A review on computational drag analysis of rocket nose cone

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Abstract

The nosecone is the front -most section of a rocket that gets in contact with the air in the direction of propagation. Undoubtedly, designing a nosecone is an important part of the rocket. During designing of it, one of the key features that are to be kept in mind is that it should regulate incoming airflow and reduce the aerodynamic drag force. Drag is known to be the opposite of the motion of propagation in any rocket while ascent. Apart from that, the design is done to overcome the excess heat generation while ascent. When a rocket or a space shuttle travels at a high speed, there will be a generation of heat due to the bow shockwave. So, to reduce that, the designing of a nosecone must be in such a way that it should face the least drag and minimal heat generation. Moreover, it must provide the best aerodynamic flow characteristics. Designing of the nosecone is done with the help of software such as Catia and Solid work, and for the analysis part, CFD software is used. The objective of this paper was to identify various types of nose cone shapes and their particular aerodynamic characteristics with a minimum value of drag at different Mach numbers. Flow simulation has been done on different shapes of nose profiles to get an efficient and effective nosecone shape.

Keywords 1

Aerodynamics, Nosecone, Drag, performance

1. Introduction

Researchers in the field of rocket science are facing an everyday challenge in designing especially of the nosecone area for the dependency of its aerodynamic performance and flow characteristics. While the rocket is at subsonic velocity, the design of the nosecone plays a crucial role in a decrement in the drag faced by the rocket. Drag can be classified into three types which are faced by the nosecone such as; pressure, skin friction, and wave. Pressure drag force depends on the body's structure. Skin friction drag force depends on the shear stress between the moving surface and fluid. Wave drag force is created due to shock waves in supersonic flow. These shockwaves cause some change in aerodynamic properties of a rocket, where we can observe the increasing rate of static pressure and static temperature and decreasing rate of Mach number, flow velocity, total pressure, and total temperature [for perfect gas] will remain the same. At the time of supersonic flow, bow shockwaves are generated due to which there is heat generation at the nosecone area, because of which mostly blunt nosecone is preferred by the researchers. The design of the nosecone should be in such a way that can avoid the boundary layer separation. There are some shapes preferred while designing nosecones such as elliptical, parabolic, conical, ogive, and Von Karman. As the rocket reaches the velocity of 5 Mach or above, there are temperature variations at every atmospheric level of the earth. So, keeping each factor that can affect its performance in mind the design is executed. So, the design is analyzed on ANSYS software to bring out the best performance and efficiency of the rocket's nosecone.

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2. Review of Literature

Current advancements in SpaceX's Falcon 1 and Falcon 9 Launch Vehicles and Dragon Spacecraft

Falcon-1 is a launch vehicle having two stages that were having a capacity for lifting 420 kilograms of weight in LEO (Low Earth Orbit). Falcon-9 and Falcon-9 heavy are upgraded versions of Falcon 1 and are capable of lifting almost 12500 kilograms to LEO and 4650 kilograms to Geostationary Transfer Orbit. Both of these launch vehicles are highly reliable and cost-efficient. Falcon- 1 is the first privately made, liquid-fuel rocket that successfully reached the orbit of the earth.

Charles C. H. Lin et al carried out their work on the ionospheric disturbances caused due to the launch of the falcon-9 rocket.

Observed the ionospheric disturbances that occurred in the launch of Falcon 9. Due to these disturbances, shock acoustic waves have been generated. The wave characteristics of concentric traveling ionosphere disturbances with periods of 10.5 to 12.7 minutes and having a wavelength of 200 to 400 Km agree with the relation of gravity wave dispersion.

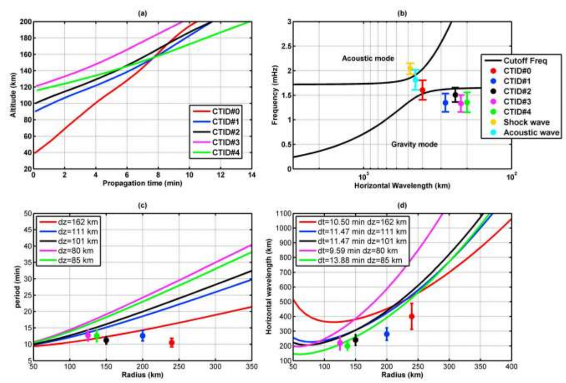

Figure 1: Various case of ionospheric disturbances

Erick G. S. Nascimento et al had done simulated dispersion of the released gas due to the explosion of SpaceX falcon-9.

