Effect of Flight velocity on Mean Flow of an Ideally Expanded Supersonic Jet – a CFD study

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1. INTRODUCTION & OBJECTIVE

In the area of aeroacoustics, one of the primary research is focused on the reduction of the jet noise specially when the thrust obtained from the nozzle is higher. Use of bypass flow in the jet engine is very helpful in reducing the aircraft noise. It is later proven through experimental and numerical analysis that the presence of the flight velocity i.e co-flow in the main jet reduces the acoustic levels significantly. Hence, studying the effects of a flow stream on the outside of jets is very useful. Lots of research is done in this area. Studies by Tanna and Morris [1] had showed that the forward flight motion modifies the jet development. Such flight motion results in an axially stretching phenomenon of the potential core and reduces radiated noise. Effect of flight velocity on jet flow field and acoustics has been studied experimentally by Benot et al [2]. It has been observed that the shock-cell pattern is lengthened in flight. This is due to the stretching of the entire flow coming from the reduced mixing layer growth rates.

Numerical studies are carried out for fully expanded jet using commercial code to estimate the mean flow properties in presence of external flow. The nozzle considered here for the simulations is a CD nozzle which is designed to deliver a Mach number (Mj) 2.0 with area ratio of 1.757 [3]. Objective of this paper is to understand the effect of free-stream flow or co-flow on the mean flow characteristics of jet.

2. METHODS OF ANALYSIS

Fluent code with Reynolds Averaged Naiver Stokes (RANS) solver is used to simulate the flow and capture the experimental observations in the jet flow development. Once the results are matched, further analysis are carried out to understand the effect of flight velocity on the development of the jet. In particular, the turbulent kinetic energy fields, potential core length etc obtained through RANS simulations are further investigated to understand the effect of velocity on acoustic generation. Computational domain along with the grid distribution pattern used is shown in Figure 2. Seven different flight velocities (0, 30, 50, 75, 100, 150, 200 m/s) are studied here. The temperature of the jet at chamber is 300K and chamber pressure of 7.82 bar.

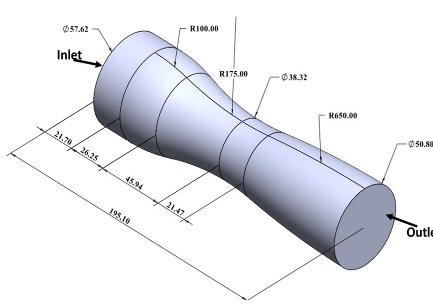

Figure 1: 3D view of simulated nozzle

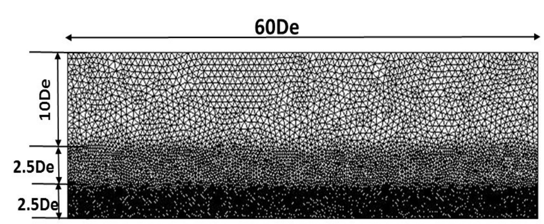

Figure 2: Domain and grid distribution

3. RESULTS

Normalised velocity (U/U_j) palette for different simulations case is shown in Figure 3. It is noticed that as the co-flow velocity (U_f) increases, the spreading of the jet reduces. Jet gets stretched due to the presence

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of free-stream. As a result, the spreading angle decreases. Jet becomes narrower, mixing with ambient reduces and higher Mach number prevails over a larger region. Similar observation is reported in literature also [4],[5]. The variation of the center line velocity variation shows that as the co-flow velocity increases, the initial portion of the jet velocity remains similar and later they start deviating. Beyond the potential core the velocity falls very sharply with the decrease of co-flow velocity. This is due to the enhanced mixing of the ambient flow with jet with the decrease of co-flow velocity. The velocity is decaying at x^{-1}. This is as per expectation.

