

Aerodynamics of projectiles with wrapped around and grid fins

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Abstract— Different kinds of control surfaces are being used on supersonic projectiles. Grid fins (GF) and Wrapped around fins (WAF) are two important control surfaces that have been used on many projectiles. Both have different aerodynamics characteristics associated with them. Viscous computational fluid dynamic simulations were used to compute the flow field around projectiles having GF and WAF mounted at the end of a 10 diameter long body having ogive nose. The computed aerodynamics coefficients are in good agreement with the available experimental data. The performed simulations help in understanding the flow physics associated with these surfaces. The variation of center of pressure with Mach has been shown to get a comparison of both configurations.

I. INTRODUCTION

With the advent of stealth technologies the research diverted toward the packaging of the weapons so that they could easily be stored before firing. The packaging not only reduces radar cross section of the weapons but also offers many advantages from aerodynamic point of view (axial force reduction). It is much advantageous to have the weapons that could easily be stored in internal weapon bays of the aircrafts etc; similarly if we could fold or pack control surfaces we could easily go the concept of tube launching mechanism for rockets and missiles. There are two important types of unconventional control surfaces/fins that have appeared on many rockets and missiles in the recent past. These are grid fins (GF) and wrapped around fins (WAF)

A grid fin is formed by small intersecting planar surfaces of small chords creating different shapes of grids. The structure of grid fins is inherently strong allowing the lattice walls to be very thin, reducing weight and the cost of materials. The grid fins are perpendicularly aligned to the flow so that air could pass through these grids. At

high supersonic speed the grid fins are more advantageous than the conventional planar fins. Due to small chords it is easy to turn the grid fin and with small force as compared to the planar fins. Also the stall at higher angles of attacks is delayed due to small chords increasing control effectiveness at higher angle of attacks. A further advantage of grid fins is that they can easily be folded down against the missile body. This folding makes the weapon more compact and easier to store or transport. This advantage is particularly attractive for weapons designed for internal weapons bays on stealth aircrafts. A lot of literature/published data are available on different aspects of grid fins

James Desprizio [1] analyzed the aerodynamics associated with the grid fins.

C Berner [2] has published the wind tunnel results of 10 different grid finned configurations. For the present study the one of the configurations from [3] was selected to simulate and get an insight into the aerodynamics associated with the grid fins. The grid fins of this configuration have a relatively simple shape with 9 square cells.

WAFs are used on spinning rockets. WAFs also have the characteristics of packaging. It could be conveniently packed around the projectile body in a tube before launch. The WAFs have similar longitudinal characteristics as that of a conventional planar fin [3]. A huge literature is available on wrapped around fins. Wrapped around fins have some interesting characteristics. Firstly they have non-zero rolling moment even at zero angle of attack and secondly they go through phenomena of roll reversal at low supersonic flow conditions. Many investigators have reported this phenomenon in open literature [4], [5] and [6]. Dahlke, C. W [7] also performed computational and experimental

study of wrapped around fins (WAF). To get an insight into the aerodynamics associated with the grid fin (GF), the configuration of Dahlke was chosen.

The objective of the present study was to get an insight into the aerodynamics associated with the two important unconventional controls surface (grid fins and wrapped around fins). The performed simulation successfully captured the flow patterns around the grid fins and wrapped around fins, which help in understanding the associated flow physics.

II. GEOMETRY AND MESHING

The structured grids for both the configuration were generated using gridgen. The near wall spacing was kept adequate to resolve the gradients. The final grid for Grid fin configuration contains 1.85 million nodes, while the wrapped around fin configuration has 2.9 million nodes. The grid independence was ensured through different generated grids.

Numerical Approach

The compressible RANS are employed as flow governing equations. The RANS in cylindrical coordinates are given as below:

Continuity equation:

$$\frac{\partial u_x}{\partial x} + \frac{1}{r} \frac{\partial(ru_r)}{\partial r} = 0 \quad (1)$$

Momentum equations:

$$\begin{aligned} \rho \frac{\partial}{\partial x}(u_x u_r) = & -\frac{\partial p}{\partial x} + 2\mu \frac{\partial^2 u_x}{\partial x^2} \\ & + \frac{1}{r} \frac{\partial}{\partial r} \left[\mu \left(\frac{\partial u_r}{\partial x} + \frac{\partial u_x}{\partial r} \right) - \rho u_x u_r \right] \end{aligned} \quad (2)$$

