Investigation on Aerodynamic Performance of Elliptical and Secant give Nose Cones

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Abstract-In this paper, the computational and experimental approach was used to study the aerodynamic performance of elliptical and secant ogive nose cone profiles. The aerodynamic characteristic’s such as pressure, coefficient of pressure, axial velocity, total drag, dynamic pressure etc. for the secant and elliptical nose cone profiles were illustrated for low subsonic speeds for the same length to diameter ratio. Simulation were carried out with inlet velocity of 25 m/s, calculated for zero angle of attack to demonstrate the flow behaviour around the nose cone profiles. The data obtained from the computational analysis of the nose cone shapes was compared with the experimental data obtained from the wind tunnel analysis in order to find out the deviation. It was found out that the elliptical nose cone experienced less skin friction drag in comparison to secant ogive. Also, the velocity near the trailing edge in case of secant ogive was found out to be more when compared to elliptical nose cone. After comparing both the nose cones on the basis of coefficient of drag, skin friction drag and total drag experienced by the body, elliptical nose cone was found to be most efficient amongst the two.

Keyword-Secant ogive, Elliptical nose cone, Static pressure, Coefficient of pressure, Drag, Computational Fluid Dynamics CFD, Velocity, Coefficient of drag.

NOMENCLATURE
D Diameter of nose cone at body tube joint
L Length of nose cone
X Distance along nose cone measured from body tube joint
Y Radius
P Power or parameter used to specify haack sub type

I. INTRODUCTION
External flows past objects leads to a variety of fluid mechanics phenomena. Primarily the character of the flow field depends on the profile of the object as such that, even the simplest shaped objects for e.g. a sphere, produces a rather complex flow. Various parameters such as size, orientation, speed and fluid properties define the flow pattern and related forces over a body. Proper understanding of the flow features around the nose is extremely important due to the placement of payload.

Payload is usually placed around the nose cone in slender bodies such as launch vehicles, rockets, missiles etc. If we consider the geometry of the main rocket engines as well as the volume of the payload along with the specific requirements of a mission, use of conical nose cone shapes along with boat tail are of extreme importance [1]. The following parameters govern the nose cone geometry as illustrated in figure 1.“The Descriptive Geometry of Nose Cone,” 1996

1. Types of Nose Cone - The selection of a particular type of nose cone depends upon the speed and the mission of the vehicle. As such there are a number of different nose cone profiles such as Secant ogive, Tangent ogive, Elliptical, Conical, Bi-conic, Parabolic, Power series, Haack series. Given below are the nose cones of interest:

| Table 1 Parameters governing nose cone geometry |
|----------|------------------|
| L | Overall length |
| R | Radius of the base |
| Y | Radius at any point x, also x varies from 0 to L |
| C/L | The full body of revolution of the nosecone is formed by rotating the profile around the centreline |

Figure 1 Nose cone Nomenclature (Source G. A. C. Sr.,)
2. Secant Ogive Nose Cone

The profile of this shape is formed by a segment of a circle as shown in figure 2, but the base of the shape is not on the radius of the circle defined by the ogive radius \( \rho \). In this case the rocket body will not be tangent to the curve of the nose at its base. Therefore, the ogive radius \( \rho \) is not determined by \( R \) and \( L \), but is one of the factors to be chosen to define the nose shape. The radius \( Y \) at any point \( x \) as \( x \) varies from 0 to \( L \) is given by equation 1 [2].

\[
Y = \frac{D}{2} * \left[ 1 - \left( \frac{X}{F} \right)^P \right] * \left[ \frac{A^P}{A^P - F^P} \right]
\]

If \( 0 < F < L \), then result is secant ogive type [2]
(\( \text{True secant ogive has } P = 2 \))
Also, \( F = 3 \) for secant ogive

![Figure 2 Secant ogive Nose cone (Source:G. A. C. Sr., “The Descriptive Geometry of Nose Cone,” 1996)](image)

3. Elliptical Ogive Nose Cone

This shape is one-half of an ellipse, with the major axis being the Centre line (C/L) and the minor axis being the base of the nose cone as shown in figure 3. This shape is efficient for subsonic flight conditions due to its blunt nose and tangent base [3]. The radius \( Y \) at any point \( x \) as \( x \) varies from 0 to \( L \) is given by equation 2.

\[
Y = \left( \frac{D}{2} \right)^P * \left[ 1 - \left( \frac{X}{L} \right)^P \right]
\]

(True ellipse has \( P = 2 \))

![Figure 3 Elliptical Nose cone (Source:G. A. C. Sr., “The Descriptive Geometry of Nose Cone,” 1996)](image)

**II. LITERATURE REVIEW**

1. Historical Background Of Nose Cone Design

Nose cone geometry has been a topic discussed for more than a century. The geometry of a nose cone is critical to an object’s aerodynamic characteristics. Yefremov and Takovitskii used the Euler equations to design nose cone designs with specified dimensions and volumes leading to minimal aerodynamic wave drag. Foster and Dulikravich used two methods in order to compare and differentiate their performance on optimization of nose shape geometry [4]. Furthermore, taking into account the aerodynamic drag, heat transfer, and payload volume, Lee et al. obtained an optimal nose cone shape through the use of a multipoint response surface design method [5].

