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Drag on Conical and Ogive Missile Nose Cones for Various Speed Regimes

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A B S T R A C T

Drag force significantly affects the efficiency and aerodynamic performance of missiles. The shock wave generated ahead of the nose cone is the primary source of wave drag, which substantially influences the overall drag. This study focuses on the drag coefficient of conical and ogive nose cones across various speed regimes. The method employed is a narrative literature review, synthesizing findings from relevant scientific sources. Based on the literature synthesis, it was found that the ogive shape generally outperforms the conical shape in subsonic and transonic regimes due to its smoother geometric profile. In the supersonic regime, however, the relative performance between the conical and ogive shapes is not absolute but is highly dependent on the fineness ratio and other geometric parameters. A conical shape with a high fineness ratio can significantly reduce wave drag, while under certain geometric conditions, the ogive still exhibits a lower drag coefficient. Consequently, the selection of a nose cone shape must simultaneously consider the operational speed regime and the fineness ratio to achieve optimal aerodynamic efficiency

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INTRODUCTION

Missiles moving through the atmosphere are subjected to various forces that can decelerate their motion. The force causing this deceleration is the drag force (Balaji et al., 2022). One of the most critical components influencing drag is the nose cone, as it is the first part to interact with the airflow and determines the characteristics of the shock wave formed around it. The shock wave induces a sudden increase in air pressure and density, directly impacting wave drag (Anderson, 2006).

Among the various types of nose cones, the conical and ogive shapes are frequently studied to represent sharp-tapered and smooth-curved profiles, respectively. The conical nose cone has a linear profile with a constant cone angle, offering geometric simplicity and ease of fabrication. In contrast, the ogive nose cone features a smooth curved profile (circular arc) that gradually blends into the vehicle body, designed to reduce shock wave intensity and aerodynamic drag. These geometric differences produce distinct shock wave characteristics: the conical shape tends to generate a detached shock wave with higher intensity, whereas the ogive shape produces a weaker attached shock wave. This distinction directly affects the drag coefficient of each configuration.

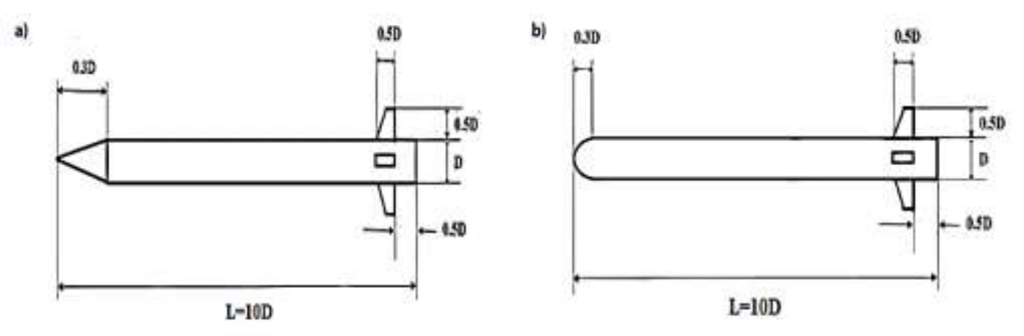

Figure 1 Dimensi Rudal dengan nose cone: a) conical dan b) ogive
Source: (Goucem & Khiri, 2024)

In addition to the geometric shape, the fineness ratio (length-to-diameter ratio) significantly influences the drag coefficient, particularly at supersonic speeds. Iyer & Pant (2020) stated that increasing the fineness ratio reduces the effective cone angle, thereby weakening the shock wave and decreasing wave drag. However, a higher fineness ratio also increases the wetted surface area, leading to higher skin friction drag. Consequently, there is a trade-off between reduced wave drag and increased skin friction drag at high fineness ratios.

