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Numerical Simulation of Aero-Acoustic Noise from Supersonic Jet Reflection Using Computational Fluid Dynamics/Boundary Element Method

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ABSTRACT: Calculating acoustic loads due to the flow field produced by the outlet flow of launch vehicles impinging on the launch pad is one of the main challenges in the space industry. The sound level of outlet flow from the engine and reflection of produced acoustic waves from the launch pad and their effect on payloads depends on the turbulence parameters, created vortices, nozzle geometry, and launch pad geometry. The present paper aims to calculate the sound level generated by supersonic flow at the outlet of the launch vehicle engine besides the sound reflection from the flow deflector below the engine using a hybrid computational fluid dynamics/ boundary element method. For this purpose, the sound produced by the nozzle outlet flow in the supersonic engine of a launch vehicle is studied. In order to observe the effect of the reflection of acoustic waves from the launch pad, results are compared between two cases (with a flow deflector and without it). Numerical simulation is performed for the three-dimensional viscous compressible turbulent flow, and the boundary element method is used to compute the propagation and reflection of acoustic waves. Obtained results indicate that the generated noise level impressively increases when considering acoustic wave reflection from the deflector. The noise level generated by the projectile engine in the presence of a jet flow deflector is higher by about 8-10 dB than in the absence of a deflector. Also, results show that the acoustic waves over the projectile become more uniform by using a deflector.

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1- Introduction

Wall jet is a phenomenon created when the launch vehicles, projectiles, and Vertical Takeoff and Landing (VTOL) planes start moving. Physical phenomena occurring during engine startup are quietly transient, and a steady jet flow is formed after a while. At the beginning of the transient jet, a strong shock wave is produced due to combustion, followed by vortex rings, and then the primary jet. Each of described phenomena causes powerful acoustic waves to generate. The shock wave is a phenomenon with low frequencies in the range of 5-200 Hz and is the reason for about 30-60% of unsuccessful rocket launches in initial phases, as it disturbs the proper performance of the projectile. Also, it causes some problems in the projectile structure and its support equipment around the launch pad on the ground [1]. The acoustic pressure level around the all reaches 160-200 dB. This wave corresponds to a 20000 Pa pressure difference (20% of atmospheric pressure), a considerable value [2]. Using the hybrid boundary element method in VAOne software, the present study examines the noise level due to the jet impinging and the effect of acoustic wave reflection from the launch pad at low frequencies.

2- Numerical Methodology

In numerical analysis software, like Ansys Fluent, the integral methods based on Lighthill's acoustic analogy, such as the Ffowcs-Williams/Hawkings (FH-W) equation, are used for noise calculations. However, these methods cannot consider the acoustic wave reflection from the wall surface. The hybrid Computational Fluid Dynamics (CFD)/ Boundary Element Method (BEM) approach is the best alternative for integral methods and is applied in most successful computational tools in aeroacoustics. Indeed, the boundary element method solves the problem by converting the Helmholtz equation to integral equations defined on the domain boundaries. In this method, the unknown variables over the boundaries are determined by dividing the boundary into some finite elements and applying integral equations to these elements [3]. So, the sound generation due to aerodynamics is considered independent of the acoustic wave propagation relative to the far field. As shown in Fig. 1, the hybrid CDF/BEM approach involves two stages: flow simulation around the studied geometry and acoustic noise calculation. In the first stage, the unsteady incompressible flow is simulated in Fluent using Navier-Stokes equations, where velocity and pressure fields are computed for the

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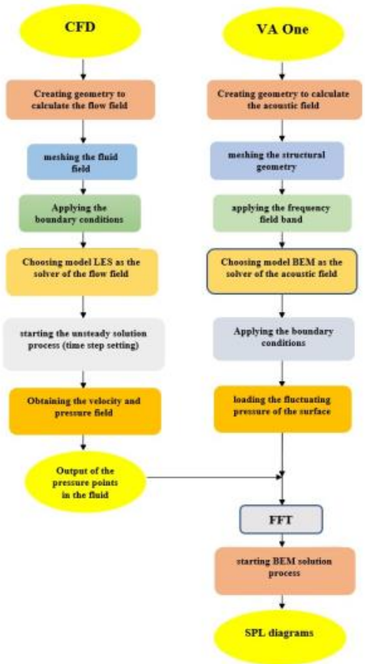

Fig. 1. Schematic flowchart of hybrid CFD/BEM approach

solution domain and used as the inputs of the acoustic solution. In the second stage, results from CFD simulations are converted from the time domain to the frequency domain by Fast Fourier Transform (FFT). Then, the propagation and reflection of acoustic waves are simulated in VAone using the BEM method. Thus, two distinct features of sound, nonlinear production and nonlinear propagation, are considered [2].

3- Problem Statement

In this study, the projectile dimensions are the same actual dimensions, as shown in Fig. 2. The studied geometry is a cylinder with a nose cone of a diameter of 1 m and a height of 15 m. The height of the wedge-shaped deflector at the engine outlet is 3 m with a 3x3 m^2 base area. The far-field domain is a semi-sphere of a 25m radius. For the outer boundary, the pressure outlet boundary condition at 1atm pressure and 300K temperature is considered. The Mach number of the jet exiting the projectile engine is assumed to be 2. Also, the outlet pressure and temperature are considered 90kPa and 1000K, respectively. The solid wall boundary condition is also applied to the projectile body and deflector surface. Also, four microphones are used for measuring the acoustic loads at different distances from the projectile.