2. Effect of Different Nose Cone Profiles On Subsonic Pressure Coefficients

The nose shape does not affect the cross-flow pressure distribution at all, however part of the adverse pressure gradient that is generated from the longitudinal flow can be changed by altering the nose shape [6]. A system of procedures was employed by Munk for analysis in order to find the minimum \( C_p \) and critical Mach number. Using Munk Airship Theory the nose dimensions were first sent through an incompressible \( C_p \) calculation from which, a distribution of incompressible pressure coefficients was formed. After that the minimum pressure coefficient that was calculated in the first step was chosen to run through an incompressible to compressible transformation known as the Karman-Tsien Correction, which is valid for subsonic Mach numbers [7].

**III. NUMERICAL METHODOLOGY**

1. Governing Equations

The two-dimensional (2D) steady axisymmetric governing equations, which govern the occurrence of the physical phenomena when there is a flow past nose cone are as follows [8]:

\[
\frac{\partial}{\partial x} (\rho u_x) + \frac{1}{r} \frac{\partial}{\partial r} (r \rho u_r) = 0
\]

(3)

Where \( x \) is the axial coordinate, \( r \) is the radial coordinate, where \( u_x \) is the axial velocity, and \( u_r \) is the radial velocity.

Momentum conservation equation (axial direction):

\[
\frac{1}{r} \frac{\partial}{\partial x} (r \rho u_x u_x) + \frac{1}{r} \frac{\partial}{\partial r} (r \rho u_x u_x) = -\frac{\partial p}{\partial x} + \frac{1}{r} \frac{\partial}{\partial r} \left( r \mu \left( \frac{\partial u_x}{\partial x} + \frac{\partial u_x}{\partial r} \right) \right) + \frac{2}{3} \left( \nabla \cdot \vec{u} \right)
\]

(4)

Momentum conservation equation (radial direction):
\[
\frac{1}{r} \frac{\partial}{\partial x} (r \mu u_x) + \frac{1}{r} \frac{\partial}{\partial r} (r \mu u_r) = -\frac{\partial p}{\partial r} + \frac{1}{r} \frac{\partial}{\partial x} \left[ \mu \left( \frac{\partial u_x}{\partial x} \right) \right] + \frac{1}{r} \frac{\partial}{\partial r} \left[ \mu \left( 2 \frac{\partial u_r}{\partial r} \right) \right] - \frac{2}{3} \left( \frac{\partial u_r}{\partial r} \right) - 2 \mu \frac{u_r}{r^2} + \frac{2}{3} \frac{\mu}{r} \left( \nabla \cdot u \right) + \frac{u_r^2}{r} + F_x + F_r
\]

\[\nabla \cdot (\rho \nabla p) = \nabla \cdot (k_{eff} \nabla T) + \rho \left( \frac{\partial (\epsilon_{eff} \cdot \nabla u)}{\partial r} \right) \]

**6. Grid Independency Test**

To ensure that the aerodynamic parameters were independent of the number of cells in the constructed grid, a grid independency test was performed. Structured grids with strictly quadrilateral cells were constructed with varying divisions i.e. 200, 225, 250, 275, 300, 325 and 300 nodes on each edge of the domain as shown in figure 6. Coefficient of drag encountered by a conical nose cone having finesse ratio 3 was considered and compared to perform the grid independency test as shown in figure 7. The name selection of the domain is given in Figure 5.

**Figure 5 Name selection.**

**Figure 6 Different mesh sizes.**

**Figure 4 Geometry (a) ellipse; (b) secant ogive.**
7. Meshing
Mesh generation is the practice of generating a polygonal mesh that approximates a geometric domain as shown in figure 8. The term “grid generation” is often used interchangeably. The mesh influences the accuracy, convergence and computation time and hence is one of the most important steps in computation analysis [9].

