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Investigation of the Effect of Noise Parameters of Jet Using Acoustic Load Calculation Algorithm on the Launch Vehicle during Lift-Off

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Abstract

During the launch of a space vehicle, the intense sound pressure levels created around the vehicle. Therefor identification and analysis of acoustical loads of launch vehicle is an important issue of consideration. In this study, for calculation of acoustic pressure levels and prediction of noise at the discharge of the nozzle jet, the presented formula of Eldred was used with the assistance of the MATLAB software and the algorithm and code were obtained to handle acoustical loads. In this research, the geometry of one launch vehicle sample was used. The effective parameters including the slope of deflector and the ratio of nozzle outlet distance from launch pad to the jet outlet diameter, were identified and investigated. The curves of sound pressure levels and contours of SPL around the launch vehicle field are obtained versus to the interval of specified frequencies.

Keywords: Jet; Sound pressure level; Calculation algorithm; Slope of deflector; ratio of distance to nozzle

1. Introduction

At the start of a launch, a spacecraft's engines are fired and a high-pressure wave emerges from their nozzles. This includes the initial wave of the Launch Vehicle. When the engines are operating at full speed, the sound field is generated primarily by the oscillating turbulence in the outflow mixing region. After the launch, as the Launch Vehicle accelerates, the sound load due to the sound pressure on it decreases. When the speed of the Launch Vehicle exceeds the speed of sound, the acoustic load due to the propulsive force in the Launch Vehicle reaches zero. The loads on the Launch Vehicle are the result of dynamic instability in the turbulent supersonic boundary layers that flow over its surface [1].

Early work by Lighthill [2, 3] demonstrated the principle that aerodynamic sound radiation is the result of turbulence, allowing a sound field generation model to be developed using a quadruple source distribution. For low-velocity flows, the physical interpretation of this concept leads to the inhomogeneous wave equation, which Lighthill was able to solve using Green's functions. Then the resulting acoustic power was shown to the eighth power, proportional to the jet speed. This jet speed has reached the power of eight, which is the law of the acoustic scale, which was started by Light Hill for subsonic jets; however, for higher velocity flows, the results of the inhomogeneous wave equation are invalid.

Kandola [4] gave an excellent review of scaling laws and presented some of their shortcomings. Using simple energy arguments, it can be shown that for very high velocity flows, the acoustic power predicted using this scaling law translates into more than one hundred percent of the propulsion power. To solve this unphysical result, the jet velocity power is reduced for the sound power radiation scale. In fact, several theories [5, 6] have been proposed to support the sound power model scaling with the third power of the jet velocity in high Mach number outflows. More empirical scaling laws have been proposed to predict jet noise levels, and the general trend is that to predict noise, the exponent of the jet velocity should be reduced for supersonic jet exit velocity.

2. Acoustic load calculation algorithm

Eldred's experimental method [7] is used to calculate the acoustic pressure levels on the Launch Vehicle.

In the first step, the calculation of the flow axis relative to the Launch Vehicle is considered according to Figure

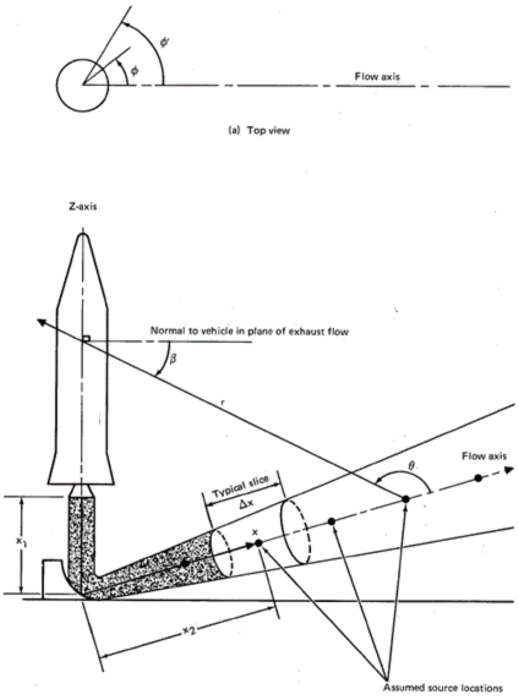


Figure 1. Schematic of Launch Vehicle geometry and position of sound sources included in Launch Vehicle output [7]

3. Geometry and flow field conditions

In this research, to model the geometry of the Launch Vehicle and use its experimental results for numerical solution with load calculation algorithm, from an article entitled "Acoustic characteristics of jet interaction with Launch Vehicle structure during launch" which was published in 2017 in the Journal of Aerospace and Launch Vehicles. It has arrived and is being used. This article is a laboratory research that was carried out experimentally at the National Space Laboratory of India by Karthikeyan and Venkatakrishnan [8]. A CAD model of this Launch Vehicle geometry along with the launch pad assembly is shown in Figure 2.

