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CALCULATION OF COMPONENT FORCES AND MOMENTS OF ARBITRARILY BANKED CRUCIFORM MISSILES WITH CONTROL DEFLECTIONS

NIELSON ENGINEERING AND RESEARCH, INCORPORATED
MOUNTAIN VIEW, CALIFORNIA

1 NOVEMBER 1976

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REPORT ONR-CR215-226-3



CALCULATION OF COMPONENT FORCES AND MOMENTS OF ARBITRARILY BANKED CRUCIFORM MISSILES WITH CONTROL DEFLECTIONS

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CONTRACT N00014-74-C-0050
ONR TASK 215-226

1 NOVEMBER 1976

ANNUAL TECHNICAL REPORT FOR PERIOD
1 OCTOBER 1975 - 30 SEPTEMBER 1976

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ONR-CR215-226-3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) CALCULATION OF COMPONENT FORCES AND MOMENTS OF ARBITRARILY BANKED CRUCIFORM MISSILES WITH CONTROL DEFLECTIONS		5. TYPE OF REPORT & PERIOD COVERED Technical Report 10-01-75 to 9-30-76 6. PERFORMING ORG. REPORT NUMBER NEAR TR 125
7. AUTHOR(s) Michael J. Hemsch, Charles A. Smith, Jack N. Nielsen, and Stanley C. Perkins, Jr.		8. CONTRACT OR GRANT NUMBER(s) N00014-74-C-0050
9. PERFORMING ORGANIZATION NAME AND ADDRESS Nielsen Engineering & Research, Inc. 510 Clyde Avenue Mountain View, California 94043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61153N-14 RR014-11-84, 1-12 ONR Task NR 215-226
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research (Code 211) 800 N. Quincy Street Arlington, VA 22217		12. REPORT DATE 1 November 1976 13. NUMBER OF PAGES 229
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Missile Aerodynamics; Guided Missiles; Aerodynamic Characteristics; Aerodynamic Canard Control; Aerodynamic Empirical Techniques; Aerodynamic Flow Patterns; Aerodynamic Vortices; Missile Aerodynamic Loads

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the development of a preliminary version of a single comprehensive code for the engineering calculation of all missile component aerodynamic forces and moments, except minimum drag, for angles of attack up to the unsteady regime. The engineering method to be described in this report is composed of five basic procedures: (1) computation of forces and moments, with no external vortices present, for individual fins in the presence of a body at arbitrary angle of

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attack and bank angle with control deflections; (2) computation of forces and moments induced on individual fins due to the presence of external vortices; (3) calculation, using an empirical method, of the strengths and positions of body vortices generated upstream of the first set of fins; (4) computation, using a vortex tracking method, of the strengths and positions of vortices between the first and second sets of fins; and (5) determination of body forces and moments due to the presence of the fins and vortices. Detailed comparisons between data and theory for determining the effectiveness of the above procedures are presented. Several important phenomena which are not accounted for in the present method are discussed and appropriate improvements to the code are recommended.



PREFACE

This technical report covers the work performed under Contract N00014-74-C-0050 from 1 October 1975 to 30 September 1976, and is the third report published under the program. The program is sponsored by the Office of Naval Research with significant assistance provided by NASA/Ames Research Center.

Commander P. R. (Bob) Hite, Office of Naval Research, is the Navy Scientific Officer. Dr. Gary T. Chapman and Mr. Gerald N. Malcolm are the NASA advisors.

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CALCULATION OF COMPONENT FORCES AND MOMENTS OF ARBITRARILY BANKED CRUCIFORM MISSILES WITH CONTROL DEFLECTIONS

by Michael J. Hemsch, Charles A. Smith,
Jack N. Nielsen, and Stanley C. Perkins, Jr.
Nielsen Engineering & Research, Inc.

1. INTRODUCTION

Under the sponsorship of the Office of Naval Research (ONR), Nielsen Engineering & Research, Inc. (NEAR) has been developing computer programs for the prediction of the aerodynamics of arbitrarily banked cruciform missiles at high angles of attack. The first two years of the work were devoted to the development of a computer code based on linear supersonic flow theory for the calculation of loadings on cruciform wing-body combinations. The results are reported in references 1 and 2. In 1974-1975, under the sponsorship of the Naval Weapons Center (NWC), China Lake, CA, NEAR developed an engineering method for calculating the induced rolling moments of cruciform missiles at angles of attack up to 20°. At the same time, under the joint sponsorship of NWC and NASA/Ames Research Center, NEAR obtained a systematic set of component-buildup data on a cruciform body-canard-tail missile up to 24° angle of attack at transonic and supersonic speeds. The data included individual fin loads. The engineering method is reported in reference 3. The data are presented in references 4 and 5.

Under the co-sponsorship of ONR and NASA/ARC, NEAR is continuing and extending the work reported in reference 3. The work involves two tasks: (1) development of a single comprehensive code for the engineering calculation of all missile component aerodynamic forces and moments, except minimum drag, for angles of attack up to the unsteady regime; and (2) comprehensive comparison of predicted results with systematic data from a variety of configurations. The work is to be accomplished in two phases. The first phase includes development of a preliminary version of the new code based on the method of reference 3. The new code is then to be compared with available systematic data up to approximately 20° angle of attack. This report describes that work. The work planned for the second phase is: (1) correction of deficiencies in the method which were uncovered in the first phase through comparison of experiment and theory, (2) extension of the method to angles of attack up to the unsteady regime, and (3) comparison of the extended method with systematic high angle of attack data obtained for that purpose.

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When the work reported herein was in the planning stage, it was thought that in the first phase a comprehensive comparison between theoretical predictions and data for a number of different missile configurations and Mach numbers would be appropriate. However, detailed comparisons of theory and experiment for individual fin loads were found to be essential for uncovering and sorting out the many and varied phenomena involved. As a result, the comparisons are directed principally toward systematic data which include individual fin loads. Where discrepancies between theory and data are found, remedies are suggested and further work outlined. To insure that the phenomena uncovered are not the result of isolated cases, several different configurations are studied.

The engineering method to be described in this report is composed of five basic procedures: (1) computation of forces and moments, with no external vortices present, for individual fins in the presence of a body at arbitrary angle of attack and bank angle with control deflections; (2) computation of forces and moments induced on individual fins due to the presence of external vortices; (3) calculation, using an empirical method, of the strengths and positions of body vortices generated upstream of the first set of fins; (4) computation, using a vortex tracking method, of the strengths and positions of vortices between the first and second sets of fins; and (5) determination of body forces and moments due to the presence of the fins and vortices.

This report and reference 3 are intended to be sufficient for an understanding of the method. Reference 3 gives a detailed description of procedures (1) and (3). Although detailed descriptions of procedures (2) and (4) are available in reports published prior to reference 3, for the sake of completeness, that work is made available in this report in Appendices A through D. Section 2 of this report presents an overall introduction to the method and describes procedure (5), the development of which is Task 1 of the present effort. Detailed comparisons between data and theory for determining the effectiveness of the above procedures (Task 2) are presented in sections 3 to 5. Section 3 is concerned with cases in which external vortex effects are unimportant (procedure (1)). Section 4 considers situations for which the effects of body vortices are important (procedures (2) and (3)) but do not require the vortex tracking of procedure (4). Section 5 compares theory and data for cases in which all of the above procedures are required. A user's manual for

the Task 1 code is presented in Appendix E. Appendix F contains extensions made to a computer code developed earlier by NEAR for ONR (refs. 1, 2, and 3). The additions were necessary for the computation of certain interference quantities used for the calculation of body forces in the presence of cruciform fins. Appendix F also includes a study of optimum panel spacing to be used for that program.

2. INTRODUCTION TO THE ENGINEERING METHOD AND DESCRIPTION OF THE EXTENSIONS FOR CALCULATING BODY FORCES AND MOMENTS

2.1 Introduction to the Engineering Method

In developing the computer program, we have adopted an analytical approach to the maximum extent possible compatible with obtaining a complete program for all forces and moments acting on the missile components except for minimum drag. However, it has been necessary to adopt semi-empirical techniques for parts of the method. By comparisons of systematic data with theoretical predictions, the shortcomings and limitations can be determined and necessary improvements identified.

To place the present method in perspective, a brief description of the phenomena involved in flow over cruciform missiles is presented. Consider the body-canard-tail configuration shown in figure 1. Experimental work on such configurations has shown that the following sources of component interference can be important for included angles of attack in the range of $0 \leq \alpha_c \leq 20^\circ$.

1. Panel-panel interference: Consider a set of opposing fins at angle of attack and roll joined together at their root chords. We will call such a configuration a "wing alone." A body can be inserted between the fins and another set of fins can be added perpendicular to the first set. Any change in loading experienced by a fin due to changes in loading of another fin is said to be due to panel-panel interference and is affected by the presence of the body.

2. Nose vortex-fin interference: At sufficiently high angles of attack, separated flow will develop on the missile upstream of the first set of fins. The presence of the separated flow over the fins will alter their loading.

3. Canard vortex-tail interference: Each of the fins in the first finned section will shed trailing vorticity. That vorticity passing the tail section will alter the loading experienced by the tail fins.

4. Afterbody vortex-tail interference: At sufficiently high angles of attack, the afterbody boundary layer will separate. The shed vorticity will roll up and interact with the tail fins altering the loadings they will experience.

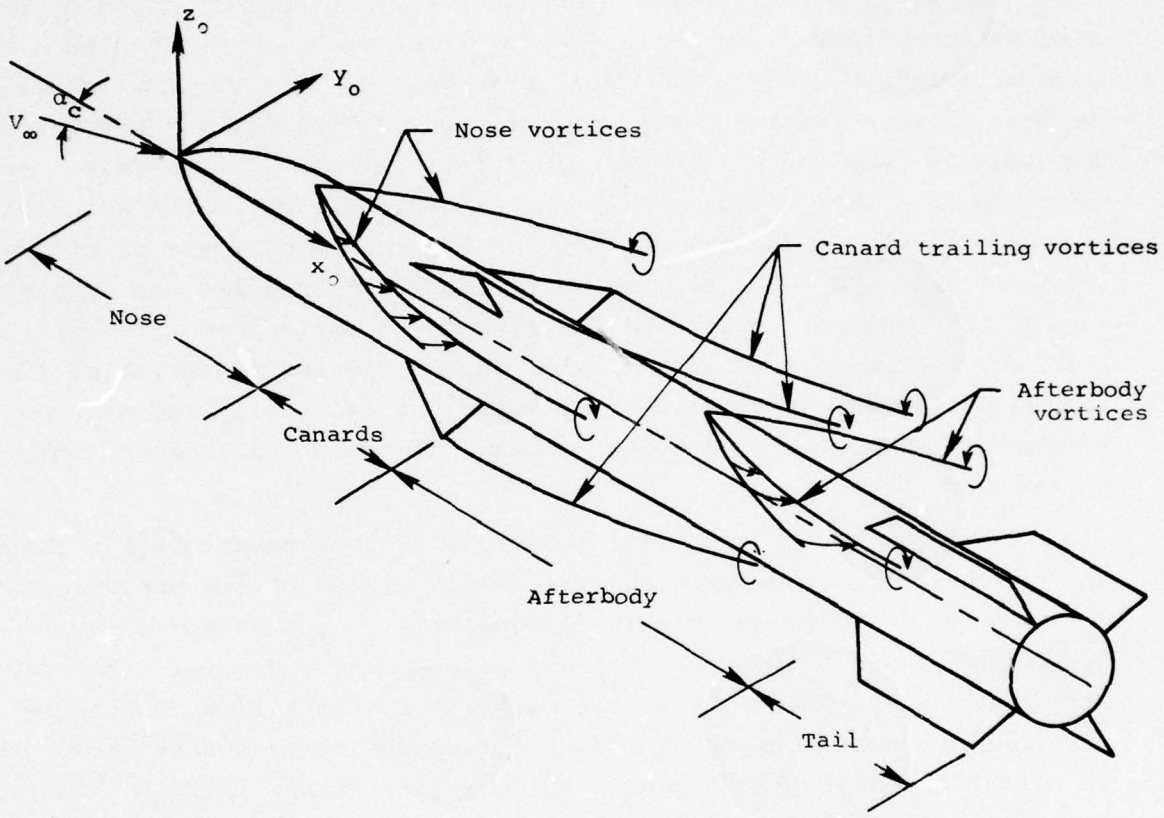


Figure 1. Banked canard-cruciform missile at angle of attack showing typical vortex field.

As discussed in the introduction, the present method models the above phenomena with five basic procedures. The first procedure computes fin forces and moments when no external vortices are present; that is, no vorticity generated upstream of the fins is present. To do this we have developed a correlation method based on the concept of an "equivalent angle of attack." The equivalent angle of attack, α_{eq}, is defined to be the angle of attack of a wing alone such that the normal force of the wing alone is twice* the actual normal force on a fin mounted on a body with arbitrary deflection and roll orientation. The various interference factors which account for fin deflection, roll orientation and ratio of fin span to body radius are described in reference 3. The Task 1 computer code requires that the wing-alone characteristics of normal force and center of pressure location be input as functions of angle of attack. The usefulness of the α_{eq} concept is demonstrated in reference 6, pages 21 to 25. The present version of this procedure is limited to symmetric deflection of opposing fins. Furthermore, only the first set of fins may be deflected. Both of these limitations are easily removed and may be during the second phase of the work. The fins must not be cambered or twisted.

The second procedure mentioned above is concerned with the changes in fin forces and moments when vortices generated upstream of the fins are present. A full description of the method used is given in Appendices A and B and will not be repeated here. However, the reader should be aware that the procedure assumes that the flow induced by the vortices can be described by linear theory and uses reverse flow methods to obtain the appropriate equivalent angle of attack increment due to the vortices. Because of the flow modeling used to track upstream vortices over a finned section, some restrictions on fin leading-edge and trailing-edge sweep exist. See Appendix A for further discussion.

For the third procedure the separated flow over the body upstream of the first set of fins is modeled as two symmetric potential line vortices. The body is assumed to be axisymmetric. It is also assumed to be cylindrical downstream of the nose. The missile station at which separation begins, that is, the station at which the vorticity is rolled up, is estimated from an empirical correlation. The vortex positions on the nose are also obtained from an empirical correlation. The strengths

*Recall that the wing alone is composed of <u>two</u> opposing fins.

of the nose vortices at the leading edge of the first finned section are then calculated using the vortex impulse theorem and two-dimensional crossflow drag coefficient correlations. A full description of this procedure is given in reference 3.

The fourth procedure is concerned with the wake over the afterbody section. The afterbody is assumed to be cylindrical. In this region, all the vortices present are tracked using slender-body theory from the trailing edge of the first set of fins to the leading edge of the second set of fins. Appendix C describes the method used to obtain the initial strengths and positions of the vortices shed by the first set of fins. Criteria for determining the axial location of the onset of boundary-layer separation and roll up of the shed vorticity from the afterbody are based on the local crossflow velocities and the presence or absence of nose vortices. If afterbody vortices form, they are assumed to grow as two potential line vortices under the influence of the vorticity shed upstream. They are allowed to grow unsymmetrically if the local flow is unsymmetrical about the plane containing the body and wind axes. The strengths of the afterbody vortices are assumed to be given by the vortex impulse theorem and two-dimensional crossflow drag correlations. A complete description of this procedure is given in Appendix D.

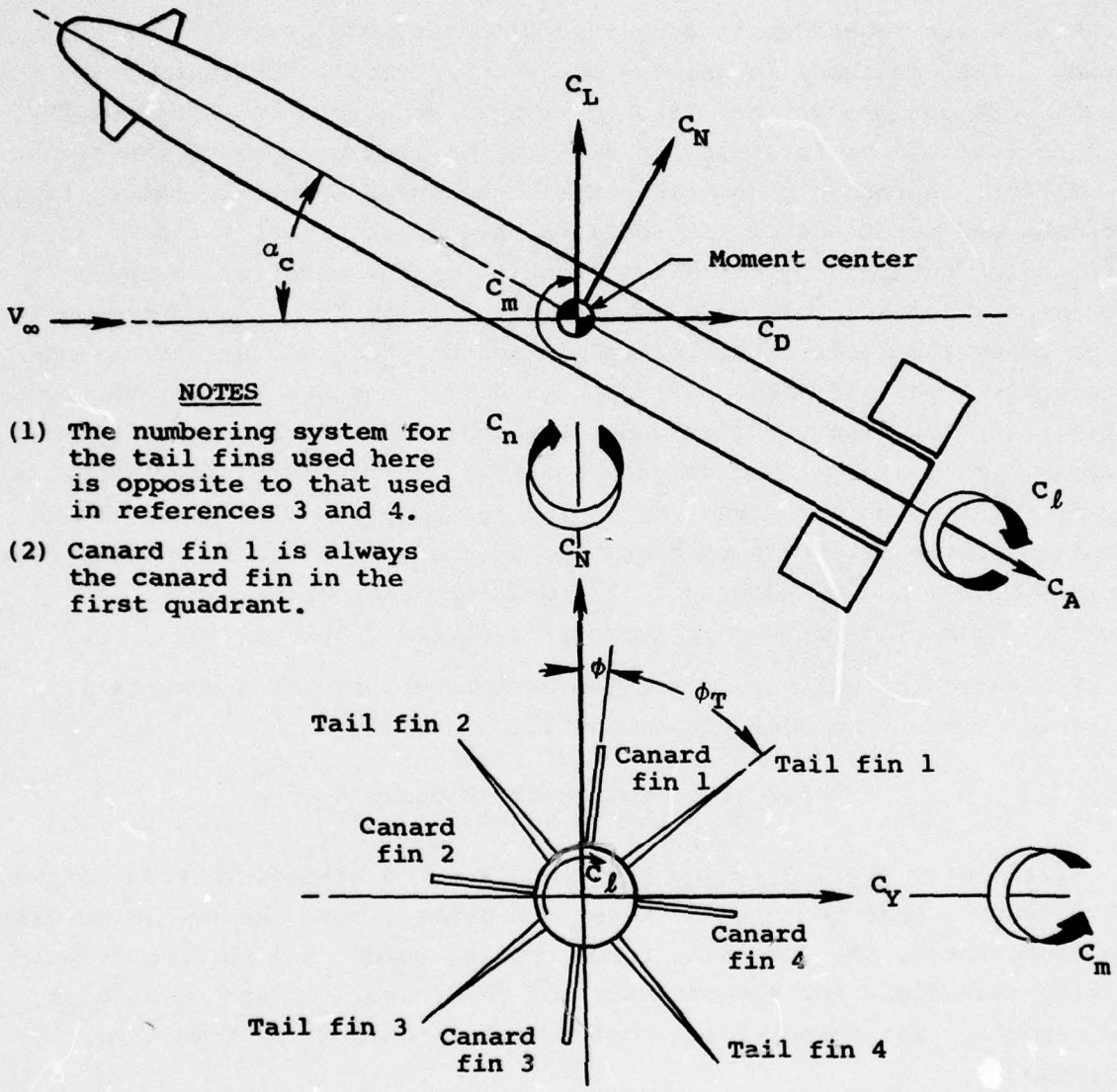
Procedure (5) which is concerned with body forces and moments is described in the remainder of section 2.

2.2 Description of Extensions to the Method

2.2.1 Nose section forces and moments.- The present version of the method assumes that the nose vortices are symmetrical. Hence, in unrolled body coordinates, the nose side force, yawing moment and rolling moment are zero (see fig. 2 for a description of the coordinate system used in this report). The normal-force coefficient is determined from the expression

$$C_N = C_{N_\alpha} \sin \alpha_c \frac{\pi a^2}{S_R} + c_{d_c} \sin^2 \alpha_c \frac{S_C}{S_R} \qquad (1)$$

If the user does not input C_{N_α}, the program uses the slender-body theory result, $C_{N_\alpha} = 2$. The two-dimensional crossflow drag coefficient is obtained from Fidler's correlations (ref. 7) for crossflow Mach numbers, M_c, less than 0.7 and from Jorgensen's correlation (ref. 8) for



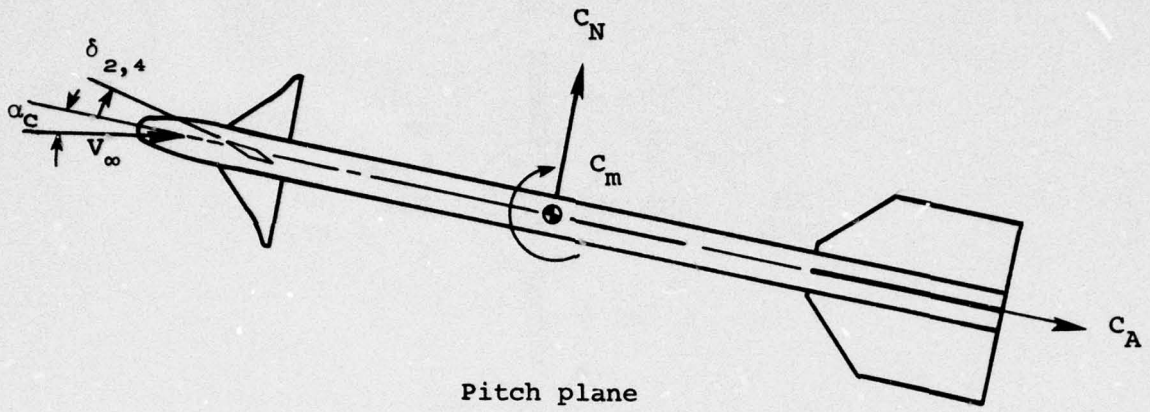
NOTES

(1) The numbering system for the tail fins used here is opposite to that used in references 3 and 4.

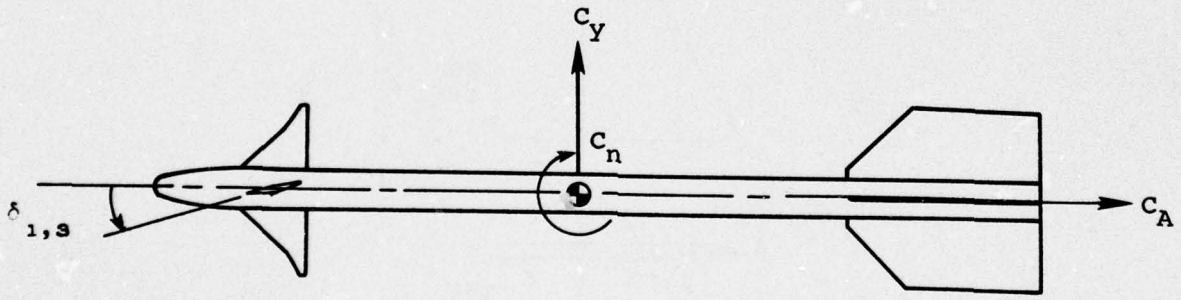
(2) Canard fin 1 is always the canard fin in the first quadrant.

(a) Total loads and fin numbering system.

Figure 2. Definition of coordinate systems.



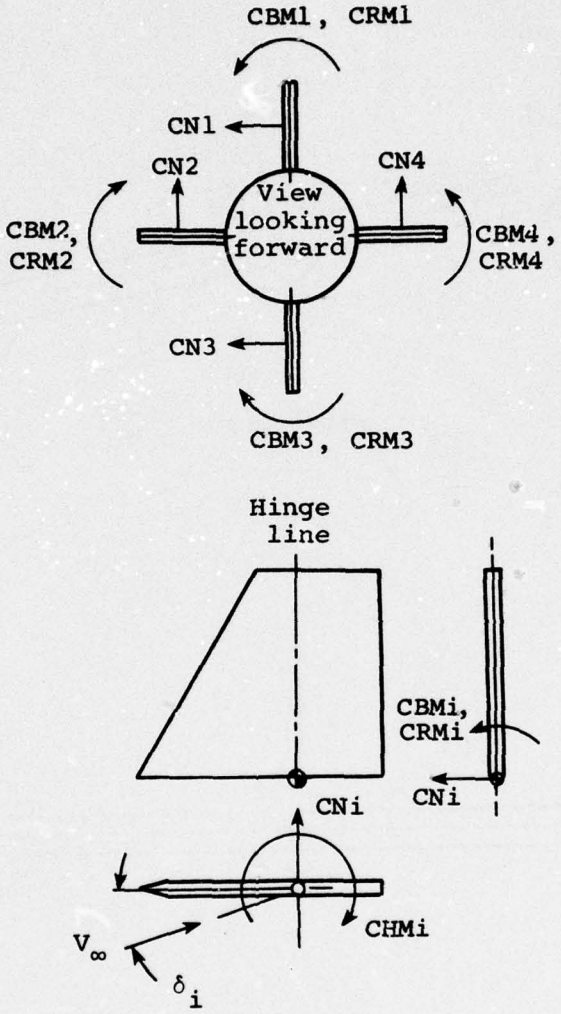
Pitch plane



Yaw plane

(b) Sign convention for canard deflection angles.

Figure 2. Continued.



NOTE: Normal forces are measured perpendicular to the fin planform and are considered to act at the intersection of the fin hinge line and root chord.

(c) Axis systems and positive sign convention for fins.

Figure 2. Concluded.

$M_c > 0.7$. Note that the usual formulation of equation (1) includes a multiplicative factor for finite length effects which is not used in the present method.

The center of pressure position for the linear term of equation (1) is obtained from the slender-body theory expression

$$\bar{x}_{linear} = x_N \left(1 - \frac{V_N}{\pi a^2 x_N} \right) \tag{2}$$

where x_N is the length of the nose and V_N is the nose volume. The code obtains S_C and V_N by numerically integrating the expressions:

$$S_C = 2 \int_{x_s}^{x_N} r(x)\,dx \tag{3}$$

$$V_N = \pi \int_{0}^{x_N} r^2(x)\,dx \tag{4}$$

using the input nose coordinates. The quantity x_s is the estimated initial axial position of flow separation on the nose (see ref. 3, pp. 10-11). Since the crossflow drag coefficient as used in the present method is not a function of axial position on the body, the axial center of pressure location of the viscous portion of the nose normal force (second term of eq. (1)) is given by

$$\bar{x}_{viscous} = \frac{2}{S_C} \int_{x_s}^{x_N} x\, r(x)\,dx \tag{5}$$

In reference 3, two methods for computing nose vortex strengths were used depending upon the length of the body up to the leading edge of the first finned section. During the course of the work for Phase I (reported herein), it was found that the method based on the crossflow drag coefficient was sufficient. The code uses only that method (see ref. 3, pp. 12-13).

2.2.2 Finned section forces and moments.- In reference 3, a method was presented for computing the normal-force coefficient for a rolled fin at angle of attack including the effects of panel-panel interference

and vortex-fin interference (see ref. 3, pp. 14-24 and Appendices A and B of this report). A method for computing the fin rolling-moment coefficient was also given (see ref. 3, pp. 29-30). This section describes the computation of all fin forces and moments.

Once the equivalent angle of attack for a given fin has been computed, the fin normal-force coefficient and center of pressure location can be found. The rolling moment for fin i has been given in reference 3 as

$$CRMi = \cos \delta_i \left\{ CNi(\alpha_{eq,p}) \frac{\bar{y}_i(\alpha_{eq,p})}{\ell_r} + \left[CNi\left(\alpha_{eq,p} + (\Delta\alpha_{eq})_v\right) - CNi(\alpha_{eq,p}) \right] \frac{\bar{y}_v}{\ell_r} \right\} \tag{6}$$

where $\alpha_{eq,p}$ is the equivalent angle of attack without the vortices present and $(\Delta\alpha_{eq})_v$ is the angle of attack induced on the fin by the vortices. The fin bending moment at the root chord follows from the normal force and rolling moment

$$CBMi = \frac{CRMi}{\cos \delta_i} - CNi \frac{a}{\ell_r} \tag{7}$$

The hinge moment is given by

$$CHMi = \frac{CNi}{\ell_r} (x_{HL} - \bar{x}_i) \tag{8}$$

The contributions of the fin forces and moments to the total missile forces and moments are given next in unrolled body coordinates.

$$C_{N_{fins}} = (CN2 \cos \delta_2 + CN4 \cos \delta_4) \cos \phi + (CN1 \cos \delta_1 + CN3 \delta_3) \sin \phi \tag{9}$$

$$C_{Y_{fins}} = (CN2 \cos \delta_2 + CN4 \cos \delta_4) \sin \phi - (CN1 \cos \delta_1 + CN3 \cos \delta_3) \cos \phi \tag{10}$$

$$C_{A_{fins}} = CN1 \sin \delta_1 + CN2 \sin \delta_2 + CN3 \sin \delta_3 + CN4 \sin \delta_4 \tag{11}$$

$$C_{m_{fins}} = C_{N_{fins}} \left(\frac{x_{MC} - x_{HL}}{\ell_r} \right)$$

$$+ (CBM2 \sin \delta_2 - CBM4 \sin \delta_4 + CHM1 + CHM3) \sin \phi$$

$$+ (CBM1 \sin \delta_1 - CBM3 \sin \delta_3 + CHM2 + CHM4) \cos \phi \tag{12}$$

$$C_{n_{fins}} = C_{Y_{fins}} \left(\frac{x_{MC} - x_{HL}}{\ell_r} \right)$$

$$- (CBM2 \sin \delta_2 - CBM4 \sin \delta_4 + CHM1 + CHM3) \cos \phi$$

$$+ (CBM1 \sin \delta_1 - CBM3 \sin \delta_3 + CHM2 + CHM4) \sin \phi \tag{13}$$

$$C_{\ell_{fins}} = - CRM1 + CRM2 + CRM3 - CRM4 \tag{14}$$

The total lift and drag due to lift for the fins are

$$C_{L_{fins}} = C_{N_{fins}} \cos \alpha_c - C_{A_{fins}} \sin \alpha_c \tag{15}$$

$$C_{D_{fins}} = C_{N_{fins}} \sin \alpha_c + C_{A_{fins}} \cos \alpha_c \tag{16}$$

In reference 9, a method based on slender-body theory is presented for computing the interference lift produced on a body at zero bank in the presence of a set of all-movable fins. For the case of $\alpha_c \neq 0$ and $\delta = 0$, an interference factor, K_B, is defined such that

$$C_{N_{B(W)}} = K_B \left. \frac{dC_{N_W}}{d\alpha} \right|_{\alpha=0} \cdot \alpha_c \quad , \quad \delta = 0 \tag{17}$$

The normal-force coefficient produced on the fins in the presence of the body is given by

$$C_{N_{W(B)}} = K_W \left. \frac{dC_{N_W}}{d\alpha} \right|_{\alpha=0} \cdot \alpha_c \quad , \quad \delta = 0 \tag{18}$$

Dividing (17) by (18) gives

$$\frac{C_{N_{B(W)}}}{C_{N_{W(B)}}} = \frac{K_B}{K_W} \quad , \quad \delta = 0 \tag{19}$$

For the case of $\alpha_c = 0$ and $\delta \neq 0$, an interference factor, k_B, is defined such that

$$C_{N_{B(W)}} = k_B \left.\frac{dC_{N_W}}{d\alpha}\right|_{\alpha=0} \cdot \delta \quad , \quad \alpha_c = 0 \tag{20}$$

The normal-force coefficient produced on the fins in the presence of the body is given by

$$C_{N_{W(B)}} = k_W \left.\frac{dC_{N_W}}{d\alpha}\right|_{\alpha=0} \cdot \delta \quad , \quad \alpha_c = 0 \tag{21}$$

Dividing (20) by (21) gives

$$\frac{C_{N_{B(W)}}}{C_{N_{W(B)}}} = \frac{k_B}{k_W} \quad , \quad \alpha_c = 0 \tag{22}$$

Nielsen (ref. 9) has shown that the ratios K_B/K_W and k_B/k_W differ by less than 5 percent over the entire range of the radius to semispan ratio. This result indicates that the fraction of wing normal force which is carried over onto the body can be assumed to be independent of the means of lift production. Hence, the present method assumes

$$C_{N_{body}} = \frac{K_B}{K_W} C_{N_{fins}} \tag{23}$$

Similarly,

$$C_{Y_{body}} = \frac{K_B}{K_W} C_{Y_{fins}} \tag{24}$$

Reference 10 gives a method for computing the axial location of the center of pressure, $\bar{x}_B$, for the force on the body due to the fins

for zero fin deflection and zero roll. We assume for the present method that $\bar{x}_B$ gives the correct value independent of the means of lift production on the fins. The moments created by the body force due to the presence of the fins are

$$C_{m_{body}} = C_{N_{body}} \frac{x_{MC} - \bar{x}_B}{\ell_r} \tag{25}$$

$$C_{n_{body}} = C_{Y_{body}} \frac{x_{MC} - \bar{x}_B}{\ell_r} \tag{26}$$

$$C_{\ell_{body}} = 0 \tag{27}$$

The user has the option of having the code compute K_B and $\bar{x}_B$ using the methods of reference 10 or of using values obtained by some other method such as the code of Appendix F.

2.2.3 Afterbody section forces and moments.- The model used in the present method for vortex tracking over the afterbody section has been discussed previously in reference 3, pages 24-28, and in reference 11, pages 6-11. The discussion is repeated and extended in Appendix D. The present code does not account for tearing of afterbody vortices.

The afterbody loading is computed from the vortex impulse theorem using the vortex strengths and positions computed by the tracking method. The vortex impulse theorem for moderate angles of attack gives the following expression for the loading on an infinitesmal length of the afterbody in the presence of vortices

$$dC_N - i\, dC_Y = \frac{4\pi a^2}{S_R} \sum_{j=1}^{NV(x)} d(\Gamma'\sigma') \tag{28}$$

where σ' is the nondimensional complex distance between a vortex and its image inside the cylinder. Since the afterbody vortices may form anywhere between the canard trailing edge and the tail leading edge, the number of vortices NV is a function of axial position.

We can integrate equation (28) to obtain the afterbody forces and moments. The results are

$$C_N - iC_Y = \frac{4\pi a^2}{S_R} \sum_{j=1}^{NV(x)} \left[(\Gamma'\sigma')_{XTLE} - (\Gamma'\sigma')_{XCTE} \right] \tag{29}$$

$$C_m - iC_n = \frac{4\pi a^2}{S_R} \sum_{j=1}^{NV(x)} \int_{XCTE}^{XTLE} (x_{MC} - x)\, d(\Gamma'\sigma') \tag{30}$$

The integral in equation (30) is approximated by numerical quadrature in the code. The lower and upper limits of the integral are the trailing edge of the canard section and the leading edge of the tail section respectively.

3. COMPARISONS WITH DATA FOR FINS WITH NO EXTERNAL VORTICES PRESENT

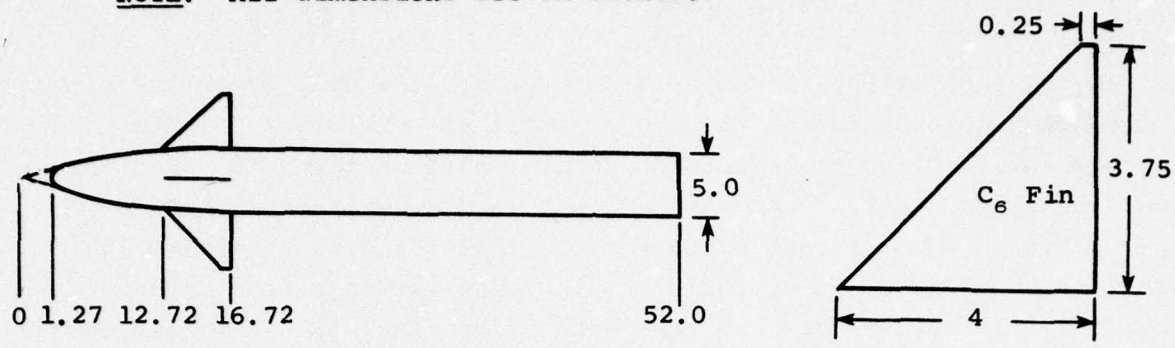
The purpose of this section is to evaluate the ability of the method to predict fin loads in the absence of external vortices. The fins and fin-body combinations to be considered are shown in figure 3. Section 3.1 considers clipped delta fins with a leading-edge sweep of 45° and a taper ratio of 0.06 (aspect ratio = 3.5). According to reference 12, such fins should have very little leading-edge vortex lift. Hence, section 3.1 is an evaluation of the method for fins with no significant vortex lift. Section 3.2 considers two sets of low-aspect-ratio fins for which fin-generated vortex lift is a substantial fraction of the total fin lift.

3.1 Moderate-Aspect-Ratio Fins

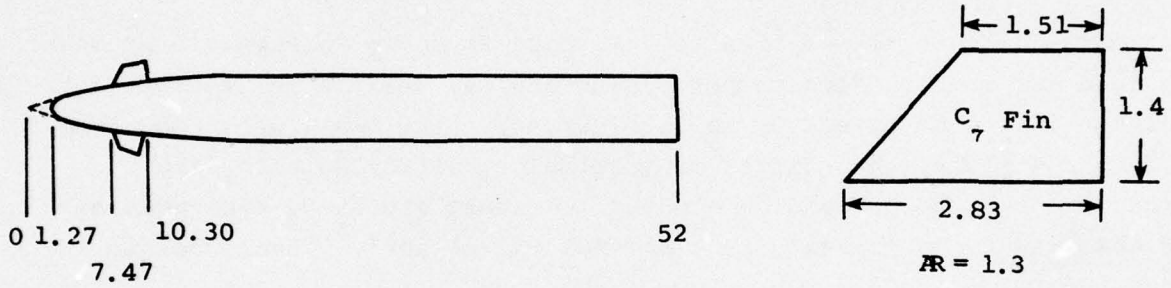
Data for this set of fins (C_6) mounted as shown in figure 3(a) were obtained for several Mach numbers, bank angles, and fin deflections for included angles of attack up to 24° (ref. 4). The tests were conducted in such a way that the effects of bank only, deflection only, and combinations of both could be studied. A small amount of nose vorticity was observed to be present (ref. 5) that may slightly affect the fin 1 loads.

The wing-alone characteristics used for the predictions are shown in figure 4. The normal force and lateral location of center of pressure data were obtained for $\alpha_c < 30°$ from reference 4. The wing-alone values were computed from fin loads measured for $\phi = 0$, no yaw control and various values of pitch control. A description and experimental verification of this procedure is given in reference 6, pages 21-25. The results were extrapolated to higher angles of attack using a procedure given by Aiello (ref. 13). The axial location of the fin center of pressure was estimated as follows. Axial locations of the center of pressure for several sets of closely related fins tested alone and on bodies (refs. 4, 14, and 15) were compared for equivalent angles of attack up to 45° (see fig. 4). A linear best fit was applied to the data wherever the scatter was not large. For $M_\infty = 0.8$, the scatter was too large to fit for $\alpha_c < 14°$ and $\bar{x}/c_r$ was arbitrarily set equal to 0.55. In each of the subsections below the discussion centers first on the effects

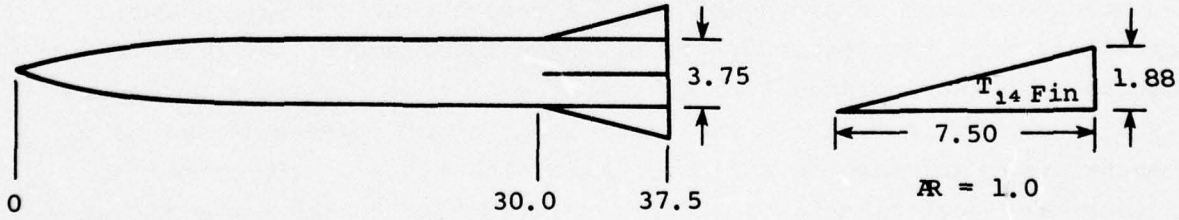
NOTE: All dimensions are in inches.



(a) Body-canard configuration no. 1 (BC 1); moderate-aspect-ratio C_6 fins mounted on 3-caliber tangent ogive nose with 7-caliber cylindrical afterbody. (MICOM-NWC tests, ref. 4).

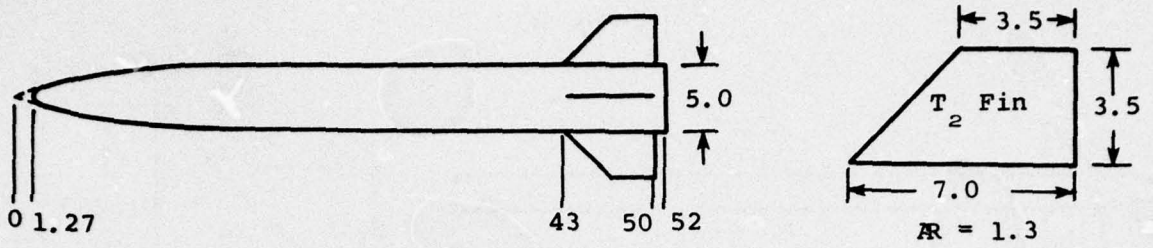


(b) Body-canard configuration no. 2 (BC 2); low-aspect-ratio C_7 fins mounted on 3-caliber tangent ogive nose with 7-caliber cylindrical afterbody (MICOM-NWC tests, ref. 4).

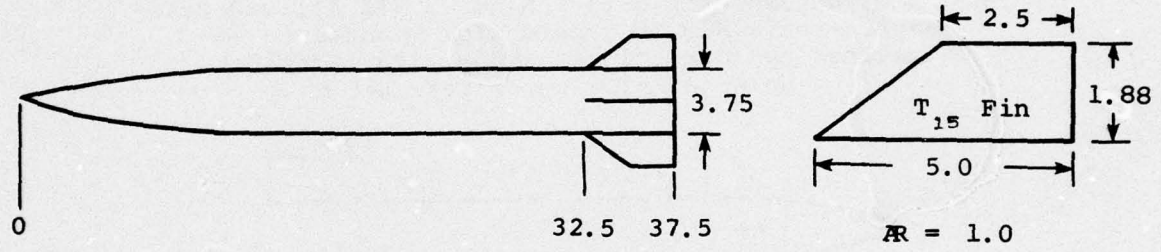


(c) Body-tail configuration no. 1 (BT 1); low-aspect-ratio T_{14} fins mounted on 10-caliber body (MICOM tests, ref. 16).

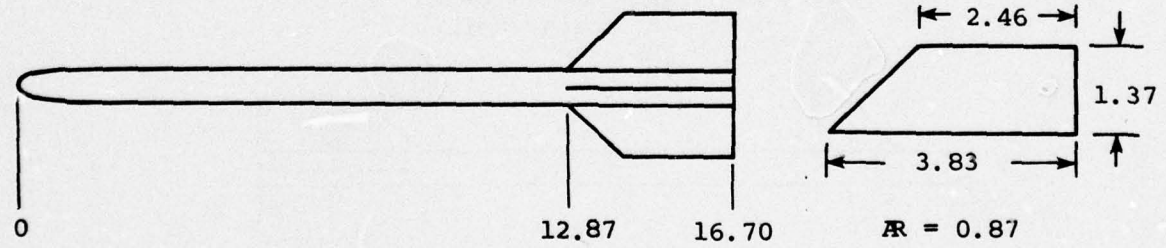
Figure 3. Configurations used for comparisons of data and theory.



(d) Body-tail configuration no. 2 (BT 2); low-aspect-ratio T_2 fins mounted on 10-caliber body (MICOM-NWC tests, ref. 4).

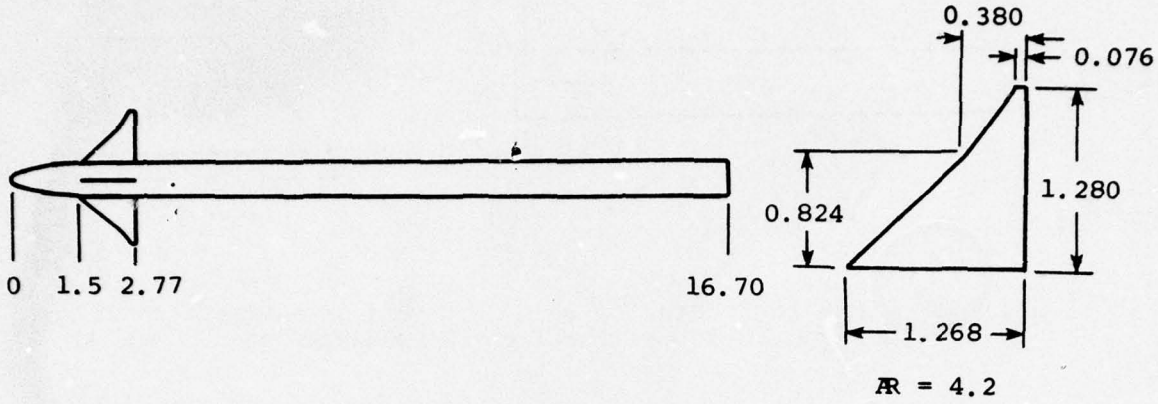


(e) Body-tail configuration no. 3 (BT 3); low-aspect-ratio T_{15} fins mounted on 10-caliber body (MICOM tests, ref. 16).

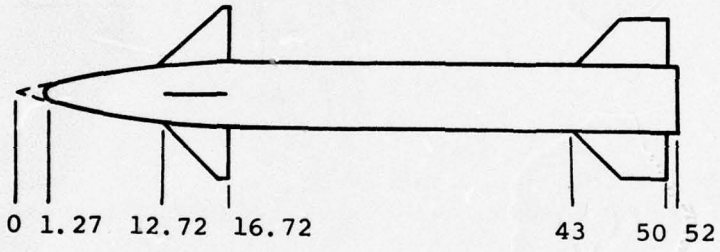


(f) Body-tail configuration no. 4 (BT 4); low-aspect-ratio AIM-9L tail fins mounted on 22-caliber body (AIM-9L tests, ref. 14).

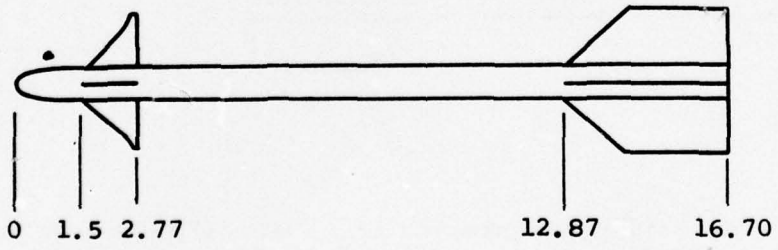
Figure 3. Continued.



(g) Body-canard configuration no. 3 (BC 3); moderate-aspect-ratio AIM-9L canard fins mounted on 20-caliber cylindrical afterbody with 2-caliber nose (AIM-9L tests, ref. 14).

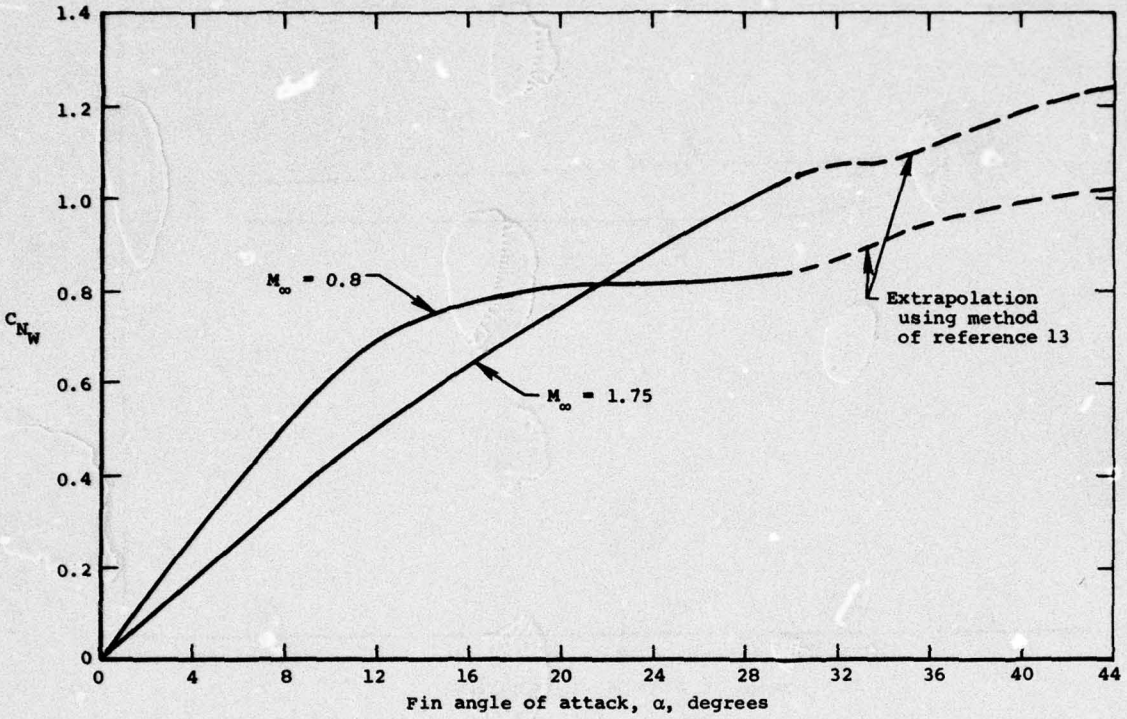


(h) Body-canard-tail configuration no. 1 (BCT 1); C_6 and T_2 fins mounted on 10-caliber body. (MICOM-NWC tests, ref. 4).



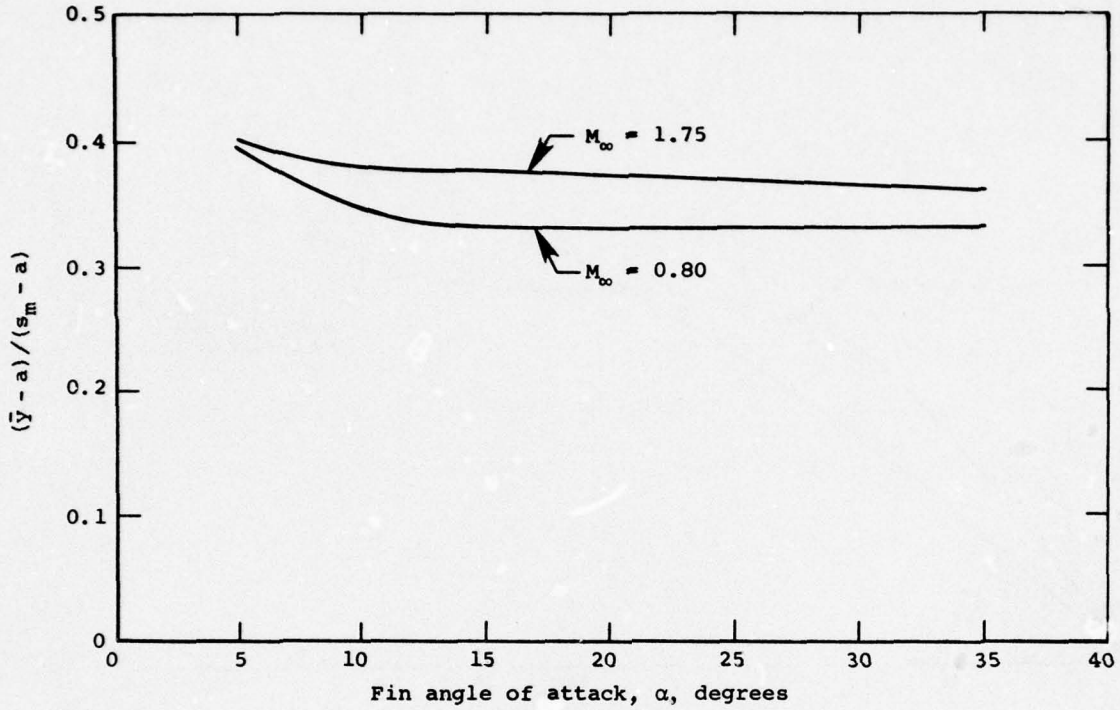
(i) Body-canard-tail configuration no. 2(BCT 2); AIM-9L model, reference 14.

Figure 3. Concluded.



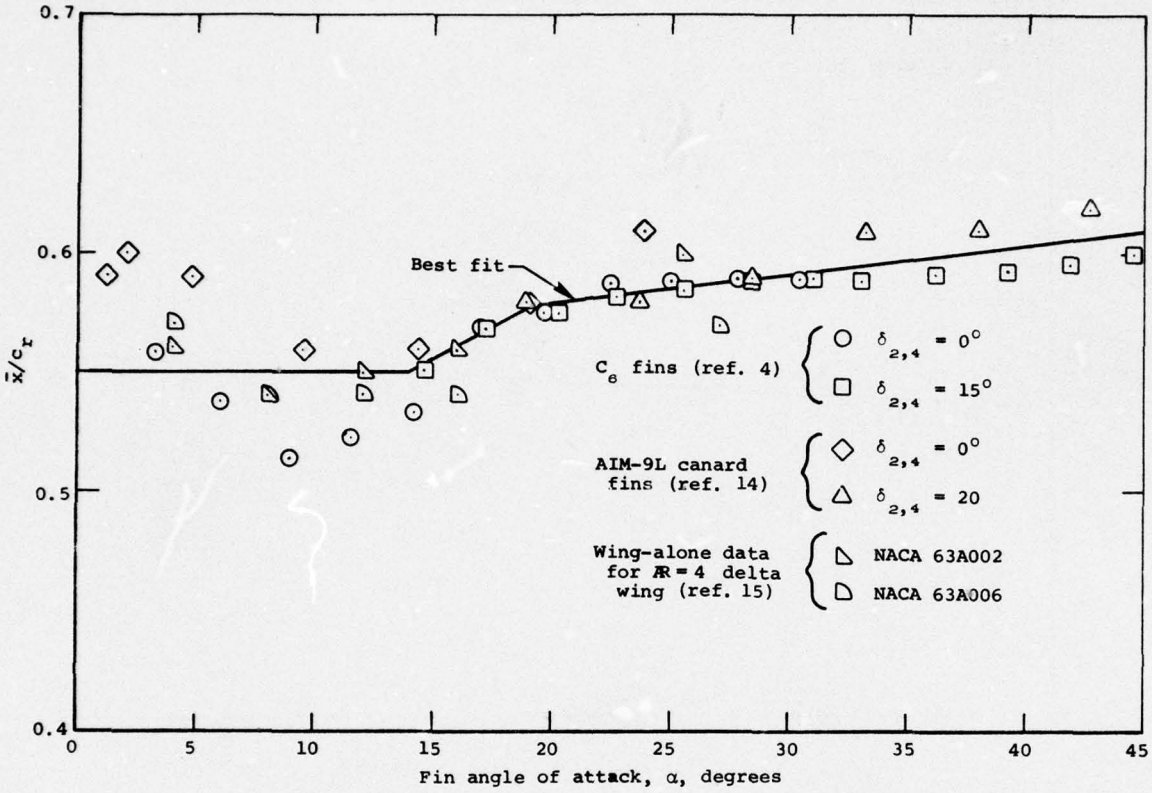
(a) Normal-force coefficient.

Figure 4. Wing-alone characteristics for moderate-aspect-ratio fins (C_6); S_R = planform area.



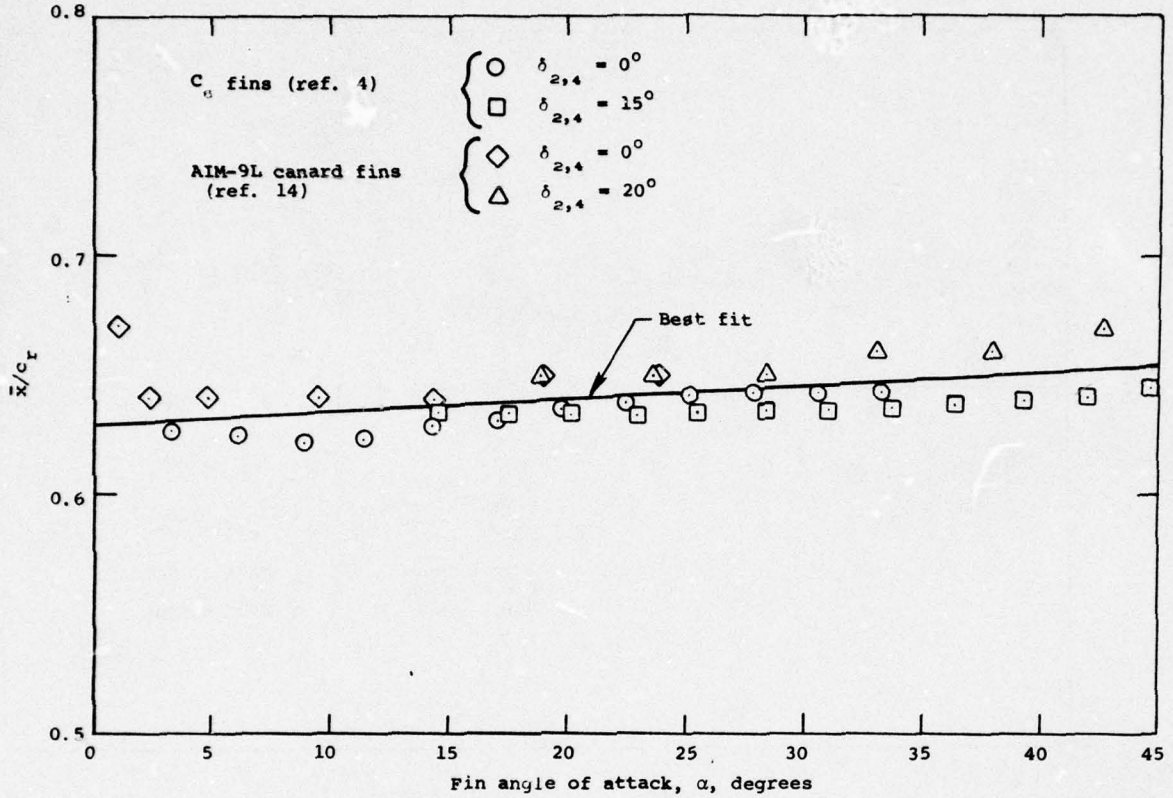
(b) Lateral center of pressure position.

Figure 4. Continued.



(c) Axial center of pressure position for $M_\infty = 0.8$.

Figure 4. Continued.



(d) Axial center of pressure position for M_∞ = 1.75.

Figure 4. Concluded.

of bank only, second on the effects of fin deflection only, and third on the combined effects of bank and fin deflection.

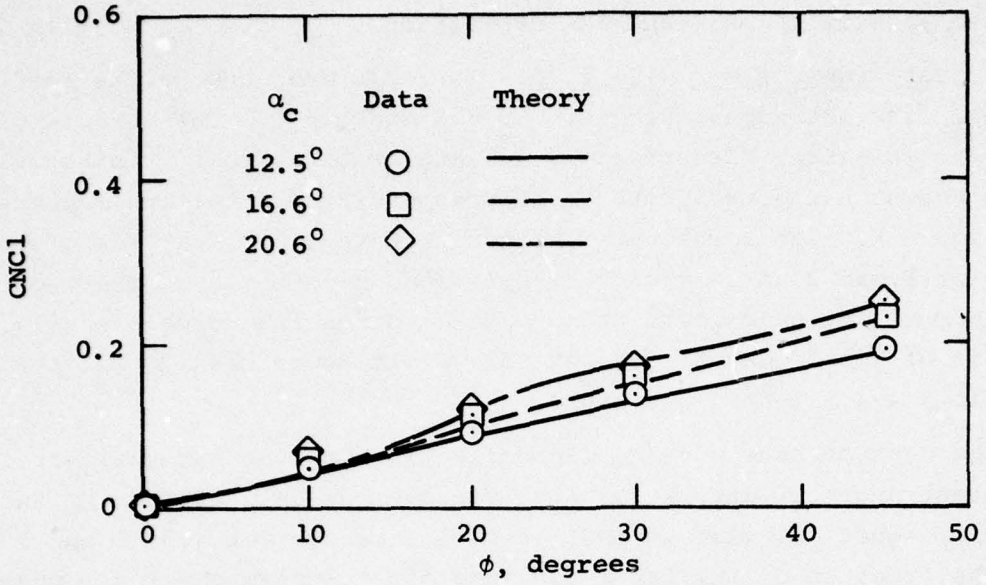
3.1.1 Supersonic flow, $M_\infty = 1.75$.- For this Mach number the leading edges of the fins are supersonic for $\alpha_c = 0$ and $\phi = 0$. The effects of bank only are presented first for several angles of attack. Fin normal forces are shown in figure 5 with the corresponding fin rolling moments shown in figure 6. The agreement is good. However, a comparison of the data for fins 1 and 2 at $\phi = 45^\circ$ reveals some discrepancy. The two fins should have the same loads at $\phi = 45^\circ$. Since the normal-force coefficients of fins 2 and 4 agree at $\phi = 0$, it seems likely that the data for fin 1 are slightly too high.

For the case of bank with no fin deflections and no external vortices, the equivalent angle of attack for each fin depends only on the K_W and $K_{\alpha\beta}$ terms of equations (23) to (26) of reference 3. For fins 1 and 2 at $\phi = 45^\circ$, the fraction of the total fin load for the case under discussion represented by the $K_{\alpha\beta}$ term ranges from 25 percent at $\alpha_c = 12.5^\circ$ to 40 percent at $\alpha_c = 20.6^\circ$. Thus, the generally good agreement exhibited in figure 5 suggests that the present method adequately accounts for bank angle when no fin vorticity is generated. The agreement for fin rolling moment is similar to that for fin normal force.

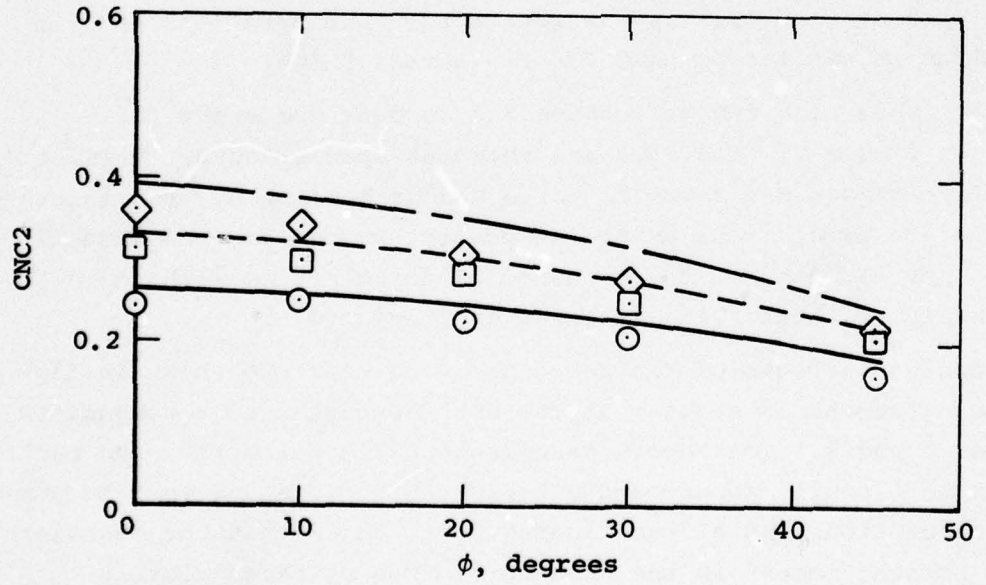
The fin loads with fin deflection and no bank are shown for $M_\infty = 1.75$ in figure 7. The data are shown as open symbols. Predictions using the Task 1 code are shown as solid and dashed lines. The agreement between data and predictions using the present method is good except for fin 3. For fin 3 the rate of change of normal force with α_c, although small, is about twice as great as predicted.

The combined effects of fin deflection and bank are shown in figure 8. The agreement is about what one would expect from a comparison with figures 5 and 7. The theory assumes that fin deflection and bank effects can be linearly superposed and figures 5, 7, and 8 seem to confirm that assumption. Note from figures 5, 6, and 7 that the behavior of the fin rolling moment in the absence of free vortices closely follows that of the fin normal force.

3.1.2 Subsonic Flow, $M_\infty = 0.8$.- At high angles of attack, the flow about body-canard configuration no. 1 (see fig. 3(a)) at $M_\infty = 0.8$ is transonic. Hence, the results of this section represent an evaluation of the method for extreme transonic flow conditions. The effects of

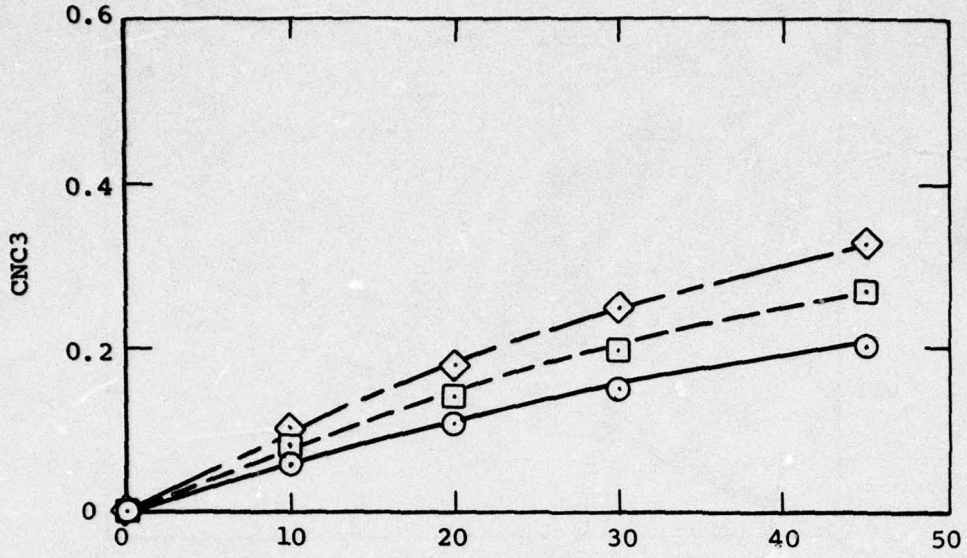


(a) Fin 1.

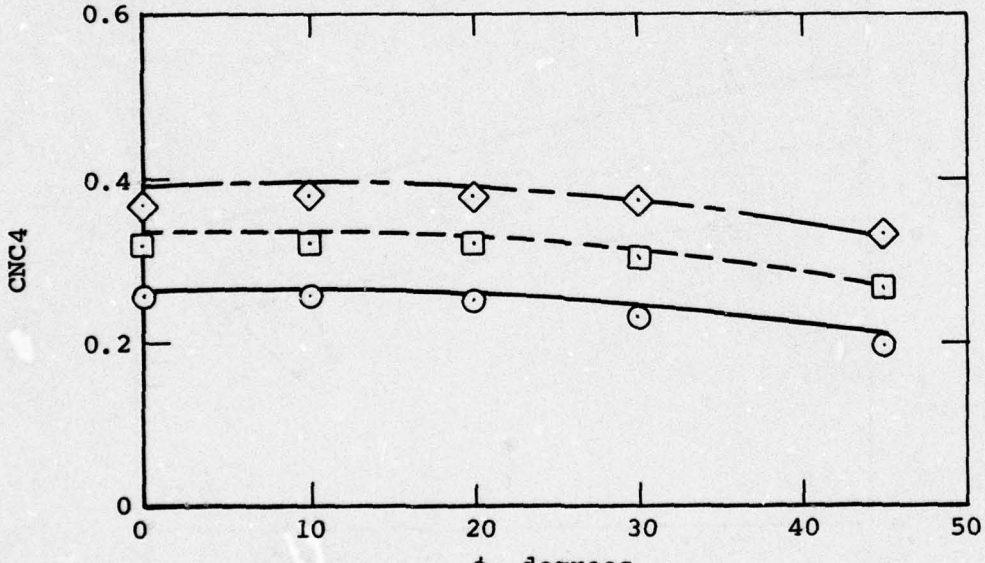


(b) Fin 2.

Figure 5. Fin normal force for bank with no fin deflection, moderate-aspect-ratio fins (C_e), BC 1, M_∞ = 1.75; S_R = model base area.



(c) Fin 3.



(d) Fin 4.

Figure 5. Concluded.

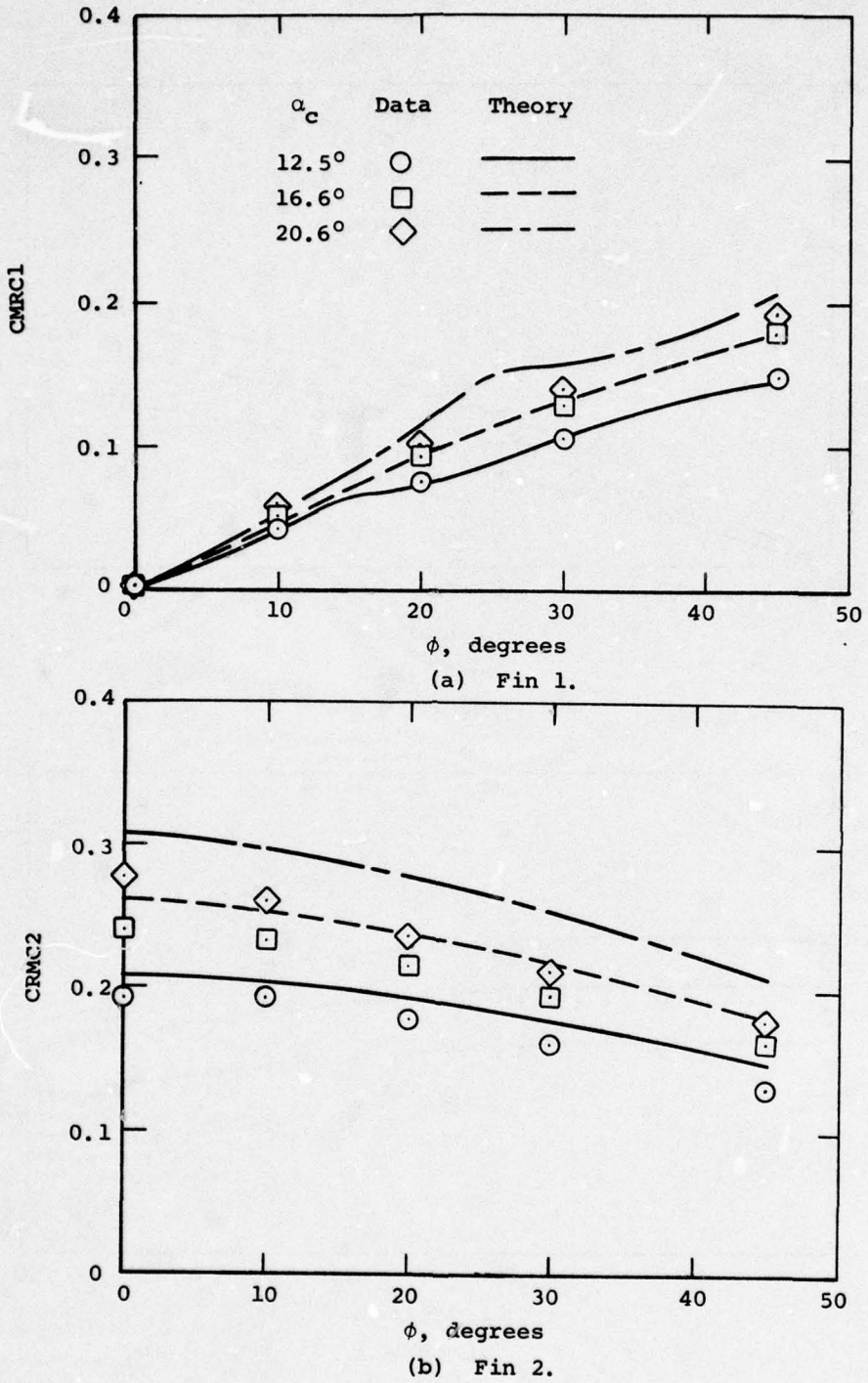
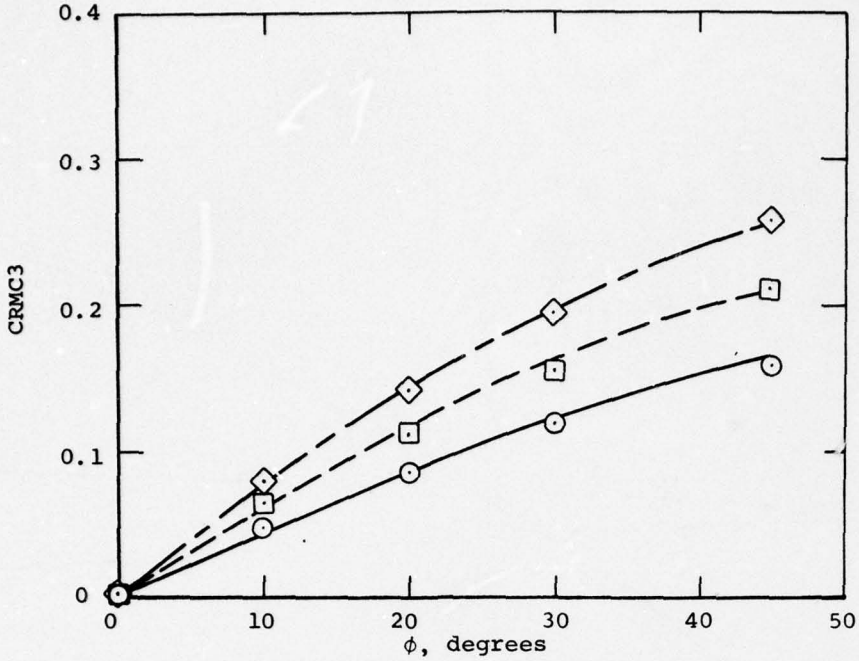
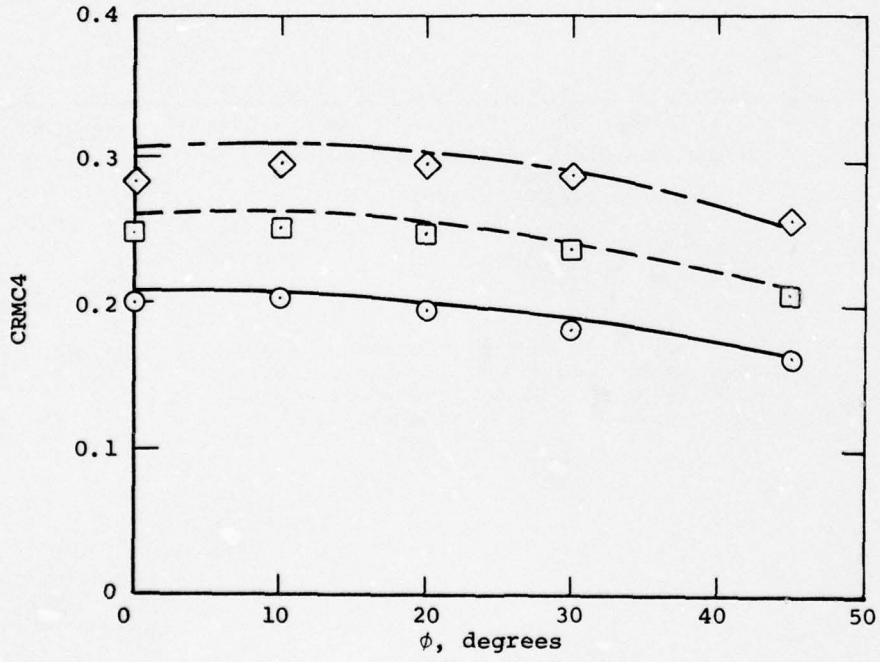


Figure 6. Fin rolling moment for bank with no fin deflection, moderate-aspect-ratio fins (C_6), BC 1, M_∞ = 1.75; S_R = model base area, ℓ_r = model base diameter.

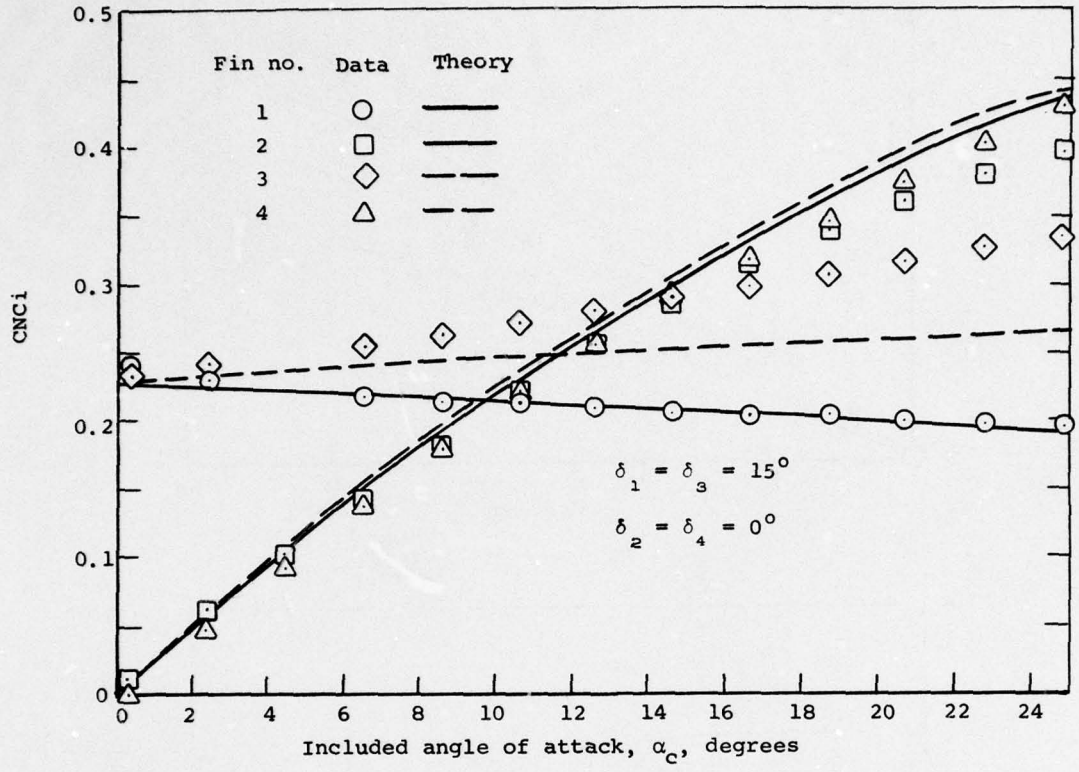


(c) Fin 3.



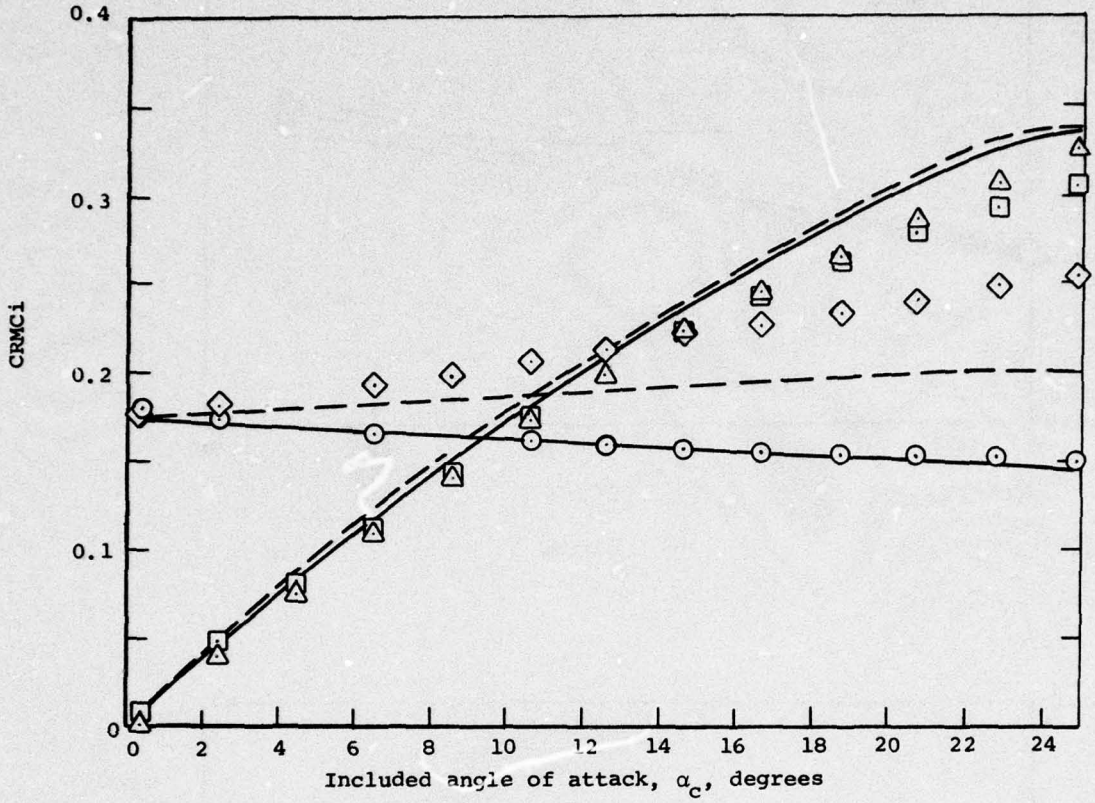
(d) Fin 4.

Figure 6. Concluded.



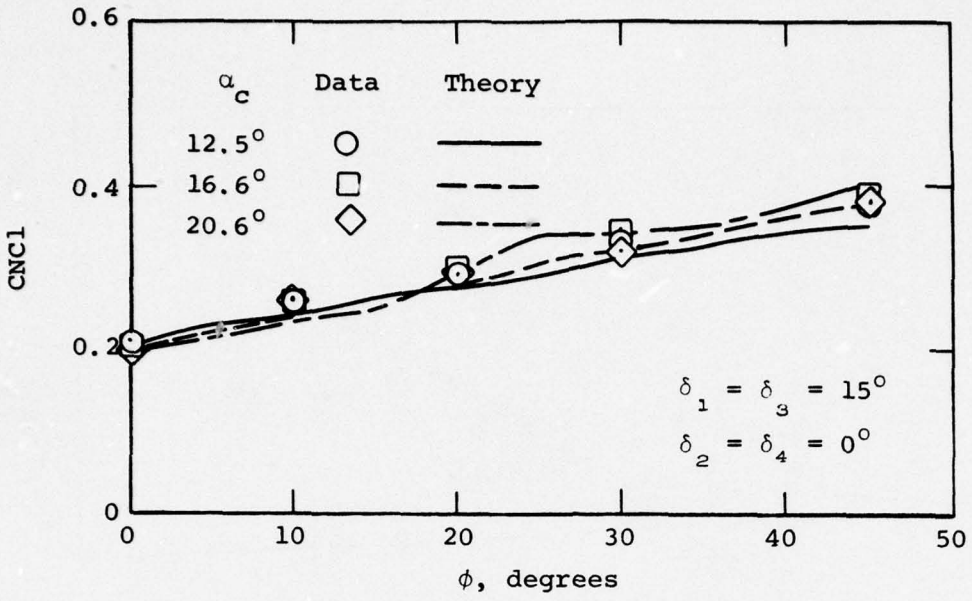
(a) Normal-force coefficient.

Figure 7. Fin normal force and rolling moment for fin deflection with no bank, moderate-aspect-ratio fins (C_e), BC 1, M_∞ = 1.75; S_R = model base area, ℓ_r = model base diameter.

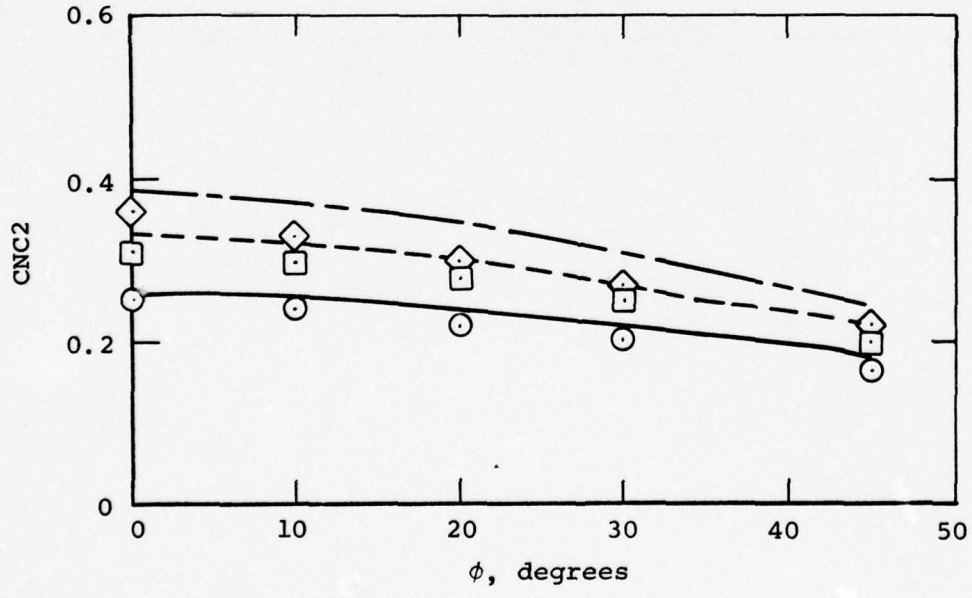


(b) Rolling-moment coefficient.

Figure 7. Concluded.

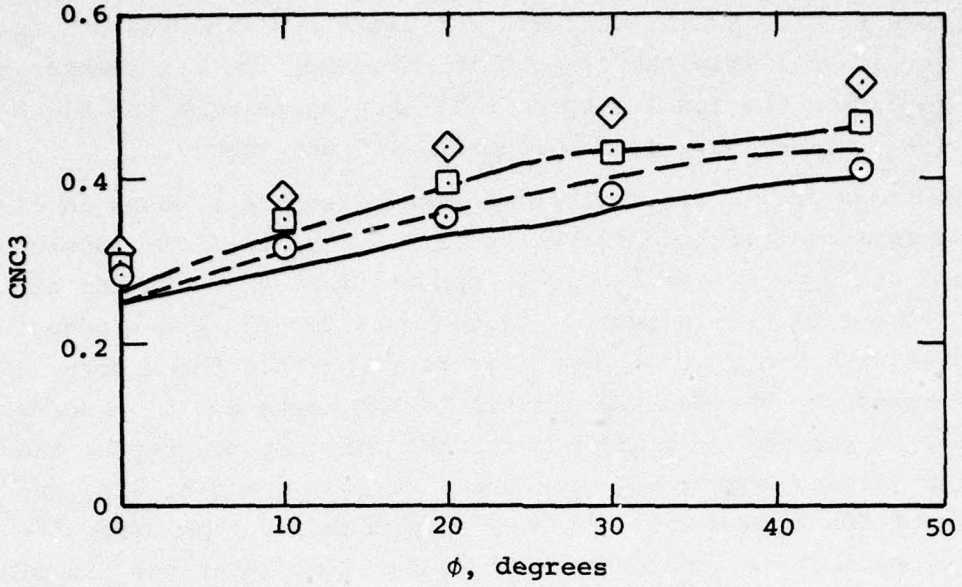


(a) Fin 1.

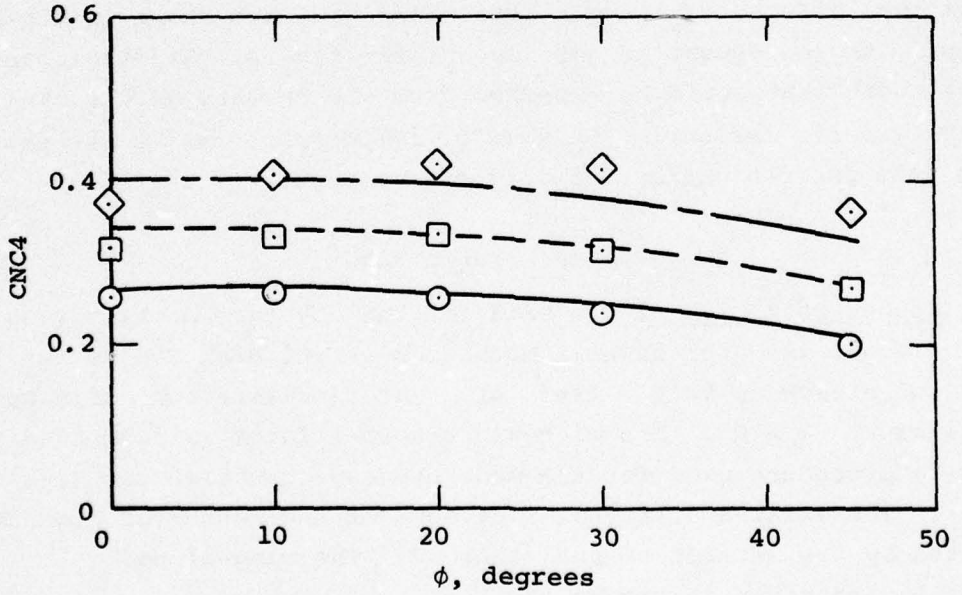


(b) Fin 2.

Figure 8. Fin normal force for combined bank and fin deflection, moderate-aspect-ratio fins (C_6), BC 1, M_∞ = 1.75; S_R = model base area.



(c) Fin 3.



(d) Fin 4.

Figure 8. Concluded.

bank only are presented in figure 9. The agreement is generally very good except for fin 1. Again, the data for fin 1 and fin 2 do not agree at $\phi = 0$. It seems likely that, for this case too, the fin 1 data are too high. Adjusting the fin 1 data so that they agree with the fin 2 data at $\phi = 45^\circ$ gives very good agreement with the theory.

