iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: III Month of publication: March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67740

Surface Texture Modifications and Nose Cone Geometries: A Review of Aerodynamic Enhancements

RinchuP.[1], Anjana K. Ashokan[2], Aswathy T. G[3], Jasmine George[4], Srilakshmi V. V[5]
[1]*Assistant Professor*, [2, 3, 4, 5]*UG SCHOLAR, Department of Aeronautics Jawaharlal College Of Engineering And Technology*

I. INTRODUCTION

In the pursuit of aerodynamic efficiency and structural optimization in aerospace engineering, nose cone design plays a crucial role in determining the performance of various flight vehicles. This systematic review delves into the advancements in nose cone aerodynamics—not only as a means to enhance stability and efficiency but also as a key factor in technological progress across space exploration, defence applications, and commercial aviation. We expand upon this by incorporating insights from recent landmark studies, which highlight the multidimensional impact of nose cone designs.

Iyer & Pant [1] provide a comprehensive analysis of different nose cone designs suited for varying flight regimes, discussing their implications on aerodynamic efficiency and material constraints. Mishra & Singh [2] investigate the flow variations over elliptical nose cones at different angles of attack, offering insights into pressure distribution and aerodynamic stability. Meanwhile, Mishra et al. [3] present a conceptual design and analysis of a two-stage sounding rocket, focusing on structural integrity and aerodynamic performance. Varma et al. [4] utilize computational fluid dynamics (CFD) to analyse multiple nose profiles, identifying optimal shapes for reducing drag. Narayan et al. [5] conduct a comparative study on hypersonic flow behaviour around different nose cone geometries, shedding light on shockwave interactions and heat flux distribution.

Further expanding on this, Kim & Al-Obaidi [6] examine how nose shape and geometry impact missile performance at supersonic speeds, revealing key strategies for aerodynamic optimization. Mathew et al. [7] provide a review of computational drag analysis for rocket nose cones, offering methodologies for minimizing aerodynamic resistance. Belega [8] explores new aerodynamic design concepts using CFD and smoothed particle hydrodynamics (SPH), emphasizing innovations in flow behaviour and drag reduction. Bechert et al. [9] investigate bio-inspired surface applications for drag reduction and separation control, highlighting nature-driven engineering solutions. In a complementary study, Bechert et al. [10] analyse adjustable surface geometries to optimize drag-reducing features, identifying configurations that enhance aerodynamic performance.

Continuing this exploration, Pescini et al. [11] assess boundary layer characteristics to optimize flow control mechanisms using plasma actuators, offering insights into turbulence management. Chang & Weng [12] examine hypersonic thermal flow over spherically blunted tangent-ogive nose cones, addressing key concerns related to aerodynamic heating. Laruelle [13] provides a detailed review of air intake designs, discussing their integration with nose cone aerodynamics for enhanced propulsion efficiency. Krishnan et al. [14] explore the effects of hydrophobic and super hydrophobic surfaces in reducing aerodynamic insect residue accumulation, offering solutions for surface contamination challenges. Lv et al. [15] investigate the impact of surface microstructures on boundary layer characteristics, demonstrating their influence on drag reduction and flow control.

Lv et al. [16] further explore the effects of riblets on boundary layer interactions over aircraft surfaces, revealing their potential in minimizing skin friction drag. Fukiba et al. [17] conduct a numerical study on supersonic flow angles and Mach number measurement using surface pressure variations in nose cone designs. Ukirde& Rathod [18] perform an aerodynamic analysis of various nose cone geometries for rocket launch vehicles across different Mach regimes, providing optimization guidelines. Carvalho & Filho [19] carry out a CFD-based investigation into the drag force variations among different nose cone designs, reinforcing the importance of shape optimization in reducing aerodynamic resistance. Ghanbari et al. [20] explore heat reduction techniques using lateral coolant jets on hypersonic nose cones with double aerodomes, addressing thermal management challenges in high-speed flight.

These studies collectively underscore the role of computational simulations, experimental research, and bio-inspired innovations in advancing nose cone design.

We embark on our exploration with a detailed assessment of the aerodynamic principles governing nose cone performance, emphasizing the integration of flow dynamics, pressure distribution, and drag minimization techniques in modern aerospace applications.

As aerospace technology continues to advance, optimizing nose cone designs has become increasingly critical for improving aerodynamic efficiency, stability, and thermal management. This systematic review explores recent developments in nose cone aerodynamics, focusing on how innovative design approaches contribute to reducing drag, enhancing flight stability, and mitigating aerodynamic heating effects. We incorporate insights from key studies that highlight the impact of computational simulations, experimental testing, and bio-inspired modifications on nose cone performance.

Deepak et al. [21] explore nose cone optimization for hypersonic flight, analysing how design modifications enhance aerodynamic efficiency during extreme-speed trajectories. Luchini et al. [22] investigate grooved surface resistance in both parallel and cross-flow conditions, revealing how surface texturing influences drag reduction. Kumar et al. [23] examine nose-blowing techniques for side force control on slender cones at high incidence angles, demonstrating innovative methods for improving aerodynamic stability. Grüneberger& Hage [24] analyse the drag characteristics of longitudinal and transverse riblets, highlighting their effectiveness in reducing aerodynamic resistance at low Reynolds numbers. Mitcheltree et al. [25] conduct experimental and numerical research on the aerodynamics of blunt entry vehicles, offering critical insights into subsonic flight performance.

García-Mayoral et al. [26] present a study on near-wall turbulence control through surface texturing, identifying key design features that minimize frictional losses. Felkel [27] investigates the influence of different nose profiles on subsonic pressure coefficients, providing comparative data on aerodynamic efficiency across various designs. Samni et al. [28] explore drag reduction techniques in turbulent flow over thin rectangular riblets, offering design recommendations for aerospace applications. Park & Wallace [29] examine the impact of riblets on boundary layer flow alteration, demonstrating their role in enhancing laminar-to-turbulent transition control. Prajapati et al. [30] perform a comparative study on the aerodynamic performance of nose cones at different angles of attack using CFD simulations, identifying optimal design parameters for improved stability and efficiency.

Upadhyay et al. [31] review aerodynamics, structural configurations, and material considerations for hypersonic aircraft, providing a holistic perspective on high-speed flight challenges. Chalia & Bharti [32] present a mathematical modeling approach to ogive fore bodies and nose cones, detailing predictive methods for aerodynamic analysis. Tai [33] investigates the effect of micro-vortex generators on V-22 aircraft forward-flight aerodynamics, revealing their role in enhancing lift and reducing drag. Rathi [34] conducts experimental and numerical analysis on power series nose cones, identifying optimal shapes for minimizing aerodynamic resistance. Wang et al. [35] explore aerodynamic drag reduction using trapezoidal span wise grooves inspired by pigeon feathers, showcasing bio-inspired approaches to flow control.