The paper describes a model for falcon-9 in 6 degrees of freedom. The model includes the launch vehicle flight from liftoff to the insertion in the orbit. This model is created in MATLAB software then it undergoes simulation to check its aerodynamic properties and engines with thrust vector control. The model is a multistage launch vehicle where the simulation immediately reduces the mass and changes the aerodynamic characteristics. The final result of the simulation gives a clear view of LV launch data and also suggested that we can use the model as a keystone for control and design of the launch schedule.

Avion's Nosecone Design:

The authors named A. Yeshwanth and PV. Senthil published their paper based on Nose Cone design and analysis of an avion in IJPAM. In subsonic conditions, the role of a rocket is very much important to reduce the drag on the entire body. The efficiency of an aircraft or rocket can increase by producing the least drag. From this paper, we came to know that by varying the Mach number, various shapes of nosecone face different values of aerodynamic drag, by reference to this we can select an optimum shape of the nosecone. We can get the minimum drag coefficient for subsonic flow in the elliptical nose profile, through which we can improve the efficiency.

Variation of Cd at various nose profiles at different Mach no. is observed. Nose Cone Designs review for different Flight Regimes

This paper gives a review of velocity Mach no. and Pressure on Conical Nosecone, Elliptical Nosecone, Parabolic Nosecone, Ogive Nosecone, and Von Karman Nosecone section of a rocket. It also helps to understand the shock structure of the Nosecone of different geometries. This paper compares the performance of various nosecone designs for different flow regimes. Elliptical Nosecone is preferable for subsonic flow regime and Von Karman is preferable for Subsonic to Transonic flow.

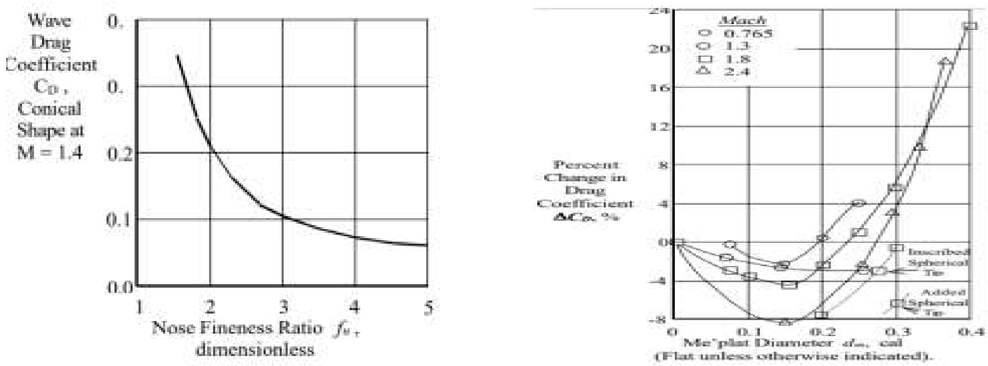

Figure 2: Graph representing wave drag and fitness ratio and Change in drag coefficient

Danish Parvez et al had done their investigation regarding the Aerodynamic performance of various nosecone types, especially elliptical and secant ogive nosecone:

In this paper comparison of performances between elliptical and secant Ogive nosecone profiles is done. The aerodynamic properties which are subjected to comparison are axial velocity, pressure, total drag, dynamic pressure, co-efficient of pressure. The two nose cone profiles are subjected to computational analysis and then placed in a wind tunnel, the experimental data obtained and data from the computational analysis are compared. A velocity of 25 m/s is used for simulation purposes. After careful comparison, it is observed that skin friction drag is less in the elliptical nose cone and velocity is more near the trailing edge of the secant ogive nose cone. After overall comparison of skin friction drag, co-efficient of drag and total drag experienced by the body. The most efficient nose cone profile amongst the two was the elliptical nose cone.

