AERODYNAMIC CHARACTERISTICS OF FOREBODY-CYLINDER COMBINATIONS OF CIRCULAR/NON-CIRCULAR CROSS SECTION AT ANGLES OF ATTACK

R.K.Sharma, P. Theerthamalai and S.Panneerselvam

Scientists, Aerodynamics Division,

Defence Research & Development Laboratory, Hyderabad - 500 058, INDIA

ABSTRACT

A method based on tangent cone and cross-flow concept has been presented for the evaluation of pressure distribution and the overall forces and moments for forebody-cylinder combinations of circular and non-circular cross sections at angles of attack in supersonic/hypersonic Mach numbers. The Tangent cone method is found to give good results for forebodies alone of arbitrary cross section but if applied over forebody-cylinder combinations, overestimates the pressure and hence, the overall forces and moments. The present method is a combinations of tangent cone method for forebody and cross flow method for cylindrical portion. The computed results on forebody-cylinder combinations of circular/non-circular cross sections using present method are in good agreement with experimental data even at angles of attack.

INTRODUCTION

The tangent cone method is very useful for rapid prediction of pressure distribution over slender bodies of revolution near zero angle of attack [Hays 66, Ande 89]. Tangent cone method applicable to bodies of arbitrary cross section is a class of high supersonic/hypersonic prediction methods based on a knowledge of the local surface inclination with respect to free stream. So far, this method has been mostly applied over forebody shapes at low angles of attack [Ande 89, Frib 69]. The tangent cone method if applied on cylindrical portion gives overestimate of pressure and hence, overall forces and moments. This is because the local inclination angle is constant on cylindrical portion. Therefore, the pressure is also constant and is equal to the value obtained on the shoulder of the forebody. In the present paper, cross flow concept has been applied on cylindrical portion to obtain pressure distribution, which compare better with experiments than the pressure computed from tangent cone method. The methodology of obtaining the pressure distribution on forebody using tangent cone and on cylindrical portion using cross flow concept has been presented in this paper. The computed results on forebody-cylinder combination of circular and non-circular cross section using tangent cone method (Tangent cone on both forebody and cylinder) and the present method (Tangent cone on forebody and cross-flow on cylinder) have been compared with test data. Good agreement has been observed between computed values using present method and the test data even at angles of attack.

TANGENT CONE METHOD

Consider a point 'i' on the body; a line drawn tangent to this point makes the angle α_L with respect to the free stream as shown by dashed line in Fig.1. This tangent line can be imagined as the surface of an equivalent cone, with a semi angle of α_L. The tangent cone approximation assumes that the pressure at point 'i' is the same as the surface pressure in the equivalent cone at a Mach number of M_∞, i.e pi is obtained directly from the cone tables [Sims 64]. The body surface is divided into large number of trapeizodal panels. Typical panelling of a body and the axis system is shown in Fig.2. The pressure acting on each panel depends on the local inclination of the panel with respect to free stream direction. The local inclination of the panel, α_L (Fig.1) w.r.t free stream is given by

$$\alpha_L = sin^{-1}\frac{V_n}{V_\infty} \qquad (1)$$

where V_n is the normal velocity and V_∞ is the magnitude of free stream velocity. The normal velocity V_n is given by

$$V_n = \vec{V}\cdot\vec{n} \qquad (2)$$

where $\vec{V}$ is the free stream velocity vector and $\vec{n}$ is the unit vector normal to the panel and is given by

$$\vec{V} = V_\infty\ cos\alpha\ \vec{i} + o\ \vec{j} + V_\infty\ sin\alpha\ \vec{k} \qquad (3)$$

$$\vec{n} = -sin\delta\ \vec{i} - cos\delta\ sin\theta\ \vec{j} + cos\delta\ cos\theta\ \ \vec{k} \qquad (4)$$

where $\vec{i}, \vec{j}\ and\ \vec{k}$ are unit vectors along x, y and z directions. δ is panel inclination angle with respect to body axis. θ is the inclination made by the plane parallel to x-axis passing through the normal to the panel, with z-axis. The local inclination angle of the panel, thus, can be written as

$$\alpha_L = sin^{-1}[-cos\alpha\ sin\delta + sin\alpha\ cos\delta\ cos\theta] \qquad (5)$$

This inclination angle alongwith freestream Mach number, is used for obtaining the pressure on a given panel using cone Tables [Sims 64].

