# Prediction of Flow Field for a 2-D Mixed Compression Supersonic Inlet

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***Abstract***
*Reynolds Averaged Navier Stokes (RANS) CFD simulation have been carried out over 2-D Axi-symmetric mixed compression supersonic inlet configuration using K-Omega turbulence model for Mach numbers ranging from 2 to 4 . The coefficient of pressure, Shock location and variation of pressure and density have been extracted and compared for all the Mach numbers . The oblique shock formation is observed in both the first ramp and second ramp for all the Mach numbers, which results in, the increase in pressure and decrease in free stream Mach number. The presence of ramp in the subsonic diffuser, leads to formation of expansion waves that results in the inlet exit flow to remain in supersonic speed.*

**Keywords** — *Supersonic inlet, Gridgen, Shock movement, Shock induced pressure rise, Boundary layer thickness.*

## I. INTRODUCTION

The introduction of turbojet engine in the aviation industries has reduced the complexity of flying and the economic losses faced by the reciprocating engines [1]. It also increased the time duration of flight, fuel economy, load carrying capability etc. The invention of ramjet and scramjet have added additional features to the aviation industries does obtaining supersonic speed i.e., greater than the speed of sound. The ramjet and scramjet engines have led to the greater applications in the field of missiles [2]. Though scramjet engines are still under research, they have huge trust in near future. The term inlet has a main role in any gas turbine engine. This is the component which decreases the free stream velocity and increases pressure. In case of ramjet and scramjet engine, inlet is the major component for increasing the pressure without the need of compressor [3]. In this paper, the flow field for a 2-D mixed compression supersonic inlet has been predicted to maximize the total pressure recovery (Intake Performance) for best performance of the engine.

## II. CONFIGURATION STUDIED

The geometric feature of inlet configuration [4] is shown in figure 1. The inlets used are of 2-D mixed compression supersonic type.

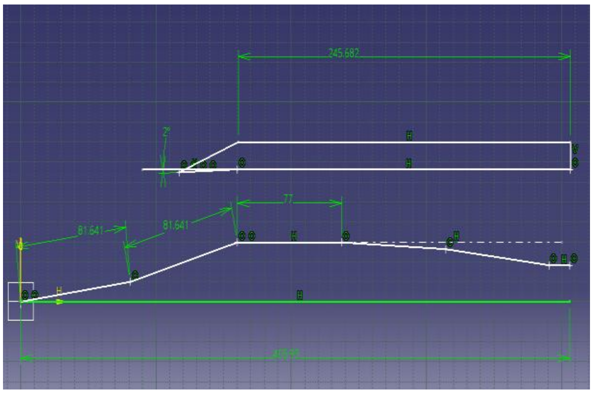

**Figure 1 Inlet configuration with 2° cowl deflection angle (All dimensions are in mm)**

## III. GRID GENERATION & CFD SOLVER

CFD is an integral part of the design process of the airframe and engines for all major aerospace companies in the world. In this paper, single block structured grid is generated inside the 2D mixed compression supersonic inlet configuration using *GRIDGEN* tool. The domain and grid distribution over the inlet configuration is shown in figure 2. The primary parameter which determines the minimum number of grid points is the boundary layer thickness. For accurate simulation of separation and shock location, the first grid point off the surface should lie within the sub layer where the velocity varies linearly with distance from the surface. To capture boundary and shock boundary layer interaction finer grids are used near the body. To reduce the computer time coarse grids are used away from the viscous layer. The core of the configuration is extended till the outer boundary for ease of simulation i.e., to avoid the base flow region, since the region of interest is only inlet. The grid is generated over only one half of the model which is Axi-symmetric.

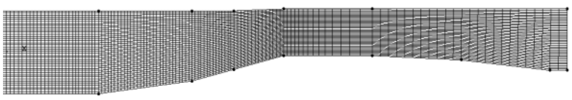

**Figure 2 Domain and Grid distribution over inlet configuration**

At supersonic free stream Mach numbers, the computational domain of dependence is unbounded and the implementation of boundary conditions becomes critical [5]. Four types of boundary conditions are applied for the computation of flow field, i.e., wall, pressure far field, symmetry, pressure outlet conditions. CFD simulation have been carried out over 2-D Axi-symmetric mixed compression supersonic inlet configuration using K-Omega turbulence model for Mach numbers ranging from 2 to 4 . All the CFD simulations have been carried out using *fluent* solver.

## IV. GRID INDEPENDENCE STUDY

The grid independence study has been carried out over 2° cowl deflection angle inlet. Three different meshes were generated and are shown in figure 3 to 5. The mesh distribution is given in Table 1. Figure 6 shows the coefficient of pressure 'Cp' distribution for three meshes namely mesh 1, mesh 2, and mesh 3. It can be seen from the figure that, for further increase in the number of meshes, no considerable rise in pressure distribution around the inlet is observed. Hence the optimum mesh size has been taken as mesh 2.