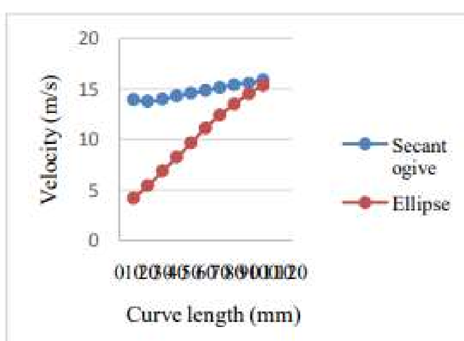

Figure 3: Velocity profile for the different nosecone

Design of Shape-Conforming Nosecone for Optimal Fluid Flow from Transonic to Supersonic Range:

In this paper, they use different types of nosecones profiles such as; rockets, missiles, and airplanes to reduce the drag at different velocities. The various kind of designs was made to show the rocket's nosecone shape transformation from parabolic to a power series profile possible, mid-flight. In the transonic region rocket experience a sharp increase in drag due to pressure forces.

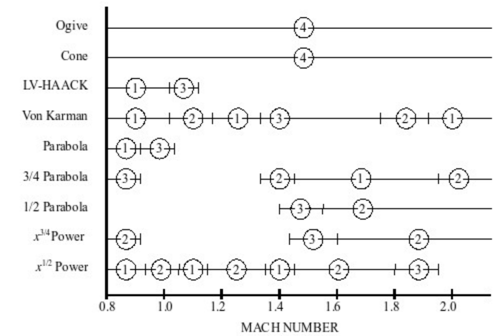

Figure 4: This figure represents optimum nosecone shapes for drag related to a mach number

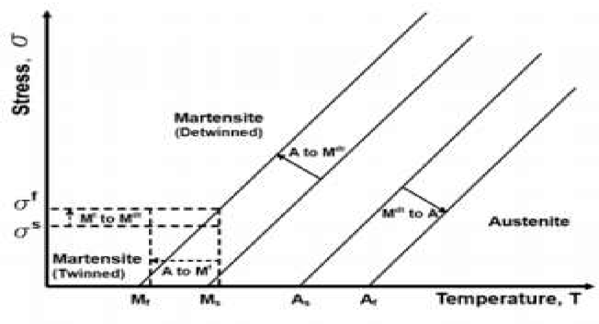

Figure 5: SMA phase diagram corresponding to stress and temperature

Matt Scifhwenning et al had done their research on structural design and rocket fabrication:

This paper shows us specific crucial areas of rockets such as Rocket's Structure, external structure, internal structure, skeleton design, skin-based design, payload deployment, internal structure, top deployment, side deployment, coupler deployment, and Payload Deployment Decision. Also calculated numerous parameters such as drag of nosecone, fin, upper stage, lower stage, base, total drag and lift forces on the nose, fin, body tube upper and body tube lower. To secure the motor in place during the flight a motor mount is required.

A comparative study on Hypersonic flow in different nose cone designs.

Ashish Narayan et al published a paper regarding hypersonic flow past nosecones of different structures. This paper gives an overview to find the parameters to get the optimum shape of the nosecone which provides the minimum value of Drag coefficient and heating. They use different types of nosecones such as spherical blunt and parabolic which are performed for various fitness ratios at 0-degree AOA. They use computational hypersonic flow on spherical blunt and parabolic nosecones to check shock flow features. Fitness ratio less than 1.2 blunt cones provides a minimum value of drag and higher values, also parabolic nosecones have superior drag reduction.

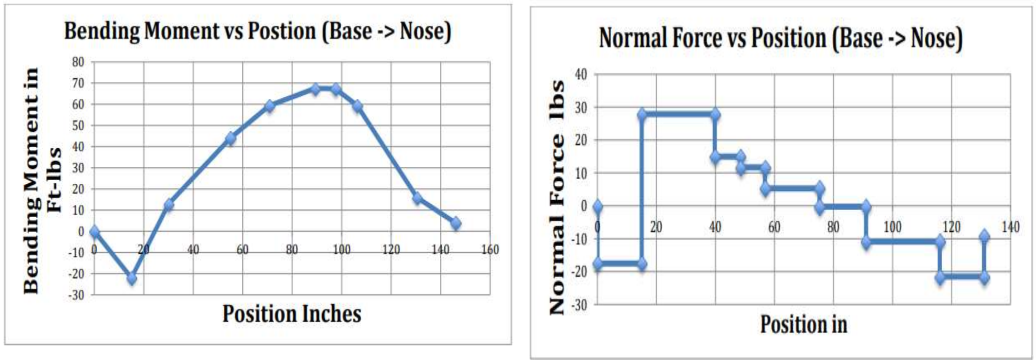

Figure 6: Generation of the bending moment along the rocket and Distribution of Normal force along the rocket

