EFFECT OF BLUNTED AERO-DISC ON AERO-SPIKED BLUNT CONE-NOSE AT HIGH SPEEDS.

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Abstract:-***High-speed flow over a blunt body generates a bow shock wave which causes high surface pressure which results in the development of high aerodynamic drags. Blunt body creates a bow shock wave at high Mach numbers which produces very high pressure in the forward hemispherical region. This leads to an increase of high wave drag during the projectile's flight through the atmosphere. It is advantageous to have a vehicle with low drag coefficient in order to minimize the thrust required from the propulsive system during the supersonic and hypersonic regime. The dynamic pressure on the surface of the blunt body can be substantially reduced by creating a low pressure region in front of the blunt body by mounting a spike on it. A spike is simply a slender rod attached to the stagnation point of the vehicle's nose. The aero-spike replaces the strong bow shock with a system of weaker shocks along with creating a zone of recirculating flow ahead of the fore body thus reducing both aero heating and drag. As a result of this, the outer flow is deflected and an oblique shock is formed. The shear surface also deflects the oncoming flow like an actual conical body would do and the initial bow shock is transformed into a weaker conical shock. The conical shock unites further downstream with the reattachment shockwave.With this simple method a drag reduction of more than 50 percent can be achieved in comparison with a blunt body without aero-disc. But this high drag reduction rates are only possible for very low angles of attack α. As the angle of attack is increased the effectiveness of the aero spike decreases. At the point of reattachment of the shockwave with the nose-cone, high pressure and temperature is developed. The use of aero-spike in this case leads to adverse effects like increase in drag force in spite of the use of aero spike.***

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

I. INTRODUCTION

Vehicles like space plane, reusable launch vehicles, missiles, etc., which fly at supersonic and hypersonic speeds, usually employ blunt nosed bodies for deceleration and thermal management. The aerodynamic drag of high speed vehicles shows significant effects in the final performance of the vehicle due to formation of bow shock wave which results in high pressure region in the vicinity of the blunt body. A blunt nosed body creates a bow shock wave at high Mach number which produces very high pressure in the forward region of the fore body, leading to a high wave drag and aerodynamic heating during the atmospheric flight.

The dynamic pressure on the surface of the blunt body can be substantially reduced by creating low pressure region in front of the blunt body. The use of the forward facing spike attached with the shape of a hemispherical blunt body appears to be most effective and simple method. Blunt body creates a bow shock wave at high Mach number, which produces very high in pressure in the forward region of the hemispherical region and this leads to increase of high wave drag and aerodynamic heating during the projectile's flight through the atmosphere.

It is advantageous to have a vehicle with low drag coefficient in order to minimize the thrust required from propulsive system during the supersonic and hypersonic regime. A spike in front of the blunt nose offers an effective method of such drag reduction. Flow past the spike creates a conical shock wave and remains away from the main body. Flow behind the conical shock wave separates on the spike and a conical shaped re-circulation zone forms in the vicinity of the stagnation region. Due to the recirculation, the pressure and wall heat flux decrease in the forward facing region of the blunt nose. However, the reattachment of the shear layer on the shoulder of the hemispherical body increases the local heat flux and pressure.

At high-speed flow past a blunt body generates a bow shock which causes a rather high surface pressure and as a result the development of a high aerodynamic drag. The pressure on the body surface can be substantially reduced if, instead of a normal shock, an oblique shock is generated by an aero spike. Many numeric and experimental studies on spiked bodies have been carried out to study the effects of aerodynamic heating and the surface pressure distributions at supersonic and hypersonic Mach numbers. The conventional aero spike produces a region of recirculating separated flow that shields the nose from the oncoming flow, and reduces aerodynamic drag; it also reduces a wall heat flux and protects the surface with electronic embedded sensors.