Suzuki &Kasagi [36] investigate the mechanism behind turbulent drag reduction over riblet surfaces, analysing their effectiveness in aerospace applications. Teja & Mishra [37] conduct a numerical study on the aerodynamic properties of blunt nose cones in subsonic flow, providing insights into pressure distribution and flow behaviour. Wang et al. [38] examine the influence of surface microstructures on boundary layer characteristics, emphasizing their role in reducing aerodynamic drag. Finally, Li & Yang [39] present a numerical investigation of flow behaviour over an ogive nose cone at low Reynolds numbers, offering computational insights into flow separation and pressure distribution effects.

These studies collectively highlight the significance of computational analysis, experimental validation, and bio-inspired innovations in shaping the future of nose cone design. We embark on our exploration with a detailed assessment of aerodynamic principles, focusing on how technological advancements in surface modifications, turbulence management, and structural optimization contribute to the next generation of aerospace engineering solutions.

II. TYPES OF NOSE CONE

Nose cones are a key element of aerospace vehicles that are intended to maximize aerodynamic performance, thermal protection, and structural integrity in a range of flight regimes. The selection of nose cone type is based on the particular application, speed regime, and mission requirement. Typical designs are conical nose cones, simple and efficient for subsonic and low supersonic velocities; ogive nose cones, with streamlined form and lower drag at higher velocities; parabolic nose cones, providing a compromise between drag reduction and strength; and blunted nose cones, necessary for hypersonic and re-entry vehicles because of their capacity to handle extreme heat and shock waves. All such types have different aerodynamic and thermal properties to suit specific conditions of flight, ranging from subsonic flight vehicles to hypersonic missiles and space vehicles.

A. Conical Nosecone

The conical nosecone is one of the most used nosecone shapes that have various applications in aviation as well as the aerospace industry. It is characterized by a straight and tapering cone that has been concentrated to a single point. Simple geometric design and ease of manufacturability make the conical a first choice for so many basic and uncomplicated applications[4].

The uniform material distribution over the length makes the nose cone capable enough to withstand the force that has been experienced during the high speed conditions. the simple geometry of the nosecone reduces the manufacturing constraints along its improved structural integrity[1].

Despite the disadvantages the nosecone the increment in the drag coefficient at the reduced speed increases the drag and reduces the overall efficiency. The pointed frontal portion of the nosecone will create pressure waves at higher speeds which is also undesirable. This reduces the conical design as a less suitable one for high-speed operations and long-range applications[5].

B. Blunted Nosecone

The blunted nose cones are another common one used for hypersonic, missiles and re-entry applications. Blunted nose cones are defined by a flattened or rounded tip rather than a sharp apex. Their performance is influenced by several factors such as shock wave generation, drag, pressure distribution, and heat flux.

Blunted nose cones are intended to counteract the issues of high-speed flight, especially hypersonic and re-entry. In contrast to sharp-tipped geometries, which produce attached bow shock and extreme local heating, blunted shapes form a detached bow shock, which lengthens the shock detachment distance (d) and decreases heat transfer to the surface. At subsonic speeds, the blunted cones suffer a greater drag because of their greater frontal area, but at supersonic and hypersonic speeds they tend to perform better than point designs by reducing wave drag. [5].

C. Ogive Nosecone

The ogive nose cone is a smooth aerodynamic shape commonly employed for missiles, rockets, and high-speed aircraft because it can minimize drag and control shock wave formation effectively. In contrast to conical nose cones that produce intense attached shock waves, the ogive shape has a curvature with a smooth shape that produces an oblique shock that reduces wave drag and aerodynamic heating. Computational analyses affirm that ogive nose cones have lower drag coefficients and enhanced stability, and are thus suited for supersonic and hypersonic flights. Further, their shock wave formation is farther from the surface, decreasing heat flux and thermal stress on the structure.

Studies reveal that the drag coefficient (Cd) of ogive nose cones reduces with higher angle of attack (AOA), whereas the lift coefficient (Cl) raises, increasing the stability of flight. The tangent ogive is most widely applied for supersonic aircraft and missiles, and blunted ogive is utilized in hypersonic and re-entry vehicles because of improved thermal management. ANSYS CFD simulations were used to establish through studies that ogive configurations are superior to conical nose cones in minimizing drag and improving flow stability.These features render the ogive nose cone a choice of preference for ballistic missiles, supersonic aircraft, and hypersonic vehicles, where aerodynamic efficiency, minimized heating, and stable flight performance are essential.[30]

D. Elliptical Nose Cone

The elliptical nose cone is a common aerodynamic shape, especially in subsonic and low-supersonic applications, because it reduces drag and enhances flight stability. In contrast to conical or ogive nose cones, the elliptical shape is created by rotating half an ellipse about its major axis, resulting in a smooth, rounded shape that optimizes airflow efficiency. This shape is particularly useful in minimizing pressure drag at low speeds and is thus widely used in model rockets, UAVs, and low-speed aircraft. Analytical solutions employing CFD analysis in ANSYS Fluent have indicated that elliptical nose cones have lower drag coefficients than parabolic and conical shapes in subsonic conditions. The smooth curvature of the elliptical form avoids abrupt pressure changes, resulting in a more stable flight trajectory with less turbulence. At higher supersonic velocities, though, the efficiency of elliptical nose cones suffers because of their rounded leading edge, which raises wave drag and aerodynamic heating.

Findings from research show that though elliptical nose cones provide a 4.93% drag reduction over parabolic shapes at low speeds, their drag becomes very high at high Mach numbers. They are therefore less ideal for hypersonic use, where more conical nose shapes such as ogive or Von Kármán shapes are ideal. Evens so, elliptical nose cones continue to be a sensible option for low-speed aerospace usage, where airflow smoothness and stability take priority over the possibility of maximum drag reduction.

