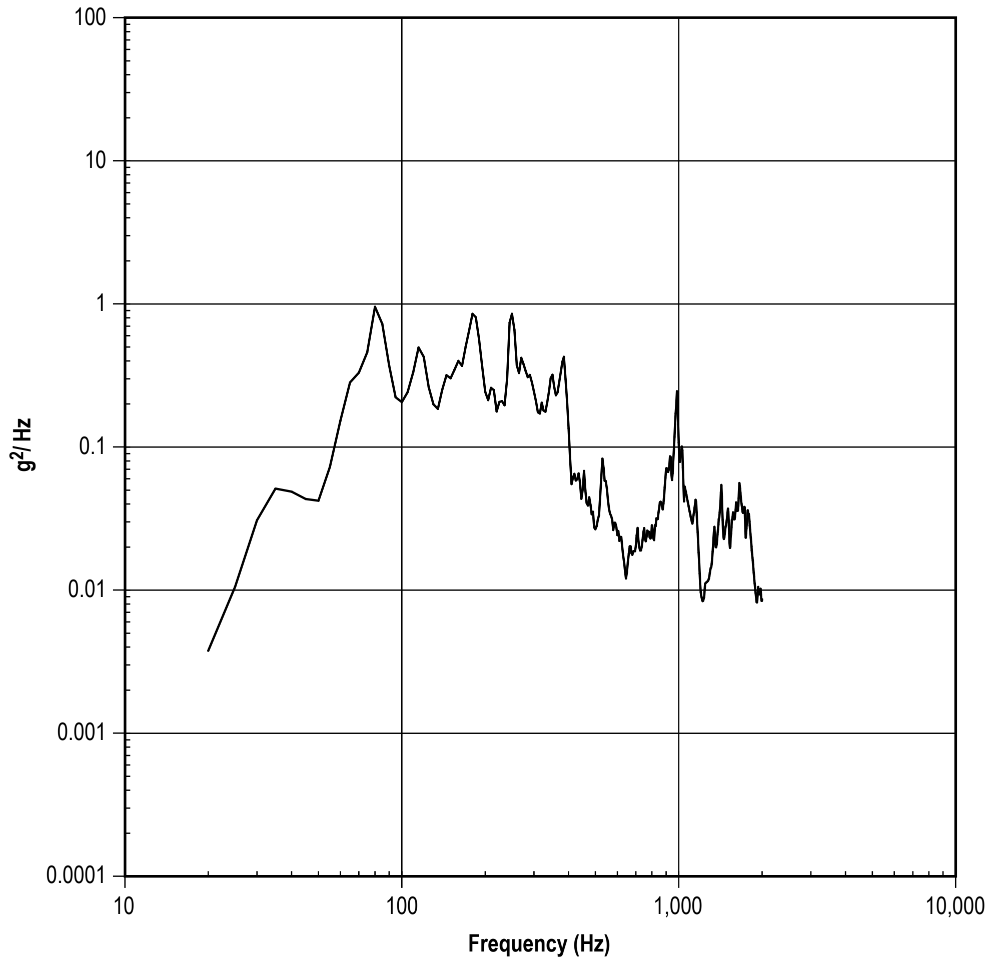

Figure 42. Ring frame PSD, radial, Max Q, 1.1–1.5 lb/ft^2.

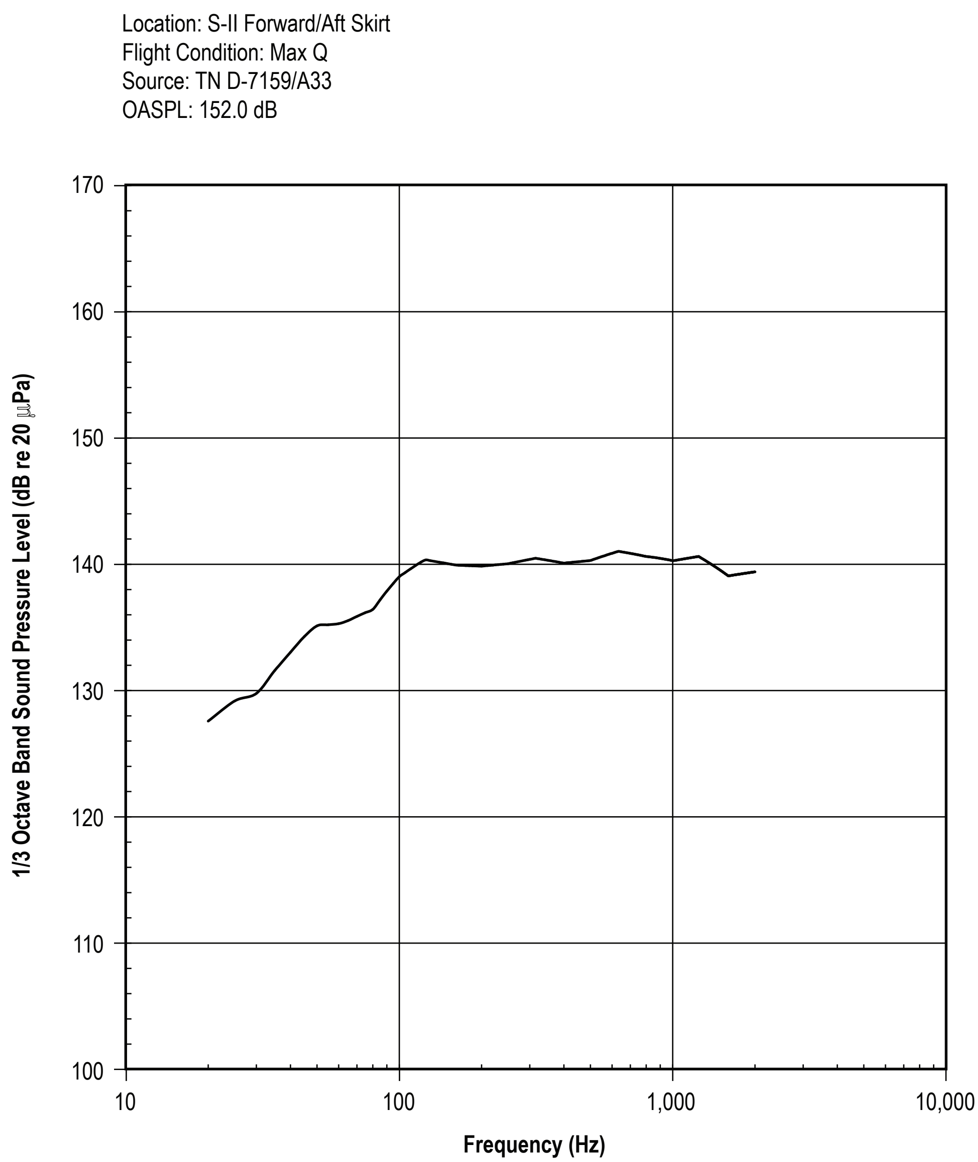

Figure 43. Saturn V acoustic spectrum, S-II forward/aft skirt, Max Q.

Document/Page No.: 7159/A35
Flight Condition: Mach 1/Max Q
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 5.76–8.63 in
Surface Wt.: 1.1–1.5 lb/ft^2
Measurements: E79-86-219 E344-200

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.04–0.07in
Ring Wt.: 1.09–1.49 lb/ft
Stringer Wt.: 0.71–1.0 lb/ft
Composite: 5.81 g_{rms}
Subzone: 11-2-2

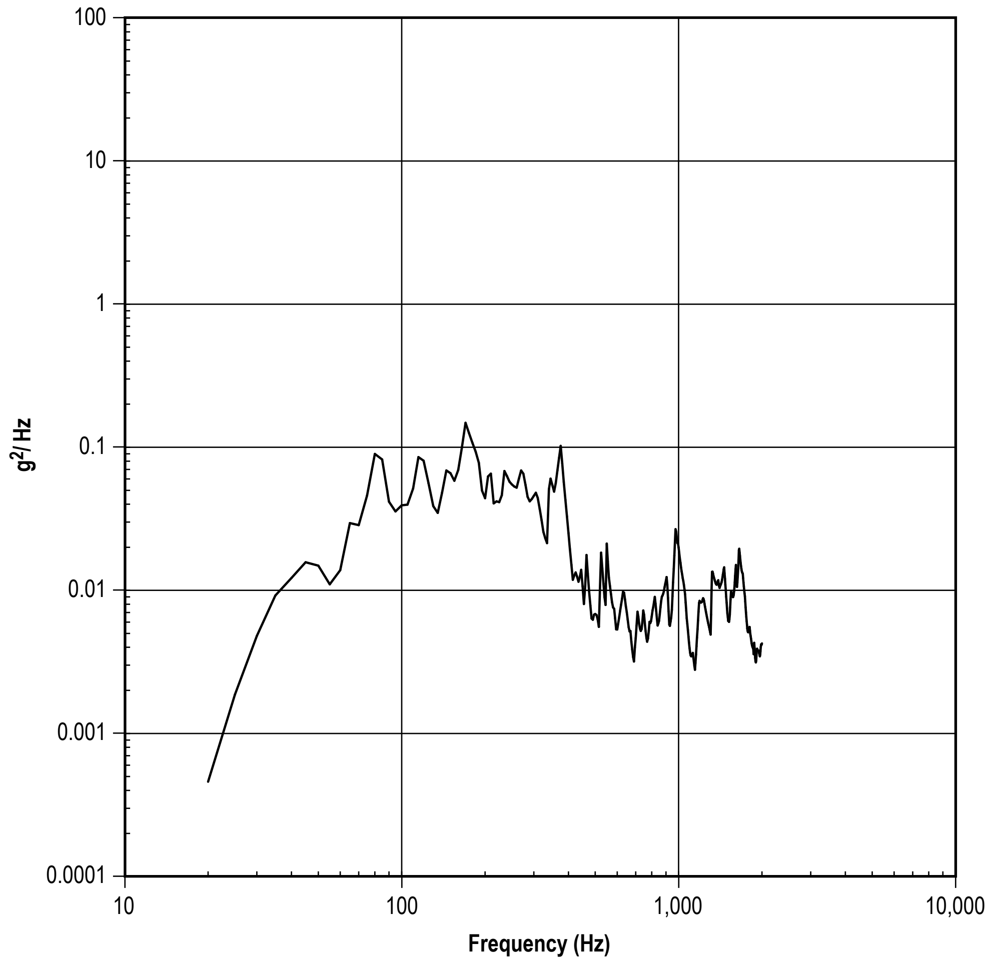

Figure 44. Ring frame PSD, radial, Mach 1/Max Q, 1.1–1.5 lb/ft^2.

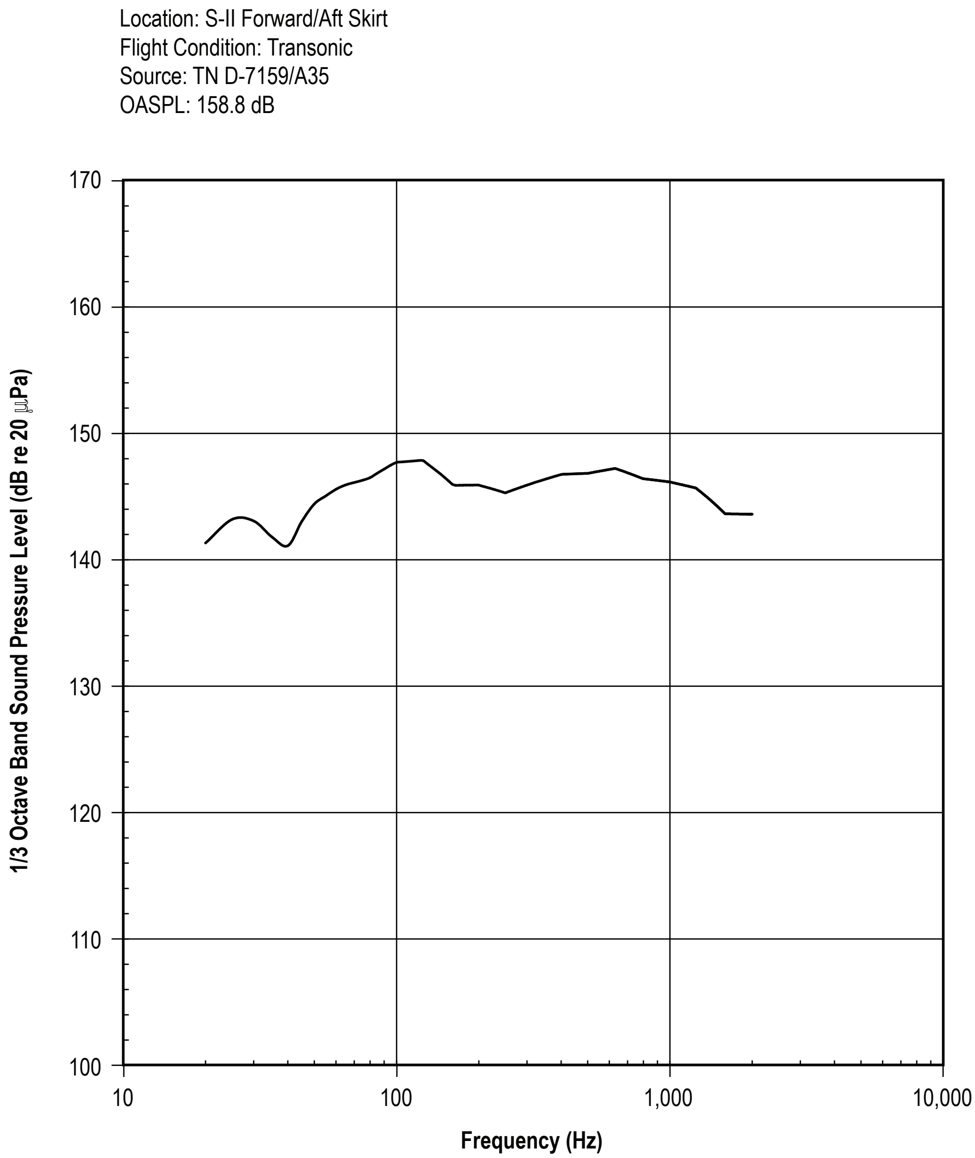

Figure 45. Saturn V acoustic spectrum, S-II forward/aft skirt, transonic.

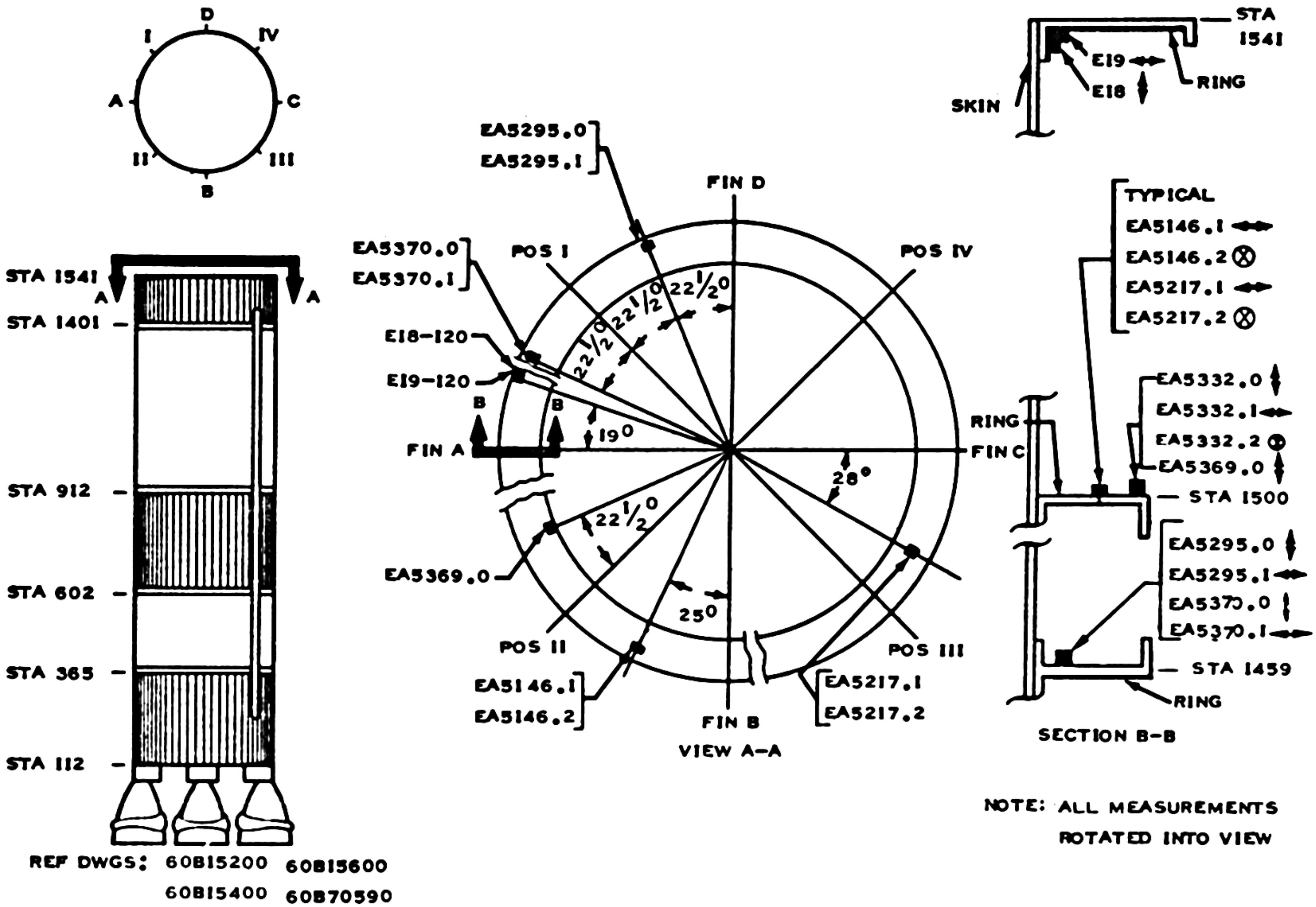

Figure 46. S-IC forward skirt rings measurement locations.

Document/Page No.: 7159/A37
Flight Condition: Static
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 5.76 in
Surface Wt.: 9.2 lb/ft^2
Measurements: E19-120

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.10 in
Ring Wt.: 5.53 lb/ft
Stringer Wt.: 1.0 lb/ft
Composite: 16.37 g_{rms}
Subzone: 7

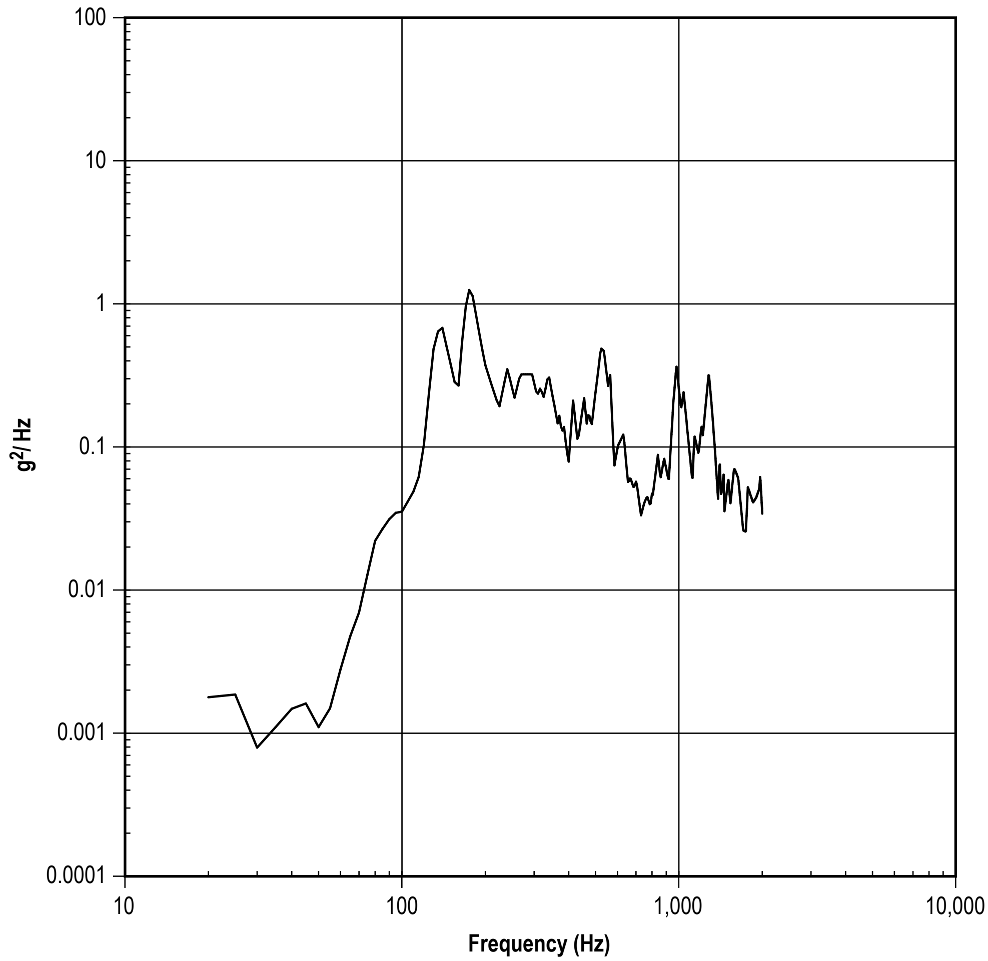

Figure 47. Ring frame PSD, radial, static, 9.2 lb/ft^2.

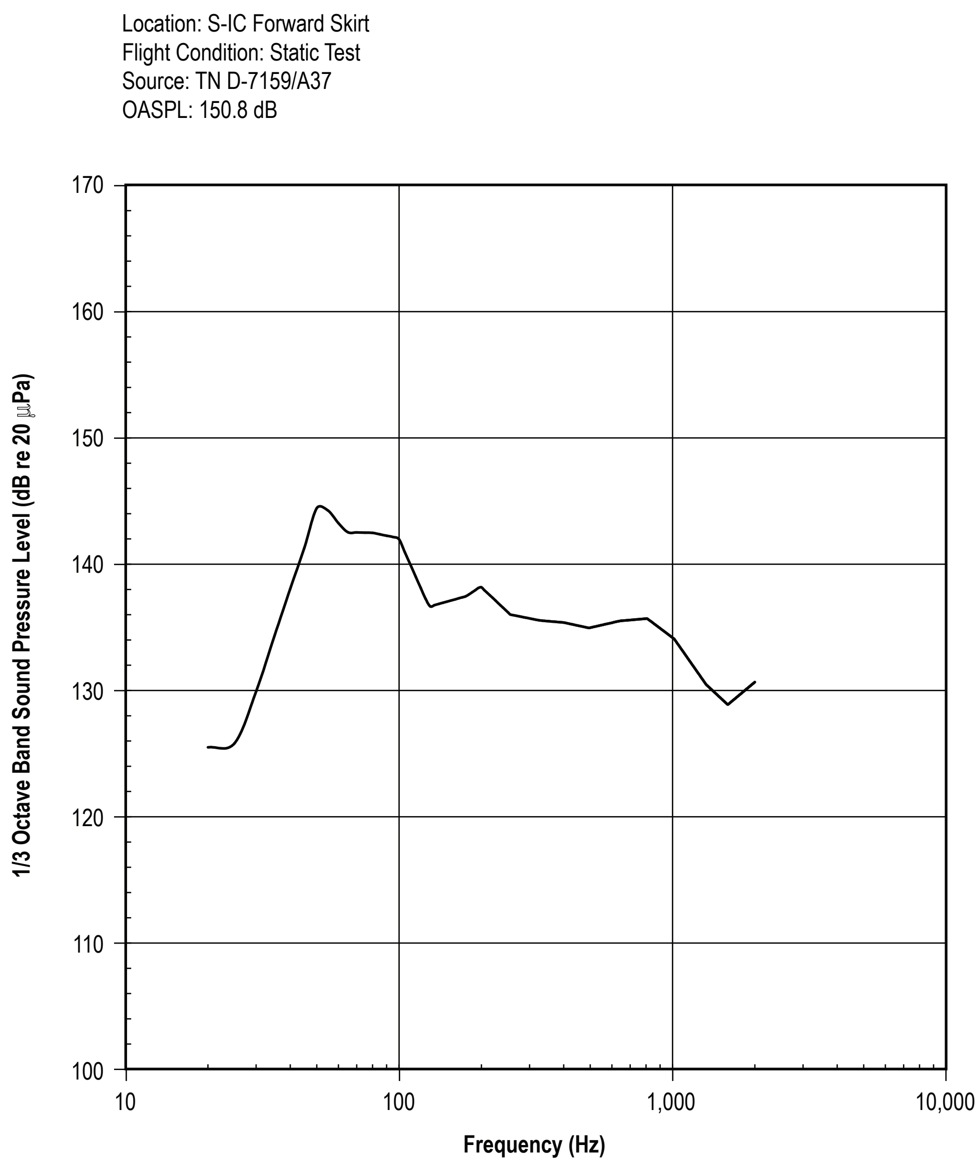

Figure 48. Saturn V acoustic spectrum, S-IC forward skirt, static test.

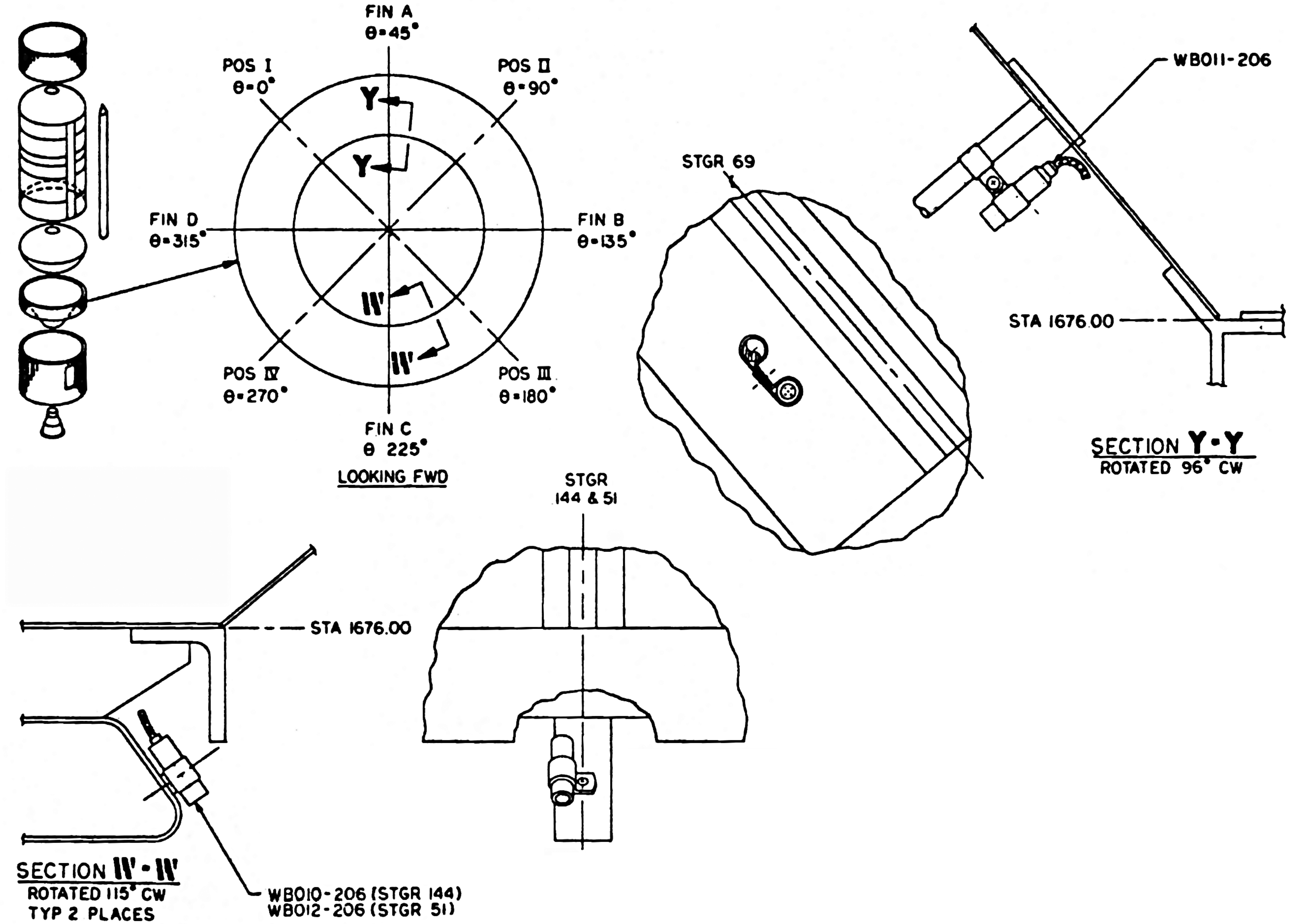

Figure 49. Zone 9: S-II stage thrust cone acoustic measurement location.

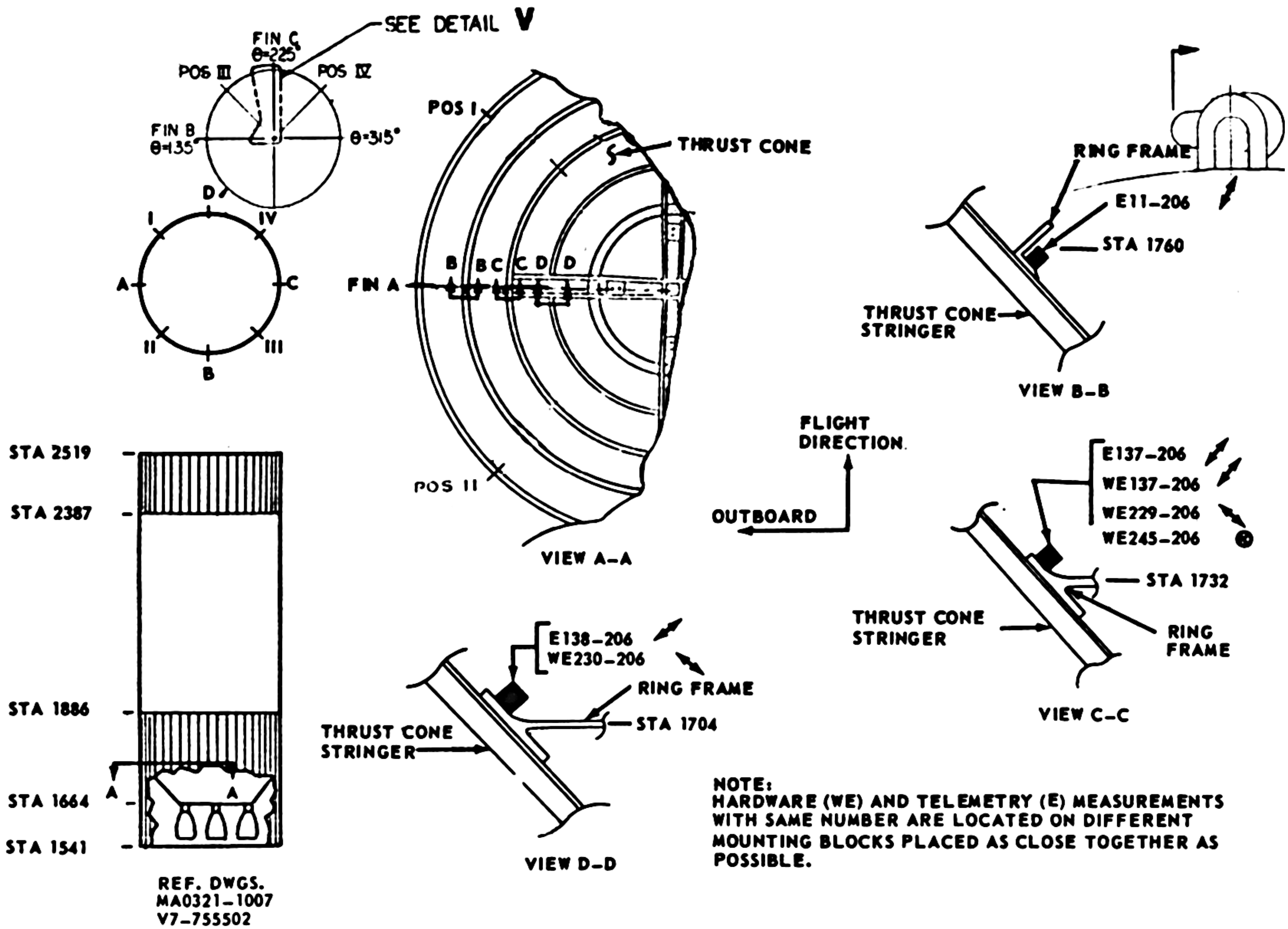

Figure 50. S-II thrust cone ring frames measurement locations.

Document/Page No.: 7159/A39	Meas. Direction: Parallel
Flight Condition: Static	Material: AL
Vehicle Diameter: 25.2 ft	Skin Thickness: 0.08–0.13in
Ring Sep.: N/A	Ring Wt.: 4.67–70.95 lb/ft
Stringer Sep.: 4.85 in	Stringer Wt.: 1.04 lb/ft
Surface Wt.: 4.7–8.0 lb/ft^2	Composite: 0.61 g_{rms}
Measurements: WE229-206	Subzone: 9-2-1-1

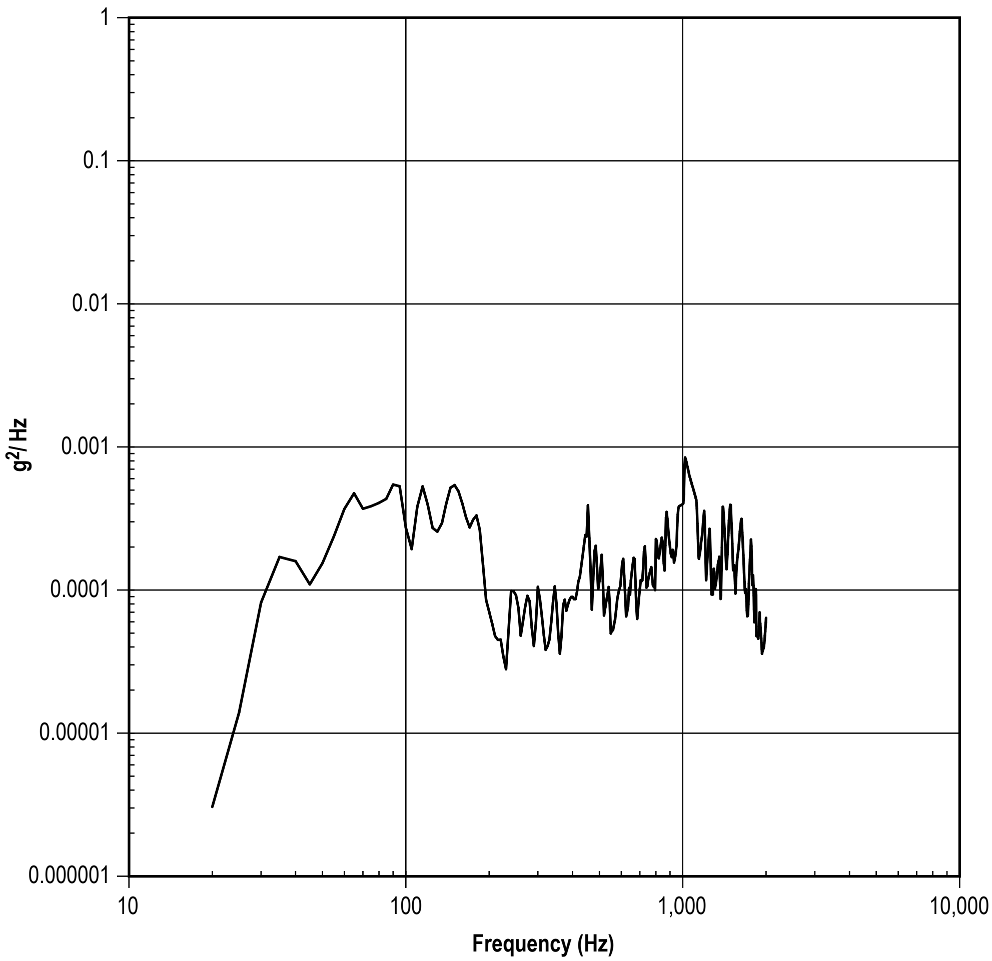

Figure 51. Ring frame PSD, parallel, static, 4.7–8.0 lb/ft^2.

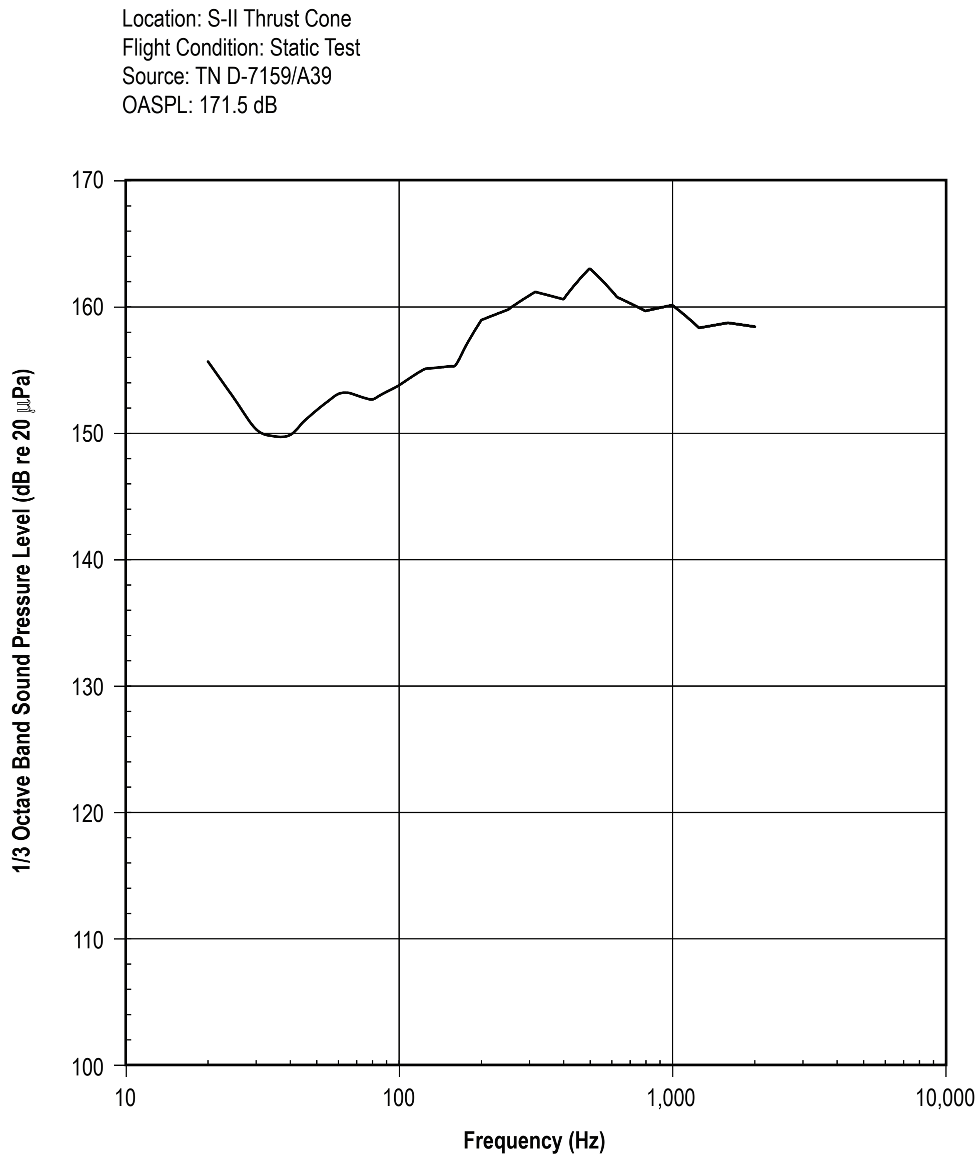

Figure 52. Saturn V acoustic spectrum, S-II thrust cone (subzone 9-2-1), static test.

Document/Page No.: 7159/A41
Flight Condition: Static
Vehicle Diameter: 17.5 ft
Ring Sep.: N/A
Stringer Sep.: 6.72 in
Surface Wt.: 13.9 lb/ft^2
Measurements: WE181-206

Meas. Direction: Normal
Material: AL
Skin Thickness: 0.13 in
Ring Wt.: 11.39 lb/ft
Stringer Wt.: 1.04 lb/ft
Composite: 2.03 g_{rms}
Subzone: 9-2-1-1

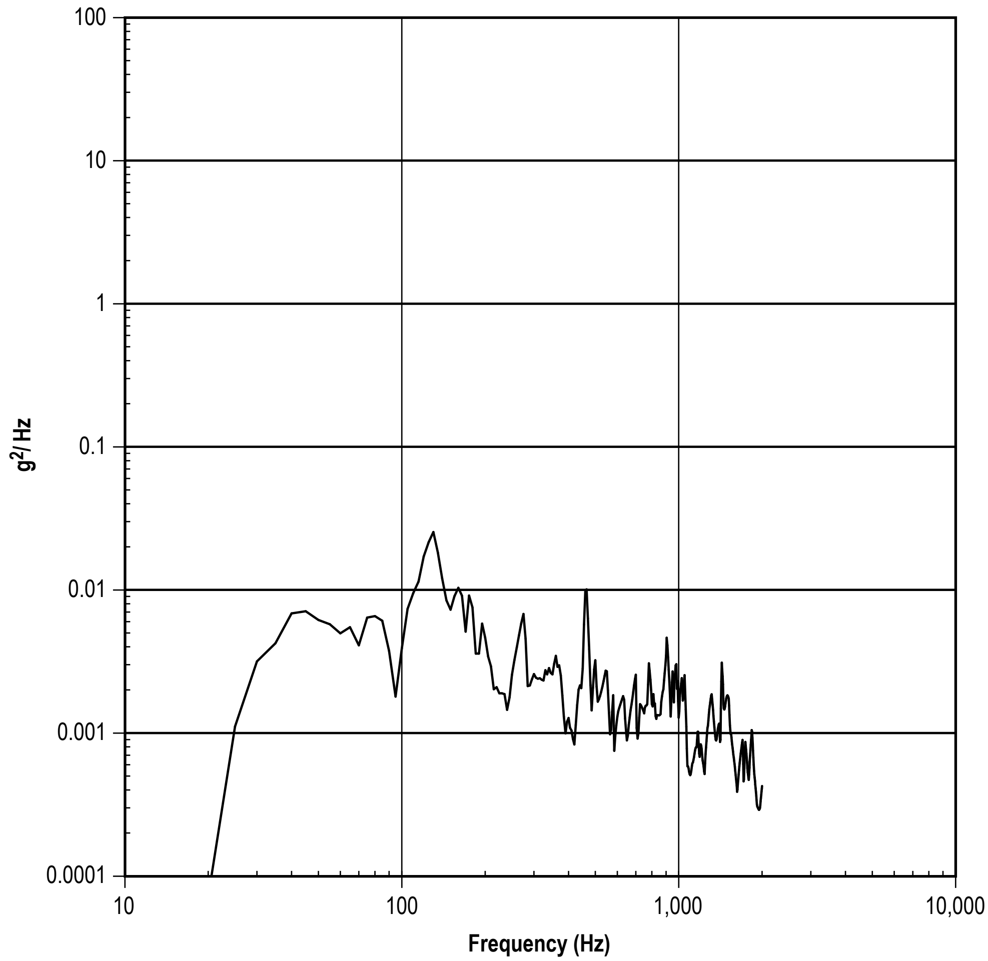

Figure 53. Ring frame PSD, normal, static, 13.9 lb/ft^2.

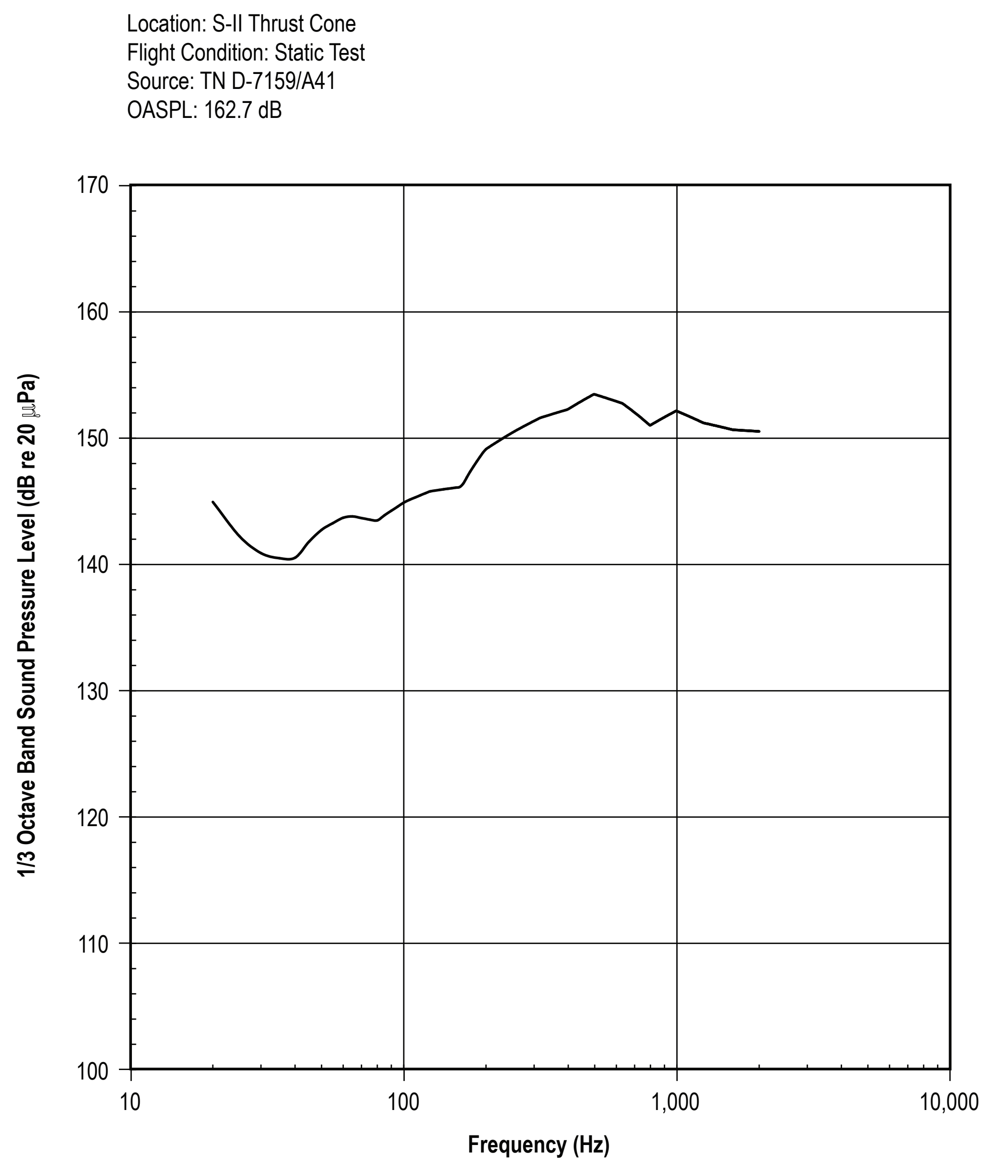

Figure 54. Saturn V acoustic spectrum, S-II thrust cone (subzone 9-2-1), static test.

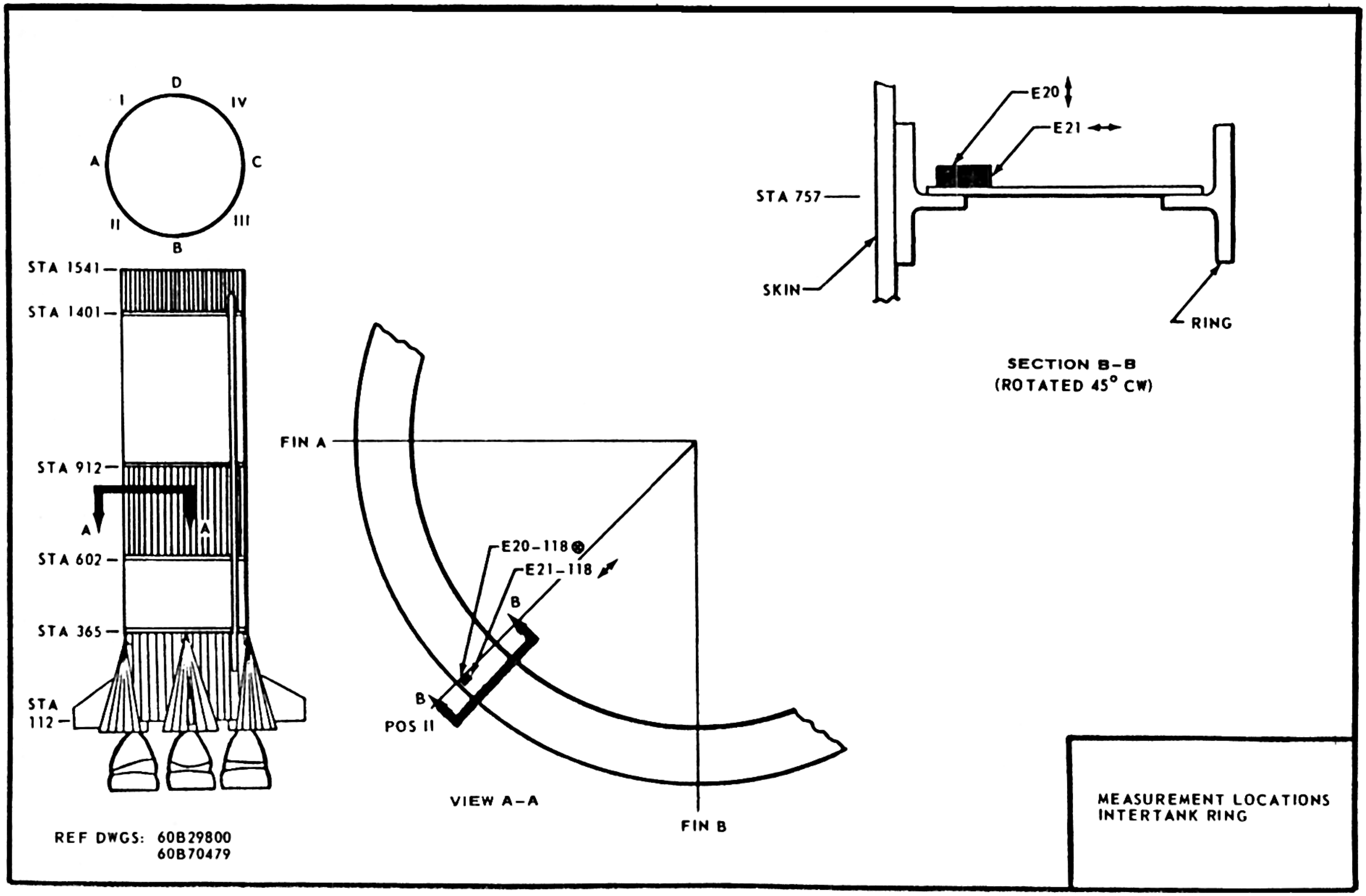

Figure 55. S-IC stage intertank ring vibration measurement location.

Document/Page No.: A43
Flight Condition: Liftoff
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 7.88 in
Surface Wt.: 6.2 lb/ft^2
Measurements: E20-118

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.185 in
Ring Wt.: 4.75 lb/ft
Stringer Wt.: N/A
Composite: 5.10 grms
Subzone: 5-2-2

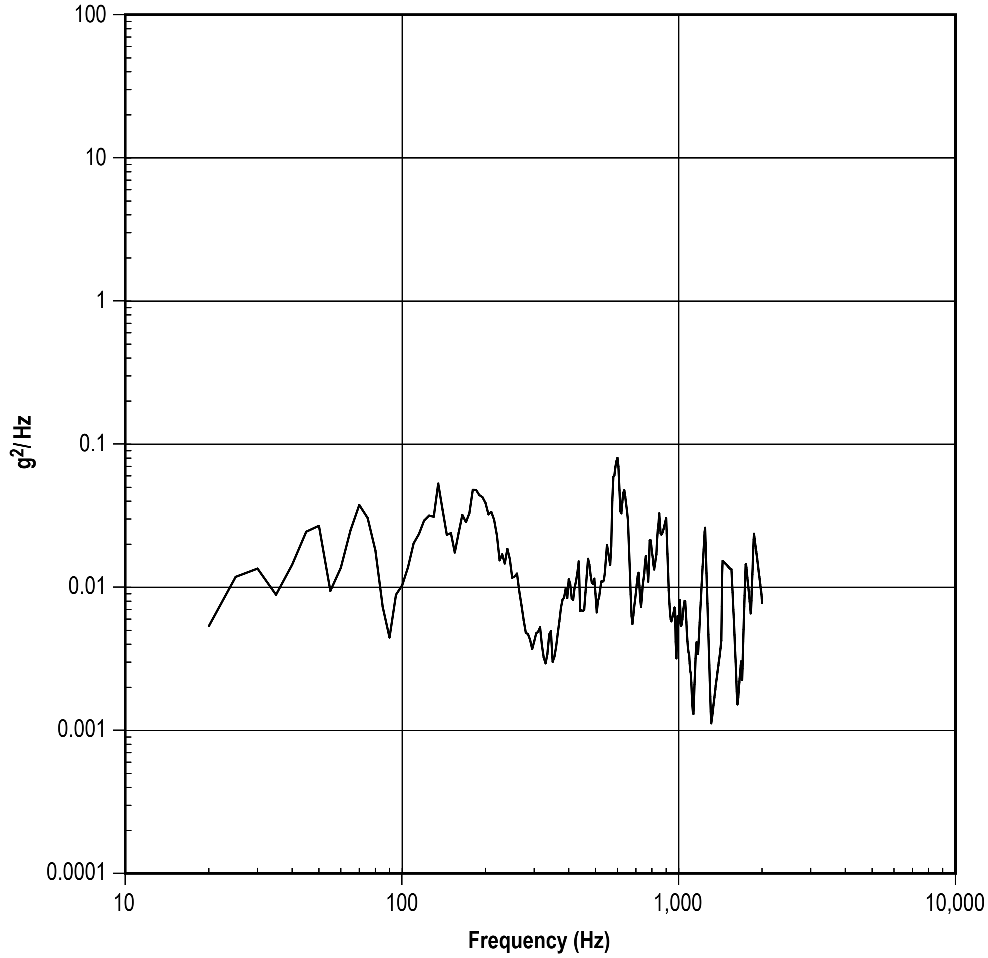

Figure 56. Ring frame PSD, longitudinal, liftoff, 6.2 lb/ft^2.

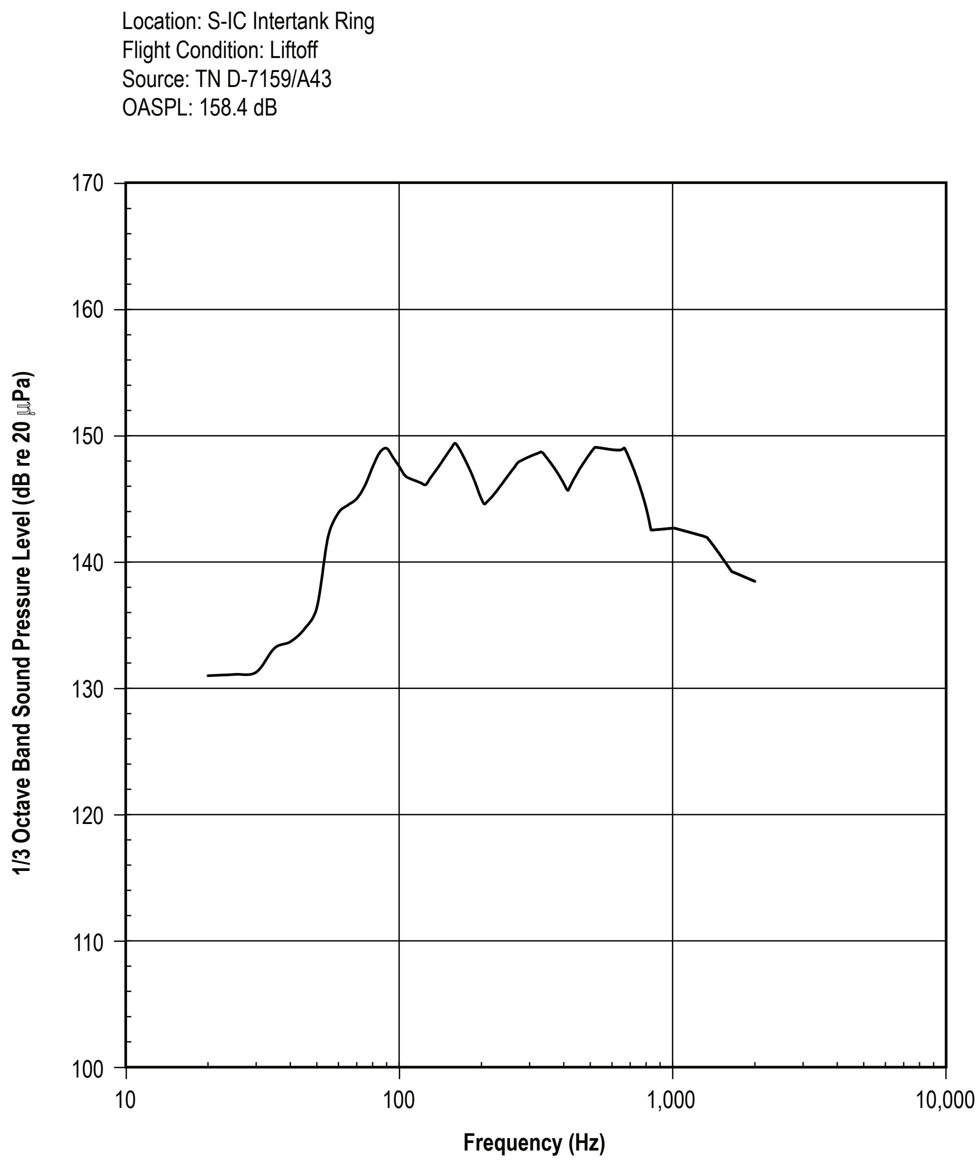

Figure 57. Saturn V acoustic spectrum, S-IC intertank ring (subzone 5-2-2), liftoff.

Document/Page No.: 7159/A45	Meas. Direction: Longitudinal
Flight Condition: Mach 1	Material: AL
Vehicle Diameter: 33 ft	Skin Thickness: 0.185 in
Ring Sep.: N/A	Ring Wt.: 4.75 lb/ft
Stringer Sep.: 7.88 in	Stringer Wt.: N/A
Surface Wt.: 6.2 lb/ft^2	Composite: 17.34 grms
Measurements: E20-118	Subzone: 5-2-2

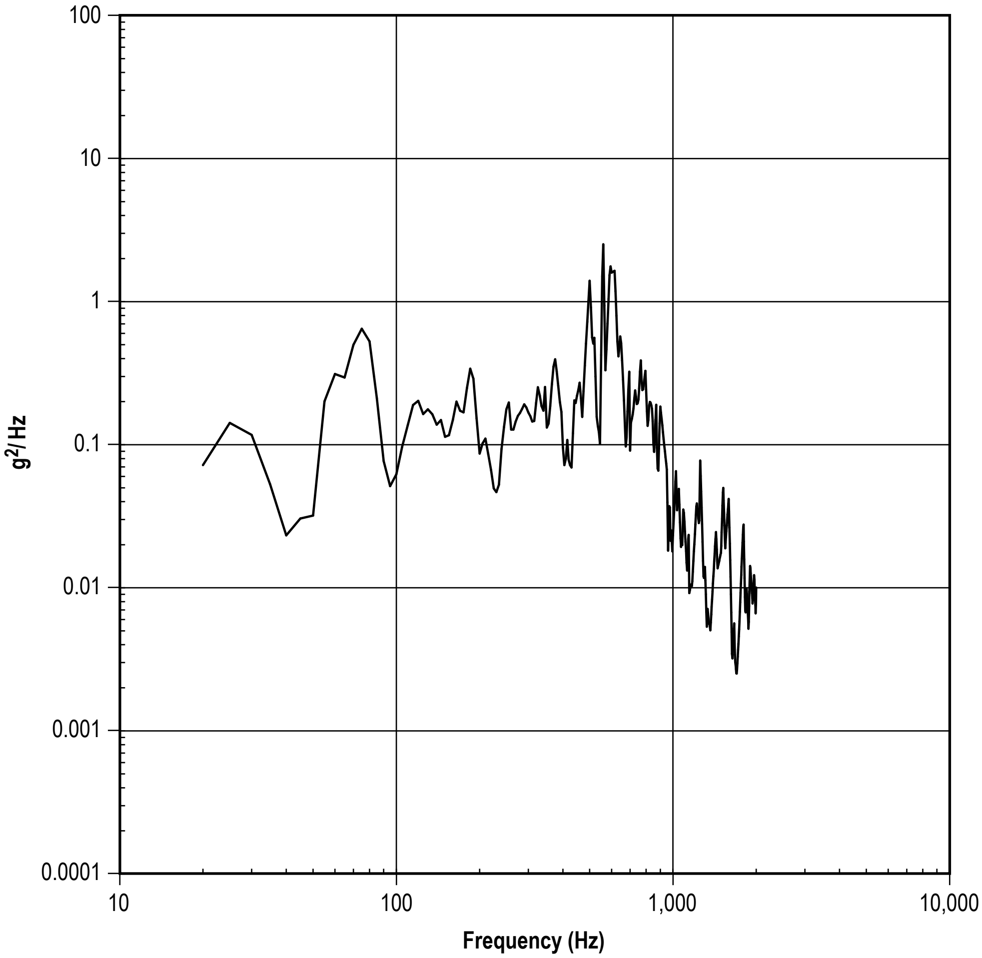

Figure 58. Ring frame PSD, longitudinal, Mach 1, 6.2 lb/ft^2.