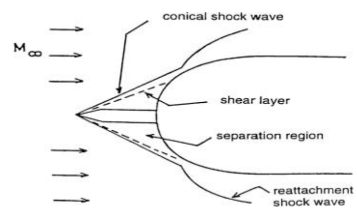

Fig.1: Flow field over spiked blunt cone nose

In principle, a blunt vehicle flying at hypersonic speeds generates a strong bow shock wave ahead of its nose, which is responsible for the high drag and aero heating levels. There have been a number of efforts devoted towards reducing both the drag and the aero heating by modifying the flow field ahead of the vehicle's nose. Of these techniques, using spikes is the simplest and the most reliable technique. A spike is simply a slender rod attached to the stagnation point of the vehicle's nose. The spike replaces the strong bow shock with a system of weaker shocks along with creating a zone of recirculating flow ahead of the fore body thus reducing both drag and aero heating[1].

Since their introduction to the high-speed vehicles domain in the late 1940s, spikes have been extensively studied using both experimental facilities and numerical simulation techniques. One of the most important aerodynamic design goals was and is the reduction of aerodynamic drag[5]. No matter whether a flight object is flying with subsonic or supersonic speed, the drag is limiting flight speed and range. A different approach in aerodynamic design for different flow regimes arises from the different sources of drag. In supersonic flight the wave drag plays the most important role. As a result a favoured round and rather blunt nose in subsonic and transonic flight has a large drawback in supersonic flight, due to the occurring bow shock. Considering only aerodynamics, sharp and pointed nose are most beneficial in supersonic flight. But the available space in a cone or a wedge shaped nose is limited. Therefore it is not practicable for the integration of avionic or a seeker.

A well-known concept of reducing the wave drag while keeping a blunt nose in supersonic flight is the Aero-spike concept. A thin rod mounted on the tip of a blunt body is the simplest design of an Aero-spike and the beneficial effect on the drag is investigated since decades. Slight variations of the initial design include cones, spheres or disks that are additionally mounted on the tip of the rod. In the ideal case the boundary layer on the rod separates along the whole rod surface due to the pressure rise over the initial bow shock[3]. The separated boundary layer forms a shear layer that reattaches under a certain angle on the blunt nose. As a result the outer flow is deflected and an oblique shock is formed. The shear surface itself also deflects the oncoming flow like an actual conical body would do and the initial bow shock is transformed to a weaker conical shock. The conical shock units further downstream with the reattachment shock. With this simple method a drag reduction of more than 50 percent can be achieved in comparison with a blunt body. But this high reduction rates are only possible for very low angles of attack α. As the angle of attack is increased the effectiveness of the Aero spike is decreases. A favoured shock system is not achievable anymore and at angles of attack > 15°, depending on the specific case, no drag reduction can be gained due to unfavourable shock.

A movable Aero-spike that points always into the flow direction even though the main body has an angle of attack could sustain the beneficial effect in the region of low and high angles of attack. The point where the effectiveness is close to zero is shifted to higher α[4]. in fact it is just a disk that is mounted to a frame. On the other end of the frame small wings are attached. The aerodynamic forces acting on the wings induce a pitching moment about the hinge and align the disk with the oncoming flow.The numerical simulation yields to small declination of the disk to the oncoming flow for high angles of attack. But neglecting this small declination the self-aligning aero disk shows a good performance. At high angle of attack and also at high pitching rates the aero disk is aligned to the oncoming flow and a wave drag reduction is sustained.

I. AERO-DISC GEOMETRY MODELLING

CONFIGURATION DESIGN

The dimensions of the blunt cone nose with and without aero-spike (with and without aero-disc) considered in the present analysis are shown in figure. The model is axisymmetric, the main body has a hemisphere-cylinder nose, and diameter D is $4.0x10^{-2}$ m. The spike consists of an aero-disc part and a cylindrical part. The diameter of the cylinder of the spike is 0.1D. Spike having a cap of radius 0.1D attached with a sting of diameter of 0.1D. The aero-disc type spike configuration utilized a disc on its nose of radius 0.1D.The diameter of the aero-disk attached to the spike is twice that of the diameter of the spike-stem. Figure 7 shows blunt cone nose with diameter D and length 1.25D. Figure 8 and 9 shows blunt cone nose with aero-spike having L/D ratios 1.5 and 2. Figure 10 shows the hemisphere aero-disc with spike lengths L of 2.0D. The spike consists of a conical part and a cylinder part as shown in respective figures. The diameter of the cylinder of the spike is 0.1 D. Figure 11 shows the blunt cone aero-disc with spike length L of 2D.

