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Abstract

An investigation has been made to predict the effects of forebody and afterbody shapes on the aerodynamic characteristics of several projectile bodies at supersonic speeds using analytical methods combined with semi-empirical design curves. The considered projectile bodies had a length-to-diameter ratio of 6.67 and included three variations of forebody shape and three variations of afterbody shape. The results, which are verified by comparison with available experimental data, indicated that the lowest drag was achieved with a cone-cylinder at the considered Mach number range. It is also shown that the drag can be reduced by boattailing the afterbody. The centre-of-pressure assumed a slightly rearward location for the ogive-cylinder configuration when compared to the configuration with boattailed afterbody where it was the most forward. With the exception of the boattailed afterbody, all the bodies indicated inherent static stability above Mach number 2 for a centre-of-gravity location at about 40% from the body nose.

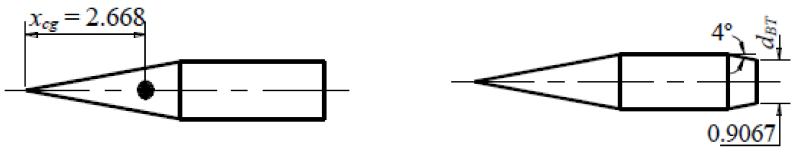
Keywords: Aerodynamics, Forebody and afterbody, Next keyword, Projectile, Supersonic speed.

1. Introduction

The shape of a projectile is generally selected on the basis of combined aerodynamic, guidance, and structural considerations. The choice of seeker, at supersonic speeds, careful selection of the nose and tail shapes is mandatory to ensure performance and operation of the over-all system.

Al-Atabi [2] showed an example how to cite a journal article in press. This is a case of one author only. The objectives of this paper is to show how you prepare and format your paper following JESTEC template.

For this purpose, below is how to five widely used projectile shapes are investigated. The geometry and full dimensions of these projectile shapes are shown body station. The supersonic Mach number range considered is from 1.6 to 5 for zero-angle of attack.



(a) Pointed-cone cylinder. **(b) Cone cylinder boat-tail (4°).**

Fig. 1. Investigated shapes of projectiles (Geometry and dimensions).

2. Prediction of Aerodynamic Coefficients

Analytical methods and design charts used for the prediction of zero-lift drag normal-force-curve slope while the design charts are produced from semi-empirical characteristics are adapted from Refs. [3, 4] and converted to numerical data, as outlined in *Appendix A*.

2.1. Zero-lift drag coefficient C_{D0}

The total zero-lift drag coefficient of the body is usually considered to be of three components; friction drag, wave drag, and base drag as shown in Eq. (1). These different components are further discussed in the following sub-sections.

$$C_{D_0} = C_{D_{fr}} + C_{D_w} + C_{D_b} \tag{1}$$

2.1.1. Friction drag coefficient

For fully-turbulent and compressible flow, the friction coefficient is given by Eq. (2) [5, 6]

$$C_{D_{fr}} = \frac{0.455()^{-2.58}}{(1+0.21M^2)^{0.467}} \frac{S_{wet}}{S_{ref}} \tag{2}$$

2.1.2. Wave drag coefficient

The main contribution to the wave drag arises from nose and afterbody. The magnitude of the wave drag depends primarily on the Mach number, the shape

and dimensions of the nose or afterbody [7-10]. Therefore, the total wave drag of the body is simply the summation of the nose and afterbody wave drags

The wave drag of pointed cone-cylinder $(C_{Dw})_{cone}$ and pointed ogive-cylinder $(C_{Dw})_{ogive}$ can be obtained from Figs. A-1 and A-2 (*Appendix A*) as a function of nose fineness ratio λ_N, and Mach number. For blunted cone-cylinder the wave drag bluntness D_0 using Eq. (4) [4]

2.2. **Normal-force-curve slope $C_{N\alpha}$**

The total normal-force-curve slope of nose-cylinder-boattail body is determined by the summation of the normal-force-curve slopes of the nose (with the effect of cylindrical part) and afterbody.