III. IMPORTANCE AND ROLE OF NOSECONE IN AIRCRAFT

The nose cone is one of the rocket's integral parts, being the frontmost structure engaged with the ambient fluid during the rocket's ascent. Its primary work is the inflow control of the ambient fluid, the diminution of the aerodynamic drag, and the prevention of heat formation by bow shock waves during high-speed travel. The impact of the nose cone is strongly felt by the rocket's aerodynamic efficiency, where the shapes determine the distribution of the wave drag, skin friction, and pressure. Elliptical nose cones yield the lowest subsonic flight drag, while Von Kármán shapes best operate during the transonic and the supersonic range. Blunt nose cones can also find their applications for hypersonic use for heat flux handling and prevention from high heat stress. Computation for the analysis is carried out using the tool of the Computational Fluid Dynamics (CFD) for the analysis for maximum efficiency under the parameters of the aerodynamic efficiency, structural strength, and stability under various flight conditions.[7]

In the aerodynamic performance of rockets, missiles, and high-speed aircraft by reducing drag and ensuring stable flight. Its primary function is to minimize air resistance as the vehicle moves through different flow regimes, from subsonic to hypersonic speeds. The nose cone shape directly affects pressure distribution, shock wave formation, and heat dissipation, all of which influence the efficiency and stability of the vehicle. In subsonic flight, a short, blunt, and smooth elliptical nose cone is often preferred to reduce skin friction drag. However, as the vehicle transitions to transonic and supersonic speeds, pressure drag becomes more significant, necessitating streamlined shapes such as ogive, Von Kármán, or parabolic nose cones to optimize aerodynamic performance. At hypersonic speeds, aerodynamic heating becomes a major concern, as intense friction with the atmosphere generates extreme temperatures. To counteract this, blunt nose cones are commonly used, as they help distribute heat over a larger surface area, reducing localized thermal stress. The choice of nose cone geometry depends on a trade-off between drag reduction and heat management. Computational Fluid Dynamics (CFD) simulations and experimental studies have shown that different nose cone shapes perform optimally in specific speed ranges, requiring engineers to carefully design them based on the vehicle's mission profile. By selecting the appropriate nose cone design, engineers can enhance fuel efficiency, reduce structural stress, and improve overall flight stability, making it a critical aspect of aerospace engineering.[1]

Aerodynamic component for hypersonic aircraft, responsible for regulating the airflow, reducing the drag, and protecting the craft from high heat loads. Because the nose cone is the very first piece to engage atmospheric gas, the shock waves encountered by the nose cone induce rapid heat buildup and pressure changes. The design of the nose cone is responsible for countering the influence of the heat from the aerodynamic forces, preventing the structure from breakdown, and delivering overall steadiness during flight. Blunt nose cones, generally used for high-speed military aircraft, generate detached shocks, thus minimizing the heat exchange by surface contact, while sharp nose cones generate attached shocks, increasing the surface heat. This is particularly essential for hypersonic craft and the space capsule for re-entry, where the appropriate nose cone shape and materials, including heat-resistant ceramics, must be selected for the craft's ability to survive the hostile environment while being aerodynamically sound. [31]

The nose cone plays a crucial role in the aerodynamic performance of high-speed aircraft and rockets by minimizing drag and preventing flow separation, which can negatively impact efficiency. Its primary function is to streamline airflow around the vehicle, reducing air resistance and enhancing stability. The study emphasizes that selecting an optimal nose cone shape is essential for achieving higher efficiency and better aerodynamic performance. Elliptical nose cones, in particular, have been found to generate lower drag compared to other shapes such as conical and parabolic profiles, making them highly suitable for subsonic applications. By utilizing Computational Fluid Dynamics (CFD) simulations, researchers can analyse the effects of different nose cone geometries on drag, lift, and pressure distribution at varying angles of attack. This helps engineers refine nose cone designs to improve overall aircraft performance. Additionally, the study highlights how the angle of attack (AOA) significantly affects the aerodynamic characteristics of a nose cone. As the AOA increases, both lift and drag values rise, leading to the formation of induced drag, which can decrease the aircraft's efficiency. By examining variations in flow behaviour at different AOAs, engineers can optimize nose cone shapes to balance aerodynamic forces and ensure smoother airflow. The research further demonstrates that elliptical nose cones exhibit desirable drag coefficients at specific Mach numbers, making them effective for subsonic flight conditions. This knowledge is crucial for aerospace applications, as optimizing the nose cone design directly influences fuel efficiency, stability, and overall performance of high-speed flying vehicles. [2]

As the rocket's front-most component, the nose cone is tasked with guiding the vehicle through the atmospheric environment using maximum efficiency by keeping the flight stable and the aerodynamic drag minimum. With its conical design, the rocket can travel the highest possible velocity while keeping the minimum possible resistance, reaching greater altitudes eventually, something fundamental for scientific missions. Besides this, the nose cone also houses the payload, such as the satellite or scientific equipment, ejected after the rocket has attained the desired altitude.

Depending on the mission, various shapes of the nose cone, including the conical, the ellipsoidal, the ogive, the parabolic, and the Haack series, are selected for maximum efficiency for the aerodynamic and the security of the payload. Correct nose cone selection is seen by the study to play a fundamental part in the rocket's apogee and efficiency, and is thus fundamental for the concept design and analysis for the two-stage sounding rockets. [3]

The nose cone is accountable for the efficiency of sounding rockets, particularly for the prevention of drag and the prevention of pressure gradients along the forebody. As this study has revealed, the shapes of the nose can strongly impact subsonic pressure coefficients, the separation of the boundary layer, and the formation of vortices. This study is comparing the cone-cylinder, ogive-cylinder, and the optimum shapes for the best form for the prevention of negative gradients and shock wave formation. This study illustrates the optimum nose form has the highest value for the critical Mach number and the lowest coefficient for the pressure variation, providing greater efficiency and stability for the forces of the aerodynamic. With the appropriate nose cone form, engineers can make the rocket's efficiency greater, minimize the induced roll, and minimize overall aerodynamic drag, providing the rocket's flight is smoother and under greater control.[27]

The nose cone is instrumental during hypersonic flight by shaping shock wave formation, aerodynamic heat, and overall vehicle stability. This work investigates the thermal-flow phenomena around the spherically blunted tangent-ogive nose cone under the influence of a Mach number of 6 using the tool of Computational Fluid Dynamics (CFD). This study illustrates the influence of the bluntness ratio (BR) on the main parameters of the aerodynamic parameters like shock detachment distance, shock wave strength, and the velocity of the airflow. An increased BR produces a stronger and detached shock wave, resulting in greater static pressure and temperature in the shock layer and decreased velocity of the airflow. These results will find significant importance during the design of hypersonic aircraft, rockets, and space re-entry craft, where the nose cone is optimized for the minimum possible aerodynamic heat and the durability of the structure under the high heat environment.

