FINAL

PREDICTION AND VALIDATION OF HIGH FREQUENCY VIBRATION RESPONSES OF NASA MARS PATHFINDER SPACECRAFT DUE TO ACOUSTIC LAUNCH LOAD USING STATISTICAL ENERGY ANALYSIS

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Biography

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Abstract

Mid and high frequency structural responses of a spacecraft during the launch condition are mainly dominated by the intense acoustic pressure field over the exterior of the launch vehicle. The prediction of structural responses due to the acoustic launch load is therefore an important analysis for engineers and scientists to correctly define various dynamics specifications of the spacecraft. A Statistical Energy Analysis model of the NASA's Mars Pathfinder spacecraft has been developed to obtain high frequency structural responses due to the acoustic launch load up to 2,000 Hz. The predicted structural responses of the spacecraft have been correlated with the test data obtained at Jet Propulsion Laboratory's acoustic reverberation chamber. Overall good agreements have been found between the SEA responses and acoustic test data in high frequencies.

Keywords

Statistical Energy Analysis, SEA, High Frequency Responses, Vibro-Acoustic Responses.

Introduction

Jet Propulsion Laboratory (JPL) is NASA's lead center for robotic exploration of the solar system. JPL's missions to Mars began in the early 1960's and recently in 1997, JPL sent a remotely controlled rover to Mars in a spacecraft named Pathfinder. Mars Pathfinder not only accomplished the demonstration of a way to deliver an instrumented lander and a free ranging robotic rover to the surface of Mars but also returned an unprecedented amount of data and outlived its primary design life. JPL is in charge of the current and future Mars missions including Mars Exploration Rover (MER) program. The MER spacecraft is scheduled to be launched in 2003.

The mission to Mars consists of various phases of flight sequences including launch, cruise, entry, descent and landing. Definition of dynamics specifications of a spacecraft during the launch condition is critical because the spacecraft experiences high frequency acoustic noise as well as low frequency structure-borne random vibrations from the launch vehicle engines and motors [1]. This paper deals with a mathematical prediction model based on Statistical Energy Analysis (SEA) approach to predict structural responses generated by the high frequency acoustic noise during the launch condition.

To investigate vibro-acoustic responses of a complicated dynamic system such as Mars Pathfinder spacecraft is challenging. The more familiar numerical methods such as Finite Element Method (FEM) or Boundary Element Method (BEM) are not efficient or accurate in high frequencies or in modally dense systems. However, SEA can be more useful to predict system responses in high frequencies because the statistical nature of the theory does not require a higher degrees of freedom model [2]. Various papers have been published to document the applications of the SEA theory to model various products. The present applications include Boeing's 737 aircraft [3] and Raytheon's Premier I small business jet aircraft [4].

In the following discussions, SEA model of the NASA's Mars Pathfinder spacecraft is explained. Next, model validation is addressed. The obtained SEA structural responses of the spacecraft are correlated with the acoustic test data obtained at JPL's acoustic reverberation chamber.

Mars Pathfinder SEA Model

The Mars Pathfinder SEA model has been developed based on the FEM model of the spacecraft. Figure 1 shows FEM model of Mars Pathfinder showing Heatshield, Backshell and Cruise Stage of the spacecraft. The free ranging rover is mounted on one side of the Lander, which is located inside the spacecraft. The SEA model does not include the cruise stage. The reasons are 1. Power input from the cruise stage to backshell due to the acoustic load is minimal. 2. Spacecraft model without the cruise stage was tested at JPL's acoustic reverberation chamber (Figure 2). Figure 3 shows Mars Pathfinder SEA model developed in AutoSEA Version 2.2. AutoSEA Version 2.2 is a SEA software package developed by the Vibro-Acoustic Sciences. The lander located inside the spacecraft is shown in Figure 3. The acoustic load level inside the payload section of the Boeing's Delta II launch vehicle is 146 dB(A) which is shown in Figure 4. Diffuse acoustic field of 146 dB(A) is modeled as external excitations in the analysis. The vibration paths from heatshield and backshell to lander are assumed to be the acoustic cavities inside the spacecraft.