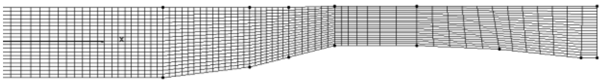

**Figure 3 Mesh 1**

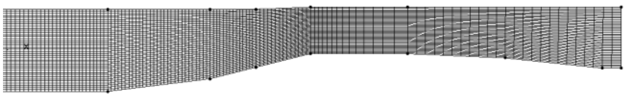

**Figure 4 Mesh 2**

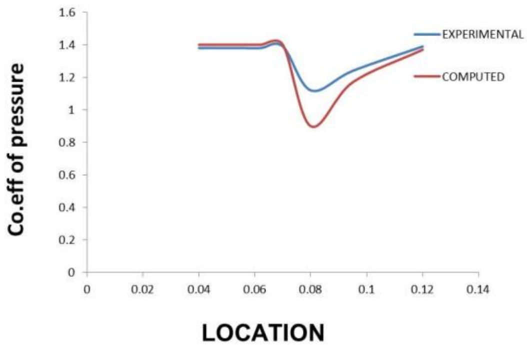


**Figure 7 The cowl lip Mach number comparison for CFD and experimental data**

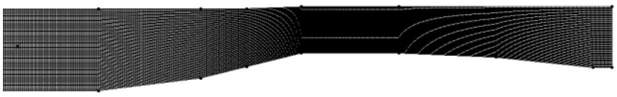

**Figure 5 Mesh 3**

**Table 1 Grid Distribution over inlet configuration**

| Mesh number | Size of the mesh | Total number of mesh points | Total number of quadrilaterals |
|---|---|---|---|
| 1 | 97 * 20 | 1940 | 1824 |
| 2 | 195 * 40 | 7800 | 7566 |
| 3 | 395 * 80 | 31600 | 31126 |

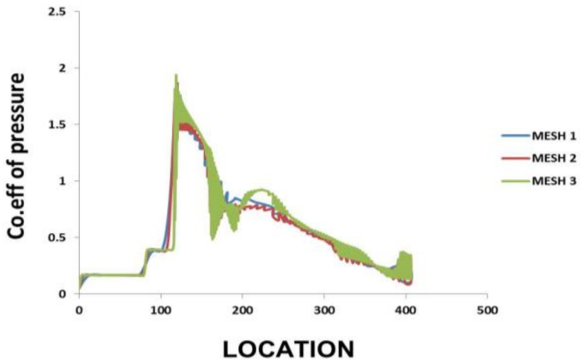


**Figure 6 The Co-efficient of pressure distribution for three different meshes**

## V. VALIDATION

CFD validation studies have been carried out at Mach number 2 for 2° cowl deflection angle inlet. Figure 7 shows the cowl lip Mach number comparison for CFD and experimental data. They are found in good agreement.

## VI. RESULTS AND DISCUSSION

CFD simulations have been carried out over the inlet configurations for Mach numbers 2, 2.5, 3, 3.5 and 4. Figure 8 shows the Coefficient of pressure, Cp comparison plot for all the Mach numbers over 2° cowl deflection angle inlet. The Cp plot shows increase in the pressure over the first ramp for all the Mach numbers, which is due to the formation of oblique shock and remains constant thereafter. Then, there is rapid increase in Cp over the second ramp due to the formation of normal shock. Aft in the throat and subsonic diffuser, Cp decreases due to the occurrence of expansion fan.

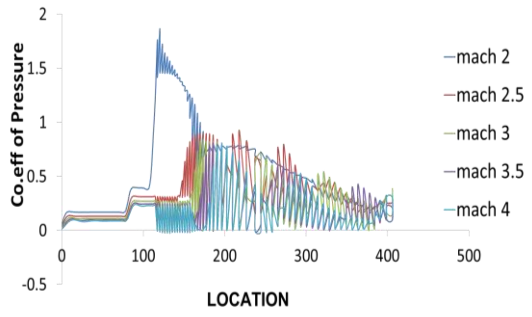


**Figure 8 Cp plot for 2° cowl deflection angle inlet for all the Mach numbers**

Figures 9 shows the Mach number contour plot for 2° cowl deflection angle inlet. The oblique shock which is formed on the first ramp impinges on the outer boundary wall for Mach number 2 and 2.5, decreases the flow Mach number, and increases the pressure and density behind the shock which can also be seen from figure 10.

