JET AIRCRAFT FUSELAGE EXTERNAL
FLUCTUATING PRESSURE LEVEL DURING CRUISE
Revision B

By Tom Irvine
Email: tom@vibrationdata.com

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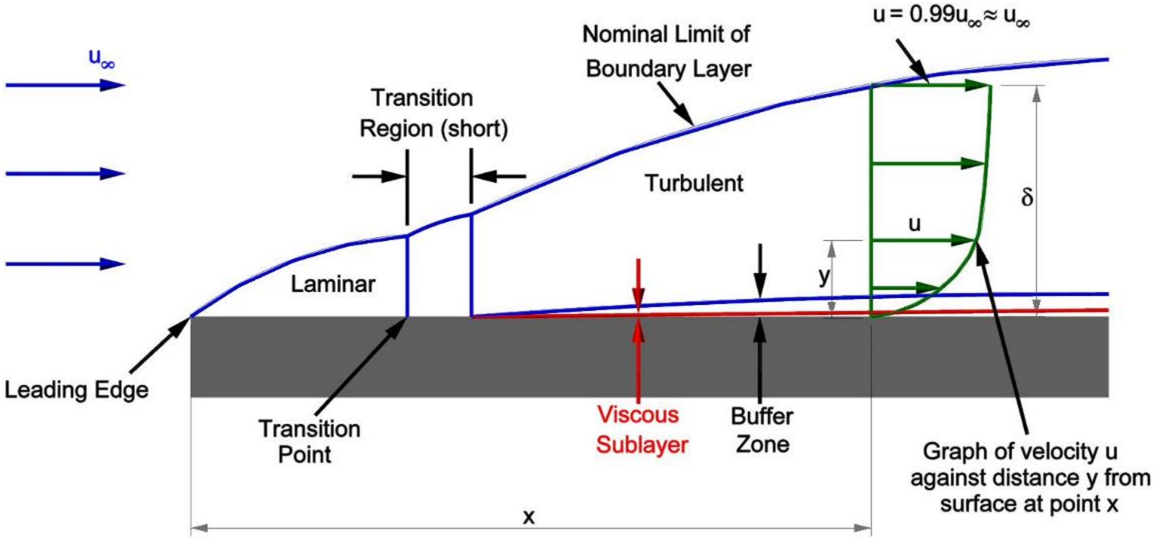

Figure 1. Boundary Layer on a Flat Plate

Image courtesy of: http://www.cortana.com

The thickness of the viscous sublayer depends on the characteristics of the particular flow and fluid; it is typically in the range of a fraction of a millimeter to many millimeters. The eddies forming in the turbulent layer are damped out by viscous shear stresses in the sublayer.

Introduction

The purpose of this paper is to present reference data and a scaling method for the determining the external fluctuating pressure level on a jet aircraft fuselage during the cruise phase of flight, for subsonic speed. This empirical method can be used for a new aircraft design before wind tunnel or flight test data becomes available.

This paper does not address cross-correlation which would be important for structural loads. Rather this paper is concerned with pressure levels at discrete points as a perquisite to avionics component vibroacoustic analysis.

Excitation Sources

Reference 1 notes:

> For the larger, jet-powered, well-streamline aircraft, high speed flows generate significant levels of turbulent boundary layer noise that usually constitutes the most important source of cabin noise during cruise.

Jet engine noise is another source. It may even be the dominant source at low frequencies. The impact of jet noise on the cabin environment is mitigated by the use of high-bypass engines with low-velocity exhaust and by locating the engines at outboard or aft positions. Further information on engine noise is given in Appendix A.