Drag effect on Blunt Nosecones in Supersonic and Hypersonic Flows

The authors named A. Hema Teja et al published this paper in 2017 regarding the Drag effect in Supersonic and Hypersonic flows on Blunt nosecones. Some forces cause stall of spacecraft and the excess amount of heat generation when it enters into the earth's atmosphere. So, to reduce that they use different kinds of nose cone shapes and they check the aerodynamic properties also which is very crucial. The blunt bodies are really helpful to lessen the drag. Apart from that it also decreases the generation of heat-flux on the body's surface Extensively. The aerodynamic characteristics of a particular cone configuration at an AOA ranging up to 180 degrees with various degrees of nose bluntness.

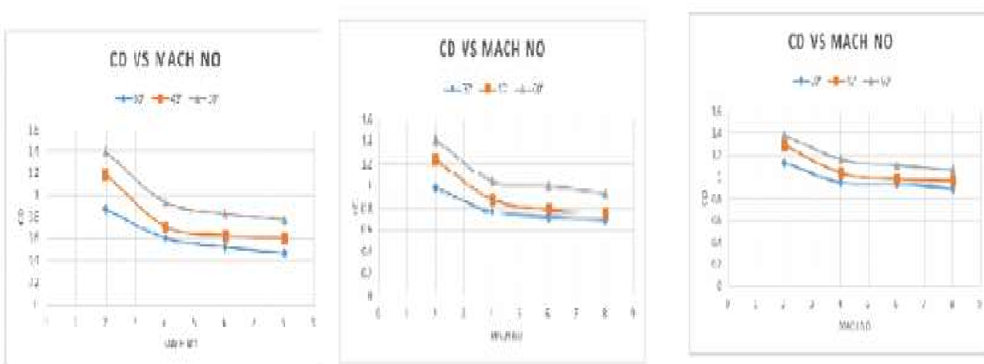

Figure 7: Coefficient of Drag vs Mach number plot for all angles of the cone (Angle of Attack = 2.5 and 5 NR = 0.1 D and 0.2 D,0.3 D

Drag force analysis by CFD on different geometries of the nosecone

The authors named Lucas de Almeida et al published this paper in Research Gate publication in 2019.The first element of the rocket that comes in contact with the air during flight is the nosecone. So, the objective of this work is to reduce drag over the nosecone structure. In this paper, the different shapes of the nosecone of the rocket have been made, and then with the help of ANSYS software, various aerodynamic parameters have been checked such as drag force. The elliptical shape shows the best aerodynamic performance after that the tangent shape and then parabolic shape. Conic nosecone shows very less aerodynamic performance to subsonic flight.

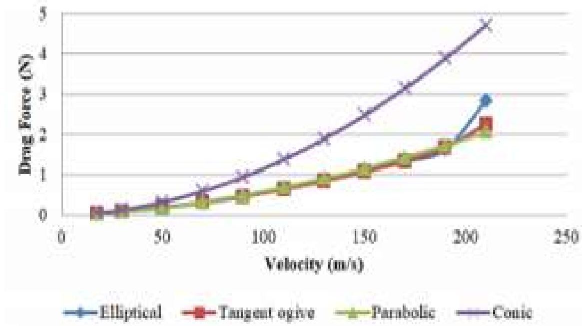

Figure 8: Drag force on different geometries of Nosecone

Shashwat Shah et al had done their research on the analysis of drag for sounding rocket nosecone.

The nosecone is an aerodynamic part of rockets as well as aircraft. To minimize the aerodynamic resistance the shape plays an important role. In this paper, they analyze different shapes of the nose to determine the geometric shape to get the optimum performance. They use the Ansys software to analyze different types of nose profiles with mach no. 0.8 to 2. In supersonic flow, there is a generation of shockwave for which some changes of aerodynamic parameters we have noticed such as mach no. decreased, static pressure increased, static temperature increase, flow velocity, and total pressure decrease. Von Karman nose cone profile is the best nosecone profile for the subsonic and supersonic region.