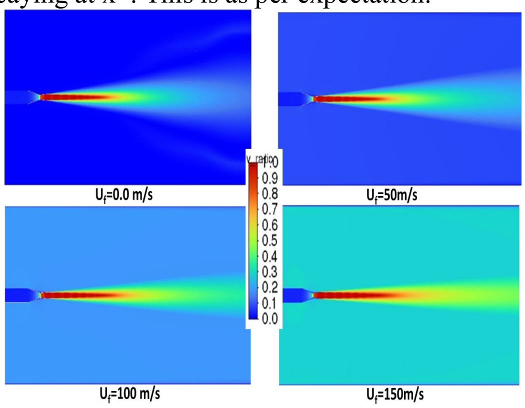


Figure 3: Jet velocity palette with co-flow

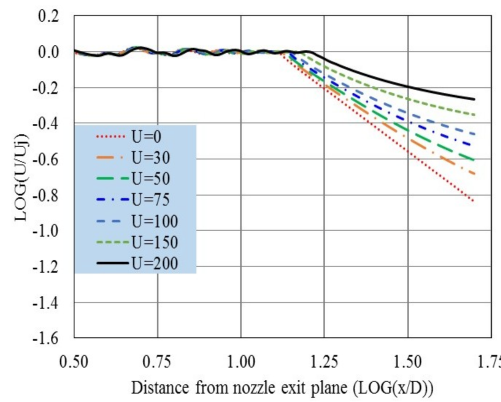


Figure 4: Variation of centre line velocity (U/Uj) along the nozzle centre line.

As mentioned earlier, with the increase of the free-stream velocity, the jet gets elongated and hence, the length of potential core increases. In Figure-6, the variation of the potential core length is plotted along with the free-stream velocity. The length of the potential core is 12.9D when there is no co-flow but it enhanced to 16.27D for co-flow velocity of 200m/s.

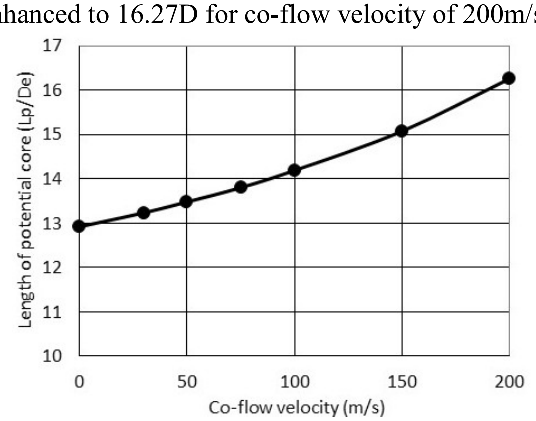
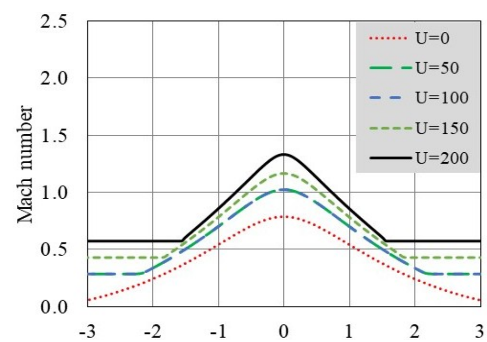


Figure 5: Variation of potential core length with co-flow velocity



Distance along the lateral direction measured from nozzle centre line (r/D)

Figure 6: Variation of Mach number at x/D=20

Beyond potential core at x/D=20, the max Mach number has reduced significantly and jet spread over a much longer distance (>3D radially without co-flow). For cases without co-flow the value of the peak Mach number is 0.75 while it is ~1.3 for U_f=200m/s. Similarly, the spread of jet is also lowest for the case with highest co-flow velocity and highest for without co-flow case (Figure 6).