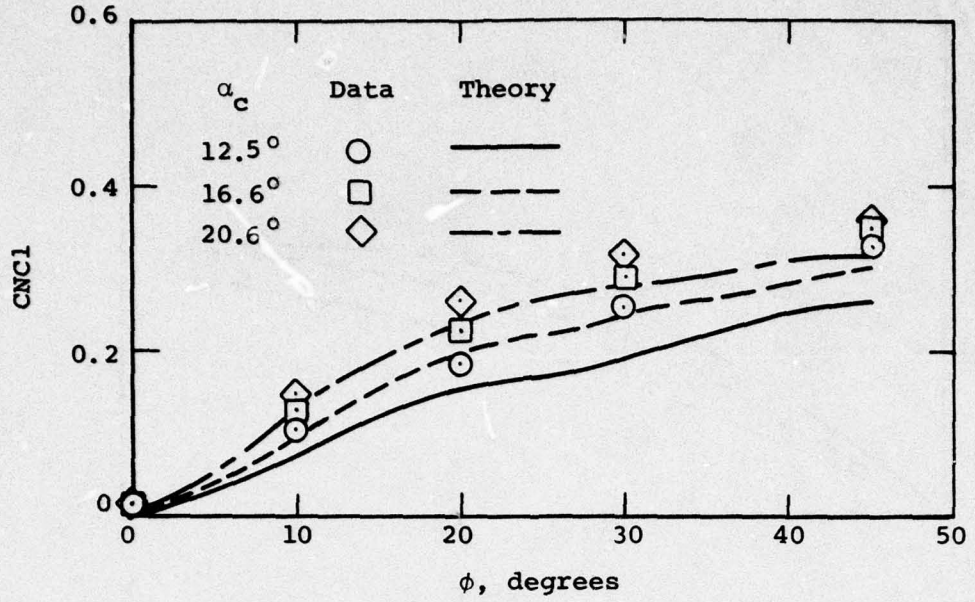
The fin loads due to fin deflection with no bank are shown in figure 10. The agreement is good except for fin 1. Since fin 1 should have the same load at $\alpha_c = 0^\circ$ as fin 3, it appears that the data for at least one of the fins are in error. If the data for fin 1 are adjusted so as to agree with fin 3 at $\alpha_c = 0^\circ$, it is found that the theory slightly overpredicts the decrease in fin normal force as α_c increases for $\alpha_c > 6^\circ$. A possible explanation for this discrepancy may be the change in fin leading-edge sweep with α_c. At $\phi = 0$ and $\alpha_c = 0$, the leading edge of fin 1 is swept 45°. As α_c increases, the effective sweep of the leading edge increases. It seems likely that the fin picks up significant vortex lift as α_c increases. This point will be discussed further in section 3.2. Note that for $\alpha_c > 16^\circ$, fin 1 seems to be favorably affected by the nose vorticity. This point will be discussed further in section 4.

The combined effects of fin deflection and bank are shown in figure 11. Again, the agreement is good except for fin 1. The discrepancy for fin 1 is about what would be expected from the results of the bank only (fig. 9) and fin deflection only (fig. 10) comparisons as discussed above. The data for fin deflection only are suspect.

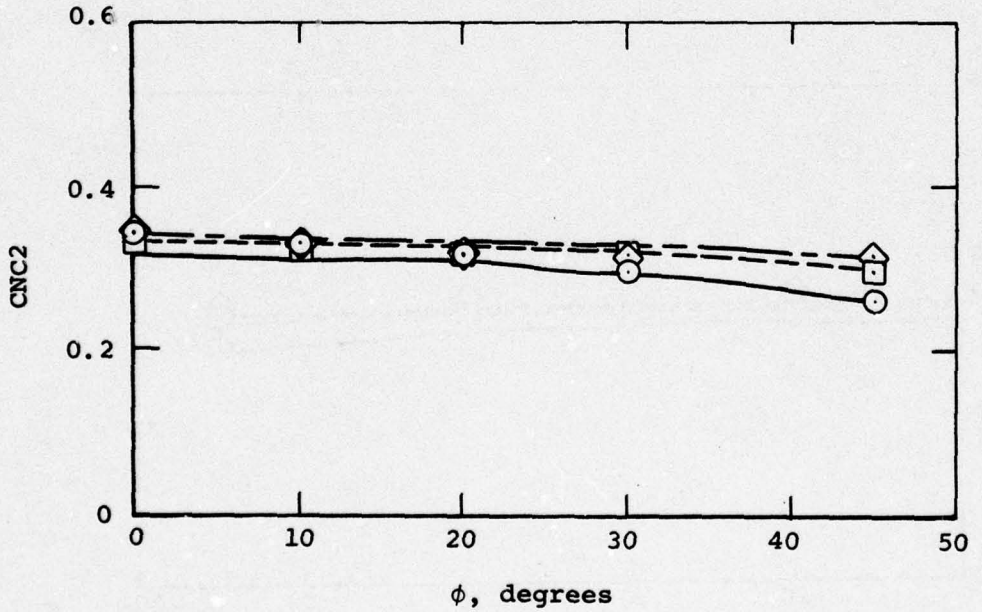
3.2 Low-Aspect-Ratio Fins

3.2.1 Aspect ratio 1.3 fins.- Data for the C_7 set of fins (see fig. 3(b)) were obtained for several Mach numbers and bank angles for model angles of attack up to 24° (ref. 4). The fins were not deflected except in pitch at $\phi = 0^\circ$. The wing-alone normal force was computed using the same procedure used for the moderate-aspect-ratio fins (see section 3.1). The axial and lateral locations of the center of pressure were estimated by the methods of reference 13. The wing-alone characteristics are given in figure 12.

Comparisons of theory and data for $M_\infty = 1.75$ for nose-canard configuration no. 2 (C_7 fins) are presented in figure 13. The data trends are similar to those observed in figure 5 for the moderate-aspect-

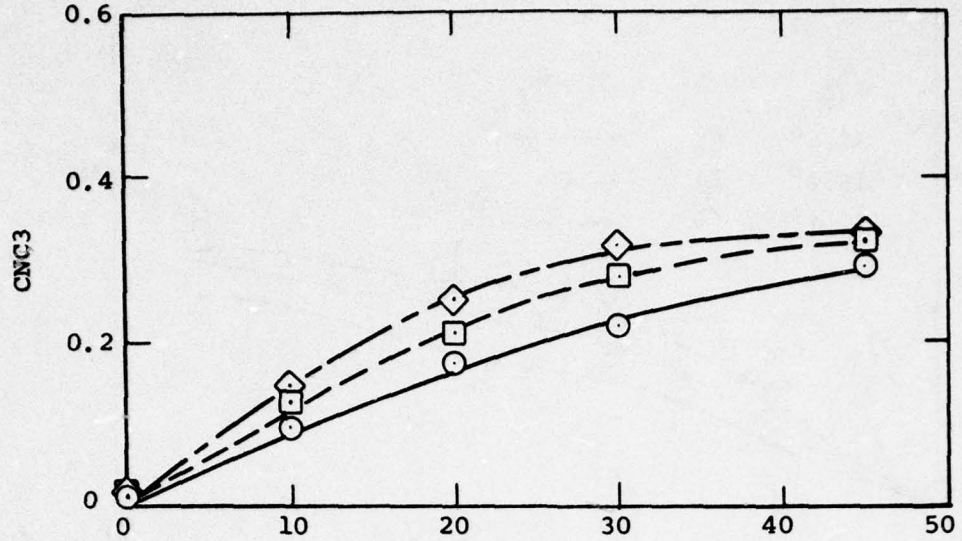


(a) Fin 1.

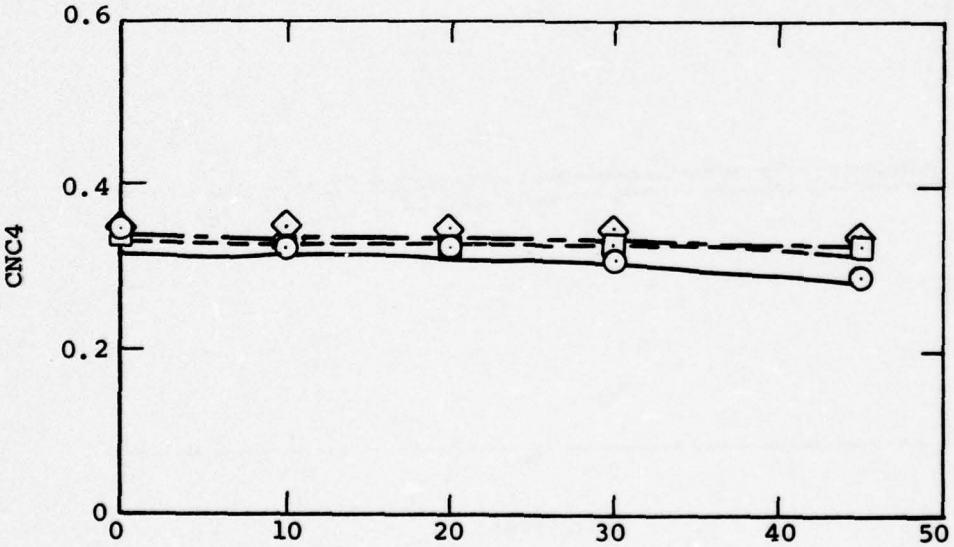


(b) Fin 2.

Figure 9. Fin normal force for bank with no fin deflection, moderate-aspect-ratio fins (C_e), BC 1, M_∞ = 0.8; S_R = model base area.



(c) Fin 3.



(d) Fin 4.

Figure 9. Concluded.

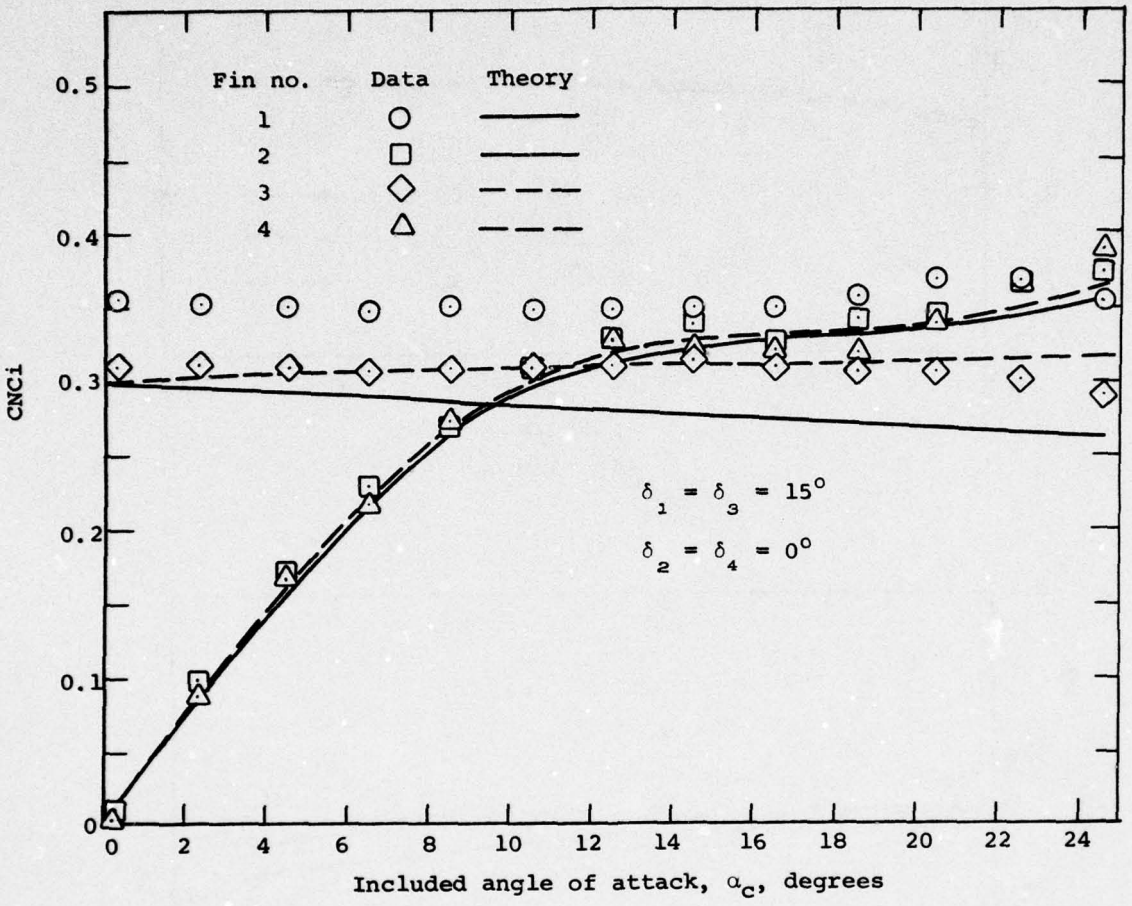
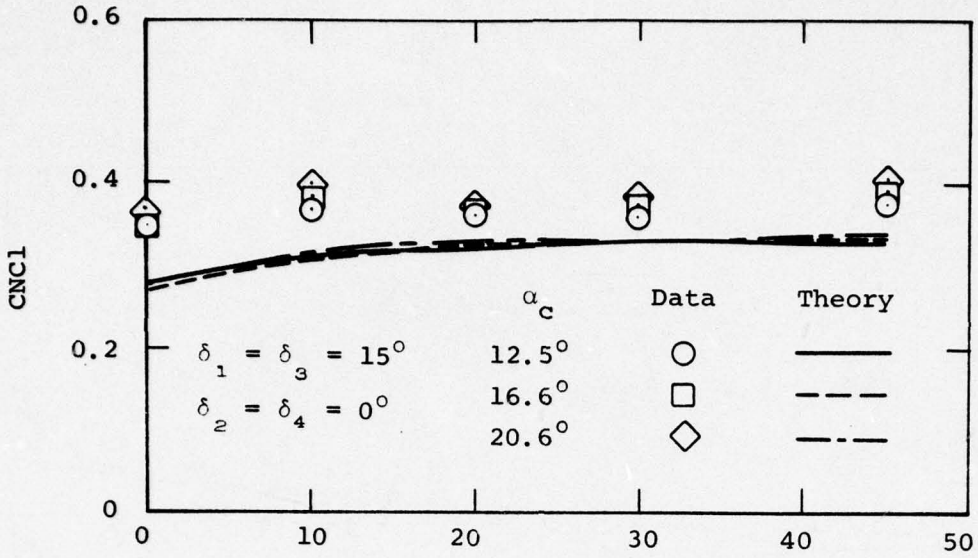
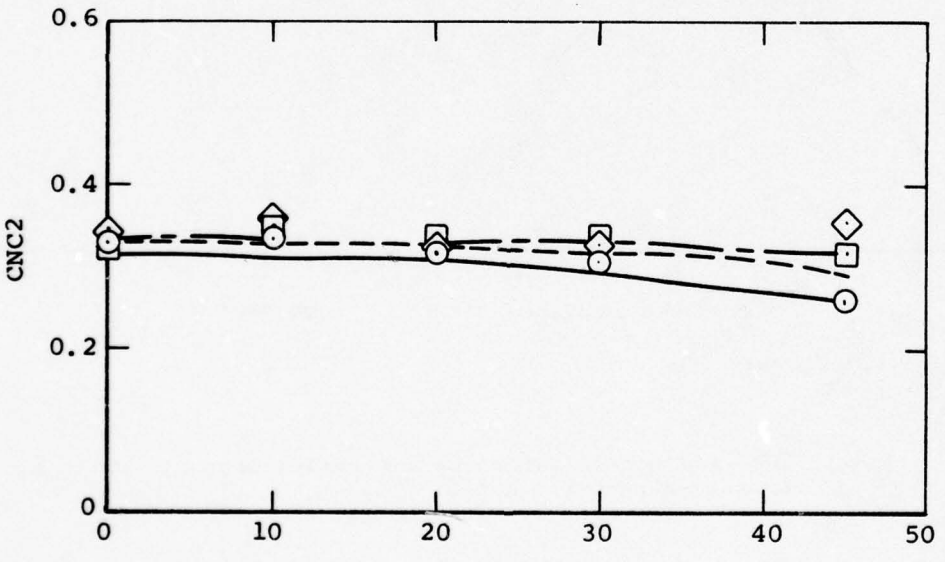


Figure 10. Fin normal force for fin deflection with no bank, moderate-aspect-ratio fins (C_6), BC 1, $M_\infty = 0.8$; S_R = model base area.

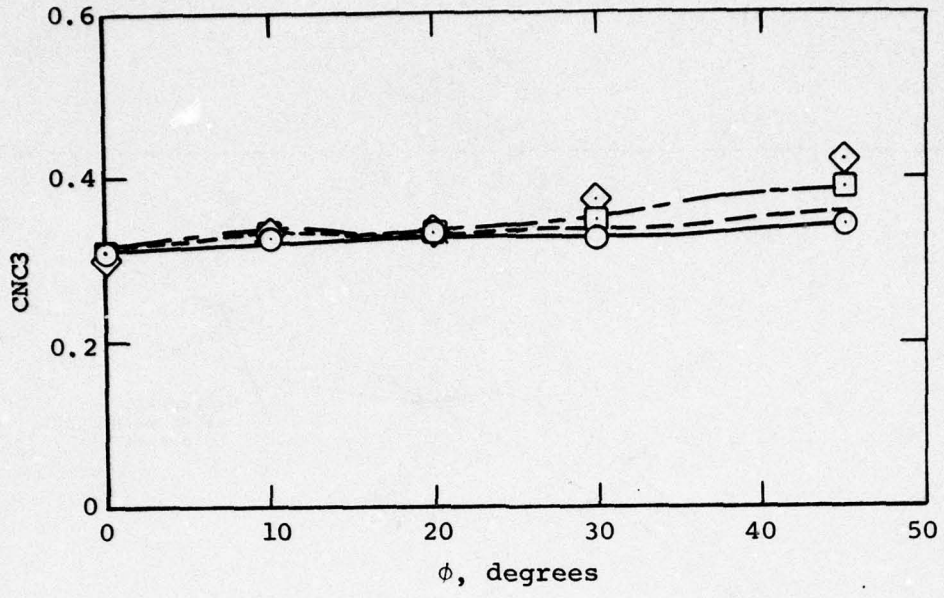


(a) Fin 1.

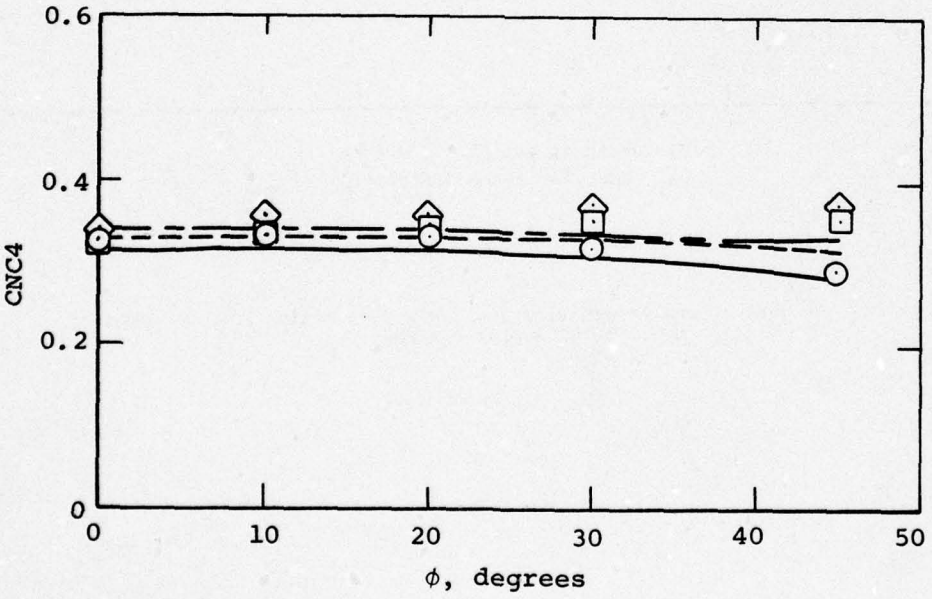


(b) Fin 2.

Figure 11. Fin normal force for combined bank and fin deflection, moderate-aspect-ratio fins (C_6), BC 1, $M_\infty = 0.8$; S_R = model base area.

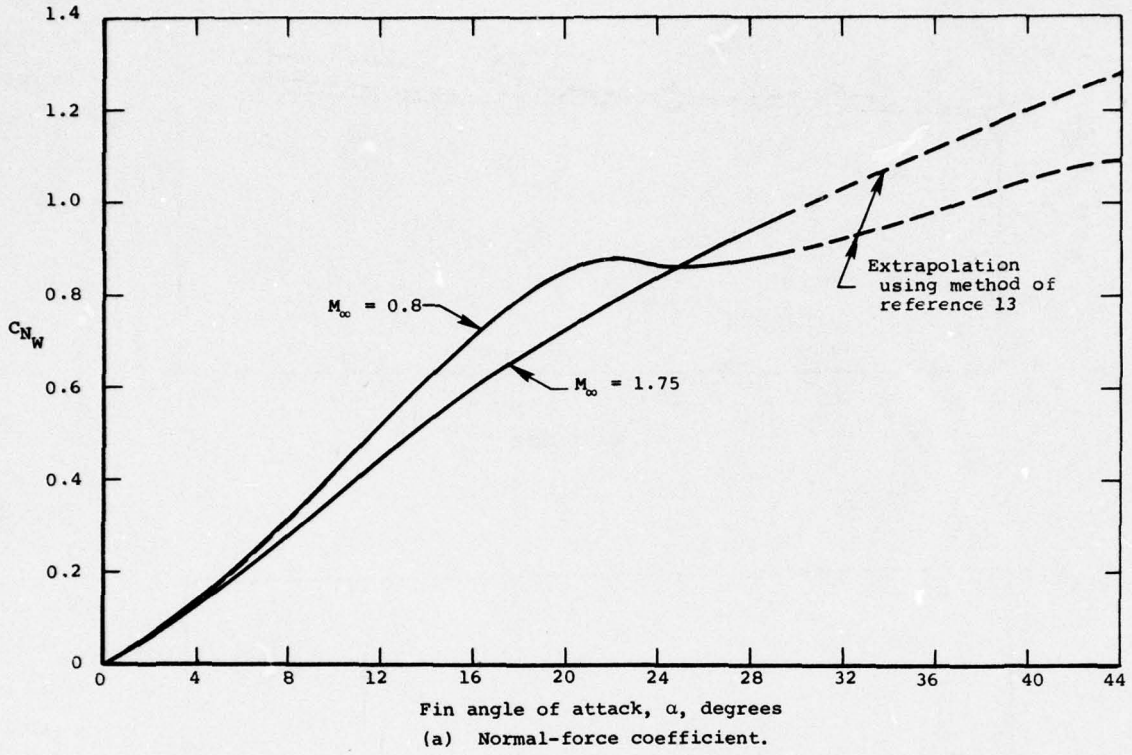


(c) Fin 3.



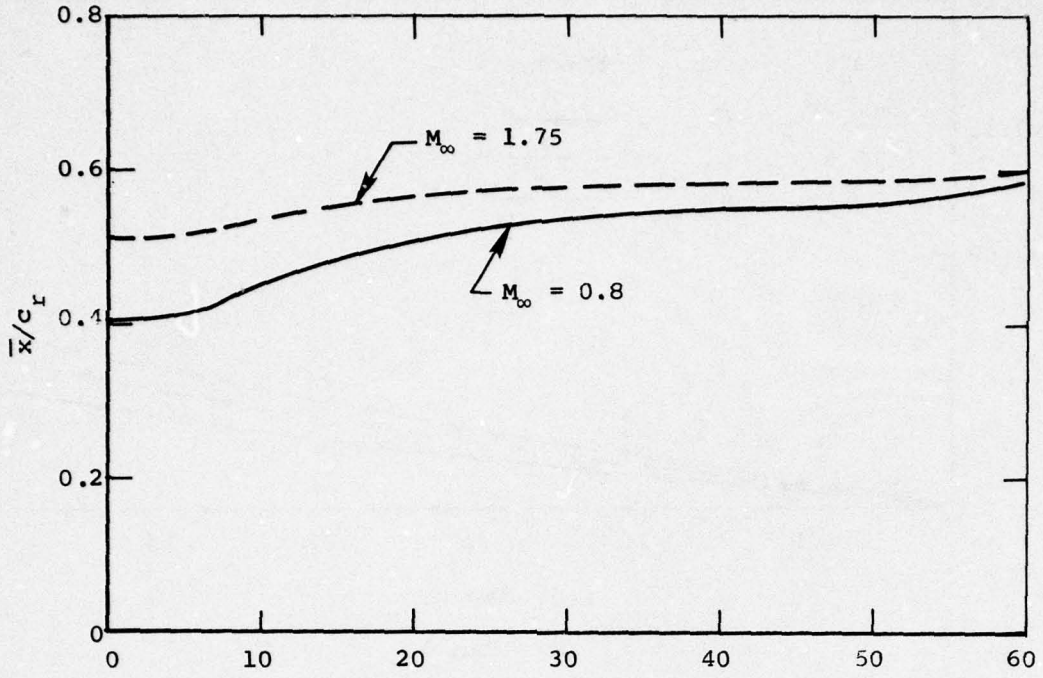
(d) Fin 4.

Figure 11. Concluded.



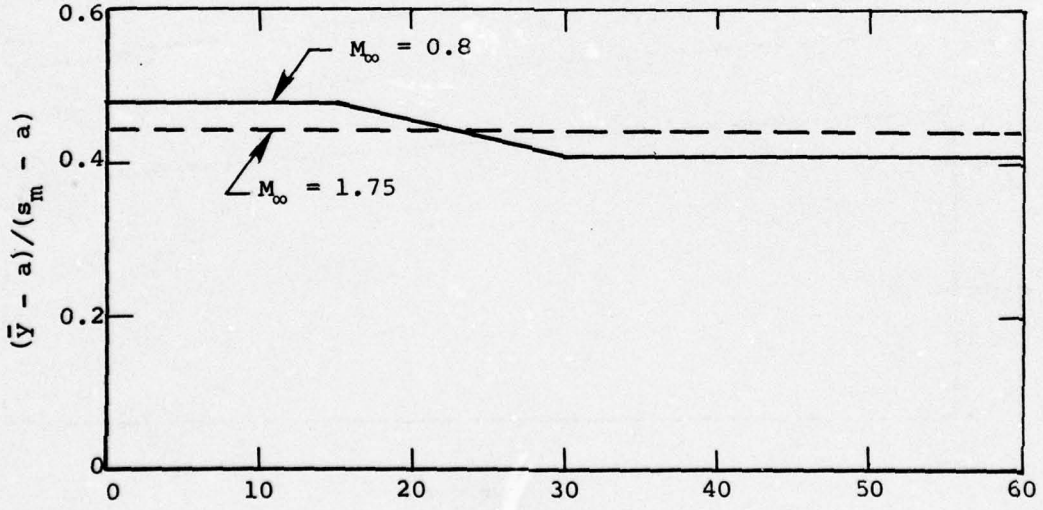
(a) Normal-force coefficient.

Figure 12. Wing-alone characteristics for low-aspect-ratio fins (C_7 and T_2); AR = 1.3, S_R = planform area.



Fin angle of attack, α, degrees

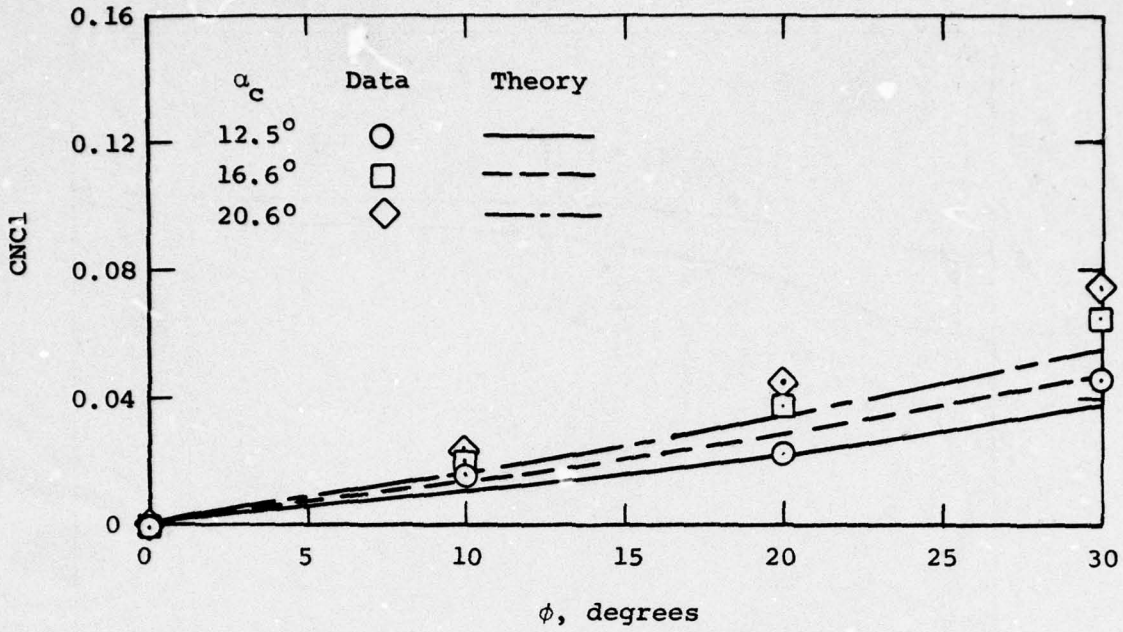
(b) Axial center of pressure position.



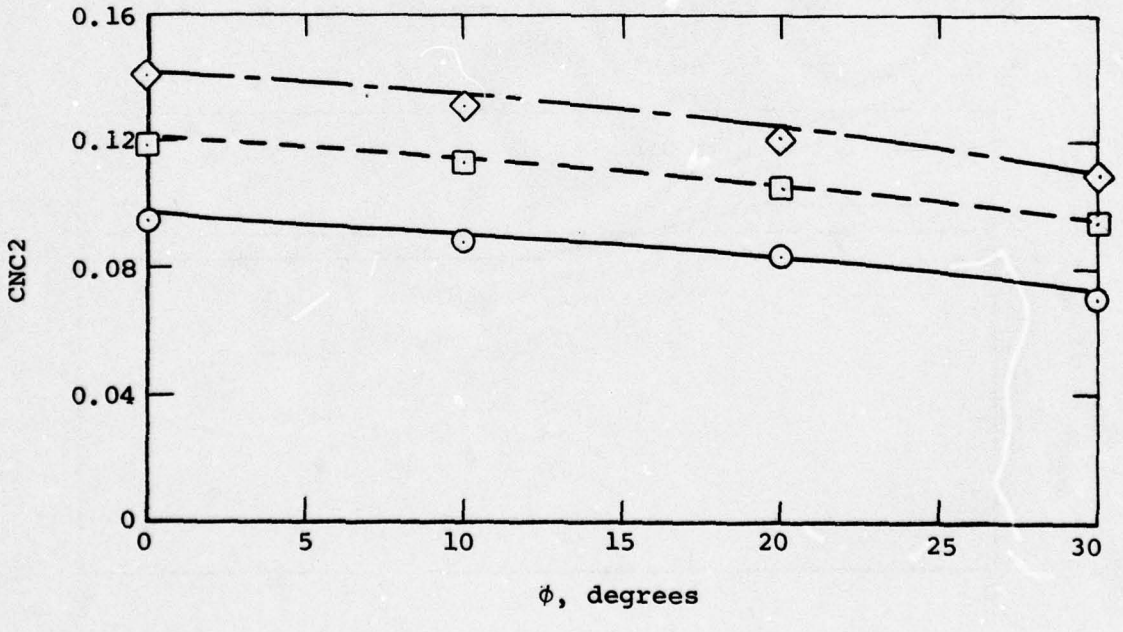
Fin angle of attack, α, degrees

(c) Lateral center of pressure position.

Figure 12. Concluded.

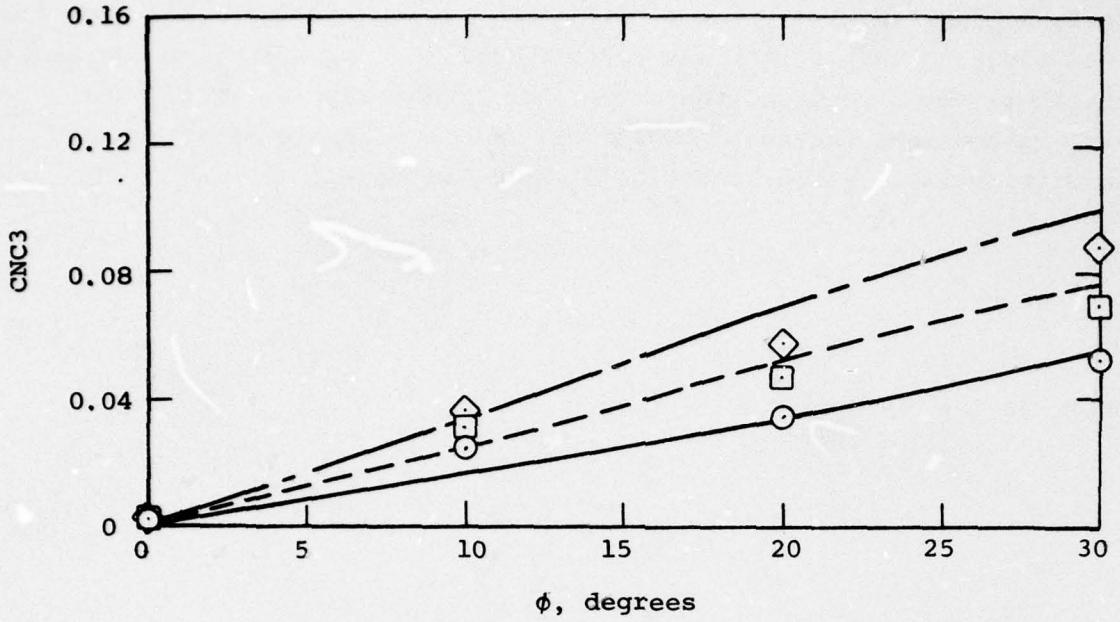


(a) Fin 1.

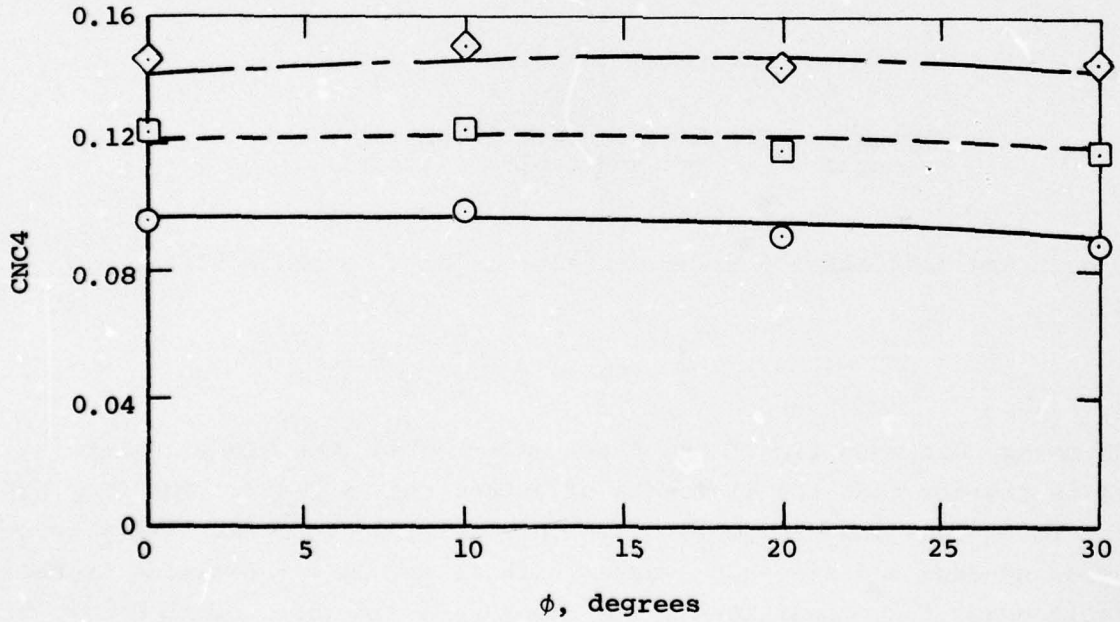


(b) Fin 2.

Figure 13. Fin normal force for bank with no fin deflection, low-aspect-ratio fins (C_7), BC 2, M_∞ = 1.75; S_R = model base area.



(c) Fin 3.



(d) Fin 4.

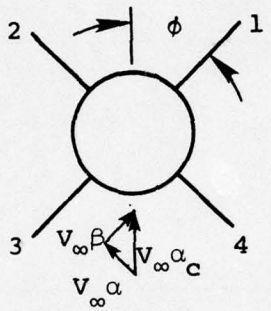
Figure 13. Concluded.

ratio fins (C_6). However, the predictions are low for fin 1 and high for fin 3. Since no such effect was observed for the C_6 fins, we are led to attribute the anomaly to the difference in fin aspect ratio. The present method uses the small angle definitions of angle of attack and angle of sideslip. Hence, for fins 1 and 3, we have

$$\alpha = \alpha_c \sin \phi \tag{31}$$

$$\beta = \alpha_c \cos \phi \tag{32}$$

as shown in the sketch below.



Sketch 1. Small angle definitions of fin 3 angle of attack and angle of sideslip.

(For high angle of attack, these definitions must be modified.) Note that

$$\frac{\beta}{\alpha} = \cot \phi \tag{33}$$

which means that when fins 1 and 3 are undeflected, the fin sideslip angle is greater than the fin angle of attack for $\phi < 45^\circ$. For the low-aspect-ratio fins under discussion in this section, it seems likely that the leading-edge and side-edge vortex lift is strongly influenced by the sideslip under such conditions. The theory used in this report does not take this phenomenon into account. In fact, the present method assumes that the ratio of vortex lift to total lift at a given angle of attack does not change with angle of sideslip.

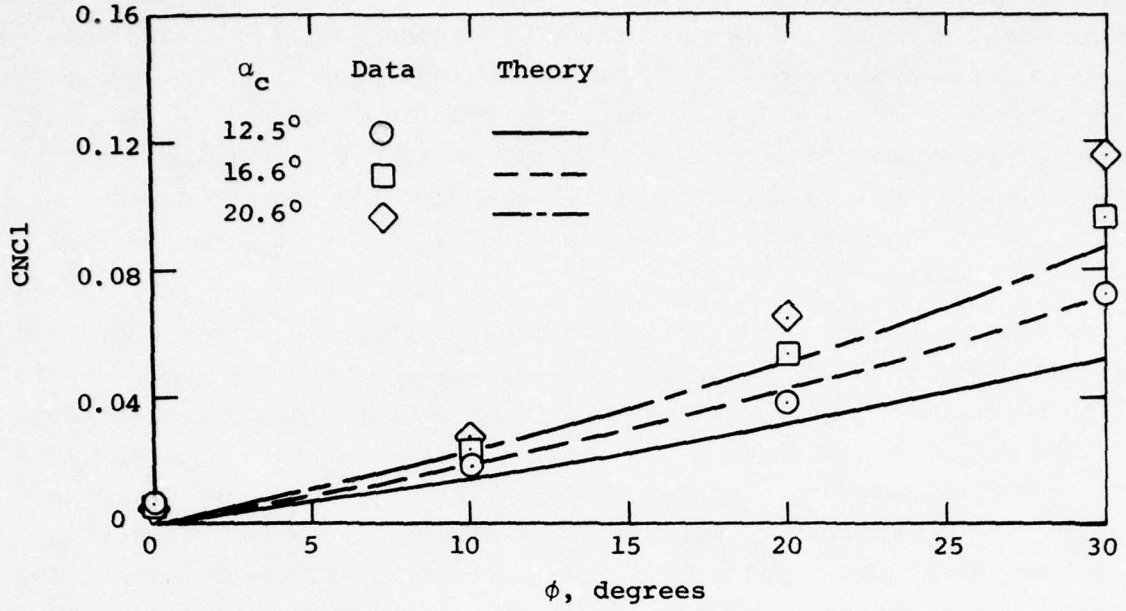
Comparisons of theory and data for the C_7 fins for $M_\infty = 0.8$ are presented in figure 14. Note that the comparisons for fins 1 and 3 are similar to those for $M_\infty = 1.75$. The theory indicates that the equivalent angles of attack for fins 1 and 3 are less than 20°. Hence, considering the wing-alone force characteristics of figure 12, we can assume that the flow over the fins is essentially attached except for edge vortices. As discussed above, the effect of sideslip on edge vortex lift may be an important phenomenon.

For discussion purposes, let us consider a fin with aspect ratio 1.3 but with a delta planform. For such a fin, all the vortex lift is due to the leading edge. It has been shown for such fins in incompressible flow at a given angle of attack with no sideslip that the ratio of vortex lift to attached flow lift decreases as the wing leading-edge sweep decreases (ref. 12). It seems likely that a similar result occurs for changes in leading-edge sweep due to sideslip. The present method assumes that, for a given angle of attack, the vortex lift remains a constant fraction of the attached flow lift as the effective leading-edge sweep changes. Hence, for fin 1, which has an increasing effective leading-edge sweep as α_c increases, the theory would underpredict the data. For the same reasons, the theory would overpredict the data for fin 3.

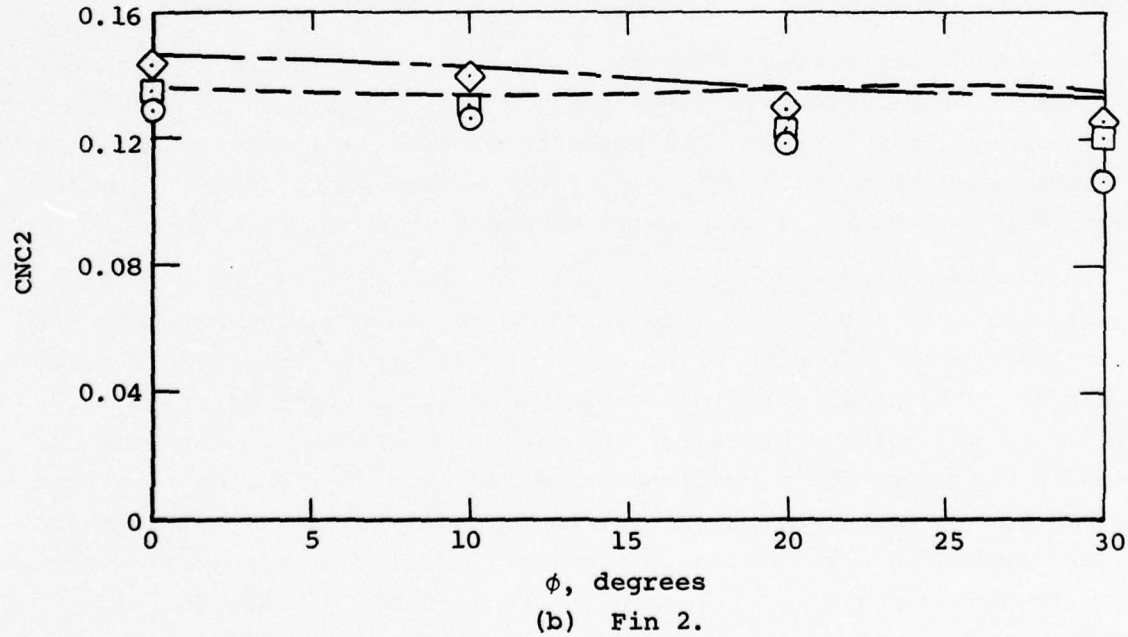
The discrepancy between data and theory shown in figure 14 for fins 2 and 4 can be traced to measurement error. Fins 2 and 4 should have the same lift at $\phi = 0$. If the data of fin 4 are adjusted so that they match the data of fin 2 at $\phi = 0$, the agreement for fin 4 is good. The agreement for fin 2 is within the apparent measurement error.

3.2.2 Aspect ratio 1.0 fins.- Data for the T_{14} set of fins of body-tail configuration no. 1 were obtained for several Mach numbers and bank angles for model angles of attack up to 45° (ref. 16). Since the body length in front of the fins was large enough to produce strong body vortices, we will give results for the windward fins only. The fins were not deflected. The wing-alone characteristics for angles of attack up to 30° were obtained by interpolation of data at several Mach numbers for fins mounted on a reflection plane (ref. 17). The data were extrapolated to higher angles of attack using the methods of reference 13. The wing-alone results are given in figure 15.

Comparisons of theory and data for $M_\infty = 2.0$ are presented in figure 16. The phenomena discussed above for the 1.3 aspect ratio fins

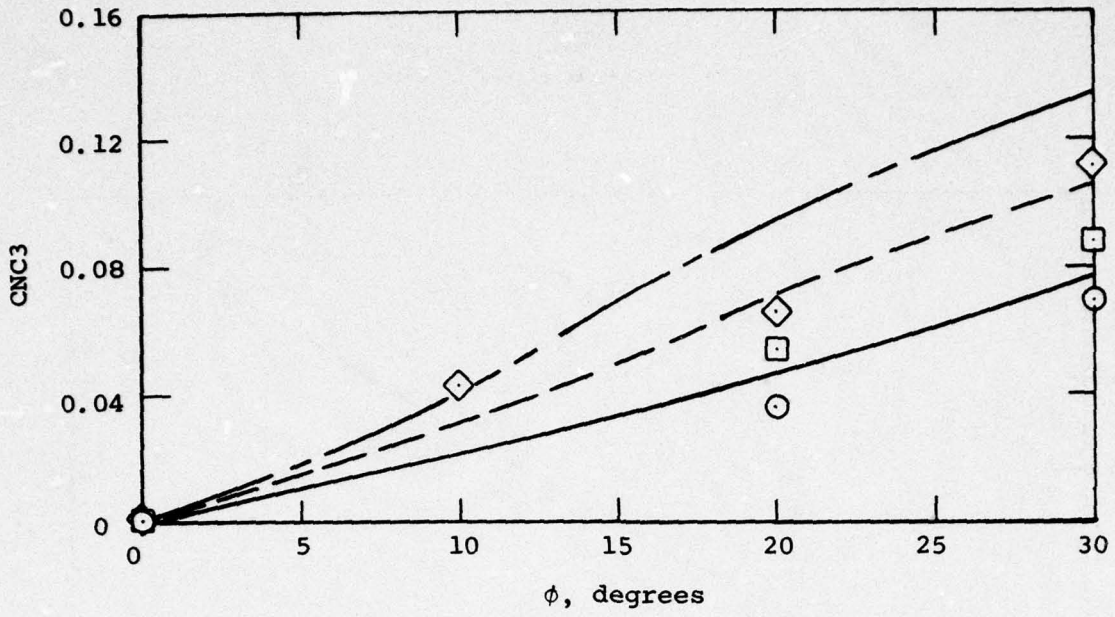


(a) Fin 1.

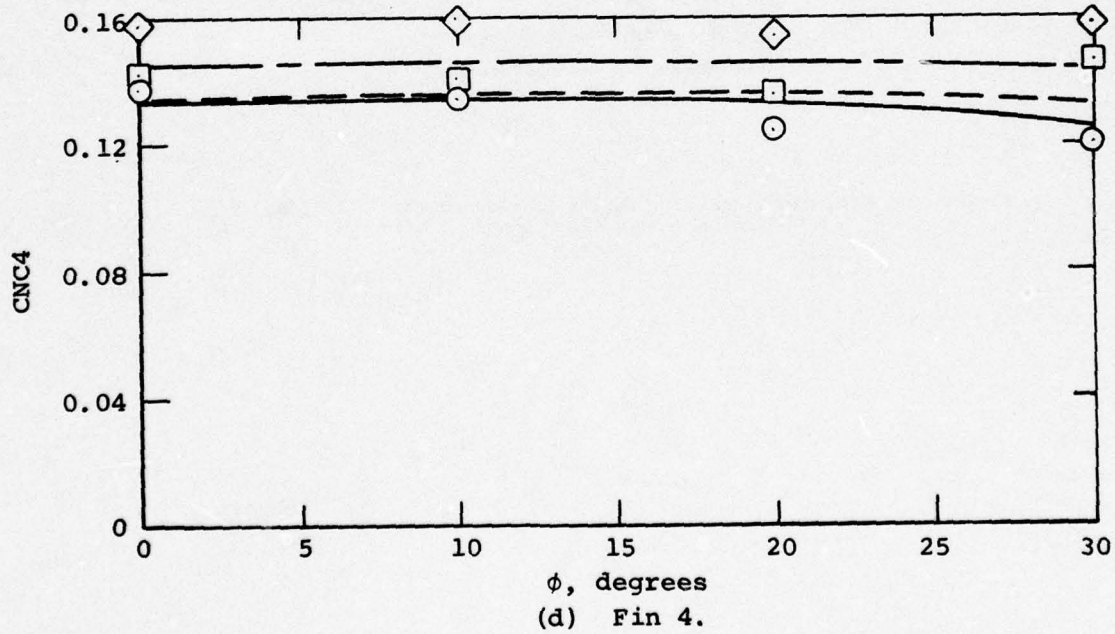


(b) Fin 2.

Figure 14. Fin normal force for bank with no fin deflection, low-aspect-ratio fins (C_7), BC 2, M_∞ = 0.8; S_R = model base area.

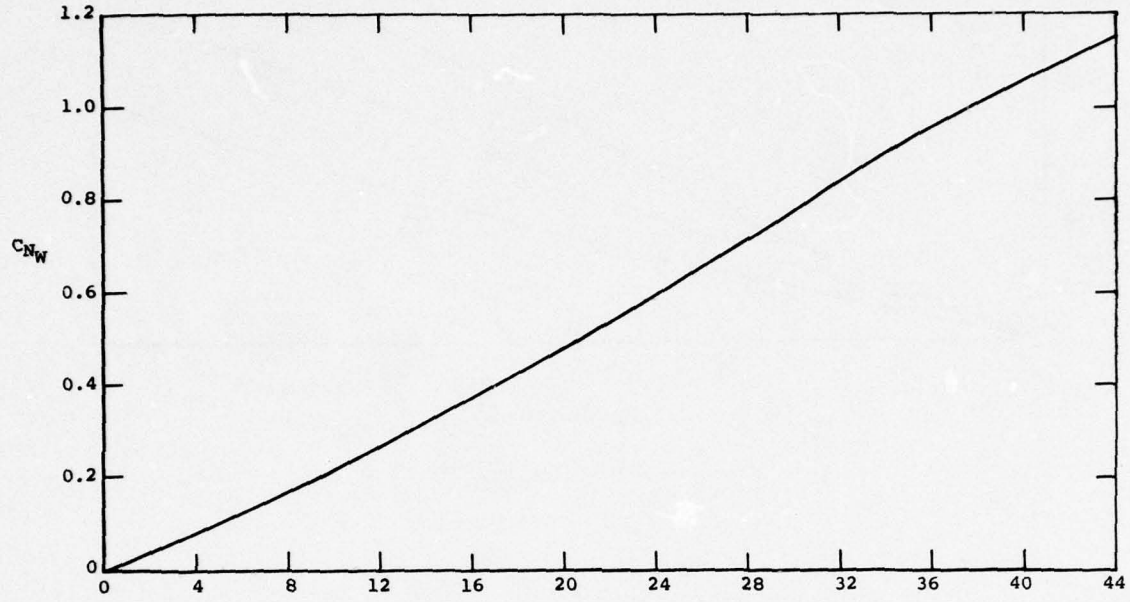


(c) Fin 3.



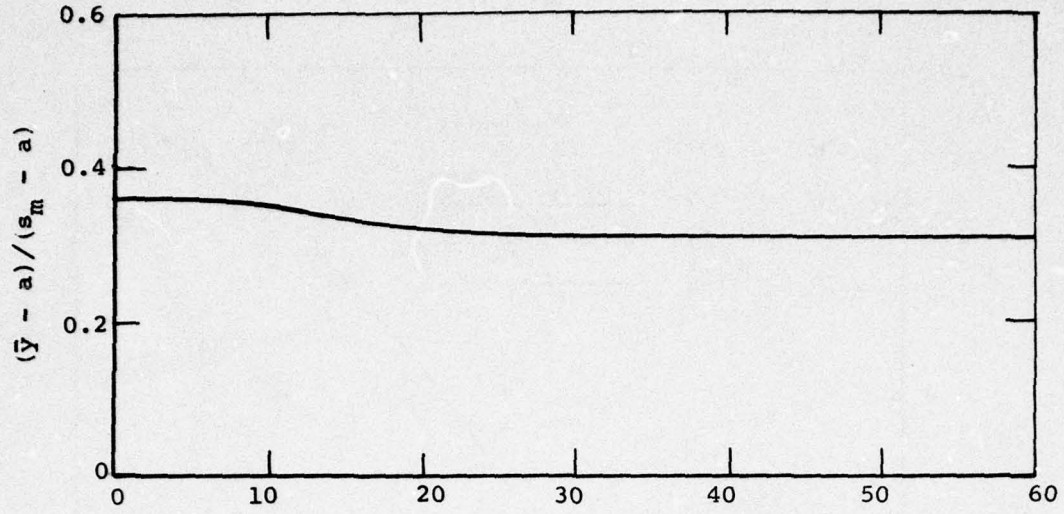
(d) Fin 4.

Figure 14. Concluded.



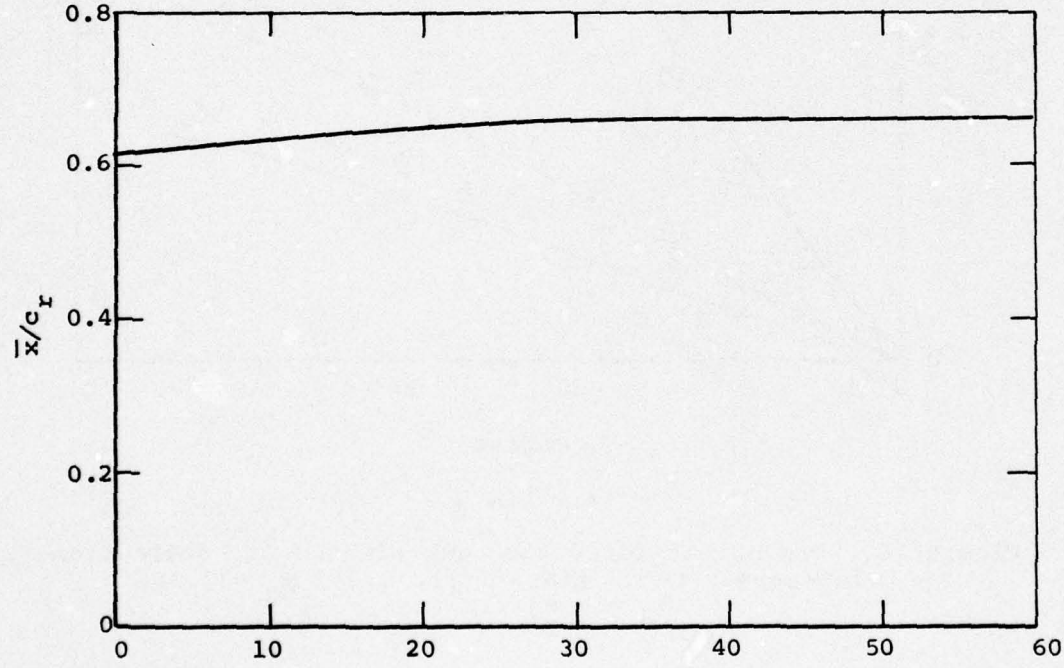
(a) Normal-force coefficient.

Figure 15. Wing-alone characteristics for low-aspect-ratio fins (T_{14}), $M_\infty = 2.0$; $AR = 1.0$, S_R = planform area.



Fin angle of attack, α, degrees

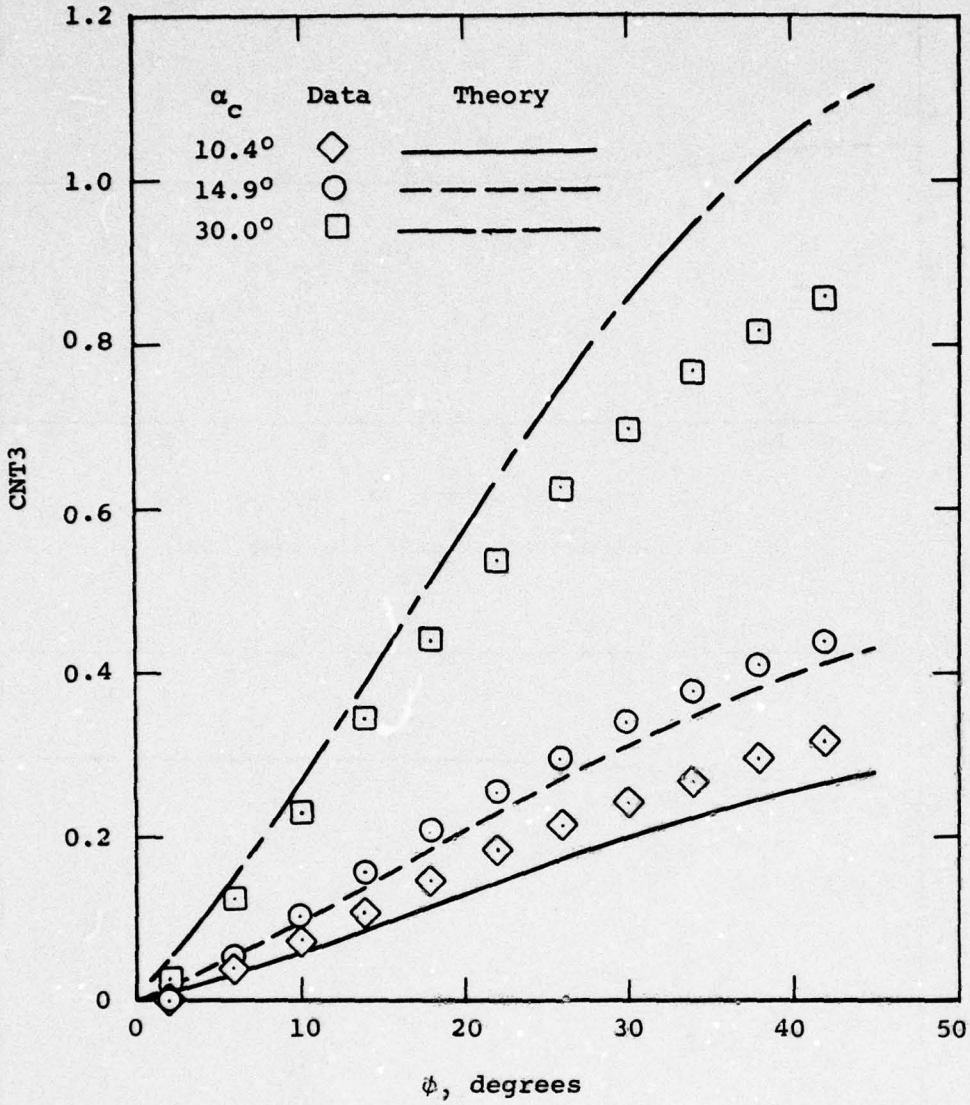
(b) Lateral center of pressure position.



Fin angle of attack, α, degrees

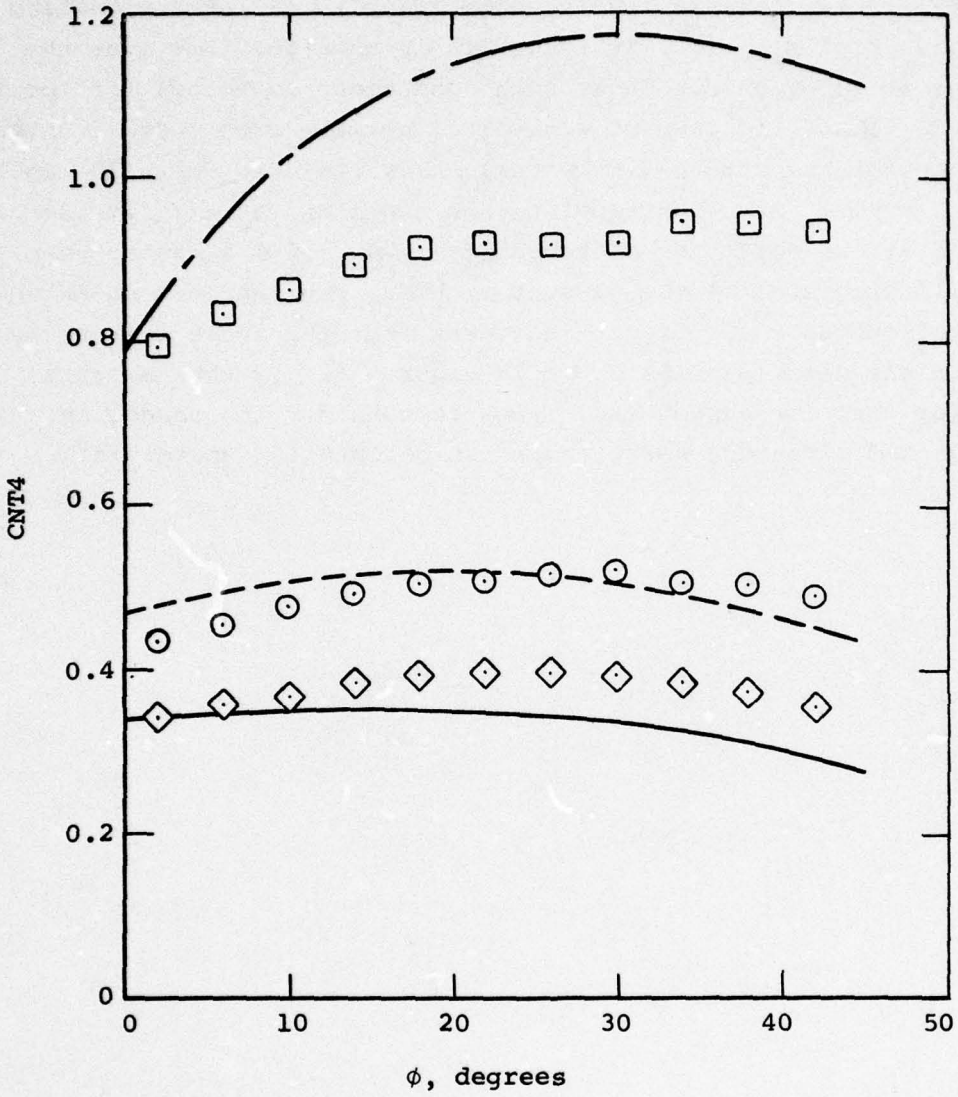
(c) Axial center of pressure position.

Figure 15. Concluded.



(a) Fin 3.

Figure 16. Fin normal force for bank with no fin deflection, low-aspect-ratio fins (T_{i4}), BT 1, M_∞ = 2.0; S_R = planform area.



(b) Fin 4.

Figure 16. Concluded.

are apparent here also. Since the T_{14} fins have delta planforms, the discussion above concerning leading-edge vortex lift is applicable. It is interesting to note that for $\alpha_c = 30^\circ$ and $\phi = 30^\circ$ fin 4 is side-slipped 15°. Since the fin leading-edge sweep is 76°, the effective sweep is 51°. For $M_\infty = 2.0$, it seems likely that the flow over the leading edge is supersonic. Under such conditions no vortex lift could be generated. Thus, the correct wing-alone normal-force curve for this case would be for the attached flow only. For fin 4 at $\alpha_c = 30^\circ$ and $\phi = 30^\circ$, $\alpha_{eq} = 45^\circ$. If we extrapolate the slope at $\alpha_c = 0$ of the curve of figure 15(a), we obtain an attached flow C_{N_W} of 0.9 rather than the value of 1.15 predicted by the present method. The improvement in the agreement between data and theory indicates that the above explanation accounts for the discrepancies shown in figure 16. It thus appears necessary for very low-aspect-ratio fins to consider the change in leading-edge and side-edge sweep angles in calculating vortex lift.

4. COMPARISONS WITH DATA FOR BODY-TAIL CONFIGURATIONS

4.1 Results for Bodies Alone

Comparisons of the theory, which uses equation (1), with data for bodies alone have been made for various fineness ratios at several Mach numbers. The results shown in figure 17 are typical. The data shown are from references 16 and 18. Agreement is generally good except when the crossflow Mach number is transonic. Either the full two-dimensional crossflow drag is not applicable for yawed bodies at transonic speeds or the transonic c_{d_c} values are suspect. Recent experimental results obtained at NASA/Ames Research Center (ref. 19) indicate that the c_{d_c} values are reasonable. Hence, the former explanation appears most likely.

In the present method the body vortex strengths and positions are based on a model of two concentrated vortices. Recently, however, Fidler, Schwind, and Nielsen (ref. 20) have shown that such a model is an oversimplification since the body vorticity can be distributed over a large area. The reader should keep this in mind when interpreting the results given below for vortex-fin interaction.

4.2 Fin Loads in the Presence of Body Vortices

The purpose of this section is to uncover phenomena not included or not properly accounted for in the present method by systematic comparison of data and theory. We will be especially interested in phenomena which become more important at higher angles of attack since they will be pertinent to the second year's work. Results for each of the leeward fins and for the windward fins are presented separately below to facilitate discussion of the various phenomena of interest. Note that fin 1 rolls through the starboard body vortex as ϕ increases. Fin 2 rolls up from a horizontal position. It is never "in" a vortex. Fins 3 and 4 should be weakly affected by the body vorticity for positive roll angles up to 45°.

4.2.1 Leeward fins, fin 1.- In addition to problems involving the use of a two-vortex model to represent distributed body vorticity, the prediction of vortex-fin interference effects must take into account the proximity of the vortex to the fin. Figure 18 illustrates this phenomenon for a rectangular wing near a free vortex which was generated upstream by

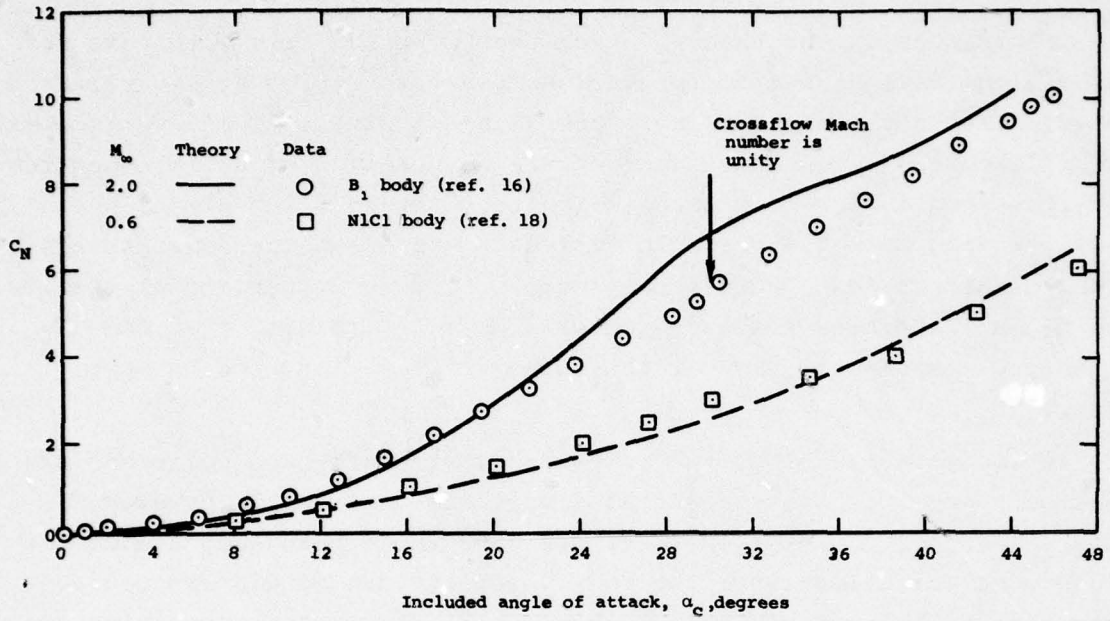


Figure 17. Comparison between theory and data for body-alone normal force.



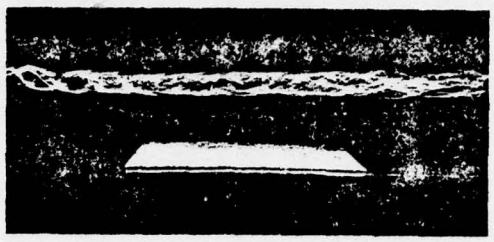
(a) Vortex far from wing; large wing thickness



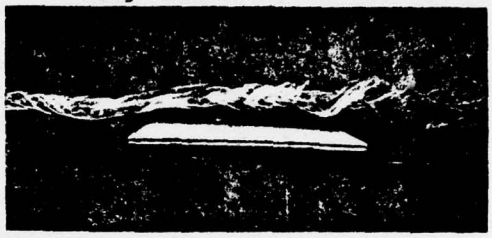
(b) Vortex close to wing; large wing thickness



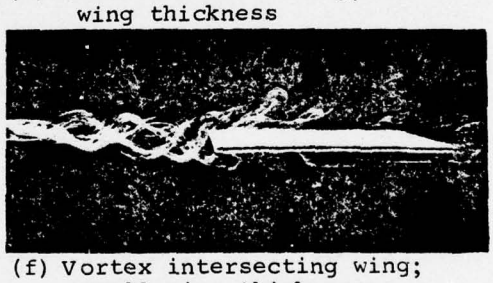
(c) Vortex intersecting wing; large wing thickness



(d) Vortex far from wing; small wing thickness



(e) Vortex close to wing; small wing thickness



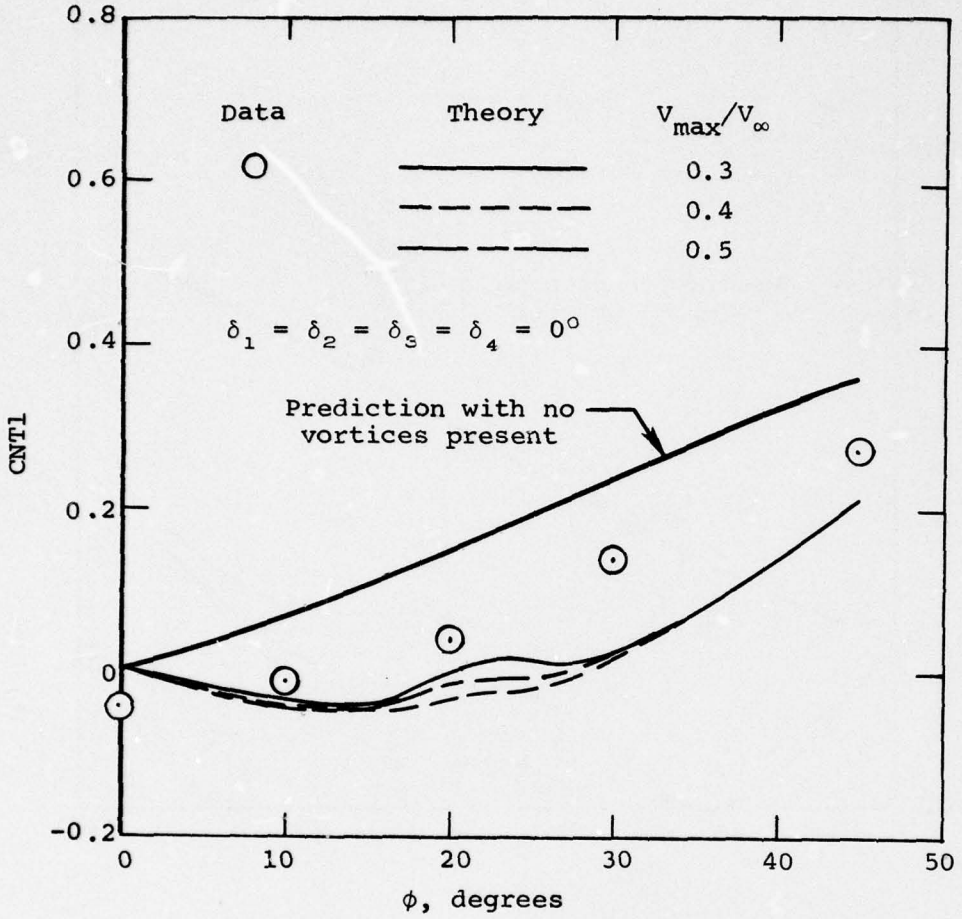
(f) Vortex intersecting wing; small wing thickness

Figure 18. Illustration of vortex-wing interference (photographs taken from ref. 21).

another wing (ref. 21). The possibility of vortex bursting and/or local wing stall is handled in the present method by limiting the maximum velocity nearby vortices can induce on the fin. A study was conducted to determine the best value of V_{max}/V_∞ for body-tail configuration no. 2 shown in figure 3(d). The wing-alone characteristics for the C_7 fins (fig. 12) were used since the T_2 fins closely approximate them in planform. The results of the study for fin 1,which rolls through the right body vortex as ϕ increases,are shown in figure 19 for $M_\infty = 1.75$ and in figure 20 for $M_\infty = 0.8$ for several angles of attack. The two cases show the effects of the simple expedient of limiting the velocity induced on the fins by the vortices. The best values of V_{max}/V_∞ appear to be 0.4 for $M_\infty = 1.75$ and 0.1 for $M_\infty = 0.8$. Since V_{max}/V_∞ may be thought of as a local stall angle (in radians), these values imply subsonic stall at low angles of attack and supersonic stall at much higher angles of attack.

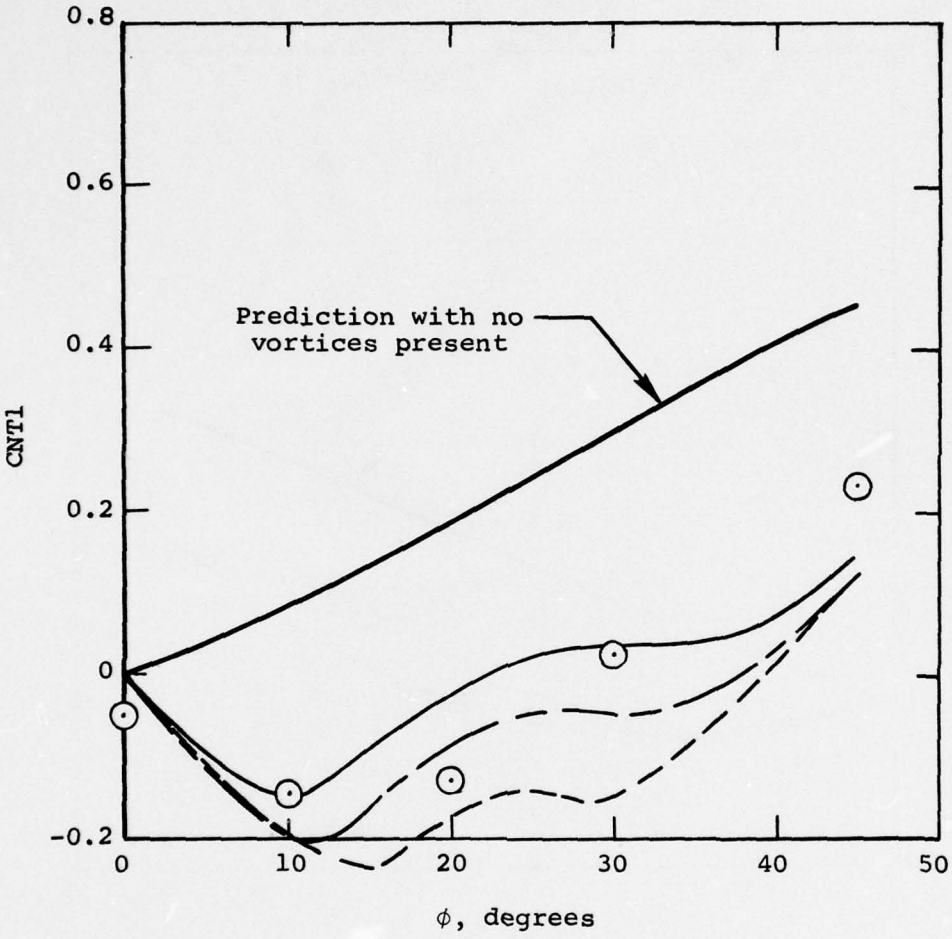
It is interesting to note that the fin 1 normal force without body vortices present is underpredicted for both $M_\infty = 1.75$ and $M_\infty = 0.8$ for the nearly identical C_7 fins (see figs. 13(a) and 14(a)). Hence, we cannot use figure 19 and 20 to determine the best choise of V_{max}/V_∞. The fin 1 results for rolling moment using $V_{max}/V_\infty = 0.4$ for $M_\infty = 1.75$ and 0.1 for $M_\infty = 0.8$ are presented in figures 21 and 22. The comparisons for the $M_\infty = 0.8$ case are satisfactory. However, the rolling moments for $M_\infty = 1.75$ are not well predicted. The rolling moment together with the normal force of a fin in a strong encounter with a vortex is a sensitive indicator of the performance of an analytical model since it requires accurate computations of the center of pressure location as well as normal force. As explained in reference 3 and in Appendix B, the present theory computes the location of the center of pressure using reverse flow theory and would be exact if the flow characteristics were linear.* Unknown nonlinear effects not accounted for by reverse flow theory may be present. Some possible effects not now included in the method are (1) vortex bursting, (2) lateral movement of a vortex as it travels over a fin, (3) increased suction due to the greater axial velocity in the vortex core, and (4) nonlinear terms in the Bernoulli pressure equation.

*Note, however, that the present code assumes that the interaction coefficients, k_{ij}, are zero when $i \neq j$. The coefficient, k_{ii}, is assumed to be one. See Appendix F.



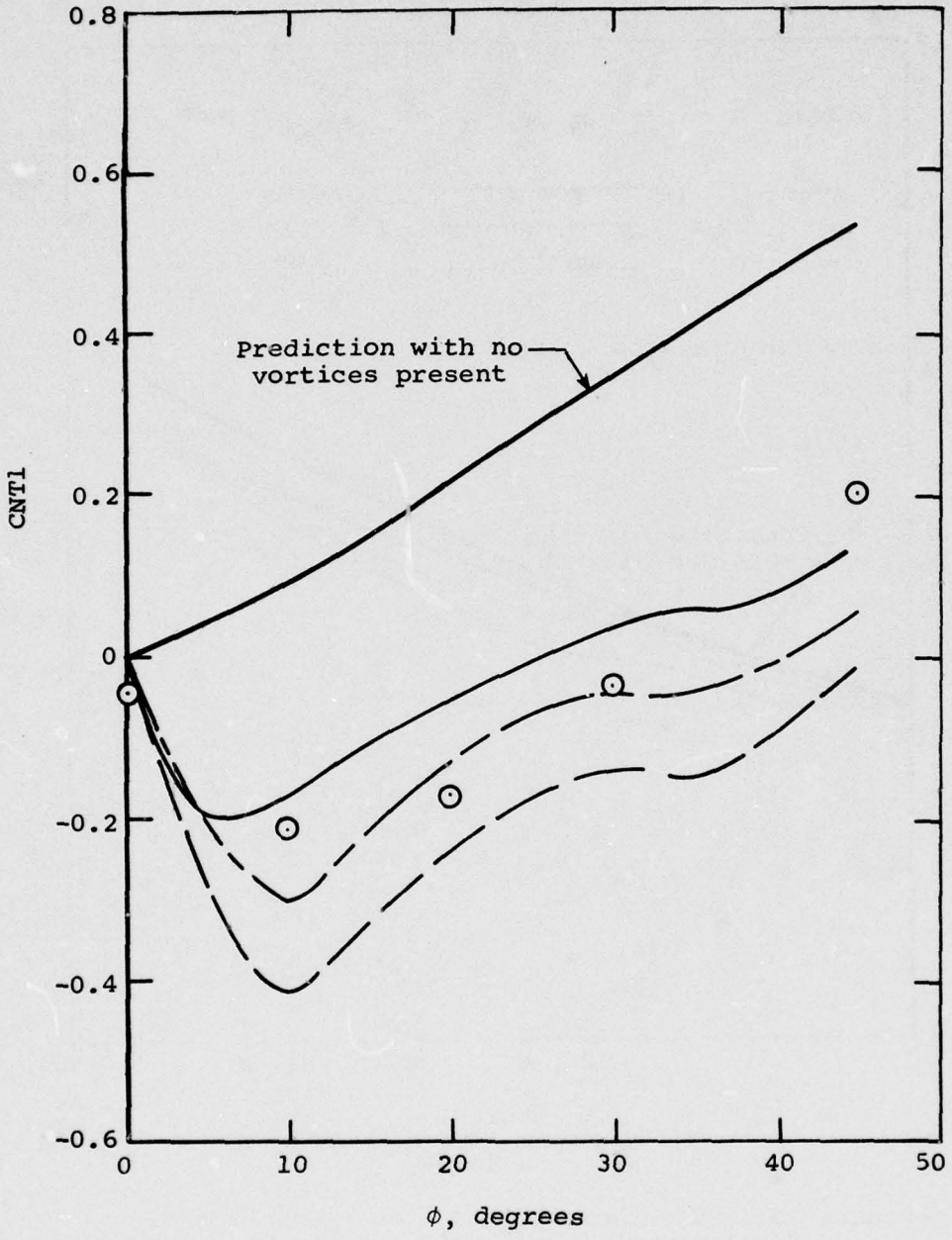
(a) $\alpha_c = 12.5^\circ$.

Figure 19. Effect of V_{max}/V_∞ on prediction of fin 1 normal force, BT 2, $M_\infty = 1.75$; S_R = model base area.



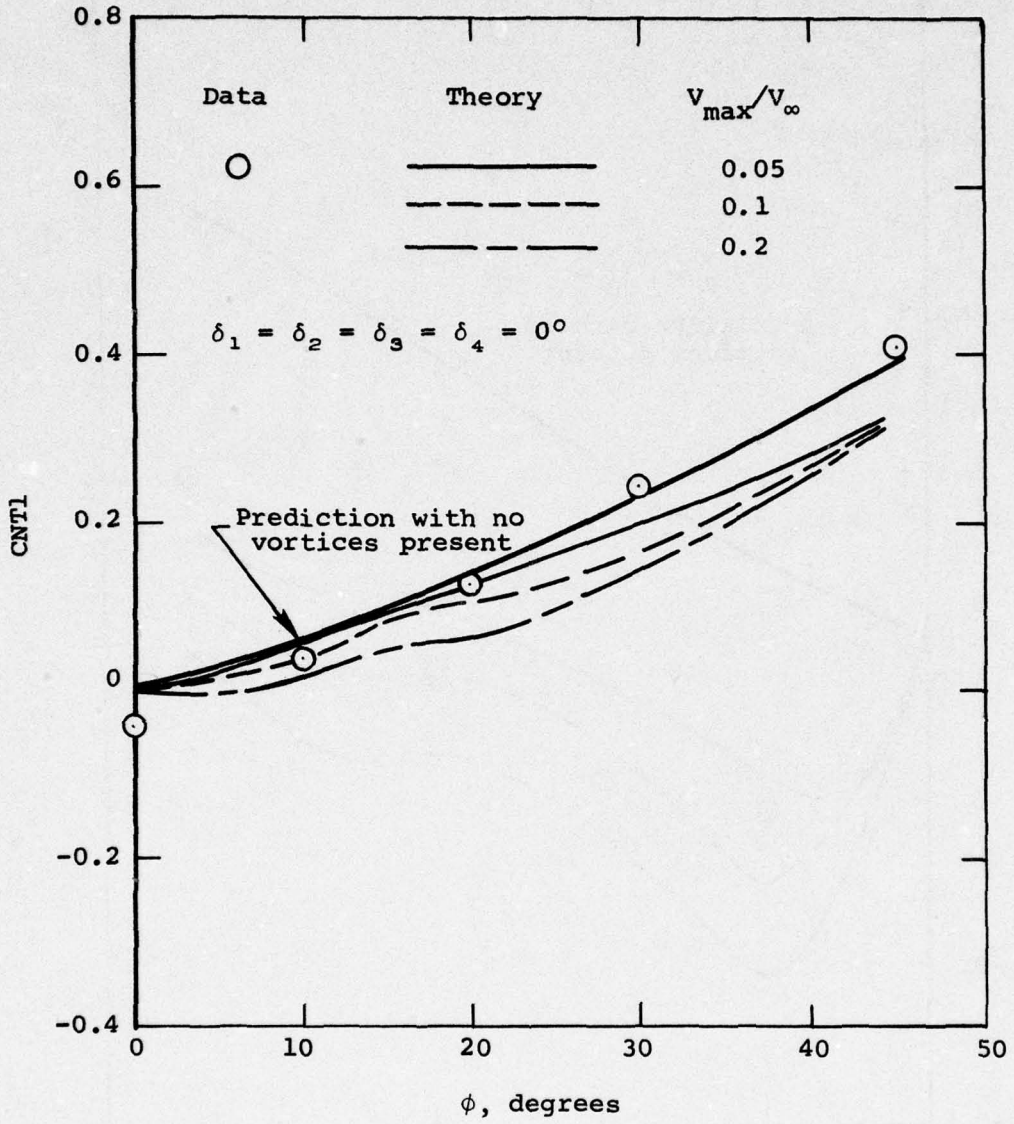
(b) $\alpha_c = 16.6^{\circ}$.

Figure 19. Continued.



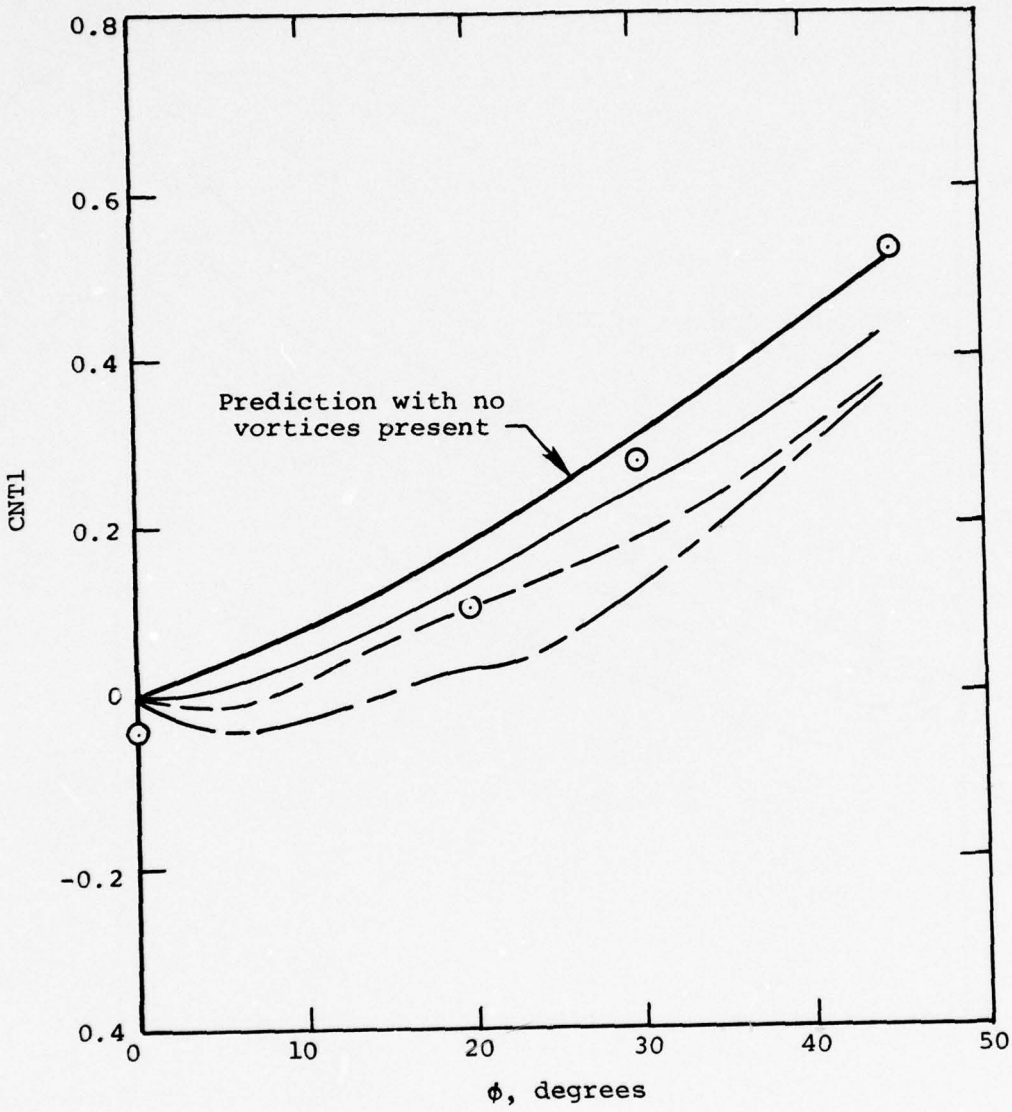
(c) $\alpha_c = 20.6^\circ$.

Figure 19.- Concluded.