Structural Subsystems

The SEA model includes approximately 130 structural subsystems representing the complete Mars Pathfinder spacecraft including heatshield, backshell and lander. The rover and the equipments located on the petals of the lander were modeled by calculating effective structural density of each petal. Approximately half the weight of the spacecraft is non-structural. Non-structural masses also have been incorporated by calculating effective densities of the structural subsystems as shown in Equation 1. The spacecraft is mainly built with Honeycomb composite materials. Structural damping loss factors of the composite materials are unknown. Damping loss factor of 1% was used for all of the structural subsystems. M and ρ represent mass and density respectively.

$$\rho_{new} = \left[\frac{M_{structural} + M_{non-structural}}{M_{structural}} \right] \cdot \rho_{structural} \qquad (1)$$

Acoustic Subsystems

The SEA model includes approximately 5 acoustic subsystems representing cavities inside the spacecraft. These cavities transmit acoustic power inputs from heatshield and backshell to lander. Absorption and fill rate of the cavities are unknown. Acoustic absorption of 0.1% was used for all of the acoustic subsystems.

Model Validation and Correlation

The obtained random vibration test data have been correlated with the SEA results at various locations of the spacecraft. Structural response of the SEA model at the heatshield center in Power Spectral Density (PSD) has been correlated with the acoustic test data in Figure 5 from 100 Hz to 2,000 Hz. Good agreement is observed across the whole frequency spectrum. The difference between the predicted response and the test data is suspected to be due to incorrect power calculation, which is determined by the diffuse acoustic spectrum and the joint acceptance of the structural subsystems. In addition, SEA model simplification or complication also contributes to the prediction inaccuracy. Despite some discrepancies between the SEA response and measured test data, the SEA model is able to predict the response reasonably well, especially in the 300 to 2,000 Hz ranges.

Figure 6 shows SEA structural response at the boundary of the heatshield in PSD. SEA response is in good agreement with the test data especially in higher frequencies above 400 Hz. One of the main reasons of discrepancies in low frequencies can be assumed to be due to the formulation of radiation efficiencies in SEA theory. Approximately half of the Mars Pathfinder's weight is non-structural and it is known that classic SEA radiation efficiencies of the mass loaded panels are not efficient in low frequencies. Several methods have been proposed to increase the accuracy of the structural responses in low frequencies. Examples include NASA Lewis / VAPEPS Path 49 method [5].

SEA structural response at the backshell center in PSD is compared with the test data in Figure 7. The SEA response is well correlated with the test data above 300 Hz. Figure 8 shows structural response of the SEA base petal model of the lander. Communication equipments and equipment shelf on the base petal have been modeled in the analysis by calculating effective density of the base petal. The measured test data of the base petal and equipment shelf have been compared with the SEA response in Figure 8. The SEA response is in good agreement with the test data.

Conclusions

A Mars Pathfinder SEA model is developed. Diffuse acoustic loading has been applied on the spacecraft as the power to the model. Predicted vibration levels have been correlated with the JPL's acoustic test data. The SEA responses have been found in good agreement with the test data. The SEA model over-predicted responses in relatively low frequencies. Radiation efficiencies should be improved to correctly predict SEA responses in low frequencies. Further model refinement and validation should also be done to improve the SEA results.

Acknowledgements

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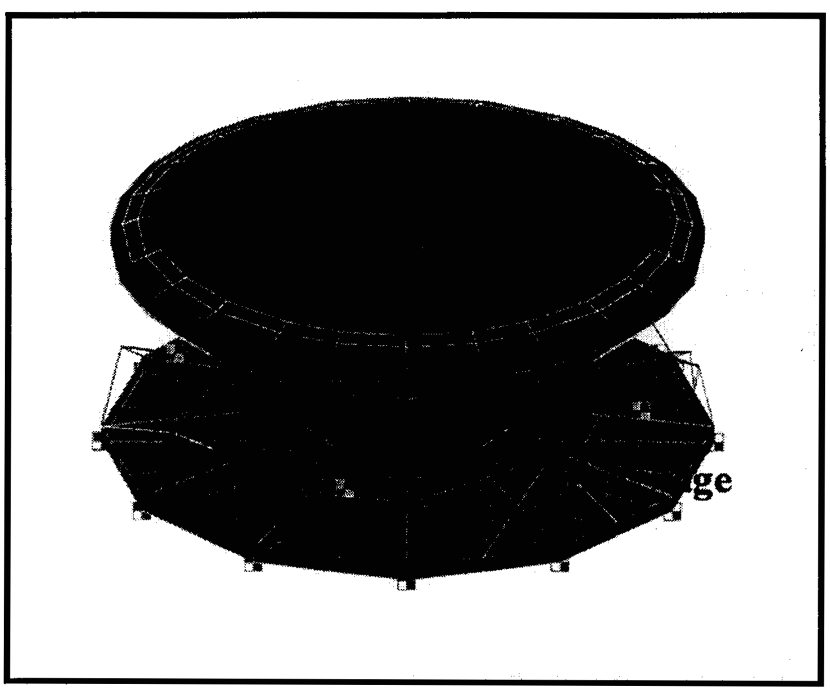