Since the acoustic radiation from a jet is dependent on the turbulence within the jet plume. Turbulent kinetic energy indicates the growth of fluctuation in the flow. It is noticed that with the increase of free-stream Mach number (i.e. co-flow velocity), the growth of mixing layer becomes slower. As a result, the TKE level also decreases. The max turbulent level which is an indication of the source of maximum acoustic level occurs close to the end of the supersonic core which is same as reported in literature [6]. The location of peak TKE moves further down with the increase in the co-flow velocity. The peak axial turbulent intensity also decreases with the increase in the co-flow velocity (Figure 8). When the co-flow velocity is about 200m/s, the TKE levels along the nozzle center line is about 50% of the TKE values when there is no co-flow (7).

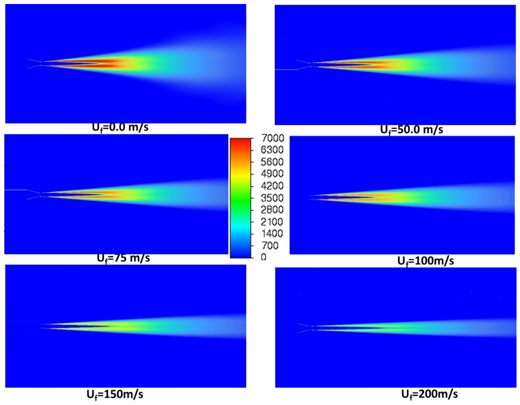


Figure 7: TKE palette along the jet symmetry plane

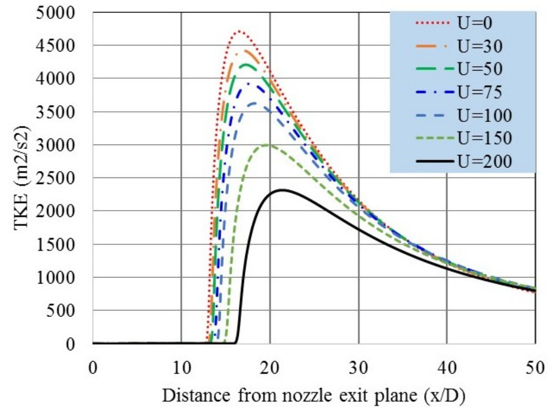


Figure 8: Variation of TKE along the jet center line

The shock-cell strength can be expressed by $P_{max}/P_{min}-1$ as suggested by Tam [7], with P_{max} (P_{min}) the maximum (minimum) pressure in each cell. Variation of the static pressure along the centre line is shown Figure 9. It is clearly seen that the amount of pressure jump decreases as one moves downstream. This is because of the dissipation of the energy of the flow due to the shear action between the jet and free-stream which is as per expectation. A quantitative analysis of the data of Norum & Shearin [8] and Norum & Brown [9] shows that an increase in the strength of the shock cells as the co-flow velocity increases after first few shock cell. This is also due to the reduction on the shear strength with the increase in the co-flow velocity which is as expected.

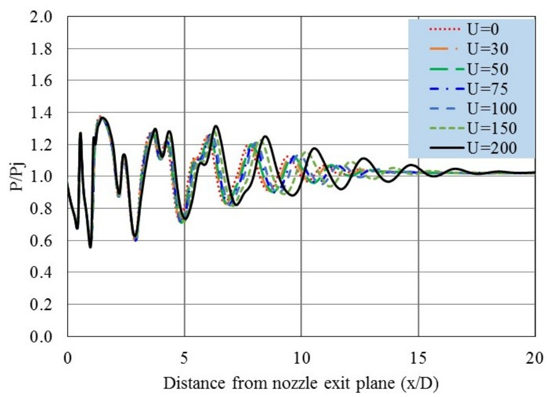


Figure 9: Variation of jet pressure along the jet center line

4. CONCLUSIONS

A series of numerical simulations are carried out for a fully expanded supersonic jet using Reynolds average Navier-Stokes calculation with 2 equation turbulence model to understand the mean flow characteristics of jet. The velocity of the ambient fluid i.e. surrounding fluid has been varied from 0 to 200m/s to understand the effect of co-flow on the mean flow field of the jet. Analysis shows that the trend of jet velocity decay, TKE variations, shock cell length etc match well with the experimental data published in literatures.

5. REFERENCES

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