Previous studies have compared the aerodynamic performance of conical and ogive nose cones under various flow conditions, yet their results show considerable variation. Using ANSYS FLUENT, Kumar (2020) concluded that the tangent ogive nose cone has a lower drag coefficient than the conical nose cone, indicating superior aerodynamic efficiency. Kim & Al-Obaidi (2023) emphasized that performance is strongly influenced by the fineness ratio, where an increase in this ratio significantly reduces wave drag, while a blunt shape creates substantial additional drag due to the formation of a detached shock or bow shock. These studies demonstrate that the relative performance of conical and ogive shapes is not absolute but depends heavily on operational conditions such as speed regime, fineness ratio, and angle of attack. This study aims to identify how shock wave characteristics influence the drag coefficient of each shape and to compare the drag coefficients of conical and ogive nose cones across various speed regimes.

LITERATURE REVIEW

Shock Wave Characteristics

Shock waves form on a nose cone when supersonic flow experiences sudden deceleration ahead of the vehicle's nose. The shock wave pattern is highly influenced by the nose cone geometry, particularly the cone angle or surface curvature. The relationship between the cone angle, Mach number, and shock wave angle is described by the Taylor-Maccoll theory for axisymmetric flow (Anderson, 2006 ; Perkins & Jorgensen, 1952). Two primary types of shock waves form ahead of the nose cone. A detached shock wave occurs when the cone angle is too large for the flow to abruptly turn and follow the surface. This shock forms a bow shock with a subsonic zone behind it, increasing stagnation pressure and wave drag. Conversely, an attached shock wave, or oblique shock, forms when the cone angle is sufficiently small, allowing the flow to turn gradually. This shock produces a more isentropic compression with lower stagnation pressure, resulting in reduced wave drag (Anderson, 2006).

For a conical nose cone with a large cone angle, the supersonic flow cannot turn abruptly to follow the surface, resulting in a high-intensity detached shock wave (Perkins & Jorgensen, 1952). Research by Nath et al., (2024) indicates that the conical configuration generates a very high shock wave–boundary layer interaction (SWBLI), leading to backflow, shock wave oscillation, and the formation of an unstable lambda-shock system. In contrast, the ogive nose cone, with its smooth curve, allows the flow to turn gradually, producing an attached oblique shock wave of lower intensity. Replacing the conical shape with an ogive has been shown to significantly reduce SWBLI, suppress shock wave oscillations, and transform the unsteady backflow into a steady flow (Nath et al., 2024). These differences in shock wave characteristics directly affect the drag coefficient of each shape (Goucem & Khiri, 2024).

The Effect of Speed Regimes on Drag Coefficient

The selection of a nose cone plays a crucial role in enhancing missile performance by minimizing drag. Iyer & Pant (2020) explain that nose cone performance is strongly dependent on the speed regime and fineness ratio, as each drag component dominates in different regimes. The total drag coefficient (C_D) consists of three main components: wave drag (C_{DW}) which is dominant at supersonic speeds and results from shock waves; skin friction drag (C_{Dsf}), which arises from viscosity and increases with the wetted surface area as the fineness ratio rises; and base drag (C_{DB}) which results from pressure at the base and is independent of nose shape (Kim & Al-Obaidi, 2023 ; Iyer & Pant, 2020). Wave drag is directly influenced by the shock wave; the stronger the shock wave, the greater the resulting wave drag.

In the subsonic regime (M<0.8), nose pressure drag approaches zero, making skin friction the dominant component. In this regime, a smooth and streamlined nose profile is advantageous as it reduces turbulence and skin friction. Balaji et al., (2022) found that a more streamlined nose cone geometry provides better aerodynamic characteristics. Elliptic and ogive shapes are the preferred choices in this regime due to their smooth profiles, which reduce surface friction.

In the transonic regime (0.8<M< 1.2), a critical phenomenon occurs involving the formation of local shock waves around the nose cone, leading to a significant surge in wave drag, known as transonic drag rise. This phenomenon arises because the flow transitions from subsonic to supersonic at certain points on the nose cone surface, accompanied by the formation of a normal shock wave. Iyer & Pant (2020) explain that in this regime, wave drag increases dramatically, making the appropriate selection of a nose cone critically important. Research by Alekhya & Manthena (2018) indicates that the Von Karman shape is the best choice in the transonic regime because it minimizes vortex strength and wave drag, although ogive and parabolic shapes are also viable options. G. Kumar & Honguntikar (2015) analyzed pressure, velocity, and other parameters on three nose cone models (Sharp, Ogive, and Blunt) for transonic flow at Mach 1 using ANSYS FLUENT. Based on a comparison of (C_D) and drag force, the ogive shape proved to be the most ideal due to its lower drag compared to the sharp and blunt shapes.