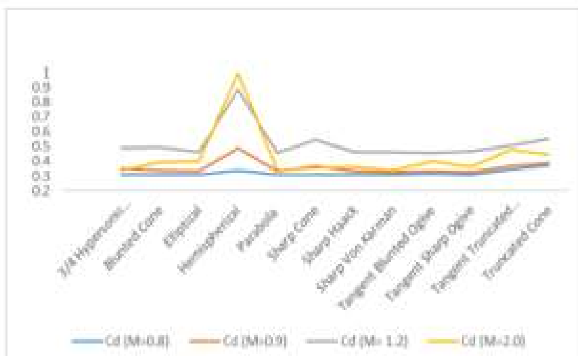

Figure 9: Comparison of coefficient of drag of different nosecone

Fedaravicious et al carried out their work on the rocket's nosecone and nozzle design to get the most efficient outcomes regarding its aerodynamic characteristics.

In this paper, airflow simulation is performed on certain types of nose cone shapes. For calculation of different parameters like airflow velocity, pressure, kinetic energy, drag, and coefficient of drag, Ansys software is used. It is being observed that during airflow simulation in a particular rocket that does not have a nozzle cone there is an increase in turbulence kinetic energy. There is almost 63% more turbulence K.E. than the rocket with nozzle cone. Moreover, the length of the nose cone cannot affect too much the coefficient of drag for the rockets with the nose cone.

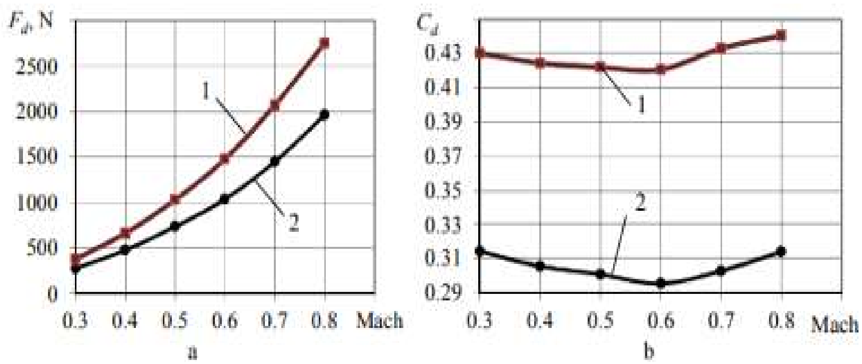

Figure 10: These graphs show the dependency of Cd and Drag force on Mach no. for Rocket 1- “A” and rocket 2- “B”.

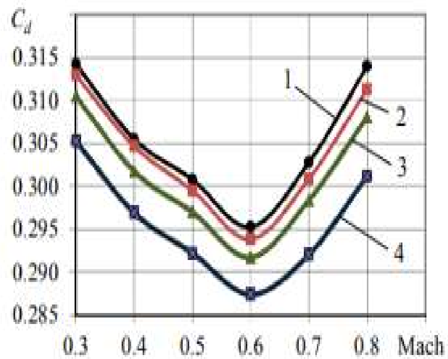

Figure 11: This graph shows the dependency of Cd on Mach number for rocket "B"- 1, rocket "C"- 2, rocket "D"- 3, and rocket "E"- 4

Nose Cone Design analysis by Using CFD and SPH:

The author Bogdan-Alexandru published a paper based on the Aerodynamic Design of Nosecone section and the author also did the Analysis on nosecone by using CFD and SPH in BELEGA publication in 2015.In this paper, the ejector channels are used in different types of the nosecone and also presented a clear view of aerodynamic characteristics of different types of the nosecone. The objective of this paper is to bring out some excellent aerodynamic qualities by designing some prototype profiles and occasional price to be used in construction tasks for missile growing their variety and effect on the goal. Overall, in this paper, it is determined which particular shape provides the best aerodynamic performance having an ejector effect.

