inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 7.6

STUDY OF SOUND SCATTERING ON LAUNCH VEHICLES INTERSTAGES DURING HORIZONTAL FIRING OF ROCKET MOTORS

P. Jeyajothiraj, A.R. Acharya

Vikram Sarabhai, Space Center, 695 022, Trivandrum, India

Tel.: +91 471 564 492 / Fax: +91 471 415 224 / Email: v_adimurthy@vssc.org

Keywords:
SOUND SCATTERING, LAUNCH VEHICLE, INTERSTAGE, JET NOISE

ABSTRACT

Experimental investigation of sound scattering on a typical launch vehicle interstage is described. In the experiment, acoustic measurements were carried out on an interstage kept vertically by the side of a rocket exhaust during horizontal static firing. Free field acoustic levels were obtained by another acoustic sensor. The effect of sound scattering was studied by analyzing the measured data. In the second part, the jet noise prediction packages for launch vehicle are suitably modified to predict noise environment during static horizontal firing. The predicted values are compared with the measurements.

1 - INTRODUCTION

Scattering of waves have attracted considerable attention from researchers working in electromagnetic fields, physical and underwater acoustic fields. Lending blue colour to the sky to that of noise prediction methods for launch vehicle – scattering effects play a major role. In the case of helicopter noise predictions the free field prediction needs to be corrected by a factor varying from -20 dB to 4 dB due to the presence of fuselage [1]. Besides, the understanding of scattering of sound on launch vehicle structures is essential for the specification of environmental test levels.

Scattering of sound waves was first investigated mathematically by Rayleigh [2] for a rigid sphere. The launch vehicle interstages and heat shield have generally cylindrical shapes. For rigid circular cylinders, a mathematical solution was developed by Morse [3]. This solution was extended to include the effect of compressional wave inside cylinder by Morse, et. al. [4] which was further modified by James J Faran Jr. [5] by taking into account the shear wave which could exist in a solid cylinder.

The scattered field, which results from sound wave incident on an elastic cylinder, differs considerably from the field obtained from the scattering on a rigid cylinder of the same shape. The incident sound field excites forced vibration of the elastic object. These vibrations give rise to sound radiation. The scattered field is partly governed by these vibrations which are determined by the dynamic characteristics of the elastic object. Hence, the scattered sound field by an object is the resultant of " rigid body scattering " which is common to both elastic and rigid scatters and of " radiation scattering " which is peculiar to elastic scattering. Sound scattering from elastic shells and stiffened elastic shells were studied by Miguel C.

Junger [6], [7]. Scattering of obliquely incident acoustic wave by solid cylinder was studied by Lawrence Flax et. al. [8], that by hollow cylinder by Fernand Leon et. al. [9] and that by cylindrical shells with deck type internal plate by Y. P. Guo [10]. In recent times, direct numerical simulation of acoustic scattering was carried out by Oliver A. Laik and Philip J. Morris for the low frequency problem (of the order of 10 Hz) [1]. In the experimental side, sound scattering on wooden cylinder (rigid) was measured by Francis M. Wiener in an anechoic chamber using a condensor microphone [11]. Sound scattering by metallic cylinder in water was studied by James J Faran Jr. [5]. Though many other experimental studies have been carried out on different types of cylinders, there is very little information available on sound scattering on launch vehicle interstage which houses a number of sensitive electronic and control system packages. In this paper experimental investigation of sound scattering on a typical launch vehicle interstage, a thin shell structure with many external stiffners, is described. The existing jet noise prediction packages were modified to predict noise environment during static horizontal firing and prediction by the modified packages are compared with the measurement.

2 - EXPERIMENTAL STUDY

The test set up is shown in Fig. 1. The rocket motor was fired horizontally. Test specimen (a typical interstage of a launch Vehicle) was mounted firmly in the vertical position. Three microphones were flush mounted on the skin of the specimen at three locations 90 degree apart at a height of 2.8 metres from ground with middle microphone (M1) facing the jet and its axis perpenticular to the jet axis. The test specimen middle microphone was at radial distance of 58.6 metres from axis of the jet and at an axial distance of 15 metres from nozzle exit. This location was selected based on the constraint of temperature rise on the specimen due to radiative heating of the jet. The free field microphone M4, was kept at the mirror image location of microphone M1 with respect to the vertical plane passing through the jet axis. The free field microphone was also facing the jet and was fixed on a stand. All the microphone locations on the specimen are shown in Fig. 1. Microphone M2 and M3 were also flush mounted on the specimen and their locations are shown in Fig. 1. Endevco model 2510 piezoelectric microphones were used for the study. The free field corrections supplied by the manufacturer were used to correct the value obtained through the free field microphone M4.

