Effect of Truncated Micro Vortex Generators on a Mach 6 Compression Corner

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Numerical simulation is performed to study the effect of truncated MVG in reducing the separation bubble formed by the shock wave boundary layer interaction in a compression corner.

In a compression corner, the flow gets effectively turned into itself due to the ramp, causing it to get compressed. This causes an oblique shockwave called as the separation shock and due to the extreme adverse pressure gradient caused by this shock, the flow separates, and a separation bubble is formed where the air keeps swirling around which results in loss of energy, mass flow rate and total pressure. It is also accompanied by local heating and high drag[5].

MVG's immersed in the boundary layer creates tip vortices which draws more energetic and fast moving air into the slow moving boundary layer in contact with the surface. The vortex formed increases the kinetic energy of the fluid at the bottom due to the intermixing and delay the separation.

In this paper, MVGs are designed and analyses of the performance characteristics is done to reduce the size of the separation bubble, thus minimizing the losses accompanied by it.

The flat plate ramp model considered in the present study is same as the one experimentally studied by Marini M[1,2]. The model consists of a flat plate of 50 mm in length attached to a ramp with ramp angle being 15 degrees. The schematic of the model is as shown in Figure 1.

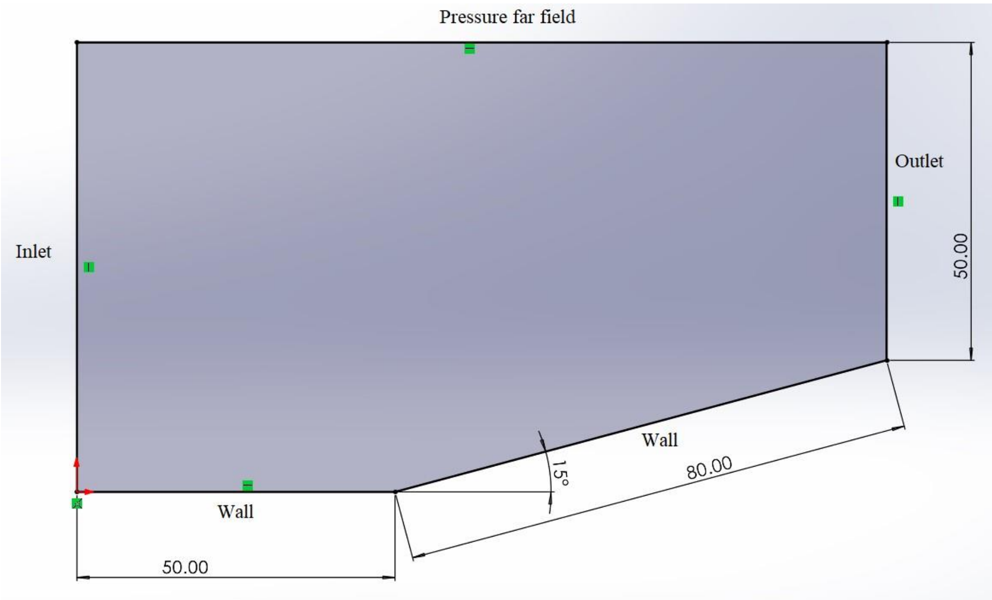


Fig. 1. 2D Compression Corner Geometry with Computational Domain

The total length of the compression corner model is 127.27mm. This model was experimentally tested in a supersonic wind tunnel with a mach number of 6. The freestream pressure and temperature were 199.4345 Pa and 131.7K respectively. The wall temperature is 300K

Numerical simulations for the current study have been performed using ANSYS Fluent 2020 R1 with mach number of 6. Density based calculations are made using Laminar model. Fluid is taken as ideal gas whose viscosity is calculated by Sutherland's three coefficient method.

The computational domain used in this study marked with boundary conditions is shown in Figure 2.