Figure 1 – Mars Pathfinder FEM Model

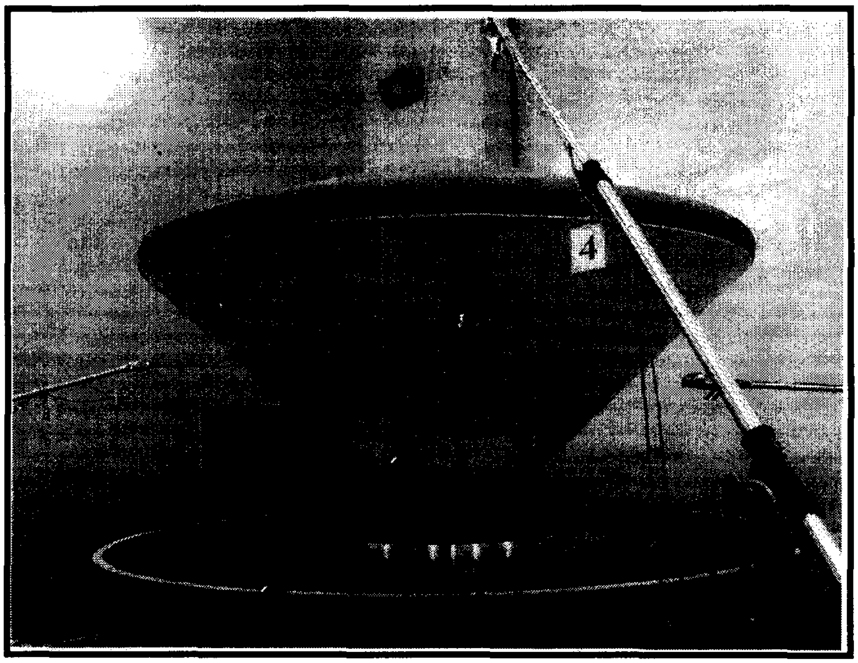

Figure 2 – Mars Pathfinder Test Model At JPL's Acoustic Chamber

