Effect of Mach number on a Compressible Impinging Round Jet: An LES study

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1. INTRODUCTION

We often encounter impinging jets in engineering applications such as rocket propulsion, turbine blade cooling and Short Take-Off Vertical Landing (STOVL) aircrafts. Such impingement of high-speed compressible jet on a flat surface at a close distance from the inlet can result in a complex interplay of shock waves, turbulent shear layers and acoustic feedback loop that results in discrete acoustic tones.
In the early stages of research, Powell [1] proposed that large-scale vortical structures are initiated from the Kelvin-Helmholtz instability generated in the shear layer. Krothapalli et al. [2] investigated the flow and acoustic characteristics of axisymmetric supersonic impinging jet at Mach numbers 1 and 1.5. To better understand the flow field and acoustic characteristics of high-speed impinging jets with variation of inlet to plate distance, Large Eddy Simulation of subsonic impinging round jet at Mach number 0.9 and Reynolds number 25000 is performed in this study. Two flow cases are studied, with Mach numbers 0.9 and 1.5 and fixed inlet-to-plate distance. The objectives of this study are to perform LES based on high-order compact finite difference scheme and explicit filtering to study compressible impinging jets and to investigate the influence of impingement distance on the instantaneous fields, mean flow characteristics and flow statistics in both the cases.

2. METHODOLOGY

2.1 Governing Equations and Discretization Methods

The governing equations for compressible flow written in a characteristic form [3], in generalized curvilinear coordinates in terms of the primitive variables and are solved using a sixth- order compact central finite difference scheme to discretize the spatial derivatives. For time-marching, a low storage, third order Runge–Kutta scheme is used. An explicit filtering approach based on the approximate deconvolution method is used for LES. An adaptive filtering approach is used for additional filtering near the shocks [4].

2.2 Flow and Computational Parameters

The domain size taken is $h \times 2\pi r_0 \times 24 r_0$, with impingement distance of $h=8r_0$ and Mach numbers 0.9 and 1.5 for the two flow cases. Here, r_0 is the jet radius at inflow. The Reynolds number based on inflow velocity and inflow jet diameter is 25,000. The number of grid points employed is 640×192×400 in axial, azimuthal, and radial directions, respectively. A *sinh* stretching is applied in the radial direction. The simulations are run on 64 cores on Paramshakti, IIT Kharagpur.

2.3 Boundary Conditions

At the inflow, the axial velocity profile is specified. A vortex inflow forcing method is used to add disturbance [4], which causes the transition of the initially laminar shear layer to turbulence.. The transverse terms in the governing equation are taken as zero at the inflow. Near the outflow in the radial direction, a sponge layer is specified [4] from $z_s=z/r_0=15$ to $z_f=z/r_0=24$, which absorbs outgoing waves and prevents spurious reflection. At the axial end of the domain, the isothermal, no- slip wall boundary condition is applied. The wall is maintained at constant temperature T_w= 300 K.

3. RESULTS

3.1 Instantaneous fields:

Instantaneous axial velocity, normalised with the inlet centreline velocity in an axial radial plane is shown shown in figure 1 which show the appearance of weak shocks and upstream propagation of acoustic waves responsible for the feedback loop is noticed.

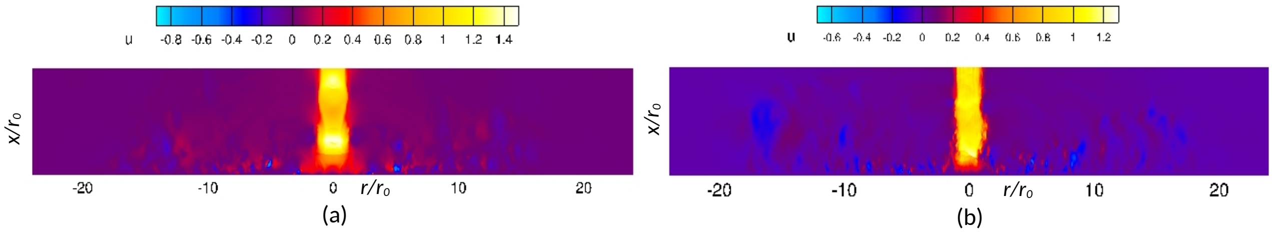

Figure 1: Instantaneous velocity variations for (a) M=0.9 case and (b) M=1.5 case

3.2 Mean flow characteristics:

The decay of centreline mean axial velocity and centreline pressure variations in the axial direction for the two cases are shown in figure 2. Here, axial velocity is normalised using the centreline velocity (u_j) at the inflow, centreline pressure is normalised using ambient pressure and axial coordinate is normalised by impinging distance. Alternate compression and expansion zones are visible in the free jet region for both the cases. As shown in the figure, the mean pressure is maximum near the stagnation region and the pressure jump is more for the supersonic case, as expected. The intensity of the shocks is also higher in case of the supersonic jet.

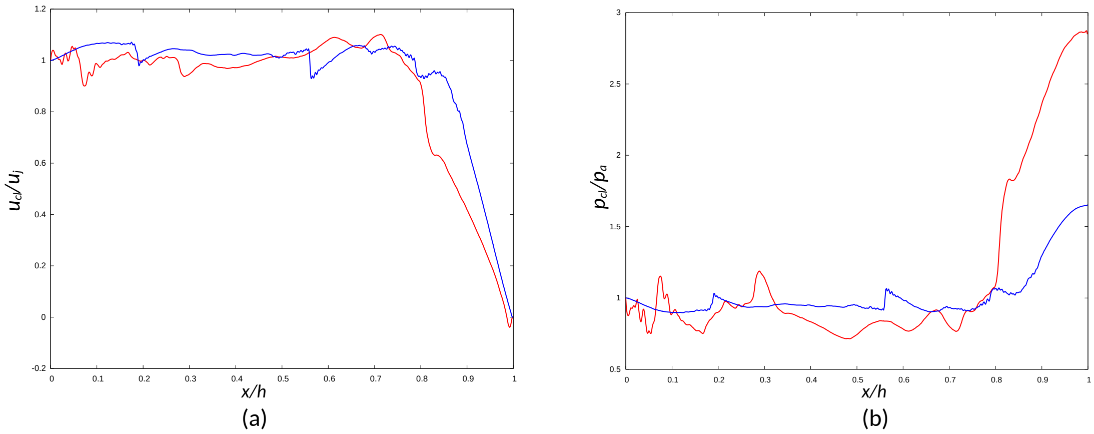

Figure 2: Variation of (a) Centreline axial velocity and (b) Centreline pressure

4. CONCLUSIONS

Large Eddy Simulation is performed for a compressible round jet impinging on a flat plate at inlet–to-plate distance of h=8r_0, where r_0 is the jet radius at the inlet. Two cases are studied with Mach numbers 0.9 and 1.5. Reynolds number is 25,000. The governing equations [3] are solved using 6th order compact finite difference scheme and an explicit filtering based LES approach [4]. Instantaneous and mean flow fields show the appearance of weak shocks in the flows. The centreline velocity and pressure variations are also plotted that show the weak shocks in the flow and how the intensity of these shocks are higher in the supersonic case. Further, we plan to present detailed turbulence statistics and methodology in the full paper. The effect of Mach number on the flow parameters and shocks can then be observed in more details.

5. REFERENCES

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