INVESTIGATION OF HEMISPHERICAL AEROSPIKE FOR BLUNT BODY AT HYPERSONIC SPEED

Aditya Shirolkar[1], Charu Chandra C[1], Dheemanth B A[1], Yash Vimalesh Revankar[1], Mahesh Kumar N[2], Chethana S Batakurki[2]

[1] *Student, Department of Mechanical Engineering, RNSIT, Karnataka, India*
[2] *Assistant Professor, Department of Mechanical Engineering, RNSIT, Karnataka, India*

ABSTRACT

Aerospace vehicles, such as re-entry vehicles, satellite launching vehicles, missiles, and rockets, operate at extremely high speeds, leading to the generation of shock waves and significant heat and drag. The high heat and drag generation significantly affect the efficiency and maneuverability of such vehicles. To counter this, the present study focuses on the design and analysis of drag reduction techniques for hypersonic vehicles, specifically investigating the effectiveness of different spikes with hemispherical aerodisk. The blunt body configuration is employed as a model, and the analysis is conducted at a hypersonic speed corresponding to Mach number 6.

The research explores the impact of varying sizes of spiked blunt bodies, considering the length of the spike to diameter of the blunt body (L/D) ratios of 1.5 and 2. The introduction of a front-facing spike effectively reduces the intensity of the bow shock at the front part of the blunt body by converting it to an oblique shock wave. Notably, a drag reduction of 60% is achieved using a spike with an L/D ratio of 1.5, while a higher reduction of 75% is attained with an L/D ratio of 2.

Additionally, the study examines the influence of altering the minor radius of the aerodisk, further evaluating its effect on reduction of the shock wave formation in the frontal region of the aerospike. The findings highlight the potential of these drag reduction techniques to enhance the aerodynamic performance of hypersonic aerospace vehicles, paving the way for improved efficiency and maneuverability in high-speed flight conditions.

Keyword: *aero-spike, blunt cone nose, aerodynamic drag, bow shock*

---

1. INTRODUCTION

The use of blunt-nosed bodies for high-speed vehicles presents a challenge due to the resulting high-pressure region around the body, leading to high shock wave, drag and aerodynamic heating. To address this issue, a forward-facing spike attached to a hemispherical blunt body can effectively reduce the drag coefficient and minimize required propulsive thrust during supersonic and hypersonic flight. This spike creates a conical shock wave that separates the flow from the main body, resulting in lower pressure and wall heat flux in the forward-facing region. While the reattachment of the shear layer on the shoulder of the hemispherical body can increase local heat flux and pressure, the use of spikes remains a reliable technique for reducing drag and aerodynamic heating. The Aero-spike, a thin rod mounted on the tip of a blunt body, has been studied for its ability to reduce shock wave and drag while maintaining a blunt nose in hypersonic flight.

2. MODELLING AND MESHING

2.1 MODELLING

Hemispherical blunt bodies without spike and with hemispherical spike of different L/D ratios (ratio of length of aerospike to diameter of blunt body) are modelled using Solidworks as shown in the figures below. A blunt body with diameter of 40mm is considered for the present study. Only half of the model is considered for simulation as symmetry conditions are used and simulation could be performed quick.

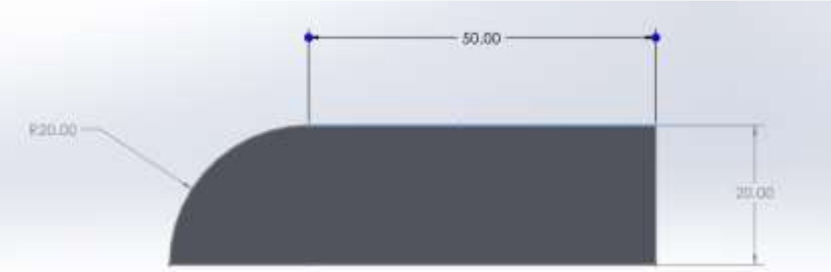

Fig – 1 Blunt Body

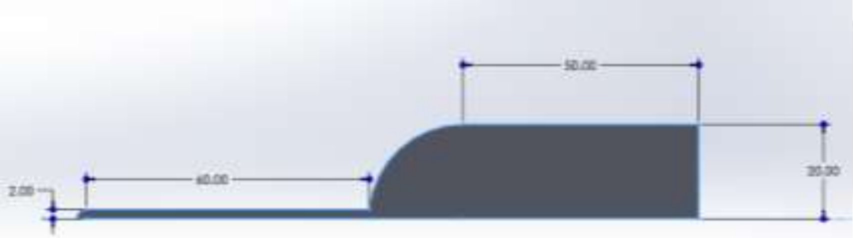

Fig – 2 Blunt body with spike L/D ratio 1.5

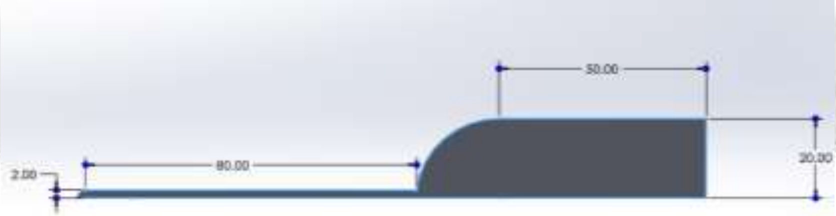

Fig – 3 Blunt body with spike L/D ratio 2

2.2 MESHING

Ansys ICEM mesh tool was used to mesh the created domain. Unstructured quadrilateral fine elements were used in between the range of 90,000 to 1,00,000 elements. Inflation layers of about 10-15 were added to the blunt body and spike region to capture accurate shock waves surrounding the region

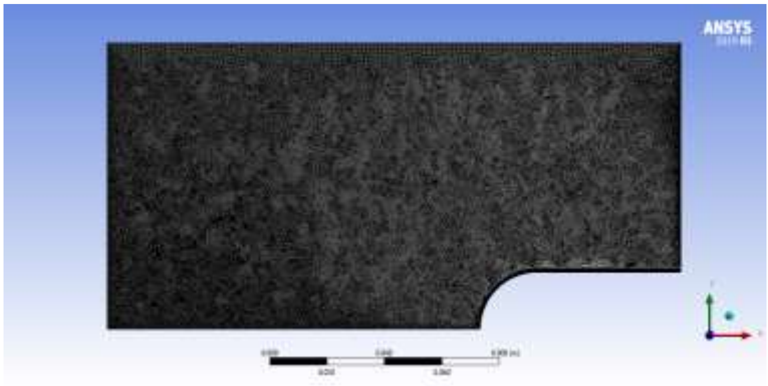

Fig – 4 Blunt body Mesh

2.3 MESH DEPENDENCY

A mesh dependency study was performed to check the accuracy of the mesh. Very fine meshes with inflation transition ratio of 0.77, 0.272 and 0.077 were used to run simulations for blunt body without spike. It was found that the results obtained were similar and most accurate with transition ratio of 0.077. Hence for further simulations of blunt body with spike the inflation transition ratio used was 0.077.