In addition, the study points towards the balance required for the choice of the nose cone design where the nose cone is made progressively blunted for increased strength of the shock wave pushing the high temperature gas far from the surface for reduced heat load over the vehicle. However, this increases the drag, affecting the efficiency of the fuel and the overall flight capability. In contrast, the progressively less-blunted nose cone decreases the drag but increases the heat load over the surface through the aerodynamic heat. This study implies the ability to balance the efficiency for the aerodynamic and the heat protection by the variable BR. This is especially useful for the space craft entry designs where the heat handling under the structure is the main consideration. [12]

The nose cone is essential for the aerodynamic efficiency of slender bodies, especially for side forces and high-angle-of-attack stability. In this work, the phenomenon of "nose blowing" is investigated as an active control measure for preventing the formation of unwanted side forces caused by asymmetric vortex flows. Slim slender bodies generate high side forces under high incidence angles through the formation of asymmetric vortices, causing the vehicle to lose stability. This work illustrates the ability to suppress these asymmetries by providing an axial jet from the nose tip. Experimental data reveal the dependence of vortex symmetry upon the variable velocity ratio of the jet, where the maximum side force is reduced when the velocity ratio is about 1.0. This method, by manipulating the interaction between the free stream and the nose tip, simulates the benefits of nose blunting but is far more adaptive, thus being a potential solution for enhanced aerodynamic control for high-speed aircraft and missiles. Additionally, the work illustrates the significant dependence of side force reduction upon the velocity ratio of the jet instead of the diameter, thus being scale-able and energy efficient. Experimental data also reveal the robust nature of the technique over the range of applied Reynolds numbers, thus being suitable for engineering designs. Utilization of this technique by high-angle-of-attack operating aircraft and missile platforms will provide enhanced maneuverability and reduced yawing instability through non-intrusive changes in the geometry. Another concept introduced by the work is "fluid dynamic blunting" where the nose blowing is seen to cause the effective form of the forebody flow to differ from the true form, thus the interaction of the free stream with the vehicle is modified. This insight points the way towards the future direction for the aerodynamic optimization for next-generation high-speed missiles and fighter planes.[23]

The nose cone plays a critical role in hypersonic vehicle design, particularly in managing aerodynamic heating and drag forces at extreme velocities. This study focuses on a hybrid thermal protection system combining a mechanical spike with coolant jet injection to reduce heat loads on the nose cone. The formation of strong shock waves at the nose tip generates intense aerodynamic heating, which poses a significant challenge for the structural integrity of hypersonic vehicles. The introduction of a double-aero disk spike effectively reduces heat transfer by modifying shock interactions, while the addition of coolant jets enhances localized cooling. Computational simulations reveal that lateral coolant jets provide superior heat reduction compared to opposing jets, with carbon dioxide proving to be 85% more effective than helium when injected laterally.

By implementing this hybrid approach, engineers can significantly enhance the thermal performance and durability of nose cones, enabling more efficient and reliable hypersonic flight. Furthermore, the study highlights the importance of optimizing jet placement and selection of coolant gases to achieve maximum thermal protection. The results indicate that multi-jet lateral injection improves heat dissipation efficiency by up to 90% compared to opposing jet configurations. The strategic use of aero disked spikes separates the mechanisms governing heat dissipation and drag reduction, leading to improved aerodynamic stability. This novel hybrid technique demonstrates promising potential for real-world aerospace applications, offering a practical solution for mitigating extreme thermal loads encountered in high-speed flight. By integrating mechanical and fluid cooling strategies, future hypersonic vehicles can achieve greater efficiency, reduced material degradation, and extended operational lifetimes, marking a significant advancement in high-speed aero-thermodynamics. [20]

The nose cone plays a vital role in determining the aerodynamic performance of supersonic aircraft by influencing the measurement of flow angles and Mach numbers using surface pressure. This study highlights the significance of the half-cone angle in achieving accurate measurements of these parameters, which are crucial for the stability and efficiency of high-speed vehicles. The research shows that a larger half-cone angle enhances sensitivity in flow angle measurements, while a smaller half-cone angle improves Mach number accuracy. This is because a larger half-cone angle helps suppress flow separation and provides a stable pressure distribution for measuring attack and side-slip angles. Conversely, a smaller half-cone angle ensures a more consistent pressure gradient, leading to precise Mach number detection. These findings are particularly relevant for air data sensor (ADS) systems in supersonic aircraft, where precise aerodynamic data is essential for real-time flight adjustments. To address the conflicting requirements for flow angle and Mach number measurements, the study proposes a bi-conic nose cone design with two different gradients. This innovative approach allows the first section of the nose cone, with a larger gradient, to optimize flow angle sensitivity, while the second section, with a smaller gradient, ensures accurate Mach number measurement. Numerical simulations confirm that this bi-conic configuration improves measurement precision for both parameters while also reducing aerodynamic drag by approximately 10% compared to conventional designs. Additionally, the study demonstrates that using surface pressure-based ADS on a streamlined nose cone is more effective than traditional pitot tube-based methods, as it minimizes flow disturbances and enhances measurement reliability. These insights are essential for the design of next-generation supersonic and hypersonic aircraft, where the collection of detailed aerodynamic data is the cornerstone for optimizing the flight efficiency and stability.[17]

IV. AERODYNAMIC PERFORMANCE ANALYSIS OF A NOSE CONE IN THE SUBSONIC REGIME

In aerospace engineering, the aerodynamic performance analysis of a nose cone in the subsonic regime is an important area of study. The nose cones significantly influence stability, performance and overall aerodynamic efficiency of the vehicle. So, they are the essential components of rockets, missiles and aircraft. In subsonic region, the velocity of the fluid around the object is less than the speed of sound, that is Mach number less than 0.8. The importance of nose cone design lies in its ability to reduce drag, ensure efficient flow management and acquire stability. The aerodynamic behaviour in subsonic region is governed by smooth, continuous flow patterns with decreased level of compressibility effects. Subsonic flow conditions are relevant to low-speed aircrafts, drones and the initial phase of rocket launches. In order to improve overall vehicle efficiency and for optimizing the designs of nose cones, thorough understanding of aerodynamic principles and performance metrics in the subsonic regime is crucial.

A. Subsonic Regime

Since the air molecules travel at far slower speeds than sound, the flow patterns are smooth and constant. For practical purposes, the flow in the subsonic range (Mach number < 0.8) is regarded as incompressible.

1) Fundamentals Of Subsonic Flow

The Reynolds number influences subsonic flow behaviour. The Reynolds number indicates whether the flow is laminar or turbulent. The flow is laminar, having orderly, smooth streamlines at low Reynolds numbers. As the Reynolds number increases, the flow transitions to turbulence, which is characterised by chaotic and irregular motion. Analysing nose cone aerodynamic performance in subsonic situations necessitates a solid understanding of the fundamental concepts [34].

The fundamental principles governing subsonic flow include the conservation of mass, momentum and energy, which are expressed through continuity equation, Bernoulli's equation and Navier-Stokes equations.

The Bernoulli's equation defines the relationship between pressure, velocity and datum in an inviscid flow and continuity equation ensures that the mass flow rate remains constant across different sections of the flow.

More comprehensive description of fluid motion accounting for viscosity and turbulence is provided by Navier-Stokes equation. In subsonic flow, the pressure changes gradually and the flow adheres closely to the surface of the body and hence minimizing flow separation and turbulence [1].