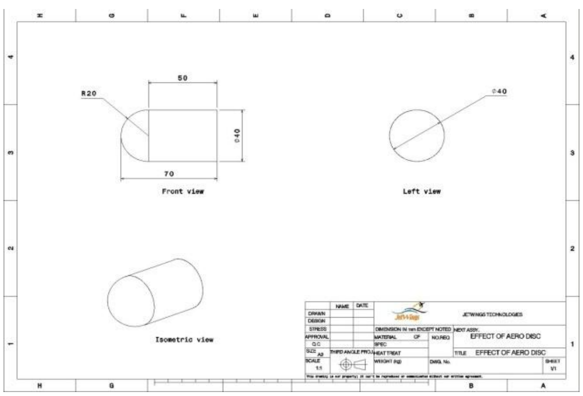

Fig.2: Drafting of blunt cone nose

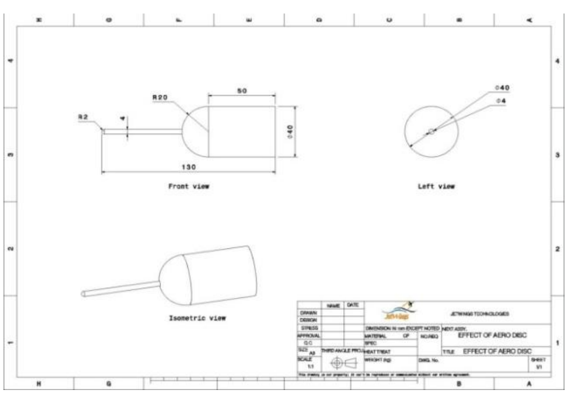

Fig.3: Drafting of aero-spike (L=1.5D) on blunt cone nose

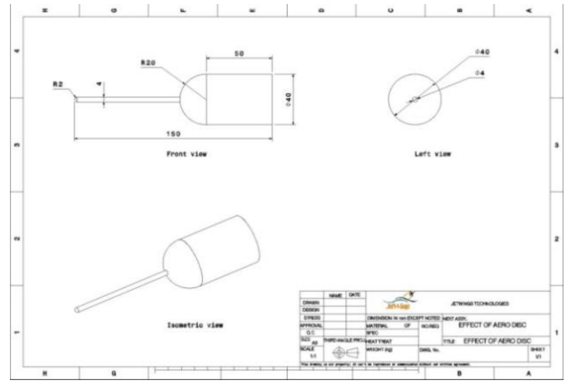

Fig.4: Drafting of aero-spike (L=2D) on blunt cone nose

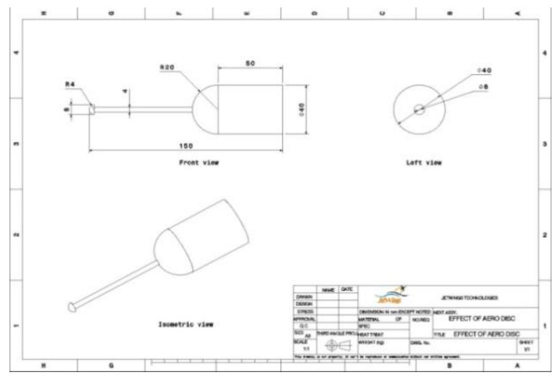

Fig.5: Drafting of hemispherical aero-disc on aero-spike (L=2D)

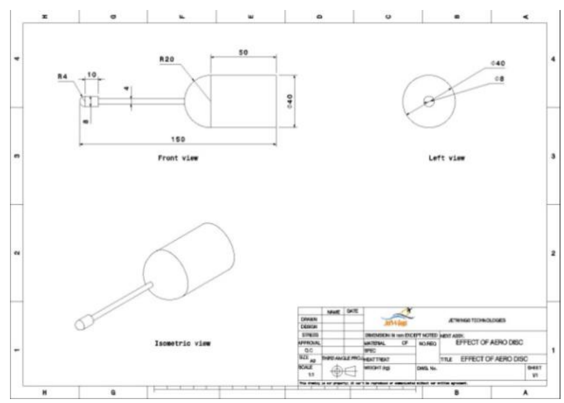

Fig.6: Drafting of blunted aero-disc on aero-spike (L=2D)

II. MODELING

The above sketches are modelled using CATIA V5.