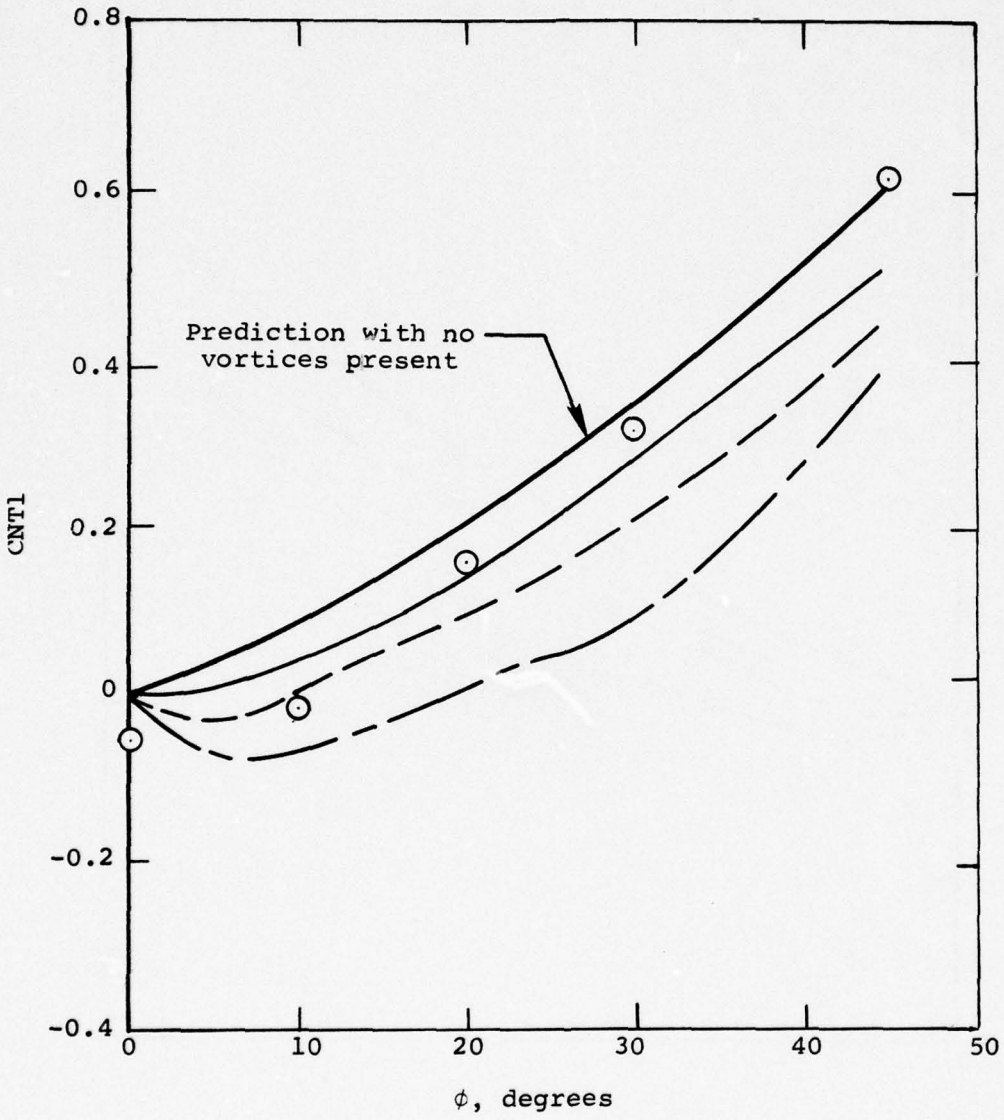
(a) $\alpha_c = 12.5^o$.

Figure 20. Effect of V_{max}/V_∞ on prediction of fin 1 normal force, BT 2, $M_\infty = 0.8$; S_R = model base area.



(b) $\alpha_c = 16.6^{\circ}$.

Figure 20. Continued.



(c) $\alpha_c = 20.6^\circ$.

Figure 20. Concluded.

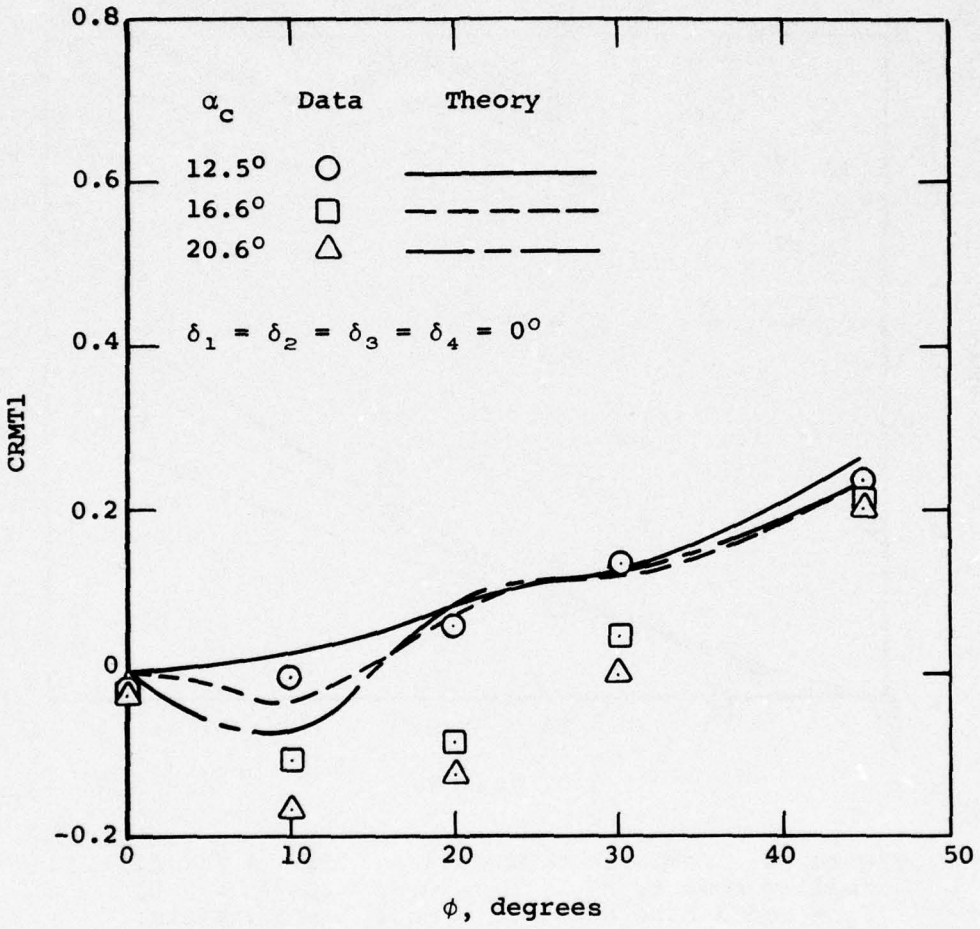


Figure 21. Comparison of data and theory for fin 1 rolling moment, BT 2, $M_\infty = 1.75$, $V_{max}/V_\infty = 0.4$; S_R = model base area, ℓ_r = model base diameter.

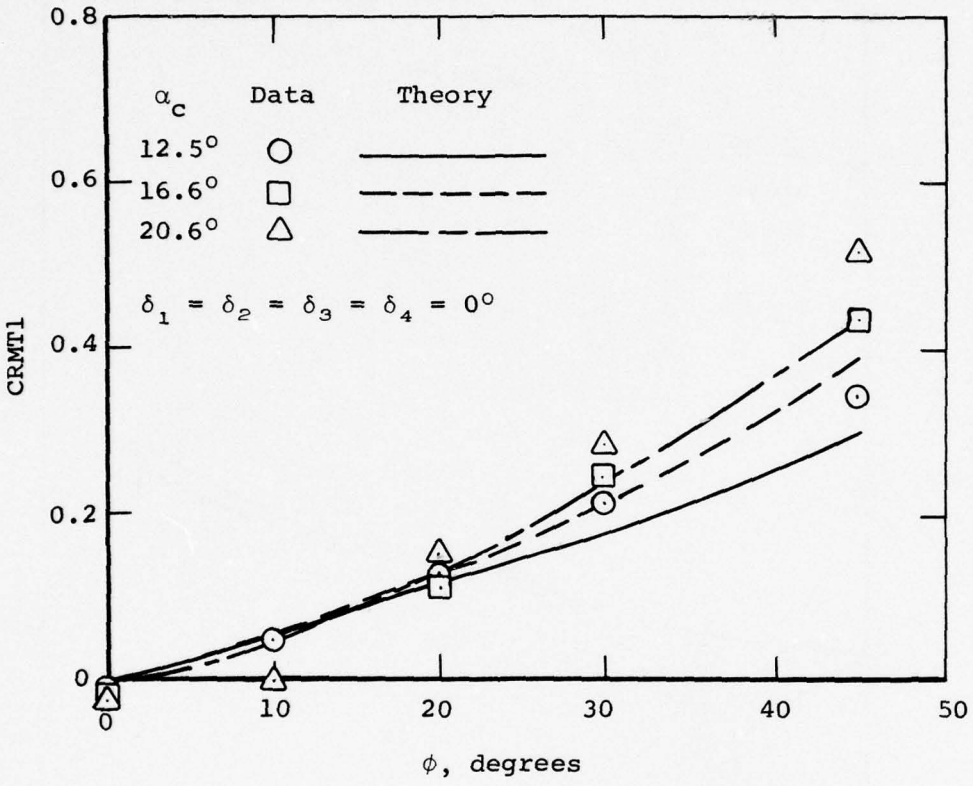
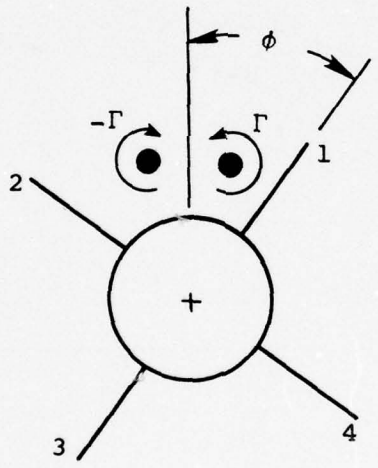


Figure 22. Comparison of data and theory for fin 1 rolling moment, BT 2, $M_\infty = 0.8$, $V_{max}/V_\infty = 0.1$; S_R = model base area, ℓ_r = model base diameter.

It was noted that the measured values of rolling moment shown in figure 21 varied with ϕ in a manner similar to those for normal force (fig. 19). An attempt was made to improve the rolling-moment predictions for $M_\infty = 1.75$ by using the wing-alone center of pressure location given by α_{eq}. The results are shown in figure 23. Note that the agreement between data and theory improved for the higher angles of attack. These results seem to indicate that the present method of Appendix B is appropriate if the vortex-fin interaction is weak. But, if the interaction is strong, additional factors are present which should be included in the theory.

4.2.2 Leeward fins, fin 2.- Comparisons between data and theory for fin 2 of body-tail configuration no. 2 which rolls up from a horizontal position closer to the port body vortex are given in figure 24 for $M_\infty = 1.75$ and in figure 25 for $M_\infty = 0.8$. See sketch 2 below. For the



Sketch 2. Rear view of body-tail configuration no. 2 showing position of body vortices in crossflow plane at the leading edge of the tail.

supersonic case, the predictions are somewhat high for $\phi = 0^\circ$. However, the trends are well predicted including the fact that at $\phi = 45^\circ$, the normal force on fin 2 decreases with increasing body angle of attack.

For the subsonic case, the agreement is good for $\alpha_c = 12.5^\circ$, but for the higher angles of attack some new phenomenon not accounted for in the theory seems to be present. In an attempt to isolate the cause of the discrepancy, the fin normal force was calculated for the case of no

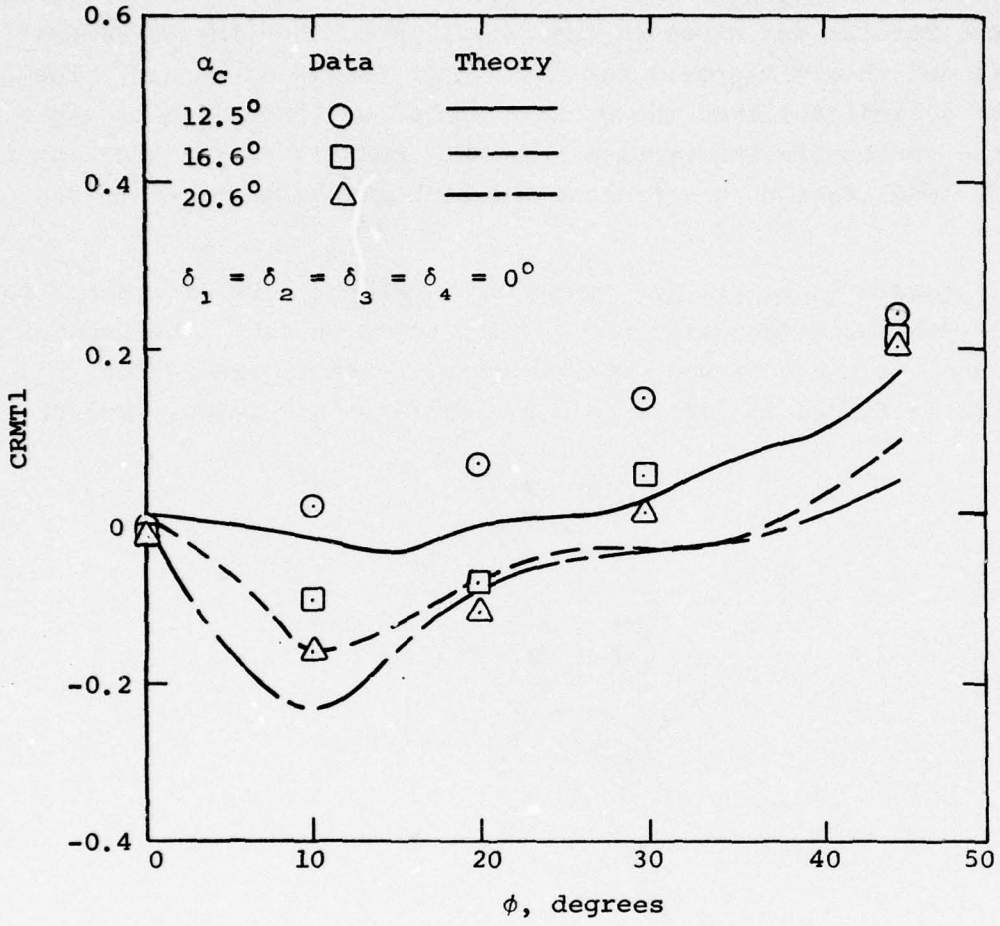


Figure 23. Comparison of data and theory for fin 1 rolling moment using α_{eq} to compute lateral position of center of pressure, BT 2, $M_\infty = 1.75$, $V_{max}/V_\infty = 0.4$; S_R = model base area, ℓ_r = model base diameter.

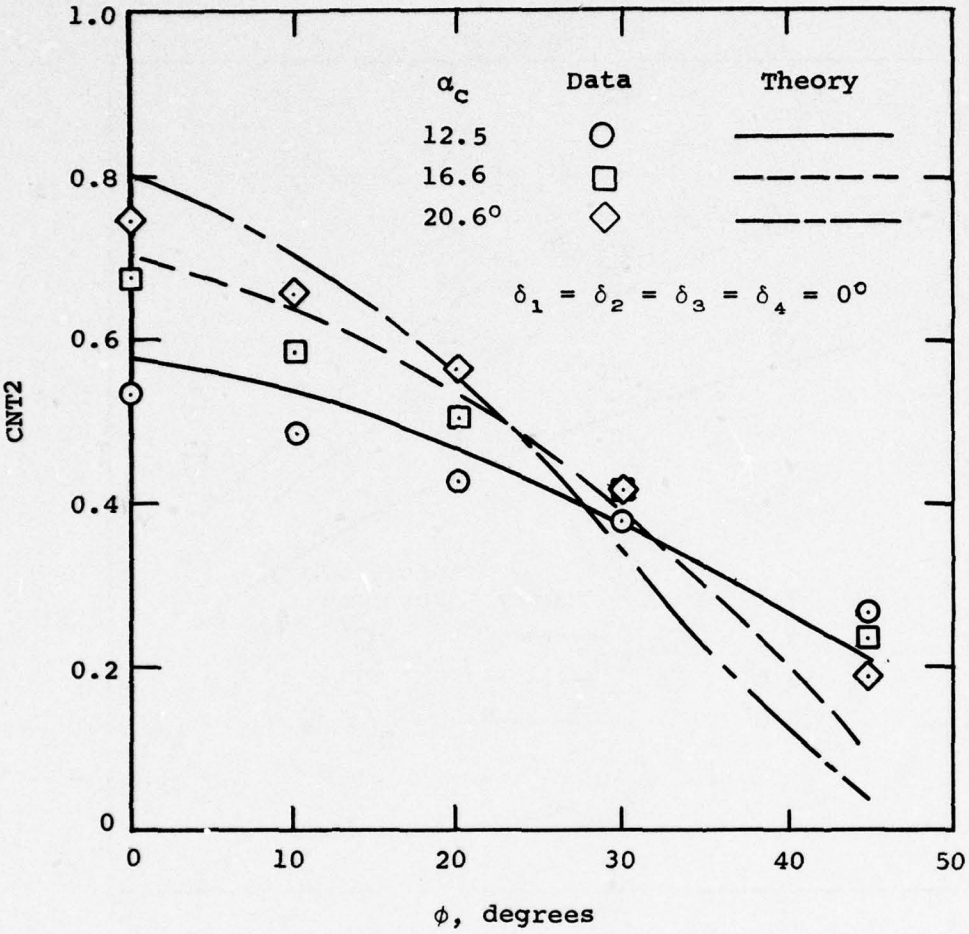


Figure 24. Comparison of data and theory for fin 2 normal force, BT 2, $M_\infty = 1.75$, $V_{max}/V_\infty = 0.4$; S_R = model base area.

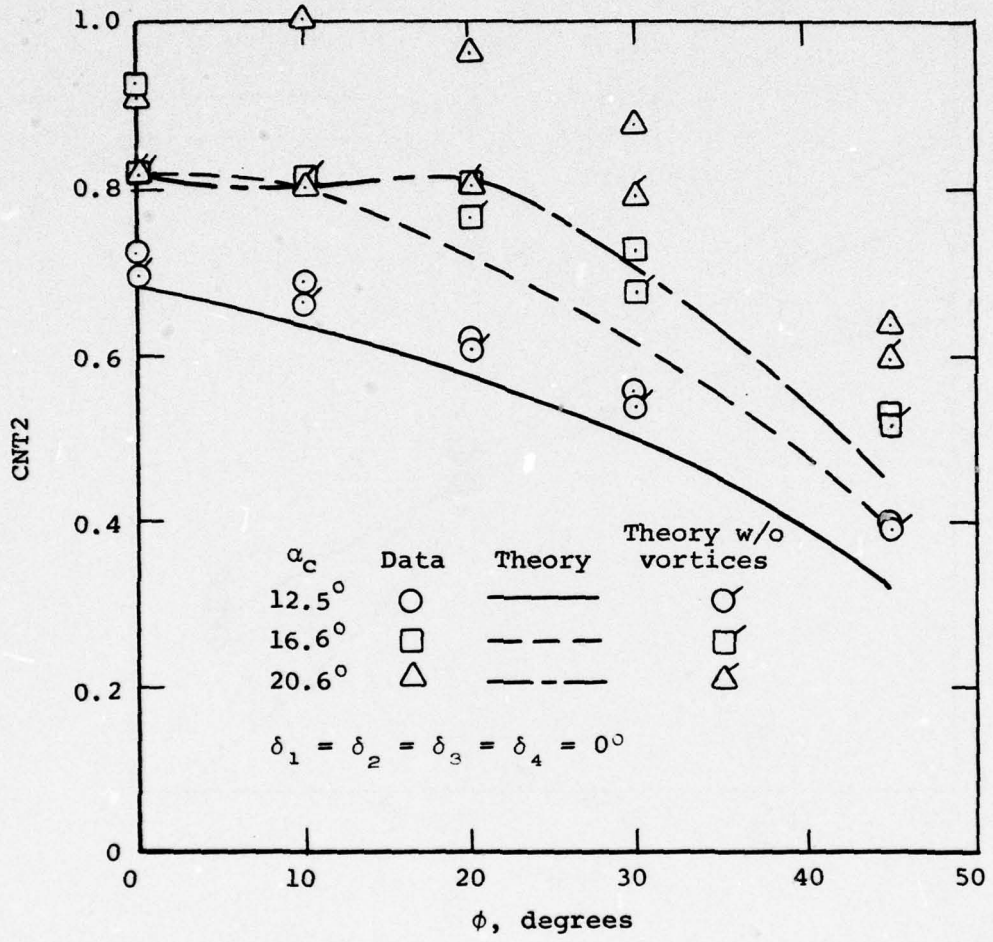


Figure 25. Comparison of data and theory for fin 2 normal force, BT 2, $M_\infty = 0.8$, $V_{max}/V_\infty = 0.1$; S_R = model base area.

body vortices present. The results are shown in figure 25 as flagged symbols. The agreement is improved somewhat especially at $\phi = 45^\circ$. However, for the smaller values of ϕ and for $\alpha_c = 16.6^\circ$ and 20.6°, the normal force is still underpredicted by a significant amount. It appears that a source of favorable lift interference is present. That this is so can be seen by referring to figure 12. (Note that the reference area for figure 12 is the planform area, 18.38 in.^{2}, and for figure 25 it is the model base area, 19.64 in.^{2}.) At $\phi = 10^\circ$ in figure 24, the measured normal force for $\alpha_c = 20.6^\circ$ is 25 percent higher than the wing-alone curve would give for the equivalent angle of attack indicated. It appears, then, that the discrepancy is due to favorable body vortex-fin interference which was unsuspected and was not included in the method.

To confirm the existence of the phenomenon, another configuration with a different ratio of fin semispan to body radius was examined also at $M_\infty = 0.8$. The configuration is body-tail configuration no. 3 shown in figure 3(e). The wing-alone normal force was taken from reference 22 and is presented in figure 26. The data were taken from reference 16 and are presented for several angles of attack in figure 27. Note the similarity between these data and the data of figure 25. The values of fin normal force which would be predicted if no body vortices were present are also shown in figure 27. It is clear that favorable vortex interference is present for $0 \leq \phi < 20^\circ$. It is interesting to note that for both cases the magnitude of the favorable interaction seems to be a function of the distance of the body vortex from the fin. In fact, when the fin is at 20° bank (second quadrant), the favorable interaction is lost. The mechanism here appears to be similar to that encountered for strake-wing interference. The phenomenon will be investigated in the second year of the present effort.

4.2.3 Windward fins.- Comparisons between data and theory for fins 3 and 4 of body-tail configuration no. 2 at $M_\infty = 0.8$ are given in figure 28. Note that the trends are similar to those of figure 14 as they should be since the fins are nearly identical in planform. The chief difference is the size of the fins relative to the body. In section 3.2, the possibility was discussed of improving the prediction for fin 3 by taking into account the dependence of vortex lift on leading-edge sweep changes due to pitch and roll.

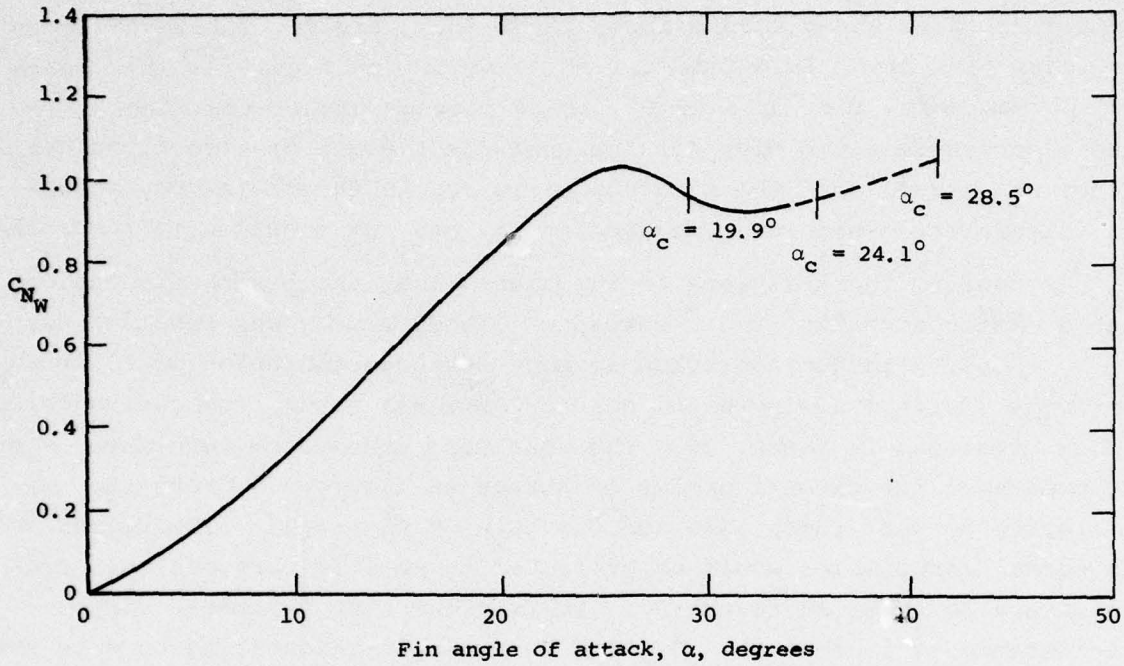


Figure 26. Wing-alone normal-force coefficient for low-aspect-ratio fins (T_{15}), M_∞ = 0.8; $\mathcal{R}$ = 1.0, S_R = planform area.

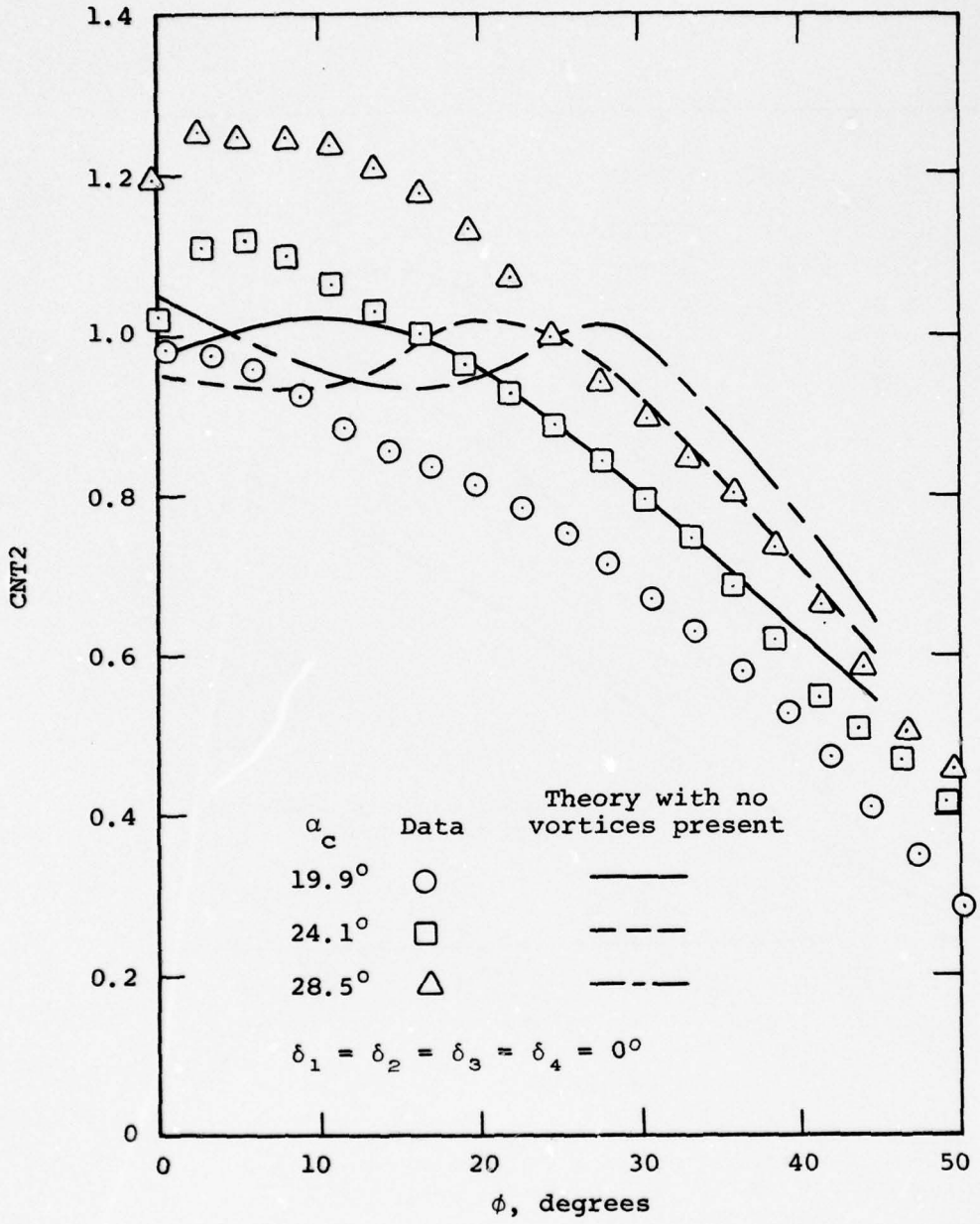
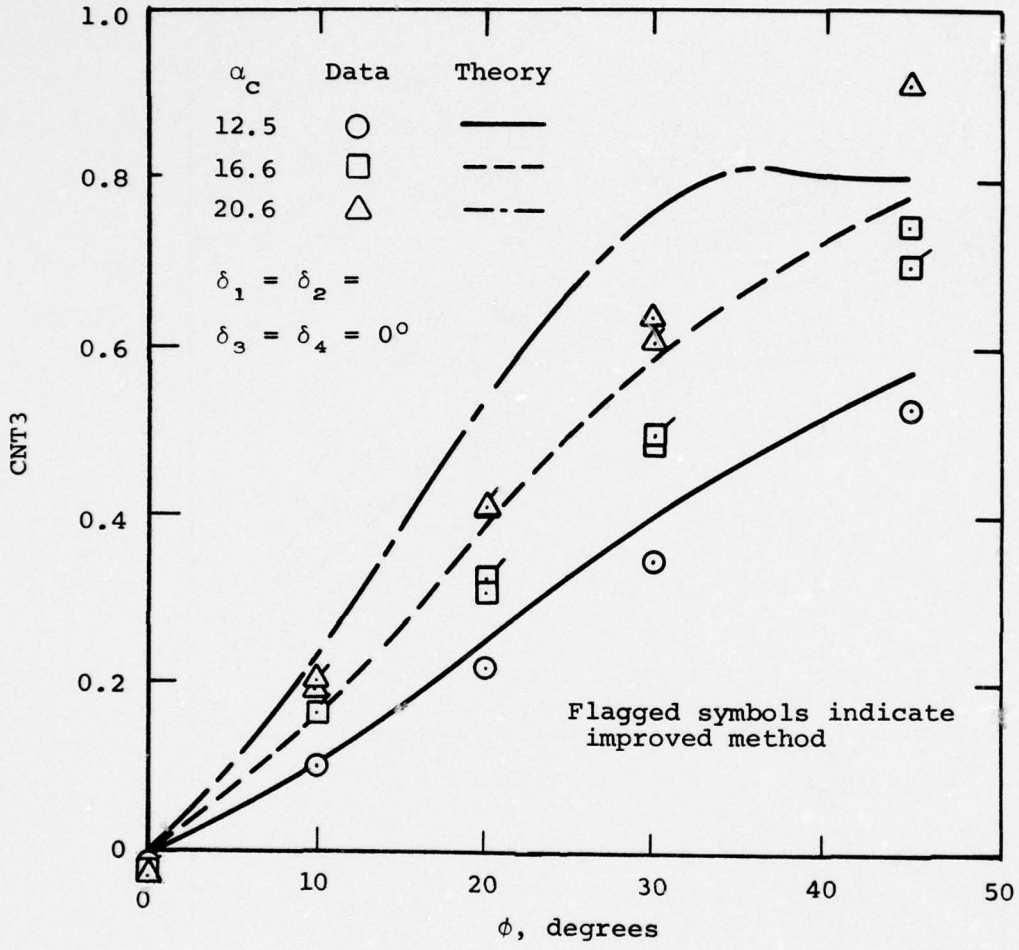
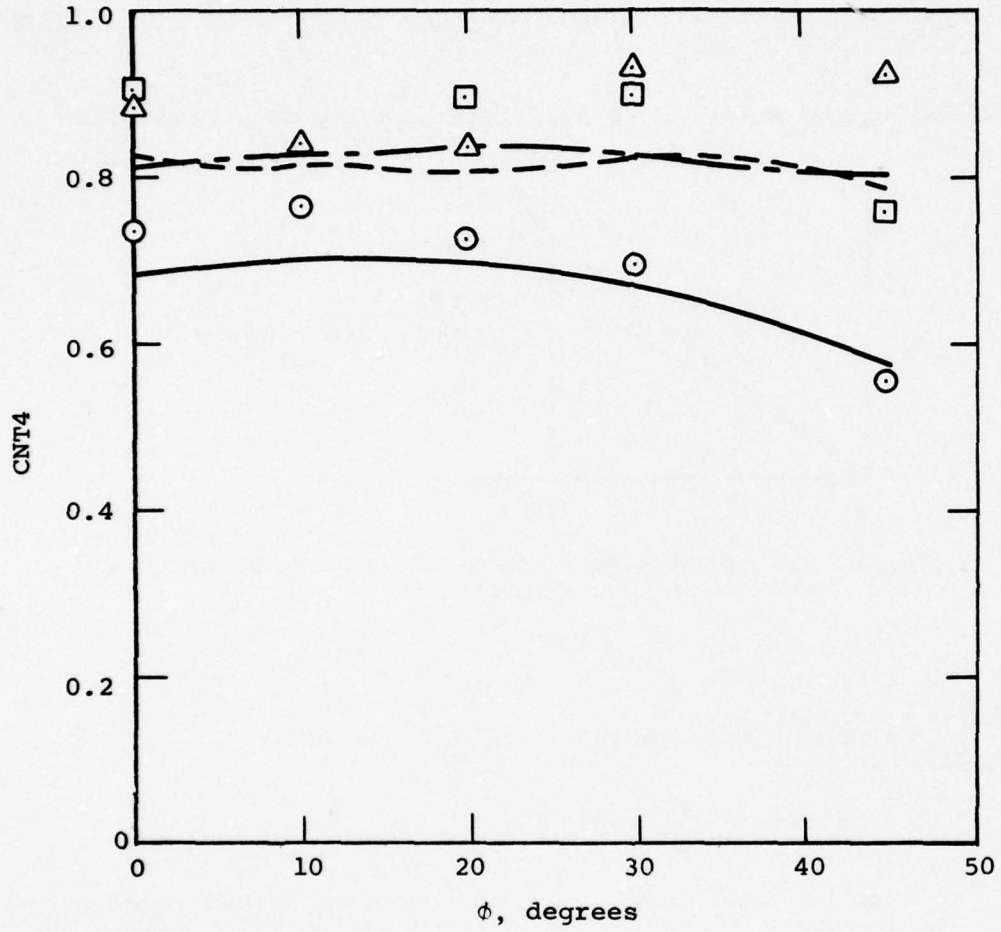


Figure 27. Comparison of data and theory for fin 2 normal force, BT 3, $M_\infty = 0.8$; S_R = fin planform area.



(a) Fin 3.

Figure 28. Comparison of data and theory for fin 3 normal force, BT 2, $M_\infty = 0.8$, $V_{max}/V_\infty = 0.1$; S_R = model base area.



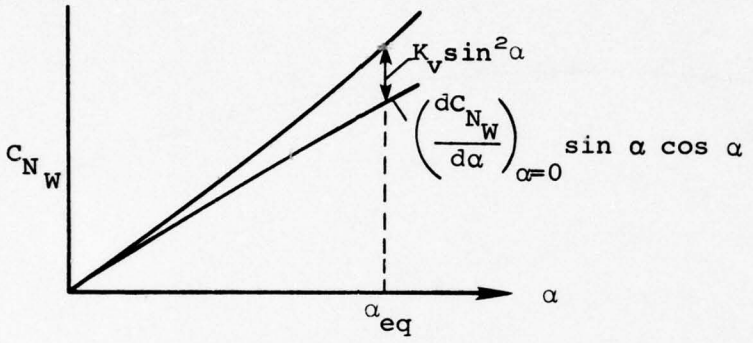
(b) Fin 4.

Figure 28. Concluded.

These improvements are based on an approximate method now described. For clarity the discussion will be made initially for triangular wings. The normal-force curve for a wing alone which develops vortex lift can be approximated by the following formula.

$$C_{N_W} = \left(\frac{dC_{N_W}}{d\alpha}\right)_{\alpha=0} \sin\alpha\cos\alpha + K_v \sin^2\alpha \qquad (34)$$

The corresponding normal-force curve has the following characteristic shape:



Sketch 3. Normal-force curve for a wing alone which develops vortex lift.

where

$\left(\frac{dC_{N_W}}{d\alpha}\right)_{\alpha=0}$ = normal-force curve slope at $\alpha = 0$

K_v = "vortex lift" constant

The constant K_v can be obtained from an experimental normal-force curve. It can also be estimated theoretically by assuming that all the leading-edge suction is converted into vortex lift (Polhamus analogy). For delta wings at subsonic speeds theoretical values of K_v depend only on leading-edge sweep angle or its equivalent, aspect ratio. For supersonic speeds, the theoretical value of K_v depends on the ratio of the tangent of the leading-edge sweep angle to the tangent of the Mach angle, or βAR. For supersonic edges, K_v is zero. Generally, not all the leading-edge suction is converted to vortex lift. The parameter K^* is defined to represent this fraction.

$$K^* = \frac{(K_v)_{exp}}{(K_v)_{theory}} \tag{35}$$

Correlations of K^* for delta wings are included in reference 12.

For a cruciform missile at included angle of attack, α_c, and roll angle, ϕ, the sweep angle of a delta wing is changed from its nominal angle at $\alpha_c = 0$. This changes both the potential normal force and the vortex normal force. The change in normal force is handled in the present method by the change in equivalent angle of attack determined using the interference factor, $K_{\alpha\beta}$. This is correct for the normal force due to potential flow. However, special consideration must be given to the vortex normal force because not only is the leading-edge suction changed by change in sideslip angle but so also is the fraction of it converted to vortex lift.

Consider first the changes in sweep angle of a delta fin leading edge as influenced by pitch and roll. For zero pitch and roll, we have

$$\Lambda_o = \cot^{-1}\left(\frac{4}{AR}\right) \tag{36}$$

For combined pitch and roll, the sweep angle, Λ_{eff}, is now

$$\Lambda_{eff} = \cot^{-1}\left(\frac{4}{AR}\right) - \alpha_c \cos\phi \tag{37}$$

From the results of reference 12, values of K^* corresponding to Λ_o and Λ_{eff} can be obtained and are designated K^*_o and K^*_{eff}.

In estimating the change in vortex normal force, we determine α_{eq} in the usual way. The curve, $(dC_{N_W}/d\alpha)_{\alpha=0} \sin\alpha\cos\alpha$, is constructed on the normal-force curve of the wing alone as shown in the preceding sketch. A "vortex normal force" is determined by subtracting the potential normal force from the experimental normal force. This vortex normal force is then scaled by the ratio, K^*_{eff}/K^*_o. This method assumes that the leading-edge suction is a constant fraction of the potential normal force as sweep angle changes. Using vortex-lattice or panel methods, we can determine the actual change in leading-edge suction with sweep angle before applying the K^* factors but have not done so in the approximate method.

An application of the above improvement in the present method has been made to fin 1 for the conditions of figure 28(a). The fin is a clipped delta fin, and it has been approximated by a delta fin with the same aspect ratio for obtaining values of K^*. In determining the potential normal force, sin α was taken as α and cos α as unity in equation (34). The pertinent wing normal-force curve is given in figure 12(a). The numerical results obtained by this "improved method" are shown in figure 28(a) by the flagged symbols. Much improved agreement with data is exhibited. It seems clear from the improvement shown in figure 28(a) that an important phenomenon not now included in the present method has been identified. Furthermore, a means for accounting for its effects has been found. Further refinement to account separately for the effects of leading edges and side edges seems desirable.

4.3 Total Loads for Body-Tail Configurations

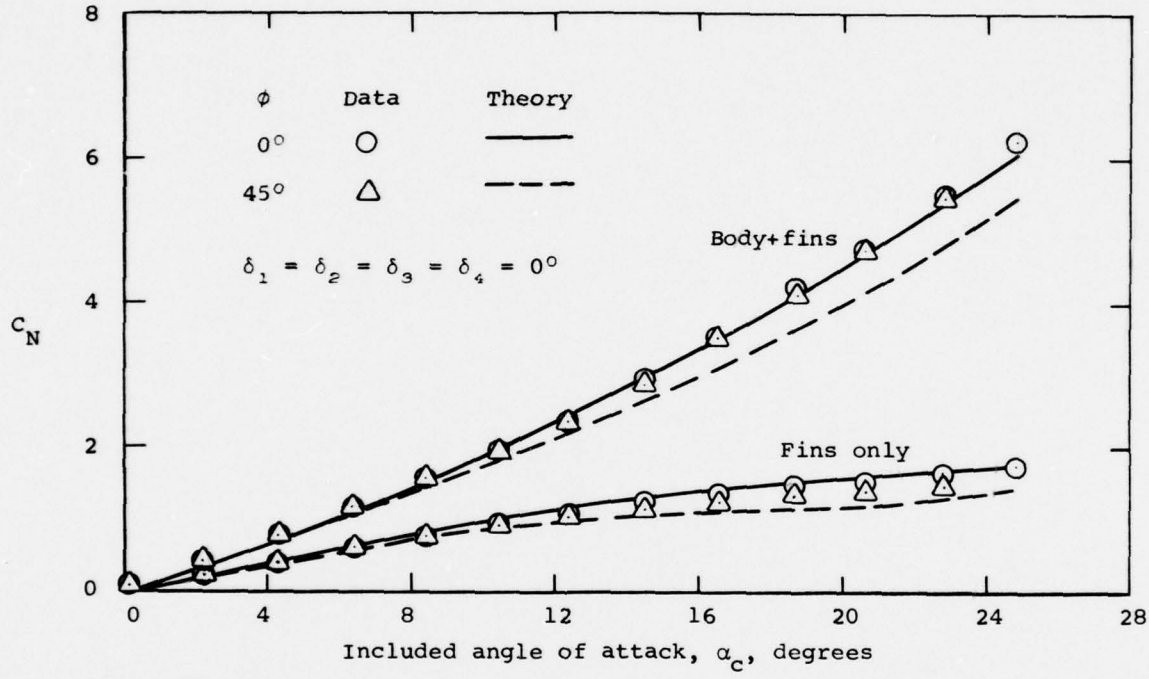
We have made comparisons of data for complete body-tail configurations with the present theory without the improvements discussed above. The results shown in figures 29-31 are typical. We will discuss the normal-force results first and then rolling moment and side force.

Generally, the agreement for total normal force is good at low α_c and fair at high α_c. Let us first consider the results for body-tail configuration no. 2 at $M_\infty = 1.75$. Note that the contribution of the tail fin loads to the normal force is well predicted. Results not presented show that the body-alone normal force for this case is also well predicted. Consideration of the axial location of the center of pressure (fig. 29(b)) also suggests that the predicted contribution to the normal force for the tail region at $\phi = 45^\circ$ is slightly low since the predicted center of pressure location is slightly forward.

For the $M_\infty = 0.8$ case, it is clear from figure 30(a) that the calculated contribution of the tail fins to normal force is somewhat low at high angles of attack. As discussed above in section 4.2.2, the discrepancy appears to be due to favorable vortex-fin interaction which is not accounted for in the present method.

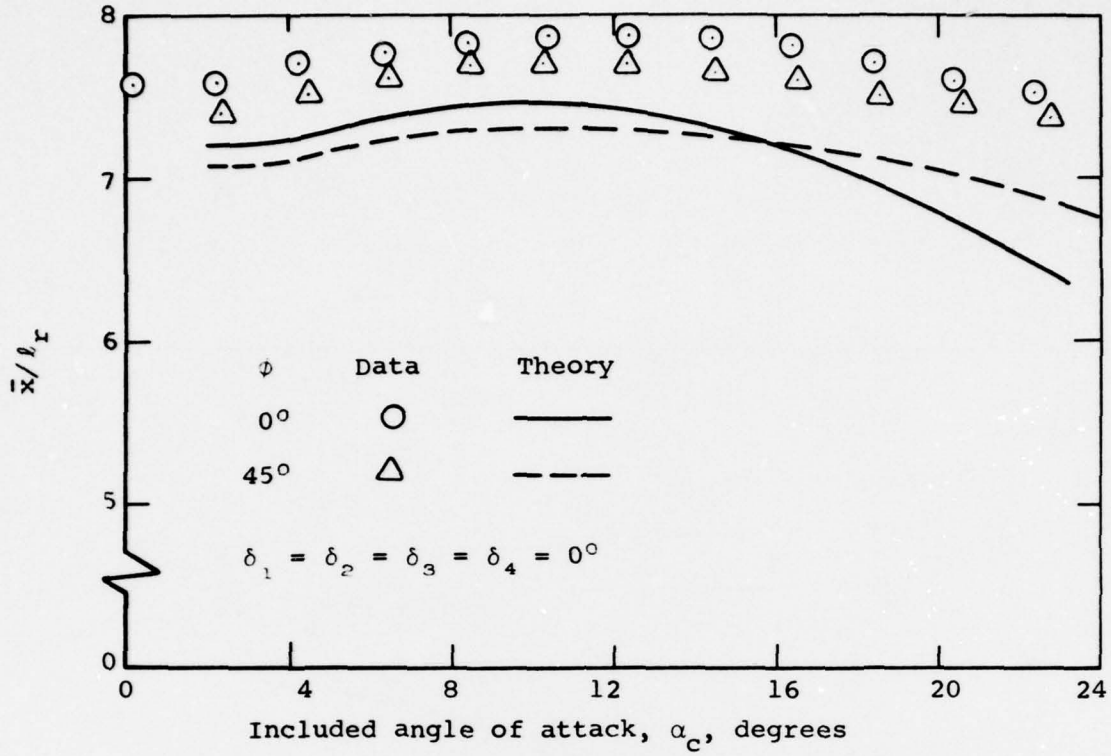
Results for the AIM-9L body and tail (body-tail configuration no. 4) are shown in figure 31 for $M_\infty = 0.8$ and a bank angle of 22.5°. The fins were undeflected. The agreement between data and theory for normal force is very good.

The induced rolling moments for the body-tail cases presented in figures 29(c) and 30(c) and 31(b) are interesting since the rolling moment is a second-order quantity (linear theory with no vortices would give zero rolling moment). The rolling moments shown correspond roughly to 2° of aileron control. The agreement between data and theory is only fair. The agreement should improve considerably if the phenomena discussed in sections 3 and 4.2 are incorporated into the method.

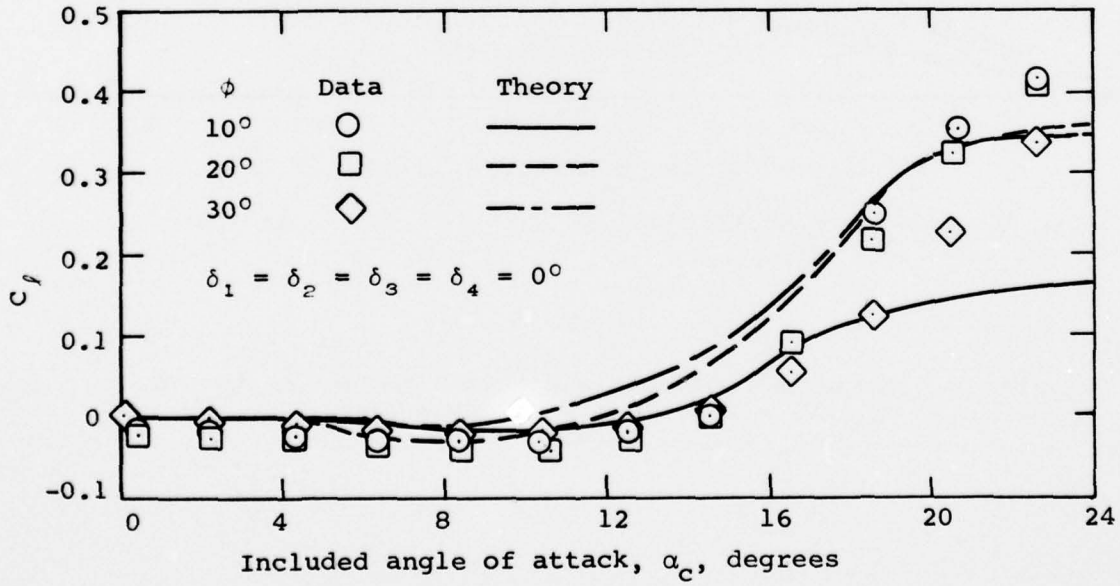


(a) Normal-force coefficient in unrolled body coordinates.

Figure 29. Comparison of data and theory for BT 2, $M_\infty = 1.75$, $V_{max}/V_\infty = 0.4$; S_R = model base area, ℓ_r = model base diameter.

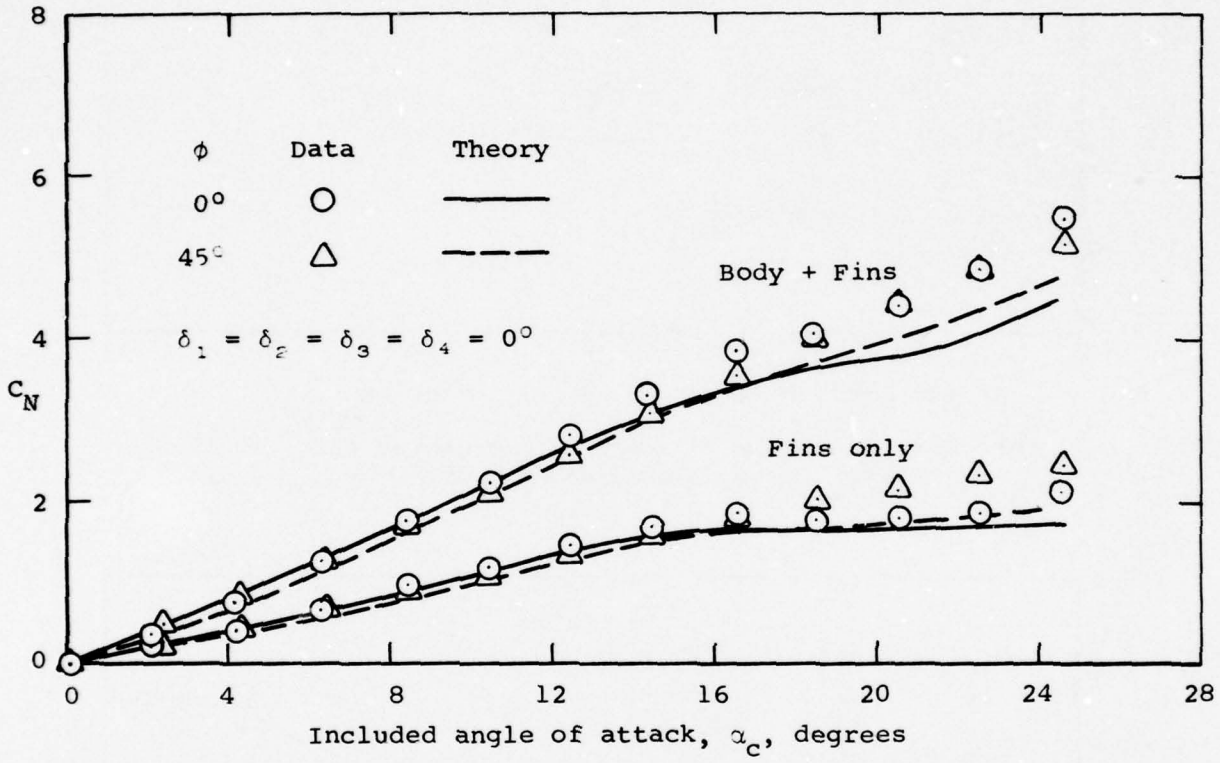


(b) Axial location of center of pressure for normal force, measured from MS 0.



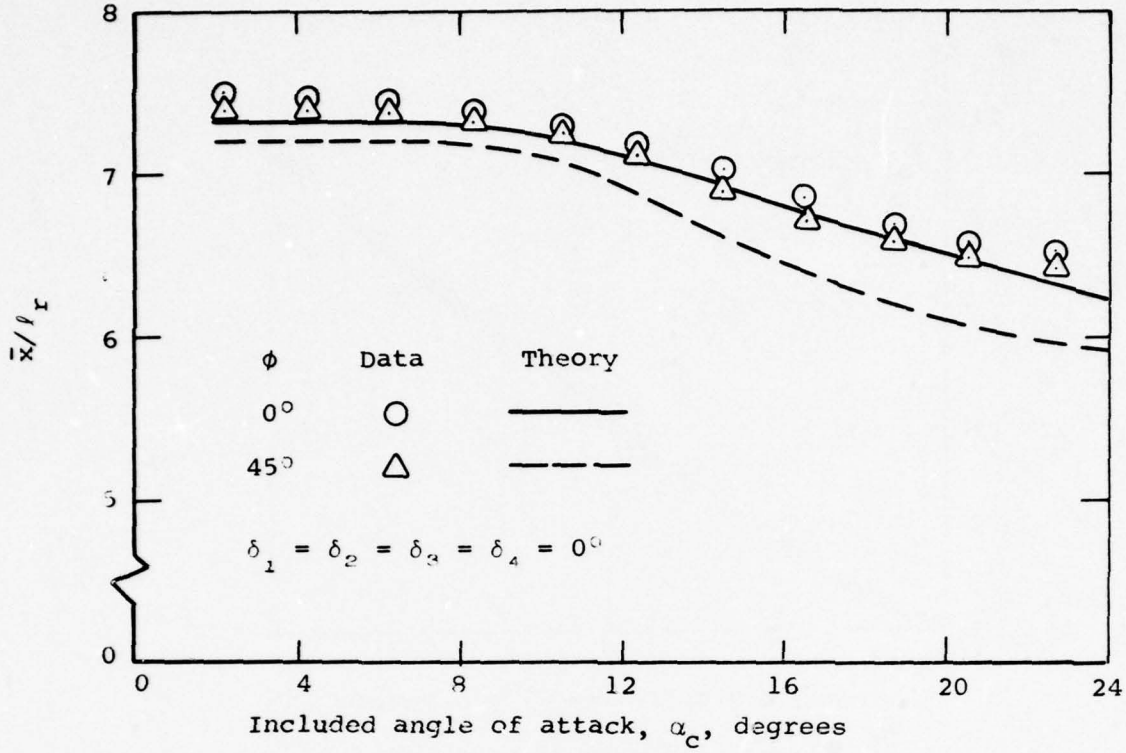
(c) Rolling-moment coefficient.

Figure 29. Concluded.

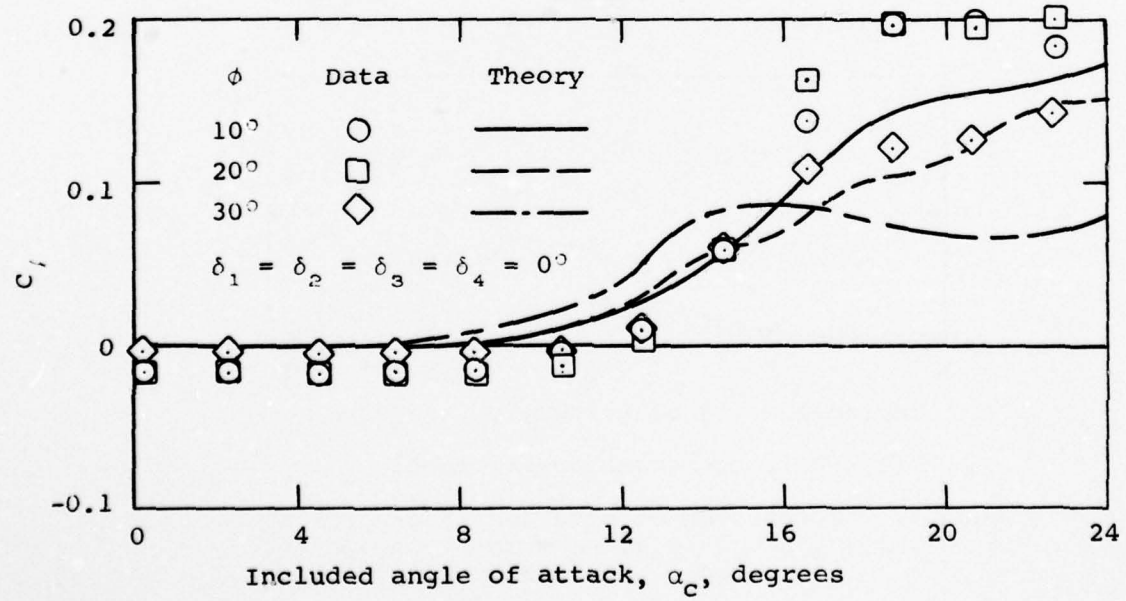


(a) Normal-force coefficient in unrolled body coordinates.

Figure 30. Comparison of data and theory for BT 2, $M_\infty = 0.8$, $V_{max}/V_\infty = 0.1$; S_R = model base area, ℓ_r = model base diameter.

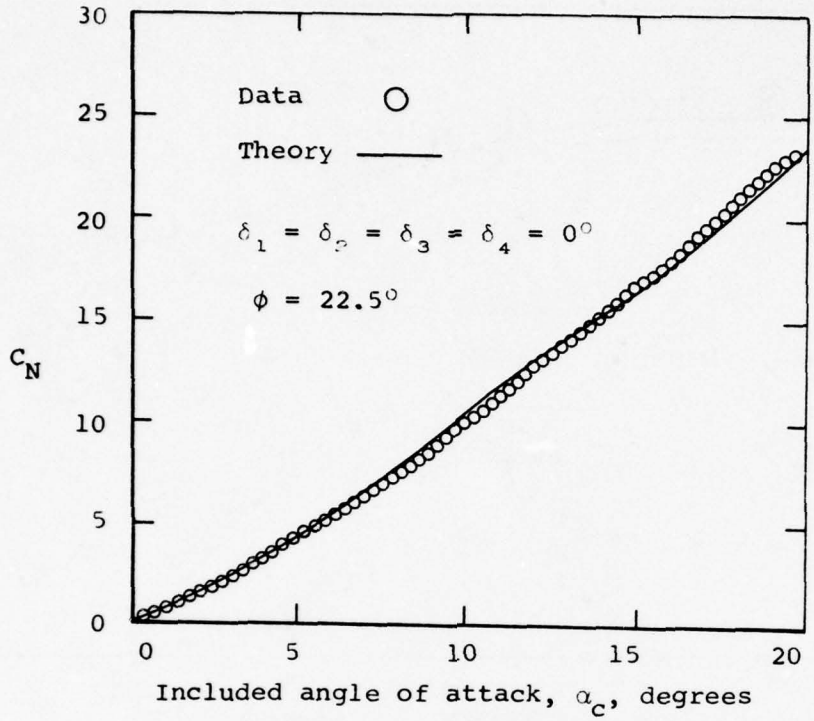


(b) Axial location of center of pressure for normal force, measured from MS 0.

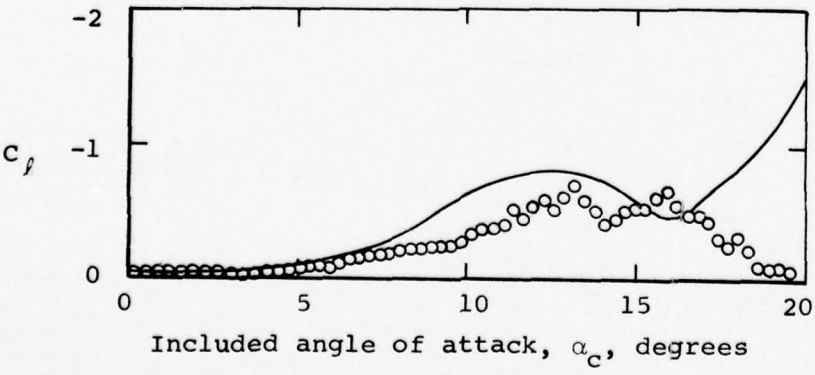


(c) Rolling-moment coefficient.

Figure 30. Concluded.



(a) Normal-force coefficient in unrolled body coordinates.



(b) Rolling-moment coefficient.

Figure 31. Comparison of data and theory for BT 4, $M_\infty = 0.8$, $V_{max}/V_\infty = 0.4$; S_R = model base area, ℓ_r = model base diameter.

5. COMPARISONS WITH DATA FOR BODY-CANARD AND BODY-CANARD-TAIL CONFIGURATIONS

This section is concerned with body-canard and body-canard-tail configurations which require vortex tracking for the calculation of forces and moments. The method used to obtain the vortex system behind the canard fins is heuristic, and its validity can best be determined by comparing its predictions with data. The method, as described in Appendix D, represents any body-generated vorticity which may form aft of the canard trailing edge as discrete vortices which change strength and position as a function of their axial positions. The first subsection below contains results for body-canard configurations (see fig. 3). Since no tail fins are present, these results are a sensitive indication of the ability of the tracking method to reproduce actual body loads in the presence of the wake over the afterbody. The second subsection below is concerned with body-canard-tail configurations (see fig. 3). These results are good tests of the ability of the tracking method to locate the vortices of the afterbody wake properly with respect to the tail fins.

5.1 Results for Body-Canard Configurations

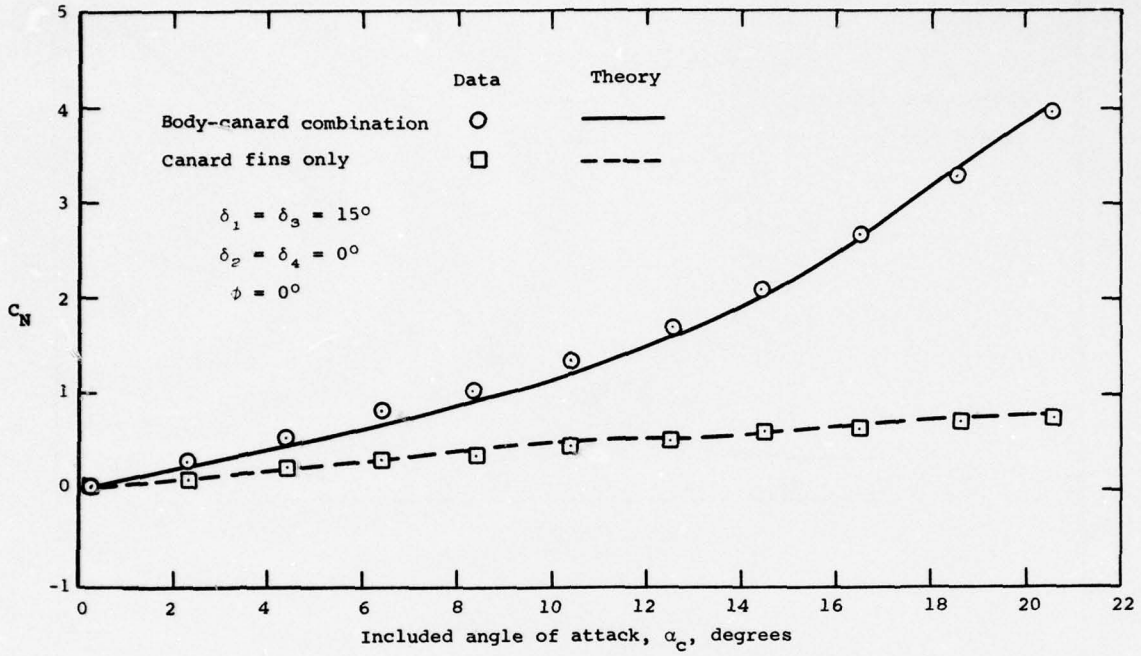
One of the features of the present method is that all vorticity is regarded as discrete and all the vorticity generated from a separation line on the body is represented by a single vortex. For example, the nose vorticity on the port side, the trailing-edge vorticity from canard fin 1 and the afterbody vorticity on the port side are each represented by a single vortex. Vapor screen (ref. 5) and laser anemometer (ref. 20) studies of the development of such vorticity indicate that more than one vortex may at times be required to represent the shed vorticity from each of these sources. It is known, for example, from the work of reference 5 that for $\alpha_c \leq 20^\circ$ the vorticity formed ahead of the canard fins of body-canard configuration no. 1 is dispersed as it moves over the fins and is no longer rolled up by the time it reaches the canard trailing edge. The present model represents such a vorticity field by a concentrated vortex which cannot disperse. The user of the code does have the option, however, of eliminating the nose vortices at the canard leading or trailing edges if he feels that they have dispersed in the actual flow. The vapor screen study of reference 5 also implied that vorticity shed from one of the windward fins can travel up and around the body and

strongly interact with the body boundary layer. The method used herein does not include this effect.

During the tests of reference 4, individual fin load data were obtained for body-canard configuration nos. 1 and 2 shown in figure 3. These data enable us to investigate the effects of afterbody wake asymmetry on total body loads. Results for body-canard configuration no. 1 are presented in figure 32 for $M_\infty = 1.75$ and zero bank. The moderate-aspect-ratio C_6 fins are deflected 15° in yaw and 0° in pitch. The comparisons show that total normal force is accurately predicted. However, side force is poorly predicted although the trend is correct. Note that the contributions of the fins to the total normal and side forces are well predicted. Hence, any discrepancies present must be attributed to the afterbody wake model.

Results for body-canard configuration no. 2 are presented in figure 33 for $M_\infty = 1.75$ and 20° bank. The low-aspect-ratio C_7 fins were undeflected. Note that the C_7 fins are considerably smaller relative to the body than the C_6 fins, yet similar results were obtained. Again, the contribution of the fins to total loads is well predicted. The agreement for total normal force is satisfactory though not quite so good as for the previous case. The results for total side force are interesting since, as in the previous case, the trend (for $\alpha_c < 24°$) is represented correctly although the magnitude is not. In this case, the side force is a second-order quantity being generally less than 10 percent of the normal force.

Another set of comparisons are presented in figure 34 for body-canard configuration no. 3 for $M_\infty = 0.8$ and zero bank. This configuration represents the AIM-9L. Note that the canards (see fig. 3(g)) are considerably larger relative to the body than the fins of body-canard configuration no. 1. Note also that the leading edge of each canard fin has a break in sweep. Although the present version of the code cannot handle breaks in leading-edge sweep, the fins can be adequately modeled with a straight leading edge running from the actual location of the leading edge of the root chord to the actual location of the tip chord. For the results of figure 34, the fins were deflected 20° in yaw and 0° in pitch. The agreement is fair for normal force and poor for side force. (Note that the side-force scale is 50 times the normal-force scale.) If more accurate side-force calculations on a percentage basis are to be made, some improvement in the afterbody vortex model is



(a) Normal-force coefficient in unrolled body coordinates.

Figure 32. Comparison of data and theory for BC 1, $M_\infty = 1.75$, $V_{max}/V_\infty = 0.4$; S_R = model base area.

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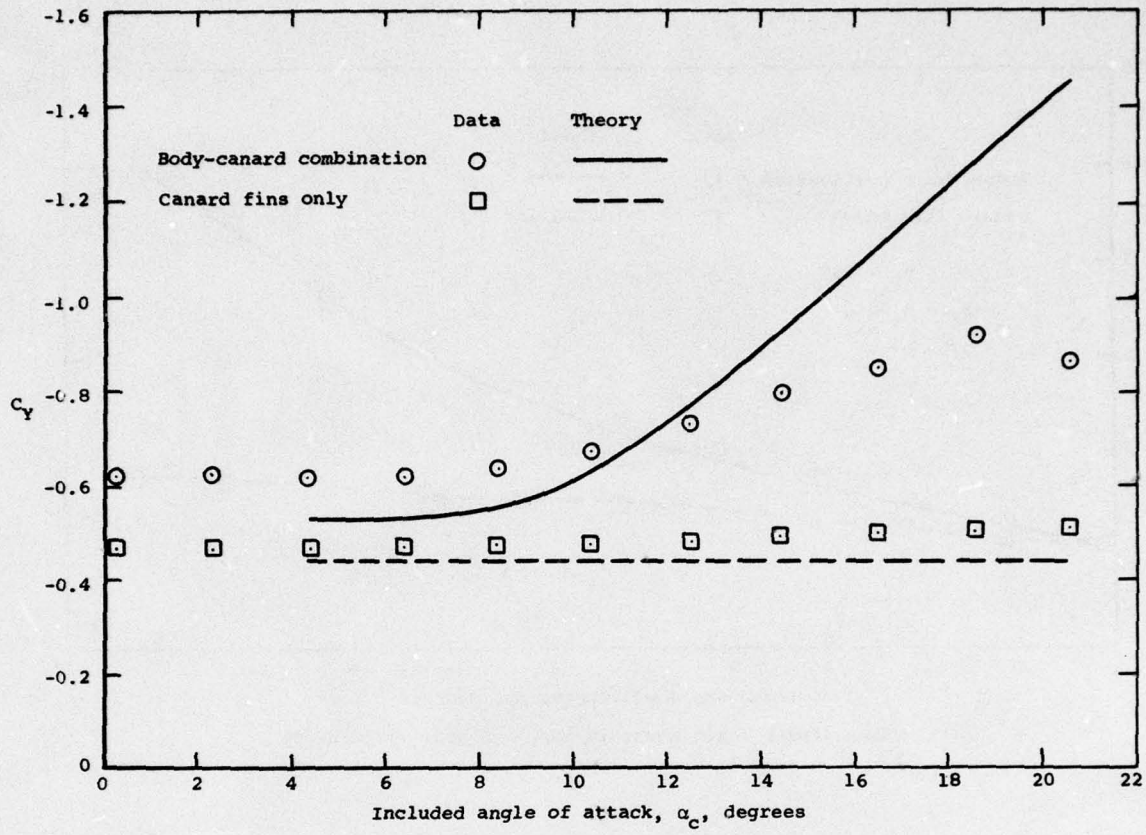
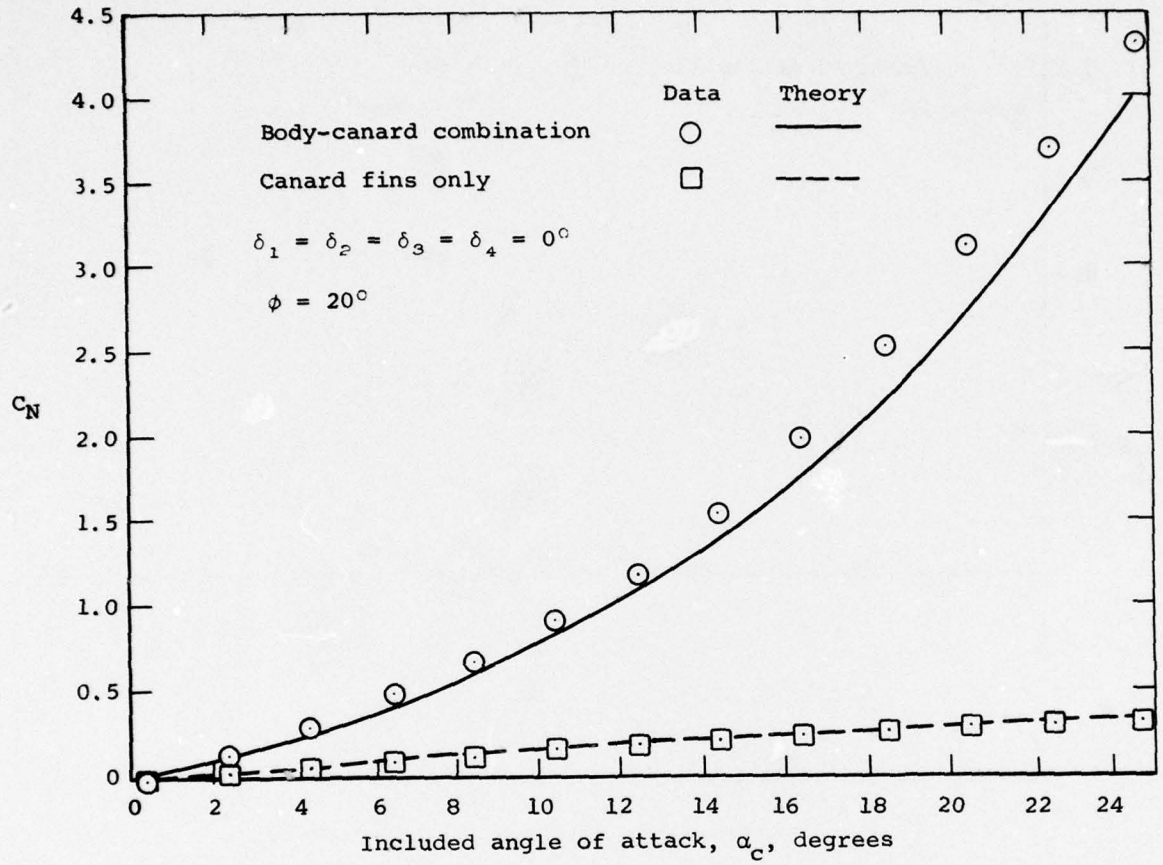


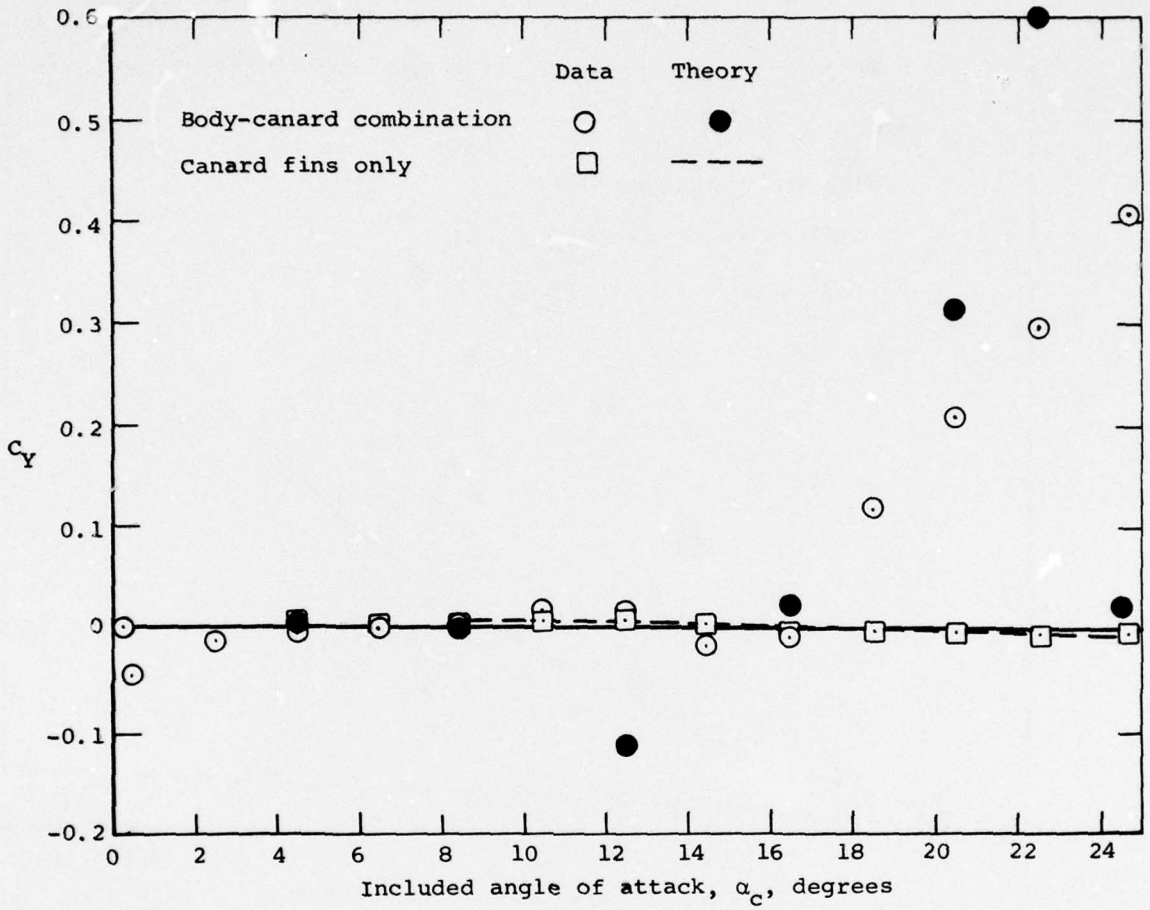
(b) Side-force coefficient in unrolled body coordinates.

Figure 32. Concluded.



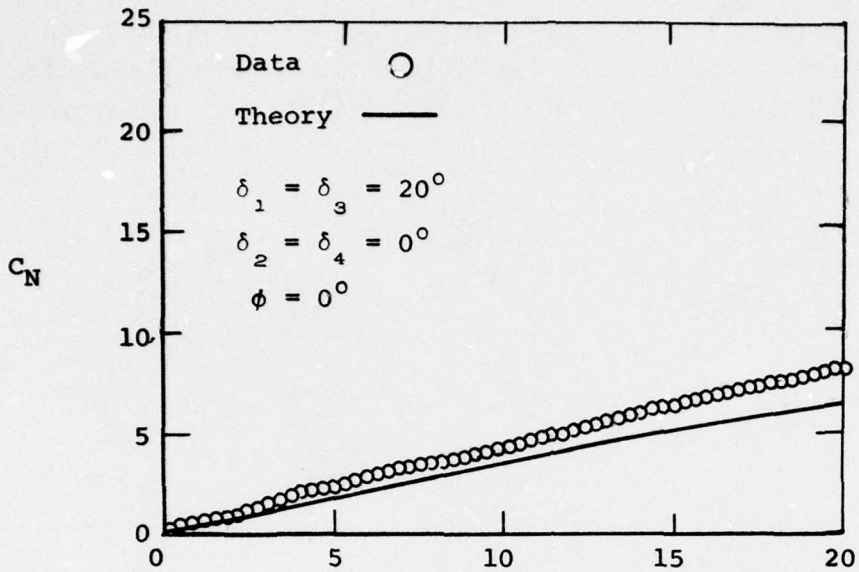
(a) Normal-force coefficient in unrolled body coordinates.

Figure 33. Comparison of data and theory for BC 2, $M_\infty = 1.75$, $V_{max}/V_\infty = 0.4$; S_R = model base area.

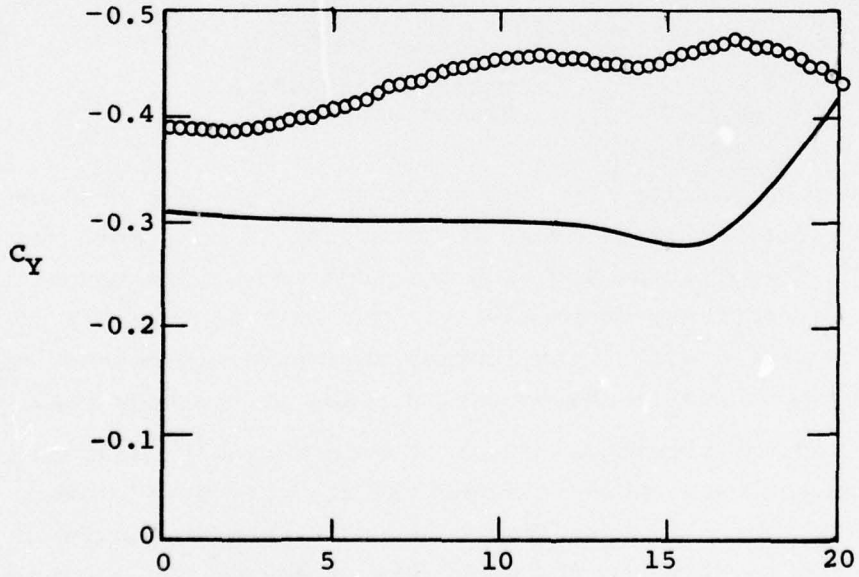


(b) Side-force coefficient in unrolled body coordinates.

Figure 33. Concluded.



(a) Normal-force coefficient in unrolled body coordinates.



(b) Side-force coefficient in unrolled body coordinates.

Figure 34. Comparison of data and theory for BC 3, $M_\infty = 0.8$, $V_{max}/V_\infty = 0.1$; S_R = model base diameter.

indicated. The sources of side force can be found by examining the vortex impulse theorem (eq. (28)) which is used to compute them. If we take the real and imaginary parts of equation (28) and integrate over the afterbody section, we obtain

$$C_N = \frac{4\pi a^2}{S_R} \sum_{j=1}^{NV(x)} \left\{ \left[\Gamma'_j y_{v,j} \left(1 - \frac{1}{r_{v,j}^2} \right) \right]_{\substack{\text{body} \\ \text{base}}} - \left[\Gamma'_j y_{v,j} \left(1 - \frac{1}{r_{v,j}^2} \right) \right]_{\substack{\text{trailing edge of} \\ \text{canard section}}} \right\} \tag{38}$$

$$C_Y = -\frac{4\pi a^2}{S_R} \sum_{j=1}^{NV(x)} \left\{ \left[\Gamma'_j z_{v,j} \left(1 - \frac{1}{r_{v,j}^2} \right) \right]_{\substack{\text{body} \\ \text{base}}} - \left[\Gamma'_j z_{v,j} \left(1 - \frac{1}{r_{v,j}^2} \right) \right]_{\substack{\text{trailing edge of} \\ \text{canard section}}} \right\} \tag{39}$$

where Γ' is nondimensionalized by $2\pi V_\infty a$ and y_v and z_v are nondimensionalized by a. If a vortex is free, its strength is constant, and its contribution to the normal force and side force depend on its movement in the y_o and z_o directions, respectively. The initial strength of an afterbody vortex is zero and its contribution to the forces depends only on its strength and position in the crossflow plane at the body base.

We have computed the predicted effect of each vortex present on the afterbody loads for the case shown in figure 32 at $\alpha_c = 20.6^\circ$. The results are given in Table 1. Note that a 5- to 10-percent change in the vertical position relative to the body axis of any of the vortices could make a large difference in the predicted side force for the afterbody section. Also large side-force contributions of alternating sign occur. The results of Table 1 clarify the need for accurate vortex tracking past the afterbody section. While the present model is capable of reproducing most of the physics, further improvement is needed if accurate results for side force are to be obtained.

TABLE 1. PREDICTED CONTRIBUTION OF VORTICES TO AFTERBODY LOADING FOR BODY-CANARD CONFIGURATION NO. 1; $M_\infty = 1.75$, $\phi = 0^\circ$, $\delta_1 = \delta_3 = 15^\circ$, $\delta_2 = \delta_4 = 0^\circ$, $\alpha_C = 20.6^\circ$, S_R = model base area.

	← CANARD TRAILING EDGE →			← BODY BASE →				
Vortex	Γ'	y_v/a	z_v/a	Γ'	y_v/a	z_v/a	C_N	C_Y
C1	0.053	0.18	1.93	0.053	0.52	3.43	0.07	-0.37
C2	-0.111	-1.87	0.	-0.111	-0.68	4.16	-0.31	1.74
C3	-0.072	0.18	-1.91	-0.072	1.22	3.59	-0.29	1.36
C4	0.115	1.87	0.	0.115	0.96	4.01	-0.20	-1.74
A_L	0.	-0.68	0.99	-0.397	-0.09	1.98	0.11	2.34
A_R	0.	1.09	0.50	0.411	1.76	2.85	2.64	-4.27
						TOTAL	2.02	-0.94

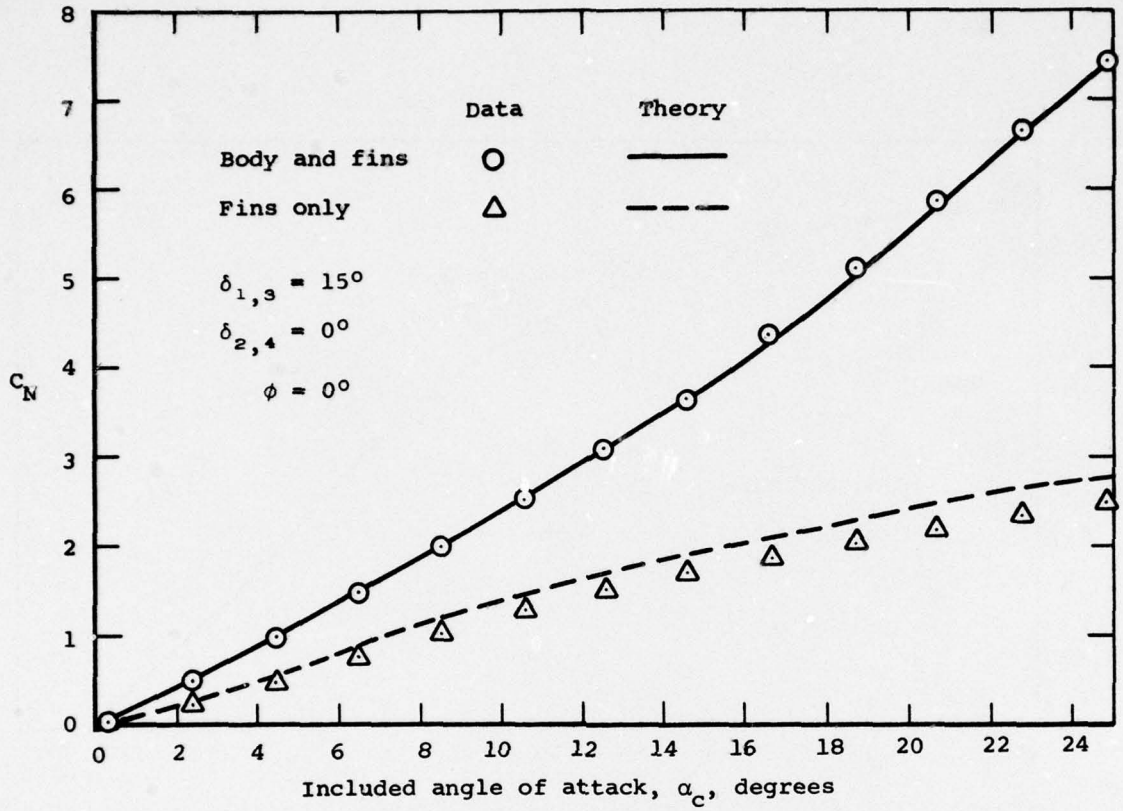
5.2 Results for Body-Canard-Tail Configurations

Comparisons between data and theory for two different body-canard-tail configurations are given in this section. The configurations are unrolled but have large yaw control deflections. Figure 35 presents results for body-canard-tail configuration no. 1 at $M_\infty = 1.75$ with zero bank. The fins are deflected 15° in yaw and 0° in pitch. The normal force is well predicted. However, the theory for side force departs increasingly from data for angles of attack above 18°. Since the contribution of the fins to the total side force is fairly well predicted, the procedure for obtaining the afterbody vortex positions and strengths on the afterbody section is the likely source of the discrepancy. The results for rolling moment are only fair.

Since the body cannot support a rolling moment, an analysis of the individual contributions of the fins to the total rolling moment should be of interest. The results are given in Table 2 for $\alpha_c = 8.5°$ and 20.6°. It is interesting to note that both the canard section and the tail section contribute substantially to the rolling moment but for different reasons. The canard section does not have significant body vorticity present. Hence, the only source of rolling moment for the canard section is differential fin loading due to sideslip. Canard fins 2 and 4 are not sideslipping as α_c increases. Therefore, fins 1 and 3 contribute most to the total rolling moment.

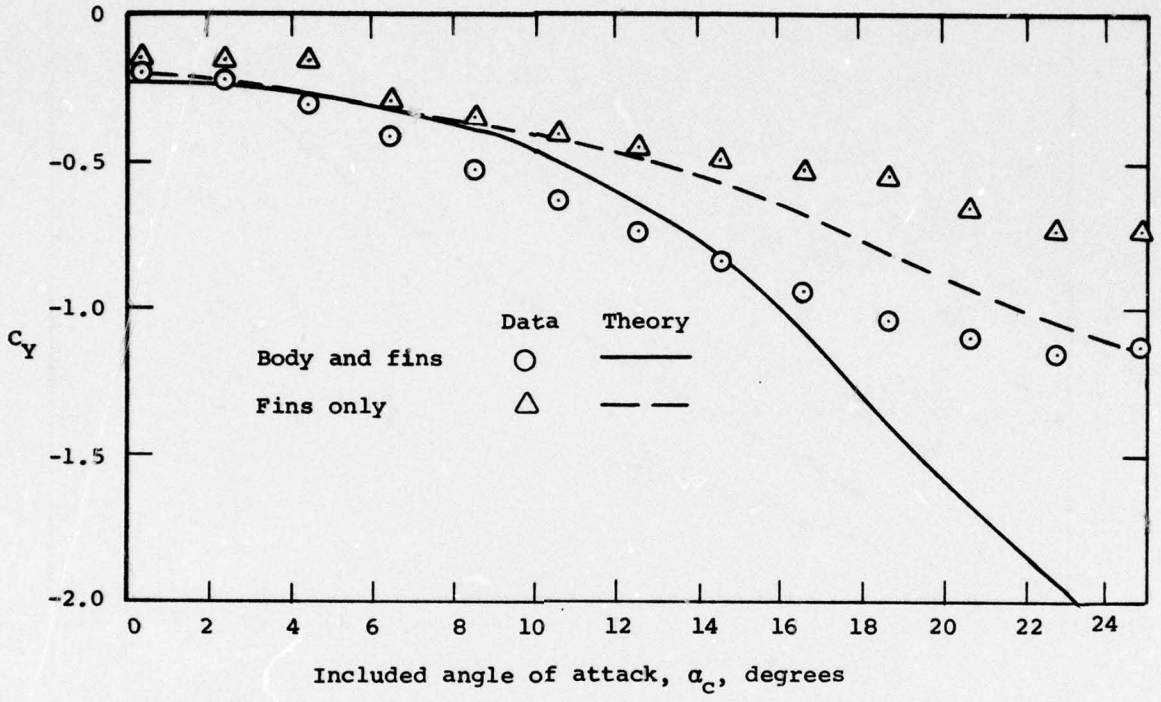
In the absence of vorticity shed by the body and canard fins, the tail section for $\phi = 0$ cannot support a rolling moment. Hence, the only source of rolling moment for the tail section is vortex-fin interference. This is clearly evident in the data for fins 1, 2, and 4. Note that the discrepancies between data and theory for individual fins are not large compared to the size of the loads seen. Yet those same discrepancies create large percentage errors in the overall rolling moment.