PRESSURE DISTRIBUTION

On Forebody

When the body surface is in compression side (i.e., if α_L is +ve) and the shock is attached (α_L < shock detachment angle), the pressure acting on a panel can be obtained directly from cone Tables as a function of local inclination, α_L and free stream Mach number. When the body surface is in compression side and the shock is detached (α_L > shock detachment angle), modified Newtonian theory is used. For body surface having expansion side (i.e., α_L is -ve), Prandtl-Meyer relation has been used.

The comparison of pressure distribution obtained on forebodies of circular, elliptical (semi-major to semi-minor ratio =3:1 and 1:3) and lobed cross-sections are shown in Fig.3 alongwith experimental data [Town 79]. It can be seen that the pressure data computed from tangent cone method agrees closely with experimental data. The pressure distribution on an ogive-cylinder body at $\alpha = 0°$ and $10°$ are shown in Fig.4. The comparison of computed results with experiment [Perk 54] is good at $\alpha = 0°$. The pressure distribution at $\alpha = 10°$ agrees with experiment on windward side but not on leeward side. This is because the Prandtl-Meyer expansion, which is used here is applicable only for 2-D flows. Hence, an empirical correction has been introduced in the present method to account for 3-D effects. The pressure distribution on the expansion side from the present method (C_p) is obtained by multiplying the Prandtl-Meyer expansion pressure coefficient by the ratio of pressure coefficient of cone to wedge with the same compression angle (i.e., $-\alpha_L$) as given by the following expression

$$C_p = \frac{(C_p)_{cone}}{(C_p)_{wedge}} \ (C_p)_{P-M \ expansion} \qquad (6)$$

The corrected pressure distribution and normal force distribution agrees better with experiment as shown in Figs.4c and 4d.

On Cylindrical Portion

Cross flow concept, has been used on cylindrical portion to obtain pressure distribution. The cross flow component has been evaluated using modified Newtonian theory as follow:
The pressure coefficient based on cross-flow dynamic pressure is

$$C_p = C_{po} \ sin^2\delta_c \qquad (7)$$

where, C_{po} is the stagnation pressure coefficient and δ_c, the inclination of the panel w.r.t the cross flow velocity direction and is given by

$$sin\delta_c = cos\delta \ cos\theta \qquad (8)$$

The pressure coefficient based on free stream dynamic pressure is

$$C_p = C_{po} \ sin^2\delta_c \ sin^2\alpha \qquad (9)$$

$$= C_{po} \ cos^2\delta \ cos^2\theta \ sin^2\alpha \qquad (10)$$

The cross flow pressure has to be added to the windward side of the body only, since the pressure coefficient evaluation is based on modified Netonian theory. The pressure at forebody-cylinder junction should be smoothly matched from tangent cone value at shoulder to cross flow value at cylinder using the forebody trend of pressure distribution as illustrated in Fig.4d.

The overall forces and moments are obtained by integration of pressure distribution on different panels. The total axial force coefficient, is obtained by adding the skin friction drag coefficient [Spal 64] and base drag coefficient [Krie 91]to the wave drag coefficient obtained by integrating the pressure along the axial direction.

VALIDATION OF THE METHOD

The pressure distribution obtained on ogive-cylinder body at Mach 1.98 using tangent cone method and present method are shown in Fig.4 alongwith experimental data [Perk 54]. It can be seen that the pressure distribution obtained from tangent cone method at zero angle of attack are in good agreement with test data as shown in Fig.4a, but at angles of attack, considerable deviation is noticed (Fig.4b, 4c). These values have been improved using present method and are in close agreement with experimental data as indicated in Fig.4b and 4c. Similarly, the normal force distribution, which is obtained by integration of pressure distribution at different axial station, also compare better with test data (Fig.4d).

Aerodynamic characteristics, i.e., lift coefficient, drag coefficient (without base drag), lift to drag ratio and centre of pressure have been obtained on an Ogive-cylinder body of circular and elliptical cross section at $M_\infty = 1.98$ and α upto $24°$. These values have been compared with experimental data [Jorg 73] in Fig.5. It can be clearly seen that the results obtained from tangent cone deviate considerably from experimental data at angles of attack, whereas the computed values obtained from present method are in good agreement with test data even at angles of attack.