3 - ANALYSIS

The overall sound pressure level history obtained from microphone M1 is compared with that of microphone M2, M3 and M4 in figures 2, 3 and 4 respectively. Microphone M1 measured the level of the entire jet. As microphone M2 was not in the line of sight of the initial portion of the jet, its levels are lower by about 3 dB with reference to microphone M1. Since microphone M3 was in the shadow region of most of the portion of the jet, the acoustic levels are about 5 dB less than that of microphone M1. The free field microphone M4, which was mounted at the mirror image point of microphone M1 read about 6 dB less compared to microphone M1. It confirms the pressure doubling on the jet facing side of the specimen. Frequency spectra of all the microphones are compared in Fig. 5. Similar differences are seen in most of the frequency band sound pressure levels of various microphones. Especially the free field microphone M4 had registered about 6 dB less than the corresponding specimen mounted microphone M1, except for 20 and 25 Hz frequency bands.

4 - JET NOISE PREDICTION METHODS

Jet noise environment during lift-off of a launch vehicle is predicted by the package JAPDSA (Jet acoustic prediction by Discrete Source Allocation) and by JAPSSD (Jet Acoustic Prediction by Spectrum Source Distribution) [12]. These methods are based on dynamic similarity and use the measured acoustic data of rocket jets. A brief description of the packages is given below.

4.1 - JAPDSA package

This package assumes that the flow consists of apparent sources of single frequency distributed at various locations in the stream with respect to the nozzle exit plane. These apparent sources are considered statistically independent of one another. Hence, their effect can be combined i.e. their mean square pressure values can be added directly to get the overall value. The apparent source location is determined by fitting data measured along a simulated vehicle to an inverse square loss curve and extrapolated to zero distance. This method assumes that no obstructions interfere with the line of sight between the vehicle and the flow. Hence, by this method, it is not possible to account for any shielding that may exist.

4.2 - JAPSDD package

In this method, noise in each frequency band, is generated throughout the flow. The rocket exhaust is divided into a number of slices. Each slice contribution to the sound pressure is estimated and added to get the jet noise level at the required location. The advantage of this method is that the shielding between the exhaust and the vehicle can be accounted. Hence, when acoustic shielding (Bucket type deflector or covering of the deflected jet) has to be considered, the second method has to be used. For other cases, first method is used, as it is simpler to apply.

It is seen that the prediction compares well with flight measurement. In the overall levels and in some of the frequency bands, the prediction is within ± 2.5 dB. In the most of the remaining frequency bands, the predicted values are within ± 5 dB of measured values.

4.3 - Modification for ground reflection

During static horizontal firing of rocket motor, ground reflections are dominant. The ground reflection effects are included by Image Source Method [13]. This method assumes that the ground is rigid.

The mirror image jet with respect to the ground is considered and the acoustic sources are distributed accordingly. The contributions from the jet as well as the image jet are added to get the jet noise level at the required location.

The free field microphone M4 levels differ from the test specimen microphone M1 levels only by the scattering effect of the body. Due to scattering of sound on solid surface, the sound pressure levels can increase by about 6 dB on the surface. As suggested by Franken [14], the levels for microphone M1 are increased by 6 dB in the frequency range given by

$$F \geq \frac{a}{\Pi d}$$

Where "F" is the frequency, "a" is the speed of sound, "d" is the diameter of the test specimen.

In the JAPSSD package the supersonic core length (one of the main parameters in the package) is only a function of Mach number. It is known that the jet noise levels are highly dependent on nozzle exit pressure ratio and to a lesser extent on the other gas parameters. Hence the JETSOUP package [15], which takes into consideration the nozzle exit conditions, is used to obtain the supersonic core length. When this core length is used in JAPSSD package, the acoustic levels predicted compares well with measurement. The comparison is shown in Fig. 6.

The predicted overall sound pressure levels by the two methods (with ground reflection) are compared with measurements from microphones M1 and M4 in Fig. 7. The overall sound pressure levels predicted by JAPSSD are closer to the measured value than those by JAPDSA. The few peaks seen in the measured data are due to higher mixing induced by secondary injection of fluid. The frequency spectra predicted by JAPDSA and by JAPSSD with measurement are compared with measurements in Fig. 8 and Fig. 9. From this figures, it is concluded the JAPSSD predicts the acoustic environment for static firing more accurately.

5 - CONCLUSION

Experimental investigation of sound scattering on a typical launch vehicle interstage was carried during the horizontal firing of a rocket motor. It is observed that the sound pressure doubling almost occurs on the side of the cylindrical specimen facing the jet due to sound scattering. To account for ground reflection, jet noise prediction packages are modified by incorporating image jet. Modified JAPSSD package (with the usage accurate supersonic core length) predicts the acoustic environment during static horizontal testing very well. More detailed measurement may lead to better understanding the scattering process launch vehicle interstages.