1. The coordinates and necessary details for the blunt cone nose with and without aero-spike design are collected.

2. The design is prepared in CATIA V5 R19 and saved in CAT.PART and IGES format.

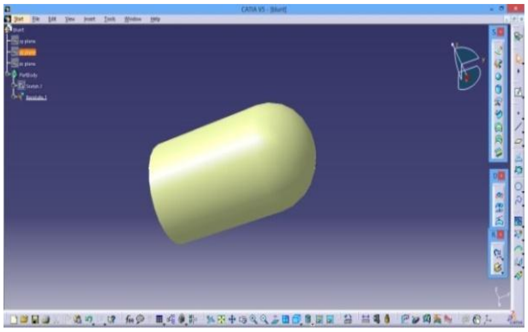

Fig.7: CATIA design of blunt cone nose

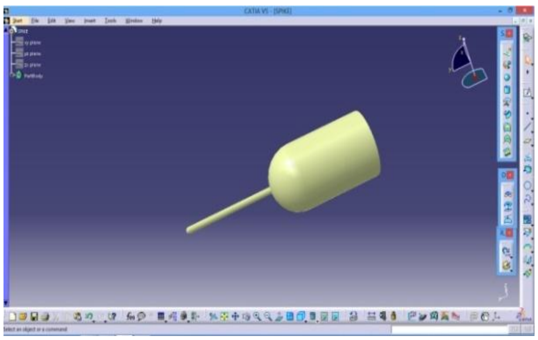

Fig.8: CATIA design of aero-spike on blunt cone nose (L=1.5D)

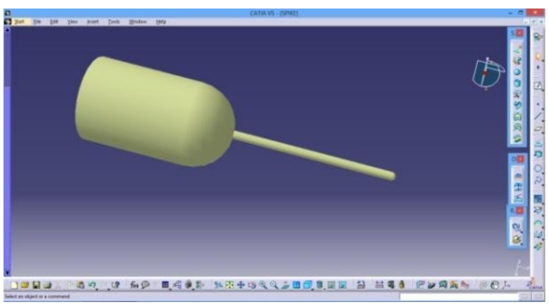

Fig 9: CATIA design of aero-spike on blunt cone nose (L=2D)

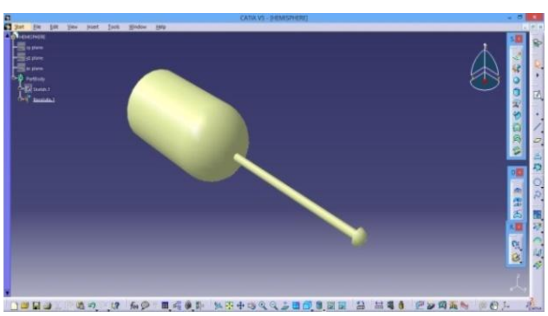

Fig.10: CATIA design of hemispherical aero-disc on aero-spike (L=2D)

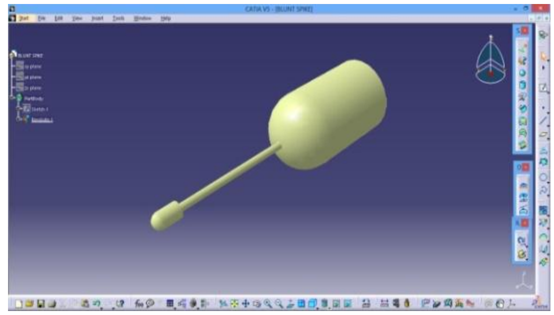

Fig.11: CATIA design of blunted aero-disc on aero-spike (L=2D)

III. MESHING

Unstructured meshing is done on the model. Topology is checked for tolerance using BUILD TOPOLOGY. Since it is a 3D model rectangular domain is used. The domain criteria are that it must be 200 times the size of the model being meshed so that the flow on the body is not affected.