8. Turbulence Models
Fluctuating velocity fields are used to characterize turbulent flows. During turbulent flow quantities such as momentum, energy, and species concentration, are mixed as a result of these fluctuations due to which the transported quantities fluctuate too. Due to their small scale and high frequency these fluctuations are computationally expensive, to simulate directly in practical engineering calculations [10]. Therefore, in order to remove the resolution of small scales, a modified set of equations that are computationally less expensive to solve are established in place of the instantaneous governing equations. These modified equations contain additional variables whose values are unknown. As a result, turbulence models are required to find these unknown variables in terms of already known quantities. [11]

9. Boundary Conditions
A double precision, implicit, pressure based solver was utilized to perform steady, inviscid, axial simulations to predict the body/airflow interaction and behaviour of various aerodynamic phenomena for airflow past secant ogive and elliptical nose cone. The incoming fluid was considered to be air with a velocity of 25 m/s calculated at zero degrees angle of attack. The simulation was carried on the above mentioned nose cones using K-ω SST turbulence model. The model was chosen for numerical analysis as this model is best suitable for flows transitioning from laminar to turbulent along with being computationally less expensive. This model also includes the skin friction drag and has a lesser sensitivity towards numerical error [12].

IV. PROBLEM SPECIFICATION
A computational and experimental approach is used to study the aerodynamic performance of elliptical and secant ogive nose cone profiles. The data obtained from the computational analysis of the nose cone profiles is then compared with the experimental data obtained from the wind tunnel analysis in order to find out the variation...
between them. The simulation involves the velocity of 25 m/s calculated at zero degrees angle of attack in order to demonstrate the flow behavior around various nose cone profiles.

V. VALIDATION OF EXPERIMENTAL SETUP
In order to validate experimental setup to conduct experimental analysis, Coefficient of Pressure (Cp) was calculated for a cylinder with dimensions (300mm x 50 mm) was found out at various angles and then compared with theoretical data as shown in figure 9. Furthermore, wind tunnel calibration was also carried out in order to determine inlet velocity.

![Figure 9Comparison between Cp theoretical and Cp experimental.](image)

Figure 10Dynamic and static pressure variation on secant ogive

![Figure 11(a)Dynamic pressure contour for Secant ogive; (b) Static pressure contour for Secant ogive](image)

VI. RESULTS AND DISCUSSIONS
1. Computational Results
Parameters such as velocity, static pressure, and dynamic pressure were obtained from the ANSYS fluent.

2. Variation In Static And Dynamic Pressure Along The Curve Length
2.1 Secant ogive
Figures 10 and 11 show the variation in dynamic and static pressure along the curve length from the tip of the profile and contours respectively. It can be observed that static pressure at the tip of the nose cone is maximum and starts decreasing gradually along the curve length whereas the value of dynamic pressure is minimum on the tip and starts increasing gradually along the curve length. All these changes can be verified by the static and dynamic contours of the Secant ogive profile as shown in figure 11.

2.2 Ellipse nose cone
The Figures 12 and 13 show the variation in dynamic and static pressure along the curve length from the tip of the profile. It can be observed that static pressure at the tip of the nose cone is maximum and starts decreasing drastically along the curve length when compared to the secant ogive. Also the value of dynamic pressure is minimum on the tip and starts increasing drastically along the curve length when compared to that of secant ogive. All these changes can be verified by the static and dynamic contours of the Secant ogive profile.
2.3 Variation in Velocity along The Curve Length
Figure 14 shows the variation of velocity along the curve length of both the secant ogive and elliptical nose cone profile respectively. As seen in the figure the variation in velocity is more in case of elliptical nose cone profile due to the generation of stagnation point at the tip of the profile caused due to the blunt shape of the profile whereas the variation in velocity in case of secant ogive is minimal due to the blunt nature of its shape.

2.4 Streamline and Vector Contours
The streamlines are used to check the behaviour of the flow while the vector controls are used to know the existence of the vortex on the surface of the profile. Figure 15 and 16 represent the streamline and vector contours over secant and elliptical nose cone profiles respectively.

2.4.1 Secant ogive

2.4.2 Ellipse nose cone
V. VARIATION OF COEFFICIENT OF DRAG BETWEEN INVISCID AND K-Ω SST MODEL

Figure 17 represents the variation between the values of coefficient of drag between the secant ogive and elliptical nose cone for both the inviscid and k-ω SST turbulence models. As illustrated in the graph it is clear that the values of Cd for both the nose cones in case of k-ω SST model is much more than the value of Cd at in viscid turbulence model. This is due to the induction of skin friction drag in case of k-ω SST turbulent model. From the graph we can further conclude at in both the cases the Cd experienced by elliptical profile is less than that of secant ogive hence, elliptical nose cone will have better aerodynamic efficiency then secant ogive under these conditions.