ACKNOWLEDGEMENTS

The authors express their heart felt thanks to Shri K. Viswanathan, Deputy Director, VAST, SHAR for providing all necessary support and encouragement to carry out the measurements. We are very much thankful to Shri S. Ramakrishnan, Project Director, for giving us the test specimen. Sincere thanks are due to Shri Sathiyanarayana GM, VAST for very useful discussions and to Shri Laxminarayana, Shri Jayaseelan, Shri KSR Anjaneyulu, Shri J. V. Rao, Shri Veera Raju and Shri Anantha Naik for the assistance given in measuring the acoustic levels. Sincere thanks are due to Dr. V. Adimurthy, Group Director, Shri S. A. Palaniswamy, Group Head, Dr R. Balu, Shri K. L. Handoo, Shri G. Muthuraman and T.Narayana, Shri C. Ravikumar for the encouragement and valuable suggestions. Thanks are due to Shri A. K. Verma and Shri M. J. Chacko for the radiative heat flux computation and to Shri Thomas C.Babu for giving his graphical software GMARK and SLIDE.

REFERENCES

1. **Oliver A. Laik and Philip J. Morris**, Direct Simulation of Acoustic Scattering by Two- and Three-Dimensional Bodies, *Journal of Aircraft*, Vol. 37(1), pp. 68-75, 2000

2. **Lord Rayleigh**, *Theory of Sound*, 1945

3. **M. Morse**, *Vibration and Sound*, 1948

4. **Morse, Lowan, Feshbash and Lax**, *Mathematical Tables*, 1946

5. **James J. Faran, Jr.**, Sound Scattering by Solid Cylinders and Spheres, *The Journal of the Acoustical Society of America*, Vol. 23(4), pp. 405-418, 1951

6. **Miguel C. Junger**, Sound Scattering by Thin Elastic Shells, *The Journal of the Acoustical Society of America*, Vol. 24(4), pp. 366-373, 1951
7. **Miguel C. Junger**, The Concept of Radiation Scattering and Its Application to Reinforced Cylindrical Shells, *The Journal of the Acoustical Society of America*, Vol. 25(5), pp. 899-903, 1953
8. **Lawrence Flax, V.K. Varadan and V.V. Varadan**, Scattering of an Obliquely Incident Acoustic Wave by an Infinite Cylinder, *The Journal of the Acoustical Society of America*, Vol. 68(6), pp. 1832-1835, 1980
9. **Fernand Leon, Florence Lecroq, Dominaque Decultot and Gerard Maze**, Scattering of an Obliquely Incident Acoustic Wave by an Infinite Hallow Cylindrical Shell, *The Journal of the Acoustical Society of America*, Vol. 91(3), pp. 1388-1397, 1992
10. **Y.P.Guo**, Acoustic Scattering from Cylindrical Shells with Deck-type Internal Plate at Obliquely incidence, *The Journal of the Acoustical Society of America*, Vol. 99(5), pp. 2701-2713, 1996
11. **Francis M. Weiner**, Sound Diffraction by Rigid Spheres and Circular Cylinders, *The Journal of the Acoustical Society of America*, Vol. 19(3), pp. 444-451, 1947
12. **P. Jeyajothraj and M. S. Sastry**, Prediction of Jet Noise Levels On Launch Vehicles and Comparison with Flight Data, In *National Aerodynamic Conference, Trivandrum*, pp. 229-244, 1999
13. **L. C. Sutherland and D.Brown**, *Prediction method for Near Field Noise Environments of VTOL Aircraft*, AFFDL-TR-71-180, 1972
14. **P. A. Franken**, *Methods of Space Vehicle Noise Prediction*, WADC Tech. Rept. 58-343, 1960
15. **P.Jeyajothiraj, M. S. Sastry and Thomas C. Babu**, *Computation of Flow Properties for Slightly Overexpaned, Underexpanded and Properly Expanded Jets*, VSSC: TR: 02: 192: 80, 1980