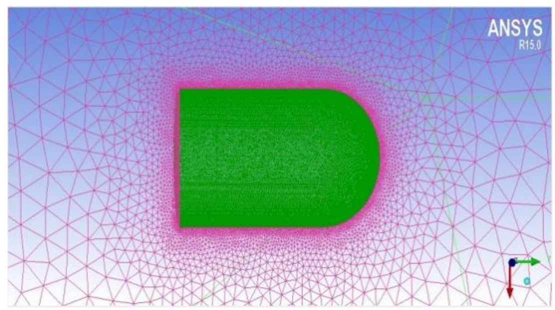

Fig.12: Grid in the vicinity of blunt cone nose

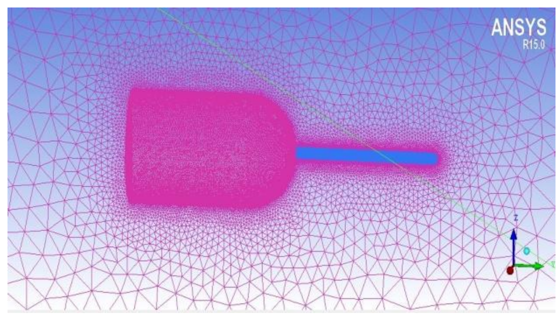

Fig.13: Grid in the vicinity of aero spike (L=1.5D)

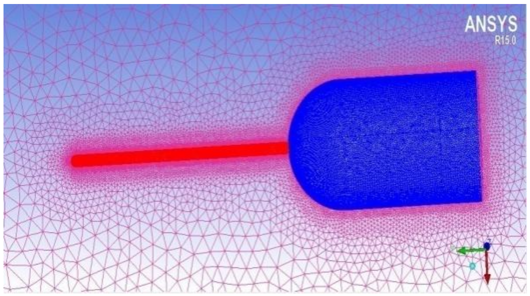

Fig.14: Grid in the vicinity of aero spike (L=2D)

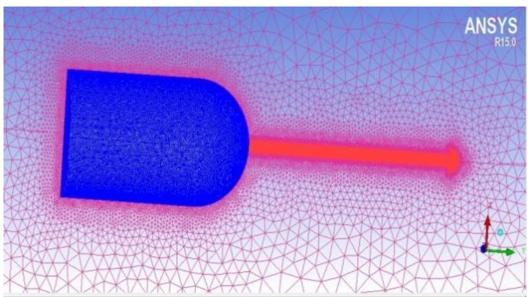

Fig.15: Grid in the vicinity of hemispherical aero-disc on aero-spike (L=2D)

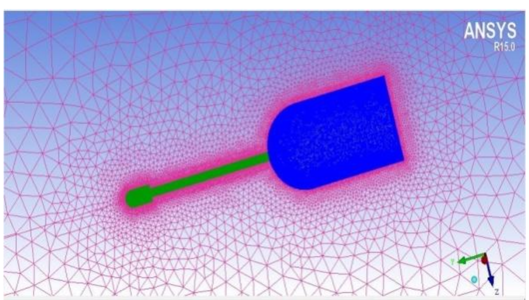

Fig.16: Grid in the vicinity of blunted aero-disc on aero-spike (L=2D)