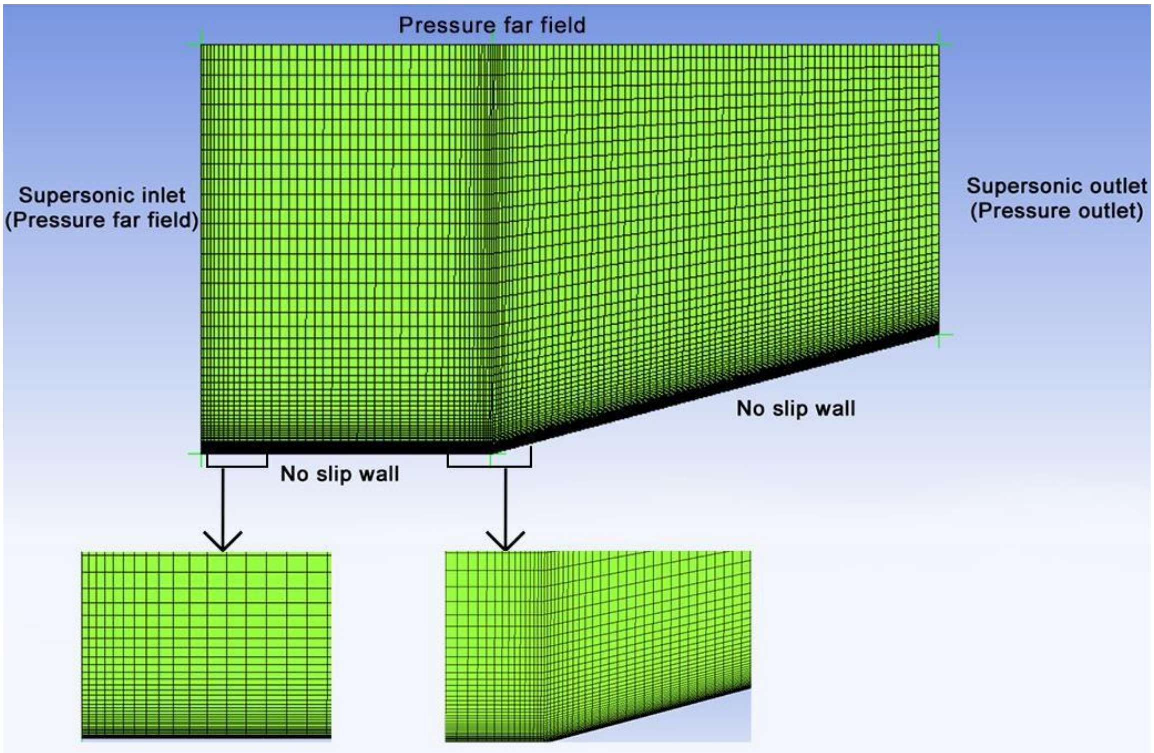


Fig. 2. Computational Domain marked with boundary conditions

To eliminate the influence of grid sizes on the investigation, grid independent study is done on the 2-dimensional model of the compression corner using 3 mesh sizes as shown in Table 1.

Overall grid size	Minimum element size near the wall	Minimum element size at the leading edge	Minimum element size at the flat plate-ramp junction
120 x 60	5 x 10^{-5}	5 x 10^{-4}	4 x 10^{-4}
180 x 75	3.75 x 10^{-5}	3.5 x 10^{-5}	2.5 x 10^{-5}
240 x 90	2.5 x 10^{-5}	2 x 10^{-5}	1 x 10^{-5}

Table 1. Details of grids used for validation

Pressure coefficient obtained from the simulations is seen to be in good agreement with the experimental values taken from Marini M[1,2] as shown in Figure 3.