Reference Data

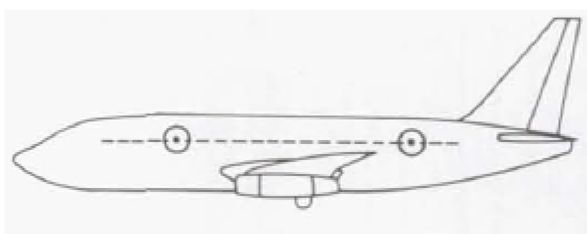

Figure 1. Boeing 737 Forward and Aft Measurement Locations

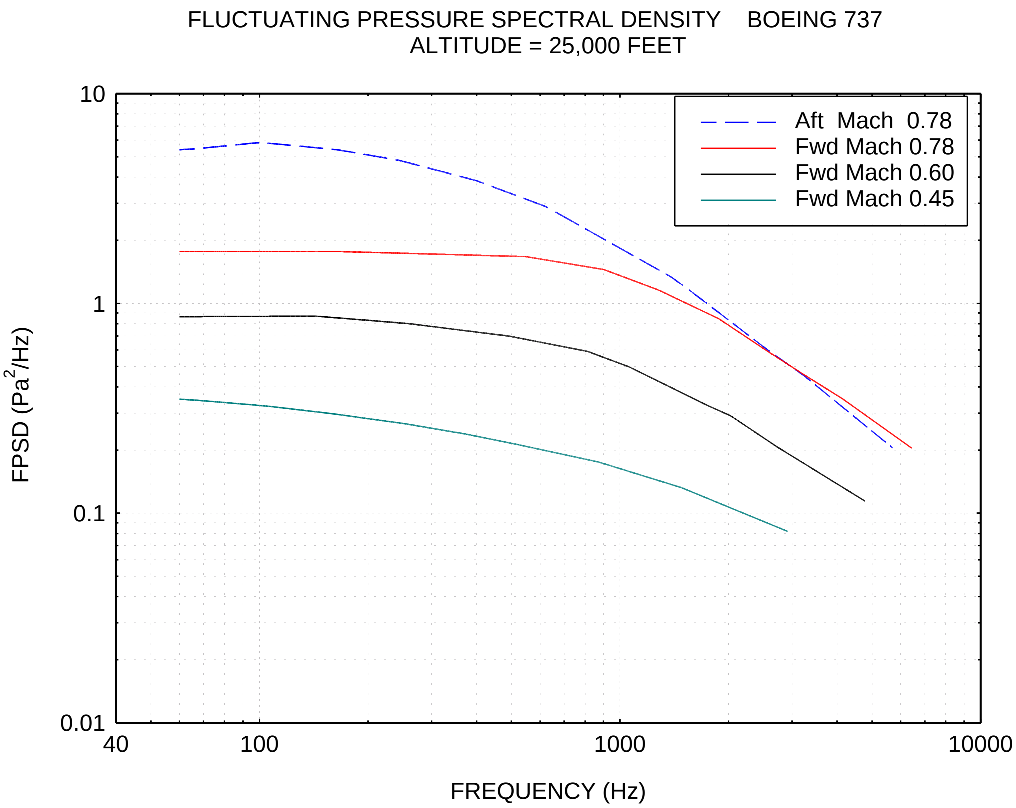

Figure 2.

The reference data is taken from Reference 1. Measurements were taken on the fuselage of a Boeing 737 aircraft flying at an altitude of 25,000 feet, as shown in the diagram in Figure 1.

The curves in Figure 2 are taken from Reference 1, page 275.

The fluctuating PSD coordinates are given in Appendix B, Table B-1. Equivalent SPL coordinates are given in Appendix C.