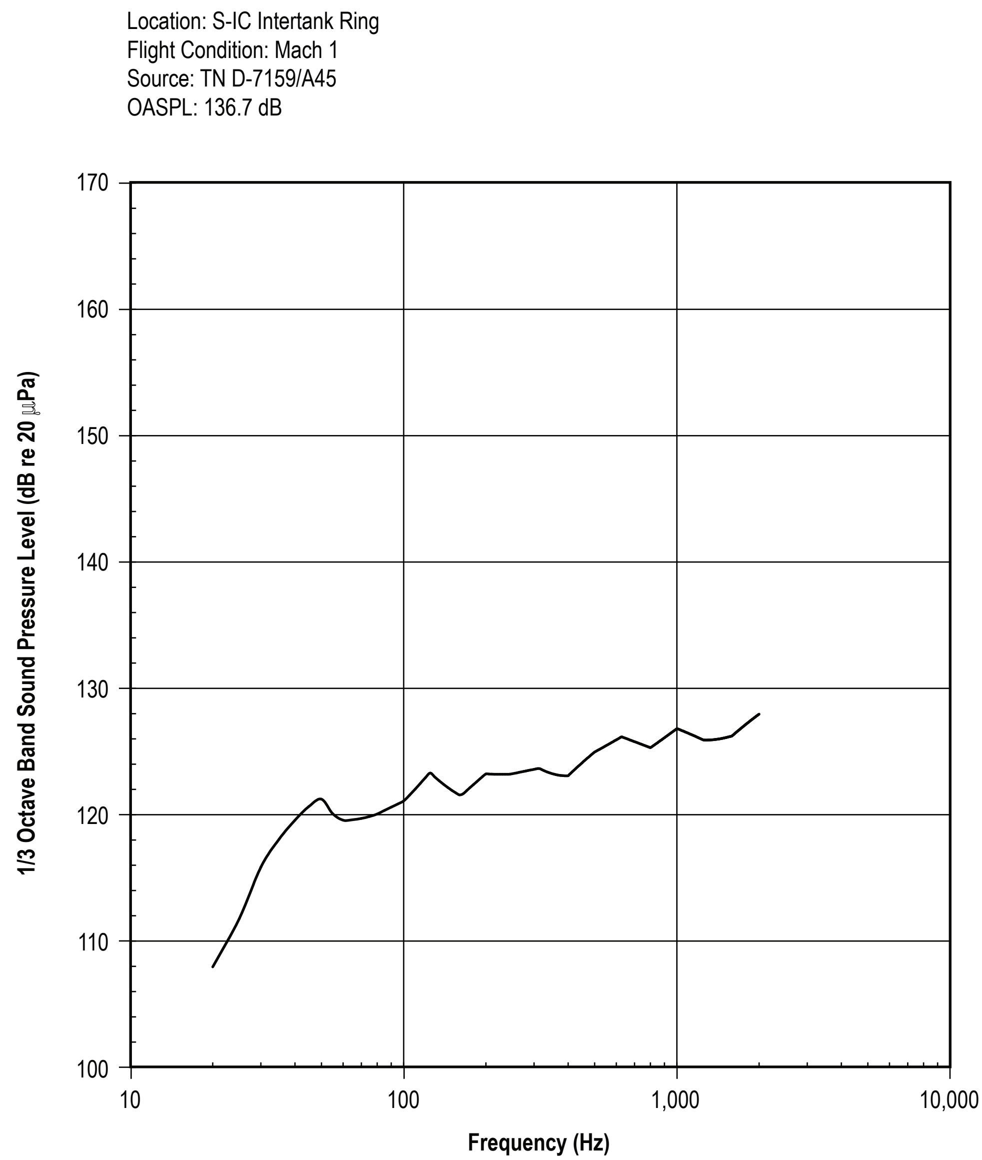

Figure 59. Saturn V acoustic spectrum, S-IC intertank ring (subzone 5-2-2), Mach 1.

Document/Page No.: 7159/A47
Flight Condition: Max Q
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 7.88 in
Surface Wt.: 6.2 lb/ft^2
Measurements: E20-118

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.185 in
Ring Wt.: 4.75 lb/ft
Stringer Wt.: N/A
Composite: 26.31 grms
Subzone: 5-2-2

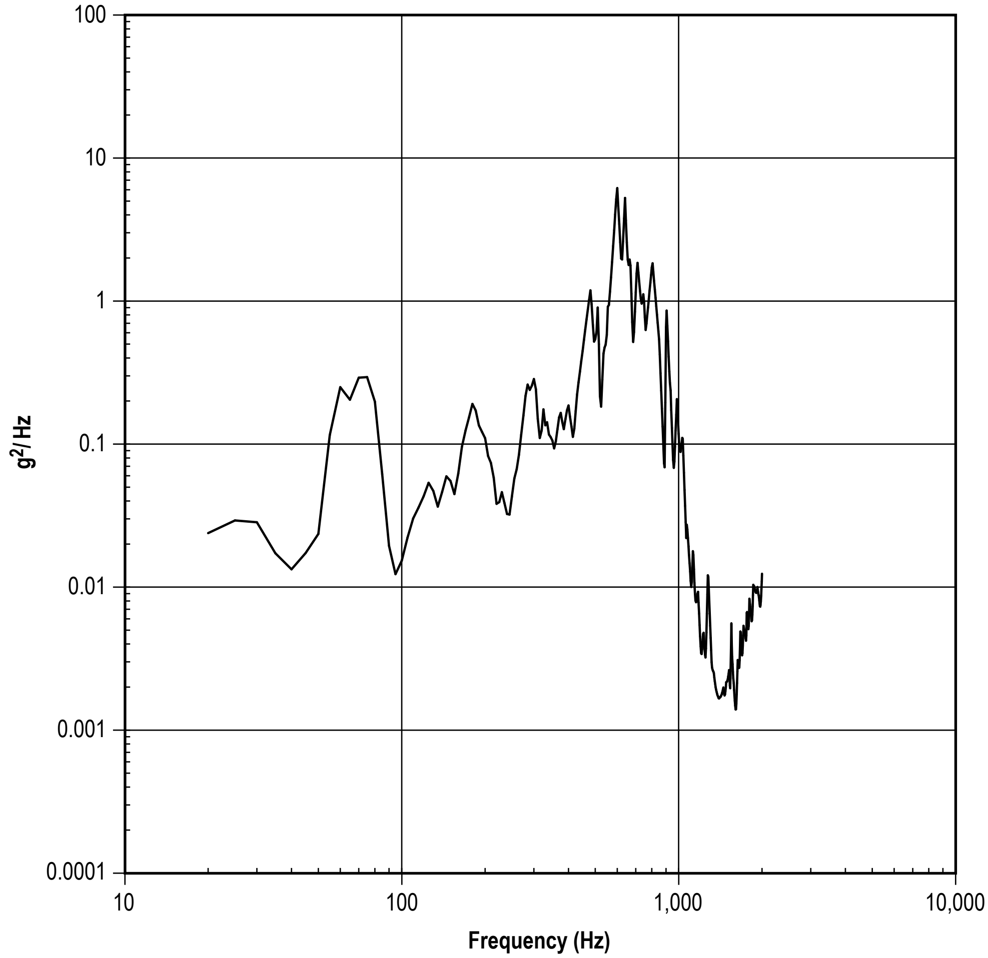

Figure 60. Ring frame PSD, longitudinal, Max Q, 6.2 lb/ft^2.

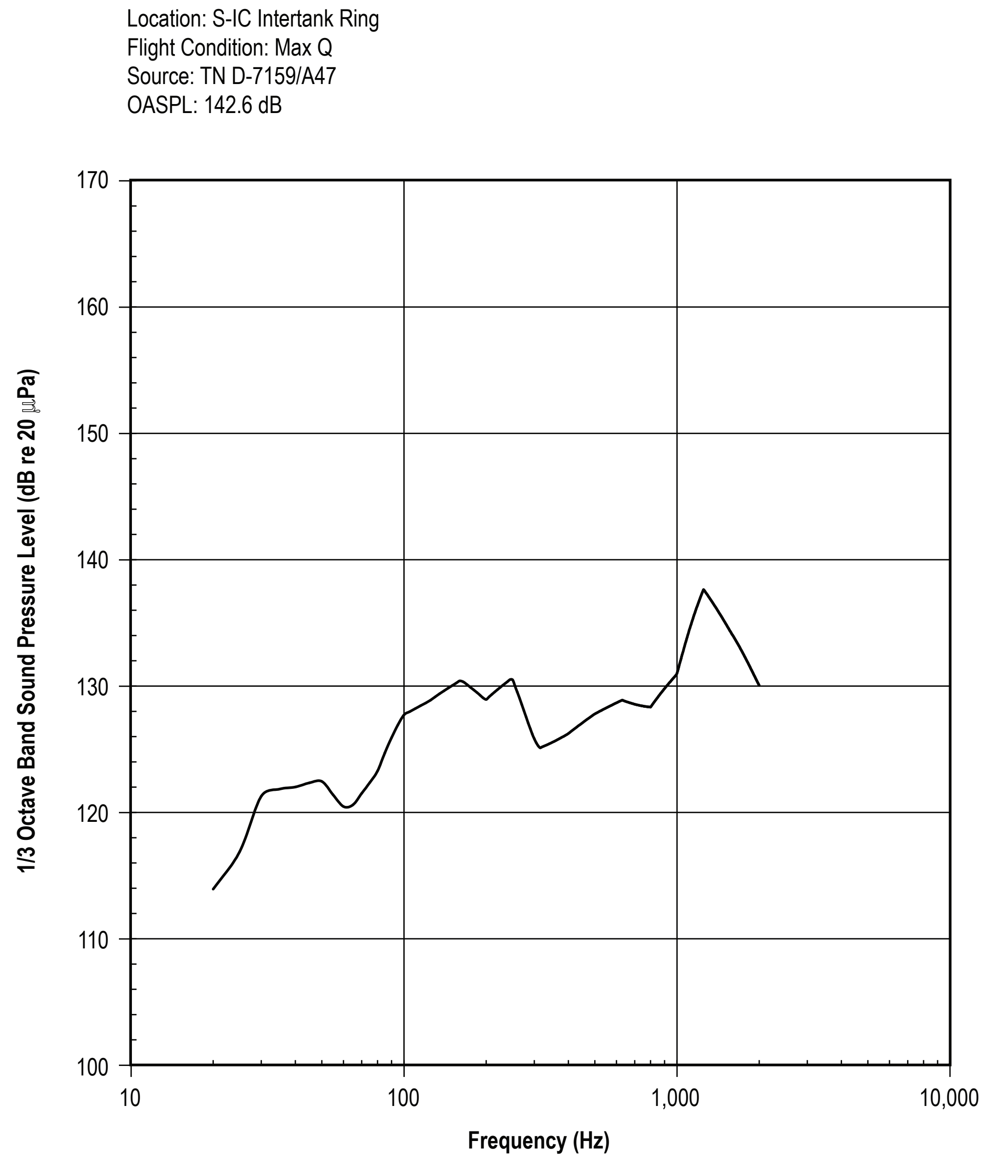

Figure 61. Saturn V acoustic spectrum, S-IC intertank ring (subzone 5-2-2), Max Q.

Document/Page No.: 7159/A49
Flight Condition: Mach 1/Max Q
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 7.88 in
Surface Wt.: 6.2 lb/ft^2
Measurements: E20-118

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.185 in
Ring Wt.: 4.75 lb/ft
Stringer Wt.: N/A
Composite: 28.39 grms
Subzone: 5-2-2

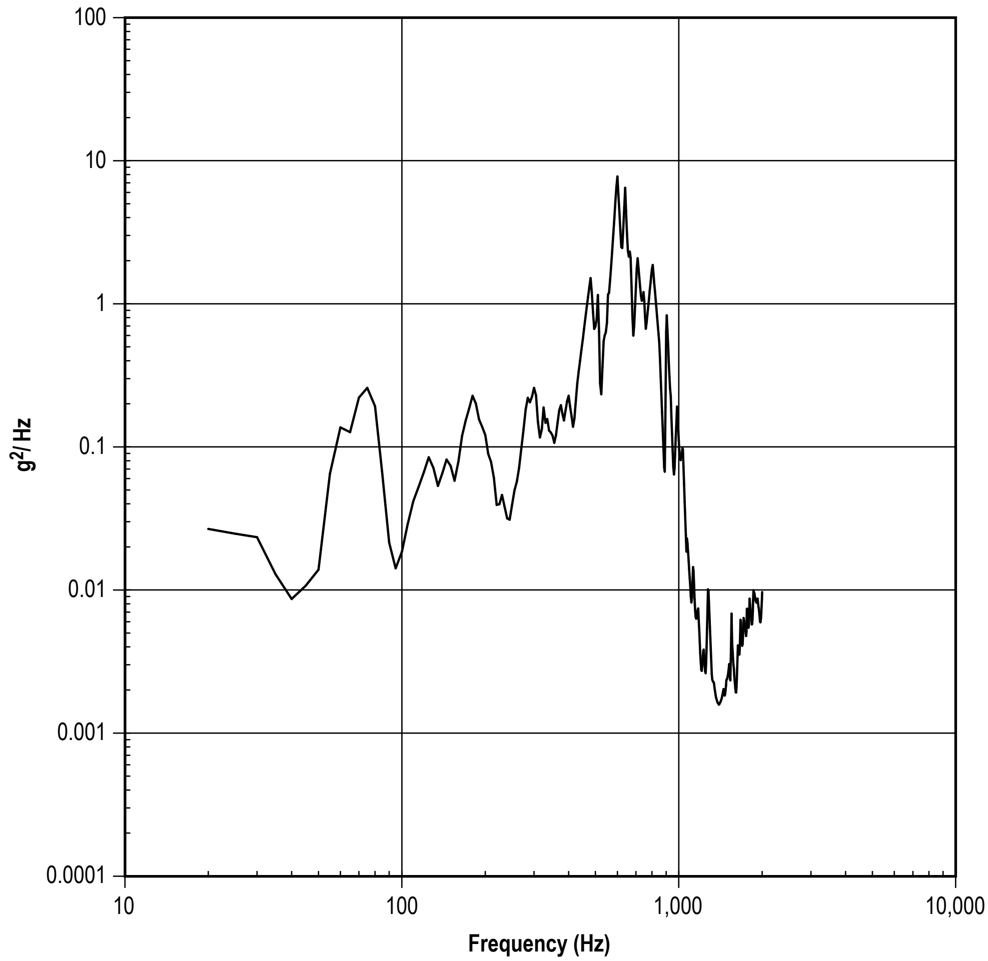

Figure 62. Ring frame PSD, longitudinal, Mach 1/Max Q, 6.2 lb/ft^2.

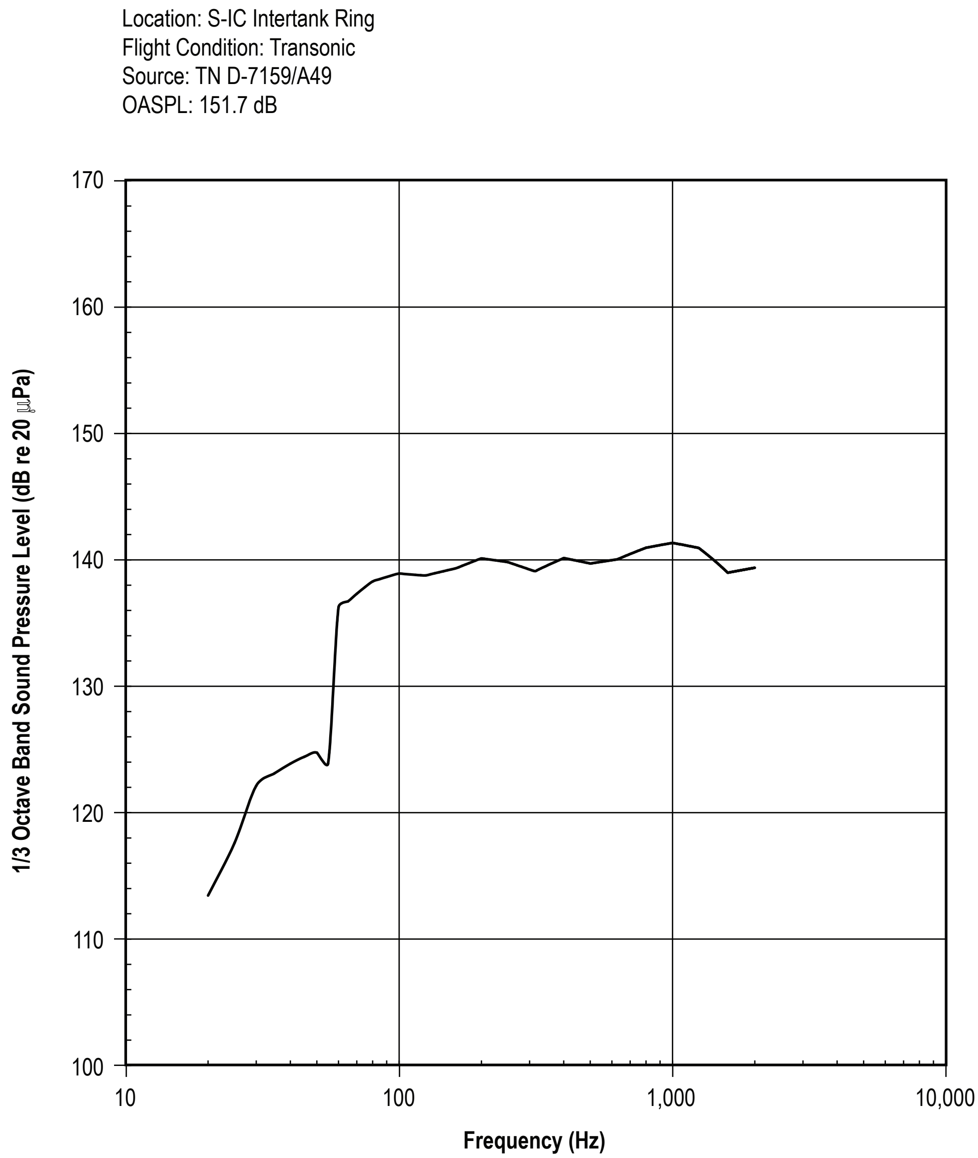

Figure 63. Saturn V acoustic spectrum, S-IC intertank ring (subzone 5-2-2), transonic.

Document/Page No.: 7159/A51
Flight Condition: Liftoff
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 7.88 in
Surface Wt.: 6.2 lb/ft^2
Measurements: E21-118

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.185 in
Ring Wt.: 4.75 lb/ft
Stringer Wt.: N/A
Composite: 24.75 grms
Subzone: 5-2-2

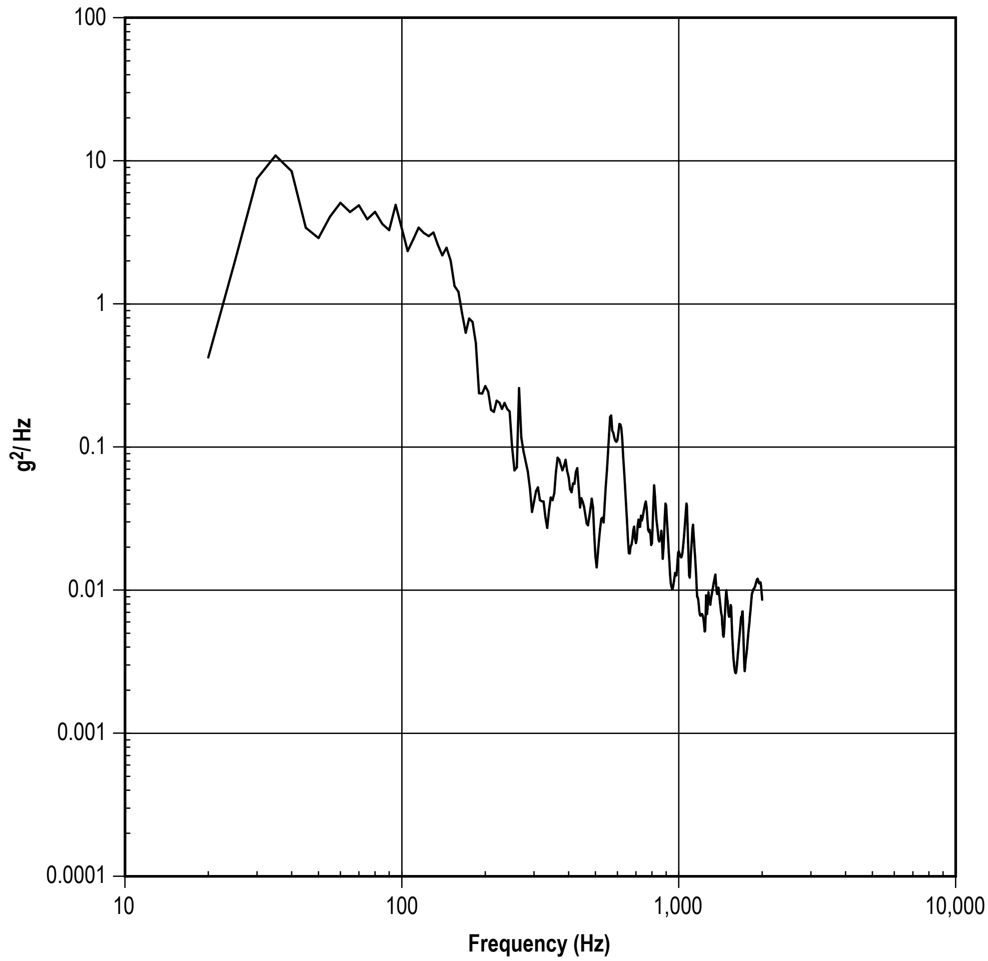

Figure 64. Ring frame PSD, radial, liftoff, 6.2 lb/ft^2.

Document/Page No.: 7159/A53	Meas. Direction: Radial
Flight Condition: Mach 1	Material: AL
Vehicle Diameter: 33 ft	Skin Thickness: 0.185 in
Ring Sep.: N/A	Ring Wt.: 4.75 lb/ft
Stringer Sep.: 7.88 in	Stringer Wt.: N/A
Surface Wt.: 6.2 lb/ft^2	Composite: 25.07 g_{rms}
Measurements: E21-118	Subzone: 5-2-2

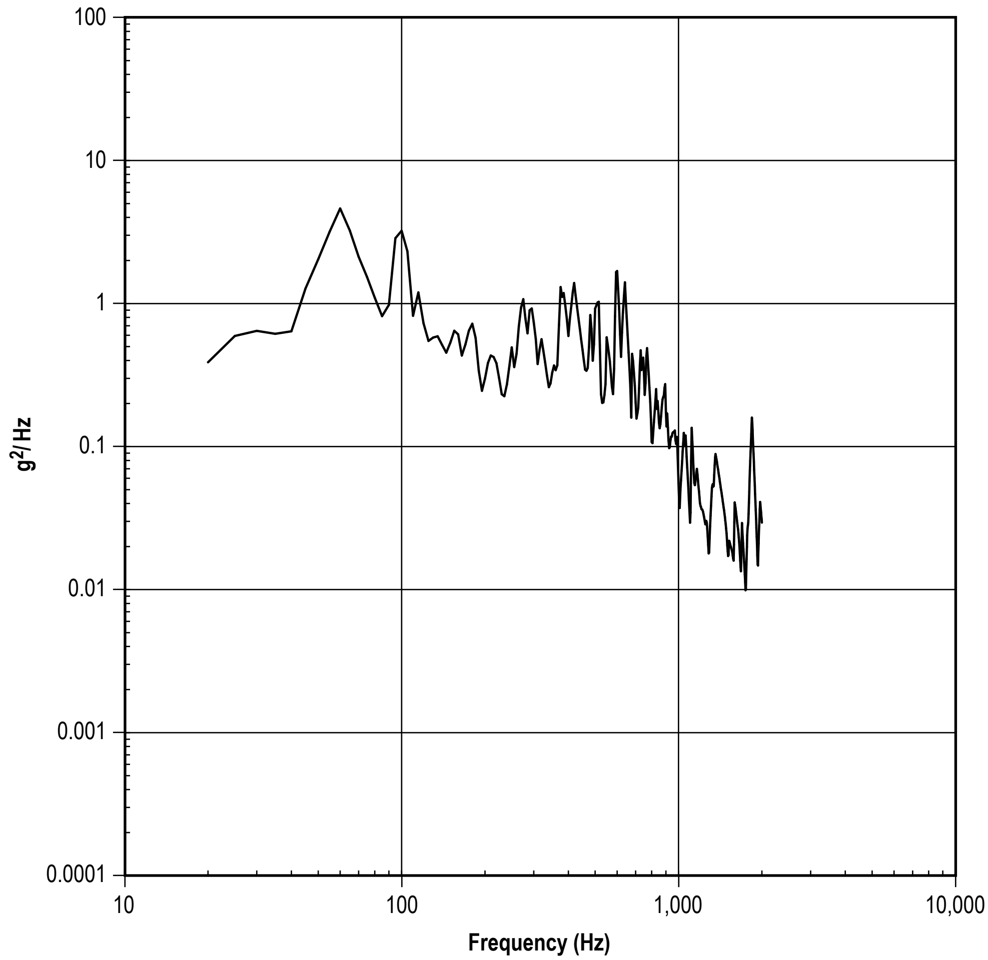

Figure 65. Ring frame PSD, radial, Mach 1, 6.2 lb/ft^2.

Document/Page No.: 7159/A55
Flight Condition: Max Q
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 7.88 in
Surface Wt.: 6.2 lb/ft^2
Measurements: E21-118

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.185 in
Ring Wt.: 4.75 lb/ft
Stringer Wt.: N/A
Composite: 32.27 g_{rms}
Subzone: 5-2-2

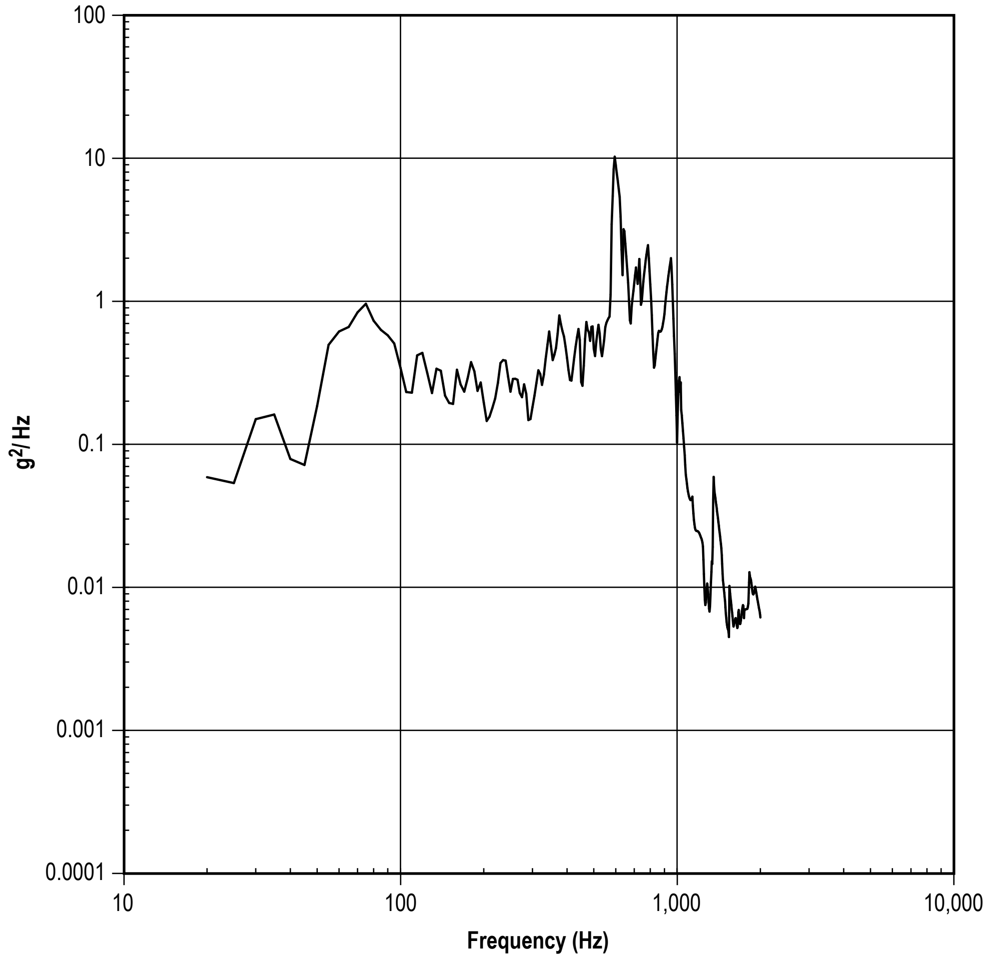

Figure 66. Ring frame PSD, radial, Max Q, 6.2 lb/ft^2.

Document/Page No.: 7159/A57	Meas. Direction: Radial
Flight Condition: Mach 1/Max Q	Material: AL
Vehicle Diameter: 33 ft	Skin Thickness: 0.185 in
Ring Sep.: N/A	Ring Wt.: 4.75 lb/ft
Stringer Sep.: 7.88 in	Stringer Wt.: N/A
Surface Wt.: 6.2 lb/ft^2	Composite: 32.28 g_{rms}
Measurements: E21-118	Subzone: 5-2-2

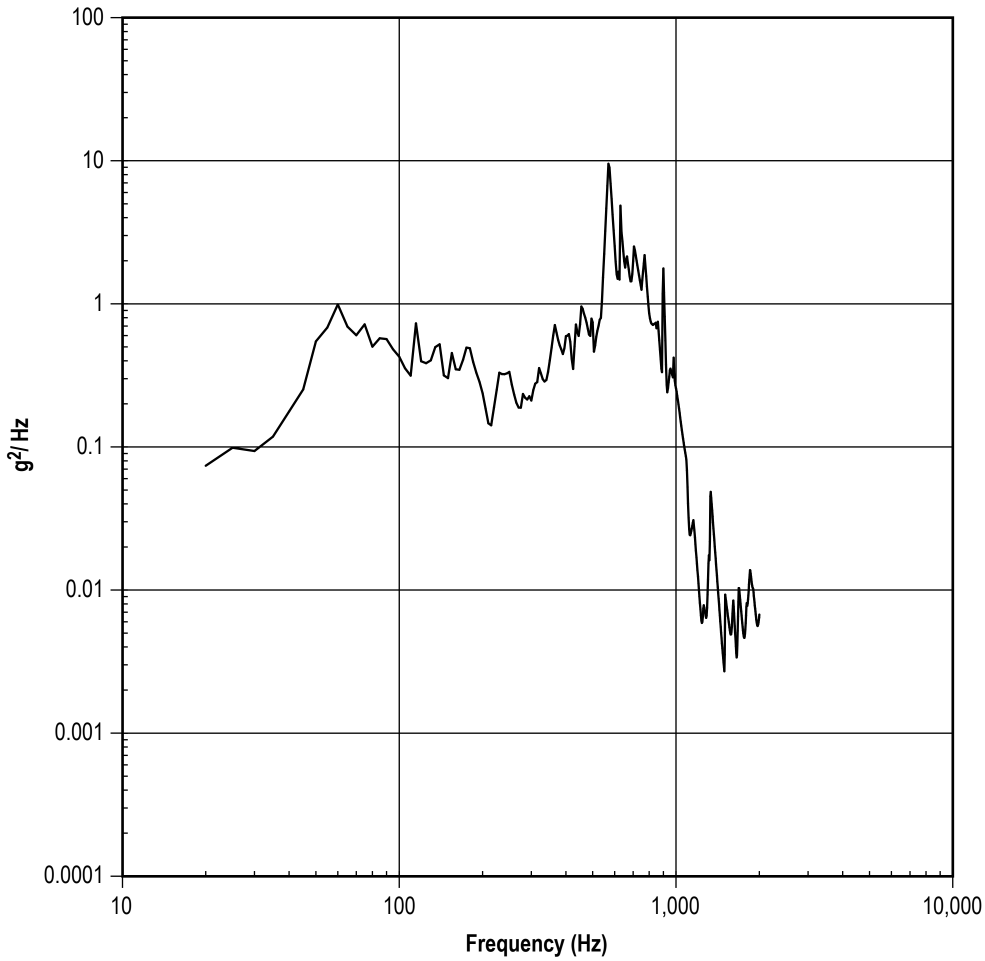

Figure 67. Ring frame PSD, radial, Mach 1/Max Q, 6.2 lb/ft^2.

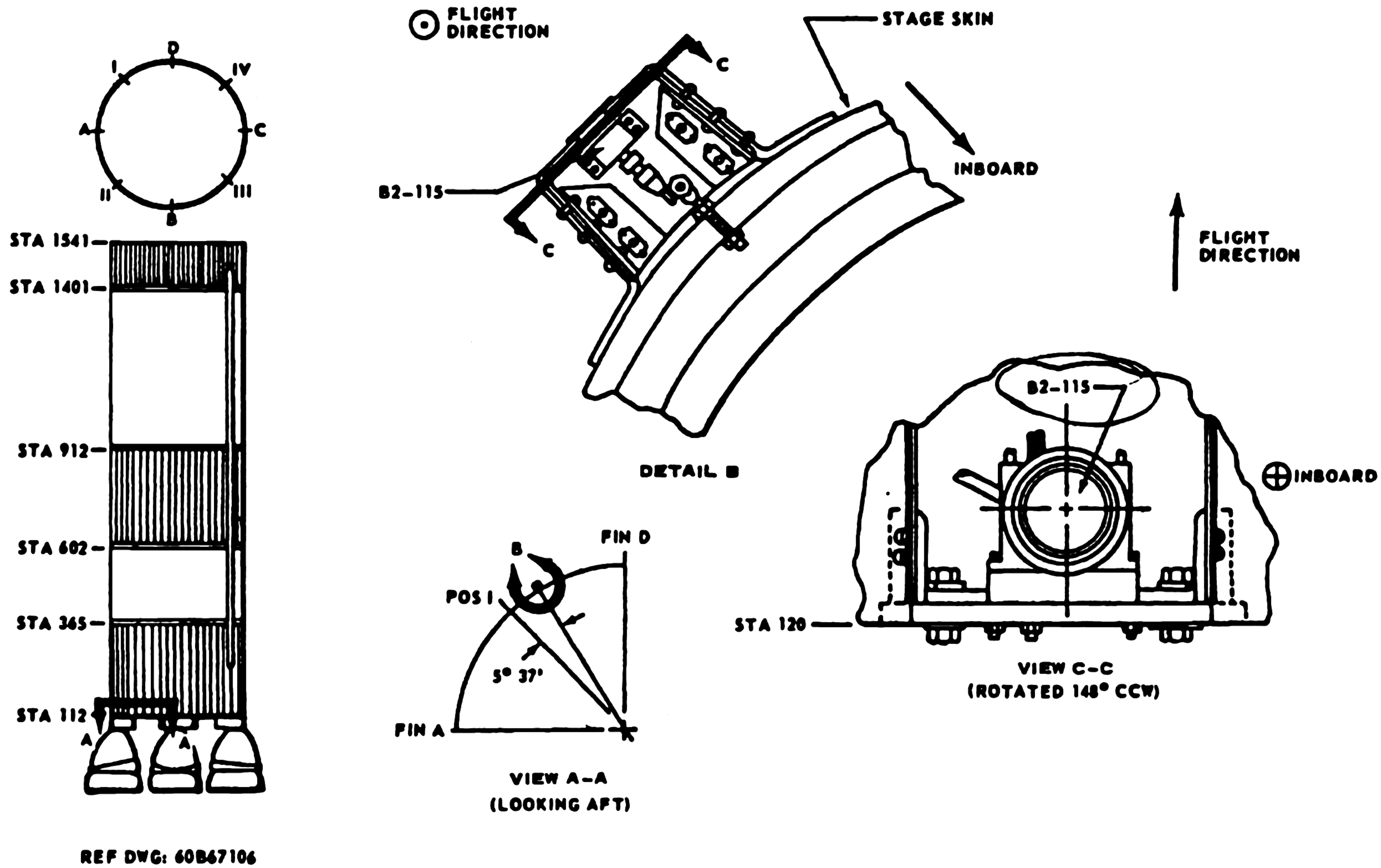

Figure 68. Zone 2: S-IC stage heat shield frame internal acoustic measurement location.

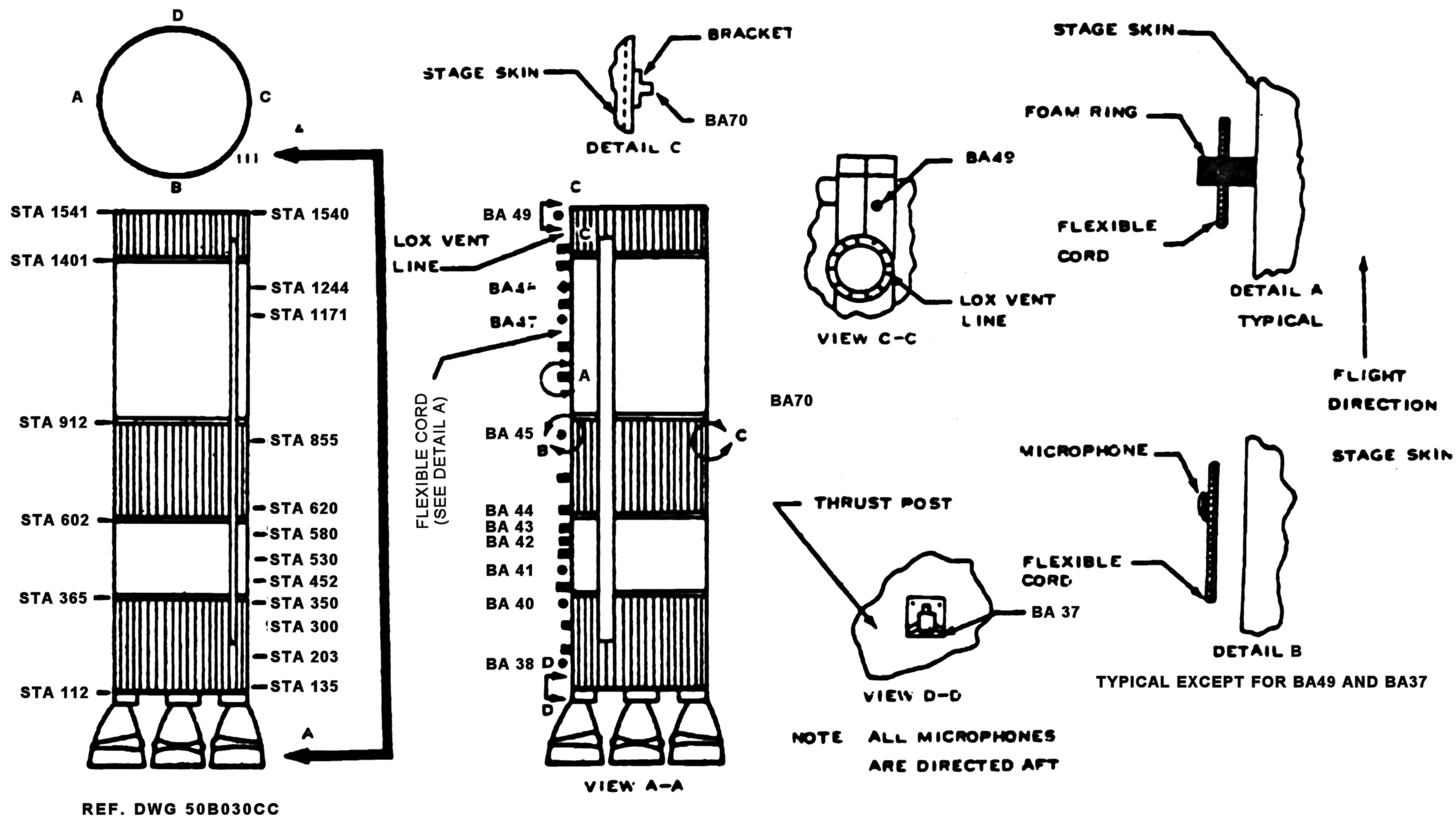

Figure 69. S-IC stage external acoustic measurement locations.

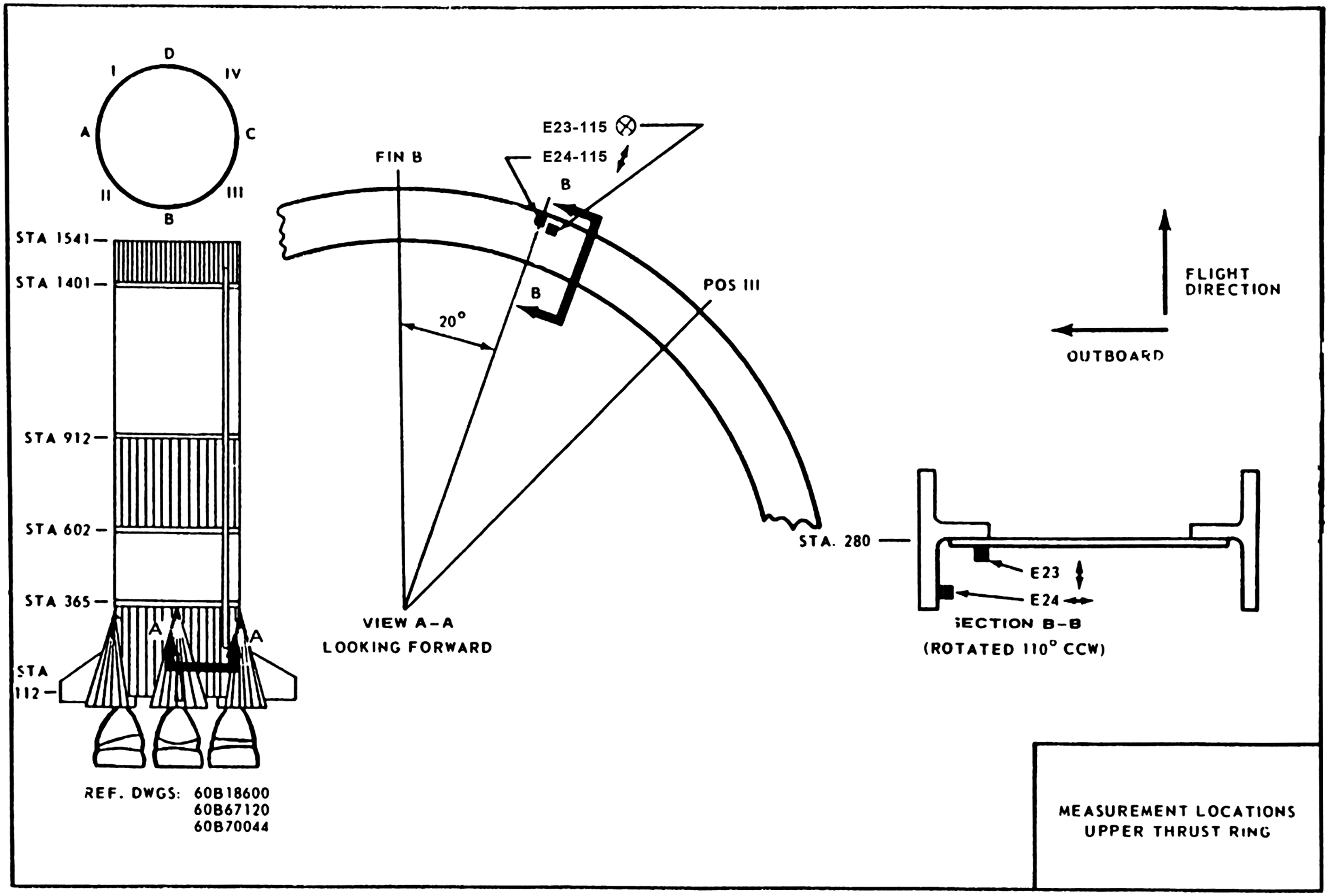

Figure 70. S-IC stage upper thrust ring vibration measurement location.

Document/Page No.: 7159/A73
Flight Condition: Liftoff
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 9.72 in
Surface Wt.: 25.6 lb/ft^2
Measurements: E23-115

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.375 in
Ring Wt.: 29.064 lb/ft
Stringer Wt.: 1.94 lb/ft
Composite: 4.26 g_{rms}
Subzone: 2-5-4

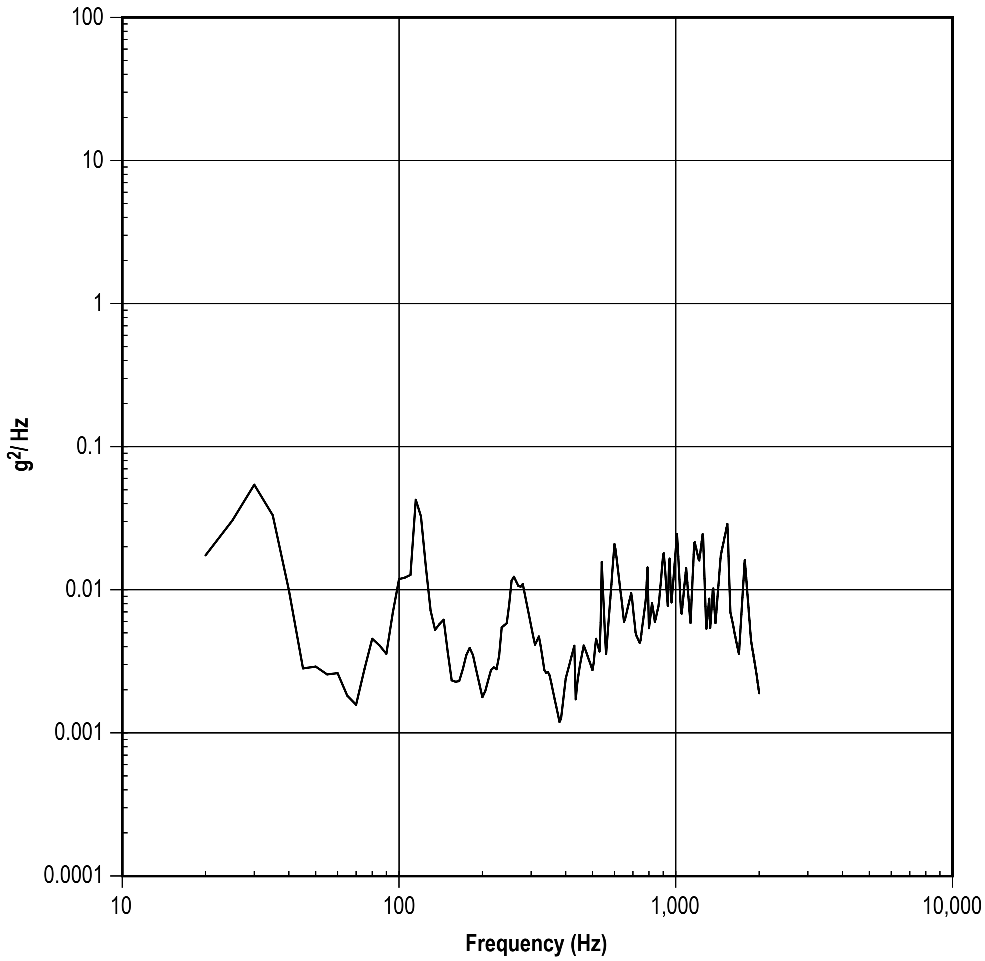

Figure 71. Ring frame PSD, longitudinal, liftoff, 25.6 lb/ft^2.

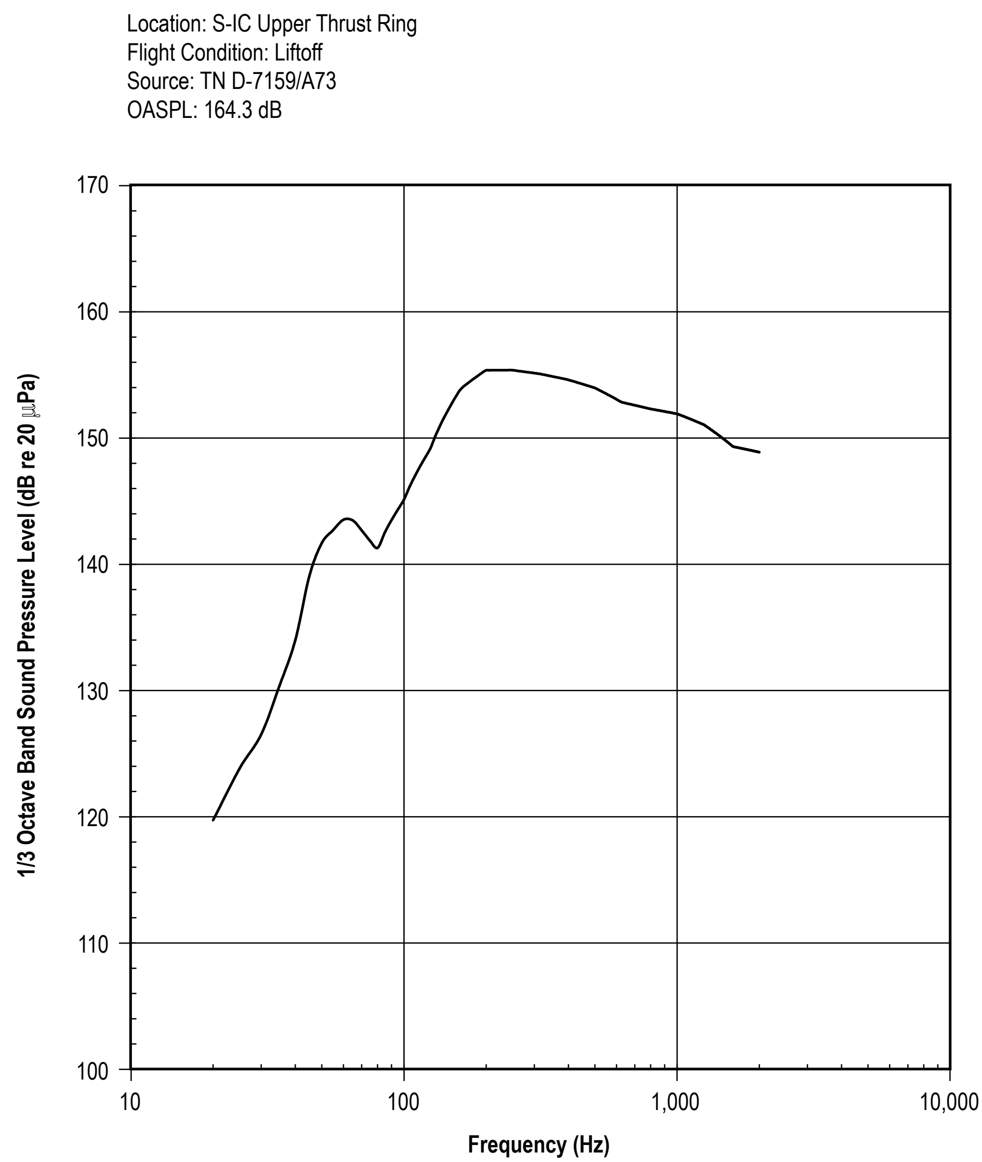

Figure 72. Saturn V acoustic spectrum, S-IC upper thrust ring (subzone 2-5-4), liftoff.

Document/Page No.: 7159/A65
Flight Condition: Mach 1
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 9.72 in
Surface Wt.: 25.6 lb/ft^2
Measurements: E23-115

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.375 in
Ring Wt.: 29.06 lb/ft
Stringer Wt.: 1.95 lb/ft
Composite: 18.94 g_{rms}
Subzone: 2-5-4

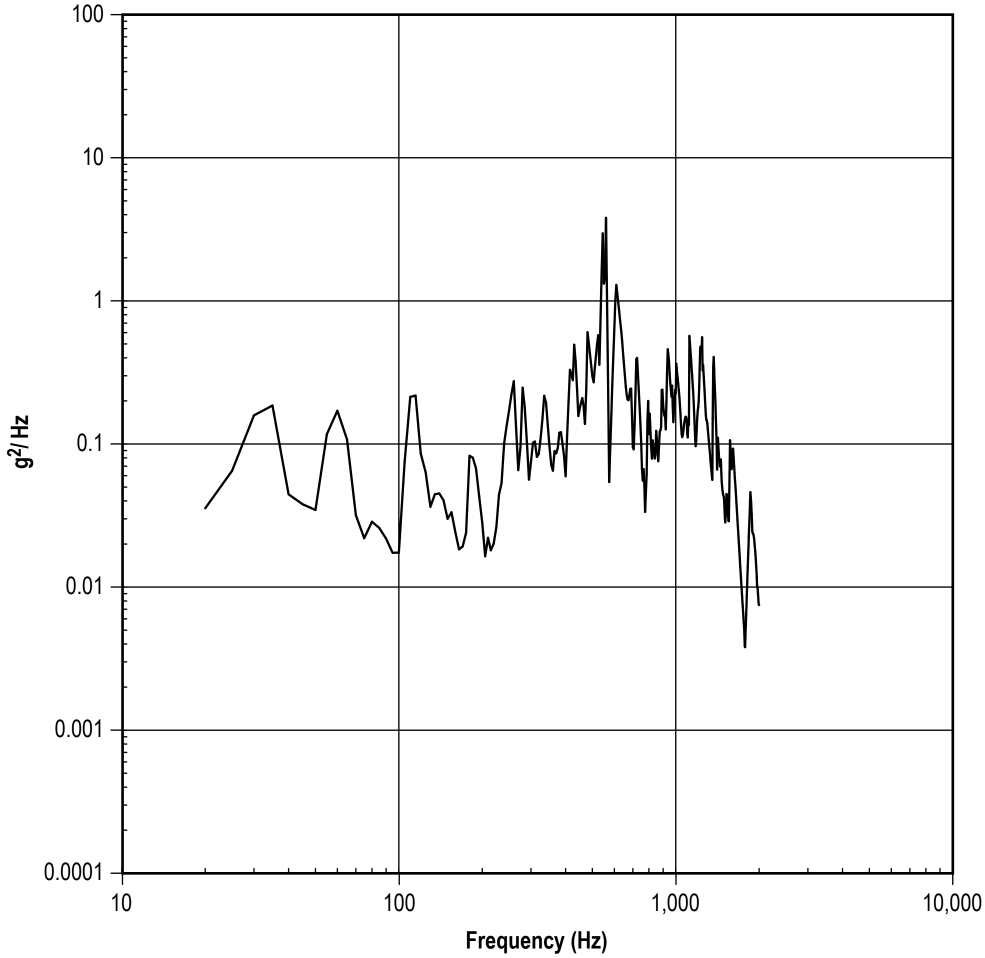

Figure 73. Ring frame PSD, longitudinal, Mach 1, 25.6 lb/ft^2.

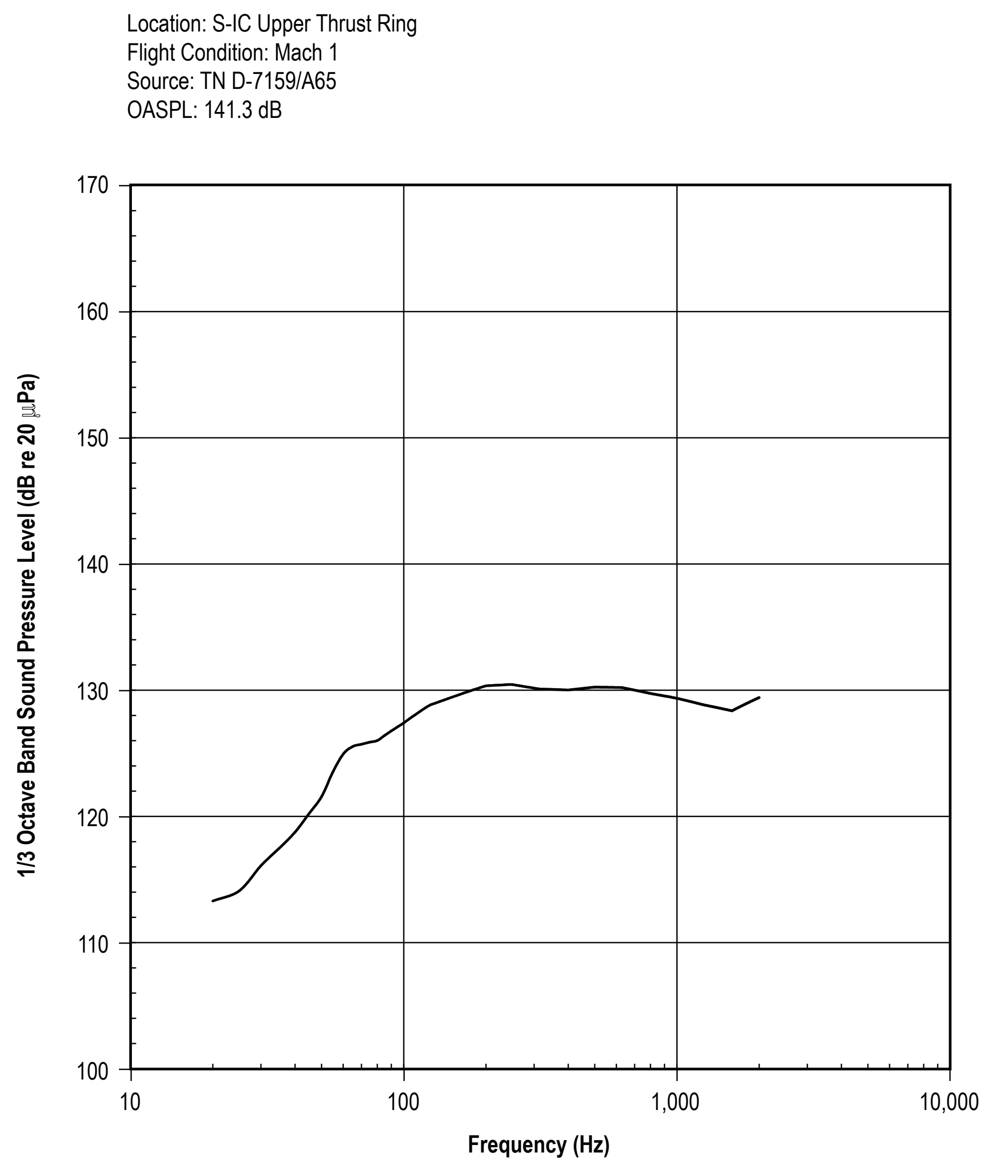

Figure 74. Saturn V acoustic spectrum, S-IC upper thrust ring (subzone 2-5-4), Mach 1.

Document/Page No.: 7159/A69	Meas. Direction: Longitudinal
Flight Condition: Mach 1/Max Q	Material: AL
Vehicle Diameter: 33 ft	Skin Thickness: 0.375 in
Ring Sep.: N/A	Ring Wt.: 29.06 lb/ft
Stringer Sep.: 9.72 in	Stringer Wt.: 1.95 lb/ft
Surface Wt.: 25.6 lb/ft^2	Composite: 10.60 g_{rms}
Measurements: E23-115	Subzone: 2-5-4

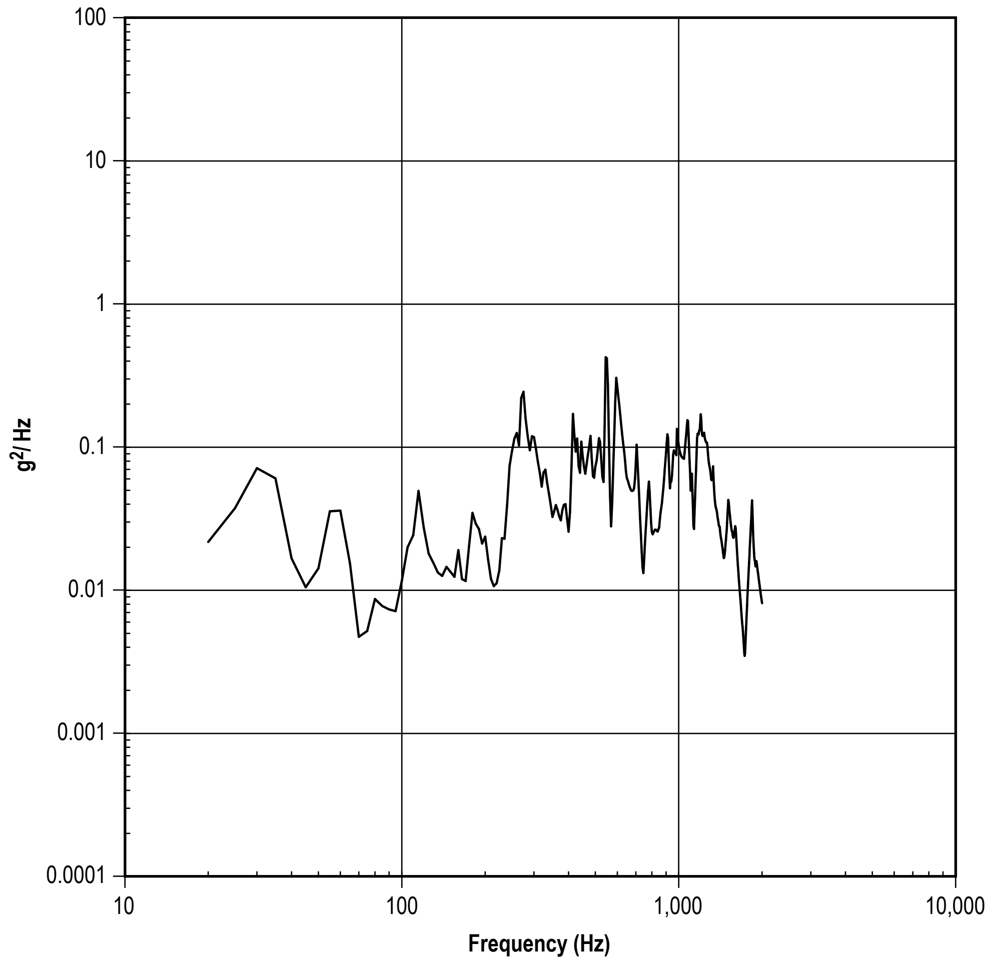

Figure 75. Ring frame PSD, longitudinal, Mach 1/Max Q, 25.6 lb/ft^2.