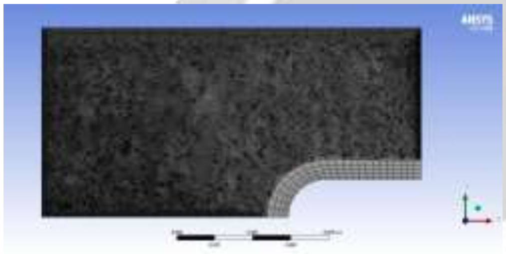

Fig – 5 Transistion Ratio 0.77

Fig – 6 Transistion Ratio 0.272

Fig – 7 Transistion Ratio 0.077

3. RESULTS AND VALIDATION

3.1 BOUNDARY CONDTIONS

A domain around the models were created and named sections were given. The boundary conditions of pressure and velocity were applied on the named sections as shown in the figure. The inlet boundary conditions included gauge pressure of 830000 Pa, Temperature 450K and velocity of Mach number 6. For outlet static pressure outlet was given. This data was obtained from experimental paper [1]. The k-ω SST turbulence model was used to solve the problem at hand.

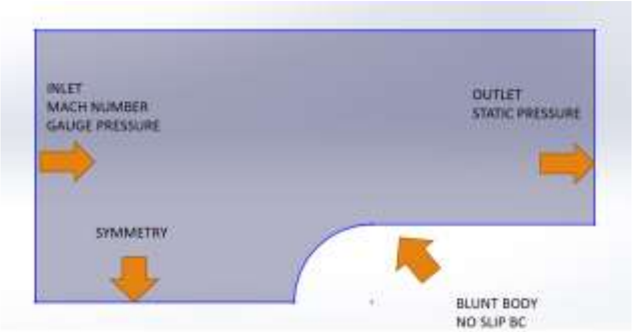

Fig – 8 Domain and boundary conditions

3.2 RESULTS

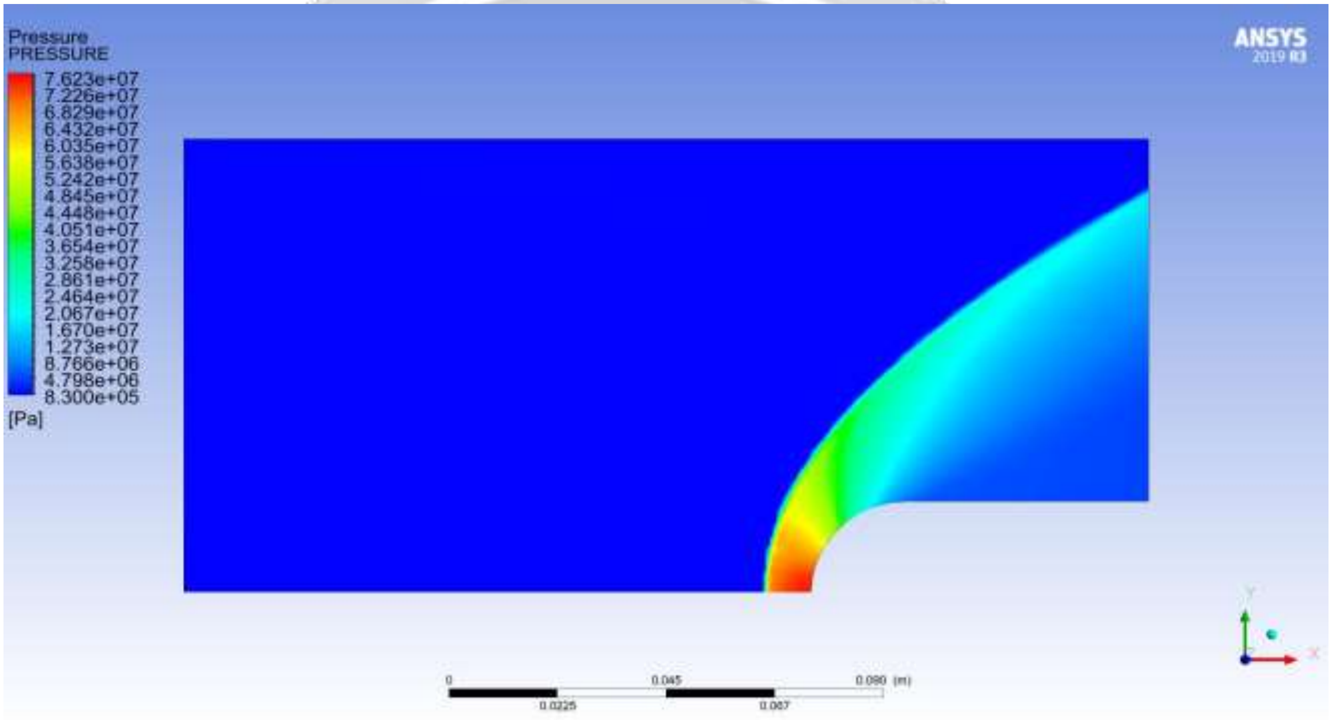

Fig – 9 Pressure contour

The contours show that there is a sudden pressure increase at stagnation point of blunt body. This sudden pressure change causes bow shock wave at the front of blunt body.

