dum 4165

Cone Method
Preliminary
PAS)
ypersonic
rogram

Sova

(NASA-TM-4165) IMPROVED TANGENT-CONE METHOD
FOR THE AERODYNAMIC PRELIMINARY ANALYSIS
SYSTEM (APAS) VERSION OF THE HYPERSONIC
ARBITRARY-BODY PROGRAM (NASA) 10 p CSCL 01A Unclas
H1/02 0261537

NASA Technical Memorandum 4165

Improved Tangent-Cone Method for the Aerodynamic Preliminary Analysis System (APAS) Version of the Hypersonic Arbitrary-Body Program

Christopher I. Cruz
Langley Research Center
Hampton, Virginia

Gregory J. Sova
Rockwell International Corporation
North American Aircraft Operations
El Segundo, California

National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Division

1990

Abstract

The Aerodynamic Preliminary Analysis System (APAS) utilizes a modified version of the Hypersonic Arbitrary-Body Program (HABP) Mark III code in its analysis rationale. Four methods are considered for incorporation into the code as the tangent-cone method. The combination of second-order slender body theory and the approximate solution of Hammitt and Murthy shows the best agreement with the exact numerical solutions and is thus included in the APAS production version of the HABP code.

Introduction

The Aerodynamic Preliminary Analysis System (APAS, refs. 1 and 2) uses a modified version of the Hypersonic Arbitrary-Body Program (HABP) Mark III code (ref. 3) in its analysis rationale. An integral part of such an analysis is the calculation of inviscid pressure distributions on arbitrary surfaces. Vehicle fuselages are often somewhat conical in shape; thus a method of predicting pressure drag for such shapes is required.

Four impact pressure methods are evaluated for their ability to predict the zero-angle-of-attack inviscid pressure coefficients of sharp cones with angles of 5°, 7.5°, 10°, 12.5°, 15°, 17.5°, 20°, 30°, 40°, and 50°. These predictions are then compared with the exact solution for air. Finally, a method is chosen for use in the APAS production version of the HABP code.

Symbols

C_p	pressure coefficient, $(p - p_\infty)/q_\infty$
K	constant in Newtonian pressure coefficient equation
M_{ns}	Mach number normal to the shock
M_∞	free-stream Mach number
p	local pressure, lbf/ft^2
p_∞	free-stream pressure, lbf/ft^2
q_∞	dynamic pressure, $\frac{1}{2}\rho_\infty V_\infty^2$
V_∞	free-stream velocity, ft/sec
δ	impact angle, deg
θ_c	cone half-angle, deg
θ_s	shock angle, deg
γ	ratio of specific heats
ρ_∞	free-stream density, lbm/ft^3

Description of Prediction Methods

The four impact methods evaluated for pressure coefficient prediction were (1) Newtonian theory (ref. 3), (2) the original HABP Mark III tangent-cone empirical method (ref. 3), (3) the Edwards tangent-cone empirical method (ref. 4), and (4) a combination of second-order slender-body theory and the approximate cone solution of Hammitt and Murthy (ref. 5).

Modified Newtonian theory yields a pressure coefficient which is a function only of impact angle:

$$C_p = K \sin^2 \delta$$

where K is equal to the stagnation-point pressure coefficient (ref. 6).

Both the HABP Mark III and the Edwards versions of the tangent-cone empirical method calculate pressure coefficient as a function of Mach number and impact angle:

$$C_p = \frac{48 M_{\mathrm{ns}}^2 \sin^2 \delta}{23 M_{\mathrm{ns}}^2 - 5}$$

The difference between these two methods lies in the empirical equations for Mach number normal to the shock. For the HABP Mark III version,

$$M_{\mathrm{ns}} = 1.090909 M_\infty \sin \delta + \exp(-1.090909 M_\infty \sin \delta)$$

For the Edwards version,

$$M_{\mathrm{ns}} = (0.87 M_\infty - 0.544) \sin \delta + 0.53$$

The last method uses a combination of second-order slender-body theory and the approximate cone solution of Hammitt and Murthy. The pressure coefficient found with this method is given by

$$C_p = \frac{p_\infty}{\frac{1}{2}\rho_\infty V_\infty^2} \left(\left(\frac{2\gamma}{\gamma + 1} M_\infty^2 \sin^2 \theta_s - \frac{\gamma - 1}{\gamma + 1} \right) \left\{ 1 + \frac{\gamma M_\infty (\theta_s - \theta_c)^2 \cos^2 \theta_s}{1 + [(\gamma - 1)/2]\, M_\infty^2 \sin^2 \theta_s} \right\}^{-1} \right)$$

Results and Discussion

Figures 1 to 10 present inviscid pressure coefficients (zero angle of attack) for sharp cones with half-angles from 5° to 50° and Mach numbers from 1.5 to 25. Each figure contains pressure coefficients calculated with each of the four prediction methods as well as exact values from the tables of Kopal (ref. 7) and Jones (ref. 8).