CONCLUSION

Methodology for obtaining aerodynamic characteristics of forebody-cylinder combinations of circular/non-circular cross sections at angles of attack using tangent cone and cross flow method has been explained in this paper. Tangent cone method gives good results for forebodies but overestimates on cylindrical portion. In the present paper, cross flow concept has been applied successfully on cylindrical portion in combination with tangent cone for forebody shapes. The results have been obtained on different bodies of circular and non-circular cross sections using tangent cone and present method and compared with experimental data. The tangent cone method deviates from test data at high angles of attack, whereas the present method compare well with test results even at angles of attack.

REFERENCES

Anderson, J.D., Jr., 1989, "Hypersonic and high temperature gas dynamics", McGraw-Hill Book Company, New-York.

Friberg, E.G. and Walchner, O., 1969, "Pressure correlation for blunted slender cones", AIAA Journal, Vol.7, pp.1619

Hayes, W.D. and Probstein, R.F., 1966, "Hypersonic Flow Theory", 2nd ed., Vol. 1, Academic Press, New York, pp. 522-526

Jorgensen, L.H., 1973, "A method for estimating aerodynamic static aerodynamic characteristics for slender bodies of circular and non-circular cross sections alone and with lifting surfaces at angles of attack from 0 to 90 degree", NASA TN D 7228.

Krieger, R.J. and Vukelich, S.R., 1991, "Tactical missile drag", Tactical Aerodynamics : Prediction methodology edited by M.R. Mendenhall, Vol.142, Progress in Astronautics and Aeronautics, AIAA, NewYork, pp.1-34.

Perkins, E.W. and Jorgensen, L.H., 1954, "Comparison of experimental and theoretical normal force distributions (including Reynolds number effects) on an ogive-cylinder body at Mach number 1.98", NACA TN 3716.

Sims, J.L., 1964, "Tables for supersonic flow of air around right circular cones at zero angles of attack", NASA SP 3004.

Spalding, D.B. and Chi, S.W., 1964, "The drag of a compressible turbulent boundary layeron a smooth flat plate with and without heat transfer", Journal of Fluid Mechanics, Vol.18, Pt.1, pp.117-143

Townsend, J.C., et al, 1979, "Surface pressure data on a series of cinical forebodies at Mach numbers from 1.7 to 4.5 and combined angles of attack and sideslip", NASA TM - 78808
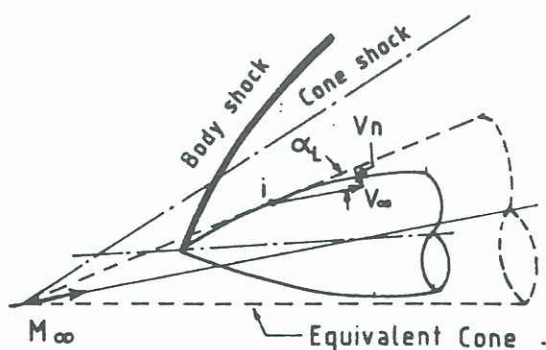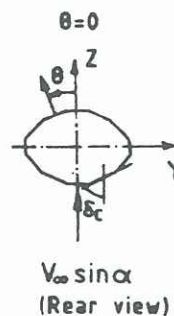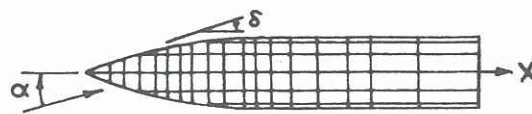
FIGURE-2 TYPICAL PANEL DIVISION
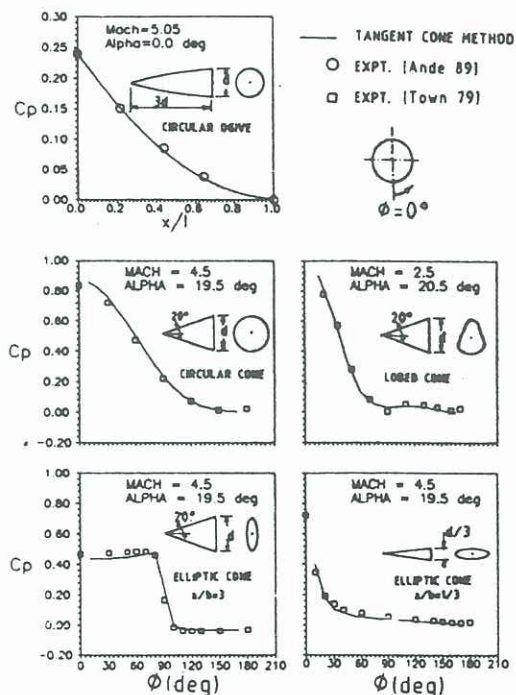