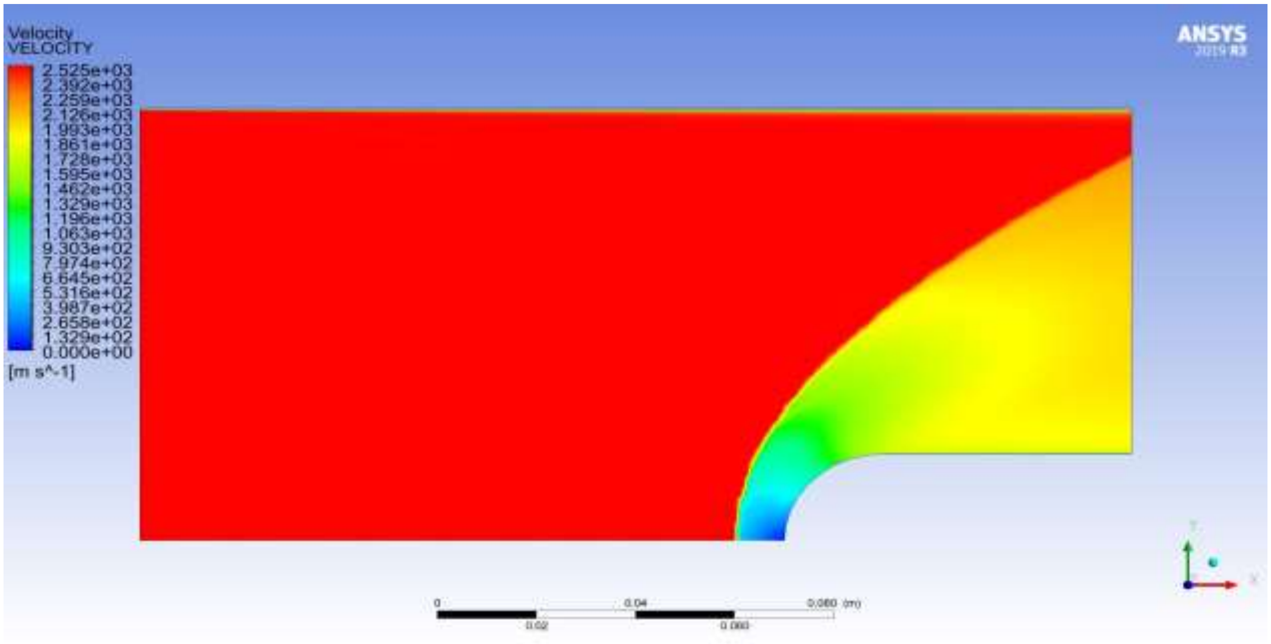

Fig - 10 Velocity contour

The contour shows that there is sudden decrease in velocity at the stagnation point of blunt body. Therefore, the drag experienced is highest at the stagnation point of the blunt body.

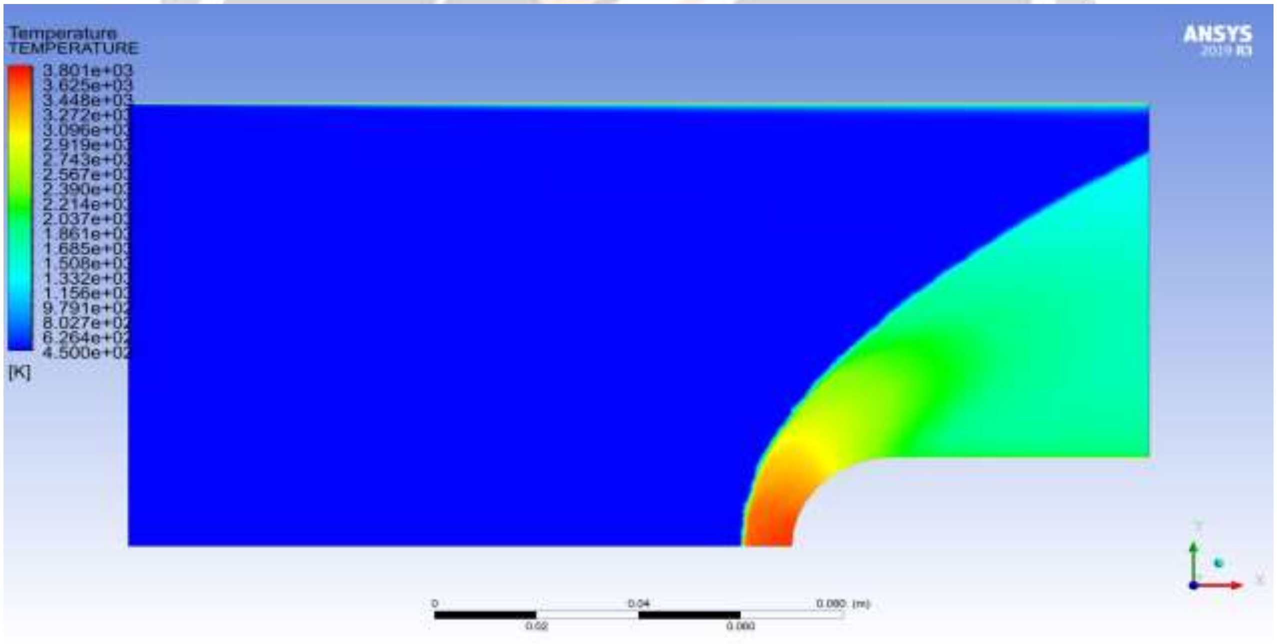

Fig – 11 Temperature contour

The bow shock waves and high drag cause heat generation at the frontal surface of the blunt body.