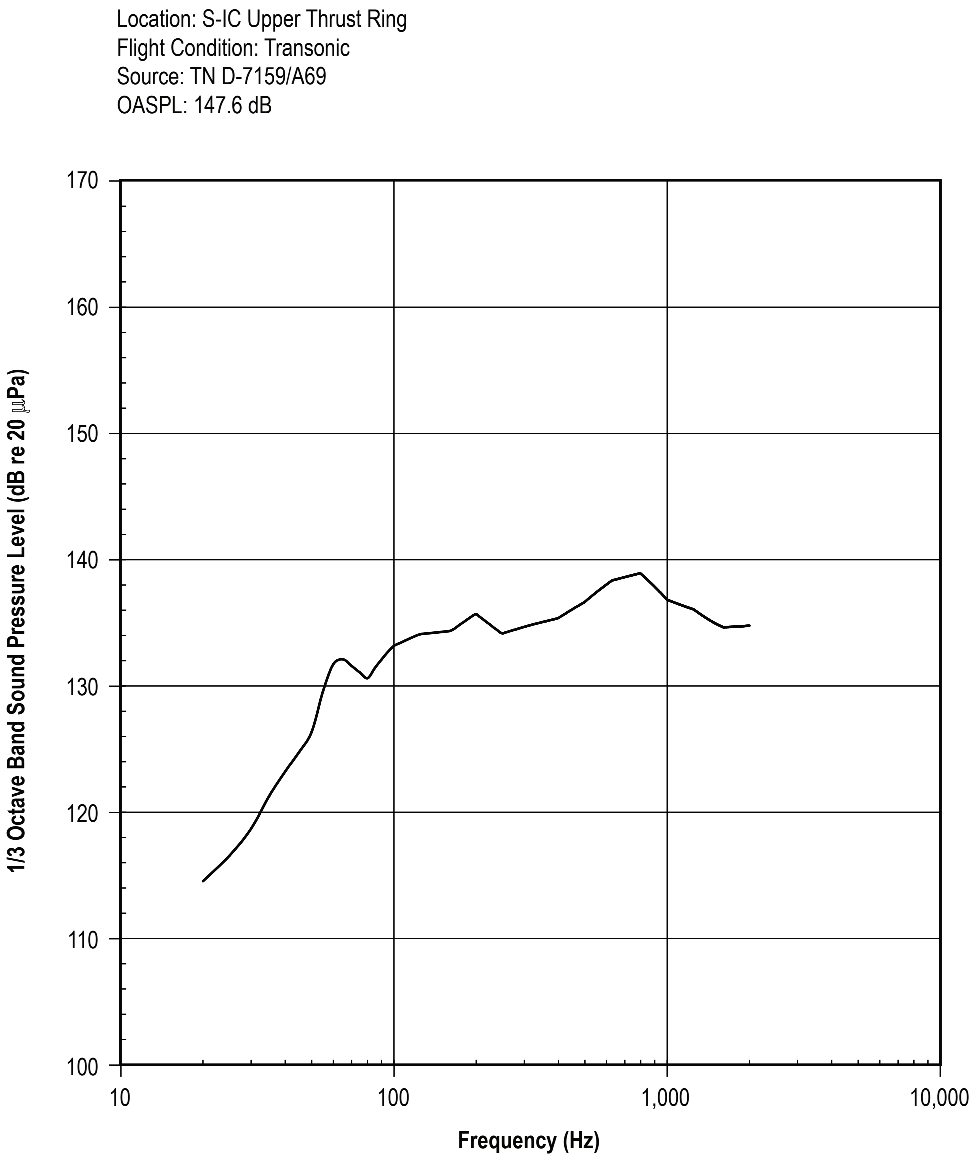

Figure 76. Saturn V acoustic spectrum, S-IC upper thrust ring (subzone 2-5-4), transonic.

Document/Page No.: 7159/A75
Flight Condition: Liftoff
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 9.72 in
Surface Wt.: 25.6 lb/ft^2
Measurements: E24-115

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.375 in
Ring Wt.: 29.06 lb/ft
Stringer Wt.: 1.95 lb/ft
Composite: 3.55 g_{rms}
Subzone: 5-2-2

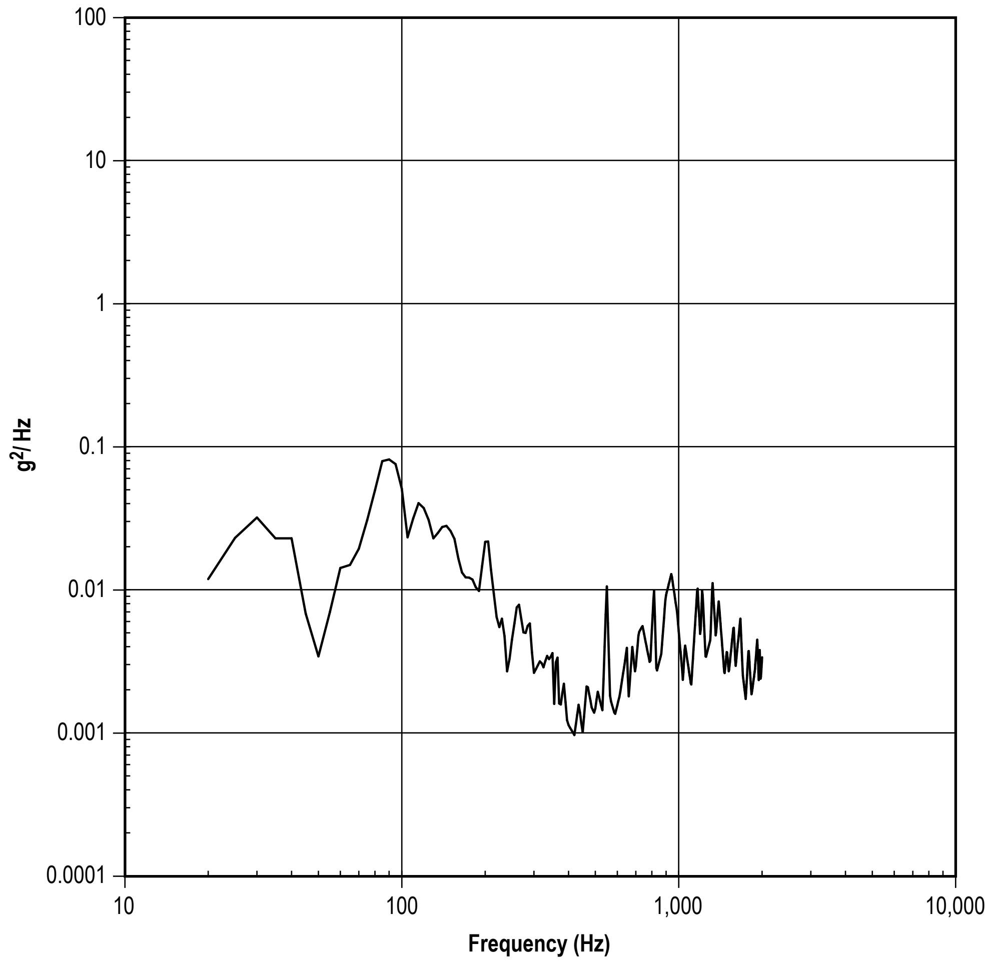

Figure 77. Ring frame PSD, radial, liftoff, 25.6 lb/ft^2.

Document/Page No.: 7159/A77
Flight Condition: Mach 1
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 9.72 in
Surface Wt.: 25.6 lb/ft^2
Measurements: E24-115

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.375 in
Ring Wt.: 29.06 lb/ft
Stringer Wt.: 1.95 lb/ft
Composite: 12.10 g_{rms}
Subzone: 5-2-2

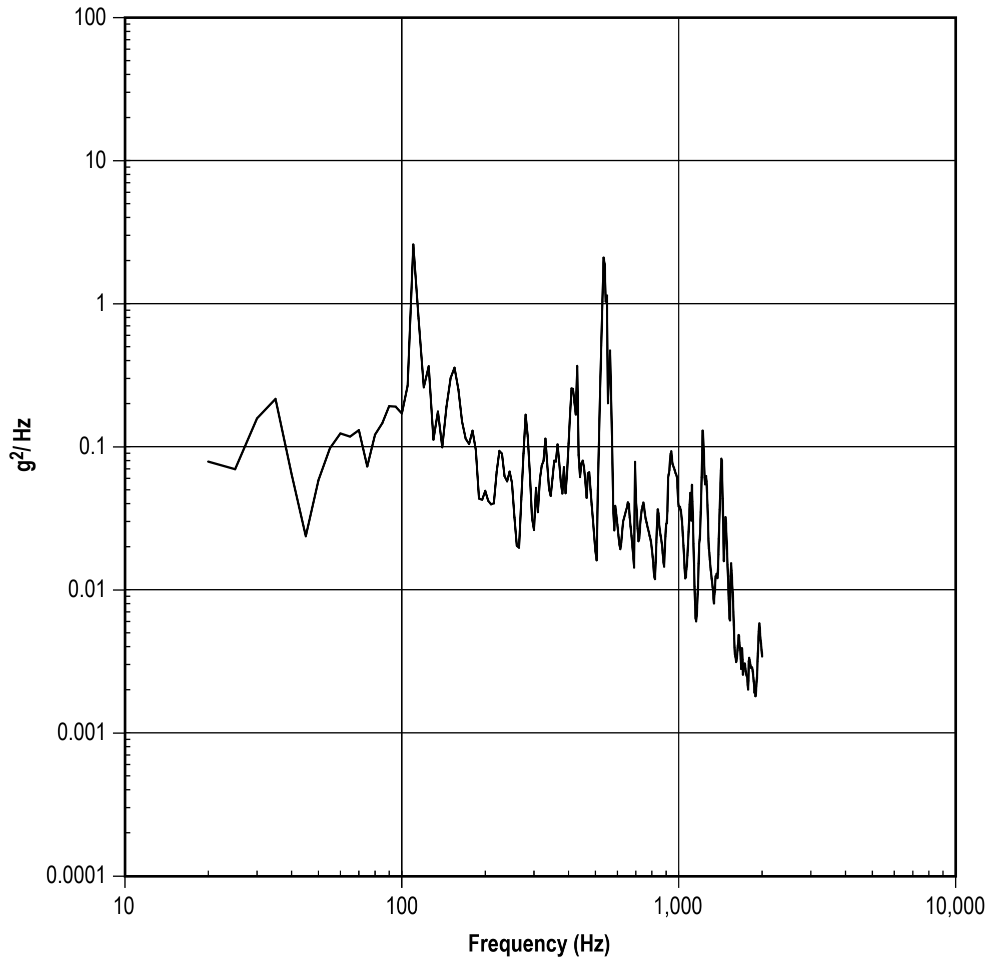

Figure 78. Ring frame PSD, radial, Mach 1, 25.6 lb/ft^2.

Document/Page No.: 7159/A79
Flight Condition: Max Q
Vehicle Diameter: 33 ft
Ring Sep.: N/A
Stringer Sep.: 9.72 in
Surface Wt.: 25.6 lb/ft^2
Measurements: E24-115

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.375 in
Ring Wt.: 29.06 lb/ft
Stringer Wt.: 1.95 lb/ft
Composite: 8.45 g_{rms}
Subzone: 5-2-2

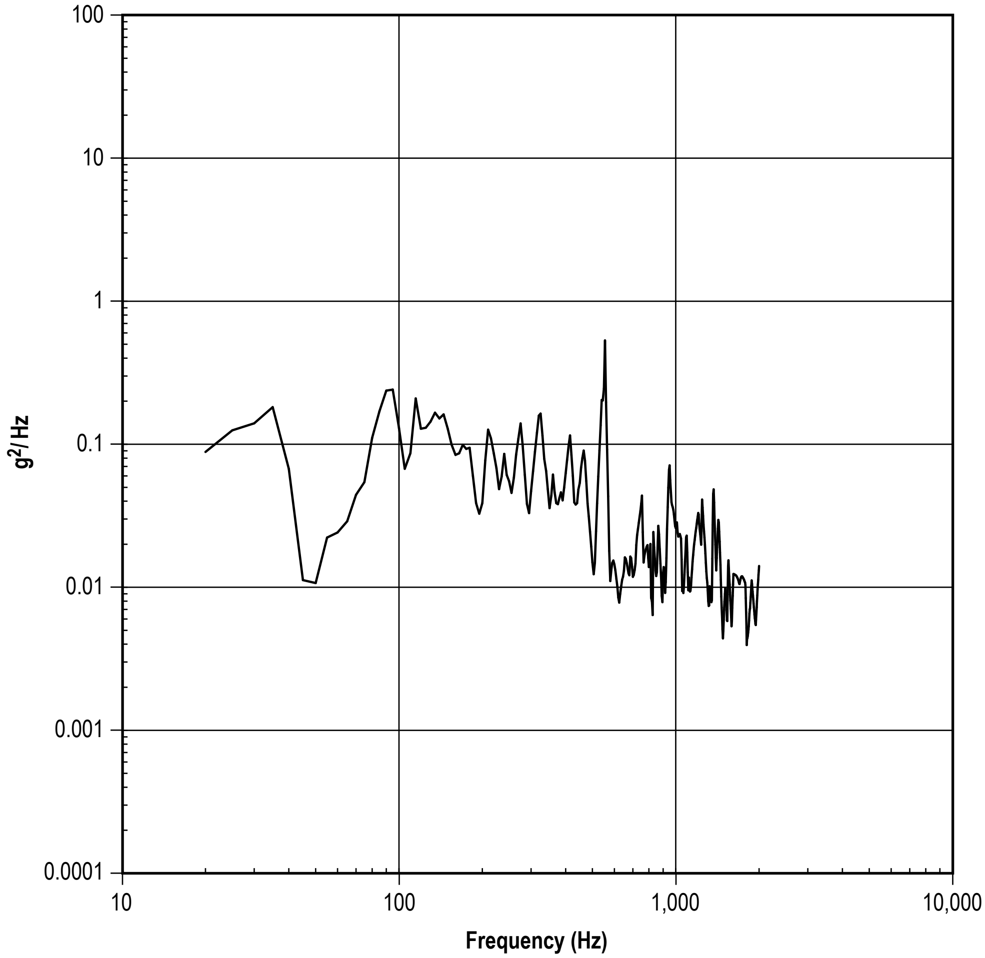

Figure 79. Ring frame PSD, radial, Max Q, 25.6 lb/ft^2.

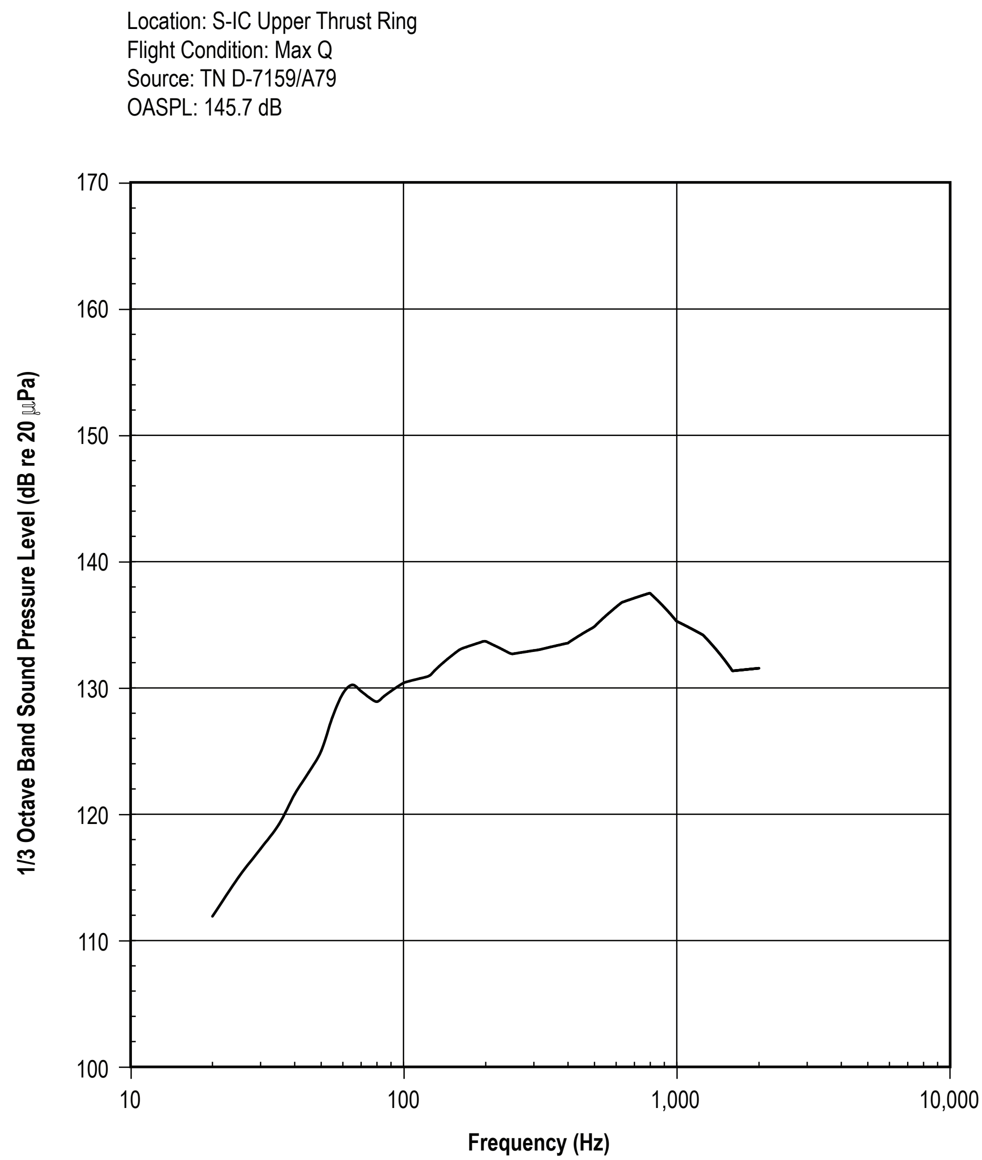

Figure 80. Saturn V acoustic spectrum, S-IC upper thrust ring (subzone 2-5-4), Max Q.

Document/Page No.: 7159/A81	Meas. Direction: Radial
Flight Condition: Mach 1/Max Q	Material: AL
Vehicle Diameter: 33 ft	Skin Thickness: 0.375 in
Ring Sep.: N/A	Ring Wt.: 29.06 lb/ft
Stringer Sep.: 9.72 in	Stringer Wt.: 1.95 lb/ft
Surface Wt.: 25.6 lb/ft^2	Composite: 6.75 g_{rms}
Measurements: E24-115	Subzone: 5-2-2

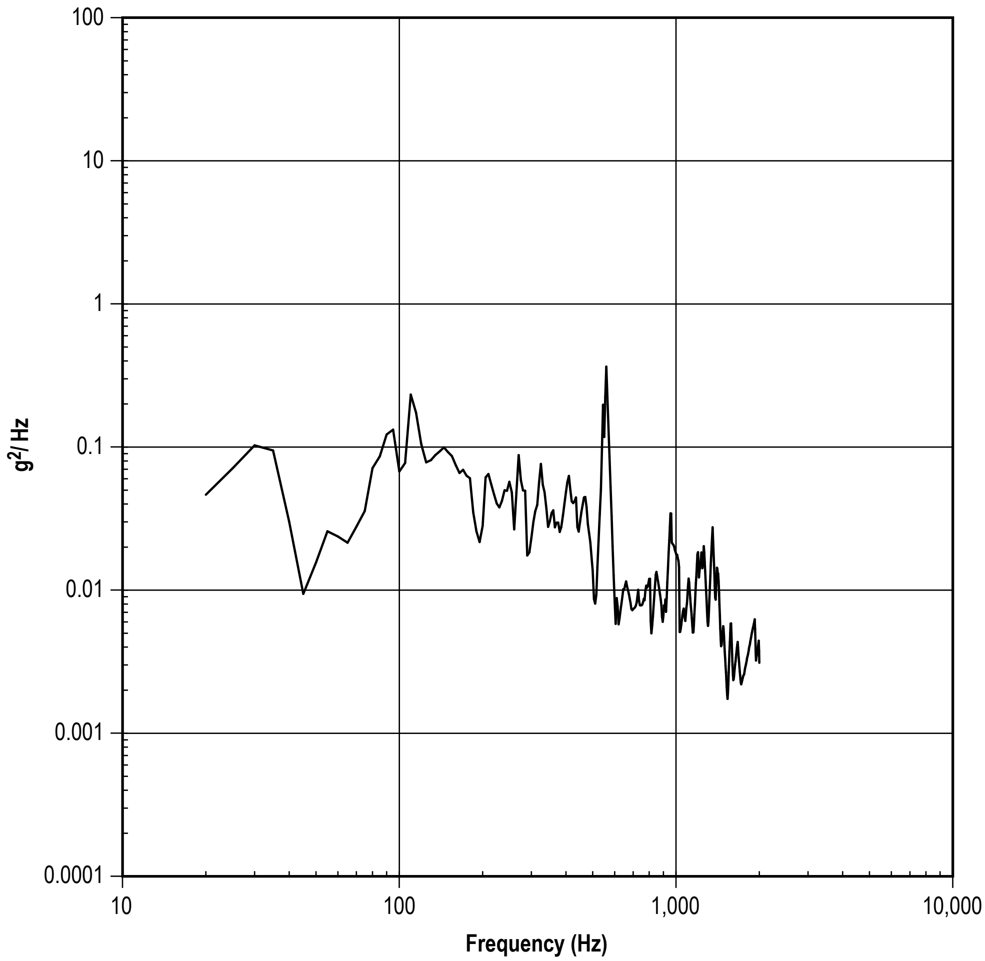

Figure 81. Ring frame PSD, radial, Mach 1/Max Q, 25.6 lb/ft^2.

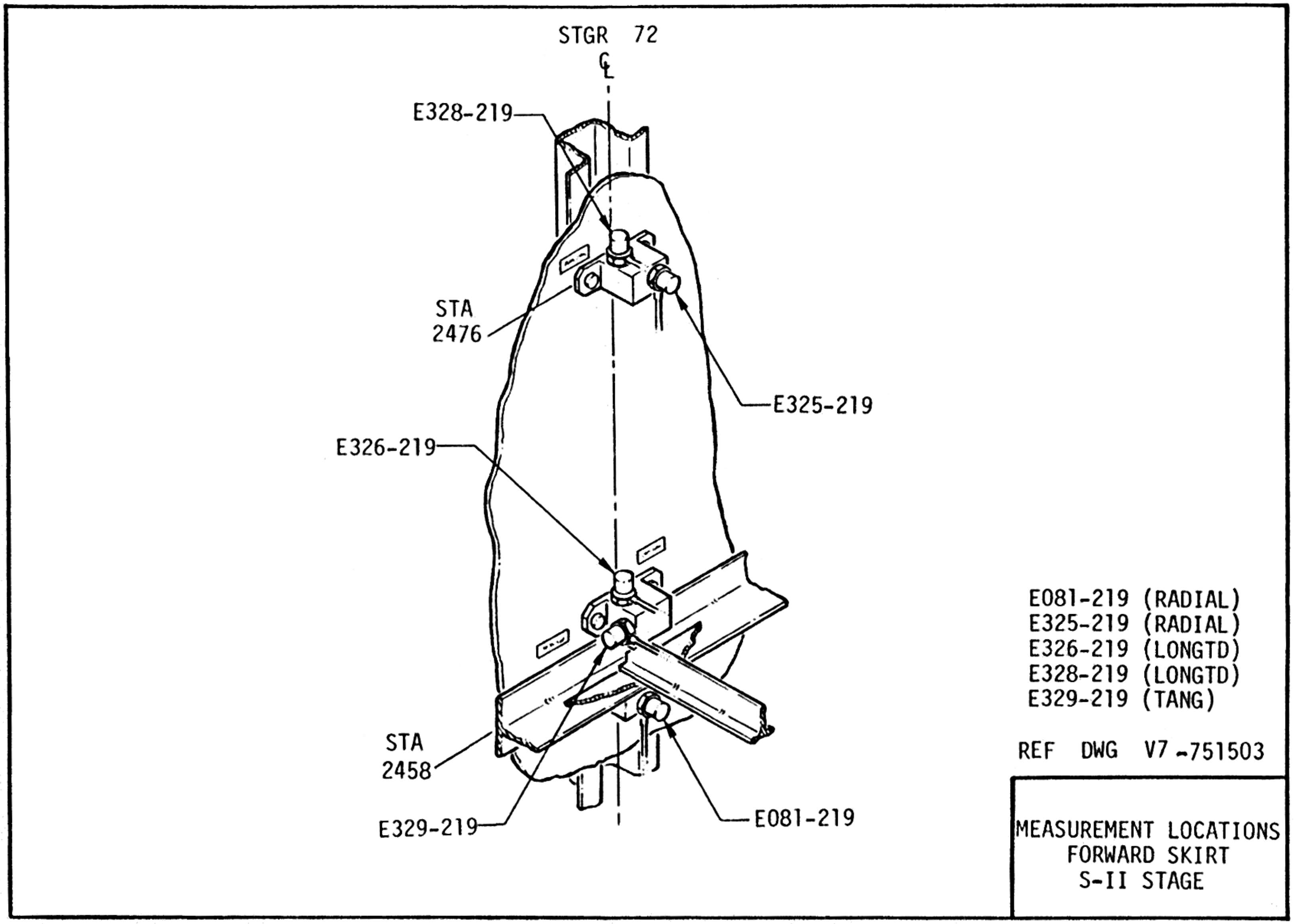

Figure 82. S-II stage forward skirt vibration measurement locations.

Document/Page No.: 7159/A87
Flight Condition: Liftoff
Vehicle Diameter: 33 ft
Ring Sep.: 19.0 in
Stringer Sep.: 8.47 in
Surface Wt.: 3.3 lb/ft^2
Measurements: Unknown

Meas. Direction: Normal
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: N/A
Stringer Wt.: 10.41 lb/ft
Composite: 20.66 g_{rms}
Subzone: 11-2-2

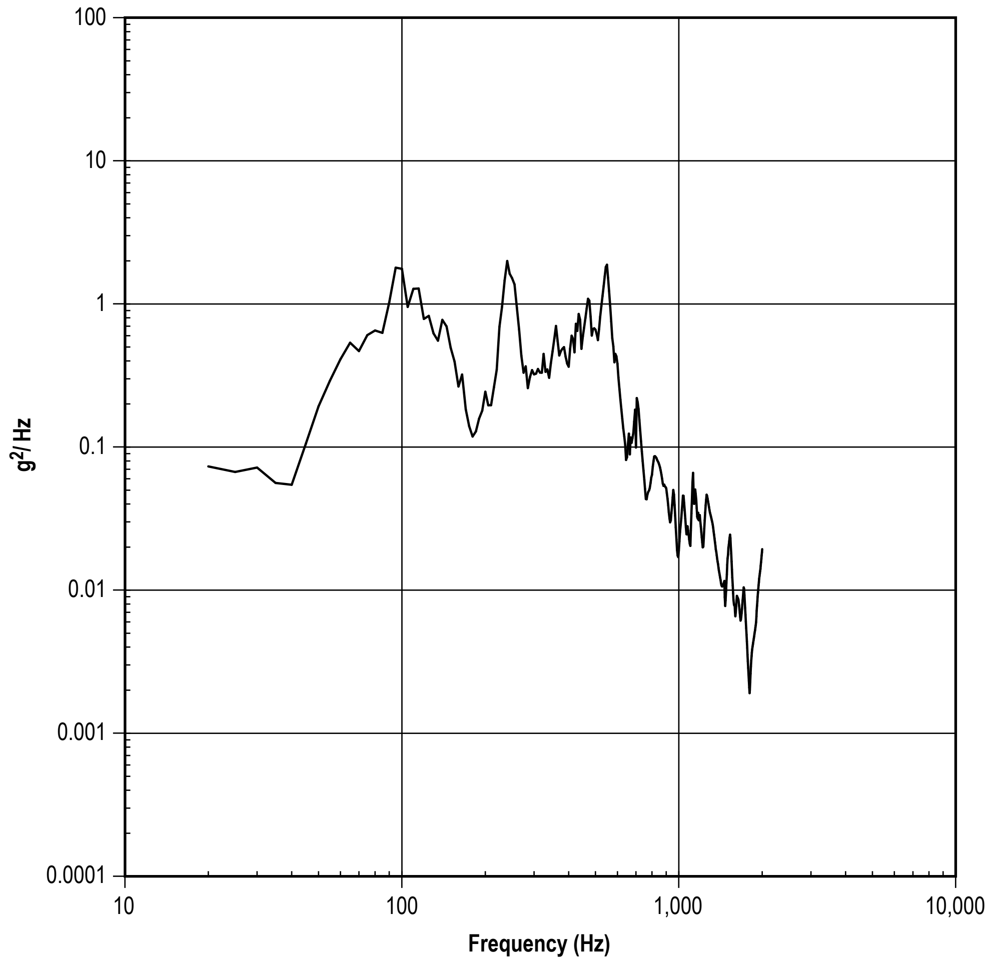

Figure 83. Skin-stringer PSD, normal, liftoff, 3.3 lb/ft^2.

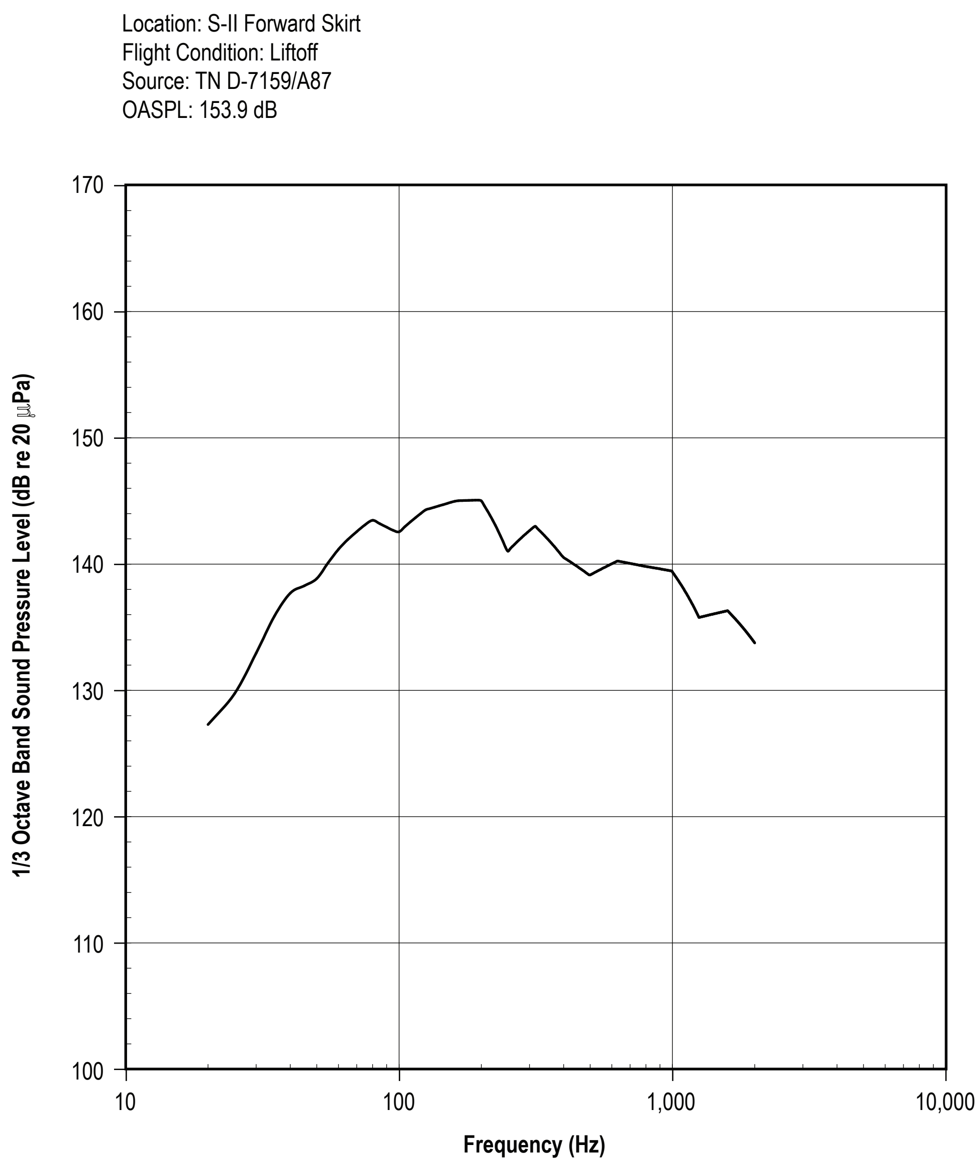

Figure 84. Saturn V acoustic spectrum, S-II forward skirt (subzone 11-2-2), liftoff.

Document/Page No.: 7159/A89
Flight Condition: Liftoff
Vehicle Diameter: 33 ft
Ring Sep.: 36.0 in
Stringer Sep.: 8.63 in
Surface Wt.: 1.5 lb/ft^2
Measurements: E326-219 E329-219

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: N/A
Stringer Wt.: 0.71 lb/ft
Composite: 1.42 g_{rms}
Subzone: 11-2-2

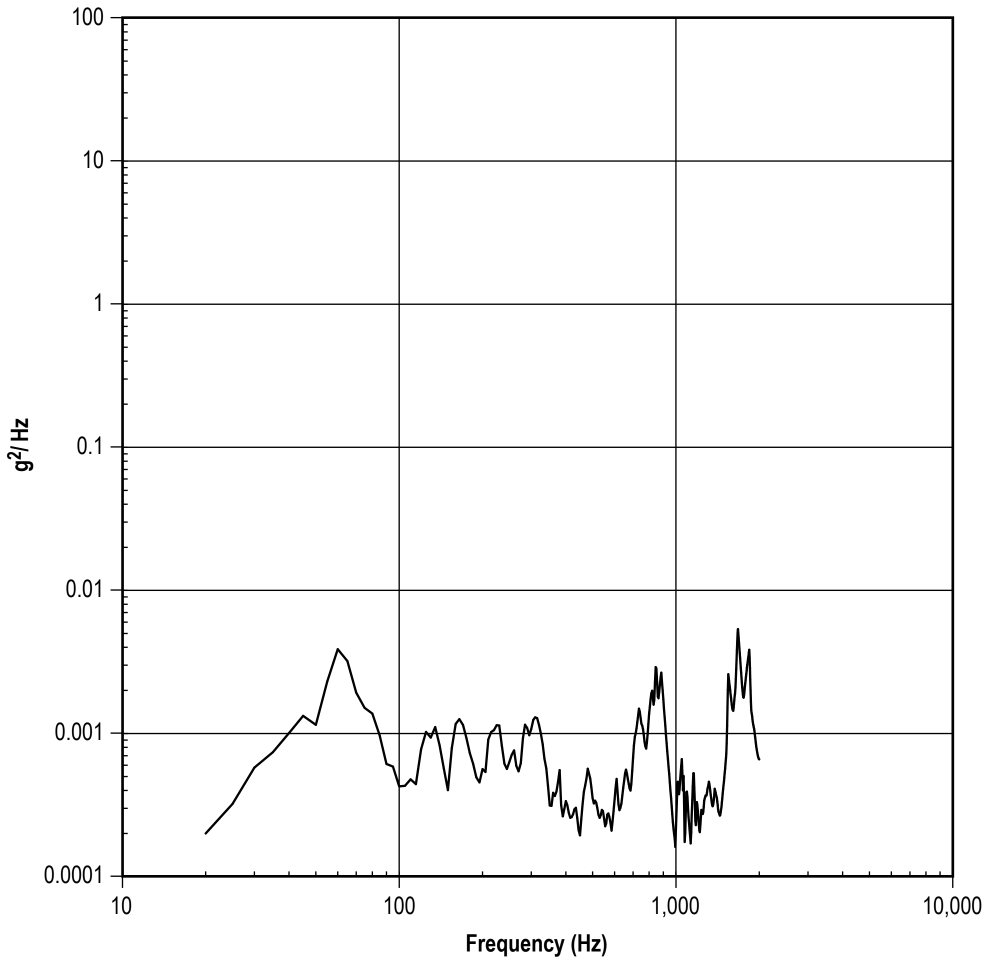

Figure 85. Skin-stringer PSD, longitudinal, liftoff, 1.5 lb/ft^2.

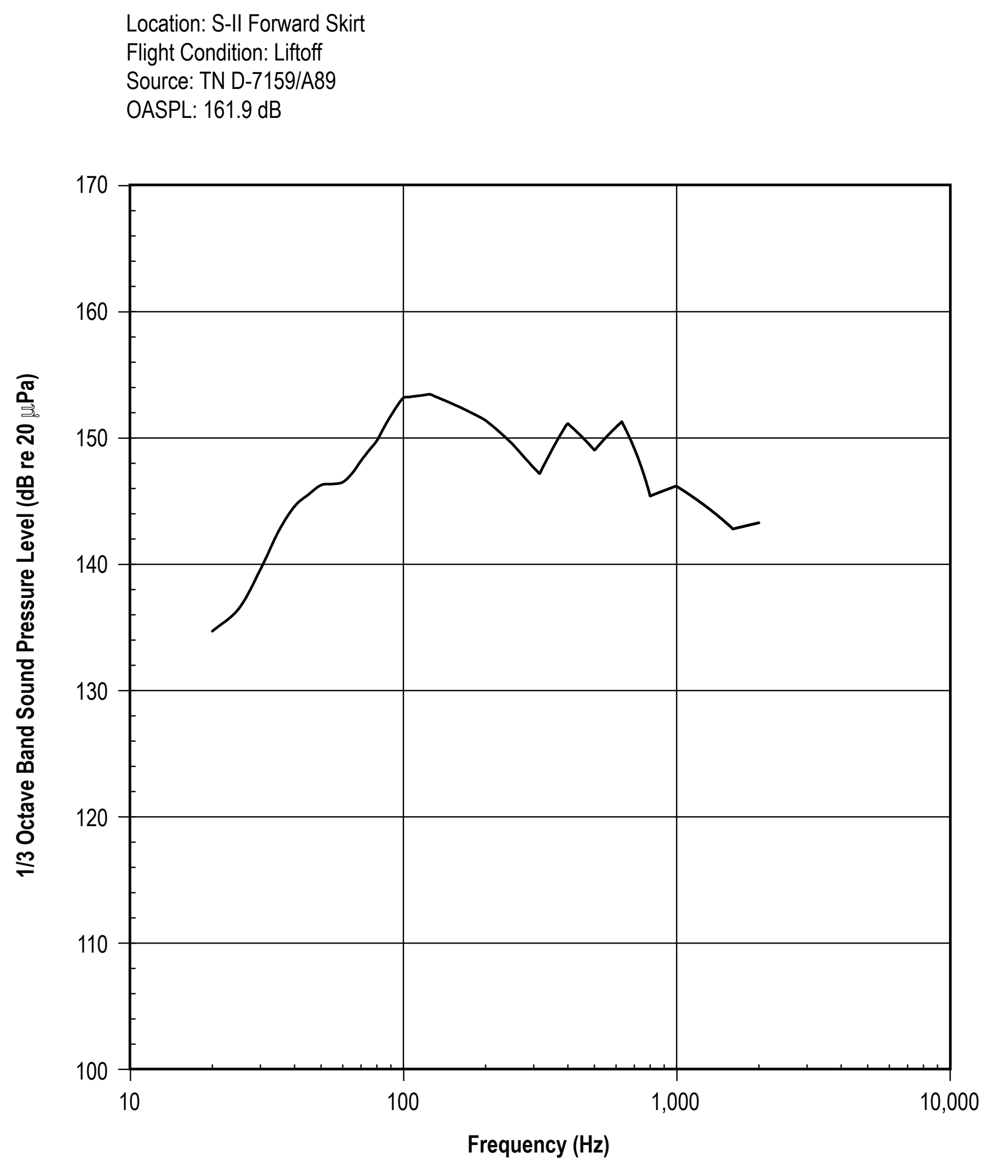

Figure 86. Saturn V acoustic spectrum, S-II forward skirt (subzone 11-2-2), liftoff.

Document/Page No.: 7159/A91	Meas. Direction: Longitudinal
Flight Condition: Mach 1	Material: AL
Vehicle Diameter: 33 ft	Skin Thickness: 0.040 in
Ring Sep.: 36.0 in	Ring Wt.: N/A
Stringer Sep.: 8.63 in	Stringer Wt.: 0.71 lb/ft
Surface Wt.: 1.5 lb/ft^2	Composite: 2.18 g_{rms}
Measurements: E326-219 E329-219	Subzone: 11-2-2

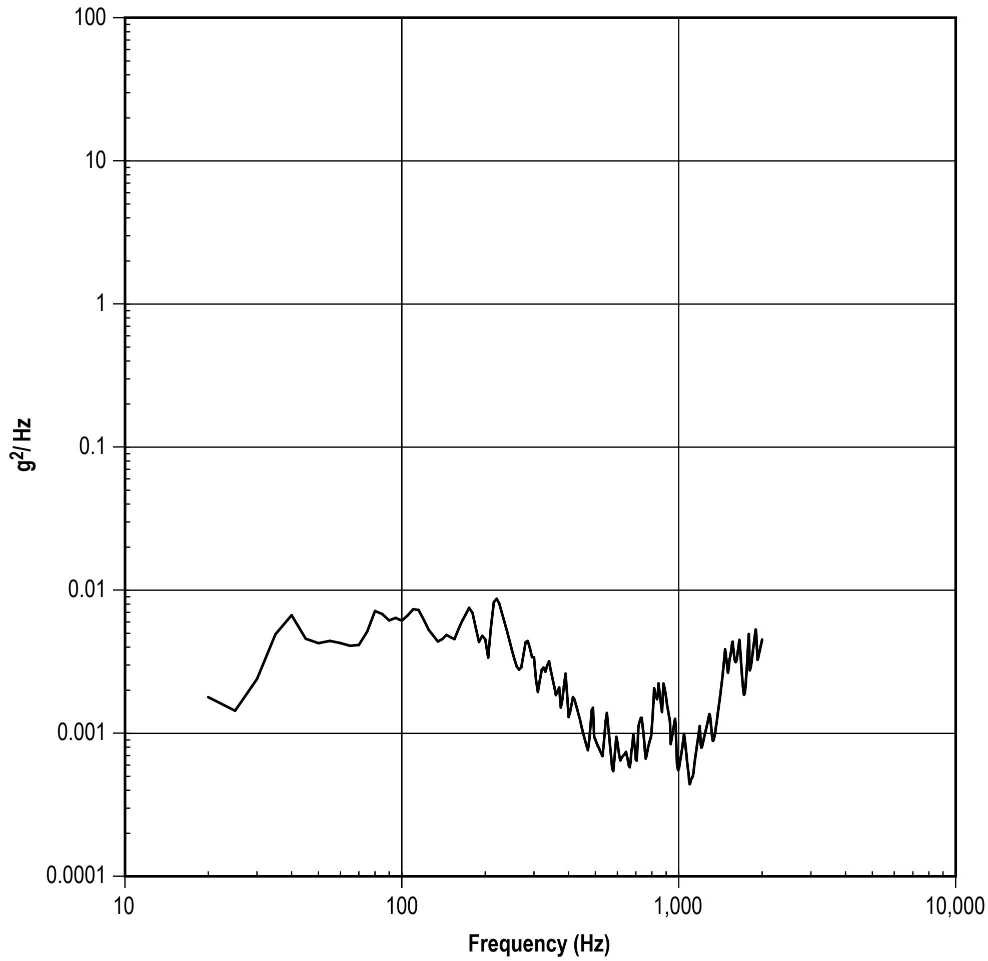

Figure 87. Skin-stringer PSD, longitudinal, Mach 1, 1.5 lb/ft^2.

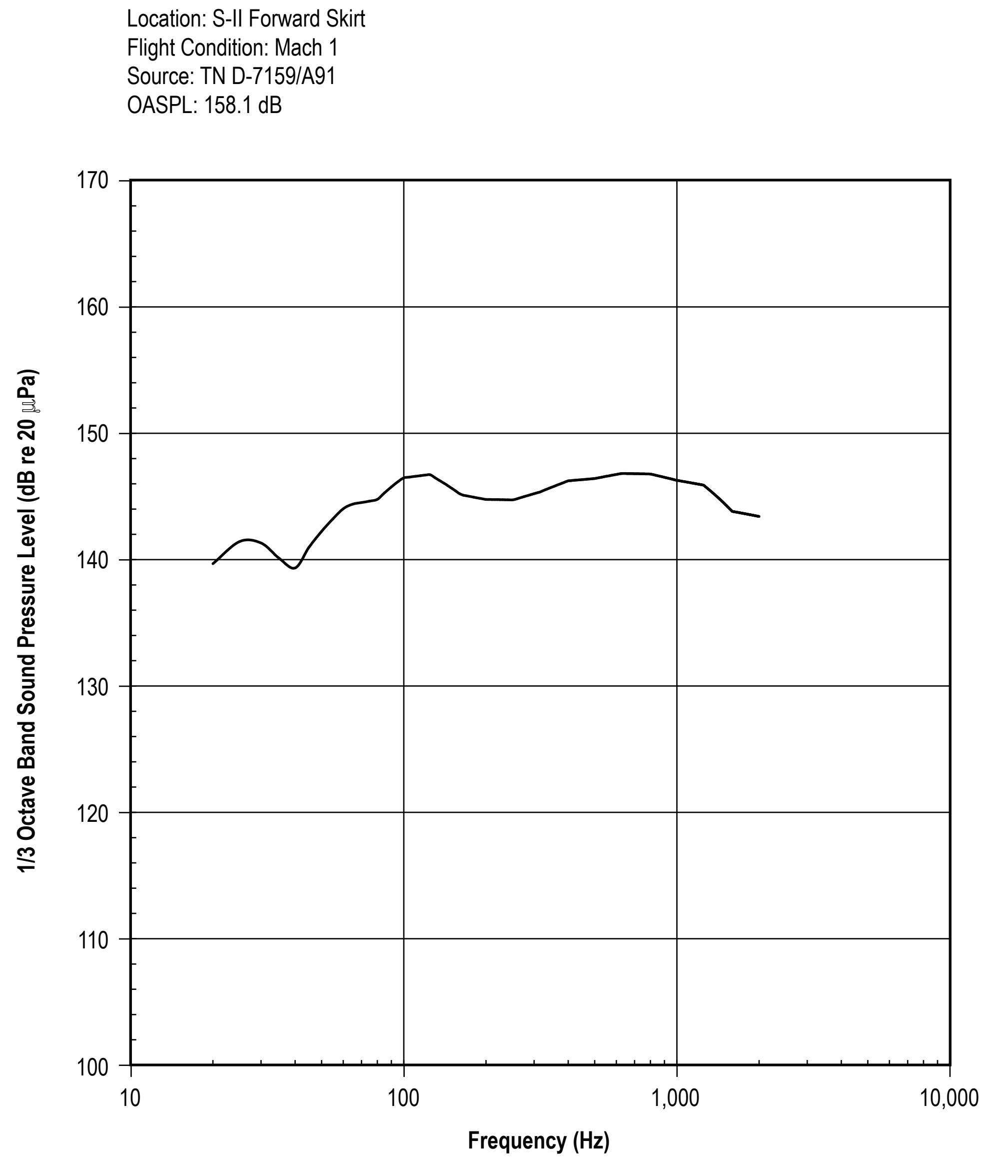

Figure 88. Saturn V acoustic spectrum, S-II forward skirt (subzone 11-2-2), Mach 1.

Document/Page No.: 7159/A93
Flight Condition: Max Q
Vehicle Diameter: 33 ft
Ring Sep.: 36.0 in
Stringer Sep.: 8.63 in
Surface Wt.: 1.5 lb/ft^2
Measurements: E326-219 E329-219

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: N/A
Stringer Wt.: 0.71 lb/ft
Composite: 1.91 g_{rms}
Subzone: 11-2-2

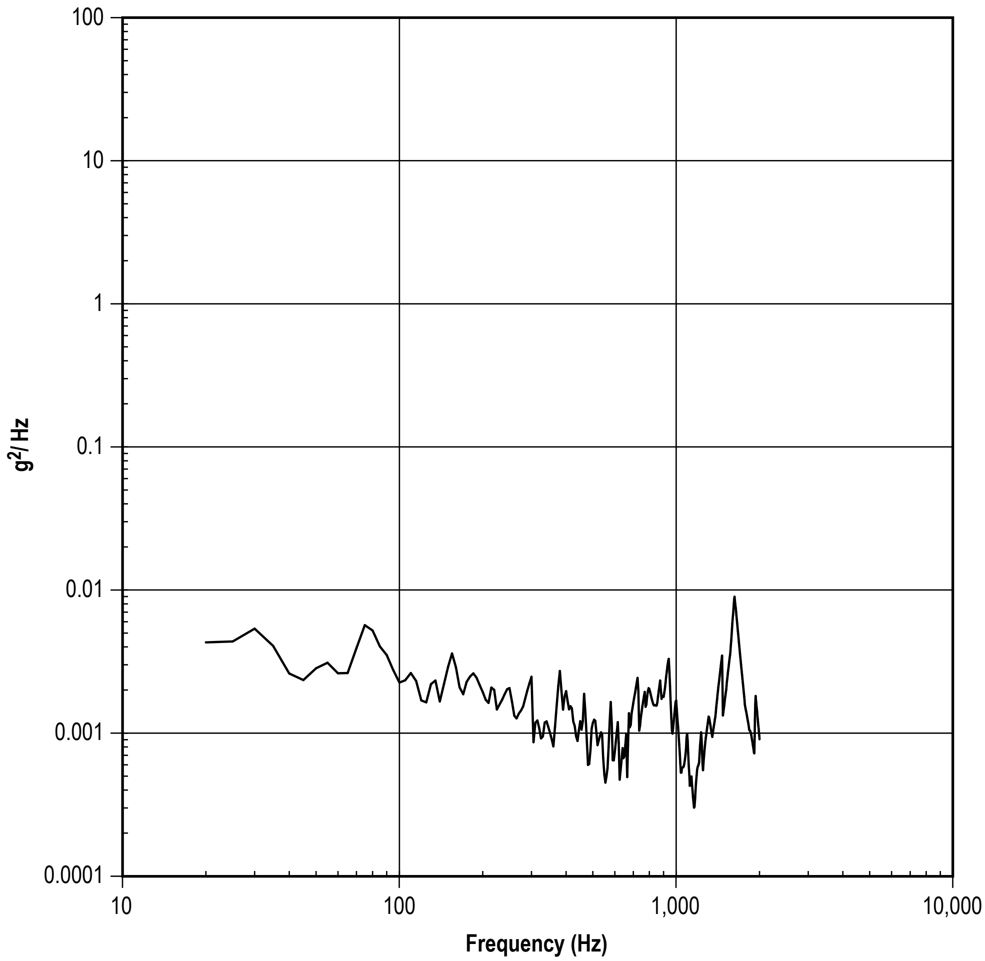

Figure 89. Skin-stringer PSD, longitudinal, Max Q, 1.5 lb/ft^2.

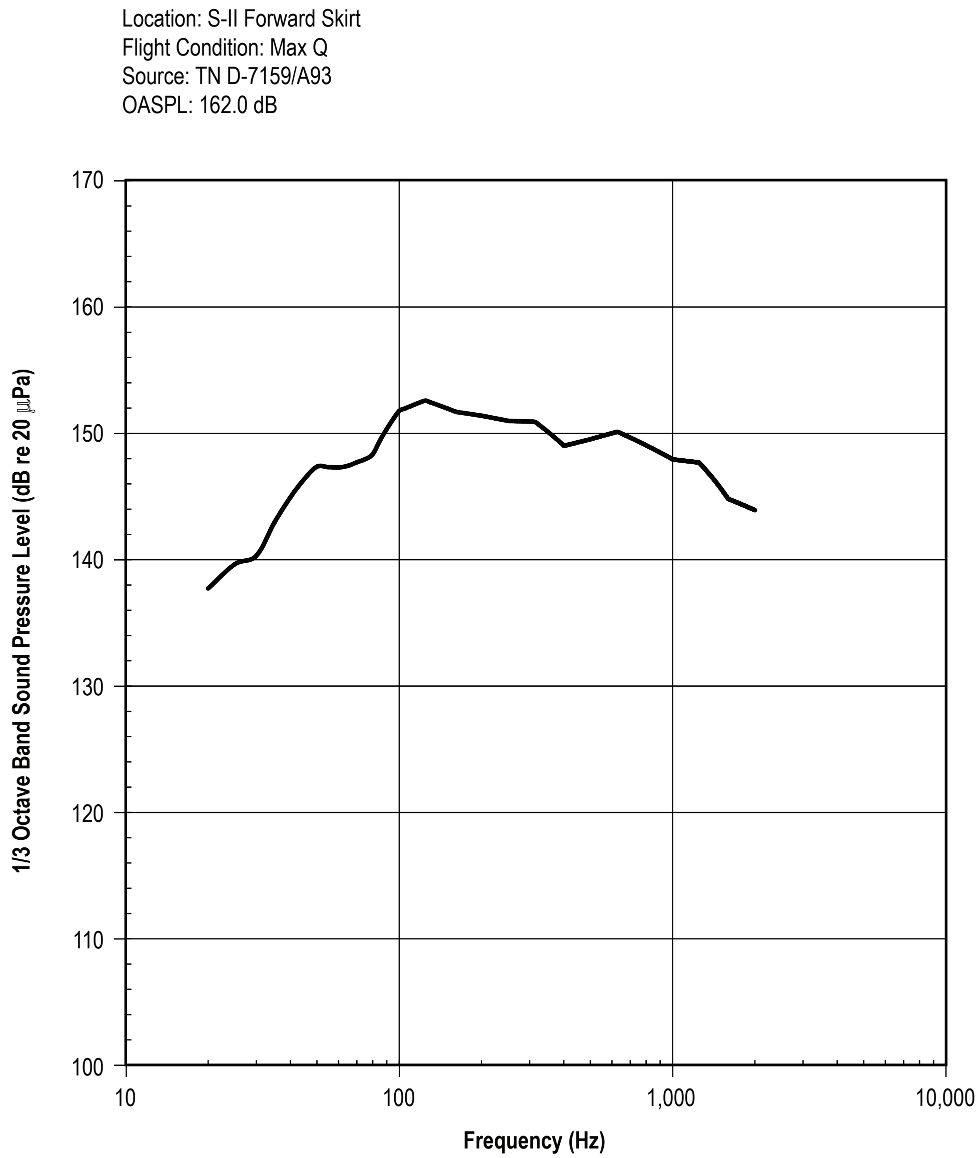

Figure 90. Saturn V acoustic spectrum, S-II forward skirt (subzone 11-2-2), Max Q.

Document/Page No.: 7159/A95
Flight Condition: Mach 1/Max Q
Vehicle Diameter: 33 ft
Ring Sep.: 36.0 in
Stringer Sep.: 8.63 in
Surface Wt.: 1.5 lb/ft^2
Measurements: E326-219 E329-219

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: N/A
Stringer Wt.: 0.71 lb/ft
Composite: 4.41 g_{rms}
Subzone: 11-2-2

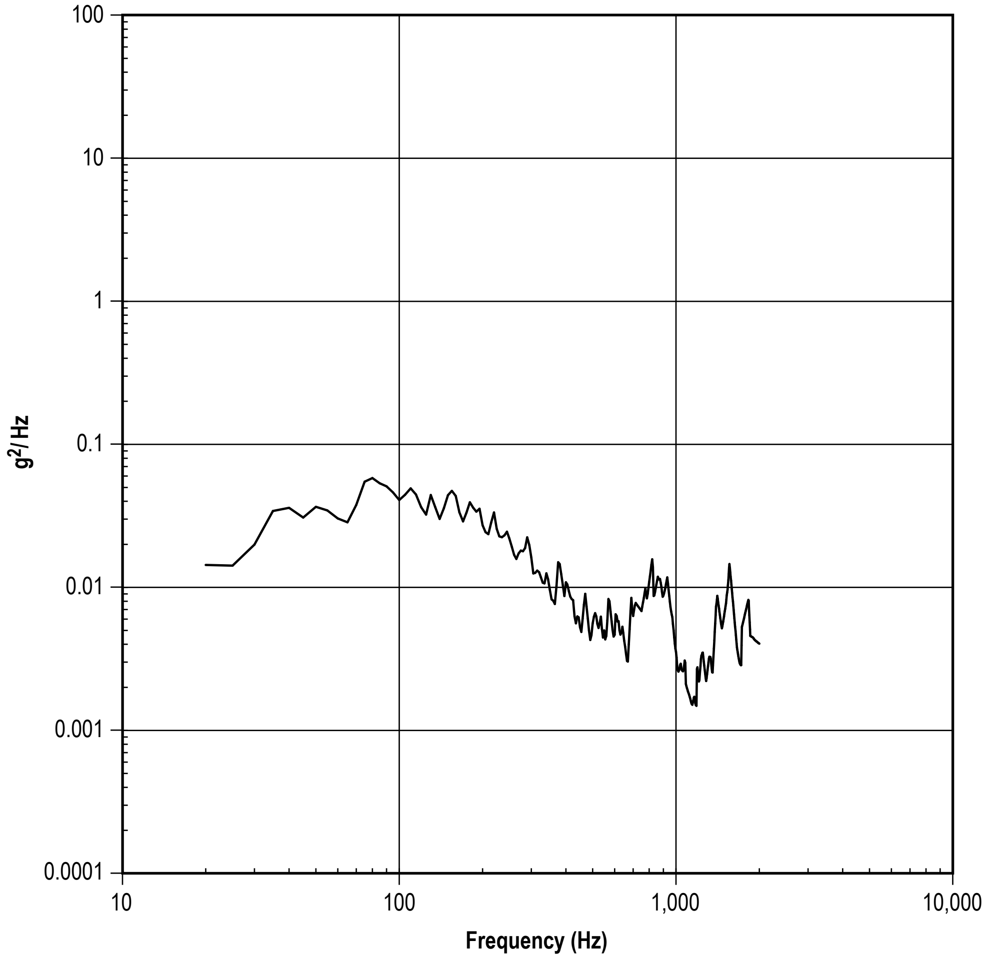

Figure 91. Skin-stringer PSD, longitudinal, Mach 1/Max Q, 1.5 lb/ft^2.