For all cone half-angles investigated, Newtonian theory underpredicts pressure coefficient throughout the entire Mach number range. Adjustment of the Newtonian constant from $K = 2$ to $K = 2(\gamma + 1) \times (\gamma + 7)/(\gamma + 3)^2$ (ref. 1) would give a reasonable result for Mach numbers greater than 10, when the inviscid pressure coefficient is relatively constant with respect to Mach number.

The HABP Mark III tangent-cone empirical method does a better job than Newtonian theory, but at Mach numbers less than 5 it also greatly underpredicts the exact solutions, as shown in figures 7 to 10.

The Edwards tangent-cone empirical method is a vast improvement over the HABP Mark III method. At smaller cone half-angles, results from the Edwards method match the exact values closely for Mach numbers of 1.5 and up. However, as cone half-angle increases, the discrepancy between the results from the Edwards method and the exact values grows larger.

By far, the best of the methods evaluated is that referred to in figures 1 to 10 as the "2nd Order Slender Body + Hammitt/Murthy" method. With few exceptions, this method predicts the inviscid pressure coefficient at zero angle of attack with great accuracy. (In most cases, there is less than 1 percent difference between predictions and the exact values of Kopal and Jones.) Figures 9 and 10 show the peculiarities which can occur when this method is used for large cone half-angles. This degeneration of calculated pressure coefficient corresponds to the physical existence of detached shocks for larger cone half-angles at low supersonic speeds. It is important to note, however, that even with these discontinuities, this method is still far superior to the other three methods considered.

Conclusions

The combination of second-order slender-body theory and the approximate cone solution of Hammitt and Murthy is the superior method of those evaluated. It is thus included in the Aerodynamic Preliminary Analysis System (APAS) production version of the Hypersonic Arbitrary-Body Program (HABP) code as the tangent-cone method. The Newtonian theory, original HABP Mark III tangent-cone, and Edwards tangent-cone methods all have applicability within given restrictions, but outside of these restrictions they may yield misleading results.

NASA Langley Research Center
Hampton, VA 23665-5225
January 4, 1990

References

1. Bonner, E.; Clever, W.; and Dunn, K.: *Aerodynamic Preliminary Analysis System II. Part I—Theory.* NASA CR-165627, 1981.
2. Divan, P.: *Aerodynamic Preliminary Analysis System II. Part II—User's Manual.* NASA CR-165628, 1981.
3. Gentry, Arvel E.: *Hypersonic Arbitrary-Body Aerodynamic Computer Program (Mark III Version). Volume I—User's Manual.* Rep. DAC 61552, Vol. I (Air Force Contract Nos. F33615 67 C 1008 and F33615 67 C 1602), McDonnell Douglas Corp., Apr. 1968. (Available from DTIC as AD 851 811.)
4. Pittman, Jimmy L. (appendix by C. L. W. Edwards): *Application of Supersonic Linear Theory and Hypersonic Impact Methods to Three Nonslender Hypersonic Airplane Concepts at Mach Numbers From 1.10 to 2.86.* NASA TP-1539, 1979.
5. Hammitt, A. G.; and Murthy, K. R.: *Approximate Solutions for Supersonic Flow Over Wedges and Cones.* AFOSR TN 59-304, U.S. Air Force, Apr. 1959. (Available from DTIC as AD 213 088.)
6. Truitt, Robert Wesley: *Hypersonic Aerodynamics.* Ronald Press Co., c.1959.
7. Staff of Computing Section, Center of Analysis (under the direction of Zdeněk Kopal): *Tables of Supersonic Flow Around Cones.* Tech. Rep. No. 1 (NOrd Contract No. 9169), Massachusetts Inst. of Technology, 1947.
8. Jones, D. J.: *Tables of Inviscid Supersonic Flow About Circular Cones at Incidence* $\gamma = 1.4$. AGARDograph 137, Pt. I, Nov. 1969.