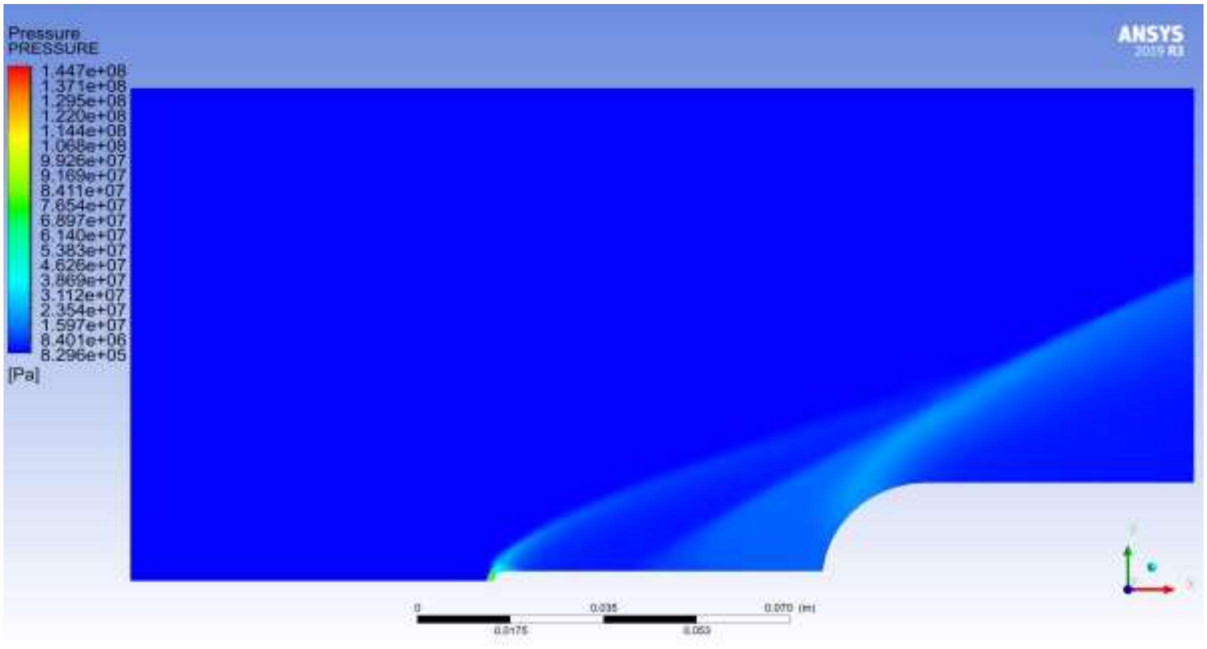

Fig - 12 Pressure contour with spike L/D ratio 1.5

The contour shows that there is a sudden pressure increase at stagnation point of aero-spike. This sudden pressure change causes bow shock wave at the front of aero-spike.

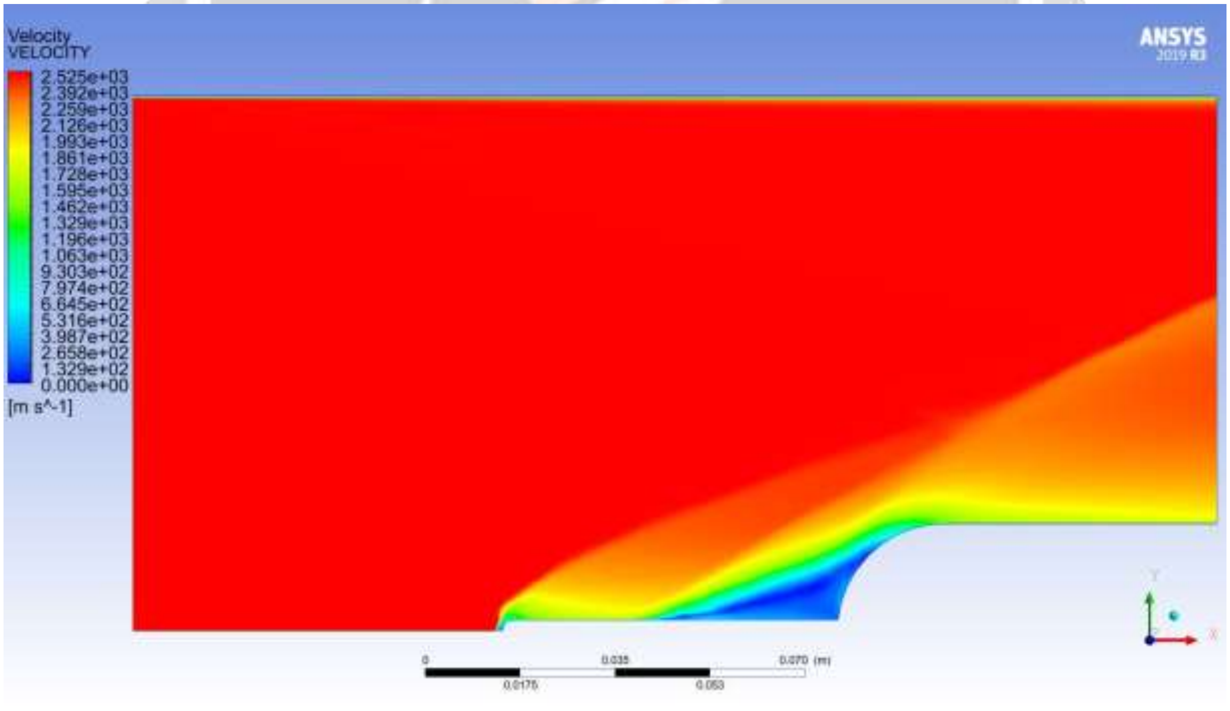

Fig - 13 Velocity contour with spike L/D ratio 1.5

The contour shows that there is sudden decrease in velocity at the stagnation point of aero spike. Therefore, the drag experienced is highest at the stagnation point of the aero spike.