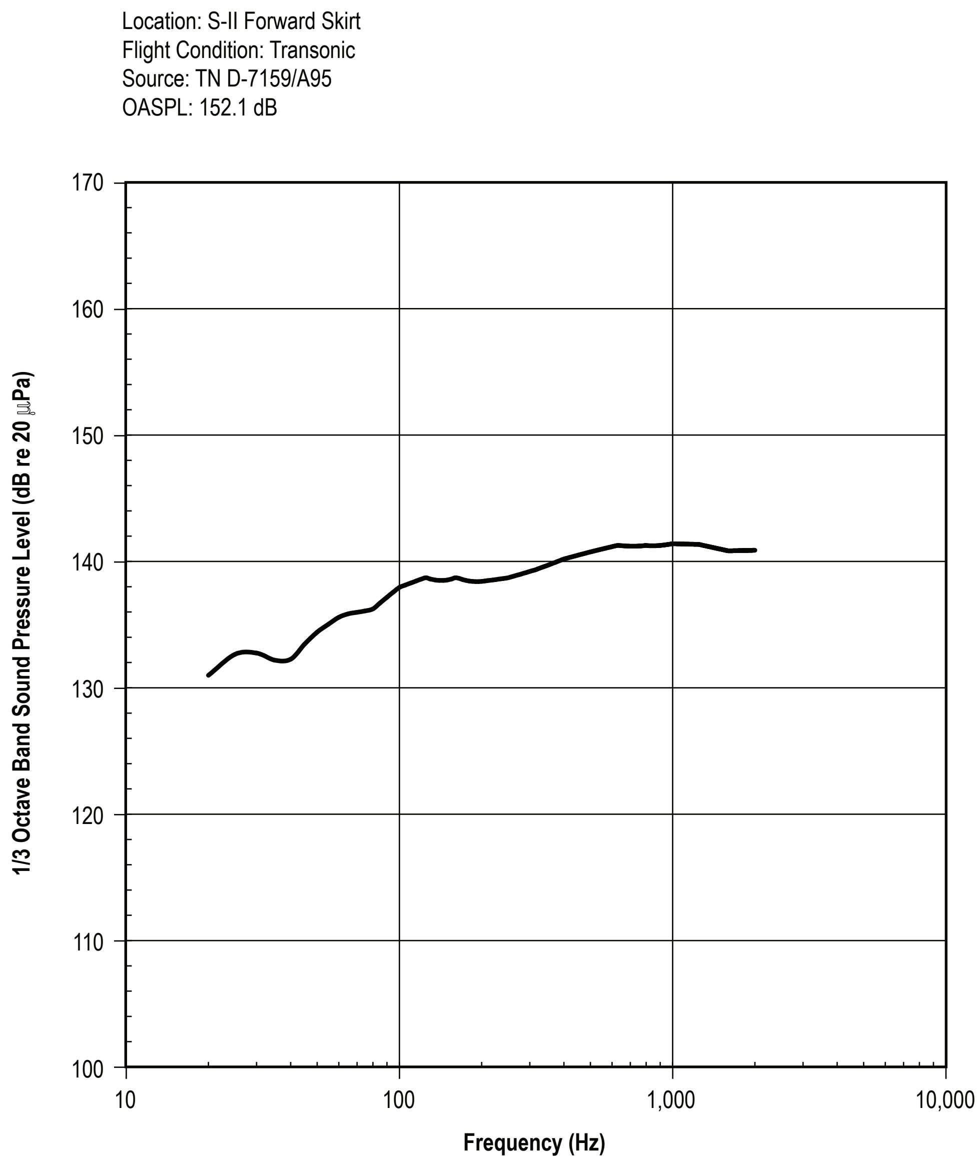

Figure 92. Saturn V acoustic spectrum, S-II forward skirt (subzone 11-2-2), transonic.

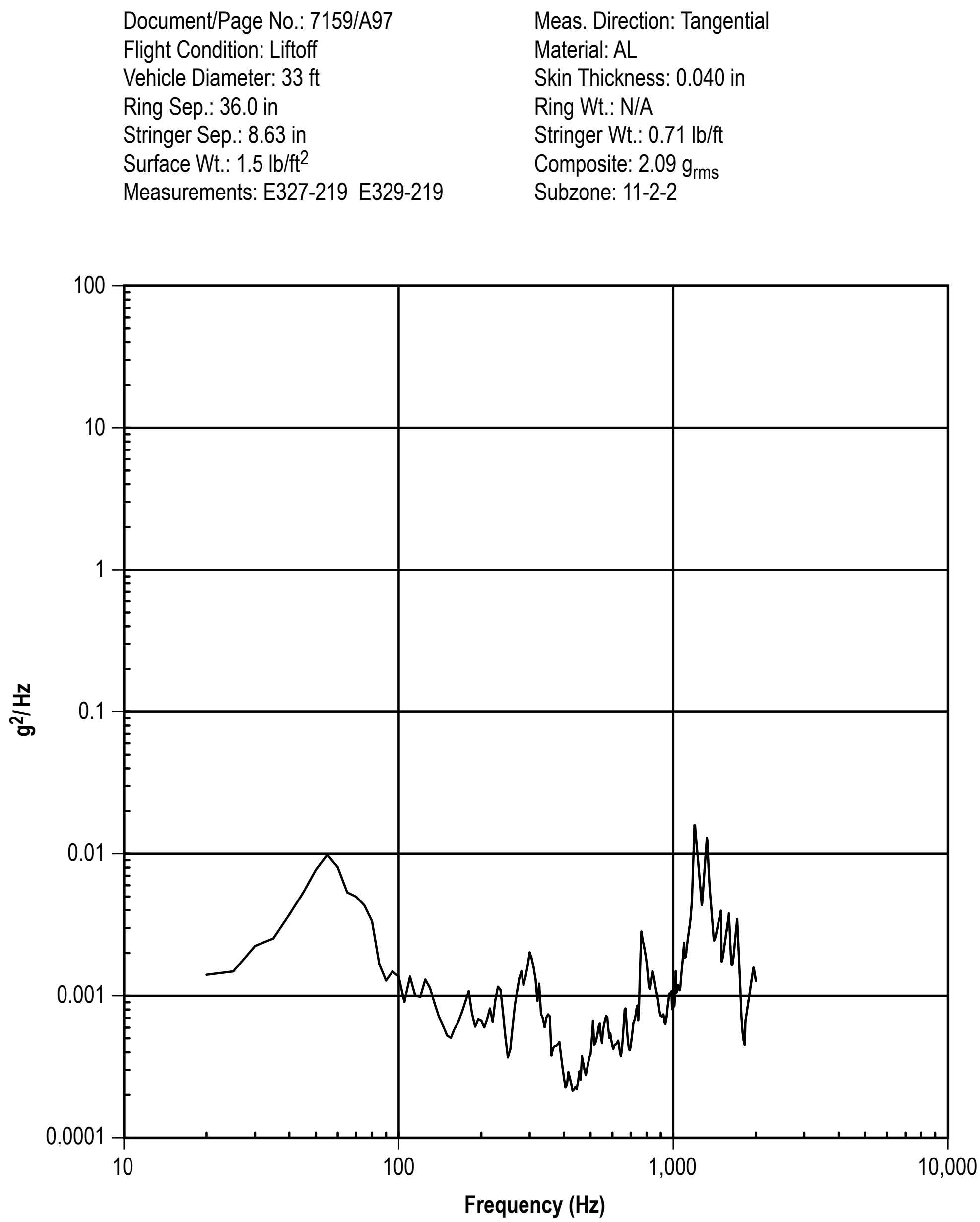

Figure 93. Skin-stringer PSD, tangential, liftoff, 1.5 lb/ft^2.

Document/Page No.: 7159/A99
Flight Condition: Mach 1
Vehicle Diameter: 33 ft
Ring Sep.: 36.0 in
Stringer Sep.: 8.63 in
Surface Wt.: 1.5 lb/ft^2
Measurements: E327-219 E329-219

Meas. Direction: Tangential
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: N/A
Stringer Wt.: 0.71 lb/ft
Composite: 4.63 g_{rms}
Subzone: 11-2-2

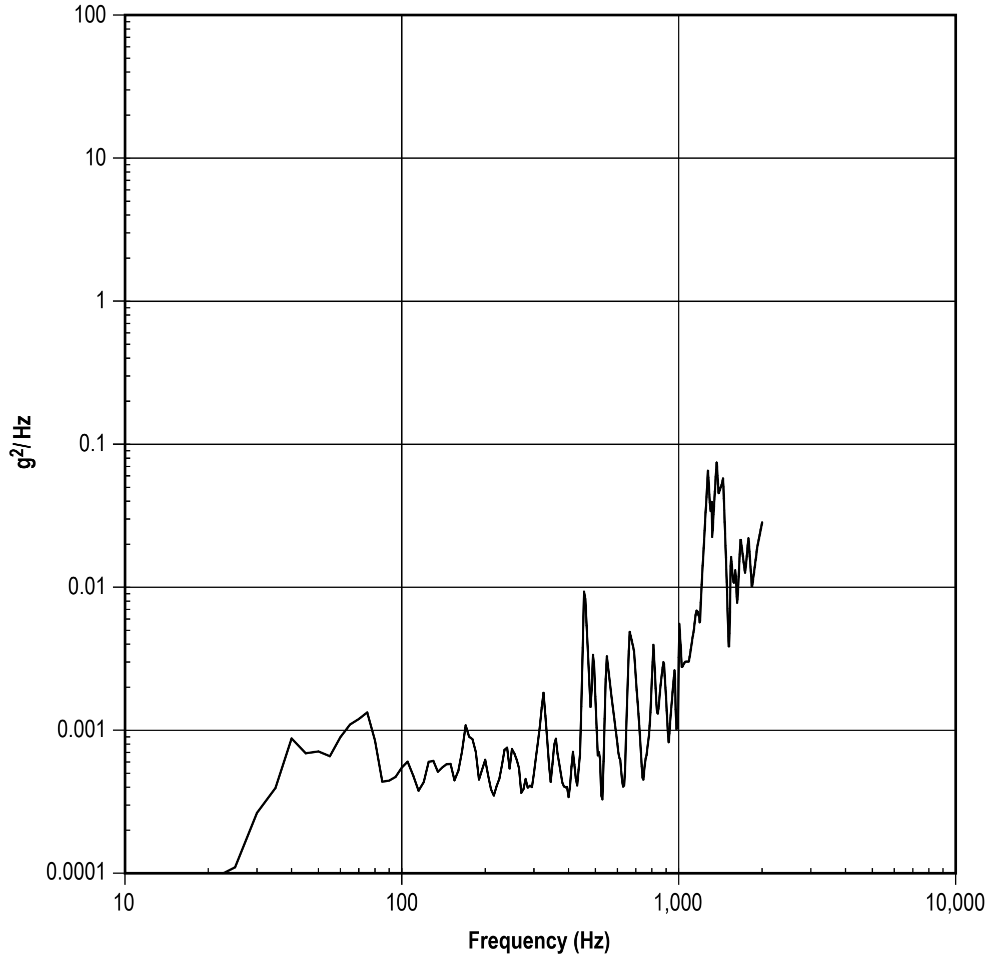

Figure 94. Skin-stringer PSD, tangential, Mach 1, 1.5 lb/ft^2.

Document/Page No.: 7159/A101
Flight Condition: Max Q
Vehicle Diameter: 33 ft
Ring Sep.: 36.0 in
Stringer Sep.: 8.63 in
Surface Wt.: 1.5 lb/ft^2
Measurements: E327-219 E329-219

Meas. Direction: Tangential
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: N/A
Stringer Wt.: 0.71 lb/ft
Composite: 4.19 g_{rms}
Subzone: 11-2-2

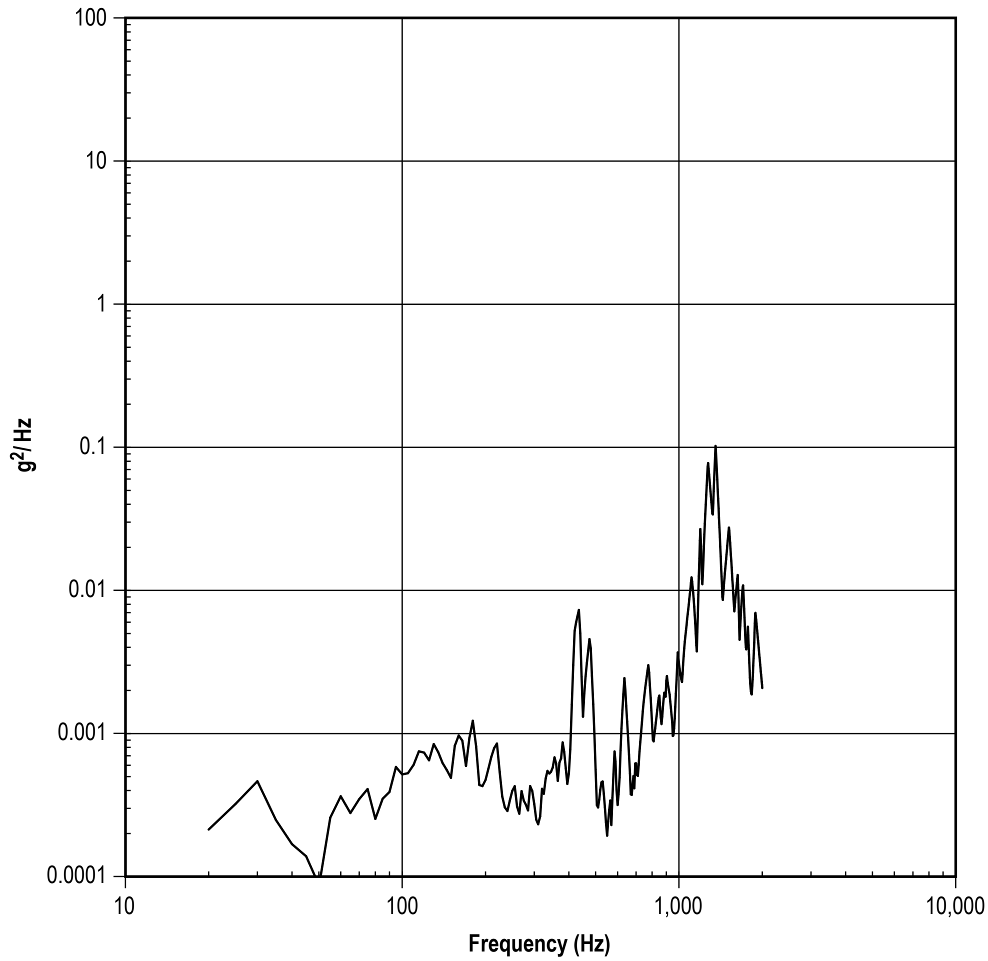

Figure 95. Skin-stringer PSD, tangential, Max Q, 1.5 lb/ft^2.

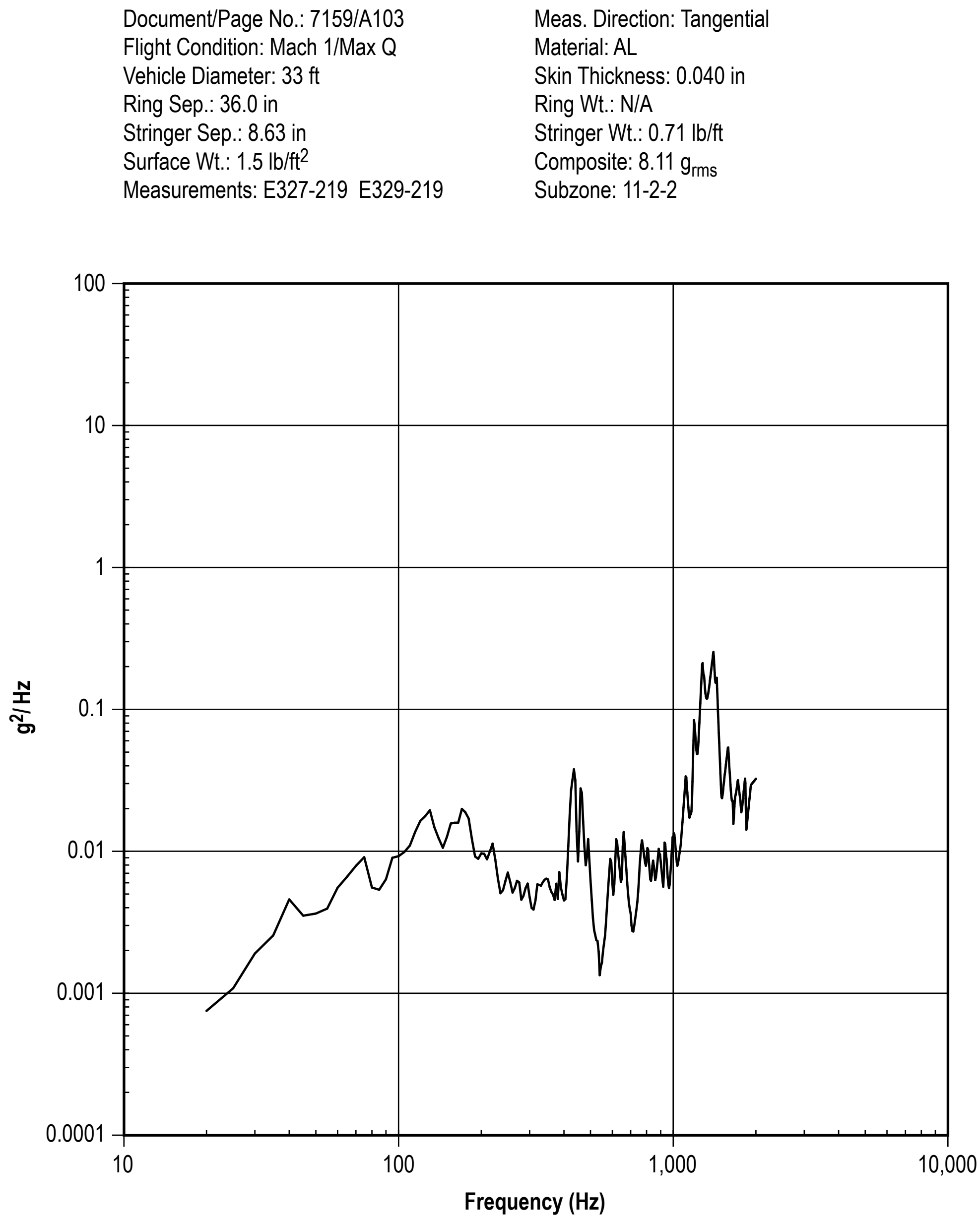

Figure 96. Skin-stringer PSD, tangential, Mach 1/Max Q, 1.5 lb/ft^2.

Document/Page No.: 7159/A105
Flight Condition: Liftoff
Vehicle Diameter: 33 ft
Ring Sep.: 36.0 in
Stringer Sep.: 8.63 in
Surface Wt.: 1.5 lb/ft^2
Measurements: E325-219

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.040 in
Ring Wt.: N/A
Stringer Wt.: 0.71 lb/ft
Composite: 6.03 g_{rms}
Subzone: 11-2-2

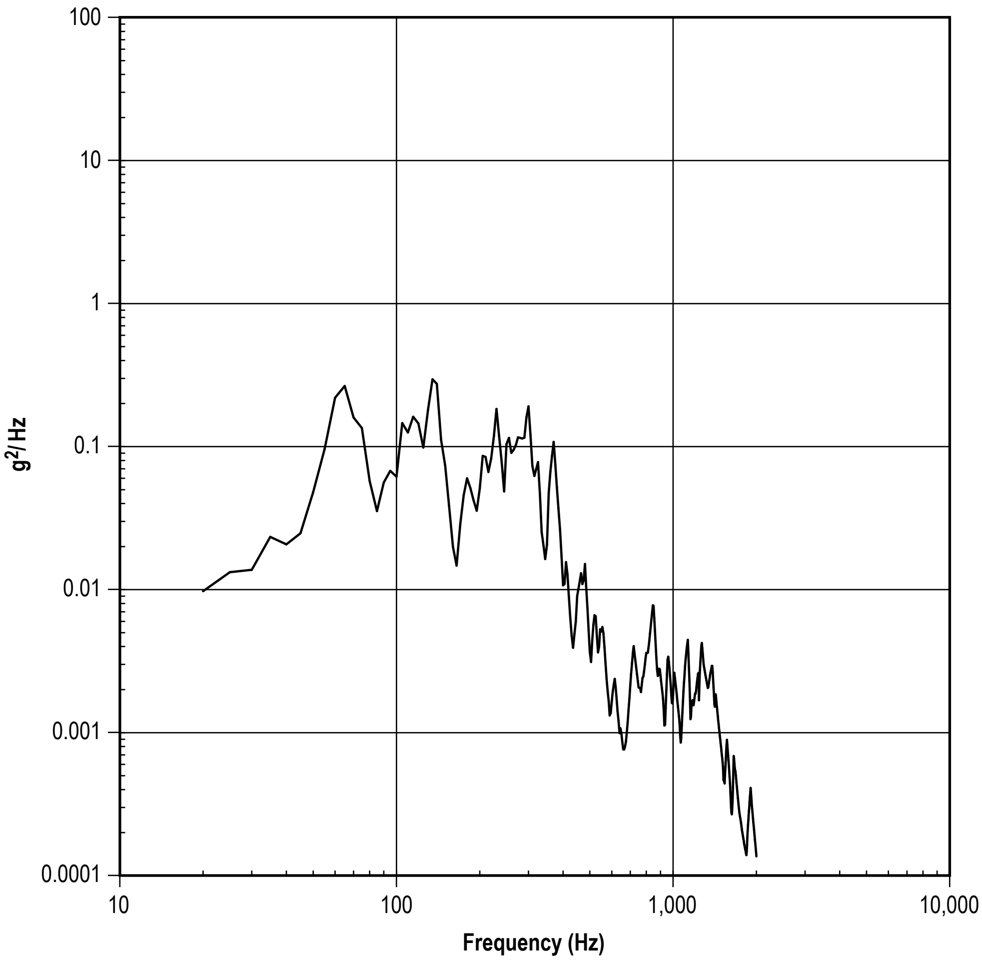

Figure 97. Skin-stringer PSD, radial, liftoff, 1.5 lb/ft^2.

Document/Page No.: 7159/A107	Meas. Direction: Radial
Flight Condition: Mach 1	Material: AL
Vehicle Diameter: 33 ft	Skin Thickness: 0.040 in
Ring Sep.: 36.0 in	Ring Wt.: N/A
Stringer Sep.: 8.63 in	Stringer Wt.: 0.71 lb/ft
Surface Wt.: 1.5 lb/ft^2	Composite: 4.25 g_{rms}
Measurements: E325-219	Subzone: 11-2-2

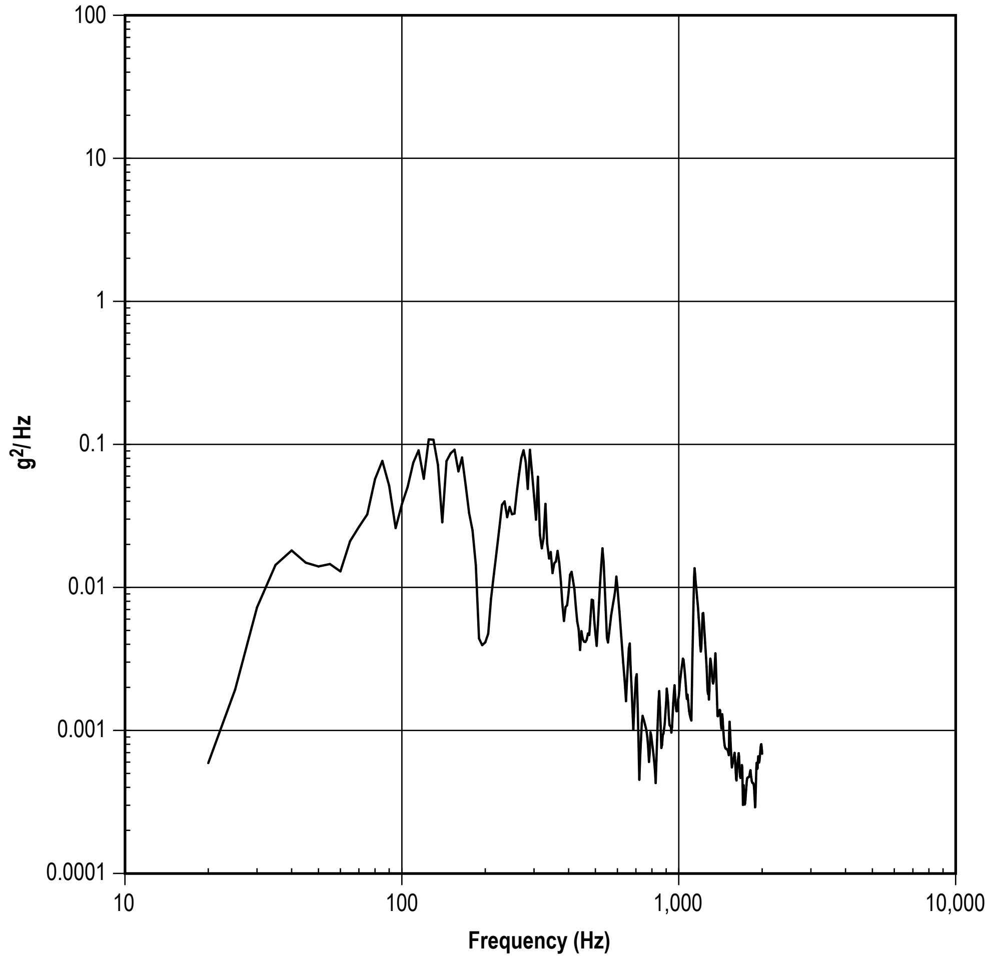

Figure 98. Skin-stringer PSD, radial, Mach 1, 1.5 lb/ft^2.

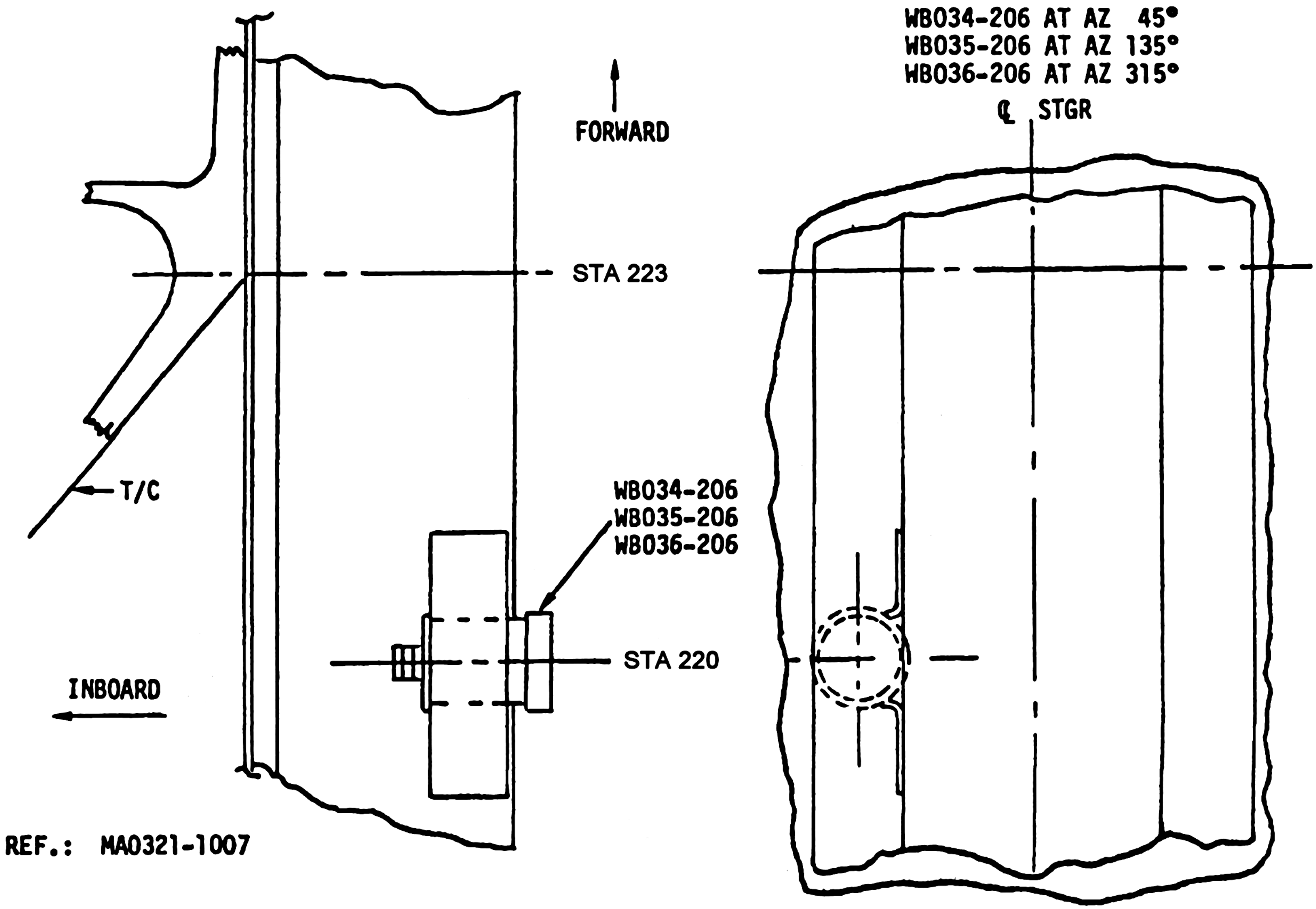

Figure 99. Zone 9: S-II stage aft skirt external acoustic measurement location.

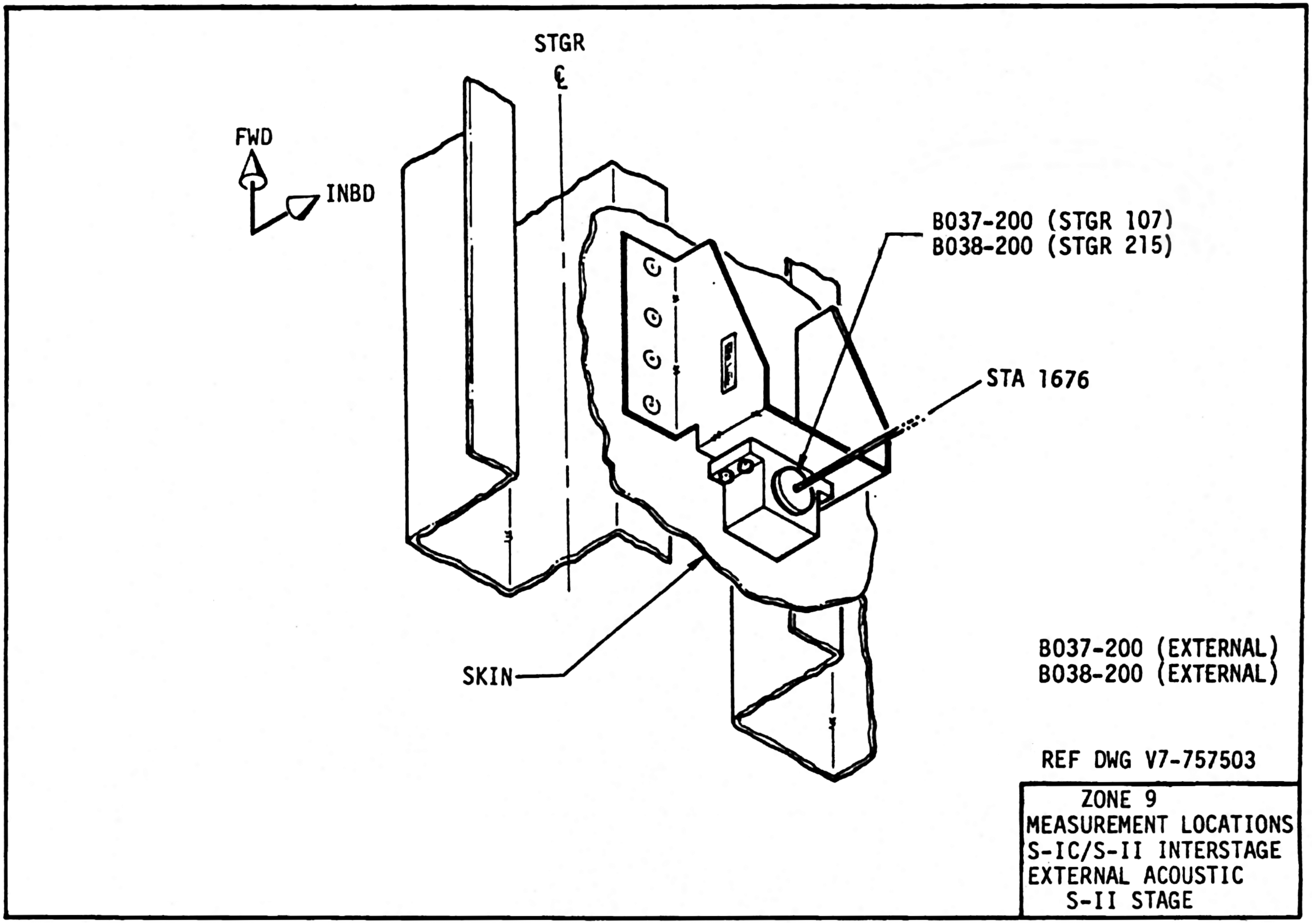

Figure 100. Zone 9: S-II/S-IC interstage external acoustic measurement location.

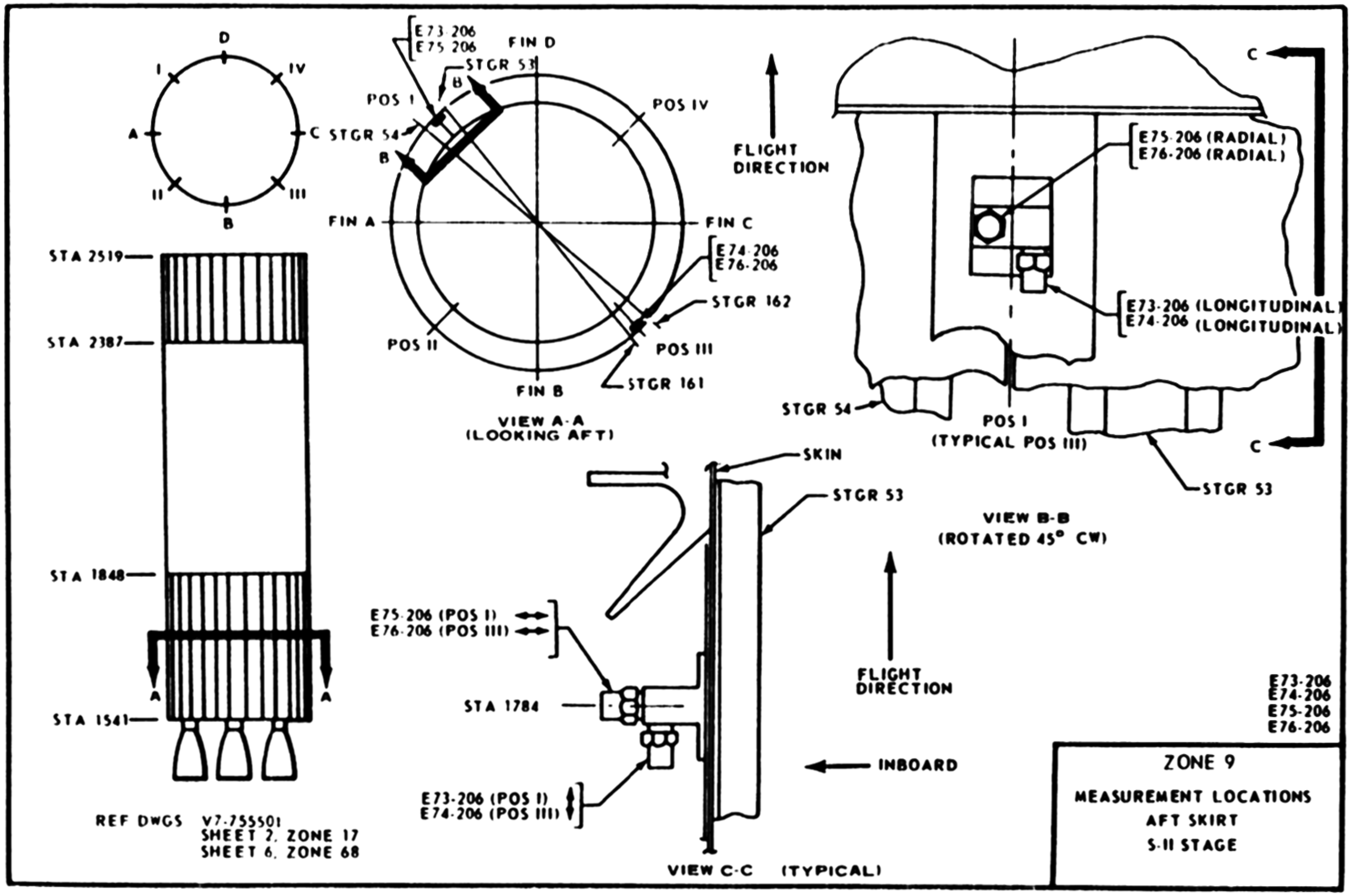

Figure 101. S-II stage aft skirt vibration measurement locations.

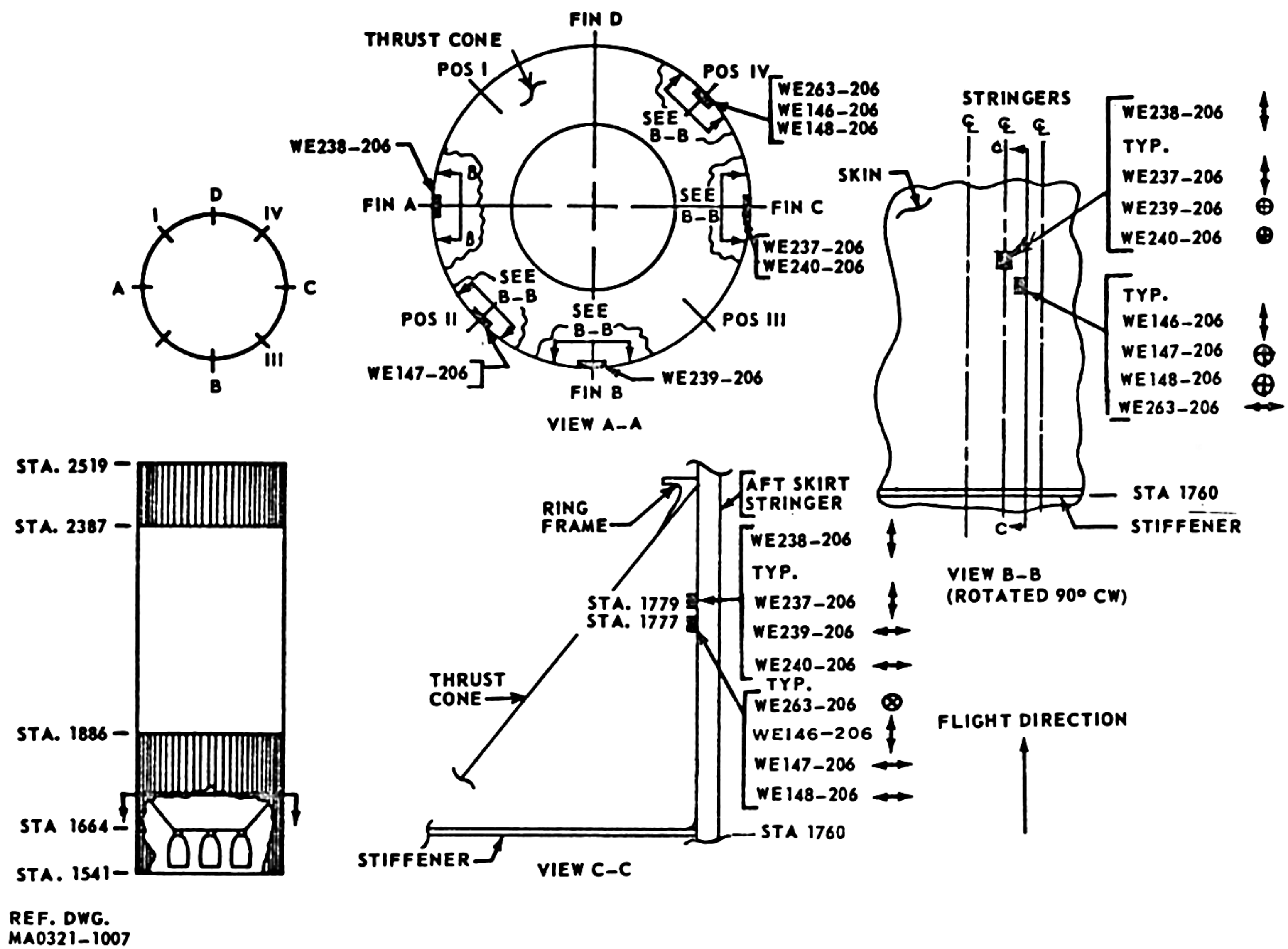

Figure 102. S–II aft skirt skin/stringer vibration measurement locations.

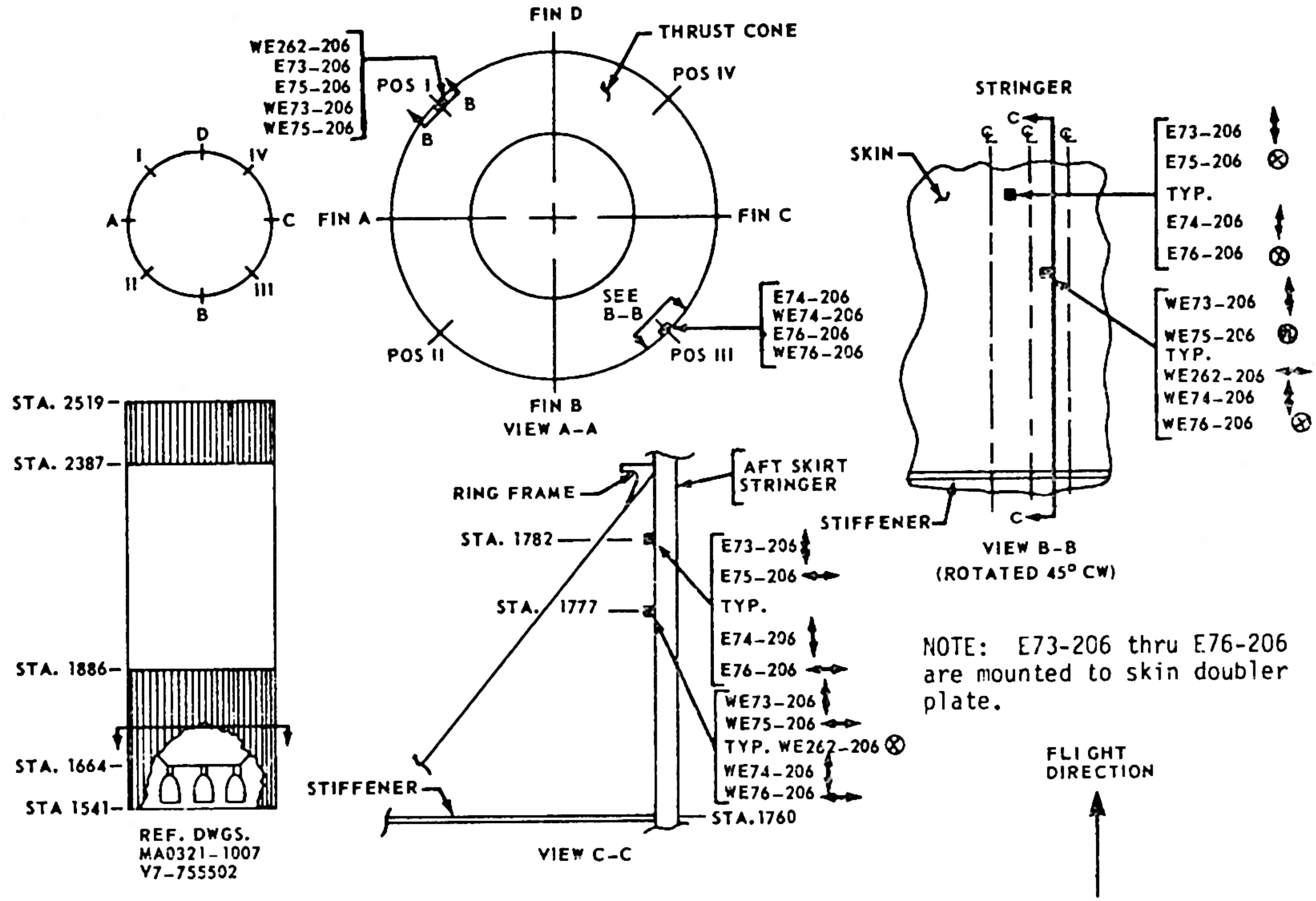

Figure 103. S-II aft skirt skin/stringer vibration measurement locations.

Document/Page No.: 7159/A109
Flight Condition: Static
Vehicle Diameter: 33 ft
Ring Sep.: 27.0 in
Stringer Sep.: 5.76 in
Surface Wt.: 2.8 lb/ft^2
Measurements: WE146-206 E74-206

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.071 in
Ring Wt.: N/A
Stringer Wt.: 0.86 lb/ft
Composite: 9.03 g_{rms}
Subzone: 9-3-2

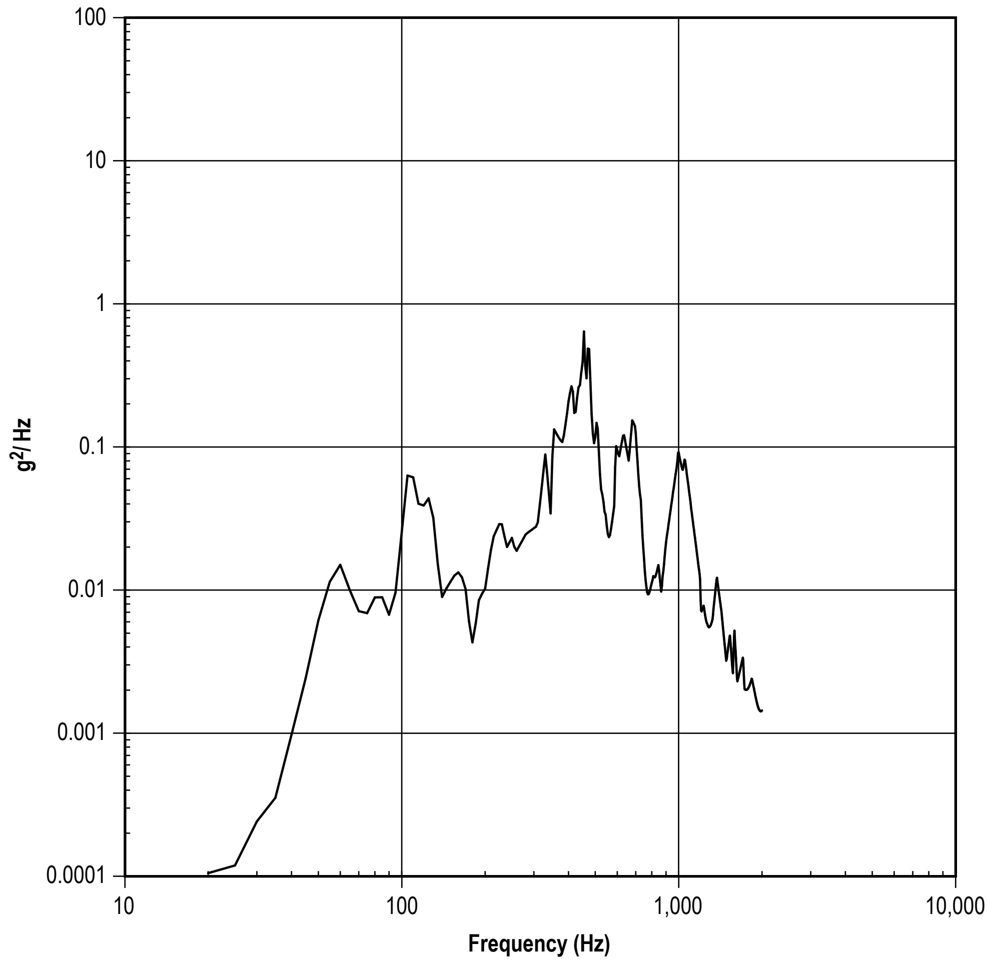

Figure 104. Skin-stringer PSD, longitudinal, static, 2.8 lb/ft^2.

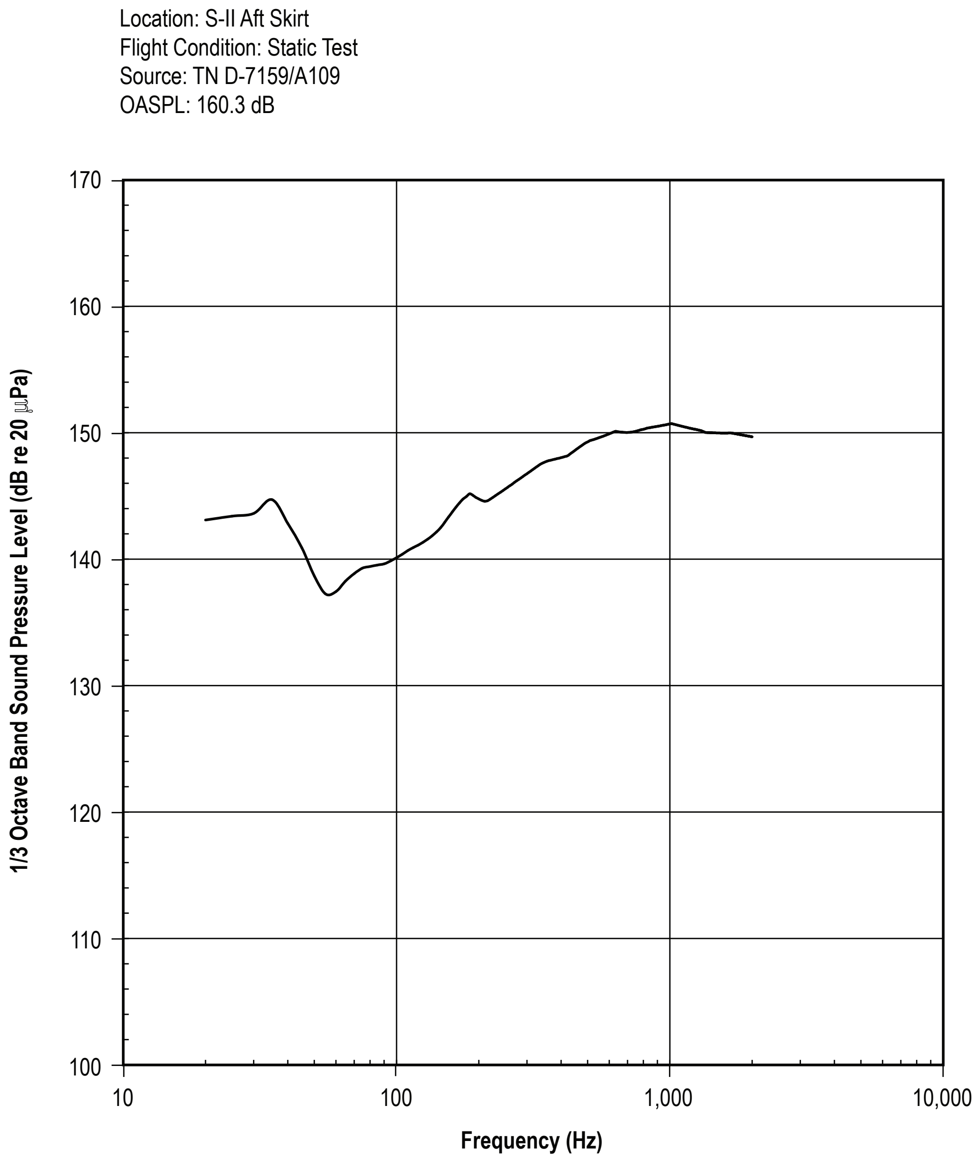

Figure 105. Saturn V acoustic spectrum, S-II aft skirt (subzone 9-3-2), static test.

Document/Page No.: 7159/A111
Flight Condition: Mach 1
Vehicle Diameter: 33 ft
Ring Sep.: 27.0 in
Stringer Sep.: 5.76 in
Surface Wt.: 2.8 lb/ft^2
Measurements: E351-206 E76-206

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.071 in
Ring Wt.: N/A
Stringer Wt.: 0.86 lb/ft
Composite: 56.49 g_{rms}
Subzone: 9-3-2

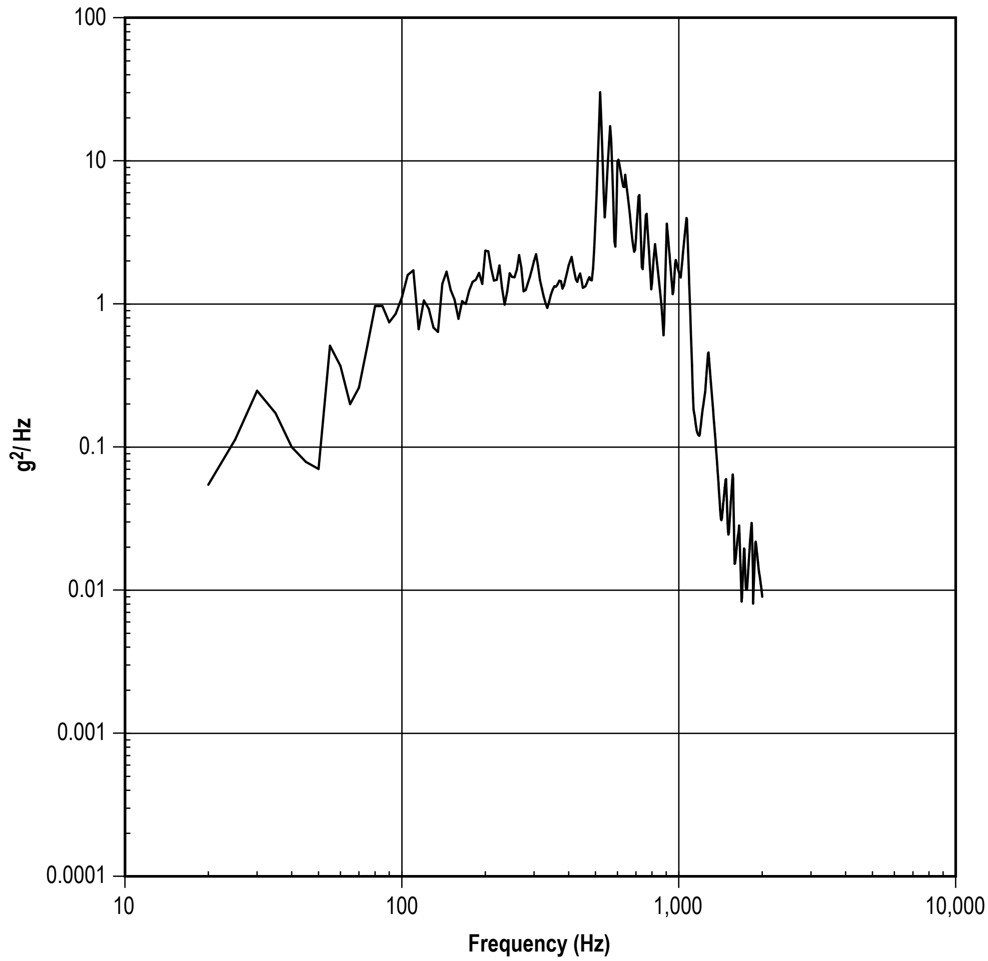

Figure 106. Skin-stringer PSD, radial, Mach 1, 2.8 lb/ft^2.

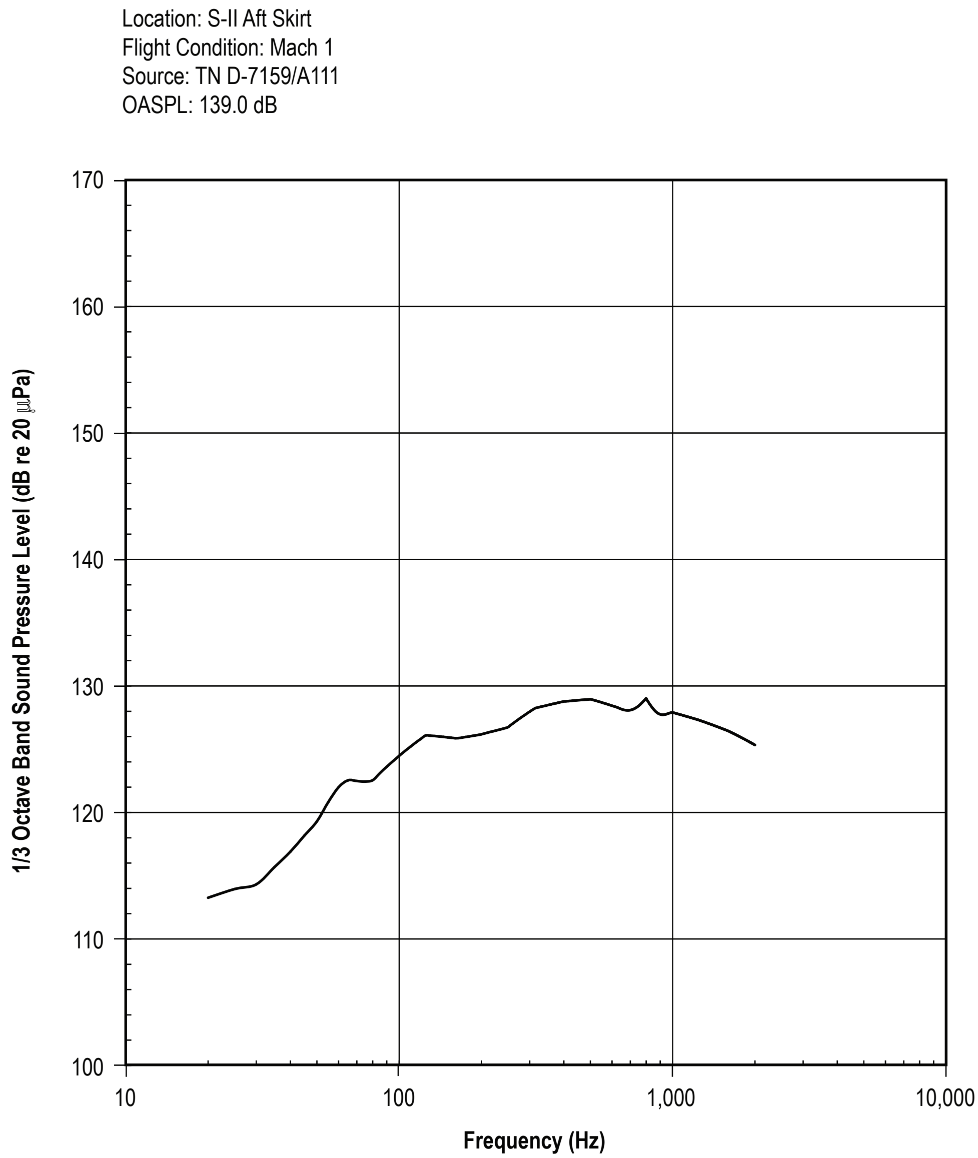

Figure 107. Saturn V acoustic spectrum, S-II aft skirt (subzone 9-3-2), Mach 1.

Document/Page No.: 7159/A113
Flight Condition: Max Q
Vehicle Diameter: 33 ft
Ring Sep.: 27.0 in
Stringer Sep.: 5.76 in
Surface Wt.: 2.8 lb/ft^2
Measurements: E351-206 E76-206

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.071 in
Ring Wt.: N/A
Stringer Wt.: 0.86 lb/ft
Composite: 90.88 g_{rms}
Subzone: 9-3-2

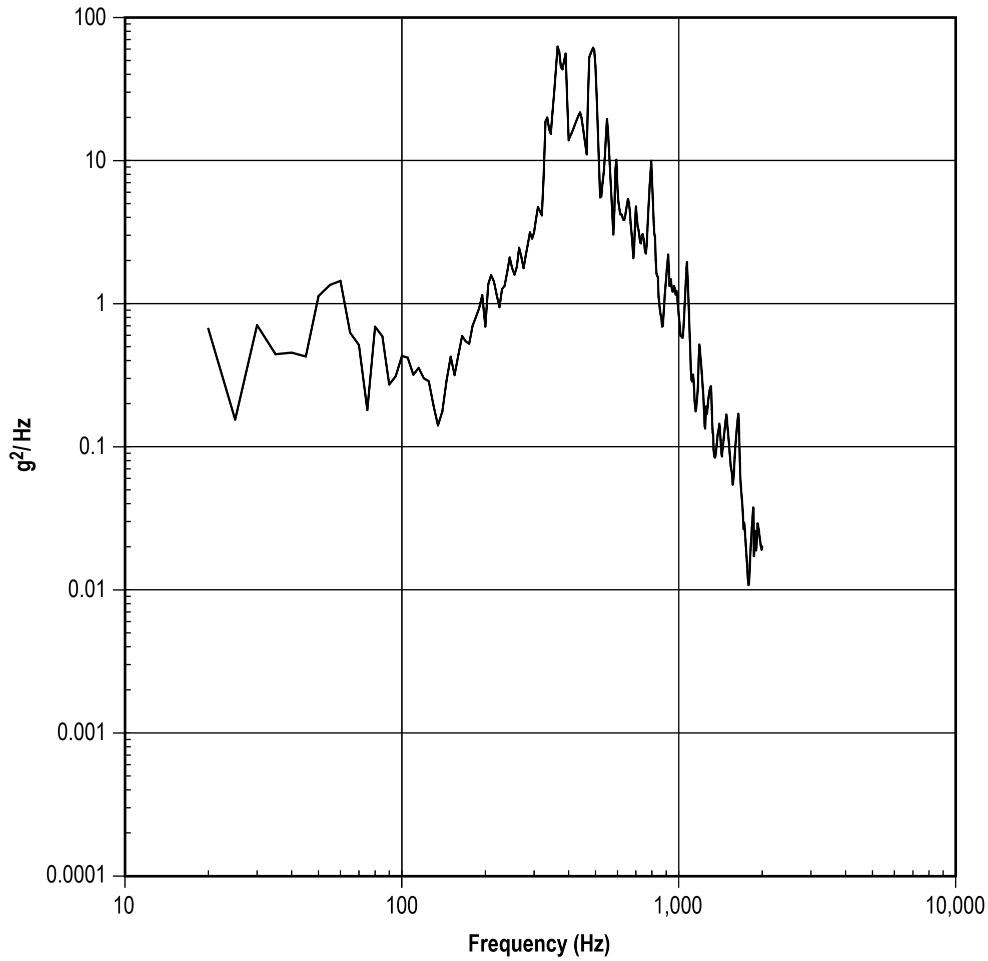

Figure 108. Skin-stringer PSD, radial, Max Q, 2.8 lb/ft^2.