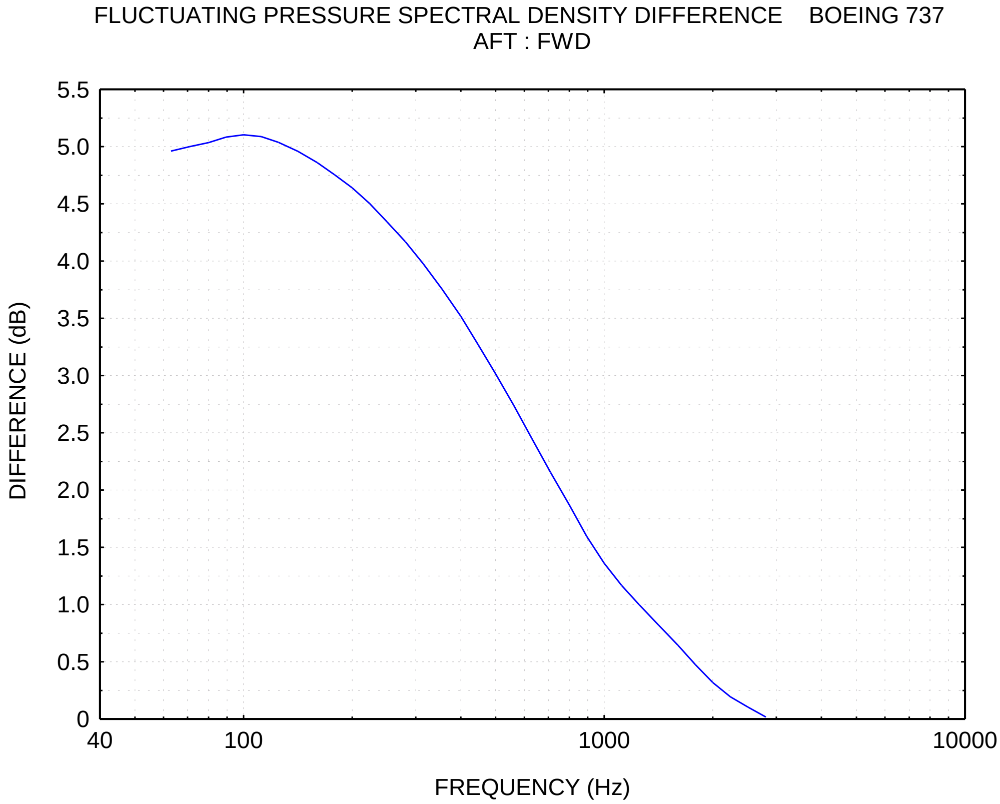

Figure 3.

The curve in Figure 3 is taken as the Forward FPSD relative to the Aft FPSD for the case of Mach 0.78. Assume that the same difference would occur for other Mach cases.

The coordinates for Figure 3 are given in Appendix B, Table A-2.

Scaling Method

The overall fluctuating pressure level, loosely referred to as sound pressure level (SPL), can be estimated using a formula from Reference 2.

$$\mathrm{SPL(dB)} = 104.6 + 40 \log\left(\frac{V}{100}\right) + 20 \log\left(\frac{\rho_e}{\rho_{sl}}\right) \quad \text{, ref 20 micro Pa} \tag{1}$$

where

V	True air speed (ft/sec)
ρ_e	Air density at altitude
ρ_{sl}	Air density at sea level

The air density variables may have any reasonable unit as long as the same unit is used for each.

With some further work, the overall fluctuating pressure level from equation (1) could be used to scale one of the curves in Figure 2 for a given air speed and air density.

Equivalent Scaling Method

The following scaling method is given in Reference 4. The pressure P_{rms} is

$$P_{rms} = 0.006\left(0.5\rho_o U^2\right) \tag{2}$$

where

ρ_o	air density at altitude
U	free-stream velocity

The decibel format is

$$\mathrm{SPL(dB)} = 20\log\left(\frac{P_{rms}}{P_{ref}}\right) = 20\log\left(\frac{0.006\left(0.5\rho_o U^2\right)}{P_{ref}}\right),\ P_{ref} = 20 \text{ micro Pa} \tag{3}$$

The scaling methods in equations (1) and (3) yield essentially the same result.

Extended Scaling Formula

Reference 4 also gives a scaling formula which accounts for the Mach number.

$$P_{rms} = \frac{0.006}{\left(1+0.14M^2\right)}\left(0.5\rho_o U^2\right) \tag{4}$$

Equation (4) is valid for both subsonic and supersonic flow.