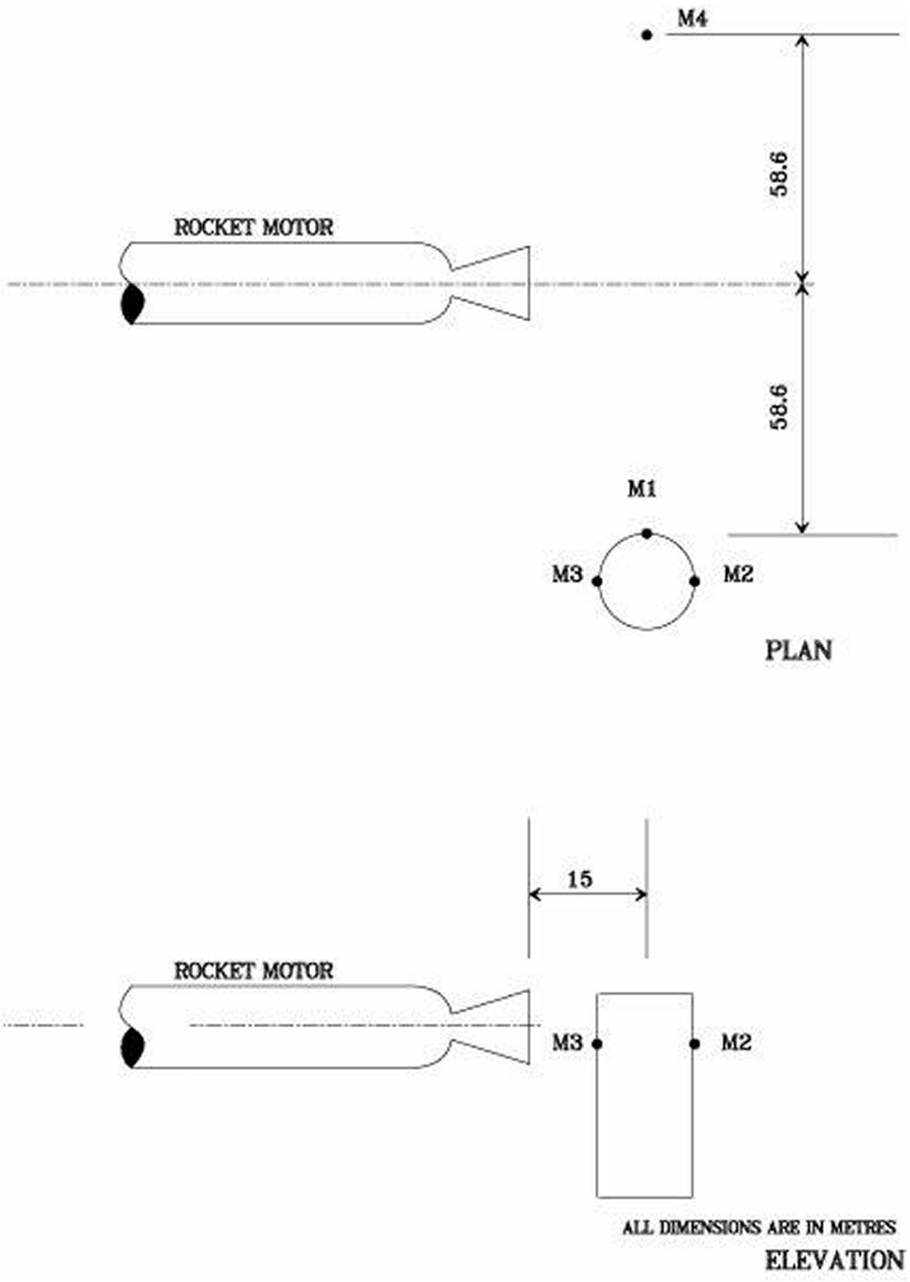
M4
58.6
ROCKET MOTOR
58.6
M1
M3
M2
PLAN
15
ROCKET MOTOR
M3
M2
ALL DIMENSIONS ARE IN METRES
ELEVATION

Figure 1.