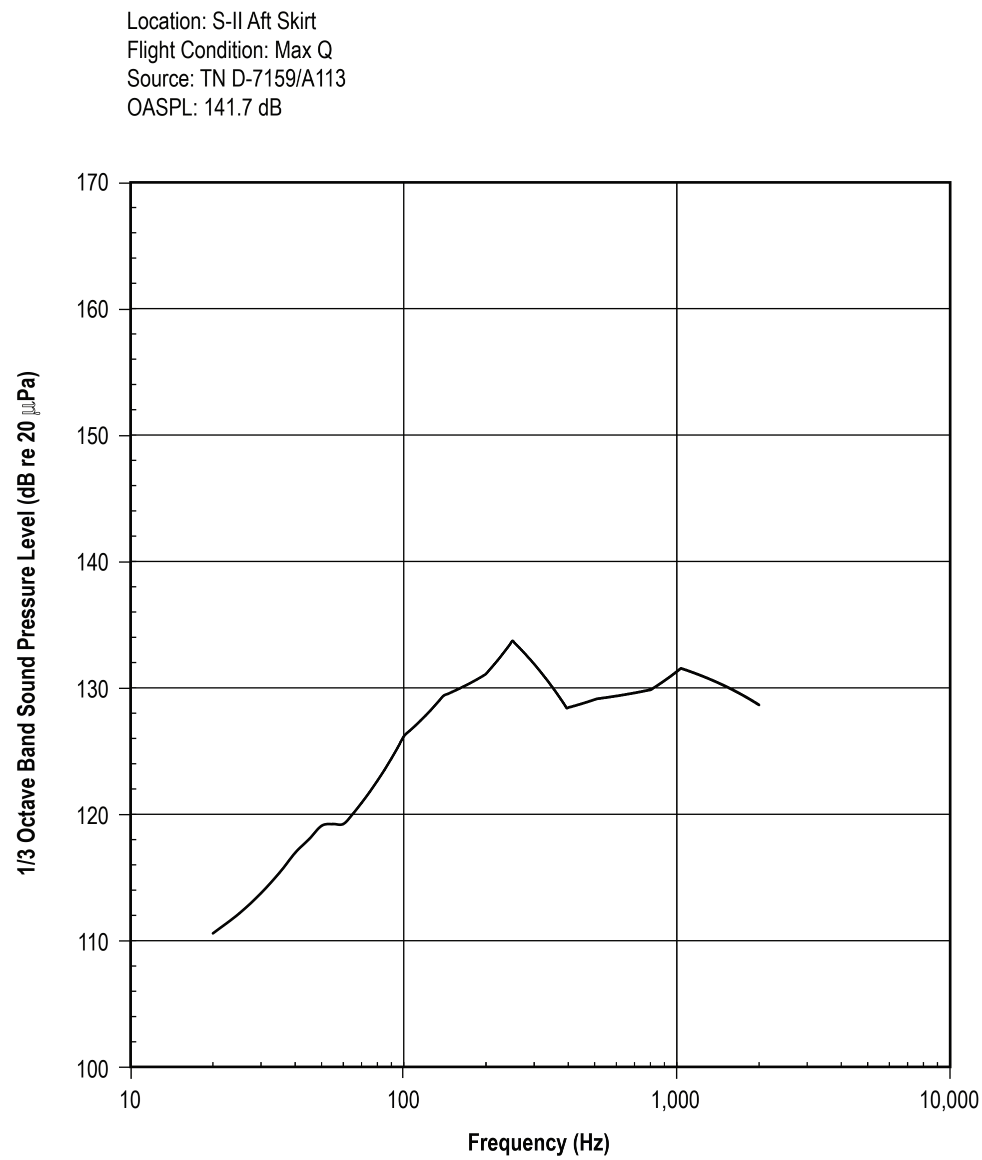

Figure 109. Saturn V acoustic spectrum, S-II aft skirt (subzone 9-3-2), Max Q.

Document/Page No.: 7159/A115
Flight Condition: Mach 1/Max Q
Vehicle Diameter: 33 ft
Ring Sep.: 27.0 in
Stringer Sep.: 5.76 in
Surface Wt.: 2.8 lb/ft^2
Measurements: E351-206 E76-206

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.071 in
Ring Wt.: N/A
Stringer Wt.: 0.86 lb/ft
Composite: 67.06 g_{rms}
Subzone: 9-3-2

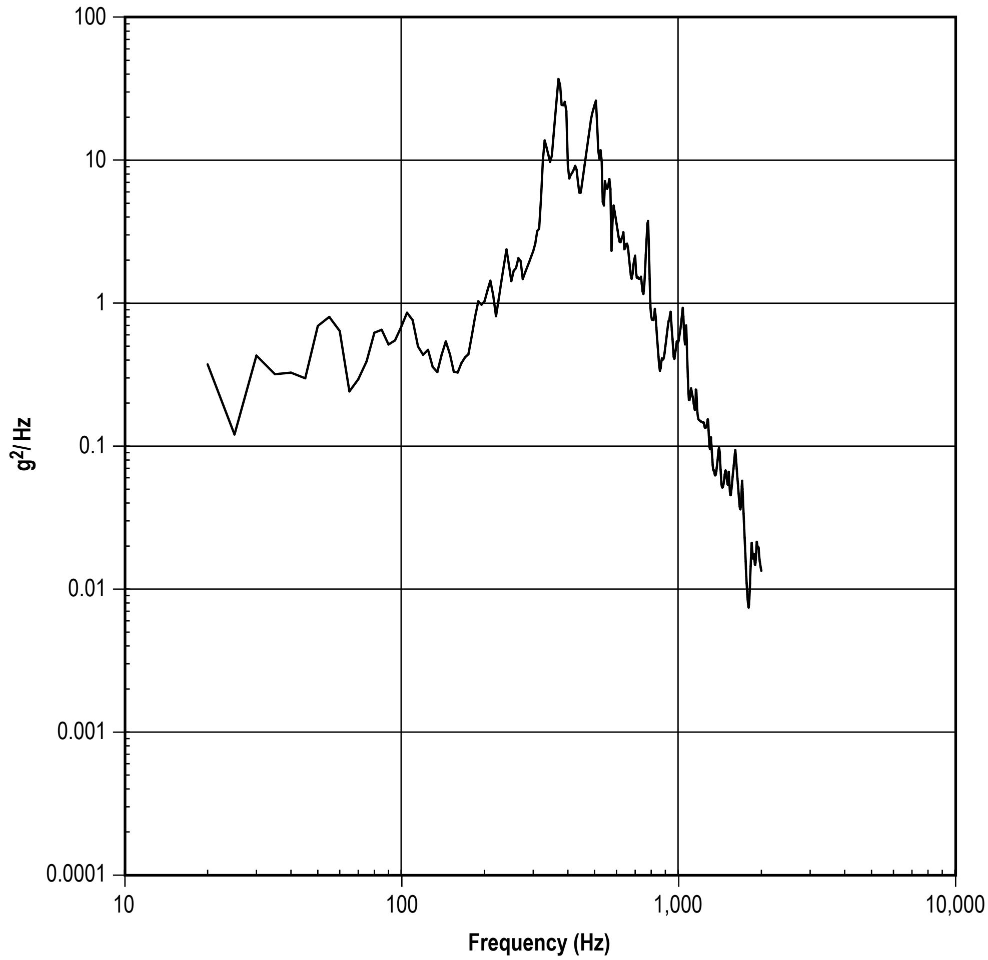

Figure 110. Skin-stringer PSD, radial, Mach 1/Max Q, 2.8 lb/ft^2.

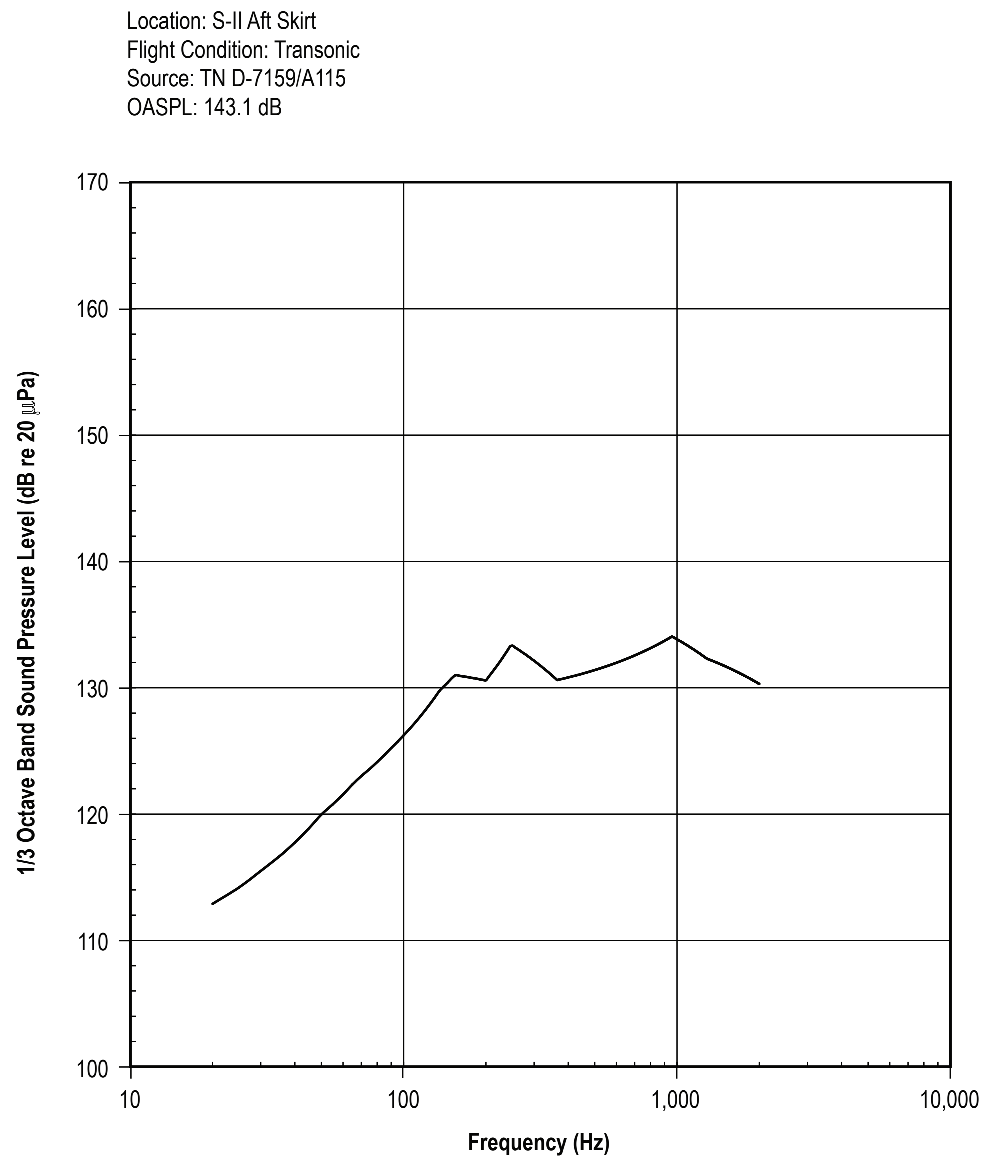

Figure 111. Saturn V acoustic spectrum, S-II aft skirt (subzone 9-3-2), transonic.

Document/Page No.: 7159/A117
Flight Condition: Static
Vehicle Diameter: 33 ft
Ring Sep.: 27.0 in
Stringer Sep.: 5.76 in
Surface Wt.: 2.8 lb/ft^2
Measurements: E76-206 E75-206 WE240-206
E76-206 WE239-206 WE148-206

Meas. Direction: Radial
Material: AL
Skin Thickness: 0.071 in
Ring Wt.: N/A
Stringer Wt.: 0.86 lb/ft
Composite: 39.77 g_{rms}
Subzone: 9-3-2

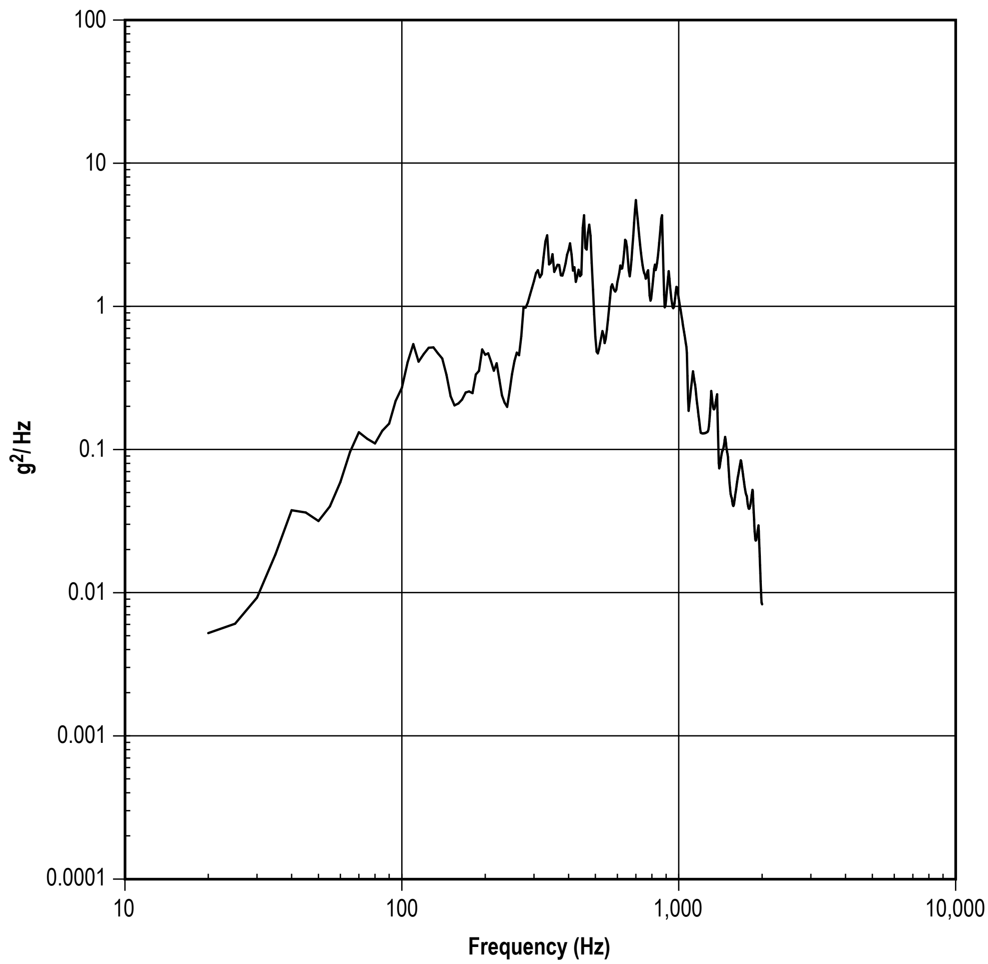

Figure 112. Skin-stringer PSD, radial, static, 2.8 lb/ft^2.

Document/Page No.: 7159/A119
Flight Condition: Static
Vehicle Diameter: 22 ft
Core Density: 3.10 lb/ft^3
Surface Wt.: 1.12 lb/ft^2

Meas. Direction: Radial
Material: AL Honeycomb
Overall Thickness: 1.0 in
Outer Plate Thickness: 0.030 in
Composite: 67.60 g_{rms}

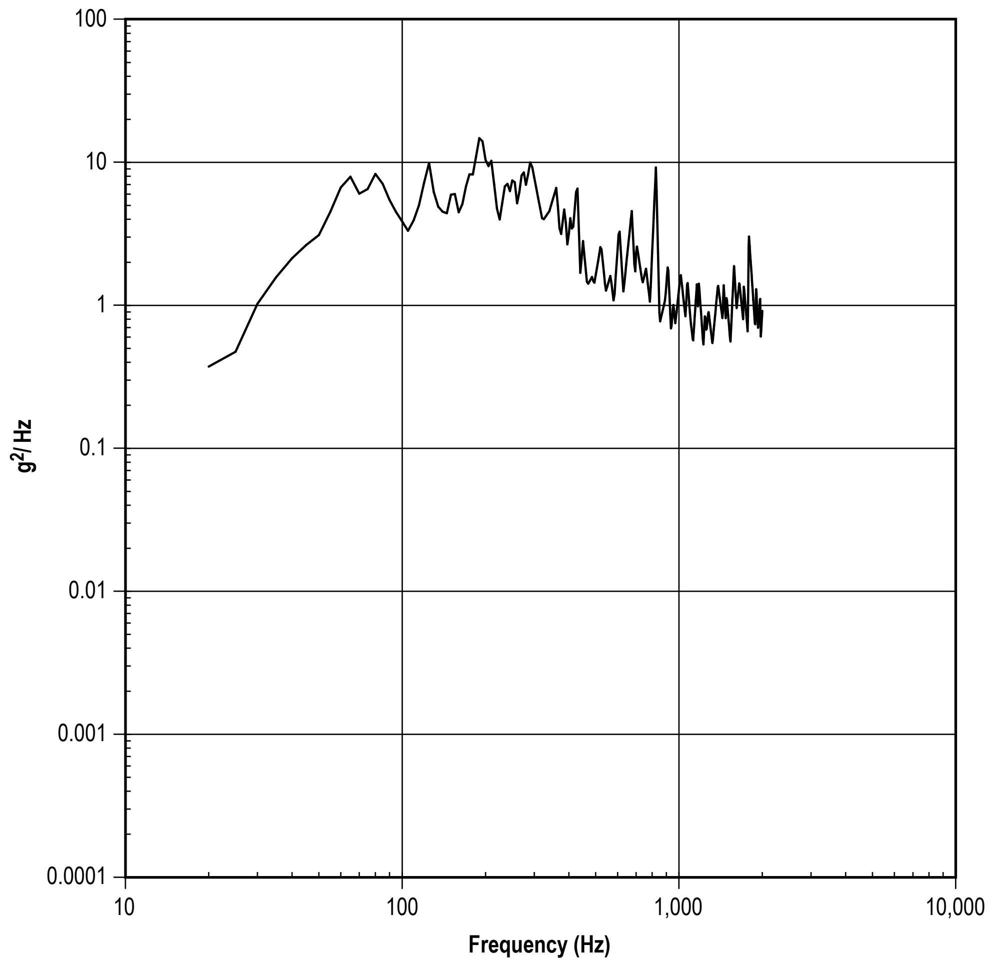

Figure 113. Honeycomb PSD, radial, static, 1.1 lb/ft^2.

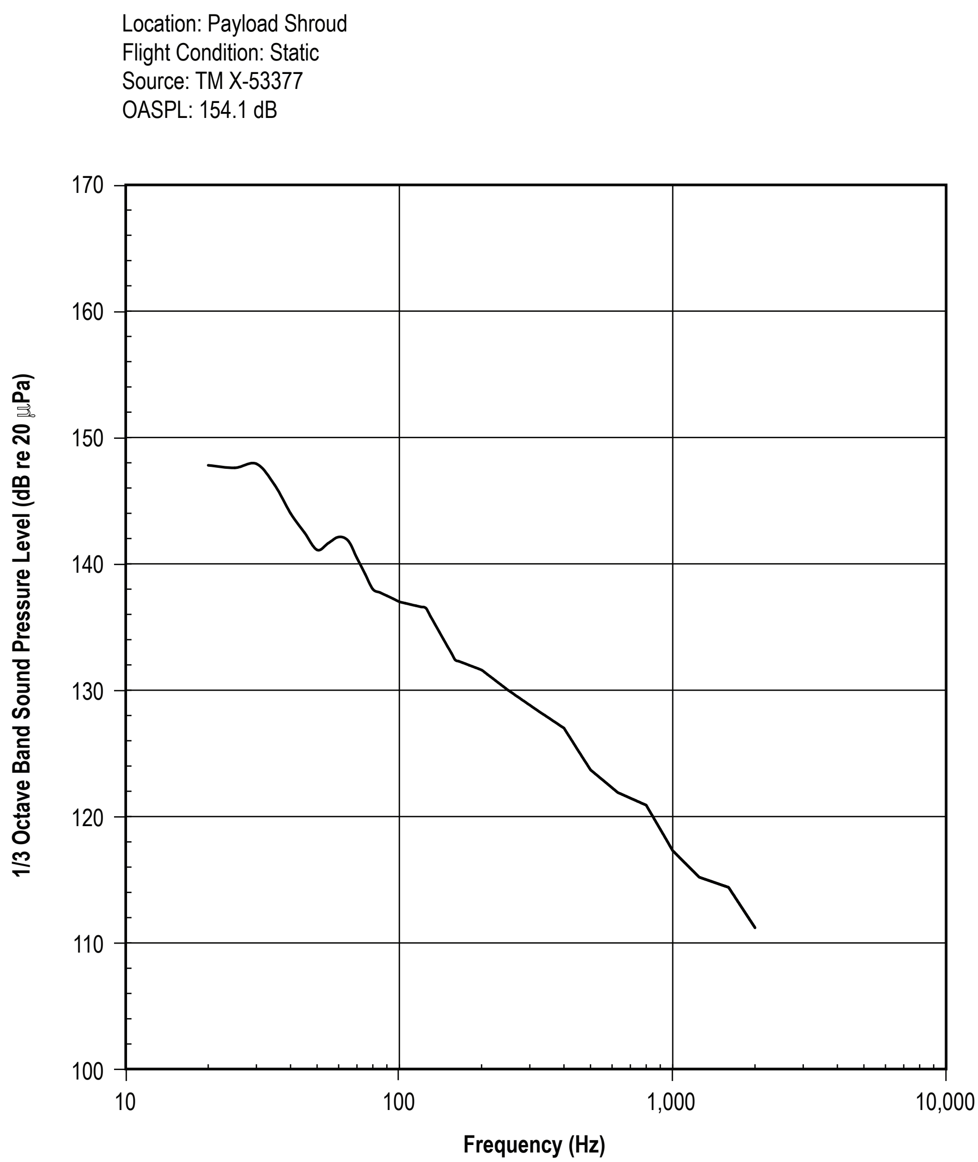

Figure 114. Saturn V acoustic spectrum, payload shroud, static test.

APPENDIX B—TITAN III VIBRATION AND ACOUSTIC DATA

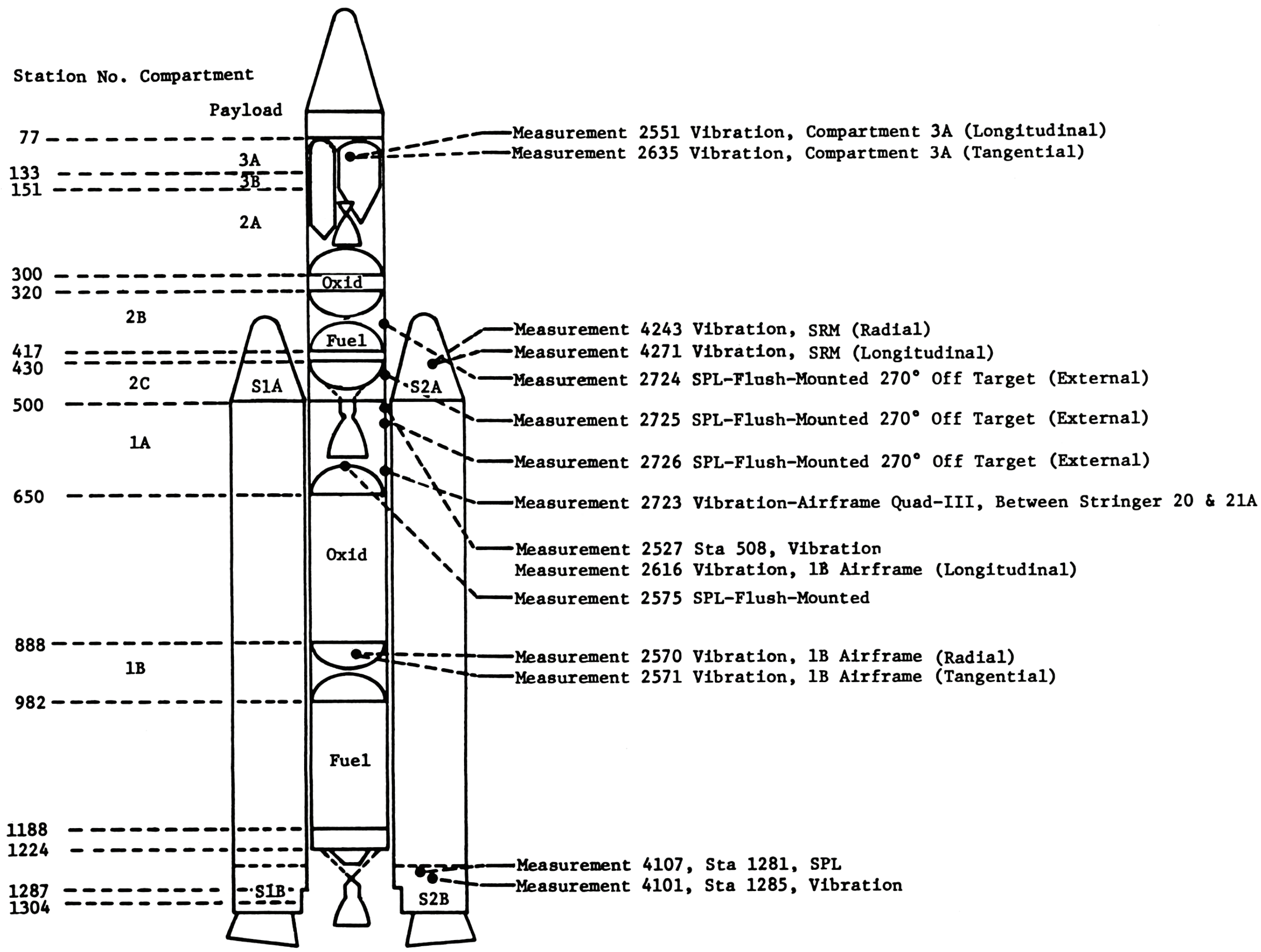

Figure 115. Titan IIIC vehicle compartment and station designations.

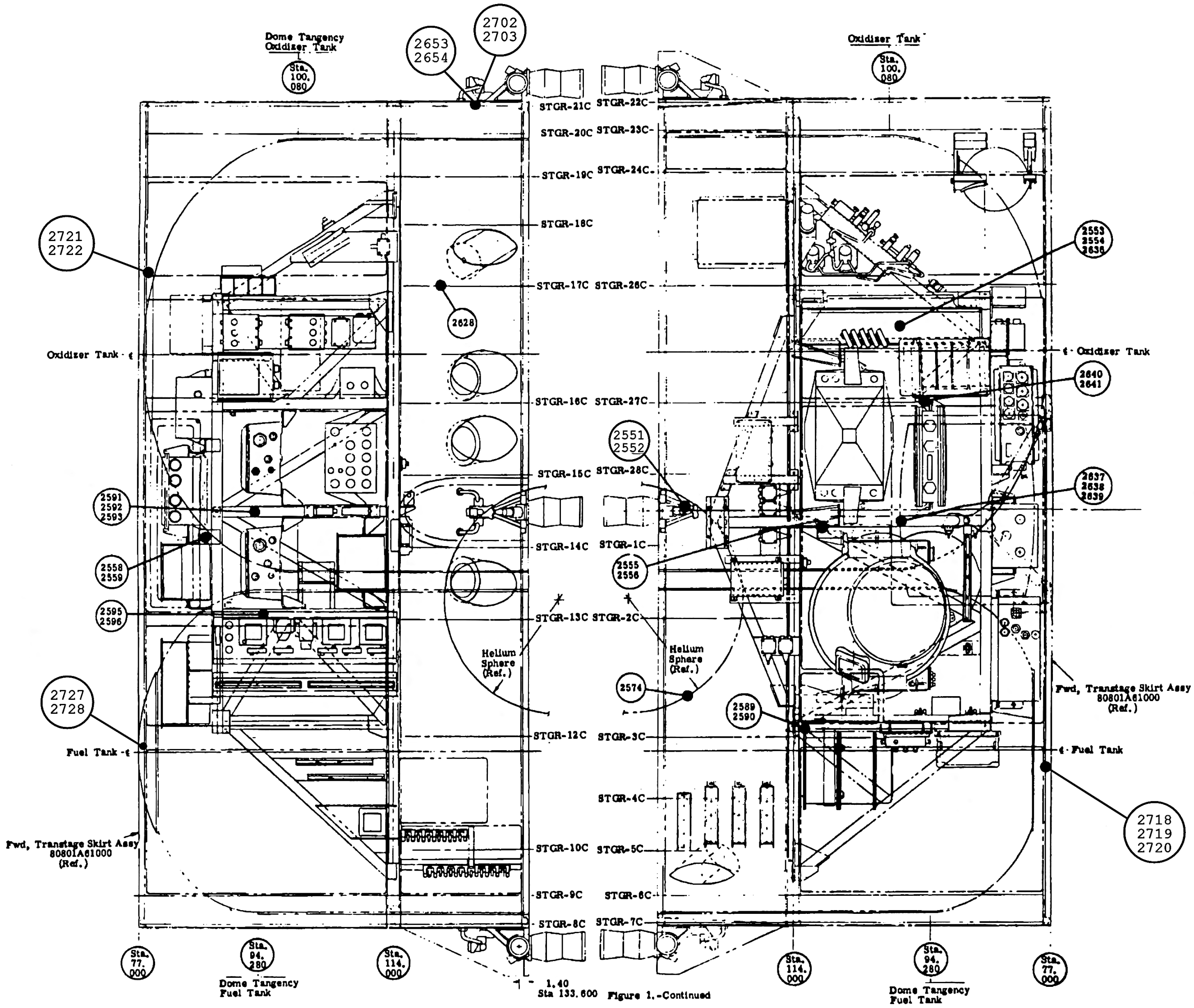

Figure 116. Compartment 3A measurement locations.

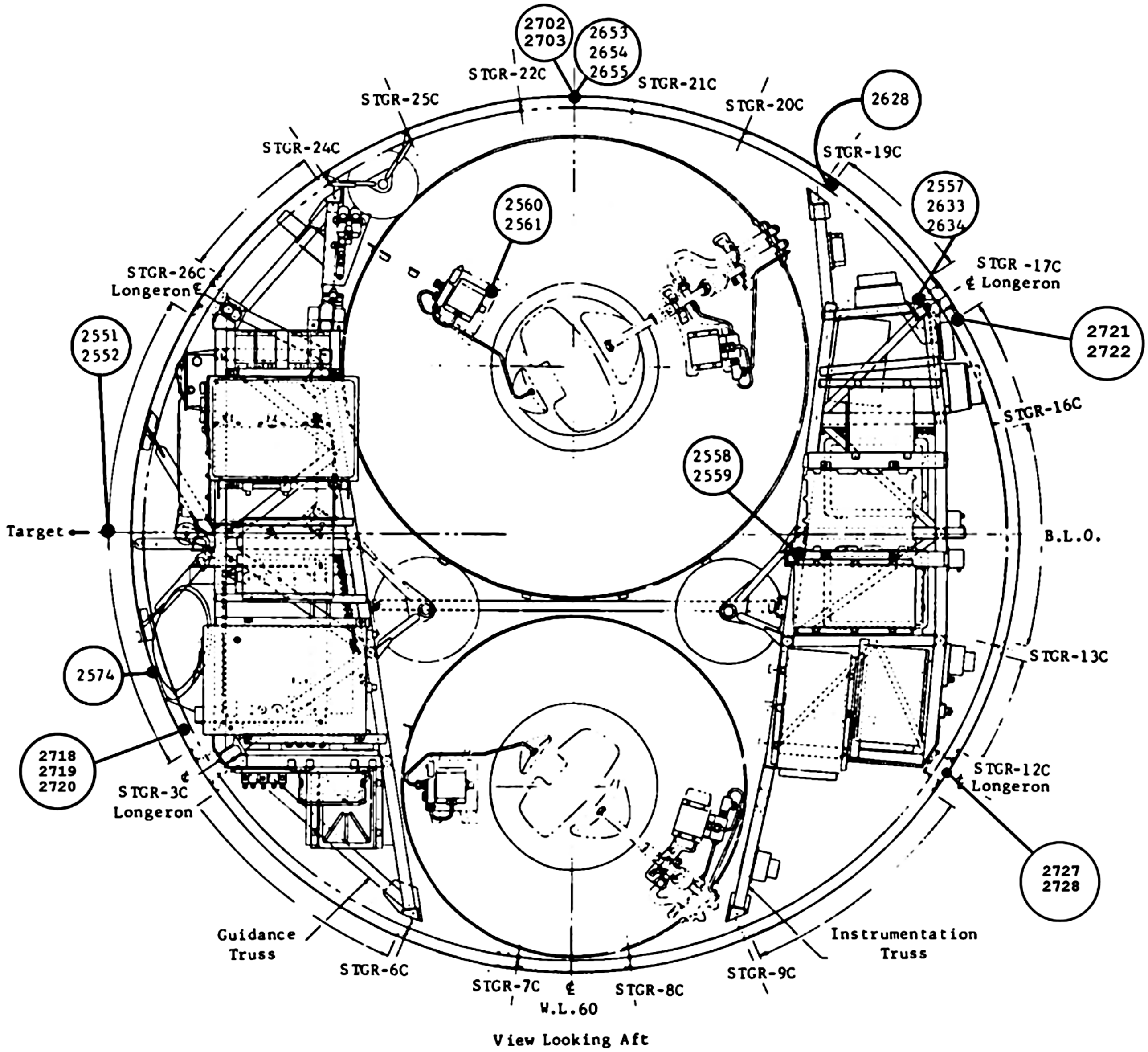

Figure 117. Compartment 3A instrumentation and guidance truss measurement locations.

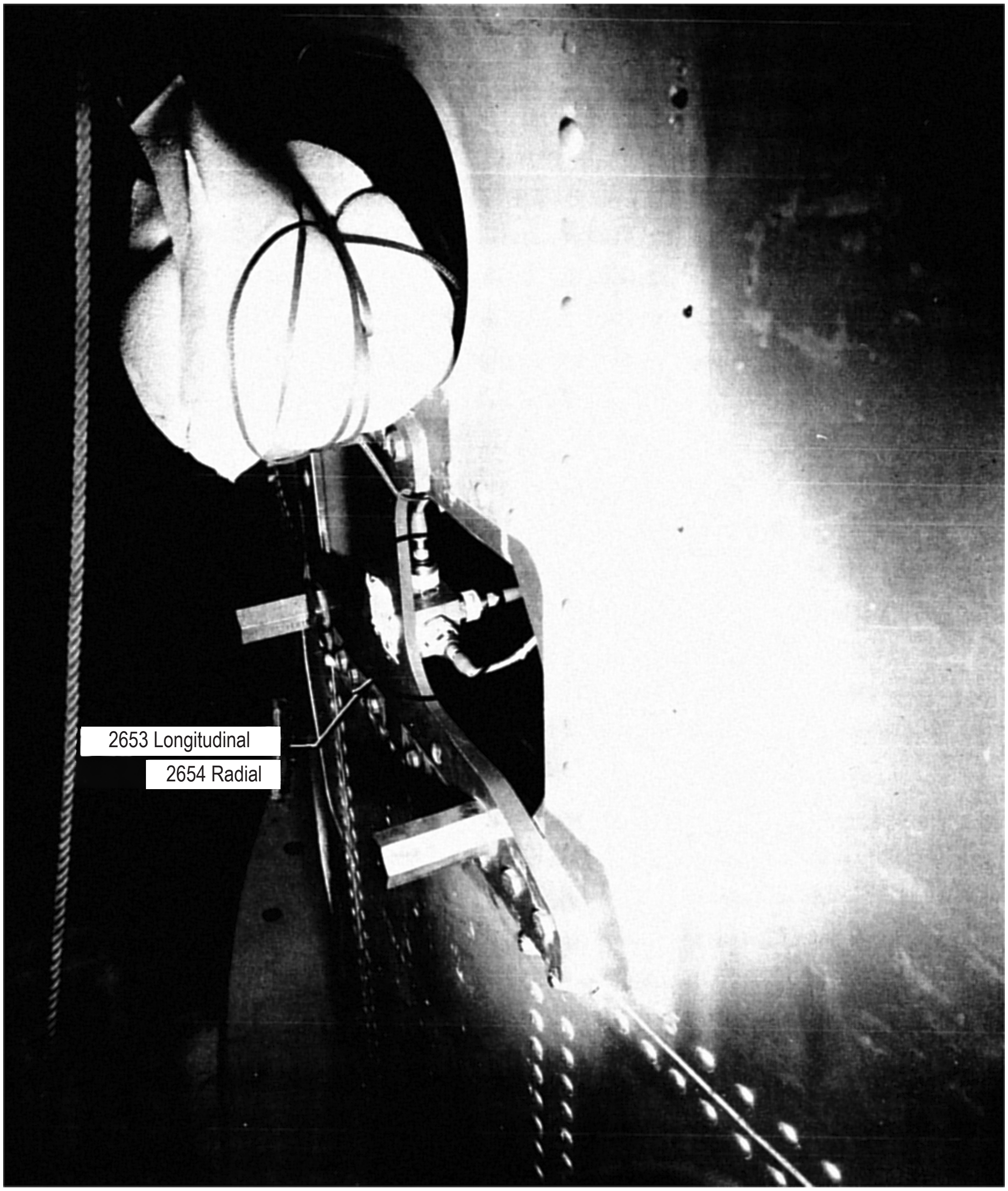

Figure 118. Vibration measurements 2562 and 2563, compartment 3A, at mounting point of attitude control nozzles, station 130.

Document/Page No.: MCR75440/A192
Flight Condition: Mach 1/Max Q
Vehicle Diameter: 10 ft
Ring Sep.: 37 in
Stringer Sep.: 14.2 in
Surface Wt.: 2.28 lb/ft^2
Measurements: 2727

Meas. Direction: Longitudinal
Material: 7178 AL
Skin Thickness: 0.028 in
Ring Wt.: 1.48 lb/ft
Stringer Wt.: 2.38 lb/ft
Composite: 10.06 g_{rms}
Compartment: 3A, 3B

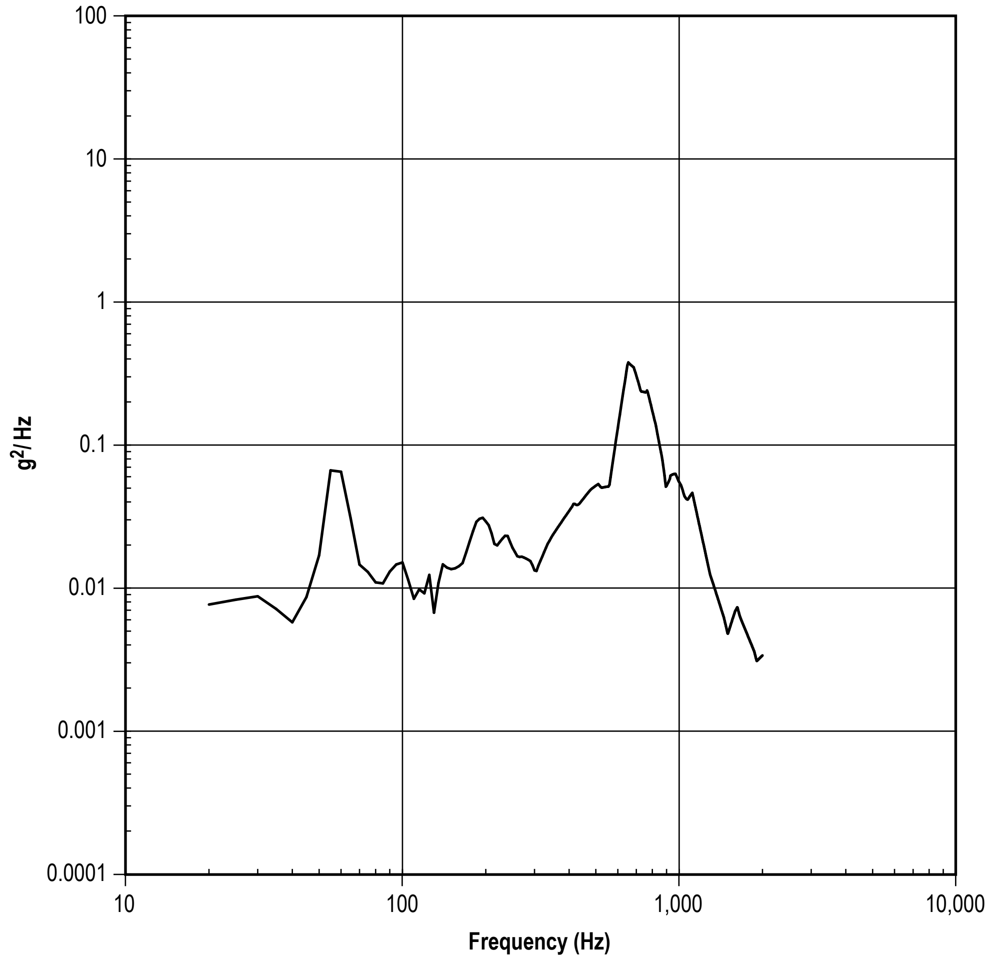

Figure 119. P/L truss vibration PSD, longitudinal, Mach 1/Max Q, 2.28 lb/ft^2.

Document/Page No.: MCR75440/A193	Meas. Direction: Radial
Flight Condition: Mach 1/Max Q	Material: 7178 AL
Vehicle Diameter: 10 ft	Skin Thickness: 0.028 in
Ring Sep.: 37 in	Ring Wt.: 1.48 lb/ft
Stringer Sep.: 14.2 in	Stringer Wt.: 2.38 lb/ft
Surface Wt.: 2.28 lb/ft^2	Composite: 9.44 g_{rms}
Measurements: 2728	Compartment: 3A, 3B

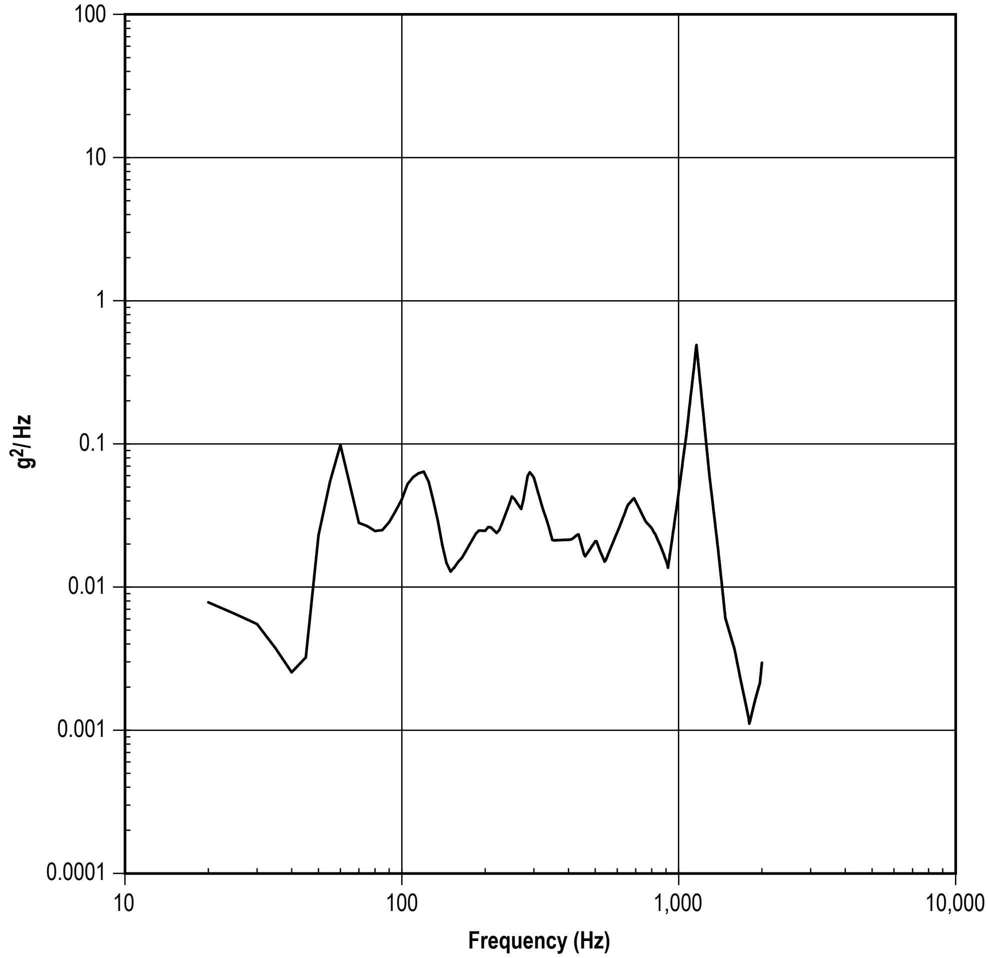

Figure 120. P/L truss vibration PSD, radial, Mach 1/Max Q, 2.28 lb/ft^2.

Document/Page No.: MCR75440/A182	Meas. Direction: Longitudinal
Flight Condition: Liftoff	Material: 7075 AL
Vehicle Diameter: 10 ft	Skin Thickness: 0.028 in
Ring Sep.: 37 in	Ring Wt.: 1.48 lb/ft
Stringer Sep.: 16.3 in	Stringer Wt.: 0.24 lb/ft
Surface Wt.: 2.49 lb/ft^2	Composite: 11.94 g_{rms}
Measurements: 2718, 2721	Compartment: 3A, 3B

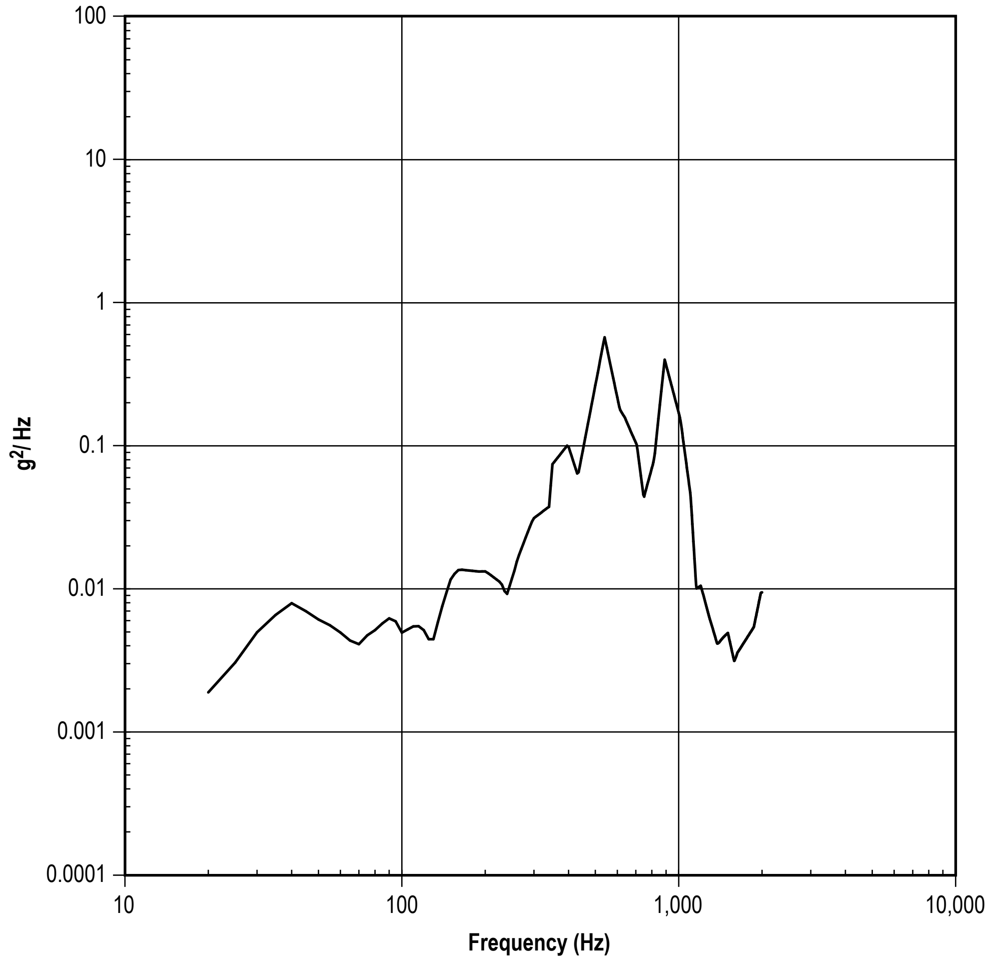

Figure 121. Ring frame vibration PSD, longitudinal, liftoff, 2.49 lb/ft^2.

Document/Page No.: MCR75440/A190
Flight Condition: Mach 1
Vehicle Diameter: 10 ft
Ring Sep.: 37 in
Stringer Sep.: 16.3 in
Surface Wt.: 2.49 lb/ft^2
Measurements: 2718, 2721

Meas. Direction: Longitudinal
Material: 7075 AL
Skin Thickness: 0.028 in
Ring Wt.: 1.48 lb/ft
Stringer Wt.: 0.24 lb/ft
Composite: 2.23 g_{rms}
Compartment: 3A, 3B

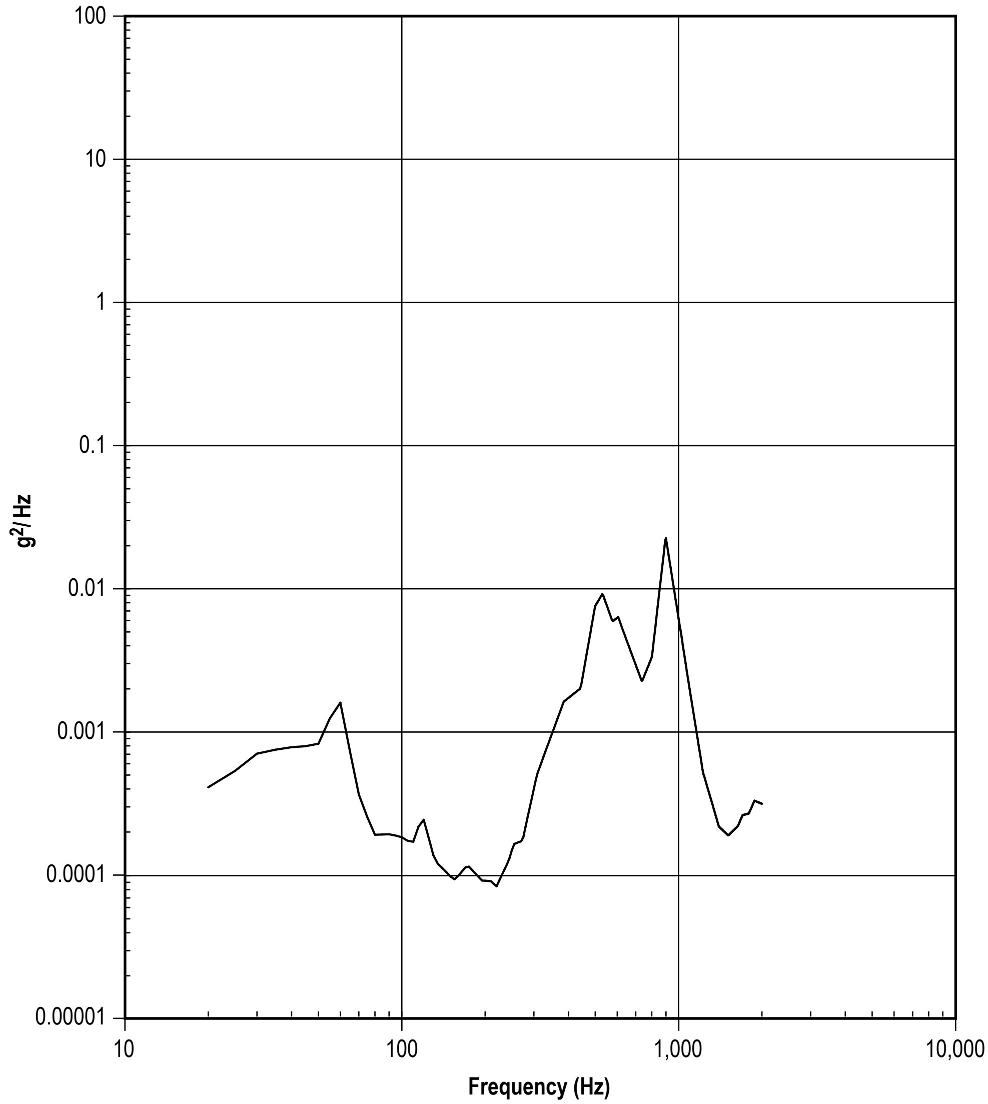

Figure 122. Ring frame vibration PSD, longitudinal, Mach 1, 2.49 lb/ft^2.

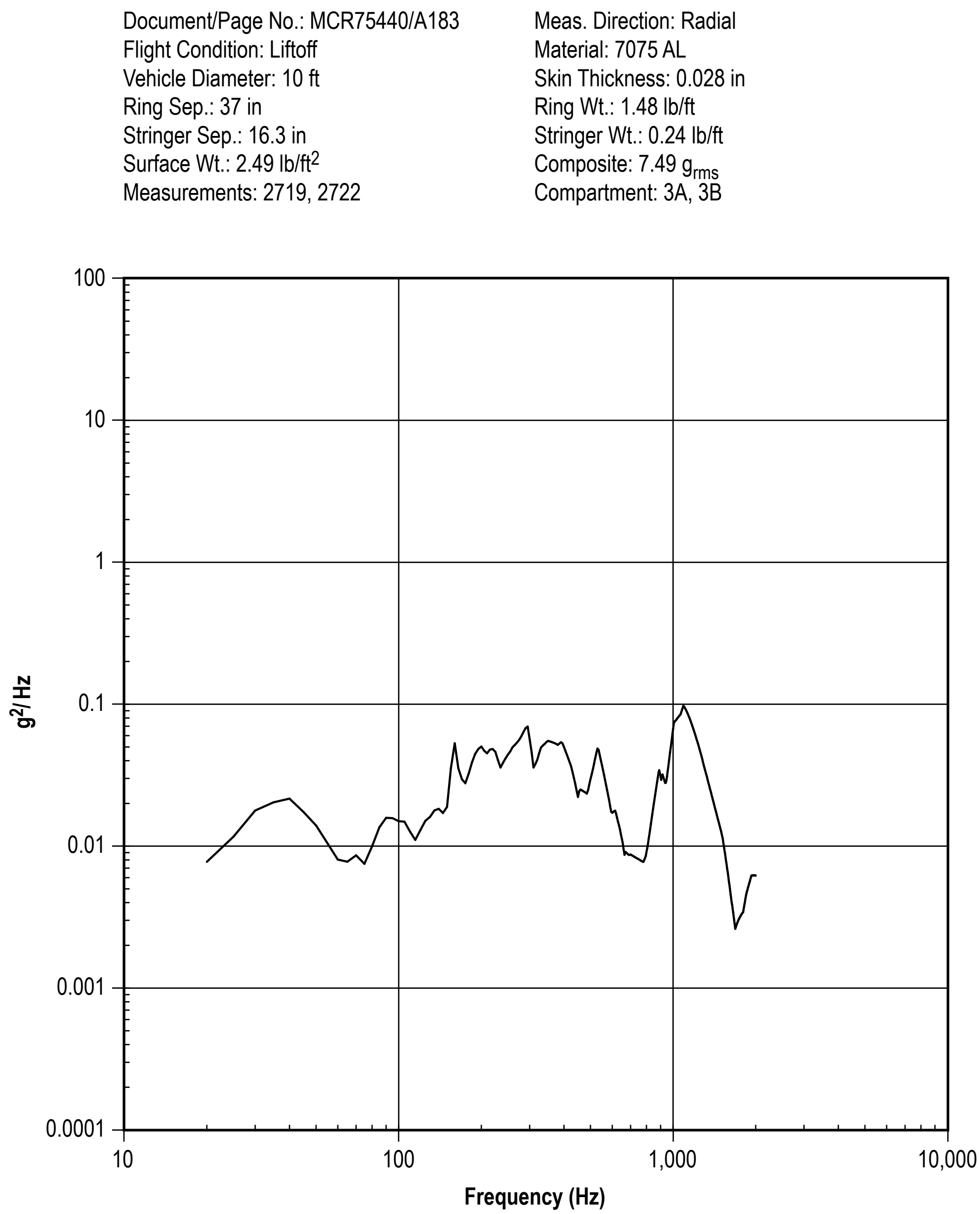

Figure 123. Ring frame vibration PSD, radial, liftoff, 2.49 lb/ft^2.

Document/Page No.: MCR75440/A191
Flight Condition: Mach 1
Vehicle Diameter: 10 ft
Ring Sep.: 37 in
Stringer Sep.: 16.3 in
Surface Wt.: 2.49 lb/ft^2
Measurements: 2719, 2722

Meas. Direction: Radial
Material: 7075 AL
Skin Thickness: 0.028 in
Ring Wt.: 1.48 lb/ft
Stringer Wt.: 0.24 lb/ft
Composite: 2.25 g_{rms}
Compartment: 3A, 3B

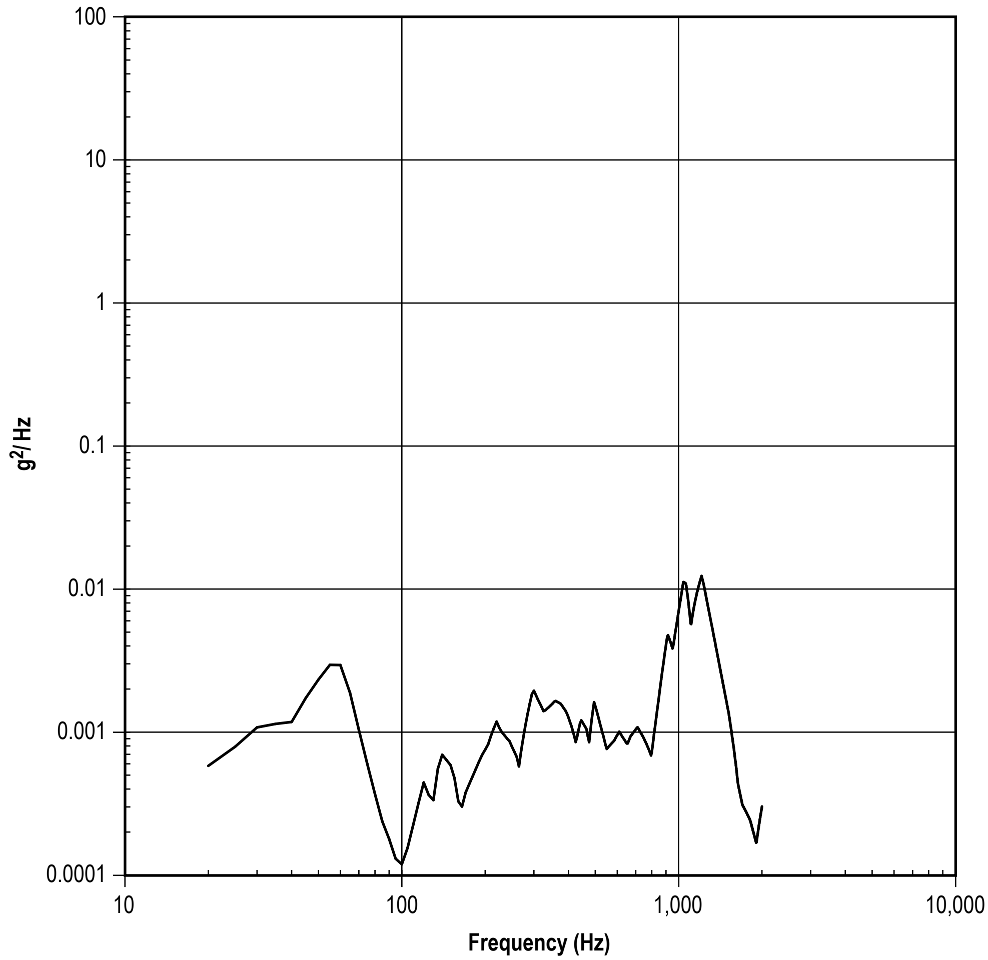

Figure 124. Ring frame vibration PSD, radial, Mach 1, 2.49 lb/ft^2.