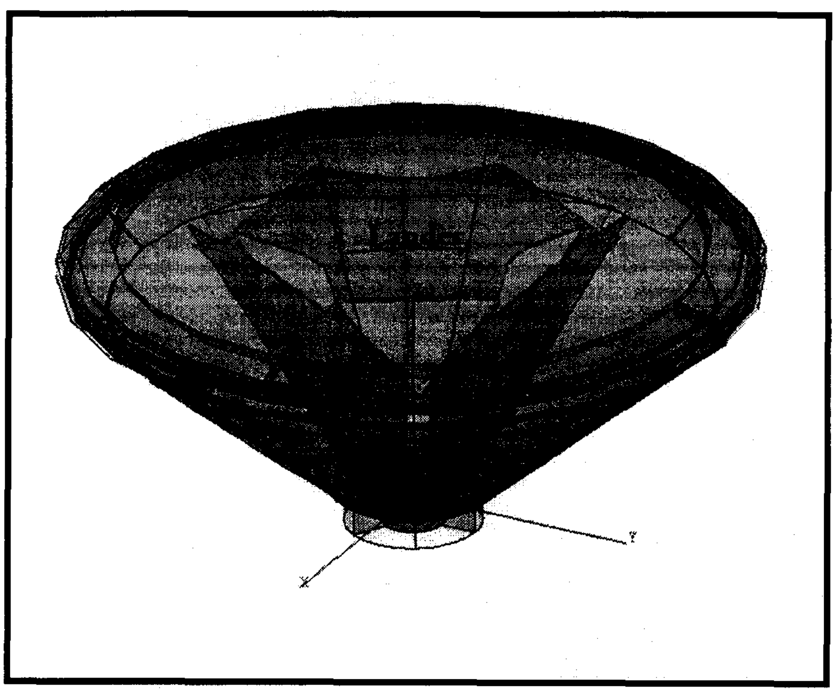

Figure 3 – Mars Pathfinder SEA Model

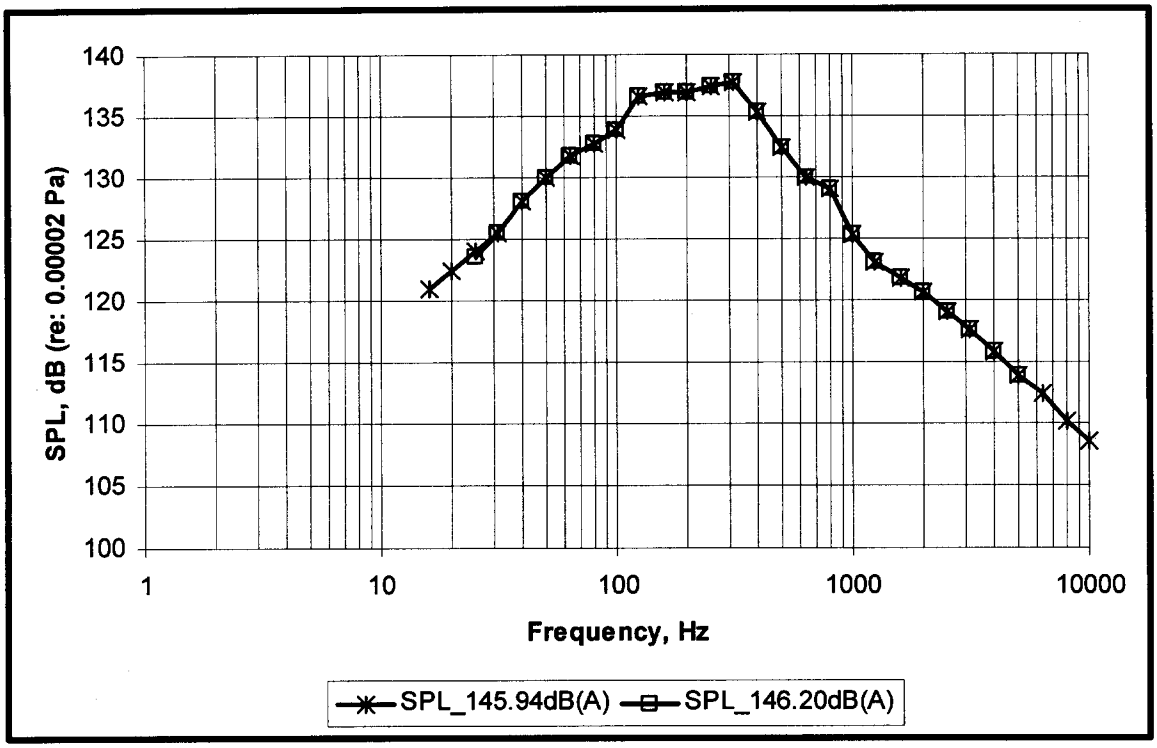

Figure 4 – Acoustic Load Level 146 dB(A)