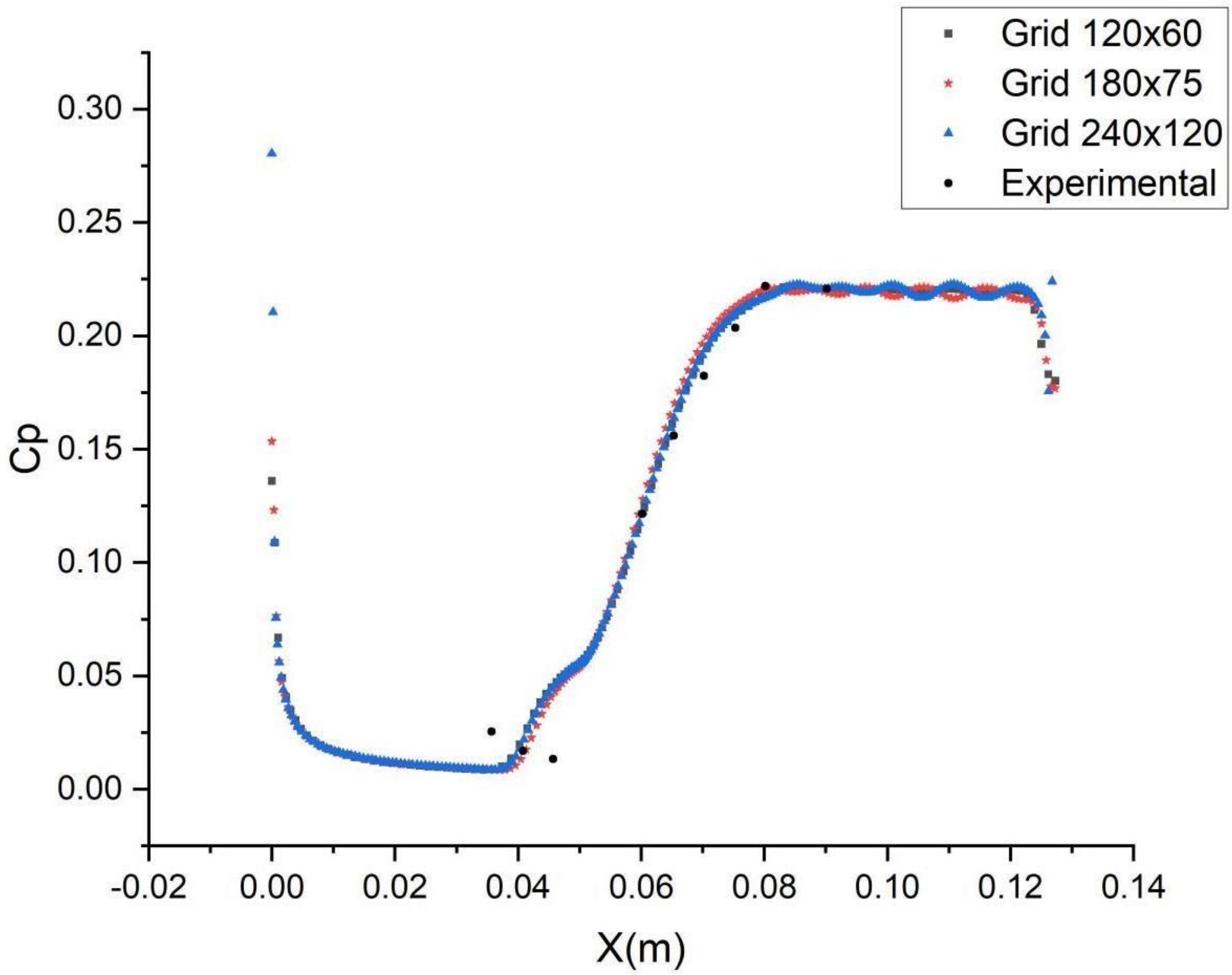
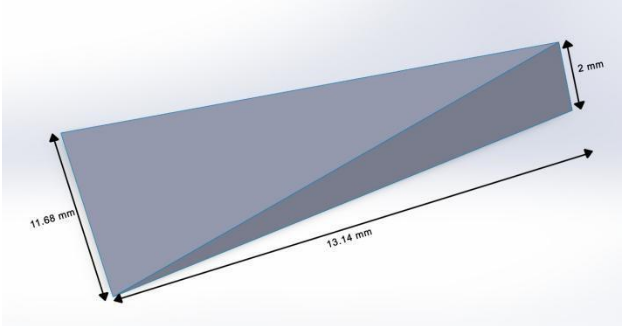
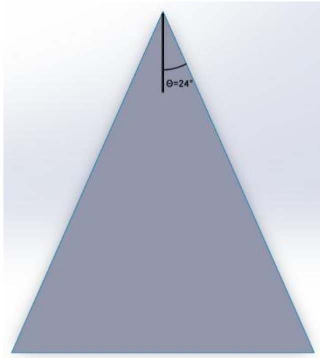


Fig. 3. Comparative study of pressure coefficient on surface of compression corner and grid independent study

It is seen clearly from the above figure that the results are independent of the number of mesh elements used. Optimum results can be seen for the grid size 240 x 90 and therefore it is used for further analysis.

Conventional MVG[3] is placed in the compression corner with the tip at a distance of 30mm from the inlet. Truncated MVGs (new design) is then placed and the distances and positions are maintained the same as before. 3D model of the conventional[3] and truncated MVGs are shown in Table 2 below.