IV. BOUNDARY CONDITIONS CALCULATIONS

Reference values

Stagnation pressure, P_o= 8.3 bar = 830000 Pa

Stagnation temperature, T_o= 450 K

Mach number, M = 6

Reynolds's number, R_{ed}= 0.5 x 106

Adiabatic index, γ = 1.4

Therefore,

Static pressure, P = 525.69 Pa

Static temperature, T = 54.88 K

Therefore,

Density, ρ=0.033 kg/m3

M=V/a

Therefore,

Fluid velocity, V= 891.36 m/s

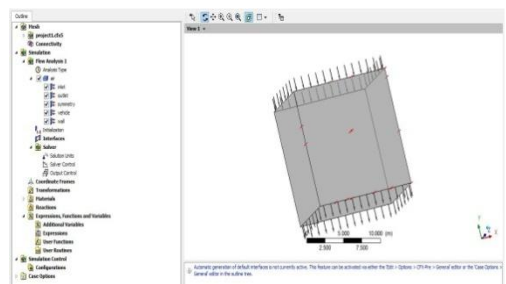

Fig.17: Configuration settings

V. RESULT AND DISCUSSION

BLUNT CONE NOSE

From the analysis results, we got

Drag =7.4185 N

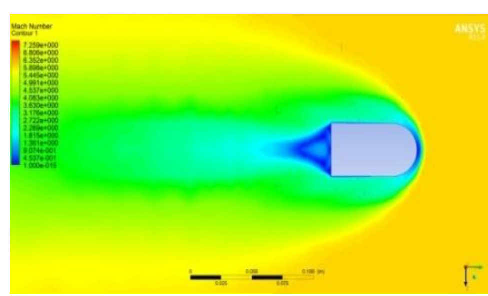

Fig.18: Mach number contour

Maximum Mach number= 7.78

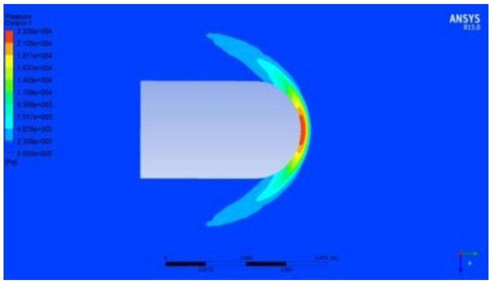

Fig. 19: pressure contour

Maximum pressure = 23959.7 Pa

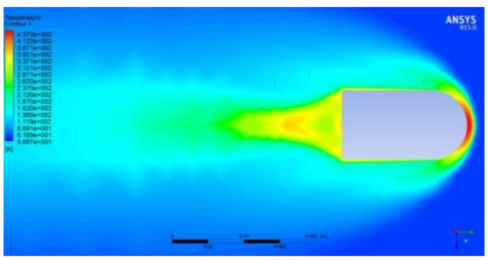

Fig.20: temperature contour

Maximum temperature = 450.44 K

AERO-SPIKE (L=1.5D) ON BLUNT CONE NOSE

From analysis results, we got that

Drag =5.4635N

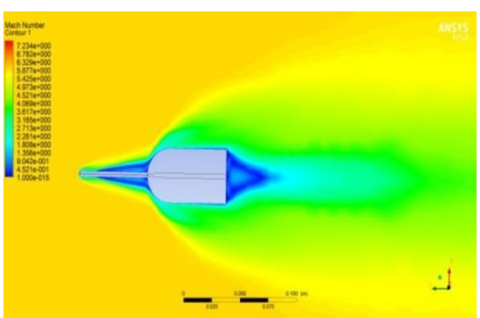

Fig.21: Mach number contour

Maximum Mach number = 7.82

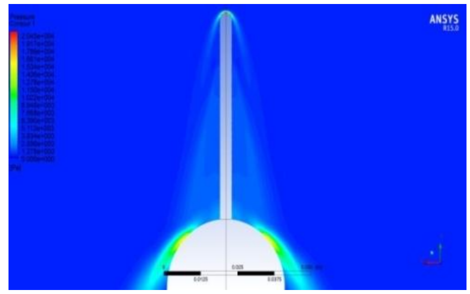

Fig.22: Pressure contour for whole body

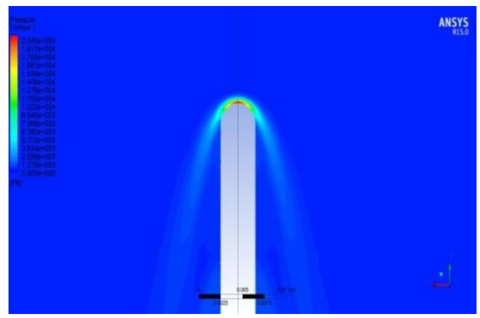

Fig.23: Pressure contour at the tip of the aero-spike

Maximum pressure = 21088 Pa

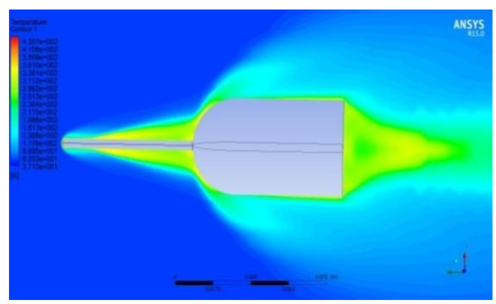

Fig.24: Temperature contour

Maximum temperature = 448.17 K

AERO-SPIKE (L=2D) ON BLUNT CONE NOSE

From analysis result, we got that

Drag = 4.62726

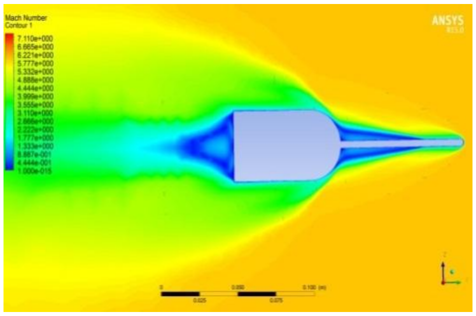

Fig.25: Mach number contour

Maximum Mach number = 8

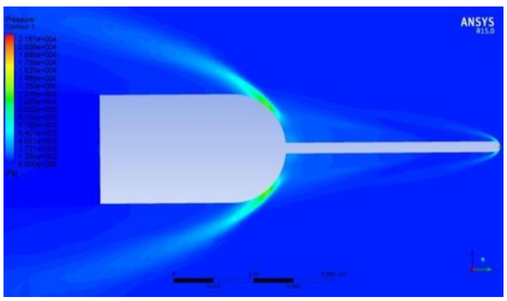

Fig.26: Pressure contour

Maximum pressure= 22591 Pa

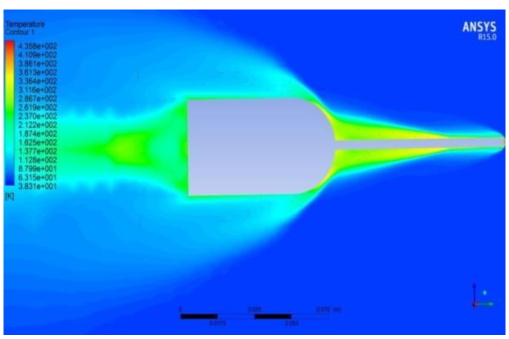

Fig.27: Temperature contour

Maximum temperature = 448.2 K

HEMISPHERICAL AERO-DISC ON BLUNT CONE NOSE

