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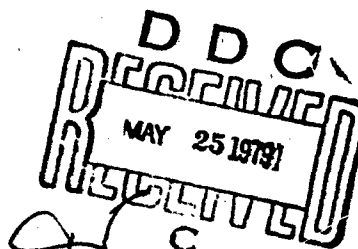
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Aerodynamic Stability Technology for Maneuverable
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Computer Program

Martin Marietta Corporation
Orlando Division
P. O. Box 5837
Orlando, Florida 32805



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Air Force Flight Dynamics Laboratory
Air Force Wright Aeronautical Laboratories
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

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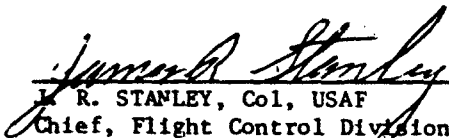


WILLIAM H. LANE
Project Engineer
Control Dynamics Branch



R. O. ANDERSON, Chief
Control Dynamics Branch
Flight Control Division

FOR THE COMMANDER



R. STANLEY, Col, USAF
Chief, Flight Control Division
Air Force Flight Dynamics Laboratory

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A procedure for estimating the effects of asymmetric lee-side vortices on slender missile configurations with and without tails is developed, using both theoretical and empirical inputs. A computerized model of the procedure which calculates induced side forces, yawing moments, tail forces and rolling moments is presented. Program flow charts, input instructions and sample cases are provided. Comparisons between experimental data and program calculations show acceptable preliminary design level accuracies.			

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FOREWORD

This report was prepared for the U.S. Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, under Contract Number F33615-75-C-3052.

The work reported herein was performed at the Orlando Division of Martin Marietta Aerospace as a part of Project 8219, "Stability and Control for Aerospace Vehicles", Work Unit 82190117, "Aerodynamic Stability Technology for Maneuverable Missiles".

This work was performed during the period February 1975 to December 1976. The principal investigators were J. E. Fidler and G. F. Aiello. The technical monitor for AFFDL was Mr. William H. Lane.

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TABLE OF CONTENTS

	<u>Page</u>
1.0 Introduction	1
2.0 Flow Field Description	6
3.0 Construction of Flow Field Model	10
4.0 Force and Moment Computational Techniques	25
5.0 Comparisons Between Computed and Experimental Results	32
6.0 Program Users Manual	39
6.1 Input and Output Formats	39
6.2 Program Flow Charts	43
6.3 Program Listing	53
6.4 Sample Inputs/Outputs	79
6.5 Program Limitations	83
References	85

LIST OF ILLUSTRATIONS

Figure	Title	Page
1	Comparison of Pitch and Yaw Moments (Isolated Body, $M = 0.8$)	3
2	Comparison of Pitching and Yawing Moments (Body - Tail, $M = 0.8$)	5
3	Schematic of Lee Side Vortex Pattern	7
4	Schematic of Flowfield Model	12
5	Vortex Strength Parameter (Sub-critical Re_c)	14
6	Basic Crossflow Drag Curves for Γ_g Scaling	15
7	Comparison Between Predicted and Experimental Point where Vortex is Shed into Street	21
8	Growing Vortex's Trajectory	22
9	Fineness Ratio Effects	28
10	Bluntness Ratio Effects	28
11	Comparison Between Predicted and Experimental Vertical Fin Normal Force	33
12	Comparison Between Predicted and Experimental Results (Body Alone)	35
13	Comparison Between Predicted and Experimental Results (Body + Tail)	36
14	Sign Convention	42

LIST OF SYMBOLS

A	Reference area
a	Body radius
AR	Tail aspect ratio
C_A	Axial force coefficient
C_{dc}	Crossflow drag coefficient
CETAMC	Yawing moment coefficient
C_L	Lift coefficient
C_l	Rolling moment coefficient
C_N	Normal force coefficient
C_n	Yawing moment coefficient
C_Y	Side force coefficient
d	Missile body diameter
e	Axial extent of base influence
F	Vorticity flux
g	Axial distance over which boundary layer is shed to form vortex
h	Vortex street lateral dimension
K	Coefficient in vortex strength equation
l	length
z	Vertical distance between vortices of like sign
M	Mach number
m	Number of vortices in wake at a given axial location on the body
n	Frequency with which vortices of like sign are shed
p	Spanwise distance from tail root to tip
$\bar{R}$	Radial limit of vortex influence on a body

LIST OF SYMBOLS (CONT'D)

R_e	Reynolds number
r	Radial distance from center of body
S	Strouhal number = $nd/Vsina$
U_s	Circumferential velocity at edge of boundary layer at separation
V	Freestream velocity
v	Velocity induced normal to tail leading edge in the y direction
x	Axial distance along body
Y	Side force
y	Lateral distance normal to body axis
z	Distance above and normal to body axis
α	Angle of attack
δ	Nose half angle
σ	Angle between growing vortex cores and body axis
θ_s	Circumferential separation point angular orientation
ξ	Angle between street vortex cores and body axis
Γ	Vortex strength
$\Gamma(x)$	Local value of strength in a growing vortex
$\Gamma/Vdsina$	Vortex dimensionless strength parameter
ρ	Freestream density
ϕ	Roll angle
χ	Separation angle parameter
λ	Tail taper ratio

SUBSCRIPTS

a	Axial direction
B	Body
c	Crossflow
i	Induced, vortex indicator
L, R	Left and right sides of body, respectively
o	Initial condition
s	Denotes vortices, starting with third from missile nose
T	Tail
x	Denotes conditions at axial station x
1, 2	First and second vortices, respectively

SUMMARY

A computerized engineering model is presented for estimating the effects of asymmetric lee-side vortices on slender missile configurations. The procedure was developed using both empirically determined quantities and theoretical techniques. Empirical inputs define both vortex locations and street vortex strengths; whereas, potential flow considerations guide in the definition of initial vortex strengths and induced forces and moments. The procedure is applicable to bodies with and without tails. Calculable effects are: induced side forces, yawing moments, tail forces, and rolling moments. The procedure was applied to a number of different combinations of geometries and flow conditions and the results compared against experimental data. These comparisons, while not exact, have shown the procedure to be suitably accurate for preliminary design purposes. Using this procedure, a user can estimate the magnitude but not necessarily the direction of vortex induced forces and moments and the angle of attack at which they first appear. Uncertainty in direction is attributed to the randomness associated with formation and subsequent shedding of the initial pair of vortices. Nose geometry irregularities greatly influence the side of the body from which the initial vortex separates.

A users manual for this computerized procedure is also provided. The manual includes user instructions, a program listing, sample inputs, and sample outputs.

1.0 INTRODUCTION

In recent years, increased maneuverability requirements for air-to-air missiles have dictated corresponding increases in angles of attack, particularly for those vehicles which perform slewing maneuvers. Maximum angles for such missiles can now reach 180 degrees. As a result of these developments, the flow fields with which the aerodynamicist has to deal are much more complex, and traditional methods for predicting aerodynamic characteristics are inadequate to deal with all the problems involved. One example of method deficiency is found in the angle of attack range 25-50 degrees. Here, steady, asymmetric vortex patterns usually develop in the body wake and can induce large side forces and yawing and rolling moments which are detrimental to missile controllability. Few methods are currently available for predicting these forces and moments or for analyzing the complex flow fields which produce them. The effects are particularly acute in the subsonic-transonic speed range. At Mach numbers greater than about 1.5, however, they tend to diminish rapidly.

The flow phenomena involved and their effects have received considerable attention recently, ⁽¹⁻⁹⁾ although wake vortex effects and asymmetry have been reported by earlier authors. ⁽¹⁰⁻¹³⁾ Among the earliest studies were those of Allen and Perkins ⁽¹⁰⁾ and Perkins and Jorgensen, ⁽¹¹⁾ in which some of the basic flow structure in the wake was investigated and the onset of vortex asymmetry observed. More recent work by Thomson and Morrison ⁽¹⁾ and Thomson ^(2,8) determined details of the wake flow field and the associated vortex characteristics through direct flow probing. In that work, attention was drawn to the strong similarities between the three-dimensional asymmetric wake and its two-dimensional counterpart, the von Karman vortex street.

Measurements were made of vortex strengths, spacing and shedding frequency. The data of Reference 1 have often formed the basis for follow-on work to determine vortex effects on slender missiles^(5,8) or for the computation of wake flow characteristics.⁽⁶⁾ The measurements form part of the basis for the present work, with suitable modifications for various flow parameter changes.

Recent wind tunnel investigations performed by Martin Marietta showed marked evidence of asymmetric vortex effects. The magnitudes of typical induced quantities are shown in Figures 1 and 2. In Figure 1, pitch and yaw plane moment data up to 60 degrees angle of attack are shown for an isolated body composed of an ogive-cylinder of 10:1 total slenderness ratio. Beginning around 25 degrees angle of attack, considerable yawing moments were induced due to asymmetries. The addition of tails to the body (Figure 2) results in the generation of yawing moments which are almost as large as the pitching moments. In addition to the problem of magnitudes is that of unpredictable sign.^(1,3,4) Random changes in direction of forces and moments have been observed, sometimes related to changing flow conditions, but often interpreted to be caused by small manufacturing imperfections near the missile nose^(1,3,4). In fact, significant changes in induced force and moment magnitudes and signs can be produced by rotation of all or parts of the body.^(1,3,4) This has further, serious implications for missile controllability.

It is clear that techniques are required for calculating the forces and moments induced by asymmetric vortex wakes. Some work has already been done in this area^(8,9) for slender bodies at subcritical crossflow Reynolds number. The procedure presented in this document deals with that case also, but goes further in considering supercritical crossflow Reynolds and Mach

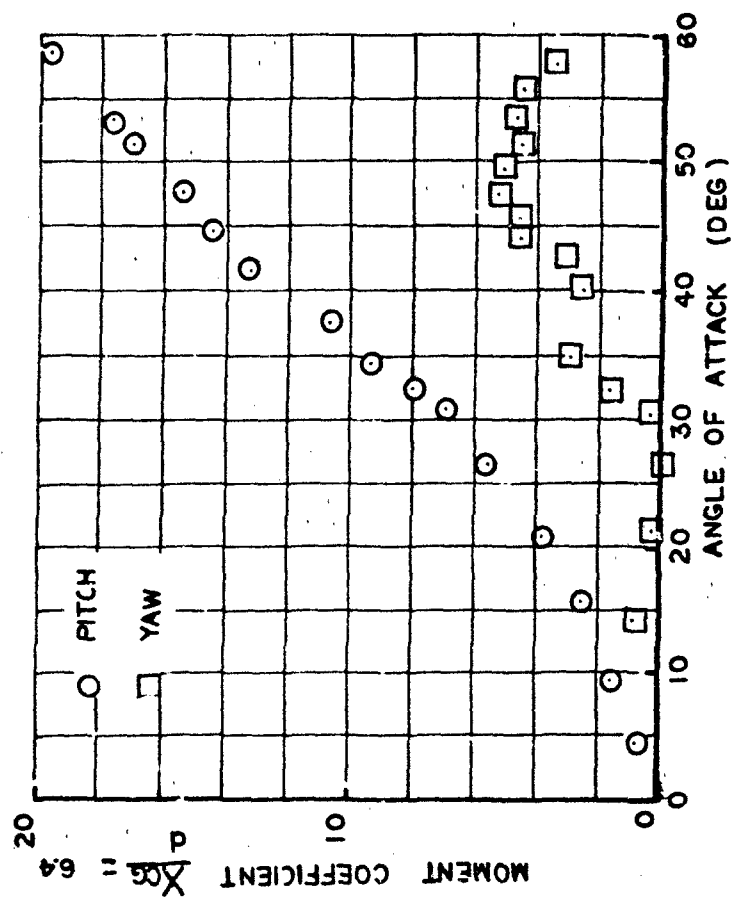
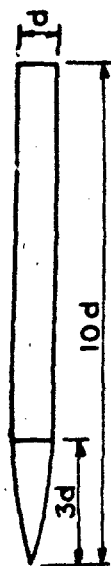


FIGURE 1 COMPARISON OF PITCH AND YAW MOMENTS
(ISOLATED BODY $M=0.8$)

number effects for bodies with and without tails. This technique is semi-empirical, drawing upon the experimental evidence referred to above, but modifying it for different flow conditions and supplementing it with analytical results and techniques. To make this technique more readily useable, it has been programmed for digital computation.

The layout of this document is as follows: first, a general description of the flowfield is presented, followed by descriptions of the techniques used to model the asymmetric vortex wake and calculate the induced forces and moments. Following these, there is a section presenting comparisons between predicted results and experimentally measured data. Finally, there is the information necessary to operate the program, i.e., user instructions, a program flow chart and listing, sample inputs/outputs and an indication of program limitations.

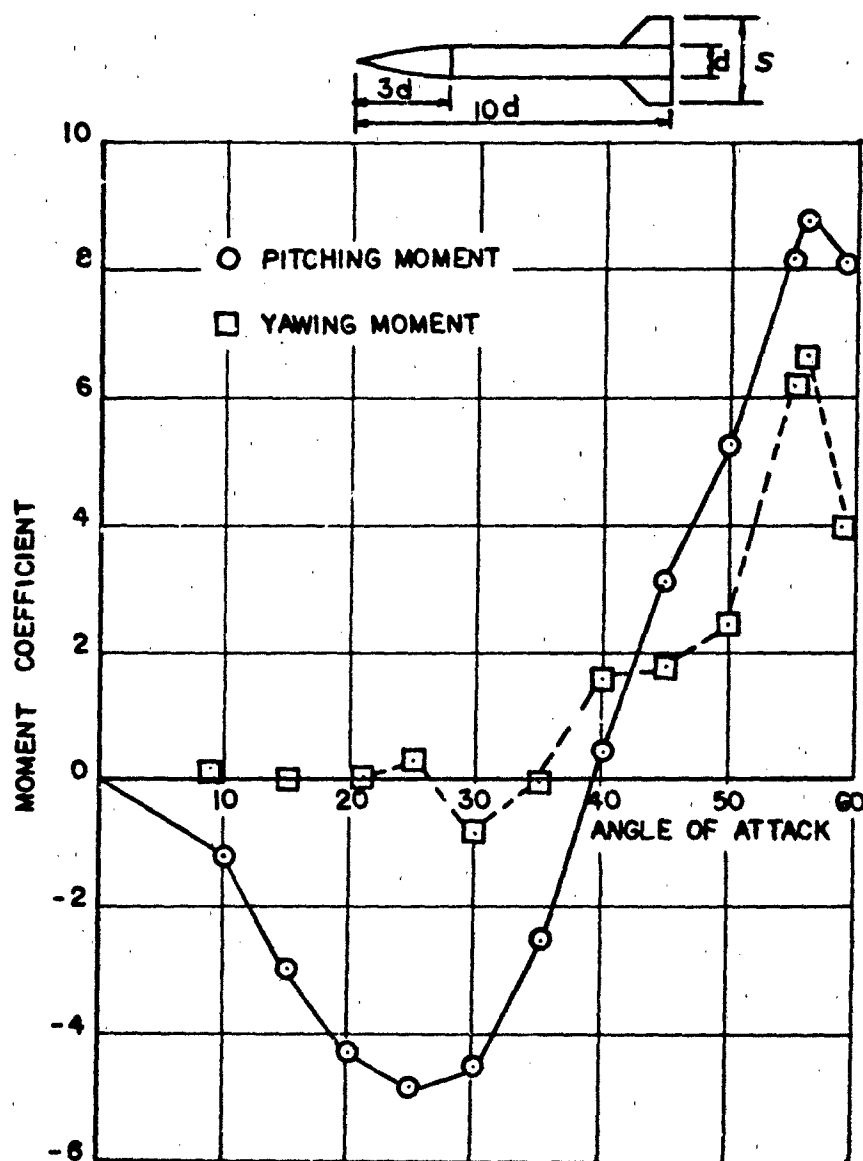


FIGURE 2 COMPARISON OF PITCHING AND YAWING MOMENTS
(BODY-TAIL $M=0.8$)

2.0 FLOWFIELD DESCRIPTION

When a slender missile body is placed at angle of attack in a uniform flow, the boundary layer generally separates on either side of the body and forms a lee side wake. Separation usually begins near the rear when the missile reaches about 6 degrees angle of attack. The wake takes the form of a pair of symmetrically-disposed, counter-rotating vortices fed by vorticity shed from the separating boundary layer. As angle of attack increases the axial extents, sizes and strengths of the vortex increase also.

In general, vortex size and strength also increase towards the rear of the body. Several authors have formulated descriptions of vortex development along slender bodies in terms of two-dimensional, impulsively-started flows around cylinders. These formulations relate flow development with time, measured either from the beginning of impulsive two-dimensional motion or from the instant a fluid particle makes contact with a three-dimensional body. In the latter case, time is defined by distance travelled along the body and the axial component of freestream velocity. For the two-dimensional case, the motion of the vortex cores as time passes (i.e., vortex size and strength increase) theoretically follows a path known as the Föoppl line.⁽¹⁴⁾ Use has been made of this result in the present work, as will be described later.