<table>
<tr><td>MVG</td><td>Isometric View</td><td>Top View</td></tr>
<tr><td>Conventional MVG</td><td>
</td><td>
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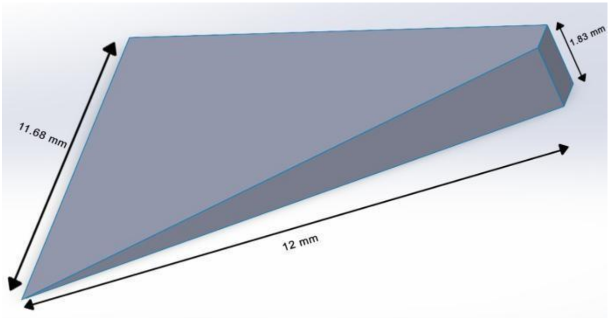
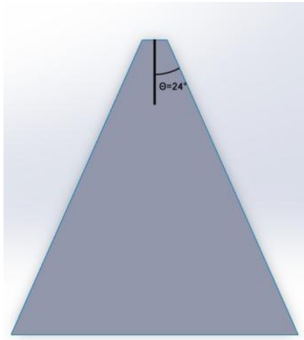
<tr><td>Truncated MVG (Cut at 12mm)</td><td>
</td><td>
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Table 2. Isometric and top view of Conventional and Truncated MVGs

Three variations of the truncated MVG were analysed. The cuts are made at 10mm, 12mm and 12.5mm from the base of the MVG. The 3D model of the Conventional MVG[3] placed in the compression corner is shown in Figure 4. The other MVGs are placed in a similar way.

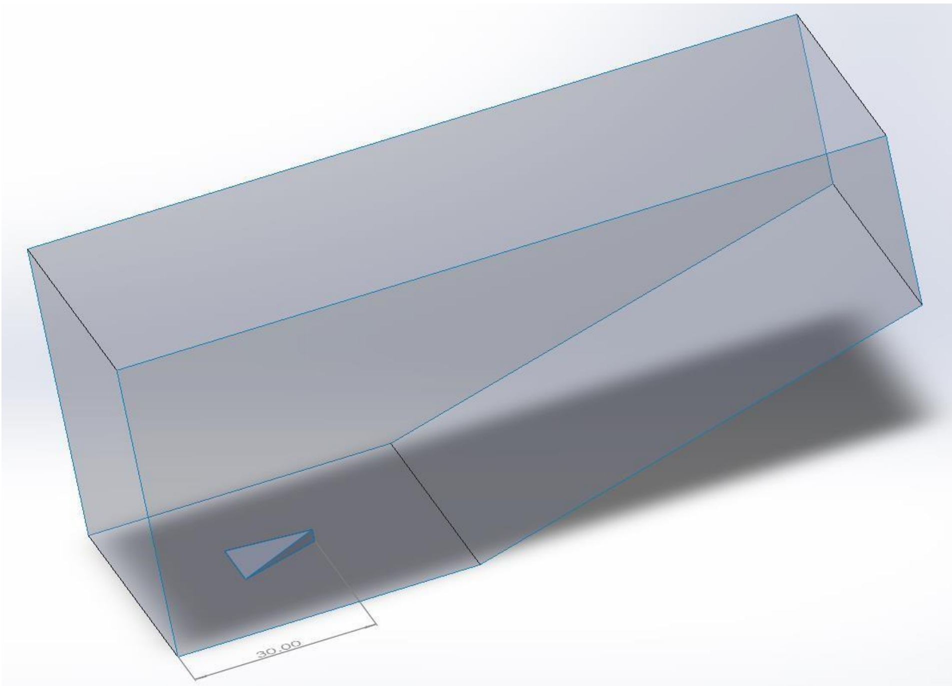

Fig. 4. 3D model of Conventional MVG placed on surface of compression corner

Numerical simulation is performed for all the aforementioned cases and the pressure coefficient values at a plane 2mm from the leftmost plane of the computational domain are plotted and compared in Figure 5.