From analysis result, we got that

Drag = 6.1185N

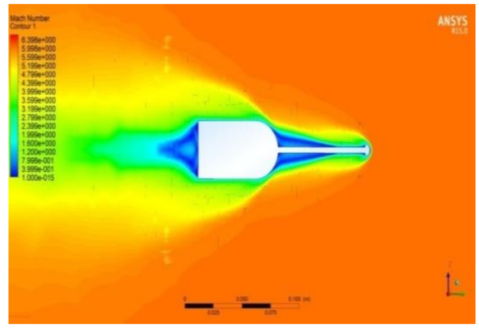

Fig.28: Mach number contour

Maximum Mach number= 6.81

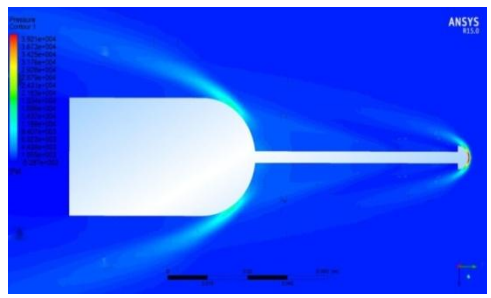

Fig.29: Pressure contour

Maximum pressure= 42120 Pa

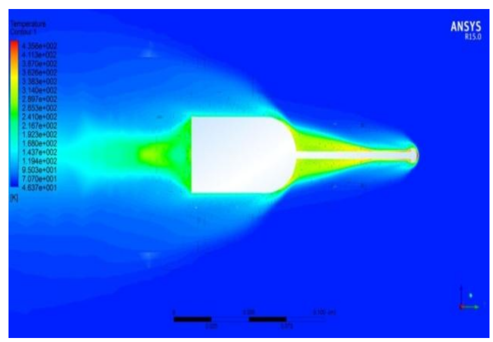

Fig.30: Temperature contour

Maximum temperature= 448.49 K

BLUNTED AERO-DISC ON BLUNT CONE NOSE

From the analysis result, we got that

Drag = 3.08798N

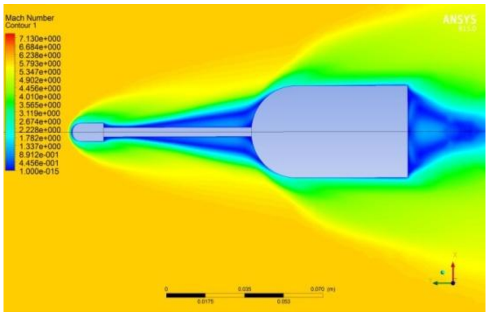

Fig.31: Mach number contour

Maximum Mach number = 7.51

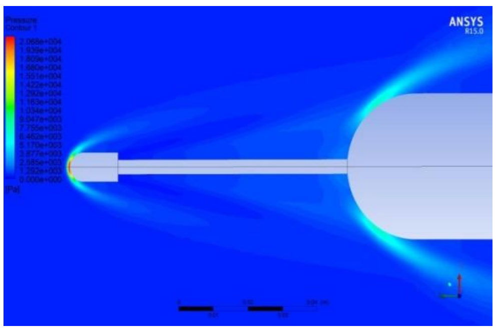

Fig.32: Pressure contour

Maximum pressure = 21476 K

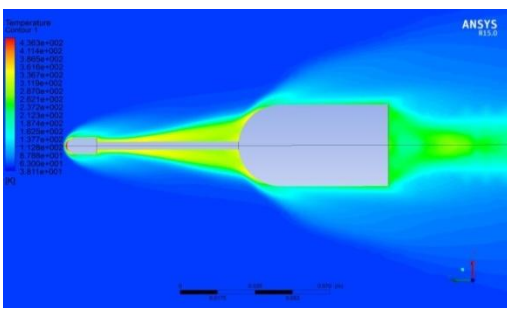

Fig.33: Temperature contour

Maximum temperature = 449.2 K

COMPARISON

Configuration	Drag (N)	Temperature(K)
Blunt cone nose	7.41875	450.44
Aero spike(L/D=1.5)	5.4635	448.17
Aero spike(L/D=2)	4.62726	448.2
Hemispherical Aerodisc	6.11855	448.49
Blunted Aero disc	3.08798	449.2

From the results, we can see that blunted aero-disc on blunt cone nose give more reduction in drag compared to other configurations. About 58% reduction in drag is obtained while using the blunted aero-disc configuration. Blunted aero-disc has low temperature value compared to blunt cone nose without aero-disc (even though it has high value compared to other configuration).

VI. CONCLUSION AND FUTURE WORK

Flow field around forward facing blunt cone nose with aero-spike of different shape and length to diameter ratio has been calculated at a free stream Mach number of 6 and zero degree angle of attack. The flow field features around the spiked body is dependent on the shape of the aero-spike. The bow shock wave formation is found over the spherical and blunted spike which gives different separation zone over the blunt body. Thus, the flow