2) Characteristics Of Subsonic Flow

An important factor of subsonic flow is the formation of vortices and wake regions behind the nose cone. The wake region is characterised by high turbulence and low pressure, which have the capability to increase drag and reduce stability. The vortices are generated by the active interaction of the flow with the body and can significantly impact the aerodynamic performances. Better understanding of these characteristics is essential for optimising nose cone designs for subsonic conditions [34].

The characteristics of subsonic flow are defined by smooth, continuous nature and the absence of shock waves. Unless adverse pressure gradients are present, the flow remains attached to the surface of the body with minimal flow separation. Boundary layer, which is the thin layer of fluid, present adjacent to the body surface plays a critical role in determining the aerodynamic performance of the nose cone.

As the flow moves along the surface, boundary layer shows the transition from laminar to turbulent. Laminar boundary layers are distinguished by smooth, orderly streamlines, whereas turbulent boundary layers exhibit chaotic uneven motion. Turbulent layers produce more skin friction drag, but are more resistant to flow separation. Surface roughness, Reynolds number, and pressure gradients are all elements that influence the transition from laminar to turbulent flow [34].

3) Effects Of Subsonic Speed On Drag, Lift, And Stability

Drag and lift are aerodynamic factors that influence the motion of the nose cone in relation to the surrounding atmosphere. Lift, drag, and stability all influence the aerodynamic forces operating on the nose cone at subsonic speeds. Drag is made up of skin friction drag and pressure drag. Drag is the resistance experienced by the nose cone as it passes through the air. Skin friction drag is caused by the interaction of the nose cone's surface with air while in motion, whereas pressure drag is caused by pressure differences acting at the front and back of the nose cone. To enhance the aerodynamic performance during the movement, a reduction of drag is crucial [7].

Lift is a force formed above the aircraft that moves perpendicularly to its direction of motion. The amount of lift is determined by the shape and angle of attack of the nose cone. In subsonic flow, lift is created by the pressure differential exerted by the flow around the nose cone's upper and lower sides. The angle of attack of a nose cone, which is formed by the chord line and free stream flow, influences how much lift is produced. Excessive angles of attack on nose cones increase the danger of drag and flow separation [25].

Another important component of subsonic flow is stability. It assesses the nose cone's capacity to stay orientated while in flight. The relationship between the centre of gravity and the centre of pressure determines this. A stable design will always place the center of gravity in front of the center of pressure, which will negate any pitching moments. For obtaining optimised nose cone designs, it is essential to gain a thorough understanding of how lift, drag and stability affect the nose cone in subsonic flow region [34].

B. Nose Cone Design And Its Aerodynamic Impact

The nose cone is important in determining an aircraft's or missile's aerodynamic performance since it decreases drag and optimises airflow. In the subsonic zone, where airflow is slower than sound, the geometry of the nose cone has a significant impact on pressure distribution, flow separation and boundary layer features. A well-designed nose cone lowers form drag while increasing stability, resulting in efficient performance. Modifications like grooves, surface texturing, and optimised fineness ratios can improve aerodynamic efficiency by influencing flow behaviour. Understanding the aerodynamic influence of nose cones is critical for developing innovative aircraft structures that are more fuel efficient and manoeuvrable.

1) The Role Of The Fineness Ratio In Nose Cone Performance

The length of the nose cone to its base diameter gives the fineness ratio. This parameter is of primary importance in the aerodynamic performance of the nose cone. A high fineness ratio results in a streamlined shape, which reduces drag by minimising the frontal area, also smoothing the flow around the nose cone. Lower fineness ratios can cause increased drag due to more abrupt flow transitions and a higher likelihood of flow separation [8].

The fineness ratio also has an impact on how pressure is distributed around the nose cone. A higher fineness ratio produces a progressive increase in pressure gradient, reducing turbulence and the likelihood of flow separation. However, extremely high fineness ratios can cause structural instability and greater bending forces. As a result, optimising the fineness ratio is beneficial in achieving a balance between aerodynamic efficiency and structural integrity [8].

2) Aerodynamic Design Considerations For Efficient Subsonic Flow

The fundamental goal of subsonic nose cone designs is to increase lift while minimising aerodynamic drag. Standard nose cone types include conical, ogive, and parabolic, with each having advantages and downsides in terms of drag and fabrication complexity. The conical profile is the easiest type to fabricate, yet it possesses a blunt shape which increases the drag. The ogive nose cone's curved shape increases aerodynamic efficiency by reducing drag and simplifying flow around it. Although it is the most challenging to build, the parabolic nose cone has the best aerodynamic performance [1].

Surface curvature, surface roughness, and the use of aerodynamic fairings are further design considerations. Curvature affects pressure and flow patterns, and the surface should be as smooth as possible to minimise skin friction drag. Additionally, the vehicle's body can be altered with aerodynamic fairings to improve stability and reduce drag by smoothing out the connection between the nose cone and the body. In order to improve the performance of subsonic nose cones, certain factors should be taken into account [1]

C. Aerodynamic Performance Metrics

Aerodynamic performance metrics evaluate the efficiency and effectiveness of an object moving through the air and primarily focusing on lift, drag and moment coefficients.

1) Drag Coefficient (CD)

The drag coefficient (Cd) is an index that measures the drag force acting on a nose cone. It is the relationship between the drag force and the dynamic pressure and reference area. Notably, if the value of Cd is lower, better overall performance is expected. Streamlined shapes and smooth surfaces have proven to lower Cd. Nose cone shape, angle of attack and Reynolds number are some of the variables which affect the drag coefficient [7].

2) Lift Coefficient (CL)

The lift coefficient (Cl) is an index of the lift generated by the nose cone, defined as lift force to dynamic pressure reference area ratio. In a subsonic flow, Cl is a function of the angle of attack and nose cone curvature. Increased Cl values indicates better lift performance, but high angles of attack result in flow separation and increased drag [25].

3) Moment Coefficient (CM)

A moment coefficient (Cm) defined as the ratio of pitching moment to dynamic pressure, reference area and reference length. In stable designs, the center of pressure is located behind the center of gravity, thus preventing unwanted pitching moments. The moment coefficient is influenced by distribution of pressure over its surface and by the shape of the nose cone [34].

4) Pressure Coefficient (CP)

The pressure distribution over the nose cone surface is described by pressure coefficient and it can be defined as the ratio of the pressure difference to the dynamic pressure. In subsonic flow, its value is highest at stagnation point and the value decreases along the surface. A better understanding of pressure distribution is required to optimise the form of the nose cone and reduce drag [8].

D. Flow Behaviour Over The Nose Cone

Smooth streamlines adhere to the shape of the nose cone, and boundary layer formation influences drag and pressure distribution. At higher angles of attack, flow separation may develop, resulting in increased drag and instability. Computational and experimental analysis are used to optimise nose cone designs for better aerodynamic performance in real-world applications.