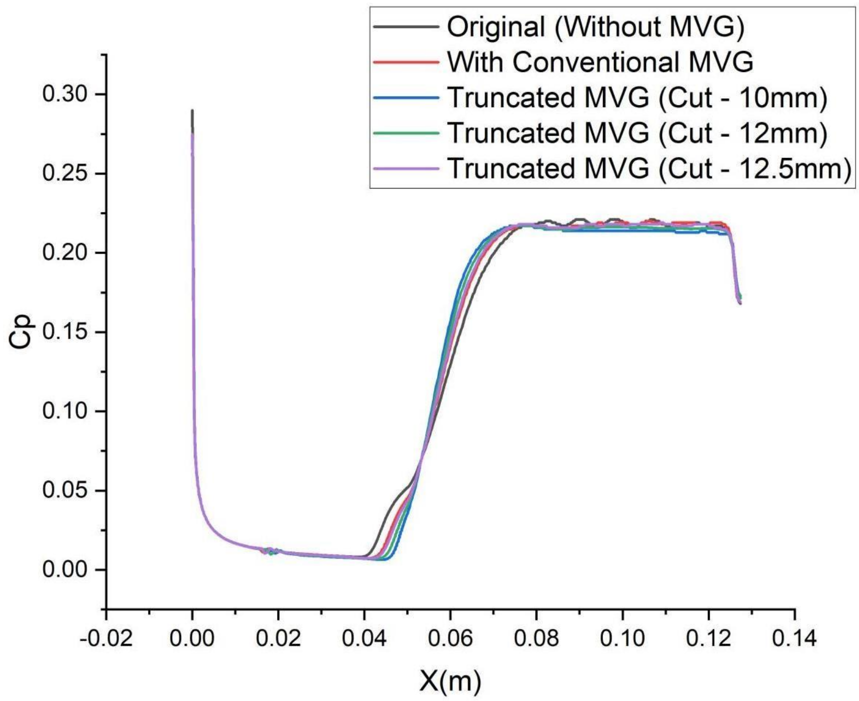

Fig. 5. Comparison of surface pressure coefficient distribution at a plane 2mm from leftmost plane of the computational domain

The X wall shear stress for all the cases are also plotted in Figure 6.

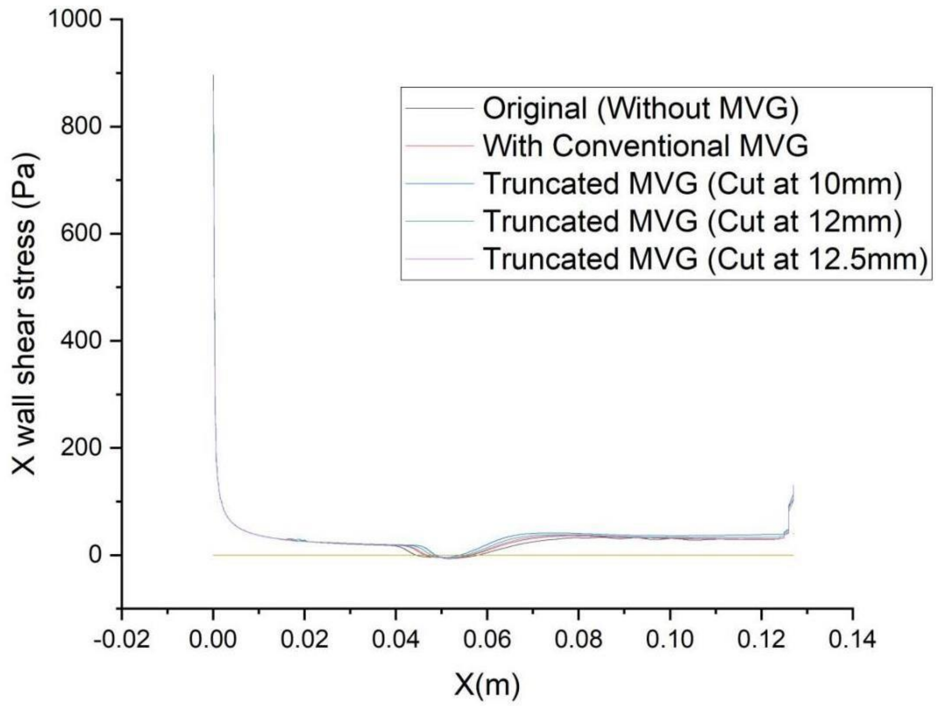

Fig. 6. Comparison of surface X Wall Shear Stress distribution on a plane 2mm from leftmost plane of the computational domain

The mach number contours for all the cases is shown in Figure 7. It can be clearly seen from all 3 images that the separation is delayed by putting any MVG. The truncated MVG with cut at 10mm produces the best result as the separation bubble is the smallest in that case.