VI. EXPERIMENTAL AND COMPUTATIONAL RESULT COMPARISON

1. Comparison of Static Pressure For Secant Ogive And Elliptical Nose Cone

From the graph in the figure 18 we can conclude that the range of static pressure in case of ellipse ogive is much more than that of secant ogive. Furthermore, the nature of the curve for both the nose cones as seen is different. It is observed that the change in absolute pressure in case of ellipse is steeper when compared to that of secant ogive. This happen mainly due to the nature of shape of both the nose cones while secant ogive being more pointed towards its trailing edge doesn’t create that much of stagnation whereas on the other hand the ellipse nose cone profile being more blunt creates a stagnation point much higher than that of the secant ogive.

2. Comparison of Coefficient of Pressure For Secant Ogive And Elliptical Nose Cone

From the graph in figure 19 we can observe that the nature of curve for coefficient of pressure variation in
both secant ogive and elliptical nose cone is similar. The only difference between the two is that while the values of Cp start decreasing gradually in terms of secant ogive, while the decrement in Cp in case of elliptical nose cone is steeper. The driving factor behind this type of behaviour is the bluntness of the leading edge of both the profiles. The stagnation created due to bluntness of the ellipse nose cones at the leading edge also leads to this steep decrease of value in Cp as compared to secant ogive. Since secant ogive is pointed at its leading edge the flow doesn’t stagnate at the leading edge as much as it does in case of ellipse as a result of which the Cp values start decreasing gradually.

3. Comparison of Velocity For Secant Ogive And Elliptical Nose Cone

The curves in figure 20 compares both the CFD and the experimental values of the velocity over the curve length of both the profiles. It is observed from the curve that the velocity at both the leading and the trailing edge is more in terms of secant ogive. In fact in case of secant ogive there is 64% increment in the velocity at the leading edge and 8.09% increment when compared to that of the ellipse profile. These profiles exhibit this kind of behaviour due to the formulation of stagnation point at the leading edge since the elliptical profile is blunter in comparison with the secant ogive. As a result it takes much longer for the fluid to accelerate over elliptical profile in comparison to secant ogive.

**VILOBSERVATIONS**

After plotting and reviewing both the CFD and experimental data the following observations were made. In Table 4, 5 and 6 the deviation % between the experimental and numerical values for static pressure, coefficient of pressure and velocity has been represented for secant ogive. The same has been done in Tables 7, 8 and 9 for the elliptical nose cone.
The deviation in the following results is mainly due to human and mechanical error. The experimental analysis has been done on 3D profiles whereas the numerical analysis was carried out in 2D which might add to the deviation in the results.
VIII. CONCLUSION AND FUTURE SCOPE OF WORK

In this paper, the computational and experimental approach was used to study the aerodynamic performance of various nose cone such as pressure, coefficient of pressure, absolute pressure, axial velocity etc. of the various nose cone profiles were obtained for low subsonic conditions profiles for the same length to diameter ratio. The study involves an inlet velocity of 25 m/s that is calculated for zero angle of attack. The data obtained from the computational analysis of these nose cones profiles was then compared with experimental data obtained from wind tunnel analysis in order to find the deviation.

Coefficient of drag was the key parameter for the selection of the optimum shape for the subsonic flow range between secant ogive and elliptical nose cone profile. In the case of secant ogive nose cone the velocity was found to be 18.167 m/s near the trailing edge. The coefficient of pressure was found to be maximum at the tip of the nose cone while dynamic pressure was maximum at the trailing edge of the nose cone. The total drag experienced by secant ogive was 3.31 N corresponding to 0.12118659 value of Cd. In the case of elliptical cone the velocity was found to be 16.696 m/s near the trailing edge.

The coefficient of pressure was found to be maximum at the tip of the nose cone while dynamic pressure increased drastically as compared to secant ogive and was maximum at the trailing edge of the nose cone. The total drag experienced by secant ogive was 2.91 N corresponding to 0.11218659 value of Cd i.e. Coefficient of drag. Therefore we can conclude that on the basis of drag experienced by both the nose cone the elliptical nose cone experiences less drag when compared to that of secant ogive hence elliptical ogive would perform better at these conditions when compared to the secant ogive.

These profiles can further be used in hypersonic and supersonic flow range and data such as velocity, dynamic pressure, static pressure and total drag over these profiles can be calculated in order to find the optimum profile in these flow ranges. There are also other profiles such as hemispherical, elliptical, power series, hack series that can be further tested for various aerodynamic parameters and optimum profile can be selected for different flow ranges or as per mission requirement.

REFERENCES