When the body angle of attack reaches about 25 degrees, the symmetric nature of the wake disappears. The two vortices are joined by a third, beginning again at the body rear, and the wake becomes asymmetric. As angle is increased further, more vortices join the flow until the wake contains several which have been shed from the body. An idealized model of the flow field is shown in Figure 3. A section taken through the wake shows

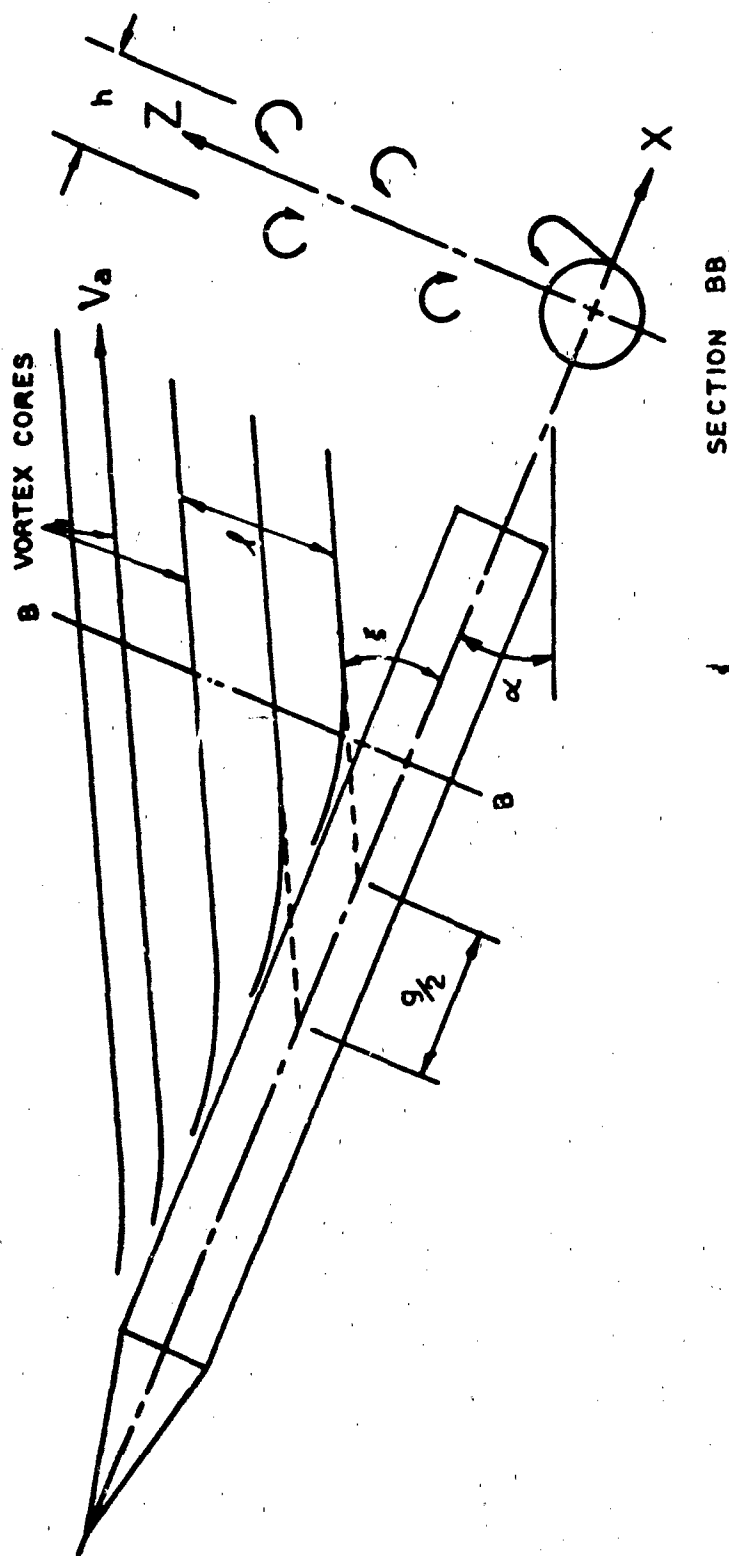


FIGURE 3 SCHEMATIC OF LEE SIDE VORTEX PATTERN

it to resemble the von Karman vortex street, well known in the literature on two-dimensional flows. Not all of the vortices are fully shed, however; two usually remain close to the body, receiving vorticity from the shedding boundary layers. If angle of attack continues to increase these, too, will be fully shed into the wake when their strength reaches some critical value. Their places will be taken by yet other growing vortices.

While a growing vortex is receiving vorticity from the boundary layer, i.e., before it reaches full strength, it tends to stay close to the body. Thomson and Morrison⁽¹⁾ showed schlieren photographs which implied that the vortex core is somewhat curved while it is forming. Not until full strength has been reached does the core become straight and parallel to the rest of the vortices in the street. This core behavior is indicated in Figure 3.

It has been determined that a marked similarity exists between the manifestations and effects of two- and three-dimensional asymmetric vortex wakes.⁽¹⁾ In fact, the von Karman street stability criterion that the ratio of lateral street dimension, h , to the distance between vortices of like sign, l , given by $h = 0.281l$, has been shown to apply to both cases (Figure 3). However, in the wake of Figure 3 no lateral motion of the vortex cores relative to the body takes place. The two-dimensional phenomenon of increasing distance between vortex core and body as time increases is analogized in the same way as for the symmetrical vortices. That is to say, the wake is steady and the motion of a fluid particle along a (stationary) vortex core may again be described in equivalent time by its axial velocity and distance traveled. Through use of this analogy, Thomson⁽²⁾ and Thomson and Morrison⁽¹⁾ were able to deduce the strengths of asymmetric wake vortices as well as their effects upon body crossflow drag. Thomson⁽⁸⁾ recently extended this work to deal with induced side forces and yawing moments on bodies at subcritical crossflow Reynolds numbers.

At still higher angles of attack, say greater than 50 degrees, the wake begins to display unsteadiness. The vortex cores show definite lateral displacements relative to the body and the induced forces and moments become time-dependent. The procedure presented in this document does not consider this case. Attention is directed only to the phenomena in the angle of attack range from 25 to 50 degrees and their effects upon missile aerodynamic characteristics.

3.0 CONSTRUCTION OF FLOW FIELD MODEL

Development of a procedure to predict the effects of an asymmetric vortex wake on configuration aerodynamics requires the development of a realistic flow field model. A flow field model, reflecting the state-of-the-art, can be developed using semi-empirical inputs based on the data of References 1, 2, 8 and 16 and theoretical results (14,15)

Vortex strengths and locations have been made compatible with the findings of Reference 1 and suitably scaled to broaden their ranges of applicability. In addition, theoretical results on the locations of wake vortices and their images have been introduced and the contribution of nose potential lift to vortex strength has been considered. Both shed and growing vortices are treated, making use in part, of a vorticity-conservation concept. (6) Each of the above components of the model is described in detail beginning with vortex strength.

Vortex Strength

Detailed flow surveys have shown (1,8) that not all the wake vortices are of the same strength. Generally, the first vortex from the nose originates near the nose/body junction and has the smallest strength in the wake, Γ_1 , say. The second vortex separates soon after the first and has a somewhat higher strength, Γ_2 . From the third vortex onwards, all have approximately the same strength, $\Gamma_s (>\Gamma_2)$, and their spacing and strength are analogous to those of the vortices in a von Karman street. While the first and second vortex strengths will contain contributions from the (potential) nose lift, the "street" vortices are wholly fed with vorticity from the separating body boundary layer. Reference 8 presents detailed information on dimensionless vortex strength, Γ_s , for various angles of attack at subcritical crossflow Reynolds number. For the first two vortices, strength is calculated using concepts from potential flow theory.

The first and second vortex strengths must contain a contribution from the potential flow lift of the nose. The strength of the first vortex, Γ_1 , may be estimated if it is assumed that the nose is replaced by a horizontal lifting line of constant strength, Γ_1 located at the nose/body junction (Figure 4). All of the nose lift is assumed generated by this line and the associated trailing vortices will have its strength provided they receive no further vorticity, from the shedding boundary layer for example. The first vortex shed, near the nose body junction, will probably contain only potential-flow-generated circulation. To calculate vortex strength Γ_1 is straight forward. It can be shown⁽¹⁵⁾ that the coefficients of normal and axial force acting on the nose are predicted by slender body theory to be:

$$C_N = 2 \sin \alpha \text{ and } C_A = C_{A_0} - \sin^2 \alpha$$

where the reference area is that of the body cross section. Converting these quantities to lift coefficient yields

$$C_L = C_N \cos \alpha - C_A \sin \alpha$$

If C_{A_0} is assumed negligible (as it will be, compared to the axial forces generated at the high angles of attack here) this expression becomes after some manipulation

$$\begin{aligned} L &= \frac{\rho}{8} V^2 \pi d^2 (2 \sin \alpha \cos \alpha + \sin^3 \alpha) \\ &= \rho \Gamma_1 dV \end{aligned}$$

The latter expression is the well-known Kutta-Joukowski theorem. Finally, the equation may be rearranged to yield:

$$\frac{\Gamma_1}{Vd \sin \alpha} = \frac{\pi}{8} (2 \cos \alpha + \sin^2 \alpha) \quad (1)$$

This dimensionless vortex strength may be compared with measurements from flow field surveys.⁽¹⁾ Using an angle of 30 degrees, equation (1) yields a dimensionless strength of 0.78. The corresponding measured strengths

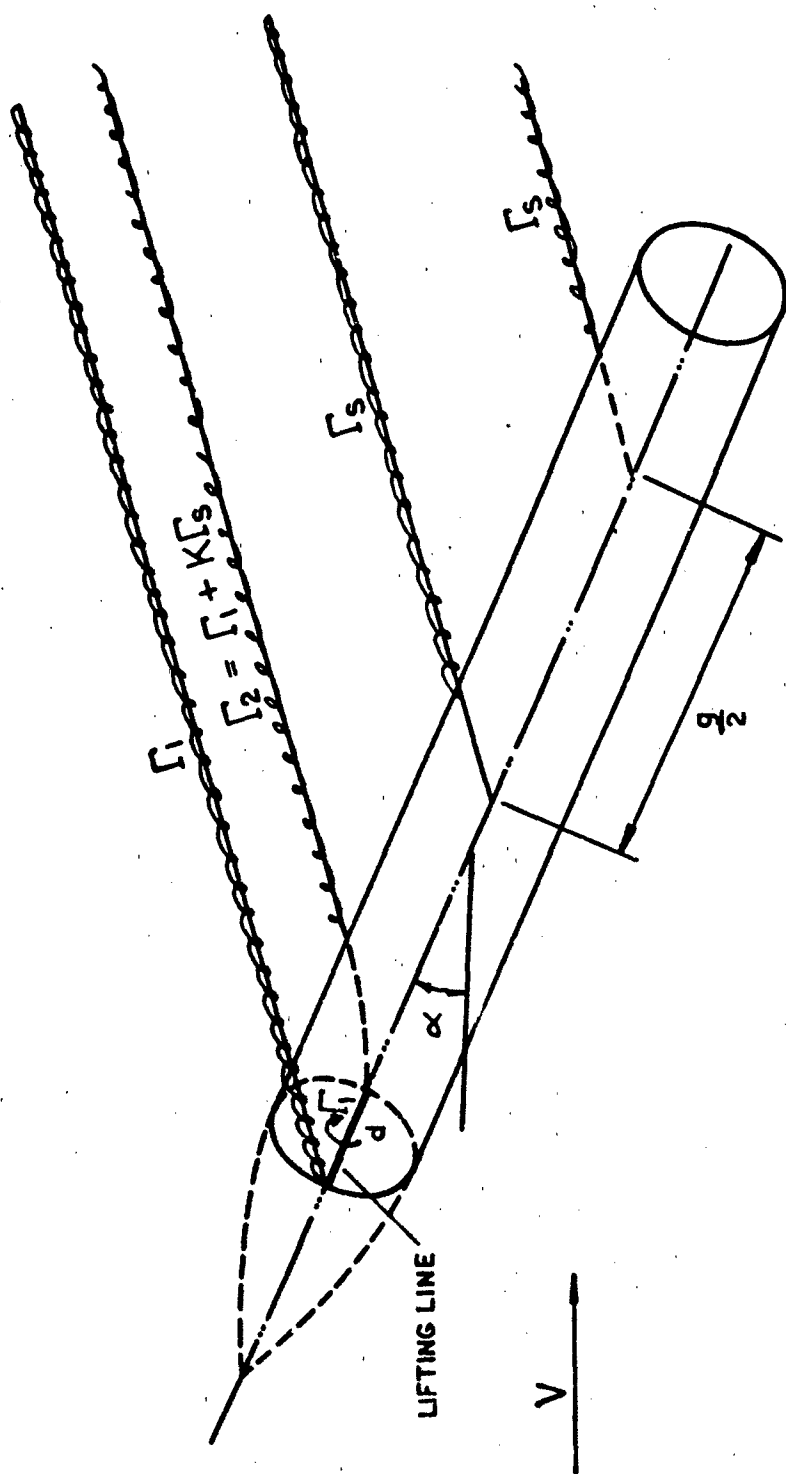


FIGURE 4 SCHEMATIC OF FLOWFIELD MODEL

from Reference 1 show a range of values from 0.3 to 1.1 with a mean value of 0.7. This compares quite well with the predicted value. Where it is found that the first vortex is shed forward of the nose/body junction, its strength is simply determined by using the local nose diameter in equation (1).

There should be little or no effect of Reynolds number on Γ_1 since the strength is determined by potential flow considerations. On the other hand, Γ_s is wholly produced by viscous flow and is strongly affected by crossflow Reynolds number (R_{ec}), which influences the characteristics of the boundary layer shed to form the street vortices. The second vortex, being shed downstream from the nose/body junction, is modeled here as a "mixed vortex," i.e., a potential flow vortex which receives additional vorticity from the shedding boundary layer just aft of the nose (Figure 4). Formally, Γ_2 is expressed as:

$$\Gamma_2 = \Gamma_1 + K \Gamma_s$$

K was found empirically to be about 0.22 from the wake survey data of Reference 1.

For street vortex strength at subcritical R_{ec} , the data shown in Figure 5 were used (8). In order to scale Γ_s for supercritical R_{ec} , use was made of von Karman's result (14) that crossflow drag coefficient, C_{dc} , is approximately proportional to the street vortex strength, Γ_s (the expression for C_{dc} contains terms in Γ_s and Γ_s^2 ; however, the latter accounts for less than 10 percent of the total; hence, C_{dc} is approximately proportional to Γ_s). Data obtained from Martin Marietta investigations into crossflow drag (16) produced the information of Figure 6, which shows that for low crossflow Mach number, crossflow Reynolds number has a strong influence on crossflow drag. Above the critical crossflow Reynolds number (about 10^5), C_{dc} shows a significant decrease below the subcritical value. Hence, Γ_s , too, will be significantly reduced. An increase in crossflow Mach number, M_c , is required to increase both C_{dc} and

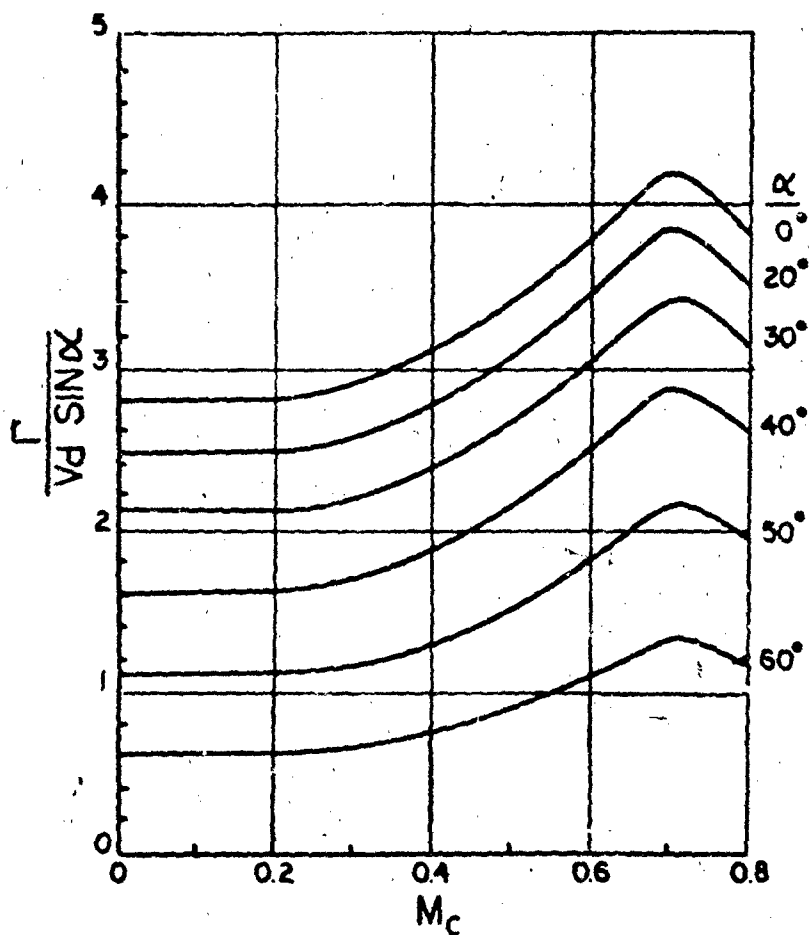
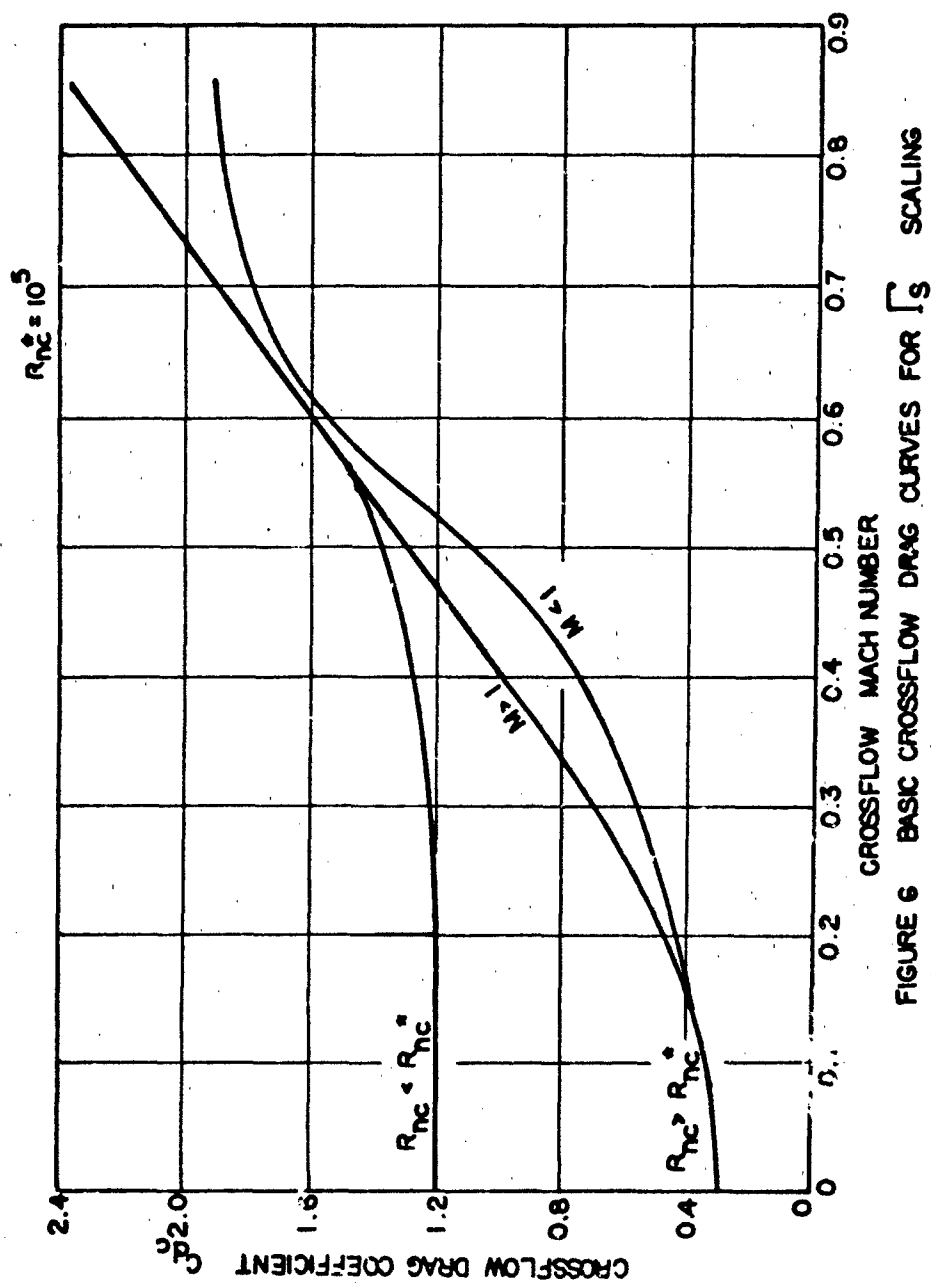


FIGURE 5 VORTEX STRENGTH PARAMETER
SUB CRITICAL R_{ec}



Γ_s . Accordingly, for $R_{ec} > 10^5$ the subcritical R_{ec} values of Γ_s from Figure 5 are scaled in the same ratio as C_{dc} from Figure 6.