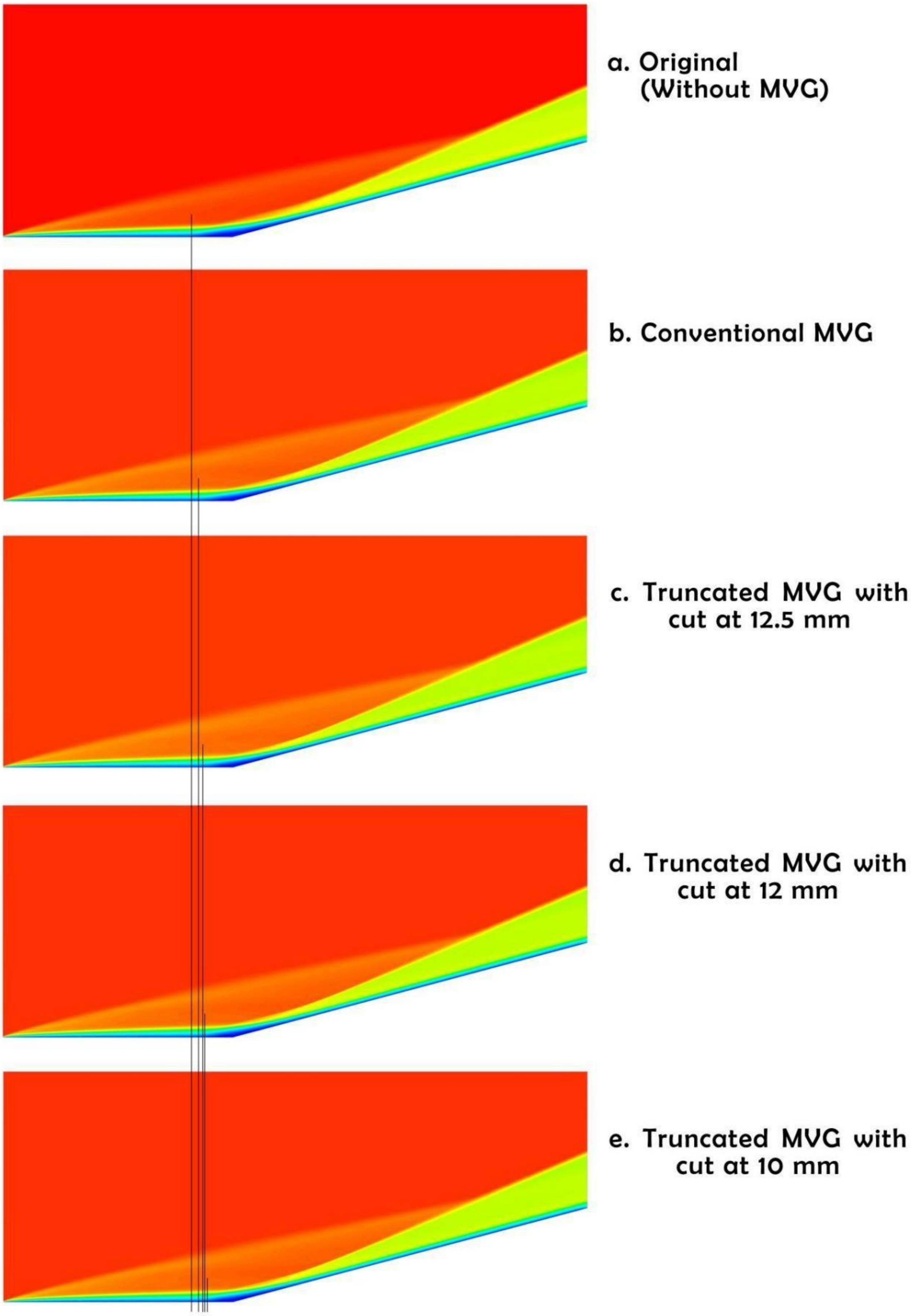

Fig. 7. Mach number contours of all the cases at a plane 2mm from leftmost plane of computational domain (Lines showing starting of separation)

The percentage increase in total pressure recovery was calculated between the truncated MVG with a 10 mm size and the conventional MVG, resulting in a value of 20%.

References

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