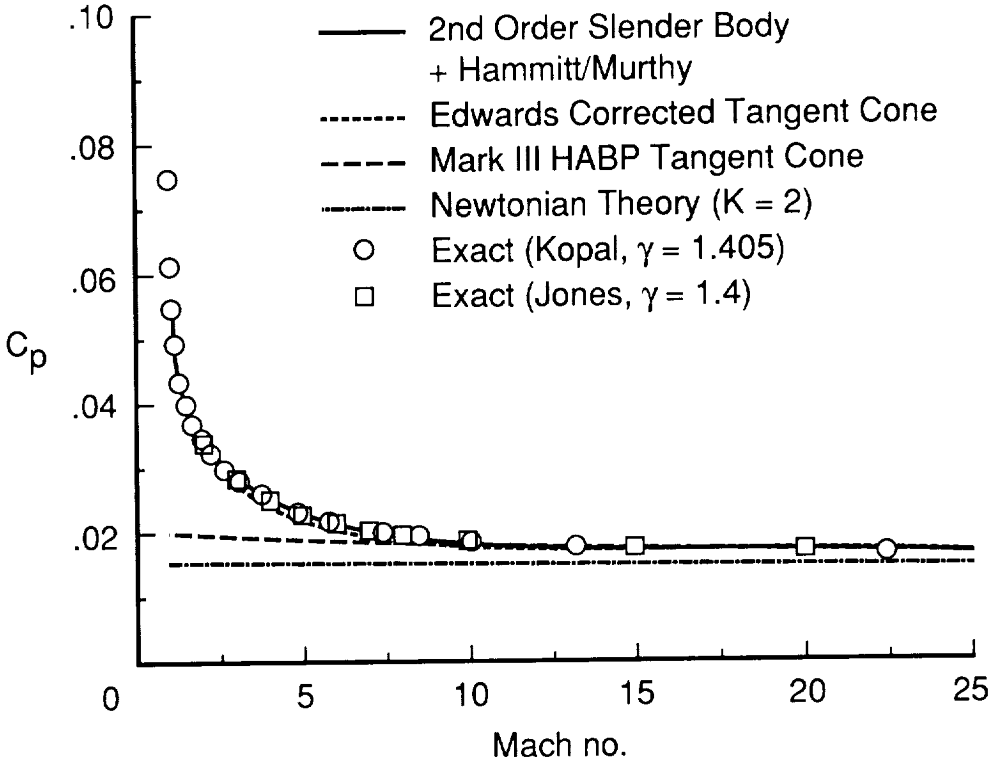

Figure 1. Pressure coefficient versus Mach number for 5° sharp cone.

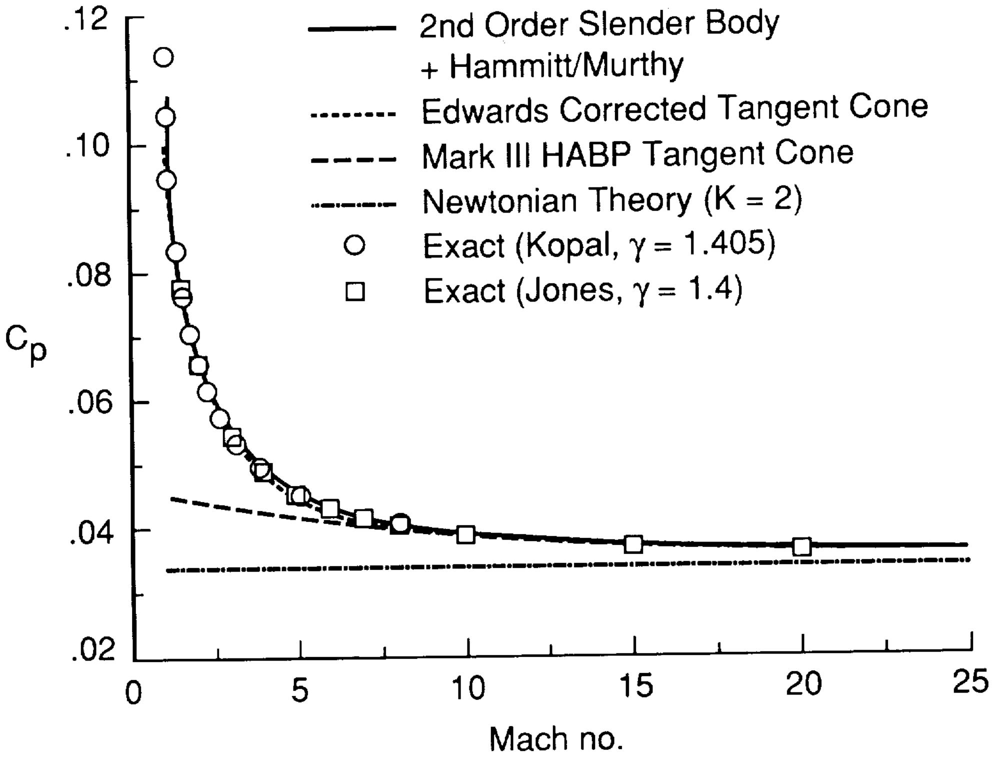

Figure 2. Pressure coefficient versus Mach number for 7.5° sharp cone.