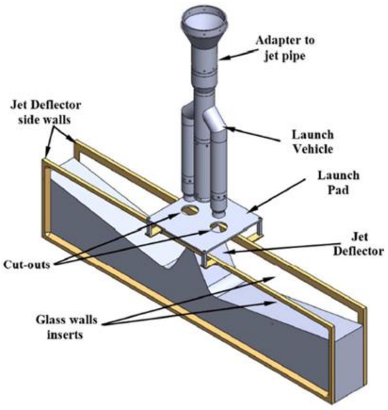


Figure 2. CAD model of different Launch Vehicle components used in the article [8]

In this model, a two-way guide is used. The radius of twist at the end of the jet stream deflector slope is equal to the nozzle exit diameter (De) and its total length is 1 meter. Conical nozzles are chosen to simulate the nozzle of the Launch Vehicle. The Mach number of the designed nozzles is equal to 2. The outlet diameter of each nozzle is 0.03175 m, which is used as the reference length De. During the test, the nozzle pressure ratio, that is; the static pressure of the jet is kept equal to 7.82 to the ambient pressure. The ambient pressure and reference temperature are taken as 13.25 psi (91355 Pascal) and 300 kelvin, respectively. To achieve the ideal expansion at the nozzle outlet, the static pressure of about 714396 Pascal is required at the inlet of the model.

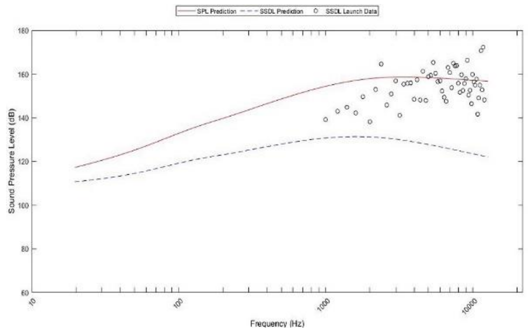
4. Results

All obtained graphs for acoustic pressure level based on frequencies have "Sound Spectral Density Level" (SSDL). The density level of the sound spectrum is calculated by subtracting the frequency bandwidth (Δf) from the sound pressure level (SPL). As shown in the Kinzler equation [9] below,

$$SSDL = SPL - 10\log_{10}[\Delta f] \tag{1}$$

The frequencies used in this analysis are in third octaves: 19/7, 24/8, 31/3, 39/4, 49/6, 62/5, 78/7, 99/2, 125, 157/5, 198/4, 250, 315, 396/9, 500, 630, 793/7, 1000, 1259/9, 1587/4, 2000, 2519/8, 3174/8, 4000, 5039/7, 6349/6, 8000 and 10079/4.

To observe the effect of the flow guiding slope, three values of zero, ten and twenty degrees are considered for it. The contour of the acoustic pressure levels in the Launch Vehicle flow field were obtained using the third Wilby equation model and considering the diffraction surface in Figures 3 and 4. To compare the results, the ratio of the distance of the jet nozzle from the launch platform to the diameter of the nozzle is equal to 4 and the exit jet speed is 1740 m/s and at a fixed diameter of 31.75 mm for the Launch Vehicle jet nozzle.



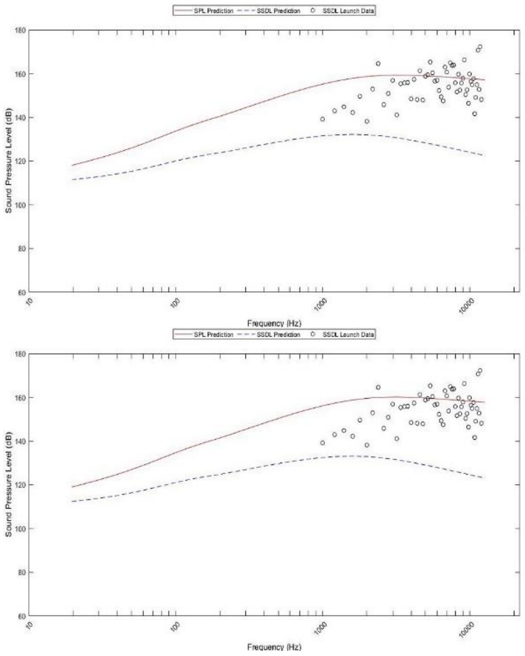
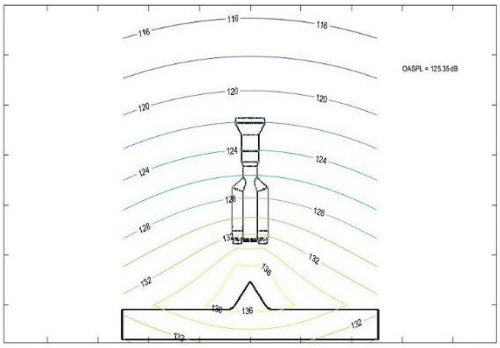
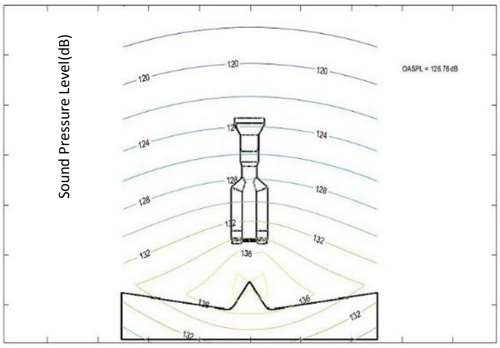