In the supersonic regime (M>1.2), the selection of a nose cone involves a compromise among the various drag components. Increasing the fineness ratio reduces wave drag, as a more slender geometry remains within the Mach cone with minimal airflow disturbance, but it also increases skin friction drag due to the larger wetted surface area (Iyer & Pant, 2020 ; Chang et al., 2023). (However, overall, the total drag does not change significantly as long as the increase in fineness ratio remains within certain limits (Iyer & Pant, 2020).

METHODS

This study constitutes a narrative literature review. Literature searches were conducted in the Google Scholar, ScienceDirect, and NASA NTRS databases using the following keywords: "drag coefficient" OR "coefficient of drag" AND "nose cone" AND ("conical" OR "ogive") AND "supersonic." The publication period targeted was the last ten years (2016–2026), with several fundamental classical sources also included. The selected articles were those that discussed the drag coefficient of conical or ogive nose cones, presented quantitative data, and were published in reputable journals or institutional sources.

RESULTS

Drag Coefficient

Alekhya & Manthena (2018) analyzed nose drag across the Mach number range of 0.4 to 3.0 at a zero angle of attack (α = 0°). As shown in Table 1, the ogive shape exhibits a lower drag coefficient at Mach 0.4–1.2 (subsonic to transonic), while the sharp increase in (C_D) at Mach 1.2 indicates the transonic effect caused by shock wave formation, which drastically increases wave drag. At Mach 2.0 and 3.0 (supersonic), the conical shape exhibits a significant reduction in drag coefficient due to its geometric slenderness.

Table 1. Drag Coefficients of Conical and Ogive Nose Cones

Mach	Conical (C_D)	Ogive (C_D)
0.4	0.267	0.208
0.8	0.302	0.224
1.2	0.428	0.406
2.0	0.303	0.312
3.0	0.209	0.225

Source: (Alekhya & Manthena, 2018)

Goucem & Khiri (2024) analyzed the drag coefficient over the supersonic range (Mach 1.5–5.0) at a zero angle of attack (α = 0°). The ogive consistently exhibited a lower drag coefficient than the conical shape, with (C_D) decreasing as the Mach number increased for both geometries. The variation in (C_D) is presented in Table 2, for which the data are predictive values interpreted from Figure 2.

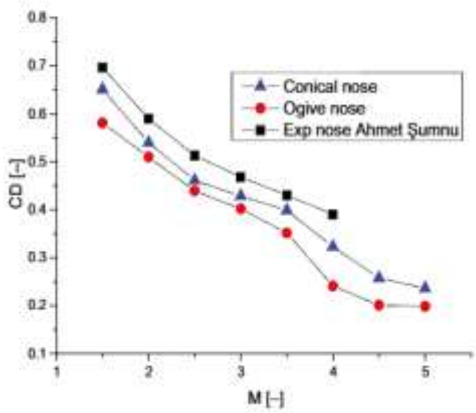

Figure 2. Curves of the Drag Coefficient Changing with Mach Number for an Angle of Attack Of 0°
Source: (Goucem & Khiri, 2024)

Table 2. Mach Number (M) Vs. Drag Coefficient (C_D)

Mach (M)	Conical (C_D)	Ogive (C_D)
1.5	~0.65	~0.58
2.0	~0.54	~0.51
2.5	~0.46	~0.44
3.0	~0.43	~0.40
3.5	~0.40	~0.35
4.0	~0.32	~0.24
4.5	~0.26	~0.20
5.0	~0.24	~0.20

Note: The data in Table 2 are estimated values obtained from Figure 2.