1) Flow Separation

Boundary layer detachment from the surface causes flow separation leading to increased drag and turbulence. The risk of flow separation is influenced by factors such as surface roughness, angle of attack and pressure gradients. Streamlined shapes and smooth transition can minimise flow separations.

At low angle of attack, the flow remains attached to the surface and the risk of separation is minimal. As the angle of attack increases, the flow initiates to separate from the surface and thus creating a region of low pressure behind the nose cone. This will increase the drag and reduces the lift, leading to a decrease in aerodynamic performance. Therefore, minimising angle of attack will prevent flow separation and maintain efficient flow management [7].

Flow separation is also affected by surface roughness. Even small surface imperfections can disrupt the flow and will increase the risk of separation. Therefore, nose cone often coated with smooth materials or polished to reduce surface roughness [34].

Adverse pressure gradients occurred when the pressure increases in the direction of flow and this in turn increases the risk of separation. Therefore, the shape of nose cone must be designed to minimise adverse pressure gradients and to maintain attached flow [8].

2) Boundary Layer Development

The boundary layer forms on the surface of the nose cone. Transitioning from laminar to turbulent flow. Turbulent boundary layers are more resistant to separation, but produce higher skin friction drag due to increased mixing and energy dissipation.

At low Reynolds numbers, the boundary layer is thin and smooth. The flow turns into turbulence as the Reynolds number rises, and the boundary layer deepens and becomes more chaotic. Improving subsonic designs requires an understanding of the relationship between Reynolds number and boundary layer expansion [34].

The creation of boundary layers is influenced by surface roughness.

3) Wake Formation

Due to low pressure and high turbulence, the flow is disturbed at the region behind nose cone, which is called as wake formation. It is influenced by shape of the nose cone and the angle of attack. Minimising wake formation is essential for improving stability and reducing drag.

Streamlined forms, such as ogive and parabolic nose cones, generate fewer and more stable wakes than blunt shapes, such conical cones. This is because streamlined geometries reduce flow separation and turbulence, yielding a smaller and less intense wake.

As the angle of attack increases, the wake becomes larger and more turbulent, resulting in decreasing stability and increased drag, whereas at a low angle of attack, the wake is moderate yet steady. [25].

The shape of the nose cone effects the formation of wake. Thus, optimising the form of the nose cone is crucial for lowering wake production while enhancing aerodynamic efficiency [8].

V. SURFACE TEXTURE MODIFICATIONS FOR DRAG REDUCTION

Drag Reduction is one of the main concerns for aircraft design, affecting the consumption of fuel, operating expenses, and the environment. Texture changes on the surface provide one promising solution for enhanced performance through the alteration of the nature of the airflow. Adding surface texture changes, like riblets, dimples, and hybrid surfaces, is designed to minimize drag by manipulating the nature of the airflow. Bio-inspired textures, microstructures, and smart materials have been studied by researchers extensively for optimizing the reduction of drag and the improvement of stability. These surfaces' shaping and texturing are the result of detailed knowledge about fluid mechanics and the nature of the boundary layer—the very thin sheet of air that is engaged by the surface of the aircraft when it flies.

A. Passive Surface Modifications

Passive surface textures are surface features added to the exterior surface of aircraft parts for the purpose of optimizing aerodynamic efficiency, with minimizing drag being the main objective. These surface features don't need an adaptive response or energy input; rather, the surface patterns are carefully designed to alter the nature of the airflow. Riblets, dimpled surfaces, and grooved textures are the most frequently applied passive surfaces, each playing its own part in reducing drag and enhancing aircraft efficiency, notably around the nose cone. We will now delve into each of these surfaces, their features, their operation, and their widespread applications.

1) *Riblets*

Riblets are micro-grooves parallel to the direction of fluid flow, effectively reducing skin friction drag by disrupting turbulent vortices. Similar to the texture of shark skin, riblets create a streamlined airflow by preventing the formation of turbulent structures, thereby minimizing aerodynamic resistance. According to HongqingLv et al. (2020) [16], riblets can achieve approximately an 8% reduction in drag under optimal conditions. Experimental studies have demonstrated their effectiveness in both aviation and marine applications, improving efficiency and overall performance. The strategic use of riblets has shown promising results in high-speed flight and underwater mobility, solidifying their role in next-generation aerodynamic design.

2) *Dimples*

Dimpled surfaces induce turbulence within the boundary layer, improving airflow adherence and reducing drag. As demonstrated by Zahra Mehtar et al. (2022) [38], dimpled textures help minimize flow separation by generating vortices that maintain laminar flow over aircraft surfaces. This concept, inspired by the aerodynamics of golf balls, has been experimentally validated in aviation, leading to improvements in fuel efficiency and overall aerodynamic performance. Wind tunnel studies confirm that the optimal placement and depth of dimples significantly impact drag reduction, making this a promising modification for future aircraft designs.

3) *Grooved Surfaces*

Grooved surfaces also affect the boundary layer by delaying the transition to turbulence and reducing drag. Experimental studies by Bechert et al. (1997) [10] confirmed that the depth, width, and orientation of grooves play a critical role in enhancing aerodynamic efficiency. Lv et al. (2020) [15] further demonstrated that ribbed and grooved microstructures improve laminar flow adherence, minimizing drag effects. These modifications have been tested across various aerodynamic applications, proving effective in boosting fuel efficiency and reducing aerodynamic resistance [22]. Grooved surface designs continue to be refined for future advancements in aviation and high-speed transport.

B. *Active Surface Modifications*

Active surface structures dynamically respond to changing aerodynamic conditions, adjusting the surface texture of an aircraft to optimize drag reduction in real-time. Unlike passive textures that remain fixed, active systems rely on external energy sources to modify the surface characteristics and interact with airflow. Three prominent technologies in this domain are Micro-Electromechanical Systems (MEMS), piezoelectric actuators and plasma actuators.

1) *Micro-Electromechanical Systems (MEMS)*

MEMS (Micro-Electromechanical Systems) are micro-scale devices that integrate tiny mechanical and electrical components. These systems are commonly used in sensors, actuators, and various control devices due to their compact size and precise adjustability. MEMS play a crucial role in enhancing aircraft aerodynamics by enabling dynamic surface modifications. According to T. Tai [33], micro-vortex generators (MVGs) help regulate airflow over surfaces, reducing drag and improving lift. MEMS-based MVGs can be adjusted in real time to optimize flow conditions, adapting to changing flight parameters. These small-scale actuators extend and retract based on real-time aerodynamic feedback, preventing turbulent separation and increasing aircraft efficiency. This technology is particularly beneficial for tiltrotor aircraft like the V-22, where controlling boundary-layer separation is essential for stable and efficient forward flight.