Document/Page No.: MCR75440/A142
Flight Condition: Liftoff
Vehicle Diameter: 10 ft
Ring Sep.: 19.6 in
Stringer Sep.: 11 in
Surface Wt.: 2.49 lb/ft^2
Measurements: 2551, 2653, 2702

Meas. Direction: Longitudinal
Material: 2014 AL
Skin Thickness: 0.028 in
Ring Wt.: 0.84 lb/ft
Stringer Wt.: 0.38 lb/ft
Composite: 8.50 g_{rms}
Compartment: 3A, 3B

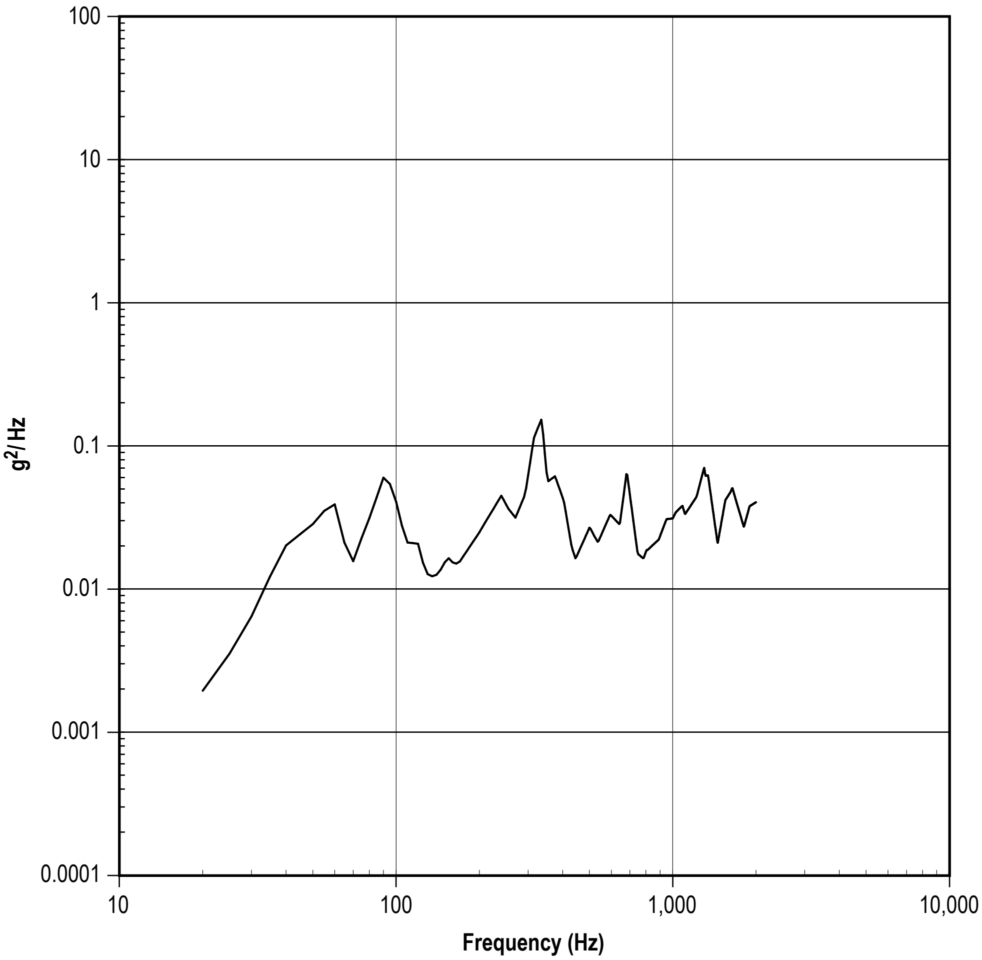

Figure 125. Skin-stringer vibration PSD, longitudinal, liftoff, 2.49 lb/ft^2.

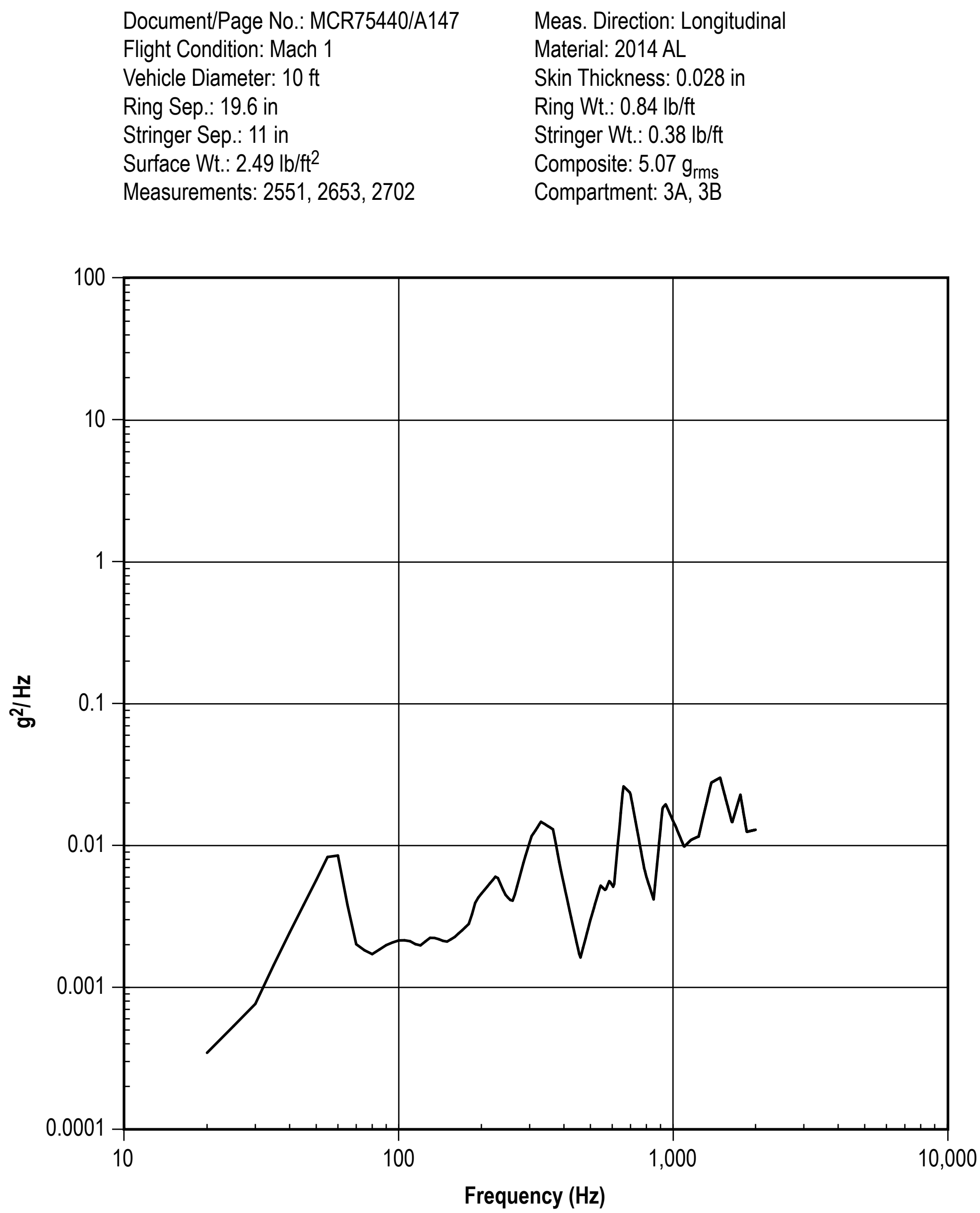

Figure 126. Skin-stringer vibration PSD, longitudinal, Mach 1, 2.49 lb/ft^2.

Document/Page No.: MCR75440/A180
Flight Condition: Liftoff
Vehicle Diameter: 10 ft
Ring Sep.: 19.6 in
Stringer Sep.: 13 in
Surface Wt.: 2.49 lb/ft^2
Measurements: 2552, 2703, 2654

Meas. Direction: Radial
Material: 2014 AL
Skin Thickness: 0.028 in
Ring Wt.: 0.84 lb/ft
Stringer Wt.: 0.376 lb/ft
Composite: 15.41 g_{rms}
Compartment: 3A, 3B

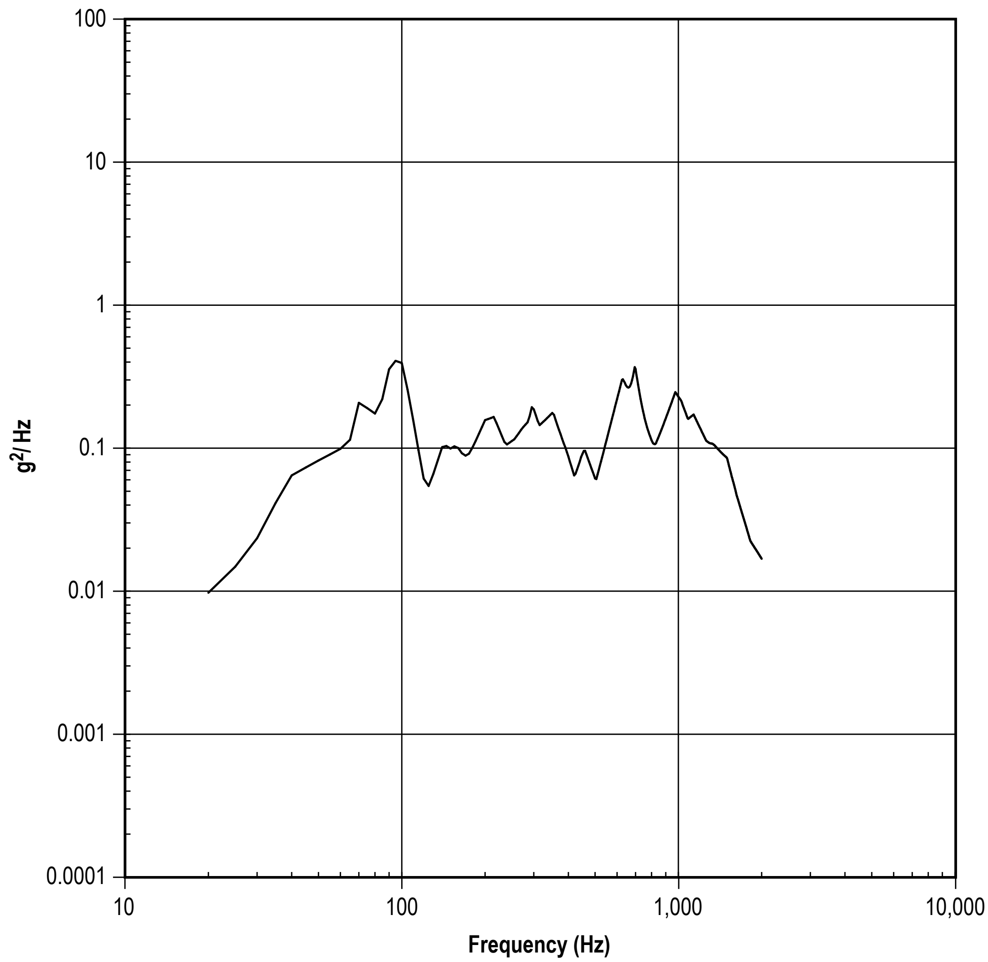

Figure 127. Skin-stringer vibration PSD, radial, liftoff, 2.49 lb/ft^2.

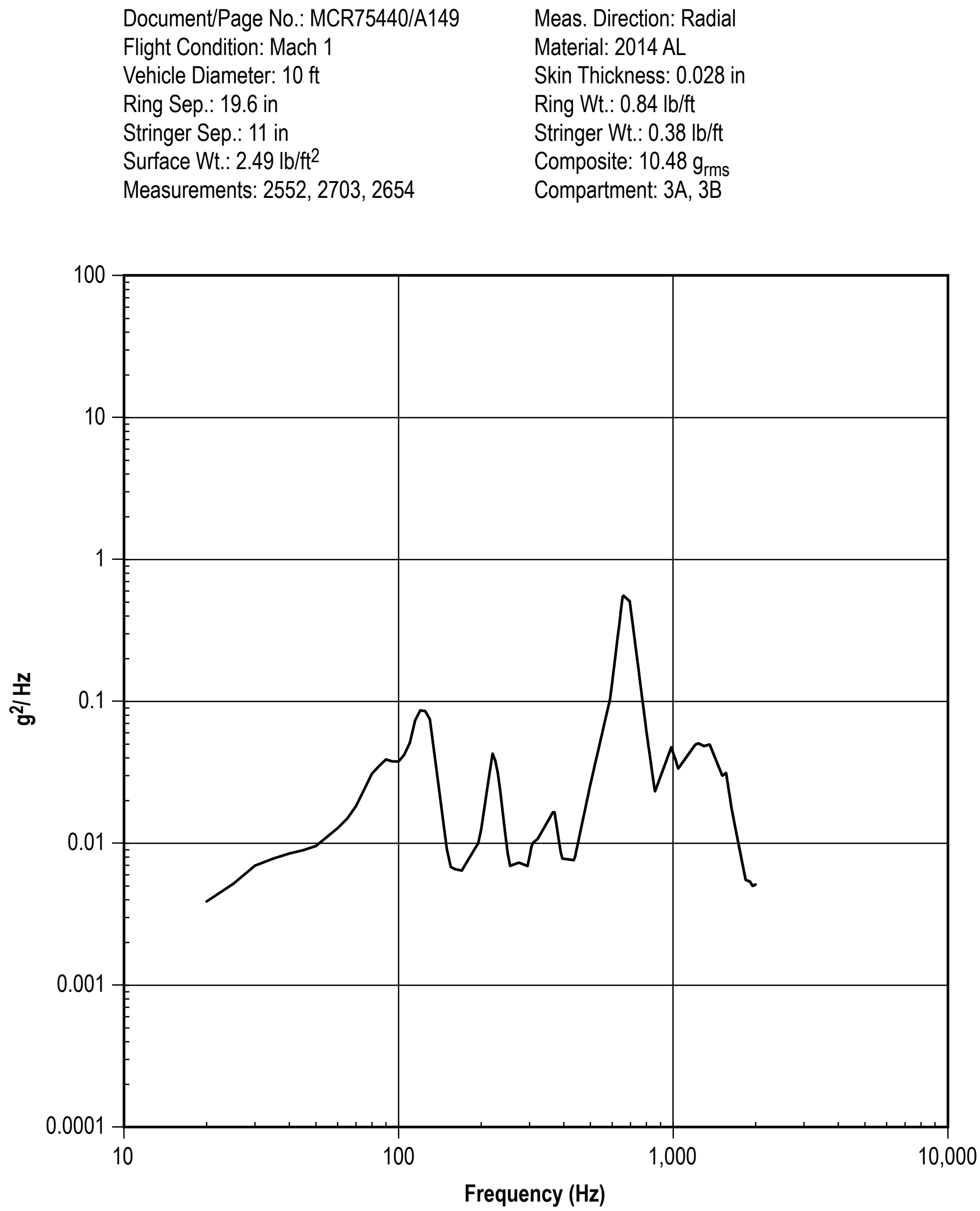

Figure 128. Skin-stringer vibration PSD, radial, Mach 1, 2.49 lb/ft^2.

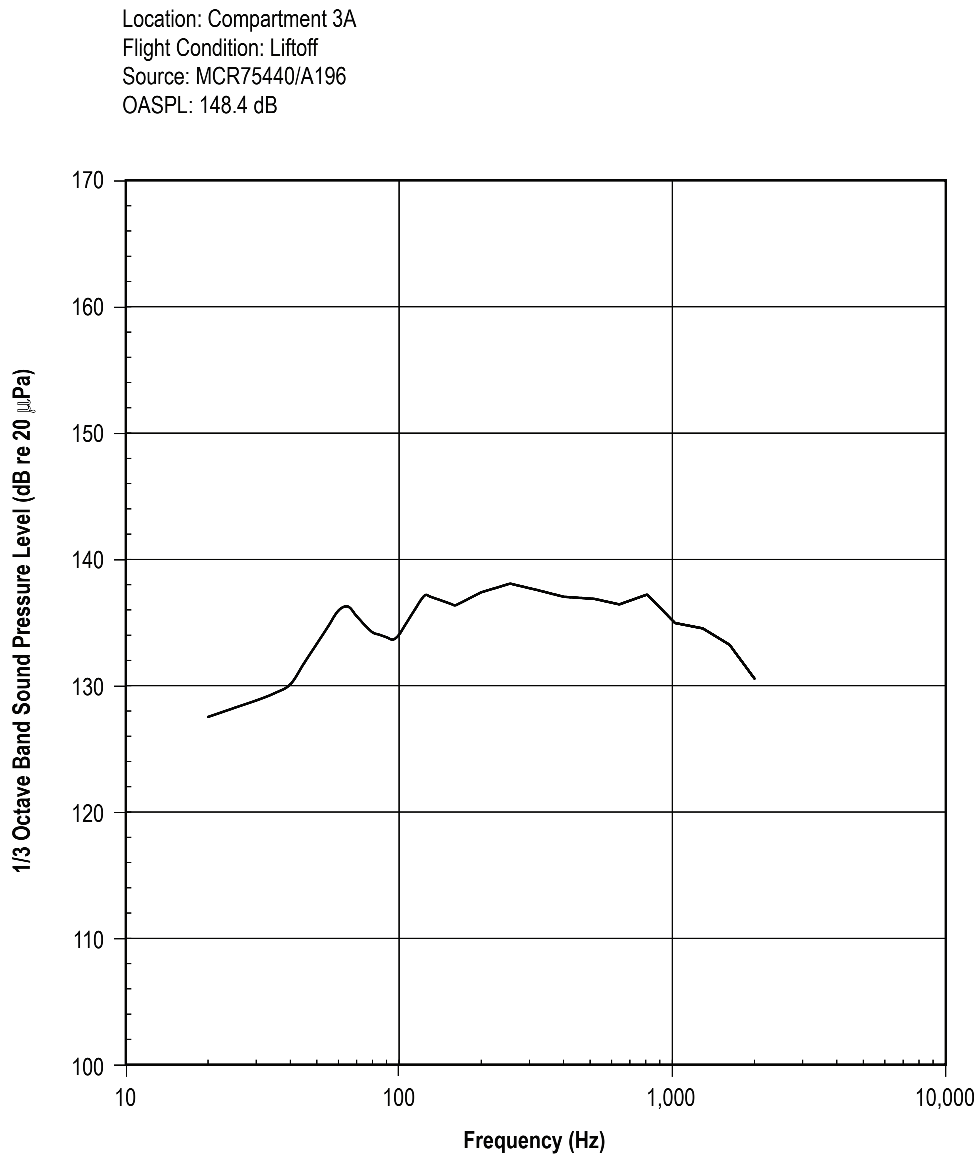

Figure 129. Titan III acoustic spectrum, compartment 3A, liftoff.

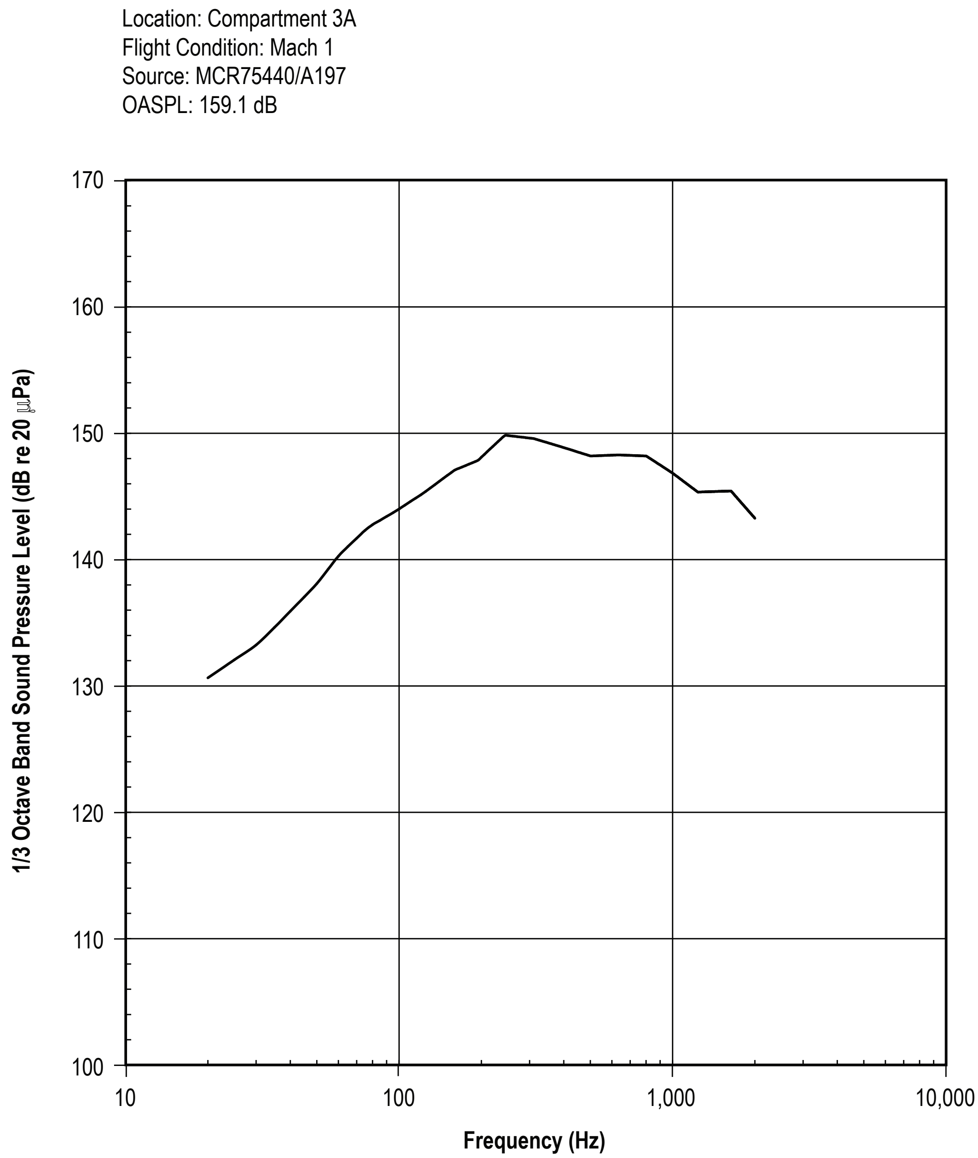

Figure 130. Titan III acoustic spectrum, compartment 3A, Mach 1.

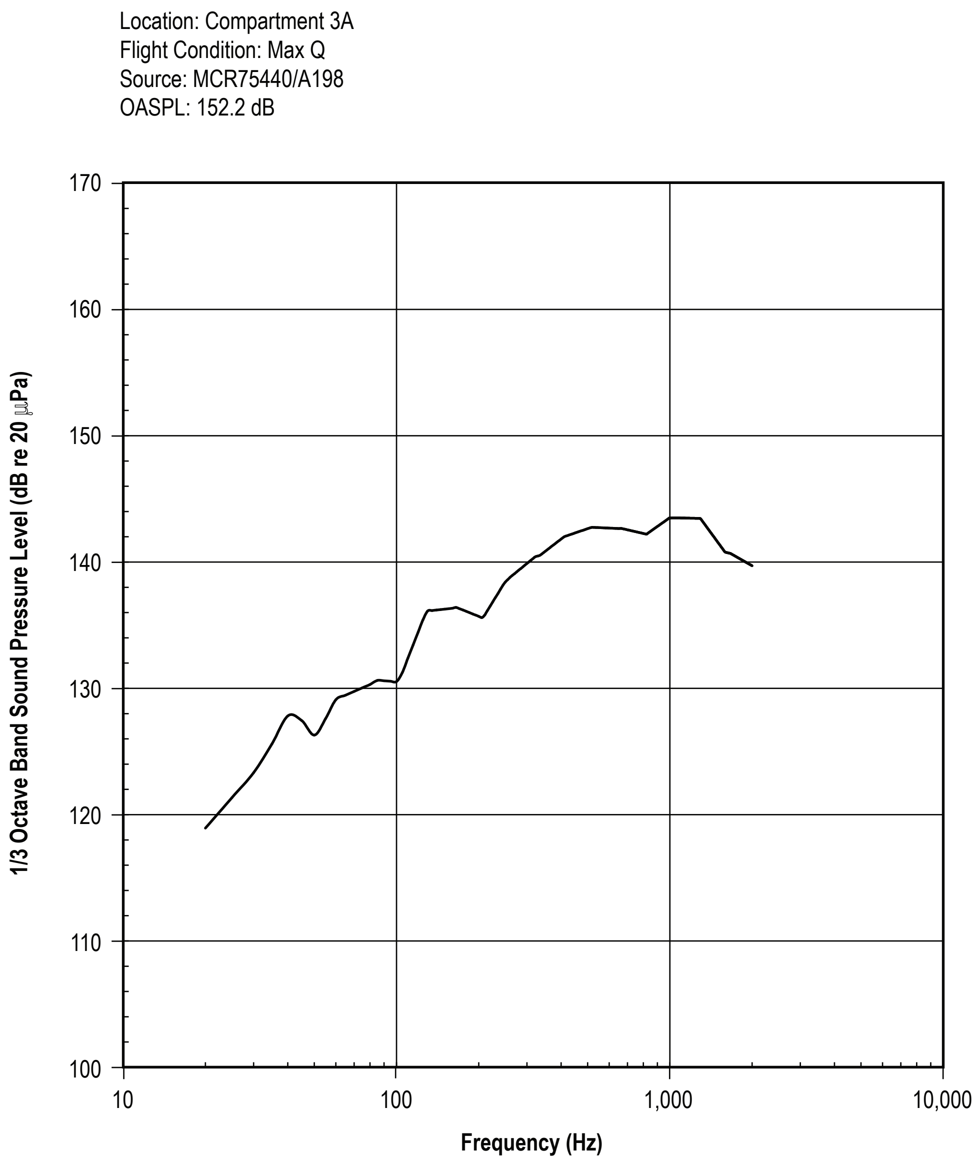

Figure 131. Titan III acoustic spectrum, compartment 3A, Max Q.

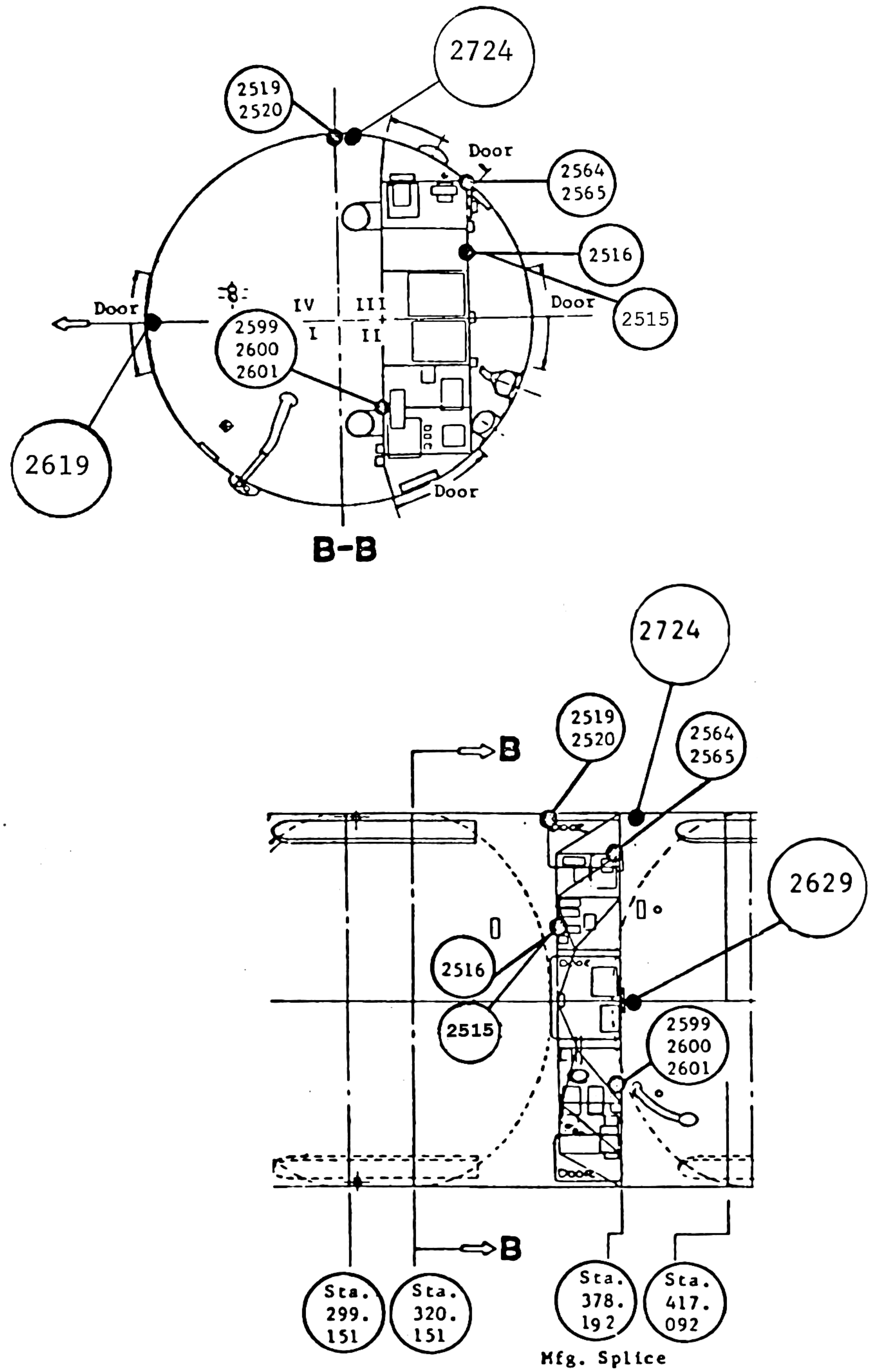

Figure 132. Compartment 2B measurement locations.

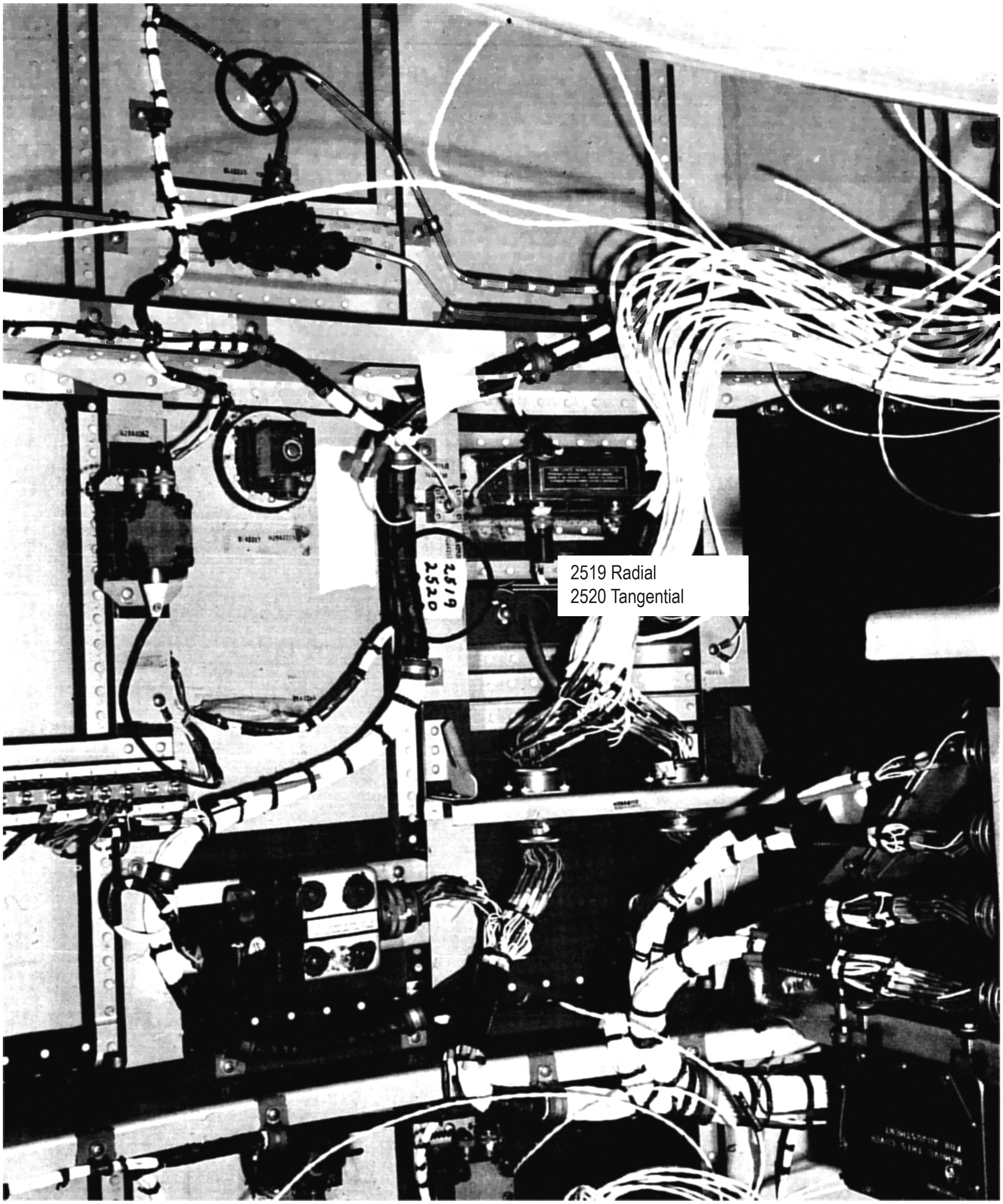

Figure 133. Vibration measurements 2519 and 2520, compartment 2B, station 360.

Document/Page No.: MCR75440/A127
Flight Condition: Liftoff
Vehicle Diameter: 10 ft
Ring Sep.: 22 in
Stringer Sep.: 10.5 in
Surface Wt.: 2.7 lb/ft^2
Measurements: 2519

Meas. Direction: Radial
Material: 7075 AL
Skin Thickness: 0.040 in
Ring Wt.: 0.32–.77 lb/ft
Stringer Wt.: 0.85 lb/ft
Composite: 15.76 g_{rms}
Compartment: 2B

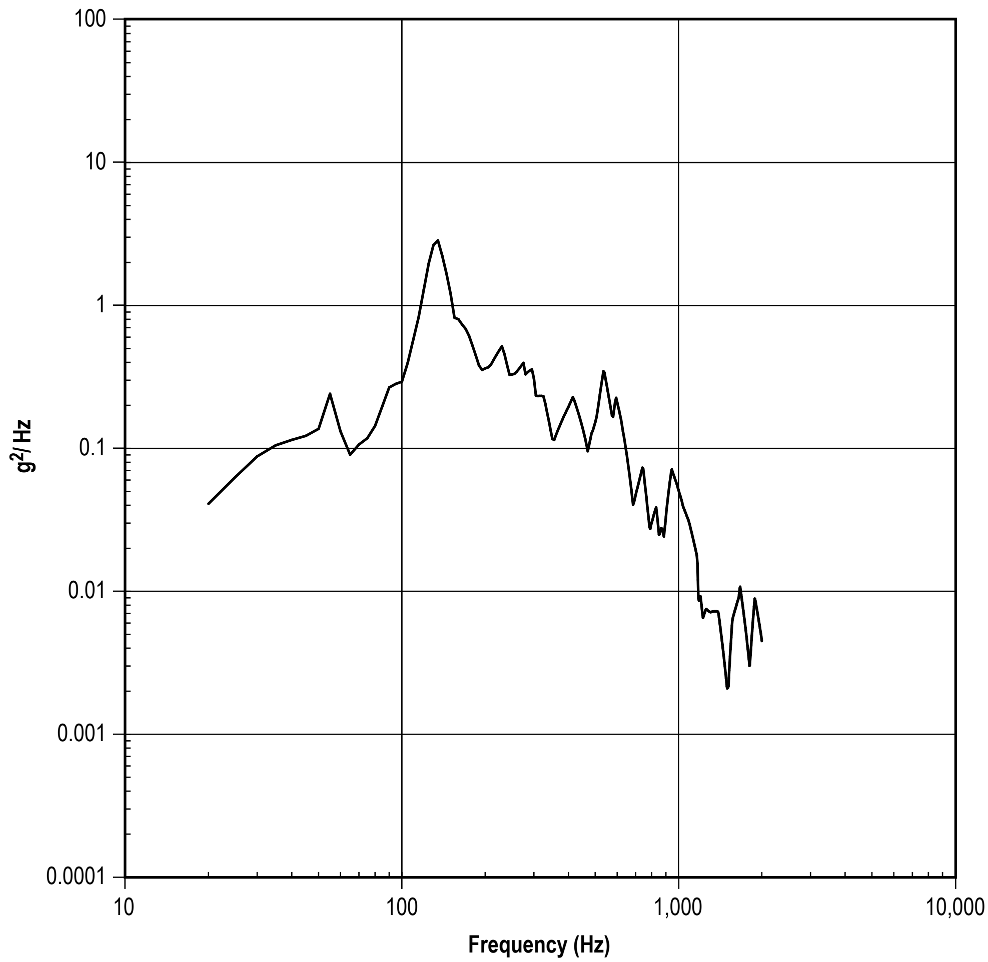

Figure 134. Skin-stringer vibration PSD, radial, liftoff, 2.7 lb/ft^2.

Document/Page No.: MCR75440/A128	Meas. Direction: Tangential
Flight Condition: Liftoff	Material: 7075 AL
Vehicle Diameter: 10 ft	Skin Thickness: 0.040 in
Ring Sep.: 22 in	Ring Wt.: 0.32–.77 lb/ft
Stringer Sep.: 10.5 in	Stringer Wt.: 0.85 lb/ft
Surface Wt.: 2.7 lb/ft^2	Composite: 18.07 g_{rms}
Measurements: 2520	Compartment: 2B

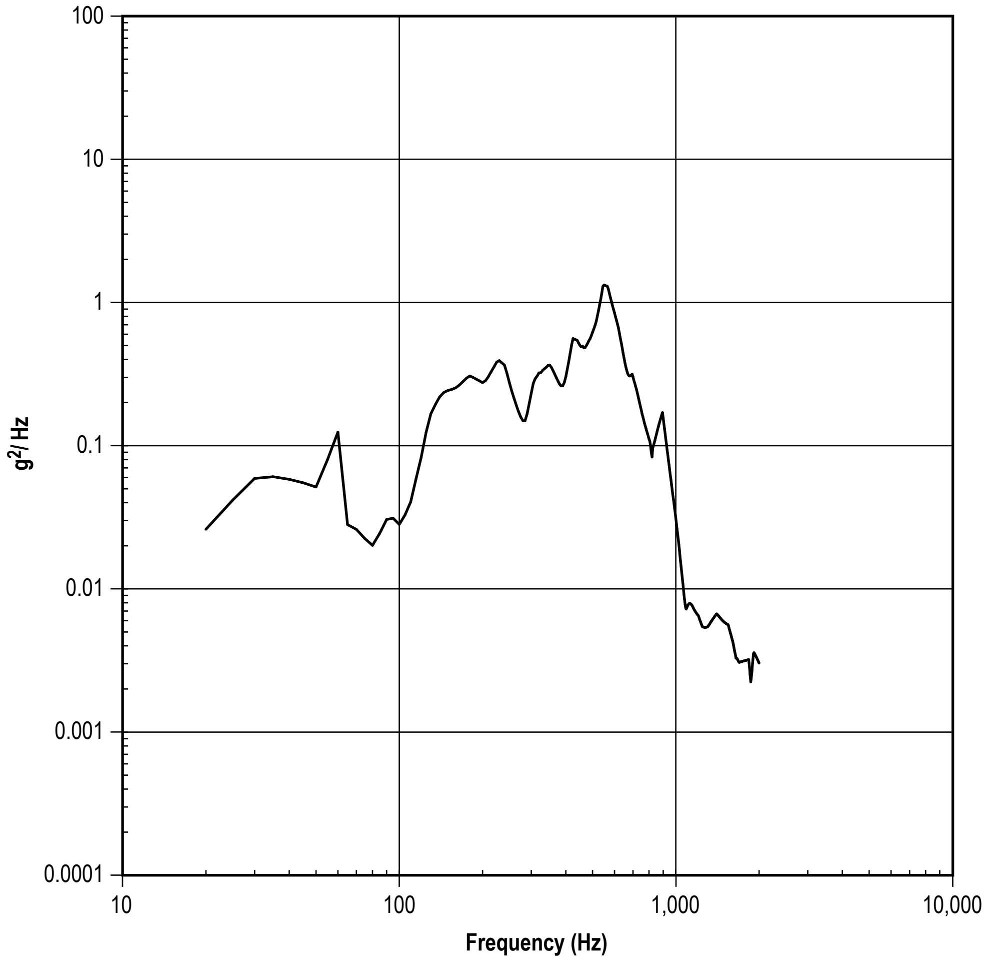

Figure 135. Skin-stringer vibration PSD, tangential, liftoff, 2.7 lb/ft^2.

Document/Page No.: MCR75440/A129
Flight Condition: Mach 1
Vehicle Diameter: 10 ft
Ring Sep.: 22 in
Stringer Sep.: 10.5 in
Surface Wt.: 2.7 lb/ft^2
Measurements: 2520

Meas. Direction: Tangential
Material: 7075 AL
Skin Thickness: 0.040 in
Ring Wt.: 0.32–.77 lb/ft
Stringer Wt.: 0.85 lb/ft
Composite: 7.78 g_{rms}
Compartment: 2B

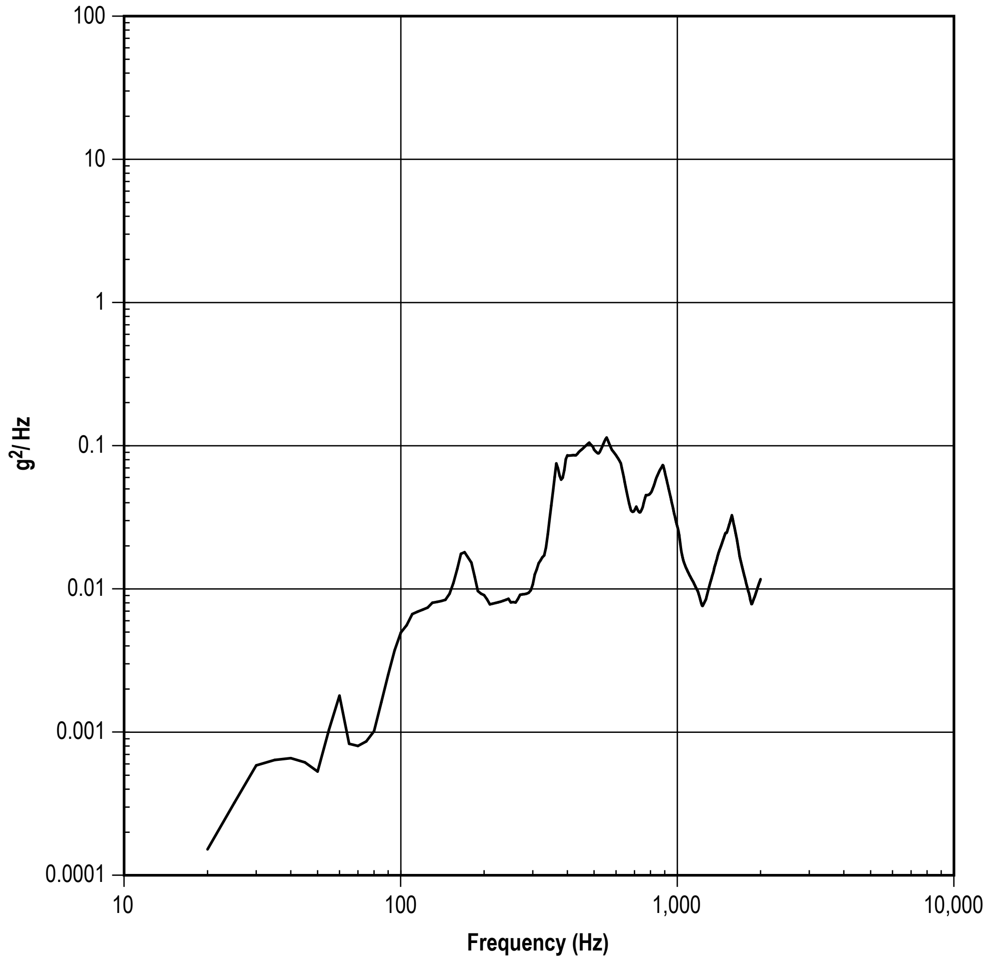

Figure 136. Skin-stringer vibration PSD, tangential, Mach 1, 2.7 lb/ft^2.

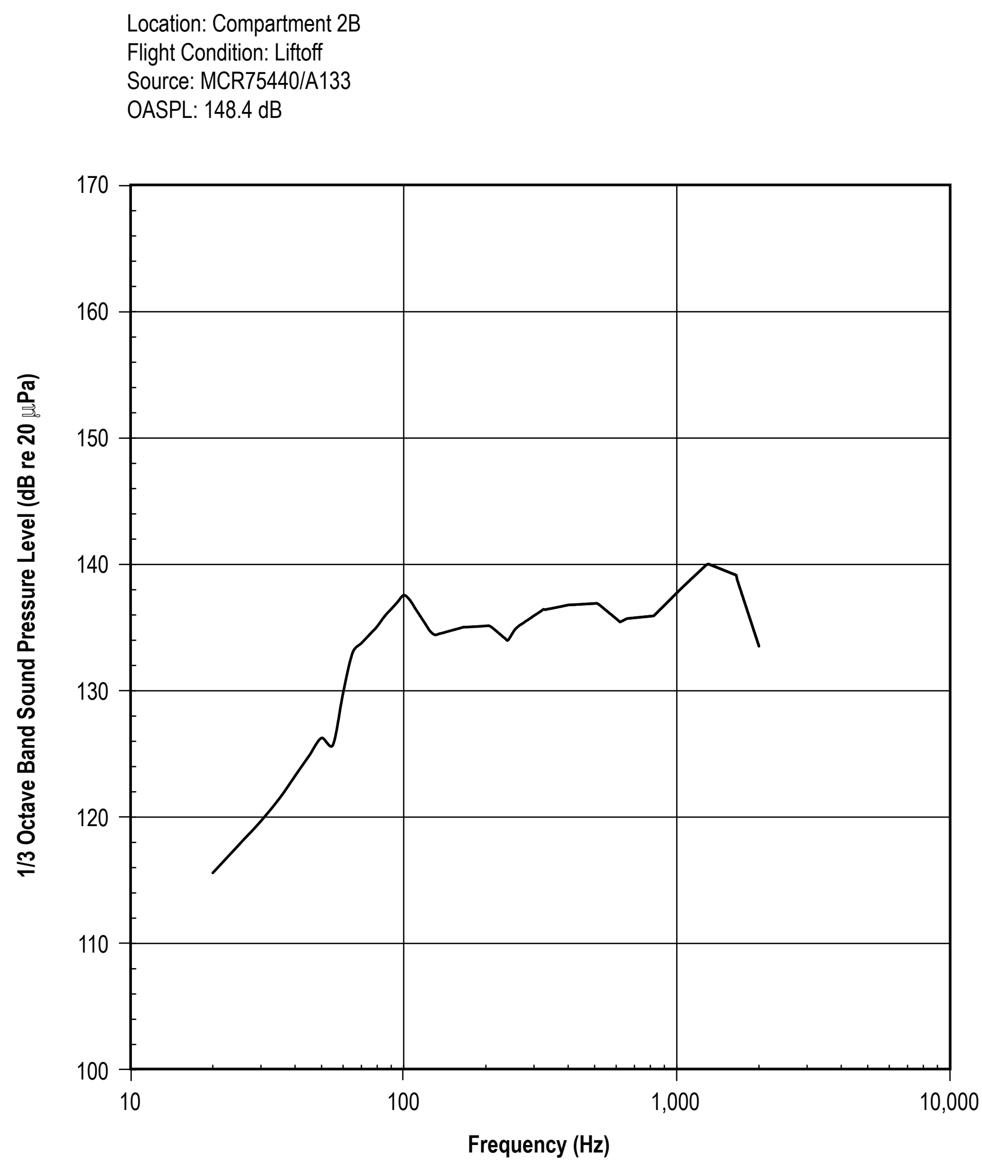

Figure 137. Titan III acoustic spectrum, compartment 2B, liftoff.

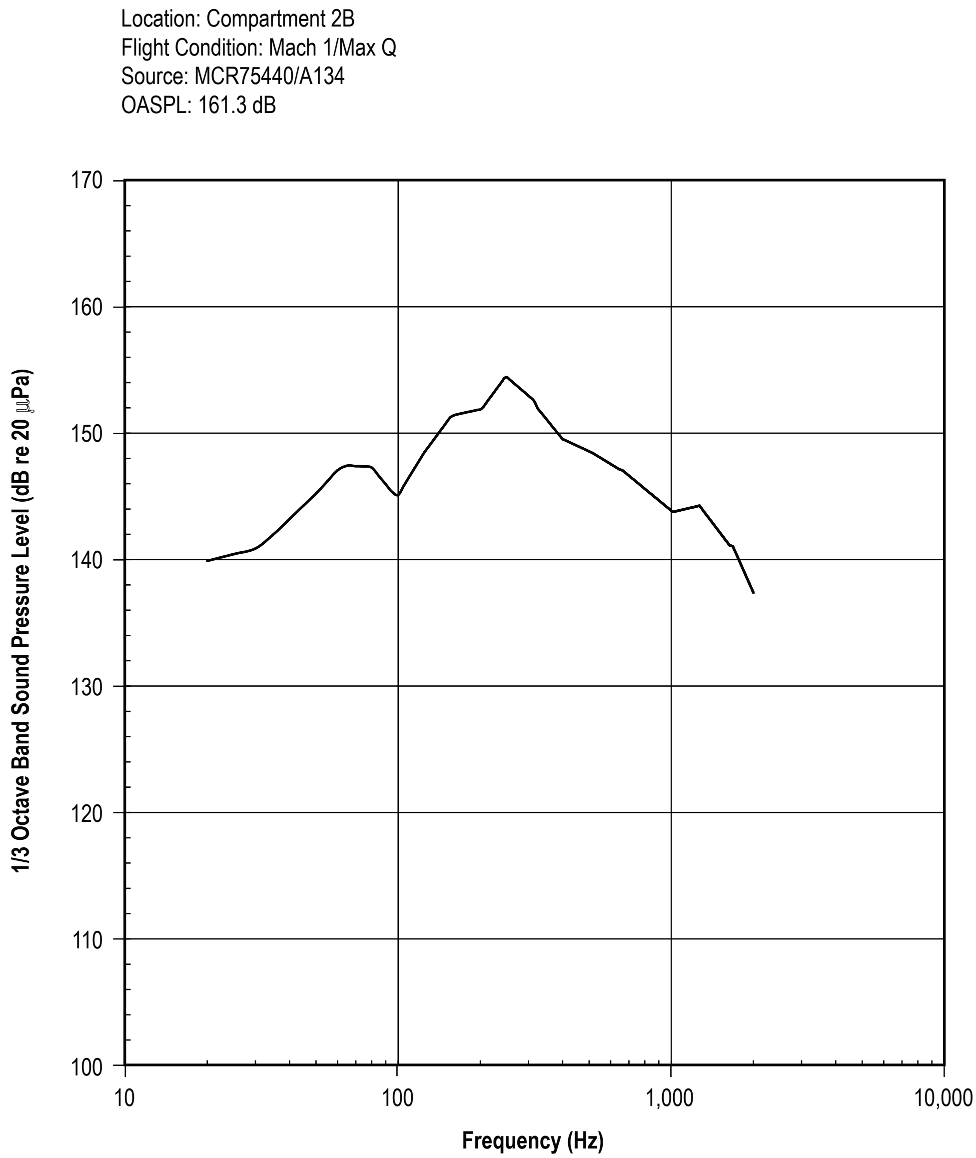

Figure 138. Titan III acoustic spectrum, compartment 2B, Mach 1/Max Q.

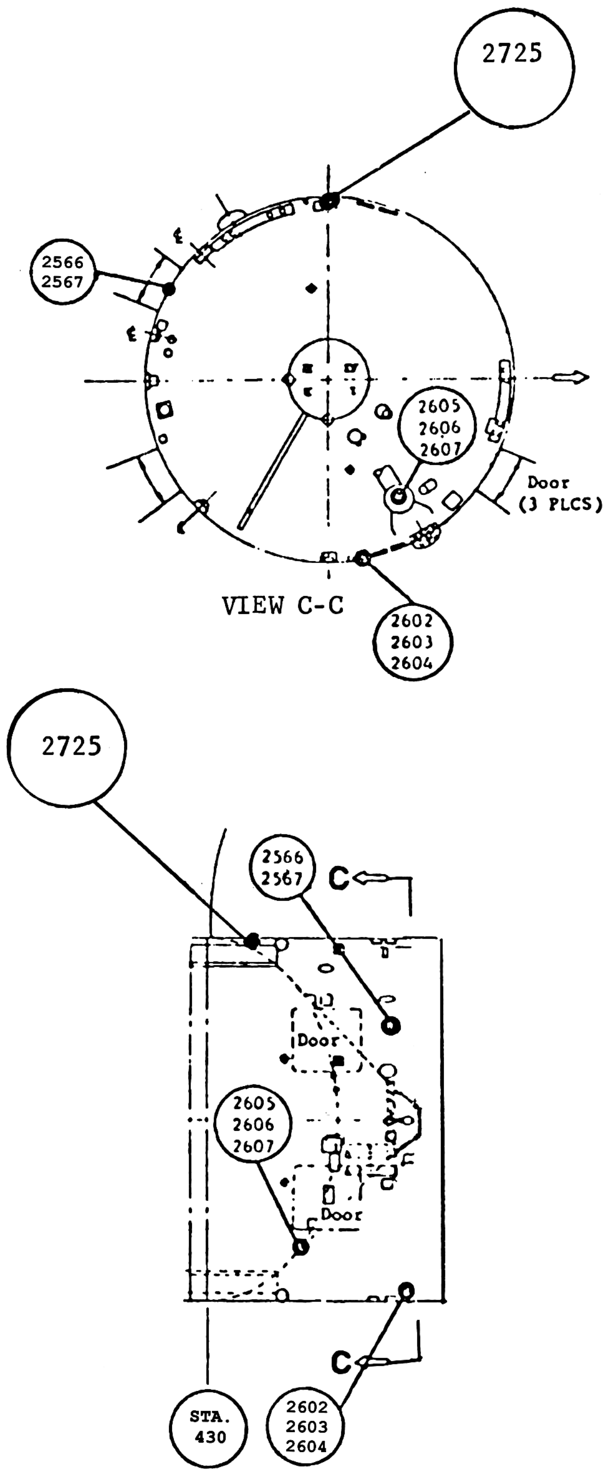

Figure 139. Compartment 2C measurement locations.

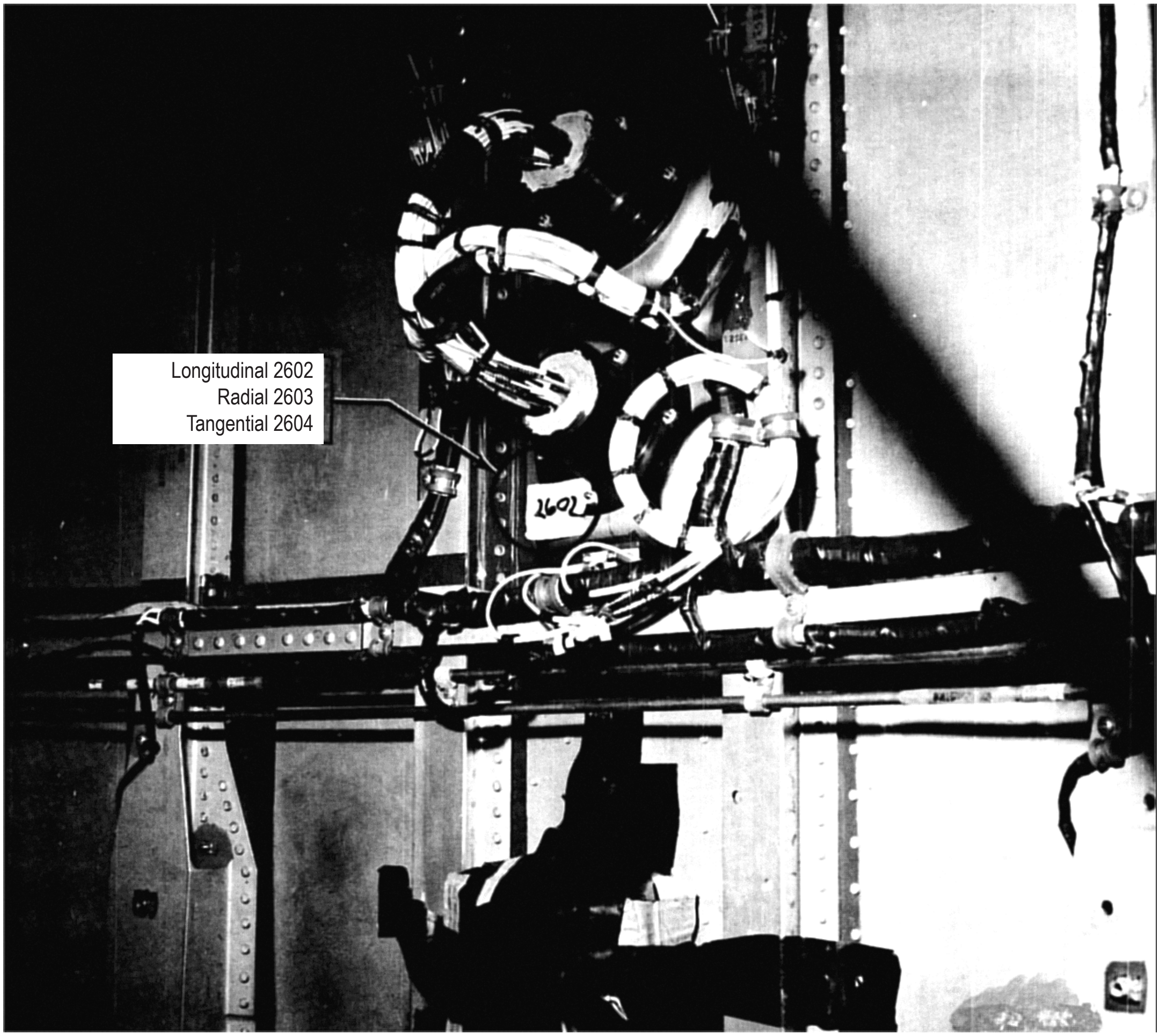

Figure 140. Vibration measurements 2602, 2603, and 2604, compartment 2C, station 473.

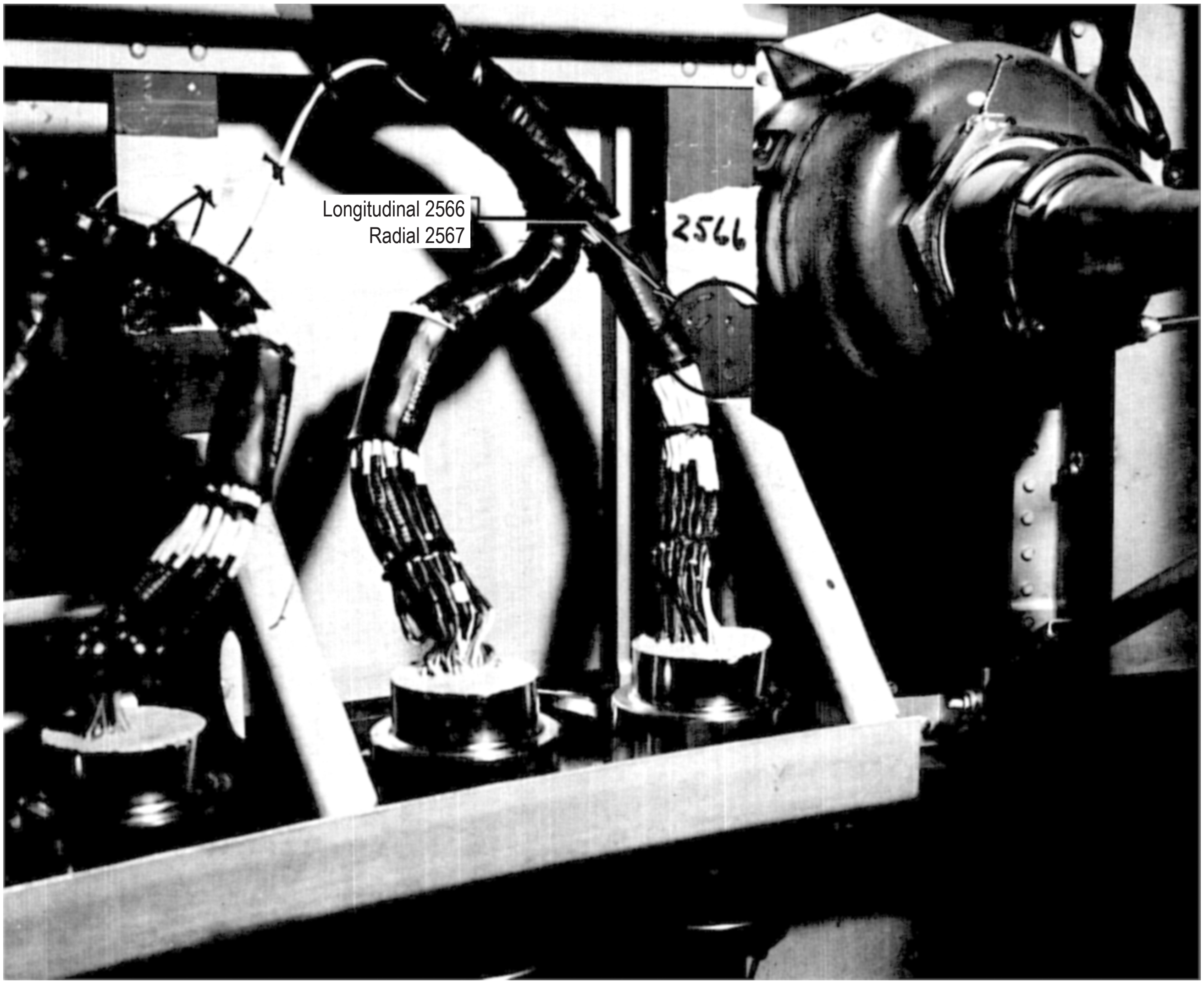

Figure 141. Vibration measurements 2566 and 2567, compartment 2C, station 493.