The dynamic pressure q is

$$q = 0.5\rho_o U^2 \tag{5}$$

By substitution,

$$P_{rms} = \frac{0.006\ q}{1+0.14M^2} \tag{6}$$

$$\frac{P_{rms}}{q} = \frac{0.006}{1+0.14M^2} \tag{7}$$

Power Spectral Density

Reference 4 also gives a power spectrum formula.

A preferred method is given in Reference 5. See the attached flow case in this reference.

References

1. NASA Reference Publication 1258, Vol. 2, WRDC Technical Report 90-3052, Acoustics of Flight Vehicles: Theory and Practice, 1991.
2. NASA TN D-1086, Sound Pressures and Correlations of Noise on the Fuselage of a Jet Aircraft in Flight, 1961.
3. T. Irvine, Prediction of Sound Pressure Levels on Rocket Vehicles During Ascent, Revision E, Vibrationdata, 2011.
4. M. Lowson, Prediction of Boundary Layer Pressure Fluctuations, AFFDL-TR-67-167, Wright-Patterson AFB.
5. T. Irvine, Prediction of Sound Pressure Levels on Rocket Vehicles During Ascent, Revision E, Vibrationdata, 2011.

APPENDIX A

Jet Engine Noise

Turbofan blades undergo supersonic motion.

The total Mach number depends on the blade tangential velocity and on the airflow speed. Note that the speed of sound varies with air temperature, which varies with altitude.

Aerodynamic shock waves form in the airflow around the blades. The shock waves combine at the fan shaft frequency and its integer harmonics.

Minute differences in the blade dimensions due to manufacturing tolerances contribute to this effect. The shock wave in front of each blade has unique physical properties accordingly.

The resulting sound is referred to as *buzz-saw noise.* It is also known as Multiple Pure Tone (MPT) noise.