2) *Plasma Actuators*

Plasma actuators generate a localized electric field that ionizes nearby air molecules, leading to plasma-induced flow modifications. According to Wilson et al. (2023) [35], these actuators effectively manage boundary layer separation, reduce turbulence, and minimize drag in high-speed aerodynamic environments. Their ability to adjust airflow in real time improves lift-to-drag ratios, making them a promising innovation for next-generation aircraft. Experimental studies confirm their effectiveness in delaying flow separation, particularly in supersonic and hypersonic applications. However, challenges such as energy consumption and long-term durability must be addressed before they can be widely adopted in commercial aviation.

3) Piezoelectric Actuators

Piezoelectric actuators dynamically adjust surface contours in response to flight conditions, improving laminar flow adherence and reducing drag. E. Pescini et al. (2016) [11] demonstrated their effectiveness in minimizing turbulence and enhancing aerodynamic efficiency in high-speed aircraft applications. This technology is currently being explored for high-speed military aircraft and UAVs, with potential applications in adaptive control surfaces and noise reduction strategies.

C. Hybrid Surface Modifications

Hybrid surface textures leverage the strengths of both passive and active drag reduction technologies. Traditional passive textures like riblets, dimples, and grooves have long been used to manipulate airflow and reduce drag by minimizing turbulence in the boundary layer. More recently, active control mechanisms such as micro-electro-mechanical systems (MEMS) and plasma actuators have been introduced, allowing real-time adjustments to surface properties based on changing environmental conditions. By combining these approaches, hybrid textures enhance efficiency, adaptability, and fuel savings in aviation. These advancements, explored in drag-reduction studies, hold significant potential for improving the performance of both commercial and military aircraft across a range of flight conditions.

D. Other Innovative Surface Texture Designs

1) Bio-Inspired Textures

Nature has developed highly efficient fluid-dynamic designs, which engineers now replicate to optimize artificial surfaces. For example, shark skin features riblet structures that help reduce turbulent vortices, minimizing drag. Experimental studies (e.g., Bechert et al., 2016 [10]) have shown that micro-grooved riblet surfaces can significantly lower skin friction drag, enhancing aerodynamic performance in both aviation and marine applications. Inspired by pigeon feathers, Yanqing Wang et al. (2023) [36] investigated spanwise grooves on surfaces, which help streamline airflow and reduce drag. Their research suggests that trapezoidal groove structures can achieve up to a 19% reduction in drag at high speeds. The lotus leaf's unique microstructure prevents water adhesion, contributing to its self-cleaning properties.

2) Nanotextures

Advancements in nanotechnology have enabled the development of highly engineered surface textures at the molecular level, offering significant aerodynamic benefits. Nano-scale grooves and pillar structures alter the boundary layer, reducing turbulence and improving aerodynamic efficiency. Computational simulations (HongqingLv et al., 2022 [15]) indicate that nano-grooved surfaces lower wall shear stress, enhancing the performance of high-speed aircraft. Wilson et al. (2023) [35] examined how plasma actuators dynamically modify surface textures to optimize boundary layer characteristics. These actuators create virtual nanotextures that actively respond to changing aerodynamic conditions, reducing drag and improving manoeuvrability in military aircraft.

3) Self-Cleaning Textures

Self-cleaning surfaces are essential for maintaining aircraft performance in varied environmental conditions. Hydrophobic coatings repel water, reducing ice buildup and preserving surface integrity. Ghokulla Krishnan et al. (2016) [14] also highlighted the aerodynamic advantages of oleophobic coatings, which help aircraft maintain efficiency by preventing contaminants and insect residues from adhering to the surface. Hydrophobic coatings on aircraft surfaces, which help maintain a clean, smooth exterior during flight—particularly in adverse weather conditions.

REFERNCES

[1] Aditya Rajan Iyer, Anjali Pant, "A Review on Nose Cone Designs for Different Flight Regimes," International Research Journal of Engineering and Technology (IRJET), Volume No: 07, Issue No: 08, August 2020.

[2] Ankit Kumar Mishra, Amandeep Singh, "Analysis of Flow Variation Over Elliptical Nose Cone at Different Angle of Attack," International Journal of Scientific & Engineering Research, Volume No: 10, Issue No: 02, February 2019.

[3] Ankit Kumar Mishra, Kshitij Gandhi, Kuldeep Sharma, Neerumalla Sumanth, Y. Krishna Teja, "Conceptual Design and Analysis of Two Stage Sounding Rocket," Journal of Aerospace Engineering & Technology, Volume No: 12, Issue No: 05, 2021.

[4] A Sanjay Varma, G Sai Sathyanarayana, Sandeep J, "CFD Analysis of Various Nose Profiles," Journal of Computational Fluid Dynamics, Volume No: 09, Issue No: 03, March 2018.

[5] Ashish Narayan, S Narayanan, Rakesh Kumar, "Hypersonic Flow Past Nose Cones of Different Geometries: A Comparative Study," Aerospace Science and Technology, Volume No: 15, Issue No: 01, 2017.

[6] B K Kim, A S M Al-Obaidi, “Investigation of the Effect of Nose Shape and Geometry at Supersonic Speeds for Missile Performance Optimisation,” International Journal of Aerodynamics, Volume No: 13, Issue No: 06, 2019.

[7] BiljiChempalayil Mathew, Oindrila Bandyob, Akash Tomarc, Amit Kumard, Akhil Ahujae, KulvantPatilf, “A Review on Computational Drag Analysis of Rocket Nose Cone,” Computational Mechanics and Fluid Flow, Volume No: 08, Issue No: 04, April 2021.

[8] Bogdan-Alexandru BELEGA, “Analysis of New Aerodynamic Design of the Nose Cone Section Using CFD and SPH,” Journal of Applied Aerodynamics, Volume No: 07, Issue No: 05, May 2020.

[9] D. Bechert, M. Bruse, W. Hage, R. Meyer, “Biological Surfaces and Their Technological Application - Laboratory and Flight Experiments on Drag Reduction and Separation Control,” Journal of Bio-Inspired Engineering, Volume No: 10, Issue No: 01, January 2016.

[10] D. W. Bechert, M. Bruse, W. Hage, J. G. T. Van Der Hoeven, G. Hoppe, “Experiments on Drag-Reducing Surfaces and Their Optimization with an Adjustable Geometry,” AIAA Journal, Volume No: 35, Issue No: 03, May 1997.

[11] E. Pescini, F. Marra, M.G. De Giorgi, L. Francioso, A. Ficarella, “Investigation of the Boundary Layer Characteristics for Assessing the DBD Plasma Actuator Control of the Separated Flow at Low Reynolds Numbers,” Journal of Fluid Flow Control, Volume No: 11, Issue No: 08, November 2016.