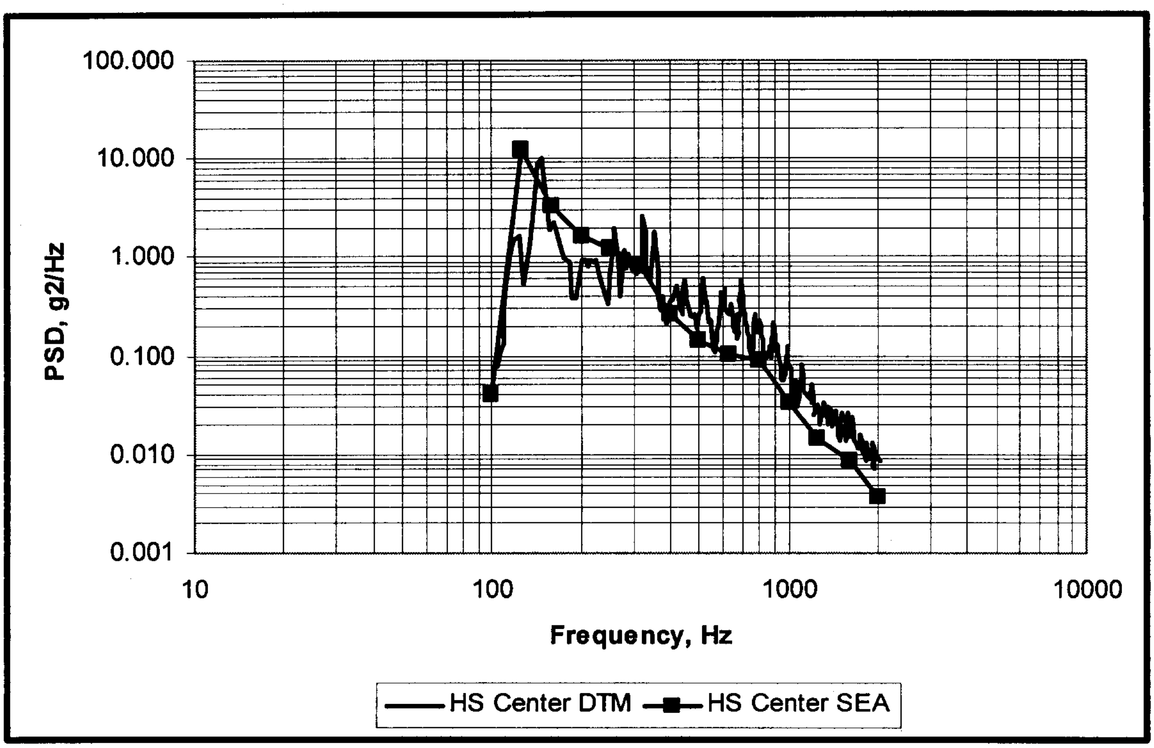

Figure 5 – SEA Response At Heatshield Center Compared With Test Data

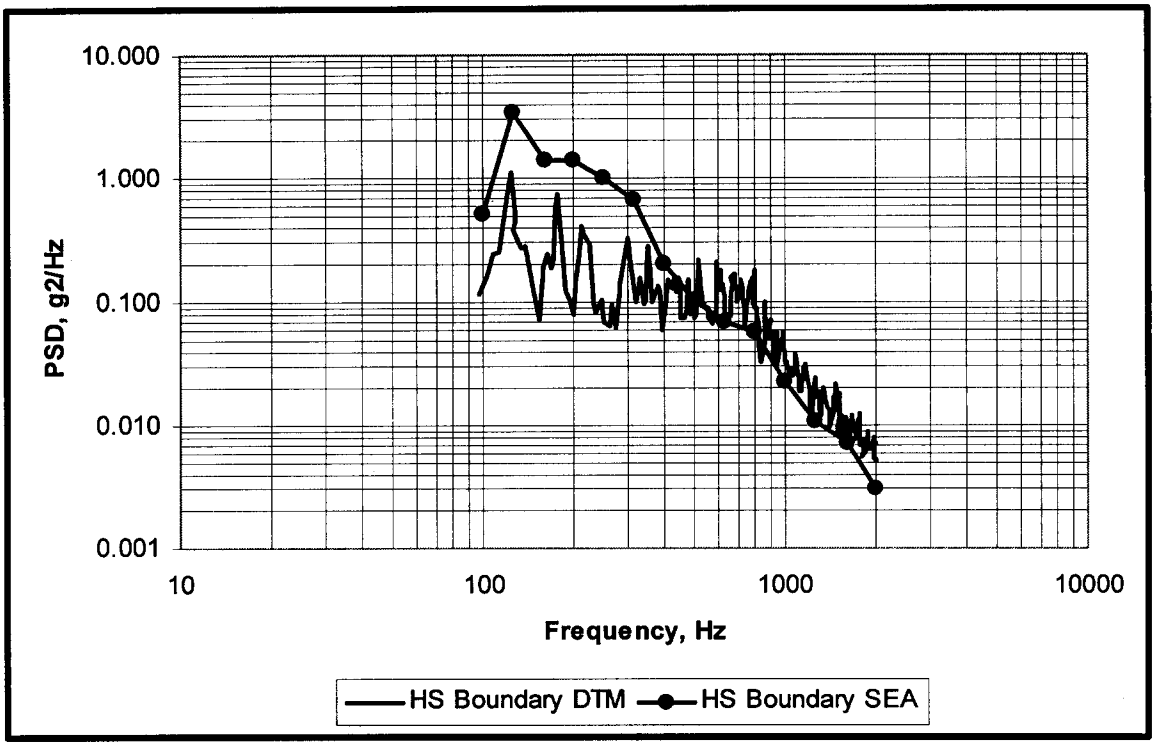