In order to illuminate further the mechanisms underlying the relationship between crossflow Reynolds number and vortex strength, recent work by Fidler⁽⁶⁾ will be briefly described. It may be shown that the strength of a lee side asymmetric vortex can be related to the flux of crossflow vorticity leaving the body at the circumferential separation point defined by θ_s . Further, the vorticity flux shed over axial distance g (at fixed angle of attack) in unit time is:

$$F_B = \text{const} \int_0^g U_s^2 dx$$

The vorticity thus shed diffuses through the vortex to produce the circulation Γ_s . Equating the flux F_B to that flowing along a wake vortex of core velocity V_a yields an expression for vortex strength:

$$\Gamma_s = \frac{\text{const}}{V_a} \int_0^g U_s^2 dx$$

Now U_s , the circumferential velocity at the boundary layer edge at separation, is a function of θ_s . In the two-dimensional case⁽¹⁷⁾ it has been found experimentally that when crossflow Reynolds number is subcritical, θ_s lies near the meridian of the cylinder and the associated separation velocity U_s is larger than in the supercritical Reynolds number case, where the separation point lies far over on the cylinder lee side. Continuing the analogy between two and three dimensions indicates that crossflow Reynolds number affects Γ_s through its effects; first upon θ_s , which in turn determines U_s which defines the vorticity flux flowing from the body and diffuses through the vortex to produce Γ_s . Hence, subcritical R_{ec} produces larger Γ values than does supercritical R_{ec} , provided crossflow Mach number is low.

The foregoing discussions deal with fully-developed vortices which have left the immediate vicinity of the body and joined the asymmetric wake pattern. However, consideration must be given to the street vortices while they are forming close to the body. As previously discussed, these growing vortices are fed by vorticity from the separating body boundary layer. Assuming rapid diffusion of vorticity the local vortex strength $\Gamma(x)$ formed by shedding a boundary layer over distance x may be written (see previous equation).

$$\Gamma(x) = \text{const} \int_0^x U_s^2 dx$$

Furthermore, it has been experimentally determined⁽⁴⁾ that for those portions of the body where street vortices are being formed and for given flow conditions, the circumferential location of boundary layer separation, θ_s , is approximately constant with x . Hence, U_s , the circumferential velocity at the boundary layer edge at separation is also constant. Thus the local vortex strength is seen to be directly proportional to x , i.e.,

$\Gamma(x) = \Gamma_s x/g$ where g is the distance over which boundary layer fluid is shed to form a street vortex.

One final item affecting the strengths of forming vortices has been considered. It has been shown by Thomson⁽⁸⁾ that as a growing vortex nears the base of the body, the rate at which its strength increases is reduced due to base proximity. Thomson's data indicate that the growth rate is only 40 percent of normal. The axial extent of the region over which the base influence is felt is given by

$$e = \frac{d^2}{2 S l \tan \alpha}$$

The model contains this feature.

At any body axial station, then, the strengths of all the vortices

are calculable from the combined theoretical/empirical procedures described above. The next stage in flow field model construction is to locate the vortices relative to the body so that their effects may be calculated.

Vortex Location and Spacing

The problem of locating vortex cores in space relative to the body must be handled separately for vortices growing near the body (i.e., those being fed with vorticity from the separating boundary layer) and for shed vortices which can be considered part of the wake street. In the former case, use is made of theoretical results from two-dimensional potential flow theory; in the latter, systematic experimental evidence, suitably scaled for flow parameter changes, is employed. The case of growing vortices will be described first.

Growing Vortices

In order to model the trajectory followed by a growing vortex, two reference points are required. The first is the circumferential location on the body at which the boundary layer separates. The second is the point in space at which the vortex has reached full strength and can be said to have joined the street.

The first point is located by the empirical relationship

$$\theta_s = \sin^{-1} (3 \tan \delta / 2 \tan \alpha)$$

The angle thus defined places separation in the general region typical of laminar/turbulent boundary layers. Since the means of determining vortex strength does not rely upon an exact knowledge of the separation point location, the above approximation is sufficient for present purposes. If the determination of vortex strength had required use of the Kutta condition, or some estimate of vorticity flux leaving the body, the angle

θ_s would have been required with some accuracy. In the present method however, vortex strength is defined otherwise and a rough estimate of the separation angle is sufficient.

The second point for anchoring the growing vortex trajectories was taken as the intersection of the Foppl and von Karman lines along which the symmetric and asymmetric vortex cores were known to move respectively. Use of this point was justified as follows:

As discussed earlier, the appearance of vortices in the wake shows, at the earliest stage, a symmetric pair. At any axial station, increasing angle of attack produces increased vortex size and strength as well as an outward movement of the core approximately following the Foppl line. It was reasoned that at the first appearance of asymmetry, one of the vortices on the Foppl line would change its trajectory and proceed outwards along a new path defined by the von Karman stability relationship described earlier. The second vortex would perform similarly and this would then set up the spacing of vortices in the street. It was hypothesized then, that in order to continue the spacing pattern, the intersection of the Foppl and von Karman lines would denote the point at which all vortices reached full strength and were shed into the street. In order to test this hypothesis the schlieren photographs of Thomson and Morrison ⁽¹⁾ were examined to determine the distance from the body where vortex feeding from the boundary layer ceased, i.e., the point at which the growing vortex cores became straight and joined the street. It was found that the points thus defined covered a band of values from 2 to 2.5 diameters above the body and at a lateral distance defined by the von Karman stability criterion. To determine the theoretical location of the shedding point, the following procedure was used. With the equation, (14), $2 r y = r^2 - a^2$,

the Foppl line was drawn relative to the cylinder of Figure 7. The data of Reference 1 were used in the equation $d/l = S/\chi$ to determine l , the spacing between street vortices of like sign for subcritical crossflow Reynolds numbers. Then the von Karman relation $h = 0.281l$ was used to superimpose the street vortex location line on Figure 7. The intersection of the Foppl and von Karman lines was found to lie within the experimentally-determined range given above. It was concluded then, that this intersection point provided a good estimate of the location at which the vortices stopped growing and were shed to form part of the street. For the purposes of this engineering flow model the growing vortex core was assumed to move linearly between the two anchor points. The resulting core trajectory model is shown (foreshortened) in Figure 8.

Street Vortices

From the Foppl/von Karman line intersection the vortex cores stream back into the wake as straight lines, making angle ξ with the body axis. This angle was measured by Thomson and Morrison,⁽¹⁾ related to the rate at which a fluid particle flowing along the core increases its distance from the body, and thence analogized to the two-dimensional von Karman street. ξ is related to missile angle of attack through the parameter $\chi = \tan \xi / \tan \alpha$ ⁽¹⁾. If the point on the body from which a vortex emanates is known, then its core location in space may be partly determined using χ . For the purposes of this work χ was assumed unaffected by changes in cross-flow Reynolds number.

Vortex starting points on the body were estimated in Reference 1 as being the intersection point of the body axis and the extrapolated street vortex cores. Since these positions were obtained for tailless bodies, the

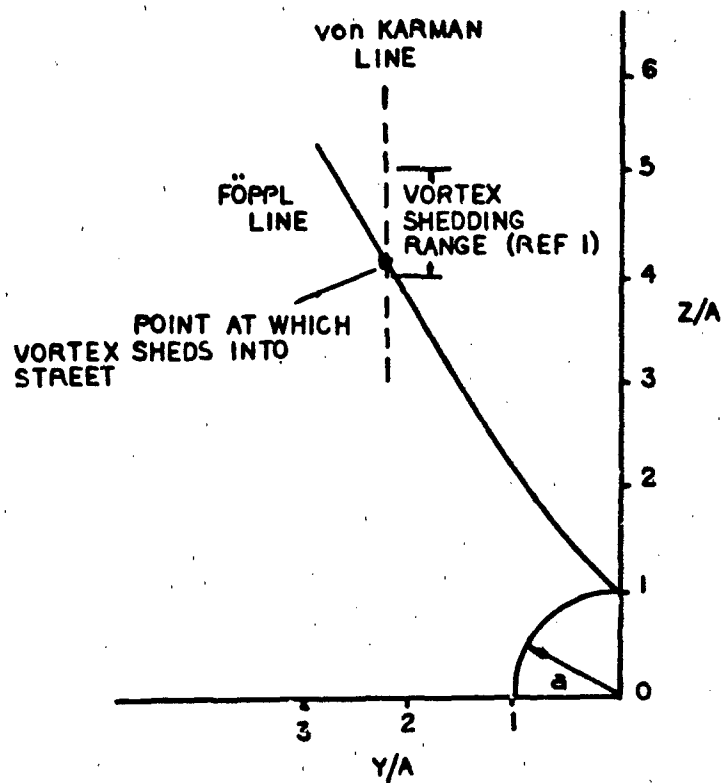


FIGURE 7 COMPARISON BETWEEN PREDICTED AND EXPERIMENTAL POINT WHERE VORTEX IS SHED INTO STREET

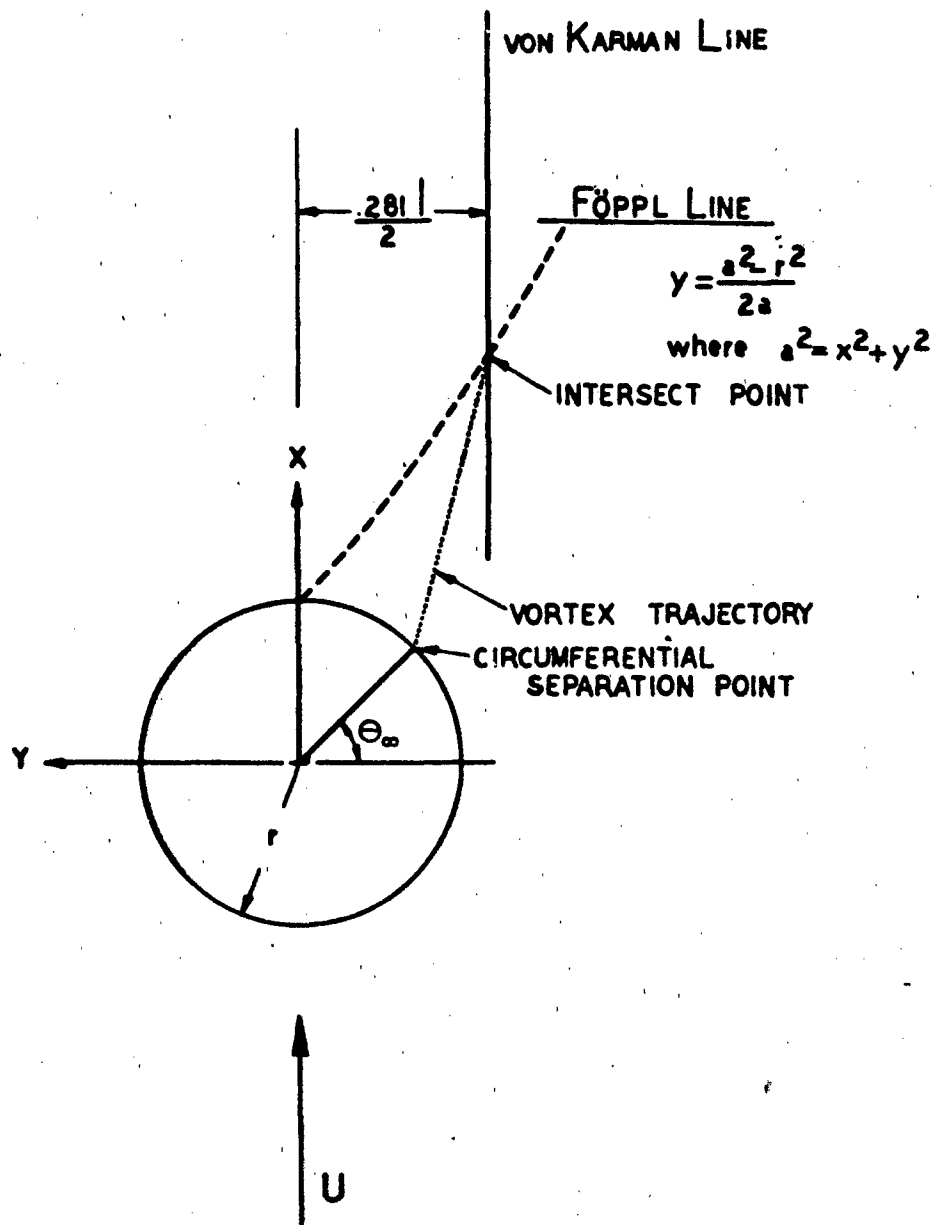


FIGURE 8 GROWING VORTEX'S TRAJECTORY

present work assumes that in the presence of tails, body vortex formation ceases at the body/tail leading edge intersection. Provided the Strouhal number, S , is known, the starting points of wake vortices can be determined. Further, using the relation ⁽¹⁾ $d/l = S/\chi$, the lateral spacing, l , between vortices of like sign, and hence $0.281l$, the von Karman-deduced criterion for lateral spacing can be determined. The vortex cores can now be located in space relative to the body at any point along their lengths. At this stage, however, the information is sufficient only for subcritical cross-flow Reynolds numbers.

The quantity on which attention must be concentrated when scaling vortex locations for crossflow Reynolds number is the Strouhal number, S . This measure of the rate at which vortices of like sign are shed from the body has been shown to exhibit strong similarities between the two- and three-dimensional cases. In Reference 1, S was determined experimentally to have values near 0.2 for a wide range of crossflow Mach numbers. This compares well with the two-dimensional value at subcritical crossflow Reynolds number. It is known however, ⁽⁸⁾ that for cylinders, S varies with crossflow Reynolds number and increases to values in the range 0.3 to 0.5 at supercritical Re_c . This has a direct effect on vortex spacing, both longitudinal and lateral. For bodies alone then, $S = 0.2$ is used for subcritical Re_c . It has been found that a value of $S = 0.35$ gives the best results for supercritical Re_c . For bodies with tails, the rate of vortex formation is influenced by the presence of the tails. Experimental evidence indicates that the effect is to reduce the rate of formation to that defined by $S = 0.2$ regardless of whether the crossflow Reynolds number is sub- or supercritical. Accordingly, for bodies with tails, $S = 0.2$ is used throughout.

Using the above empirical and theoretical inputs, a model can be constructed of the asymmetric wake produced by a slender missile configuration at high angles of attack. This model includes the number and locations of vortices in the wake and their strengths, suitably scaled for Mach number and Reynolds number effects. Both growing and shed vortices are included in the model. Having constructed a model of the wake, the next step is to consider its effect on the missile configuration.

4.0 FORCE AND MOMENT COMPUTATIONAL TECHNIQUES

Having established a technique to model the wake produced by a slender missile configuration at high angles of attack, the next step is to calculate the forces and moments induced on the configuration by the wake. This section presents a computational procedure to do this for bodies alone and then for bodies with tails. In either case, the procedure calls for the calculation of incremental effects produced on various configuration segments and then integration of these effects to determine the forces and moments induced by the wake.

This computational procedure was designed with the intent that it not be overly complicated. With this in mind, the following basic assumption was made concerning the location within the body of the image vortices required to preserve the velocity tangency condition on the surface of the body at each axial station. These image vortices are located in the body on a plane perpendicular to the vortex core; however, this raises a problem because of the inclination of the vortex cores relative to the body axis. A cross-section normal to the stream cores shows an elliptical body section, inside which the location of image vortices is not simply accomplished. In keeping with the simple nature of this model it was decided that, if possible, image vortices should be located by means of the circle theorem.⁽¹⁴⁾ This was accomplished by resolving the vortex circulation vectors normal and parallel to the body axis. By ignoring the former as having no relevance in the two-dimensional section model, the latter components plus their images could then be used to determine forces and moments. The use of images was not necessary for body quantities, but was, however, mandatory for tailed regions of the missiles. These points are discussed below.