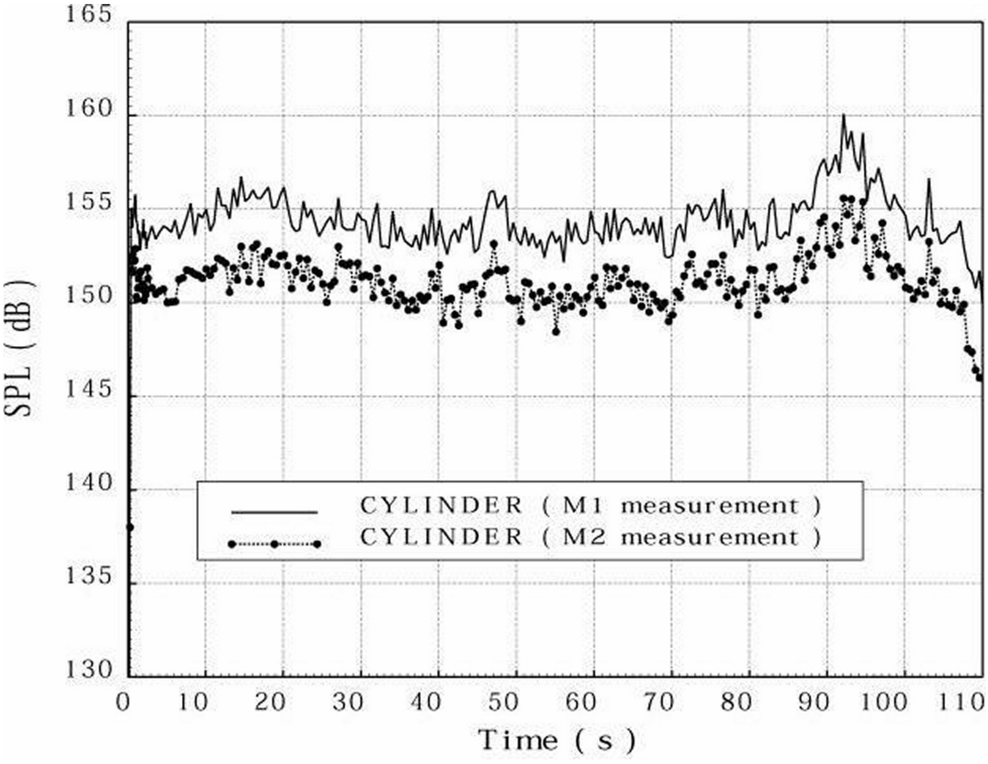

Figure 2.

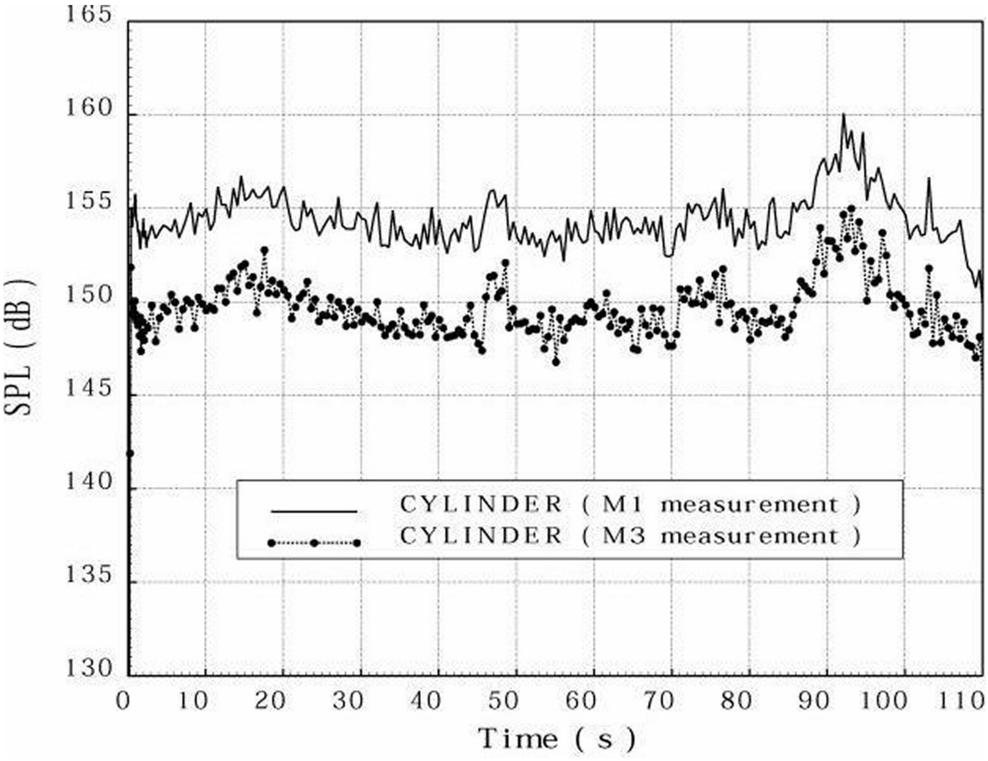

Figure 3.