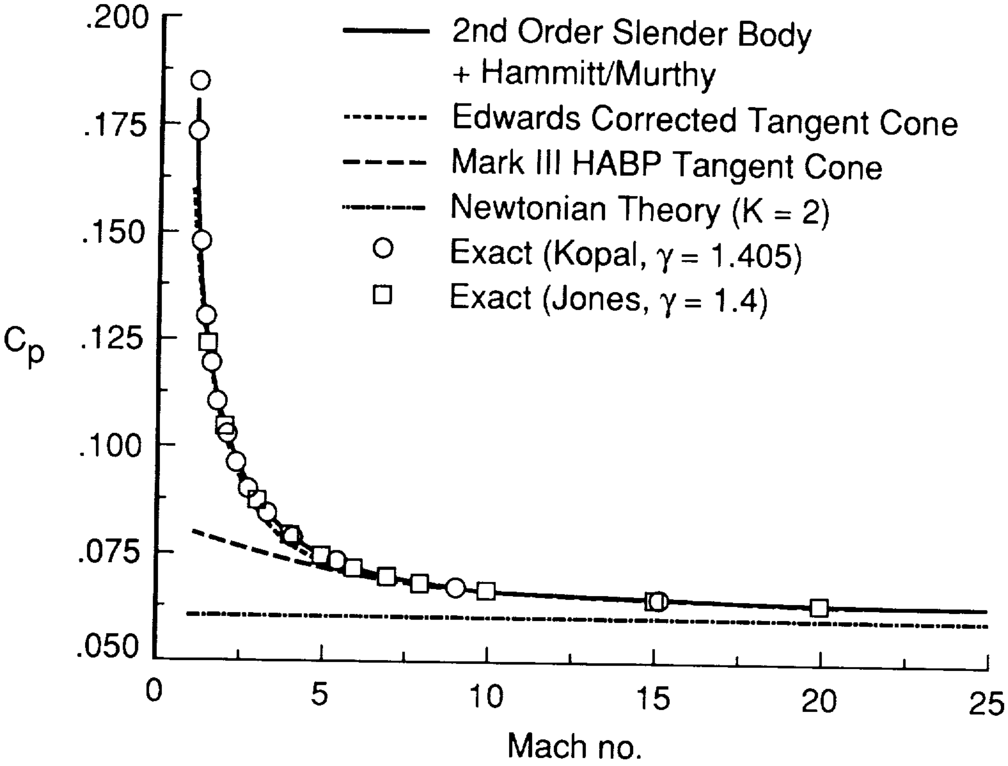

Figure 3. Pressure coefficient versus Mach number for 10° sharp cone.