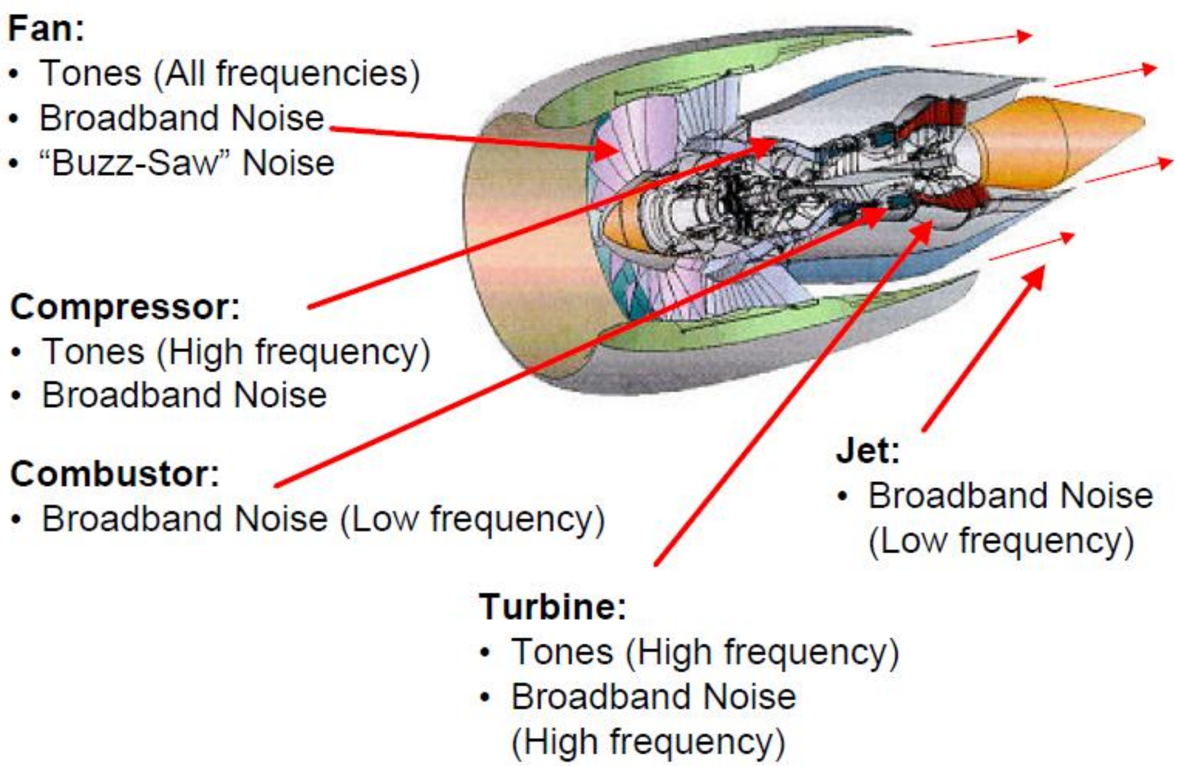

Figure A-1. Turbofan Engine Noise Sources

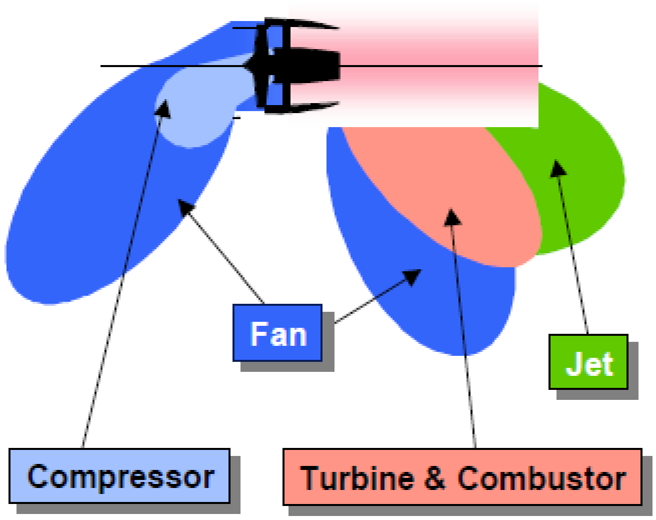

Figure A-2. Turbofan Engine Radiation Pattern

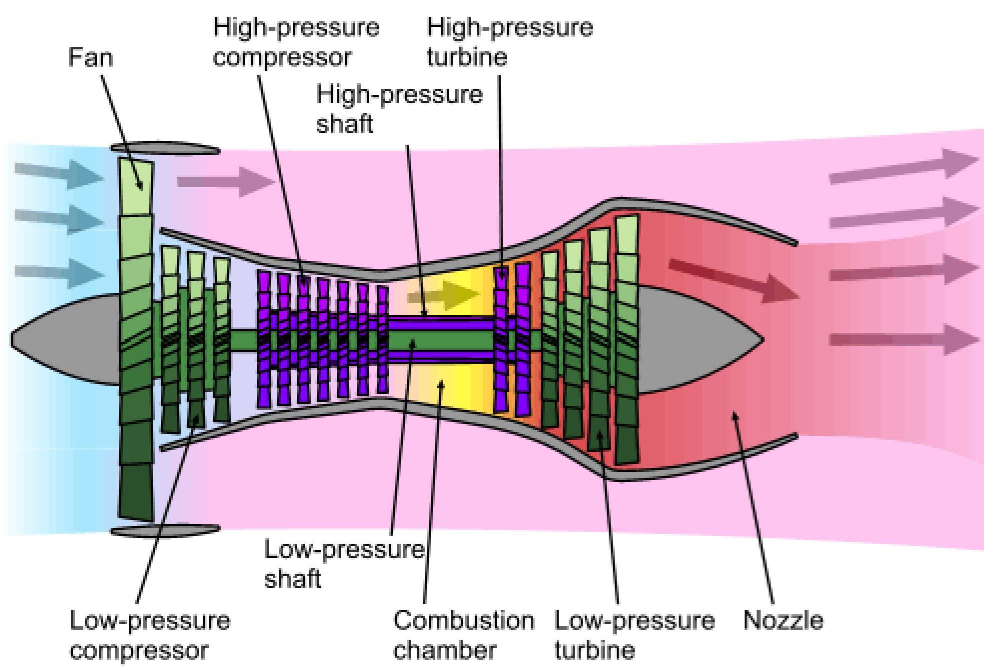

Figure A-3. Turbofan Engine Subsystems

The engine has two concentric rotors, which operate at different speeds. The low-pressure shaft drives the fan and the low-pressure turbine. The other shaft drives the compressor and high-pressure turbine.

APPENDIX B

Table B-1. Data Points for Figure 2				
Freq (Hz)	Aft M=0.78 (Pa^2/Hz)	Fwd M=0.78 (Pa^2/Hz)	Fwd M=0.60 (Pa^2/Hz)	Fwd M=0.45 (Pa^2/Hz)
63.0	5.43E+00	1.77E+00	8.65E-01	3.47E-01
71.0	5.53E+00	1.77E+00	8.65E-01	3.42E-01
80.0	5.63E+00	1.77E+00	8.66E-01	3.37E-01
89.4	5.74E+00	1.77E+00	8.67E-01	3.32E-01
100.0	5.82E+00	1.77E+00	8.67E-01	3.26E-01
111.8	5.76E+00	1.77E+00	8.68E-01	3.20E-01
125.0	5.65E+00	1.77E+00	8.68E-01	3.13E-01
141.4	5.53E+00	1.77E+00	8.67E-01	3.05E-01
160.0	5.42E+00	1.77E+00	8.56E-01	2.97E-01
178.9	5.28E+00	1.76E+00	8.44E-01	2.90E-01
200.0	5.10E+00	1.75E+00	8.30E-01	2.82E-01
223.6	4.94E+00	1.74E+00	8.18E-01	2.75E-01
250.0	4.75E+00	1.73E+00	8.05E-01	2.68E-01
280.6	4.51E+00	1.73E+00	7.87E-01	2.59E-01