It is interesting to see which of the vortices present in the wake influence each fin. Calculated and measured vortex positions for several angles of attack at the leading edge of the tail root chord are presented in figure 36. Note that the predictions of the present method place the left afterbody vortex too far to the right and the right afterbody vortex too high.



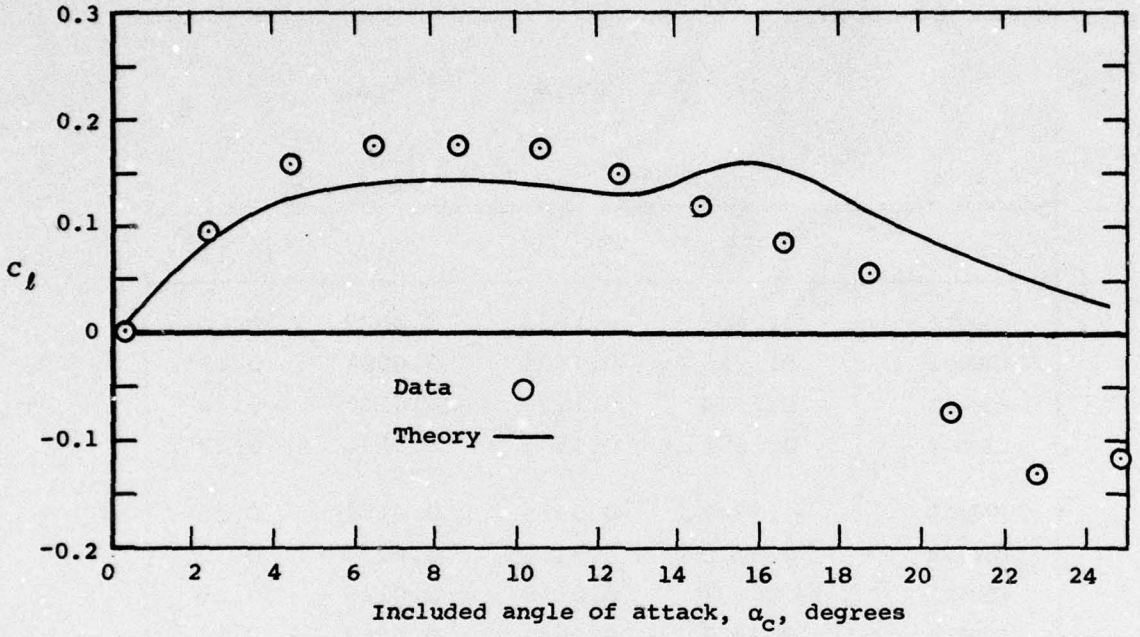
(a) Normal-force coefficient in unrolled body coordinates.

Figure 35. Comparison of data and theory for BCT 1, M_∞ = 1.75, V_{max}/V_∞ = 0.4; S_R = model base area, ℓ_r = model base diameter.



(b) Side-force coefficient in unrolled body coordinates.

Figure 35. Continued.



(c) Rolling-moment coefficient.

Figure 35. Concluded.

TABLE 2. ANALYSIS OF ERROR IN ROLLING MOMENT FOR BODY-CANARD-TAIL CONFIGURATION NO. 1; $M_\infty = 1.75$, $\phi = 0$, $\delta_1 = \delta_3 = 15^\circ$, $\delta_2 = \delta_4 = 0^\circ$, S_R = model base area, ℓ_r = model base diameter.

(a) $\alpha_c = 8.5^\circ$.

$$\epsilon_i \equiv (CRMi)_{theory} - (CRMi)_{data}$$

$$\epsilon_T \equiv \left[(C_\ell)_{theory} - (C_\ell)_{data}\right]_{all\ fins}$$

	Data	Theory	ϵ_i	$\epsilon_i/\lvert\epsilon_T\rvert$
CRMC1	0.1605	0.1634	0.0029	0.06
CRMC2	0.1423	0.1504	0.0081	0.17
CRMC3	0.1974	0.1829	-0.0145	-0.30
CRMC4	0.1392	0.1545	0.0153	0.32
CRMT1	-0.0747	-0.0575	0.0172	0.36
CRMT2	0.3170	0.3454	0.0284	0.59
CRMT3	-0.0001	0.0118	0.0119	0.25
CRMT4	0.2457	0.2924	0.0467	0.97
$(C_\ell)_{canard\ fins}$	0.0400	0.0154		
$(C_\ell)_{tail\ fins}$	0.1459	0.1223		
$(C_\ell)_{all\ fins}$	0.1859	0.1377		

$$\frac{\left[(C_\ell)_{theory} - (C_\ell)_{data}\right]_{canard\ fins}}{\left[(C_\ell)_{theory} - (C_\ell)_{data}\right]_{all\ fins}} = 0.51$$

$$\frac{\left[(C_\ell)_{theory} - (C_\ell)_{data}\right]_{tail\ fins}}{\left[(C_\ell)_{theory} - (C_\ell)_{data}\right]_{all\ fins}} = 0.49$$

TABLE 2. CONCLUDED

(b) $\alpha_c = 20.6^\circ$.

	Data	Theory	ϵ_i	$\epsilon_i/\lvert\epsilon_T\rvert$
CRMC1	0.1512	0.1494	-0.0018	-0.01
CRMC2	0.2775	0.3018	0.0243	0.16
CRMC3	0.2395	0.1968	-0.0427	-0.29
CRMC4	0.2854	0.3102	0.0248	0.17
CRMT1	0.1446	0.1272	-0.0174	-0.12
CRMT2	0.6094	0.7496	0.1402	0.95
CRMT3	-0.0044	0.0434	0.0478	0.32
CRMT4	0.6083	0.6250	0.0167	0.11
$(C_\ell)_{\substack{\text{canard}\\\text{fins}}}$	0.0804	0.0391		
$(C_\ell)_{\substack{\text{tail}\\\text{fins}}}$	-0.1479	0.0408		
$(C_\ell)_{\substack{\text{all}\\\text{fins}}}$	-0.0675	0.0799		

$$\frac{\left[(C_\ell)_{\text{theory}} - (C_\ell)_{\text{data}}\right]_{\substack{\text{canard}\\\text{fins}}}}{\left[(C_\ell)_{\text{theory}} - (C_\ell)_{\text{data}}\right]_{\substack{\text{all}\\\text{fins}}}} = -0.28$$

$$\frac{\left[(C_\ell)_{\text{theory}} - (C_\ell)_{\text{data}}\right]_{\substack{\text{tail}\\\text{fins}}}}{\left[(C_\ell)_{\text{theory}} - (C_\ell)_{\text{data}}\right]_{\substack{\text{all}\\\text{fins}}}} = 1.28$$

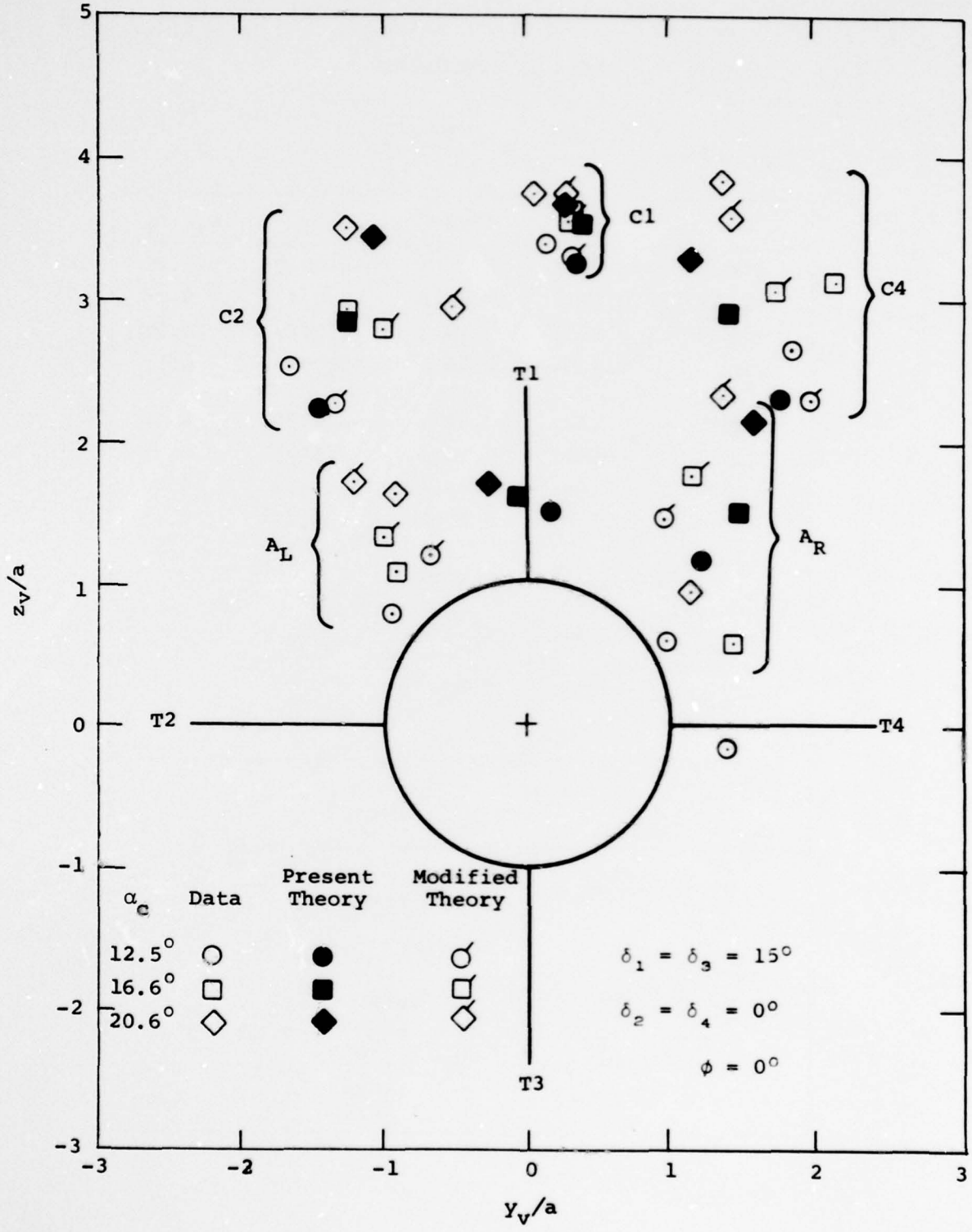


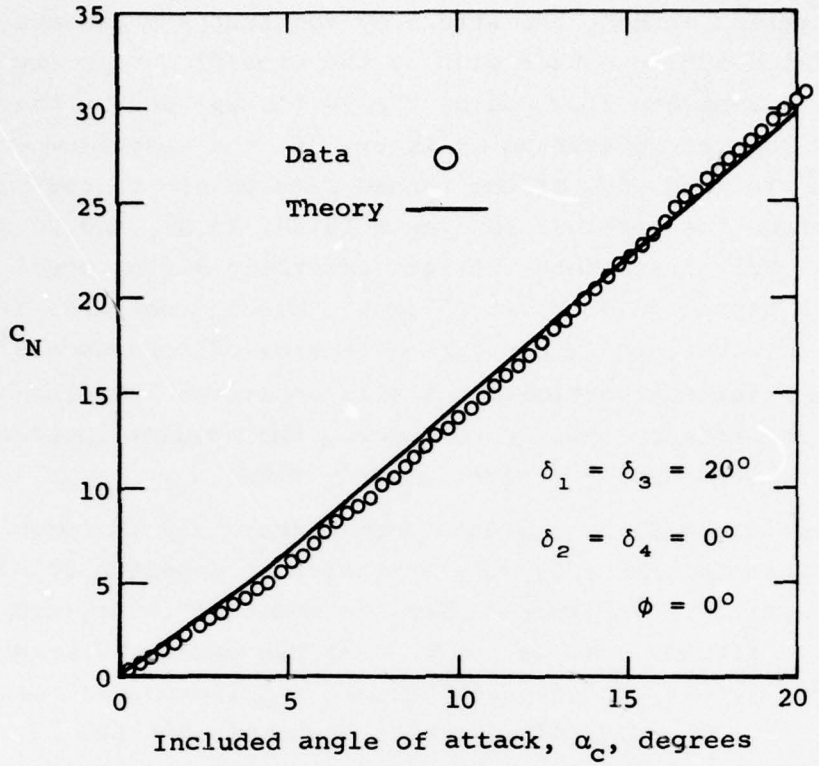
Figure 36. Measured and predicted vortex positions at x/a = 17.2 for BCT 1, M_∞ = 1.75.

In the present method, the afterbody vortices are assumed to be initially located 50° on either side of the crossflow velocity vector given by the free-stream flow and by the vorticity shed by the canard section. For the case presented in figure 36, the crossflow velocity vector at the trailing edge of the canard fins points to the right 25°, 19°, and 15° from the vertical for α_c = 12.5°, 16.6°, and 20.6°, respectively. This means that the left afterbody vortex would be started in the second quadrant at 65°, 59°, and 55° measured clockwise from fin T2. However, the vapor screen results of reference 5* indicate that the left afterbody vorticity actually separates from the body much lower in the second quadrant. Furthermore, the angular location of the separation line does not vary significantly with α_c.

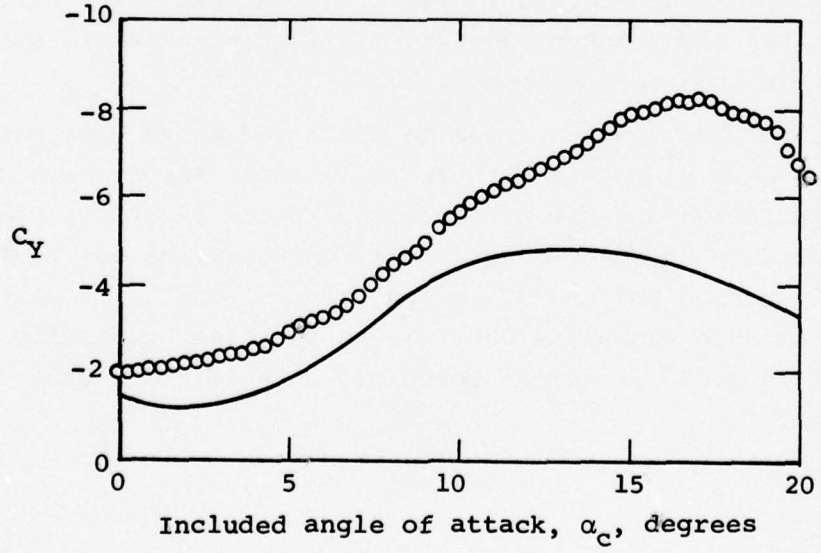
An attempt was made to represent more accurately the physics for this case by assuming the afterbody vorticity to separate 60° on either side of the vertical. The results for the modified theory are presented in figure 36 as flagged symbols. Note that the agreement between data and theory for A_L is considerably better. No improvement was obtained for A_R, however. The data of reference 5 showed that the C3 vortex moved up and to the right as it moved downstream. At some point along the body depending upon α_c, it came close enough to the body surface to interact with the body boundary layer. From that point aft, it was combined with the right afterbody vortex. That behavior is not accounted for in the present method.

In order to show that the results discussed above were not limited to an isolated case, comparisons between data and theory were made for another configuration and are presented in figure 37. The model is the AIM-9L of reference 14 (body-canard-tail configuration no. 2, fig. 3(i)). The model is unrolled and has 20° of yaw control and 0° of pitch control. The free-stream Mach number is 0.8. As in the case previously discussed, the agreement is good for normal force but only fair for side force and rolling moment.

*See also figure 20 of reference 4.

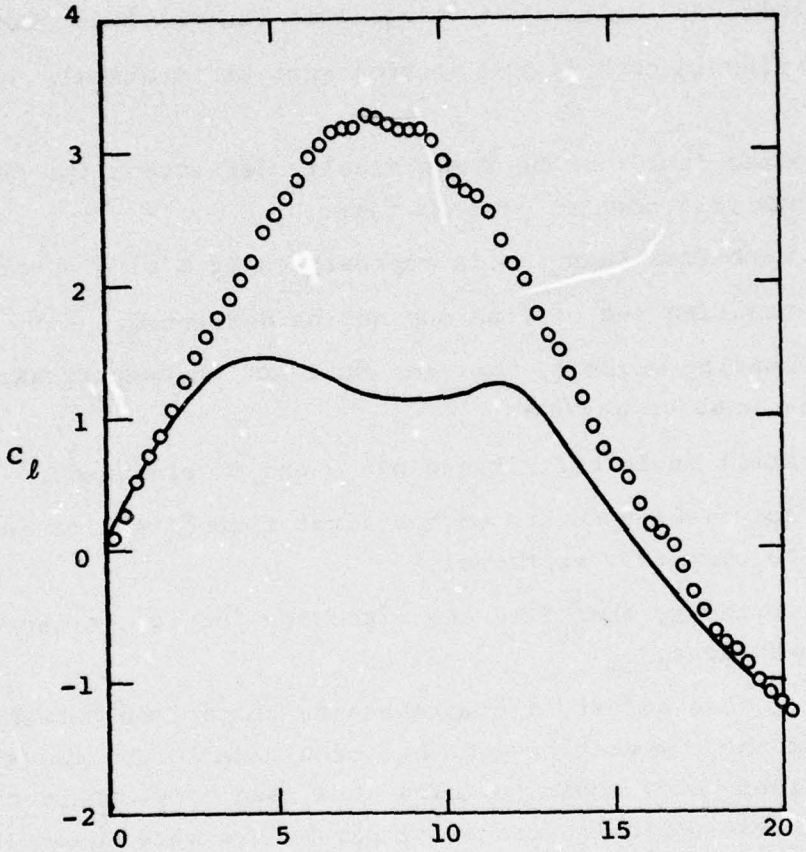


(a) Normal-force coefficient in unrolled body coordinates.



(b) Side-force coefficient in unrolled body coordinates.

Figure 37. Comparison of data and theory for BCT 2, $M_\infty = 0.8$, $V_{max}/V_\infty = 0.1$; S_R = model base area, ℓ_r = model base diameter.



(c) Rolling-moment coefficient.

Figure 37. Concluded.

6. CONCLUDING REMARKS

This report covers the first year's work in a two-year effort to develop a computer program for determining the forces and moments on the individual components of cruciform missiles at high angles of attack. The program is intended for use at subsonic, transonic, and supersonic speeds. It presently accommodates arbitrary roll angles, pitch control, and yaw control. It is, however, subject to the following limitations.

1. The fins in each finned section must be identical, uncambered, and untwisted.

2. Opposing fins must be symmetrically deflected; the program does not accommodate roll control at this time.

3. The wake from each fin is represented by a single vortex.

4. The trailing set of fins may not be deflected.

5. The leading edges of the fins must not be sweptforward, and the trailing edges must be unswept.

6. The small angle definitions of α and β are used.

7. The body wake upstream of the first finned section is represented by two discrete symmetric vortices.

8. The vorticity shed from the afterbody section is represented by two discrete vortices.

As part of this effort, a comprehensive comparison between data and predictions of the computer program has been made for bodies alone, body-tail combinations, body-canard combinations, and body-canard-tail combinations. The following ranges of parameters were covered:

Angle of Attack:	0° - 24°	for finned missiles
	0° - 47°	for bodies alone
Mach Number:	0.8 - 2.0	
Roll Angle:	0° - 45°	
Control Deflection:	0° - 20°	
Fin Aspect Ratio:	0.87 - 4.2	

The following conclusions can be drawn from the study:

1. For the bodies alone, accurate results were obtained except when the crossflow Mach number was near unity. The two-dimensional crossflow drag coefficients used in the procedure are too large under these circumstances.

2. For computing individual fin loads, the equivalent angle of attack concept is generally adequate except for two new vortical effects not included in the method as described in the next two items.

3. As a missile rolls, its fin leading and trailing edges undergo sweep changes. These sweep changes cause changes in the leading-edge and side-edge suctions as well as the fractions of these suctions converted to vortex lift. This effect, not included in the computer program, can cause significant changes in panel normal force particularly for low-aspect-ratio fins.

4. Increased panel normal force can result under certain conditions as a result of possible favorable vortex interference. This occurred for the left horizontal fin (T2) in the 16° to 29° range for angles of roll between 0° and 30° with low-aspect-ratio fins.

5. In general, normal force and axial location of center of pressure were well predicted by the method for complete configurations.

6. For no control deflections, a cruciform configuration can develop side forces and rolling moments principally as a result of nose, afterbody, or canard vortices. In the range of angle of attack considered here, the side force is typically about 10 percent of the normal force, and the rolling moment corresponds to 2° of roll control on all four fins. The errors in predicting these quantities are of the order of 50 percent. Improving the accuracy of these predictions will depend to a considerable degree on developing a better model for predicting the vortex path over the afterbody and the afterbody vortex strengths and predictions.

In the second year's work we plan to compare the theory with additional diagnostic data, particularly that which will be obtained to angles of attack of about 50° in the Ames Research Center 11-Foot Wind Tunnel under a NASA/Ames Research Center contract. Changes in the computer program to improve its accuracy at high angles of attack are contemplated, and certain of the limitations and shortcomings discussed above will be removed.

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APPENDIX A

PROCEDURE FOR COMPUTATION OF VORTEX PATHS IN THE PRESENCE OF A CRUCIFORM WING-BODY COMBINATION

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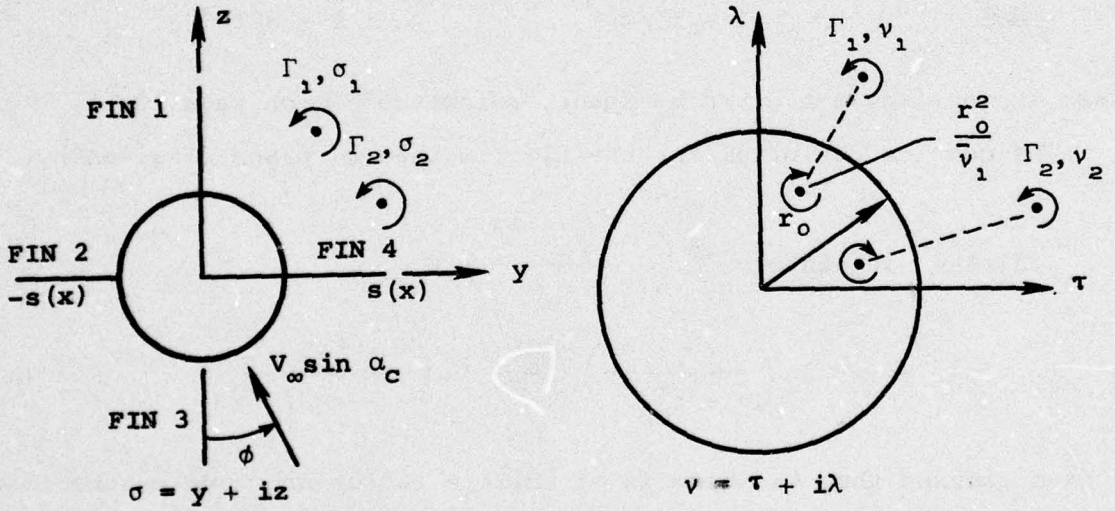
APPENDIX A

PROCEDURE FOR COMPUTATION OF VORTEX PATHS IN THE PRESENCE OF A CRUCIFORM WING-BODY COMBINATION

The determination of the loading on a finned section of a missile due to the presence of a set of vortices requires that the paths of the vortices be known. A procedure for computing those paths has been previously derived (refs. 9, 12, and A.1) and is repeated below. It is based on slender-body theory and assumes that the vortices can be "tracked" in a crossflow plane which is perpendicular to the body axis and which moves downstream at $V_\infty \cos \alpha_c$. The body boundary conditions are properly handled by imaging the external vortices. Since the image system for a cruciform wing-body combination would be quite complex, the actual configuration in the crossflow plane is transformed into a circle as shown in the sketch below. The sketch shows two asymmetrical vortices in the presence of a cruciform wing-body combination at combined pitch and roll.



Sketch A.1 Computational planes for vortex tracking.

The vortices are assumed to be discrete potential vortices moving as Lagrangian fluid particles. We will derive the equation of motion of Γ_1 with Γ_2 present, and then generalize the results to many vortices.

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The fin semispan, s, will be considered to be a function of the distance along the body axis, x. No effects of fin deflection on vortex paths are included.

Consider first the transformation and its derivatives of the cruciform wing-body combination in the σ plane into the circle of radius, r_o in the ν plane.

$$\sigma^2\left(1 + \frac{a^4}{\sigma^4}\right) = \nu^2\left(1 + \frac{r_o^4}{\nu^4}\right) \tag{A.1}$$

$$r_o^2 = \frac{1}{2}\, s^2\left(1 + \frac{a^4}{s^4}\right) \tag{A.2}$$

$$\frac{d\nu}{d\sigma} = \frac{\sigma}{\nu}\left(\frac{1 - a^4/\sigma^4}{1 - r_o^4/\nu^4}\right) \tag{A.3}$$

$$\frac{d^2\nu}{d\sigma^2} = \frac{d\nu}{d\sigma}\left[\frac{1}{\nu}\left(3 - \frac{4}{1 - r_o^4/\nu^4}\right)\left(\frac{d\nu}{d\sigma}\right) - \frac{1}{\sigma}\left(3 - \frac{4}{1 - a^4/\sigma^4}\right)\right] \tag{A.4}$$

These expressions are given by Spahr, reference A.1, on page 10.

The complex potential for the flow in the ν plane is given by

$$W(\nu) = -iV_\infty \sin\alpha_c e^{-i\phi}\left(\nu - \frac{r_o^2 e^{2i\phi}}{\nu}\right)$$

$$- \frac{i\Gamma_1}{2\pi}\ln\left(\frac{\nu - \nu_1}{\nu - r_o^2/\bar{\nu}_1}\right) - \frac{i\Gamma_2}{2\pi}\ln\left(\frac{\nu - \nu_2}{\nu - r_o^2/\bar{\nu}_2}\right) \tag{A.5}$$

We have assumed that the body is of uniform radius and have put no image vortices at the center of the body. The direction of the flow at infinity is unchanged under the transformation.

The complex potential $W_1[\nu(\sigma)]$ for the complex velocity $v_1 - iw_1$ of vortex, Γ_1, <u>in the σ plane</u> is the total complex potential $W(\nu)$ for the flow including the vortices minus the singularity at vortex, Γ_1.

$$W_1[\nu(\sigma)] = -iV_\infty \sin\alpha_c e^{-i\phi}\left(\nu - \frac{r_o^2 e^{2i\phi}}{\nu}\right) - \frac{i\Gamma_1}{2\pi}\ln\left(\frac{1}{\nu - r_o^2/\bar{\nu}_1}\right)$$

$$- \frac{i\Gamma_2}{2\pi}\ln\left(\frac{\nu - \nu_2}{\nu - r_o^2/\bar{\nu}_2}\right) + \frac{i\Gamma_1}{2\pi}\ln\left(\frac{\sigma - \sigma_1}{\nu - \nu_1}\right) \qquad \text{(A.6)}$$

The complex velocity of vortex, Γ_1, in the σ plane is given by

$$v_1 - iw_1 = \left.\frac{dW_1}{d\sigma}\right|_{\sigma=\sigma_1} \qquad \text{(A.7)}$$

In reference 9 it is shown that

$$\underset{\substack{\nu\to\nu_1\\ \sigma\to\sigma_1}}{\text{Limit}} \frac{d}{d\sigma}\ln\left(\frac{\sigma - \sigma_1}{\nu - \nu_1}\right) = -\frac{1}{2}\left(\frac{d\sigma}{d\nu}\right)\left(\frac{d^2\nu}{d\sigma^2}\right)_{\sigma=\sigma_1} \qquad \text{(A.8)}$$

The velocity $v_1 - iw_1$ is thus given by

$$v_1 - iw_1 = \frac{d}{d\sigma}\left[-iV_\infty \sin\alpha_c e^{-i\phi}\left(\nu - \frac{r_o^2 e^{2i\phi}}{\nu}\right) + \frac{i\Gamma_1}{2\pi}\ln\left(\nu - \frac{r_o^2}{\bar{\nu}_1}\right)\right.$$

$$\left. - \frac{i\Gamma_2}{2\pi}\ln\left(\frac{\nu - \nu_2}{\nu - r_o^2/\bar{\nu}_2}\right)\right] - \frac{i\Gamma_1}{2\pi}\left(\frac{d\sigma}{d\nu}\right)\left(\frac{d^2\nu}{d\sigma^2}\right) \qquad \text{(A.9)}$$

all evaluated at $\sigma = \sigma_1$. Carrying out the operation yields

$$v_1 - iw_1 = \left[-iV_\infty \sin\alpha_c e^{-i\phi}\left(1 + \frac{r_o^2 e^{2i\phi}}{\nu_1^2}\right) + \frac{i\Gamma_1}{2\pi}\left(\frac{1}{\nu_1 - r_o^2/\bar{\nu}_1}\right)\right.$$

$$\left. - \frac{i\Gamma_2}{2\pi}\left(\frac{1}{\nu_1 - \nu_2} - \frac{1}{\nu_1 - r_o^2/\bar{\nu}_2}\right)\right]\left(\frac{d\nu}{d\sigma}\right)_{\sigma=\sigma_1} - \frac{i\Gamma_1}{2\pi}\left(\frac{d\sigma}{d\nu}\right)\left(\frac{d^2\nu}{d\sigma^2}\right)_{\sigma=\sigma_1} \qquad \text{(A.10)}$$

If there are n external vortices, $\Gamma_1, \Gamma_2, \ldots, \Gamma_n$, then equation (A.10) will have the form

$$v_1 - iw_1 = \left[-iV_\infty \sin \alpha_c e^{-i\phi} \left(1 + \frac{r_o^2 e^{2i\phi}}{\nu_1^2} \right) + \frac{i\Gamma_1}{2\pi} \left(\frac{1}{\nu_1 - r_o^2/\bar{\nu}_1} \right) \right.$$

$$\left. - i \sum_{k=1}^{n} \frac{\Gamma_k}{2\pi} \left(\frac{1}{\nu_1 - \nu_k} - \frac{1}{\nu_1 - r_o^2/\bar{\nu}_k} \right) \right] \left(\frac{d\nu}{d\sigma} \right)_{\sigma=\sigma_1} - \frac{i\Gamma_1}{4\pi} \left(\frac{d\sigma}{d\nu} \right) \left(\frac{d^2\nu}{d\sigma^2} \right)_{\sigma=\sigma_1} \tag{A.11}$$

For the jth vortex, we can write

$$v_j - iw_j = \left[-iV_\infty \sin \alpha_c e^{-i\phi} \left(1 + \frac{r_o^2 e^{2i\phi}}{\nu_j^2} \right) + \frac{i\Gamma_i}{2\pi} \left(\frac{1}{\nu_i - r_o^2/\bar{\nu}_i} \right) \right.$$

$$\left. - i \sum_{\substack{k=1 \\ k \neq j}}^{n} \frac{\Gamma_k}{2\pi} \left(\frac{1}{\nu_j - \nu_k} - \frac{1}{\nu_j - r_o^2/\bar{\nu}_k} \right) \right] \left(\frac{d\nu}{d\sigma} \right)_{\sigma=\sigma_j} - \frac{i\Gamma_j}{2\pi} \left(\frac{d\sigma}{d\nu} \right) \left(\frac{d^2\nu}{d\sigma^2} \right)_{\sigma=\sigma_j} \tag{A.12}$$

In determining the trajectories of vortices passing by a cruciform finned section of a missile, the positions and strengths of the vortices must be given at some initial value of x. Then the appropriate equations of motion for the vortices are

$$\frac{dy_j}{dt} = v_j \quad \text{and} \quad \frac{dz_j}{dt} = w_j \tag{A.13}$$

Since the crossflow plane is moving downstream with the speed, $V_\infty \cos \alpha_c$, we have

$$\frac{dx}{dt} = V_\infty \cos \alpha_c \tag{A.14}$$

Substituting equation (A.14) into (A.13) gives

$$\frac{dy_j}{dx} = \frac{v_j}{V_\infty} \frac{1}{\cos \alpha_c} \quad \text{and} \quad \frac{dz_j}{dx} = \frac{w_j}{V_\infty} \frac{1}{\cos \alpha} \tag{A.15}$$

The set of differential equations (A.15) together with the initial conditions and the set of algebraic relations (A.12) form a system of ordinary first-order initial value differential equations which can be solved by standard integration routines.

The present method uses small angle approximations throughout. Hence, the quantity $\cos \alpha_c$ in equations (A.15) is set equal to one. When the influence of the fins is to be ignored, the code sets $s(x) = a$.

The following relationships can be used to go back and forth between the σ and ν planes:

$$\sigma^2 = \frac{(\nu^2 + r_o^4/\nu^2) + \sqrt{(\nu^2 + r_o^4/\nu^2)^2 - 4a^4}}{2} \tag{A.16}$$

$$\nu^2 = \frac{(\sigma^2 + a^4/\sigma^2) + \sqrt{(\sigma^2 + a^4/\sigma^2)^2 - 4r_o^4}}{2} \tag{A.17}$$

The roots are to be chosen such that corresponding points are always in corresponding quadrants.

REFERENCE

A.1. Spahr, J. R.: Theoretical Prediction of the Effects of Vortex Flows on the Loading, Forces and Moments of Slender Aircraft. NASA TR-R-101, 1961.

APPENDIX B

REVERSE FLOW METHOD FOR COMPUTATION OF FIN FORCES AND MOMENTS IN THE PRESENCE OF VORTICES

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APPENDIX B

REVERSE FLOW METHOD FOR COMPUTATION OF FIN FORCES AND MOMENTS IN THE PRESENCE OF VORTICES

B.1. INTRODUCTION

The purpose of this appendix is to present the procedure used in the code MLOADS to compute the effects of vortices on the loading experienced by a cruciform wing-body combination. The reverse flow method used herein was originally developed for the calculation of forces and moments on an external store in a nonuniform flow field and was presented in reference B.1. The development below closely follows that of Appendix I of reference B.1.

In the procedure under discussion the body is at zero angle of attack and the fins are undeflected so that only the loading due to vortices will be computed.

B.2. DISCUSSION OF METHOD

Our problem is to determine the fin normal forces and rolling moments due to an external vortex passing a cruciform fin-body combination. The first step is to determine the changes in fin twists due to the vortex. The vortex is assumed to be rectilinear and parallel to the fin, and it induces an angle of attack normal to the i'th fin, $\alpha_{v,i}(t)$, which can be established by methods which will be discussed. It is possible using a reverse flow theorem to determine the force which is normal to the fin planform and acts on the fin-body combination. We then multiply the fin-body normal force by the ratio, $K_W/(K_W + K_B)$, to obtain an estimate of the normal force acting on the fin. We divide the normal force acting on the fin by the fin-alone normal force for unit angle of attack and obtain an equivalent angle of attack $(\Delta\alpha_{eq})_{v,i}$ on the i'th fin due to the vortex. This procedure can be carried out using either linear theory or slender-body theory provided the same theory is used throughout. Any bias is minimized since a normal-force ratio is utilized to obtain an equivalent angle of attack.

The next step is to use the nonlinear normal-force curve for the fin alone to determine the fin force associated with $(\Delta\alpha_{eq})_{v,i}$. This fin force depends at what point on the normal-force curve the fin is

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operating before account is taken of $(\Delta\alpha_{eq})_{v,i}$. The associated force acting on the body is then obtained by multiplying the fin normal force by the ratio, K_B/K_W. The procedure can be applied to all four fins to obtain the normal-force and side-force components of the fin-body combination.

With respect to rolling moment, it is possible to obtain the rolling moment acting on the wing-body due to the fin twist associated with a vortex using reverse flow theorems. This rolling moment is due in part to direct roll associated with the fin in question and by reverse roll associated with the other fins. If the rolling moment (about the body axis) is divided by the fin-alone normal force calculated by the same theory as the rolling moment, then an effective lever arm for the fin is established. This lever arm includes the effects of reverse roll and is thus closer to the body axis than if reverse roll had been neglected. The nonlinear rolling moment due to the fin can then be calculated by multiplying the nonlinear fin normal force by this lever arm.

The detailed derivations of the equations based on this method are now given.

B.3. BOUNDARY CONDITIONS INDUCED ON FINS BY VORTICES

The procedure for calculating the distribution of induced angle of attack normal to the fins is as follows:

1. Specify the spanwise fin coordinates at which the induced angle of attack is to be calculated.

2. Calculate the velocities induced at those coordinates by the Biot-Savart law for all the vortices present.

3. From the velocities computed for each point, determine the component normal to the fin.

4. Depending upon the option of the user, limit the velocity which may be induced on the fin.

The code gives the user a number of options concerning the induced angle of attack. The options are: (1) impose no limit on the angle of attack which may be induced on the fin; (2) assume that each vortex has a viscous core; or (3) limit the maximum velocity which may be induced on

a fin to a specified fraction of V_∞. If either option (1) or (2) is selected, $\alpha_{v,i}$ is set equal to the arc tangent of the ratio of the induced velocity to V_∞. If option (3) is selected, $\alpha_{v,i}$ is set equal to the ratio of the induced velocity to V_∞ or V_{max}/V_∞, whichever is smaller.

B.4. DETERMINATION OF LOADING ACTING ON FINNED SECTION

Since it is based on integral theorems, the reverse flow method cannot give the loading on individual fins. Rather, it gives the overall loading on the finned section due to the flow field seen by each fin This is sufficient for small angles of attack for which the fin loading characteristics are linear. However, when the fin loading characteristics are nonlinear, an extension to the reverse flow method is required. The extension used in the present method is based on the equivalent angle of attack concept. The procedure we will use is as follows:

1. Compute the normal force or side force acting on the fin-body configuration due to the fin twist associated with the vortices using a combination of reverse flow theory and slender-body theory.

2. Estimate the fraction of the normal force or side force acting on the fin by multiplying the quantity calculated in (1) by the ratio, $K_W/(K_W + K_B)$.

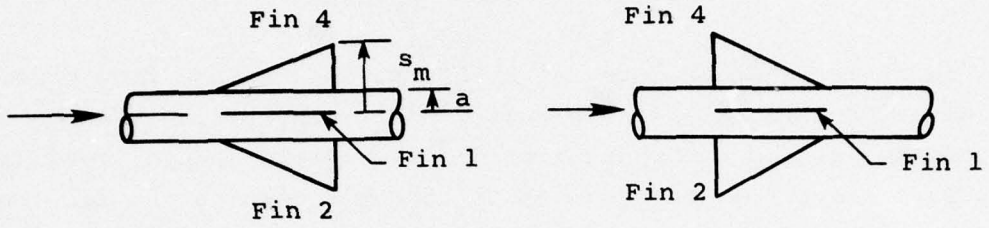
3. Divide the fin force of (2) by the slope of the slender-body theory fin-alone normal-force curve to obtain an equivalent angle of attack, $(\Delta\alpha_{eq})_v$. Using this quantity with the fin-alone nonlinear normal-force curve will give the nonlinear fin normal force in the presence of the body.

4. Using the same theory as in (2) above, calculate the total rolling moment acting on the finned section due to the fin twist associated with the vortex.

5. Divide the result of (4) by the result of (2) to get a moment arm for the force due to $(\Delta\alpha_{eq})_v$.

B.4.1 Computation of Equivalent Angle of Attack for Each Fin

Consider now a cruciform finned section with a circular body in direct flow and in reverse flow as shown. We will consider the force normal to the plane of fins 2 and 4 first and generalize the results to an arbitrary fin. The fins are undeflected.



Sketch B.1. Direct and reverse flow.

Let S_B be the body planform area and let S_1, S_2, S_3, and S_4 be the planform areas for the fins. Let P_d and α_d be the fin loading coefficient and the local angle of attack in direct flow, and let P_r and α_r be the corresponding quantities in reverse flow. Then, the reverse flow theorem (ref. 9, p. 221) gives

$$\iint_{\substack{S_B+S_1+S_2\\+S_3,S_4}} P_r\alpha_d dS = \iint_{\substack{S_B+S_1+S_2\\+S_3+S_4}} P_d\alpha_r dS \qquad \text{(B.1)}$$

Choose the following specific values of angles of attack and pressure coefficients

Direct			Reverse		
$\alpha_d = 0$	on	S_B, S_1, S_3	$\alpha_r = 1$	on	S_B
$\alpha_d = \alpha_{v,i}$	on	S_2, S_4	$\alpha_r = 1$	on	S_2, S_4
$P_d = P_d$			$\alpha_r = 0$	on	S_1, S_3
			$P_r = P_3$		

Then, (B.1) becomes

$$\iint_{S_B+S_1+S_2+S_3+S_4} P_d dS = \iint_{S_2} \alpha_{v,2} P_3 dS + \iint_{S_4} \alpha_{v,4} P_3 dS \qquad (B.2)$$

where P_3 is the loading for a wing-body combination at unit angle of attack and no yaw or pitch control. The force normal to the plane of fins 2 and 4 acting on the finned section is

$$N = q_\infty \iint_{S_B+S_2+S_4} P_d dS \qquad (B.3)$$

Substituting (B.2) into (B.3) gives

$$N = q_\infty \int_a^{s_m} \int_{\ell.e.}^{t.e.} \alpha_{v,2}(x,t) P_3 dx\, dt + q_\infty \int_a^{s_m} \int_{\ell.e.}^{t.e.} \alpha_{v,4}(x,t) P_3 dx\, dt \qquad (B.4)$$

where the dummy variable t refers to integration along the span of the fins. Let the span-load distribution associated with P_3 be $(cc_\ell)_3$ such that

$$(cc_\ell)_3 = \int_{\ell.e.}^{t.e.} P_3 dx \qquad (B.5)$$

Now we assume that $\alpha_{v,i}$ varies slowly in the chordwise x-direction so that substitution of (B.5) into (B.4) gives

$$N = q_\infty \int_a^{s_m} \bar{\alpha}_{v,2} (cc_\ell)_3 dt + q_\infty \int_a^{s_m} \bar{\alpha}_{v,4} (cc_\ell)_3 dt \qquad (B.6)$$

The normal forces acting on S_2 and S_4 are not given by this result since part of the load due to each integral can appear on the body and the opposing fin. Here $(cc_\ell)_3$ is the span loading on the fins for the configuration in reverse flow with both body and panels at unit angle of attack with no yaw or pitch control. From reference 9, equation (5-15), we have the slender-body theory expression for the span loading:

$$(cc_\ell)_3 = 4\left[\left(s_m + \frac{a^2}{s_m}\right)^2 - \left(y + \frac{a^2}{y}\right)^2\right]^{1/2} \tag{B.7}$$

In order to obtain the normal force on each individual fin and thereby carry out item 2 of the procedure described above, we multiply equation (B.6) by $K_W/(K_W + K_B)$ and consider each term to be the force acting on the fin over which the integration is taking place. We can follow the same procedure for fins 1 and 3 with the following result for fin i:

$$N_{\text{fin } i} = \frac{q_\infty K_W}{K_W + K_B} \int_a^{s_m} \bar{\alpha}_{v,i}(t)\,(cc_\ell)_3\,dt \tag{B.8}$$

The slender-body normal-force slope for the fin is $\pi q_\infty (s_m - a)^2$. Hence, carrying out item 3 of the procedure described at the beginning of this section, we find

$$(\Delta\alpha_{eq})_v = \frac{F_{\text{fin } i}}{\pi q_\infty (s_m - a)^2}$$

$$= \frac{K_W}{\pi(K_W + K_B)(s_m - a)^2} \int_a^{s_m} \bar{\alpha}_{v,i}(t)\,(cc_\ell)_3\,dt \tag{B.9}$$

Without the vortex present, the i'th fin operates at $(\alpha_{eq,p})_i$. The difference in normal force at $[\alpha_{eq,p} + \Delta(\alpha_{eq})_v]_i$ and at $(\alpha_{eq,p})_i$ in the fin-alone nonlinear normal-force curve is the nonlinear normal force on the fin associated with the vortex. It must be multiplied by (K_B/K_W) to obtain the nonlinear contribution due to body carryover.

B.4.2 Computation of the Moment Arm for the Rolling Moment Associated with Each Fin due to the Vortex

The reverse-flow theorem for all the fins with the body aligned in the free-stream direction (i.e., $\alpha = 0$ on body) is

$$\iint_{\substack{S_1+S_2\\+S_3+S_4}} \alpha_d P_r\,dS = \iint_{\substack{S_1+S_2\\+S_3+S_4}} \alpha_r P_d\,dS \tag{B.10}$$

Choose the direct and reverse flow conditions as follows:

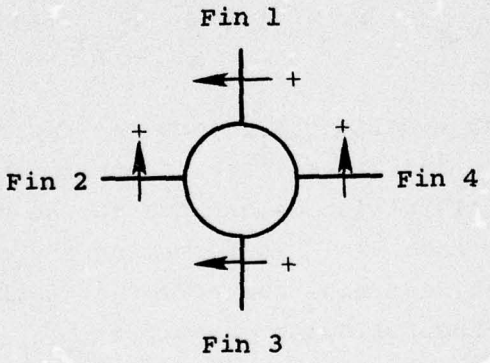
$$\alpha_d = \alpha_{v,i}(x,t) \qquad \alpha_r = \omega t/V_\infty$$

$$P_d = P_d \qquad P_r = P_6$$

where t is the spanwise coordinate for each fin measured from the body axis. Note that α_r corresponds to the distribution of angle of attack which would be seen by a configuration rolling at the rate of ω radians per second clockwise. Then, (B.10) becomes

$$\frac{\omega}{V_\infty} \iint_{S_1+S_2+S_3+S_4} tP_d dS = -\iint_{S_1} \alpha_{v,1}(x,t) P_6 dS + \iint_{S_2} \alpha_{v,2}(x,t) P_6 dS + \iint_{S_3} \alpha_{v,3}(x,t) P_6 dS - \iint_{S_4} \alpha_{v,4}(x,t) P_6 dS \quad \text{(B.11)}$$

where $\alpha_{v,i}$ has the sign convention shown in the sketch below.



Sketch B.2. Sign convention for $\alpha_{v,i}$.

The total rolling moment for the finned section is:

$$M_\ell = q_\infty \iint_{S_1+S_2+S_3+S_4} tP_d dS \quad \text{(B.12)}$$

Substituting (B.11) into (B.12) gives

$$M_\ell = \frac{q_\infty V_\infty}{\omega}\left[- \int_a^{s_m} \int_{\ell.e.}^{t.e.} \alpha_{v,1}(x,t)\, P_6\, dx\, dt + \int_a^{s_m} \int_{\ell.e.}^{t.e.} \alpha_{v,2}(x,t)\, P_6\, dx\, dt \right.$$

$$\left. + \int_a^{s_m} \int_{\ell.e.}^{t.e.} \alpha_{v,3}(x,t)\, P_6\, dx\, dt - \int_a^{s_m} \int_{\ell.e.}^{t.e.} \alpha_{v,4}(x,t)\, P_6\, dx\, dt \right] \qquad \text{(B.13)}$$

Let the span loading for the reverse flow case above be

$$(cc_\ell)_6 = \frac{V_\infty}{\omega} \int_{\ell.e.}^{t.e.} P_6\, dx \qquad \text{(B.14)}$$

Recall our original assumption that $\alpha_{v,i}$ is constant in the chordwise direction, and substitute (B.14) into (B.13). The result is

$$M_\ell = q_\infty \left[- \int_a^{s_m} \bar{\alpha}_{v,1}(t)\, (cc_\ell)_6\, dt + \int_a^{s_m} \bar{\alpha}_{v,2}(t)\, (cc_\ell)_6\, dt \right.$$

$$\left. + \int_a^{s_m} \bar{\alpha}_{v,3}(t)\, (cc_\ell)_6\, dt - \int_a^{s_m} \bar{\alpha}_{v,4}(t)\, (cc_\ell)_6\, dt \right] \qquad \text{(B.15)}$$

The integrals in equation (B.15) do not represent the actual rolling moments exerted on the individual fins. Rather, they represent the contribution to the total rolling moment due to the distribution of angle of attack induced on each fin. To determine the actual rolling moment for each fin, we must determine the effect of each fin on every other fin. Let us define the following quantities.

$$M_{\ell_{\text{fin } i}} \equiv \text{rolling moment induced on fin i} \qquad \text{(B.16)}$$

$$I_i \equiv \mu\, q_\infty \int_a^{s_m} \bar{\alpha}_{v,i}(t)\, (cc_\ell)_6\, dt \qquad \text{(B.17)}$$

$$\mu \equiv \begin{cases} -1 , & i = 1 \\ +1 , & i = 2 \\ +1 , & i = 3 \\ -1 , & i = 4 \end{cases} \tag{B.18}$$

$$k_{ij} \equiv \text{fraction of } I_j \text{ contributing to rolling moment of fin } i \tag{B.19}$$

Using the above definitions, we can write

$$\begin{bmatrix} M_{\ell,1} \\ M_{\ell,2} \\ M_{\ell,3} \\ M_{\ell,4} \end{bmatrix} = \begin{bmatrix} k_{11} & k_{12} & k_{13} & k_{14} \\ k_{21} & k_{22} & k_{23} & k_{24} \\ k_{31} & k_{32} & k_{33} & k_{34} \\ k_{41} & k_{42} & k_{43} & k_{44} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} \tag{B.20}$$

Note that

$$k_{1i} + k_{2i} + k_{3i} + k_{4i} = 1$$

so that equation (B.15) is recovered.

In principle, the k_{ij} can be computed by slender-body theory or by linear theory computer codes such as CRFWBD (Appendix F). However, for $i \neq j$, the coefficients are generally considerably less than one although not negligible. However, we neglect them in the present approximate method for calculating the individual fin rolling moments and assume that

$$k_{ij} = \begin{cases} 1 , & i = j \\ 0 , & i \neq j \end{cases} \tag{B.21}$$

Substituting the approximation of (B.21) into (B.20) gives the following rolling moment for each fin:

$$M_{\ell_{\text{fin } i}} = \mu q_\infty \int_a^{s_m} \alpha_{v,i}(t) (cc_\ell)_e dt \tag{B.22}$$

The slender-body theory expression for $(cc_\ell)_e$ is given by Adams and Dugan (ref. B.2, eq. (18)):

$$(cc_\ell)_e = \frac{8R^2}{\pi}\left[\cos 2\theta \tanh^{-1}\left(\frac{\sin 2\theta}{\sin 2\gamma}\right) - \cos 2\gamma \tanh^{-1}\left(\frac{\tan 2\theta}{\tan 2\gamma}\right)\right]$$

$$+ \frac{4R^2}{\pi}\left[K(k_1)\sin 4\theta - 2k_1 \cos A_1 K(k_1) Z(A_1,k_1)\right] \tag{B.23}$$

where

$$R = \frac{1}{2}\sqrt{s_m^2 + \frac{a^4}{s_m^2}} \tag{B.24}$$

$$\cos 2\theta = \frac{1}{4R^2}\left(t^2 + \frac{a^4}{t^2}\right) = \frac{s^2}{t^2}\left(\frac{a^4 + t^4}{a^4 + s_m^4}\right) \tag{B.25}$$

$$\cos 2\gamma = \frac{a^2}{2R^2} \tag{B.26}$$

$$k_1 = \sin 2\gamma \tag{B.27}$$

$$K(k_1) = \int_0^{\pi/2} \frac{d\bar{z}}{1 - k_1^2 \sin^2 \bar{z}}$$

$$= \text{complete elliptic integral of first kind with modulus } k_1 \tag{B.28}$$

$$A_1 = \sin^{-1}\left(\frac{\sin 2\theta}{\sin 2\gamma}\right) \tag{B.29}$$

$$Z(A_1,k_1) = \text{Jacobi zeta function} \tag{B.30}$$

$$K(k_1)Z(A_1,k_1) = K(k_1)E(A_1,k_1) - E(\pi/2,k_1)F(A_1,k_1) \tag{B.31}$$

$$F(A_1,k_1) = \int_0^{A_1} \frac{d\bar{z}}{\sqrt{1 - k_1^2 \sin^2 \bar{z}}} = \text{incomplete elliptic integral of the first kind} \tag{B.32}$$

$$E(\pi/2,k_1) = \int_0^{\pi/2} \sqrt{1 - k_1^2 \sin^2 \bar{z}}\ d\bar{z} = \text{complete elliptic integral of second kind} \quad (B.33)$$

$$E(A_1,k_1) = \int_0^{A_1} \sqrt{1 - k_1^2 \sin^2 \bar{z}}\ d\bar{z} = \text{incomplete elliptic integral of second kind} \quad (B.34)$$

In equation (B.23) as $\theta \to \gamma$; that is, as $t \to a$, the first of the two principal terms becomes indeterminate. It is possible to show that

$$\lim_{\theta \to \gamma} \left[\cos 2\theta \tanh^{-1}\left(\frac{\sin 2\theta}{\sin 2\gamma}\right) - \cos 2\gamma \tanh^{-1}\left(\frac{\tan 2\theta}{\tan 2\gamma}\right)\right] = -\cos 2\gamma \log(\cos 2\gamma) \quad (B.35)$$

Thus, the span loading at the juncture between the fin and body, t = a, is

$$(cc_\ell)_e = \frac{8R^2}{\pi}\left[-\cos 2\gamma \log(\cos 2\gamma) + 0.5\, K(k_1) \sin 4\theta\right] \quad (B.36)$$

To obtain the moment arm for the fin load represented by $(\Delta\alpha_{eq})_v$, we divide $M_{\ell_{fin\ i}}$ by $N_{fin\ i}$; that is,

$$\bar{y}_{v_i} = \frac{M_{\ell_{fin\ i}}}{N_{fin\ i}} \quad (B.37)$$

The total rolling moment is then obtained by multiplying $\bar{y}_{v_i}$ by each corresponding fin nonlinear normal force as obtained in item 3 of the procedure described above.

REFERENCES

B.1. Goodwin, F. K., Dillenius, M. F. E., and Nielsen, J. N.: Prediction of Six-Degree-of-Freedom Store Separation Trajectories at Speeds up to the Critical Speed. Volume I - Theoretical Methods and Comparisons with Experiment. Nielsen Engineering & Research, Inc., AFFDL-TR-72-83, Vol. I, Oct. 1974.

B.2. Adams, G. J. and Dugan, D. W.: Theoretical Damping in Roll and Rolling Moment Due to Differential Wing Incidence for Slender Cruciform Wings and Wing-Body Combinations. NACA Rept. 1088, 1952.

APPENDIX C

PROCEDURE FOR COMPUTING STRENGTHS AND POSITIONS OF FIN TRAILING VORTICES

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APPENDIX C

PROCEDURE FOR COMPUTING STRENGTHS AND POSITIONS OF FIN TRAILING VORTICES

In setting up a model of a single vortex per fin we must specify the vortex strengths and the lateral position of the center of vorticity. Using the equivalent angle of attack concept, we can obtain a good estimation of the fin normal force and lateral center of pressure position. The single-vortex-per-panel model is compatible with this input data. To go to more vortices per fin requires knowledge of the span-load distribution.

At low angles of attack, the span-load distribution of slender wings tends to be elliptical. At high angles of attack, the wing loading tends to be uniform, and for a delta wing the span loading tends to be linear. As an approximation to actual span loadings consider a superposition of an elliptical loading plus a linear loading. We will now derive expressions for the normal force and rolling moment associated with elliptic and linear span loadings.

$$(cc_\ell)_L = a_L(1 - \eta) \; ; \; \eta = \frac{y - a}{s_m - a} \tag{C.1}$$

$$(cc_\ell)_e = a_e\sqrt{1 - \eta^2} \tag{C.2}$$

By definition,

$$CN = \frac{\int_a^{s_m} (cc_\ell)\,dy}{S_R} \tag{C.3}$$

$$CRM = \frac{\int_a^{s_m} y(cc_\ell)\,dy}{S_R \ell_r} \tag{C.4}$$

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Now the first integral can be written as

$$\int_a^{s_m} (cc_\ell)\,dy = (s_m - a)\int_0^1 (cc_\ell)\,d\eta$$

$$= (s_m - a)\left[a_L \int_0^1 (1 - \eta)\,d\eta + a_e \int_0^1 \sqrt{1 - \eta^2}\,d\eta\right] \qquad (C.5)$$

$$\int_a^{s_m} (cc_\ell)\,dy = (s_m - a)\left[\frac{a_L}{4} + a_e\left(\frac{\pi}{4}\right)\right] \qquad (C.6)$$

Thus

$$CN = \frac{s_m - a}{S_R}\left[\frac{a_L}{2} + a_e\left(\frac{\pi}{4}\right)\right] \qquad (C.7)$$

For the rolling moment, we obtain

$$CRM = \frac{a\int_a^{s_m} (cc_\ell)\,dy + (s_m - a)\int_a^{s_m} \eta(cc_\ell)\,dy}{S_R \ell_r}$$

$$= \frac{a(s_m - a)}{S_R \ell_r}\left(\frac{a_L}{2} + \frac{\pi}{4}\,a_e\right)$$

$$+ \frac{(s_m - a)^2}{S_R \ell_r}\left[a_L \int_0^1 \eta(1 - \eta)\,d\eta + a_L \int_0^1 \eta\sqrt{1 - \eta^2}\,d\eta\right]$$

$$= \frac{a(s_m - a)}{S_R \ell_r}\left(\frac{a_L}{2} + \frac{\pi}{4}\,a_e\right) + \frac{(s_m - a)^2}{S_R \ell_r}\left(\frac{a_L}{6} + \frac{a_e}{3}\right) \qquad (C.8)$$

The lateral location of the center of pressure is simply given by

$$\bar{y} = \frac{\ell_r CRM}{CN} = a + (s_m - a)\,\frac{\left(\frac{a_L}{6} + \frac{a_e}{3}\right)}{\left(\frac{a_L}{2} + \frac{\pi}{4}\,a_e\right)} \qquad (C.9)$$

or in nondimensional form

$$\bar{\eta} = \frac{\bar{y} - a}{s_m - a} = \frac{\left(\frac{a_L}{6} + \frac{a_e}{3}\right)}{\left(\frac{a_L}{2} + \frac{\pi}{4} a_e\right)} \tag{C.10}$$

Solving for a_e/a_L, we find

$$\frac{a_e}{a_L} = \frac{\frac{1}{2}\bar{\eta} - \frac{1}{6}}{\frac{1}{3} - \frac{\pi}{4}\bar{\eta}} \tag{C.11}$$

This gives the ratio a_e/a_L in terms of the lateral location of the center of pressure. The fin normal-force coefficient, CN, then permits us to obtain a_L from equation (C.7) as follows:

$$a_L = \frac{S_R CN}{(s_m - a)\left(\frac{1}{2} + \frac{\pi}{4}\frac{a_e}{a_L}\right)} \tag{C.12}$$

Having a_e and a_L corresponding to the data, we now must find the vortex strength, Γ, and its lateral position, y_v^*. The lateral position, y_v^*, is at the centroid of the trailing vorticity given by the following expression (see ref. 9, pp. 144-153):

$$y_v^* = a + \frac{\int_a^{s_m} y \frac{d(cc_\ell)}{dy}\, dy}{\int_a^{s_m} \frac{d(cc_\ell)}{dy}\, dy} \tag{C.13}$$

Carrying out the indicated operations yields

$$\frac{y_v^* - a}{s_m - a} = \frac{\frac{a_L}{2} + \frac{\pi}{4} a_e}{a_L + a_e} \tag{C.14}$$

Assuming that the part of the bound vortex outside the body represents the fin normal force, we can write

$$\rho_\infty V_\infty \Gamma (y_v^* - a) = \frac{1}{2} \rho_\infty V_\infty^2 S_R C_N \tag{C.15}$$

Substituting (C.7) into (C.15), we obtain

$$\frac{\Gamma}{V_\infty} = \frac{1}{2}\,\frac{s_m - a}{y_v^* - a}\left(\frac{a_L}{2} + \frac{\pi}{4}\,a_e\right) \tag{C.16}$$

Substituting (C.14) into (C.16) gives

$$\Gamma' \equiv \frac{\Gamma}{2\pi V_\infty a} = \frac{1}{4\pi a}\,(a_L + a_e) \tag{C.17}$$

Equations (C.14) and (C.17) give the desired vortex strength and position.

APPENDIX D

METHOD FOR COMPUTING VORTEX POSITIONS AND STRENGTHS OVER AFTERBODY SECTION

APPENDIX D

METHOD FOR COMPUTING VORTEX POSITIONS AND STRENGTHS OVER AFTERBODY SECTION

D.1. INTRODUCTION

The purpose of this appendix is to describe the method used by the code MLOADS to track vortices downstream of the first finned section. The method consists of three procedures: (1) determination of the starting positions of the afterbody vortices; (2) tracking of all the vortices present over the afterbody section; and (3) determination of the strengths of the two afterbody vortices as functions of axial location. The code MLOADS uses the method described in reference 3 for procedure (1) with one exception. In the method of reference 3, afterbody vortices are not started unless the direction of the crossflow velocity vector is within 90° of the vertical axis, z_o. In the present version of the code, the user selects an angle OMEGA. If the crossflow velocity vector is not within $\pm$OMEGA of z_o, afterbody vortices are not allowed to form. Procedures (2) and (3) are described in the sections below.

D.2. TRACKING OF VORTICES OVER THE AFTERBODY SECTION

We assume that the vortex centers move as Lagrangian fluid points in a crossflow plane moving with the speed $V_\infty \cos \alpha_c$. The complex velocity for vortex j in the presence of a circular body and the other vortices may be obtained from equation (A.10) by setting $dv/d\sigma \equiv 1$ and $r_o = a$. The result is

$$v_j - iw_j = -iV_\infty \sin \alpha_c \left(1 + \frac{a^2}{\sigma_j^2}\right) - \frac{i}{2\pi} \sum_{\substack{k=1 \\ k \neq j}}^{n} \Gamma_k \left(\frac{1}{\sigma_j - \sigma_k} - \frac{1}{\sigma_j - a^2/\bar{\sigma}_k}\right)$$

$$+ \frac{i}{2\pi} \frac{\Gamma_j}{\sigma_j - a^2/\bar{\sigma}_j} \qquad \text{(D.1)}$$

where n is the number of vortices present. We may now repeat the development following equation (A.12) to get

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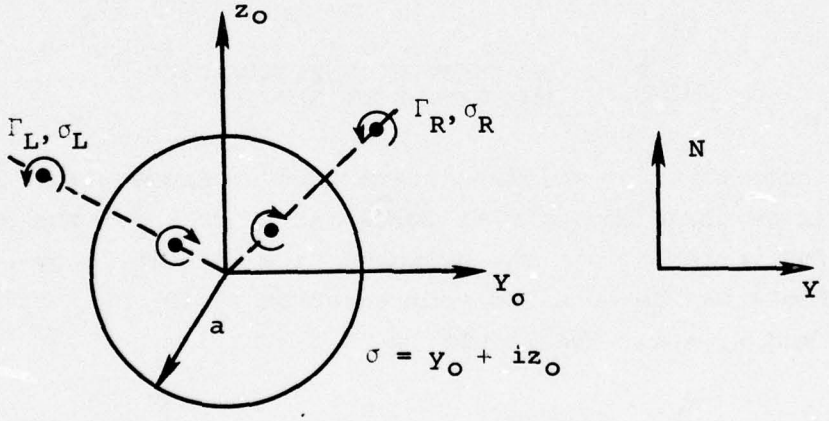
$$\frac{dy_j}{dx} = \frac{v_j}{V_\infty} \frac{1}{\cos \alpha_c} \quad \text{and} \quad \frac{dz_j}{dx} = \frac{w_j}{V_\infty} \frac{1}{\cos \alpha_c} \tag{D.2}$$

Again, the present version of the code uses small angle approximations and $\cos \alpha_c$ in (D.2) is set equal to one. The differential equations (D.2) and the algebraic relations (D.1) provide a system of ordinary first-order initial value differential equations which can be solved by standard integration routines. The system is complete if no afterbody vortices are present. If afterbody vortices are present, two of the Γ_k are unknown functions of x. Differential equations for the afterbody vortex strengths are derived in the next section.

D.3. DERIVATION OF DIFFERENTIAL EQUATIONS FOR THE STRENGTHS OF THE AFTERBODY VORTICES

Consider a crossflow plane, shown in sketch D.1, containing the afterbody cross section, and let afterbody vortices Γ_L and Γ_R appear at stations σ_L and σ_R in the crossflow plane. The other vortices are not shown for simplicity.



Sketch D.1. Computational plane.

In a small axial distance, dx, the afterbody increments in normal force and side force are given by the vortex impulse theorem (eq. (28)).

$$dN - i\, dY = \rho_\infty V_\infty d\left[\Gamma_L \left(\sigma_L - \frac{a^2}{\bar{\sigma}_L}\right) + \Gamma_R \left(\sigma_R - \frac{a^2}{\bar{\sigma}_R}\right)\right] \tag{D.3}$$

If Γ_L and Γ_R are constant, then the resulting terms on the right-hand side of equation (D.2) are differentials of vortex position and are associated with inviscid forces on the afterbody. If Γ_L and Γ_R are not constant because of vortex feeding sheets, then additional terms containing differentials of Γ_L and Γ_R appear which are associated with crossflow drag. If we use the subscript v to indicate that part of $dN - i\,dY$ due to viscous crossflow, then

$$dN_v - i\,dY_v = \rho_\infty V_\infty \left[\left(\sigma_L - \frac{a^2}{\bar{\sigma}_L} \right) d\Gamma_L + \left(\sigma_R - \frac{a^2}{\bar{\sigma}_R} \right) d\Gamma_R \right] \tag{D.4}$$

Now we will assume that the crossflow drag is in the same direction as the crossflow velocity vector, θ. Then,

$$dN_v - i\,dY_v = D_v(\sin\theta - i\cos\theta) \tag{D.5}$$

where D_v is the crossflow drag force on the elemental length of cylinder, Δx. In terms of the crossflow drag coefficient, D_v is

$$D_v = c_{d_c} q_\infty \sin^2\alpha_{cr}\; 2a\,dx \tag{D.6}$$

Substitution of (D.5) and (D.6) into (D.4) gives

$$\rho_\infty V_\infty \left[\left(\sigma_L - \frac{a^2}{\bar{\sigma}_L} \right) \frac{d\Gamma_L}{dx} + \left(\sigma_R - \frac{a^2}{\bar{\sigma}_R} \right) \frac{d\Gamma_R}{dx} \right] = 2a\, c_{d_c} q_\infty \sin^2\alpha_{cr} (\sin\theta - i\cos\theta) \tag{D.7}$$

Equation (D.7) gives two scalar first-order initial value ordinary differential equations which can be solved simultaneously with equation (D.2).

APPENDIX E

MLOADS, A COMPUTER PROGRAM FOR CALCULATING THE COMPONENT FORCES AND MOMENTS OF ARBITRARILY BANKED CRUCIFORM MISSILES WITH CONTROL DEFLECTIONS

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APPENDIX E

MLOADS, A COMPUTER PROGRAM FOR CALCULATING THE COMPONENT FORCES AND MOMENTS OF ARBITRARILY BANKED CRUCIFORM MISSILES WITH CONTROL DEFLECTIONS

E.1. INTRODUCTION

The purpose of this appendix is to describe the operation of the computer code MLOADS in sufficient detail to permit understanding and use of the program. The program computes forces and moments for each fin, for each section of the configuration, and for the complete configuration. Minimum drag is not computed. Intermediate output gives vortex strengths and positions along the body. The code, through the integer control variable,NFIN, is capable of handling the following missile configurations:

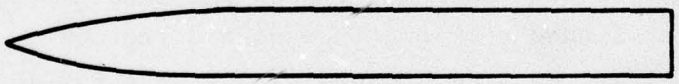
NFIN = 1: body-alone consisting of nose and cylindrical afterbody

NFIN = 2: body-tail combination (finner)

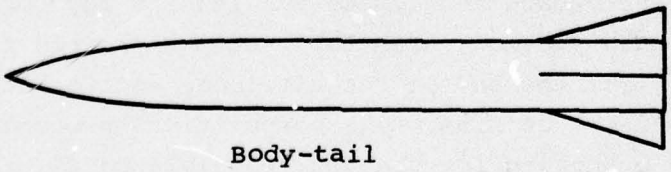
NFIN = 3: body-canard combination (body-wing)

NFIN = 4: body-canard-tail combination (body-wing-tail)

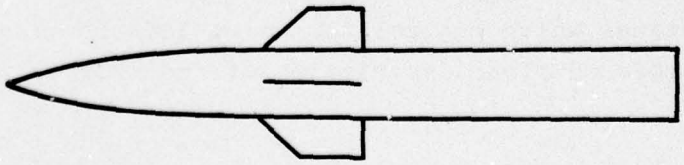
Typical examples of the above configurations are given in the sketch below.



Body-alone



Body-tail



Body-canard

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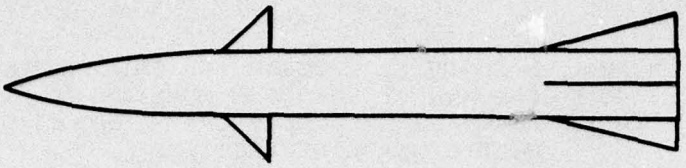

Body-canard-tail

Sketch E.1. Examples of missile configurations.

A description of the engineering method used is given in reference 3 and in the main text and Appendices A through D of this report.

The program is written in FORTRAN IV (029 punch) and has been run on the CDC 6600 and 7600 machines. No files other than INPUT and OUTPUT are required. The program conforms to the ANSI standard Fortran language except for the program definition statement and for several DATA statements. For a body-tail combination, the running time is roughly 0.08 CPU second per data point on the CDC 7600. For a body-canard-tail combination, the running time is about 0.5 CPU second per data point on the CDC 7600. Run times on the CDC 6600 are about six times those for the CDC 7600.

E.2. PROGRAM DESCRIPTION

For computational purposes, the missile to be studied is divided into four sections as shown in figure 1 of the main text. The nose section is defined to be from the nose tip to the leading edge of the root chord of the first finned section. The canard section (first finned section) is defined to be from the end of the nose section to the trailing edge of the first set of fins. The afterbody section is defined to be from the end of the canard section to the leading edge of the root chord of the second finned section. The tail section (second finned section) is defined to be from the end of the afterbody section to the trailing edge of the second set of fins. The computations proceed as shown in figure E.1. The branching for the four possible configurations is shown in figure E.2. The main program MLOADS controls the flow of operations. It calls the routines which control the operations for each section of the missile. A more complete description of the program operation is given below.

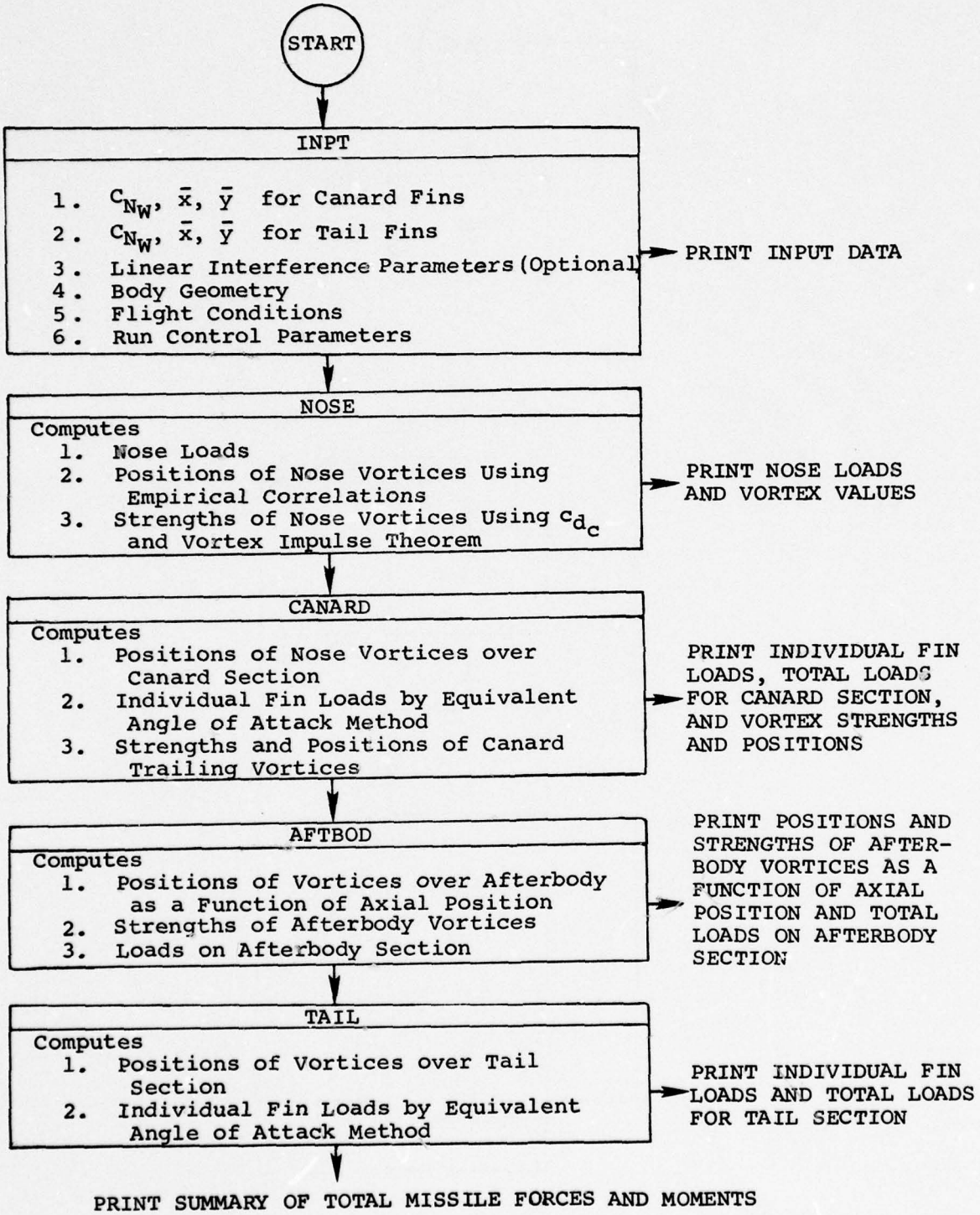

Figure E.1. Flow of program computations.

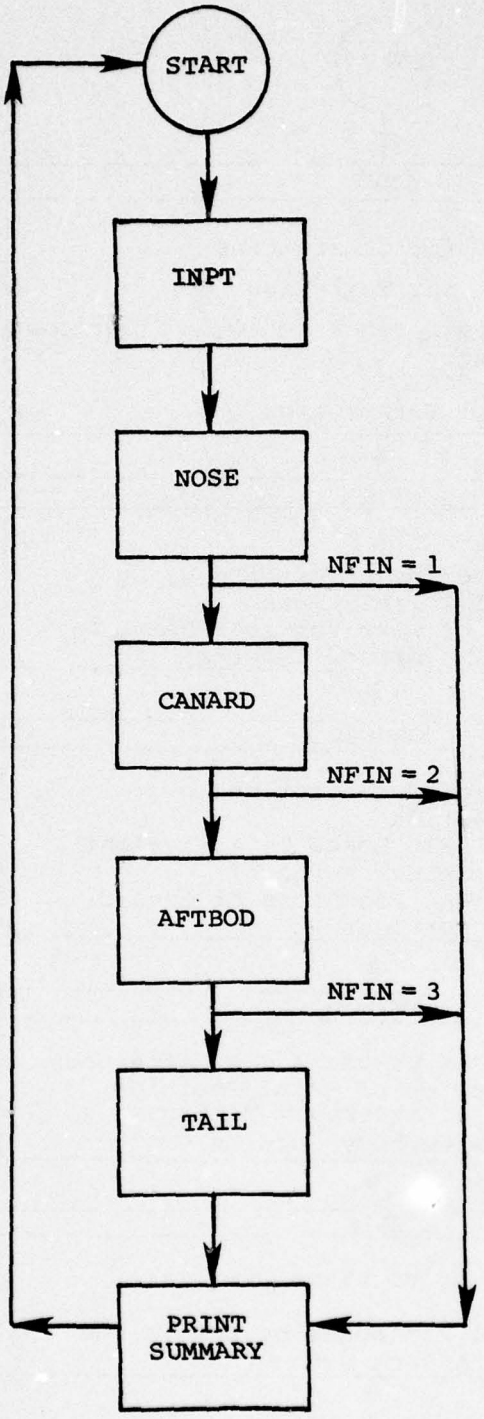

Figure E.2. Schematic description of control of MLOADS operations by NFIN.

E.2.1 Calculation Procedure

After reading in the run identification information, the subprogram INPT reads in body geometry, run control parameters, flow conditions, and any required empirical information not built into the program. All length quantities are then normalized by the body radius and all areas are normalized by the square of the body radius. The user has the option of allowing the code to compute the necessary interference parameters or of reading them in. If the user selects the former option, the methods of slender-body theory and reference 10 are employed. The user may read in any or all of the interference parameters.

The user must read in the wing-alone characteristics for each set of fins. These characteristics include the normal-force coefficient, spanwise location of the fin center of pressure and chordwise location of the fin center of pressure as functions of angle of attack.

After all the input has been read in and all required interference factors have been computed, the main program MLOADS calls subroutine NOSE. This routine first computes the axial starting location of the nose vortices (if present). The locations and strengths of the nose vortices in the crossflow plane at the leading edge of the root chord of the first finned (canard) section are computed next. The subroutine then computes the forces and moments on the nose and returns control to MLOADS.

If NFIN = 1, the driver program prints a summary of the overall forces and moments and reads in a new data set. If NFIN $\geq$ 2, subroutine CANARD is called. This routine computes the fin and body loadings for the first set of fins downstream of the nose.* The individual fin forces and moments in the absence of nose vortices are computed first. The routine then calls the routine CRUTRJ which computes the positions of the nose vortices over the canard section. The discrete vortex model used to represent the nose vorticity may not adequately represent the flow when the separated flow from the nose is diffuse or when a vortex is close to a fin. With the present model, it is possible for a vortex to be captured by its image and to travel completely around the body. Such behavior has not been observed in flow visualization studies and the predicted loads obtained when a vortex is "captured" do not agree

*Note that if the configuration is a body-tail combination, the tail section results are computed by subroutine CANARD and are output under the headings for "CANARD SECTION."

with experiment. We have found that the present model gives best results when the presence of the fins is ignored during the vortex tracking procedure. The user can exercise this option by setting the logical variable NEARC equal to .TRUE. This option is recommended. The user may also choose to ignore the nose vortices over all or part of the missile if he believes they have dispersed. This control is achieved through the parameter NVORT.

When CRUTRJ has finished tracking the nose vortices, it stores their locations in the crossflow planes at the fin area centroid and at the fin trailing edge and returns control to CANARD. Subroutine CANARD then calls REVFLO which computes the equivalent angle of attack and spanwise location of the center of pressure for the loading due to the nose vortices. Subroutine REVFLO assumes the vortices to be infinite line vortices parallel to the body axis. The vortex locations at the fin area centroid are used.

When REVFLO returns control to CANARD, the total fin forces and moments and body forces and moments (for the canard section) are computed. The strengths and positions of the vortices shed from each fin are calculated next. After the above information has been printed out, control is returned to MLOADS.

If NFIN = 2, the driver program prints a summary of the overall forces and moments and reads in a new data set. If NFIN $\geq$ 3, subroutine AFTBOD is called. This routine tracks the trailing vortices from the first set of fins and the nose vortices (if present) over the afterbody section. The routine also decides if afterbody vortices should be shed and computes their starting locations. If afterbody vortices are formed, they are tracked along with the other vortices present. The strengths of the afterbody vortices as functions of axial position are also computed. Once the vortex trajectories have been computed for the afterbody section, the forces and moments on the afterbody section are computed and control is returned to MLOADS.

If NFIN = 3, MLOADS prints a summary of the overall forces and moments and reads in a new data set. If NFIN = 4, subroutine TAIL is called. This routine proceeds in a manner similar to CANARD except that the trailing vortices of the tail fins are ignored. When TAIL has finished, it returns control to MLOADS. Subroutine MLOADS then computes and prints out the total forces and moments for the configuration and reads in a new data set.

E.2.2 Program Limitations and Precautions

The program makes a number of assumptions about the missile configuration and the flow field which are listed in section 6 of the main text.

E.2.3. Description of Subroutines

Subroutine INPT reads in all input and nondimensionalizes it.

Subroutine NOSE computes nose vortex positions and strengths and nose forces and moments.

Subroutine CANARD controls the subroutines which compute vortex strengths and positions, individual fin forces and moments, body forces and moments and total forces and moments for the canard section.

Subroutine ALFAQ computes equivalent angles of attack for individual fins in the absence of vortices.

Subroutine VORTEX computes the strengths and positions of the vortices shed from the trailing edges of the canard fins.

Subroutine CRUTRJ computes the paths of free vortices in the presence of a cruciform wing-cylindrical body section.

Subroutine FCT computes derivatives needed by the differential equation solver of CRUTRJ.

Subroutine SHAPE provides the body and fin coordinates needed by FCT.

Subroutine DASCRU is the differential equation solver used by CRUTRJ and AFTBOD.

Subroutine REVFLO computes the equivalent angles of attack and spanwise locations of the centers of pressure for a set of fins due to the presence of vortices.

Subroutine SIMSON is a Simpson's rule integration package used by REVFLO.

Subroutine VEL computes the velocities induced on a set of fins by the vortices present for use by REVFLO.

Subroutines CEL1, CEL2, ELI1, and ELI2 are IBM SSP subroutines for computing elliptic integrals. They are called by REVFLO.

Subroutine LNTRP is a linear interpolation routine.

Subroutine CURVES is a BLOCK DATA routine for initializing a number of empirical tables used in the program.

Subroutine AFTBOD computes vortex positions and strengths and body loading for the afterbody section.

Subroutine DERIV computes derivatives needed by the differential equation solver of AFTBOD.

Subroutine TAIL controls the subroutines which compute vortex strengths and positions, individual fin forces and moments, body forces and moments and total forces and moments for the tail section.

Subroutines CHRT8, EQ24, EQ26, EQ30, EQ31, and CH1416 are used to compute K_B and $\bar{x}_B$ based on the methods of reference 10. These subroutines are described in reference E.1.

Subroutine INTFAC calculates any interference parameters which have not been input.

E.3. DESCRIPTION OF INPUT

This section describes the input for the program MLOADS. In the following discussion, the contents of all input cards are specified. All possible input variables are listed at the end of this section in the order of appearance in the input deck. The input format for all cards is shown in figure E.3 and the item numbers also refer to that figure. A sample input is described in section E.6 which discusses a sample case.

Item 1

These cards provide identification of the run. The information on them is printed on the first page of the output.

Item 2

This item includes the variable NFIN which specifies the configuration. The following configurations may be studied:

NFIN = 1: body-alone configuration

NFIN = 2: body-tail configuration

NFIN = 3: body-canard configuration

NFIN = 4: body-canard-tail configuration

Item 3

This optional item is read if NFIN ≥ 2 and includes integer control parameters for the first set of fins. The first six specify whether the various interference parameters are to be input by the user or are to be determined by the program. The quantities NCNC, NCPXC, and NCPYC specify the number of entries in the tables which describe the wing-alone characteristics. Since the fins are assumed to be uncambered and untwisted, the wing-alone characteristics should be input for positive α_{eq} only.

Also in this item is NI, the number of integration intervals plus one, used in the Simpson's rule integration routine called by REVFLO. The value of NI must be odd. A suitable value for NI depends on how close a vortex is to a fin. If a vortex is close to a fin, NI should be at least 51.

The quantity NXOUTC is the number of stations for which vortex positions are to be output. A value between 5 and 10 should be sufficient to monitor the vortex trajectories over the canard (first finned) section.

The quantity NAFTC is used if NFKBC and/or NFXBC are zero and $M_\infty > 1$; that is, K_B and/or $\bar{x}_B$ are to be determined by the code. For supersonic speeds, lift on the body due to the presence of the fins can be generated downstream of the fin trailing edges. If NAFTC = 1, the code will assume that there is sufficient body surface downstream of the fin trailing edges to fully develop that lift. If NAFTC = 2, it is assumed that there is no body after the fins. If NFIN ≥ 3, always use NAFTC = 1. If NFIN = 2, the user should input NAFTC = 2 unless it is clear that significant lift carryover will be developed downstream of the fins.

The last integer variable on this card is NVORT. This variable is used to control the influence of the nose vortices. It has been observed (refs. 4 and 5) that nose vorticity for $\alpha_c \leq 20^\circ$ may disperse over the canard section. Since the present model for nose vorticity is incapable of representing such a situation, the user has the option of ignoring the influence of nose vorticity downstream. The options are:

NVORT = 0: nose vortices, if present, are tracked over entire configuration

NVORT = 1: nose vortices are ignored downstream of the leading edge of the canard root chord

NVORT = 2: nose vortices are ignored downstream of the trailing edge of the canard root chord

Item 4

This optional item is read if NFIN $\geq$ 3. The quantity NXOUTB is equal to the number of integration intervals used in the calculations of afterbody loading. It is also the number of axial stations at which vortex positions and strengths are output. As a rule of thumb, use a value of NXOUTB greater than the length of the afterbody in body diameters. If the vortex positions change drastically between output stations, KXOUTB should be increased.

Item 5

This optional item is read if NFIN = 4. The parameters have the same function as those in Item 3. For example, NXOUTT has the same purpose for the tail section as NXOUTC has for the canard section.

Item 6

The logical quantity TURB is used to determine which branch of the crossflow drag coefficient table is to be used in NOSE and AFTBOD. For crossflow Mach numbers below 0.6, the laminar and turbulent values of c_{d_c} differ. If there is doubt about which type of flow separation is present, use TURB = .TRUE.

The logical variables NEARC and NEART are used to control the influence of the fins on vortex trajectories over a finned section. If these variables are set equal to .TRUE., the influence of the fins is ignored. This option has given the best agreement with experiment.

Item 7

This item contains flight conditions and fin deflection angles.

Item 8

This optional item is read if NFIN $\geq$ 2. It is possible that an indefinite condition may result if PHI is zero and the fins are undeflected. It is recommended that PHI = 0.01 be used for an unbanked configuration with undeflected fins.

Item 9

This item contains some required reference information. The variable XMC is the moment center measured from MS 0.

Item 10

This optional information for the first set of fins is input if NFIN $\geq$ 2. The variable CPXRC is the reference length which was used to nondimensionalize the chordwise location of the fin center of pressure for the wing-alone tables. Typically, this length is equal to the root chord of the fin. Similarly, CPYRC is the reference length for the lateral location of the fin center of pressure. This value is usually the exposed semispan of the fin. The last variable is SRCAN which is the reference area used for the fin normal-force table. It is usually the wing-alone planform area.

Item 11

This optional information is input if NFIN = 4. It is similar to Item 10 and is the corresponding information for the second set of fins.

Item 12

This information is input if NFIN $\geq$ 2. It is concerned with control of vortex trajectory calculations and with the influence a vortex may have on a fin. The first variable, RO, enables the user to approximate the effects of viscous cores for the vortices in determining the velocities which may be induced on the fins. If RO is positive, it is interpreted as the ratio of the vortex core radius to the body radius. If RO is negative, its magnitude is interpreted as the maximum allowed fraction of the free-stream velocity which can be induced normal to the fins. The best agreement with experiment has been obtained with RO = -0.1 for $M_\infty < 1$ and RO = -0.4 for $M_\infty > 1$.

Subroutine CRUTRJ calculates the trajectories of the vortices in the presence of fins. It uses a differential equation solver, DASCRU, to solve the equations of motion of the vortices. The input variable, DXI, is the initial integration interval required by DASCRU for the trajectory calculations. It is nondimensionalized by the body radius. The initial interval can be automatically reduced by DASCRU by as much as a factor of 100 in an attempt to provide the desired accuracy. A value of DXI between 0.02 and 0.05 should work for most cases. When two vortices get very close together, or when a vortex gets very near the wing or body, a smaller value of DXI may be required.

The desired accuracy in the vortex trajectory calculations, referred to in the previous paragraph, is controlled through the input variable

EPS. This variable also controls the vortex strength calculations of the afterbody vortices. The value of EPS should be set equal to one half the desired accuracy. For instance, if EPS is set to 5×10^{-4}, this usually results in a solution accurate to three significant figures.