The oblique shock which is again formed on the second ramp corner collides with the normal shock created on the cowl lip and forms a lambda shock. Hence the flow behind the normal shock decelerates to subsonic flow field by increasing the pressure and density. The flow near tthroat is accelerated due to the expansion fans created near the throat section which decreases the pressure and density in the throat region. Thus the flow remains supersonic at the throat region. The flow downstream of the throat section is further accelerated due to the formation of expansion fan in the divergent passage. Thus the flow remains supersonic at the exit of inlet. For Mach numbers 3, 3.5 and 4, the expansion fans are formed at the cowl lip, which increases the flow Mach number near the cowl lip, which is not observed for Mach number 2 and 2.5. The oblique shock formed at first ramp impinges inside the cowl lip near the throat for Mach number 3.5. The expansion fan near the cowl lip becomes stronger. For Mach number 4, the oblique shock formed on the first ramp and second ramp collides near the throat region.

## VII. CONCLUSION

CFD simulations have been carried out for 2° cowl deflection angle inlet configuration that are near to high supersonic Mach number range. The following observations are made:

1. The oblique shock formation is observed in both the first ramp and second ramp for all the three configurations, which results in, the increase in pressure and decrease in free stream Mach number.

2. The presence of ramp in the subsonic diffuser, leads to formation of expansion waves that results in the inlet exit flow to remain in supersonic speed.

3. For high Mach numbers, the cowl lip experiences the formation of expansion waves which results in the increase in flow Mach number more than that of the free stream Mach number near the cowl lip. The Normal shock is observed over the cylinder region for all Mach number results in increase in pressure .

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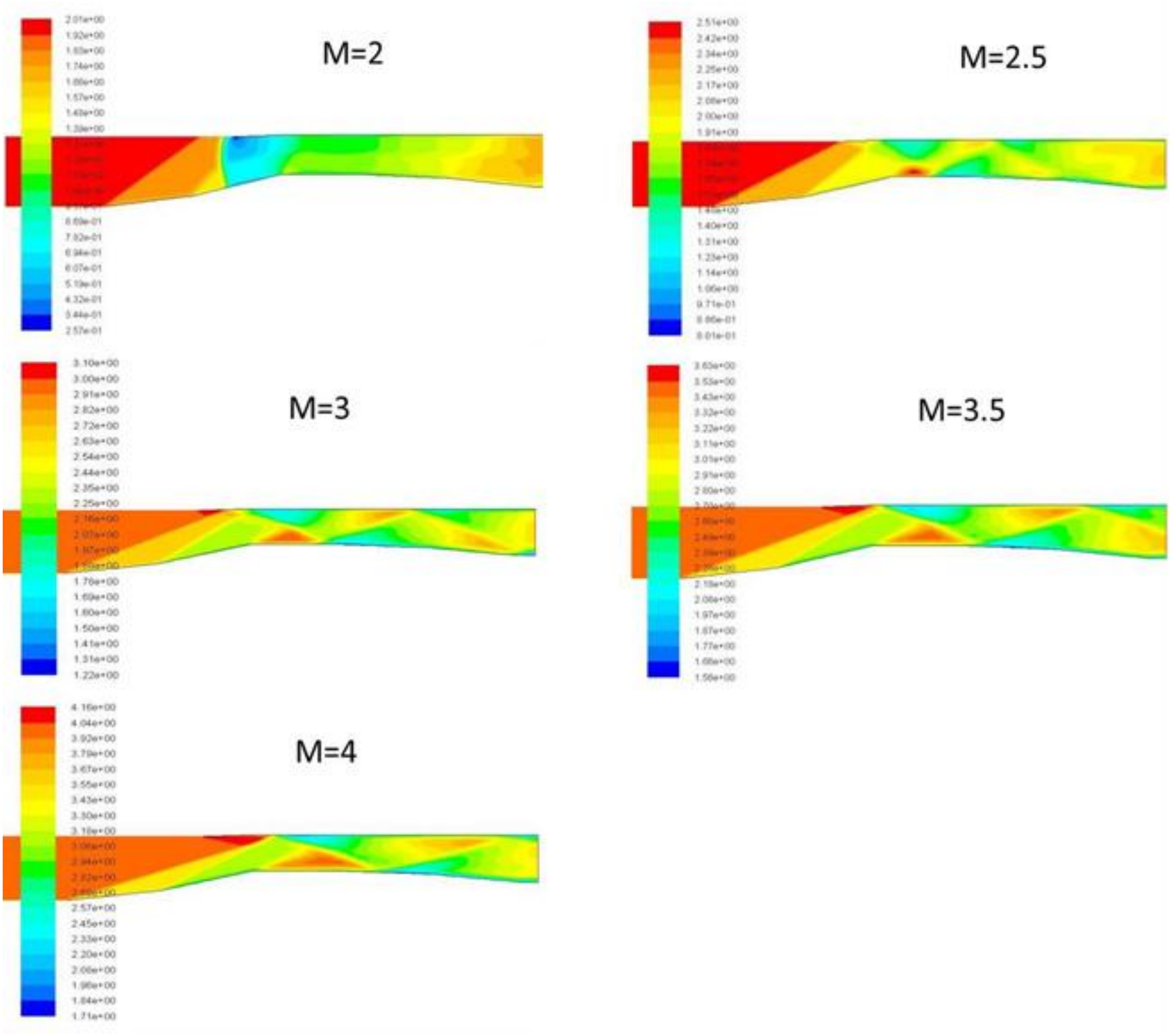