DISCUSSION

Drag Coefficient across Various Regimes

The comparison of drag coefficients between the conical and ogive shapes across different speed regimes reveals a clear trend. In the subsonic regime ($M < 0.8$), the ogive exhibits a lower (C_D) due to its smooth profile, which reduces turbulence and skin friction. In the transonic regime ($0.8 < M < 1.2$), a wave drag surge occurs for both shapes; however, the ogive remains superior because its smooth curve produces a weaker shock wave. In the supersonic regime, the findings from the literature show considerable variation, highly dependent on geometric parameters. Goucem & Khiri (2024) and Şumnu et al., (2020) reported that the ogive produces a lower drag coefficient in the Mach 1.5 to 5.0 range. Alekhya & Manthena (2018), however, found that the conical shape has a lower drag coefficient than the ogive at Mach 2.0 and 3.0. This discrepancy indicates that the fineness ratio and the specific details of each geometric profile play a crucial role in determining aerodynamic performance at supersonic speeds.

The results from the primary sources show diverse patterns, aligning with (P. K. Kumar, 2020) in that the ogive excels under certain conditions, while also being consistent with the findings of Kim & Al-Obaidi (2023) that the fineness ratio strongly influences performance, especially at supersonic velocities. The differing outcomes are not indicative of contradictions but rather reflect the inherent complexity of aerodynamics, which is highly sensitive to speed regime and geometric parameters.

Transonic Drag Rise

The transonic drag rise phenomenon represents a critical point in comparing the performance of conical and ogive shapes. In the transonic regime (Mach 0.8–1.2), the surge in drag coefficient occurs due to the formation of a normal shock wave around the nose cone, where the local flow reaches supersonic speeds even though the vehicle's overall velocity remains below Mach 1 (Stoney, 1957 ; Liu et al., 2024). Eghlima & Mansour (2016) investigated the shock wave standoff distance in front of various nose shapes at transonic speeds (Mach 1.01–1.2) and found that the shock wave characteristics in this regime are highly sensitive to nose cone geometry. Liu et al., (2024) added that in the transonic regime, shock waves are typically unstable and prone to oscillation, leading to severe flow conditions around the cylinder and contributing to a significant drag surge.

The difference in the magnitude of the drag surge between the conical and ogive shapes in the transonic regime is attributed to their differing geometric profiles. Nath et al., (2024) directly compared the two shapes at transonic speeds (Mach ~0.94) and found that the sharp cone angle of the conical shape generates a stronger shock wave, resulting in a more significant drag surge. Replacing the conical shape with an ogive significantly reduces the shock wave-boundary layer interaction (SWBLI), shock wave oscillation, and pressure fluctuations. The ogive's smooth curve facilitates a more gradual flow transition, producing a weaker shock wave and a lower drag surge (Partington & Baker, 1982). The implications of this phenomenon for missile design are substantial: in the transonic regime, the correct choice of nose cone is critical because the drag surge can significantly reduce aerodynamic efficiency. The ogive, with its lower drag surge, becomes the preferred choice for applications operating in the transonic speed range.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Based on the literature review comparing the drag coefficients of conical and ogive nose cones across various speed regimes, the following conclusions can be drawn:

1. Shock waves directly influence the drag coefficient through the wave drag component (C_DW). The stronger the shock wave, the greater the resulting wave drag.
2. In general, the ogive shape exhibits a lower drag coefficient in the subsonic and transonic regimes, as well as in some supersonic studies, owing to its smooth profile. However, under specific conditions-for example, at a high fineness ratio-the conical shape can achieve a lower (C_D) at supersonic speeds.

Recommendations

Optimization of the fineness ratio is necessary to achieve the minimum drag for each nose cone variation, given the trade-off between reducing wave drag and increasing skin friction drag.

FURTHER STUDY

1. Conduct experimental studies under standardized test conditions (Mach number, fineness ratio, angle of attack).
2. Develop empirical correlations for the drag coefficient of conical and ogive shapes over the hypersonic Mach range with varying fineness ratios.

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