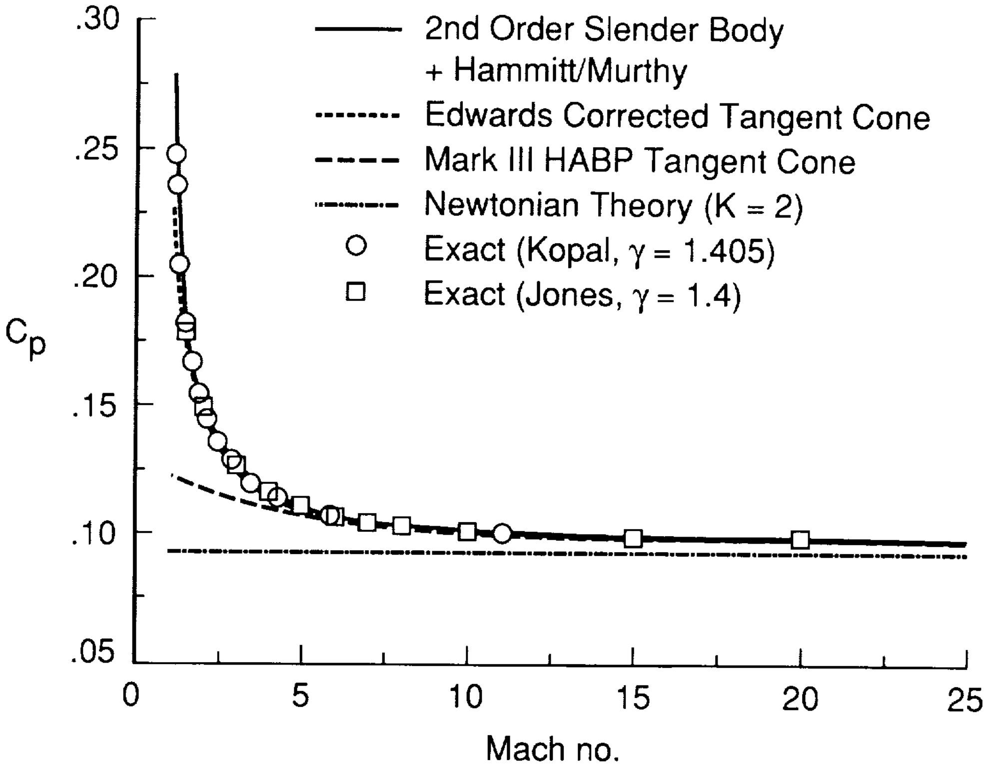

Figure 4. Pressure coefficient versus Mach number for 12.5° sharp cone.

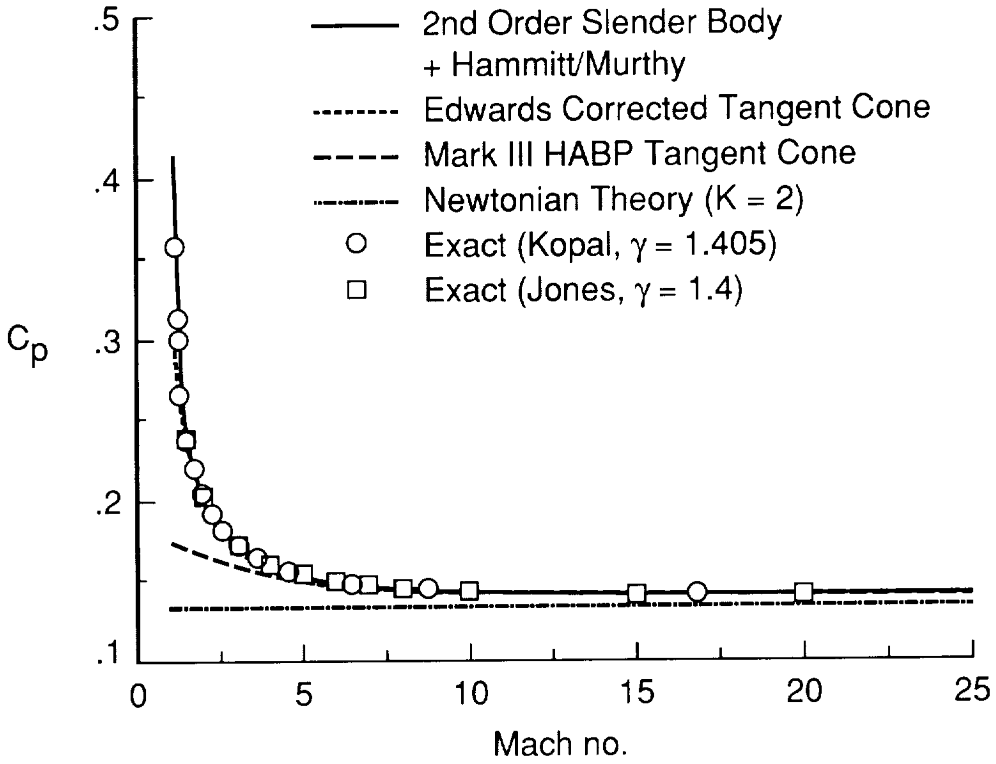

Figure 5. Pressure coefficient versus Mach number for 15° sharp cone.