4- Results and Discussion

Fig. 3 shows the velocity contour of the jet impinging on the deflector surface. The fluid flow exits the jet outlet with the maximum velocity and pours along the negative *z* direction over the inclined plane. When the flow impinges upon the top of the deflector, it is split into two parts. At the beginning of the inclined plane, the flow velocity is steel maximum, and then it decreases downstream. Figs. 4 and 5 demonstrate two noise contours; each one shows the Overall Sound Pressure Level (OSPL) over the vertical and horizontal interface for two launching cases. Contours over the vertical interface show that a large part of acoustic waves is infiltrated into the rigid body. Then, some waves can be reflected from the surface after wave radiation. As can be seen, the reflection of generated noise leads to the formation of several acoustic sources over the projectile body.

Figs. 4 and 5(a) show the noise contour for the projectile with no jet flow deflector. Along the central core of the jet inside the projectile, the noise level is 135-140 dB. The maximum noise level occurs over the projectile body; each irradiates as an individual acoustic source. Figs. 4 and 5(b) illustrate the projectile's noise contour with a jet flow deflector. The maximum mixing occurs beneath the central core of jet flow over the deflector surface, showing a noise level of 185 dB. Also, the noise level inside the projectile is in the range of 140-150 dB. Fig. 4(b) indicates the flow diffusion and diversion over the jet flow deflector with the maximum noise occurring over the inclined plane.

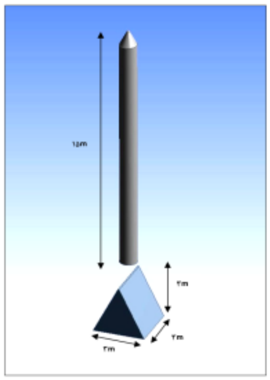

Fig. 2. Dimensions of the projectile and jet flow deflector

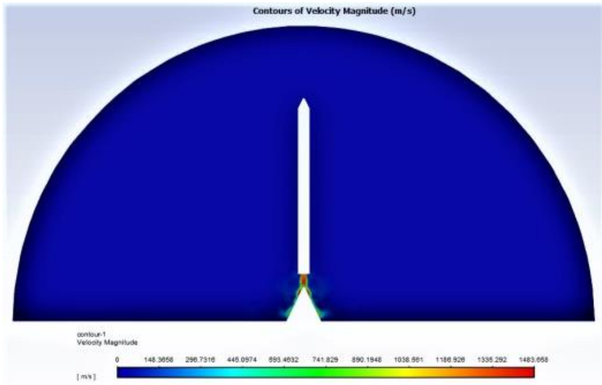

Fig. 3.Velocity contour

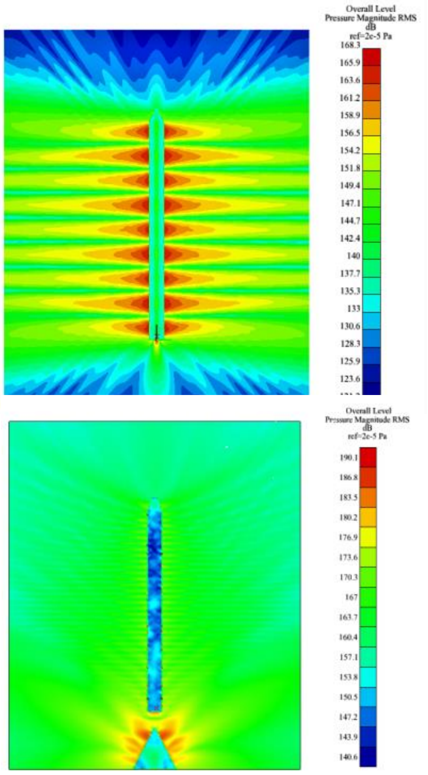

Fig. 4. a)Vertical interface of the projectile without jet flow deflector, and b) vertical interface of the projectile with a jet flow deflector.

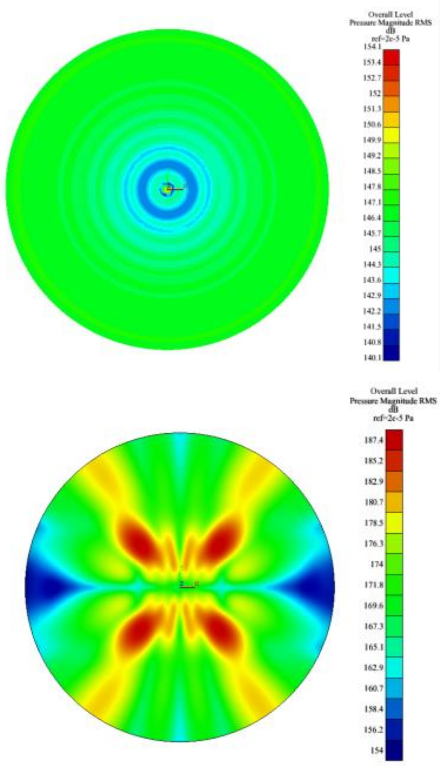

Fig. 5. a) Horizontal interface of the projectile without jet flow deflector, and b) horizontal interface of the projectile with a jet flow deflector.

5- Conclusions

The flow diverting surfaces are imposed to the maximum noise level at 150-250 Hz frequencies.

The noise generated by jet impinging in the presence of a flow deflector is higher by 8-10 dB than in its absence. In the case of no flow deflector, the fluctuating surface pressure is concentratedly maximum parallel to the central core of the jet. In the presence of the flow deflector, the fluctuating surface pressure is not concentrated anywhere and uniformly increases all over the projectile.

The hybrid CFD/BEM approach efficiently computes the near-field noise and its propagation at the far field. It can resolve the problem associated with calculating reflected acoustic waves from walls.

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