FIGURE-1 TANGENT CONE METHOD

FIGURE-3 COMPARISON OF COMPUTED AND EXPERIMENTAL PRESSURE DISTRIBUTION ON FOREBODIES OF DIFFERENT CROSS-SECTIONS
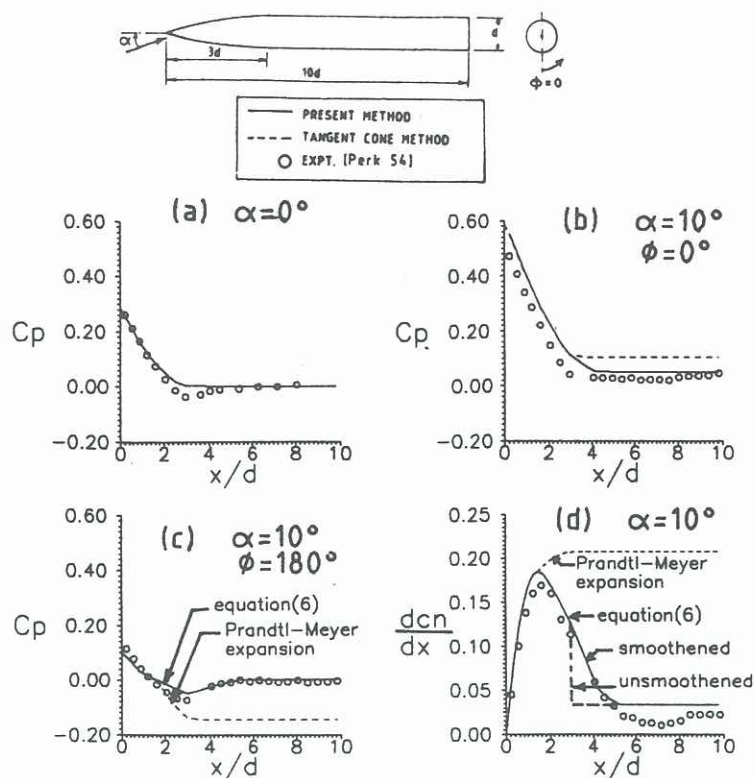
FIGURE-4 COMPARISON OF COMPUTED PRESSURE AND NORMAL FORCE DIS-
TRIBUTION WITH EXPERIMENTAL DATA ON AN OGIVE-CYLINDER BODY; l/d=10,
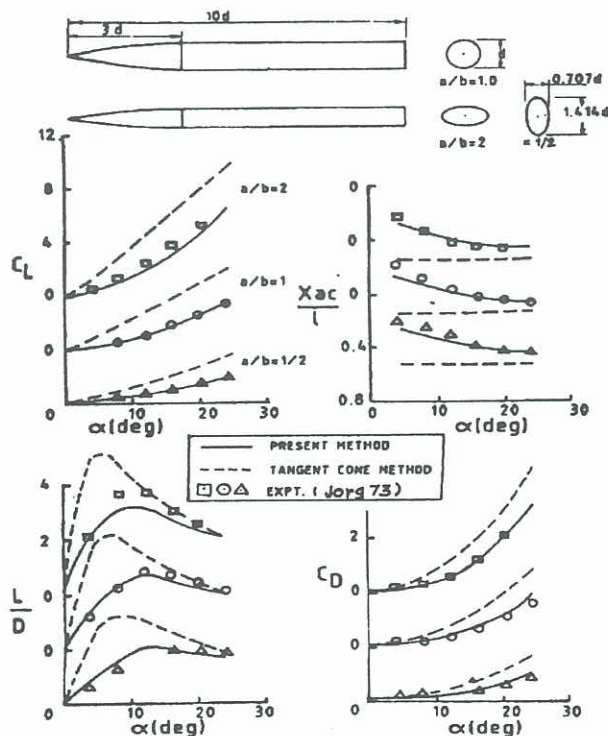M_∞=1.98

FIGURE-5 COMPARISON OF COMPUTED AERODYNAMIC CHARACTERISTICS WITH
EXPERIMENTAL DATA FOR OGIVE-CYLINDER BODY OF CIRCULAR AND ELLIP-
TICAL CROSS-SECTION; l/d=10, M_∞=1.98, $Re = 6.7x10^6$