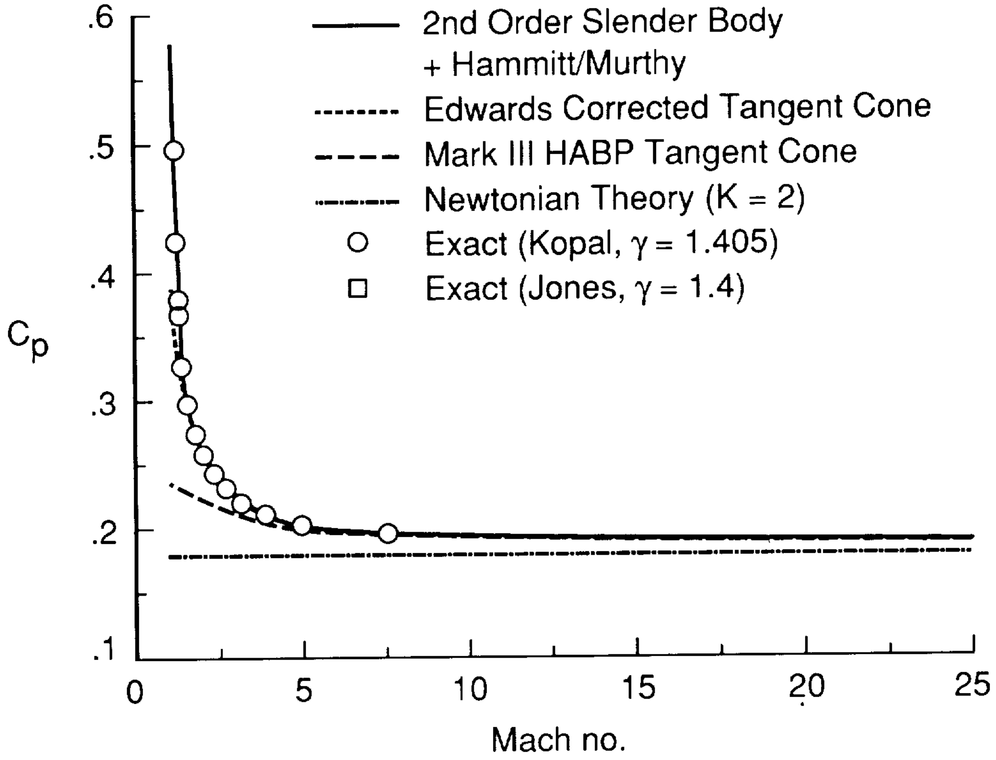

Figure 6. Pressure coefficient versus Mach number for 17.5° sharp cone.

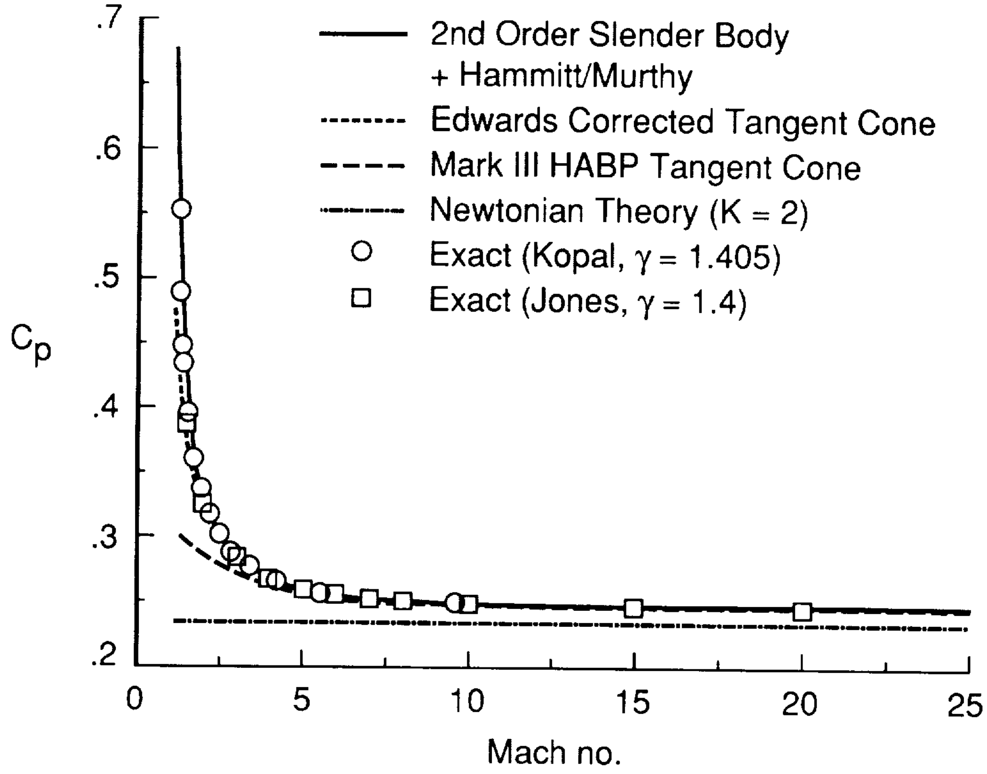

Figure 7. Pressure coefficient versus Mach number for 20° sharp cone.