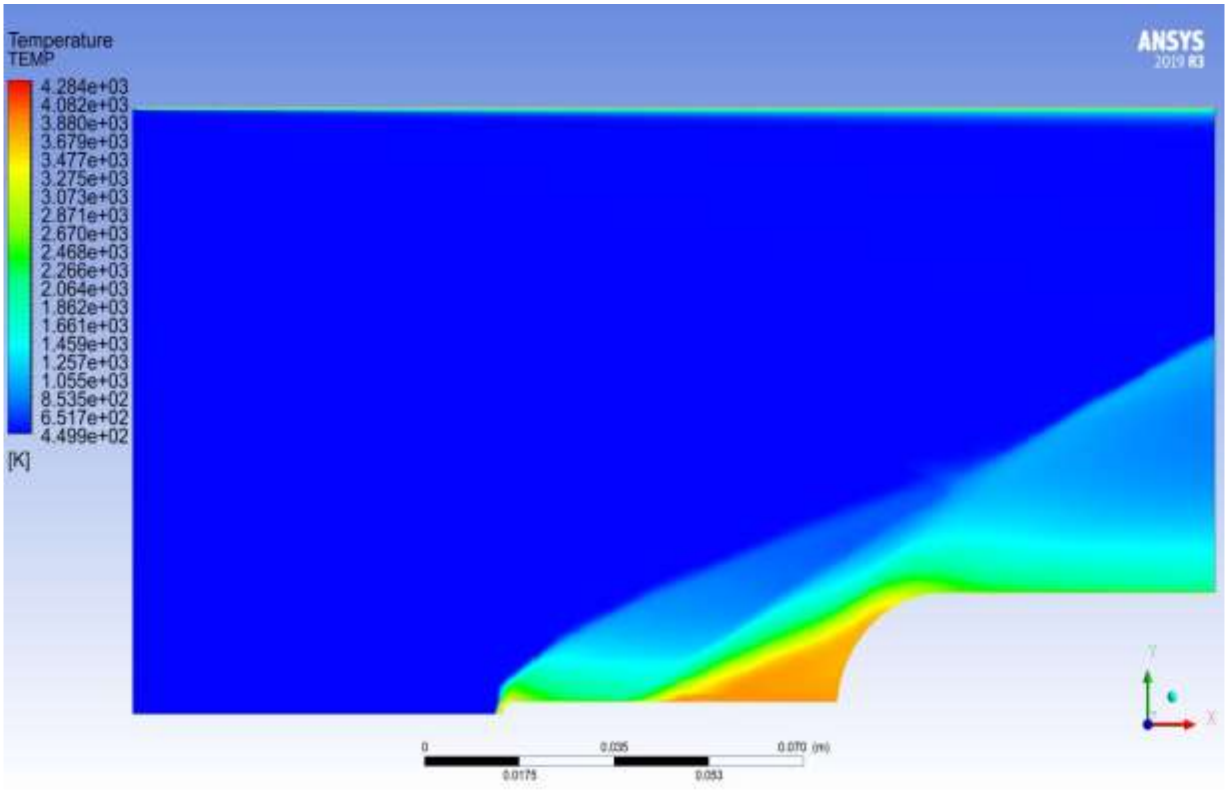

Fig - 14 Temperature contour with spike L/D ratio 1.5

From the temperature contour we observe that the temperature rises after shock wave which will affect more heating on the surface of aero spike. The maximum temperature attained is at stagnation point of aero disk. It gradually decreases behind the aero disk and towards the blunt body.

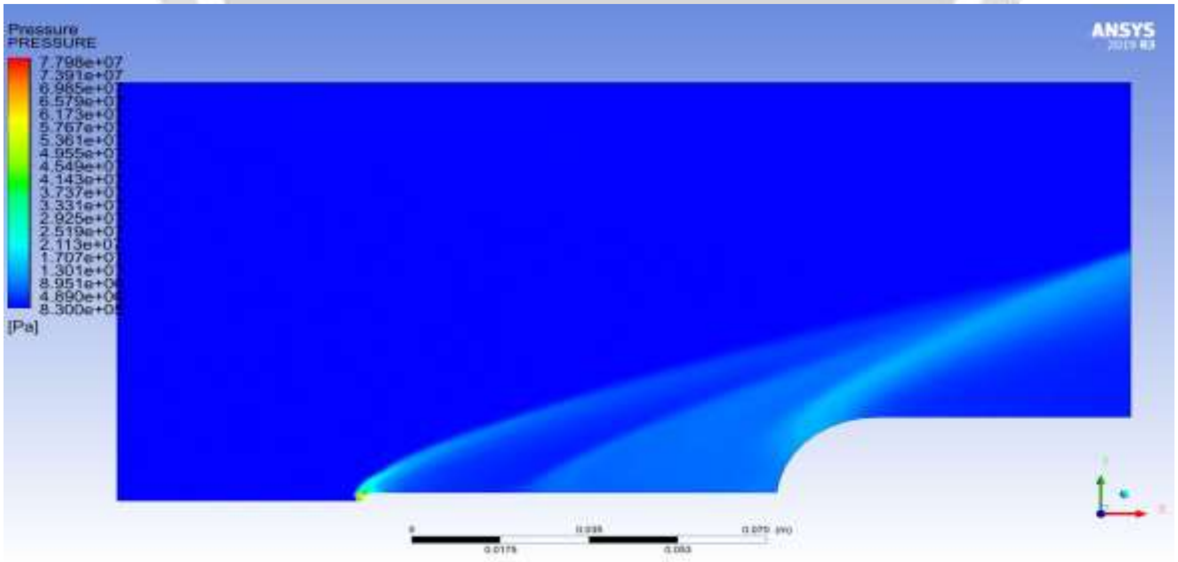

Fig – 15 Pressure contour with spike L/D ratio 2

Maximum pressure produced in this case is lower when compared to blunt body with aero spike L/D ratio 1.5.

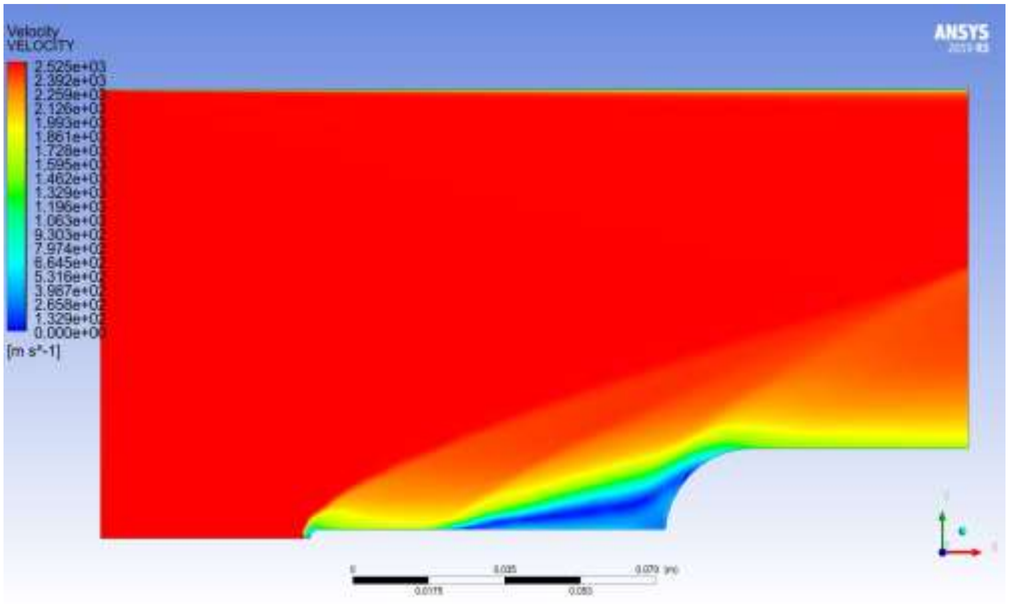

Fig – 16 Velocity contour with spike L/D ratio 2

Velocity contour shows similar results to L/D 1.5.