$$\begin{aligned} \rho \frac{\partial}{\partial x}(u_x u_r) = & -\frac{\partial p}{\partial x} + \mu \left(\frac{\partial u_x}{\partial r} + \frac{\partial u_r}{\partial x} \right) \\ & + \frac{1}{r} \frac{\partial}{\partial r} \left[2\mu \frac{\partial u_r}{\partial r} - \rho u_r u_r \right] - \frac{2}{r^2} \mu u_x \\ & + \frac{\rho}{r} u_\theta \end{aligned} \quad (3)$$

$$\rho \frac{\partial}{\partial x} u_x u_\theta = \mu \frac{\partial^2 u_\theta}{\partial x^2} + \frac{1}{r} \frac{\partial}{\partial r} \left[\mu \frac{\partial u_\theta}{\partial r} - \rho u_r u_\theta \right] - \frac{\rho u_\theta}{r^2} - \frac{\rho}{r} u_r u_\theta \quad (4)$$

The turbulence was incorporated through $k - \epsilon$ turbulence model with standard wall function. $k - \epsilon$ model is considered advantageous as it is mesh independent far from wall, however in the near wall region mesh has to be fine enough to capture the flow details. Due to mesh independence far from the wall the mesh for such a complex configuration (such as grid fins) could be easily managed. The equation were solved using ANSYS Fluent 13 v.

III. RESULTS AND DISCUSSIONS

Grid Fin Configuration: The grid fin configuration was simulated at various Mach numbers ranging from 0.8 to 3. The computed results are in close agreement with available experimental results [3]. In supersonic flow conditions the flow separation occurs near the grid fins, which is due to a recirculating region formed in front of the solid base of the fin. The separation of boundary layer and the recirculation, results in a recompression shock in front of the grid fin close to the wall. This region causes the flow to collide with the fin at an angle close to the angle of shock. Flow speed causes the flow to be swallowed in the web of the grid fins making a web bow shock in front of the fin. After the flow leaves the grid fin small web near wakes are observed behind the web cell walls generating multiple shock waves and expansions. Figure 4 shows the schematic of the flow at supersonic conditions near the grid fins. Same could be observed in the Mach number contours at supersonic Mach number in figure 5.

Wrapped around fin Configuration: The WAF configuration was simulated at various Mach numbers 0.8 to 3.0 to get an insight into the aerodynamics associated with the wrapped around fins. There are some interesting features associated with the WAF. WAF configurations experience a rolling moment at zero incidences and secondly these undergo through a phenomenon of roll reversal at low supersonic flow regimes.

As the flows passes by the fin due to curvature of the fin on the concave side there is a convergence of the flow

while on convex side it diverges, causing a flow asymmetry. Figure 6 and figure 7 shows the variation of static pressure at mid span and at the mid chord location of the wrapped around fins respectively. There is a clear asymmetry in the flow field, which causes a roll moment even at zero angle of attack. A similar fact could be observed in figure 8 and figure 9 which show Mach number, pressure distribution at a plane at 10% of the fin chord length. Figure 10 display the pressure contours near the fin body junction. At the body surface on concave side of the fin the pressure is higher as compared to convex side causing a flow asymmetry on the body, which is responsible for the non zero rolling moment at zero incidences.

The reported data about roll moment coefficient of the WAF is largely scattered as shown in the figure 11. This could be attributed to the different approaches used for analysis and experimentation. Figure 12 displays the comparison of computed roll moment coefficient vs Mach number with reported data. Figure 13 displays the behavior of the flow in the vicinity of the fin body junction. In the present study the cross over point was at Mach 8 which is in agreement with JPL data [7], the flow behaves differently in the fin body junction around this Mach number. Before the cross over point(at Mach 1.7) the flow remains subsonic in the vicinity of the fin body junction, while at Mach 1.9 (after the cross over point it changes from subsonic to supersonic, which could be the cause of the roll reversal at low supersonic condition of WAF. Figures 14 and 15 displays the Mach number contours at mid span between fin passages. There is a change in Mach number contours between the fin passages changing the roll from negative to positive in values. Similarly figure 16 and 17 displays the pressure between the fin passages.

Figure 18 and 19 displays the variation of axial force coefficients with Mach for Grid fin and wrapped around fin configurations respectively. The axial force in case of grid finned configuration is more as compared to wrapped around fins configuration. The grid fins are

aligned perpendicular to the flow in contrast to WAF configuration where the fins are parallel to the flow. Figure 20 and 21 shows the variation of centre of pressure with Mach. The grid fin configuration looks less stable as compared to wrapped around configuration as the variation of center of pressure is in larger interval as compared to WAF. In Present study the simulation of WAF were carried out in static condition (without spin), the spinning of the projectile also enhances the stability.