Experimental observations show that when two vortices of like sign become very close to one another they often combine or coalesce to form one vortex. This situation is included in the program through the variable RVORT. If vortices are not combined and they get too close, then computation time can increase dramatically. The variable RVORT is entered as a separation distance in terms of body radii. When two vortices of like sign are within this distance of each other, they are combined to form one vortex of strength equal to the two original strengths and at a position between the two proportional to the original strengths. A value of 0.5 for RVORT has been found to be satisfactory.

Item 13

This item is also optional and contains the last of the program control information. The first two variables in this item govern the shedding of the afterbody vortices. Hence, this item must be entered if an afterbody is present behind the first set of fins (i.e., if NFIN $\geq$ 3).

The first variable in this item is RVOA, which is the radial distance from the body centerline in body radii at which the afterbody vortices are to be placed initially. The suggested range of values for RVOA is 1.2 to 1.5. The results presented in this report were computed with RVOA = 1.2. If RVOA is too small, the afterbody vortices tend to be captured by their own images.

The second control variable in this item is OMEGA. This is an angle, measured from the z_o axis within which the crossflow velocity vector must lie in order for afterbody vortices to be formed. This crossflow velocity vector is determined by first computing the upwash and sidewash at the body axis due to the external vortices. The quantity $\sin \alpha_c$ is then added to the upwash to account for the flow of the free stream around the cylindrical body. The resultant vector is the crossflow velocity vector. If OMEGA is set equal to zero, no afterbody vortices will form unless the flow is perfectly symmetrical about the plane containing the wind and body axes. If OMEGA is set equal to 180°, afterbody vortices may form regardless of the strength and direction of the crossflow velocity. A value of OMEGA = 45° is recommended.

The last variable on this card is XTLE which is the axial location of the end of the afterbody section.

Item 14

This item describes the nose section back to the first set of fins. The first card contains the number of entries, NNOSE, in the table of nose coordinates and an integer variable, NCA, indicating whether the slope of the linear normal-force curve, C_{N_α}, is to be read in. If NCA equals zero, then C_{N_α} is assigned the value 2.0 by the program. Otherwise, a value for C_{N_α} is to be read in two cards later.

Following NNOSE and NCA, the two variables TIPRAD and ETAN are entered. The variable TIPRAD is the radius of the spherical nose tip. For the case of a pointed nose, this value is zero. If the nose is pointed, then ETAN is the nose half-angle. If the nose is blunted, then ETAN is the angle between the body axis and the tangent to the nose at the juncture of the spherical cap and the rest of the nose (see ref. 3, p. 11).

If NCA is not equal to zero, the linear normal-force coefficient slope (DCNDA) is read in next. Following this optional input, the nose coordinates are entered, first the axial coordinates, then the corresponding radial coordinates. All axial locations are to be measured from missile station zero (MS 0). Thus, the value of XNOSE(1) is the axial location of the nose tip measured from MS 0.

Item 15

If NFIN = 1, then the body length is entered in this item. The program defines the nose as extending to the leading edge of the root chord of the first set of fins, XCLE. Thus, for the body-alone case, the body length is entered as XCLE in this item.

Item 16

This optional item is entered if NFIN $\geq$ 2. This item contains information describing the first set of fins. On the first card of this item are the relevant geometric parameters that describe the fins. If a fin with a rectangular planform is to be specified, the user must set the leading-edge sweep to some small positive value. This should be accomplished by making XCTIPL > XCLE by a small number, say 0.01. Following this geometric information are three empirical curves that describe the fin wing-alone characteristics. The first curve is the

normal-force curve, entered as corresponding values of angle of attack (ALFCNC) and normal-force coefficient (CNWC). There are NCNC pairs of values. The second empirical curve is the chordwise center of pressure location as a function of angle of attack. These axial locations are measured from the leading edge of the root chord. The NCPXC values are entered in the same fashion as the normal-force curve. Next, the table for the spanwise location of the wing-alone center of pressure is entered. The spanwise distance is measured from the root chord. There are NCPYC pairs of values.

Following these empirical curves, any or all of the interference factors for this set of fins may be entered. As discussed previously, the method of calculation of each interference factor is controlled by an integer flag. If the value of the flag is zero, then the corresponding interference factor is not entered but is calculated internally. If the value of the flag is one, then the interference parameter is entered here for the first set of fins and at the end of Item 17 for the second set of fins. The integer flags corresponding to the interference factors for the set of fins of Item 16 were entered in Item 3. Each card is read if any of the information on it is needed. The quantities which are not needed are ignored.

Item 17

This item is similar to Item 16 in that it contains the corresponding information for the second set of fins. Hence, this item is entered only when NFIN = 4. In addition to geometrical information, the first card contains the interdigitation angle. This is the angle by which the tail fins are rolled with respect to the canard fins. The axial location of the tail fin root chord leading edge was entered in Item 13. Just as in Item 16, the three empirical curves describing the wing-alone characteristics are entered next. The last two cards, if they are entered, contain the fin interference factors. The integer flags that determine whether or not the interference factors for this fin are entered are in Item 5. Each card is read if any of the information on it is needed. The quantities which are not needed are ignored.

Item 18

This card ends the process of entering data. It should be the last card and follow all the data cards for the case(s) to be run. The computer program stops the search for more data and the run is finished.

Item No. 1:

(1) Format (16I5), 1 card

Column Number	5
Program Variable	NCARDS

(2) Format (20A4), NCARDS cards

Column Number	1-80
Program Variable	HEAD

Item No. 2:

(1) Format (16I5)

Column Number	5	10
Program Variable	NFIN	NALFA

Item No. 3: Optional

(1) Format (16I5)

Column Number	5	10	15	20	25	30	35	40	45
Program Variable	NFKWC	NFLKW	NFKABC	NFKD	NFKBC	NFXBC	NCNC	NCPXC	NCPYC

50	55	60	65	70
NI	NPHI	NXOUTC	NAFTC	NVORT

Item No. 4: Optional

(1) Format (16I5)

Column Number	5
Program Variable	NXOUTB

Figure E.3(a). Input formats for computer program MLOADS.

Item No. 5: Optional

(1) Format (16I5)

Column Number	5	10	15	20	25	30	35	40	45
Program Variable	NFKWT	NFKABT	NFKBT	NFXBT	NCNT	NCPXT	NCPYT	NXOUTT	NAFTT

Item No. 6:

(1) Format (16L5)

Column Number	5	10	15
Program Variable	TURB	NEARC	NEART

Item No. 7:

(1) Format (8F10.5), 1 card

Column Number	10	20	30	40	50
Program Variable	FMACH	DELTA(1)	DELTA(2)	DELTA(3)	DELTA(4)

(2) Format (8F10.5), 8 values of ALFAC per card

Column Number	10	20		10 × NALFA
Program Variable	ALFAC(1)	ALFAC (2)	. . .	ALFAC(NALFA)

Item No. 8: Optional

(1) Format (8F10.5), 8 values of PHI per card

Column Number	10	20	. . .	10 × NPHI
Program Variable	PHI(1)	PHI(2)	. . .	PHI(NPHI)

Figure E.3(b). Continued.

Item No. 9:

(1) Format (8F10.5)

Column Number	10	20	30	40	
Program Variable	LROUT	SROUT	XMC	A	

Item No. 10: Optional

(1) Format (8F10.5)

Column Number	10	20	30	
Program Variable	CPXRC	CPYRC	SRCAN	

Item No. 11: Optional

(1) Format (8F10.5)

Column Number	10	20	30	
Program Variable	CPXRT	CPYRT	SRTAIL	

Item No. 12: Optional

(1) Format (8F10.5)

Column Number	10	20	30	40	
Program Variable	RO	DXI	EPS	RVORT	

Item No. 13: Optional

(1) Format (8F10.5)

Column Number	10	20	30	
Program Variable	RVOA	OMEGA	XTLE	

Item No. 14:

(1) Format (16I5), 1 card

Column Number	5	10	
Program Variable	NNOSE	NCA	

Figure E.3(c). Continued.

(2) Format (8F10.5), 1 card

Column Number	10	20
Program Variable	TIPRAD	ETAN

(3) Optional, Format (8F10.5), 1 card

Column Number	10
Program Variable	DCNDA

(4) Format (8F10.5), 8 values of XNOSE per card

Column Number	10	20	. . .	10 × NNOSE
Program Variable	XNOSE(1)	XNOSE(2)	. . .	XNOSE(NNOSE)

(5) Format (8F10.5), 8 values of RNOSE per card

Column Number	10	20	. . .	10 × NNOSE
Program Variable	RNOSE(1)	RNOSE(2)	. . .	RNOSE(NNOSE)

Item No. 15: Optional

(1) Format (8F10.5)

Column Number	10
Program Variable	XCLE

Item No. 16: Optional

(1) Format (8F10.5), 1 card

Column Number	10	20	30	40	50	60	70
Program Variable	ARC	SPANC	XCHL	XCLE	XCTIPL	XCTE	XFC

(2) Format (8F10.5), 8 values of ALFCNC per card

Column Number	10	20	. . .	10 × NCNC
Program Variable	ALFCNC(1)	ALFCNC(2)	. . .	ALFCNC(NCNC)

Figure E.3(d). Continued.

(3) Format (8F10.5), 8 values of CNWC per card

Column Number	10	20	. . .	10 × NCNC
Program Variable	CNW(1)	CNWC(2)	. . .	CNWC(NCNC)

(4) Format (8F10.5), 8 values of ACPXC per card

Column Number	10	20	. . .	10 × NCPXC
Program Variable	ACPXC(1)	ACPXC(2)	. . .	ACPXC(NCPXC)

(5) Format (8F10.5), 8 values of CPXC per card

Column Number	10	20	. . .	10 × NCPXC
Program Variable	CPXC(1)	CPXC(2)	. . .	CPXC(NCPXC)

(6) Format (8F10.5), 8 values of ACPYC per card

Column Number	10	20	. . .	10 × NCPYC
Program Variable	ACPYC(1)	ACPYC(2)	. . .	ACPYC(NCPYC)

(7) Format (8F10.5), 8 values of CPYC per card

Column Number	10	20	. . .	10 × NCPYC
Program Variable	CPYC(1)	CPYC(2)	. . .	CPYC(NCPYC)

(8) Optional, Format (8F10.5), 1 card

Column Number	10	20	30	40
Program Variable	KWC	LKW	KBC	XBC

Figure E.3(e). Continued.

(9) Optional, Format (8F10.5), 1 card

Column Number	10	20	30	40	50	60
Program Variable	KABC(1)	KABC(2)	KABC(3)	KABC(4)	KD(1)	KD(2)

70	80
KD(3)	KD(4)

Item No. 17: Optional

(1) Format (8F10.5), 1 card

Column Number	10	20	30	40	50	60
Program Variable	ART	SPANT	XTTIPL	XTTE	XFT	PHIT

(2) Format (8F10.5), 8 values of ALFNCT per card

Column Number	10	20	. . .	10 × NCNT
Program Variable	ALFCNT(1)	ALFCNT(2)	. . .	ALFCNT(NCNT)

(3) Format (8F10.5), 8 values of CNWT per card

Column Number	10	20	. . .	10 × NCNT
Program Variable	CNWT(1)	CNWT(2)	. . .	CNWT(NCNT)

(4) Format (8F10.5), 8 values of ACPXT per card

Column Number	10	20	. . .	10 × NCPXT
Program Variable	ACPXT(1)	ACPXT(2)	. . .	ACPXT(NCPXT)

(5) Format (8F10.5), 8 values of CPXT per card

Column Number	10	20	. . .	10 × NCPXT
Program Variable	CPXT(1)	CPXT(2)	. . .	CPXT(NCPXT)

Figure E.3(f). Continued.

(6) Format (8F10.5), 8 values of ACPYT per card

Column Number	10	20	. . .	10×NCPYT	
Program Variable	ACPYT(1)	ACPYT(2)	. . .	ACPYT(NCPYT)	

(7) Format (8F10.5), 8 values of CPYT per card

Column Number	10	20	. . .	10 × NCPYT	
Program Variable	CPYT(1)	CPYT(2)	. . .	CPYT(NCPYT)	

(8) Optional, Format (8F10.5), 1 card

Column Number	10	20	30	40	50	60	70	
Program Variable	KWT	KBT	XBT	KABT(1)	KABT(2)	KABT(3)	KABT(4)	

Item No. 18:

(1) Format (16I5)

Column Number	5	
Program Variable	999	

Figure E.3(g). Concluded.

E.4. SYMBOL LISTING

This section lists all input variables in the order in which they are entered, gives the algebraic symbol if one exists, and a brief definition. Refer to figure E.3 for the proper input format.

Program Variable	Algebraic Symbol (If Applicable)	Comments
Item 1		Alphanumeric information to identify the run.
NCARDS		Number of cards used to identify the run; NCARDS $\geq$ 1.
HEAD(I)		(NCARDS) cards of alphanumeric information for identification of the run; $1 \leq I \leq$ NCARDS.
Item 2		
NFIN		Integer specifying type of configuration. NFIN = 1 Body-alone. NFIN = 2 Body-tail. NFIN = 3 Body-canard. NFIN = 4 Body-canard-tail.
NALFA		Number of angles of attack for which calculations are to be made; $1 \leq$ NALFA ≤ 10.
Item 3 (optional)		Optional input to be entered if NFIN $\geq$ 2.
NFKWC		Integer flag indicating how K_W for canard section is to be determined. NFKWC = 0 Determined by code. NFKWC = 1 K_W is input.
NFLKW		Integer flag indicating how k_W for canard section is to be determined. NFLKW = 0 Determined by code. NFLKW = 1 k_W is input.
NFKABC		Integer flag indicating how $K_{\alpha\beta}$ for canard section is to be determined. NFKABC = 0 Determined by code. NFKABC = 1 $K_{\alpha\beta}$ is input.
NFKD		Integer flag indicating how $K_{\alpha\delta}$ for canard section is to be determined. NFKD = 0 Determined by code. NFKD = 1 $K_{\alpha\delta}$ is input.

Program Variable	Algebraic Symbol (If Applicable)	Comments
NFKBC		Integer flag indicating how K_B for canard section is to be determined. NFKBC = 0 Determined by code. NFKBC = 1 K_B is input.
NFXBC		Integer flag indicating how $\bar{x}_B$ for canard section is to be determined. NFXBC = 0 Determined by code. NFXBC = 1 $\bar{x}_B$ is input.
NCNC		Number of entries in table for canard wing-alone normal force coefficient; $2 \leq$ NCNC ≤ 20.
NCPXC		Number of entries in table for the chordwise location of the canard wing-alone center of pressure; $2 \leq$ NCPXC ≤ 20.
NCPYC		Number of entries in table for the spanwise location of the canard wing-alone center of pressure; $2 \leq$ NCPYC ≤ 20.
NI		One plus the number of intervals to be used in the Simpson's rule integration package in REVFLO; must be odd; $1 \leq$ NI ≤ 99.
NPHI		Number of roll angles for which calculations are to be made; $1 \leq$ NPHI ≤ 10.
NXOUTC		Number of axial stations along the canard at which vortex locations are to be output.
NAFTC		Integer flag indicating whether afterbody is present downstream of the first set of fins for computation of body carryover lift; ignored if NFKBC and NFXBC $\neq 0$. NAFTC = 1 Afterbody present. NAFTC = 2 No afterbody present.
NVORT		Integer flag indicating how far along body influence of nose vortices is to be felt. NVORT = 0 Influence of nose vortices felt along entire body. NVORT = 1 Influence of nose vortices felt up to leading edge of canard root chord. NVORT = 2 Influence of nose vortices felt up to trailing edge of canard root chord.
Item 4 (optional)		Optional input to be read in if NFIN ≥ 3.
NXOUTB		Number of axial stations along the afterbody at which vortex locations are to be output (see Item 4 of section E.3).

Program Variable	Algebraic Symbol (If Applicable)	Comments
Item 5 (optional)		Optional input to be read in if NFIN = 4.
NFKWT		Integer flag indicating how K_W for tail section is to be determined. NFKWT = 0 Determined by code. NFKWT = 1 K_W is input.
NFKABT		Integer flag indicating how $K_{\alpha\beta}$ for tail section is to be determined. NFKABT = 0 Determined by code. NFKABT = 1 $K_{\alpha\beta}$ is input.
NFKBT		Integer flag indicating how K_B for tail section is to be determined. NFKBT = 0 Determined by code. NFKBT = 1 K_B is input.
NFXBT		Integer flag indicating how $\bar{x}_B$ for tail section is to be determined. NFXBT = 0 Determined by code. NFXBT = 1 $\bar{x}_B$ is input.
NCNT		Number of entries in table for tail wing-alone normal force; $2 \leq$ NCNT ≤ 20.
NCPXT		Number of entries in table for the chordwise location of the tail wing-alone center of pressure; $2 \leq$ NCPXT ≤ 20.
NCPYT		Number of entries in table for the spanwise location of the tail wing-alone center of pressure; $2 \leq$ NCPYT ≤ 20.
NXOUTT		Number of axial stations along the tail at which vortex locations are to be output.
NAFTT		Integer flag indicating whether afterbody is present downstream of second set of fins for calculation of body carryover lift; ignored if NFKBT and NFXBT $\neq 0$. NAFTT = 1 Afterbody present. NAFTT = 2 No afterbody present.
Item 6		
TURB		Logical variable stating whether crossflow on body is laminar or turbulent. TURB = .TRUE. Crossflow is turbulent. TURB = .FALSE. Crossflow is laminar.

Program Variable	Algebraic Symbol (If Applicable)	Comments
NEARC		Logical variable stating whether canard fins are to be ignored for vortex tracking over canard section; NEARC is ignored if NFIN $<$ 2. NEARC = .TRUE. Ignore fins. NEARC = .FALSE. Include influence of fins.
NEART		Logical variable stating whether tail fins are to be ignored for vortex tracking over tail section; NEART is ignored if NFIN $<$ 4. NEART = .TRUE. Ignore fins. NEART = .FALSE. Include influence of fins.
Item 7		
FMACH	M_∞	Free-stream Mach number.
DELTA(J)	$\delta(J)$	Deflection angles in degrees of canard fins; $1 \leq J \leq 4$; J = number of canard fin.
ALFAC(K)	$\alpha_c(K)$	Body angle of attack in degrees; $1 \leq K \leq$ NALFA.
Item 8 (optional)		Optional input to be read in if NFIN $\geq$ 2.
PHI(L)	$\phi(L)$	Bank angle in degrees; angle between z and z_o axes; positive measured clockwise viewed from rear; $1 \leq L \leq$ NPHI.
Item 9		
LROUT	ℓ_r	Reference length used in center of pressure calculations.
SROUT	S_R	Reference area used in force calculations.
XMC	x_{MC}	Moment center of missile, dimensional.
A	a	Radius of missile, dimensional.
Item 10 (optional)		Optional input to be read in if NFIN $\geq$ 2.
CPXRC		Reference length used in table for chordwise location of canard wing-alone center of pressure, dimensional.
CPYRC		Reference length used in table for spanwise location of canard wing-alone center of pressure, dimensional.
SRCAN		Reference area used in table for canard wing-alone normal-force coefficient, dimensional.

Program Variable	Algebraic Symbol (If Applicable)	Comments
Item 11 (optional)		Optional input to be read in if NFIN = 4.
CPXRT		Reference length used in table for chordwise location of tail wing-alone center of pressure, dimensional.
CPYRT		Reference length used in table for spanwise location of tail wing-alone center of pressure, dimensional.
SRTAIL		Reference area used in table for tail wing-alone normal-force coefficient, dimensional.
Item 12 (optional)		Optional input to be read in if NFIN $\geq$ 2.
RO		If RO $\geq$ 0, RO is the ratio of the vortex core radius to the body radius; if RO $\leq$ 0, RO is the negative of the maximum fraction of the free-stream velocity which may be induced normal to the fins.
DXI		Maximum value of integration interval in body radii for vortex tracking.
EPS		Accuracy criterion used in DASCRU.
RVORT		If the separation distance in body radii between vortices of like sign is less than RVORT, vortices are combined (afterbody section only).
Item 13 (optional)		Optional input to be read in if NFIN $\geq$ 3.
RVOA	r_v/a	Distance from body centerline at which afterbody vortices are positioned initially, nondimensionalized by body radius.
OMEGA		Angle measured from z_o axis within which the crossflow velocity vector must lie in order for afterbody vortices to be formed, degrees.
XTLE		Location of end of afterbody section; position of leading edge of tail root chord if second set of fins are present and axial position of body base if only one set of fins present.
Item 14		
NNOSE		Number of entries in the table of nose coordinates; 2 $\leq$ NNOSE $\leq$ 20.

Program Variable	Algebraic Symbol (If Applicable)	Comments
NCA		Integer flag specifying whether C_{N_α} of nose is to be entered. NCA = 0 C_{N_α} not entered. NCA ≠ 0 C_{N_α} entered.
TIPRAD		Nose tip radius, dimensional.
ETAN	η	Half angle of body nose for pointed body; or angle between tangent to nose at juncture of spherical cap and rest of nose and the body axis, degrees.
DCNDA	C_{N_α}	Slope of nose normal-force coefficient at $\alpha_c = 0$; entered if NCA ≠ 0.
XNOSE(M)		Axial location entries in nose coordinate table from a nose tip; $1 \leq M \leq$ NNOSE; XNOSE(1) is axial location of nose tip from MS 0, dimensional.
RNOSE(M)		Corresponding radial location entries in nose coordinate table; $1 \leq M \leq$ NNOSE, dimensional.
Item 15 (optional)		Optional input to be read in if NFIN = 1.
XCLE		Length of body, dimensional.
Item 16 (optional)		Optional input to be read in if NFIN ≥ 2.
ARC	AR	Aspect ratio of canard fins.
SPANC	s_m	Maximum semispan, measured from body centerline, of canard fins, dimensional.
XCHL	x_{HL}	Axial distance to canard hinge line, measured from MS 0, dimensional.
XCLE		Axial distance to leading edge of canard root chord, measured from MS 0, dimensional.
XCTIPL		Axial distance to leading edge of canard tip chord, measured from MS 0, dimensional; XCTIPL > XCLE (see Item 16 of section D.3).
XCTE		Axial distance to canard trailing edge, measured from MS 0, dimensional.
XFC		Axial distance to area centroid of canard fin planform, measured from MS 0, dimensional.

Program Variable	Algebraic Symbol (If Applicable)	Comments
ALFCNC(N)		Angle of attack entries in canard wing-alone normal-force table, degrees; $2 \leq N \leq$ NCNC.
CNWC(N)		Corresponding normal-force coefficient entries in canard wing-alone normal-force table; $2 \leq N \leq$ NCNC.
ACPXC(II)		Angle of attack entries in canard wing-alone table for chordwise location of center of pressure, degrees, $2 \leq II \leq$ NCPXC.
CPXC(II)		Corresponding entries for chordwise locations of center of pressure in canard wing-alone table, nondimensional; $2 \leq II \leq$ NCPXC, measured from leading edge of canard root chord.
ACPYC(IJ)		Angle of attack entries in canard wing-alone table for spanwise location of center of pressure, degrees; $2 \leq IJ \leq$ NCPYC.
CPYC(IJ)		Corresponding entries for spanwise locations of center of pressure in canard wing-alone table, nondimensional; $2 \leq IJ \leq$ NCPYC, measured from fin root chord.
KWC	K_W	Wing-body interference factor for canard normal force.
LKW	k_W	Wing-body interference factor for canard fin deflection.
KBC	K_B	Wing-body interference factor for lift carryover from canard fins to body.
XBC	$\bar{x}_B$	Center of pressure for K_B load based on fraction of root chord measured from leading edge of canard root chord.
KABC(IK)		Wing-body interference factor associated with $\alpha\beta$ coupling on canard fins; $1 \leq IK \leq 4$; IK = number of canard fin.
KD(IL)	$K_D(IL)$	Wing-body interference factor associated with $\alpha\delta_V$ and $\beta\delta_H$ coupling on canard fins; $1 \leq IL \leq 4$; IL = number of canard fin.
Item 17 (optional)		Optional input to be read in if NFIN = 4.
ART	AR	Aspect ratio of tail fins.
SPANT	s_m	Maximum semispan, measured from body centerline, of tail fins, dimensional.

Program Variable	Algebraic Symbol (If Applicable)	Comments
XTTIPL		Axial distance to leading edge of tail tip chord, measured from MS 0, dimensional; XTTIPL > XTLE (see Item 16 of section E.3).
XTTE		Axial distance to tail fin trailing edge, measured from MS 0, dimensional.
XFT		Axial distance to area centroid of tail fin planform, measured from MS 0, dimensional.
PHIT	ϕ_T	Interdigitation angle between tail fins and canard fins, measured clockwise from canard fin no. 1 to tail fin no. 1, degrees
ALFCNT(IM)		Angle of attack entries in tail wing-alone normal-force table, degrees; $2 \leq IM \leq NCNT$.
CNWT(IM)		Corresponding normal-force coefficient entries in tail wing-alone normal-force table; $2 \leq IM \leq NCNT$.
ACPXT(IN)		Angle of attack entries in tail wing-alone table for chordwise location of center of pressure, degrees; $2 \leq IN \leq NCPXT$, measured from leading edge of tail root chord.
CPXT(IN)		Corresponding entries for chordwise locations of center of pressure in tail wing-alone table, nondimensional; $2 \leq IN \leq NCPXT$.
ACPYT(KI)		Angle of attack entries in tail wing-alone table for spanwise location of center of pressure, degrees; $2 \leq KI \leq NCPYT$.
CPYT(KI)		Corresponding entries for spanwise locations of center of pressure in tail wing-alone table, nondimensional; $2 \leq KI \leq NCPYT$, measured from fin root chord.
KWT	K_W	Wing-body interference factor for tail normal force.
KBT	K_B	Wing-body interference factor for lift carryover from tail fin to body.
XBT	$\bar{x}_B$	Center of pressure for K_B based on percentage of root chord measured from leading edge of tail root chord.
KABT(KK)		Wing-body interference factor associated with $\alpha\beta$ coupling on tail fins; $1 \leq KK \leq 4$; KK = number of tail fin.
Item 18		
999		This card causes the program to stop searching for more data and the run is stopped.

E.5. DESCRIPTION OF OUTPUT

This section describes the output of the computer program. The contents of each of the output items is specified and discussed. A sample output is included in the next section which discusses the sample case.

The output consists of a minimum of four items and a maximum of seven, depending upon the type of configuration. The first item consists of the input data and takes up the first three pages. The run identification and missile geometry appear on the first page. The second page contains reference lengths, reference areas, and flight conditions. Included with the flight conditions are the values of TURB, NEARC, and NEART listed under the headings, "turbulent flow," "vortices are near canard," and "vortices are near tail," respectively. The third and last page of this item contains the tables for the wing-alone characteristics for both sets of fins. The program operation variables are also given on this page.

The second output item appears on page four and is a listing of all interference parameters used in the program and their source. The number zero for the source of an interference parameter indicates that that particular parameter was calculated by the code. If the value for the source is one, the interference parameter was input by the user.

Page five marks the beginning of the force and moment results. Three items of information are given at the beginning of the output for each of the individual sections: (1) the name of the particular section (e.g., nose); (2) the value of α_c; and (3) the bank angle, ϕ. Following the output for the last section of the configuration is a summary giving total forces and moments. The forces and moments are all presented in coefficient form with SROUT as the reference area and LROUT as the reference length. In addition, the force and moment coefficients are listed as components along the appropriate Cartesian axes. The coefficients in unrolled coordinates are listed as CZO, normal force; CYO, side force, CXO, axial force; CMZO, yawing moment; CMYO, pitching moment; and CMXO, rolling moment. The same convention is used for the values in rolled coordinates. Note that CZO = C_N, CYO = C_Y, CXO = C_A, CMXO = $-C_\ell$, CMYO = C_m, and CMZO = $-C_n$. Also printed is the contribution to the lift and drag coefficient from each section.

The loads on the nose section are reported on the fifth page of the output beginning with the axial starting position of the nose vortices, if any. If nose vortices have formed, their nondimensional strength (normalized by $2\pi V_\infty a$) and their positions in the crossflow plane at the end of the nose section are presented next. Then the nose forces and moments are printed.

The results from the canard section (or first finned section) start on page six. Presented first are results for the individual fins in the absence of vortices. For each fin the following information is given: (1) the equivalent angle of attack; (2) the fin normal-force coefficient; and (3) the location of the fin center of pressure normalized by LROUT. The value CPX is measured from the root chord leading edge, and CPY is measured from the body centerline.

If nose vortices have formed and if their influence over the canard section is to be calculated (i.e., if NVORT is not equal to one), the results from CRUTRJ giving the trajectory of the vortices over the fin section are presented next. Positions in the crossflow plane in both rolled and unrolled coordinates are given at NXOUTC+2 axial locations, the first one being the root chord leading edge. Other output locations are at intervals of (XCTE - XCLE)/NXOUTC with the positions at the axial location of the area centroid also given. It is the vortex positions at the fin area centroid that are used in computing the vortex induced effects. Immediately following the vortex trajectory information are the vortex induced equivalent angles of attack and corresponding spanwise locations of the centers of pressure for each fin. The spanwise locations of the centers of pressure are measured from the body centerline and are nondimensionalized by the body radius.

Next are listed the strengths and positions of the canard fin trailing vortices in the crossflow plane at the canard fin trailing edge. One vortex is generated per fin. Total individual fin loads are presented next. For each fin the total equivalent angle of attack is used to determine the force normal to the fin (CN), the location of the normal-force center of pressure (CPX and CPY), the fin rolling moment (CRM), bending moment about the root chord (CBM), and hinge moment (CHM). These individual fin loads are then summed and added to the forces and moments acting on the body in the presence of the fins. The totals are given in both rolled and unrolled coordinates. If a body-tail missile

is being run, the results from the tail section, being the first set of fins, appear here.

Following the canard section results are the load contributions from the afterbody section. These results are presented in the form of vortex, flow field, and force information for each of the NXOUTB axial stations specified. From left to right the printout reads: X/A, the axial station, nondimensionalized by the body radius; I, the identification number of the vortices; GAMMA(I), the nondimensional strength of the vortices at X/A; Y(I)/A, the nondimensional y_o-coordinate of the vortices; Z(I)/A, the nondimensional z_o-coordinate of the vortices; FLOANG, the inverse sine in degrees of the magnitude of the crossflow velocity vector nondimensionalized by V_∞; THETA, the polar angle in degrees of the crossflow velocity vector measured from the positive y_o-axis counterclockwise; NORMAL FORCE, the increment of normal force acting on the afterbody over the preceding interval; and SIDE FORCE, the increment of side force acting on the afterbody over the preceding interval. If two vortices are combined (i.e., if two vortices of like sign come within a distance of RVORT of each other), then their strengths are added and the indexing of the vortices is rearranged as described in the output. The contribution of the afterbody section to the total loads in the unrolled body coordinate system is presented after the trajectory information.

Results for the tail section appear next. The format is the same as for the canard section with the exception of hinge moment. The contribution of the tail section to the axial force is always zero because the tail panels do not deflect.

The final item of output is the summary of the total forces and moments on the configuration in both rolled and unrolled coordinates. Included in this section is the axial center of pressure due to the total normal force (CPX) and the axial center of pressure due to the total side force (CPY).

E.6. SAMPLE CASE

In this section we describe a sample case to illustrate the use of the computer program. The case consists of a body-canard-tail configuration at supersonic speed, unrolled, at an angle of attack, and with yaw control.

```
   5
MICOM-NWC BODY-CANARD-TAIL CASE WITH C6 AND T2 FINS
    MACH NUMBER IS 1.75
    BANK ANGLE IS ZERO DEGREES
    YAW CONTROL IS 15 DEGREES
    PITCH CONTROL IS ZERO DEGREES
   4     1
   0     0     0     0     1     1    13     3    15    51     1    10     1     2
  10
   1     0     1     1    19    11     4    10     1
   T     T     T
1.75       15.0        0.0         15.0        0.0
     16.6
  0.0
  5.0       19.63495     26.0        2.5
  4.0         3.75       15.94
        7.          3.5        36.75
-.40          .05          .0001      0.5
1.2         45.0         43.
  19     1
  .56         16.72
2.44
     1.274       1.324       1.424       1.524       1.673         2.0         2.5         3.0
       4.0         5.0         6.0         7.0         8.0         9.0        10.0        11.0
      12.0        13.0        15.0
       0.0       0.2313     0.38144     0.46637     0.53722     0.63539     0.77878     0.91612
  1.17285     1.40598     1.61587     1.80285     1.96720     2.10916     2.22894     2.32670
  2.40260     2.45674         2.5
  3.53        6.25        15.00       12.72       16.47       16.72       15.38
  0.0         10.         20.         30.         35.         40.         45.         50.
  55.         60.         70.         80.         90.
  0.0         .429        .762       1.048       1.10        1.19        1.25        1.34
  1.38        1.43        1.53        1.58        1.58
 0.0         45.0        90.0
 .630        .655        .667
  0.0         5.0        10.0        15.0        20.0        25.0        30.0        35.0
  40.0        45.0        50.0        60.0        70.0        80.0        90.0
  .438        .403        .383        .378        .374        .370        .365        .361
  .358        .355        .350        .345        .340        .335        .333
 0.0          4.0        .3601       .9548
     1.33          6.          46.5          50.         47.28          0.
       0.0         3.1         5.81         8.41        11.08        13.73        16.39        19.07
    24.43        29.83        35.0         40.0         45.0         50.0         55.0         60.0
      70.0         80.0         90.0
       0.0       0.0899      0.1942       0.3039       0.4092       0.5106       0.6142       0.6948
   0.8553       0.9840       1.1046       1.1952       1.2677       1.3599       1.4066       1.4511
   1.5455       1.5878       1.5900
0.0         5.0         10.0        20.0        30.0        40.0        50.0        60.0
 70.0        80.0        90.0
 .514        .514        .538        .564        .577        .582        .586        .599
 .599        .607        .615
 0.0        30.0        60.0        90.0
 .444        .444        .444        .444
   1.4312       .4838       .7877
999
```

Figure E.4. Input for sample case; body-canard-tail configuration.

CALCULATION OF AERODYNAMIC LOADS ON A CRUCIFORM MISSILE

MICOM-NWC BODY-CANARD-TAIL CASE WITH C6 AND T2 FINS
MACH NUMBER IS 1.75
BANK ANGLE IS ZERO DEGREES
YAW CONTROL IS 15 DEGREES
PITCH CONTROL IS ZERO DEGREES

********** MISSILE BODY GEOMETRY **********

MISSILE IS A CANARD-TAIL COMBINATION

*** NOSE GEOMETRY ***

NOSE TIP RADIUS	NOSE HALF ANGLE
.56000	16.72000

NOSE COORDINATES

XNOSE	1.274	1.324	1.424	1.524	1.673	2.000	2.500	3.000	4.000	5.000	6.000	7.000	8.000	9.00010.00011.00012.00013.00015.000			
RNOSE	0.000	.231	.381	.465	.537	.635	.779	.916	1.173	1.406	1.616	1.803	1.967	2.109	2.229	2.327	2.403	2.457	2.500

LINEAR NORMAL FORCE COEFFICIENT SLOPE IS 2.440

*** CANARD GEOMETRY ***

ASPECT RATIO	SPAN	HINGE LINE	ROOT LEADING EDGE	TIP LEADING EDGE	TRAILING EDGE	X POS. CENTROID
3.53000	6.25000	15.00000	12.72000	16.47000	16.72000	15.38000

*** BODY GEOMETRY ***

BODY RADIUS 2.50000 CENTER OF MOMENTS 25.00000

*** TAIL GEOMETRY ***

ASPECT RATIO	SPAN	ROOT LEADING EDGE	TIP LEADING EDGE	TRAILING EDGE	X POS. CENTROID	PHIT
1.33000	6.00000	43.00000	45.50000	50.00000	47.28000	0.000

Figure E.5(a). Output for sample case; body-canard-tail configuration.

********** REFERENCE LENGTHS AND AREAS **********

REFERENCE LENGTHS

OUTPUT LENGTH = 5.[illegible]

CPXRC = 4.00000 CPYRC = 3.75000

CPXRT = 7.00000 CPYRT = 3.50000

REFERENCE AREAS

OUTPUT AREA = 19.63495

CANARD WING-ALONE REF. AREA = 15.94000

TAIL WING-ALONE REF. AREA = 36.75000

********** FLIGHT CONDITIONS **********

MACH NUMBER	TURBULENT FLOW
1.750	T

CANARD DEFLECTION ANGLES	
PANEL	ANGLE
1	15.000
2	0.000
3	15.000
4	0.000

ANGLES OF ATTACK 16.60

ROLL ANGLES 0.00

Figure E.5(b). Continued.

********** EMPIRICAL INPUT **********

CANARD WING-ALONE DATA

NORMAL FORCE		CENTER OF PRESSURE			
ANGLE	CNWC	ANGLE	CPX	ANGLE	CPY
0.00	0.000	0.00	.630	0.00	.438
10.00	.429	45.00	.655	5.00	.434
20.00	.762	90.00	.667	10.00	.383
30.00	1.048	0.00	0.000	15.00	.378
35.00	1.100	0.00	0.000	20.00	.374
40.00	1.190	0.00	0.000	25.00	.373
45.00	1.250	0.00	0.000	30.00	.365
50.00	1.340	0.00	0.000	35.00	.361
55.00	1.380	0.00	0.000	40.00	.358
60.00	1.430	0.00	0.000	45.00	.355
70.00	1.530	0.00	0.000	50.00	.350
80.00	1.580	0.00	0.000	55.00	.345
90.00	1.580	0.00	0.000	70.00	.340
0.00	0.000	0.00	0.000	80.00	.335
0.00	0.000	0.00	0.000	90.00	.333
0.00	0.000	0.00	0.000	0.00	0.000
0.00	0.000	0.00	0.000	0.00	0.000
0.00	0.000	0.00	0.000	0.00	0.000
0.00	0.000	0.00	0.000	0.00	0.000
0.00	0.000	0.00	0.000	0.00	0.000

TAIL WING-ALONE DATA

NORMAL FORCE		CENTER OF PRESSURE			
ANGLE	CNWT	ANGLE	CPX	ANGLE	CPY
0.00	0.000	0.00	.514	0.00	.444
3.10	.090	5.00	.514	30.00	.444
5.81	.194	10.00	.533	60.00	.444
8.41	.304	20.00	.554	90.00	.444
11.08	.409	30.00	.577	0.00	0.000
13.73	.511	40.00	.582	0.00	0.000
16.39	.614	50.00	.585	0.00	0.000
19.07	.695	60.00	.589	0.00	0.000
24.45	.855	70.00	.589	0.00	0.000
29.83	.984	80.00	.587	0.00	0.000
35.00	1.105	90.00	.615	0.00	0.000
40.00	1.195	0.00	0.000	0.00	0.000
45.00	1.268	0.00	0.000	0.00	0.000
50.00	1.360	0.00	0.000	0.00	0.000
55.00	1.407	0.00	0.000	0.00	0.000
60.00	1.451	0.00	0.000	0.00	0.000
70.00	1.546	0.00	0.000	0.00	0.000
80.00	1.588	0.00	0.000	0.00	0.000
90.00	1.590	0.00	0.000	0.00	0.000
0.00	0.000	0.00	0.000	0.00	0.000

********** PROGRAM OPERATION **********

RO	RVOA	NXOUTC	NYOUTB	NXOUTT	NI	DXI	EPS	OMEGA	RVORT
-.400	1.200	10	10	10	51	.050	.00010	45.000	.50

NOSE VORTICES ARE RUN TO CANARD TRAILING EDGE

VORTICES ARE NEAR CANARD T

VORTICES ARE NEAR TAIL T

Reproduced from best available copy.

Figure E.5(c). Continued.

INTERFERENCE FACTORS		SOURCE
KWC	= 1.3443	1
LKW	= .9392	0
KABC(1)	= .5021	0
KABC(2)	= .5020	
KABC(3)	= .5021	
KABC(4)	= .5020	
KD(1)	= .0790	0
KD(2)	= .3850	
KD(3)	= .0790	
KD(4)	= .3850	
KBC	= .3671	1
XBC	= .9548	1
KWT	= 1.4342	1
KABT(1)	= .4968	0
KABT(2)	= .4968	
KABT(3)	= .4968	
KABT(4)	= .4968	
KBT	= .4838	1
XBT	= .7877	1

THE FOLLOWING LOAD CALCULATIONS ARE FOR ALPHA = 15.600 AND PHI = 0.000

********** CONTRIBUTION OF NOSE SECTION TO TOTAL LOADS **********

NOSE VORTICES HAVE FORMED AT X/A = 3.30325

STRENGTHS AND POSITIONS OF VORTICES AT LEADING EDGE OF CANARD ROOT CHORD

I	GAMMA/2PIVA	YO/A	ZO/A
1	.06317	.6041	1.0869
2	-.06317	-.6041	1.0869

NORMAL FORCE COEFFICIENT AND PITCHING MOMENT COEFFICIENT
IN UNROLLED BODY COORDINATES

CZB	CMYB
.00242	2.97754

CL = .769

CD = .229

Figure E.5(d). Continued.

********** CANARD SECTION RESULTS FOR ALPHA = 16.600 AND PHI = 0.000 **********

RESULTS DUE TO PANEL-PANEL INTERFERENCE

PANEL	ALPHAEQ	CN	CPX	CPY
1	12.1316	.2029	.5094	.7857
2	22.[illegible]090	.3326	.5133	.7793
3	15.9234	.2542	.5111	.7829
4	22.7871	.3417	.5141	.7788

*** VORTEX TRACKING RESULTS OVER FINS ***

X	VORTEX	Y	Z	YO	ZO
.5088E+01	1	.6041E+00	.1087E+01	.6041E+00	.1087E+01
	2	-.6041E+00	.1087E+01	-.6041E+00	.1087E+01
.5248E+01	1	.5957E+00	.1106E+01	.5957E+00	.1106E+01
	2	-.5957E+00	.1106E+01	-.5957E+00	.1106E+01
.5408E+01	1	.5871E+00	.1126E+01	.5871E+00	.1126E+01
	2	-.5871E+00	.1126E+01	-.5871E+00	.1126E+01
.5568E+01	1	.5784E+00	.1147E+01	.5784E+00	.1147E+01
	2	-.5784E+00	.1147E+01	-.5784E+00	.1147E+01
.5728E+01	1	.5696E+00	.1167E+01	.5696E+00	.1167E+01
	2	-.5696E+00	.1167E+01	-.5696E+00	.1167E+01
.5888E+01	1	.5609E+00	.1188E+01	.5609E+00	.1188E+01
	2	-.5609E+00	.1188E+01	-.5609E+00	.1188E+01
.6048E+01	1	.5521E+00	.1208E+01	.5521E+00	.1208E+01
	2	-.5521E+00	.1208E+01	-.5521E+00	.1208E+01
.6152E+01	1	.5464E+00	.1222E+01	.5464E+00	.1222E+01
	2	-.5464E+00	.1222E+01	-.5464E+00	.1222E+01
.6312E+01	1	.5376E+00	.1243E+01	.5376E+00	.1243E+01
	2	-.5376E+00	.1243E+01	-.5376E+00	.1243E+01
.6472E+01	1	.5289E+00	.1264E+01	.5289E+00	.1264E+01
	2	-.5289E+00	.1264E+01	-.5289E+00	.1264E+01
.6632E+01	1	.5202E+00	.1285E+01	.5202E+00	.1285E+01
	2	-.5202E+00	.1285E+01	-.5202E+00	.1285E+01
.6688E+01	1	.5172E+00	.1293E+01	.5172E+00	.1293E+01
	2	-.5172E+00	.1293E+01	-.5172E+00	.1293E+01

Figure E.5(e) Continued.

	FIN 1	FIN 2	FIN 3	FIN 4
VORTEX INDUCED EQUIVALENT ANGLE OF ATTACK, DEGREES	.9743E-13	-.4733E+00	-.8341E-14	-.4003E+00
CENTER OF PRESSURE FOR VORTEX INDUCED LOADS	.8294E+00	.8137E+00	.9726E+00	.8137E+00

STRENGTHS AND POSITIONS OF CANARD VORTICES AT CANARD TRAILING EDGE

		ROLLED COORDINATES		UNROLLED COORDINATES	
PANEL	GAMMA/2PIVA	Y/A	Z/A	Y0/A	Z0/A
1	.0548	.1781	1.9255	.1781	1.9255
2	-.0921	-1.8898	-0.0000	-1.8898	0.0000
3	-.0699	.1781	-1.9094	.1781	-1.9094
4	.0450	1.8872	-0.0000	1.8872	0.0000

*** TOTAL CANARD FIN LOADS INCLUDING VORTEX EFFECTS ***

PANEL	ALPHAEQ	CN	CPX	CPY	CRM	CBM	CHM
1	12.1316	.2029	.5094	.7857	.1540	.0590	-.0198
2	21.6061	.3260	.5136	.7793	.2573	.0933	-.0189
3	15.9234	.2542	.5111	.7829	.1922	.0719	-.0140
4	22.3862	.3370	.5139	.7788	.2642	.0957	-.0195

*** CONTRIBUTION OF CANARD SECTION TO TOTAL LOADS ***

UNROLLED COORDINATES				ROLLED COORDINATES			
CXO =	.1183	CMXO =	-.0314	CX =	.1183	CMX =	-.0314
CYO =	-.5594	CMYO =	1.7567	CY =	-.5594	CMY =	1.7567
CZO =	.8424	CMZO =	1.1696	CZ =	.8424	CMZ =	1.1696
CL =	.7735						
CD =	.3241						

Figure E.5(f). Continued.

********** AFTERBODY SECTION RESULTS FOR ALPHA = 16.00 AND PHI = 0.000 **********

***** VORTEX TRACKING RESULTS OVER AFTERBODY *****

X/A	I	GAMMA(I)	YO(I)/A	ZO(I)/A	FLOANG	THETA	NORMAL FORCE	SIDE FORCE
.6689E+01	1	.5482E-01	.1782E+00	.1926E+01	11.43	71.00		
	2	-.9215E-01	-.1390E+01	0.				
	3	-.6988E-01	.1781E+00	-.1909E+01				
	4	.9496E-01	.1887E+01	0.				

*** AFTERBODY VORTICES HAVE FORMED AT X/A = 5.69

THE LEFT VORTEX POSITION IS YO/A =-.618 AND ZO/A =1.029

THE RIGHT VORTEX POSITION IS YO/A =1.120 AND ZO/A = .433

.7739E+01	1	.5482E-01	.1933E+00	.2124E+01	11.74	71.20	.0313	.0233
	2	-.9215E-01	-.1865E+01	.3256E+00				
	3	-.6988E-01	.2433E+00	-.1715E+01				
	4	.9496E-01	.1899E+01	.3274E+00				
	5	-.1522E-01	-.4295E+00	.1166E+01				
	6	.1661E-01	.1018E+01	.6423E+00				
.8790E+01	1	.5482E-01	.2105E+00	.2314E+01	12.37	71.92	.0390	.0248
	2	-.9215E-01	-.1825E+01	.6474E+00				
	3	-.6988E-01	.3378E+00	-.1528E+01				
	4	.9496E-01	.1900E+01	.6494E+00				
	5	-.3164E-01	-.2993E+00	.1262E+01				
	6	.3715E-01	.9539E+00	.7355E+00				
.9842E+01	1	.5482E-01	.2305E+00	.2504E+01	13.29	73.16	.0503	.0245
	2	-.9215E-01	-.1779E+01	.9594E+00				
	3	-.6988E-01	.4729E+00	-.1341E+01				
	4	.9496E-01	.1892E+01	.9669E+00				
	5	-.4916E-01	-.2143E+00	.1349E+01				
	6	.6144E-01	.9410E+00	.8277E+00				
.1089E+02	1	.5482E-01	.2529E+00	.2689E+01	14.48	75.19	.0642	.0192
	2	-.9215E-01	-.1739E+01	.1261E+01				
	3	-.6988E-01	.6725E+00	-.1125E+01				
	4	.9496E-01	.1971E+01	.1287E+01				
	5	-.6758E-01	-.1596E+00	.1407E+01				
	6	.8876E-01	.9711E+00	.8517E+00				
.1194E+02	1	.5482E-01	.2757E+00	.2867E+01	15.83	78.64	.0817	.0070
	2	-.9215E-01	-.1645E+01	.1593E+01				
	3	-.6988E-01	.9340E+00	-.8132E+00				
	4	.9496E-01	.1933E+01	.1599E+01				
	5	-.8662E-01	-.1234E+00	.1463E+01				
	6	.1178E+00	.1026E+01	.9478E+00				

Figure E.5(g). Continued.

.1300E+02	1	.1482E-01	.3142E+00	.3233E+01	16.91	83.59	.0491	-.0140
	2	-.9215E-01	-.1579E+01	.1941E+01				
	3	-.6988E-01	.1103E+01	-.3558E+00				
	4	.9496E-01	.1779E+01	.1896E+01				
	5	-.1064E+00	-.1055E+00	.1505E+01				
	6	.1472E+00	.1593E+01	.9548E+00				
.1405E+02	1	.5482E-01	.3215E+00	.3196E+01	17.28	87.98	.1110	-.0464
	2	-.9215E-01	-.1508E+01	.2122E+01				
	3	-.6988E-01	.1272E+01	.1063E+00				
	4	.9496E-01	.1716E+01	.2176E+01				
	5	-.1254E+00	-.9483E-01	.1536E+01				
	6	.1745E+00	.1167E+01	.1043E+01				
.1510E+02	1	.5482E-01	.3394E+00	.3346E+01	17.11	89.89	.0841	-.0780
	2	-.9215E-01	-.1430E+01	.2395E+01				
	3	-.6988E-01	.1413E+01	.4377E+00				
	4	.9496E-01	.1652E+01	.2439E+01				
	5	-.1433E+00	-.8397E-01	.1560E+01				
	6	.1975E+00	.1265E+01	.1169E+01				
.1615E+02	1	.5482E-01	.3535E+00	.3484E+01	16.81	90.32	.0769	-.0958
	2	-.9215E-01	-.1346E+01	.2656E+01				
	3	-.6988E-01	.1572E+01	.7609E+00				
	4	.9496E-01	.1588E+01	.2687E+01				
	5	-.1603E+00	-.8420E-01	.1585E+01				
	6	.2159E+00	.1394E+01	.1339E+01				
.1720E+02	1	.5482E-01	.3644E+00	.3608E+01	16.55	90.37	.0844	-.1045
	2	-.9215E-01	-.1258E+01	.2903E+01				
	3	-.6988E-01	.1982E+01	.1215E+01				
	4	.9496E-01	.1524E+01	.2923E+01				
	5	-.1769E+00	-.7665E-01	.1616E+01				
	6	.2307E+00	.1537E+01	.1567E+01				

*** CONTRIBUTION OF AFTERBODY SECTION TO TOTAL LOADS IN UNROLLED BODY COORDINATES **

CYB = -.240 CMYB = -.824

CZB = .712 CMZB = .901

CL = .683

CD = .234

Figure E.5(h). Continued.

********** TAIL SECTION RESULTS FOR ALPHA = 16.60[illegible] AND PHI = [illegible] **********

RESULTS [illegible] TO PANEL-PANEL INTERFERENCE

PANEL	ALPHAEQ	CN	CPX	CPY
1	0.0000	.0000	.7196	.8108
2	23.7579	.7811	.7964	.8108
3	0.0000	.0000	.7196	.8108
4	23.7579	.7811	.7964	.8108

*** VORTEX TRACKING RESULTS OVER FINS ***

X	VORTEX	Y	Z	YO	ZO
.1720E+02	1	.3644E+00	.3608E+01	.3644E+00	.3608E+01
	2	-.1258E+01	.2903E+01	-.1258E+01	.2903E+01
	3	.1982E+01	.1215E+01	.1982E+01	.1215E+01
	4	.1524E+01	.2923E+01	.1524E+01	.2923E+01
	5	-.7665E-01	.1616E+01	-.7665E-01	.1616E+01
	6	.1537E+01	.1567E+01	.1537E+01	.1567E+01
.1748E+02	1	.3669E+00	.3638E+01	.3669E+00	.3638E+01
	2	-.1233E+01	.2966E+01	-.1233E+01	.2966E+01
	3	.2054E+01	.1369E+01	.2054E+01	.1369E+01
	4	.1507E+01	.2984E+01	.1507E+01	.2984E+01
	5	-.7343E-01	.1626E+01	-.7343E-01	.1626E+01
	6	.1572E+01	.1639E+01	.1572E+01	.1639E+01
.1776E+02	1	.3690E+00	.3667E+01	.3690E+00	.3667E+01
	2	-.1209E+01	.3028E+01	-.1209E+01	.3028E+01
	3	.2113E+01	.1536E+01	.2113E+01	.1536E+01
	4	.1490E+01	.3044E+01	.1490E+01	.3044E+01
	5	-.6917E-01	.1637E+01	-.6917E-01	.1637E+01
	6	.1604E+01	.1717E+01	.1604E+01	.1717E+01
.1804E+02	1	.3709E+00	.3694E+01	.3709E+00	.3694E+01
	2	-.1186E+01	.3089E+01	-.1186E+01	.3089E+01
	3	.2156E+01	.1714E+01	.2156E+01	.1714E+01
	4	.1474E+01	.3105E+01	.1474E+01	.3105E+01
	5	-.6385E-01	.1649E+01	-.6385E-01	.1649E+01
	6	.1633E+01	.1799E+01	.1633E+01	.1799E+01
.1832E+02	1	.3726E+00	.3721E+01	.3726E+00	.3721E+01
	2	-.1162E+01	.3149E+01	-.1162E+01	.3149E+01
	3	.2179E+01	.1899E+01	.2179E+01	.1899E+01
	4	.1457E+01	.3165E+01	.1457E+01	.3165E+01
	5	-.5746E-01	.1662E+01	-.5746E-01	.1662E+01
	6	.1656E+01	.1884E+01	.1656E+01	.1884E+01
.1860E+02	1	.3741E+00	.3746E+01	.3741E+00	.3746E+01
	2	-.1138E+01	.3208E+01	-.1138E+01	.3208E+01
	3	.2182E+01	.2086E+01	.2182E+01	.2086E+01
	4	.1441E+01	.3226E+01	.1441E+01	.3226E+01
	5	-.5002E-01	.1677E+01	-.5002E-01	.1677E+01
	6	.1673E+01	.1971E+01	.1673E+01	.1971E+01

Figure E.5(i) Continued.

.1883E+02	1	.3754E+00	.3774E+01	.3754E+00	.3774E+01
	2	-.1113E+01	.3269E+01	-.1113E+01	.3269E+01
	3	.2163E+01	.2270E+01	.2163E+01	.2270E+01
	4	.1424E+01	.3287E+01	.1424E+01	.3287E+01
	5	-.4155E-01	.1692E+01	-.4155E-01	.1692E+01
	6	.1689E+01	.2057E+01	.1689E+01	.2057E+01
.1891E+02	1	.3756E+00	.3772E+01	.3756E+00	.3772E+01
	2	-.1112E+01	.3272E+01	-.1112E+01	.3272E+01
	3	.2159E+01	.2291E+01	.2159E+01	.2291E+01
	4	.1422E+01	.3294E+01	.1422E+01	.3294E+01
	5	-.4052E-01	.1694E+01	-.4052E-01	.1694E+01
	6	.1686E+01	.2066E+01	.1686E+01	.2066E+01
.1919E+02	1	.3769E+00	.3795E+01	.3769E+00	.3795E+01
	2	-.1089E+01	.3328E+01	-.1089E+01	.3328E+01
	3	.2120E+01	.2465E+01	.2120E+01	.2465E+01
	4	.1407E+01	.3356E+01	.1407E+01	.3356E+01
	5	-.3096E-01	.1710E+01	-.3096E-01	.1710E+01
	6	.1692E+01	.2150E+01	.1692E+01	.2150E+01
.1947E+02	1	.3782E+00	.3815E+01	.3782E+00	.3815E+01
	2	-.1067E+01	.3384E+01	-.1067E+01	.3384E+01
	3	.2067E+01	.2626E+01	.2067E+01	.2626E+01
	4	.1391E+01	.3419E+01	.1391E+01	.3419E+01
	5	-.2051E-01	.1727E+01	-.2051E-01	.1727E+01
	6	.1695E+01	.2229E+01	.1695E+01	.2229E+01
.1975E+02	1	.3797E+00	.3835E+01	.3797E+00	.3835E+01
	2	-.1045E+01	.3438E+01	-.1045E+01	.3438E+01
	3	.2034E+01	.2772E+01	.2034E+01	.2772E+01
	4	.1377E+01	.3483E+01	.1377E+01	.3483E+01
	5	-.9220E-02	.1746E+01	-.9220E-02	.1746E+01
	6	.1694E+01	.2304E+01	.1694E+01	.2304E+01
.2000E+02	1	.3813E+00	.3851E+01	.3813E+00	.3851E+01
	2	-.1025E+01	.3486E+01	-.1025E+01	.3486E+01
	3	.1996E+01	.2889E+01	.1996E+01	.2889E+01
	4	.1365E+01	.3542E+01	.1365E+01	.3542E+01
	5	.1402E-02	.1763E+01	.1402E-02	.1763E+01
	6	.1693E+01	.2367E+01	.1693E+01	.2367E+01

Figure E.5(j). Continued.

	FIN 1	FIN 2	FIN 3	FIN 4
VORTEX INDUCED EQUIVALENT ANGLE OF ATTACK, DEGREES	.9473E+01	.8126E+00	.2416E+01	-.7271E+01
CENTER OF PRESSURE FOR VORTEX INDUCED LOADS	.1635E+00	.1023E+01	.9525E+00	.9387E+00

*** TOTAL TAIL FIN LOADS INCLUDING VORTEX EFFECTS ***

PANEL	ALPHAEQ	CN	CPX	CPY	CRM	CBM
1	4.4758	.1337	.7196	.8138	.0109	-.0559
2	24.5596	.8029	.7964	.8138	.6445	.2439
3	2.4134	.0656	.7196	.8138	.0313	-.0016
4	16.4869	.5775	.7964	.8138	.5378	.2490

*** CONTRIBUTION OF TAIL SECTION TO TOTAL LOADS ***

UNROLLED COORDINATES				ROLLED COORDINATES			
CXO =	0.0000	CMXO =	-.1270	CX =	0.0000	CMX =	-.1270
CYO =	-.2667	CMYO =	-7.8938	CY =	-.2667	CMY =	-7.8938
CZO =	1.8470	CMZO =	-1.1245	CZ =	1.8470	CMZ =	-1.1245
CL =	1.7700						
CD =	.5277						

*** SUMMARY OF TOTAL LOADS IN BODY COORDINATES ***

ALPHA = 16.600 PHI = 0.000

UNROLLED COORDINATES				ROLLED COORDINATES			
CXO =	.11832	CMXO =	-.15838	CX =	.11832	CMX =	-.15838
CYO =	-1.06615	CMYO =	-3.98339	CY =	-1.06615	CMY =	-3.98339
CZO =	4.20433	CMZO =	.94644	CZ =	4.20433	CMZ =	.94644
CL =	3.99560	CPX =	6.14745				
CD =	1.31451	CPY =	4.31228				

END OF CALCULATIONS FOR ALPHA SWEEP AT PHI = 0.000

END OF CALCULATIONS FOR THIS CASE

Figure E.5(k). Concluded.

The configuration is shown in figure 3(h) of the main text and is the MICOM-NWC model of reference 4 with the N_3 nose, the C_6 canard fins, and the T_2 tail fins. The angle of attack is 16.6°, the model is at a bank angle of 0°, and the yaw panels (canard panels 1 and 3) are deflected 15°. The pitch panels are not deflected. Mach number is 1.75 and the crossflow is considered turbulent. The values of five interference factors (KBC,XBC,KWT,KBT,XBT) were input. These values were obtained from running the wing-body computer program CRFWBD described in Appendix F and reference 3. The influence of nose vortices is calculated to the canard trailing edge (NVORT = 2). Both NEARC and NEART are set equal to .TRUE. The maximum vortex induced velocity on the fins is limited to 0.4 V_∞ (RO = -0.4). Afterbody vortices (if they form) are initially positioned at 1.2 radii from the body axis (RVOA = 1.2). Finally, vortices of like sign are combined along the afterbody if they come within a distance of 0.5 body radii of one another (RVORT = 0.5). The input deck for this case is shown in figure E.4. The output is presented in figure E.5.

E.7. PROGRAM LISTING

The program is written in FORTRAN IV computer language (029 punch). The program consists of a main program, MLOADS, and twenty-eight subprograms. Each source deck is identified in columns 73 through 80 by a three-character identification and a three-digit number sequencing the cards within that deck. The program listing is given on the following pages. The table below will act as a table of contents for the listing.

PROGRAM	IDENTIFICATION	PAGE NO.
MLOADS	M01	197
INPT	M02	198
NOSE	M03	200
CANARD	M04	202
ALFAQ	M05	203
VORTEX	M06	203
CRUTRJ	M07	204

PROGRAM	IDENTIFICATION	PAGE NO.
FCT	M08	205
SHAPE	M09	205
DASCRU	M10	205
REVFLO	M11	206
SIMSON	M12	207
VEL	M13	207
CEL1	M14	208
CEL2	M15	208
ELI1	M16	208
ELI2	M17	208
LNTRP	M18	209
CURVES	M19	209
AFTBOD	M20	210
DERIV	M21	212
TAIL	M22	212
CHRT8	M23	213
EQ24	M24	214
EQ26	M25	214
EQ30	M26	214
EQ31	M27	214
CH1416	M28	214
INTFAC	M29	216

REFERENCE

E.1. Mendenhall, M. R., Goodwin, F. K., Dillenius, M. F. E., and Kline, D. M.: Computer Programs for Calculating the Static Longitudinal Aerodynamic Characteristics of Wing-Body-Tail Configurations. NASA CR-2474, Jan. 1975.

```
      PROGRAM MLOADS(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                  M01    2
C                                                                            M01    3
C        THIS PROGRAM CALCULATES THE LOADS INCLUDING INDUCED ROLL AND        M01    4
C        DRAG DUE TO LIFT ON ARBITRARILY BANKED CRUCIFORM CANARD             M01    5
C        MISSILES.                                                           M01    6
C                                                                            M01    7
      COMMON/CBODY/A,ARC,ANT,BPANC,BPANT,XCHL,XCLE,XCTIPL,XCTE,              M01    8
     2   XTLE,XTTIPL,XTTE,BRUUT,LROUT,BRCAN,BRTAIL,CPYRC,CPXRC,              M01    9
     3   TIPRAD,ETAN,RNOSE(20),RNOSE(20),PHIT,XFC,XFT,CPXRT,CPYRT,EPSN       M01   10
     4  ,NNOSE,XNC                                                          M01   11
      COMMON/CFLAG/NFKWC,NFKWT,NFLKW,NFKABC,NFKABT,NFKD,NFKBC,NFKBT,         M01   12
     2   NFXBC,NFXBT,NAPTC,NAPTT                                             M01   13
      COMMON/CFLT/ALPAC(10),PHI(10),DELTA(4),PMACH,TURB,NALPA,NPHI,DCNDA=M01   14
      COMMON/COP/DXI,NXOUTC,NXOUTB,NXOUTT,RO,NI,OMEGA,EPS,RVOA,NEARC,        M01   15
     2NEART,NFIN,RVORT2,NVORT                                               M01   16
      COMMON/CKPACS/KWC,LKW,KABC(4),KD(4),KWT,KABT(4),KBC,KBT,XBC,XBT        M01   17
      COMMON/CVRTX/NV,GAM(10),YO(10),ZO(10)                                  M01   18
      COMMON/CAPT/CDC,C1,APTVOR                                              M01   19
      COMMON/NOSDTA/G(11,2),XYV(11),Y(11,2),ZPCN(11),MC(22),DRAG(22,3)       M01   20
      COMMON/CLDB/CYWR,CZNR,CMYNR,CMZNR,CZNUR,CMYNUR,CXCR,CYCR,CZCR,         M01   21
     2CMXCR,CMYCR,CMZCR,CXCUR,CYCUR,CZCUR,CMXCUR,CMYCUR,CMZCUR,CLC,CDCF,=M01   22
     3CYAR,CZAR,CMYAR,CMZAR,CYAUR,CZAUR,CMYAUR,CMZAUR,CYTR,CZTR,CMXTR,      M01   23
     4CMYTR,CMZTR,CYTUR,CZTUR,CMXTUR,CMYTUR,CMZTUR,CLT,CDTF                 M01   24
     5,CLN,CDN,CLA,CDA                                                      M01   25
      REAL LROUT,KWC,LKW,KABC,KD,KWT,KABT,KBC,KBT                           M01   26
      DIMENSION DUM1(4)                                                     M01   27
      LOGICAL TURB,NEARC,NEART,APTVOR                                       M01   28
C                                                                           M01   29
C        READ IN AND PRINT INPUT DATA                                       M01   30
C                                                                           M01   31
  100 CALL INPT                                                             M01   32
      IF(NFIN.EQ.1)GO TO 150                                                M01   33
C                                                                           M01   34
C CALCULATE INTERFERENCE FACTORS FOR CANARD REGION                          M01   35
C                                                                           M01   36
      CALL INTPAC(NAPTC,NFKWC,NFLKW,NFKABC,NFKD,NFKBC,NFXBC,KWC,LKW,        M01   37
     2   KABC,KD,KBC,XBC,BPANC,ARC,XCLE,XCTIPL,XCTE,PMACH,1)                 M01   38
C                                                                           M01   39
C        PRINT OUT INTERFERENCE FACTORS FOR FIRST SET OF FINS.              M01   40
C                                                                           M01   41
      WRITE(6,1001)                                                         M01   42
      WRITE(6,1002) KWC,NFKWC                                               M01   43
      IF (NFIN .GE. 3) WRITE(6,1003) LKW,NFLKW                              M01   44
      WRITE(6,1015) KABC(1),NFKABC,KABC(2),KABC(3),KABC(4)                  M01   45
      IF (NFIN .GE. 3) WRITE(6,1016) KD(1),NFKD,KD(2),KD(3),KD(4)           M01   46
      WRITE(6,1017) KBC,NFKBC                                               M01   47
      WRITE(6,1018) XBC,NFXBC                                               M01   48
      IF (NFIN .LT. 4) GO TO 150                                            M01   49
      IF(NFIN.LT.4)GO TO 150                                                M01   50
C                                                                           M01   51
C CALCULATE INTERFERENCE FACTORS FOR TAIL REGION.                           M01   52
C                                                                           M01   53
      CALL INTPAC(NAPTT,NFKWT,0,NFKABT,0,NFKBT,NFXBT,KWT,DUM,KABT,DUM1,     M01   54
     2   KBT,XBT,BPANT,ART,XTLE,XTTIPL,XTTE,PMACH,2)                         M01   55
C                                                                           M01   56
C        PRINT OUT INTERFERENCE FACTORS FOR SECOND SET OF FINS.             M01   57
C                                                                           M01   58
      WRITE(6,1019) KWT,NFKWT                                               M01   59
      WRITE(6,1020) KABT(1),NFKABT,KABT(2),KABT(3),KABT(4)                  M01   60
      WRITE(6,1021) KBT,NFKBT                                               M01   61
      WRITE(6,1022) XBT,NFXBT                                               M01   62
  150 CONTINUE                                                              M01   63
C                                                                           M01   64
C        LOADS WILL BE CALCULATED FOR A RANGE OF ANGLES OF ATTACK AND       M01   65
C        ROLL.                                                              M01   66
C                                                                           M01   67
      DO 1000 J=1,NPHI                                                      M01   68
      DO 900 I=1,NALPA                                                      M01   69
      WRITE(6,1006) ALPAC(I),PHI(J)                                         M01   70
C                                                                           M01   71
C        INITIALIZE ALL LOADS                                               M01   72
C                                                                           M01   73
      CXR=0.0                                                               M01   74
      CYR=0.0                                                               M01   75
      CZR=0.0                                                               M01   76
      CMXR=0.0                                                              M01   77
      CMYR=0.0                                                              M01   78
      CMZR=0.0                                                              M01   79
      CXUR=0.0                                                              M01   80
      CYUR=0.0                                                              M01   81
      CZUR=0.0                                                              M01   82
      CMXUR=0.0                                                             M01   83
      CMYUR=0.0                                                             M01   84
      CMZUR=0.0                                                             M01   85
      CL=0.0                                                                M01   86
      CD=0.0                                                                M01   87
C                                                                           M01   88
C        CALCULATE LOADS ON NOSE.  THE OPTION TO OVERRIDE THIS PORTION      M01   89
C        OF THE PROGRAM IS THE LOGICAL VARIABLE NONOSE.  OTHER              M01   90
C        INFORMATION MAY INDICATE THAT THE NOSE DOES NOT CONTRIBUTE         M01   91
C        SIGNIFICANTLY TO THE TOTAL LOAD.  TO OVERRIDE CALCULATION OF       M01   92
C        NOSE LOADS SET NONOSE TO TRUE.  OTHERWISE SET VALUE FALSE.         M01   93
C        THE THEORETICAL DEVELOPMENT FOR NOSE LOADS IS PRESENTLY            M01   94
C        CONTAINED IN NEAR TR 65.                                           M01   95
C                                                                           M01   96
      CALL NOSE(ALPAC(I),PHI(J))                                            M01   97
      CYR=CYNR                                                              M01   98
      CZR=CZNR                                                              M01   99
      CMYR=CMYNR                                                            M01  100
      CMZR=CMZNR                                                            M01  101
      CZUR=CZNUR                                                            M01  102
      CMYUR=CMYNUR                                                          M01  103
      CL=CLN                                                                M01  104
      CD=CDN                                                                M01  105
C                                                                           M01  106
C        IF A BODY ALONE IS BEING INVESTIGATED THEN STOP CALCULATIONS       M01  107
C        HERE.                                                              M01  108
C                                                                           M01  109
      IF(NFIN.EQ.1) GO TO 700                                               M01  110
C                                                                           M01  111
C        NOW CALCULATE LOADS DUE TO CANARDS INCLUDING ANY EFFECTS OF        M01  112
C        NOSE VORTICES PASSING OVER THE CANARDS.  THEORETICAL               M01  113
C        DESCRIPTION CONTAINED IN NEAR TR 65.                               M01  114
C                                                                           M01  115
      CALL CANARD(ALPAC(I),PHI(J))                                          M01  116
      CXR=CXCR                                                              M01  117
      CYR=CYR+CYCR                                                          M01  118
      CZR=CZR+CZCR                                                          M01  119
      CMXR=CMXCR                                                            M01  120
      CMYR=CMYR+CMYCR                                                       M01  121
      CMZR=CMZR+CMZCR                                                       M01  122
      CXUR=CXCUR                                                            M01  123
      CYUR=CYCUR                                                            M01  124
      CZUR=CZUR+CZCUR                                                       M01  125
      CMXUR=CMXCUR                                                          M01  126
      CMYUR=CMYUR+CMYCUR                                                    M01  127
      CMZUR=CMZUR+CMZCUR                                                    M01  128
      CL=CL + CLC                                                           M01  129
      CD=CD + CDCF                                                          M01  130
C                                                                           M01  131
C        IF A BODY-TAIL MISSILE IS BEING INVESTIGATED THEN STOP THE         M01  132
C        PROGRAM AFTER CANARD.                                              M01  133
C                                                                           M01  134
      IF(NFIN.EQ.2) GO TO 700                                               M01  135
C                                                                           M01  136
C        DETERMINE LOADS ON AFTERBODY OF MISSILE.                           M01  137
C                                                                           M01  138
      CALL AFTBOD(ALPAC(I),PHI(J))                                          M01  139
      CYR=CYR+CYAR                                                          M01  140
      CZR=CZR+CZAR                                                          M01  141
      CMYR=CMYR+CMYAR                                                       M01  142
      CMZR=CMZR+CMZAR                                                       M01  143
      CYUR=CYUR+CYAUR                                                       M01  144
      CZUR=CZUR+CZAUR                                                       M01  145
      CMYUR=CMYUR+CMYAUR                                                    M01  146
      CMZUR=CMZUR+CMZAUR                                                    M01  147
      CL=CL+CLA                                                             M01  148
      CD=CD+CDA                                                             M01  149
C                                                                           M01  150
C        IF TAIL EFFECTS ARE NOT TO BE INCLUDED THEN STOP THE PROGRAM       M01  151
C        AFTER AFTBOD.                                                      M01  152
C                                                                           M01  153
      IF(NFIN.EQ.3) GO TO 700                                               M01  154
      CALL TAIL(ALPAC(I),PHI(J))                                            M01  155
      CYR=CYR+CYTR                                                          M01  156
```

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      CZR=CZR+CZTR                                                      M01  157
      CMXR=CMXR+CMXTR                                                   M01  158
      CMYR=CMYR+CMYTR                                                   M01  159
      CMZR=CMZR+CMZTR                                                   M01  160
      CYUR=CYUR+CYTUR                                                   M01  161
      CZUR=CZUR+CZTUR                                                   M01  162
      CMXUR=CMXUR+CMXTUR                                                M01  163
      CMYUR=CMYUR+CMYTUR                                                M01  164
      CMZUR=CMZUR+CMZTUR                                                M01  165
      CL=CL+CLT                                                         M01  166
      CD=CD+CDTF                                                        M01  167
  700 CONTINUE                                                          M01  168
C                                                                       M01  169
C         PRINT OUT SUMMARY OF TOTAL LOADS FOR THIS COMBINATION OF ANGLE M01  170
C         OF ATTACK AND ROLL ANGLE.                                     M01  171
C                                                                       M01  172
      IF(CZUR,EQ,0,0) GO TO 101                                         M01  173
      CPX= XMC/LROUT -CMYUR/CZUR                                        M01  174
      GO TO 102                                                         M01  175
  101 CPX=9999999999999.                                                M01  176
  102 IF(CYUR,EQ,0,0)  GO TO 103                                        M01  177
      CPY= XMC/LROUT + CMZUR/CYUR                                       M01  178
      GO TO 104                                                         M01  179
  103 CPY=9999999999999.                                                M01  180
  104 WRITE(6,1007)                                                     M01  181
      WRITE(6,1008) ALFAC(I),PHI(J)                                     M01  182
      WRITE(6,1009)                                                     M01  183
      WRITE(6,1012) CXUR,CMXUR,CXR,CMXR                                 M01  184
      WRITE(6,1011) CYUR,CMYUR,CYR,CMYR                                 M01  185
      WRITE(6,1010) CZUR,CMZUR,CZR,CMZR                                 M01  186
      WRITE(6,1013) CL,CPX                                              M01  187
      WRITE(6,1014) CD,CPY                                              M01  188
  900 CONTINUE                                                          M01  189
 1000 WRITE(6,1004) PHI(J)                                              M01  190
      WRITE(6,1005)                                                     M01  191
      GO TO 100                                                         M01  192
C                                                                       M01  193
 1001 FORMAT(1H1,20X,20HINTERFERENCE FACTORS,10X,6HSOURCE)              M01  194
 1002 FORMAT(1H0,24X,3HXWC,5X,2H= ,F6,4,12X,11)                         M01  195
 1003 FORMAT(25X,3HLKW,5X,2H= ,F6,4,12X,I1)                             M01  196
 1004 FORMAT(///,5X,48HEND OF CALCULATIONS FOR ALPHA SWEEP AT PHI =   ,M01  197
     2F6,3)                                                             M01  198
 1005 FORMAT(/////,5X,33HEND OF CALCULATIONS FOR THIS CASE)             M01  199
 1006 FORMAT(1H1,9X,48HTHE FOLLOWING LOAD CALCULATIONS ARE FOR ALPHA = ,M01  200
     2F6,3,3X,11HAND PHI = ,F6,3)                                       M01  201
 1007 FORMAT(/////,38X,52H***  SUMMARY OF TOTAL LOADS IN BODY COORDINATEM01  202
     28  ***)                                                           M01  203
 1008 FORMAT(1H0,48X,8HALPHA = ,F6,3,5X,6HPHI = ,F6,3)                  M01  204
 1009 FORMAT(1H0,30X,20HUNROLLED COORDINATES,27X,18HROLLED COORDINATES) M01  205
 1010 FORMAT(1H0,22X,5HCZO =,F10,5,5X,6HCMZO =,F10,5,10X,5HCZ = ,F10,5,5M01  206
     2X,6HCMZ = ,F10,5)                                                 M01  207
 1011 FORMAT(1H0,22X,5HCYO =,F10,5,5X,6HCMYO =,F10,5,10X,5HCY = ,F10,5,5M01  208
     2X,6HCMY = ,F10,5)                                                 M01  209
 1012 FORMAT(1H0,22X,5HCXO =,F10,5,5X,6HCMXO =,F10,5,10X,5HCX = ,F10,5,5M01  210
     2X,6HCMX = ,F10,5)                                                 M01  211
 1013 FORMAT(1H0,32X,5HCL = ,F10,5,5X,6HCPX = ,F10,5)                   M01  212
 1014 FORMAT(1H0,22X,5HCD = ,F10,5,5X,6HCPY = ,F10,5)                   M01  213
 1015 FORMAT(25X,10HKABC(1) = ,F6,4,12X,I1,/,25X,10HKABC(2) = ,F6,4,/,25M01  214
     2X,10HKABC(3) = ,F6,4,/,25X,10HKABC(4) = ,F6,4)                    M01  215
 1016 FORMAT(25X,10HKO(1)   = ,F6,4,12X,I1,/,25X,10HKO(2)   = ,F6,4,/,25M01  216
     2X,10HKO(3)   = ,F6,4,/,25X,10HKO(4)   = ,F6,4)                    M01  217
 1017 FORMAT(25X,3HKBC,5X,2H= ,F6,4,12X,I1)                             M01  218
 1018 FORMAT(25X,3HXBC,5X,2H= ,F6,4,12X,I1)                             M01  219
 1019 FORMAT(1H0,20X,3HKWT,5X,2H= ,F6,4,12X,I1)                         M01  220
 1020 FORMAT(25X,10HKABT(1) = ,F6,4,12X,I1,/,25X,10HKABT(2) = ,F6,4,/,25M01  221
     2X,10HKABT(3) = ,F6,4,/,25X,10HKABT(4) = ,F6,4)                    M01  222
 1021 FORMAT(25X,3HXBT,5X,2H= ,F6,4,12X,I1)                             M01  223
 1022 FORMAT(25X,3HXBT,5X,2H= ,F6,4,12X,I1)                             M01  224
      END                                                               M01  225
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      SUBROUTINE INPT                                                   M02    2
C                                                                       M02    3
C         THIS SUBROUTINE READS IN AND PRINTS OUT ALL INPUT DATA. IN    M02    4
C         ADDITION,ALL INPUT DATA WITH DIMENSIONS OF LENGTH ARE MADE    M02    5
C         NON-DIMENSIONAL WITH RESPECT TO THE BODY RADIUS. THE DATA ARE M02    6
C         DIVIDED INTO FOUR GROUPS: BODY GEOMETRY,FLIGHT CONDITIONS,    M02    7
C         EMPIRICAL INFORMATION, AND PROGRAM OPERATION CONTROLS. REFER  M02    8
C         TO THE USER'S MANUAL FOR A DESCRIPTION OF EACH GROUP.         M02    9
C                                                                       M02   10
      COMMON/CBODY/A,ARC,ART,SPANC,SPANT,XCHL,XCLE,XCTIPL,XCTE,         M02   11
     2   XTLE,XTTIPL,XTTE,SRDUT,LROUT,SRCAN,SRTAIL,CPYRC,CPXRC,         M02   12
     3   TIPRAD,ETAN,XNOSE(20),RNOSE(20),PMIT,XFC,XFT,CPXRT,CPYRT,EPSN  M02   13
     4   ,NNOSE,XMC                                                     M02   14
      COMMON/CFLAG/NFKWC,NFKRT,NFLKW,NFKABC,NFKABT,NFKD,NFKBC,NFKBT,    M02   15
     2   NFXBC,NFXBT,NAFTC,NAFTT                                        M02   16
      COMMON/CFLT/ALFAC(10),PHI(10),DELTA(4),MACH,TURB,NALFA,NPHI,DCNDA M02   17
      COMMON/CCNC/NCNC,ALFCNC(20),CNWC(20)                              M02   18
      COMMON/CCPC/NCPXC,NCPYC,ACPXC(20),ACPYC(20),CPXC(20),CPYC(20)     M02   19
      COMMON/CCNT/NCNT,ALFCNT(20),CNWT(20)                              M02   20
      COMMON/CCPT/NCPXT,NCPYT,ACPXT(20),ACPYT(20),CPXT(20),CPYT(20)     M02   21
      COMMON/COP/DXI,NXOUTC,NXOUTB,NXOUTT,RO,NI,OMEGA,EPS,RVOA,NEARC,   M02   22
     2NEART,NFIN,RVORT2,NVORT                                           M02   23
      COMMON/CKFACS/KWC,LKW,KABC(4),KD(8),KWT,KABT(4),KBC,KBT,XBC,XBT   M02   24
C                                                                       M02   25
      REAL LROUT,KWC,LKW,KABC,KD,KWT,KABT,KBC,KBT                       M02   26
C                                                                       M02   27
      LOGICAL TURB,NEARC,NEART                                          M02   28
C                                                                       M02   29
      DIMENSION HEAD(20)                                                M02   30
C                                                                       M02   31
C         READ IN AND PRINT DESCRIPTION OF RUN                          M02   32
C                                                                       M02   33
      READ(5,100)NCARDS                                                 M02   34
      IF(NCARDS,NE,999) GO TO 1000                                      M02   35
      WRITE(6,101)                                                      M02   36
      STOP                                                              M02   37
 1000 WRITE(6,102)                                                      M02   38
      DO 1010 I=1,NCARDS                                                M02   39
      READ(5,103) HEAD                                                  M02   40
 1010 WRITE(6,104) HEAD                                                 M02   41
C                                                                       M02   42
C         READ IN ALL INTEGER FLAGS                                     M02   43
C                                                                       M02   44
      READ(5,100) NFIN,NALFA                                            M02   45
      IF (NFIN .GE. 2) READ(5,100) NFKWC,NFLKW,NFKABC,NFKD,NFKBC,NFXBC, M02   46
     2NCNC,NCPXC,NCPYC,NI,NPHI,NXOUTC,NAFTC,NVORT                       M02   47
      IF (NFIN .GE. 3) READ(5,100) NXOUTB                               M02   48
      IF (NFIN .EQ. 4) READ(5,100) NFKWT,NFKABT,NFKBT,NFXBT,NCNT,NCPXT, M02   49
     2   NCPYT,NXOUTT,NAFTT                                             M02   50
C                                                                       M02   51
C         READ IN ALL LOGICAL VARIABLES                                 M02   52
C                                                                       M02   53
      READ(5,108) TURB,NEARC,NEART                                      M02   54
C         READ IN ALL FLIGHT INFORMATION                                M02   55
C                                                                       M02   56
      READ(5,115) FMACH,(DELTA(I),I=1,4)                                M02   57
      READ(5,115) (ALFAC(J),J=1,NALFA)                                  M02   58
      IF( NFIN,EQ,1) GO TO 6                                            M02   59
      IF (NFIN .GE. 2) READ(5,115) (PHI(K),K=1,NPHI)                    M02   60
      GO TO 5                                                           M02   61
    6 DO 7 I=1,10                                                       M02   62
    7 PHI(I)=0,0                                                        M02   63
C                                                                       M02   64
C         READ IN ALL REFERENCE INFORMATION                             M02   65
C                                                                       M02   66
    5 READ(5,115) LROUT,SRDUT,XMC,A                                     M02   67
      IF (NFIN .GE. 2) READ(5,115) CPXRC,CPYRC,SRCAN                    M02   68
      IF (NFIN .EQ. 4) READ(5,115) CPXRT,CPYRT,SRTAIL                   M02   69
C                                                                       M02   70
C         READ IN ALL PROGRAM CONTROL INFORMATION                       M02   71
      IF (NFIN .GE. 2) READ(5,115) RO,DXI,EPS,RVORT                     M02   72
      IF (NFIN .GE. 2) RVORT2=RVORT*RVORT                               M02   73
      IF (NFIN .GE. 3) READ(5,115) RVOA,OMEGA,XTLE                      M02   74
C                                                                       M02   75
C         READ IN BODY GEOMETRY                                         M02   76
C                                                                       M02   77
      READ(5,100) NNOSE,NCA                                             M02   78
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AD-A034 722 NIELSEN ENGINEERING AND RESEARCH INC MOUNTAIN VIEW CALIF F/G 16/4
CALCULATION OF COMPONENT FORCES AND MOMENTS OF ARBITRARILY BANK--ETC(U)
NOV 76 M J HEMSCH, C A SMITH, J N NIELSEN N00014-74-C-0050