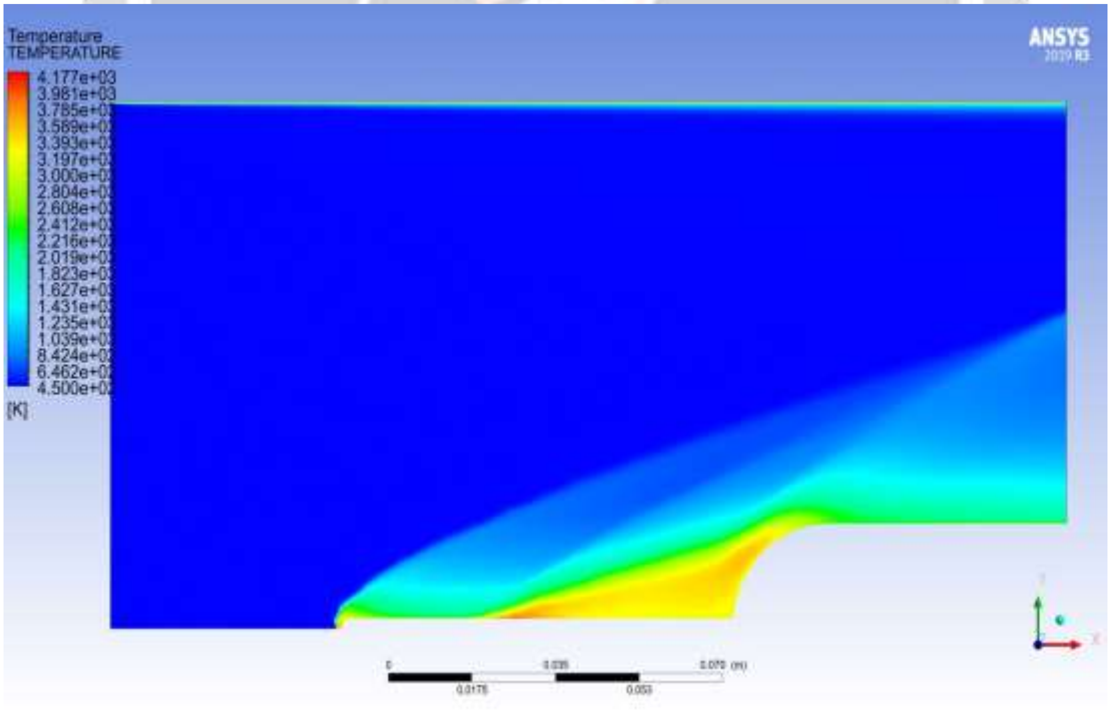

Fig – 17 Temperature contour with spike L/D ratio 2

The temperatures generated behind the aero disk are further reduced.

The simulation was run for models with minor radius of 3mm and 4mm as well to compare the resultant shockwaves. The pressure contours are shown in the figure below.