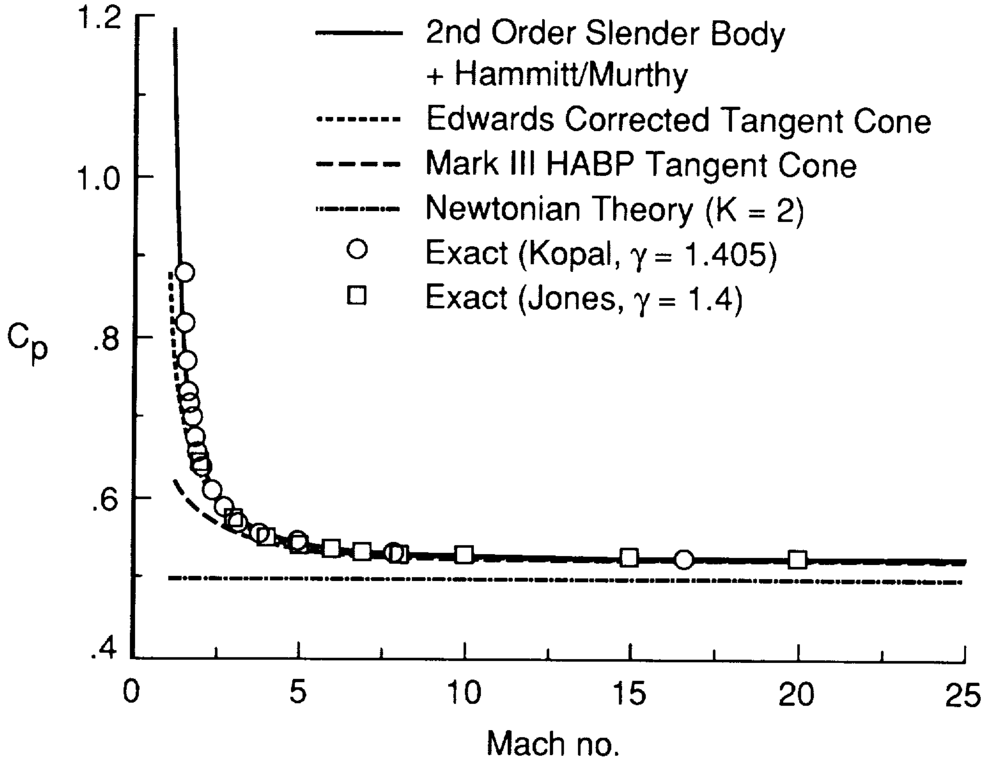

Figure 8. Pressure coefficient versus Mach number for 30° sharp cone.

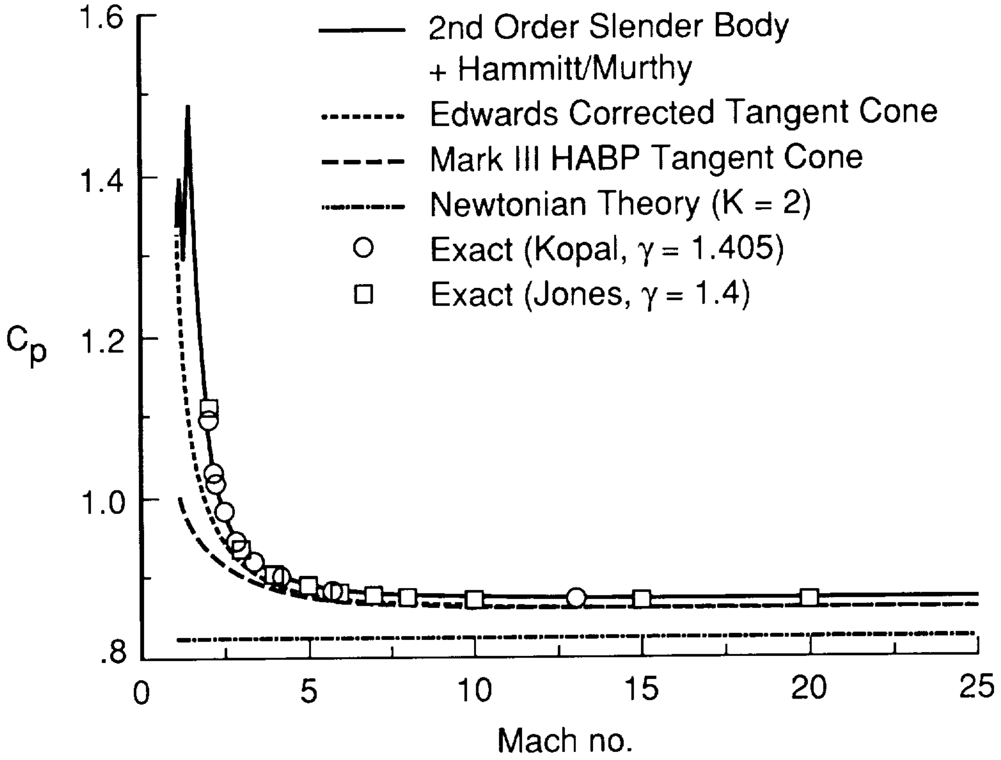

Figure 9. Pressure coefficient versus Mach number for 40° sharp cone.