UNCLASSIFIED NEAR-TR-125 ONR-CR215-226-3 NL

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      READ(5,115) TIPRAD,ETAN                                                M02  79
      IF (NCA .EQ. 0) DCNDA=2.                                               M02  80
      IF (NCA .NE. 0) READ(5,115) DCNDA                                      M02  81
      READ(5,115) (XNOSE(L),L=1,NNOSE)                                       M02  82
      READ(5,115) (RNOSE(M),M=1,NNOSE)                                       M02  83
      EPS=TIPRAD/A                                                           M02  84
      IF (NPIN .GE. 2) GO TO 205                                             M02  85
      READ(5,115) XCLE                                                       M02  86
      GO TO 210                                                              M02  87
  205 READ(5,115) ARC,SPANC,XCHL,XCLE,XCTIPL,XCTE,XFC                        M02  88
      READ(5,115) (ALFCNC(N),N=1,NCNC)                                       M02  89
      READ(5,115) (CNNC(I1),I1=1,NCNC)                                       M02  90
      READ(5,115) (ACPXC(I2),I2=1,NCPXC)                                     M02  91
      READ(5,115) (CPXC(I3),I3=1,NCPXC)                                      M02  92
      READ(5,115) (ACPYC(I4),I4=1,NCPYC)                                     M02  93
      READ(5,115) (CPYC(I5),I5=1,NCPYC)                                      M02  94
      IF (NFKHC .NE. 0 .OR. NFLKH .NE. 0 .OR. NFKBC .NE. 0 .OR. NFXBC        M02  95
     2   .NE. 0) READ(5,115) KHC,LKH,KBC,XBC                                 M02  96
      IF (NFKABC .NE. 0 .OR. NFKD .NE. 0) READ(5,115) (KABC(II),KD(II),      M02  97
     2   II=1,4)                                                             M02  98
      IF (NPIN .LT. 4) GO TO 210                                             M02  99
      READ(5,115) ART,SPANT,XTTIPL,XTTE,XFT,PHIT                             M02 100
      READ(5,115) (ALFCNT(IJ),IJ=1,NCNT)                                     M02 101
      READ(5,115) (CNNT(IK),IK=1,NCNT)                                       M02 102
      READ(5,115) (ACPXT(IL),IL=1,NCPXT)                                     M02 103
      READ(5,115) (CPXT(IM),IM=1,NCPXT)                                      M02 104
      READ(5,115) (ACPYT(IN),IN=1,NCPYT)                                     M02 105
      READ(5,115) (CPYT(J1),J1=1,NCPYT)                                      M02 106
      IF (NFKHT .NE. 0 .OR. NFKBT .NE. 0 .OR. NFXBT .NE. 0 .OR. NFKABT       M02 107
     2.NE.0) READ(5,115) KHT,KBT,XBT,(KABT(J2),J2=1,4)                       M02 108
  210 CONTINUE                                                               M02 109
C                                                                            M02 110
C       PRINT OUT ALL INPUT DATA                                             M02 111
C                                                                            M02 112
      WRITE(6,105)                                                           M02 113
      GO TO (220,230,240,250),NPIN                                           M02 114
  220 WRITE(6,170)                                                           M02 115
      GO TO 260                                                              M02 116
  230 WRITE(6,171)                                                           M02 117
      GO TO 260                                                              M02 118
  240 WRITE(6,172)                                                           M02 119
      GO TO 260                                                              M02 120
  250 WRITE(6,173)                                                           M02 121
  260 CONTINUE                                                               M02 122
      WRITE(6,106)                                                           M02 123
      WRITE(6,107)                                                           M02 124
      WRITE(6,109) TIPRAD,ETAN                                               M02 125
      WRITE(6,110)                                                           M02 126
      WRITE(6,111) (XNOSE(K),K=1,NNOSE)                                      M02 127
      WRITE(6,112) (RNOSE(L),L=1,NNOSE)                                      M02 128
      WRITE(6,118) DCNDA                                                     M02 129
      IF(NPIN.LT.2) GO TO 270                                                M02 130
      WRITE(6,113)                                                           M02 131
      WRITE(6,114)                                                           M02 132
      WRITE(6,116)ARC,SPANC,XCHL,XCLE,XCTIPL,XCTE,XFC                        M02 133
  270 WRITE(6,117)                                                           M02 134
      WRITE(6,119)A,XMC                                                      M02 135
      IF (NPIN .EQ. 1) WRITE(6,174) XCLE                                     M02 136
      IF (NPIN .NE. 4) GO TO 275                                             M02 137
      WRITE(6,120)                                                           M02 138
      WRITE(6,121)                                                           M02 139
      WRITE(6,123)ART,SPANT,XTLE,XTTIPL,XTTE,XFT,PHIT                        M02 140
  275 WRITE(6,124)                                                           M02 141
      WRITE(6,125)                                                           M02 142
      WRITE(6,126) LROUT                                                     M02 143
      IF (NPIN .GE. 2) WRITE(6,127) CPXRC,CPYRC                              M02 144
      IF (NPIN .EQ. 4) WRITE(6,128) CPXRT,CPYRT                              M02 145
      WRITE(6,129)                                                           M02 146
      WRITE(6,130) SROUT                                                     M02 147
      IF (NPIN .GE. 2) WRITE(6,131) SRCAN                                    M02 148
      IF (NPIN .EQ. 4) WRITE(6,132) SRTAIL                                   M02 149
      WRITE(6,133)                                                           M02 150
      WRITE(6,134)                                                           M02 151
      WRITE(6,136)FMACH,TURB                                                 M02 152
      WRITE(6,138) (I,DELTA(I),I=1,4)                                        M02 153
      WRITE(6,140) (ALFAC(L),L=1,NALFA)                                      M02 154
      IF (NPIN .GE. 2) WRITE(6,141) (PHI(M),M=1,NPHI)                        M02 155
      IF (NPIN .LT. 2) GO TO 450                                             M02 156
      WRITE(6,142)                                                           M02 157
      WRITE(6,143)                                                           M02 158
      WRITE(6,144)                                                           M02 159
      WRITE(6,148) (ALFCNC(I5),CNNC(I5),ACPXC(I5),CPXC(I5),ACPYC(I5),        M02 160
     2   CPYC(I5),ALFCNT(I5),CNNT(I5),ACPXT(I5),CPXT(I5),ACPYT(I5),          M02 161
     3   CPYT(I5),I5=1,20)                                                   M02 162
  450 CONTINUE                                                               M02 163
      WRITE(6,156)                                                           M02 164
      WRITE(6,157)                                                           M02 165
      WRITE(6,159) RO,RVOA,NXOUTC,NXOUTB,NXOUTT,NI,DXI,EPS,OMEGA,RVORT       M02 166
      NVOR=NVORT+1                                                           M02 167
      GO TO (500,501,502),NVOR                                               M02 168
  500 WRITE(6,189)                                                           M02 169
      GO TO 503                                                              M02 170
  501 WRITE(6,190)                                                           M02 171
      GO TO 503                                                              M02 172
  502 WRITE(6,191)                                                           M02 173
  503 WRITE(6,164)                                                           M02 174
      WRITE(6,165) NEARC,NEART                                               M02 175
C                                                                            M02 176
C       NON-DIMENSIONALIZE ALL LENGTHS BY BODY RADIUS AND ALL AREAS BY       M02 177
C       BODY RADIUS SQUARED.                                                 M02 178
C                                                                            M02 179
      LROUT=LROUT/A                                                          M02 180
      SROUT=SROUT/A**2                                                       M02 181
      XMC=XMC/A                                                              M02 182
      DO 1 I=1,NNOSE                                                         M02 183
      XNOSE(I)=XNOSE(I)/A                                                    M02 184
      RNOSE(I)=RNOSE(I)/A                                                    M02 185
    1 CONTINUE                                                               M02 186
      IF (NPIN .GE. 2) GO TO 3                                               M02 187
      XCLE=XCLE/A                                                            M02 188
      GO TO 4                                                                M02 189
    3 CONTINUE                                                               M02 190
      CPXRC=CPXRC/A                                                          M02 191
      CPYRC=CPYRC/A                                                          M02 192
      SPANC=SPANC/A                                                          M02 193
      SRCAN=SRCAN/A**2                                                       M02 194
      XCHL=XCHL/A                                                            M02 195
      XCLE=XCLE/A                                                            M02 196
      XCTE=XCTE/A                                                            M02 197
      XCTIPL=XCTIPL/A                                                        M02 198
      XFC=XFC/A                                                              M02 199
      IF(NPIN.EQ.3) XTLE= XTLE/A                                             M02 200
      IF  (NPIN .NE. 4) GO TO 4                                              M02 201
      CPXRT=CPXRT/A                                                          M02 202
      CPYRT=CPYRT/A                                                          M02 203
      SPANT=SPANT/A                                                          M02 204
      SRTAIL=SRTAIL/A**2                                                     M02 205
      XFT=XFT/A                                                              M02 206
      XTLE=XTLE/A                                                            M02 207
      XTTIPL=XTTIPL/A                                                        M02 208
      XTTE=XTTE/A                                                            M02 209
    4 CONTINUE                                                               M02 210
      RETURN                                                                 M02 211
C                                                                            M02 212
  100 FORMAT(16I5)                                                           M02 213
  101 FORMAT(//////,5X,22H***** END OF RUN *****)                            M02 214
  102 FORMAT(1H1,37X,55HCALCULATION OF AERODYNAMIC LOADS ON A CRUCIFORM M02 215
     2MISSILE,//////)                                                        M02 216
  103 FORMAT(20A4)                                                           M02 217
  104 FORMAT(25X,20A4)                                                       M02 218
  105 FORMAT(//////,130H**********************************************************M02 219
     2*** MISSILE BODY GEOMETRY **********************************************M02 220
     3**********)                                                            M02 221
  106 FORMAT(////,16X,21H*** NOSE GEOMETRY ***)                              M02 222
  107 FORMAT(1H0,5X,15HNOSE TIP RADIUS,5X,15HNOSE HALF ANGLE)                M02 223
  108 FORMAT(16L5)                                                           M02 224
  109 FORMAT(6X,F10.5,10X,F10.5)                                             M02 225
  110 FORMAT(1H0,14X,16HNOSE COORDINATES)                                    M02 226
  111 FORMAT(1H0,1X,5HXNOSE,3X,20F6.3)                                       M02 227
  112 FORMAT(1H0,1X,5HRNOSE,3X,20F6.3)                                       M02 228
  113 FORMAT(////,16X,23H*** CANARD GEOMETRY ***)                            M02 229
  114 FORMAT(1H0,2X,12HASPECT RATIO,10X,6HSPAN,6X,10HHINGE LINE,5X,17HROOTM02 230
     2OT LEADING EDGE,5X,16HTIP LEADING EDGE,5X,13HTRAILING EDGE,5X,15HXM02 231
     3 POS, CENTROID)                                                        M02 232
  115 FORMAT(8F10.5)                                                         M02 233
  116 FORMAT(3(5X,F10.5),4(10X,F10.5))                                       M02 234
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 117 FORMAT(///,16X,21H*** BODY GEOMETRY ***)                                    M02  235
 118 FORMAT(1H0,4X,42HLINEAR NORMAL FORCE COEFFICIENT SLOPE IS  ,F6.3)           M02  236
 119 FORMAT(1H0,9X,13HBODY RADIUS  ,F10.5,5X,19HCENTER OF MOMENTS  ,F10M02  237
    1.5)                                                                        M02  238
 120 FORMAT(///,16X,21H*** TAIL GEOMETRY ***)                                   M02  239
 121 FORMAT(1H0,2X,12HASPECT RATIO,10X,4HSPAN,5X,17HROOT LEADING EDGE,5M02  240
    2X,16HTIP LEADING EDGE,5X,13HTRAILING EDGE,5X,15HX POS. CENTROID,5XM02  241
    3,4HPHIT)                                                                   M02  242
 123 FORMAT(2(5X,F10.5),4(10X,F10.5),5X,F5.3)                                   M02  243
 124 FORMAT(1H1,46H*********************************************,3X,27M02  244
    2HREFERENCE LENGTHS AND AREAS,3X,50H*********************************M02  245
    3**********)                                                               M02  246
 125 FORMAT(///,15X,17HREFERENCE LENGTHS)                                       M02  247
 126 FORMAT(1H0,9X,16HOUTPUT LENGTH = ,F10.5)                                   M02  248
 127 FORMAT(1H0,9X,8HCPXRC = ,F10.5,5X,8HCPYRC = ,F10.5)                        M02  249
 128 FORMAT(1H0,9X,8HCPXRT = ,F10.5,5X,8HCPYRT = ,F10.5)                        M02  250
 129 FORMAT(///,15X,15HREFERENCE AREAS)                                         M02  251
 130 FORMAT(1H0,9X,14HOUTPUT AREA = ,F10.5)                                     M02  252
 131 FORMAT(1H0,9X,30HCANARD WING-ALONE REF. AREA = ,F10.5)                     M02  253
 132 FORMAT(1H0,9X,28HTAIL WING-ALONE REF. AREA = ,F10.5)                       M02  254
 133 FORMAT(5(/),54H*********************************************************M02  255
    2***,3X,17HFLIGHT CONDITIONS,3X,54H*********************************M02  256
    3**********)                                                               M02  257
 134 FORMAT(///,15X,11HMACH NUMBER,5X,16HTURBULENT FLOW,5X,24HCANARD DEM02  258
    2FLECTION ANGLE8)                                                           M02  259
 136 FORMAT(18X,F5.3,12X,L5,15X,5HPANEL,6X,5HANGLE)                             M02  260
 138 FORMAT(99X,I3,7X,F7.3)                                                     M02  261
 140 FORMAT(//,5X,16HANGLES OF ATTACK,10F10.2)                                  M02  262
 141 FORMAT(1H0,9X,11HROLL ANGLES,10F10.2)                                      M02  263
 142 FORMAT(1H1,54H*********************************************************M02  264
    2***,3X,15HEMPIRICAL INPUT,3X,54H*********************************M02  265
    3**********)                                                               M02  266
 143 FORMAT(///,20X,22HCANARD WING-ALONE DATA,46X,20HTAIL WING-ALONE DAM02  267
    8TA,///,7X,12HNORMAL FORCE,15X,18HCENTER OF PRESSURE,20X,12HNORMAL FM02  268
    3ORCE,19X,18HCENTER OF PRESSURE)                                            M02  269
 144 FORMAT(1H0,4X,5HANGLE,6X,4HCNWC,5X,5HANGLE,7X,3HCPX,5X,5HANGLE,7X,M02  270
    23HCPY,10X,5HANGLE,6X,4HCNWT,5X,5HANGLE,7X,3HCPX,5X,5HANGLE,7X,3HCPM02  271
    3Y)                                                                         M02  272
 148 FORMAT((3(5X,F5.2,9X,F5.3),5X,3(5X,F5.2,5X,F5.3)))                         M02  273
 150   FORMAT(///,54H*********************************************************M02  274
    2***,3X,17HPROGRAM OPERATION:,3X,54H*********************************M02  275
    3**********)                                                               M02  276
 157 FORMAT(///,7X,2HRO,7X,4HRVOA,5X,6HNXOUTC,6X,6HNXOUTB,6X,6HNXOUTT,7HM02  277
    2X,2HNI,7X,3HDXI,7X,3HEPB,8X,5HOMEGA,7X,5HRVORT)                            M02  278
 159 FORMAT(2(5X,F5.3),4(5X,I5),5X,F5.3,5X,F7.5,5X,F7.3,1X,F7.2)                M02  279
 164 FORMAT(1H0,5X,24HVORTICES ARE NEAR CANARD,10X,22HVORTICES ARE NEARM02  280
    2 TAIL)                                                                     M02  281
 165 FORMAT(17X,L1,33X,L1)                                                      M02  282
 170 FORMAT(1H0,24X,27HMISSILE IS AN ISOLATED BODY)                             M02  283
 171 FORMAT(1H0,24X,44HMISSILE IS A BODY-TAIL COMBINATION OR FINNER)            M02  284
 172 FORMAT(1H0,24X,34HMISSILE IS A FINNER WITH AFTERBODY)                      M02  285
 173 FORMAT(1H0,24X,36HMISSILE IS A CANARD-TAIL COMBINATION)                    M02  286
 174 FORMAT(1H0,9X,13HBODY LENGTH  ,F10.5)                                      M02  287
 189 FORMAT(1H0,1X,36HNOSE VORTICES ARE RUN TO END OF BODY)                     M02  288
 190 FORMAT(1H0,1X,44HNOSE VORTICES ARE RUN TO CANARD LEADING EDGE)             M02  289
 191 FORMAT(1H0,1X,45HNOSE VORTICES ARE RUN TO CANARD TRAILING EDGE)            M02  290
                                                                                M02  291
C                                                                               M02  292
     END
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      SUBROUTINE NOSE(ALFAC,PHEE)                                               M03    2
                                                                                M03    3
C        THIS PROGRAM CALCULATES THE AXIAL STARTING POSITIONS OF NOSE           M03    4
C        VORTICES, THE POSITIONS OF THESE VORTICES IN THE CROSSFLOW             M03    5
C        PLANE AT THE CANARD LEADING EDGE, AND THE STRENGTHS OF THE             M03    6
C        VORTICES AT THE CANARD LEADING EDGE.  FOR DISCUSSION OF THE            M03    7
C        PROCEDURE REFER TO NEAR TR 85.                                         M03    8
C                                                                               M03    9
      COMMON/CBODY/A,ARC,ART,BPANC,BPANT,XCHL,XCLE,XCTIPL,XCTE,                 M03   10
     2   XTLE,XTTIPL,XTTE,BROUT,LROUT,BRCAN,BRTAIL,CPYRC,CPXRC,                 M03   11
     3   TIPRAD,ETAN,XNOSE(20),RNOSE(20),PHIT,XPC,XPT,CPXRT,CPYRT,EPSN          M03   12
     4   ,NNOSE,XMC                                                             M03   13
      COMMON/COP/DXI,NXOUTC,NXOUTB,NXOUTT,RO,NI,OMEGA,EPS,RVOA,NEARC,          M03   14
     2NEART,NFIN,RVORT2,NVORT                                                   M03   15
      COMMON/CFLT/ALPC(10),PHI(10),DELTA(8),FMACH,TURB,NALFA,NPHI,DCNDA         M03   16
      COMMON/CVRTX/NV,GAM(10),YO(10),ZO(10)                                     M03   17
      COMMON/NOBDTA/G(11,2),XYV(11),Y(11,2),ZPCN(11),MC(22),DRAG(22,3)          M03   18
      COMMON/CAFT/CDC,C1,AFTVOR                                                 M03   19
      COMMON/CLDS/CYNR,CZNR,CMYNR,CMZNR,CZNUR,CMYNUR,DUM(36),CLN,CDN,           M03   20
     2   DUM1(2)                                                                M03   21
      LOGICAL TURB,AFTVOR                                                       M03   22
      REAL MSINA,LROUT,MC                                                       M03   23
 9000 FORMAT(29H0NO NOSE VORTICES ON MISSILE,/,54H0ANGLE OF ATTACK IS LESM03   24
     2S THAN OR EQUAL TO FOUR DEGREES)                                          M03   25
 9010 FORMAT(1H0,19X,72HSTRENGTHS AND POSITIONS OF VORTICES AT LEADING EM03   26
     2DGE OF CANARD ROOT CHORD)                                                 M03   27
 9020 FORMAT(1H0,29X,1HI,4X,11HGAMMA/2PIVA,8X,4HY0/A,5X,4HZ0/A)                 M03   28
 9030 FORMAT(1H0,26X,6HCL = ,F7.3,//,27X,4HCD = ,F7.3)                          M03   29
 9050 FORMAT(26X,I5,4X,F6.5,5X,F7.4,3X,F7.4)                                    M03   30
 9060 FORMAT(1H0,85HNOSE VORTICES COMMENCE DOWNSTREAM OF CANARD LEADING M03   31
     2EDGE, HENCE, NEGLECT NOSE VORTICES)                                       M03   32
 9070 FORMAT(3(/),20X,56HNORMAL FORCE COEFFICIENT AND PITCHING MOMENT COM03   33
     2EFFICIENT,/,30X,28HIN UNROLLED BODY COORDINATES)                          M03   34
 9080 FORMAT(1H0,26X,3HCZO,12X,4HCMYO)                                          M03   35
 9100 FORMAT(1H0,9X,35HNOSE VORTICES HAVE FORMED AT X/A = ,F10.5)               M03   36
 9320 FORMAT(1H0,21X,F10.5,5X,F10.5)                                            M03   37
 9520 FORMAT(1H0,129H*************************************  CONTRIBUTM03   38
     2ION OF NOSE SECTION TO TOTAL LOADS  ****************************M03   39
     3**********)                                                              M03   40
C                                                                               M03   41
C     DETERMINE AXIAL STARTING POSITIONS OF NOSE VORTICES, XS,                  M03   42
C     USING METHOD OF TRAS FIG.3.                                               M03   43
C     XS AND XC ARE NORMALIZED WRT BODY RADIUS                                  M03   44
C                                                                               M03   45
      WRITE(6,9520)                                                             M03   46
      SALFAC=SIN(ALFAC/57.29578)                                                M03   47
      PI=3.14159                                                                M03   48
      IF(ALFAC.GT.0.0) GO TO 1000                                               M03   49
      WRITE (6,9000)                                                            M03   50
      NV=0                                                                      M03   51
      AFTVOR=.FALSE.                                                            M03   52
      GO TO 3950                                                                M03   53
C                                                                               M03   54
 1000 IF (EPSN .GT. 0.2) GO TO 1300                                             M03   55
      IF(ETAN.GT.30.0) GO TO 1300                                               M03   56
      IF(ALFAC.LT.ETAN) GO TO 1290                                              M03   57
      XS=0.0                                                                    M03   58
      GO TO 2000                                                                M03   59
 1200 XS=32.0*(1.0-SQRT((ALFAC-4.0)/(ETAN-4.0)))                                M03   60
      GO TO 2000                                                                M03   61
 1300 XS=(2.0*10.0/(ALFAC-4.0))+XNOSE(1)                                        M03   62
 2000 WRITE(6,9100) XS                                                          M03   63
C                                                                               M03   64
C        SEE IF NOSE VORTICES FORM AFT OF CANARD LEADING EDGE.  IF SO           M03   65
C        GO NO FURTHER AND INSTEAD ASSUME NO NOSE VORTICES ARE FORMED           M03   66
C                                                                               M03   67
      IF (XCLE .GT. XS) GO TO 2050                                              M03   68
      WRITE(6,9060)                                                             M03   69
      NV=0                                                                      M03   70
      AFTVOR=.FALSE.                                                            M03   71
      GO TO 3950                                                                M03   72
 2050 CONTINUE                                                                  M03   73
      NV=2                                                                      M03   74
      AFTVOR=.TRUE.                                                             M03   75
C                                                                               M03   76
C     DETERMINE POSITIONS OF NOSE VORTICES, YV AND ZV, AT CANARD                M03   77
C     LEADING EDGES, USING DATA CORRELATIONS OF NEAR TR 85 FIG.4.               M03   78
C                                                                               M03   79
C     YV AND ZV ARE NORMALIZED WRT LOCAL BODY RADIUS.                           M03   80
C     NORMALIZED XS IS DENOTED XSC, MUST BE LESS THAN 10.0                      M03   81
C                                                                               M03   82
      XSC=(XCLE-XS)*SALFAC                                                      M03   83
      CALL LNTRP(XYV,ZPCN,11,XSC,ZV)                                            M03   84
      JM=1                                                                      M03   85
      IF (FMACH .GT. 1.) JM=2                                                   M03   86
      CALL LNTRP(XYV,Y(1,JM),11,XSC,YV)                                         M03   87
C                                                                               M03   88
C        YO AND ZO ARE ARRAYS FOR ACCUMULATING POSITIONS OF ALL VORTICES        M03   89
C        GAM IS AN ARRAY FOR THE VORTEX STRENGTHS.  IF THERE ARE NOSE           M03   90
C        VORTICES THE FIRST TWO ELEMENTS OF THE ARRAYS REPRESENT THE            M03   91
C        VALUES FOR THESE NOSE VORTICES.                                        M03   92
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C                                                                       M03   93
      Y0(1)=YV                                                          M03   94
      Y0(2)=-YV                                                         M03   95
      Z0(1)=ZV                                                          M03   96
      Z0(2)=ZV                                                          M03   97
C                                                                       M03   98
C        DETERMINE PLANFORM AREA FROM POSITION OF VORTEX SEPARATION     M03   99
C        TO THE SMALLER OF THE TWO DISTANCES; (A)DISTANCE TO THE        M03  100
C        SHOULDER AND (B)DISTANCE TO THE CANARD ROOT CHORD LEADING EDGE,M03  101
C                                                                       M03  102
      SC=0.0                                                            M03  103
      IF (XB .GE. XNOSE(NNOSE)) GO TO 10                                M03  104
      CALL LNTRP(XNOSE,RNOSE,NNOSE,XB,RB)                               M03  105
      DO 2 K=2,NNOSE                                                    M03  106
      IF (XB .LT. XNOSE(K)) GO TO 3                                     M03  107
    2 CONTINUE                                                          M03  108
    3 IF (XNOSE(K) .LT. XCLE) GO TO 4                                   M03  109
      CALL LNTRP(XNOSE,RNOSE,NNOSE,XCLE,RCLE)                           M03  110
      SC=(RB+RCLE)*(XCLE-XB)                                            M03  111
      GO TO 10                                                          M03  112
    4 CONTINUE                                                          M03  113
      SC=(RB+RNOSE(K))*(XNOSE(K)-XB)                                    M03  114
      IF (K .EQ. NNOSE) GO TO 10                                        M03  115
      K1=K+1                                                            M03  116
      DO 6 IJ=K1,NNOSE                                                  M03  117
      IF (XNOSE(IJ) .GT. XCLE) GO TO 7                                  M03  118
      SC=SC+(RNOSE(IJ)+RNOSE(IJ-1))*(XNOSE(IJ)-XNOSE(IJ-1))             M03  119
    6 CONTINUE                                                          M03  120
      GO TO 10                                                          M03  121
    7 CALL LNTRP(XNOSE,RNOSE,NNOSE,XCLE,RCLE)                           M03  122
      SC=SC+(RNOSE(IJ-1)+RCLE)*(XCLE-XNOSE(IJ-1))                       M03  123
   10 CONTINUE                                                          M03  124
C                                                                       M03  125
C        PLANFORM AREA FOR VORTEX STRENGTHS,                            M03  126
C                                                                       M03  127
      IF (XCLE .GE. XNOSE(NNOSE)) GO TO 12                              M03  128
      SCVRT=SC                                                          M03  129
      GO TO 15                                                          M03  130
   12 IF (XB .GT. XNOSE(NNOSE)) GO TO 14                                M03  131
      SCVRT=SC+2.*(XCLE-XNOSE(NNOSE))                                   M03  132
      RCLE=1.                                                           M03  133
      GO TO 15                                                          M03  134
   14 SCVRT=2.*(XCLE-XB)                                                M03  135
      RCLE=1.                                                           M03  136
   15 CONTINUE                                                          M03  137
C                                                                       M03  138
C        CALCULATE STRENGTHS OF NOSE VORTICES BY VORTEX IMPULSE THEOREM M03  139
C                                                                       M03  140
      RVSQ=YV*YV+ZV*ZV                                                  M03  141
      MBINA=FMACH*BALFAC                                                M03  142
      JD=3                                                              M03  143
      IF (FMACH .LT. 1.) JD=2                                           M03  144
      IF (.NOT. TURB) JD=1                                              M03  145
      CALL LNTRP(MC,DRAG(1,JD),22,MBINA,CDC)                            M03  146
      GAM(1)=.039789*CDC*SCVRT*(BALFAC**2)/(RCLE*YV*                    M03  147
     &   (1.0-1.0/RVSQ))                                                M03  148
      GAM(2)=-GAM(1)                                                    M03  149
C                                                                       M03  150
C        PRINT OUT VORTEX STRENGTHS AND POSITIONS AT CANARD ROOT CHORD  M03  151
C        LEADING EDGE                                                   M03  152
C                                                                       M03  153
      WRITE(6,9010)                                                     M03  154
      WRITE(6,9020)                                                     M03  155
      WRITE(6,9050) (I1,GAM(I1),Y0(I1),Z0(I1),I1=1,2)                   M03  156
C                                                                       M03  157
C        CALCULATION OF NOSE LOADS. THERE ARE THREE CONTRIBUTIONS TO THEM03  158
C        NOSE LOADS: (1)POTENTIAL FORCE TO MIN, (2)VISCOUS DRAG TO MIN, M03  159
C        AND (3)VISCOUS DRAG FROM THE SHOULDER TO THE CANARD ROOT CHORD M03  160
C        LEADING EDGE. MIN IS THE DISTANCE TO THE SHOULDER OR THE CANARDM03  161
C        ROOT CHORD LEADING EDGE, WHICHEVER IS LESS. NOSE LOADS         M03  162
C        CONTRIBUTE ONLY TO THE NORMAL FORCE AND THE PITCHING MOMENT.   M03  163
C                                                                       M03  164
C        REQUIRED CONVERSION FACTORS                                    M03  165
C                                                                       M03  166
      PI=3.14159                                                        M03  167
C                                                                       M03  168
C        NOSE LOADS DUE TO THE POTENTIAL FORCE                          M03  169
C                                                                       M03  170
 3950 CN=DCNDA*BALFAC*PI/SROUT                                          M03  171
C                                                                       M03  172
C        IN ORDER TO DETERMINE THE CENTER OF PRESSURE OF THE POTENTIAL  M03  173
C        NORMAL FORCE,MUST FIRST CALCULATE THE NOSE VOLUME BACK TO THE  M03  174
C        SHOULDER                                                       M03  175
C                                                                       M03  176
      VNOSE=0.0                                                         M03  177
      DO 20 I=2,NNOSE                                                   M03  178
      VNOSE=VNOSE+(XNOSE(I)-XNOSE(I-1))*(RNOSE(I)**2+RNOSE(I)*RNOSE(I-1)M03  179
     2   +RNOSE(I-1)**2)                                                M03  180
   20 CONTINUE                                                          M03  181
      VNOSE=VNOSE*PI/3.                                                 M03  182
      XN=XNOSE(NNOSE)                                                   M03  183
      XBARP=XN*(1.-VNOSE/(PI*XN))                                       M03  184
      CZN=CN                                                            M03  185
      CMYN=CN*(XMC-XBARP)/LROUT                                         M03  186
      IF (ALFAC .LE. 0.) GO TO 50                                       M03  187
      IF (XB .GE. XCLE) GO TO 50                                        M03  188
C                                                                       M03  189
C        NOSE LOADS DUE TO THE VISCOUS LIFT FROM XB TO THE MINIMUM OF   M03  190
C        XCLE AND THE SHOULDER, NO CONTRIBUTION IF VORTICES FORM AFT    M03  191
C        OF THE SHOULDER.                                               M03  192
C                                                                       M03  193
      IF (XB .GE. XN) GO TO 30                                          M03  194
      CN=CDC*(BALFAC**2)*SC/SROUT                                       M03  195
      IF (XNOSE(K) .LT. XCLE) GO TO 21                                  M03  196
      XBARD=RB*XCLE**2-2.*RB*XB**2+2.*RCLE*XCLE**2-RCLE*XB**2           M03  197
     2   -RCLE*XB*XCLE+RB*XB*XCLE                                       M03  198
      GO TO 27                                                          M03  199
   21 XK=XNOSE(K)                                                       M03  200
      RK=RNOSE(K)                                                       M03  201
      XBARD=RB*XK**2-2.*RB*XB**2+2.*RK*XK**2                            M03  202
     2   -RK*XB**2-RK*XK*XB+RB*XB*XK                                    M03  203
      IF (K .EQ. NNOSE) GO TO 27                                        M03  204
      DO 22 I1=K1,NNOSE                                                 M03  205
      XI1=XNOSE(I1)                                                     M03  206
      RI1=RNOSE(I1)                                                     M03  207
      XI1M1=XNOSE(I1-1)                                                 M03  208
      RI1M1=RNOSE(I1-1)                                                 M03  209
      IF(XI1 .GE. XCLE) GO TO 25                                        M03  210
      XBARD=XBARD+RI1M1*XI1**2-2.*RI1M1*XI1M1**2+2.*RI1*XI1**2-RI1      M03  211
     2  *XI1M1**2-RI1*XI1*XI1M1+RI1M1*XI1*XI1M1                         M03  212
   22 CONTINUE                                                          M03  213
      GO TO 27                                                          M03  214
   25 XBARD=XBARD+RI1M1*XCLE**2-2.*RI1M1*XI1M1**2+2.*RCLE*XCLE**2-RCLE  M03  215
     2   *XI1M1**2-RCLE*XI1M1*XCLE+RI1M1*XI1M1*XCLE                     M03  216
   27 XBARD=XBARD/(3.*SC)                                               M03  217
      CZN=CZN+CN                                                        M03  218
      CMYN=CMYN+CN*(XMC-XBARD)/LROUT                                    M03  219
   30 CONTINUE                                                          M03  220
C                                                                       M03  221
C        LOADS DUE TO THE VISCOUS LIFT ON THE NOSE FROM THE SHOULDER    M03  222
C        TO THE LEADING EDGE OF THE CANARD ROOT CHORD, NO CONTRIBUTION  M03  223
C        IF LEADING EDGE IS BEFORE SHOULDER.                            M03  224
C                                                                       M03  225
      IF (XCLE .LE. XN) GO TO 50                                        M03  226
      IF (XB .GT. XN) XN=XB                                             M03  227
C                                                                       M03  228
C        IF XBC IS GREATER THAN 6,USE THE VORTEX IMPULSE THEOREM AND    M03  229
C        THE VORTEX STRENGTH CORRELATIONS OF MENDENHALL AND NIELSEN,    M03  230
C        NASA CR 2073, OTHERWISE USE THE CROSSFLOW DRAG COEFFICIENT     M03  231
C        METHOD.                                                        M03  232
C                                                                       M03  233
      CN3=CDC* SALFAC**2 *2.*(XCLE-XN)/SROUT                            M03  234
      XBARD1=0.5*(XCLE+XN)                                              M03  235
      CZN=CZN+CN3                                                       M03  236
      CMYN=CMYN+CN3*(XMC-XBARD1)/LROUT                                  M03  237
   50 CONTINUE                                                          M03  238
C                                                                       M03  239
C        ASSIGN NOSE LOADS TO VALUES IN ROLLED(R) AND UNROLLED(UR)      M03  240
C        COORDINATES.                                                   M03  241
C                                                                       M03  242
C        UNROLLED COORDINATES                                           M03  243
C                                                                       M03  244
      CZNUR=CZN                                                         M03  245
      CMYNUR=CMYN                                                       M03  246
C                                                                       M03  247
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C       ROLLED COORDINATES                                              M03  248
C                                                                       M03  249
      PHIR=PHEE/57.29578                                                M03  250
      ALFAR=ALFAC/57.29578                                              M03  251
      CZNR=CZN*COS(PHIR)                                                M03  252
      CYNR=-CZN*SIN(PHIR)                                               M03  253
      CMYNR=CMYN*COS(PHIR)                                              M03  254
      CMZNR=-CMYN*SIN(PHIR)                                             M03  255
C                                                                       M03  256
C       COEFFICIENTS OF LIFT AND DRAG DUE TO NOSE SECTION,              M03  257
C                                                                       M03  258
      CLN=CZNR*COS(ALFAR)                                               M03  259
      CDN=CZNR*SIN(ALFAR)                                               M03  260
C                                                                       M03  261
C       PRINT OUT NORMAL FORCE COEFFICIENT AND PITCHING MOMENT          M03  262
C       COEFFICIENT DUE TO NOSE SECTION,                                M03  263
C                                                                       M03  264
      WRITE(6,9070)                                                     M03  265
      WRITE(6,9080)                                                     M03  266
      WRITE(6,9320) CZNR,CMYNR                                          M03  267
      WRITE(6,9030) CLN,CDN                                             M03  268
      IF(NVORT.EQ.1) NV=0                                               M03  269
      RETURN                                                            M03  270
      END                                                               M03  271


      SUBROUTINE CANARD(ALFAC,PHI)                                      M04    2
C                                                                       M04    3
C       THIS SUBROUTINE CALCULATES ALL LOADS ON THE CANARDS OF A        M04    4
C       CRUCIFORM CONFIGURED MISSILE,INCLUDING INDUCED ROLLING MOMENT,  M04    5
C                                                                       M04    6
      COMMON/CBODY/A,ARC,ART,SPANC,SPANT,XCNL,XCLE,XCTIPL,XCTE,         M04    7
     2   XTLE,XTTIPL,XTTE,SROUT,LROUT,SRCAN,SRTAIL,CPYRC,CPXRC,         M04    8
     3   TIPRAD,ETAN,XNOSE(20),RNOSE(20),PHIT,XFC,XFT,CPXRT,CPYRT,EPSN  M04    9
     4   ,NNOSE,XNC                                                     M04   10
      COMMON/CFLT/DUM(20),DELTA(4),PMACH,TURB,NALPA,NPHI,DCNDA          M04   11
      COMMON/CCNC/NCNC,ALPCNC(20),CNNC(20)                              M04   12
      COMMON/CCPC/NCPXC,NCPYC,ACPXC(20),ACPYC(20),CPXC(20),CPYC(20)     M04   13
      COMMON/COP/DXI,NXOUTC,NXOUTB,NXOUTT,RO,NI,OMEGA,EPS,RVOA,NEARC,   M04   14
     2NEART,NPIN,RVORT2,NVORT                                           M04   15
      COMMON/CKPACB/XNC,LKN,KABC(4),KD(4),KNT,KABT(4),KBC,KBT,XBC,XBT   M04   16
      COMMON/CVRTX/NV,GAM(10),YO(10),ZO(10)                             M04   17
      COMMON/CMBMP/XNLE,XNTIPL,XNTIPT,XNTE,BBW                          M04   18
      COMMON/CLDB/DUM1(6),CXC,CYC,CZC,CMXC,CMYC,CMZC,CXCO,CYCO,CZCO,    M04   19
     2CMXCO,CMYCO,CMZCO,CLC,CDCF,DUM2(24)                               M04   20
      REAL LROUT,XNC,LKN,KABC,KD,KNT,KABT,KBC,KBT,KRATIO                M04   21
      LOGICAL TURB,NEARC,NEART                                          M04   22
      DIMENSION          CNCANO(4),CPCANO(4),AEO(4),YCP(4),AEQT(4),     M04   23
     2   CNCANT(4),YBAR(4),DLTA(4),CRMC(4),YOF(10),ZOF(10)              M04   24
      DIMENSION CMM(4),CBMC(4),XCPC(4)                                  M04   25
      DIMENSION ALFAE(4)                                                M04   26
      PHIR=PHI/57.29578                                                 M04   27
C                                                                       M04   28
C       FIRST DETERMINE THE EQUIVALENT ANGLES OF ATTACK DUE TO          M04   29
C       PANEL-PANEL INTERFERENCE,                                       M04   30
C                                                                       M04   31
      CALL ALFAG(PHI,DELTA,ALFAC,ARC,KNC,LKN,KABC,KD,ALFAE)             M04   32
      WRITE(6,501) ALFAC,PHI                                            M04   33
      WRITE(6,502)                                                      M04   34
      WRITE(6,503)                                                      M04   35
C                                                                       M04   36
C       NEXT DETERMINE THE NORMAL FORCE COEFFICIENT AND CENTER OF       M04   37
C       PRESSURE FOR PANEL-PANEL INTERFERENCE,                          M04   38
C                                                                       M04   39
      DO 1000 I=1,4                                                     M04   40
      CALL LNTRP(ALFCNC,CNNC,NCNC,ABS(ALFAE(I)),CNCANO(I))              M04   41
      CNCANO(I)=SIGN(CNCANO(I),ALFAE(I))                                M04   42
      CNCANO(I)=0.5*CNCANO(I)*SRCAN/SROUT                               M04   43
      CALL LNTRP(ACPYC,CPYC,NCPYC,ABS(ALFAE(I)),CPCANO(I))              M04   44
      YBAR(I)=(CPCANO(I)*CPYRC+1.0)/LROUT                               M04   45
      CALL LNTRP(ACPXC,CPXC,NCPXC,ABS(ALFAE(I)),XCPC(I))                M04   46
      XCPC(I)=XCPC(I)*CPXRC/LROUT                                       M04   47
      WRITE(6,504) (I,ALFAE(I),CNCANO(I),XCPC(I),YBAR(I))               M04   48

 1000 CONTINUE                                                          M04   49
C                                                                       M04   50
C       IF NOSE VORTICES ARE PRESENT CALCULATE THEIR EFFECT,            M04   51
C                                                                       M04   52
      IF (NV .EQ. 0) GO TO 2500                                         M04   53
C                                                                       M04   54
C       IF NOSE VORTICES ARE NEAR A WING SET SPAN EQUAL TO BODY RADIUS, M04   55
C                                                                       M04   56
      SB=SPANC                                                          M04   57
      IF (NEARC) SB=1.0                                                 M04   58
C                                                                       M04   59
C       DETERMINE POSITIONS AND STRENGTHS OF NOSE VORTICES AT AXIAL     M04   60
C       LOCATION OF WING CENTROID,                                      M04   61
C                                                                       M04   62
      X=LE*XCLE                                                         M04   63
      X=TIPL*XCTIPL                                                     M04   64
      X=TIPT*XCTE                                                       M04   65
      X=TE*XCTE                                                         M04   66
      CALL CRUTRJ(ALFAC,PHI,DXI,NXOUTC,XFC,YOF,ZOF,EPS)                 M04   67
C                                                                       M04   68
C       CALCULATE EQUIVALENT ANGLE OF ATTACK AND Y-COORDINATE OF        M04   69
C       CENTER OF PRESSURE DUE TO NOSE VORTICES,                        M04   70
C                                                                       M04   71
      KRATIO=KNC/(KNC+KBC)                                              M04   72
      CALL REVFLO(NI,NV,SPANC,PHI,RO,AEQ,YCP,YOF,ZOF,KRATIO)            M04   73
C                                                                       M04   74
C       IF NOSE VORTICES ARE DESTROYED BY INTERACTION WITH CANARDS,     M04   75
C       SET NV BACK TO ZERO,                                            M04   76
C                                                                       M04   77
      IF(NVORT.EQ.2) NV=0                                               M04   78
      DO 1800 I=1,4                                                     M04   79
      YCP(I)=YCP(I)/LROUT                                               M04   80
 1800 CONTINUE                                                          M04   81
C                                                                       M04   82
C       DETERMINE VORTEX INDUCED NORMAL FORCE COEFFICIENT AND           M04   83
C       EQUIVALENT ANGLE OF ATTACK,                                     M04   84
C                                                                       M04   85
      DO 2000 J=1,4                                                     M04   86
      AEQT(J)=ALFAE(J)+AEQ(J)                                           M04   87
      CALL LNTRP(ALFCNC,CNNC,NCNC,ABS(AEQT(J)),CNCANT(J))               M04   88
      CALL LNTRP(ACPXC,CPXC,NCPXC,ABS(AEQT(J)),ANS)                     M04   89
      XCPC(J)=ANS*CPXRC/LROUT                                           M04   90
      CALL LNTRP(ACPYC,CPYC,NCPYC,ABS(AEQT(J)),CPCANO(J))               M04   91
      CPCANO(J)=CPCANO(J)*CPYRC/(SPANC+1.)                              M04   92
      CNCANT(J)=SIGN(CNCANT(J),AEQT(J))                                 M04   93
      CNCANT(J)=0.5*CNCANT(J)*BRCAN/SROUT                               M04   94
 2000 CONTINUE                                                          M04   95
      GO TO 3500                                                        M04   96
C                                                                       M04   97
C       IF NO NOSE VORTICES ASSIGN ZERO TO VORTEX INDUCED EQUIVALENT    M04   98
C       ANGLES OF ATTACK AND NORMAL FORCE COEFFICIENTS,                 M04   99
C                                                                       M04  100
 2500 DO 3000 K=1,4                                                     M04  101
      CNCANT(K)=CNCANO(K)                                               M04  102
      YCP(K)=0.0                                                        M04  103
      AEQT(K)=ALFAE(K)                                                  M04  104
 3000 CONTINUE                                                          M04  105
C                                                                       M04  106
C       NOW DETERMINE INDIVIDUAL PANEL INDUCED ROLLING MOMENTS,         M04  107
C                                                                       M04  108
 3500 DO 4000 L=1,4                                                     M04  109
      DLTA(L)=DELTA(L)/57.295780                                        M04  110
      CRMC(L)=(CNCANO(L)*YBAR(L)+(CNCANT(L)-CNCANO(L))*YCP(L))*         M04  111
     2   COS(DLTA(L))                                                   M04  112
 4000 CONTINUE                                                          M04  113
C                                                                       M04  114
C       WE ARE NOW IN A POSITION TO CALCULATE THE STRENGTHS AND         M04  115
C       STARTING POSITIONS OF THE CANARD TRAILING VORTICES.  THE        M04  116
C       PROCEDURE THAT WE WILL FOLLOW IS DESCRIBED IN NEAR TM 85,       M04  117
C       PAGES 18 AND 19,                                                M04  118
C                                                                       M04  119
      CALL VORTEX(CPCANO,CNCANT,PHI)                                    M04  120
      NV=NV+8                                                           M04  121
C                                                                       M04  122
C       NOW CALCULATE THE LOADS DUE TO THE CANARD SECTION, THERE ARE    M04  123
C       THREE CONTRIBUTIONS TO THE CANARD LOADS, (1)INDIVIDUAL FIN      M04  124
C       LOADS, (2)BODY LOADS DUE TO THE PRESENCE OF THE FINS, AND       M04  125
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C        (3)LOADS DUE TO BODY ALONE,                                          M04  126
C                                                                             M04  127
C        INDIVIDUAL FIN LOADS                                                 M04  128
C                                                                             M04  129
      C1=(XCHL-XCLE)/LROUT                                                    M04  130
      DO 4500 M=1,4                                                           M04  131
      CHM(M)=CNCANT(M)*(C1-XCPC(M))                                           M04  132
 4500 CBMC(M)=CRMC(M)/COS(DLTA(M))-CNCANT(M)/LROUT                            M04  133
C                                                                             M04  134
C        SUMMATION OF FIN LOADS                                               M04  135
C                                                                             M04  136
      CXCC=CNCANT(1)*SIN(DLTA(1))+CNCANT(2)*SIN(DLTA(2))                      M04  137
     2   +CNCANT(3)*SIN(DLTA(3))+CNCANT(4)*SIN(DLTA(4))                       M04  138
      CYCC=-CNCANT(1)*COS(DLTA(1))-CNCANT(3)*COS(DLTA(3))                     M04  139
      CZCC=CNCANT(2)*COS(DLTA(2))+CNCANT(4)*COS(DLTA(4))                      M04  140
      CMXC=CRMC(1)-CRMC(2)-CRMC(3)+CRMC(4)                                    M04  141
      CMYC=CNCANT(2)*COS(DLTA(2))*(XMC-XCHL)/LROUT                            M04  142
     2   +CNCANT(4)*COS(DLTA(4))*(XMC-XCHL)/LROUT+CBMC(1)*SIN(DLTA(1))       M04  143
     3   -CBMC(3)*SIN(DLTA(3))+CHM(2)+CHM(4)                                 M04  144
      CMZC=CNCANT(1)*COS(DLTA(1))*(XMC-XCHL)/LROUT                            M04  145
     2   +CNCANT(3)*COS(DLTA(3))*(XMC-XCHL)/LROUT+CBMC(2)*SIN(DLTA(2))       M04  146
     3   -CBMC(4)*SIN(DLTA(4))+CHM(1)+CHM(3)                                 M04  147
C                                                                             M04  148
C        BODY LOADS DUE TO THE PRESENCE OF THE FINS,                          M04  149
C                                                                             M04  150
      CYCB=CYCC*KBC/KMC                                                       M04  151
      CZCB=CZCC*KBC/KMC                                                       M04  152
C                                                                             M04  153
C        TOTAL LOADS IN CANARD SECTION                                        M04  154
C                                                                             M04  155
      XBCC=XBC+CPXRC+XCLE                                                     M04  156
      CX=(XMC-XBCC)/LROUT                                                     M04  157
      CXC=CXCC                                                                M04  158
      CYC=CYCC+CYCB                                                           M04  159
      CZC=CZCC+CZCB                                                           M04  160
      CMYC=CMYC+CZCB*CX                                                       M04  161
      CMZC=CMZC-CYCB*CX                                                       M04  162
C                                                                             M04  163
C        CANARD LOADS IN UNROLLED BODY COORDINATES                            M04  164
C                                                                             M04  165
      ALFAR=ALFAC/57.295780                                                   M04  166
      CXCO=CXC                                                                M04  167
      CYCO=CYC*COS(PHIR)+CZC*SIN(PHIR)                                        M04  168
      CZCO=-CYC*SIN(PHIR)+CZC*COS(PHIR)                                       M04  169
      CMXCO=CMXC                                                              M04  170
      CMYCO=CMYC*COS(PHIR)+CMZC*SIN(PHIR)                                     M04  171
      CMZCO=-CMYC*SIN(PHIR)+CMZC*COS(PHIR)                                    M04  172
      CLC=CZCO*COS(ALFAR)-CXCO*SIN(ALFAR)                                     M04  173
      CDCF=CZCO*SIN(ALFAR)+CXCO*COS(ALFAR)                                    M04  174
      WRITE(6,505)                                                            M04  175
      WRITE(6,506)                                                            M04  176
      WRITE(6,507) (IL,AEGT(IL),CNCANT(IL),XCPC(IL),YBAR(IL),CRMC(IL),        M04  177
     2   CBMC(IL),CHM(IL),IL=1,4)                                             M04  178
      WRITE(6,508)                                                            M04  179
      WRITE(6,514)                                                            M04  180
      WRITE(6,509) CXCO,CMXCO,CXC,CMXC                                        M04  181
      WRITE(6,510) CYCO,CMYCO,CYC,CMYC                                        M04  182
      WRITE(6,511) CZCO,CMZCO,CZC,CMZC                                        M04  183
      WRITE(6,512) CLC                                                        M04  184
      WRITE(6,513) CDCF                                                       M04  185
      RETURN                                                                  M04  186
  501 FORMAT(1H1,71H********************************   CANARD SECTION RM04  187
     2ESULTS FOR ALPHA = ,F6.3,11H AND PHI = ,F6.3,35H   *****************M04  188
     3******************)                                                     M04  189
  502 FORMAT(1H0,29X,39HRESULTS DUE TO PANEL-PANEL INTERFERENCE)              M04  190
  503 FORMAT(1H0,24X,5HPANEL,3X,7HALPHAEQ,8X,2HCN,10X,3HCPX,9X,3HCPY,/)      M04  191
  504 FORMAT(23X,I5,4(5X,F7.4))                                               M04  192
  505 FORMAT(///,34X,57H***  TOTAL CANARD FIN LOADS INCLUDING VORTEX EFFM04  193
     2ECTS  ***)                                                              M04  194
  506 FORMAT(1H0,19X,5HPANEL,3X,7HALPHAEQ,8X,2HCN,10X,3HCPX,9X,3HCPY,9X,M04  195
     23HCRM,9X,3HCBM,9X,3HCHM,/)                                              M04  196
  507 FORMAT(18X,I5,4X,F8.4,5X,F7.4,5X,F7.4,5X,F7.4,5X,F7.4,5X,F7.4,5X,FM04  197
     27.4)                                                                    M04  198
  508 FORMAT(1H0,19X,55H***  CONTRIBUTION OF CANARD SECTION TO TOTAL LOAM04  199
     208  ***)                                                               M04  200
  509 FORMAT(1H0,34X,6HCXO = ,F8.4,6X,7HCMXO = ,F8.4,14X,5HCX = ,F8.4,7XM04  201
     2,6HCMX = ,F8.4)                                                         M04  202
  510 FORMAT(1H0,34X,6HCYO = ,F8.4,6X,7HCMYO = ,F8.4,14X,5HCY = ,F8.4,7XM04  203
     2,6HCMY = ,F8.4)                                                         M04  204
  511 FORMAT(1H0,34X,6HCZO = ,F8.4,6X,7HCMZO = ,F8.4,14X,5HCZ = ,F8.4,7XM04  205
     2,6HCMZ = ,F8.4)                                                         M04  206
  512 FORMAT(1H0,35X,5HCL = ,F8.4)                                            M04  207
  513 FORMAT(1H0,35X,5HCD = ,F8.4)                                            M04  208
  514 FORMAT(1H0,41X,20HUNROLLED COORDINATES,30X,18HROLLED COORDINATES)       M04  209
      END                                                                     M04  210
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      SUBROUTINE ALFAG(PHI,DELTA,ALFAC,AR,KN,LKH,KAB,KD,ALFAE)                M05    2
C                                                                             M05    3
C        THIS SUBROUTINE DETERMINES THE EQUIVALENT ANGLE OF ATTACK DUE        M05    4
C        TO PANEL-PANEL INTERFERENCE FOR CRUCIFORM CONFIGURED LIFTING         M05    5
C        SURFACES.  REFER TO NEAR TR 85 FOR THEORETICAL DEVELOPMENT.          M05    6
C                                                                             M05    7
      REAL KN,LKH,KAB(4),KD(4),KNAC                                           M05    8
      DIMENSION DELTA(4),ALFAE(4)                                             M05    9
      DATA RADCF/57.2957795/                                                  M05   10
C                                                                             M05   11
C        SET UP TERMS FOR CALCULATIONS OF EQUIVALENT ANGLES OF ATTACK         M05   12
C                                                                             M05   13
      KNAC=KN*ALFAC                                                           M05   14
      FBAR=(4.0/AR)/RADCF                                                     M05   15
      PHIR=PHI/RADCF                                                          M05   16
      SINPHI=SIN(PHIR)                                                        M05   17
      COSPHI=COS(PHIR)                                                        M05   18
      A2BC=(ALFAC**2)*SINPHI*COSPHI                                           M05   19
      ACP=ALFAC*COSPHI                                                        M05   20
      ASP=ALFAC*SINPHI                                                        M05   21
C                                                                             M05   22
C        NOW DETERMINE THE ANGLES OF ATTACK                                   M05   23
C                                                                             M05   24
      ALFAE(1)=KNAC*SINPHI+LKH*DELTA(1)+FBAR*(-KAB(1)*A2BC                    M05   25
     2   -KD(2)*DELTA(1)*ACP+KD(1)*DELTA(2)*ASP)                              M05   26
      ALFAE(2)=KNAC*COSPHI+LKH*DELTA(2)+FBAR*(-KAB(2)*A2BC                    M05   27
     2   -KD(2)*DELTA(2)*ASP+KD(1)*DELTA(1)*ACP)                              M05   28
      ALFAE(3)=KNAC*SINPHI+LKH*DELTA(3)+FBAR*(KAB(3)*A2BC                     M05   29
     2   +KD(4)*DELTA(3)*ACP+KD(3)*DELTA(4)*ASP)                              M05   30
      ALFAE(4)=KNAC*COSPHI+LKH*DELTA(4)+FBAR*(KAB(4)*A2BC                     M05   31
     2   +KD(4)*DELTA(4)*ASP+KD(3)*DELTA(3)*ACP)                              M05   32
C                                                                             M05   33
C        PRINT THE EQUIVALENT ANGLES OF ATTACK.                               M05   34
C                                                                             M05   35
      RETURN                                                                  M05   36
      END                                                                     M05   37
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      SUBROUTINE VORTEX(ETA,CNCANT,PHI)                                       M06    2
C                                                                             M06    3
C        THIS SUBROUTINE CALCULATES THE STRENGTHS AND POSITIONS OF THE        M06    4
C        CANARD TRAILING VORTICES.                                            M06    5
C                                                                             M06    6
      COMMON/CBODY/A,ARC,ART,BPANC,BPANT,XCHL,XCLE,XCTIPL,XCTE,               M06    7
     2   XTLE,XTTIPL,XTTE,BROUT,LROUT,BRCAN,BRTAIL,CPYRC,CPXRC,               M06    8
     3   TIPRAD,ETAN,XNOSE(20),RNOSE(20),PHIT,XPC,XPT,CPXRT,CPYRT,EPSN        M06    9
     4   ,NNOSE,XMC                                                           M06   10
      COMMON/CFLT/DUM(20),DELTA(4),FMACH,TURB,NALFA,NPHI,DCNDA                M06   11
      COMMON/CVRTX/NV,GAM(10),Y0(10),Z0(10)                                   M06   12
      REAL LROUT                                                              M06   13
      LOGICAL TURB                                                            M06   14
      DIMENSION ETA(4),CNCANT(4)                                              M06   15
      DIMENSION AEBYAL(4),AL(4),FSPAN(4),YYSUBA(4),YBYA(4),ZBYA(4)            M06   16
      DIMENSION DELTAR(4),DELTAY(4)                                           M06   17
      WRITE(6,520)                                                            M06   18
      PI=3.1415927                                                            M06   19
      C1=1.0/9.0                                                              M06   20
      C2=1.0/3.0                                                              M06   21
      C3=PI/4.0                                                               M06   22
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      WRITE(6,929)                                                      M06   23
      WRITE(6,911)                                                      M06   24
      ARM1=XCTE-XCHL                                                    M06   25
      DO 30 I=1,6                                                       M06   26
      AEBYAL(I)=(0.5*ETA(I)-C1)/(C2-ETA(I)*C3)                          M06   27
      AL(I)=(CNCANT(I)*BROUT)/((SPANC-1.)*(0.5+C3*AEBYAL(I)))           M06   28
      INV=I+NV                                                          M06   29
      GAM(INV)=(1.0/(4.0*PI))*AL(I)*(1.0+AEBYAL(I))                     M06   30
      IF (I .EQ. 2 .OR. I .EQ. 3) GAM(INV)=-GAM(INV)                    M06   31
C                                                                       M06   32
C        FSPAN IS THE FRACTION OF THE SPAN THAT THE VORTEX IS OUTBOARD   M06   33
C        OF THE FIN ROOT.                                               M06   34
C                                                                       M06   35
      FSPAN(I)=(0.5*(PI/4.0)*AEBYAL(I))/(1.0+AEBYAL(I))                 M06   36
      YVSUBA(I)=FSPAN(I)*(SPANC-1.0)+1.0                                M06   37
C                                                                       M06   38
C        THIS POSITION IS RELATIVE TO THE FINS.  WE MUST NOW TRANSFORM  M06   39
C        THIS TO ROLLED BODY COORDINATES AND THEN TO UNROLLED BODY      M06   40
C        COORDINATES.  FURTHERMORE, IT IS ONLY THE Z-COORDINATE FOR     M06   41
C        THE VERTICAL PANELS (1 AND 3) AND THE Y-COORDINATE FOR THE     M06   42
C        HORIZONTAL PANELS (2 AND 4).  THE Y-COORDINATE OF THE VERTICAL M06   43
C        PANELS IS EQUAL TO THE Z-COURDINATE OF THE HORIZONTAL PANELS   M06   44
C        AND IS    YSUBV/A=(DISTANCE FROM FIN HINGE LINE TO FIN         M06   45
C        TRAILING EDGE) TIMES THE SINE OF THE DEFLECTION ANGLE AND      M06   46
C        DIVIDED BY THE BODY RADIUS.                                    M06   47
C                                                                       M06   48
      DELTAR(I)=DELTA(I)/57.295780                                      M06   49
   30 DELTAY(I)=ARM1*SIN(DELTAR(I))                                     M06   50
C                                                                       M06   51
C        ASSIGN COORDINATES OF VORTEX STARTING POSITIONS IN ROLLED      M06   52
C        BODY COORDINATES                                               M06   53
C                                                                       M06   54
      YBYA(1)=DELTAY(1)                                                 M06   55
      ZBYA(1)=YVSUBA(1)                                                 M06   56
      YBYA(2)=-YVSUBA(2)                                                M06   57
      ZBYA(2)=-DELTAY(2)                                                M06   58
      YBYA(3)=DELTAY(3)                                                 M06   59
      ZBYA(3)=-YVSUBA(3)                                                M06   60
      YBYA(4)=YVSUBA(4)                                                 M06   61
      ZBYA(4)=-DELTAY(4)                                                M06   62
C                                                                       M06   63
C        CONVERT TO UNROLLED BODY COORDINATES.                          M06   64
C                                                                       M06   65
      PHIR=PHI/57.295780                                                M06   66
      DO 100 I=1,4                                                      M06   67
      INV=I+NV                                                          M06   68
      Y0(INV)=YBYA(I)*COS(PHIR)+ZBYA(I)*SIN(PHIR)                       M06   69
      Z0(INV)=-YBYA(I)*SIN(PHIR)+ZBYA(I)*COS(PHIR)                      M06   70
      WRITE(6,912) I,GAM(INV),YBYA(I),ZBYA(I),Y0(INV),Z0(INV)           M06   71
  100 CONTINUE                                                          M06   72
      RETURN                                                            M06   73
  911 FORMAT(1H0,19X,5HPANEL,5X,11HGAMMA/2PIVA,7X,3HY/A,9X,3HZ/A,12X,4HYM M06   74
     20/A,6X,4HZ0/A,/)                                                  M06   75
  912 FORMAT(18X,I5,8X,F7.4,7X,F7.4,3X,F7.4,8X,F7.4,3X,F7.4)            M06   76
  920 FORMAT(///,19X,66HSTRENGTHS AND POSITIONS OF CANARD VORTICES AT CAM M06   77
     3HARD TRAILING EDGE)                                               M06   78
  929 FORMAT(1H0,44X,18HROLLED COORDINATES,9X,20HUNROLLED COORDINATES)   M06   79
      END                                                               M06   80
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      SUBROUTINE CRUTRJ(ALPHAC,PHI,DXI,NXOUT,XF,Y0F,Z0F,EPS)            M07    2
C                                                                       M07    3
C     PROGRAM FOR CALCULATING THE PATHS OF FREE VORTICES IN THE         M07    4
C          PRESENCE OF A CRUCIFORM-WING-BODY COMBINATION.               M07    5
C          BODY RADIUS IS CONSTANT.  ALL LENGTHS ARE NONDIMENSIONALIZED M07    6
C          BY THE BODY RADIUS. THE VORTEX STRENGTH IS NONDIMENSIONALIZEDM07    7
C          BY 2*PI*A*VINF.                                              M07    8
C          NO IMAGE VORTEX AT BODY CENTERLINE                           M07    9
C                                                                       M07   10
      COMPLEX       EYE,EMIPHI,E2IPHI                                   M07   11
      EXTERNAL FCT                                                      M07   12
      DIMENSION Y(20),WKAREA(60),Y0F(10),Z0F(10),YY(10),ZZ(10)          M07   13
      COMMON/CHSHP/     XNLE,XNTIPL,XNTIPT,XNTE,SSN                     M07   14
      COMMON/CVRTX/NV,GAM(10),Y0(10),Z0(10)                             M07   15
      COMMON/CFCT/ALPHA,EYE,EMIPHI,E2IPHI                               M07   16
C                                                                       M07   17
 1000 FORMAT(///,1H ,11X,1HX,       6X,6HVORTEX,6X,1HY,13X,1HZ,15X,2HY0,1HM07   18
     13X,2HZ0)                                                          M07   19
 1001 FORMAT(1H0,E14.8,I6,2E14.8,3X,2E14.8)                             M07   20
 1002 FORMAT(15X,I6,2E14.4,3X,2E14.4)                                   M07   21
 1003 FORMAT(63H0INITIAL STEP SIZE WAS REDUCED BY A FACTOR OF 100 AND CONM07   22
     1NVERGENCE WAS NOT OBTAINED.)                                      M07   23
 1004 FORMAT(///,43X,43H***  VORTEX TRACKING RESULTS OVER FINS  ***)     M07   24
C                                                                       M07   25
      EYE=CMPLX(0.0,1.0)                                                M07   26
      RAD=57.29578                                                      M07   27
      DXOUT=(XNTE-XNLE)/FLOAT(NXOUT)                                    M07   28
      IF(XF.GT.XNTE)XF=XNTE                                             M07   29
      ALPHA=SIN(ALPHAC/RAD)                                             M07   30
      PHE=PHI/RAD                                                       M07   31
      EMIPHI=CEXP(-EYE*PHE)                                             M07   32
      E2IPHI=CEXP(2.0*EYE*PHE)                                          M07   33
      NDIM=2*NV                                                         M07   34
      DO 18 J=1,NV                                                      M07   35
      JN=2*J                                                            M07   36
      RA=SQRT(Y0(J)**2+Z0(J)**2)                                        M07   37
      THA=ATAN2(Z0(J),Y0(J))                                            M07   38
      IF (THA.LT.0.0) THA=6.2831853+THA                                 M07   39
      THA=THA+PHE                                                       M07   40
      YT=RA*COS(THA)                                                    M07   41
      Y(JN-1)=YT                                                        M07   42
      YY(J)=YT                                                          M07   43
      ZT=RA*SIN(THA)                                                    M07   44
      Y(JN)=ZT                                                          M07   45
      ZZ(J)=ZT                                                          M07   46
   18 CONTINUE                                                          M07   47
C                                                                       M07   48
      WRITE(6,1004)                                                     M07   49
      WRITE(6,1000)                                                     M07   50
      N=1                                                               M07   51
      WRITE(6,1001)XNLE,N,YY(1),ZZ(1),Y0(1),Z0(1)                       M07   52
      DO 10 N=2,NV                                                      M07   53
      WRITE(6,1002)N,YY(N),ZZ(N),Y0(N),Z0(N)                            M07   54
   10 CONTINUE                                                          M07   55
      XBEG=XNLE                                                         M07   56
   30 XOUT=XBEG+DXOUT                                                   M07   57
      DX=DXI                                                            M07   58
      IF(XBEG.LT.XF.AND.XOUT.GE.XF)XOUT=XF                              M07   59
      IF(XOUT.GE.XNTE)XOUT=XNTE                                         M07   60
      CALL DASCRU(FCT,XBEG,XOUT,DX,NDIM,Y,WKAREA,IER,EPS)               M07   61
      IF(IER.EQ.33)GO TO 100                                            M07   62
      N=1                                                               M07   63
      YT=Y(1)                                                           M07   64
      YY(1)=YT                                                          M07   65
      ZT=Y(2)                                                           M07   66
      ZZ(1)=ZT                                                          M07   67
      RA=SQRT(YT*YT+ZT*ZT)                                              M07   68
      THETA=ATAN2(ZT,YT)                                                M07   69
      IF(THETA.LT.0.)THETA=6.2831853+THETA                              M07   70
      THETA=THETA+PHE                                                   M07   71
      Y0T=RA*COS(THETA)                                                 M07   72
      Y0(1)=Y0T                                                         M07   73
      Z0T=RA*SIN(THETA)                                                 M07   74
      Z0(1)=Z0T                                                         M07   75
      WRITE(6,1001)XOUT,N,YT,ZT,Y0T,Z0T                                 M07   76
      DO 20 N=2,NV                                                      M07   77
      NN=2*N                                                            M07   78
      YT=Y(NN-1)                                                        M07   79
      YY(N)=YT                                                          M07   80
      ZT=Y(NN)                                                          M07   81
      ZZ(N)=ZT                                                          M07   82
      RA=SQRT(YT*YT+ZT*ZT)                                              M07   83
      THETA=ATAN2(ZT,YT)                                                M07   84
      IF(THETA.LT.0.)THETA=6.2831853+THETA                              M07   85
      THETA=THETA+PHE                                                   M07   86
      Y0T=RA*COS(THETA)                                                 M07   87
      Y0(N)=Y0T                                                         M07   88
      Z0T=RA*SIN(THETA)                                                 M07   89
      Z0(N)=Z0T                                                         M07   90
      WRITE(6,1002)N,YT,ZT,Y0T,Z0T                                      M07   91
   20 CONTINUE                                                          M07   92
      IF(XOUT.NE.XF)GO TO 25                                            M07   93
```

```
      DO 22 I=1,NV                                                      M07   94
      YOP(I)=YO(I)                                                      M07   95
   22 ZOP(I)=ZO(I)                                                      M07   96
   25 IF(XOUT.GE.XMTE)RETURN                                            M07   97
      XBEG=XOUT                                                         M07   98
      GO TO 30                                                          M07   99
  100 WRITE(6,1003)                                                     M07  100
      RETURN                                                            M07  101
      END                                                               M07  102
```

```
      SUBROUTINE FCT(Y,X,NDIM,Z)                                        M08    2
C                                                                       M08    3
C THIS ROUTINE IS USED BY CRUTRJ.                                       M08    4
C                                                                       M08    5
      COMPLEX SIG,SIG8,CTA,CTB,CNUB,CNU,SIGMA,ENU,CENU,CTC,CTD,DND8,    M08    6
     1 D2ND8,CVEL,EYE,EMIPHI,E2IPHI                                     M08    7
      DIMENSION SIGMA(10),ENU(10),CENU(10),Y(20),Z(20)                  M08    8
      COMMON/CVRTX/NV,GAM(10),YO(10),ZO(10)                             M08    9
      COMMON/CFCT/ALPHA,EYE,EMIPHI,E2IPHI                               M08   10
C                                                                       M08   11
C     LOOK UP BODY RADIUS AND LOCAL WING SEMISPAN                       M08   12
C                                                                       M08   13
      CALL SHAPE (X,S)                                                  M08   14
      S2=S*S                                                            M08   15
      S4=S2*S2                                                          M08   16
      RZ2=0.5*S2*(1.0+1./S4)                                            M08   17
      RZ4=RZ2*RZ2                                                       M08   18
C                                                                       M08   19
C     CALCULATE SIGMA AND NU FOR ALL VORTICES                           M08   20
C                                                                       M08   21
      NV=NDIM/2                                                         M08   22
      DO 1 N=1,NV                                                       M08   23
      K=2*N                                                             M08   24
      SIG=CMPLX(Y(K-1),Y(K))                                            M08   25
      SIG8=SIG*SIG                                                      M08   26
      CTB=SIG8+1./SIG8                                                  M08   27
      CTA=CTB*CTB-4.0*RZ4                                               M08   28
      CTA=CSQRT(CTA)                                                    M08   29
      YT=Y(K-1)                                                         M08   30
      ZT=Y(K)                                                           M08   31
      IF (ABS(ZT).GT.ABS(YT)) CTA=-CTA                                  M08   32
      CNUB=0.5*(CTB+CTA)                                                M08   33
      CNUB=CSQRT(CNUB)                                                  M08   34
      IF (YT.LT.0.0) CNUB=-CNU                                          M08   35
      IF (YT.EQ.0.0.AND.ZT.LT.0.0) CNUB=-CNU                            M08   36
      SIGMA(N)=SIG                                                      M08   37
      ENU(N)=CNU                                                        M08   38
      CENU(N)=CONJG(CNU)                                                M08   39
    1 CONTINUE                                                          M08   40
C                                                                       M08   41
C     CALCULATE VELOCITIES                                              M08   42
C                                                                       M08   43
      DO 2 J=1,NV                                                       M08   44
      SIG=SIGMA(J)                                                      M08   45
      CNU=ENU(J)                                                        M08   46
      CTC=1.0-1./(SIG**4)                                               M08   47
      CTD=1.0-RZ4/(CNU**4)                                              M08   48
      DND8=SIG*CTC/(CNU*CTD)                                            M08   49
      D2ND8=DND8*(DND8*(3.0-4.0/CTD)/CNU-(3.0-4.0/CTC)/SIG)             M08   50
      CVEL=-EYE*ALPHA*EMIPHI*(1.0+RZ2*E2IPHI/(CNU*CNU))                 M08   51
      DO 3 I=1,NV                                                       M08   52
      CTA=1.0/(CNU-RZ2/CENU(I))                                         M08   53
      IF (I.EQ.J) GO TO 4                                               M08   54
      CTA=CTA+1.0/(ENU(I)-CNU)                                          M08   55
    4 CVEL=CVEL+EYE*GAM(I)*CTA                                          M08   56
    3 CONTINUE                                                          M08   57
      CVEL=CVEL+DND8*0.5*EYE*GAM(J)*D2ND8/DND8                          M08   58
      JJ=2*J                                                            M08   59
      Z(JJ)=-AIMAG(CVEL)                                                M08   60
      Z(JJ-1)=REAL(CVEL)                                                M08   61
    2 CONTINUE                                                          M08   62
      RETURN                                                            M08   63
      END                                                               M08   64
```

```
      SUBROUTINE SHAPE (X,S)                                            M09    2
C                                                                       M09    3
C THIS ROUTINE IS CALLED BY FCT                                         M09    4
C                                                                       M09    5
C      TABLE LOOK-UP OF BODY COORDINATES                                M09    6
C                                                                       M09    7
      COMMON/C-SHP/      XNLE,XNTIPL,XNTIPT,XNTE,SBN                    M09    8
      IF (X.GT.XNLE .AND. X.LT.XNTIPL) GO TO 31                         M09    9
      IF (X.GE.XNTIPL .AND. X.LE.XNTIPT) GO TO 35                       M09   10
      IF (X.GT.XNTIPT.AND. X.LT.XNTE) GO TO 32                          M09   11
   31 S=(X-XNLE)/(XNTIPL-XNLE)*(SBN-1.)+1.                              M09   12
      GO TO 40                                                          M09   13
   35 S=SBN                                                             M09   14
      GO TO 40                                                          M09   15
   32 S=(XNTE-X)/(XNTE-XNTIPT)*(SBN-1.)+1.                              M09   16
   40 CONTINUE                                                          M09   17
      IF(S.LT.1.)S=1.                                                   M09   18
      RETURN                                                            M09   19
      END                                                               M09   20
```

```
      SUBROUTINE DASCRU (F,A,B,H,N,X0,WK,IER,ES)                        M10    2
C                                                                       M10    3
      DIMENSION          WK(1),X0(1)                                    M10    4
      INTEGER            BN                                             M10    5
      LOGICAL            BE,BH,BR,BX                                    M10    6
C                                ES SHOULD BE SET TO .5 TIMES THE       M10    7
C                                DESIRED RELATIVE PRECISION OF          M10    8
C                                THE SOLUTION                           M10    9
      DATA               ZERO,PS,OPS,THREE,FOUR/0.,.5,1.5,3.,4./        M10   10
      IER = 0                                                           M10   11
      IF(A - B) 4,100,4                                                 M10   12
    4 IB1=N+N                                                           M10   13
      IB2=IB1+N                                                         M10   14
      WK(N+1)=1.1*ABS(H)                                                M10   15
      BH=.TRUE.                                                         M10   16
      BR=.TRUE.                                                         M10   17
      BX=.TRUE.                                                         M10   18
C                                CHECK FOR THE PROPER SIGN OF H         M10   19
      H=SIGN(ABS(H),B-A)                                                M10   20
      X=A                                                               M10   21
    5 X8=X                                                              M10   22
      DO 10  J=1,N                                                      M10   23
         IJK0=N+J                                                       M10   24
         WK(IJK0)=X0(J)                                                 M10   25
   10 CONTINUE                                                          M10   26
   15 HS=H                                                              M10   27
      Q=X+H-B                                                           M10   28
      BE=.TRUE.                                                         M10   29
      IF(.NOT.((H.GT.ZERO.AND.Q.GE.ZERO).OR.(H.LT.ZERO.AND.Q.LE.ZERO))) M10   30
     1    GO TO 20                                                     M10   31
      H=B-X                                                             M10   32
      BR=.FALSE.                                                        M10   33
   20 H3=H/THREE                                                        M10   34
C                                CALCULATE SOLN. AT X+H                 M10   35
      DO 90  S=1,5                                                      M10   36
         CALL F(X0,X,N,WK)                                              M10   37
         DO 70  I=1,N                                                   M10   38
            Q=H3*WK(I)                                                  M10   39
            IJK0=N+I                                                    M10   40
            IJK1=IB1+I                                                  M10   41
            IJK2=IB2+I                                                  M10   42
            GO TO (25,30,35,40,45),S                                    M10   43
   25       R=Q                                                         M10   44
            WK(IJK1)=Q                                                  M10   45
            GO TO 50                                                    M10   46
   30       R=PS*(Q+WK(IJK1))                                           M10   47
            GO TO 50                                                    M10   48
   35       R=THREE*Q                                                   M10   49
            WK(IJK2)=R                                                  M10   50
            R=.375*(R+WK(IJK1))                                         M10   51
            GO TO 50                                                    M10   52
   40       R=WK(IJK1)+FOUR*Q                                           M10   53
            WK(IJK1)=R                                                  M10   54
```

```
      R=OPS*(R-WK(IJK2))
      GO TO 50
   45 R=PS*(Q+WK(IJK1))
      Q= ABS(R+R - OPS*(Q+WK(IJK2)))
   50 XO(I)=WK(IJK0)+R
      IF(BH.NE.5) GO TO 70
C                                   AUTOMATIC STEP CHANGE
      E=ABS(XO(I))
      R=ES
      IF(E.GE.1.E-3) R=E*ES
C                                   TEST ADJUSTMENT OF THE STEP
      IF(Q.LT.R .OR.(.NOT. BX)) GO TO 65
      BR=.TRUE.
      BH=.FALSE.
      H=PS*H
      IF(ABS(H).GE.HMIN) GO TO 55
C                                   THE STEP IS HALVED RESTORE X AND XO,
C                                   AND GO BACK FOR REPEATED INTEGRATION
C                                   WITH THIS NEW STEP
      H=SIGN(1.,H)*HMIN
      BX=.FALSE.
   55 DO 60  J=1,N
        IJK0=N+J
        XO(J)=WK(IJK0)
   60 CONTINUE
      X=XS
      GO TO 15
   65 IF(Q.GE.0.03125*R) BE=.FALSE.
   70 CONTINUE
      GO TO (75,90,80,85,90),BH
   75 X=X+H3
      GO TO 90
   80 X=X+PS*H3
      GO TO 90
   85 X=X+PS*H
   90 CONTINUE
C                                   TEST A POSSIBLE DOUBLING OF THE STEP
      IF(.NOT.(BE.AND.BH.AND.BR)) GO TO 95
      H=H+H
      BX=.TRUE.
   95 BH=.TRUE.
      IF(BR) GO TO 5
      H=HS
      IF(BX .OR. BE) GO TO 9005
      IER = 33
      GO TO 9005
  100 DO 105 I=1,N
        XO(I)=ZERO
  105 CONTINUE
 9005 RETURN
      END
```

```
      SUBROUTINE REVFLO(NI,NVOR,SOA,PHI,RZOA,AEQ,YCP,YVS,ZVS,KRATIO)
C
C PROGRAM TO CALCULATE FORCES AND MOMENTS ON A CRUCIFORM WING-BODY COMB-
C  INATION DUE TO INTERACTION OF AN UPSTREAM-GENERATED SYSTEM OF
C  VORTICES WITH FINS.  THE CENTER VORTEX REQUIRED BY THE CIRCLE THEOREM
C  IS NOT INCLUDED.
C
      DIMENSION YF(99),CCL6(99),DUMF(99),YVF(10),ZVF(10),W1(99),W2(99),
     1V1(99),V2(99),CCL3(99),DUMR(99),ANG(4,99),CN(4),CRM(4),AEQ(4),
     2YCP(4),YVS(10),ZVS(10)
      COMMON/CVRTX/NV,GAM(10),DUM(20)
      REAL KRATIO
C
  103 FORMAT (1H1)
  111 FORMAT(1H ,///,34X,5HFIN 1,10X,5HFIN 2,10X,5HFIN 3,10X,5HFIN 4/1H
     1,1X,25HVORTEX INDUCED EQUIVALENT/1H ,2X,24HANGLE OF ATTACK, DEGREE
     2S,E13.4,3E15.4)
  112 FORMAT(1H0,4X,22HCENTER OF PRESSURE FOR/1H ,5X,20HVORTEX INDUCED L
     1OADS,E14.4,3E15.4)
C
C
```

```
C  PROGRAM USES THE CONVENTION THAT FIN 1 IS THE UPPER VERTICAL FIN AND
C    THE REST ARE NUMBERED COUNTERCLOCKWISE WHEN VIEWED FROM THE REAR.
C    V1 ACTS ON FIN 3 TO THE RIGHT, V2 ACTS ON FIN 1 TO THE RIGHT, W1
C    ACTS ON FIN 4 UP, W2 ACTS ON FIN 2 UP.
C
C      INITIALIZATION
C
      RAD=57.29578
      PI=3.1415927
      PHE=PHI/RAD
      SINP=SIN(PHE)
      COSP=COS(PHE)
      DO 2 N=1,NVOR
      YVF(N)= YVS(N)*COSP-ZVS(N)*SINP
    2 ZVF(N)= YVS(N)*SINP+ZVS(N)*COSP
C
      WRITE (6,103)
C
C      COMPUTE FLOW ANGLES ALONG PANELS
C
      NM1=NI-1
      DYA=(SOA-1.)/FLOAT(NM1)
      DO 4 N=1,NI
      YF(N)=1.+DYA*(FLOAT(N)-1.)
    4 CONTINUE
      IF(RZOA.LT.-1.E-6)GO TO 60
C
C
C USE VISCOUS CORE AND ARCTANGENT TO LIMIT VELOCITIES.
C
      CALL VEL (YF,YVF,ZVF,W1,W2,V1,V2,NVOR,GAM,NI,    RZOA)
      DO 50 N=1,NI
      ANG(1,N)=-ATAN(V2(N))
      ANG(2,N)=ATAN(W2(N))
      ANG(3,N)=-ATAN(V1(N))
   50 ANG(4,N)=ATAN(W1(N))
      GO TO 65
C
C
C MAGNITUDES OF VELOCITIES ARE LIMITED TO VMAX/VINF EQUALS RO.
C
   60 CALL VEL(YF,YVF,ZVF,W1,W2,V1,V2,NVOR,GAM,NI,0.)
      DO 61 N=1,NI
      ANG(1,N)=-V2(N)
      ANG(2,N)=W2(N)
      ANG(3,N)=-V1(N)
   61 ANG(4,N)=W1(N)
      VMAX=-RZOA
      DO 62 I=1,4
      DO 62 N=1,NI
      IF(ABS(ANG(I,N)).GT.VMAX)ANG(I,N)=SIGN(VMAX,ANG(I,N))
   62 CONTINUE
C
C      COMPUTE SECTION LOADING COEFFICIENTS
C
   65 SOA2=SOA*SOA
      SM3=(SOA+1./SOA)**2
      DO 20 N=1,NM1
      YM3=(YF(N)+1./YF(N))**2
      CCL3(N)=4.*SQRT(SM3-YM3)
   20 CONTINUE
      CCL3(NI)=0.
C
      ROA2=0.25*(SOA2+1./SOA2)
      C2GAM=0.5/ROA2
      S2GAM=SQRT(1.-C2GAM*C2GAM)
      AK1=S2GAM
      CK=1.-AK1*AK1
      CALL CEL1 (AKK1,AK1,IER)
      CALL CEL2 (EPIK1,AK1,1.,0.,CK,IER)
      DO 8 N=1,NM1
      YFOA2=YF(N)*YF(N)
      C2THT=0.25*(YFOA2+1./YFOA2)/ROA2
      S2THT=SQRT(1.-C2THT*C2THT)
      S4THT=2.*S2THT*C2THT
      IF (N.EQ.1) GO TO 9
      A1=ASIN(S2THT/S2GAM)
```

```
      T2THT=S2THT/C2THT                                                 M11  100
      T2GAM=S2GAM/C2GAM                                                 M11  101
      HTAN1=0.5*ALOG((1.+S2THT/S2GAM)/(1.-S2THT/S2GAM))                 M11  102
      HTAN2=0.5*ALOG((1.+T2THT/T2GAM)/(1.-T2THT/T2GAM))                 M11  103
      TANAI=TAN(AI)                                                     M11  104
      CALL ELI1 (EAIK1,TANAI,C2GAM)                                     M11  105
      CALL ELI2 (EAIK1,TANAI,C2GAM,1.0,CK)                              M11  106
      AKK1Z=AKK1*EAIK1-EPIK1*FAIK1                                      M11  107
      CCL&(N)=8.*ROA2*(C2THT*HTAN1-C2GAM*HTAN2)/PI                      M11  108
      CCLA(N)=CCL&(N)+4.*ROA2*(AKK1*S4THT-2.*AK1*COS(A1)*AKK1Z)/PI      M11  109
      GO TO 8                                                           M11  110
    9 CCL&(N)=8.*ROA2*(-C2GAM*ALOG  (C2GAM)+0.5*AKK1*S4THT)/PI          M11  111
    8 CONTINUE                                                          M11  112
      CCL&(NI)=0.                                                       M11  113
C                                                                       M11  114
C     COMPUTE FORCE AND MOMENT COEFFICIENTS                             M11  115
C                                                                       M11  116
      DO 200 I=1,4                                                      M11  117
      DO 201 N=1,NI                                                     M11  118
      DUMF(N)=ANG(I,N)*CCL3(N)                                          M11  119
  201 DUMR(N)=ANG(I,N)*CCL&(N)                                          M11  120
      CALL SIMSON(NI,DUMF,DYA,CN(I))                                    M11  121
  200 CALL SIMSON(NI,DUMR,DYA,CRM(I))                                   M11  122
      CONST=RAD*KRATIO/(PI*(SOA**2))                                    M11  123
C                                                                       M11  124
C        ASSIGN VORTEX-INDUCED EFFECTS TO INDIVIDUAL PANELS IN TERMS    M11  125
C        OF CORRECTIONS TO THE EQUIVALENT ANGLES OF ATTACK, THE TERM    M11  126
C        KRATIO TAKES OUT THE EFFECT ON THE BODY LEAVING ONLY VORTEX    M11  127
C        INDUCED EFFECTS ON THE FINS.                                   M11  128
C                                                                       M11  129
      DO 225 J=1,4                                                      M11  130
      AEQ(J)=CN(J)*CONST                                                M11  131
  225 YCP(J)=CRM(J)/CN(J)/KRATIO                                        M11  132
      WRITE(6,111)AEQ(1),AEQ(2),AEQ(3),AEQ(4)                           M11  133
      WRITE(6,112)YCP(1),YCP(2),YCP(3),YCP(4)                           M11  134
      RETURN                                                            M11  135
      END                                                               M11  136
```

```
      SUBROUTINE SIMSON(N,F,DX,SUM)                                     M12    2
      DIMENSION F(101)                                                  M12    3
      SUM=F(1)+F(N)                                                     M12    4
      DO 1 I=2,N,2                                                      M12    5
    1 SUM=SUM+4.0*F(I)                                                  M12    6
      M=N-2                                                             M12    7
      DO 2 I=3,M,2                                                      M12    8
    2 SUM=SUM+2.0*F(I)                                                  M12    9
      SUM=DX*SUM/3.0                                                    M12   10
      RETURN                                                            M12   11
      END                                                               M12   12
```

```
      SUBROUTINE VEL (YF,YVF,ZVF,M1,M2,V1,V2,NVOR,GAM,NI,   RZOA)       M13    2
C                                                                       M13    3
C     SUBROUTINE TO CALCULATE VELOCITIES ON PANEL                       M13    4
C                                                                       M13    5
      DIMENSION YF(99),GAM(10),YVF(10),ZVF(10),M1(99),M2(99),V1(99),    M13    6
     1V2(99)                                                            M13    7
C                                                                       M13    8
      DO 1 N=1,NI                                                       M13    9
      M1(N)=0.0                                                         M13   10
      M2(N)=0.0                                                         M13   11
      V1(N)=0.0                                                         M13   12
      V2(N)=0.0                                                         M13   13
    1 CONTINUE                                                          M13   14
C                                                                       M13   15
      DO 2 N=1,NI                                                       M13   16
      DO 2 M=1,NVOR                                                     M13   17
      RVF2=YVF(M)**2 + ZVF(M)**2                                        M13   18
      ZABS=ABS(ZVF(M))                                                  M13   19
      GAMM=ATAN2((YF(N)-YVF(M)),ZABS)                                   M13   20
      GAMMI=ATAN2((YF(N)-YVF(M)/RVF2),ZABS/RVF2)                        M13   21
      RR=SQRT((YF(N)-YVF(M))**2 + ZVF(M)**2)                            M13   22
      RRI=SQRT((YF(N)-YVF(M)/RVF2)**2 + (ZVF(M)/RVF2)**2)               M13   23
      IF (RR-RZOA) 10,11,11                                             M13   24
   10 DM1=GAM(M)*RR*       SIN(GAMM)/(RZOA*RZOA) - GAM(M)*      SIN(GAMMIM13   25
     1)/RRI                                                             M13   26
      GO TO 12                                                          M13   27
   11 DM1=GAM(M)*      SIN(GAMM)/RR - GAM(M)*      SIN(GAMMI)/RRI      M13   28
C                                                                       M13   29
   12 YF(N)=-YF(N)                                                      M13   30
      GAMM=ATAN2((YF(N)-YVF(M)),ZABS)                                   M13   31
      GAMMI=ATAN2((YF(N)-YVF(M)/RVF2),ZABS/RVF2)                        M13   32
      RR=SQRT((YF(N)-YVF(M))**2 + ZVF(M)**2)                            M13   33
      RRI=SQRT((YF(N)-YVF(M)/RVF2)**2 + (ZVF(M)/RVF2)**2)               M13   34
      IF (RR-RZOA) 13,14,14                                             M13   35
   13 DM2=GAM(M)*RR*       SIN(GAMM)/(RZOA*RZOA) - GAM(M)*      SIN(GAMMIM13   36
     1)/RRI                                                             M13   37
      GO TO 15                                                          M13   38
   14 DM2=GAM(M)*      SIN(GAMM)/RR - GAM(M)*      SIN(GAMMI)/RRI      M13   39
C                                                                       M13   40
   15 YABS=ABS(YVF(M))                                                  M13   41
      DEL=ATAN2((ZVF(M)-YF(N)),YABS)                                    M13   42
      DELI=ATAN2((ZVF(M)/RVF2-YF(N)),YABS/RVF2)                         M13   43
      RR=SQRT(YVF(M)**2 + (ZVF(M)-YF(N))**2)                            M13   44
      RRI=SQRT((YVF(M)/RVF2)**2 + (ZVF(M)/RVF2-YF(N))**2)               M13   45
      IF (RR-RZOA) 16,17,17                                             M13   46
   16 DV1=GAM(M)*RR*       SIN(DEL)/(RZOA*RZOA) - GAM(M)*      SIN(DELI)/M13   47
     1RRI                                                               M13   48
      GO TO 18                                                          M13   49
   17 DV1=GAM(M)*      SIN(DEL)/RR - GAM(M)*      SIN(DELI)/RRI       M13   50
C                                                                       M13   51
   18 YF(N)=-YF(N)                                                      M13   52
      DEL=ATAN2((ZVF(M)-YF(N)),YABS)                                    M13   53
      DELI=ATAN2((ZVF(M)/RVF2-YF(N)),YABS/RVF2)                         M13   54
      RR=SQRT(YVF(M)**2 + (ZVF(M)-YF(N))**2)                            M13   55
      RRI=SQRT((YVF(M)/RVF2)**2 + (ZVF(M)/RVF2-YF(N))**2)               M13   56
      IF (RR-RZOA) 19,20,20                                             M13   57
   19 DV2=GAM(M)*RR*       SIN(DEL)/(RZOA*RZOA) - GAM(M)*      SIN(DELI)/M13   58
     1RRI                                                               M13   59
      GO TO 21                                                          M13   60
   20 DV2=GAM(M)*      SIN(DEL)/RR - GAM(M)*      SIN(DELI)/RRI       M13   61
C                                                                       M13   62
   21 M1(N)=M1(N)+DM1                                                   M13   63
      M2(N)=M2(N)+DM2                                                   M13   64
      V1(N)=V1(N)+DV1                                                   M13   65
      V2(N)=V2(N)+DV2                                                   M13   66
    2 CONTINUE                                                          M13   67
      RETURN                                                            M13   68
      END                                                               M13   69
```

```
      SUBROUTINE CEL1(RES,AK,IER)                                       M14   2
C                                                                       M14   3
      IER=0                                                             M14   4
C                                                                       M14   5
C     TEST MODULUS                                                      M14   6
C                                                                       M14   7
      GEO=1.-AK*AK                                                      M14   8
      IF(GEO)1,2,3                                                      M14   9
    1 IER=1                                                             M14  10
      RETURN                                                            M14  11
C                                                                       M14  12
C     SET RESULT VALUE =OFLOW                                           M14  13
C                                                                       M14  14
    2 RES=1.E30                                                         M14  15
      RETURN                                                            M14  16
    3 GEO=SQRT(GEO)                                                     M14  17
      ARI=1.                                                            M14  18
    4 AARI=ARI                                                          M14  19
      TEST=AARI*1.E-4                                                   M14  20
      ARI=GEO+ARI                                                       M14  21
C                                                                       M14  22
C     TEST OF ACCURACY                                                  M14  23
C                                                                       M14  24
      IF(AARI-GEO-TEST)6,6,5                                            M14  25
    5 GEO=SQRT(AARI*GEO)                                                M14  26
      ARI=0.5*ARI                                                       M14  27
      GO TO 4                                                           M14  28
    6 RES=3.14159265/ARI                                                M14  29
      RETURN                                                            M14  30
      END                                                               M14  31
```