315.0	4.28E+00	1.72E+00	7.68E-01	2.50E-01
355.0	4.05E+00	1.71E+00	7.48E-01	2.42E-01
400.0	3.84E+00	1.70E+00	7.30E-01	2.33E-01
447.2	3.58E+00	1.69E+00	7.13E-01	2.24E-01
500.0	3.33E+00	1.68E+00	6.94E-01	2.15E-01
561.3	3.09E+00	1.66E+00	6.68E-01	2.06E-01
630.0	2.85E+00	1.60E+00	6.42E-01	1.98E-01
709.9	2.54E+00	1.55E+00	6.17E-01	1.89E-01
800.0	2.27E+00	1.50E+00	5.92E-01	1.81E-01
894.4	2.04E+00	1.45E+00	5.56E-01	1.73E-01
1000.0	1.83E+00	1.36E+00	5.18E-01	1.63E-01

Table B-1. Data Points for Figure 2 (continued)				
Freq (Hz)	Aft M=0.78 (Pa^2/Hz)	Fwd M=0.78 (Pa^2/Hz)	Fwd M=0.60 (Pa^2/Hz)	Fwd M=0.45 (Pa^2/Hz)
1118.0	1.65E+00	1.26E+00	4.77E-01	1.54E-01
1250.0	1.47E+00	1.17E+00	4.32E-01	1.44E-01
1414.2	1.29E+00	1.06E+00	3.89E-01	1.35E-01
1600.0	1.12E+00	9.65E-01	3.52E-01	1.25E-01
1788.9	9.66E-01	8.81E-01	3.21E-01	1.16E-01
2000.0	8.34E-01	7.88E-01	2.94E-01	1.07E-01
2236.1	7.21E-01	6.94E-01	2.61E-01	9.89E-02
2500.0	6.21E-01	6.09E-01	2.29E-01	9.13E-02
2806.2	5.38E-01	5.35E-01	2.01E-01	8.47E-02
3150.0	4.66E-01	4.70E-01	1.77E-01	-
3549.7	3.96E-01	4.13E-01	1.56E-01	-
4000.0	3.37E-01	3.65E-01	1.38E-01	-
4472.1	2.88E-01	3.20E-01	1.23E-01	-
5000.0	2.46E-01	2.78E-01	1.15E-01	-

