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Analysis of Acoustic Wave from Supersonic Jets Impinging to an Inclined Flat Plate

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Abstract: For the prediction and reduction of acoustic loading of launch vehicle at lift-off, acoustic wave radiated from ideally-expanded supersonic cold jets impinging to an 45-degree-inclined flat-plate (representative of a flame deflector) located 5D downstream from the nozzle exit is investigated numerically with the help of the experimental work. It turns out that dominant noise source is classified into two types: (1) the Mach wave radiation from free jet before the impingement and supersonic wall jet after the impingement, (2) the acoustic wave generated where the jet shear-layer interacts with plate shock and following shock train. Those features are clearly observed by applying the Proper Orthogonal Decomposition (POD) analysis to the numerical results. Prediction accuracy of 5 dB in OASPL is obtained in the current numerical simulation.

Keywords: Aeroacoustics, Launcher Acoustics, Large-Eddy Simulation.

1 Introduction

Propulsive power generated by the rocket engine is so significant that intense acoustic wave is radiated from the exhaust plume. Since the acoustic wave causes severe acoustic loading to the payload, prediction and reduction of the acoustic level around the launch vehicle at lift-off is quite important design issue taken into account early in the design process of the launch-pad. Several studies have been performed to understand and predict the launcher acoustics [1-4], but mechanism of acoustics radiated from the rocket plume impinging to the flame deflector is not evident yet. As such knowledge is essential to improve acoustic environment of launch vehicle, the present study aims to determine the noise generation from ideally-expanded cold jets impinging to a simplified flame deflector.

2 Problem Statement and Numerical Setup

Ideally-expanded cold jets with the exit Mach number of 1.8 and 2.0 are employed in this study. For simplicity, a flat plate inclined with 45 deg is located 5D downstream from the nozzle exit. (D: nozzle exit diameter) The jet impinges to the inclined plate within the potential-core length. D is 20mm and the Reynolds number based on the nozzle exit is $1.64x10^6$ in the experiment carried out by the University of Tokyo.
The computations are carried out with JAXA's in-house codes LANS3D, and UPACS-LES. Implicit LES is conducted by the LANS3D. While, the UPACS-LES employs the zonal LES/RANS hybrid method. The turbulent boundary-layer on the inclined plate is computed by the RANS with the Spalart-Allmaras model, and rest of the region is calculated by the LES with the standard SGS model.

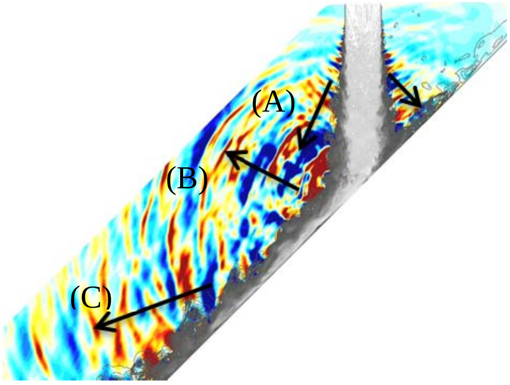

Fig.1 Acoustic field shown by the static pressure. Grey-colored contour line is the dynamic pressure.

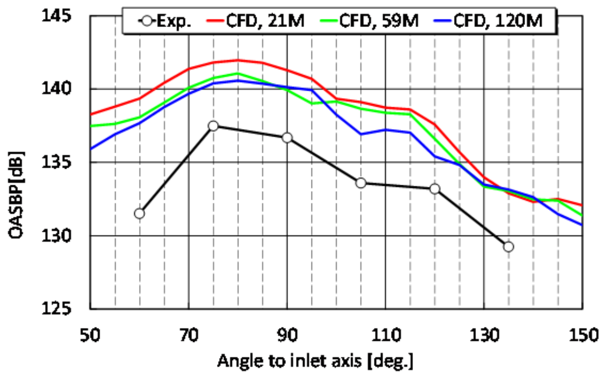

Fig.2 Comparison of OASPL distribution at 40D far from the impinging point.

3 Results and Future Work

Figure 1 shows the static pressure on the symmetry plane [5]. The characteristics of acoustic fields are clarified. The acoustic wave (A) is the Mach wave radiation from the free jet before impinging to the inclined plate. The acoustic wave (C) is also the Mach wave which is radiated from the supersonic wall jet after the impingement. The Mach wave (A) and (C) propagate obliquely downstream. While, the acoustic wave (B) is found to be generated around the jet impingement region, and to propagate spherically. Through the analysis, it is found that the acoustic wave (B) originates where the vortex structure of the shear-layer interacts with the plate shock and following shock train. In the presentation, discussion on the acoustic field based on the POD analysis will be conducted [6]. In Fig.2, OASPL distribution measured at 40D far from the impingement point is compared with the numerical results of three grids having 21M, 59M, and 120M points. It is observed that all the numerical results overestimate at all the microphone locations, and sufficient grid convergence is not achieved. Maximum difference of 5dB is observed at 60 degree from the jet axis. The CFD results are also compared with the high-speed Schlieren image, PSDs at the microphones, and wall pressure distributions. Through the comparison, accuracy of the presented numerical method is discussed.

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