IV. CONCLUSION

The results shown are in a reasonable agreement with the available published data. Moreover the performed simulation successfully captured the complex flow physics associated with the unconventional fins, which helped in understanding the flow physics. The grid fin X_{cp} is varying in wide interval as compared to WAF, indicating loss of stability for grid fins configuration. We could infer that from stability point of view the WAF is more advantageous as compared grid fin configuration.

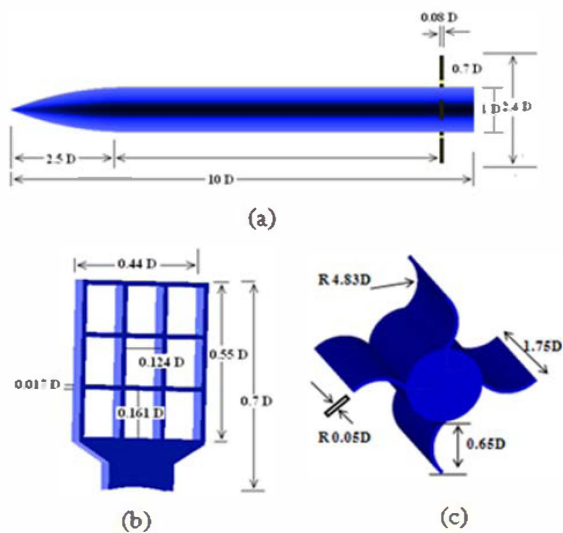
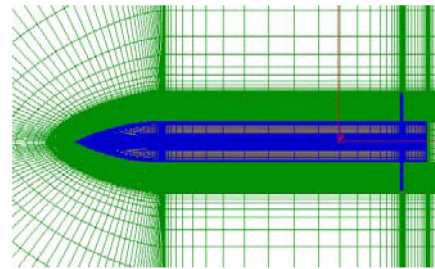
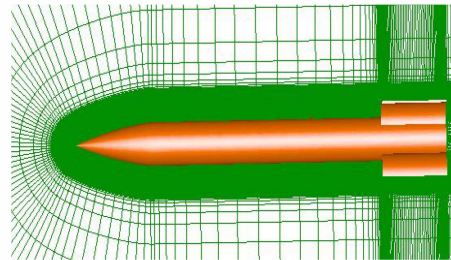


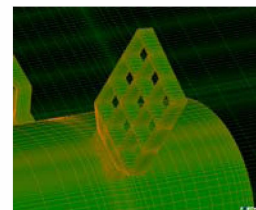
Figure 1 : Geometric detail of Configuration, (a) Nose cylinder body, (b) Grid fin, (c) Wrapped around fin



(a) Grid for Gird fin configuration



(b) Grid for wrapped around fin configuration



(c) Grid on grid fin surface



(d) Grid on WAF surface

Figure 2 : Grid Display

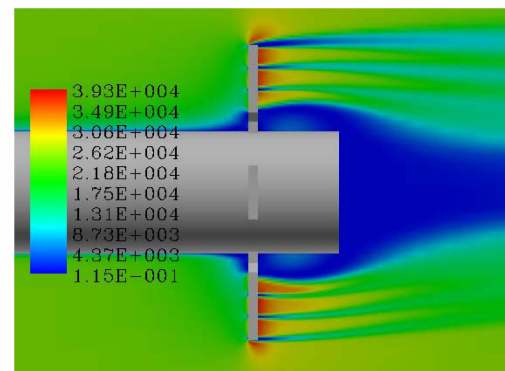


Figure 3: Contours of static pressure

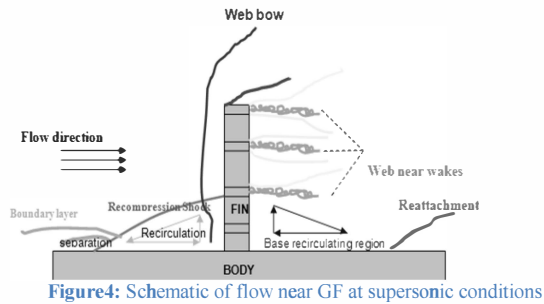


Figure4: Schematic of flow near GF at supersonic conditions

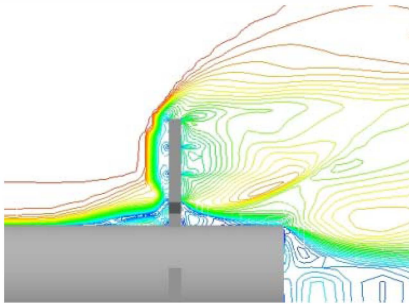


Figure 5: Contours of Mach number near Grid fins at $M=3.0$, $\alpha=0^\circ$

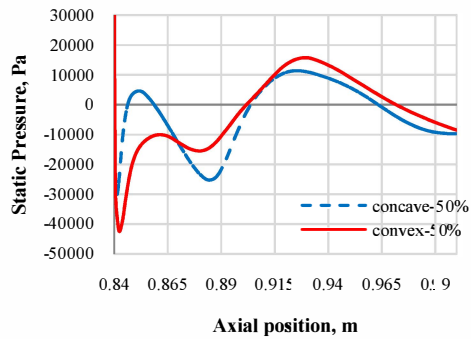


Figure 6: Static pressure vs axial location at mid span ($M=1.6$)