Figure 3.Acoustic pressure levels of the Launch Vehicle for the LV1 microphone using the directional index of the third Wilby equation and with the surface diffraction for the direction gradient of the output flow with values of zero, 10 and 20 degrees (in dB).





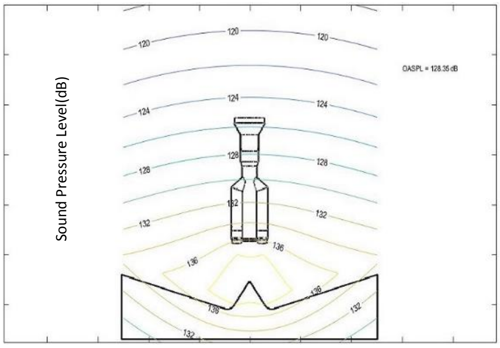


Figure 4. The contour of the Launch Vehicle acoustic pressure levels for the LV1 microphone using the directional index of the third Wilby equation and with the surface diffraction for the slope of the output flow guide with values of zero, 10 and 20 degrees at an average frequency of 2120 Hz (in dB).

In Figure 5, the values calculated from the solution are compared graphically with the values of the overall acoustic pressure level obtained from the test in the reference article, 8. The results show that the resolution difference in the near field microphones are close to each other, but this difference is large for the far field. This indicates that the solution performed in the near field is more acceptable and basically this method is implemented for the near field.

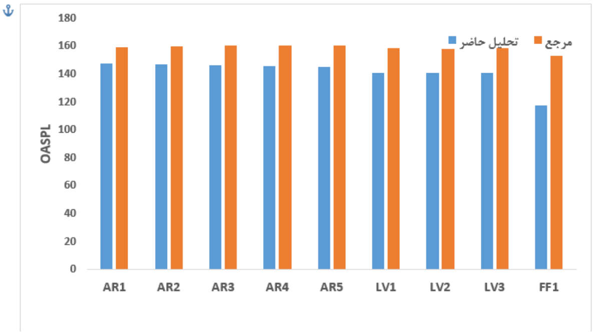


Figure 5. Comparison of the results obtained from the numerical code with the results reported in reference 8

5. Conclusion

In the near field, a gradual change in the average values of the acoustic pressure is created by increasing the angle of the jet outlet. In some cases, it increases by 0.6 to 1.5 dB for every 10 degrees of angle increase. For the far field, increasing the slope does not have much effect and the average values of the acoustic pressure level remain almost constant. Among the mentioned variables, the number of engines, by examining the Launch Vehicles with one and two engines, has the least effect on the changes in the acoustic pressure levels.

The quantity of the ratio of the distance of the nozzle jet from the launch platform to the size of the jet diameter, which was experimentally tested and analyzed in reference [17] in three values of 4, 8 and 12. To evaluate the effect of this parameter on the acoustic load of the Launch Vehicle in the present study, the directional index model of the third Wilby equation was used, which is more accurate in predicting the acoustic field than other directional models. For further analysis, two values of zero and 16 were also added to the studies. As shown in Table 2, for microphones LV1, LV2, and LV3, as the distance ratio increases, the average acoustic pressure values increase by about one decibel for each value of this ratio. For microphones AR1, AR2, AR3, AR4 and AR5 this increase is less. The trend of the changes in the measured values for the microphones is in good agreement with the calculation results of the used models. For the FF1 microphone, this process is completely opposite. In such a way that in the calculations, the acoustic pressure level decreases with the increase of the distance ratio, while in the experimental measurement, this trend is increasing.

The results obtained from the written code and the laboratory results of reference 17 are slightly different, and this difference is more for the remote microphones. This point indicates that the solution performed in the near field is more acceptable and basically, this method is implemented for the near field

6. References

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