RELIABLE METHODS FOR PREDICTING THE SOUND FROM CLUSTERED ROCKET ENGINES

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Abstract High area ratio rocket engines generate strong vibro-acoustic loads primarily during transient operations, like start-up and shut-down of the engine. These loads can adversely affect the launch vehicle and its payload. Thus, an accurate prediction of the loads produced during engine start-up is pertinent to the safety and reliability of the launch vehicle. The present work focuses on developing a robust framework for predicting these loads using laboratory scale rocket nozzles tested in the fully anechoic chamber at The University of Texas at Austin. This encompasses corrections for the observer position relative to the prominent source region, as well as scaling factors to correct for geometric factors. The test campaign encompasses single, two, three and four nozzle clusters, as well as differences in nozzle geometry and operating conditions (nozzle pressure ratio).

MOTIVATION

The focus of the present work is on developing a reliable framework for predicting the vibro-acoustic loads generated by both single and multiple nozzle configurations using laboratory scale data. Laboratory scale tests offer an opportunity to problem solve, in advance, the vibroacoustic loads that are generated by the launch vehicle in order to make better use of full-scale test data[2, 3, 4, 6, 9]. However, accurate scaling laws are required in order to quantify the effectiveness of the laboratory scale data, where the full scale system is concerned.

EXPERIMENTAL DESCRIPTION

Here, a comprehensive series of experiments were conducted in the fully anechoic chamber at The University of Texas at Austin using various nozzle configurations. Details of the facility are described elsewhere [2, 3, 4] and comprises an acoustically treated chamber located with an open-circuit wind tunnel. A modular test rig is placed along the centerline of the chamber and allows various nozzle hardware to be tested in the absence of an ejecter-diffuser. For the measurements discussed here, four eighth-inch pre-polarized, pressure field, condenser microphones (G.R.A.S.) were placed in the near acoustic field of several different nozzles. All microphones were scanned simultaneously at a rate of 500 kS/s with 16 bit resolution. A fourth order Butterworth-low pass filter attenuates frequencies above 140 KHz. Two truncated parabolic contour nozzles with an area ratio of 38 were tested. The throat diameters of these two nozzles comprised 19.05 mm and 6.35 mm. These two nozzles were tested to determine the effect that geometric scale has on the far-field sound. A second series of tests were then conducted using multiple nozzle configurations. This involved the smaller nozzle being configured into a cluster of two, three and four in order to imitate a parallel staging of the rocket. [1, 9].

ACOUSTIC SCALING

For geometrically scaled nozzles, the sound pressure level L can be predicted as a function of the number of nozzles n, the nozzle exit diameter D_e and the observer distance R: [5, 7, 8]. The approach considers the acoustic power (L_W) as a fraction (η) of the mechanical power (W_M) of the rocket so that,

$$L_W = 10\log_{10}(W_A/W_{ref}), \tag{1}$$

where $W_A = \eta W_M$ and the reference power (W_{ref}) is valued at 1 pW. The mechanical power is estimated to be $W_M = 0.5\dot{m}U_j^2$ while the acoustic efficiency is determined from,

$$\eta = K\left(\frac{\gamma_j}{\gamma_\infty}\right)\left(\frac{a^*}{a_\infty}\right)^3\left(\frac{1}{C_v}\frac{a^*}{U_j}\right)^2. \tag{2}$$

Here, a^* is the sonic velocity at the nozzle throat; C_v is a nozzle velocity coefficient valued at 0.98; $K = 0.0012$ is a variable constant taken from Lighthill's model. Scaling from one rocket to another involves the ratio of sound intensities,

$$L_{p,2} = L_{p,1} + 10\log_{10}\left(\frac{I_2}{I_1}\right), \tag{3}$$

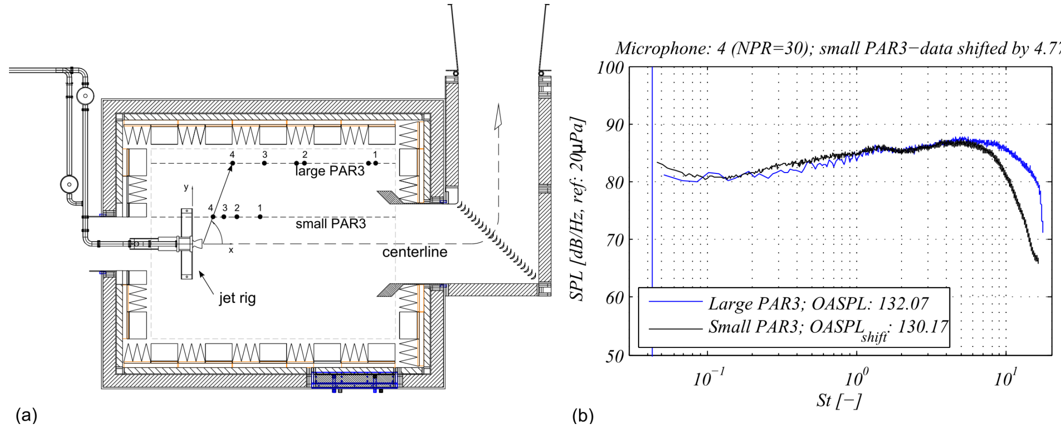

Figure 1. (a) Plan view of the anechoic chamber at the University of Texas at Austin with the microphone positions for the small and the large nozzle testing. (b) Normalized amplitude values of the acoustic intensity given in decibels for the small and the large nozzle as a function of the Strouhal number. [1, 9]

where,

$$\frac{I_2}{I_1} = \frac{n_2 D_{j,2}}{n_1 D_{j,1}} \frac{\eta_2}{\eta_1} \frac{\dot{m}_{j,2}}{\dot{m}_{j,1}} \left(\frac{U_{j,2}}{U_{j,1}}\right)^2 \left(\frac{r_1}{r_2}\right)^2. \tag{4}$$

It is known that the location of most intense sound generation ($L_p = x_p/D_j$) resides between the end of the potential core and the supersonic tip. This requires one to estimate an equivalent diameter (D_j). Assuming that mass flow is conserved, $\dot{m}^* = \dot{m}_j$ and $\dot{m}_j = \rho_j A_j U_j$, that the flow is shock free, and that $P_\infty = \rho_j R T_j$, it can be shown that ($D_j = D_e$),

$$D_j = \frac{2}{M_j} \sqrt{\frac{\dot{m}^* U_j}{\pi P_\infty \gamma_j}}. \tag{5}$$

Here, the input to this scaling model is simply the nozzle pressure ratio (P_0/P_j), throat diameter D^* and the total temperature of the gas T_0. Thus, for the region where the most intense sound is generated, this is estimated using $L_{ss} = x_{ss}/D_j = 5.0M_j^{1.8} + 0.8$, where $L_t = x_p/D_j \approx L_{ss}/M_j^{0.85}$ and $x_{p,eff} = L_p \cdot D_j - x_{D_e,D_j} = x_t = x_{D_e,D_j}$[11, 10]. A sample set of results from this analysis are shown in figure 1(b) where two different microphone positions are exemplarily used to show the comparison of the measured data of the small nozzle with the predicted data using the aforementioned recipe and the small nozzle data set. The results of the Power Spectral Density diagrams and the calculation of the overall sound pressure levels demonstrate the agreement between the predicted and the measured data and demonstrates the validity of the approach used. The full paper will include the remainder of the results comprises the prediction of the cluster of three and four nozzles based on the data-set of a single nozzle with an equal shape[9].

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