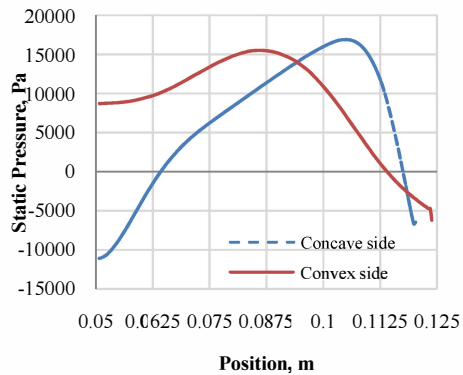


Figure 7: Static Pressure vs location at mid chord location ($M=1.6$)

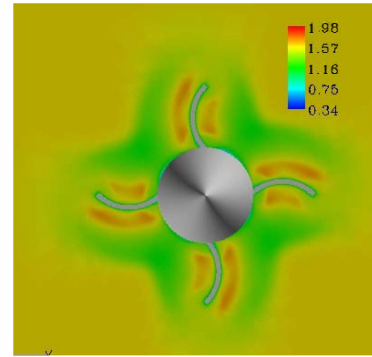


Figure 8: Mach profile at 10% axial (chord)

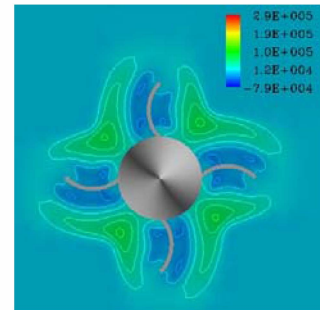


Figure 9: Pressure profile at 10% axial (chord) location for $M=1.6$

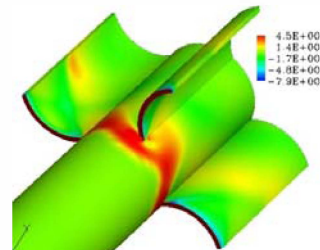


Figure 10: Pressure contours at on solid surface at $M=1.6$

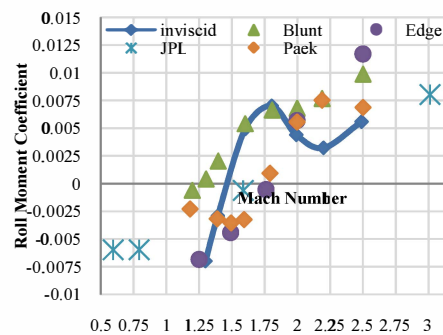


Figure 11 : Roll moment coefficient vs Mach

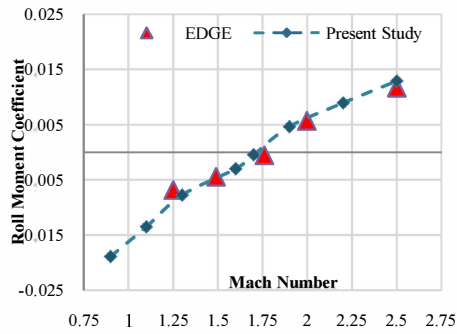


Figure 12 : Roll moment coefficient vs Mach, comparison of present work with EDGE [6]

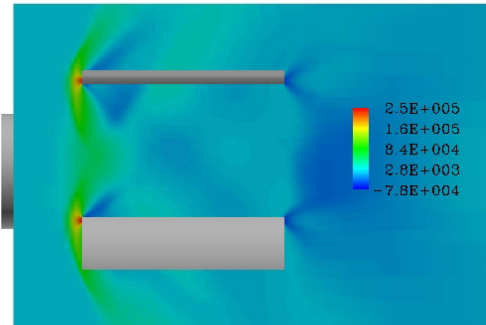


Figure 16: Pressure at mid span (M=1.7)