Body Forces and Moments

The calculation of body forces and moments begins with the determination of the incremental force on each body segment. In order to calculate this force, the local net circulation of all the vortices in the wake must be known. Further, these vortices must have their circulation vectors resolved parallel to the body as described above. At any axial station from the nose, there are usually several wake vortices of strength Γ_g and two growing vortices, one on the left side, having strength $\Gamma_L(x)$ and another on the right, of strength $\Gamma_R(x)$. Since g is the axial distance over which a vortex grows to full strength then $x_R = x_L + g/2$ assuming $\Gamma_R > \Gamma_L$. To resolve the strengths parallel to the body axis, the angle σ for growing and ξ for street vortices were used respectively. Side force on unit length of the body was calculated using the Kutta-Joukowski expression.

$$\delta Y = \rho V \sin \alpha \left\{ [\Gamma_R(x) - \Gamma_L(x)] \cos \sigma + \left\{ \sum_{i=1}^m \left(\frac{\bar{R} - r_i}{\bar{R}} \right) \Gamma_{R_i} - \sum_{i=1}^{m+1} \left(\frac{\bar{R} - r_i}{\bar{R}} \right) \Gamma_{L_i} \right\} \cos \xi \right\}$$

Where it has been assumed, for illustration, that there are $(m+1)$ fully developed vortices on the left side of the body and m on the right. The term $(\bar{R} - r_i)/\bar{R}$ is an empirical factor accounting for the attenuation of fully developed vortex effects on the body as their distances from it increases. r_i is the actual distance of the vortex from the body and $\bar{R}$ is an arbitrary distance at which vortex effect is assumed to have attenuated to zero. The smallest value of r_i is defined by the Föppl/von Karman intersection point. This formulation was an attempt to model the expected vortex attenuation effect empirically. As will be shown later, it was found that the best representation of forces and moments was obtained when the street vortex strength was allowed to attenuate to zero immediately after shedding.

Total side force Y and yawing moment YM are calculated by numerically integrating along the body length. At this stage in the computerized version of the procedure, an option is provided allowing the user to calculate the effect of varying nose fineness and bluntness ratios. This option uses the data of References 3 and 19 to scale the total body side force and yawing moment for various nose fineness and bluntness ratios. The calculation of individual side forces and yawing moments outlined above, employs the flowfield model developed using the empirical data from Reference 1 to determine street vortex strength and vortex separation points. These empirical inputs were derived from wind tunnel data for a configuration having a 3.798 fineness ratio conic nose. The data of Reference 3, obtained from tests of configurations with noses of fineness ratios of 2, 3 and 4, show that the maximum absolute value of side force, $|CY|_{MAX}$, generally tended to increase with increased fineness ratio for noses with little or no bluntness (see Figure 9). To account for this effect, the data of Figure 9 were used to produce scale factors by which the basic output, based on a 3.798 fineness ratio nose, could be scaled.

The data of Reference 3 also indicated that increases in nose bluntness generally tended to reduce the maximum value of side force. Figure 10 shows the effects of blunting a fineness ratio 4.0 nose. Data were also available for fineness ratio 2.0 and 3.0 nose configurations with bluntnesses of 0, 5, 10, 20 and 50 percent. These data were used to produce scale factors by which the values of side force, already corrected for fineness ratio, could be scaled.

Schlieren photographs in Reference 3 indicate that variations in fineness ratio impact the location at which vortices are shed and that variations in

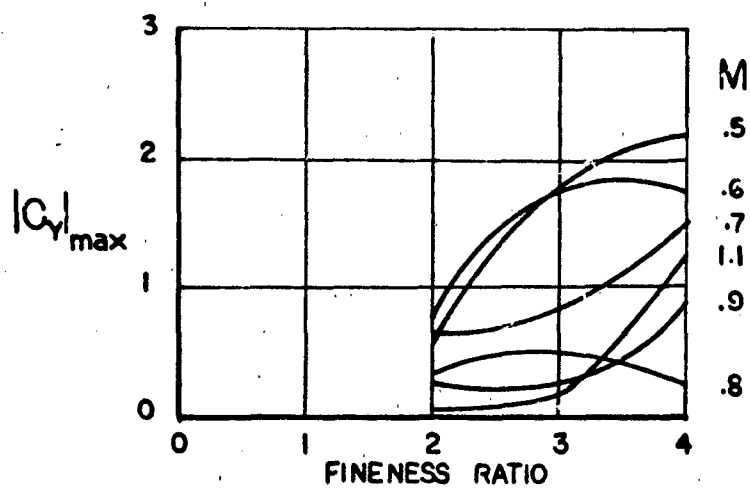


FIGURE 9 FINENESS RATIO EFFECTS

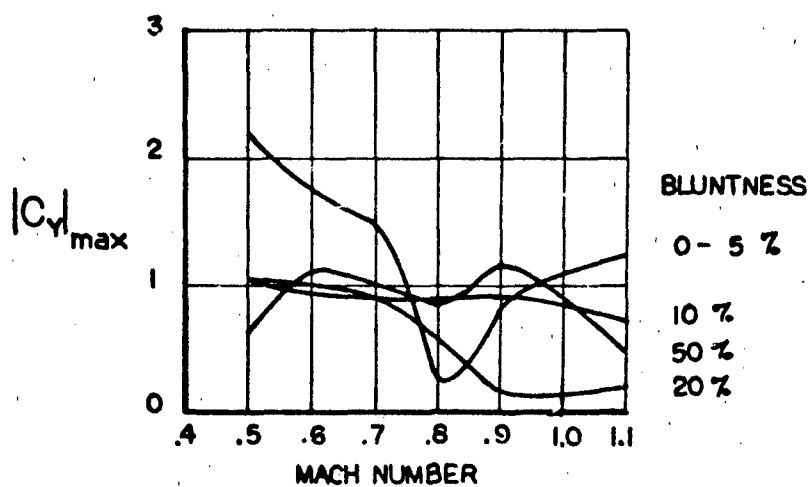


FIGURE 10 BLUNTNESS RATIO EFFECTS

fineness ratio impact the location at which vortices are shed and that variations in nose bluntness delay vortex separation. This is to say that variations in nose geometry influence the structure of the asymmetric wake. Rather than attempting to modify the flowfield model presented in Section 3.0, the scaling technique outlined above was employed in keeping with the simplified nature of the model.

Caution is advised when employing the above scaling technique for nose fineness and bluntness ratio variations. The warning is necessary because the data ^{3,19} used to derive the scaling factors were mean values and data showing considerable scatter. It is also possible that an independent test of these same configurations could produce considerably different data due to the dynamic nature of the vortex shedding phenomenon.

Tail Forces and Moments

Induced side forces, yawing moments and rolling moments due to the presence of tails can arise even when no asymmetry exists in the wake vortex pattern. This is because of varying net angles of attack of the various tails when the missile is rolled at arbitrary angles. Hence, in order to be certain that experimental data indicate the presence of vortex asymmetry, it is necessary to be selective in choosing missile roll attitudes. For a cruciform missile, roll angles of 0 "plus" and 45 degrees "cross" are the only attitudes where, in the absence of wake asymmetry, zero side forces, rolling moments and yawing moments occur (assuming, of course, no tail deflections). The present model has been compared against experimental data from cruciform missiles and hence the above two roll angles will be referred to exclusively.

The procedure for calculating induced tail forces will be described for a vertical lee-side tail such as could be used on a cruciform missile in "plus" attitude. The major elements of the treatment are most expeditiously described for this case, although the complete procedure will handle tails

at any roll angle so that the program can treat bodies at arbitrary roll or whose tails number other than four.

The first step in the process is to determine, for each vortex, the sidewash velocity induced normal to the tail leading edge at each spanwise station. Since the effects of image vortices must be considered and it is preferred that the circle theorem be used, the wake vortex circulation vector is resolved parallel to the body axis as before. In this case, however, instead of simply resolving Γ_s through some angle analogous to ξ as was done for the body above, a new strength is defined which will produce the same values of sidewash velocity as did the original vortex. A single vortex in the wake plus its images will induce some distribution of sidewash velocity v along the tail leading edge. The average value of this sidewash is

$$\frac{1}{p} \int_a^p v dz$$

If now the average sidewash is divided by the axial velocity $V \cos \alpha$, the average angle of attack induced on the tail is obtained. Using the result from slender body theory, that for low aspect ratio tails typical of missile configurations the slope of normal force coefficient is given by $\pi AR/2$, the normal force coefficient induced on the tail due to the i^{th} vortex may be expressed formally as

$$C_{N_i} = \frac{\pi AR A_T}{2p V \cos \alpha A_B} \int_a^p v_i dz \quad (3)$$

In order to determine rolling moment induced on the missile due to the vertical tail, the resultant normal force is assumed to act at the centroid of the sidewash velocity distribution or, for the i^{th} vortex

$$C_{l_i} = C_{N_i} \left\{ a + \frac{\int_0^p v_i z dz}{\int_0^p v_i dz} \right\} \frac{A_T}{A_B} \quad (4)$$

The total induced forces and moments are obtained by summing the effects of all vortices in the wake.

Yawing moment induced by the tail is calculated by assuming that the resultant loading is located at the mid-point of the leading edge.

The above procedure has been generalized to handle tails at any roll angle. In this way, the contributions of all tails to side forces and yawing and rolling moments may be determined.

Since arbitrary roll angles can be considered, this raises potential problems when a vortex core intersects the leading edge. For potential vortices of the kind used here, flow velocities become extremely high near the core, resulting in unrealistically high induced sidewash angles. This problem was circumvented by introducing into each vortex a solid core of radius 0.25 body radius.⁽¹⁸⁾

When the tail intersects this core, calculations are discontinued. If the core passes over a tail while angle of attack is increasing, the forces and moments are faired across the gap within which calculations are not performed. This procedure has proved quite satisfactory in practice.

Instead of the slender body theory approach to tail force, strip theory might have been employed. It was felt, however, that the former was more appropriate for the low aspect ratio tails for which the program would probably be used. The program is flexible enough, however, that strip theory could be easily introduced if it were considered necessary.

5.0 COMPARISONS BETWEEN COMPUTED AND EXPERIMENTAL RESULTS

At this stage then, the effects of the wake vortices on bodies and tails are calculable. Comparisons will now be presented between predicted and experimental forces and moments to illustrate the performance of this engineering model. Bodies alone and with cruciform tails will be considered. The effect of varying the number of vortices considered will be shown.

Program predictions have been compared against various experimental data generated on a selection of the Martin Marietta Aerodynamic Research models. (16) The basic model used for high angle data generation was a 10 caliber tangent ogive/cylinder. This body was tested alone and with several sets of cruciform tails affixed. Each tail was individually instrumented so that program predictions of vertical tail forces and moments could be checked for "plus" attitudes. For tails other than vertical, the program would predict only the incremental force generated on them by the asymmetric wake. Freestream effects were not taken into account, and hence forces for non-vertical tails will not be discussed. However, since the differences between non-vertical tails due to asymmetric effects were presumed to be valid for "plus" and "cross" attitudes, the program was used to predict rolling moments for these attitudes.

The first comparison is shown in Figure 11. Here, program predictions of normal force on a vertical lee side tail fixed to the body are compared against experimental data. Also shown is the effect of considering all of the vortices in the wake and of using only those vortices closest to the body, i.e., the growing vortices. It will be seen that the magnitude of tail force is predicted within a few percent using only the growing vortices, while use of all vortices produces a significant discrepancy. The angle at which asymmetry begins is matched only fairly, but the angle at which the appearance of a new wake vortex drives the tail force in the opposite

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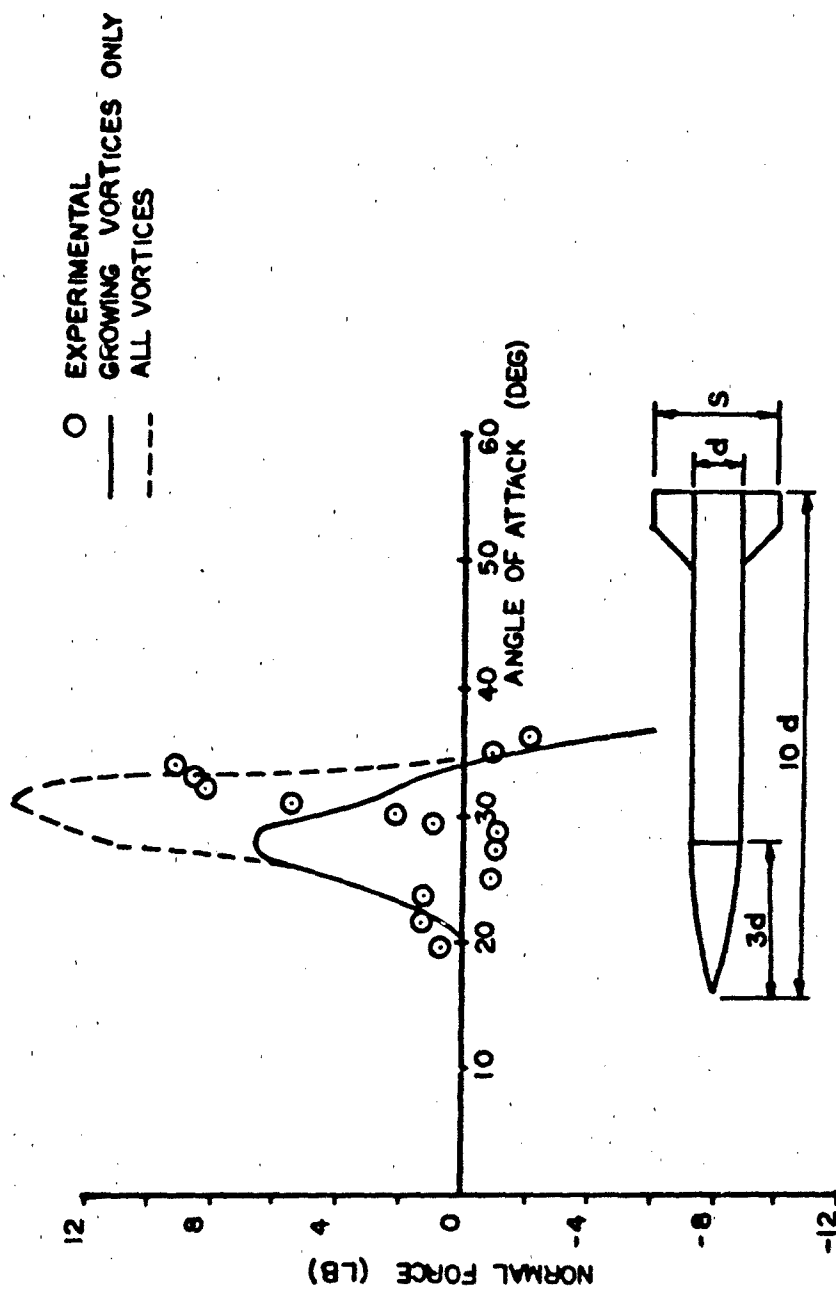


FIGURE 11 COMPARISON BETWEEN PREDICTED AND EXPERIMENTAL VERTICAL FIN NORMAL FORCE

direction is matched within a few degrees. From this evidence, it is concluded that the growing vortices tend to dominate the tail aerodynamic characteristics. The second comparison is shown in Figures 12a and b. Here, predictions of isolated body side force and yawing moments are compared against test data. Again, the effects of considering all of the wake vortices separately from the growing vortices are considered. To make the distinction clearer, no attenuation of non-growing vortex effects has been included. It will be seen that use of all the vortices produces divergent results which have none of the oscillatory character typical of asymmetric effects and evidenced by the data. This is because the net wake circulation remains unchanged in sign, regardless of the number of vortices present. Use of the growing vortices only, on the other hand, yields quite good matching of force and moment magnitudes, as well as angles of onset and new vortex appearance, at least until several vortices are present. While matching is not exact at the higher angles it is clear that use of the program will produce satisfactory preliminary design level estimates for isolated bodies.

Lastly, comparisons are shown between predictions and data for the 10 caliber body with a variety of tails. Based on the results for tails and bodies, these comparisons contain the effects of growing vortices only. Figures 13 a, b, and c show side force, yawing moment and rolling moment comparison respectively. Prediction accuracy is generally satisfactory. In most cases the magnitudes of the quantities are predicted quite closely. On the other hand, the onset of asymmetry and the appearance of new vortices are not always so accurately reproduced.

The results of Figures 11-13 indicate that the vortices growing in the vicinity of the body dominate the induced effects. This appears intuitively correct, particularly in the context of the two-dimensional analogy. There, the vortices closest to the body would be expected to produce the pressure

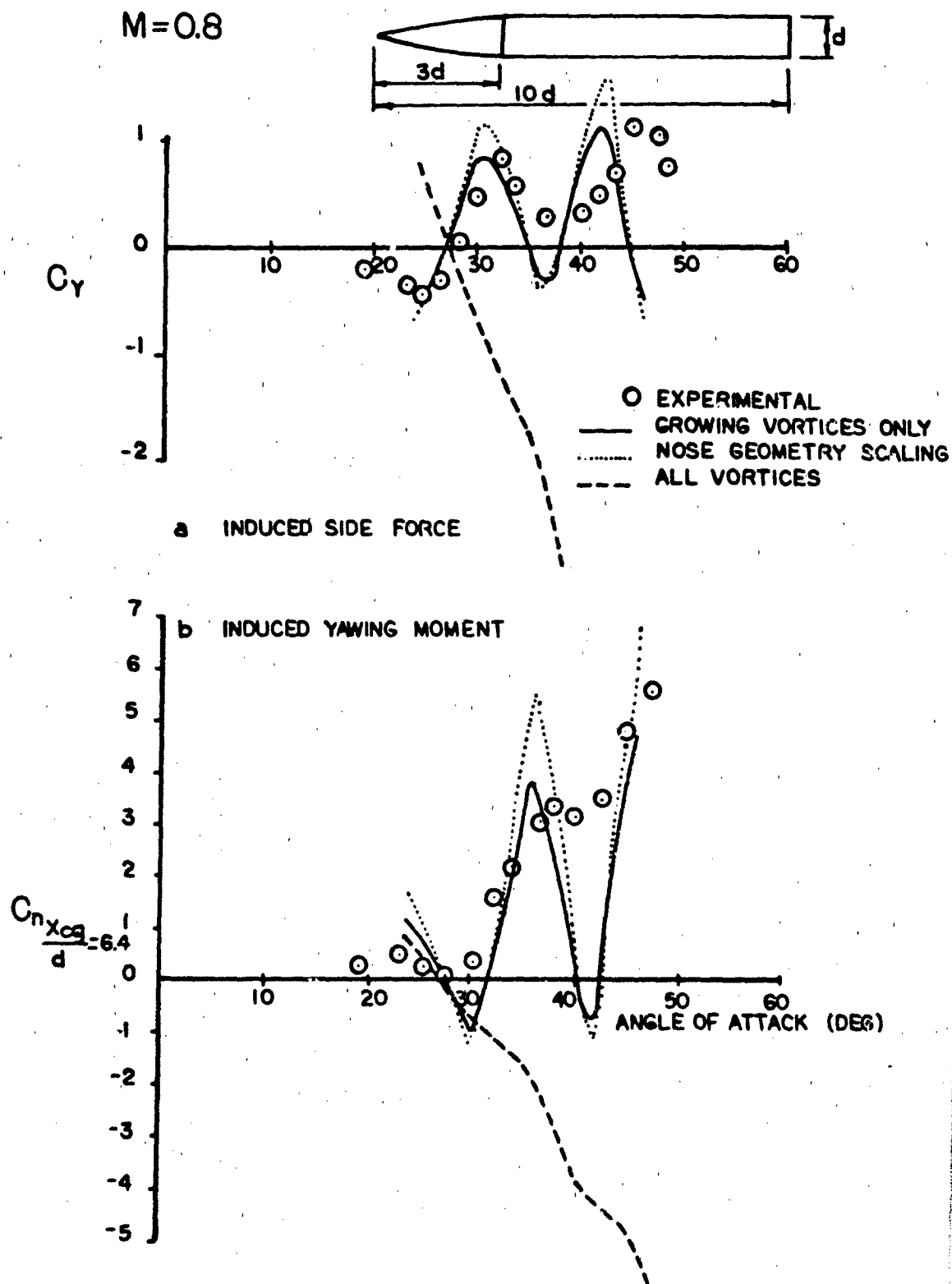


FIGURE 12 COMPARISON BETWEEN PREDICTED AND EXPERIMENTAL RESULTS (BODY ALONE)