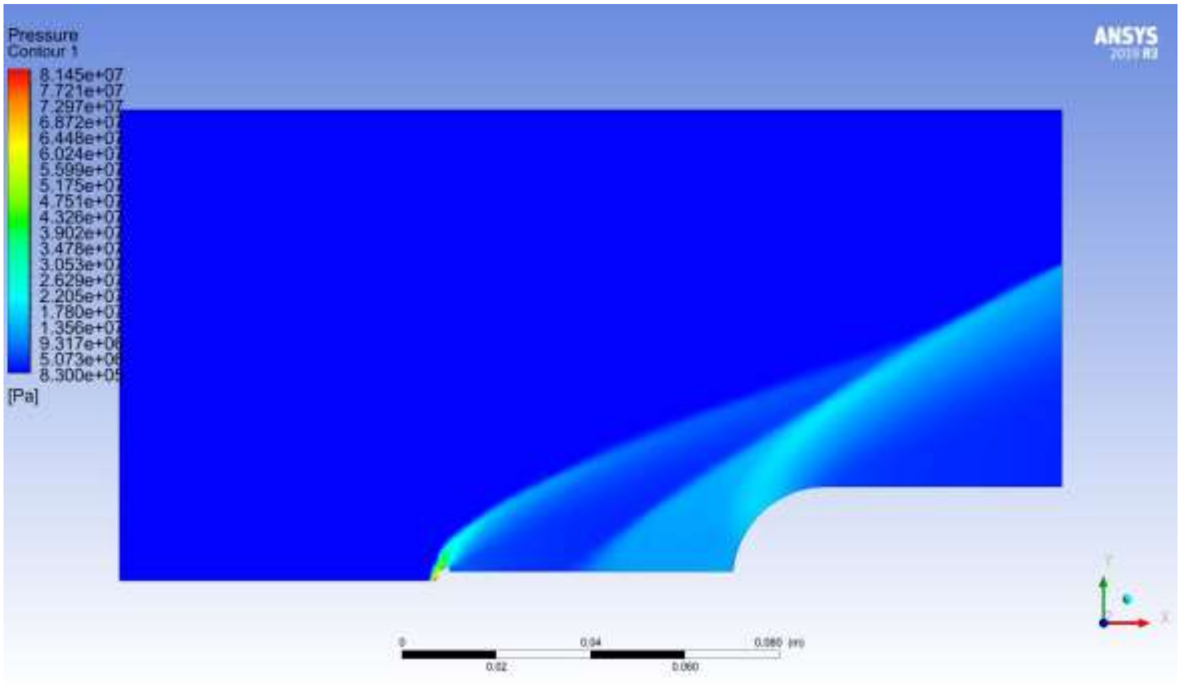

Fig – 18 Pressure contour with minor radius 3 L/D 1.5

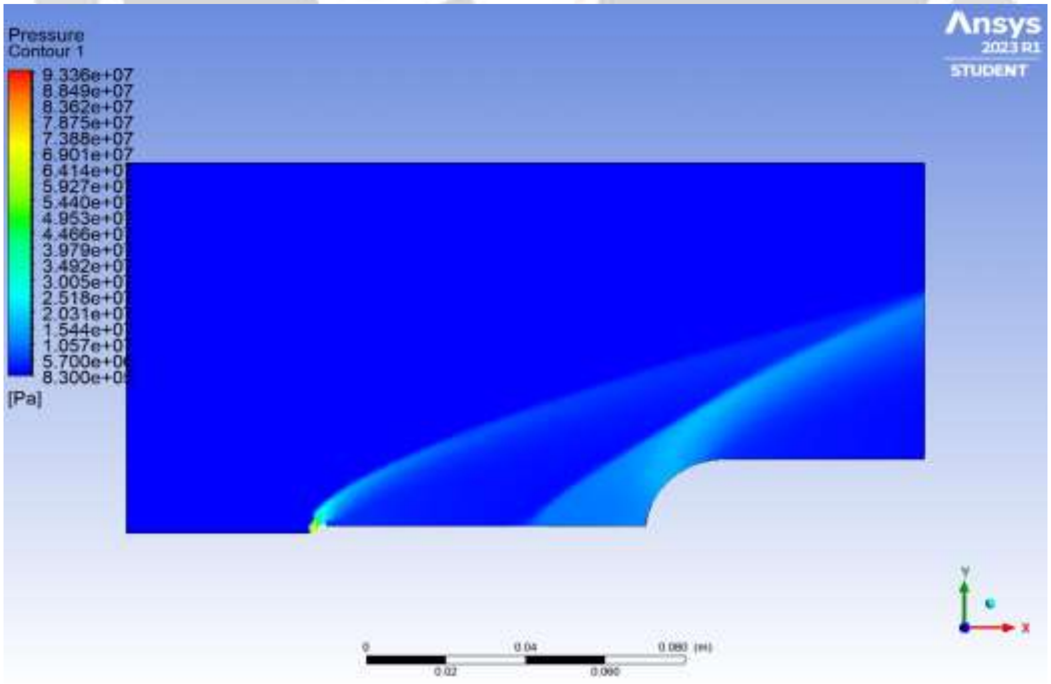

Fig – 19 Pressure contour with minor radius 3 L/D 2

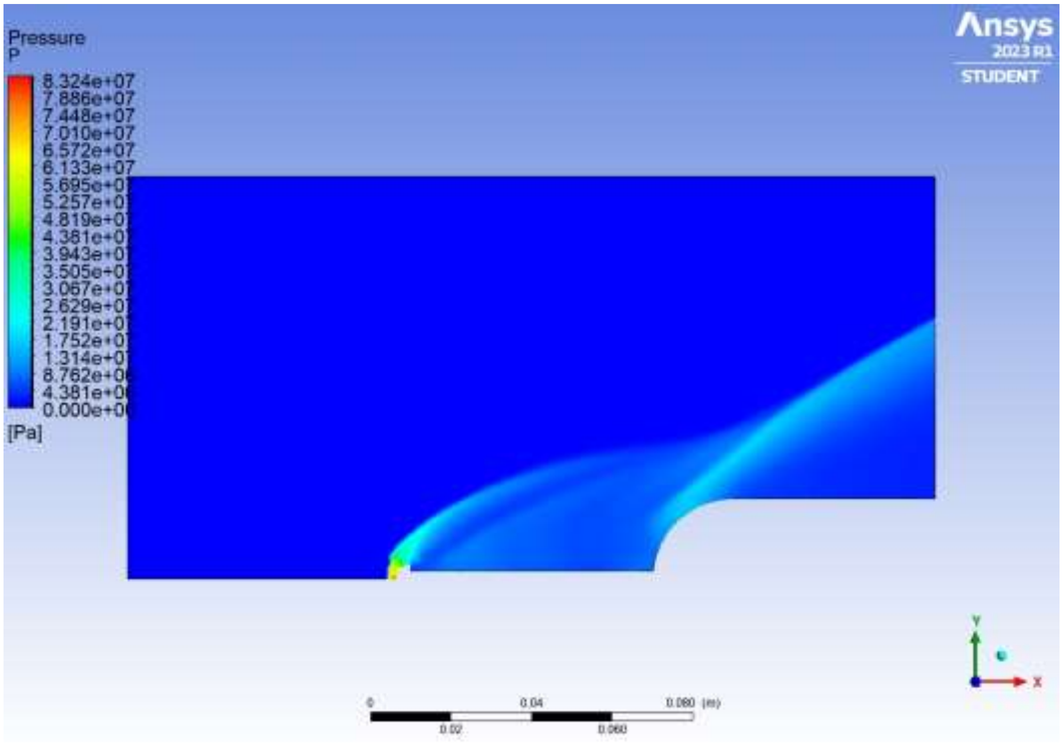

Fig – 20 Pressure contour with minor radius 4 L/D 1.5

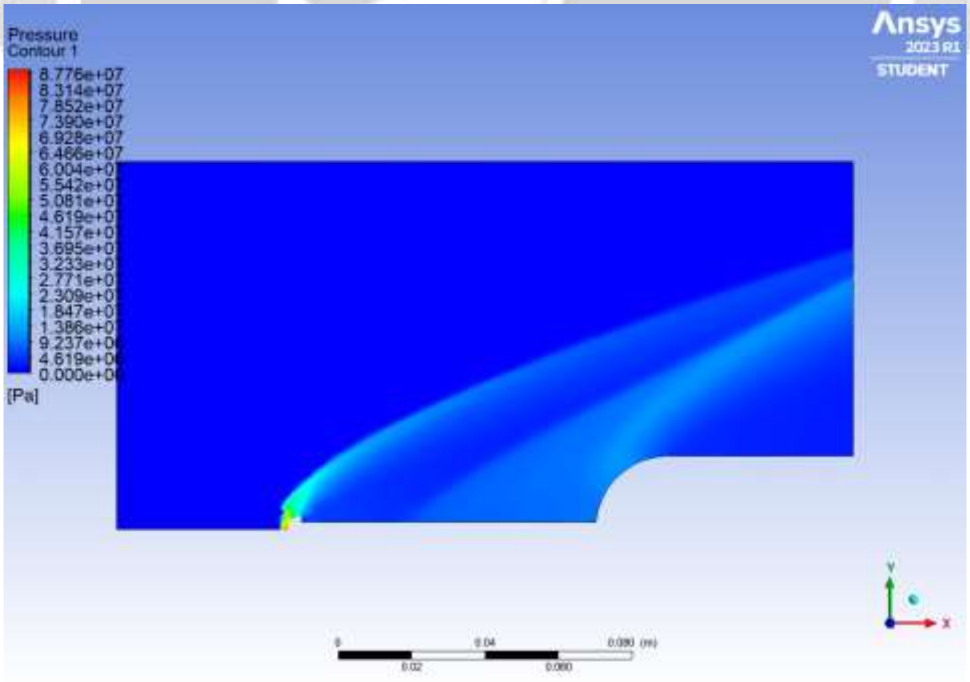

Fig – 21 Pressure contour with minor radius 4 L/D 2

We can observe that there is an increase in the angle of conical shockwaves as we increase the minor radius of the aerodisk. Hence there is a change in the angle of conical shockwaves and the reattachment zone.

3.3 VALIDATION

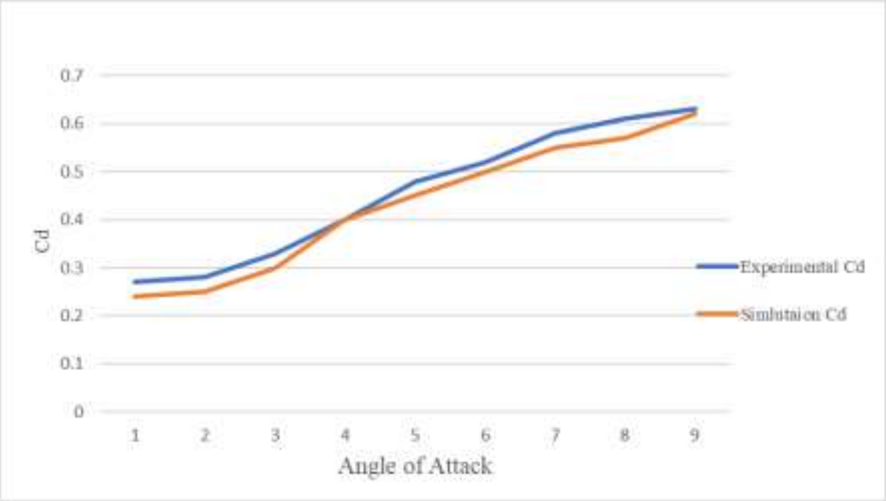

Chart - 1 Cd vs Angle of attack for Blunt body with spike L/D 1.5

The above graph depicts the variation of coefficient of drag with change in angle of attack for blunt body with aerospike L/D 1.5 for both experimental and simulation data [1]. It can be observed that the Cd obtained from simulation is similar to experimental values with less than 5% variation. Hence, we can conclude that the results obtained through simulation are valid.

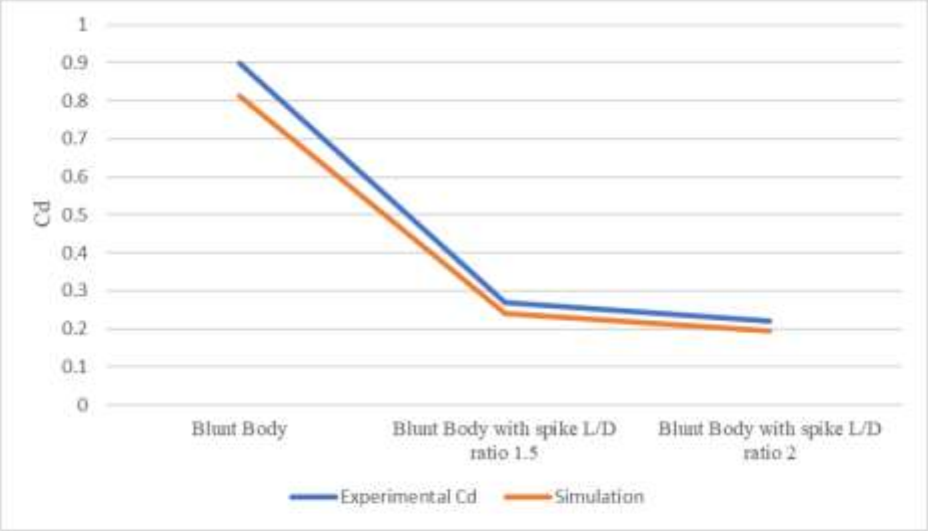

Chart – 2 Comparison with experimental data

The above graph shows the comparison of Cd value for blunt body with and without spikes, obtained from experimentation and simulation [1]. It can be observed that the Cd value decreases with increase in the length of spike. Drag reduction of 60% is observed using spike L/D ratio 1.5 and 75% using spike L/D ratio of 2.

4. CONCLUSION

In comparison of flow around a blunt body with an aerospike attachment to a blunt body without one, the former experienced less drag and heat generated at the front region. The study also showed that increasing the length of the aerospike reduced the drag coefficient for different body length to diameter ratios of 1.5 and 2.0. These findings suggest that the use of an aerospike attachment can improve the aerodynamic performance of blunt bodies. The study also showed that the increase in minor radius of the aerodisk can increase in angle of conical shockwaves and bring a change in the reattachment zone.

REFERENCES

[1]. R. Kalimuthu and E. Rathakrishnan, 2008, Aerospike for Drag Reduction in Hypersonic Flow, ASEE Joint Propulsion Conference & Exhibit, AIAA 2008-4707.
[2]. Barzegar Gerdroodbary and S.M Hosseinalipour M, 2010, Numerical simulation of hypersonic flow over highly blunted cones with spike, Acta Astronautica 180–193.
[3]. Gauer M and Paull A, Numerical Investigation of a Spiked Nose Cone at Hypersonic Speeds, Journal of Spacecraft and Rockets, 2008.
[4]. Computational Fluid Dynamics The Basics with Applications, John D. Anderson, Jr. Department of Aerospace Engineering University of Maryland, International Editions 1995.