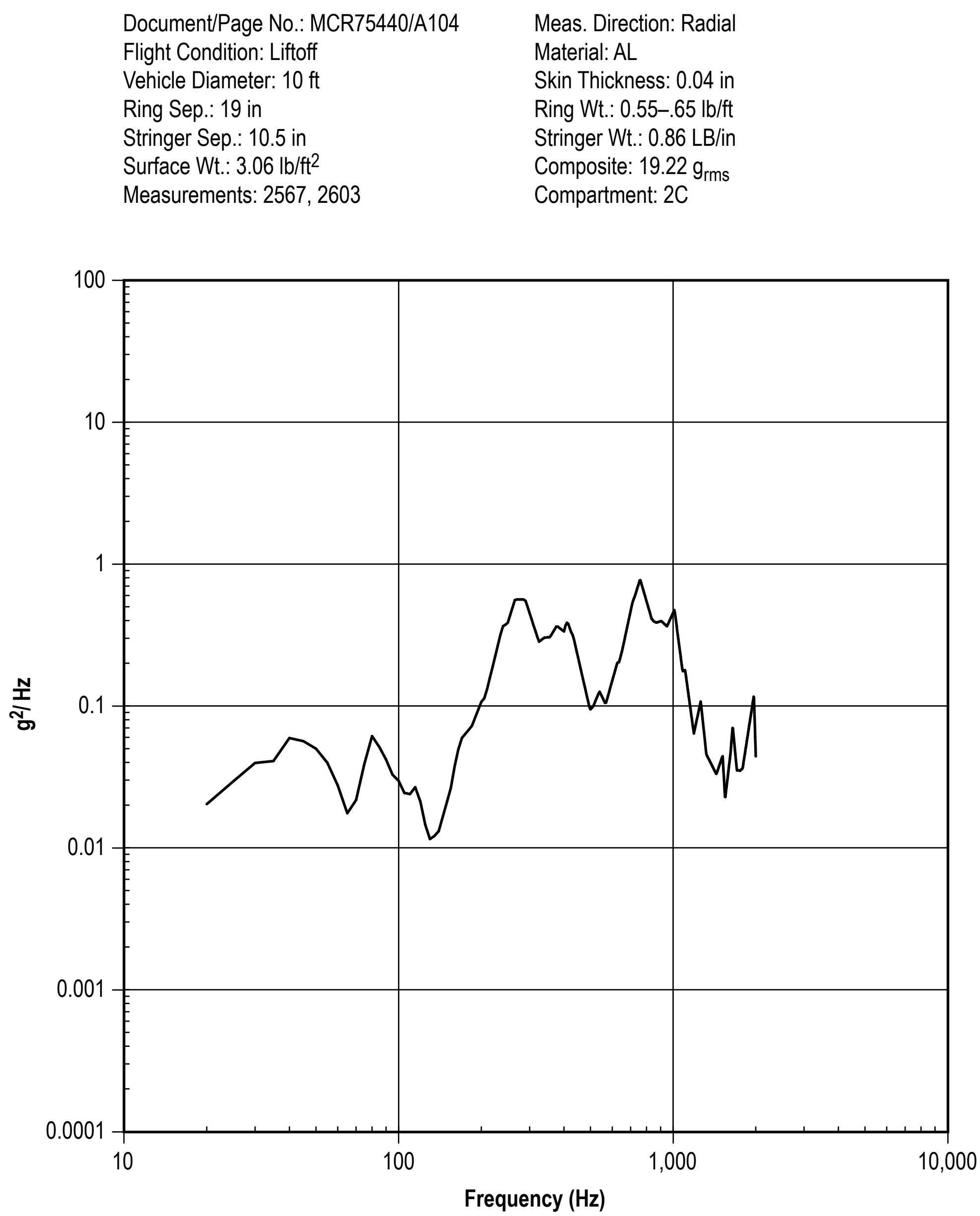

Figure 142. Skin-stringer vibration PSD, radial, liftoff, 3.06 lb/ft^2.

Document/Page No.: MCR75440/A106	Meas. Direction: Radial
Flight Condition: Mach1/Max Q	Material: AL
Vehicle Diameter: 10 ft	Skin Thickness: 0.04 in
Ring Sep.: 19 in	Ring Wt.: 0.55–.65 lb/ft
Stringer Sep.: 10.5 in	Stringer Wt.: 0.86 lb/ft
Surface Wt.: 3.06 lb/ft^2	Composite: 9.12 g_{rms}
Measurements: 2567, 2603	Compartment: 2C

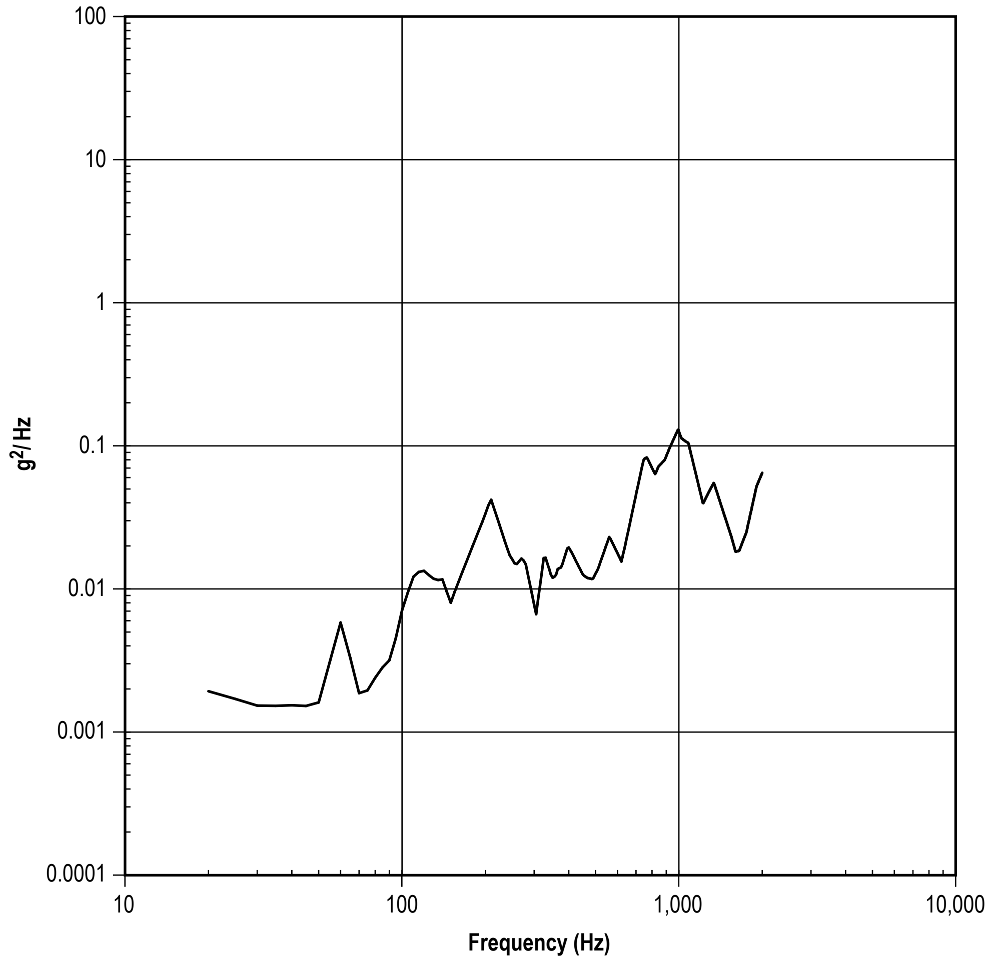

Figure 143. Skin-stringer vibration PSD, radial, Mach 1, Max Q, 3.06 lb/ft^2.

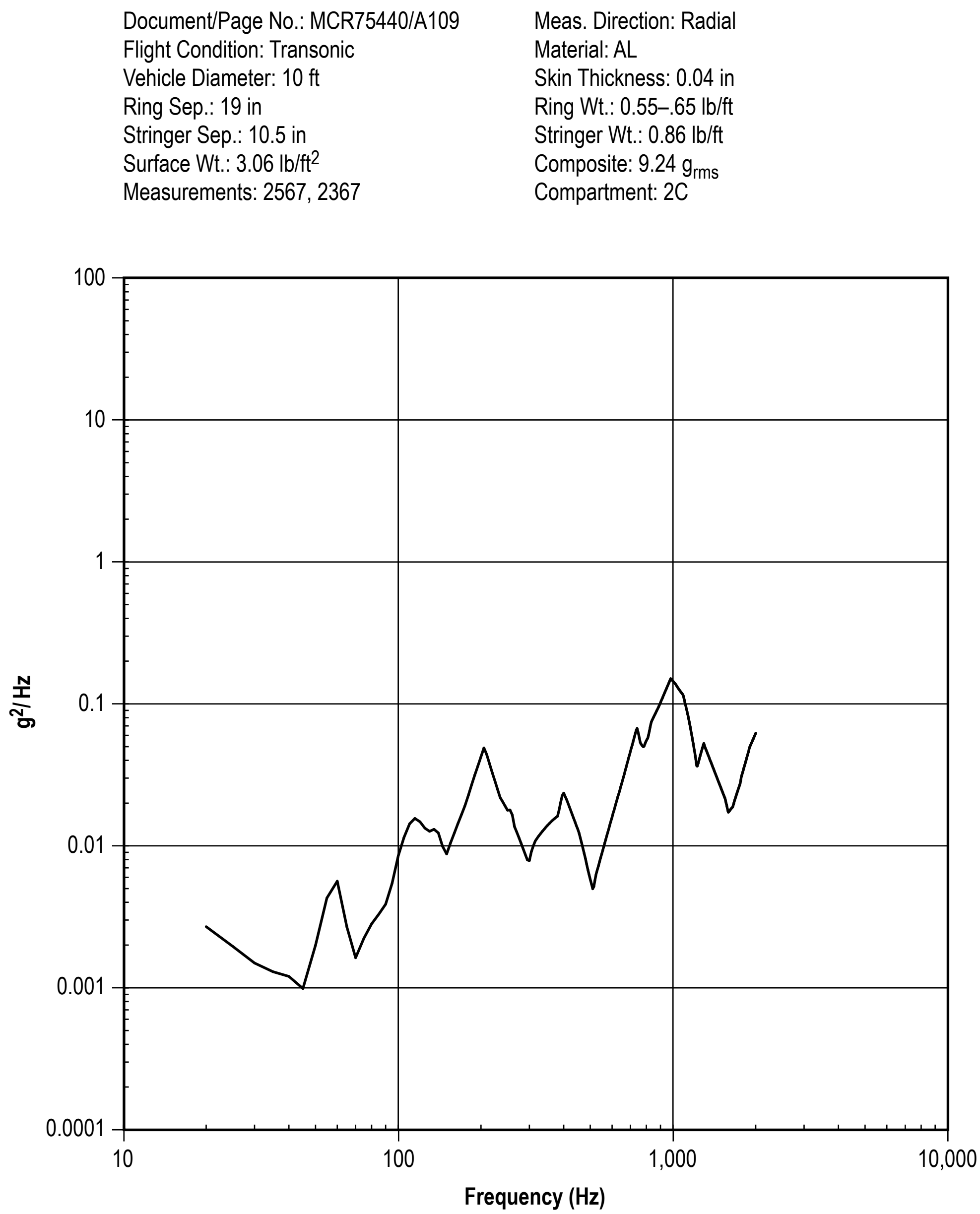

Figure 144. Skin-stringer vibration PSD, radial, transonic, 3.06 lb/ft^2.

Document/Page No.: MCR75440/A107
Flight Condition: Liftoff
Vehicle Diameter: 10 ft
Ring Sep.: 19 in
Stringer Sep.: 10.5 in
Surface Wt.: 3.06 lb/ft
Measurements: 2566, 2602

Meas. Direction: Longitudinal
Material: AL
Skin Thickness: 0.04 in
Ring Wt.: 0.55–.65 lb/ft
Stringer Wt.: 0.86 lb/ft
Composite: 6.23 g_{rms}
Compartment: 2C

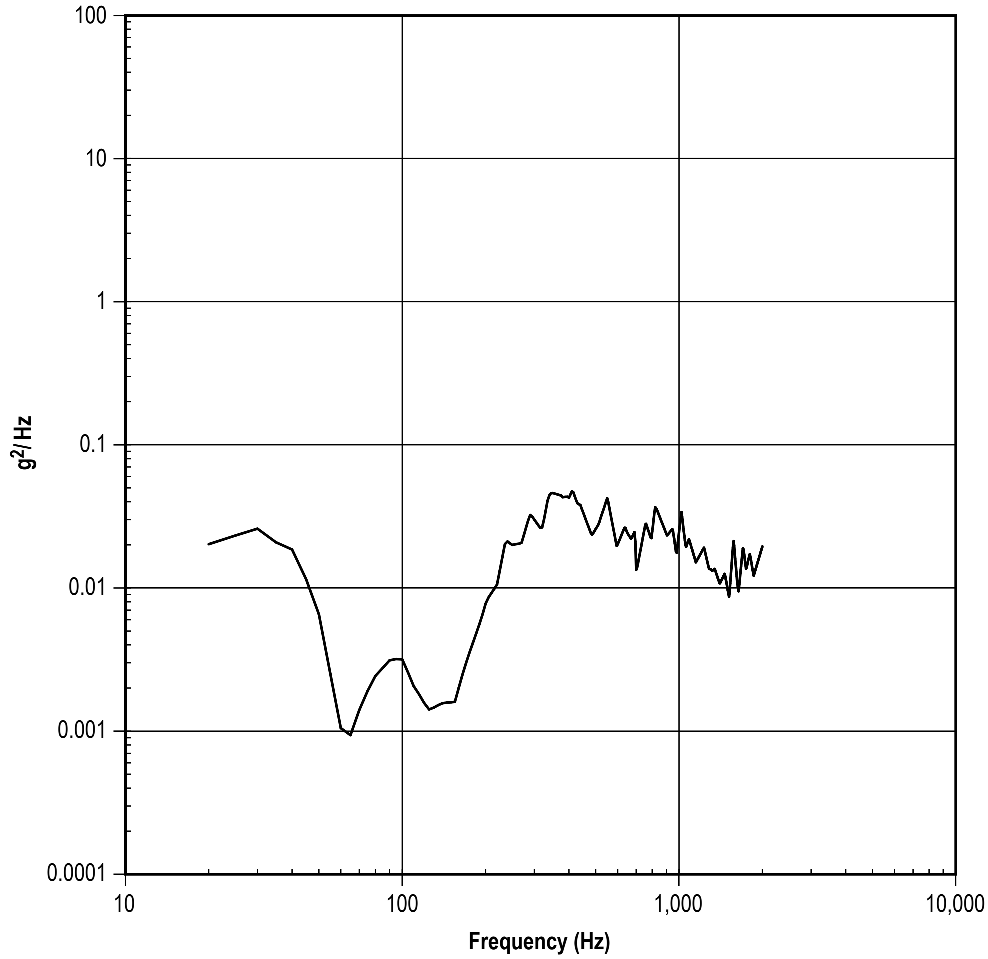

Figure 145. Skin-stringer vibration PSD, longitudinal, liftoff, 3.06 lb/ft.

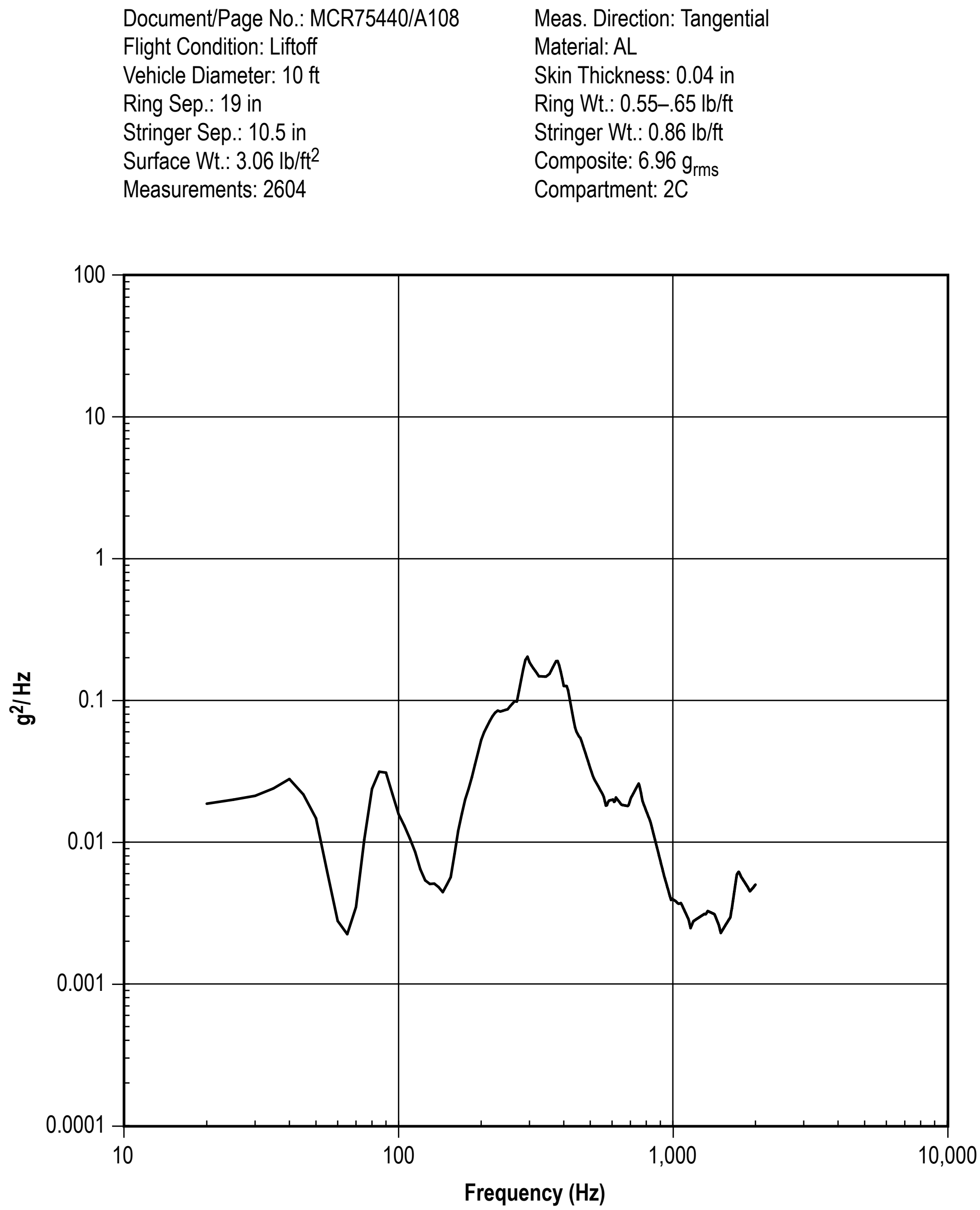

Figure 146. Skin-stringer vibration PSD, tangential, liftoff, 3.06 lb/ft^2.

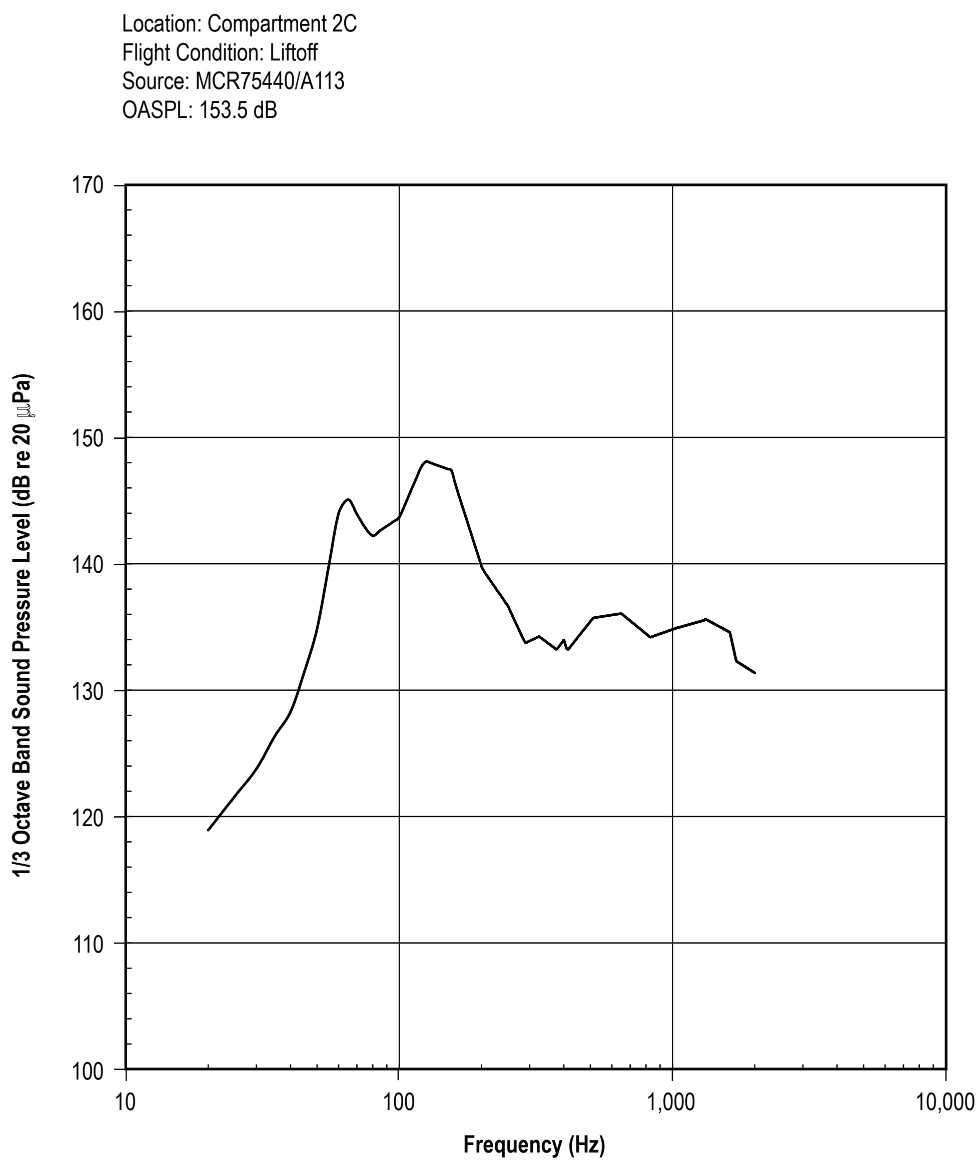

Figure 147. Titan III acoustic spectrum, compartment 2C, liftoff.

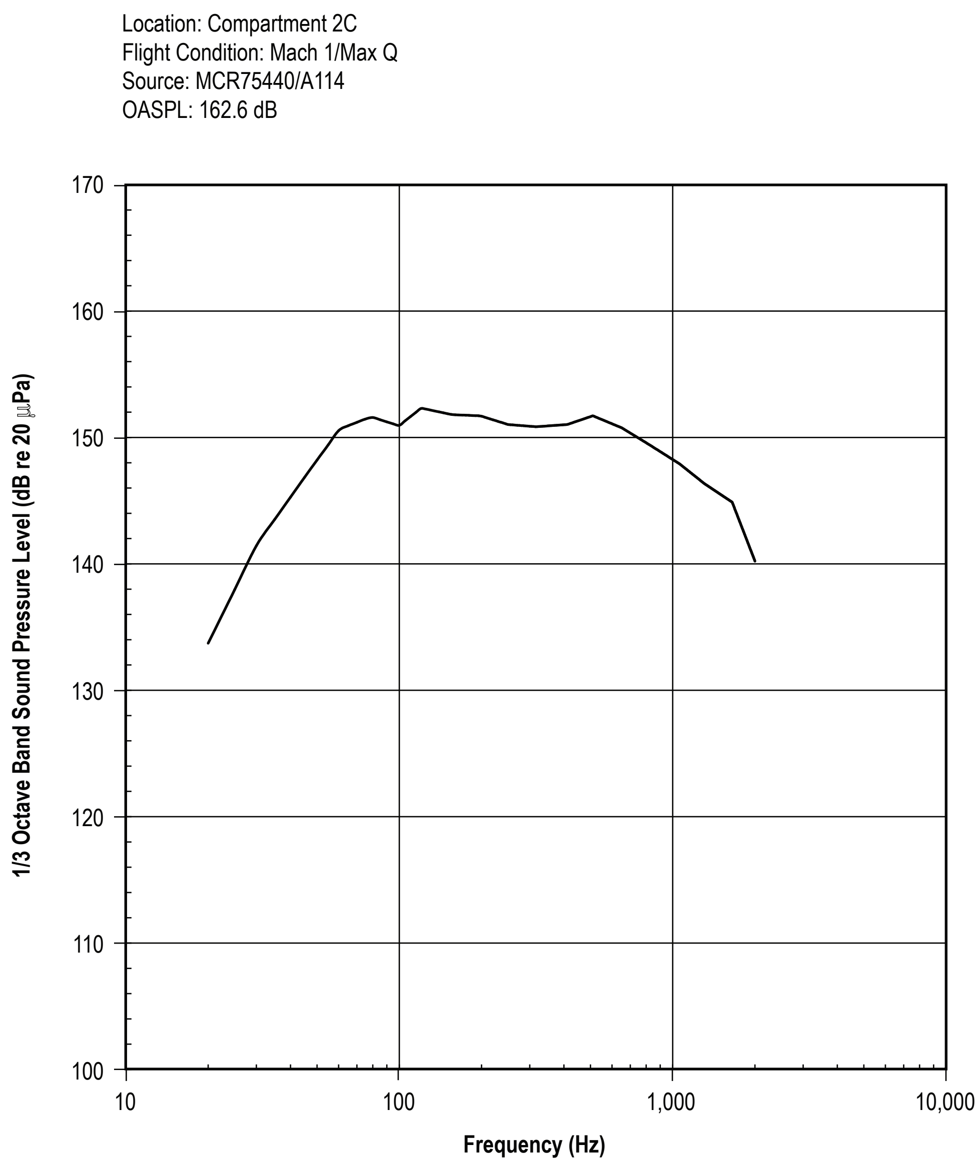

Figure 148. Titan III acoustic spectrum, compartment 2C, Mach 1/Max Q.

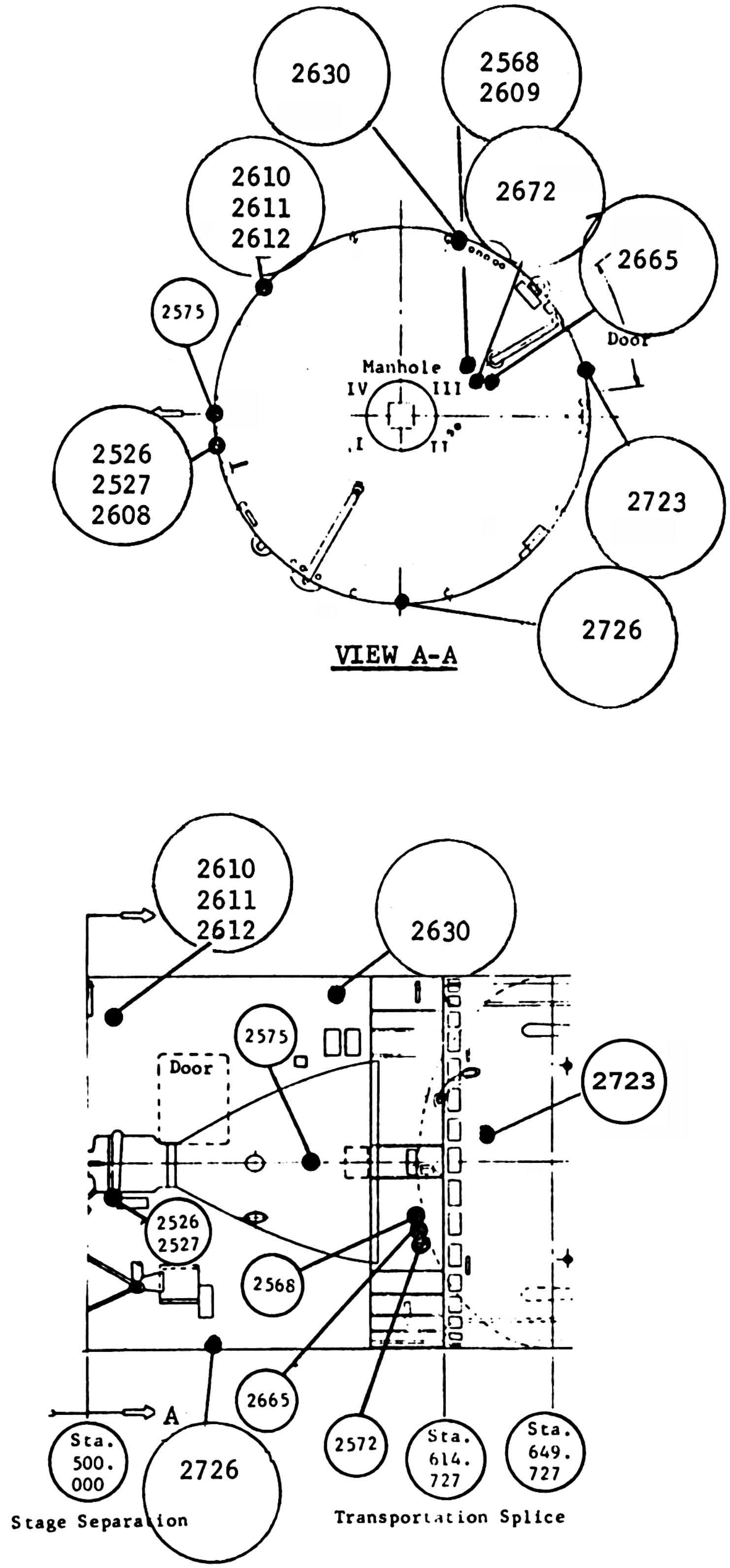

Figure 149. Compartment 1A measurement locations.

Document/Page No.: MCR75440/A88	Meas. Direction: Radial
Flight Condition: Mach 1	Material: 7075 AL
Vehicle Diameter: 10 ft	Skin Thickness: 0.241 in
Ring Sep.: 20 in	Ring Wt.: 1.8 lb/ft
Stringer Sep.: 10.5 in	Stringer Wt.: 1.06 lb/ft
Surface Wt.: 4.52 lb/ft^2	Composite: 5.63 g_{rms}
Measurements: 2723	Compartment: 1A

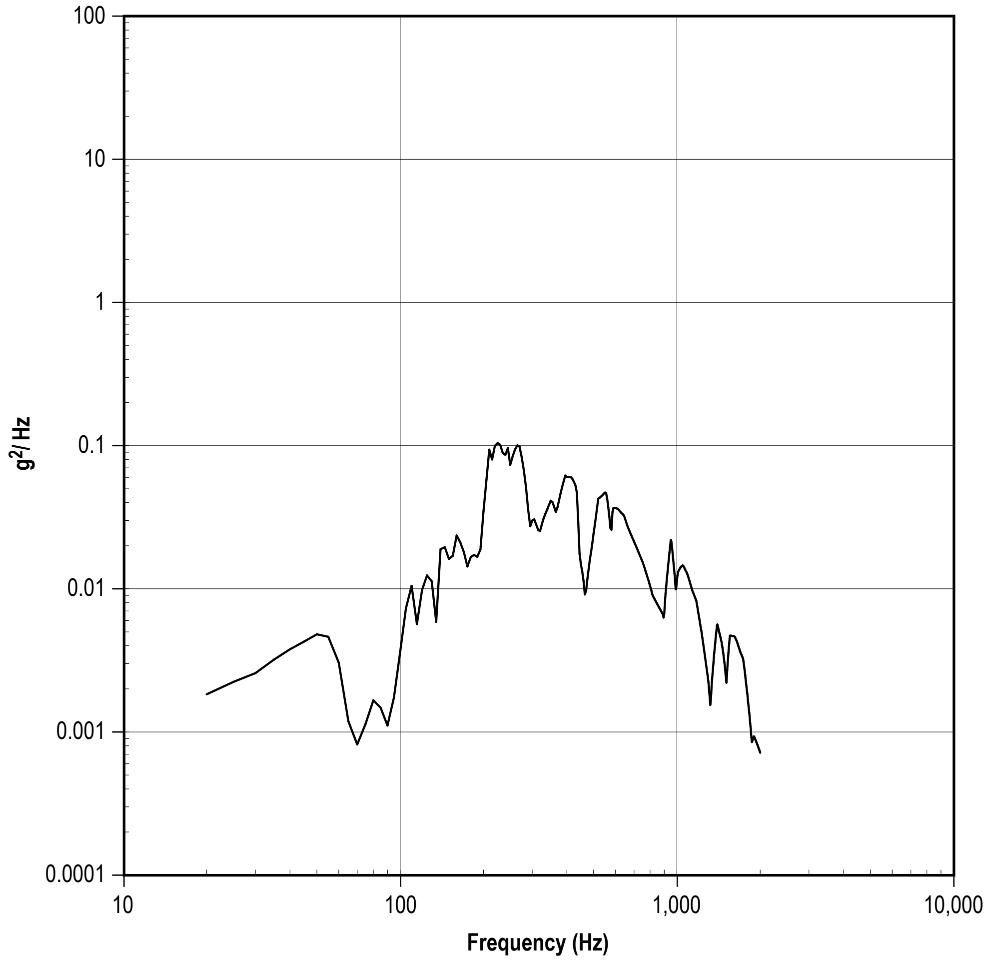

Figure 150. Skin-stringer vibration PSD, radial, Mach 1, 4.52 lb/ft^2.

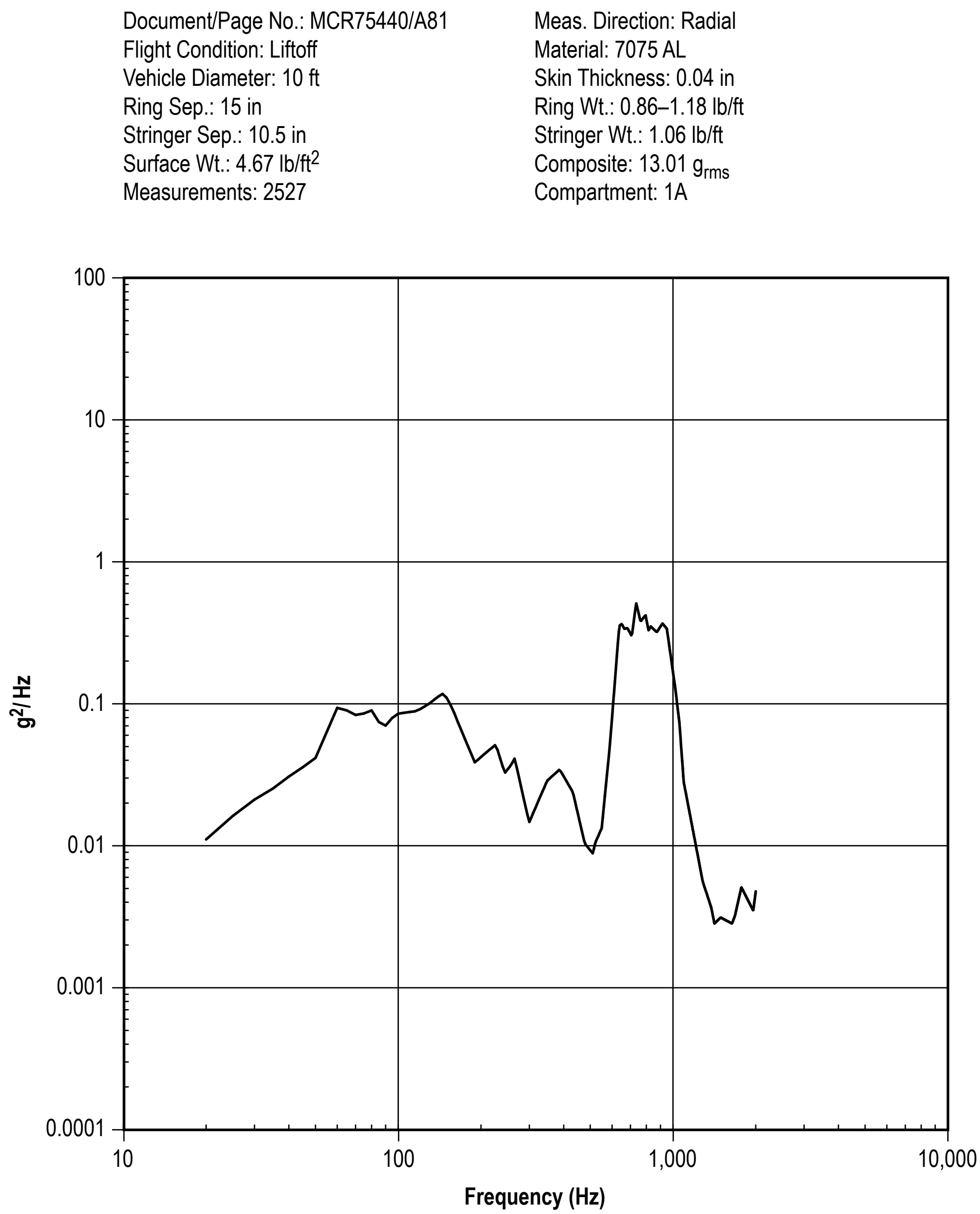

Figure 151. Skin-stringer vibration PSD, radial, liftoff, 4.67 lb/ft^2.

Document/Page No.: MCR75440/A83
Flight Condition: Transonic
Vehicle Diameter: 10 FT
Ring Sep.: 15 in
Stringer Sep.: 10.5 in
Surface Wt.: 4.67 lb/sq.ft
Measurements: 2527

Meas. Direction: Radial
Material: 7075 AL
Skin Thickness: 0.04 in
Ring Wt.: 0.86–1.18 lb/ft
Stringer Wt.: 1.06 lb/ft
Composite: 28.54 g_{rms}
Compartment: 1A

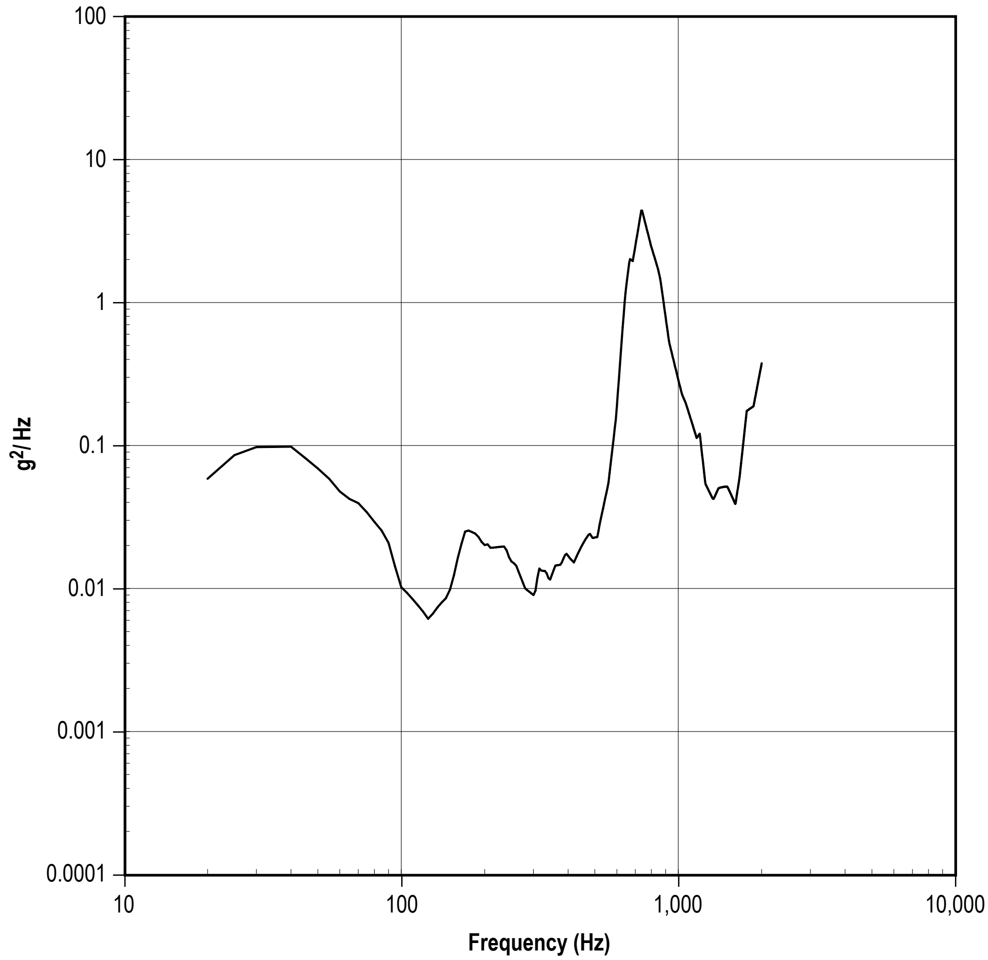

Figure 152. Skin-stringer vibration PSD, radial, transonic, 4.67 lb/ft^2.

Document/Page No.: MCR75440/A90
Flight Condition: Liftoff
Vehicle Diameter: 10 ft
Ring Sep.: 8–15 in
Stringer Sep.: 10.5 in
Surface Wt.: 4.67 lb/ft^2
Measurements: 2612

Meas. Direction: Tangential
Material: 7075 AL
Skin Thickness: 0.04 in
Ring Wt.: 1.18 lb/ft
Stringer Wt.: 1.06 lb/ft
Composite: 5.06 g_{rms}
Compartment: 1A

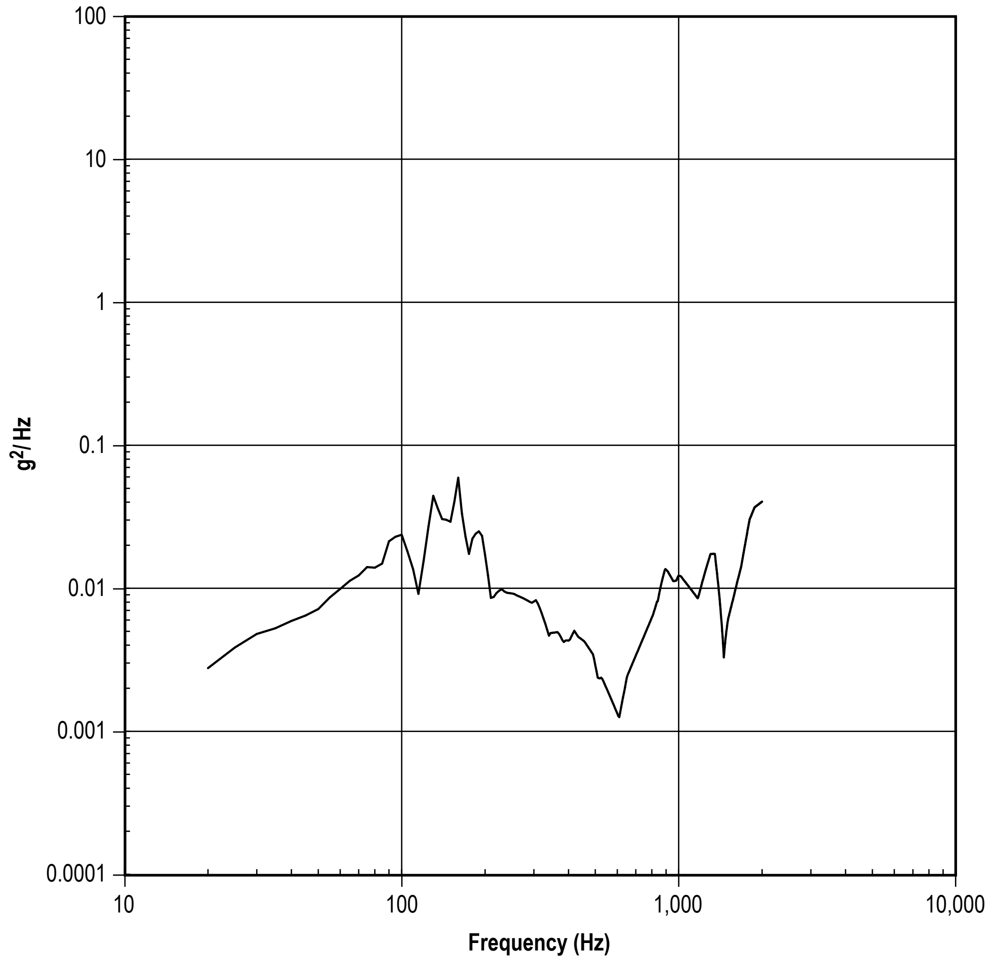

Figure 153. Skin-stringer vibration PSD, tangential, liftoff, 4.67 lb/ft^2.

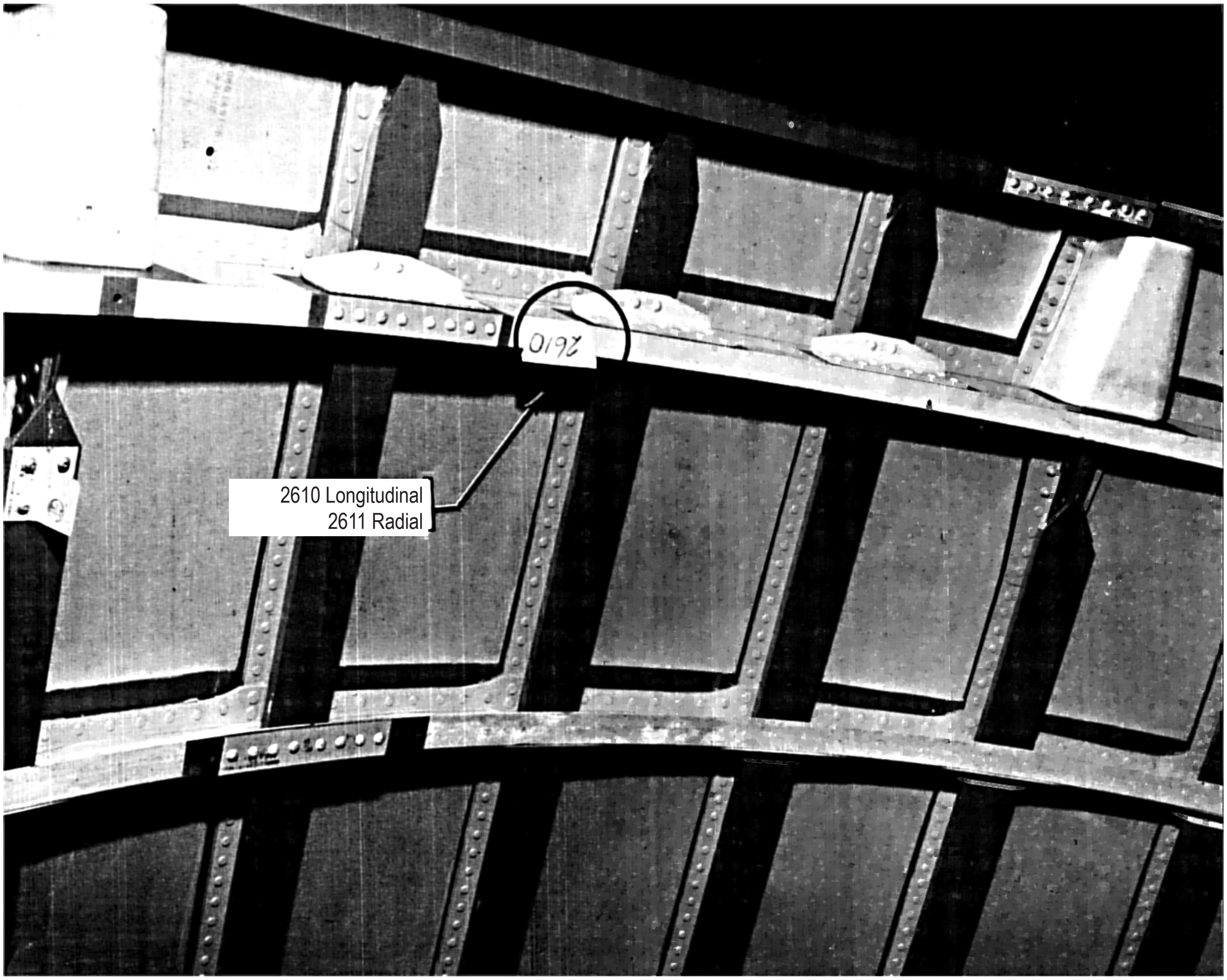

Figure 154. Vibration measurements 2610 and 2611, compartment 1A, station 508.

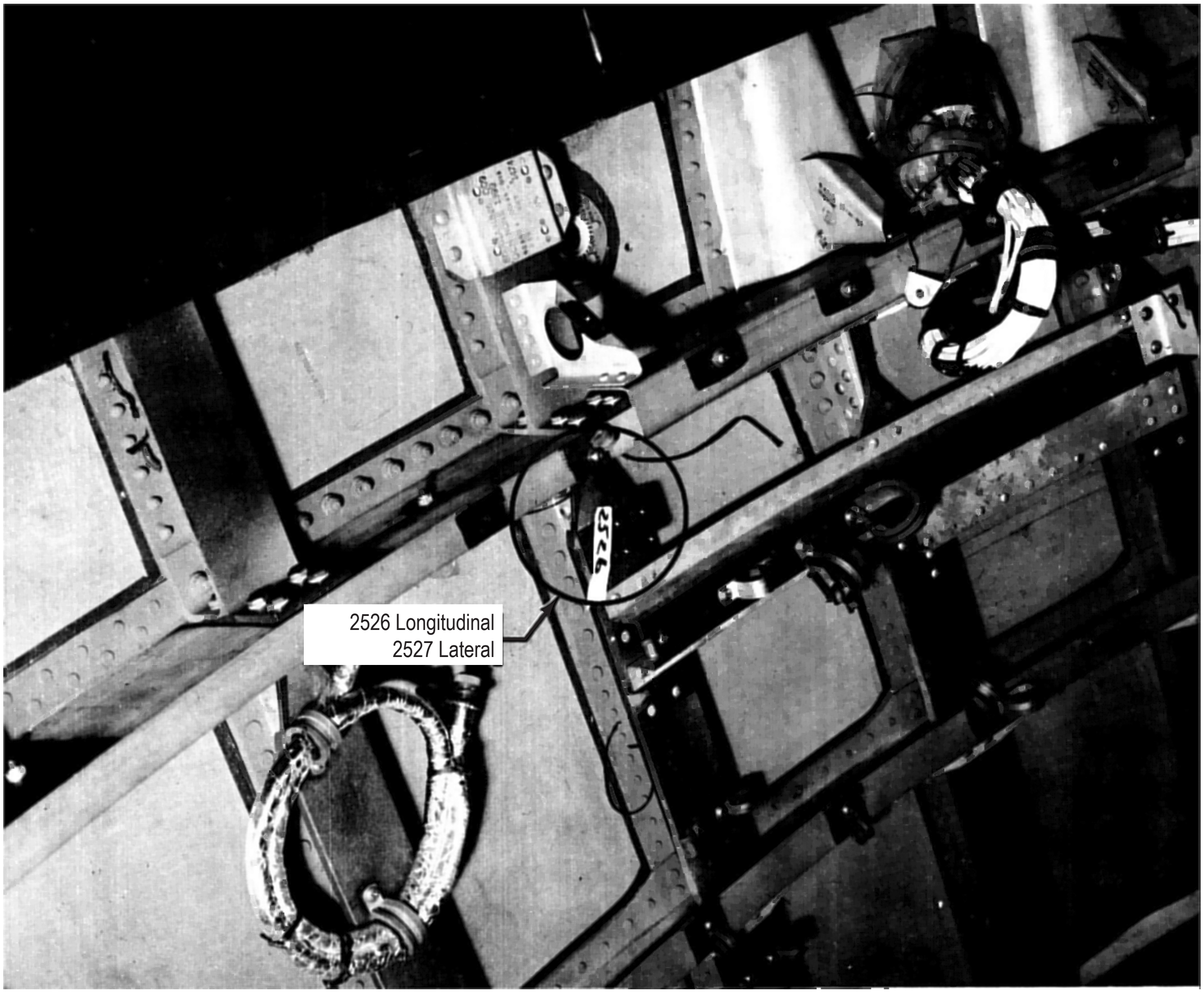

Figure 155. Vibration measurements 2526 and 2527, compartment 1A, station 508.

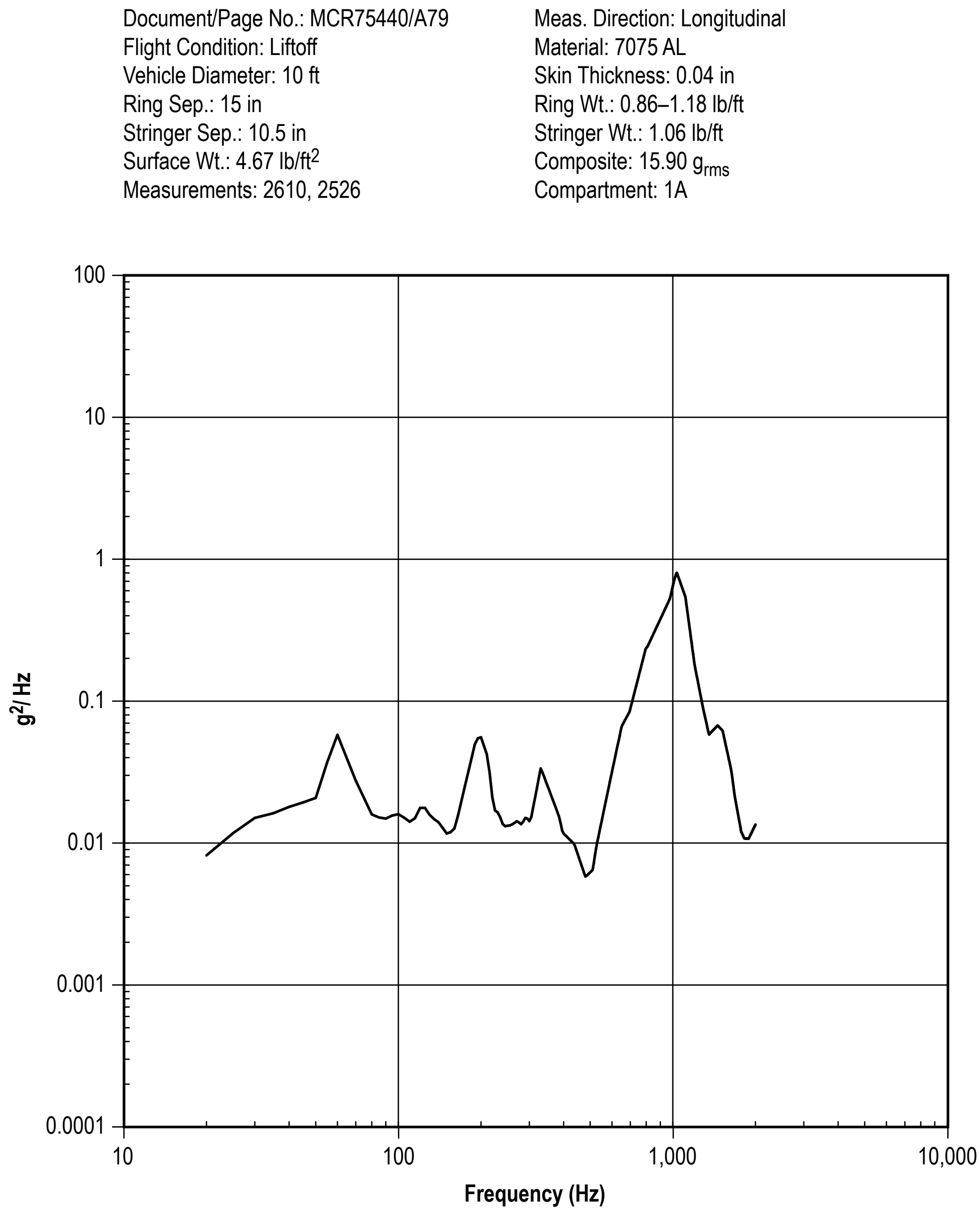

Figure 156. Skin-stringer vibration PSD, longitudinal, liftoff, 4.67 lb/ft^2.

Document/Page No.: MCR75440/A77	Meas. Direction: Radial
Flight Condition: Liftoff	Material: 7075 AL
Vehicle Diameter: 10 ft	Skin Thickness: 0.04 in
Ring Sep.: 8–15 in	Ring Wt.: 1.18 lb/ft
Stringer Sep.: 10.5 in	Stringer Wt.: 1.06 lb/ft
Surface Wt.: 4.67 lb/ft^2	Composite: 13.79 g_{rms}
Measurements: 2611, 2608, 2723	Compartment: 1A

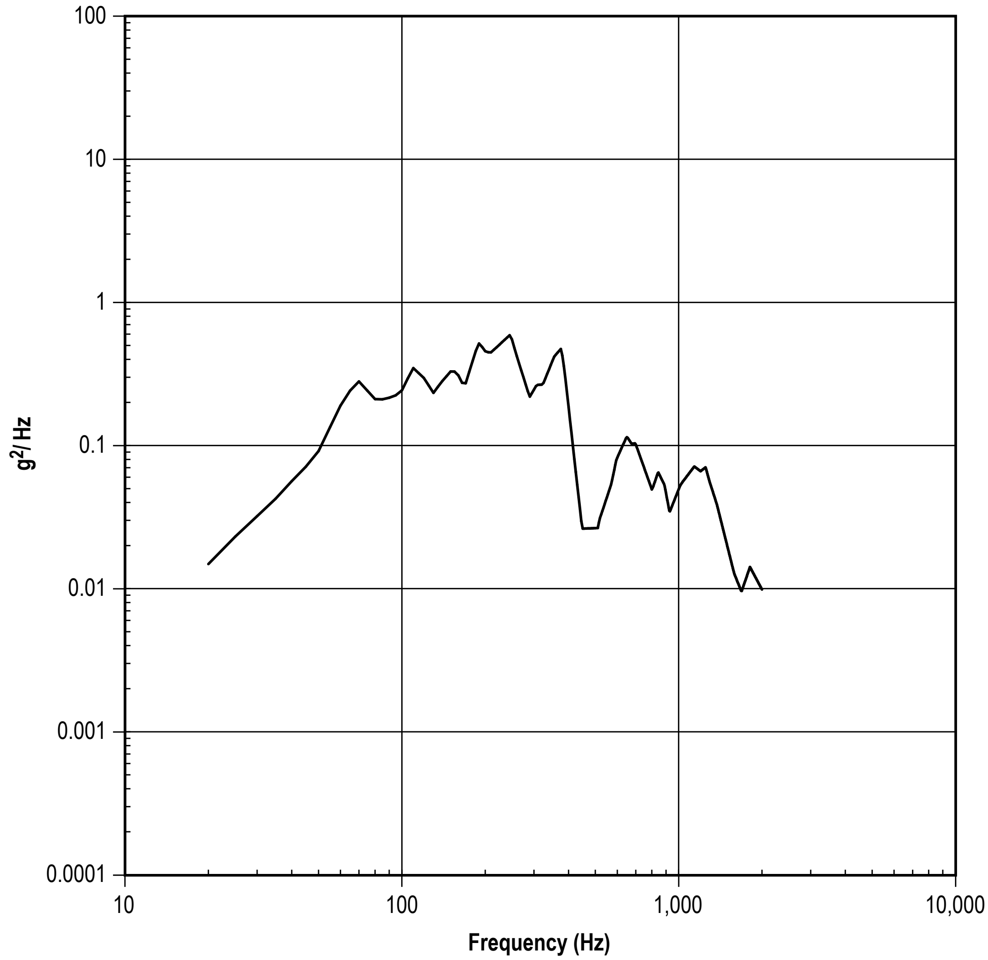

Figure 157. Skin-stringer vibration PSD, radial, liftoff, 4.67 lb/ft^2.