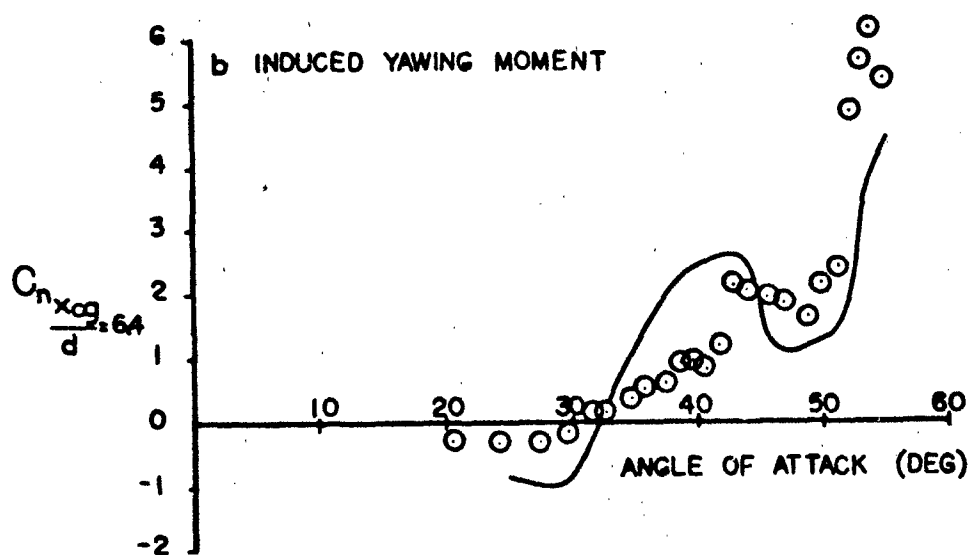
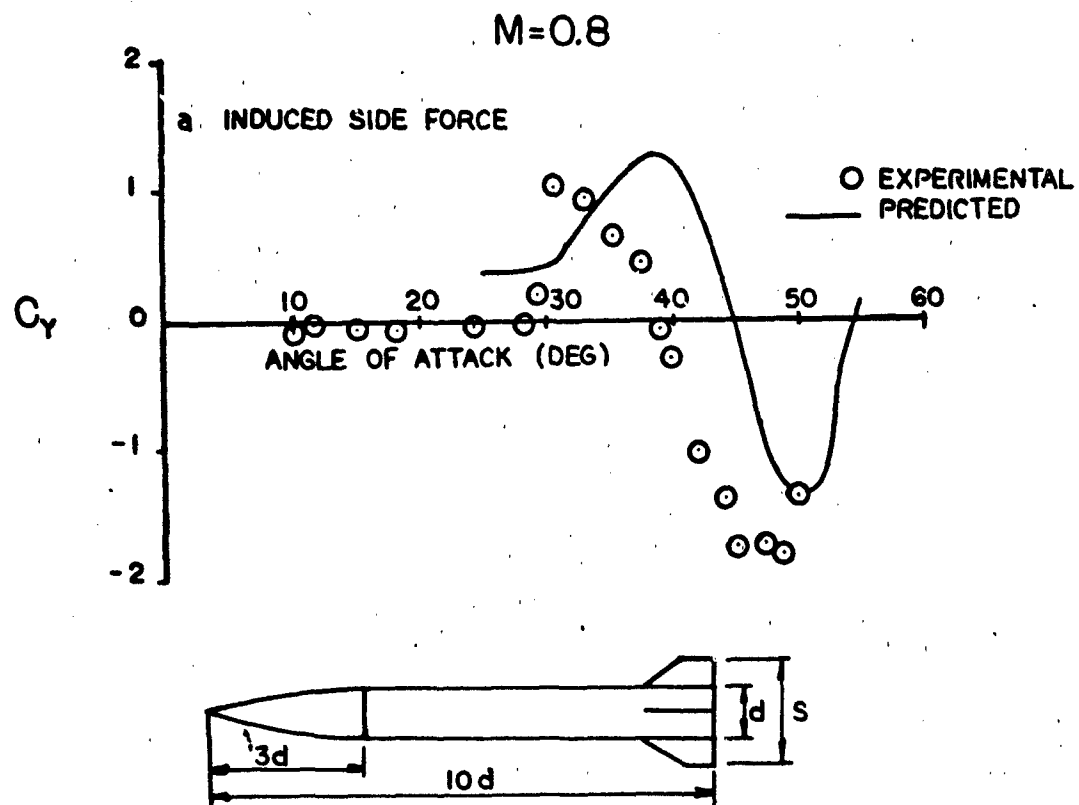


FIGURE 13 COMPARISON BETWEEN PREDICTED AND EXPERIMENTAL RESULTS (BODY+TAIL)

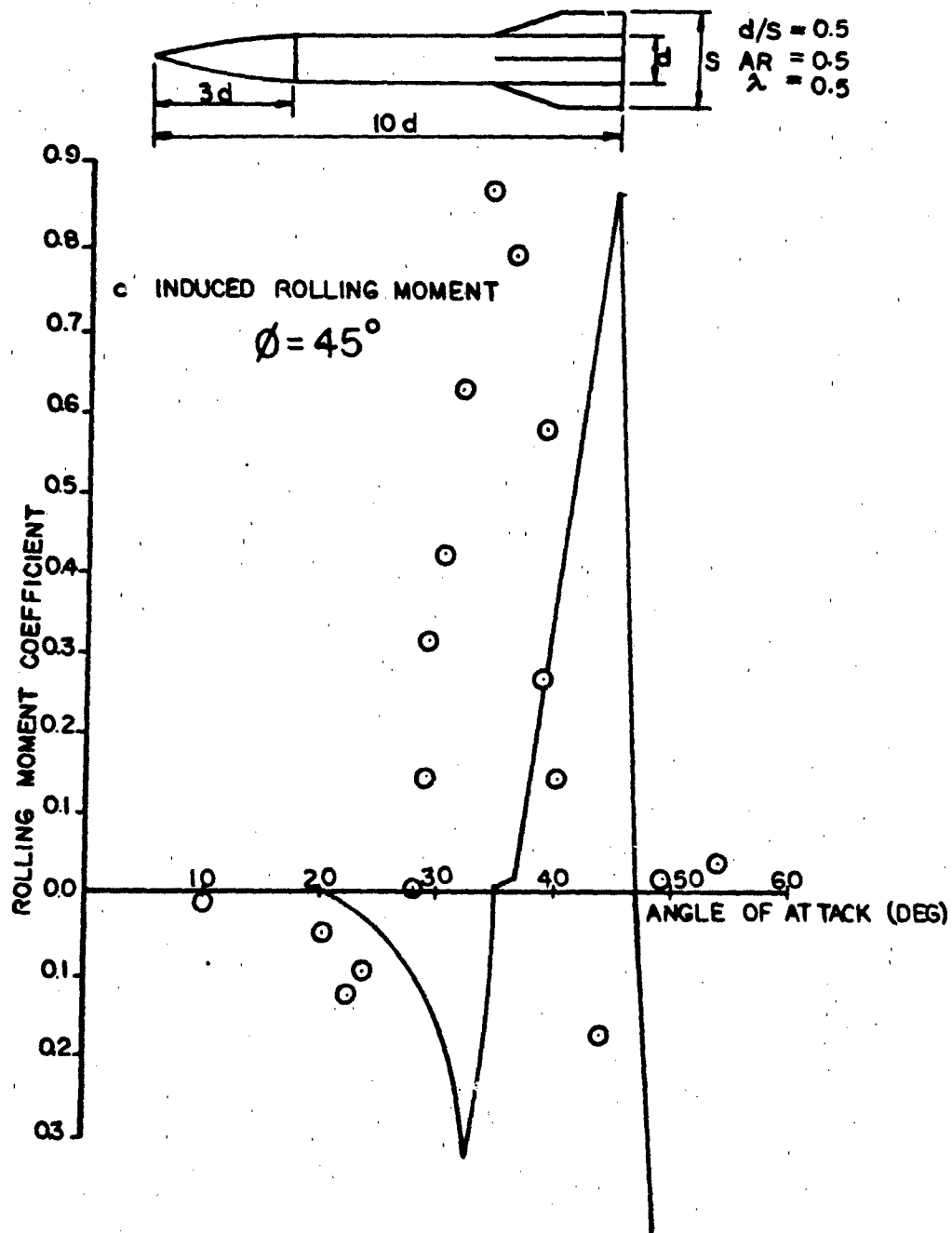


FIGURE 13 CONTINUED

and velocity distributions which generate the forces and moments, with the remainder of the vortices having little effect as they pass downstream. It is not unexpected then, that the three-dimensional case should give similar results. However, although the street vortices have been shown to have relatively little impact, the experimental information on their strengths and shedding frequencies remains of central importance since it defines the bounds of growing vortex strength and shedding frequency.

In general, the model performs quite reasonably. In view of the changes in force and moment data magnitudes and signs which can be obtained by rotation of test models, (1, 3,4) some degree of fortuitousness might be assigned to the results shown. On the other hand, it is unlikely that any measured forces and moments will be significantly greater than those calculated since the model contains all the essential elements of the vortex flowfield, both in magnitude and locations. In addition, it is felt that the means of calculating flow field effects are adequately founded in theory.

6.0 PROGRAM USERS MANUAL

6.1 Input and Output Formats

Input Format:

The input requirements for this program are relatively simple. The input can be separated into 9 basic groups. The following gives information concerning each grouping.

Group I - Flow field data

a. Format: 4F10.0

b. Variables:

VINF - Free stream velocity in ft/sec

FSMN - Free stream Mach number

RHOINF - Free stream density in $\frac{\text{lb sec}^2}{\text{ft}^4}$

ANU - Kinematic viscosity in ft^2/sec

Group II - Body Data

a. Format: 6F10.0, 2I3

b. Variables:

D - Maximum body cross sectional diameter in ft.

SREF - Body reference area in ft^2

NOSEL - Nose length in ft.

BODYL - Body length in ft.

XMC - Moment reference measured from the nose in ft. (absolute value)

DELTA - Nose half angle in deg. $\Delta = \tan^{-1} \left(\frac{\text{body radius}}{\text{nose length}} \right)$

NS - Number of segments into which the finless portion of the body is to be divided. (Maximum of 100 segments)

IDCONF - Configuration Type (0 = Body, 1 = Body + Tail)

Group III - Fin Data (Input only if IDCONF = 1)

a. Format: (7F10.0)

b. Variables:

- XF - Axial distance in feet from nose to physical fin root chord leading edge. Measured negative from nose aft. (See Figure 14)
- YF - Distance in yaw plane from body centerline to fin root chord leading edge. Measured in feet. (See Figure 14)
- ZF - Distance in pitch plane from body centerline to fin root chord leading edge. Measured in feet. (See Figure 14)
- XFMAX - Axial distance in feet from nose to fin tip chord leading edge. Measured negative from nose aft. (See Figure 14)
- YFMAX - Distance in yaw plane from body centerline to fin tip chord leading edge. Measured in feet. (See Figure 14)
- ZFMAX - Distance in pitch plane from body centerline to fin tip chord leading edge. Measured in feet. (See Figure 14)
- SREFT - Tail single panel reference area in ft.²

The above measurements apply to a single lee-side fin in the pitch plane of a non-rolled missile.

Group IV - Indicators

a. Format: (313)

. Variables

NAOA - Number of angles of attack to be considered. As many as 30 angles of attack may be entered per run.

NTYPE - Nose type indicator

NTYPE	Nose Shape
1	Cone
2	Tangent Ogive

NLAM - Number of roll angles to be considered. As many as 30 roll angles may be entered per run.

Group V - Angles of Attack

a. Format: (8F10.0)

b. Variables:

AOAD - Angles of attack in degrees (See Figure 14)

Group VI - Roll Angles

a. Format: (8F10.0)

b. Variables:

RA* = Roll angles in degrees (See Figure 14)

*Locates fin positions relative to leeside vertical,
RA = 0.0

Group VII - Radial Vortex Limit

a. Format: (F10.0)

b. Variables:

GAMLIM - Radius at which the influence of a vortex on the
body goes to zero. (diameters)

Group VIII - Nose Fineness and Bluntness Ratio Option

a. Format: (I1,F10.0)

b. Variables

IOPT1 - Option indicator

(0 = Do not use option, 1 = use option)

BRN - Bluntness ratio in percent $\left(\frac{\text{Nose tip radius}}{\text{Nose base radius}} \times 100 \right)$

Group IX: Run Configuration Indicator

a. Format: (I1)

b. Variables:

IRUN - Run indicator (1 - another run follows,
0 = terminate computations)

Output Format:

Output format will be determined by the nature of the configuration being analyzed. Output for isolated bodies consist of angles of attack, side force coefficients (CY) and yawing moment coefficients (CETAMC) about the moment center input by the user. If the fineness and bluntness ratio scaling option is selected, output will be scaled and repeated. Output for body plus tail configurations consist of angles of attack, induced side force coefficient (CY), yawing moment coefficient (CETAMC) about the user input moment reference center and rolling moments. Additionally, for a fin located in the leeside vertical plane (RA = 0.0), the force normal to the fin is also printed out.

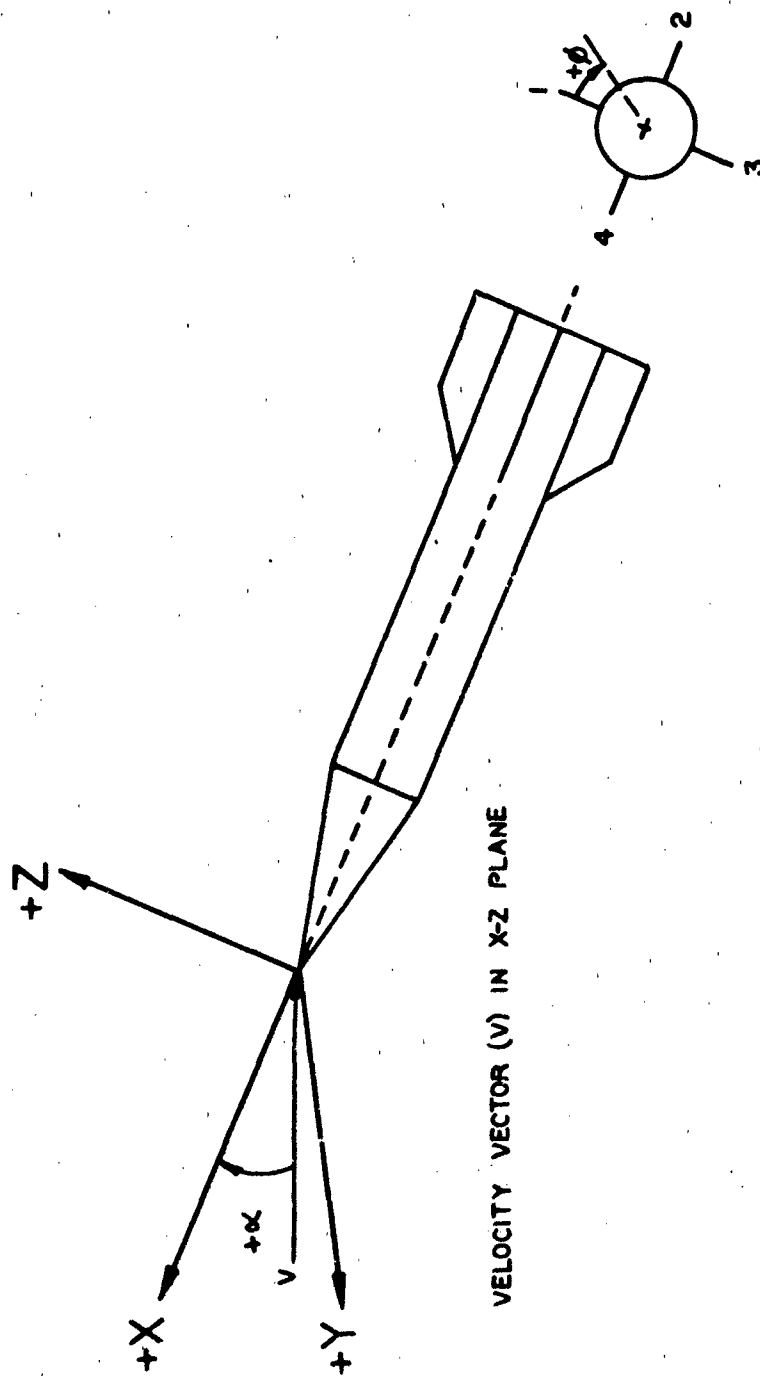


FIGURE 14 SIGN CONVENTION

6.2 Program Flow Charts

Two program flow charts are presented. The first (Chart 1) is a generalized flow chart designed to provide the user a basic map of program functions. The second flow chart (Chart 2) is designed to give the user requiring a working knowledge of program functions a more detailed breakdown of program logic.

Descriptive statements are also contained in the program listing in order to facilitate tracing the steps through the program.