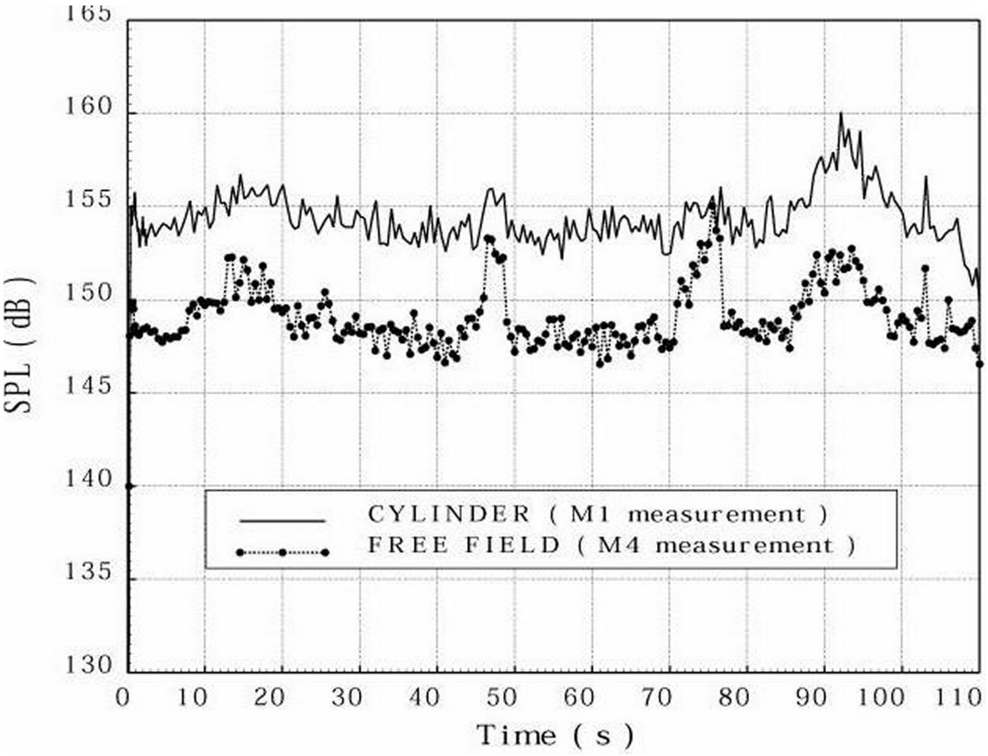

Figure 4.

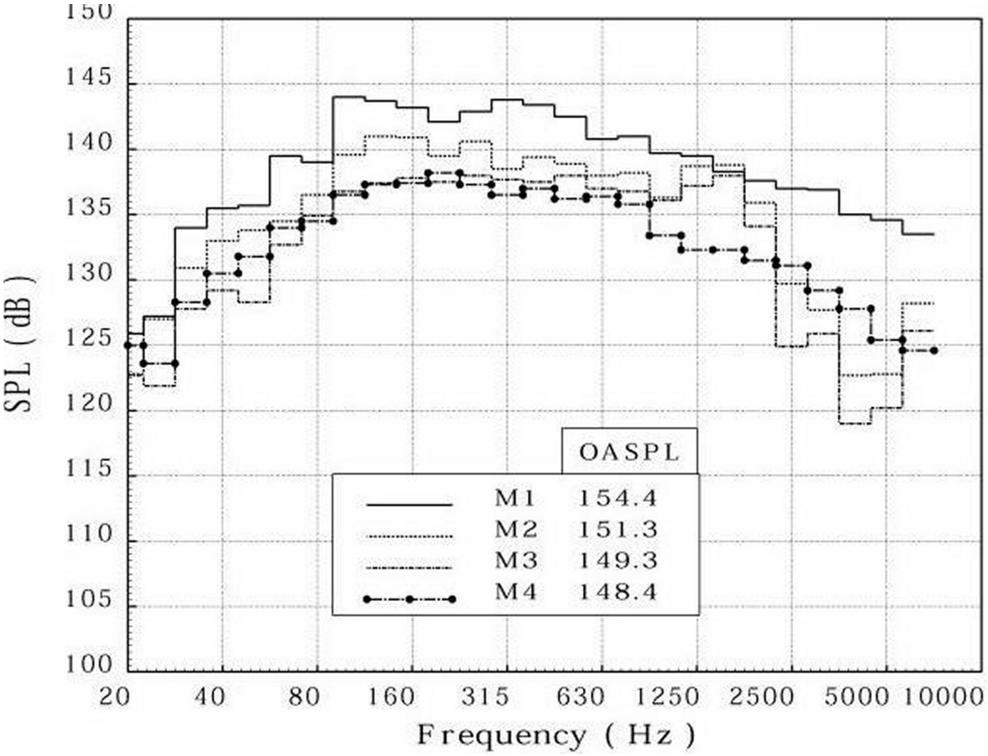

Figure 5.