field, immediately behind the aero disk shows a complex flow field due to back-disk geometry as compared to the simple spike. To take advantage of the forward facing spike for more efficient drag reduction, the reattachment point of the shear layer on the body should be moved backward by choosing the optimal spike length with suitable geometrical configuration of the spike nose. The drag of the blunt body is remarkably influenced by the spike length and spike shape.

Blunt cone nose without aero-spike shows less efficiency in terms of drag and heat transfer. When aero-spike of length 1.5D is used on blunt cone nose there is 26% reduction in drag. When the spike length is increased to 2D there is a drag reduction of 38%. From this result it is clear that as the spike length is increased there is a significant increase in drag reduction.

When hemispherical aero-disc is used, there is 18% reduction in drag, which is not as efficient as the spike configuration.

The blunted aero-disc model gives maximum efficiency in terms of drag reduction and reduction in heat transfer. There is 58% reduction in drag while using this configuration when compared to the blunt cone nose model without any spike attached to it. As the L/D ratio 2 is found more effective it is used for analysis of all configurations.

Thus, from all the above analysis results and contour diagrams it is clear that blunted aero-disc model on blunt cone nose (L/D=2) is the best configuration out of all other analyzed models.

This high reduction in drag is applicable only for small angle of attacks. For high angle of attacks a self aligning aero-disc can be used which aligns itself in the same direction as the free stream. So it can be considered as a future work.

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