Numerical Analysis of Shockwave Boundary Layer Interaction

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1. INTRODUCTION AND OBJECTIVE

Shock wave–boundary layer interactions (SBLI) occur when a shock wave and a boundary layer converge. Since both are present in nearly every supersonic flow, such interactions are common. The most obvious way they arise is when an externally generated shockwave impinges on a surface with an already tripped boundary layer. Another way these interactions occur is when the surface gradient changes sharply, producing a strong flow compression near the body. In supersonic flow, such compressions typically generate a shock wave that originates within the boundary layer. The effect on the viscous flow is analogous to that of an externally impinging shockwave.

The external consequences of SBLI include control loss, excessive aerodynamic heating, and unsteadiness. The internal consequences include pressure losses, distortion intensification, and, in extreme cases, engine unstart. With the rapid advancement of high-speed aircraft, SBLI has become a subject of great importance to mitigate risks that have historically caused failures in several aircraft.

These consequences can be reduced using flow control techniques. Flow control is categorized into: Active control techniques, such as steady/pulsed microjets, suction, and plasma jets. Passive control techniques, such as vortex generators, surface bumps, and cavities placed on the tripped boundary layer surface where shock impingement occurs.This study presents computational analyses of two models: one standard flat-plate model and another with vortex generators mounted for flow control.

2. METHODS OF ANALYSIS

The computational geometry was created using *SolidWorks 2024 (student edition)*. The standard case consisted of a wedge with a half-angle of 12.5°, used to generate the shockwave. A flat plate was placed parallel to the wedge at a distance of 25 mm. The second case included vortex generators mounted on the flat plate.

Meshing of the geometries was carried out in *ANSYS Workbench*. Figure 2 illustrates the mesh for the standard model, which was generated under identical conditions for both cases. The physics preference was set to CFD, and a grid independence study was performed to validate the mesh quality.

Boundary conditions:

- Inlet: Pressure far-field type, with a gauge pressure of 6000 Pa.
- Turbulence model: k–ω SST, chosen for its accuracy in resolving boundary layer interactions

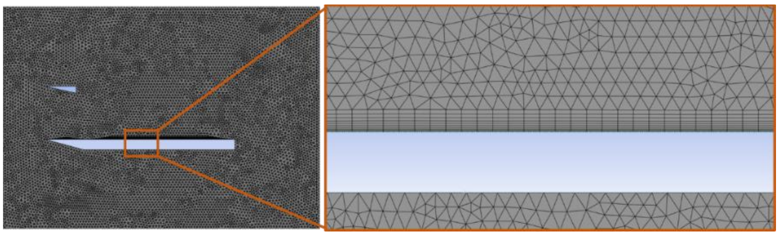

Figure 2: Grid generation of standard geometry

3. RESULTS

a. Velocity Contours

The velocity results highlight the differences between the standard model and the configuration with vortex generators (VGs). In the standard case, a strong reflection of the incident shockwave is observed, accompanied by a large separation bubble at the impingement region. The velocity in this zone reduces drastically to approximately 100 m/s, indicating severe momentum loss and boundary layer separation.

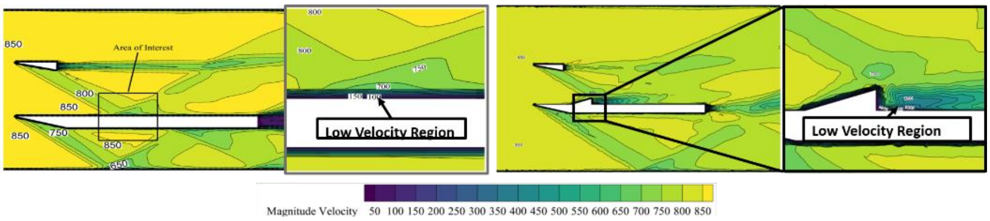

Figure 5: Velocity Contours

In contrast, the VG model exhibits the formation of streamwise vortices that enhance momentum transfer into the near-wall region. As a result, separation is almost fully suppressed, and the reflected shock is significantly weakened and diffused. Downstream recovery of velocity is much quicker, demonstrating better flow stability and resistance to shock-induced separation.

b. Temperature Contours

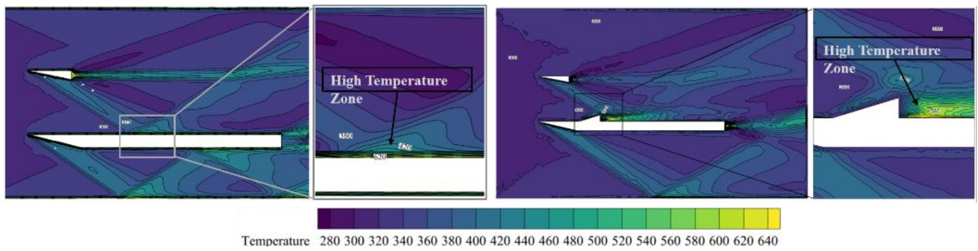

Figure 6: Temperature Contours

Temperature distributions show the effect of shock impingement on surface heating. In the standard model, the maximum temperature reaches approximately 640 K at the impingement point, creating a localized hotspot due to strong compressive heating. With VGs, the peak temperature drops to approximately 580 K, indicating improved mixing and reduced thermal gradients. This moderation of temperature rise demonstrates that vortex generators can mitigate aerodynamic heating, thereby reducing material stress and heat load on high-speed surfaces.

4. CONCLUSION

This study performed a computational investigation of shockwave–boundary layer interaction (SBLI) over a flat plate with and without the use of passive flow control through vortex generators. The results, presented in terms of velocity and temperature contours, clearly showed the beneficial role of vortex generators in modifying the flow structure. In the standard model, strong shock reflection, formation of a large separation bubble, and significant local heating were identified, with maximum temperatures approaching 640 K. By contrast, the model with vortex generators exhibited reduced shock reflection, suppression of separation, and improved near-wall momentum transfer due to streamwise vortices. This led to not only enhanced flow stability but also a reduction in peak temperatures by nearly 60 K, thereby lowering the aerodynamic heating effect. Overall, these findings reinforce the potential of vortex generators as an effective and simple passive control strategy to mitigate adverse SBLI phenomena. Their ability to reduce separation, improve boundary layer robustness, and alleviate thermal loading makes them valuable for extending the operational envelope and reliability of supersonic and high-speed aerospace vehicles.

5. REFERENCES

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