Chart 1. Top Level Program Flow Chart

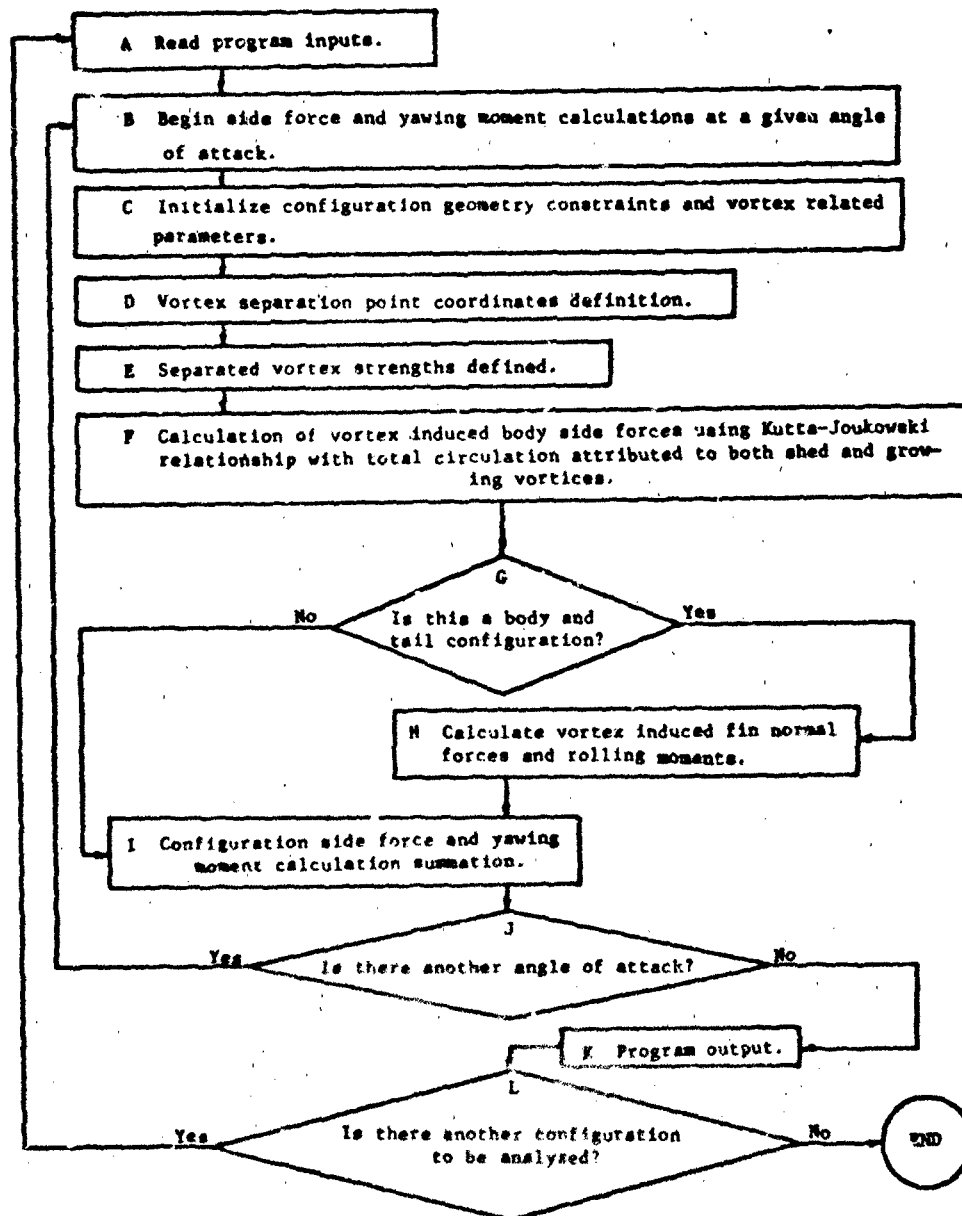


Chart 2. Detailed Program Flow Chart

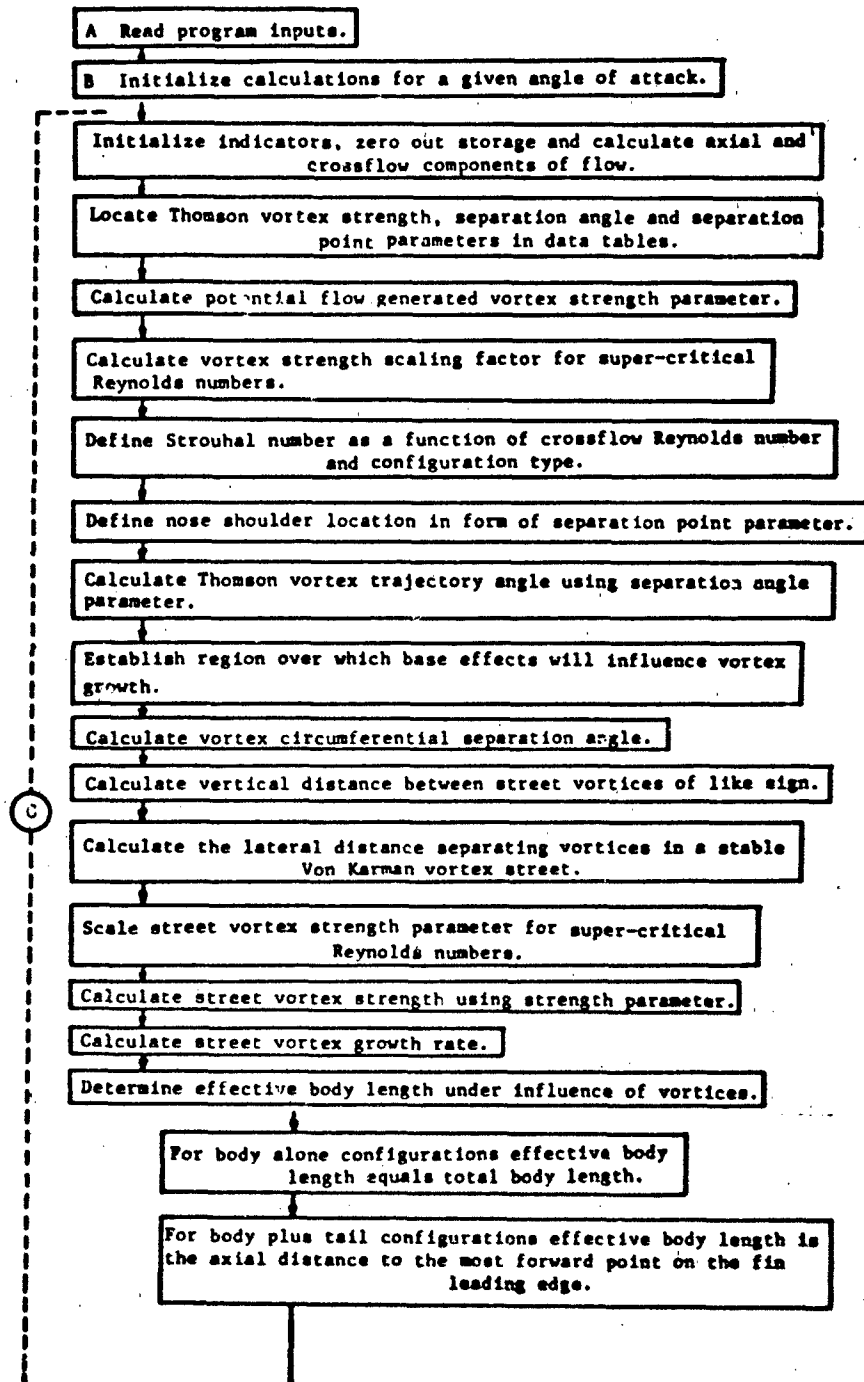


Chart 2. (continued)

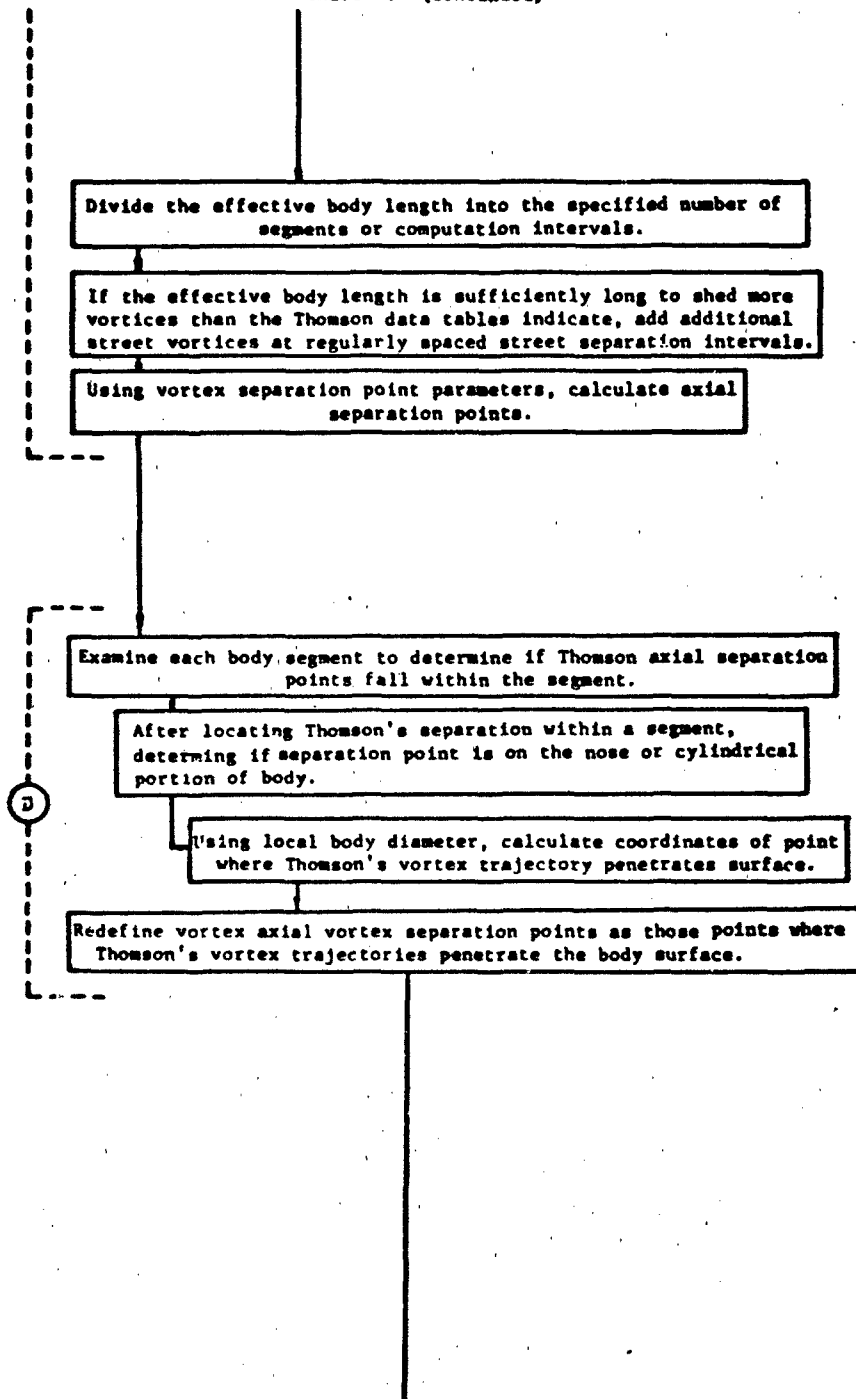


Chart 2. (continued)

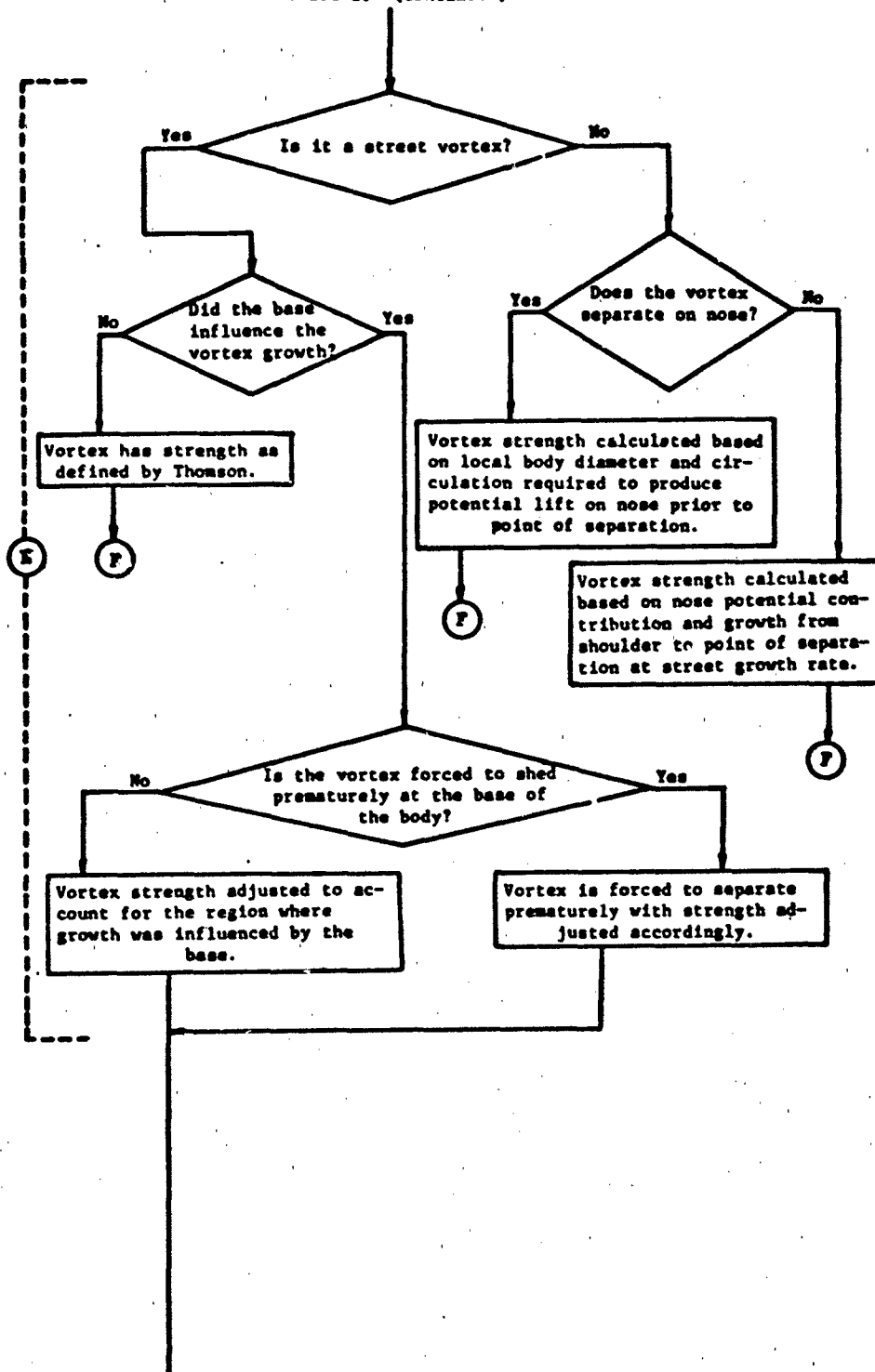


Chart 2. (continued)

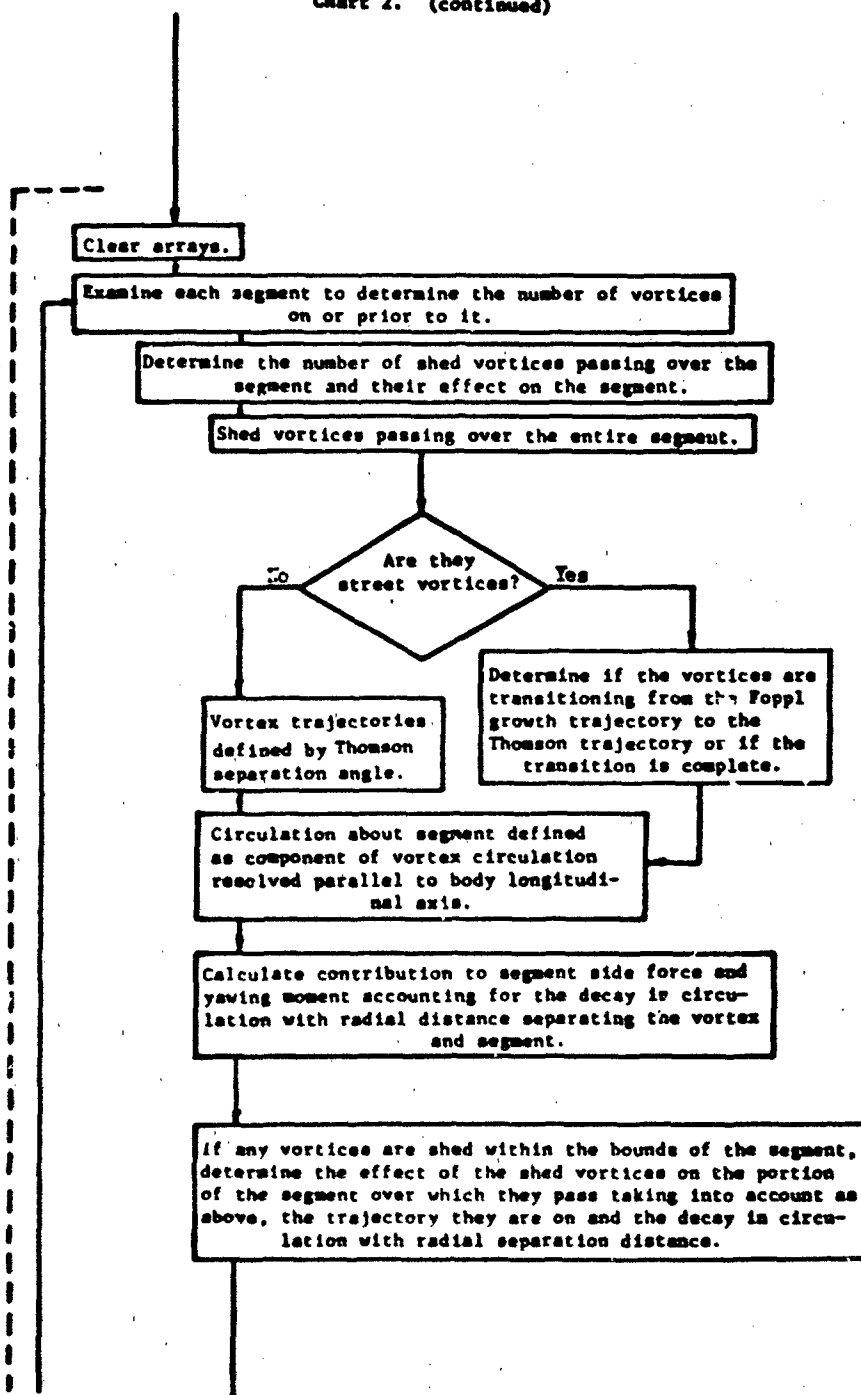


Chart 2. (continues)