**Figure 9 Contours of Mach number for 2° cowl deflection angle inlet**

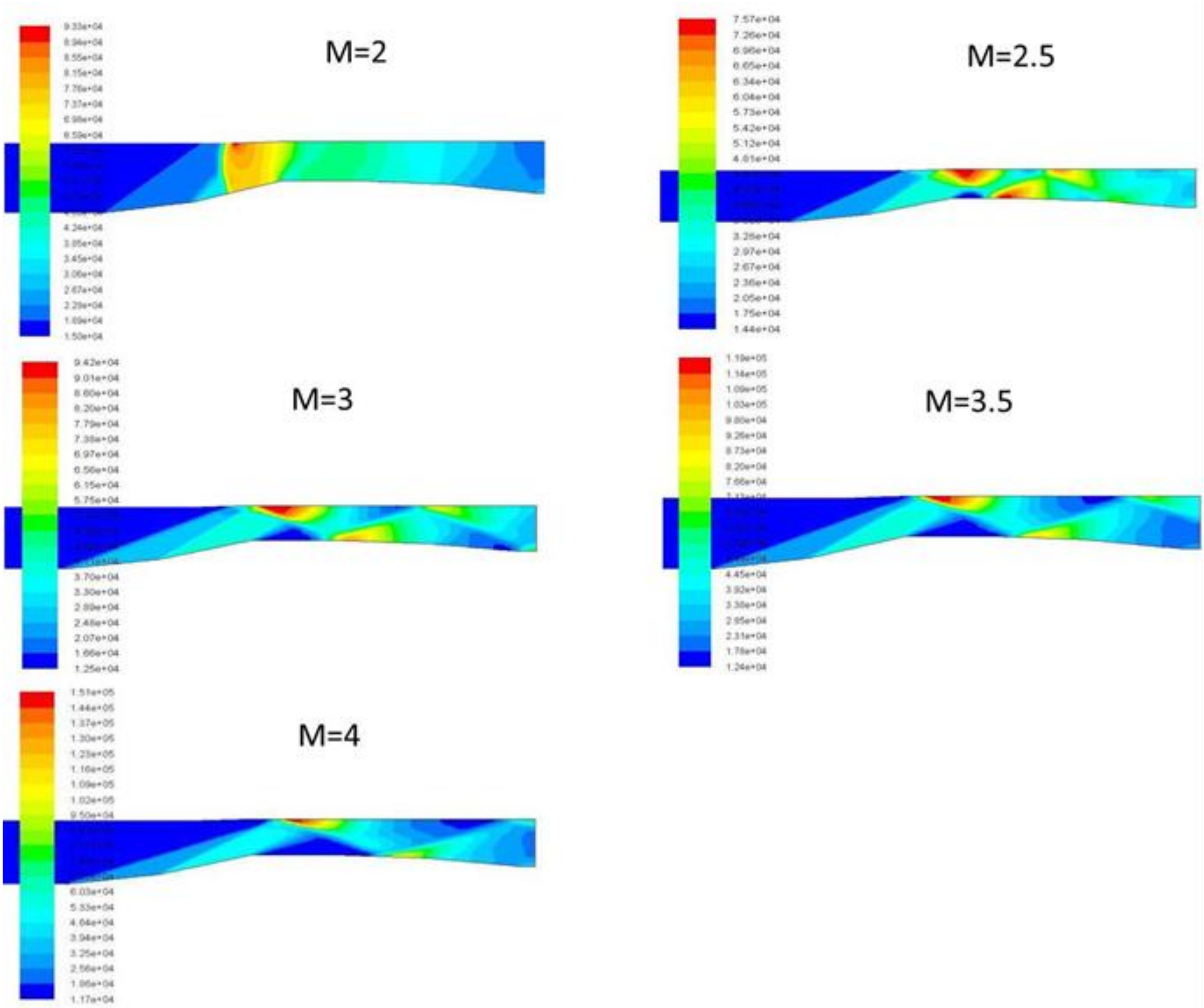


**Figure 10 Contours of static pressure for 2° cowl deflection angle inlet**