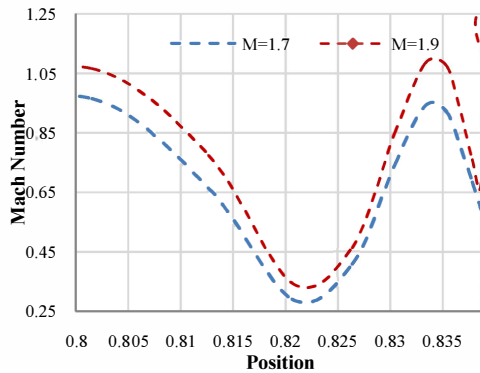


Figure 13 : Mach number profile in vicinity of fin body junction

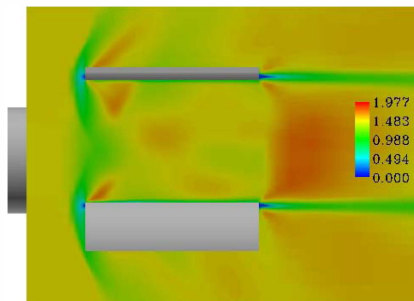


Figure 14: Mach number at mid span (M=1.7)

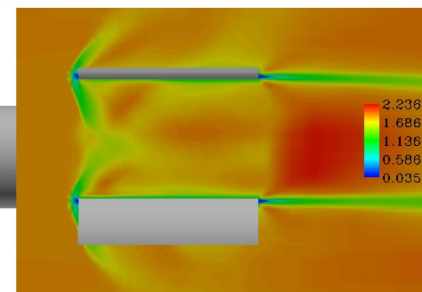


Figure 15 : mach number at mid span (M=1.9)

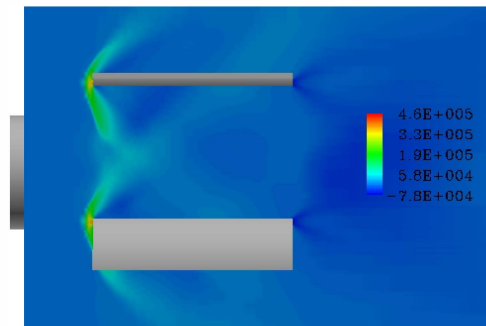


Figure 17 : Pressure at mid span (M=1.9)

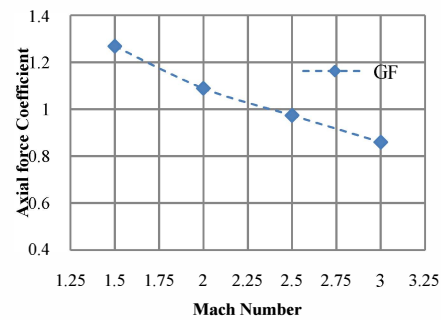


Figure 18 : Axial Force Coefficient for Grid Fin Configuration

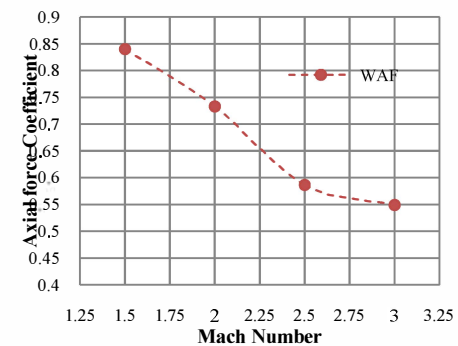


Figure 19: Axial Force Coefficient for WAF Configuration

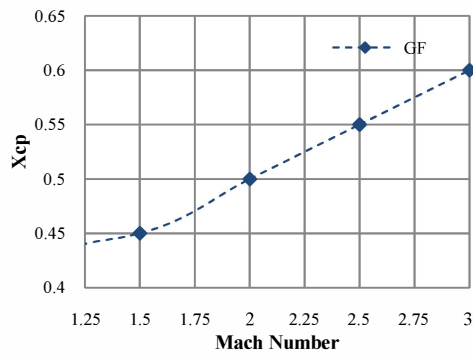


Figure 20 : Xcp vs. Mach for GF

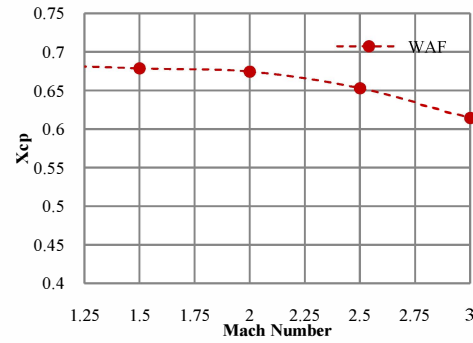


Figure 21: Xcp vs. Mach for WAF

V. REFERENCE

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7. Dahlke, C. W., "The effect of Wrap-Around Fins on aerodynamic stability and rolling moment