```
      SUBROUTINE CEL2(RES,AK,A,B,IER)                                   M15   2
C                                                                       M15   3
      IER=0                                                             M15   4
C                                                                       M15   5
C     TEST MODULUS                                                      M15   6
C                                                                       M15   7
      GEO=1.-AK*AK                                                      M15   8
      IF(GEO)1,2,6                                                      M15   9
    1 IER=1                                                             M15  10
      RETURN                                                            M15  11
C                                                                       M15  12
C     SET RESULT VALUE = OVERFLOW                                       M15  13
C                                                                       M15  14
    2 IF(B)3,5,4                                                        M15  15
    3 RES=-1.E30                                                        M15  16
      RETURN                                                            M15  17
    4 RES=1.E30                                                         M15  18
      RETURN                                                            M15  19
    5 RES=A                                                             M15  20
      RETURN                                                            M15  21
C                                                                       M15  22
C     COMPUTE INTEGRAL                                                  M15  23
C                                                                       M15  24
    6 GEO=SQRT(GEO)                                                     M15  25
      ARI=1.                                                            M15  26
      AA=A                                                              M15  27
      AN=A+B                                                            M15  28
      MM=B                                                              M15  29
    7 MM=M+AA*GEO                                                       M15  30
      MM=M+M                                                            M15  31
      AA=AN                                                             M15  32
      AARI=ARI                                                          M15  33
      ARI=GEO+ARI                                                       M15  34
      AN=M/ARI+AN                                                       M15  35
C                                                                       M15  36
C     TEST OF ACCURACY                                                  M15  37
C                                                                       M15  38
      IF(AARI-GEO-1.E-6*AARI)9,9,8                                      M15  39
    8 GEO=SQRT(GEO+AARI)                                                M15  40
      GEO=GEO+GEO                                                       M15  41
      GO TO 7                                                           M15  42
    9 RES=.785398816*AN/ARI                                             M15  43
      RETURN                                                            M15  44
      END                                                               M15  45
```

```
      SUBROUTINE ELI1(RES,X,CK)                                         M16   2
C                                                                       M16   3
      IF(X)2,1,2                                                        M16   4
    1 RES=0.                                                            M16   5
      RETURN                                                            M16   6
    2 IF(CK)4,3,4                                                       M16   7
    3 RES=ALOG(ABS(X)+SQRT(1.+X*X))                                     M16   8
      GOTO 13                                                           M16   9
    4 ANGLE=ABS(1./X)                                                   M16  10
      GEO=ABS(CK)                                                       M16  11
      ARI=1.                                                            M16  12
      PIM=0.                                                            M16  13
    5 SQGEO=ARI*GEO                                                     M16  14
      AARI=ARI                                                          M16  15
      ARI=GEO+ARI                                                       M16  16
      ANGLE=-SQGEO/ANGLE+ANGLE                                          M16  17
      SQGEO=SQRT(SQGEO)                                                 M16  18
      IF(ANGLE)7,6,7                                                    M16  19
C     REPLACE 0 BY SMALL VALUE                                          M16  20
    6 ANGLE=SQGEO*1.E-8                                                 M16  21
    7 TEST=AARI*1.E-4                                                   M16  22
      IF(ABS(AARI-GEO)-TEST)10,10,8                                     M16  23
    8 GEO=SQGEO+SQGEO                                                   M16  24
      PIM=PIM+PIM                                                       M16  25
      IF(ANGLE)9,5,5                                                    M16  26
    9 PIM=PIM+3.1415927                                                 M16  27
      GOTO 5                                                            M16  28
   10 IF(ANGLE)11,12,12                                                 M16  29
   11 PIM=PIM+3.1415927                                                 M16  30
   12 RES=(ATAN(ARI/ANGLE)+PIM)/ARI                                     M16  31
   13 IF(X)14,15,15                                                     M16  32
   14 RES=-RES                                                          M16  33
   15 RETURN                                                            M16  34
      END                                                               M16  35
```

```
      SUBROUTINE ELI2(R,X,CK,A,B)                                       M17   2
C                                                                       M17   3
C        TEST ARGUMENT                                                  M17   4
      IF(X)2,1,2                                                        M17   5
    1 R=0.                                                              M17   6
      RETURN                                                            M17   7
C        TEST MODULUS                                                   M17   8
    2 C=0.                                                              M17   9
      D=0.5                                                             M17  10
      IF(CK)7,3,7                                                       M17  11
    3 R=SQRT(1.+X*X)                                                    M17  12
      R=(A-B)*ABS(X)/R+B*ALOG(ABS(X)+R)                                 M17  13
C        TEST SIGN OF ARGUMENT                                          M17  14
    4 R=R+C*(A-B)                                                       M17  15
      IF(X)5,6,6                                                        M17  16
    5 R=-R                                                              M17  17
```

```
      6 RETURN                                                          M17   18
C           INITIALIZATION                                              M17   19
      7 AN=(B+A)+0.5                                                    M17   20
        AARA                                                            M17   21
        R=0                                                             M17   22
        AN=ABS(1./X)                                                    M17   23
        PIM=0.                                                          M17   24
        I8I=0                                                           M17   25
        ARI=1.                                                          M17   26
        GEO=ABS(CK)                                                     M17   27
C           LANDEN TRANSFORMATION                                       M17   28
      8 R=AA+GEO+R                                                      M17   29
        SGEO=ARI+GEO                                                    M17   30
        AARAN                                                           M17   31
        AARI=ARI                                                        M17   32
C           ARITHMETIC MEAN                                             M17   33
        ARI=GEO+ARI                                                     M17   34
C           SUM OF SINE VALUES                                          M17   35
        AN=(R/ARI+AA)+0.5                                               M17   36
        AANG=ABS(ANG)                                                   M17   37
        ANG=-SGEO/ANG+ANG                                               M17   38
        PIMA=PIM                                                        M17   39
        IF(ANG)10,9,11                                                  M17   40
      9 AN8=-1.E-8+AANG                                                 M17   41
     10 PIM=PIM+3.1415927                                               M17   42
        I8I=I8I+1                                                       M17   43
     11 AANG=ARI+ARI+ANG+ANG                                            M17   44
        P=D/SQRT(AANG)                                                  M17   45
        IF(I8I-4)13,12,12                                               M17   46
     12 I8I=I8I-4                                                       M17   47
     13 IF(I8I-2)15,14,14                                               M17   48
     14 P=-P                                                            M17   49
     15 C=C+P                                                           M17   50
        D=D+(AARI-GEO)+0.5/ARI                                          M17   51
        IF(ABS(AARI-GEO)-1.E-4+AARI)17,17,16                            M17   52
     16 SGEO=SQRT(SGEO)                                                 M17   53
C           GEOMETRIC MEAN                                              M17   54
        GEO=SGEO+SGEO                                                   M17   55
        PIM=PIM+PIMA                                                    M17   56
        I8I=I8I+I8I                                                     M17   57
        GOTO 8                                                          M17   58
C           ACCURACY WAS SUFFICIENT                                     M17   59
     17 R=(ATAN(ARI/ANG)+PIM)+AN/ARI                                    M17   60
        C=C+D+ANG/AANG                                                  M17   61
        GOTO 4                                                          M17   62
        END                                                             M17   63
```

```
      SUBROUTINE LNTRP(ABSC,ORD,N,X,Y)                                  M18    2
C                                                                       M18    3
C     THIS SUBROUTINE CALCULATES Y AS A FUNCTION OF X BY LINEARLY       M18    4
C     INTERPOLATING BETWEEN GIVE POINTS.  ABSC IS AN ARRAY              M18    5
C     REPRESENTING VALUES ALONG THE X-AXIS AND ORD IS AN ARRAY          M18    6
C     REPRESENTING THE CORRESPONDING VALUES ALONG THE Y-AXIS.  X IS     M18    7
C     THE PARTICULAR VALUE OF THE INDEPENDENT VARIABLE FOR WHICH THE    M18    8
C     VALUE OF THE FUNCTION,REPRESENTED BY Y,IS DESIRED. N IS THE       M18    9
C     NUMBER OF POINTS FOR WHICH DATA IS GIVEN.                         M18   10
C                                                                       M18   11
      DIMENSION ABSC(20),ORD(20)                                        M18   12
C                                                                       M18   13
C     DETERMINE BETWEEN WHICH TWO DATA POINTS THE PARTICULAR VALUE      M18   14
C     OF X,THE INDEPENDENT VARIABLE,LIES.                               M18   15
C                                                                       M18   16
      DO 10 J=2,N                                                       M18   17
      I=J                                                               M18   18
      IF (X .LT. ABSC(I)) GO TO 20                                      M18   19
   10 CONTINUE                                                          M18   20
      IF (X .GT. ABSC(N)) WRITE(6,50)                                   M18   21
C                                                                       M18   22
C     COMPUTE THE CORRESPONDING VALUE OF Y BY LINEARLY INTERPOLATING    M18   23
C     BETWEEN GIVEN DATA POINTS.                                        M18   24
C                                                                       M18   25
   20 Y=ORD(I)+(ORD(I)-ORD(I-1))+(ABSC(I)-X)/(ABSC(I)-ABSC(I-1))        M18   26
      RETURN                                                            M18   27
   50 FORMAT(1H0,79HVALUE EXCEEDS RANGE OF AVAILABLE DATA,RESULT EXTRAPOM18   28
     2LATED FROM LAST DATA POINT.)                                      M18   29
      END                                                               M18   30
```

```
      BLOCK DATA CURVES                                                 M19    2
C                                                                       M19    3
C     THIS SUBPROGRAM LISTS THE DATA FROM VARIOUS CURVES AND TABLES     M19    4
C     USED IN DETERMINING THE LOADS ON CRUCIFORM MISSILES.              M19    5
C                                                                       M19    6
C     THE FOLLOWING ARE THE ITEMS IN THIS SUBPROGRAM.                   M19    7
C                                                                       M19    8
C     XP          A/SM VALUES USED TO DETERMINE SLENDER BODY THEORY     M19    9
C                 VALUES OF THE INTERFERENCE FACTORS.                   M19   10
C     RKAB        SLENDER BODY THEORY VALUES OF K ALPHA BETA            M19   11
C     SBTKDP      SLENDER BODY THEORY VALUES OF K ALPHA DELTA FOR       M19   12
C                 DEFLECTED PANELS.                                     M19   13
C     SBTKUP      SLENDER BODY THEORY VALUES OF K ALPHA DELTA FOR       M19   14
C                 UNDEFLECTED PANELS.                                   M19   15
C     GSUB        NON-DIMENSIONAL VORTEX STRENGTH FOR SUBSONIC FLOW.    M19   16
C     GSUP        NON-DIMENSIONAL VORTEX STRENGTH FOR SUPERSONIC FLOW.  M19   17
C     XYV         (XSUBC-XSUBS)/SIN(ALFAC)                              M19   18
C     YSUB        YV/R FOR SUBSONIC FLOW.                               M19   19
C     YSUP        YV/R FOR SUPERSONIC FLOW.                             M19   20
C     ZFCN        ZV/R.                                                 M19   21
C     MC          CROSS FLOW MACH NUMBERS AT WHICH DRAG COEFFICIENTS     M19   22
C                 ARE SPECIFIED.                                        M19   23
C     TUSUB       CROSS FLOW DRAG COEFFICIENTS FOR TURBULENT SUBSONIC   M19   24
C                 FLOW.                                                 M19   25
C     TUSUP       CROSS FLOW DRAG COEFFICIENTS FOR TURBULENT SUPERSONICM19   26
C                 FLOW.                                                 M19   27
C     LAMFN       CROSS FLOW DRAG COEFFICIENTS FOR LAMINAR FLOW.        M19   28
C                                                                       M19   29
      COMMON/CSBTKS/XP(11),RKAB(11),SBTKDP(11),SBTKUP(11)               M19   30
      COMMON/NOSDTA/G(11,2),XYV(11),Y(11,2),ZFCN(11),MC(22),DRAG(22,3)  M19   31
      COMMON/CCNC/NCNC,ALFCNC(20),CNWC(20)                              M19   32
      COMMON/CCPC/NCPXC,NCPYC,ACPXC(20),ACPYC(20),CPXC(20),CPYC(20)     M19   33
      COMMON/CCNT/NCNT,ALFCNT(20),CNWT(20)                              M19   34
      COMMON/CCPT/NCPXT,NCPYT,ACPXT(20),ACPYT(20),CPXT(20),CPYT(20)     M19   35
      COMMON/CDP/DXI,NXOUTC,NXOUTB,NXOUTT,RD,NI,OMEGA,EPS,RVOA,NEARC,   M19   36
     2NEART,NFIN,RVORT2,NVORT                                           M19   37
      REAL MC                                                           M19   38
      DATA XP/0.,0.,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0/            M19   39
      DATA RKAB/0.382,0.447,0.490,0.508,0.502,0.471,0.417,0.342,0.248,  M19   40
     20.127,0.0/                                                        M19   41
      DATA SBTKDP/0.500,0.477,0.457,0.426,0.385,0.332,0.273,0.206,0.137,M19   42
     20.068,0.0/                                                        M19   43
      DATA SBTKUP/0.250,0.201,0.153,0.112,0.079,0.052,0.031,0.017,0.007,M19   44
     20.002,0.0/                                                        M19   45
      DATA G/.313,.313,.330,.395,.489,.614,.764,.884,.990,1.065,1.097,  M19   46
     2   .576,.595,.666,.764,.896,1.059,1.228,1.372,1.491,1.567,1.592/  M19   47
      DATA XYV/0.,0.,1.,0.,2.,0.,3.,0.,4.,0.,5.,0.,6.,0.,7.,0.,8.,0.,9.,0.,10.,0./ M19   48
      DATA Y/.406,.427,.448,.469,.489,.508,.526,.545,.561,.578,.594,    M19   49
     2   .597,.611,.629,.652,.669,.685,.700,.713,.724,.732,.736/        M19   50
      DATA ZFCN/1.016,1.155,1.300,1.446,1.580,1.712,1.840,1.955,2.058,  M19   51
     2   2.136,2.203/                                                   M19   52
      DATA MC/0.00,0.10,0.20,0.30,0.40,0.50,0.60,0.70,0.80,0.90,1.00,   M19   53
     2   1.10,1.20,1.30,1.40,1.60,1.80,2.00,2.40,2.80,3.20,8.00/        M19   54
      DATA DRAG/1.20,1.20,1.20,1.21,1.263,1.374,1.503,1.647,1.80,1.95,  M19   55
     2   2.03,1.80,1.65,1.57,1.52,1.47,1.43,1.40,1.37,1.33,1.30,1.30,  M19   56
     3   .290,.335,.425,.553,.732,1.073,1.503,1.648,1.80,1.95,2.03,1.80,M19   57
     4   1.65,1.57,1.52,1.47,1.43,1.40,1.37,1.33,1.30,1.30,.290,.338,  M19   58
     5   .447,.682,.966,1.257,1.503,1.648,1.80,1.95,2.03,1.80,1.65,1.57,M19   59
     6   1.52,1.47,1.43,1.40,1.37,1.33,1.30,1.30/                       M19   60
      DATA ALFCNC/20+0.0/                                               M19   61
      DATA CNWC/20+0.0/                                                 M19   62
      DATA ACPXC/20+0.0/                                                M19   63
      DATA CPXC/20+0.0/                                                 M19   64
      DATA ACPYC/20+0.0/                                                M19   65
      DATA CPYC/20+0.0/                                                 M19   66
      DATA ALFCNT/20+0.0/                                               M19   67
      DATA CNWT/20+0.0/                                                 M19   68
      DATA ACPXT/20+0.0/                                                M19   69
      DATA CPXT/20+0.0/                                                 M19   70
```

```
      DATA ACPYT/20*0.0/                                                M19   71
      DATA CPYT/20*0.0/                                                 M19   72
      DATA DXI,NXOUTC,NXOUTB,NXOUTT,RO,NI,OMEGA,EPS,RVOA,NEARC,NEART,   M19   73
     2   NFIN,RVORT2/0.,0,0,0,0,0.,0,0.,0.,0.,.FALSE.,.FALSE.,0.0,/     M19   74
      END                                                               M19   75
      SUBROUTINE AFTBOD(ALPHAC,PHEE)                                    M20    2
C                                                                       M20    3
C   PROGRAM TO CHASE CANARD AND BODY VORTICES FROM TRAILING EDGE OF     M20    4
C    CANARDS TO LEADING EDGE OF TAIL.  AFTEBODY IS ASSUMED TO BE        M20    5
C    CYLINDRICAL WITH CONSTANT RADIUS.  BOUND VORTEX STRENGTHS ARE      M20    6
C    COMPUTED USING VORTEX IMPULSE THEOREM AND CROSSFLOW DRAG           M20    7
C    COEFFICIENTS AS DESCRIBED IN NEAR TR 79.                           M20    8
C                                                                       M20    9
      COMMON/CBODY/A,ARC,ART,SPANC,SPANT,XCHL,XCLE,XCTIPL,XCTE,         M20   10
     2   XTLE,XTIPL,XTTE,SROUT,LROUT,SRCAN,SRTAIL,CPYRC,CPXRC,          M20   11
     3   TIPRAD,ETAN,XNOSE(20),RNOSE(20),PHIT,XFC,XFT,CPXRT,CPYRT,EPSN  M20   12
     4   ,NNOSE,XMC                                                     M20   13
      COMMON/CFLT/ALFAC(10),PHI(10),DELTA(4),FMACH,TURB,NALFA,NPHI,DCNDAM20   14
      COMMON/COP/DXI,NXOUTC,NXOUTB,NXOUTT,RO,NI,OMEGA,EPS,RVOA,NEARC,   M20   15
     2NEART,NFIN,RVORT2,NVORT                                           M20   16
      COMMON/CVRTX/NV,GAM(10),YO(10),ZO(10)                             M20   17
      COMMON/CAPT/CDC,C1,AFTVOR                                         M20   18
      COMMON/NOSDTA/G(11,2),XYV(11),YV(11,2),ZPCN(11),MC(22),DRAG(22,3) M20   19
      COMMON/CLDS/DUM1(20),CYR,CZR,CMYR,CMZR,CYO,CZO,CMYO,CMZO,DUM2(12) M20   20
     2,CLN,CDN,CLA,CDA                                                  M20   21
      REAL MC,LROUT,MSINA                                               M20   22
      DIMENSION Y(22),WORK(88),GAMF(10)                                 M20   23
      EXTERNAL DERIV                                                    M20   24
      LOGICAL TURB,NEARC,NEART,AFTVOR                                   M20   25
      COMPLEX S,TEMP,C1COMP,CFOLD,CFNEW,CFSUM,CMSUM,DCFSUM              M20   26
      DATA FORPI/12.5663706/                                            M20   27
C                                                                       M20   28
C                                                                       M20   29
 1000 FORMAT(1H0,9X,3HX/A,4X,1HI,7X,8HGAMMA(I),8X,7HYO(I)/A,            M20   30
     18X,7HZO(I)/A,9X,6HFLOANG,10X,5HTHETA,3X,12HNORMAL FORCE,5X,10HSIDE M20   31
     1 FORCE)                                                           M20   32
 1001 FORMAT(//,1H ,E12.4,I5,3E15.4,2F15.2,2F15.4)                      M20   33
 1002 FORMAT(13X,I5,3E15.3)                                             M20   34
 1003 FORMAT(63H0INITIAL STEP SIZE WAS REDUCED BY A FACTOR OF 100 AND COM20   35
     1NVERGENCE WAS NOT OBTAINED.)                                      M20   36
 1004 FORMAT(//,44H *** AFTERBODY VORTICES HAVE FORMED AT X/A =,F5.2,//,M20   37
     137H   THE LEFT VORTEX POSITION IS Y0/A =,F5.3,12H  AND Z0/A =,   M20   38
     2F5.3,//38H   THE RIGHT VORTEX POSITION IS Y0/A =,F5.3,12H  AND Z0/M20   39
     3A =,F5.3)                                                         M20   40
 1005 FORMAT(1H0,6HVORTEX,I2,11H AND VORTEX,I2,20H HAVE BEEN COMBINED,//M20   41
     2)                                                                 M20   42
 1006 FORMAT(//,10X,84H*** CONTRIBUTION OF AFTERBODY SECTION TO TOTAL LOM20   43
     1ADS IN UNROLLED BODY COORDINATES **,//,40X,5HCYO =,F7.3,19X,6HCMYOM20   44
     2 =,F8.3,//,40X,5HCZO =,F7.3,19X,6HCMZO =,F8.3)                    M20   45
 1007 FORMAT(1H0,39X,4HCL =,F7.3,//,40X,4HCD =,F7.3)                    M20   46
 1008 FORMAT(1H1,72H**********************************   AFTERBODY SECTION M20   47
     2RESULTS FOR ALPHA = ,F6.3,11H AND PHI = ,F6.3,34H   **************M20   48
     3**********)                                                       M20   49
 1009 FORMAT(1H0,39X,52H*****  VORTEX TRACKING RESULTS OVER AFTERBODY  *M20   50
     2****)                                                             M20   51
C                                                                       M20   52
C                                                                       M20   53
      WRITE(6,1008) ALPHAC,PHEE                                         M20   54
      WRITE(6,1000)                                                     M20   55
      WRITE(6,1000)                                                     M20   56
      ALPHA=ALPHAC/57.29578                                             M20   57
      C1=SIN(ALPHA)                                                     M20   58
      DXOUT=(XTLE-XCTE)/FLOAT(NXOUTB)                                   M20   59
      C1COMP=CMPLX(C1,0.)                                               M20   60
      XOUT=XCTE                                                         M20   61
      FPIB=FORPI/SROUT                                                  M20   62
      CFNEW=CMPLX(0.,0.)                                                M20   63
      CFSUM=CFNEW                                                       M20   64
      CMSUM=CFNEW                                                       M20   65
C                                                                       M20   66
C        DETERMINE CROSSFLOW DRAG COEFFICIENT FOR LATER USE IN FORCE    M20   67
C        CALCULATIONS FROM FIG.6 OF NEAR TR 85.                         M20   68
C                                                                       M20   69
      MSINA=FMACH*C1                                                    M20   70
      JD=3                                                              M20   71
      IF (FMACH .LT. 1.) JD=2                                           M20   72
      IF (.NOT. TURB) JD=1                                              M20   73
      CALL LNTRP(MC,DRAG(1,JD),22,MSINA,CDC)                            M20   74
C                                                                       M20   75
C   CALCULATE INITIAL CONDITIONS AND PRINT OUT VALUES AT TRAILING EDGE  M20   76
C    OF CANARD  FINS.                                                   M20   77
C                                                                       M20   78
      NCOMBV=0                                                          M20   79
      DO 11 I=1,10                                                      M20   80
   11 GAMF(I)=0.0                                                       M20   81
      TEMP=C1COMP                                                       M20   82
      DO 10 I=1,NV                                                      M20   83
      S=CMPLX(YO(I),ZO(I))                                              M20   84
      TEMP=TEMP-GAM(I)/S                                                M20   85
      Y(2*I-1)=YO(I)                                                    M20   86
      Y(2*I)=ZO(I)                                                      M20   87
      CFNEW=CFNEW+GAM(I)*(S-1./CONJG(S))                                M20   88
   10 CONTINUE                                                          M20   89
      UPWASH=REAL(TEMP)                                                 M20   90
      SIWASH=AIMAG(TEMP)                                                M20   91
      THETA=ATAN2(UPWASH,SIWASH)*57.29578                               M20   92
      FLOANG=57.29578*ABS(ASIN(SQRT(UPWASH*UPWASH+SIWASH*SIWASH)))      M20   93
      I=1                                                               M20   94
      WRITE(6,1001)XCTE,I,GAM(1),YO(1),ZO(1),FLOANG,THETA               M20   95
      DO 12 I=2,NV                                                      M20   96
      WRITE(6,1002)I,GAM(I),YO(I),ZO(I)                                 M20   97
   12 CONTINUE                                                          M20   98
C                                                                       M20   99
C   CHECK TO SEE IF AFTERBODY VORTICES BEGIN AT CANARD TRAILING EDGE.   M20  100
C                                                                       M20  101
      IF(THETA.LT.(90.-OMEGA).OR.THETA.GT.(90.+OMEGA).OR.(FLOANG.LT.4.))M20  102
     1GO TO 20                                                          M20  103
C                                                                       M20  104
      IF(AFTVOR)GO TO 200                                               M20  105
C                                                                       M20  106
C   AFTERBODY VORTICES DO NOT BEGIN AT CANARD TRAILING EDGE.  AXIAL     M20  107
C    STARTING POSITION WILL BE ESTIMATED FROM FLOANG VALUES USING EQUA- M20  108
C    TION (2) IN NMC TP 5761 ONCE THETA VALUE IS WITHIN OMEGA DEGREES   M20  109
C    OF 90 DEGREES.                                                     M20  110
C                                                                       M20  111
   20 AFTVOR=.FALSE.                                                    M20  112
      NINCR=0                                                           M20  113
      XBEG=XCTE                                                         M20  114
      NDIM=2*NV                                                         M20  115
C                                                                       M20  116
C BEGINNING OF INTEGRATION (TRACKING) LOOP.                             M20  117
C                                                                       M20  118
   22 CONTINUE                                                          M20  119
      CFOLD=CFNEW                                                       M20  120
      XOUT=XBEG+DXOUT                                                   M20  121
      IF(XOUT.GE.XTLE)XOUT=XTLE                                         M20  122
      DX=DXI                                                            M20  123
      CALL DASCRU(DERIV,XBEG,XOUT,DX,NDIM,Y,WORK,IER,EPS)               M20  124
      IF(IER.EQ.33)GO TO 999                                            M20  125
      CFNEW=CMPLX(0.,0.)                                                M20  126
      TEMP=C1COMP                                                       M20  127
      IEND=NV                                                           M20  128
      IF(.NOT.AFTVOR)GO TO 25                                           M20  129
      IEND=IEND-2                                                       M20  130
      GAM(NV-1)=Y(NDIM-1)                                               M20  131
      GAM(NV)=Y(NDIM)                                                   M20  132
      S=CMPLX(Y(2*NV-3),Y(2*NV-2))                                      M20  133
      CFNEW=CFNEW+GAM(NV-1)*(S-1./CONJG(S))                             M20  134
      IF(NCOMBV.EQ.1) TEMP=TEMP-GAMF(IEND+1)/S                          M20  135
      S=CMPLX(Y(2*NV-1),Y(2*NV))                                        M20  136
      CFNEW=CFNEW+GAM(NV)*(S-1./CONJG(S))                               M20  137
      IF(NCOMBV.EQ.1) TEMP=TEMP-GAMF(IEND+2)/S                          M20  138
C                                                                       M20  139
   25 DO 30 I=1,IEND                                                    M20  140
      S=CMPLX(Y(2*I-1),Y(2*I))                                          M20  141
      CFNEW=CFNEW+GAM(I)*(S-1./CONJG(S))                                M20  142
   30 TEMP=TEMP-GAM(I)/S                                                M20  143
C                                                                       M20  144
      DCFSUM=FPIB*(CFNEW-CFOLD)                                         M20  145
      CFSUM=CFSUM+DCFSUM                                                M20  146
      CMSUM=CMSUM+DCFSUM*(XMC-XBEG-.5*DXOUT)/LROUT                      M20  147
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```
      CZO=REAL(DCFSUM)                                                  M20  148
      CYO=-AIMAG(DCFSUM)                                                M20  149
      UPWASH=REAL(TEMP)                                                 M20  150
      SIWASH=AIMAG(TEMP)                                                M20  151
      THETA=ATAN2(UPWASH,SIWASH)*57.29578                               M20  152
      FLOANG=57.29578*ABS(ASIN(SQRT(UPWASH*UPWASH*SIWASH*SIWASH)))      M20  153
      I=1                                                               M20  154
      WRITE(6,1001)XOUT,I,GAM(1),Y(1),Y(2),FLOANG,THETA,CZO,CYO         M20  155
      DO 32 I=2,NV                                                      M20  156
   32 WRITE(6,1002)I,GAM(I),Y(2*I-1),Y(2*I)                             M20  157
C                                                                       M20  158
C DETERMINE IF ANY VORTICES SHOULD BE COMBINED.                         M20  159
C                                                                       M20  160
   34 NV1= NV-1                                                         M20  161
      DO 2012 I=1,NV1                                                   M20  162
      JSTART=I+1                                                        M20  163
      DO 2012 J=JSTART,NV                                               M20  164
      DELY=Y(2*J-1)-Y(2*I-1)                                            M20  165
      DELZ=Y(2*J)-Y(2*I)                                                M20  166
      RR=DELY*DELY+DELZ*DELZ                                            M20  167
      IF(RR.LE.RVORT2.AND.GAM(I)/GAM(J).GE.0.)GO TO 2011                M20  168
 2012 CONTINUE                                                          M20  169
      GO TO 33                                                          M20  170
 2011 WRITE(6,1005)I,J                                                  M20  171
      RATIO=ABS(GAM(J))/(ABS(GAM(I))+ABS(GAM(J)))                       M20  172
      Y(2*J-1)=Y(2*I-1)+DELY*RATIO                                      M20  173
      Y(2*J)=Y(2*I)+DELZ*RATIO                                          M20  174
      GAM(J)=GAM(I)+GAM(J)                                              M20  175
      IF(.NOT.APTVOR.OR.J.LE.IEND) GO TO 2013                           M20  176
      GAMP(J)=GAM(I)                                                    M20  177
      NCOMBV=1                                                          M20  178
C                                                                       M20  179
C SCALE DOWN ARRAY SIZE TO ELIMINATE INGESTED VORTEX                    M20  180
C                                                                       M20  181
 2013 NV=NV-1                                                           M20  182
      IEND=NV                                                           M20  183
      TEMP=C1COMP                                                       M20  184
      CFNEW=CMPLX(0.,0.)                                                M20  185
      NDIM=NDIM-2                                                       M20  186
      DO 2020 II=I,NV                                                   M20  187
      Y(2*II-1)=Y(2*II+1)                                               M20  188
      Y(2*II)=Y(2*II+2)                                                 M20  189
      IF(APTVOR.AND.NCOMBV.EQ.1) GAMP(II)=GAMP(II+1)                    M20  190
 2020 GAM(II)=GAM(II+1)                                                 M20  191
      IF(.NOT.APTVOR) GO TO 3029                                        M20  192
      Y(NDIM-1)=GAM(NV-1)                                               M20  193
      Y(NDIM)=GAM(NV)                                                   M20  194
      IEND=NV-2                                                         M20  195
      GCMPLX(Y(2*NV-3),Y(2*NV-2))                                       M20  196
      CFNEW=CFNEW + GAM(NV-1)*(G-1./CONJG(G))                           M20  197
      IF(NCOMBV.EQ.1) TEMP=TEMP-GAMP(IEND+1)/G                          M20  198
      GCMPLX(Y(2*NV-1),Y(2*NV))                                         M20  199
      CFNEW=CFNEW + GAM(NV)  *(G-1./CONJG(G))                           M20  200
      IF(NCOMBV.EQ.1) TEMP=TEMP-GAMP(IEND+2)/G                          M20  201
 3029 DO 3030 I=1,IEND                                                  M20  202
      GCMPLX(Y(2*I-1),Y(2*I))                                           M20  203
      CFNEW=CFNEW + GAM(I)*(G-1./CONJG(G))                              M20  204
 3030 TEMP=TEMP-GAM(I)/G                                                M20  205
C                                                                       M20  206
      UPWASH=REAL(TEMP)                                                 M20  207
      SIWASH=AIMAG(TEMP)                                                M20  208
      THETA=ATAN2(UPWASH,SIWASH)*57.29578                               M20  209
      FLOANG=57.29578*ABS(ASIN(SQRT(UPWASH*UPWASH*SIWASH*SIWASH)))      M20  210
      I=1                                                               M20  211
      WRITE(6,1001)XOUT,I,GAM(1),Y(1),Y(2),FLOANG,THETA,CZO,CYO         M20  212
      DO 3032 I=2,NV                                                    M20  213
 3032 WRITE(6,1002)I,GAM(I),Y(2*I-1),Y(2*I)                             M20  214
      GO TO 34                                                          M20  215
C                                                                       M20  216
   33 CONTINUE                                                          M20  217
C                                                                       M20  218
      XBEG=XOUT                                                         M20  219
      IF ((XBEG + 1.E-6) .LT. XTLE) GO TO 40                            M20  220
C                                                                       M20  221
C   TRACKING IS COMPLETE, END OF INTEGRATION LOOP.                      M20  222
C                                                                       M20  223
      DO 35 I=1,NV                                                      M20  224
      Y0(I)=Y(2*I-1)                                                    M20  225
   35 Z0(I)=Y(2*I)                                                      M20  226
C                                                                       M20  227
C        ASSIGN AFTERBODY LOADS TO VALUES IN ROLLED(R) AND UNROLLED(UR) M20  228
C        COORDINATES.                                                   M20  229
C                                                                       M20  230
C        UNROLLED COORDINATES                                           M20  231
C                                                                       M20  232
      CZO=REAL(CFSUM)                                                   M20  233
      CYO=-AIMAG(CFSUM)                                                 M20  234
      CMYO=REAL(CMSUM)                                                  M20  235
      CMZO=-AIMAG(CMSUM)                                                M20  236
      CLA=CZO*COS(ALPHA)                                                M20  237
      CDA=CZO*SIN(ALPHA)                                                M20  238
      WRITE(6,1006) CYO,CMYO,CZO,CMZO                                   M20  239
      WRITE(6,1007) CLA,CDA                                             M20  240
C                                                                       M20  241
C        ROLLED COORDINATES                                             M20  242
C                                                                       M20  243
      PHIR=PHEE/57.29578                                                M20  244
      CYR=CYO*COS(PHIR)+CZO*SIN(PHIR)                                   M20  245
      CZR=CYO*SIN(PHIR)+CZO*COS(PHIR)                                   M20  246
      CMYR=CMYO*COS(PHIR)+CMZO*SIN(PHIR)                                M20  247
      CMZR=CMYO*SIN(PHIR)-CMZO*COS(PHIR)                                M20  248
      RETURN                                                            M20  249
C                                                                       M20  250
C   TRACKING IS NOT COMPLETE                                            M20  251
C                                                                       M20  252
   40 IF(APTVOR)GO TO 22                                                M20  253
C                                                                       M20  254
C CHECK TO SEE IF AFTERBODY VORTICES SHOULD BE STARTED                  M20  255
C                                                                       M20  256
      IF(NINCR.LE.0)GO TO 200                                           M20  257
      FLOSUM=FLOAT(NINCR)*FLOAVE+FLOANG                                 M20  258
      NINCR=NINCR+1                                                     M20  259
      FLOAVE=FLOSUM/FLOAT(NINCR)                                        M20  260
      IF(FLOAVE.LE.0.)GO TO 22                                          M20  261
      XSTART=.010/(FLOAVE+.)                                            M20  262
      IF (XSTART .GT. (DXOUT*FLOAT(NINCR))) GO TO 22                    M20  263
      APTVOR=.TRUE.                                                     M20  264
      GO TO 202                                                         M20  265
C                                                                       M20  266
C   CHECK TO SEE IF THETA IS WITHIN RANGE AND FLOANG IS AT LEAST FOUR   M20  267
C    DEGREES.  IF SO, THEN BEGIN CALCULATION OF STARTING LENGTH OF      M20  268
C    AFTERBODY VORTICES.                                                M20  269
C                                                                       M20  270
  100 IF (THETA .LT. (90.-OMEGA) .OR. THETA .GT. (OMEGA+90.) .OR.       M20  271
     2   FLOANG .LT. 4.) GO TO 22                                       M20  272
      NINCR=1                                                           M20  273
      FLOAVE=FLOANG                                                     M20  274
      GO TO 22                                                          M20  275
C                                                                       M20  276
  200 XBEG=XCTE                                                         M20  277
  202 NV=NV+2                                                           M20  278
      NDIM=2*NV+2                                                       M20  279
C                                                                       M20  280
C   INITIALIZATION OF AFTERBODY VORTEX STRENGTHS.                       M20  281
C                                                                       M20  282
      Y(NDIM-1)=0.                                                      M20  283
      Y(NDIM)=0.                                                        M20  284
C                                                                       M20  285
C   CALCULATE INITIAL POSITIONS OF AFTERBODY VORTICES.  THEY WILL BE    M20  286
C    PLACED 90 DEGREES ON EITHER SIDE OF THETA AT RVOA FROM BODY        M20  287
C    CENTERLINE.                                                        M20  288
C                                                                       M20  289
      ANG=(THETA+90.)/57.29578                                          M20  290
      Y(2*NV-3)=RVOA*COS(ANG)                                           M20  291
      Y(2*NV-2)=RVOA*SIN(ANG)                                           M20  292
      ANG=(THETA-90.)/57.29578                                          M20  293
      Y(2*NV-1)=RVOA*COS(ANG)                                           M20  294
      Y(2*NV)=RVOA*SIN(ANG)                                             M20  295
      WRITE(6,1004)XOUT,Y(2*NV-3),Y(2*NV-2),Y(2*NV-1),Y(2*NV)           M20  296
      GO TO 22                                                          M20  297
C                                                                       M20  298
  999 WRITE(6,1003)                                                     M20  299
      RETURN                                                            M20  300
      END                                                               M20  301
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      SUBROUTINE DERIV(V,X,NDIM,DERV)                                   M21   2
C                                                                       M21   3
C     PROGRAM CALCULATES THE DERIVATIVES NEEDED FOR THE DIFFERENTIAL EQUA-M21   4
C     TION SOLVER DASCRU.  THE Y0(J) AND Z0(J) POSITIONS ARE STORED IN  M21   5
C     Y(2*J-1) AND Y(2*J) RESPECTIVELY.  THE STRENGTHS OF THE AFTERBODY M21   6
C     VORTICES (IF PRESENT) ARE STORED IN THE Y(NDIM-1) AND Y(NDIM)     M21   7
C     LOCATIONS.  IF AFTERBODY VORTICES ARE PRESENT, NDIM=2*NV+2.  OTHER-M21   8
C     WISE, NDIM=2*NV.                                                  M21   9
C                                                                       M21  10
      COMMON/CVRTX/NV,GAM(10),Y0(10),Z0(10)                             M21  11
      COMMON/CAPT/CDC,C1,AFTVOR                                         M21  12
      LOGICAL AFTVOR                                                    M21  13
      COMPLEX B(10),TEMP,BJ,BCONJ(10),BJD                               M21  14
      DIMENSION Y(22),DERY(22)                                          M21  15
      DATA TWOPI/.1591549/                                              M21  16
C                                                                       M21  17
      NV=(NDIM-2)/2                                                     M21  18
      IF(.NOT.AFTVOR)GO TO 10                                           M21  19
      GAM(NV-1)=Y(NDIM-1)                                               M21  20
      GAM(NV)=Y(NDIM)                                                   M21  21
      GO TO 12                                                          M21  22
   10 NV=NV+1                                                           M21  23
   12 CONTINUE                                                          M21  24
C                                                                       M21  25
      DO 20 I=1,NV                                                      M21  26
      B(I)=CMPLX(Y(2*I-1),Y(2*I))                                       M21  27
   20 BCONJ(I)=1./CONJG(B(I))                                           M21  28
C                                                                       M21  29
C     CALCULATION OF VORTEX VELOCITIES.                                 M21  30
C                                                                       M21  31
      DO 30 J=1,NV                                                      M21  32
      BJ=B(J)                                                           M21  33
      BJD=1./BJ                                                         M21  34
      TEMP=C1*(1.+BJD*BJD)+GAM(J)*(-1./(BJ-BCONJ(J)))                   M21  35
      NJ2=2*J                                                           M21  36
C                                                                       M21  37
      DO 25 K=1,NV                                                      M21  38
      IF(K.EQ.J)GO TO 25                                                M21  39
      TEMP=TEMP+GAM(K)*(1./(BJ-B(K))-1./(BJ-BCONJ(K)))                  M21  40
   25 CONTINUE                                                          M21  41
C                                                                       M21  42
      DERY(NJ2-1)=AIMAG(TEMP)                                           M21  43
   30 DERY(NJ2)=REAL(TEMP)                                              M21  44
C                                                                       M21  45
      IF(.NOT.AFTVOR)RETURN                                             M21  46
C                                                                       M21  47
C     CALCULATION OF RATE OF CHANGE OF STRENGTH OF AFTERBODY VORTICES BY M21  48
C     THE METHOD OF NWC TP 5761.                                        M21  49
C                                                                       M21  50
      N=NV-2                                                            M21  51
      TEMP=CMPLX(C1,0.)                                                 M21  52
      DO 40 I=1,N                                                       M21  53
      TEMP=TEMP-GAM(I)/B(I)                                             M21  54
   40 CONTINUE                                                          M21  55
C                                                                       M21  56
      UPWASH=REAL(TEMP)                                                 M21  57
      SIWASH=AIMAG(TEMP)                                                M21  58
      THETA=ATAN2(UPWASH,SIWASH)                                        M21  59
      SINTH=SIN(THETA)                                                  M21  60
      COSTH=COS(THETA)                                                  M21  61
      D=TWOPI*CDC*(UPWASH*UPWASH+SIWASH*SIWASH)                         M21  62
      TEMP=B(NV-1)                                                      M21  63
      Y1=REAL(TEMP)                                                     M21  64
      Z1=AIMAG(TEMP)                                                    M21  65
      TEMP=B(NV)                                                        M21  66
      Y2=REAL(TEMP)                                                     M21  67
      Z2=AIMAG(TEMP)                                                    M21  68
      R1SQ=Y1*Y1+Z1*Z1                                                  M21  69
      R2SQ=Y2*Y2+Z2*Z2                                                  M21  70
      DENOM=Y1*Z2-Y2*Z1                                                 M21  71
      D=D/DENOM                                                         M21  72
      DERY(NDIM-1)=D*(Z2*SINTH+Y2*COSTH)/(1.-1./R1SQ)                   M21  73
      DERY(NDIM)=D*(Y1*COSTH+Z1*SINTH)/(1.-1./R2SQ)                     M21  74
C                                                                       M21  75
      RETURN                                                            M21  76
      END                                                               M21  77
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      SUBROUTINE TAIL(ALFAC,PHI)                                        M22   2
C                                                                       M22   3
C        THIS PROGRAM DETERMINES THE LOADS ON THE TAIL SURFACES,        M22   4
C        INCLUDING LOADS INDUCED BY THE PRESENCE OF VORTICES.           M22   5
C                                                                       M22   6
      COMMON/CBODY/A,ARC,ART,SPANC,SPANT,XCNL,XCLE,XCTIPL,XCTE,         M22   7
     2   XTLE,XTTIPL,XTTE,BROUT,LROUT,BRCAN,BRTAIL,CPYRC,CPXRC,         M22   8
     3   TIPRAD,ETAN,RNOSE(20),RNOSE(20),PHIT,XPC,XFT,CPXRT,CPYRT,EPSN  M22   9
     4   ,NNOSE,XMC                                                     M22  10
      COMMON/CFLT/DUM(20),DELTA(4),FMACH,TURB,NALFA,NPHI,DENDA          M22  11
      COMMON/CCNT/NCNT,ALFCNT(20),CNNT(20)                              M22  12
      COMMON/CCPT/NCPXT,NCPYT,ACPXT(20),ACPYT(20),CPXT(20),CPYT(20)     M22  13
      COMMON/COP/DXI,NXOUTC,NXOUTB,NXOUTT,RO,NI,OMEGA,EPS,RVOA,NEARC,   M22  14
     2NEART,NFIN,RVORT2,NVORT                                           M22  15
      COMMON/CVRTX/NV,GAM(10),Y0(10),Z0(10)                             M22  16
      COMMON/CKFACS/KMC,LKM,KABC(4),KD(4),KMT,KABT(4),KBC,KBT,XBC,XBT   M22  17
      COMMON/CMSHP/XMLE,XMTIPL,XMTIPT,XMTE,BBM                          M22  18
      COMMON/CLDS/DUM1(28),CYT,CZT,CMXT ,CMYT,CMZT,CYTO,CZTO,CMXTO,     M22  19
     2CMYTO,CMZTO,CLT,CDTF,DUM2(4)                                      M22  20
      DIMENSION CNTO(4),AEQ(4),YCP(4),AEQT(4),CNTAIL(4),CPYEQ(4),CMMT(4)M22  21
      REAL LROUT,KMC,LKM,KABC,KD,KMT,KABT,KBC,KBT,KRATIO                M22  22
      LOGICAL TURB,NEARC,NEART                                          M22  23
      DIMENSION DUMY(4),YOF(10),ZOF(10)                                 M22  24
      DIMENSION ALFAE(4),XCPT(4),CBMT(4)                                M22  25
      DATA DUMY/4*0./                                                   M22  26
      WRITE(6,101) ALFAC,PHI                                            M22  27
      WRITE(6,102)                                                      M22  28
C                                                                       M22  29
C        THE FIRST STEP IS TO FIND THE EFFECTS OF PANEL-PANEL           M22  30
C        INTERFERENCE.  THIS INCLUDES DETERMINING THE EQUIVALENT ANGLE  M22  31
C        OF ATTACK,NORMAL FORCE COEFFICIENT,AND CENTER OF PRESSURE FOR  M22  32
C        EACH FIN.                                                      M22  33
C                                                                       M22  34
      PHE=PHI+PHIT                                                      M22  35
      CALL ALFAO(PHE,DUMY,ALFAC,ART,KMT,0.,KABT,DUMY,ALFAE)             M22  36
      DO 1000 I=1,4                                                     M22  37
      CALL LNTRP(ALFCNT,CNNT,NCNT,ABS(ALFAE(I)),CNTO(I))                M22  38
      CNTO(I)=SIGN(CNTO(I),ALFAE(I))*(0.5*BRTAIL/BROUT)                 M22  39
      CALL LNTRP(ACPXT,CPXT,NCPXT,ABS(ALFAE(I)),XCPT(I))                M22  40
      XCPT(I)=XCPT(I)*CPXRT/LROUT                                       M22  41
      CALL LNTRP(ACPYT,CPYT,NCPYT,ABS(ALFAE(I)),CPYEQ(I))               M22  42
      CPYEQ(I)=(CPYEQ(I)*CPYRT*I.)/LROUT                                M22  43
 1000 WRITE(6,103) (I,ALFAE(I),CNTO(I),XCPT(I),CPYEQ(I))               M22  44
C                                                                       M22  45
C        DETERMINE THE TRAJECTORIES OF THE FREE VORTICES OVER THE TAIL  M22  46
C        SURFACES.                                                      M22  47
C                                                                       M22  48
      XMLE=XTLE                                                         M22  49
      XMTIPL=XTTIPL                                                     M22  50
      XMTIPT=XTTE                                                       M22  51
      XMTE=XTTE                                                         M22  52
      BBM=BSPANT                                                        M22  53
C                                                                       M22  54
C        IF VORTICES ARE NEAR A FIN SET SPAN EQUAL TO BODY RADIUS.      M22  55
C                                                                       M22  56
      IF(NEART)BBM=1.                                                   M22  57
      CALL CRUTRJ(ALFAC,PHE,DXI,NXOUTT,XFT,YOF,ZOF,EPS)                 M22  58
C                                                                       M22  59
C        POSITIONS OF THE VORTICES IN THE CROSSFLOW PLANE OVER THE FIN  M22  60
C        AREA CENTROID IS NOW ESTABLISHED.                              M22  61
C                                                                       M22  62
C                                                                       M22  63
C        WE HAVE NOW DETERMINED EQUIVALENT ANGLES AND NORMAL FORCE      M22  64
C        COEFFICIENTS FOR THE CASE OF NO VORTICES. NOW WE CALL REVFLO   M22  65
C        TO FIND THE EFFECTS INDUCED BY THE VORTICES.                   M22  66
C                                                                       M22  67
      KRATIO=KMT/(KMT+KBT)                                              M22  68
      CALL REVFLO(NI,NV,BPANT,PHE,RO,AEQ,YCP,YOF,ZOF,KRATIO)            M22  69
      DO 1500 M=1,4                                                     M22  70
      YCP(M)=YCP(M)/LROUT                                               M22  71
 1500 CONTINUE                                                          M22  72
C                                                                       M22  73
C        ADD THE TWO EQUIVALENT ANGLES.                                 M22  74
C                                                                       M22  75
      DO 2000 J=1,4                                                     M22  76
 2000 AEQT(J)=ALFAE(J)+AEQ(J)                                           M22  77
C                                                                       M22  78
C        NOW FIND THE NORMAL FORCE DUE TO THE TOTAL EQUIVALENT ANGLE    M22  79
```

```
C
      DO 3000 K=1,4                                                          M22   80
      CALL LNTRP(ALFCNT,CNNT,NCNT,ABS(AEQT(K)),CNTAIL(K))                    M22   81
      CNTAIL(K)=SIGN(CNTAIL(K),AEQT(K))*(0.5*SRTAIL/SROUT)                   M22   82
 3000 CONTINUE                                                               M22   83
C                                                                            M22   84
C        WE ARE NOW IN A POSITION TO CALCULATE THE ROLLING MOMENTS.          M22   85
C                                                                            M22   86
      DO 5000 II=1,4                                                         M22   87
      CRMT(II)=(CNTO(II)*CPYEQ(II)*(CNTAIL(II)-CNTO(II))*YCP(II))            M22   88
 5000 CONTINUE                                                               M22   89
C                                                                            M22   90
C        TOTAL ROLLING MOMENT                                                M22   91
C                                                                            M22   92
      CMXT=CRMT(1)+CRMT(2)+CRMT(3)+CRMT(4)                                   M22   93
      CMXTO=CMXT                                                             M22   94
C                                                                            M22   95
C        CALCULATE THE LOADS DUE TO THE TAIL SECTION, THE TWO                M22   96
C        CONTRIBUTIONS TO THE TAIL LOADS ARE (1)INDIVIDUAL FIN LOADS         M22   97
C        AND (2)BODY LOADS DUE TO THE PRESENCE OF THE FINS.                  M22   98
C                                                                            M22   99
C        INDIVIDUAL FIN LOADS                                                M22  100
C                                                                            M22  101
      DO 5500 IK=1,4                                                         M22  102
 5500 CBMT(IK)=CRMT(IK)=CNTAIL(IK)/LROUT                                     M22  103
C                                                                            M22  104
C        SUMMATION OF FIN LOADS                                              M22  105
C                                                                            M22  106
      CE=XTLE/LROUT                                                          M22  107
      C3=XMC/LROUT                                                           M22  108
      CYTT=CNTAIL(1)+CNTAIL(3)                                               M22  109
      CZTT=CNTAIL(2)+CNTAIL(4)                                               M22  110
      CMYT=CNTAIL(2)*(C3-(XCPT(2)+C2))+CNTAIL(4)*(C3-(XCPT(4)+C2))           M22  111
      CMZT=CNTAIL(1)*(C3-(XCPT(1)+C2))+CNTAIL(3)*(C3-(XCPT(3)+C2))           M22  112
C                                                                            M22  113
C        BODY LOADS DUE TO THE PRESENCE OF THE FINS.                         M22  114
C                                                                            M22  115
      CYTB=CYTT*KBT/KNT                                                      M22  116
      CZTB=CZTT*KBT/KNT                                                      M22  117
C                                                                            M22  118
C        TOTAL LOADS IN TAIL SECTION.                                        M22  119
C                                                                            M22  120
      CYT=CYTT+CYTB                                                          M22  121
      CZT=CZTT+CZTB                                                          M22  122
      XBTT= XBT+CPXRT + XTLE                                                 M22  123
      C4= (XMC-XBTT)/LROUT                                                   M22  124
      CMYT=CMYT+CZTB*C4                                                      M22  125
      CMZT=CMZT-CYTB*C4                                                      M22  126
C                                                                            M22  127
C        LOADS IN UNROLLED BODY COORDINATES.                                 M22  128
C                                                                            M22  129
      ALFAR=ALFAC/57.295780                                                  M22  130
      PHI1=(PHI+PHIT)/57.295780                                              M22  131
      CXT=0.0                                                                M22  132
      CXTO=0.0                                                               M22  133
      CYTO=CYT*COS(PHI1)+CZT*SIN(PHI1)                                       M22  134
      CZTO=-CYT*SIN(PHI1)+CZT*COS(PHI1)                                      M22  135
      CMYTO=CMYT*COS(PHI1)+CMZT*SIN(PHI1)                                    M22  136
      CMZTO=-CMYT*SIN(PHI1)+CMZT*COS(PHI1)                                   M22  137
      CLT=CZTO*COS(ALFAR)                                                    M22  138
      CDTF=CZTO*SIN(ALFAR)                                                   M22  139
      WRITE(6,106)                                                           M22  140
      WRITE(6,105) (IJ,AEQT(IJ),CNTAIL(IJ),XCPT(IJ),CPYEQ(IJ),CRMT(IJ),     M22  141
     2   CBMT(IJ),IJ=1,4)                                                    M22  142
      WRITE(6,106)                                                           M22  143
      WRITE(6,112)                                                           M22  144
      WRITE(6,107) CXTO,CMXTO,CXT,CMXT                                       M22  145
      WRITE(6,108) CYTO,CMYTO,CYT,CMYT                                       M22  146
      WRITE(6,109) CZTO,CMZTO,CZT,CMZT                                       M22  147
      WRITE(6,110) CLT                                                       M22  148
      WRITE(6,111) CDTF                                                      M22  149
      RETURN                                                                 M22  150
  101 FORMAT(70H1**********************************   TAIL SECTION RESULTM22  151
     2S FOR ALPHA = ,F6.3,11H AND PHI = ,F6.3,37H   **********************M22  152
     3**************)                                                        M22  153
  102 FORMAT(1H0,29X,39HRESULTS DUE TO PANEL-PANEL INTERFERENCE,///,29X,5HM22  154
     2HPANEL,3X,7HALPHAEQ,8X,2HCN,10X,3HCPX,9X,3HCPY,/)                     M22  155
  103 FORMAT(23X,I5,4(5X,F7.4))                                              M22  156
  104 FORMAT(///,30X,55H***  TOTAL TAIL FIN LOADS INCLUDING VORTEX EFFECM22  157
     2TS  ***,/,20X,5HPANEL,5X,7HALPHAEQ,8X,2HCN,10X,3HCPX,9X,3HCPY,9X,3M22  158
     3HCRM,9X,3HCBM,/)                                                      M22  159
  105 FORMAT(16X,I5,5X,F7.4,5X,F7.4,5X,F7.4,5X,F7.4,5X,F7.4,5X,F7.4)         M22  160
  106 FORMAT(1H0,20X,55H***  CONTRIBUTION OF TAIL SECTION TO TOTAL LOADSM22  161
     2  ***)                                                                M22  162
  107 FORMAT(1H0,34X,6HCXO = ,F8.4,6X,7HCMXO = ,F8.4,16X,5HCX = ,F8.4,7XM22  163
     2,6HCMX = ,F8.4)                                                       M22  164
  108 FORMAT(1H0,34X,6HCYO = ,F8.4,6X,7HCMYO = ,F8.4,16X,5HCY = ,F8.4,7XM22  165
     2,6HCMY = ,F8.4)                                                       M22  166
  109 FORMAT(1H0,34X,6HCZO = ,F8.4,6X,7HCMZO = ,F8.4,16X,5HCZ = ,F8.4,7XM22  167
     2,6HCMZ = ,F8.4)                                                       M22  168
  110 FORMAT(1H0,35X,5HCL = ,F8.4)                                           M22  169
  111 FORMAT(1H0,35X,5HCD = ,F8.4)                                           M22  170
  112 FORMAT(1H0,41X,20HUNROLLED COORDINATES,30X,16HROLLED COORDINATES)      M22  171
      END                                                                    M22  172
```

```
      FUNCTION CHRTB (BAR,B,R,CT,CR,SWPLE)                                   M23   2
C                                                                            M23   3
C     CALCULATE BETA*D(CL)/D(ALPHA) FOR SUPERSONIC MACH NUMBERS, CHART BM23   4
C          OF REPORT 1307                                                    M23   5
C                                                                            M23   6
      DIMENSION BA(11),CL(3),CHB(11,4)                                       M23   7
      DATA RAD/57.295578/                                                    M23   8
      DATA BA/0.0,0.5,1.0,1.5,2.0,2.5,3.0,4.0,5.0,6.0,10.0/                  M23   9
      DATA CHB/                                                              M23  10
     1 0.0, 0.79, 1.45, 2.07, 2.59, 3.02, 3.41, 4.00, 4.00, 4.00, 4.00,  M23  11
     2 0.0, 0.86, 2.09, 2.73, 3.01, 3.55, 3.65, 3.76, 3.82, 3.86, 4.00,  M23  12
     3 0.0, 0.80, 1.81, 2.65, 3.12, 3.36, 3.52, 3.70, 3.79, 3.82, 4.00,  M23  13
     4 0.0, 0.86, 2.02, 2.67, 3.00, 3.20, 3.34, 3.51, 3.60, 3.65, 4.00/  M23  14
      IF (BAR.LE.10.0) GO TO 10                                              M23  15
      CHRTB=0.0                                                              M23  16
      RETURN                                                                 M23  17
   10 I=0                                                                    M23  18
   11 I=I+1                                                                  M23  19
      IF (BAR.GE.BA(I)) GO TO 11                                             M23  20
      IM=I-1                                                                 M23  21
      IP=I                                                                   M23  22
      DXBA=(BAR-BA(IM))/(BA(IP)-BA(IM))                                      M23  23
      TAPER=CT/CR                                                            M23  24
      IF (TAPER.LT.0.5) GO TO 20                                             M23  25
      DXBL=(TAPER-0.5)/0.5                                                   M23  26
      TA=CHB(IM,3)+DXBA*(CHB(IP,3)-CHB(IM,3))                                M23  27
      TB=CHB(IM,4)+DXBA*(CHB(IP,4)-CHB(IM,4))                                M23  28
      CHRTB=TA+DXBL*(TB-TA)                                                  M23  29
      RETURN                                                                 M23  30
   20 CTLE=(B-R)*TAN(SWPLE/RAD)                                              M23  31
      SWPMC=RAD*ATAN((CTLE+0.5*(CT-CR))/(B-R))                               M23  32
      SWPTE=RAD*ATAN((CTLE+CT-CR)/(B-R))                                     M23  33
      DXBL=TAPER/0.5                                                         M23  34
      IF (SWPMC.LE.0.0) GO TO 30                                             M23  35
      JM=2                                                                   M23  36
      JP=1                                                                   M23  37
      DXCL=SWPMC/(SWPMC-SWPTE)                                               M23  38
      GO TO 40                                                               M23  39
   30 JM=1                                                                   M23  40
      JP=2                                                                   M23  41
      DXCL=SWPLE/(SWPLE-SWPMC)                                               M23  42
   40 DO 50 K=1,3                                                            M23  43
   50 CL(K)=CHB(IM,K)+DXBA*(CHB(IP,K)-CHB(IM,K))                             M23  44
      TA=CL(JM)+DXCL*(CL(JP)-CL(JM))                                         M23  45
      TB=CL(3)                                                               M23  46
      CHRTB=TA+DXBL*(TB-TA)                                                  M23  47
      RETURN                                                                 M23  48
      END                                                                    M23  49
```

```
      FUNCTION EQ24(BM,TAPER,BDCR,ROB)                                  M24    2
C                                                                       M24    3
C     CALCULATE KB(N)*BCLAM OR KB(T)*BCLAT FROM EQ 24 FOR M GREATER THANM24    4
C          1.0, VALUE OF THE ASPECT RATIO PARAMETER GREATER THAN 4, AND M24    5
C          MB GREATER THAN 1                                            M24    6
C                                                                       M24    7
      IF (ROB.LE.0.0) GO TO 10                                          M24    8
      IF (ROB.GE.1.0) GO TO 20                                          M24    9
      TA=1.0+BM                                                         M24   10
      TB=TA+BDCR                                                        M24   11
      TC=SQRT(BM*BM-1.0)                                                M24   12
      TD=BM/TA                                                          M24   13
      TE=TD*(((TB+BM)/BM)**2)* ACOS((1.0+TB)/(BM+TB))                   M24   14
      TF=TC*(SQRT(1.0+2.0*BDCR)-1.0)/TA                                 M24   15
      TG=1.0+1.0/BDCR                                                   M24   16
      TH=TC+BDCR*BDCR*ALOG(TG+SQRT(TG*TG-1.0))/BM                       M24   17
      TI=BM* ACOS(1.0/BM)/TA                                            M24   18
      EQ24=8.0*BM*(TE+TF-TH-TI)/(3.14159*(1.0+TAPER)*BDCR*(1.0/ROB-1.0))M24   19
      EQ24=EQ24/TC                                                      M24   20
      RETURN                                                            M24   21
   10 EQ24=0.0                                                          M24   22
      RETURN                                                            M24   23
   20 EQ24=2.0                                                          M24   24
      RETURN                                                            M24   25
      END                                                               M24   26
```

```
      FUNCTION EQ26(BM,TAPER,BDCR,ROB)                                  M25    2
C                                                                       M25    3
C     CALCULATE KB(N)*BCLAM OR KB(T)*BCLAT FROM EQ 26 FOR M GREATER THANM25    4
C          1.0, VALUE OF ASPECT RATIO PARAMETER GREATER THAN 4, AND     M25    5
C          MB LESS THAN OR EQUAL TO 1                                   M25    6
C                                                                       M25    7
      IF (ROB.LE.0.0) GO TO 10                                          M25    8
      IF (ROB.GE.1.0) GO TO 20                                          M25    9
      TA=BM/(1.0+BM)                                                    M25   10
      TB=BDCR/TA                                                        M25   11
      TC=1.0+TB                                                         M25   12
      TD=SQRT(1.0/TC)                                                   M25   13
      TE=SQRT(TC)*(TC+1.0)+2.0-TB*TB*(0.5*ALOG(1.0+TD)-0.5*ALOG(1.0-TD))M25   14
      EQ26=16.0*TA*TA*TE/(3.14159*(1.0+TAPER)*BDCR*(1.0/ROB-1.0))       M25   15
      RETURN                                                            M25   16
   10 EQ26=0.0                                                          M25   17
      RETURN                                                            M25   18
   20 EQ26=2.0                                                          M25   19
      RETURN                                                            M25   20
      END                                                               M25   21
```

```
      FUNCTION EQ30(BM,TAPER,BDCRA,ROB)                                 M26    2
C                                                                       M26    3
C     CALCULATE KB(N)*BCLAM OR KB(T)*BCLAT FROM EQ 30 FOR M GREATER THANM26    4
C          1.0, VALUE OF THE ASPECT RATIO PARAMETER GREATER THAN 4, AND M26    5
C          MB GREATER THAN 1.  NO AFTERBODY.                            M26    6
C                                                                       M26    7
      IF (ROB.LE.0.0) GO TO 10                                          M26    8
      IF (ROB.GE.1.0) GO TO 20                                          M26    9
      BDCR=BDCRA                                                        M26   10
      RRF=1.0                                                           M26   11
      IF (BDCR.LE.1.0) GO TO 1                                          M26   12
      BDCR=1.0                                                          M26   13
      RRF=BDCRA                                                         M26   14
    1 TA=SQRT(BM*BM-1.0)                                                M26   15
      TB=1.0+BM/BDCR                                                    M26   16
      TC=1.0/BDCR                                                       M26   17
      TD=TC+TC                                                          M26   18
      TE=TB*TB* ACOS((BM+TC)/TB)-BM*BM*TD* ACOS(1.0/BM)+BM*TD*TA* ASIN(BM26   19
     1DC)-TA*ALOG(TC+SQRT(TC*TC-1.0))                                   M26   20
      EQ30=8.0*BDCR*TE/(3.14159*TA*(TAPER+1.0)*(1.0/ROB-1.0)*RRF)       M26   21
      RETURN                                                            M26   22
   10 EQ30=0.0                                                          M26   23
      RETURN                                                            M26   24
   20 EQ30=2.0                                                          M26   25
      RETURN                                                            M26   26
      END                                                               M26   27
```

```
      FUNCTION EQ31(BM,TAPER,BDCRA,ROB)                                 M27    2
C                                                                       M27    3
C     CALCULATE KB(N)*BCLAM OR KB(T)*BCLAT FROM EQ 31 FOR M GREATER THANM27    4
C          1.0, VALUE OF ASPECT RATIO PARAMETER GREATER THAN 4, AND     M27    5
C          MB GREATER THAN 1.  NO AFTERBODY.                            M27    6
C                                                                       M27    7
      IF (ROB.LE.0.0) GO TO 10                                          M27    8
      IF (ROB.GE.1.0) GO TO 20                                          M27    9
      BDCR=BDCRA                                                        M27   10
      RRF=1.0                                                           M27   11
      IF (BDCR.LE.1.0) GO TO 1                                          M27   12
      BDCR=1.0                                                          M27   13
      RRF=BDCRA                                                         M27   14
    1 TA=SQRT(BM)                                                       M27   15
      TB=1.0+BM/BDCR                                                    M27   16
      TC=1.0/BDCR+1.0                                                   M27   17
      TD=1.0+BM                                                         M27   18
      TE=TB*SQRT(TC*TB)                                                 M27   19
      TF=((1.0/BDCR)**2)+BM*TA                                          M27   20
      TG=BM*((1.0/BDCR)**2)*TD*(ATAN(SQRT(1.0/BM))-ATAN(SQRT(TC/TB)))   M27   21
      TH=SQRT(BM*TC/TB)                                                 M27   22
      TI=TD*(0.5*ALOG(1.0+TH)-0.5*ALOG(1.0-TH))/TA                      M27   23
      EQ31=16.0*TA*BDCR*(TE-TF+TG-TI)/(3.14159*TD*(TAPER+1.0)*(1.0/ROB  M27   24
     1+1.0)*RRF)                                                        M27   25
      RETURN                                                            M27   26
   10 EQ31=0.0                                                          M27   27
      RETURN                                                            M27   28
   20 EQ31=2.0                                                          M27   29
      RETURN                                                            M27   30
      END                                                               M27   31
```

```
      SUBROUTINE CH14(6,R,SMPLE,CT,CR,FMACH,ARPARM,NAFTER,BDCR,XBCR,    M28    2
     1SMB,TAPER,ROB,BAR)                                                M28    3
C                                                                       M28    4
C     SUBROUTINE TO CALCULATE BODY CENTER OF PRESSURE DUE TO WING OR     M28    5
C          TAIL, CHART 14, 15, OR 16 OF REPORT 1307,  IN TABLE 7 OF THATM28    6
C          REPORT THIS QUANTITY IS IN BOX 57 OR 73.                     M28    7
C                                                                       M28    8
      DIMENSION BD14B(6),XB14B(6,2),BA15(7),              TA15(7,4),    M28    9
     1TB15(7,4),TC15(7,4),TD15(7,4),TE15(7,4),TF15(7,4),TG15(7,4),TH15(7M28   10
     2,4),TI15(7,4),BA16(8),              TA16(8,4),TB16(8,4),TC16(8,4)M28   11
     3,TD16(8,4),TE16(8,4),TF16(8,4),TG16(8,4),TH16(8,4),TI16(8,4)      M28   12
      DIMENSION XB15A(7,4,3),XB15B(7,4,3),XB15C(7,4,3),                 M28   13
     1XB16A(8,4,3),XB16B(8,4,3),XB16C(8,4,3)                            M28   14
      DIMENSION VA(6,3,3),V(3,3)                                        M28   15
      EQUIVALENCE (XB15A(1,1,1),TA15(1,1)),(XB15A(1,1,2),TB15(1,1)),    M28   16
     1(XB15A(1,1,3),TC15(1,1)),(XB15B(1,1,1),TD15(1,1)),                M28   17
     2(XB15B(1,1,2),TE15(1,1)),(XB15B(1,1,3),TF15(1,1)),                M28   18
     3(XB15C(1,1,1),TG15(1,1)),(XB15C(1,1,2),TH15(1,1)),                M28   19
     4(XB15C(1,1,3),TI15(1,1))                                          M28   20
      EQUIVALENCE (XB16A(1,1,1),TA16(1,1)),(XB16A(1,1,2),TB16(1,1)),    M28   21
     1(XB16A(1,1,3),TC16(1,1)),(XB16B(1,1,1),TD16(1,1)),                M28   22
     2(XB16B(1,1,2),TE16(1,1)),(XB16B(1,1,3),TF16(1,1)),                M28   23
     3(XB16C(1,1,1),TG16(1,1)),(XB16C(1,1,2),TH16(1,1)),                M28   24
     4(XB16C(1,1,3),TI16(1,1))                                          M28   25
      DATA RAD/57.29578/                                                M28   26
      DATA BD14B/0.0, 0.2, 0.4, 0.6, 0.8, 1.0/                          M28   27
      DATA XB14B/0.500, 0.590, 0.637, 0.658, 0.665, 0.667,              M28   28
```

```
     1            0.500, 0.575, 0.622, 0.646, 0.660, 0.667/
      DATA BA15/ 0.0, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0/
      DATA BA16/ 0.0, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 1000.0/
      DATA TA15/ 0.00, 0.13, 0.25, 0.34, 0.40, 0.48, 0.50,
     1           0.00, 0.15, 0.30, 0.41, 0.50, 0.63, 0.72,
     2           0.00, 0.25, 0.45, 0.60, 0.75, 0.95, 1.13,
     3           0.00, 0.37, 0.65, 0.90, 1.12, 1.50, 1.80/
      DATA TB15/ 0.00, 0.14, 0.27, 0.38, 0.46, 0.50, 0.50,
     1           0.00, 0.21, 0.40, 0.57, 0.67, 0.82, 0.90,
     2           0.00, 0.32, 0.58, 0.79, 0.95, 1.20, 1.42,
     3           0.00, 0.60, 0.97, 1.24, 1.48, 1.90, 2.31/
      DATA TC15/ 0.00, 0.09, 0.34, 0.46, 0.50, 0.50, 0.50,
     1           0.00, 0.26, 0.55, 0.69, 0.77, 0.89, 1.00,
     2           0.00, 0.48, 0.78, 0.98, 1.13, 1.42, 1.68,
     3           0.00, 0.77, 1.17, 1.50, 1.80, 2.39, 2.98/
      DATA TD15/ 0.26, 0.35, 0.43, 0.47, 0.50, 0.50, 0.50,
     1           0.26, 0.40, 0.51, 0.59, 0.65, 0.73, 0.80,
     2           0.26, 0.47, 0.63, 0.75, 0.85, 1.02, 1.15,
     3           0.26, 0.60, 0.84, 1.05, 1.21, 1.53, 1.85/
      DATA TE15/ 0.14, 0.30, 0.42, 0.47, 0.50, 0.50, 0.50,
     1           0.14, 0.38, 0.54, 0.64, 0.71, 0.81, 0.90,
     2           0.14, 0.48, 0.70, 0.87, 1.00, 1.23, 1.43,
     3           0.14, 0.67, 1.00, 1.27, 1.52, 1.96, 2.43/
      DATA TG15/ 0.50, 0.50, 0.50, 0.50, 0.50, 0.50, 0.50,
     1           0.50, 0.54, 0.58, 0.61, 0.65, 0.71, 0.77,
     2           0.50, 0.59, 0.68, 0.76, 0.84, 1.01, 1.16,
     3           0.50, 0.70, 0.88, 1.05, 1.21, 1.52, 1.83/
      DATA TH15/ 0.27, 0.41, 0.48, 0.50, 0.50, 0.50, 0.50,
     1           0.27, 0.46, 0.58, 0.66, 0.71, 0.81, 0.90,
     2           0.27, 0.58, 0.76, 0.88, 1.00, 1.20, 1.41,
     3           0.27, 0.74, 1.04, 1.28, 1.50, 1.96, 2.40/
      DATA TA16/ .000, .108, .162, .195, .215, .238, .250, .250,
     1           .000, .085, .128, .152, .168, .187, .194, .194,
     2           .000, .070, .110, .132, .147, .165, .170, .170,
     3           .000, .062, .099, .120, .135, .153, .160, .160/
      DATA TB16/ .000, .095, .155, .197, .223, .244, .250, .250,
     1           .000, .085, .140, .173, .194, .215, .221, .221,
     2           .000, .075, .125, .162, .185, .205, .210, .210,
     3           .000, .068, .115, .154, .175, .197, .204, .204/
      DATA TC16/ .000, .100, .158, .190, .210, .230, .250, .250,
     1           .000, .100, .158, .190, .210, .230, .250, .250,
     2           .000, .100, .158, .190, .210, .230, .250, .250,
     3           .000, .100, .158, .190, .210, .230, .250, .250/
      DATA TD16/ .250, .250, .250, .250, .250, .250, .250, .250,
     1           .250, .263, .275, .284, .290, .301, .305, .305,
     2           .250, .270, .286, .300, .309, .321, .325, .325,
     3           .250, .275, .294, .308, .317, .329, .335, .335/
      DATA TE16/ .140, .163, .190, .210, .225, .242, .250, .250,
     1           .140, .177, .210, .233, .250, .269, .275, .275,
     2           .140, .185, .220, .243, .260, .279, .285, .285,
     3           .140, .195, .230, .253, .268, .287, .291, .291/
      DATA TG16/ .500, .465, .432, .400, .370, .320, .286, .286,
     1           .500, .483, .467, .457, .440, .417, .409, .409,
     2           .500, .496, .492, .487, .483, .476, .473, .473,
     3           .500, .504, .507, .510, .511, .512, .514, .514/
      DATA TH16/ .250, .250, .250, .250, .250, .250, .250, .250,
     1           .250, .275, .292, .305, .315, .327, .330, .330,
     2           .250, .280, .304, .321, .336, .353, .360, .360,
     3           .250, .290, .315, .332, .353, .372, .380, .380/
      DO 1 J=1,7
      DO 1 K=1,4
      TP15(J,K)=TC15(J,K)
    1 TI15(J,K)=TC15(J,K)
      DO 2 J=1,8
      DO 2 K=1,4
      TP16(J,K)=TC16(J,K)
    2 TI16(J,K)=TC16(J,K)
      CTLE=(B-R)*TAN(SWPLE/RAD)
      SWPMC=RAD*ATAN((CTLE+0.5*(CT-CR))/(B-R))
      SWPTE=RAD*ATAN((CTLE+CT-CR)/(B-R))
      IF (FMACH.LE.1.0) GO TO 100
      IF (ARPARM.LT.4.0) GO TO 100
C
C     CHART 14
C
      IF (NAFTER.EQ.0) GO TO 50
C
C     CHART 14(A)
C
      IF (BDCR.GT.1.0) GO TO 25
      IF (BDCR.GT.0.4) GO TO 10
      XBCR=0.5+0.55*BDCR
      RETURN
   10 IF (BDCR.GT.0.8) GO TO 15
      XBCR=0.72+0.5*(BDCR-0.4)
      RETURN
   15 XBCR=0.92+0.4*(BDCR-0.8)
      RETURN
   25 IF (SMB.GT.0.2) GO TO 30
      XBCR=1.0+0.378*(BDCR-1.0)
      RETURN
   30 IF (SMB.GT.2.0) GO TO 35
      XBCR=1.0+0.4*(BDCR-1.0)
      RETURN
   35 XBCR=1.0+0.411*(BDCR-1.0)
      RETURN
C
C     CHART 14(B)
C
   50 IF (BDCR.LT.1.0) GO TO 55
      XBCR=0.667
      RETURN
   55 L=1
      IF (SMB.GT.1.0) L=2
      J=0
   60 J=J+1
      IF (BDCR.GT.BD14B(J)) GO TO 60
      JM=J-1
      XBCR=XB14B(JM,L)+(XB14B(J,L)-XB14B(JM,L))*(BDCR-BD14B(JM))/
     1(BD14B(J)-BD14B(JM))
      RETURN
C
C     CHART 15 AND 16
C
  100 IF (SWPMC.LE.0.0) GO TO 105
      LM=2
      LP=3
      DXCL=SWPMC/(SWPMC-SWPTE)
      GO TO 110
  105 LM=1
      LP=2
      DXCL=1.0
      IF (TAPER.NE.1.0) DXCL=SWPLE/(SWPLE-SWPMC)
  110 IF (TAPER.LE.0.5) GO TO 115
      KM=2
      KP=3
      DXBL=(TAPER-0.5)/0.5
      GO TO 120
  115 KM=1
      KP=2
      DXBL=TAPER/0.5
  120 IF (ROB.GT.0.2) GO TO 125
      JM=1
      JP=2
      DXRB=ROB/0.2
      GO TO 135
  125 IF (ROB.GT.0.4) GO TO 130
      JM=2
      JP=3
      DXRB=(ROB-0.2)/0.2
      GO TO 135
  130 JM=3
      JP=4
      DXRB=(ROB-0.4)/0.2
  135 IF (FMACH.LE.1.0) GO TO 200
C
C     CHART 15
C
      I=0
  140 I=I+1
      IF (BAR.GE.BA15(I)) GO TO 140
      IM=I-1
      IP=I
      DXBA=(BAR-BA15(IM))/(BA15(IP)-BA15(IM))
      DO 145 K=KM,KP
      DO 145 J=JM,JP
      VA(J,K,1)=XB15A(IM,J,K)+DXBA*(XB15A(IP,J,K)-XB15A(IM,J,K))
```

```
      VA(J,K,2)=XB15B(IM,J,K)+DXBA*(XB15B(IP,J,K)-XB15B(IM,J,K))          M28  184
  145 VA(J,K,3)=XB15C(IM,J,K)+DXBA*(XB15C(IP,J,K)-XB15C(IM,J,K))          M28  185
      DO 150 L=LM,LP                                                     M28  186
      DO 150 K=KM,KP                                                     M28  187
  150 V(K,L)=VA(JM,K,L)+DXRB*(VA(JP,K,L)-VA(JM,K,L))                     M28  188
      VALA=V(KM,LM)+DXBL*(V(KP,LM)-V(KM,LM))                             M28  189
      VALB=V(KM,LP)+DXBL*(V(KP,LP)-V(KP,LP))                             M28  190
      XBCR=VALA+DXCL*(VALB-VALA)                                         M28  191
      RETURN                                                             M28  192
C                                                                        M28  193
C     CHART 16                                                           M28  194
C                                                                        M28  195
  200 I=0                                                                M28  196
  210 I=I+1                                                              M28  197
      IF (BAR.GE.BA16(I)) GO TO 210                                      M28  198
      IM=I-1                                                             M28  199
      IP=I                                                               M28  200
      DXBA=(BAR-BA16(IM))/(BA16(IP)-BA16(IM))                            M28  201
      DO 220 K=KM,KP                                                     M28  202
      DO 220 J=JM,JP                                                     M28  203
      VA(J,K,1)=XB16A(IM,J,K)+DXBA*(XB16A(IP,J,K)-XB16A(IM,J,K))         M28  204
      VA(J,K,2)=XB16B(IM,J,K)+DXBA*(XB16B(IP,J,K)-XB16B(IM,J,K))         M28  205
  220 VA(J,K,3)=XB16C(IM,J,K)+DXBA*(XB16C(IP,J,K)-XB16C(IM,J,K))         M28  206
      DO 230 L=LM,LP                                                     M28  207
      DO 230 K=KM,KP                                                     M28  208
  230 V(K,L)=VA(JM,K,L)+DXRB*(VA(JP,K,L)-VA(JM,K,L))                     M28  209
      VALA=V(KM,LM)+DXBL*(V(KP,LM)-V(KM,LM))                             M28  210
      VALB=V(KM,LP)+DXBL*(V(KP,LP)-V(KM,LP))                             M28  211
      XBCR=VALA+DXCL*(VALB-VALA)                                         M28  212
      RETURN                                                             M28  213
      END                                                                M28  214
```

```
      SUBROUTINE INTFAC(NAFT,NFKH,NFLKH,NFKAB,NFKD,NFKB,NFXB,KH,LKH,KAB,M29    2
     1HD,KB,XB,BM,AR,XLE,XTIPL,XTE,FMACH,ND)                             M29    3
C                                                                        M29    4
C THIS ROUTINE CALCULATES BY SLENDER BODY THEORY OR THE METHODS OF NACA  M29    5
C    REPORT 1307 THOSE INTERFERENCE FACTORS WHICH HAVE NOT BEEN INPUT.   M29    6
C    IF ND = 2, FIN DEFLECTION FACTORS ARE NOT CALCULATED.               M29    7
      COMMON/ESBTKB/XP(11),KABP(11),BBTKDP(11),BBTKUP(11)                M29    8
      REAL KH,LKH,KAB(4),KD(4),KB,KABP,KBBCL,M                           M29    9
      DATA RAD/57.29578/,CON81/.3183099/,CON82/1.5707963/,CON83/.1013212M29   10
     */,CON84/2.4674011/,CON85/3.1415927/,CON86/6.2831853/               M29   11
C                                                                        M29   12
      TERM1=BM=1.                                                        M29   13
      BM2=BM=BM                                                          M29   14
      TERM2=BM2=1.                                                       M29   15
      TERM3=BM2=1.                                                       M29   16
      X=SQRT(TERM3=TERM3-TERM2=TERM2)                                    M29   17
      TERM6=ATAN2(TERM2,X)                                               M29   18
      TERM5=BM=1.                                                        M29   19
      TERM6=BM=TERM1                                                     M29   20
      IF(NFKH.EQ.0)KH=CON81/TERM1=2=(CON82=TERM2=TERM2/BM2+TERM3=TERM3/M29   21
     1BM2+TERM4=2.=TERM2/BM)                                             M29   22
      IF(NFLKH.EQ.0.AND.ND.EQ.1)LKH=CON83=(CON84=TERM5=TERM5/BM2+       M29   23
     1CON85=(TERM3/TERM6)=2=TERM4=CON86=TERM5/TERM6+TERM3=TERM3/(TERM6 M29   24
     2=TERM6)=TERM6=TERM6=4.=TERM5/TERM6=TERM6+8./(TERM1=TERM1)=ALOG(.5=M29   25
     3TERM3/BM))                                                         M29   26
      IF(NFKAB.NE.0)GO TO 20                                             M29   27
      CALL LNTRP(XP,KABP,11,1,/BM,XX)                                    M29   28
      DO 10 I=1,4                                                        M29   29
   10 KAB(I)=XX                                                          M29   30
   20 IF(NFKD.NE.0.OR.ND.EQ.2)GO TO 30                                   M29   31
      CALL LNTRP(XP,BBTKUP,11,1,/BM,KD(1))                               M29   32
      KD(3)=KD(1)                                                        M29   33
      CALL LNTRP(XP,BBTKDP,11,1,/BM,KD(2))                               M29   34
      KD(4)=KD(2)                                                        M29   35
C                                                                        M29   36
C CALCULATION OF BODY INTERFERENCE FACTORS BY METHODS OF NACA REPORT      M29   37
C    1307.                                                               M29   38
C                                                                        M29   39
   30 BETA=SQRT(ABS(FMACH=FMACH-1.))                                     M29   40
      BAR=BETA=AR                                                        M29   41
      MH=TERM1/(XTIPL-XLE)                                               M29   42
      BM=BETA=M                                                          M29   43
      CT=XTE-XTIPL                                                       M29   44
      CR=XTE-XLE                                                         M29   45
      TR=CT/CR                                                           M29   46
      TERM7=BM=(TR+1.)=(1./BM+1.)                                        M29   47
      BDCR=2.=BETA/(XTE-XLE)                                             M29   48
      BMPLE=ATAN(1./M)=RAD                                               M29   49
      IF(NFKB.NE.0)GO TO 230                                             M29   50
      IF(FMACH.GT.1..AND.TERM7.GT.4.)GO TO 100                           M29   51
C                                                                        M29   52
C KB IS CALCULATED FROM SLENDER BODY THEORY.                             M29   53
C                                                                        M29   54
      KB=TERM5=TERM5/BM2=KH                                              M29   55
      GO TO 230                                                          M29   56
C                                                                        M29   57
C KB IS CALCULATED FROM PLANAR MODEL                                     M29   58
C                                                                        M29   59
  100 IF(NAFT.EQ.2)GO TO 200                                             M29   60
C                                                                        M29   61
C THERE IS AN AFTERBODY BEHIND FINS.                                     M29   62
C                                                                        M29   63
      IF(BM.LE.1.)GO TO 110                                              M29   64
      KBBCL=EQ24(BM,TR,BDCR,1./BM)                                       M29   65
      GO TO 120                                                          M29   66
  110 KBBCL=EQ26(BM,TR,BDCR,1./BM)                                       M29   67
  120 KB=KBBCL/CHART8(BA,BM,1.,CT,CR,BMPLE)                              M29   68
      GO TO 230                                                          M29   69
C                                                                        M29   70
C THERE IS NO AFTERBODY BEHIND FINS.                                     M29   71
C                                                                        M29   72
  200 IF(BM.LE.1.)GO TO 210                                              M29   73
      KBBCL=EQ30(BM,TR,BDCR,1./BM)                                       M29   74
      GO TO 220                                                          M29   75
  210 KBBCL=EQ31(BM,TR,BDCR,1./BM)                                       M29   76
  220 KB=KBBCL/CHART8(BA,BM,1.,CT,CR,BMPLE)                              M29   77
  230 IF(NFKB.NE.0)RETURN                                                M29   78
      CALL CM1416(BM,1.,BMPLE,CT,CR,FMACH,TERM7,2=NAFT,BDCR,XB,BM,TR,    M29   79
     1 1./BM,BA)                                                         M29   80
      RETURN                                                             M29   81
      END                                                                M29   82
```

APPENDIX F

MODIFICATIONS TO CRFWBD, A COMPUTER PROGRAM FOR CALCULATING AERODYNAMIC CHARACTERISTICS OF CRUCIFORM WING-BODY COMBINATIONS IN SUPERSONIC FLOW

APPENDIX F

MODIFICATIONS TO CRFWBD, A COMPUTER PROGRAM FOR CALCULATING AERODYNAMIC CHARACTERISTICS OF CRUCIFORM WING-BODY COMBINATIONS IN SUPERSONIC FLOW*

F.1. INTRODUCTION

This appendix describes several changes and extensions to the computer program CRFWBD first discussed in Appendix A of reference 3. In addition, a study was made to determine the effect on fin loading of various panel sizes used to cover the fin planform and body interference shell. The results of this investigation are also included. Only the modifications to the program CRFWBD which were made during the course of the present study will be discussed in this appendix. The user should consult Appendix A of reference 3 for a complete description of the original code. The modified program is written in the FORTRAN IV language for the CDC 7600 machine. The modified routines are punched in 029. The user should note that the original routines are all punched in 026.

F.2. MODIFICATIONS TO CRFWBD

The first change to the program was to remove all calls to the previously system-supplied subroutine REQFL. This subroutine computed the actual dimension requirement for the aerodynamic coefficient matrix FVN. In the current version this matrix is given the fixed dimension corresponding to the maximum number of constant u-velocity panels allowed and is placed in large core memory. The maximum number of constant u-velocity panels available has been increased from 250 to 350. Thus, the dimension of FVN is 350×350 or 122,500.

Several modifications were made to subroutine LOADS to compute the lift carryover onto the body. In addition, the variable BIL (for body interference length) has been added to namelist INPUT to allow the user to select the length (measured from the leading edge of the fin root chord) over which the wing exerts lift carryover onto the body. In general, the minimum length that should be chosen is determined by the intersection of the Mach cone from the trailing edge of the root chord with the body centerline.

*The work described in this appendix was performed by Dr. M.F.E. Dillenius of Nielsen Engineering & Research, Inc.

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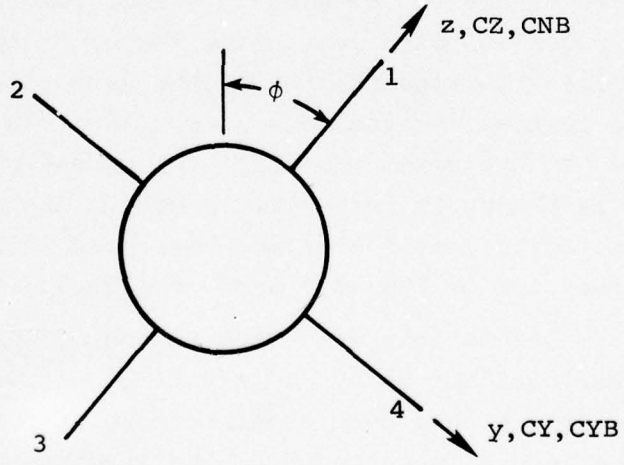
Certain output has been added to allow calculation of the distribution of lift carryover onto the body and, specifically, to aid in the determination of the K_B and $\bar{x}_B$ factors described in the main text of this report. Loading information for each body ring has been added to the section of the code concerned with the properties of the body influence panels. This information includes: (1) the contribution from each ring to the force in the z-direction (i.e., along fin 1), CZ, (2) the force in the y-direction (i.e., along fin 4), CY, and (3) the moments about the z and y axes taken with the root chord leading edge as moment center.* The moments are designated CZMOM and CYMOM respectively. In addition, the accumulated normal and side forces due to lift carryover (CNB and CYB) and the locations of the axial centers of pressure (XCP,CZ and XCP,CY) are given as a function of the number of rings in the axial direction. To determine lift carryover, the user should look at the contribution to CZ and CY from each ring. In general, these quantities will increase for each successive ring in the axial direction to a maximum and then decrease. The ring experiencing maximum CZ and/or CY is then the last ring over which lift carryover is dominant (in successive rings wake effects become dominant). The lift carryover is then determined from the accumulated CZ and CY over the affected body rings by vectorial addition and XCP,CZ and XCP,CY are the corresponding centers of pressure.



Sketch F.1. Coordinate system used for body loading due to lift.

*Note that the x,y,z coordinate system used here is for rolled body coordinates. See sketch F.1.

F.3. LOADING CONVERGENCE STUDY

F.3.1 Modeling of Missile Body

A study was undertaken to investigate the effect on the fin loading of the number of line sources/sinks and doublets distributed along the body centerline to model the missile body. Specifically, the magnitude of the velocity component normal to the fin surfaces was calculated for different numbers of body singularities. It was found that for cross-flow planes aft of the shoulder of an ogive-cylinder at angle of attack, the computed upwash varied smoothly with distance away from the body. At every point, the magnitude of the upwash appeared to converge rapidly with increasing numbers of body singularities. As a rule of thumb, the number of body singularities over the length spanned by the fins should be at least equal to the number of constant u-velocity panels laid in a chordwise row on the fins.

F.3.2 Modeling of Fins for Wing-Alone Case

The effect of the number of constant u-velocity panels distributed over the fins and body interference shell were studied in a systematic manner. First a wing-alone was considered. The normal force was computed for many combinations of chordwise and spanwise numbers of panels. It was concluded that the normal force approaches a definite limit as the number of chordwise rows is increased while the number of panels in each row is kept constant. For typical missile fin planforms, a layout of 9 panels spanwise and 4 panels chordwise should give good results. This recommendation is based both on the findings from the convergence studies for a wing alone and on comparison with experimental data.

F.3.3 Modeling of Fins and Body Interference Shell for Wing-Body Case

Next, the effect of the number of panels on the fins and interference shell for a cruciform fin-body combination was investigated. Based on the results of many calculations of the normal forces acting on the fins, it was concluded that the size of the panels in the interference shell should be comparable to the size of the panels on the fins in the chordwise row at the fin-body junction. Thus, the number of panels in the

interference shell in the axial direction should equal the number of panels in a chordwise row on the fins. The number of panels on the circumference of the interference shell should be selected such that the panel width is comparable to the span of the chordwise row of panels on the fin at the fin-body junction.

For the case of an unrolled, cruciform fin-body configuration at angle of attack and with the vertical panels deflected for yaw control, the contribution to rolling moment from the deflected fins (termed direct roll) can be determined with good accuracy using 12 panels on the circumference and 4 along the body length spanned by the fins. In accordance with the above recommendations, each fin should be covered with 3 or 4 chordwise rows with 4 panels in each row. In contrast, the contribution to the rolling moment from the undeflected, horizontal fins (termed reverse roll) was very small for the case considered. Furthermore, the convergence was not monotonic. In this instance, the number of panels required to reach a limiting value exceeded the maximum number allowed by the computer program.

F.4. PROGRAM LISTING

A listing is given below of the two subroutines affected by the modifications discussed above. Other subroutines were changed only to make COMMON statements compatible or to remove calls to the system-supplied subroutine REQFL and to place the aerodynamic coefficient matrix FVN in large core memory. The following subroutines have been written in the FORTRAN IV language (029 punch) for the CDC 7600 computer.

PROGRAM	IDENTIFICATION	PAGE NO.
CRFWBD	WB01	223
LOADS	WB03	227