$$C_{N_a} = \left(C_{N_a}\right)_N + \left(C_{N_a}\right)_{BT} \tag{7}$$

where $(C_{N\alpha})_{cone}$ is the normal-force-curve slope of pointed cone with$\beta/\lambda_N^{'}$ and

2.3. **Location of the centre-of-pressure x_{cp}**

The identification of the location of the centre of pressure of a projectile body is motivated by the need for calculating aerodynamic moments, stability and structural analyses. The centre-of-pressure location of bodies composed of conical noses and cylindrical afterbodies is determined as follows [5]

3. Computer Programme: Validation and Verification

To ensure the validity and accuracy of the calculations, the results are compared to typical projectile configurations (as shown in Figs. 2 and 3) are selected for this purpose. The specifications of the models and test conditions are shown in Table 1.

Table 1. Test model Specifications and test conditions.

	Model No. 1 [2]	**Model No. 2 [7]**
Configuration Type	Cone-cylinder	Ogive-cylinder
Body fineness ratio	13	12.2
Nose fineness ratio	3	7.5
Body Diameter, *d* (inches)	1	6
Reference length, L_{ref}	*d*	*d*
Testing angle of attack (deg.)	0 – 6	0

Figures 2 and 3 show the comparison between the current results and the wind tunnel experimental data. Figure 2 shows that at low angles of attack the normal force coefficients are in excellent agreement with the experimental data. This is to be expected due to the assumption of small angle of attack. The figure also shows that the current results are closer (average percentage error less than 0.5%) to the experimental data than those predicted analytically (average percentage error

about 6%) by Shahbahang and Rao [2]. This is expected as the analytical methods .

A comparison of base drag coefficient as a function of Mach number is shown in Fig. 3. The comparison shows that at low supersonic Mach numbers the average percentage error is 12%, while at higher Mach number the accuracy is excellent (error less than 2%). At low supersonic Mach numbers the base drag contribution drag contribution is the largest [8]. However the obtained accuracy is still within design of projectiles and missiles [9].

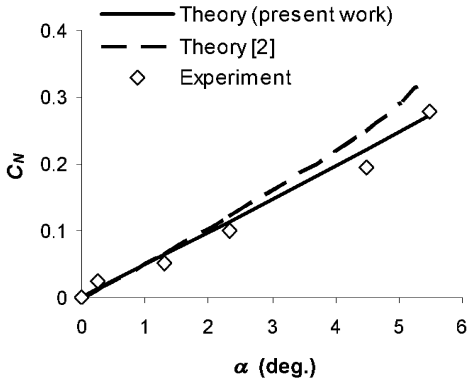


Fig. 2. Variation of normal force vs. angle of attack at M = 1.77.

4. Results and Discussion

The prediction of the aerodynamic coefficients of the investigated projectiles shown in Fig. 1 was carried using the methods and the computer programme described above. The effects of forebody and afterbody shapes on the aerodynamics at supersonic speeds are analysed in this paper.

4.1. Effect of forebody

Figure 4(a) shows the effect of nose shape on C_{D0} with cylindrical afterbody as a function of Mach number. The drag of cone-cylinder combination was the lowest at the considered Mach numbers. It is clear that the bluntness of nose causes the drag to increase.

For conical, ogival, and blunted cone forebody shapes, an inherent static stability occurs for a centre-of-gravity location of about 40% body length at Mach number above around 1.6, 1.8 and 2 respectively. Such a centre-of-gravity location may not be difficult to achieve with a projectile [10].

4.2. Effect of afterbody

For the projectile configuration comprising conical forebody and boattail, the effect of boattail shape on the drag is shown in Fig. 5(a) as a function of Mach number. For that the higher the angle of boattail the lower is the drag.

5. Conclusions

An investigation has been made of the effects of forebody and afterbody shapes of a curves. Some concluding observations from the investigation are given below.

- A pointed cone-cylinder produced the lowest drag at the considered Mach number range, and the highest drag was produced by the blunted cone-cylinder.
- Configurations with boattail have higher wave drag but appreciably lower base drag with a resultant decrease of total drag. The decrease of the boattail angle increases the base drag but reduced the projectile wave drag with a resultant decrease of the total drag.