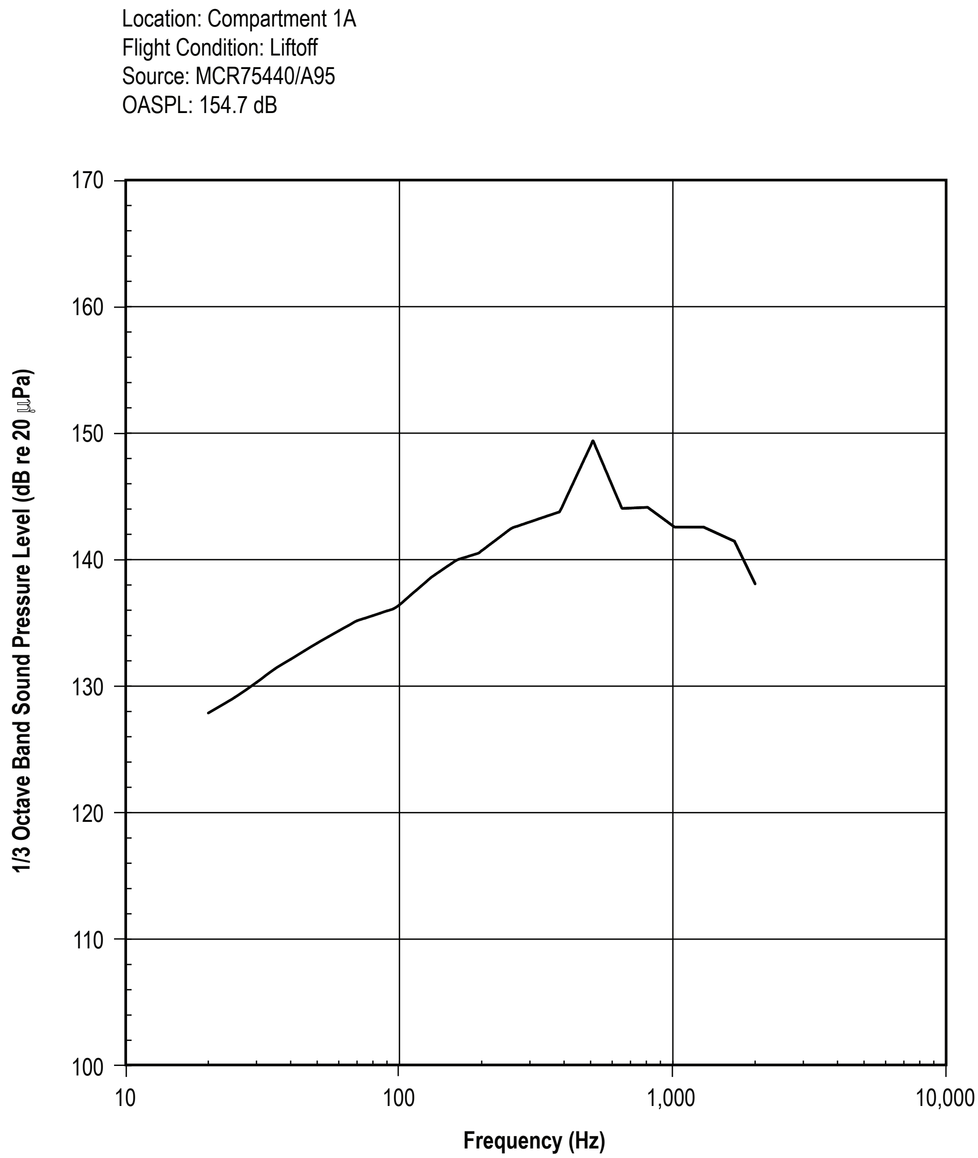

Figure 158. Titan III acoustic spectrum, compartment 1A, liftoff.

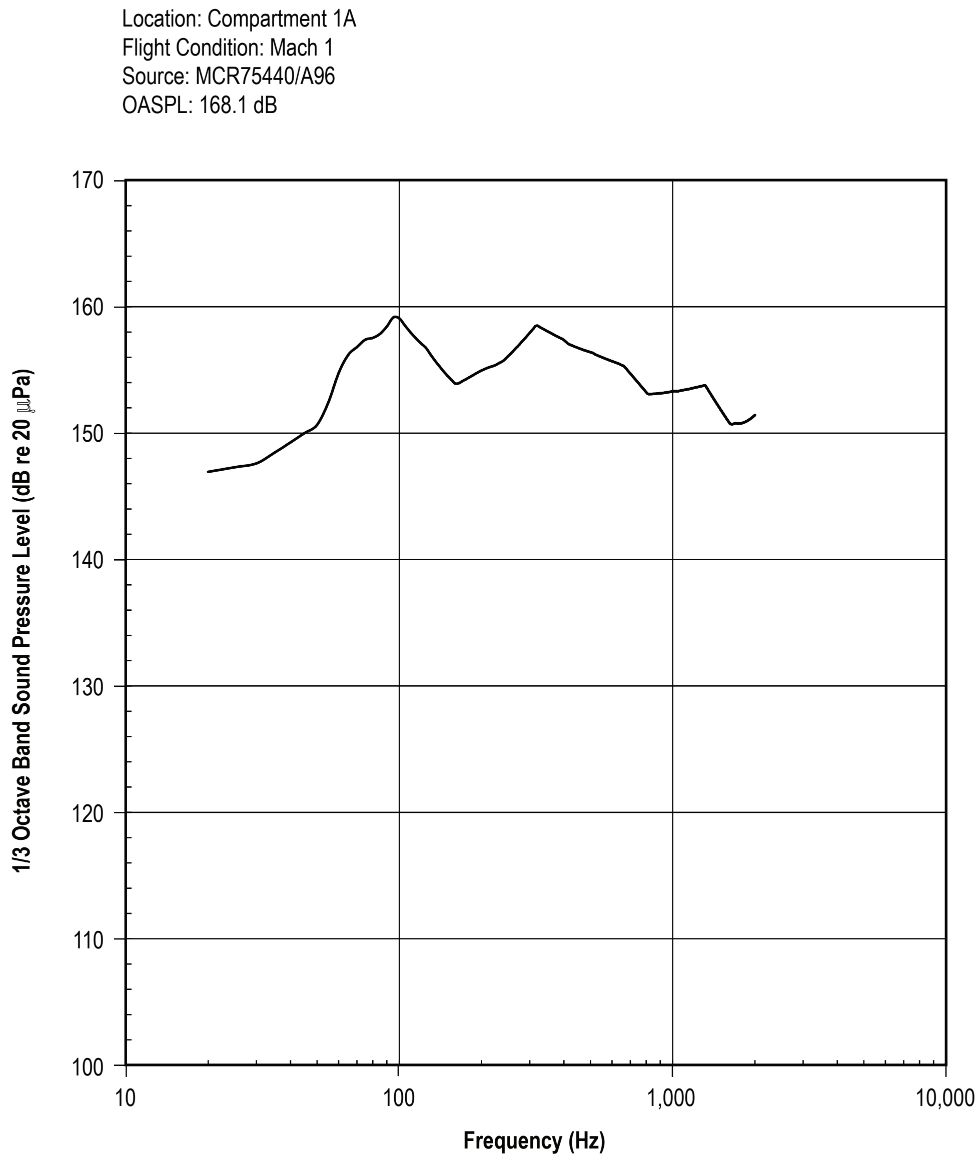

Figure 159. Titan III acoustic spectrum, compartment 1A, Mach 1.

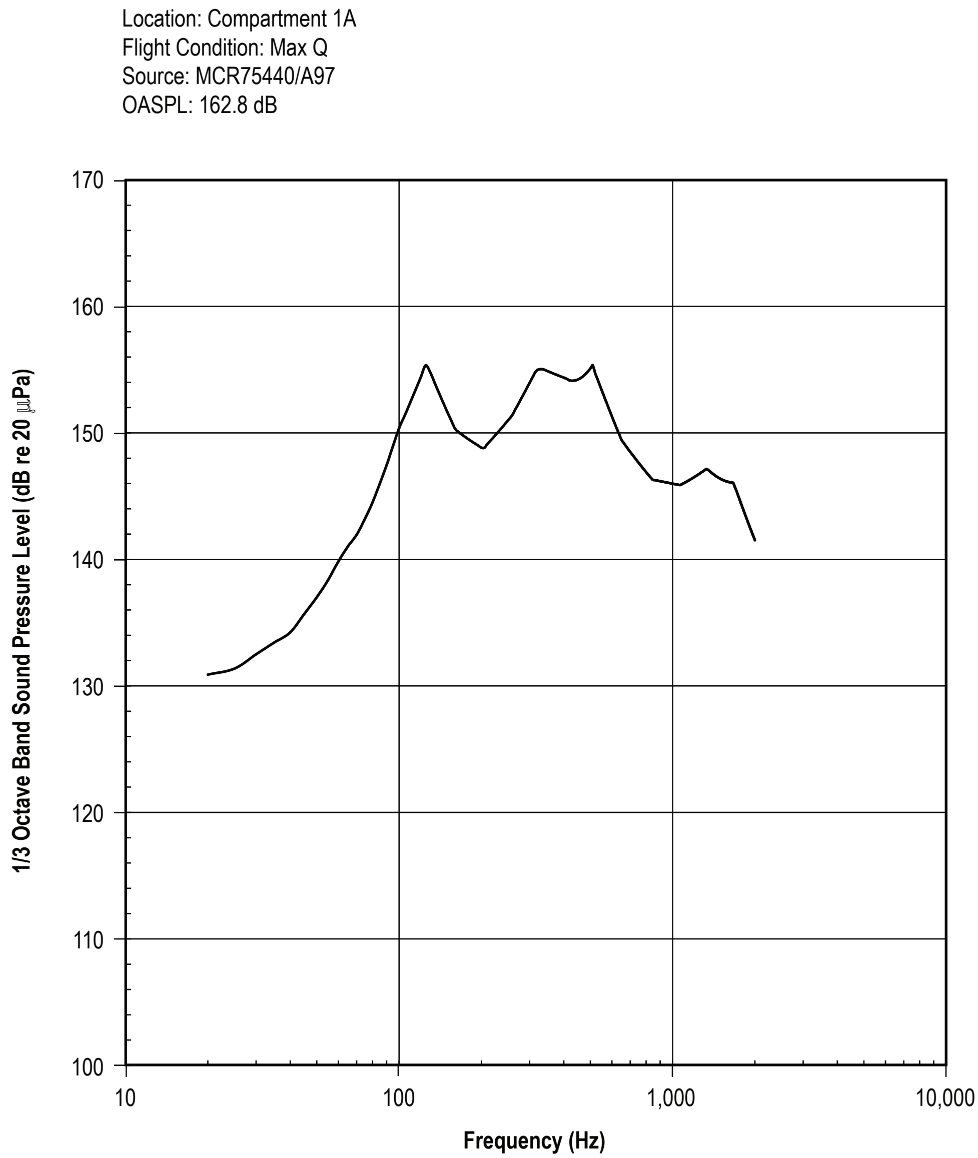

Figure 160. Titan III acoustic spectrum, compartment 1A, Max Q.

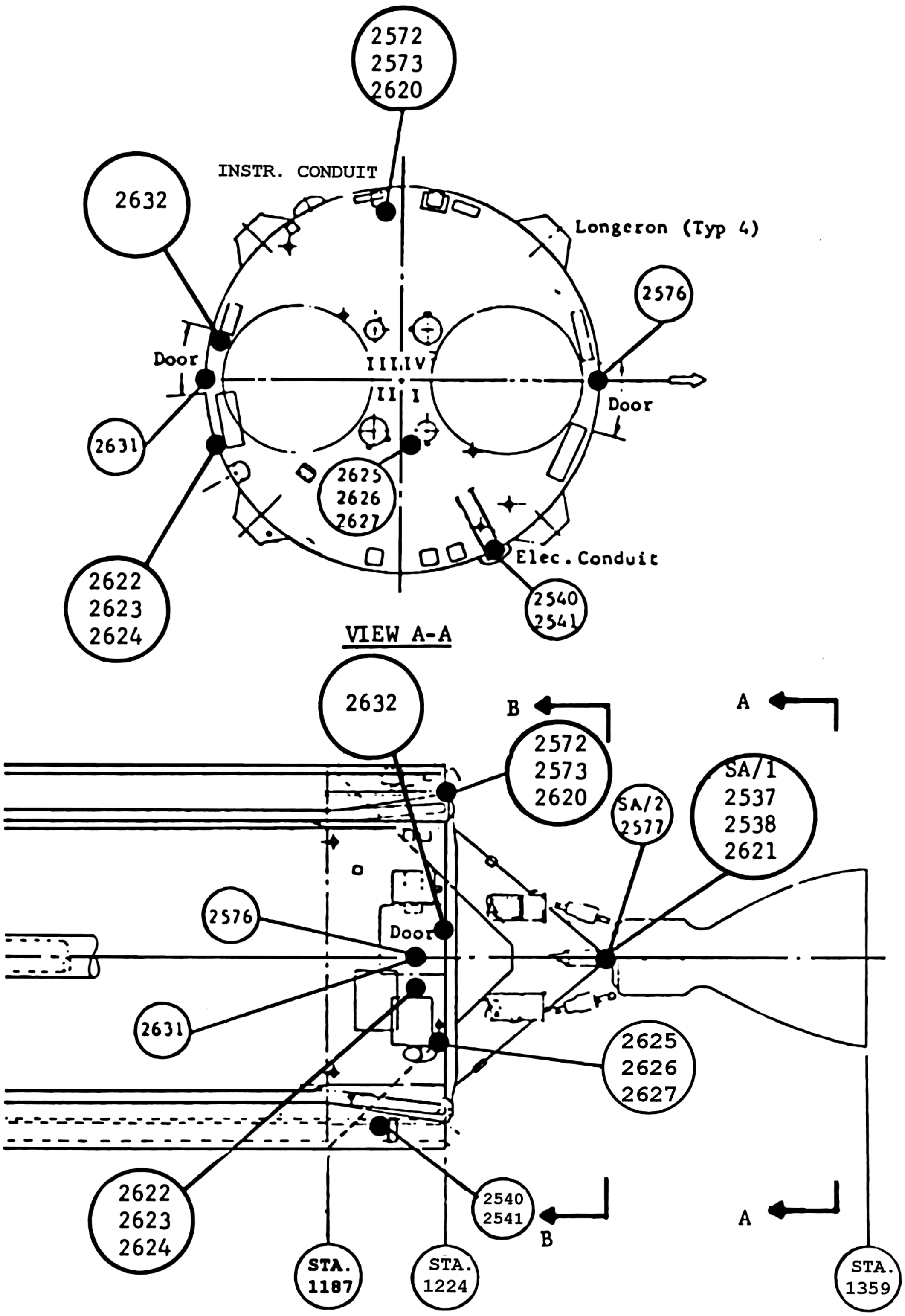

Figure 161. Compartment 1C measurement locations.

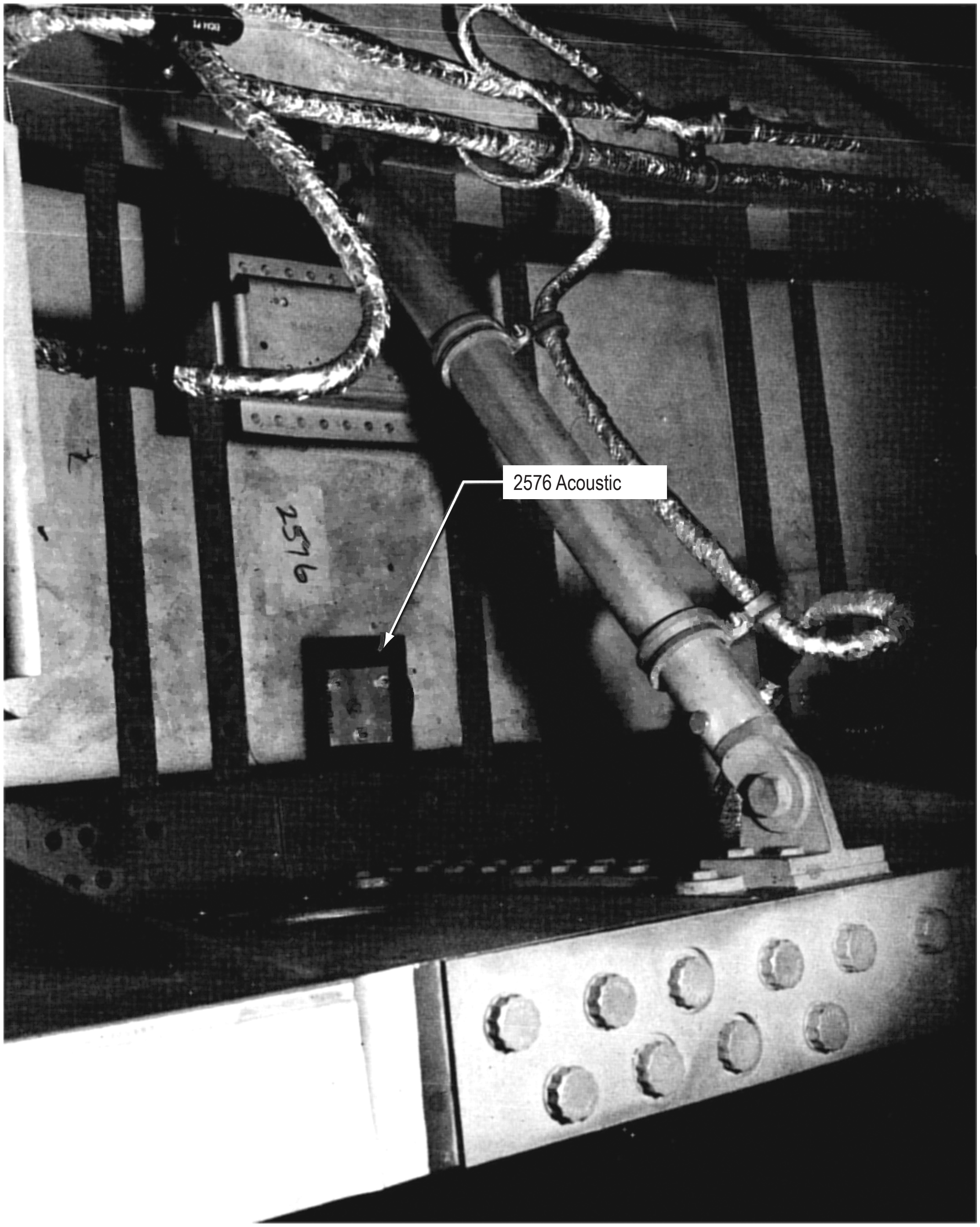

Figure 162. Compartment 1C acoustic measurement, station 1219.

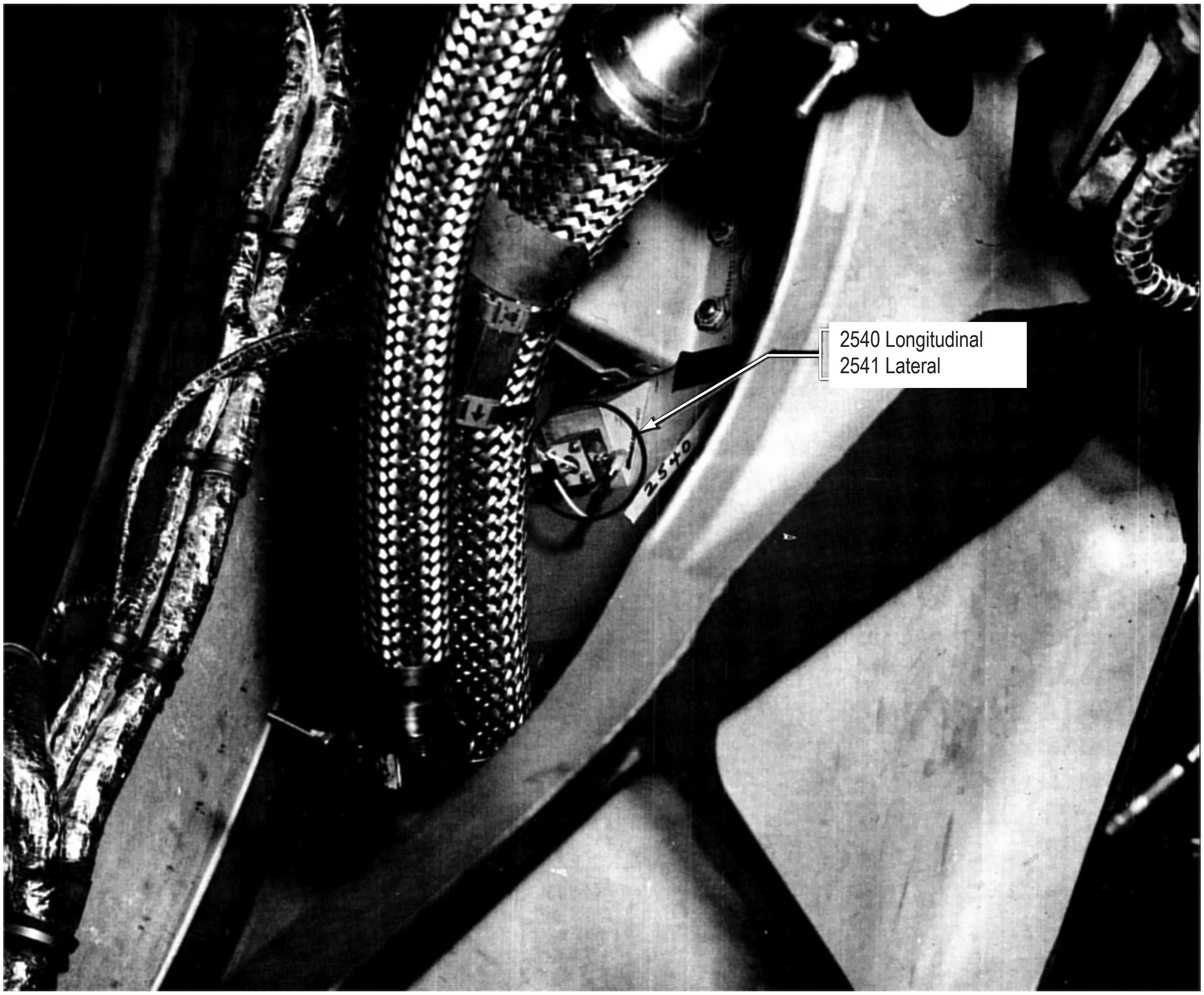

Figure 163. Vibration measurements 2540 and 2541, compartment 1C, station 1214.

Document/Page No.: MCR75440/A40	Meas. Direction: Longitudinal
Flight Condition: Liftoff	Material: 2014 AL
Vehicle Diameter: 10 ft	Skin Thickness: 0.25 in
Ring Sep.: 20 in	Ring Wt.: 3.9–4.21 lb/ft
Stringer Sep.: 10.5 in	Stringer Wt.: 0.732 lb/ft
Surface Wt.: 8.4 lb/ft^2	Composite: 4.05 g_{rms}
Measurements: 2540	Compartment: 1C

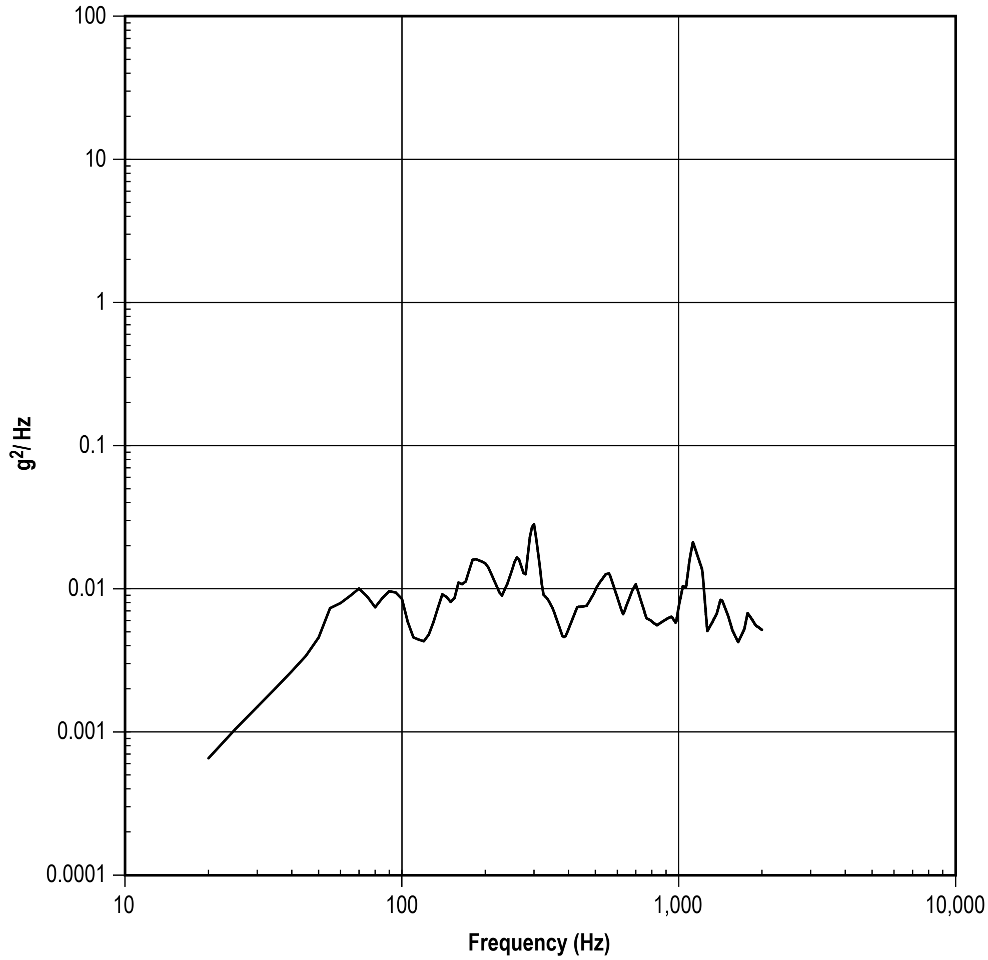

Figure 164. Skin-stringer vibration PSD, longitudinal, liftoff, 8.4 lb/ft^2.

Document/Page No.: MCR75440/A49
Flight Condition: Liftoff
Vehicle Diameter: 10 ft
Ring Sep.: 20 in
Stringer Sep.: 10.5 in
Surface Wt.: 8.4 lb/ft^2
Measurements: 2623

Meas. Direction: Radial
Material: 2014 AL
Skin Thickness: 0.07 in
Ring Wt.: 3.9–4.21 lb/ft
Stringer Wt.: 0.84 lb/ft
Composite: 12.42 g_{rms}
Compartment: 1C

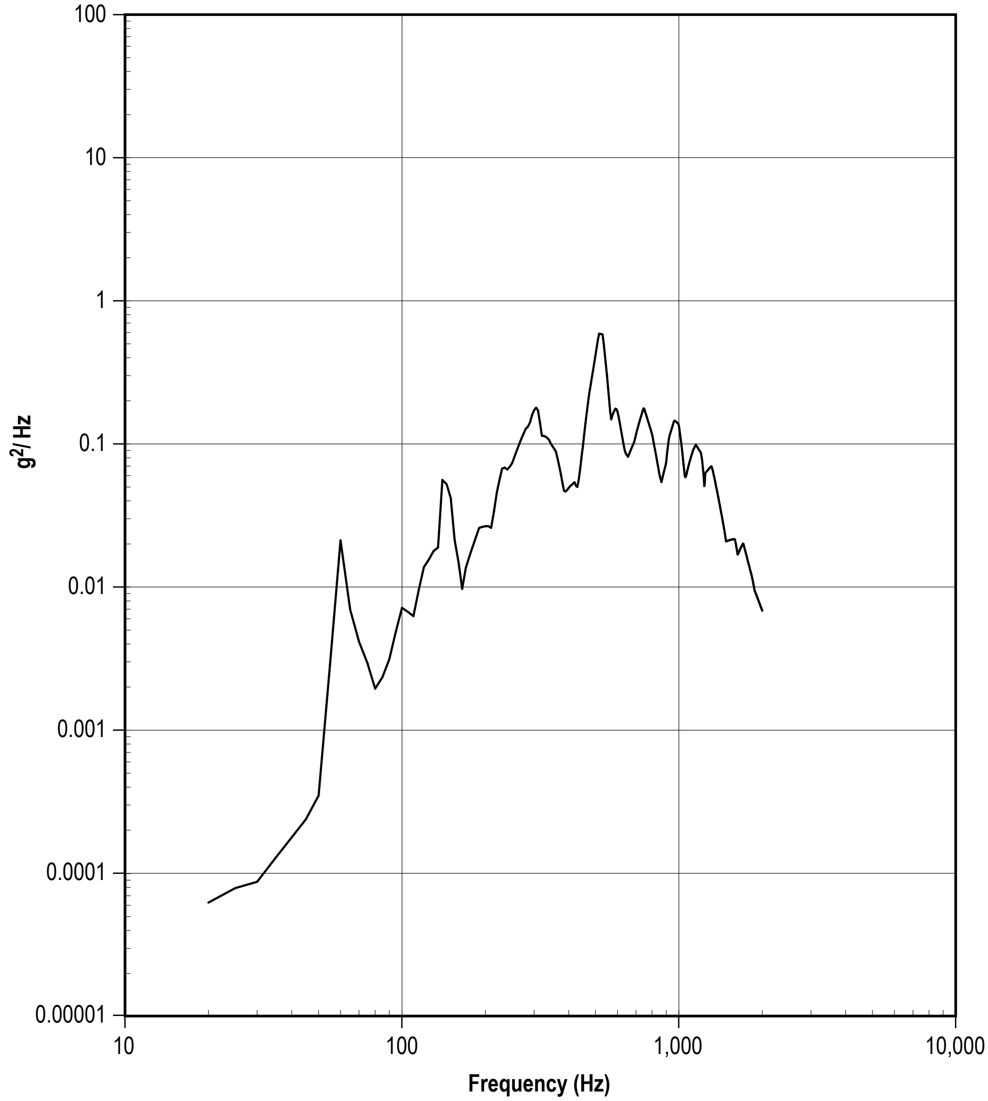

Figure 165. Skin-stringer vibration PSD, radial, liftoff, 8.4 lb/ft^2.

Document/Page No.: MCR75440/A51-2
Flight Condition: Liftoff
Vehicle Diameter: 10 ft
Ring Sep.: 20 in
Stringer Sep.: 10.5 in
Surface Wt.: 12.08 lb/ft^2
Measurements: 2541

Meas. Direction: Radial
Material: 2014 AL
Skin Thickness: 0.25 in
Ring Wt.: 3.9–4.21 lb/ft
Stringer Wt.: 0.732 lb/ft
Composite: 10.79 g_{rms}
Compartment: 1C

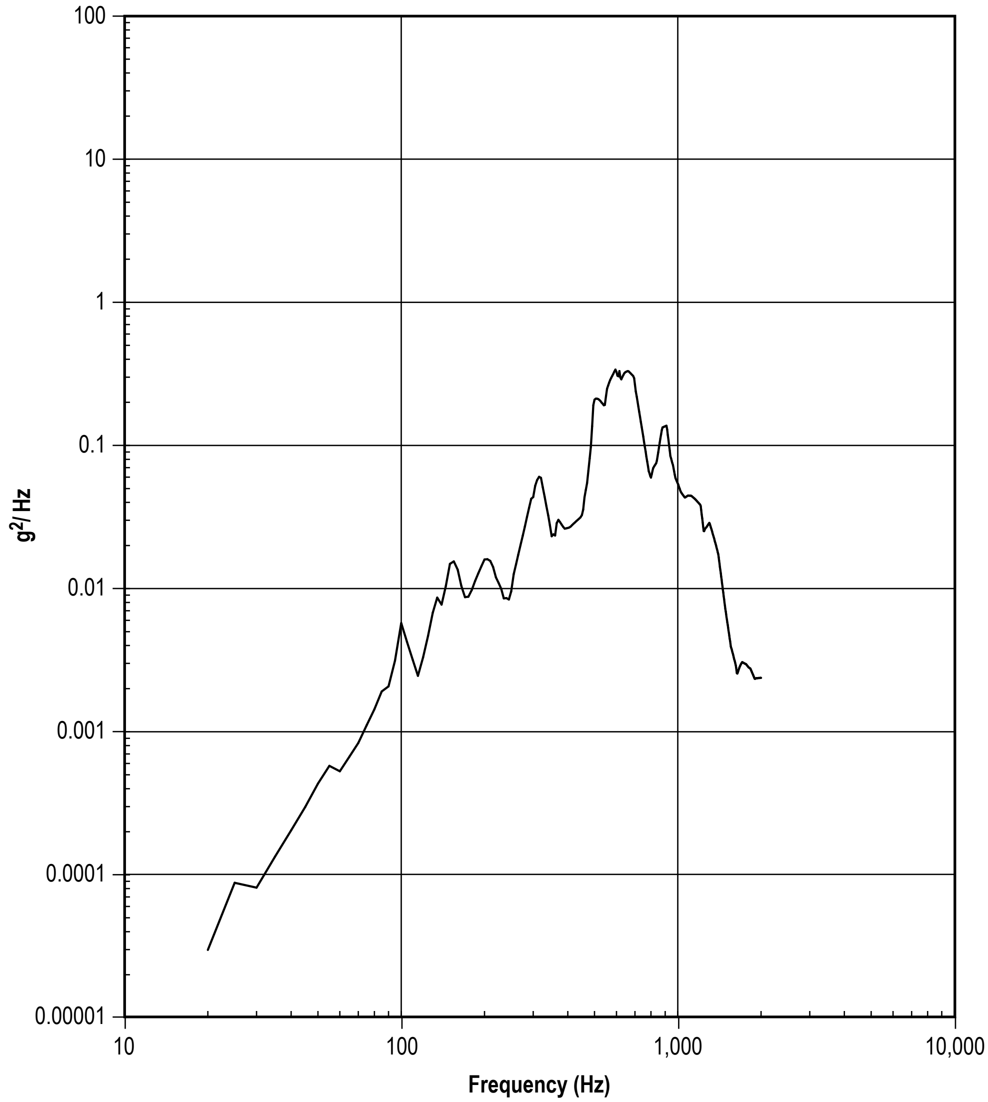

Figure 166. Skin-stringer vibration PSD, radial, liftoff, 12.08 lb/ft^2.

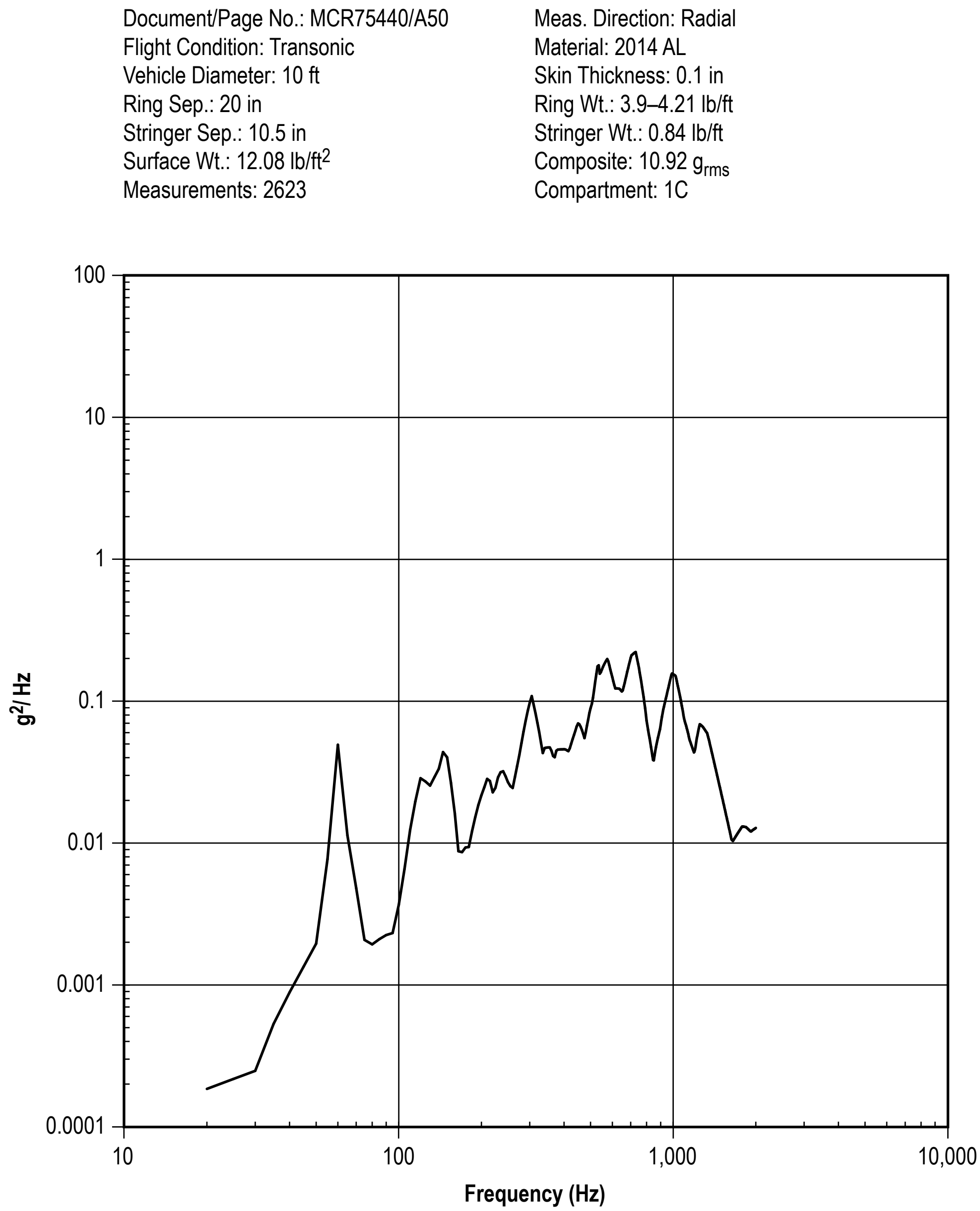

Figure 167. Skin-stringer vibration PSD, radial, transonic, 12.08 lb/ft^2.

Document/Page No.: MCR75440/A51
Flight Condition: Liftoff
Vehicle Diameter: 10 ft
Ring Sep.: 20 in
Stringer Sep.: 10.5 in
Surface Wt.: 12.08 lb/ft^2
Measurements: 2541

Meas. Direction: Tangential
Material: 2014 AL
Skin Thickness: 0.1 in
Ring Wt.: 3.9–4.21 lb/ft
Stringer Wt.: 0.84 lb/ft
Composite: 4.83 g_{rms}
Compartment: 1C

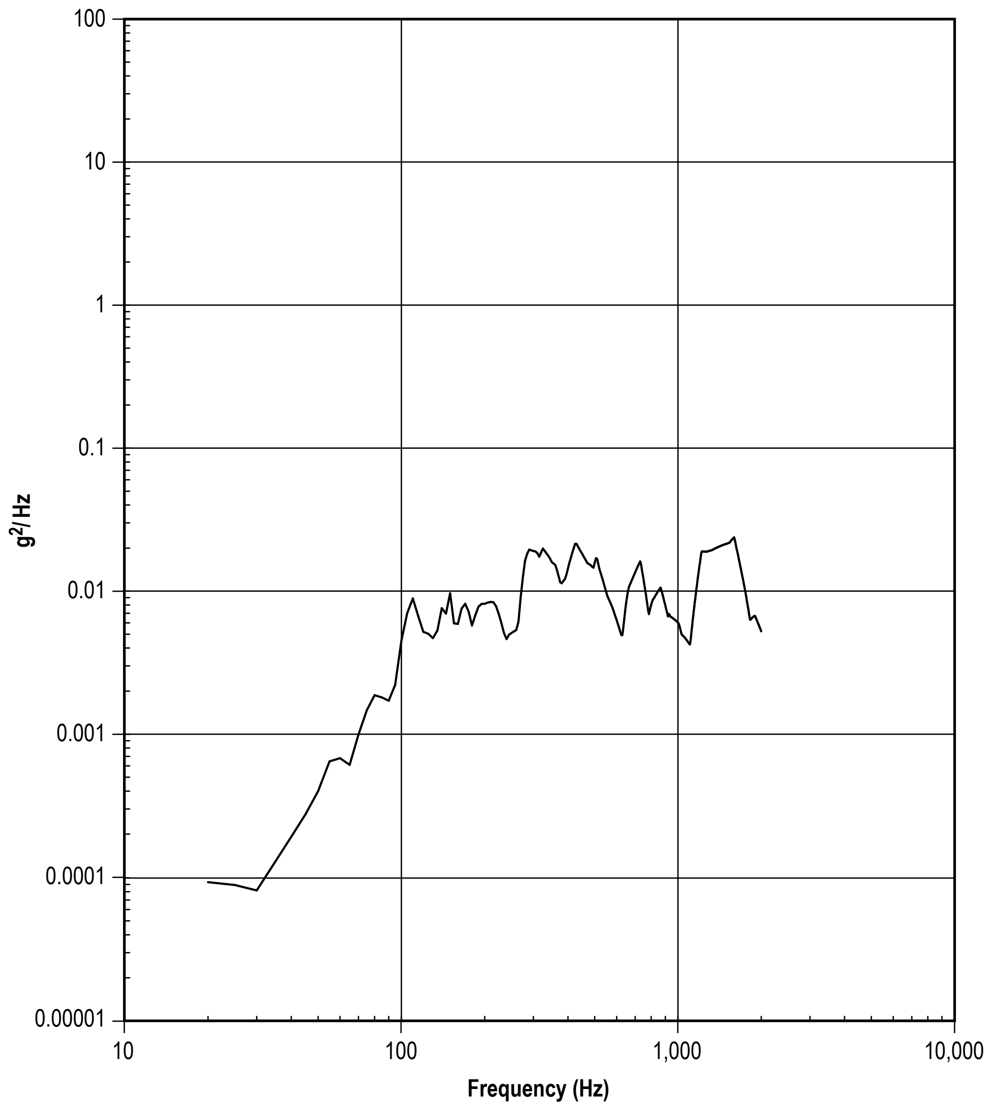

Figure 168. Skin-stringer vibration PSD, tangential, liftoff, 12.08 lb/ft^2.

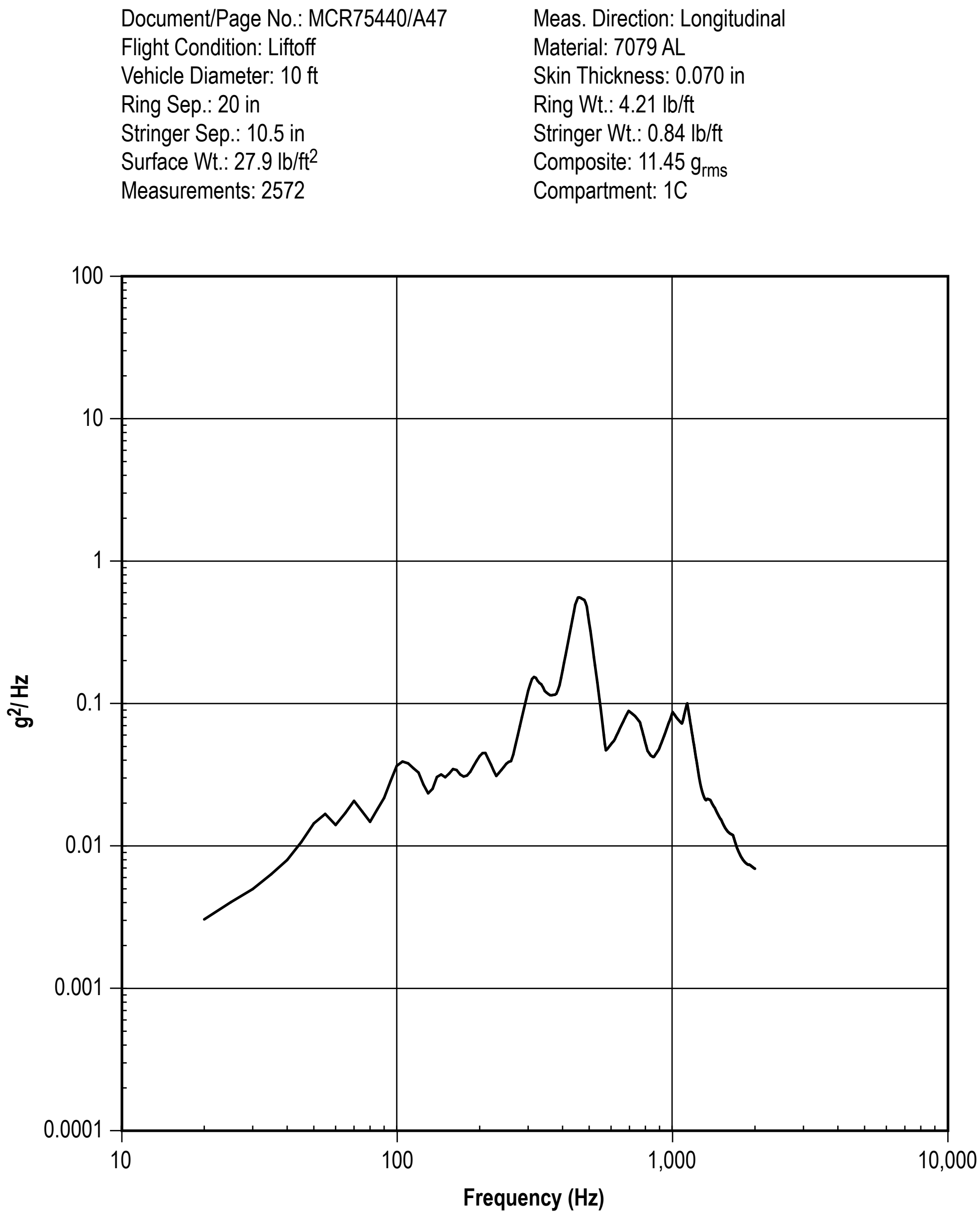

Figure 169. Skin-stringer vibration PSD, longitudinal, liftoff, 27.9 lb/ft^2.

Document/Page No.: MCR75440/A38
Flight Condition: Liftoff
Vehicle Diameter: 10 ft
Ring Sep.: 20 in
Stringer Sep.: 10.5 in
Surface Wt.: 27.9 lb/ft^2
Measurements: 2573

Meas. Direction: Radial
Material: 7079 AL
Skin Thickness: 0.070 in
Ring Wt.: 4.2 lb/ft
Stringer Wt.: 0.84 lb/ft
Composite: 5.74 g_{rms}
Compartment: 1C

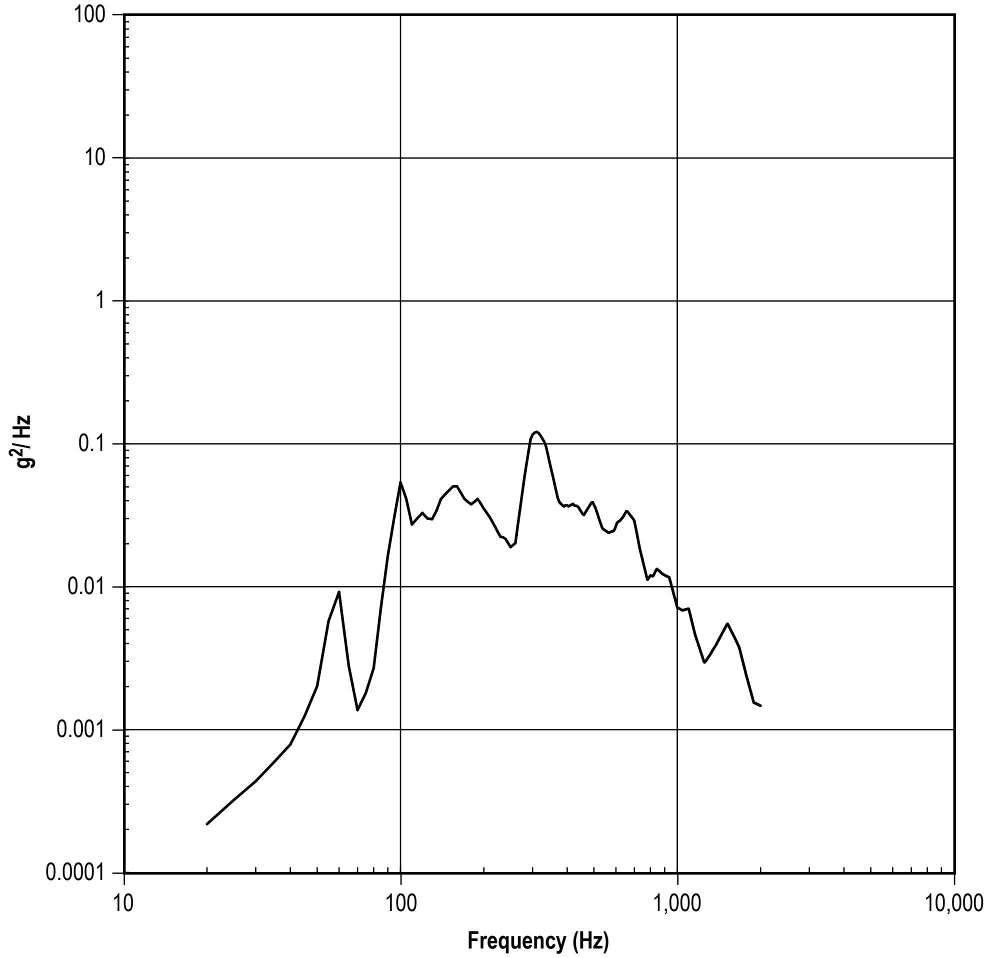

Figure 170. Skin-stringer vibration PSD, radial, liftoff, 27.9 lb/ft^2.

Document/Page No.: MCR75440/A48
Flight Condition: Transonic
Vehicle Diameter: 10 ft
Ring Sep.: 20 in
Stringer Sep.: 10.5 in
Surface Wt.: 27.9 lb/ft^2
Measurements: 2573

Meas. Direction: Radial
Material: 7079 AL
Skin Thickness: 0.070 in
Ring Wt.: 4.2 lb/ft
Stringer Wt.: 0.84 lb/ft
Composite: 7.81 g_{rms}
Compartment: 1C

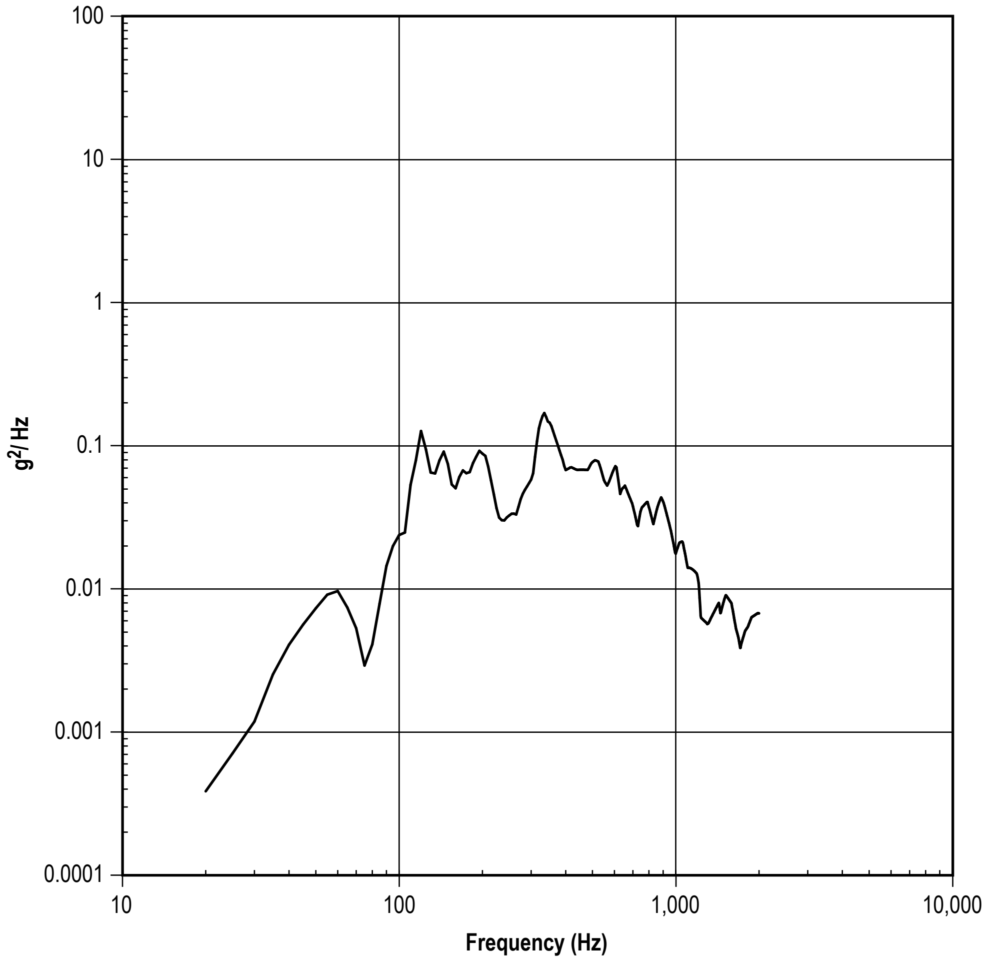

Figure 171. Skin-stringer vibration PSD, radial, transonic, 27.9 lb/ft^2.

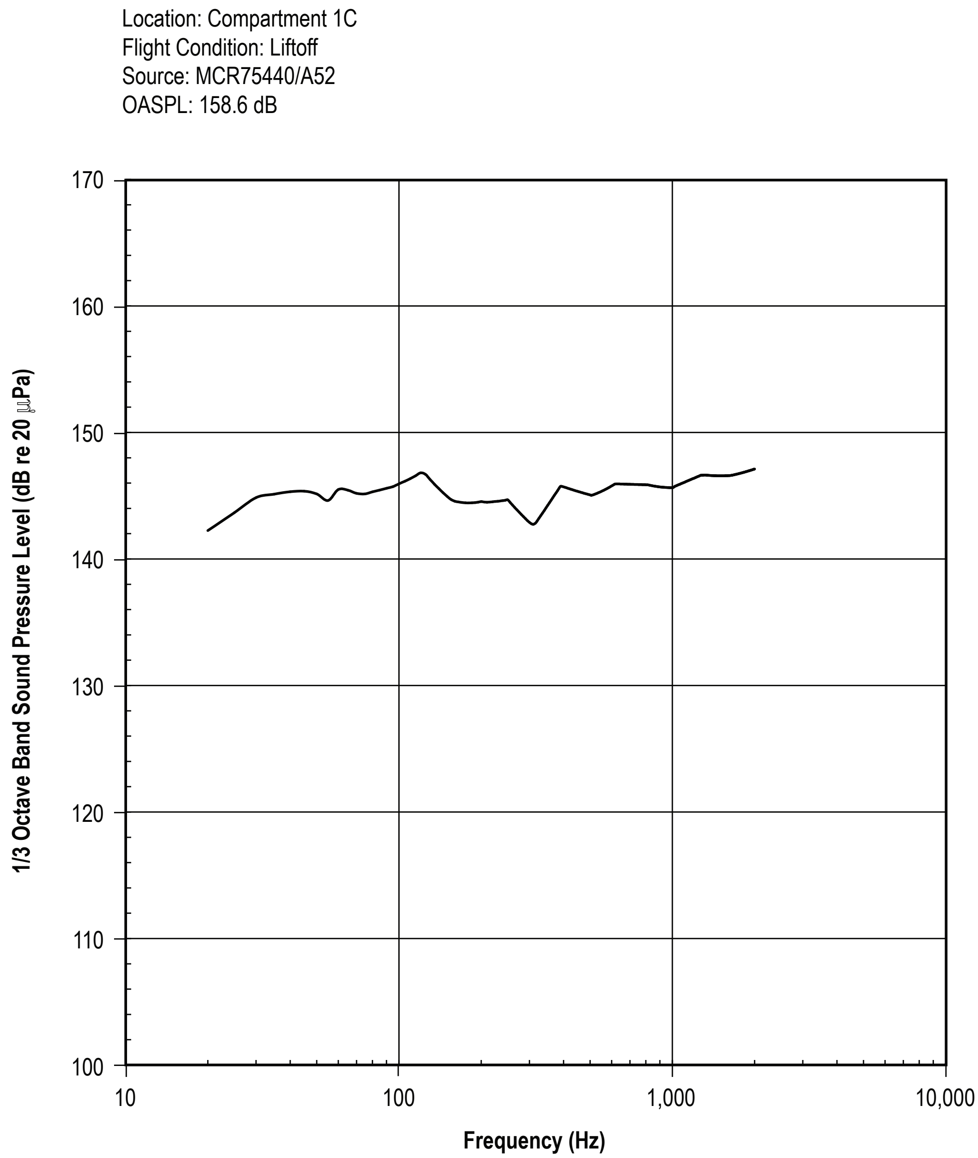

Figure 172. Titan III acoustic spectrum, compartment 1C, liftoff.

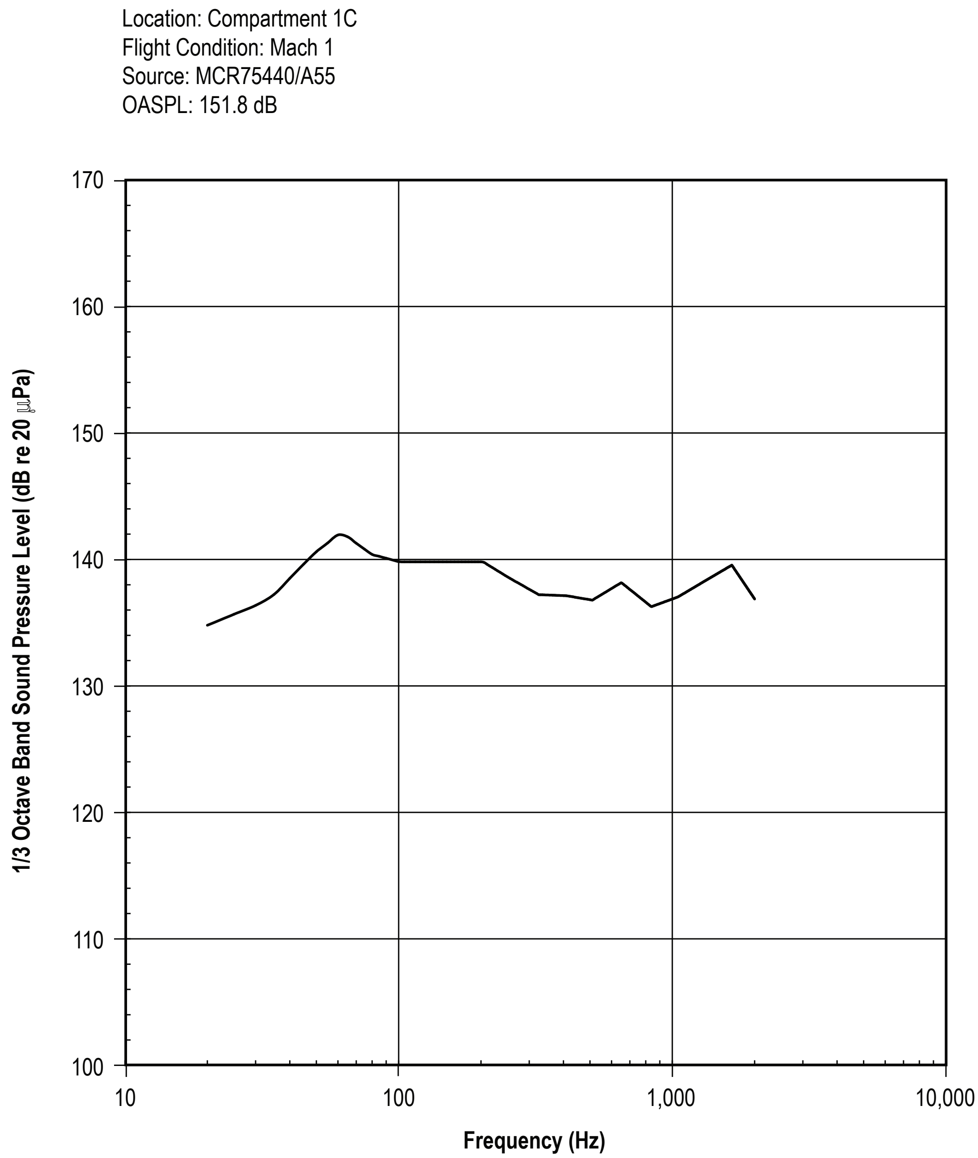

Figure 173. Titan III acoustic spectrum, compartment 1C, Mach 1.

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14. ABSTRACT
This is an update to TN D-7159, "Development and Application of Vibroacoustic Structural Data Banks in Predicting Vibration Design and Test Criteria for Rocket Vehicle Structures", which was originally published in 1973. Errors in the original document have been corrected and additional data from the Titan III program have been included. Methods for using the vibroacoustic databanks for vibration test criteria development are shown, as well as all of the data with drawings and pictures of the measurement locations. An Excel spreadsheet with the data included is available from the author.

15. SUBJECT TERMS
vibroacoustic criteria, random vibration criteria, flight vibration data

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