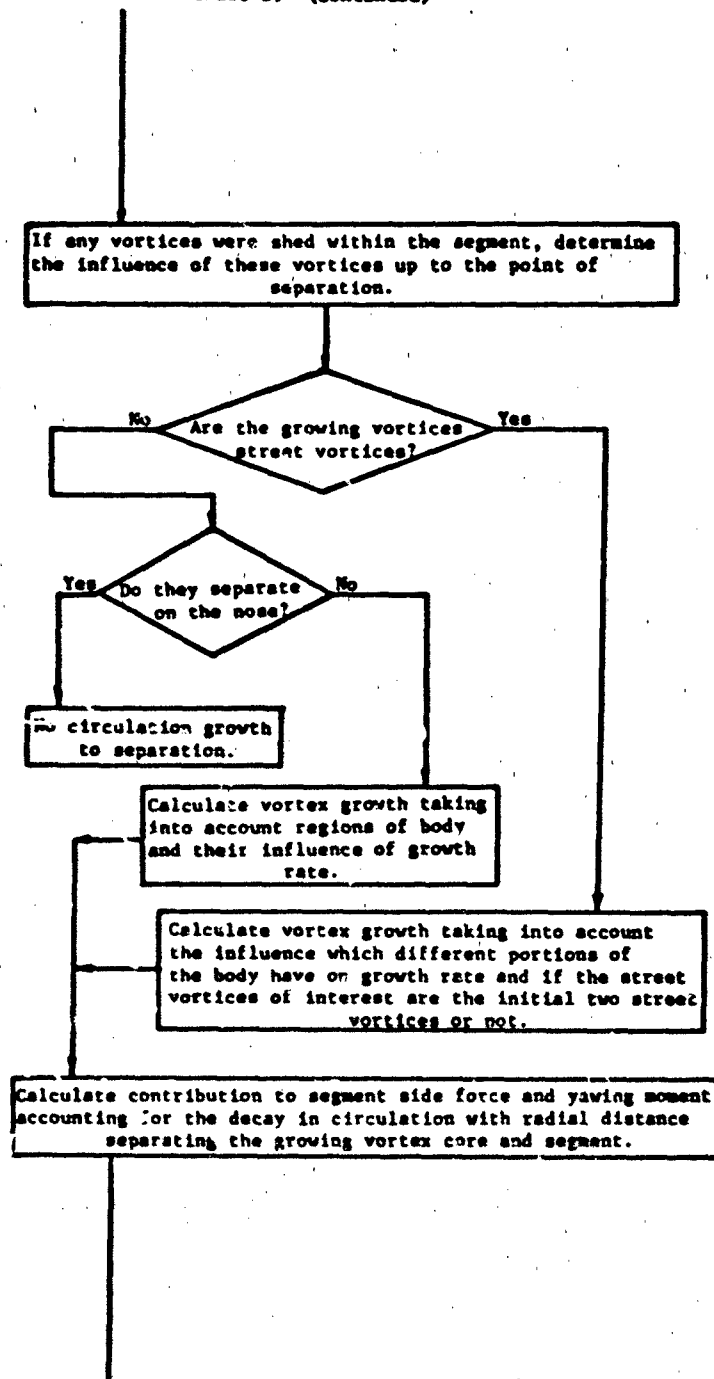


Chart 2. (continued)

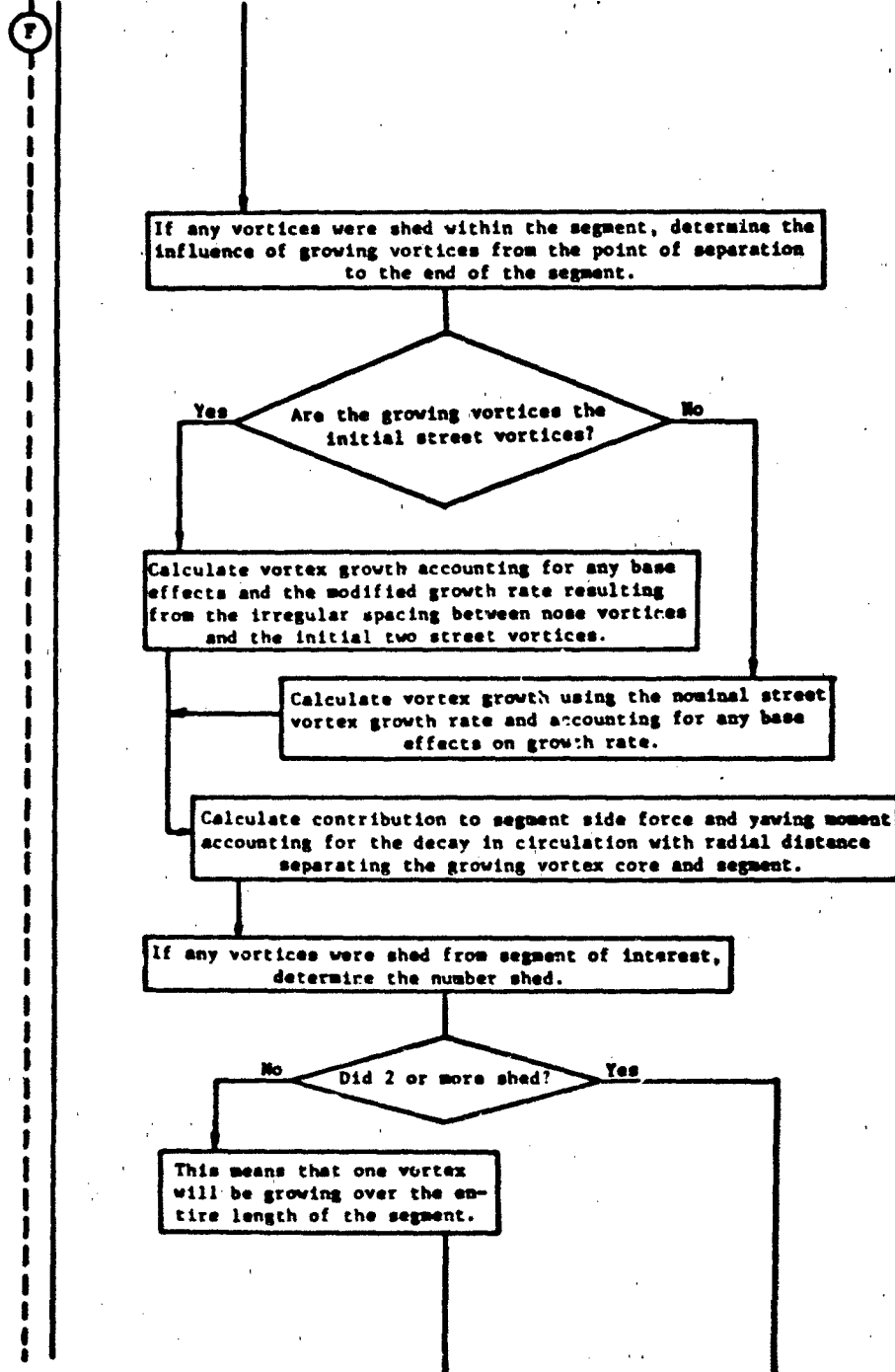


Chart 2. (continued)

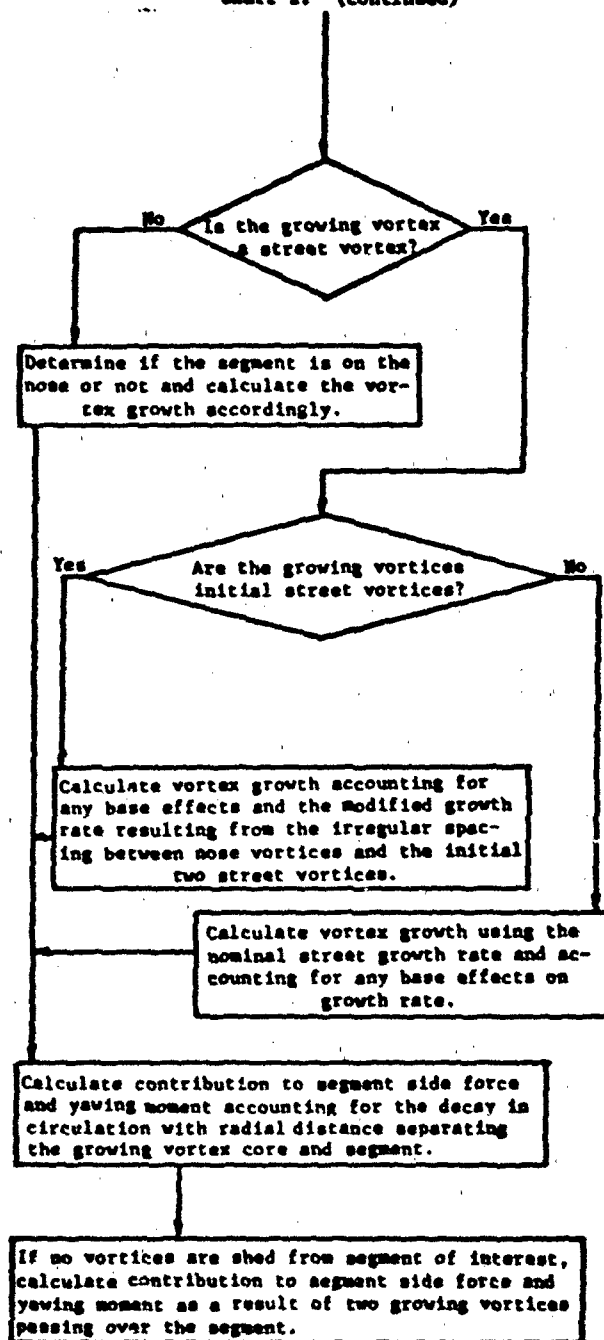
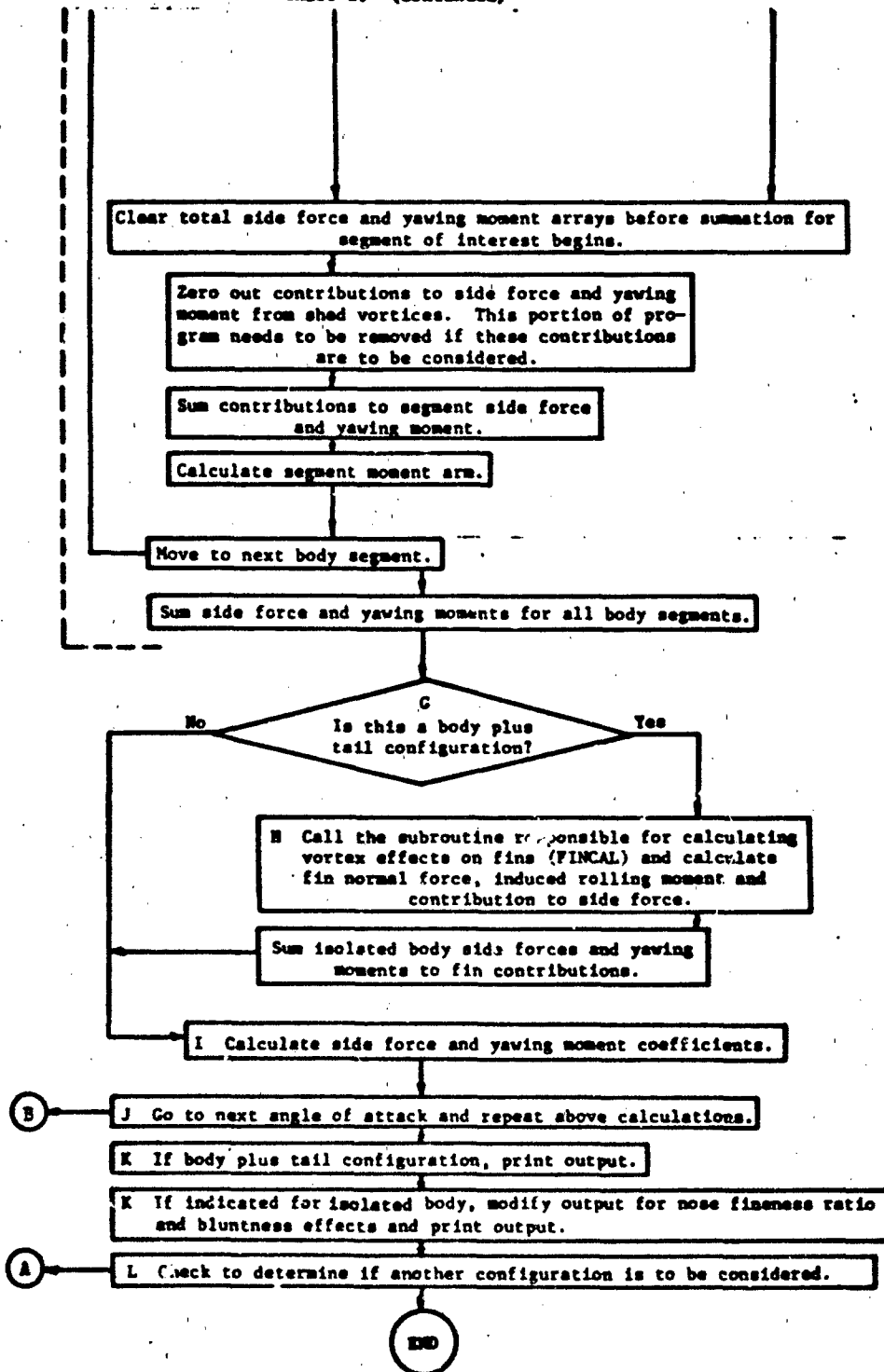


Chart 2. (continued)



6.3 Program Listing

MAIN

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REAL LAM,NUSE,ALAM)
DIMENSION GSEP(20),ASEP(20),AUAD(30),A7A2(30),GAMSU(20)
DIMENSION GAMPC(20),GANT(100),SF(100),CY(100)
DIMENSION YMOA(100),CETA(100),GSEP(20),GSEPY(20),GSEPZ(20)
DIMENSION A3SEP(20),A4(30)
DIMENSION FMGSC(20),SPSV(20),FMGDSV(20),GOUTS(20)
DIMENSION FMGOUT(20),GHUAS(20),FMHUS(20),GHU(20),FMGBU(20)
DIMENSION CETAMC(100)
DIMENSION FAT(100),FNFQ(30)
DIMENSION SFPC(20),SFPSV(20),SFHITS(20),SERHIS(20),CFGBJ(20)
DIMENSION TMACHC(17),TALPHA(6),TGAMP(17,6)
DIMENSION ISKIP(30),SROLN(30)
DIMENSION TXI(17),TGSEP(17,7)
DATA TGAMP/ 2.8 , 2.8 , 2.8 , 2.8 , 2.81 , 2.84 , 2.9 , 3.0 , 3.11
2 , 3.28 , 3.41 , 3.5 , 3.5 , 4.0 , 4.19 , 4.03 , 3.0 , 2.48 , 2.49
3 , 2.48 , 2.49 , 2.49 , 2.5 , 2.55 , 2.45 , 2.78 , 2.92 , 3.09
4 , 3.28 , 3.44 , 3.58 , 3.84 , 3.72 , 3.5 , 2.1 , 2.1 , 2.1
5 , 2.11 , 2.13 , 2.15 , 2.26 , 2.38 , 2.51 , 2.68 , 2.85 , 3.06
6 , 3.27 , 3.42 , 3.35 , 3.12 , 1.5 , 1.5 , 1.6 , 1.41 , 1.62
7 , 1.65 , 1.63 , 1.77 , 1.88 , 2.0 , 2.12 , 2.3 , 2.5 , 2.7
8 , 2.88 , 2.74 , 2.5 , 1.1 , 1.1 , 1.1 , 1.1 , 1.11 , 1.13 , 1.17
9 , 1.2 , 1.29 , 1.39 , 1.5 , 1.64 , 1.81 , 2.0 , 2.12 , 2.09
1 , 1.93 , .61 , .61 , .51 , .62 , .53 , .54 , .67 , .7 , .75 , .81
2 , .9 , .99 , 1.1 , 1.21 , 1.31 , 1.29 , 1.18 /
DATA TMACHC/ 0.0 , 0.05 , 0.1 , 0.15 , 0.2 , 0.25 , 0.30 , 0.35 ,
2 , 0.4 , 0.45 , 0.5 , 0.55 , 0.6 , 0.65 , 0.7 , 0.75 ,
3 , .8 /
DATA TALPHA/ 0.0 , 20.0 , 30.0 , 40.0 , 50.0 , 60.0 /
DATA TGSEP/ .12 , .16 , .19 , .23 , .26 , .29 , .32 , .35 , .39 ,
1 , .42 , .45 , .47 , .50 , .52 , .53 , .56 , .58 , .23
2 , .27 , .3 , .34 , .30 , .42 , .47 , .5 , .53 , .57
3 , .59 , .52 , .54 , .67 , .63 , .7 , .72 , .53 , .57
4 , .71 , .76 , .8 , .93 , .87 , .9 , .93 , .97 , 1.0
5 , 1.02 , 1.05 , 1.08 , 1.1 , 1.12 , 1.13 , 1.18 , 1.23 , 1.27
6 , 1.32 , 1.35 , 1.38 , 1.42 , 1.44 , 1.46 , 1.48 , 1.5 , 1.52
7 , 1.53 , 1.56 , 1.57 , 1.58 , 1.6 , 1.68 , 1.73 , 1.78 , 1.82
8 , 1.96 , 1.94 , 1.92 , 1.94 , 1.97 , 1.98 , 2.0 , 2.02 , 2.04
9 , 2.06 , 2.09 , 2.09 , 2.1 , 2.18 , 2.23 , 2.28 , 2.32 , 2.36
1 , 2.4 , 2.43 , 2.45 , 2.47 , 2.48 , 2.5 , 2.52 , 2.53 , 2.56
2 , 2.58 , 2.59 , 2.6 , 2.68 , 2.73 , 2.78 , 2.82 , 2.86 , 2.9
3 , 2.93 , 2.96 , 2.98 , 3.01 , 3.03 , 3.06 , 3.09 , 3.09 , 3.1
4 , 3.11 , 3.12 /
DATA TXI / .912 , .312 , .812 , .812 , .81 , .81 , .805 , .8 , .793
1 , .785 , .775 , .754 , .735 , .71 , .67 , .647 , .57 /
.....
READ INPUT DATA AND INITIALIZE VORTEX PARAMETERS
.....
READ FREE STREAM CONDITIONS
41 READ(5,1)UINF,FMV,PHO,INF,AVU
1 FORMAT(4F10,0)
2 FORMAT(4F10,0,2I3)
3 FORMAT(3I3)
4 FORMAT(11,F10,0)
: READ CONFIGURATION INFORMATION
READ(5,2)D,SREF,NOSEL,MOUCL,ALC,DELTA,NS,TDCONF
IF(TDCONF.EQ.0)GO TO 20
: READ FIN DATA FOR BODY PLUS TAIL CONFIGURATIONS
READ(5,1)XF,YF,ZF,XFMAX,YFMAX,ZFMAX,SREFT