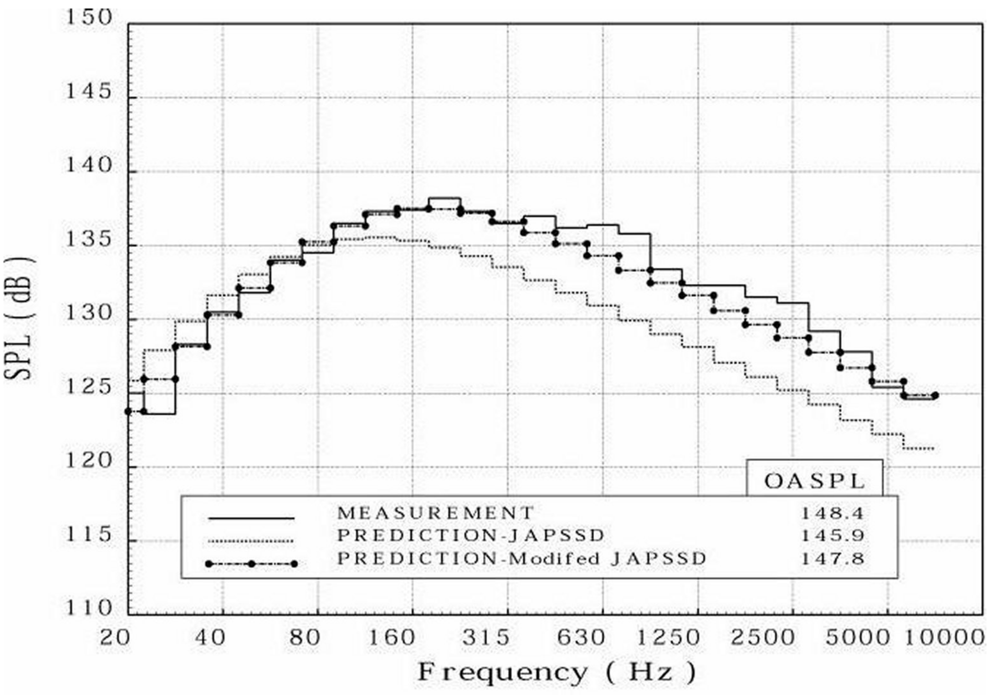

Figure 6.

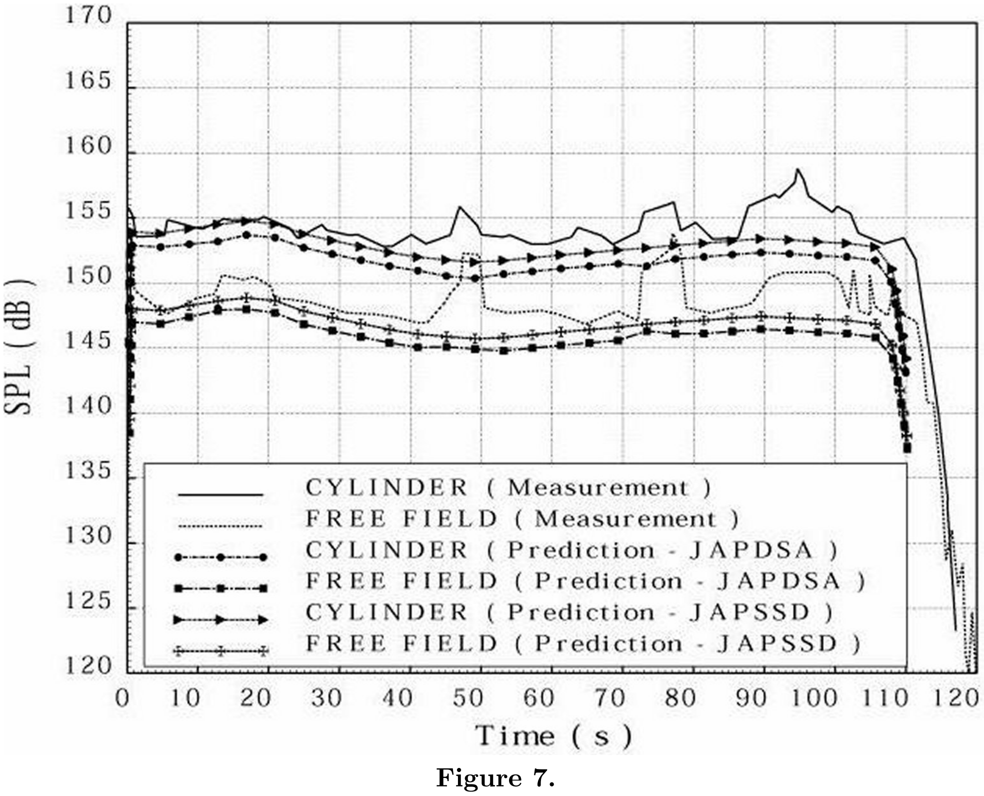

Figure 7.