```
      PROGRAM CRFWBD(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)                 WB01   1
C                                                                           WR01   2
C     THIS VERSION IS A MODIFIED FORM OF THE NWC VERSION OF FEB.,1975,      WR01   3
C     IT HAS BEEN MODIFIED FOR OPERATION ON THE AMES CDC 7600 COMPUTER      WR01   4
C     BY REMOVING CALLS TO NEQFL (A BOEING COMPUTER SERVICES ROUTINE),      WB01   5
C     DIMENSIONING FVN TO 62500 (250 SQUARED), AND PLACING FVN IN LARGE     WB01   6
C     CORE MEMORY,  NEAR STAFF, JAN.,1976.                                  WB01   7
C                                                                           WR01   8
C     PLANAR OR CRUCIFORM WING-BODY PROGRAM, SUPERSONIC FLOW                WR01   9
C     SET UP GEOMETRY, COORDINATES, AERODYNAMIC INFLUENCE COEFFICIENT       WR01  10
C     MATRIX                                                                WB01  11
C                                                                           WB01  12
      DIMENSION YR(50),YRT(50),YLT(50),MEAD(20)                             WR01  13
      DIMENSION RMB(350)                                                    WB01  14
      DIMENSION ZUT(50),ZDT(50)                                             WB01  15
      DIMENSION BDU(350),BDV(350),BDW(350)                                  WB01  16
C                                                                           WB01  17
      LOGICAL ASYM,BODY  ,DELTA                                             WB01  18
C                                                                           WB01  19
      COMMON/THRUST/CN,XBAR(350),ZBAR(350),YCPT(350),VNOR(350),CIRC(350)    WB01  20
     1   ,PNLC(350),NCW,MSWR,MSWL,MSWU,MSWD,NRP,NWP,N3P,B2,B2V,XCPT(350)    WB01  21
     2   ,ZCPT(350)                                                         WB01  22
      COMMON/VWNOR/SWPPLE(350),SWPPTE(350),ZLF(350),ZRF(350),ZLB(350),      WB01  23
     1   ZRB(350),ASYM,UCHK,VCHK,WCHK,II,IP,CONST,BETAR,SINBET,COSBET       WB01  24
      COMMON FVN(122500)                                                    WB01  25
      COMMON /VELARG/X,Y,Z,U,V,W,A,EM,BETA,SLOPE,TLRNC,TIPY                 WB01  26
      COMMON/PRESB/DELTP(350),XRF(350),XRB(350),XLF(350),XLB(350),          WB01  27
     1   YLC(350),YRC(350),COSALF,NPANLS,ARWING,FMACH,ALFA,FN(350),         WB01  28
     2   SINALF,DELTA                                                       WB01  29
      COMMON /IPR/NPR,I,J                                                   WB01  30
      COMMON/SWEEPS/VSWLER(50),VSWTER(50),VSWLEL(50),VSWTEL(50),            WB01  31
     1   VSWLEU(50),VSWTEU(50),VSWLED(50),VSWTED(50),LVSWP,LEFT,FAC,        WB01  32
     2   NC=B,ARPNL(350),WIDTH(350)                                         WB01  33
      COMMON/TRANS/NBIP,RB,DX,NBIP,XFBIP(200),SNT(200),CST(200),            WB01  34
     1   SNT2(200),CST2(200)                                                WB01  35
      COMMON /TILT/ANGLR,ANGLL,ANGLU,ANGLD,DELR,DELL,DELU,DELD              WB01  36
      COMMON /BVEL/BDU,BDV,BDW                                              WB01  37
      COMMON/WBTR/XWLE                                                      WB01  38
      COMMON/REF/BREF,REFL                                                  WB01  39
      COMMON/CRUX/NCRX                                                      WB01  40
      COMMON/NONLIN/NWBP,NOLINP,TOTLR,BODY,ALFR,NOUT,NPRESS,NOCPT,NDRAG     WB01  41
      COMMON/SPSANG/SINALC,COSALC,SINPHI,COSPHI                             WB01  42
      COMMON/VRTXV/VVRTX(350),KVRTX(350),NVRTPL,NVRTX                       WB01  43
C                                                                           WB01  44
      LEVEL 2,FVN                                                           WB01  45
C                                                                           WB01  46
      DATA PI/3.1415926535 79/                                              WB01  47
      DATA QUIT/4HZZZZ/                                                     WB01  48
C                                                                           WB01  49
      NAMELIST /INPUT/CRP,SWLEP,SWTEP,NCW,MSWR,MSWL,ALFAC,PHI,B2,FMACH,    WB01  50
     1LVSWP,     FAC,      NFVNPR,      TOLFAC,MSWU,MSWD,SWLEV,SWTEV,      WB01  51
     1  CRPV,B2V,NCRX,RB,NBDCR,DELR,DELL,DELU,DELD,SREF,REFL,NOLINP,       WB01  52
     1NOUT,NPR,NDRAG,NVRTX,NPRESS,VRTMAX,NCWB,BIL                           WB01  53
C                                                                           WB01  54
C                                                                           WB01  55
    1 FORMAT (20A4)                                                         WB01  56
    2 FORMAT (1H1,20A4)                                                     WB01  57
  701 FORMAT(1H1,20X,13HWING GEOMETRY///                                    WB01  58
     1 9X,21HLEADING EDGE SWEEP = ,F10.5,2X,7HDEGREES//                     WB01  59
     2 8X,22HTRAILING EDGE SWEEP = ,F10.5,2X,7HDEGREES//                    WB01  60
     3 18X,12HTIP CHORD = ,F10.5//                                          WB01  61
     4 17X,13HROOT CHORD = ,F10.5//                                         WB01  62
     9 14X,16HWING SEMISPAN = ,F10.5//)                                     WB01  63
  702 FORMAT (//20X,15HFLOW CONDITIONS//5X,7HMACH = ,F10.5,4X,8HALPHAC=     WB01  64
     1 ,F10.5,4X,7HPHI  = ,F10.5,4X,7HALFA = ,F10.5,4X,7HBETA = ,F10.5/)    WB01  65
  703 FORMAT(1H1,18X,52H              PANEL CORNER COORDINATES FOR WING PAN  WB01  66
     1NELS)                                                                 WB01  67
  704 FORMAT (1H1,10X,30HCONTROL POINT COORDINATES FOR ,I2,14H CHORDWISE     WR01  68
     1 BY I2,36H SPANWISE PANELS ON RIGHT WING PART,2X,I2,1X,               WB01  69
     126HSPANWISE ON LEFT WING PART/53X,3HAND,I2,36H SPANWISE PANELS ON     WB01  70
     1UPPER WING PART,1X,,I2,28H SPANWISE ON LOWER WING PART//              WB01  71
     1                          5X,1HJ,6X,4HX(J),8X,4HY(J),8X,4HZ(J),      WB01  72
     X  7X,5HBU(J),9X,5HBV(J),9X,5HBW(J),10X,5HVV(J),10X,5HVV(J)//)         WB01  73
  705 FORMAT (1X,I5,2X,F10.5,2X,F10.5,2X,F10.5)                             WB01  74
  706 FORMAT(3X,I3,3X,F9.4,1X,F9.4,1X,F9.4,1H=,F9.4,1X,F9.4,1X,F9.4,1X,F9.4,  WB01  75
     1  1H=,F9.4,1X,F9.4,1X,F9.4,1H=,F9.4,1X,F9.4,1X,F9.4)                  WR01  76
  707 FORMAT(1H1,30X,20HINFLUENCE MATRIX FVN//)                             WB01  77
  708 FORMAT(/1X,56(1H=),17HRIGHT WING PANELS,57(1H=)/)                     WB01  78
  709 FORMAT(/1X,57(1H=),16HLEFT WING PANELS,57(1H=)/)                      WB01  79
  710 FORMAT(/1X,56(1H=),17HUPPER WING PANELS,57(1H=)/)                     WB01  80
  711 FORMAT(/1X,56(1H=),17HLOWER WING PANELS,57(1H=)/)                     WB01  81
  713 FORMAT(5F10.5)                                                        WB01  82
  715 FORMAT(//  30X,15HPARAMETERS USED//                                   WB01  83
     1  12X,7HASYM = ,L3/12X,8HTLRNC = ,E12.5/12X,7HLEFT = ,L3///)         WB01  84
  717 FORMAT(1H1,30X,21HSLOPES OF PANEL EDGES//6X,1HJ,5X,10HL.E. SLOPE,     WB01  85
     1  5X,10HT.E. SLOPE/)                                                 WB01  86
  718 FORMAT(5X,I3,5X,F10.5,5X,F10.5)                                       WB01  87
  722 FORMAT (//10X,23HRIGHT WING PART SPAN = ,F10.5/                       WB01  88
     110X,  23H LEFT WING PART SPAN = ,F10.5/                               WB01  89
     2 10X,23HUPPER WING PART SPAN = ,F10.5/                                WB01  90
     3 10X,23HLOWER WING PART SPAN = ,F10.5//)                              WB01  91
  723 FORMAT(//10X,7HCRPT = ,F10.5/9X,8HCRPTV = ,F10.5//)                   WB01  92
  724 FORMAT(1H1,20X,22HVERTICAL WING GEOMETRY///                           WB01  93
     1 9X,21HLEADING EDGE SWEEP = ,F10.5,2X,7HDEGREES//                     WB01  94
     2 8X,22HTRAILING EDGE SWEEP = ,F10.5,2X,7HDEGREES//                    WB01  95
     3 18X,12HTIP CHORD = ,F10.5//                                          WB01  96
     4 17X,13HROOT CHORD = ,F10.5//                                         WB01  97
     9 14X,16HWING SEMISPAN = ,F10.5//)                                     WB01  98
  725 FORMAT(1H1,30X,48HCONTROL POINT COORDINATES FOR BIP=S (WING FRAME)     WB01  99
     1//5X,1HJ,6X,4HX(J),8X,4HY(J),8X,4HZ(J)//)                             WB01 100
  726 FORMAT(///25X,35HBIP CORNER COORDINATES IN BIP FRAME)                 WB01 101
  727 FORMAT(9X,F9.4,11(1X,F9.4))                                           WB01 102
  728 FORMAT(1H1,30X,22HRIGHT HAND SIDE VECTOR//8X,1HJ,3X,6HRHS(J)//)       WB01 103
  729 FORMAT(2X,I3,2X,E12.5)                                                WB01 104
  731 FORMAT(1H1,30X,19HPRESSURE ON PANEL J//8X,1HJ,4X,4HP(J)//)            WB01 105
  732 FORMAT(/,1X,16HMINIMUM WIDTH = ,F8.5,5X,8HTLRNC = ,F12.10,5X,         WB01 106
     =8HTOTLR = ,F12.10)                                                    WB01 107
  733 FORMAT(1H0,5X,1HJ,10X,8HWIDTH(J))                                    WB01 108
  734 FORMAT(5X,I2,10X,F8.5)                                                WB01 109
  752 FORMAT (3X,60HSPECIFIED SPANWISE LOCATIONS OF OUTBOARD PANEL EDGES    WB01 110
     1 AND SWEEP ANGLES//2X,1HK,4X,4HY OR Z,7X,10HL.E. SWEEP,5X,            WB01 111
     2 10HT.E. SWEEP/23X,5HANGLE,10X,5HANGLE///)                            WB01 112
  753 FORMAT (1X,I2,2X,F10.5,5X,F10.5,5X,F10.5)                             WB01 113
  754 FORMAT (1H1,4X,18HRIGHT WING SURFACE//)                               WB01 114
  755 FORMAT (///8X,17HLEFT WING SURFACE//)                                 WB01 115
  756 FORMAT (///8X,18HUPPER WING SURFACE//)                                WB01 116
  757 FORMAT (///8X,18HLOWER WING SURFACE//)                                WB01 117
  760 FORMAT (1H1,4X,12HWING SURFACE//)                                     WB01 118
 7030 FORMAT (                              //5X,1HJ,15X,2HLF,15X,          WB01 119
     1  1H=,12X,2HLB,15X,1H=,12X,2HRF,15X,1H=,12X,2HRB/12X,1HX,9X,1HY,      WB01 120
     2  9X,1HZ,5X,1H=,3X,1HX,9X,1HY,9X,1HZ,5X,1H=,3X, 1HX,9X,1HY,9X,1HZ,   WB01 121
     3  5X,1H=,3X,1HX,9X,1HY,9X,1HZ/38X,1H=,20X,1H=,20X,1H=/130(1H=))/      WB01 122
     4  38X,1H=,20X,1H=,20X,1H=)                                           WA01 123
 7051 FORMAT(1X,I5,2X,F10.5,2X,F10.5,2X,F10.5,2X,E12.5,2X,E12.5,            WB01 124
     1  2X,E12.5,2X,E12.5,2X,E12.5)                                        WB01 125
C                                                                           WB01 126
C                                                                           WB01 127
C                                                                           WB01 128
C                                                                           WB01 129
C     DEFAULT VALUES FOR NAMELIST INPUT                                     WA01 130
C                                                                           WA01 131
      ASYM=.FALSE.                                                          WB01 132
      BODY=.FALSE.                                                          WB01 133
      FAC=0.95                                                              WB01 134
      LVSWP=0                                                               WA01 135
      TOLFAC=1.0                                                            WB01 136
      NPR=0                                                                 WB01 137
      NFVNPR=0                                                              WB01 138
      NOLINP=0                                                              WB01 139
      NOUT=0                                                                WA01 140
      NVRTX=0                                                               WB01 141
      NPRESS=0                                                              WA01 142
      PHI=0.0                                                               WB01 143
      MSWL=0                                                                WB01 144
      SWLEP=0.0                                                             WB01 145
      SWTEP=0.0                                                             WA01 146
      SWLEV=0.0                                                             WA01 147
      SWTEV=0.0                                                             WA01 148
      CRPV=0.0                                                              WA01 149
      B2V=0.0                                                               WB01 150
      MSWD=0                                                                WB01 151
      MSWU=0                                                                WA01 152
      NCRX=0                                                                WA01 153
      NBDCR=0                                                               WB01 154
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      RB=0.0                                                            WB01 155
      DELR=0.0                                                          WB01 156
      BIL=0.0                                                           WB01 157
      DELL=0.0                                                          WB01 158
      DELU=0.0                                                          WB01 159
      DELD=0.0                                                          WB01 160
      VRTMAX=0.35                                                       WB01 161
      NDRAG=1                                                           WB01 162
      DTOR=PI/180.0                                                     WB01 163
      NC=B=0                                                            WB01 164
C                                                                       WB01 165
C     WING GEOMETRY SPECIFIED IN PLANFORM,                              WB01 166
C     GEOMETRICALLY SYMMETRIC WINGS ONLY                                WB01 167
C                                                                       WB01 168
C                                                                       WB01 169
C     READ HEADER CARD                                                  WB01 170
C                                                                       WB01 171
  999 READ(5,1) HEAD                                                    WB01 172
      IF(HEAD(1).EQ.QUIT) STOP                                          WB01 173
C                                                                       WB01 174
C     READ NAMELIST INPUT                                               WB01 175
C                                                                       WB01 176
      READ (5,INPUT)                                                    WB01 177
C                                                                       WB01 178
      TIPY=B2                                                           WB01 179
      NRP=NC*=SWR                                                       WB01 180
      NRP1=NRP+1                                                        WB01 181
      NWP=NC*=(MSWR+MSWL)                                               WB01 182
      NWP1=NWP+1                                                        WB01 183
      N3P=NC*=(MSWL+MSWR+MSWU)                                          WB01 184
      N3P1=N3P+1                                                        WB01 185
      NPANLS=NC*=(MSWR+MSWL+MSWU+MSWD)                                  WB01 186
      NPANLP=NPANLS+1                                                   WB01 187
      NBIP=NC*B=NBDCR                                                   WB01 188
      NWBP=NPANLS+NBIP                                                  WB01 189
C                                                                       WB01 190
C     ANGLE OF ATTACK AND SIDESLIP ARE CALCULATED IN ACCORDANCE WITH    WB01 191
C     PITCH-ROLL TRANSFORMATION, SEE NIELSEN PAGE 5,                    WB01 192
C                                                                       WB01 193
      ALFACR=ALFAC*DTOR                                                 WB01 194
      SINALC=SIN(ALFACR)                                                WB01 195
      COSALC=COS(ALFACR)                                                WB01 196
      PHIR=PHI*DTOR                                                     WB01 197
      SINPHI=SIN(PHIR)                                                  WB01 198
      COSPHI=COS(PHIR)                                                  WB01 199
      SINALF=SINALC*COSPHI                                              WB01 200
      ALFR=ASIN(SINALF)                                                 WB01 201
      COSALF=COS(ALFR)                                                  WB01 202
      SINBET=SINALC*SINPHI                                              WB01 203
      BETAR=ASIN(SINBET)                                                WB01 204
      COSBET=COS(BETAR)                                                 WB01 205
      BETAY=BETAR/DTOR                                                  WB01 206
      ALFA=ALFR/DTOR                                                    WB01 207
C                                                                       WB01 208
      SLPLE=TAN(SWLEP*DTOR)                                             WB01 209
      SLPTE=TAN(SWTEP*DTOR)                                             WB01 210
      ASYM=(BETAY.NE.0.0).AND.(NBDCR.EQ.0)                              WB01 211
      BODY=NBDCR.NE.0                                                   WB01 212
      DELTA=DELR.NE.0..OR.DELL.NE.0..OR.DELU.NE.0..OR.DELD.NE.0.        WB01 213
C                                                                       WB01 214
      WRITE (6,2) HEAD                                                  WB01 215
C                                                                       WB01 216
      RDELR=DELR*DTOR                                                   WB01 217
      ANGLR=RDELR + ALFR                                                WB01 218
      RDELL=DELL*DTOR                                                   WB01 219
      ANGLL=ALFR+RDELL                                                  WB01 220
      RDELU=DELU*DTOR                                                   WB01 221
      ANGLU=BETAR+RDELU                                                 WB01 222
      RDELD=DELD*DTOR                                                   WB01 223
      ANGLD=BETAR+RDELD                                                 WB01 224
      BETA=SQRT(ABS(FMACH*FMACH-1     ))                                WB01 225
      CONST= 4.0*PI                                                     WB01 226
C                                                                       WB01 227
C                                                                       WB01 228
      WRITE(6,INPUT)                                                    WB01 229
C                                                                       WB01 230
C                                                                       WB01 231
C     UP TO STATEMENT 69 IS FOR WING ALONE CASE                         WB01 232
C                                                                       WB01 233
      IF(ASYM.OR.BODY.OR.NCRX.NE.0) GO TO 69                            WB01 234
      MSWRP=MSWR+1                                                      WB01 235
      IF(LVSWP.EQ.0) GO TO 25                                           WB01 236
      READ(5,713) (YR(KJ),YSWLLR(KJ),YSWTFR(KJ),KJ=1,MSWRP)            WB01 237
      GO TO 26                                                          WB01 238
C                                                                       WB01 239
C     LAY OUT THE SPANWISE LOCATION OF PANEL RMS, YR(I)IN THE PLANFORM  WB01 240
C     PLANE                                                             WB01 241
C     IF THEY WERE NOT READ IN ALREADY                                  WB01 242
C                                                                       WB01 243
   25 YR(1)=0.0                                                         WB01 244
      YR(MSWRP)=B2                                                      WB01 245
      DY=B2/MSWR                                                        WB01 246
      DO 110 I=2,MSWR                                                   WB01 247
      AI=I-1                                                            WB01 248
  110 YR(I)= YR(1)+DY*AI                                                WB01 249
   26 SPANR=B2                                                          WB01 250
      CRPT=CRP                                                          WB01 251
      GO TO 68                                                          WB01 252
C                                                                       WB01 253
C     IF WITH SIDESLIP AND WITHOUT BODY,                                WB01 254
C     YAWED WING GEOMETRY LAID OUT RELATIVE TO LINE FORMED BY           WB01 255
C     INTERSECTION OF STREAMWISE PLANE THROUGH WING ROOT CHORD LE AND   WB01 256
C     WING PLANFORM PLANE (A STREAMWISE LINE)                           WB01 257
C                                                                       WB01 258
   69 CONTINUE                                                          WB01 259
      MSWRP=MSWR+1                                                      WB01 260
      MSWLP=MSWL+1                                                      WB01 261
      MSWUP=MSWU+1                                                      WB01 262
      MSWDP=MSWD+1                                                      WB01 263
      IF(BODY) GO TO 74                                                 WB01 264
      IF (.NOT.ASYM) GO TO 74                                           WB01 265
      IF (LVSWP.NE.0) GO TO 60                                          WB01 266
      SWPLER=SWLEP=BETAY                                                WB01 267
      SWPTER=SWTEP=BETAY                                                WB01 268
      SWPLEL=SWLEP+BETAY                                                WB01 269
      SWPTEL=SWTEP+BETAY                                                WB01 270
      CRPT= CRP*(COSBET+SINBET*TAN(SWPTEL*DTOR))                        WB01 271
      SPANR= (B2/COS(SWLEP*DTOR))*COS(SWPLER*DTOR)+CTP*SINBET           WB01 272
      SPANL= (B2/COS(SWLEP*DTOR))*COS(SWPLEL*DTOR)                      WB01 273
      GO TO 76                                                          WB01 274
C                                                                       WB01 275
C     SET UP SYMMETRIC GEOMETRIC LAYOUT FOR USE LATER WITH NON SYMMETRICWB01 276
C                                                                       WB01 277
   74 SWPLER=SWLEP                                                      WB01 278
      SWPTER=SWTEP                                                      WB01 279
      SWPLEL=SWLEP                                                      WB01 280
      SWPTEL=SWTEP                                                      WB01 281
      CRPT=CRP                                                          WB01 282
      SPANR=B2                                                          WB01 283
      SPANL=B2                                                          WB01 284
   76 CONTINUE                                                          WB01 285
      IF(NCRX.EQ.0) GO TO 77                                            WB01 286
C                                                                       WB01 287
C     CASE FOR VERTICAL WING PANELS                                     WB01 288
C                                                                       WB01 289
      IF(BODY) GO TO 75                                                 WB01 290
      IF (.NOT.ASYM) GO TO 75                                           WB01 291
      SWPLEU=SWLEV+ALFA                                                 WB01 292
      SWPTEU=SWTEV+ALFA                                                 WB01 293
      SWPLED=SWLEV-ALFA                                                 WB01 294
      SWPTED=SWTEV-ALFA                                                 WB01 295
      CRPTV=CRPV*(COSALF+SINALF*TAN(SWPTEU*DTOR))                       WB01 296
      SPANU=(B2V/COS(SWLEV*DTOR))*COS(SWPLEU*DTOR)                      WB01 297
      SPAND=(B2V/COS(SWLEV*DTOR))*COS(SWPLED*DTOR)+CTPV*SINALF          WB01 298
      GO TO 77                                                          WB01 299
   75 SWPLEU=SWLEV                                                      WB01 300
      SWPTEU=SWTEV                                                      WB01 301
      SWPLED=SWLEV                                                      WB01 302
      SWPTED=SWTEV                                                      WB01 303
      CRPTV=CRPV                                                        WB01 304
      SPANU=B2V                                                         WB01 305
      SPAND=B2V                                                         WB01 306
   77 CONTINUE                                                          WB01 307
C                                                                       WB01 308
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C
      SLPWLH= TAN(SWPLEW*DTOR)
      SLPWTR= TAN(SWPTER*DTOR)
      SLPWLL= TAN(SWPLEL*DTOR)
      SLPWTL= TAN(SWPTEL*DTOR)
      IF(NCRX.EQ.0) GO TO 64
      SLPWLU=TAN(SWPLEU*DTOR)
      SLPWLD=TAN(SWPLED*DTOR)
      SLPWTU=TAN(SWPTEU*DTOR)
      SLPWTD=TAN(SWPTED*DTOR)
   64 IF(LVSWP.NE.0) GO TO 60
      GO TO 65
   60 READ (5,713) (YRT(KJ),VSWLER(KJ),VSWTER(KJ),KJ=1,MSWRP)
      SPANR=YRT(MSWRP)
      READ (5,713) (YLT(KJ),VSWLEL(KJ),VSWTEL(KJ),KJ=1,MSWLP)
      SPANL=YLT(MSWLP)
      IF(NCRX.EQ.0) GO TO 68
      READ(5,713) (ZUT(KJ),VSWLEU(KJ),VSWTEU(KJ),KJ=1,MSWUP)
      SPANU=ZUT(MSWUP)
      READ(5,713)  (ZDT(KJ),VSWLED(KJ),VSWTED(KJ),KJ=1,MSWDP)
      SPAND=ZDT(MSWDP)
      GO TO 68
   65 CONTINUE
      YRT(1)=RB
      YRT(MSWRP)=SPANR+RB
      DYR=SPANR/MSWR
      DO 51 I=2,MSWR
      AI=I-1
   51 YRT(I)=DYR*AI+RB
C
      YLT(1)=-RB
      YLT(MSWLP)=-SPANL-RB
      DYL=SPANL/MSWL
      DO 52 I=2,MSWL
      AI=I-1
   52 YLT(I)=-DYL*AI-RB
      IF(NCRX.EQ.0) GO TO 68
C
C     PANELS IN VERTICAL PLANE
C
      ZUT(1)=RB
      ZUT(MSWUP)=SPANU+RB
      DZU=SPANU/MSWU
      DO 54 I=2,MSWU
      AI=I-1
   54 ZUT(I)=DZU*AI+RB
C
      ZDT(1)=-RB
      ZDT(MSWDP)=-SPAND-RB
      DZD=SPAND/MSWD
      DO 55 I=2,MSWD
      AI=I-1
   55 ZDT(I)=-DZD*AI-RB
   68 CONTINUE
C
      IF (LVSWP.EQ.0) GO TO 79
      IF (ASYM.OR.BODY.OR.NCRX.NE.0) GO TO 28
      WRITE (6,764)
      WRITE (6,752)
      DO 29 K=1,MSWRP
   29 WRITE (6,753) K,YR(K),VSWLER(K),VSWTER(K)
      GO TO 79
   28 WRITE (6,754)
      WRITE (6,752)
      DO 80 K=1,MSWRP
   80 WRITE (6,753) K,YRT(K),VSWLER(K),VSWTER(K)
      WRITE (6,755)
      DO 81 K=1,MSWLP
   81 WRITE (6,753) K,YLT(K),VSWLEL(K),VSWTEL(K)
      IF (NCRX.EQ.0) GO TO 79
      WRITE (6,756)
      DO 82 K=1,MSWUP
   82 WRITE (6,753) K,ZUT(K),VSWLEU(K),VSWTEU(K)
      WRITE (6,757)
      DO 83 K=1,MSWDP
   83 WRITE(6,753) K,ZDT(K),VSWLED(K),VSWTED(K)
   79 CONTINUE
C
C     LAY-OUT ELEMENTAL PANELS ON WING
C
      IF(ASYM.OR.BODY.OR.NCRX.NE.0) GO TO 50
      CALL LAYOUT(SLPWLE,SLPWTE,YR,MSWRP,CRP,0,CTP)
      IF (NOUT.EQ.1) WRITE (6,715) ASYM,TLRNC,LEFT
      GO TO 53
   50 CALL LAYOUT(SLPWLR,SLPWTR,YRT,MSWRP,CRPT,0,CTP)
      IF (NOUT.EQ.1) WRITE (6,715) ASYM,TLRNC,LEFT
      CALL LAYOUT(SLPWLL,SLPWTL,YLT,MSWLP,CRPT,1,CTP)
      IF (NOUT.EQ.1) WRITE (6,715) ASYM,TLRNC,LEFT
      IF(NCRX.EQ.0) GO TO 62
      CALL LAYOUT(SLPWLU,SLPWTU,ZUT,MSWUP,CRPTV,2,CTPV)
      IF (NOUT.EQ.1) WRITE (6,715) ASYM,TLRNC,LEFT
      CALL LAYOUT(SLPWLD,SLPWTD,ZDT,MSWDP,CRPTV,3,CTPV)
      IF (NOUT.EQ.1) WRITE (6,715) ASYM,TLRNC,LEFT
C
C     LAY-OUT BODY INTERFERENCE PANELS
C
   62 IF(NBDCR.EQ.0) GO TO 53
      CALL LAYOUT(SLPWLE,SLPWTE,DUMMY,NBDCR,BIL,0,0,0)
      IF (NOUT.EQ.1) WRITE (6,715) ASYM,TLRNC,LEFT
   53 CONTINUE
C
      SMWDTH=WIDTH(1)
      IF(LVSWP .EQ.0) GO TO 545
C
C FIND MINIMUM WIDTH
      DO 535 LL=2,NPANLS
      IF(SMWDTH-WIDTH(LL) .GE.0.0) GO TO 536
  535 CONTINUE
      GO TO 540
  536 SMWDTH=WIDTH(LL)
      GO TO 535
C
  540 IF(NOUT .EQ. 0) GO TO 545
      WRITE(6,733)
      WRITE(6,734)(WIDTH(LL),LL=1,NPANLS)
  545 TLRNC=(SMWDTH*15.E-5)**2
      TOTLR=2.0*TLRNC
      WRITE(6,732)SMWDTH,TLRNC,TOTLR
C
      WRITE(6,701)  SWLEP,SWTEP,CTP,CRP,B2
      IF(NCRX.NE.0) WRITE(6,724) SWLEV,SWTEV,CTPV,CRPV,B2V
      WRITE (6,702) FMACH,ALFAC,PHI,ALFA,BETAY
      WRITE(6,722) SPANR,SPANL,SPANU,SPAND
      WRITE(6,723) CRPT,CRPTV
      IF (NOUT.NE.1) GO TO 7813
      WRITE(6,703)
      WRITE(6,7030)
      WRITE(6,708)
      WRITE(6,706) (J,XLF(J),YLC(J),ZLF(J),XLB(J),YLC(J),ZLB(J),XRF(J),
     1  YRC(J),ZRF(J),XRB(J),YRC(J),ZRB(J),J=1,NRP)
      IF(.NOT.(ASYM.          OR.BODY).AND.NCRX.EQ.0) GO TO 73
      WRITE(6,709)
      WRITE(6,706) (J,XLF(J),YLC(J),ZLF(J),XLB(J),YLC(J),ZLB(J),XRF(J),
     1  YRC(J),ZRF(J),XRB(J),YRC(J),ZRB(J),J=NRP1,NWP)
   73 IF(NCRX.EQ.0) GO TO 71
      WRITE(6,710)
      WRITE(6,706) (J,XLF(J),YLC(J),ZLF(J),XLB(J),YLC(J),ZLB(J),XRF(J),
     1  YRC(J),ZRF(J),XRB(J),YRC(J),ZRB(J),J=NWP1,N3P)
      WRITE(6,711)
      WRITE(6,706) (J,XLF(J),YLC(J),ZLF(J),XLB(J),YLC(J),ZLB(J),XRF(J),
     1  YRC(J),ZRF(J),XRB(J),YRC(J),ZRB(J),J=N3P1,NPANLS)
   71 IF(NBDCR.EQ.0) GO TO 72
      WRITE(6,726)
      WRITE(6,7030)
      WRITE(6,727) XLF(NPANLP),YLC(NPANLP),ZLF(NPANLP),XLB(NPANLP),
     1  YLC(NPANLP),ZLB(NPANLP),XRF(NPANLP),YRC(NPANLP),ZRF(NPANLP),
     1  XRB(NPANLP),YRC(NPANLP),ZRB(NPANLP)
      WRITE (6,717)
      WRITE (6,718) (J,SWPPLE(J),SWPPTE(J),J=1,NWBP)
      GO TO 7813
   72 WRITE(6,717)
      WRITE(6,718) (J,SWPPLE(J),SWPPTE(J),J=1,NPANLS)
 7813 CONTINUE
C
```

```
      DO 10 KM=1,NWBP                                                   WB01 463
      VVRTX(KM)=0.0                                                     WB01 464
      WVRTX(KM)=0.0                                                     WB01 465
      BDU(KM)=0.0                                                       WB01 466
      BDV(KM)=0.0                                                       WB01 467
   10 BDW(KM)=0.0                                                       WB01 468
C                                                                       WB01 469
C                                                                       WB01 470
C     GENERATE BODY SOURCE AND DOUBLET DISTRIBUTION AND CALCULATE       WB01 471
C     INDUCED VELOCITIES DUE TO THEM AT THE WING CONTROL POINTS         WB01 472
C     ( BDU(K), BDV(K), BDW(K) )                                        WB01 473
C                                                                       WB01 474
C     NOTE: SUBROUTINE BODY READS IN NAMELIST BODY                      WB01 475
C                                                                       WB01 476
      IF (.NOT.BODY) GO TO 7811                                         WB01 477
      CALL BODYGEN(ALFR,BETAR)                                          WB01 478
      NSTART=1                                                          WB01 479
      CALL VELCAL(NPANLS,ALFR,BETAR,NSTART)                             WB01 480
 7811 CONTINUE                                                          WB01 481
C                                                                       WB01 482
C                                                                       WB01 483
C     SUBROUTINE VRTVEL READS IN VORTEX STRENGHTS AND Y,Z LOCATIONS     WB01 484
C     ONLY IF NVRTX NE. 0                                               WB01 485
C     THERE ARE NVRTX VORTICES                                          WB01 486
C     COMPUTE EXTERNAL VORTICES INDUCED VELOCITIES AT THE WING CONTROL  WB01 487
C     POINTS                                                            WB01 488
C                                                                       WB01 489
      NSTART=1                                                          WB01 490
      N=NPANLS                                                          WB01 491
      IF (NVRTX.NE.0) CALL VRTVEL(NSTART,N)                             WB01 492
C                                                                       WB01 493
      WRITE(6,704) NCW,MSWR,MSWL,MSWU,MSWD                             WB01 494
      WRITE(6,7051) (J,XCPT(J),YCPT(J),ZCPT(J),BDU(J),BDV(J),BDW(J),   WB01 495
     1VVRTX(J),WVRTX(J),J=1,NPANLS)                                     WB01 496
      IF(.NOT.BODY) GO TO 78                                            WB01 497
      WRITE(6,725)                                                      WB01 498
      WRITE(6,705) (K,XCPT(K),YCPT(K),ZCPT(K),K=NPANLP,NWBP)           WB01 499
   78 CONTINUE                                                          WB01 500
C                                                                       WB01 501
C                                                                       WB01 502
C     SET UP INFLUENCE COEFFICIENT MATRIX                               WB01 503
C                                                                       WB01 504
C     CALCULATE THE INFLUENCE OF EACH PANEL ON EACH CONTROL POINT       WB01 505
C     II AND IF ARE THE LIMITS FOR SUMMATION OF THE INFLUENCE FUNCTION  WB01 506
C     IN SUBROUTINE VELNOR                                              WB01 507
C     IF II = IF, THE INFLUENCE OF A SINGLE PANEL AT A POINT RESULTS    WB01 508
C     AS IN THE COMPUTATION OF THE ARRAY FVN.  IF II=1 AND IF=NPANLS,   WB01 509
C     THE INFLUENCES ARE SUMMED OVER ALL PANELS, AS IN THE COMPUTATION  WB01 510
C     RESULTANT VELOCITIES BELOW....                                    WB01 511
C                                                                       WB01 512
C     === I IS THE INDEX OF THE INFLUENCING PANEL                       WB01 513
C                                                                       WB01 514
C                                                                       WB01 515
      JJ=0                                                              WB01 516
      NOCPT=0                                                           WB01 517
      DO 450 I=1,NWBP                                                   WB01 518
      II=I                                                              WB01 519
      IF=I                                                              WB01 520
C                                                                       WB01 521
C     J IS THE INDEX OF THE INFLUENCED PANEL                            WB01 522
C                                                                       WB01 523
      DO 425 J=1,NWBP                                                   WB01 524
      JB=J-NPANLS                                                       WB01 525
      CALL VELNOR(XCPT(J),YCPT(J),ZCPT(J))                              WB01 526
      JJ=JJ+1                                                           WB01 527
      IF(J.LE.NPANLS) GO TO 417                                         WB01 528
C                                                                       WB01 529
C     INFLUENCED PANEL IS A BIP.  RESOLVE WING-FRAME VELOCITIES INTO    WB01 530
C     BIP FRAME                                                         WB01 531
C                                                                       WB01 532
      CALL ROTWB (VCHK,WCHK,VV,WW,JB)                                   WB01 533
      GO TO 418                                                         WB01 534
  417 VV=VCHK                                                           WB01 535
      WW=WCHK                                                           WB01 536
  418 IF(J.GT.NHP.AND.J.LE.NPANLS) GO TO 426                            WB01 537
      FVN(JJ)=WW                                                        WB01 538
      GO TO 425                                                         WB01 539
  426 FVN(JJ)=VV                                                        WB01 540
  425 CONTINUE                                                          WB01 541
      IF (ABS(FVN(JJ)).LT.1.0E-10) FVN(JJ)=0.0                          WB01 542
  450 CONTINUE                                                          WB01 543
C                                                                       WB01 544
C     DEBUG DUMP OF THE FVN ARRAY                                       WB01 545
C                                                                       WB01 546
      IF(NFVNPR.EQ.0) GO TO 618                                         WB01 547
      WRITE (6,707)                                                     WB01 548
      CALL OUT(FVN,NWBP)                                                WB01 549
  618 CONTINUE                                                          WB01 550
      CALL LINEQS(NWBP,FVN)                                             WB01 551
C                                                                       WB01 552
C     SET UP SINGLE COLUMN MATRIX RHS FOR RIGHT HAND SIDE               WB01 553
C     IT REPRESENTS THE EXTERNALLY INDUCED VELOCITIES AND ANGLE OF      WB01 554
C     ATTACK                                                            WB01 555
C                                                                       WB01 556
C     CASE FOR WING PANEL ALL AT SAME ANGLE AS BODY                     WB01 557
C                                                                       WB01 558
      IF(DELTA) GO TO 627                                               WB01 559
      DO 620 I=1,NWBP                                                   WB01 560
      IF (I.LE.NHP.AND.ABS(WVRTX(I)).GT.VRTMAX) GO TO 631               WB01 561
      WADVRT=WVRTX(I)                                                   WB01 562
      GO TO 632                                                         WB01 563
  631 IF (WVRTX(I).LT.0.0) WADVRT=-VRTMAX                               WB01 564
      IF (WVRTX(I).GT.0.0) WADVRT= VRTMAX                               WB01 565
      GO TO 633                                                         WB01 566
  632 IF (I.GT.NHP.AND.I.LE.NPANLS.AND.ABS(VVRTX(I)).GT.VRTMAX) GO TO634WB01 567
      VADVRT=VVRTX(I)                                                   WB01 568
      GO TO 633                                                         WB01 569
  634 IF (VVRTX(I).LT.0.0) VADVRT=-VRTMAX                               WB01 570
      IF (VVRTX(I).GT.0.0) VADVRT= VRTMAX                               WB01 571
  633 CONTINUE                                                          WB01 572
      IF(I.LE.NHP) GO TO 602                                            WB01 573
      IF(I.LE.NPANLS) GO TO 604                                         WB01 574
      RHS(I)=0.0                                                        WB01 575
      GO TO 620                                                         WB01 576
  602 RHS(I)=-ALFR-BDW(I)-WADVRT                                        WB01 577
      GO TO 620                                                         WB01 578
  604 RHS(I)=BETAR-BDV(I)-VADVRT                                        WB01 579
  620 CONTINUE                                                          WB01 580
      GO TO 646                                                         WB01 581
C                                                                       WB01 582
C     RIGHT HAND SIDE FOR PANELS TILTED WITH RESPECT TO BODY            WB01 583
C                                                                       WB01 584
  627 CONTINUE                                                          WB01 585
      DO 645 K=1,NWBP                                                   WB01 586
      IF (K.LE.NHP.AND.ABS(WVRTX(K)).GT.VRTMAX) GO TO 649               WB01 587
      WADVRT=WVRTX(K)                                                   WB01 588
      GO TO 651                                                         WB01 589
  649 IF (WVRTX(K).LT.0.0) WADVRT=-VRTMAX                               WB01 590
      IF (WVRTX(K).GT.0.0) WADVRT= VRTMAX                               WB01 591
      GO TO 653                                                         WB01 592
  651 IF (K.GT.NHP.AND.K.LE.NPANLS.AND.ABS(VVRTX(K)).GT.VRTMAX) GO TO   WB01 593
     X652                                                               WB01 594
      VADVRT=VVRTX(K)                                                   WB01 595
      GO TO 653                                                         WB01 596
  652 IF (VVRTX(K).LT.0.0) VADVRT=-VRTMAX                               WB01 597
      IF (VVRTX(K).GT.0.0) VADVRT= VRTMAX                               WB01 598
  653 CONTINUE                                                          WB01 599
      IF(K.LE.NRP) GO TO 641                                            WB01 600
      IF(K.LE.NHP) GO TO 642                                            WB01 601
      IF(K.LE.N3P) GO TO 643                                            WB01 602
      IF(K.LE.NPANLS) GO TO 644                                         WB01 603
      RHS(K)=0.0                                                        WB01 604
      GO TO 645                                                         WB01 605
  641 RHS(K)=-ANGLR-RDW(K)-WADVRT                                       WB01 606
      GO TO 645                                                         WB01 607
  642 RHS(K)=-ANGLL-RDW(K)-WADVRT                                       WB01 608
      GO TO 645                                                         WB01 609
  643 RHS(K)=ANGLU-BDV(K)-VADVRT                                        WB01 610
      GO TO 645                                                         WB01 611
  644 RHS(K)=ANGLD-BDV(K)-VADVRT                                        WB01 612
  645 CONTINUE                                                          WB01 613
      IF (NOUT.EQ.0) GO TO 648                                          WB01 614
  646 CONTINUE                                                          WB01 615
                                                                        WB01 616
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      IF(NOUT.EQ.0) GO TO 648                                          WB01 617
      WRITE(6,728)                                                     WB01 618
      WRITE(6,729) (K,RHS(K),K=1,NWBP)                                 WB01 619
  648 CONTINUE                                                         WB01 620
      CALL SOLVE(RHS,FVN,NWBP)                                         WB01 621
      IF (NOUT.NE.0) WRITE(6,731)                                      WB01 622
      DO 630 I=1,NWBP                                                  WB01 623
      DEMONP=RHS(I)*CONST                                              WB01 624
      DELTP(I)=DEMONP                                                  WB01 625
      IF (ABS(DELTP(I)).LT.1.0E-10) DELTP(I)=0.0                       WB01 626
      IF (NOUT.EQ.0) GO TO 630                                         WB01 627
      WRITE(6,729) I,DELTP(I)                                          WB01 628
  630 CONTINUE                                                         WB01 629
C                                                                      WB01 630
C                                                                      WB01 631
C     CALCULATE LOADINGS ON THE WINGS OR FINS WITH LINEAR PRESSURE     WB01 632
C     LOADINGS                                                         WB01 633
C                                                                      WB01 634
      IF (NPRESS.EQ.0) CALL LOADS                                      WB01 635
C                                                                      WB01 636
C                                                                      WB01 637
C     NON LINEAR PRESSURE LOADING CALCULATION                          WB01 638
C     SURFACES                                                         WB01 639
C     NVRTPL=0 MEANS EXCLUDE VORTEX INDUCED VELOCITIES PARALLEL TO WING WB01 640
C                                                                      WB01 641
      IF (NOLINP.EQ.0) GO TO 200                                       WB01 642
      NVRTPL=0                                                         WB01 643
      CALL SPECPR                                                      WB01 644
C                                                                      WB01 645
C                                                                      WB01 646
C     REPEAT INCLUDING VORTEX VELOCITIES PARALEEL TO WING SURFACES     WB01 647
C                                                                      WB01 648
      IF (NVRTX.EQ.0) GO TO 999                                        WB01 649
      NVRTPL=1                                                         WB01 650
      CALL SPECPR                                                      WB01 651
  200 CONTINUE                                                         WB01 652
      GO TO 999                                                        WB01 653
      END                                                              WB01 654
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        SUBROUTINE LOADS                                               WB03   1
C                                                                      WB03   2
      DIMENSION FX(350),BLOAD(50),FY(350),FZ(350),DLTPG(350),BFY(200),WB03   3
     1   BFZ(200)                                                      WB03   4
C                                                                      WB03   5
      LOGICAL DELTA,ANY,ANYMORE                                        WB03   6
      LOGICAL ASYM                                                     WB03   7
C                                                                      WB03   8
      COMMON/SWEEPS/VSWLER(50),VSWTER(50),VSWLEL(50),VSWTEL(50),       WB03   9
     1   VSWLEU(50),VSWTEU(50),VSWLED(50),VSWTED(50),LVSWP,LEFT,FAC,   WB03  10
     2   NCWB,ARWNL(350),WIDTH(350)                                    WB03  11
      COMMON/PRESS/DELTP(350),XRF(350),XRB(350),XLF(350),XLB(350),     WB03  12
     1   YLC(350),YRC(350),COSALF,NPANLS,ARWING,FMACH,ALFA,FN(350),    WB03  13
     2   SINALF,DELTA                                                  WB03  14
      COMMON/THRUST/CN,XBAR(350),ZBAR(350),YCPT(350),VNOR(350),CIRC(350)WB03  15
     1   ,PNLC(350),MCW,MSWR,MSWL,MSWU,MSWD,NRP,NWP,N3P,B2,B2V,XCPT(350)WB03  16
     2   ,ZCPT(350)                                                    WB03  17
      COMMON/VWNOR/SWPPLE(350),SWPPTE(350),ZLF(350),ZRF(350),ZLB(350), WB03  18
     1   ZRB(350),ASYM,UP,VP,WP,II,IF,CONST,BETAR,SINBET,COSBET        WB03  19
      COMMON/IPR/NPR,I,J                                               WB03  20
      COMMON/TRANS/NBIP,RB,DX,WBIP,XFBIP(200),SNT(200),CST(200),       WB03  21
     1   SNT2(200),CST2(200)                                           WB03  22
      COMMON /TILT/ANGLR,ANGLL,ANGLU,ANGLD,DELR,DELL,DELU,DELD         WB03  23
      COMMON/REF/SREF,REFL                                             WB03  24
      COMMON/CRUX/NCRX                                                 WB03  25
      COMMON/BVEL/BDU(350),BDV(350),BDW(350)                           WB03  26
      COMMON/NONLIN/NWBP,NOLINP,TOTLR,BODY,ALFR,NOUT,NPRESS,NOCPT,NDRAG WB03  27
      COMMON/SPCPRS/DLTP(350),DLTP2(350),DLTP3(350),DLTP1(350)         WB03  28
      COMMON/VELARG/DUM(10),TLRNC,TIPY                                 WB03  29
C                                                                      WB03  30
C                                                                      WB03  31
  701 FORMAT(1H1,25X,21HWING PANEL PROPERTIES//2X,1HJ,5X,7HYCPT(J),3X, WB03  32
     1                  10HCHORD THRU,4X,5HPANEL,3X,8HIDCHORD,5X,     WB03  33
     1 6HDELTA=,6X,                                                   WB03  34
     1 17HGAMMA/V,3X,9HVNOR/V AT,6X,2HFX, 8X,2HFY,8X,2HFZ,8X,2HFN/    WB03  35
     1                  10X,8HCENTROID,6X,6HBPAN,5X,9HSWEEP,DEG,      WB03  36
     2  5X,2HCP,16X,10HPANEL CENTROID//)                              WB03  37
  702 FORMAT(//51X,21HSPANWISE DISTRIBUTION//)                         WB03  38
  703 FORMAT(10X,I2,5X,F10.5,2X,F10.5,2X,F10.5)                        WB03  39
  705 FORMAT (8X,I3,7X,F10.5,2X,F10.5,2X,F10.5,2X,F10.5,2X,F10.5,      WB03  40
     12X,F10.5,2X,F10.5)                                             WB03  41
  706 FORMAT (1X,I5,1X,F10.5,1X,F10.5,1X,F10.5,1X,F10.5,1X,F10.5,1X,F10.WB03  42
     1 5,1X,F10.5,1X,F10.5,1X,F10.5,1X,F10.5,1X,F10.5)               WB03  43
  707 FORMAT(1H1,20X,31HBODY INFLUENCE PANEL PROPERTIES//2X,1HJ,5X,    WB03  44
     1  7HYCPT(J),4X,6HLENGTH,6X,5HWIDTH,4X,8HTHETA(J),5X,5HFY(J),7X, WB03  45
     2  5HFZ(J),6X,5HFN(J),4X,8HDELTA=CP/)                            WB03  46
  716 FORMAT(1H1,25X,35HVELOCITIES AT PANEL CENTROID POINTS//          WB03  47
     1  10X,1HJ,11X,7HXBAR(J),5X,7HYBAR(J),5X,7HZBAR(J),9X,1HU,11X,   WB03  48
     2  1HV,11X,1HW,8X,4HVNOR//)                                      WB03  49
  717 FORMAT(1H1,40HTHRUST, LIFT, AND SIDE FORCE INFORMATION//         WB03  50
     X  11X,18HMACH NUMBER = ,E12.5/                                  WB03  51
     1  7X,18HANGLE OF ATTACK = ,F8.3,1X,7HDEGREES/                   WB03  52
     27X,18HSIDE SLIP ANGLE = ,F8.3,1X,7HDEGREES/                     WB03  53
     3 13X,12HWING AREA = ,F8.3/                                      WB03  54
     4 8X,17HREFERENCE AREA = ,F8.5/                                  WB03  55
     5 6X,19HREFERENCE LENGTH = ,F8.5///)                             WB03  56
  718 FORMAT(/29X,5HTOTAL,12X,10HRIGHT WING,9X,9HLEFT WING,8X,10HUPPER WWB03  57
     1ING,8X,10HLOWER WING/                                           WB03  58
     1  6X,19HDEFL. ANGLE DEG. = ,12X,4(6X,F12.5)/                    WB03  59
     2  20X,5HCN = ,E12.5,2(6X,E12.5)/                                WB03  60
     3  20X,5HCY = ,E12.5,36X,2(6X,E12.5)/                            WB03  61
     5  15X,10HCTHRUST = ,E12.5,4(6X,E12.5)/                          WB03  62
     6  20X,5HCL = ,E12.5,4(6X,E12.5)/                                WB03  63
     7  19X,6HCDI = ,E12.5,4(6X,E12.5)///                             WB03  64
     8  13X,12HCDI/CL**2 = ,E12.5/                                    WB03  65
     9  16X,9HCNADDV = ,E12.5/                                        WB03  66
     X  16X,9HCYADDM = ,E12.5/                                        WB03  67
     1  15X,10HCY-BIP  = E12.5/                                       WB03  68
     2  15X,10HCN-BIP  = ,E12.5///                                    WB03  69
     315X,10HROLMOMR = ,E12.5/                                        WB03  70
     315X,10HROLMOML = ,E12.5/                                        WB03  71
     315X,10HROLMOMU = ,E12.5/                                        WB03  72
     315X,10HROLMOMD = ,E12.5)                                        WB03  73
  719 FORMAT (///5X,23HROLLING MOMENT        =,F10.5/                 WB03  74
     15X,22HBETA                  =,F10.5,2X,8HDEGREES,/)             WB03  75
  721 FORMAT(/1X,20(1H=),A10,21(1H=))                                  WB03  76
  723 FORMAT(11X,1HI,6X,7HZ/(B/2),2X,10HCY*C/(2*B),2X,10HCT*C/(2*B))   WB03  77
  724 FORMAT(11X,1HI,6X,7HY/(B/2),2X,10HCN*C/(2*B),2X,10HCT*C/(2*B)/)  WB03  78
  725 FORMAT (//1X,28HU/VINF TYPE LOADING PRESSURE//)                  WB03  79
  726 FORMAT (//1X,32HBERNOUILLI TYPE LOADING PRESSURE//)              WB03  80
  727 FORMAT (//1X,36HFULL 2ND ORDER TYPE LOADING PRESSURE//)          WB03  81
  728 FORMAT (//1X,31HUBAR/VINF TYPE LOADING PRESSURE//)               WB03  82
  729 FORMAT (//1X,31H1ST ORDER TYPE LOADING PRESSURE//)               WB03  83
  730 FORMAT(/,9X,F8.4,F11.4,F10.4,F9.4/)                              WB03  84
  731 FORMAT(/,3X,9HBODY RING,5X,7HCZ,RING,3X,7HCY,RING,6X,5HCZMOM,4X, WB03  85
     1  5HCYMOM,6X,10HCNB,ACCUM.,3X,6HXCP,CZ,6X,10HCYB,ACCUM.,3X,      WB03  86
     2  6HXCP,CY/6X,I3,F15.5,F10.5,F11.5,F9.5,F15.5,F10.5,F15.5,F10.5/) WB03  87
C                                                                      WB03  88
C                                                                      WB03  89
      DATA AR=/10HRIGHT WING/,ALW/10H LEFT WING/,AUW/10HUPPER WING/,   WB03  90
     1 ADW/10HLOWER WING/                                             WB03  91
C                                                                      WB03  92
C                                                                      WB03  93
C                                                                      WB03  94
C     CALCULATE WING AND BODY PANEL INDUCED VELOCITIES AT THE CENTROID WB03  95
C     POINTS                                                           WB03  96
C                                                                      WB03  97
      IF (NDRAG.EQ.0) GO TO 513                                        WB03  98
      NOCPT=1                                                          WB03  99
      II=1                                                             WB03 100
      IF=NWBP                                                          WB03 101
      NPR=0                                                            WB03 102
      IF(NOUT.EQ.1) WRITE (6,716)                                      WB03 103
      DO 510 J=1,NPANLS                                                WB03 104
      CALL VELNOR(XBAR(J),YCPT(J),ZBAR(J))                             WB03 105
      UCT=UP                                                           WB03 106
      VCT=VP                                                           WB03 107
      WCT=WP                                                           WB03 108
      IF(J.GT.NWP) GO TO 509                                           WB03 109
      VNOR(J)=WP                                                       WB03 110
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      GO TO 512                                                          WB03 111
  509 VNOR(J)=VP                                                         WB03 112
  512 CONTINUE                                                           WB03 113
      IF (NOUT,NE,1) GO TO 510                                           WB03 114
      WRITE (6,705) J,XBAR(J),YCPT(J),ZBAR(J),UCT,VCT,WCT,VNOR(J)        WB03 115
  510 CONTINUE                                                           WB03 116
  513 CONTINUE                                                           WB03 117
C                                                                        WB03 118
C                                                                        WB03 119
C     RE-ENTER HERE FOR NONLINEAR PRESSURE LOADINGS                      WB03 120
C                                                                        WB03 121
      ENTRY SPECLD                                                       WB03 122
C                                                                        WB03 123
C     INITIALIZE VARIABLES                                               WB03 124
C                                                                        WB03 125
      DTOR=0.0174533                                                     WB03 126
      ALPAR= ALFA*DTOR                                                   WB03 127
      AREA=0.0                                                           WB03 128
      CY=0.0                                                             WB03 129
      CN=0.0                                                             WB03 130
      CNR=0.                                                             WB03 131
      CNL=0.                                                             WB03 132
      CYU=0.                                                             WB03 133
      CYD=0.                                                             WB03 134
      CTHRR=0.                                                           WB03 135
      CTHRL=0.                                                           WB03 136
      CTHRU=0.                                                           WB03 137
      CTHRD=0.                                                           WB03 138
      CNADDV=0.0                                                         WB03 139
      CYADDH=0.0                                                         WB03 140
      ROLMR=0.0                                                          WB03 141
      ROLML=0.0                                                          WB03 142
      ROLMU=0.0                                                          WB03 143
      ROLMD=0.0                                                          WB03 144
      ANY=ABVM.OR.NBIP.NE.0.          OR.NCRX.GT.0                       WB03 145
      ANYMORE=(NBIP.NE.0.          OR.NCRX.GT.0).AND.(.NOT.ABVM)         WB03 146
      BETAY= BETAR/DTOR                                                  WB03 147
C                                                                        WB03 148
      DO 902 I=1,NPANLS                                                  WB03 149
      IF (NPRESS.EQ.0) DLTPG(I)=DELTP(I)                                 WB03 150
      IF (NPRESS.EQ.1) DLTPG(I)=DLTP(I)                                  WB03 151
      IF (NPRESS.EQ.4) DLTPG(I)=DLTP1(I)                                 WB03 152
      IF (NPRESS.EQ.2) DLTPG(I)=DLTP2(I)                                 WB03 153
      IF (NPRESS.EQ.3) DLTPG(I)=DLTP3(I)                                 WB03 154
  902 CONTINUE                                                           WB03 155
C                                                                        WB03 156
C                                                                        WB03 157
C     CN CONTRIBUTION OF BODY INTERFERENCE PANELS,CNB AND CY CONTRIBUTION WB03 158
C     CYB                                                                WB03 159
C     WRITE OUT BIP PANEL PROPERTIES                                     WB03 160
C                                                                        WB03 161
      IF(NBIP.EQ.0) GO TO 160                                            WB03 162
      IF (NPRESS.NE.0) GO TO 160                                         WB03 163
      AREAP=NBIP*DX                                                      WB03 164
      WRITE (6,707)                                                      WB03 165
      K=0                                                                WB03 166
      CYB=0.0                                                            WB03 167
      CNB=0.0                                                            WB03 168
      CZTOTM=0.0                                                         WB03 169
      CYTOTM=0.0                                                         WB03 170
      DO 142 IRING=1,NCWB                                                WB03 171
      CZRING=0.0                                                         WB03 172
      CYRING=0.0                                                         WB03 173
      NBDCR=NBIP/NCWB                                                    WB03 174
      DO 141 JR=1,NBDCR                                                  WB03 175
      K=K+1                                                              WB03 176
      I=K+NPANLS                                                         WB03 177
      F=DELTP(I)*AREAP                                                   WB03 178
      FN(I)=F                                                            WB03 179
      CALL ROTM=(0.,F,BFY(K),BFZ(K),K)                                   WB03 180
      CNB=CNB+BFZ(K)/SREF                                                WB03 181
      THTI=ATAN2(SNT(K),CST(K))*57.2957795                               WB03 182
      IF(THTI.LT.0.) THTI=THTI+360.                                      WB03 183
      L=I                                                                WB03 184
      CYB=CYB+BFY(K)/SREF                                                WB03 185
      CZRING=CZRING+BFZ(K)                                               WB03 186
      CYRING=CYRING+BFY(K)                                               WB03 187
      WRITE(6,706) L,YCPT(L),DX,WBIP,THTI,BFY(K),BFZ(K),FN(L),DELTP(L)   WB03 188
  141 CONTINUE                                                           WB03 189
      CZRING=CZRING/SREF                                                 WB03 190
      CYRING=CYRING/SREF                                                 WB03 191
      IF(IRING.EQ.1) GO TO 143                                           WB03 192
      GO TO 144                                                          WB03 193
  143 XMOM=DX/2.0                                                        WB03 194
      GO TO 145                                                          WB03 195
  144 XMOM=XMOM+DX                                                       WB03 196
  145 CZMOM=CZRING*XMOM                                                  WB03 197
      CYMOM=CYRING*XMOM                                                  WB03 198
      CZTOTM=CZTOTM+CZMOM                                                WB03 199
      IF(ABS(CNB).LT.TLRNC) GO TO 146                                    WB03 200
      CYTOTM=CYTOTM+CYMOM                                                WB03 201
      CPCZB=CZTOTM/CNB                                                   WB03 202
      IF(ABS(CYB).LT.TLRNC) GO TO 146                                    WB03 203
      CPCYB=CYTOTM/CYB                                                   WB03 204
  146 WRITE(6,751) IRING,CZRING,CYRING,CZMOM,CYMOM,CNB,CPCZB,CYB,CPCYB   WB03 205
  142 CONTINUE                                                           WB03 206
  160 CONTINUE                                                           WB03 207
C                                                                        WB03 208
C                                                                        WB03 209
C     CALCULATE NORMAL FORCE, CN, AND SIDE FORCE, CY                     WB03 210
C     RIGHT HAND WING PANELS                                             WB03 211
C     CN CONTRIBUTION OF RIGHT HORIZONTAL WING, CNR                      WB03 212
C                                                                        WB03 213
C     CALCULATE CTHRST,CDI,AND *ADDITIONAL* TERMS OF CY AND CN           WB03 214
C     CONTRIBUTED TO CN BY THE VERTICAL WING, AND TO CY BY THE           WB03 215
C     HORIZONTAL WING, CNADDV AND CYADDH RESPECTIVELY                    WB03 216
C     FX,....,THRUST FORCE IN NEG. X-DIR. IN PLANE OF WING/Q*AR=WING     WB03 217
C     FY,....,SIDE FORCE IN Y-DIRECTION IN PLANE OF WING/Q*AR=WING       WB03 218
C     FZ,....,UPWARDS FORCE IN Z-DIR. IN PLANE OF VERTICAL WING          WB03 219
C                                                                        WB03 220
C     RIGHT WING                                                         WB03 221
C                                                                        WB03 222
      IF (NDRAG.NE.0) WRITE (6,701)                                      WB03 223
      DO 300 J=1,NRP                                                     WB03 224
      AREA=AREA+ARPNL(J)                                                 WB03 225
      I=J                                                                WB03 226
      F=    ARPNL(J)*DLTPG(I)                                            WB03 227
      FN(I)=F                                                            WB03 228
      YCHK= YCPT(I)*COSBET-XBAR(I)*SINBET                                WB03 229
      IF (ANYMORE  ) YCHK=YCPT(I)                                        WB03 230
      ROLMR= -FN(I)*YCHK+ROLMR                                           WB03 231
      CNR=CNR+F                                                          WB03 232
      IF (NDRAG.EQ.0) GO TO 300                                          WB03 233
      CIRC(J)=0.5*DLTPG(J)*PNLC(J)                                       WB03 234
      SLPMC=0.5*(SWPPLE(J)+SWPPTE(J))                                    WB03 235
      SWPMC=ATAN(SLPMC)*57.2957795                                       WB03 236
      FX(J)=2.*WIDTH(J)*CIRC(J)*(ANGLR*VNOR(J)+BDW(J))                   WB03 237
      FY(J)=FX(J)*SLPMC                                                  WB03 238
      CYADDH=CYADDH+FY(J)*FX(J)*BETAR                                    WB03 239
      IF (ANYMORE) CYADDH=CYADDH+FY(J)                                   WB03 240
      CTHRR=CTHRR+FX(J)*FY(J)*BETAR                                      WB03 241
      IF (ANYMORE) CTHRR=CTHRR+FX(J)                                     WB03 242
      WRITE (6,706) J,YCPT(J),PNLC(J),WIDTH(J),SWPMC,DLTPG(J),CIRC(J),   WB03 243
     1  VNOR(J),FX(J),FY(J),FZ(J),FN(J)                                  WB03 244
  300 CONTINUE                                                           WB03 245
      IF(ANY) GO TO 301                                                  WB03 246
      CNL = CNR                                                          WB03 247
      ROLML=-ROLMR                                                       WB03 248
      CTHRL=CTHRR                                                        WB03 249
      CYADDH=0.0                                                         WB03 250
      AREA=2.0*AREA                                                      WB03 251
      GO TO 311                                                          WB03 252
  301 CONTINUE                                                           WB03 253
C                                                                        WB03 254
C     LEFT WING                                                          WB03 255
C     CN CONTRIBUTION OF LEFT HORIZONTAL WING, CNL                       WB03 256
C                                                                        WB03 257
      NRP1=NRP+1                                                         WB03 258
      DO 310 J=NRP1,NMP                                                  WB03 259
      I=J                                                                WB03 260
      F=    ARPNL(J)*DLTPG(I)                                            WB03 261
      FN(I)=F                                                            WB03 262
      YCHK= YCPT(I)*COSBET-XBAR(I)*SINBET                                WB03 263
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      IF (ANYMORE  ) YCHK=YCPT(I)                                       WB03 265
      ROLML= =FN(I)*YCHK+ROLML                                          WB03 266
      CNL=CNL+F                                                         WB03 267
      IF (NDRAG,EQ,0) GO TO 310                                         WB03 268
      CIRC(J)=0,5*DLTPG(J)*PNLC(J)                                      WB03 269
      SLPMC=0,5*(S=PPLE(J) +S=PPTE(J))                                  WB03 270
      SWPMC=ATAN(SLPMC)*57,2957795                                      WB03 271
      FX(J)=2,*=IDTH(J)*CIRC(J)*(ANGLL+VNOR(J)+BDW(J))                  WB03 272
      FY(J)=FX(J)*SLPMC                                                 WB03 273
      CTHRL=CTHRL+FX(J)=FY(J)*BETAR                                     WB03 274
      IF (ANYMORE) CTHRL=CTHRL+FX(J)                                    WB03 275
      CYADDH=CYADDH+FY(J)+FX(J)*BETAR                                   WB03 276
      IF (ANYMORE) CYADDH=CYADDH+FY(J)                                  WB03 277
      WRITE (6,706) J,YCPT(J),PNLC(J),WIDTH(J),SWPMC,DLTPG(J),CIRC(J),  WB03 278
     1  VNOR(J),FX(J),FY(J),FZ(J),FN(J)                                 WB03 279
  310 CONTINUE                                                          WB03 280
  311 CONTINUE                                                          WB03 281
      IF(NHP,EQ,NPANLS) GO TO 350                                       WB03 282
C                                                                       WB03 283
C     UPPER VERTICAL WING                                               WB03 284
C     CY CONTRIBUTION OF UPPER VERTICAL WING, CYU                       WB03 285
C                                                                       WB03 286
      NHP1=NHP+1                                                        WB03 287
      DO 320 J=NHP1,N3P                                                 WB03 288
      I=J                                                               WB03 289
      F=    ARPNL(J)*DLTPG(I)                                           WB03 290
      FN(I)=F                                                           WB03 291
      ZCHK= ZCPT(I)*COSALF+XBAR(I)*SINALF                               WB03 292
      IF (ANYMORE  ) ZCHK=ZCPT(I)                                       WB03 293
      ROLMU=-FN(I)*ZCHK+ROLMU                                           WB03 294
      CYU=CYU-F                                                         WB03 295
      IF (NDRAG,EQ,0) GO TO 320                                         WB03 296
      SLPMC=0,5*(SWPPLE(J)+SWPPTE(J))                                   WB03 297
      SWPMC=ATAN(SLPMC)*57,2957795                                      WB03 298
      CIRC(J)=0,5*DLTPG(J)*PNLC(J)                                      WB03 299
      FX(J)=2,*WIDTH(J)*CIRC(J)*(ANGLU-VNOR(J)-BDV(J))                  WB03 300
      FZ(J)=FX(J)*SLPMC                                                 WB03 301
      CNADDV=CNADDV+FZ(J)=FX(J)*ALFAR                                   WB03 302
      IF (ANYMORE) CNADDV= CNADDV+FZ(J)                                 WB03 303
      CTHRU=CTHRU+FX(J)+FZ(J)*ALFAR                                     WB03 304
      IF (ANYMORE) CTHRU=CTHRU+FX(J)                                    WB03 305
      WRITE (6,706) J,YCPT(J),PNLC(J),WIDTH(J),SWPMC,DLTPG(J),CIRC(J),  WB03 306
     1  VNOR(J),FX(J),FY(J),FZ(J),FN(J)                                 WB03 307
  320 CONTINUE                                                          WB03 308
      IF(ANY) GO TO 321                                                 WB03 309
      CYD=CYU                                                           WB03 310
      ROLMD=-ROLMU                                                      WB03 311
      CNADDV=0,0                                                        WB03 312
      CTHRD=CTHRU                                                       WB03 313
      GO TO 350                                                         WB03 314
  321 CONTINUE                                                          WB03 315
C                                                                       WB03 316
C     LOWER VERTICAL WING                                               WB03 317
C     CY CONTRIBUTION OF LOWER VERTICAL WING, CYD                       WB03 318
C                                                                       WB03 319
      N3P1=N3P+1                                                        WB03 320
      DO 330 J=N3P1,NPANLS                                              WB03 321
      I=J                                                               WB03 322
      F=    ARPNL(J)*DLTPG(I)                                           WB03 323
      FN(I)=F                                                           WB03 324
      ZCHK= ZCPT(I)*COSALF+XBAR(I)*SINALF                               WB03 325
      IF (ANYMORE  ) ZCHK=ZCPT(I)                                       WB03 326
      ROLMD=-FN(I)*ZCHK+ROLMD                                           WB03 327
      CYD=CYD+F                                                         WB03 328
      IF (NDRAG,EQ,0) GO TO 330                                         WB03 329
      CIRC(J)=0,5*DLTPG(J)*PNLC(J)                                      WB03 330
      SLPMC=0,5*(SWPPLE(J)+SWPPTE(J))                                   WB03 331
      SWPMC=ATAN(SLPMC)*57,2957795                                      WB03 332
      FX(J)=2,*=IDTH(J)*CIRC(J)*(ANGLD-VNOR(J)-BDV(J))                  WB03 333
      FZ(J)=FX(J)*SLPMC                                                 WB03 334
      CNADDV=CNADDV+FZ(J)=FX(J)*ALFAR                                   WB03 335
      IF (ANYMORE) CNADDV= CNADDV+FZ(J)                                 WB03 336
      CTHRD=CTHRD+FX(J)+FZ(J)*ALFAR                                     WB03 337
      IF (ANYMORE) CTHRD=CTHRD+FX(J)                                    WB03 338
      WRITE (6,706) J,YCPT(J),PNLC(J),WIDTH(J),SWPMC,DLTPG(J),CIRC(J),  WB03 339
     1  VNOR(J),FX(J),FY(J),FZ(J),FN(J)                                 WB03 340
  330 CONTINUE                                                          WB03 341
  350 CONTINUE                                                          WB03 342
C                                                                       WB03 343
C                                                                       WB03 344
      CNR=CNR/SREF                                                      WB03 345
      CNL=CNL/SREF                                                      WB03 346
      CYU=CYU/SREF                                                      WB03 347
      CYD=CYD/SREF                                                      WB03 348
      ROLMR=ROLMR/(REFL*SREF)                                           WB03 349
      ROLML=ROLML/(REFL*SREF)                                           WB03 350
      ROLMU=ROLMU/(REFL*SREF)                                           WB03 351
      ROLMD=ROLMD/(REFL*SREF)                                           WB03 352
C                                                                       WB03 353
C                                                                       WB03 354
C                                                                       WB03 355
C     CALCULATE CDI FOR EACH WING AND TOTAL CDI, CTHRST, CN, CY         WB03 356
C                                                                       WB03 357
      IF (NDRAG,EQ,0) GO TO 201                                         WB03 358
      CDIR=CNR*ANGLR=CTHRR/SREF                                         WB03 359
      CDIL=CNL*ANGLL=CTHRL/SREF                                         WB03 360
      CDID=-CYD*ANGLD=CTHRD/SREF                                        WB03 361
      CDIU=-CYU*ANGLU=CTHRU/SREF                                        WB03 362
      CDI=CDIR+CDIL+CDIU+CDID                                           WB03 363
      CTHRST=(CTHRR+CTHRL+CTHRU+CTHRD)/SREF                             WB03 364
      CNADDV=CNADDV/SREF                                                WB03 365
      CYADDH=CYADDH/SREF                                                WB03 366
C                                                                       WB03 367
C     CALCUATE LIFT COEFFICIENT, CL FOR EACH WING                       WB03 368
C                                                                       WB03 369
      CLR=CNR*CTHRR*ANGLR/SREF                                          WB03 370
      CLL=CNL*CTHRL*ANGLL/SREF                                          WB03 371
      CLU=CTHRU*ANGLU/SREF                                              WB03 372
      CLD=CTHRD*ANGLD/SREF                                              WB03 373
      CL=CLR+CLL+CLU+CLD                                                WB03 374
      CDCLS=CDI/(CL*CL)                                                 WB03 375
  201 CONTINUE                                                          WB03 376
      CY=CYU+CYD+CYADDH                                                 WB03 377
      CN=CNR+CNL+CNADDV                                                 WB03 378
C                                                                       WB03 379
C                                                                       WB03 380
      WRITE(6,717) FMACH,ALFA,BETAY,AREA,SREF,REFL                      WB03 381
      IF (NPRESS,EQ,0) WRITE (6,725)                                    WB03 382
      IF (NPRESS,EQ,1) WRITE (6,726)                                    WB03 383
      IF (NPRESS,EQ,4) WRITE (6,729)                                    WB03 384
      IF (NPRESS,EQ,2) WRITE (6,727)                                    WB03 385
      IF (NPRESS,EQ,3) WRITE (6,728)                                    WB03 386
      CTHRR=CTHRR/SREF                                                  WB03 387
      CTHRL=CTHRL/SREF                                                  WB03 388
      CTHRU=CTHRU/SREF                                                  WB03 389
      CTHRD=CTHRD/SREF                                                  WB03 390
      WRITE (6,718) DELR,DELL,DELU,DELD,                                WB03 391
     1                          CN,CNR,CNL,CY,CYU,CYD,CTHRST,          WB03 392
     1  CTHRR,CTHRL,CTHRU,CTHRD,CL,CLR,CLL,CLU,CLD,CDI,CDIR,CDIL,      WB03 393
     2  CDIU,CDID,CDCLS,CNADDV,CYADDH,CYR,CNB,ROLMR,ROLML,ROLMU,ROLMD  WB03 394
      MSWRP=MSWR+1                                                      WB03 395
      MSWLP=MSWL+1                                                      WB03 396
      CFC=1,0/(4,0*B2)                                                  WB03 397
      IF(ASYM) GO TO 524                                                WB03 398
C                                                                       WB03 399
C     CALCULATE SPANWISE LOAD DISTRIBUTIONS                             WB03 400
C     FOR USKEWED PANEL CASES ONLY                                      WB03 401
C                                                                       WB03 402
C     THIS LOOP TO 542 IS USED FOR LEFT AND RIGHT HORIZONTAL WINGS      WB03 403
C                                                                       WB03 404
      BTH=1,/B2                                                         WB03 405
      WRITE(6,702)                                                      WB03 406
       WRITE(6,721) AR=                                                 WB03 407
      WRITE(6,724)                                                      WB03 408
      J=1                                                               WB03 409
      IL=0                                                              WB03 410
      KUL=MSWRP                                                         WB03 411
  540 CONTINUE                                                          WB03 412
      I=0                                                               WB03 413
      DO 542 K=2,KUL                                                    WB03 414
      I=I+1                                                             WB03 415
      SECFXX=0,0                                                        WB03 416
      SUM1=0,0                                                          WB03 417
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      YCHK=YCPT(J)*COSBET-XBAR(J)*SINBET                                WB03 41A
      YLOC=YCHK+BTM                                                     WB03 419
      DO 541 L=1,NC                                                     WB03 420
      SUM1=SUM1+FN(J)                                                   WB03 421
      WIDI=1./WIDTH(J)                                                  WB03 422
      IF (NDRAG.EQ.0) GO TO 541                                         WB03 423
      SECFXX=SECFXX+CFC*WIDI*(FX(J)*COSBET-FY(J)*SINBET)                WB03 424
  541 J=J+1                                                             WB03 425
      BLOAD(I)=SUM1*WIDI*BTM*0.25                                       WB03 426
  542 WRITE(6,703) I,YLOC,BLOAD(I),SECFXX                               WB03 427
      IF (NBWL.EQ.0) GO TO 549                                          WB03 428
      IF(IL.NE.0) GO TO 543                                             WB03 429
C                                                                       WB03 430
C     RE-ENTER ABOVE LOOP FOR LEFT HORIZONTAL WING                      WB03 431
C                                                                       WB03 432
      IL=1                                                              WB03 433
      KUL=NBWLP                                                         WB03 434
      WRITE(6,721) ALW                                                  WB03 435
      WRITE(6,724)                                                      WB03 436
      GO TO 540                                                         WB03 437
  543 IF(NBWU.EQ.0) GO TO 549                                           WB03 438
C                                                                       WB03 439
C     THIS LOOP TO 546 USED FOR UPPER AND LOWER WINGS, IF PRESENT       WB03 440
C                                                                       WB03 441
      KU=NBWU+1                                                         WB03 442
      WRITE(6,721) AUW                                                  WB03 443
      WRITE(6,723)                                                      WB03 444
      IL=0                                                              WB03 445
  544 CONTINUE                                                          WB03 446
      I=0                                                               WB03 447
      DO 546 K=2,KU                                                     WB03 448
      I=I+1                                                             WB03 449
      SECFXX=0.0                                                        WB03 450
      SUM1=0.0                                                          WB03 451
      ZCHK=ZCPT(J)*COSALF-XBAR(J)*SINALF                                WB03 452
      IF (ANYMORE) ZCHK=ZCPT(J)                                         WB03 453
      ZLOC=ZCHK+BTM                                                     WB03 454
      DO 545 L=1,NC                                                     WB03 455
      SUM1=SUM1+FN(J)                                                   WB03 456
      WIDI=1./WIDTH(J)                                                  WB03 457
      IF (NDRAG.EQ.0) GO TO 545                                         WB03 458
      IF (ANYMORE) GO TO 810                                            WB03 459
      SECFXX=SECFXX+CFC*WIDI*(FX(J)*COSALF+FZ(J)*SINALF)                WB03 460
      GO TO 811                                                         WB03 461
  810 SECFXX= SECFXX+CFC*WIDI*FX(J)                                     WB03 462
  811 CONTINUE                                                          WB03 463
  545 J=J+1                                                             WB03 464
      BLOAD(I)=SUM1*WIDI*BTM*0.25                                       WB03 465
  546 WRITE(6,703) I,ZLOC,BLOAD(I),SECFXX                               WB03 466
      IF(IL.NE.0) GO TO 549                                             WB03 467
C                                                                       WB03 468
C     RE-ENTER ABOVE LOOP FOR LOWER WING                                WB03 469
C                                                                       WB03 470
      IL=1                                                              WB03 471
      KU=NBWD+1                                                         WB03 472
      WRITE(6,721) ADW                                                  WB03 473
      WRITE(6,723)                                                      WB03 474
      GO TO 544                                                         WB03 475
  549 CONTINUE                                                          WB03 476
C                                                                       WB03 477
C                                                                       WB03 478
C     CLL.....ROLLING MOMENT,POSITIVE RIGHT WING DOWN                   WB03 479
C     REFERENCED TO SREF,REFL                                           WB03 480
C                                                                       WB03 481
  528 CONTINUE                                                          WB03 482
      ROLMOM=ROLWR+ROLWL+ROLWU+ROLWD                                    WB03 483
      WRITE (6,719) ROLMOM,BETAY                                        WB03 484
C                                                                       WB03 485
C                                                                       WB03 486
      RETURN                                                            WB03 487
      END                                                               WB03 488
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LIST OF SYMBOLS

A_L	left afterbody vortex
A_R	right afterbody vortex
AR	wing-alone aspect ratio
A_1	see equation (B.29)
a	body radius
a_e	proportionality coefficient for elliptic span loading; see equation (C.2)
a_L	proportionality coefficient for linear span loading; see equation (C.1)
C_A	axial-force coefficient; axial force/$q_\infty S_R$
C_D	drag coefficient; drag/$q_\infty S_R$
C_L	lift coefficient; lift/$q_\infty S_R$
C_ℓ	rolling-moment coefficient; rolling moment/$q_\infty S_R \ell_r$
C_m	pitching-moment coefficient; pitching moment/$q_\infty S_R \ell_r$
C_N	normal-force coefficient; normal force/$q_\infty S_R$
C_n	yawing-moment coefficient; yawing moment/$q_\infty S_R \ell_r$
$C_{N_{B(W)}}$	normal-force coefficient for body in the presence of fins; normal force/$q_\infty S_R$
C_{N_W}	normal-force coefficient of "wing alone" formed by joining two opposing fins; normal force/$q_\infty S_R$
$C_{N_{W(B)}}$	normal-force coefficient for two opposing fins in the presence of a body; normal force/$q_\infty S_R$
C_{N_α}	slope of nose normal-force coefficient at $\alpha_c = 0$; reference area is the base area of the nose
C_Y	side-force coefficient; side force/$q_\infty S_R$
C_6	moderate-aspect-ratio canard fins used in MICOM-NWC tests; see reference 4 and figure 3(a)
C_7	low-aspect-ratio canard fins used in MICOM-NWC tests; see reference 4 and figure 3(b)

CNC1,CNC2,etc.	normal-force coefficients associated with fins C1, C2, etc.
CNi	normal-force coefficient for fin i
CNT1,CNT2,etc.	normal-force coefficients associated with fins T1, T2, etc.
CRMi	rolling-moment coefficient for fin i
CRMC1,CRMC2,etc.	rolling-moment coefficients associated with fins C1, C2, etc.
CRMT1,CRMT2,etc.	rolling-moment coefficients associated with fins T1, T2, etc.
C1,C2,etc.	canard fins; also vortices associated with canard fins
c_{d_c}	two-dimensional crossflow drag coefficient
c_r	length of fin root chord
$(cc_\ell)_e$	elliptic span loading; see equation (C.2)
$(cc_\ell)_L$	linear span loading; see equation (C.1)
$(cc_\ell)_s$	span loading; see equation (B.5)
$(cc_\ell)_\epsilon$	span loading; see equation (B.14)
D_V	crossflow drag force on an elemental length of cylinder; see equation (D.5)
K*	fraction of fin leading-edge or side-edge suction which is converted to vortex lift
K_B	wing-body interference factor for body normal force for $\delta = 0$, $\alpha_c \neq 0$
K_W	wing-body interference factor for fin normal force for $\delta = 0$, $\alpha_c \neq 0$
K_v	vortex lift parameter; see equation (34)
$K_{\alpha\beta}$	wing-body interference factor for bank, $\delta = 0$, $\alpha_c \neq 0$
k_B	wing-body interference factor for body normal force for $\delta \neq 0$, $\alpha_c = 0$
k_W	wing-body interference factor for fin normal force for $\delta \neq 0$, $\alpha_c = 0$
k_1	see equation (B.27)

ℓ.e.	leading edge
ℓ_r	reference length
M_c	crossflow Mach number, $M_\infty \sin \alpha_c$
M_ℓ	rolling moment
M_∞	free-stream Mach number
MS 0	missile station zero; origin of coordinate system
N	normal force
N_v	normal force due to viscous crossflow
NV(x)	number of vortices in the crossflow plane located at axial position x
P	difference between pressure coefficient on suction side of fin (or body) and pressure coefficient on impact side of fin (or body)
q_∞	dynamic pressure of free stream
R	see equation (B.24)
r_o	radius of circle in transform plane; see equation (A.2)
r_v	$\sqrt{y_v^2 + z_v^2}$
r(x)	radius of nose at axial position x
S_B	body planform area in finned section
S_C	crossflow area upstream of first set of fins
S_i	planform area of fin i
S_R	reference area
s_m	semispan of fin on body
s(x)	fin semispan at axial location x
T1,T2,etc.	tail fins
T_2	low-aspect-ratio tail fins used in MICOM-NWC tests; see reference 4 and figure 3(d)
T_{14}	low-aspect-ratio tail fins used in MICOM tests; see reference 16 and figure 3(c)

T_{15}	low-aspect-ratio tail fins used in MICOM tests; see reference 16 and figure 3(e)
t	fin spanwise coordinate
t.e.	trailing edge
V_{max}	maximum normal velocity which can be induced on a fin
V_N	volume of nose from tip to shoulder
V_∞	free-stream velocity
v	velocity component in y-direction
w	velocity component in z-direction
x,y,z	missile body axes; x measured positive downstream along body rotational axis, y measured positive to right in the plane of C4, and z measured positive upward in the plane of C1; origin is located at MS 0
x_o,y_o,z_o	special set of x,y,z axes for $\phi = 0$; also called unrolled body coordinates
XCTE	axial position of the canard trailing edge
XTLE	axial position of the leading edge of the tail root chord
x_{HL}	axial position of fin hinge line measured from MS 0
x_{MC}	axial location of reference for moments acting on missile measured from MS 0
x_N	length of nose from tip to shoulder
x_s	axial location of initial separation of body nose vorticity
$\bar{x}$	axial position of center of pressure
$\bar{x}_B$	axial position of center of pressure for body normal force due to presence of fins measured from MS 0
$\bar{x}_i$	axial position of the center of pressure for fin i measured from MS 0
$\bar{x}_{linear}$	axial position of center of pressure for nose normal force due to potential flow
$\bar{x}_{viscous}$	axial location of center of pressure for nose normal force due to viscous flow
Y	side force

y_v	side force due to viscous crossflow
y_v, z_v	coordinates of vortex in the crossflow plane
y_v^*	spanwise location of centroid of fin trailing vorticity
$\bar{y}_i$ or $\bar{z}_i$	lateral location of the center of pressure for fin i measured from body centerline
$\bar{y}_v$	moment arm for normal force induced by vortices
α	fin angle of attack
α_c	included angle of attack; angle between x axis and free-stream velocity
α_{cr}	resultant angle of crossflow at body centerline due to free-stream flow and external vortices exclusion of afterbody vortices
α_{eq}	equivalent angle of attack; that angle of attack of the wing alone for which its normal force is twice that of the fin; the wing alone is formed by joining two opposing fins together
$\alpha_{eq,p}$	equivalent angle of attack when no vortices are present
$\alpha_{v,i}(x,t)$	local angle of attack induced at x,t on fin i by presence of vortices
$\bar{\alpha}_{v,i}(t)$	average of $\alpha_{v,i}(x,t)$ over chord
β	fin angle of sideslip
γ	see equation (B.26)
Γ	vortex strength
Γ'	nondimensional vortex strength; vortex strength/$2\pi V_\infty a$
$(\Delta\alpha_{eq})_v$	change in α_{eq} due to a collection of external vortices and their images
δ_1, δ_2, etc.	incidence angles associated with fins C1, C2, etc., for $\phi = 0$, δ_1 and δ_3 are positive for trailing edges to the right viewed from the rear, and δ_2 and δ_4 are positive for trailing edges down
η	nondimensional spanwise coordinate; see equation (C.1)
$\bar{\eta}$	nondimensional spanwise position of fin center of pressure; see equation (C.10)

ϑ	direction of resultant crossflow velocity at body centerline due to free-stream flow and external vortices exclusive of afterbody vortices; measured counterclockwise from position y_o-axis; also see equation (B.25)
Λ	fin leading-edge sweep
λ	ratio of fin tip chord to root chord; also complex position in the transform plane
μ	interaction coefficient for fin rolling moment due to presence of vortices; see equation (B.18)
ν	complex position in the transform plane
ρ_∞	density of fluid in free stream
ζ	complex position in the crossflow plane
ζ'	complex distance between a vortex and its image inside a cylinder nondimensionalized by the cylinder radius
ϕ	roll angle, angle between z axis and z_o axis; positive measured clockwise viewed from rear
ϕ_T	interdigitation angle, angle between canard fin C1 and tail fin T1 measured clockwise from fin C1
ω	angular rate of rotation of wing-body combination

Subscripts

body	contribution to total forces and moments due to loading seen by body in finned section
d	direct flow
fins	contribution to total forces and moments due to loading seen by all four fins in a finned section
L	left afterbody vortex; in Appendix C, refers to linear span loading
R	right afterbody vortex
r	reverse flow