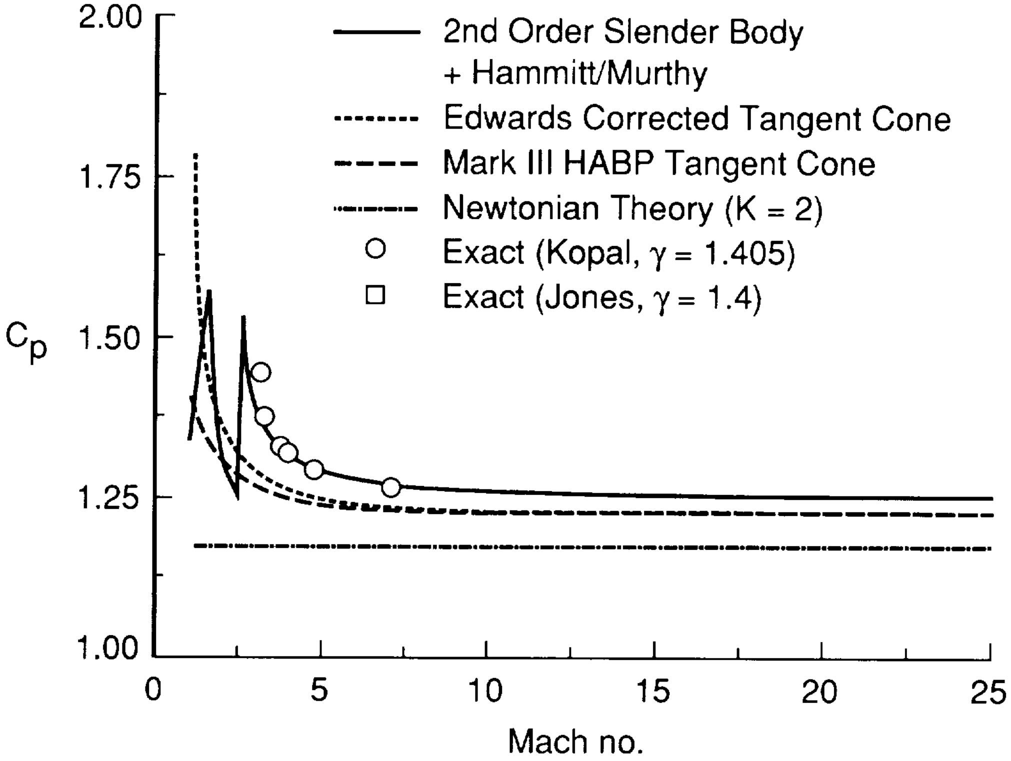

Figure 10. Pressure coefficient versus Mach number for 50° sharp cone.

National Aeronautics and Space Administration

Report Documentation Page

1. Report No. NASA TM-4165	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Improved Tangent-Cone Method for the Aerodynamic Preliminary Analysis System (APAS) Version of the Hypersonic Arbitrary-Body Program		5. Report Date February 1990
		6. Performing Organization Code
7. Author(s) Christopher I. Cruz and Gregory J. Sova		8. Performing Organization Report No. L-16404
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665-5225		10. Work Unit No. 506-49-11-01
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546-0001		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

Christopher I. Cruz: Langley Research Center, Hampton, Virginia.
Gregory J. Sova: Rockwell International Corporation, North American Operations, El Segundo, California.

16. Abstract

The Aerodynamic Preliminary Analysis System (APAS) utilizes a modified version of the Hypersonic Arbitrary-Body Program (HABP) Mark III code in its analysis rationale. Four methods are considered for incorporation into the code as the tangent-cone method. The combination of second-order slender body theory and the approximate solution of Hammitt and Murthy shows the best agreement with the exact numerical solutions and is thus included in the APAS production version of the HABP code.

17. Key Words (Suggested by Authors(s)) Hypersonics Tangent cone	18. Distribution Statement Unclassified—Unlimited Subject Category 02

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 8	22. Price A02

NASA FORM 1626 OCT 86

NASA-Langley, 1990

For sale by the National Technical Information Service, Springfield, Virginia 22161-2171