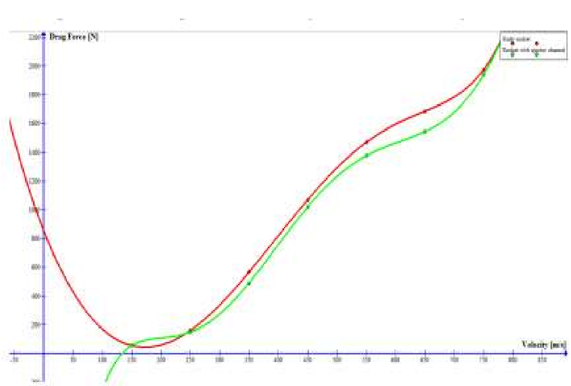

Figure 12: Comparison of drag force amount on two cases studies

Srinivas G et al had completed their work on aerodynamic characteristics and flow characterization of multistage rockets

In these times aerodynamic industries mainly focus on non-air breathing propulsion which greatly helps in space explorations. Analysis of rocket aerodynamic performances and flow characterization has become a great challenge for researchers in the respective field. This paper focuses on systematic flow analyses on single, double, and multistage rockets. The analysis is done with the help of software ANSYS. The main observations were conducted on various properties like Pressure, Velocity, density, and Temperature. The analysis revealed that Mach numbers 4 and 5 are most suitable for payload design.

V. Anjalee Kumari et al carried out her research work about the design and analysis of aircraft nosecone under certain conditions using different materials

The main purpose of the paper is to study the flow field of the air pressure of different materials like titanium, structural steel, stainless steel, aluminum alloy. In 18700 Pascal air pressure at a height of 40000 Feet. The modeling of the nosecone is done on CATIA and analysis on ANSYS. It is observed after the analysis that the most deformed material was aluminum alloy followed by titanium alloy after that both stainless steel and structural steel have the same deformation. With the result obtained by the analysis can be concluded that titanium material has the optimum deformation range. Because titanium has better properties it is widely used in aircraft nosecones these days.

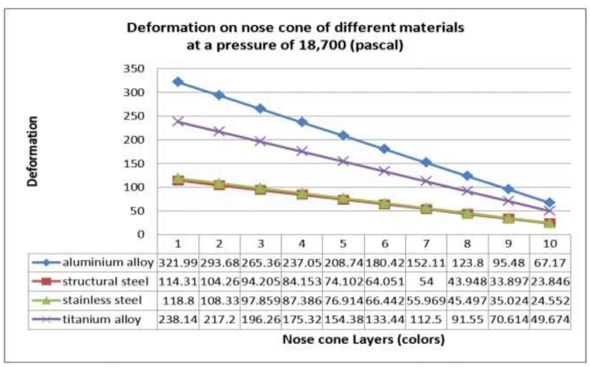

Figure 13: Change in the nosecone shape at 18700 Pa pressure for different materials

K. Akramian et al had done research on nosecone shapes in different gas mixtures in high dimensionless Knudsen numbers:

In this paper, the author has performed numerical simulation on various forms of shapes of nosecone in Knudsen numbers flow in different types of mixtures, preferably He-Xe, He-Ar, and O2–N2. In rarefaction conditions based on DSMC, a computer code had been installed to observe supersonic flow around all types of Nosecone shapes. After studying all the conditions based on two non-identical Knudsen numbers, it was concluded that the tip pressure and the mean pressure on the spherical blunt nosecone are very high and the least tip pressure is observed on the Bi-conic nosecone. Additionally, the least tip temperature and least mean surface temperature are noticed on parabolic and tangent ogive shapes. The result came out that the temperature of heavy component gas is very high in comparison to the light component gas to the part closer to the point of stagnation and surface of the cone.

Yd Dwivedi et al gave a clear view regarding variation in aerodynamic properties of different nosecones geometries:

In this paper, CFD has been done to obtain the various aerodynamic properties, velocity, and pressure of four different types of nosecones. The first shape which is having a sharp tip generated high lift and aerodynamic drag as compared to the other shape. When angles of attack were near about zero the medium taper nosecone provides better performance followed by the nosecone with the sharp tip. Till 10 degrees of AOA, Pressure distribution and velocity in the 2nd and 3rd type of the nosecones were almost identical, while the 1st type with a sharp tip was having maximum pressure values than the other three models. After comparing drag and lift generated values of all four models, the outcome is that the short tip shape is efficient till only 6 degrees and the other three models are effective till 10 degrees of Angle of attack.