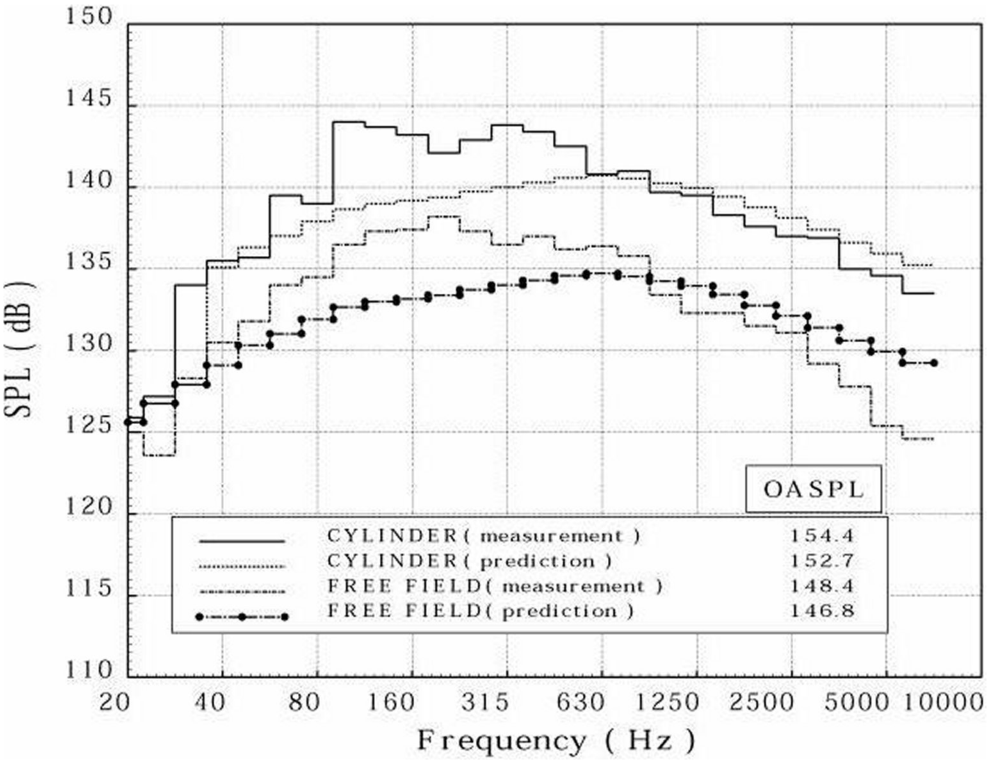

Figure 8.

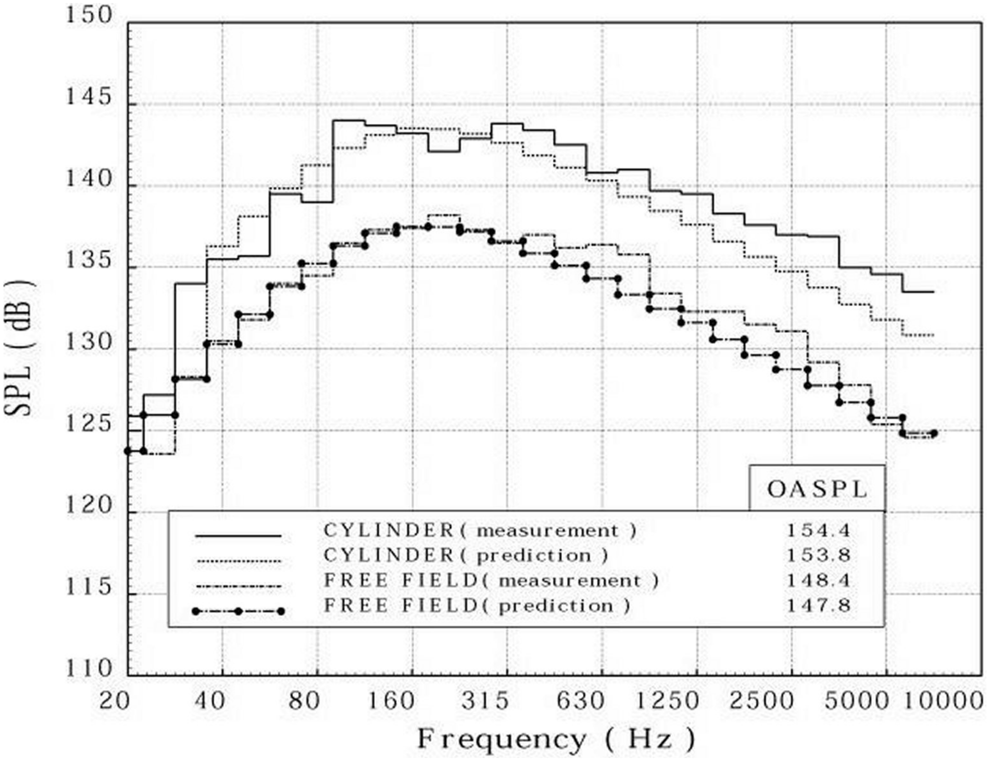

Figure 9.