Table B-2. Data Points for Figure 3	
Freq (Hz)	Aft : Fwd (dB)
63.0	4.96
71.0	5.00
80.0	5.04
89.4	5.08
100.0	5.10
111.8	5.09
125.0	5.04
141.4	4.96
160.0	4.86
178.9	4.75
200.0	4.64
223.6	4.50
250.0	4.34
280.6	4.17
315.0	3.98
355.0	3.75
400.0	3.52
447.2	3.27
500.0	3.01
561.3	2.74
630.0	2.45
709.9	2.15
800.0	1.87
894.4	1.60
1000.0	1.36
1118.0	1.17
1250.0	1.00
1414.2	0.82
1600.0	0.64
1788.9	0.48
2000.0	0.32
2236.1	0.20
2500.0	0.10
2806.2	0.02

APPENDIX C

Table C-1. Equivalent SPL Curve for Figure 2				
Center Freq (Hz)	Aft M=0.78 (dB)	Fwd M=0.78 (dB)	Fwd M=0.60 (dB)	Fwd M=0.45 (dB)
63	112.1	107.2	104.1	100.2
80	114.0	109.0	105.9	101.8
100	115.0	109.9	106.8	102.5
125	116.4	111.4	108.3	103.8
160	116.9	112.0	108.9	104.3
200	117.5	112.9	109.6	104.9
250	118.4	114.0	110.7	105.9
315	119.1	115.1	111.6	106.8
400	119.3	115.8	112.1	107.1
500	119.8	116.9	113.0	108.0
630	120.3	117.8	113.8	108.7
800	120.1	118.3	114.2	109.1
1000	120.1	118.8	114.6	109.6
1250	120.6	119.6	115.3	110.5
1600	120.0	119.3	115.0	110.5
2000	119.7	119.4	115.1	110.8
2500	119.5	119.5	115.2	111.2
3150	119.4	119.5	115.2	103.5
4000	118.8	119.1	114.9	-
5000	118.5	119.1	109.8	-
Overall SPL	131.8	130.3	125.8	120.3

APPENDIX D

Table D-1. Atmospheric Properties					
Altitude (km)	Pressure (kPa)	Mass Density (kg/m^3)	Temp. (Kelvin)	Temp. (°C)	Speed of Sound (m/sec)
0	101.3	1.226	288	14.9	340.2
1	89.85	1.112	282	8.4	336.3
2	79.47	1.007	275	1.9	332.4
3	70.09	0.9096	269	-4.7	328.5
4	61.62	0.8195	262	-11.2	324.5
5	54.00	0.7365	256	-17.7	320.4
6	47.17	0.6600	249	-24.2	316.3
7	41.05	0.5898	243	-30.7	312.1
8	35.59	0.5254	236	-37.2	307.9
9	30.73	0.4666	230	-43.7	303.7
10	26.43	0.4129	223	-50.2	299.3
11	22.62	0.3641	217	-56.2	295
12	19.33	0.3104	217	-56.2	295
13	16.51	0.2652	217	-56.2	295
14	14.11	0.2266	217	-56.2	295
15	12.06	0.1936	217	-56.2	295
16	10.30	0.1654	217	-56.2	295
17	8.801	0.1413	217	-56.2	295
18	7.519	0.1207	217	-56.2	295
19	6.424	0.1032	217	-56.2	295
20	5.489	0.0881	217	-56.2	295

The values in Table D-1 are taken from Reference are take from Reference 3. The values are approximate. The actual values depend on the time of day, season, weather conditions, etc.