Nomenclatures

C_{BT}	Boattail factor
d	Body diameter, m
x_{cp}	Centre-of-pressure location measured from the nose apex, m

Greek Symbols

α	Angle of attack, deg.
β	Mach number parameter, $\sqrt{M^2 - 1}$
θ	Semi-vertex angle of the conical nose (Fig. 1), deg.

Abbreviations

ISA	International Standard Atmosphere
JESTEC	Journal of Engineering Science and Technology
NACA	National Advisory Committee for Aeronautics
WHO	World Health Organization

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Appendix A

Computer Programme

A. 1. Introduction

A computer code, for the prediction of projectile aerodynamic characteristics as a empirical methods presented in section 2.

The computer programme can serve two main purposes: firstly, in the design provide a complete picture of the projectile over its whole flight.

A. 2. Programme Structure and Description of Subroutines

Fortran-77 language is used in programming the prediction methods. Each estimation convenience. The main flow chart of the programme is shown in Fig. A-1.

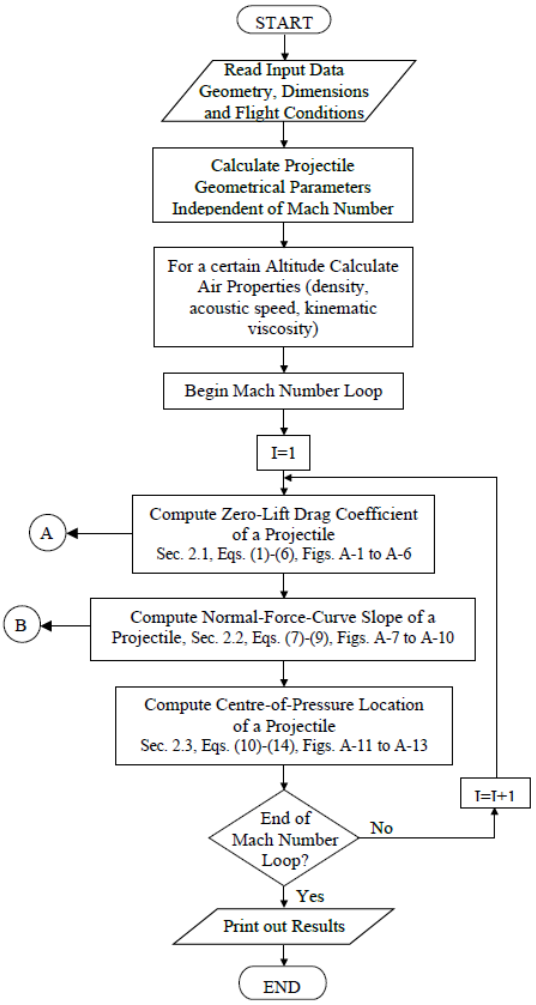


Fig. A-1. Main Flow Chart of the Computer Programme Used in this Study.

Preparation of Pre-Review Manuscript

Manuscripts, where appropriate, should contain these sections in the order: Title, Authors, Abstract, Keywords, Nomenclature, Introduction, Experimental Procedure, Theory, Results and Discussion, Conclusions, Acknowledgments (if any), References, Appendix (if any).

The manuscript may consist of text, equations, symbols, figures, tables, line-drawings, and photographs. Pre-Review Manuscripts are to be typed and formatted according to above template (MS-Word Version).

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1. Journal Article

Al-Atabi, M.T.; Chin, S.B.; and Luo, X.Y. (2005). Flow structures in tubes with segmental baffles. *Journal of Flow Visualization and Image Processing*, 45(2), 1412-1420.

2. Journal Article in Press

Al-Atabi, M.T.; Chin, S.B.; and Luo, X.Y. (in press). Flow visualization in tubes with segmental baffles. *Journal of Visualization.*

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Roberson, J.A.; and Crowe, C.T. (1997). *Engineering fluid mechanics* (6th ed.). New York: John Wiley and Sons Inc.

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Al-Atabi, M.T.; Chin, S.B.; and Luo, X.Y. (2004). An experimental study of the flow in an idealized human cystic duct. *Proceedings of the First Asian Pacific Conference on Biomechanics*. Osaka, Japan, 33-34.

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