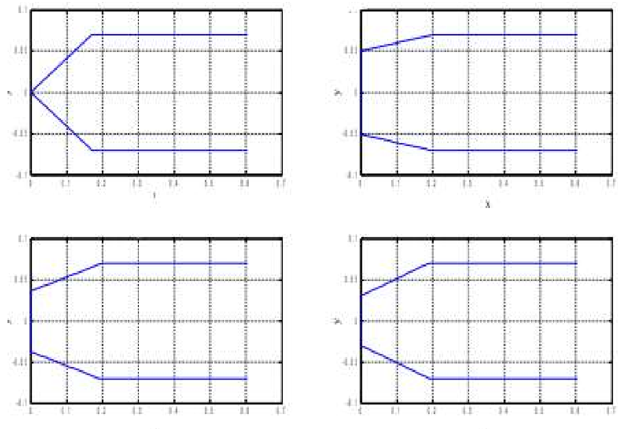

Figure 14: All four shapes of Nosecone

Ashish Narayan et al carried out their research work about using Taper spikes for reducing Drag and heating.

In the case of hypervelocity vehicles, the rocket nosecone faces maximum drag, and also at the same time shockwave generation will be there. The main motive is to reduce the drag force by analyzing different kinds of shapes of the nosecone. Moreover, in this paper taper spike and stepped taper spike configuration is used in the front of blunted and parabolic nosecone to control drag force and heating. Using stepped taper spikes in parabolic nosecones gives less aerodynamic drag. This work gives a clear view of shock features and their effects in taper spikes and step taper spike nosecone. Heat flux generation is maximum in the front of the nosecone. By using taper spikes and step taper spikes in front of the nosecone, heat flux generation can be reduced.

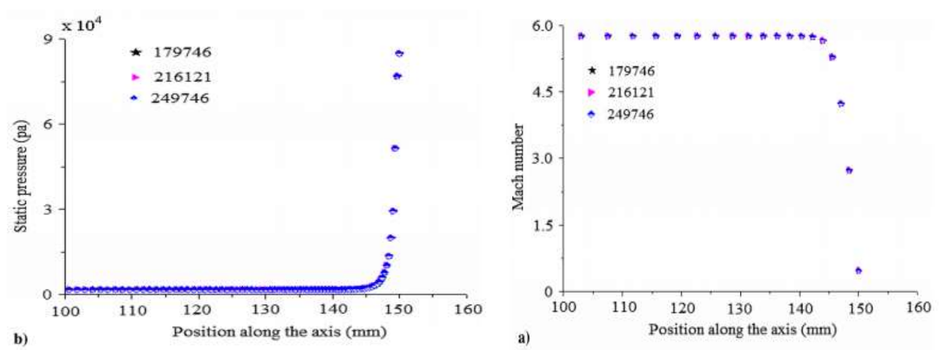

Figure 15: Change in Mach number with position along the axis

2.1. Critical Analysis

Nowadays designing of a rocket nosecone is very tough task for researchers. For a various range of flows (for instance, subsonic to hypersonic flow), we need different kinds of nosecone profiles to get more efficiency and stability. The researchers designed various kinds of shapes of nosecones in which some are suitable for subsonic flow and some are good for transonic flow, supersonic flow, and so on. Researchers designed different geometries of nosecone profile in design software and also, they did simulation at different mach numbers and angle of attack to check shock wave structure, drag value, and other aerodynamic parameters. Most of the designs are helpful to reduce drag value and having less effect of a shock wave. Apart from that, heat flux generation also plays an important role in it. To reduce this heat generation, researchers prefer a blunt type of shape. That's why most of the Rocket nose cones are blunted.

3. Conclusion

CFD is used to analyze different nosecone shapes where the main aim is to finalize the best shape variant to provide maximum efficiency to the spacecraft in terms of aerodynamic parameters. The result is as follows. In the case of subsonic flow, the most effective shape that can be designed for the nosecone is elliptical followed by the tangent and parabolic shapes, whereas in the case of subsonic to transonic flow, Von Karman shape is preferred and lastly the conical shape shows the least aerodynamic performance. In the case of hypersonic flow, there will be the generation of aerodynamic heat. So, to avoid that the nosecone geometry is designed accordingly. Moreover, the research is going on with new types of nosecone geometries to overcome certain drawbacks to obtain a particular profile having minimum drag, heat flux generation, and bow shock wave.

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