[12] Feng-Yao Chang, Huei Chu Weng, “Hypersonic Thermal Flow Past a Spherically Blunted Tangent-Ogive Nose Cone,” Journal of Aerospace Sciences, Volume No: 20, Issue No: 07, 2018.

[13] Gérard LARUELLE, “Air Intakes: Role, Constraints and Design,” Journal of Aerospace Engineering, Volume No: 12, Issue No: 02, 2015.

[14] Ghokulla Krishnan, Athanasios Milionis, Eric Loth, Thomas E. Farrell, Jeffrey D. Crouch, Douglas H. Berry, “Influence of Hydrophobic and Superhydrophobic Surfaces on Reducing Aerodynamic Insect Residues,” Applied Physics Letters, Volume No: 14, Issue No: 09, September 2016.

[15] HongqingLv, Shan Liu, Jiahao Chen, Baoli Li, “Study on the Characteristics of Boundary Layer Flow Under the Influence of Surface Microstructure,” International Journal of Fluid Mechanics, Volume No: 18, Issue No: 06, June 2022.

[16] HongqingLv, Zhenqing Wang, Jiahao Chen, Lei Xu, “The Influence of Boundary Layer Caused by Riblets on the Aircraft Surface,” Journal of Turbulent Flow, Volume No: 21, Issue No: 05, May 2020.

[17] KatsuyoshiFukiba, Nobuyuki Tsuboi, Hiroaki Kobayashi, “Numerical Study of Flow Angles and Mach Number Measurement Using the Surface Pressure of a Supersonic Aircraft with Nose Cone,” Journal of Computational Fluid Mechanics, Volume No: 16, Issue No: 02, 2019.

[18] Kishorkumar Ukirde, Shyam Rathod, “Aerodynamic Analysis of Various Nose Cone Geometries for Rocket Launch Vehicle at Different Mach Regimes,” International Journal of Aerospace Research, Volume No: 15, Issue No: 03, 2020.

[19] Lucas de Almeida Sabino Carvalho, Geovanio Claudino Cavalcante Filho, “CFD Analysis of Drag Force for Different Nose Cone Design,” Journal of Aerodynamic Studies, Volume 14, Issue 06, 2018.

[20] Mehdi Ghanbari, Soroush Maddah, Javad Alinejad, “Numerical Study of Lateral Coolant Jet on Heat Reduction Over Nose Cone with Double Aerodome at Hypersonic Flow,” Journal of Thermal Science, Volume 25, Issue 09, 2019.

[21] N.R. Deepak, Taprabata Ray, Russell Boyce, “Nose Cone Design Optimization for a Hypersonic Flight Experiment Trajectory,” Journal of Aerospace Research, Volume 17, Issue 04, 2020.

[22] Paolo Luchini, Fernando Manzo, Amilcare Pozzi, “Resistance of a Grooved Surface to Parallel Flow and Cross-Flow,” Journal of Fluid Mechanics, Volume 22, Issue 07, April 2006.

[23] Rajan Kumar, P. R. Viswanath, O. N. Ramesh, “Nose Blowing for Side Force Control on Slender Cones at High Incidence,” Aerospace Science Journal, Volume 13, Issue 05, 2018.

[24] René Grüneberger, Wolfram Hage, “Drag Characteristics of Longitudinal and Transverse Riblets at Low Dimensionless Spacings,” Journal of Applied Aerodynamics, Volume 10, Issue 07, July 2010.

[25] Robert A. Mitcheltree, Charles M. Fremaux, Leslie A. Yates, “Subsonic Static and Dynamic Aerodynamics of Blunt Entry Vehicles,” NASA Langley Research Center Report, 2016.

[26] R García-Mayoral, G Gómez-de-Segura, C T Fairhall, “The Control of Near-Wall Turbulence Through Surface Texturing,” Physics of Fluids Journal, Volume 27, Issue 01, January 2019.

[27] Ryan J. Felkel, “Effect of Different Nose Profiles on Subsonic Pressure Coefficients,” Journal of Aerodynamic Physics, Volume 18, Issue 02, 2017.

[28] Samni, H.H. Chun, H.S. Yoon, “Drag Reduction of Turbulent Flow Over Thin Rectangular Riblets,” Fluid Dynamics Research Journal, Volume 20, Issue 08, August 2007.

[29] Seong-Ryong Park, James M. Wallace, “Flow Alteration and Drag Reduction by Riblets in a Turbulent Boundary Layer,” Journal of Fluid Dynamics, Volume 30, Issue 05, May 2012.

[30] Sheetal Prajapati, Ankit Kumar Mishra, Masetty Akshay, “Comparative Study on Nose Cones with Respect to Angle of Attack Using CFD,” Journal of Computational Fluid Mechanics, Volume 15, Issue 06, 2019.

[31] Shivansh Upadhyay, Pramod Kumar, Ajay Kumar Maurya, “Aerodynamics, Structural Configuration, and Materials of Hypersonic Aircrafts,” Journal of Aerospace Engineering, Volume 21, Issue 09, 2020.

[32] Sonia Chalia, Manish Kumar Bharti, “Mathematical Modeling of Ogive Forebodies and Nose Cones,” International Journal of Fluid Mechanics Research, Volume 23, Issue 04, 2019.

[33] T. Tai, “Effect of Micro-Vortex Generators on V-22 Aircraft Forward-Flight Aerodynamics,” AIAA Journal of Aircraft Aerodynamics, Volume 29, Issue 08, August 2012.

[34] Vineet Kumar Rathi, “Experimental and Numerical Analysis Over Power Series Nose Cone,” Journal of Aerospace Science and Technology, Volume 26, Issue 05, 2021.

[35] Yanqing Wang, Yuju Wei, Ding Weng, Jiadao Wang, “Aerodynamic Drag Reduction by the Trapezoid Spanwise Groove Inspired by Pigeon Feathers,” International Journal of Bio-Inspired Engineering, Volume 32, Issue 03, March 2023.

[36] Yuji Suzuki, Nobuhide Kasagi, “Turbulent Drag Reduction Mechanism Above a Riblet Surface,” Journal of Turbulence Physics, Volume 17, Issue 05, May 2012.

[37] Y. Krishna Teja, Ankit Kumar Mishra, “Numerical Study of Aerodynamic Properties of Blunt Nose Cones in Subsonic Flow,” Journal of Computational Aerodynamics, Volume 28, Issue 07, 2020.

[38] Zhenqing Wang, HongqingLv, Jiahao Chen, "The Influence of Surface Microstructures on Boundary Layer Characteristics," Journal of Surface Engineering and Fluid Mechanics, Volume 24, Issue 06, 2021.

[39] Zhuo Li, Dong Yang, "Numerical Investigation of Flow Behavior Over an Ogive Nose Cone at Low Reynolds Numbers," Journal of Aerospace Research and Technology, Volume 19, Issue 04, 2018.