Figure 6 – SEA Response At Heatshield Boundary Compared With Test Data

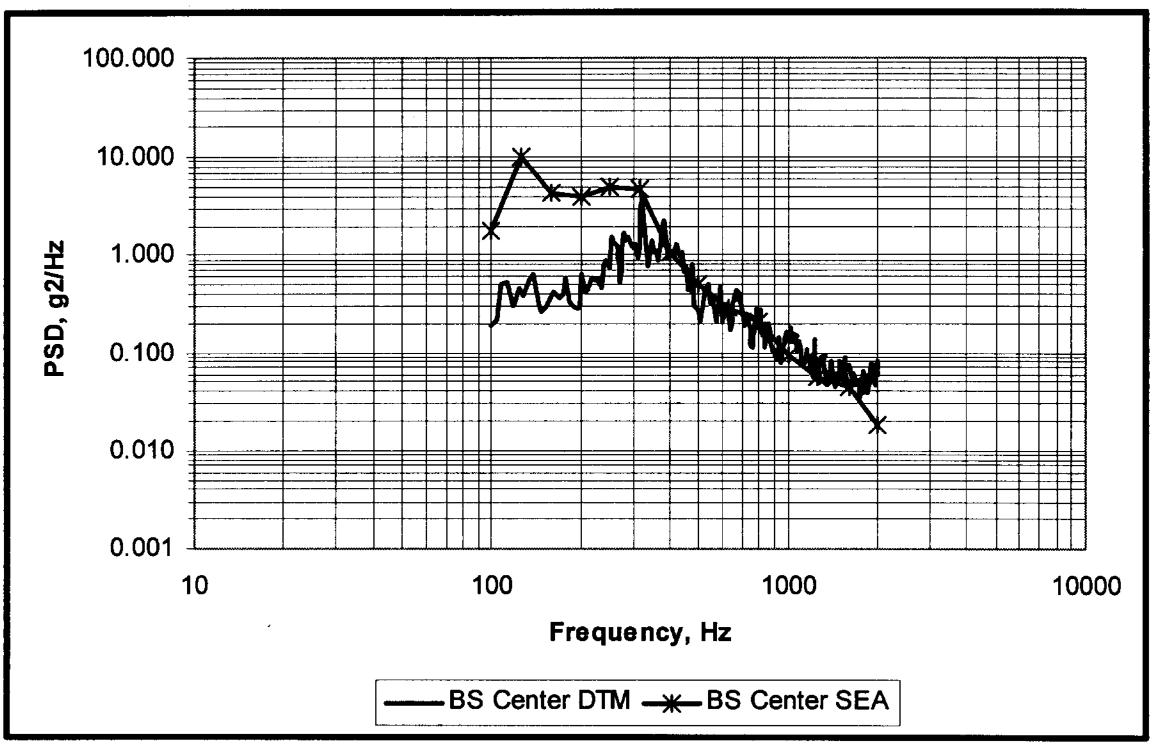

Figure 7 – SEA Response At Backshell Center Compared With Test Data