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20	DELTA=DELTA/57.29577	0000700
C	READ NUMBER OF ANGLES OF ATTACK, NOSE TYPE AND NUMBER OF ROLL	
C	ANGLES	0000760
C	READ(5,3)NAOA,NTYPE,N,NM	0000820
C	READ ANGLES OF ATTACK	0000860
C	READ(5,1)(AA(I),I=1,N,AA)	0000910
C	READ ROLL ANGLES	0000917
C	READ(5,1)(RA(I),I=1,N,RA)	0000920
C	READ RADIAL LIMIT OF VORTEX INFLUENCE	0000930
C	READ(5,1)GAMLIM	0000940
C	READ NOSE FINENESS AND BLUNTNES OPTION DATA	0000950
C	READ(5,4)OPT,HRH	0000960
C	START ANGLE OF ATTACK LOOP	0000970
	DO 51 I=1,NAOA	0000980
	AA(I)=AA(I)/57.29577	0000990
51	CONTINUE	0001000
	DO 52 I=1,NAOA	0001010
	ISKIP(I)=0	0001020
	ISTOP=0	0001030
	NORA=1	0001040
	LAM=RA(VOR)	0001050
	LAMJ=LAM	0001060
	LAM=LAM/57.29577	0001070
	IF(1/DCOS(LAM).GT.1)GO TO 21	0001080
	XFR=AF	0001090
	YFR=-1.*(1/2.)*SIN(LAM)	0001100
	ZFR=(1/2.)*COS(LAM)	0001110
21	DO 414 K=1,N5	0001120
	SF(K)=0.0	0001130
414	CONTINUE	0001140
	DO 415 J=1,20	0001150
	ARGEP(J)=0.0	0001160
415	CONTINUE	0001170
	CY(I)=0.0	0001180
	SRO_M(I)=0.0	0001190
	CETA(I)=0.0	0001200
	CETAMC(I)=0.0	0001210
C	CROSS FLOW VELOCITY AND MACH NUMBER	
	VC=VINF*SIN(AA(I))	0001220
	CFMN=FSMN*SIN(AA(I))	0001230
C	AXIAL VELOCITY AND MACH NUMBER	
	AMAA=FSMN*COS(AA(I))	0001240
	VHFA=VINF*COS(AA(I))	0001250
	AOA=AA(I)	0001260
	IF(CFMN.GT.0.8)GO TO 32	0001270
C	GO TO NEXT ANGLE OF ATTACK IF CROSS FLOW MACH DATA EXCEEDED	
	DO 30 II=1,17	0001280
	IIP1=II+1	0001290
	IF(IIP1.GT.17)GO TO 31	0001300
C	LOCATE CROSS FLOW MACH NUMBER IN DATA TABLE	
	IF(CFMN.GE.1MACHC(II).AND.CFMN.LE.1MACHC(IIP1))GO TO 32	0001310
30	CONTINUE	
32	DO 34 K=1,6	
	KP1=K+1	
	IF(KP1.GT.6)GO TO 31	
	IF(AOA.GE.ALPHA(K).AND.AOA.LE.ALPHA(KP1))GO TO 35	
34	CONTINUE	
C	INTERPOLATE FOR THOMSON VORTEX STRENGTH PARAMETER AND THOMSON	

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C SEPARATION ANGLE PARAMETER
35 A=(TMACHC(II)-CFMV)/(TMACHC(II)-TMACHC(IIP1)) 0001320
    TGK=TGAMP(II,K)-(A*(TGAMP(II,K)-TGAMP(IIP1,K))) 0001330
    TGKPI=(TGAMP(II,KPI)-(A*(TGAMP(II,KPI)-TGAMP(IIP1,KPI)))) 0001340
    B=(TALPHA(K)-AOA)/(TALPHA(K)-TALPHA(KPI)) 0001350
    GAM=TGK-(H*(TGK-TGKPI)) 0001360
    XI=TXI(II)-(A*(TXI(II)-TXI(IIP1))) 0001370
    DO 52 JJ=1,7 0001380
C INTERPOLATE FOR THOMSON SEPARATION POINT PARAMETER
    GSEPP(JJ)=TSSEP(II,JJ)-(A*(TGSEP(II,JJ)-TGSEP(IIP1,JJ))) 0001390
62 CONTINUE 0001400
    GO TO 36 0001410
31 GAM=0.0 0001420
C CROSS FLOW REYNOLDS NUMBER
36 RNC=VC*O/ANJ 0001430
    PI=3.14159 0001440
C VORTEX STRENGTH PARAMETER BASED ON BASE POTENTIAL LIFT
    GAM2=(PI/8.)*(2.*COS(AOAR(1))+(SIN(AOAR(1))*2.)) 0001450
C VORTEX STRENGTH SCALING FACTOR
    IF(FSMN.LE.1.0)RAT1=.25*(.196*(CFMV)+(.17556*(CFMV**2.)) 0001460
    IF(FSMN.GT.1.0.AND.CFMV.LT.0.15)RAT1=.25*(.1957*(CFMV)+ 0001470
    1(.17556*(CFMV**2.)) 0001480
    IF(FSMN.GT.1.0.AND.CFMV.GE.0.15.AND.CFMV.LE.0.55)RAT1= 0001490
    10.25-(7.55754*(CFMV)+(7.7698*(CFMV**2.))-(0.159*(CFMV**3.)) 0001500
    IF(FSMN.GT.1.0.AND.CFMV.GT.0.55)RAT1=1.0 0001510
C STRUHAL NUMBER
    S=.2 0001520
    IF(RNC.GT.1.E+05)S=.35 0001530
    IF(1DCONV.E.1)S=.2 0001540
C SHOULDER LOCATION IN TERMS OF SEPARATION POINT PARAMETER
    ANSEL=NOSE*TAN(AOAR(1))*S/D 0001550
C THOMSON VORTEX SEPARATION ANGLE
    E=ATAN(XI*TAN(AOAR(1))) 0001560
C LENGTH OF BODY INFLUENCED BY BASE EFFECTS
    EBASE=O/(2.*TAN(E)) 0001570
    AXLE=H*YL-EBASE 0001580
    ARGMENT=.5*TAN(DELTA)/TAN(AOAR(1)) 0001590
    IF(ARGMENT.GT.1.0)GO TO 52 0001600
C CIRCUMFERENTIAL SEPARATION ANGLE
    THETA=ASIN(1.5*TAN(DELTA)/TAN(AOAR(1))) 0001610
C VERTICAL DISTANCE BETWEEN VORTICES OF LIKE SIGN
    DL=O*XI/S 0001620
C STABLE VORTEX STREET LATERAL SEPARATION DISTANCE
    H=.281*DL 0001630
    IF(RNC.LT.1.E+05)GO TO 55 0001640
C SCALE THOMSON VORTEX STRENGTH FOR SUPERCRITICAL CROSS FLOW
C REYNOLDS NUMBERS
    GAM=GAMP*RAT1 0001650
C THOMSON STREET VORTEX STRENGTH
55 GAM=GAMP*VINF*O*SIN(AOAR(1)) 0001660
    GAM1=GAM 0001670
C AXIAL DISTANCE BETWEEN SEPARATION POINTS FOR STREET VORTICES OF
C LIKE SIGN
    DG=(GSEPP(7)-GSEPP(3))*J/(TAN(AOAR(1))*S) 0001680
    DGA1=GAM1 0001690
C STREET VORTEX GROWTH RATE
    GRATE=DGA1/DG 0001700
C EFFECTIVE BODY LENGTH

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      441
      IF (IDCONF.EQ.0) XF=-30JYL
      EH0JYL = XF
      BODY SEGMENT LENGTH
      SEG_L=ABS(EH0JYL)/45
      DO 500 J=1,20
      IF (J.LT.8) GO TO 300
      JM2=J-2
      GSEPT(J)=GSEPT(JM2)+.05
      GO TO 600
      C
      VORTEX AXIAL SEPARATION POINTS AS DEFINED BY THOMSON
      300 GSEPT(J)=GSEP(J)*.7/(TAN(AUAK(I))*.5)
      600 CONTINUE
      C
      *****
      C
      CALCULATIONS TO DETERMINE COORDINATES OF ACTUAL SURFACE SEPARATION
      C
      POINTS USING THOMSON DATA, CIRCUMFERENTIAL SEPARATION ANGLES AND
      C
      LOCAL BODY DIAMETERS
      C
      *****
      AXI=0.0
      J=1
      603 AXL=AXL + SEG_L
      AXLM1=AXL-SEG_L
      604 IF (GSEPT(J).LE.AXL AND GSEPT(J).GT.AXLM1) GO TO 502
      GO TO 603
      602 IF (GSEPT(J).GT.NOSE_030) TO 604
      IF (NTYPE.EQ.2) GO TO 605
      C
      CONTINUE NOSE LOCAL RADIUS CALCULATIONS
      SIG=ASIN((D/2.)/NOSEL)
      RAXL=RAXL*TAN(SIG)
      RAXLM1=AXLM1*TAN(SIG)
      Y2PRM=RAXL*SIN(THETA1)
      Y2=RAXL*1+SIN(THETA1)
      Y2PRM=(Y2+Y2PRM)/2.
      REMSEG=RAXL-GSEPT(J)
      DELY=REMSSEG*TAN(E)
      STEP=RAXL
      IF (DELY.LT.Y2PRM) GO TO 604
      DELG=Y2PRM/TAN(E)
      GSEP(J)=GSEPT(J)+DELG
      GSEP(J)=Y2PRM
      GSEP(J)=Y2PRM/TAN(THETA1)
      J=J+1
      IF (J.GT.20) GO TO 507
      GO TO 604
      606 STEP=STEP+SEG_L
      STEPM1=STEP-SEG_L
      RAXL=STEP*TAN(SIG)
      RAXLM1=STEPM1*TAN(SIG)
      Y2PRM=RAXL*SIN(THETA1)
      Y2=RAXL*1+SIN(THETA1)
      Y2PRM=(Y2+Y2PRM)/2.
      DELG=Y2PRM/TAN(E)
      GSEP(J)=GSEP(J)+DELG
      IF (GSEP(J).GT.STEPM1) GO TO 506
      GSEP(J)=Y2PRM
      GSEP(J)=Y2PRM/TAN(THETA1)
      J=J+1
      IF (J.GT.20) GO TO 507
      GO TO 604

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TANGENT DRIVE LOCAL RADIUS CALCULATIONS

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605 TORAD=(1/4.)*((NOSE_**2.)/U)
RAXL=SQRT((TORAD**2.)-((AXL-NOSEL)**2.))*((D/2.)-TORAD)
RAXL_M1=SQRT((TORA)**2.)-((AXL_M1-NOSEL)**2.))*((D/2.)-TORAD)
Y2PRM=RAXL*SIN(THETA1)
Y2=RAXL_M1*SIN(THETA1)
Y2HAR=(Y2PRM+Y2)/2.
REMSEG=AXL-3SEPT(J)
DELY=REMSEG*TAN(E)
STEP=AXL
IF(DELY,LT,Y2HAR)GO TO 509
DEL3=Y2HAR/TAN(F)
GSEP(J)=GSEP(J)+DE_G
GSEPY(J)=Y23A2
GSEPZ(J)=Y23A2/TAN(THETA1)
J=J+1
IF(J,GT,20)GO TO 507
GO TO 608

609 STEP=STEP+SEG
STEP_M1=STEP-SEG
RAXL=SQRT((TORA)**2.)-((STEP-NOSEL)**2.))*((D/2.)-TORAD)
RAXL_M1=SQRT((TORA)**2.)-((STEP_M1-NOSEL)**2.))*((D/2.)-TORAD)
Y2PRM=RAXL*SIN(THETA1)
Y2=RAXL_M1*SIN(THETA1)
Y2HAR=(Y2+Y2PRM)/2.
DEL3=Y2HAR/TAN(F)
GSEP(J)=GSEP(J)+DE_G
IF(GSEP(J),GT,STEP)GO TO 609
GSEPY(J)=Y23A2
GSEPZ(J)=Y23A2/TAN(THETA1)
J=J+1
IF(J,GT,20)GO TO 507
GO TO 608

VORTICES SEPARATE FROM CYLINDRICAL BODY SECTION

604 Y2HAR=(D/2.)*SIN(THETA1)
DEL3=Y2HAR/TAN(F)
GSEP(J)=GSEP(J)+DE_G
GSEPY(J)=Y23A2
GSEPZ(J)=Y23A2/TAN(THETA1)
J=J+1
IF(J,GT,20)GO TO 507
GO TO 608

607 VCOJNT=0
*****
ADJUST VORTEX STRENGTHS ACCOUNTING FOR VISC EFFECTS AND BASE
INFLUENCE ON GROWTH RATE
*****
JSTCH=0
DO 33 J=1,20
IF(J,GT,21)GO TO 95
IF(J,EQ,1)GO TO 97
IF(ABS(GSEP(1)),GE,NOSEL)GO TO 94
97 IF(3SEP(J),GE,NOSEL)GO TO 94
IF(NTYPE,EQ,2)GO TO 97
SIG=ASIN((D/2.)/NOSEL)
DCS=2.*3SEP(J)*TAN(SIG)
GO TO 100
99 TORAD=(1/4.)*((NOSE_**2.)/U)

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RCS=SQRT((TORAD**2.)-(AJS(GSEP(1)-NASEL))**2.)*
00002720
1((D/2.)-TORAD)
00002730
DCS=2.*WCS
00002740
VORTEX STRENGTH FOR VORTICES SEPARATING ON NOSE SECTION
100 GAM=GAMP2*VIN*SI(ADAN(I))*DCS
00002750
GO TO 96
00002760
98 PGAM=GAMP2*VIN*SI(ADAN(I))*D
00002770
DELX1=GSEP(J)-NASEL
00002780
GAM=PGAM*DELX1*GRATE1
00002790
IF (GAM.GT.GAM1) GAM=GAM1
00002800
96 IF (J.GT.1) GAM=-1.*GAM
00002810
GSEP(J)=-1.0*GSEP(J)
00002820
IF (ABS(GSEP(J)).GT.AXLE) GO TO 701
00002830
GAMSV(J)=GAM
00002840
GO TO 702
00002850
>TREET VORTEX STRENGTH WHEN INFLUENCED BY BASE
701 JM2=J-2
00002860
VORTEX STRENGTH ADJUSTED TO ACCOUNT FOR BASE EFFECTS
IF (ABS(GSEP(JM2)).GT.AXLE) GAMSV(J)=.4*GRATE*(ABS(GSEP(J))-ABS(GSEP(JM2)))
00002870
1P(JM2))
00002880
IF (ABS(GSEP(JM2)).LT.AXLE) GAMSV(J)=GRATE*(AXLE-ABS(GSEP(JM2)))*
00002890
10.4*GRATE*(ABS(GSEP(J))-AXLE)
00002900
IF (GAM.LT.0.0) GAMSV(J)=-GAMSV(J)
00002910
702 IF (ABS(GSEP(J)).LE.ABS(EBODYL)) GO TO 301
00002920
VORTEX STRENGTH CALCULATIONS FOR VORTICES FORCED TO SEPARATE
PREMATURELY BY THE EFFECTIVE BODY LENGTH
JM=J-1
00002930
JM2=J-2
00002940
BODY=ABS(EBODYL)
00002950
IF (NCOUNT.EQ.0.AND.ABS(GSEP(JM)).EQ.ABS(EBODYL)) GO TO 302
00002960
IF (NCOUNT.EQ.1) GO TO 302
00002970
NCOUNT = NCOUNT+1
00002980
CALL XYZ(4,0),THETA1,ABSEP(J),GSEP(J),GSEP(JM2),CHDDV,GSEPY(J),GSEP(JM2)
00002990
1Z(J),A1,A2)
00003000
AGSEP(J)=GSEP(J)
00003010
SEPARATION POINT FIXED AT EFFECTIVE BODY LENGTH
GSEP(J)=BODY
00003020
IF (ABS(GSEP(JM2)).GT.AXLE) GAMSV(J)=.4*GRATE*(ABS(GSEP(J))-
00003030
ABS(GSEP(JM2)))
00003040
IF (ABS(GSEP(JM2)).LT.AXLE) GAMSV(J)=GRATE*(AXLE-ABS(GSEP(JM2)))*
00003050
10.4*GRATE*(ABS(GSEP(J))-AXLE)
00003060
IF (GAM.LT.0.0) GAMSV(J)=-GAMSV(J)
00003070
GO TO 301
00003080
302 CALL XYZ(4,0),THETA1,ABSEP(J),GSEP(J),GSEP(JM2),CHDDV,GSEPY(J),GSEP(JM2)
00003090
1Z(J),A1,A2)
00003100
AGSEP(J)=GSEP(J)
00003110
GSEP(J)=BODY
00003120
IF (ABS(GSEP(JM2)).GT.AXLE) GAMSV(J)=.4*GRATE*(ABS(GSEP(J))-
00003130
ABS(GSEP(JM2)))
00003140
IF (ABS(GSEP(JM2)).LT.AXLE) GAMSV(J)=GRATE*(AXLE-ABS(GSEP(JM2)))*
00003150
10.4*GRATE*(ABS(GSEP(J))-AXLE)
00003160
IF (GAM.LT.0.0) GAMSV(J)=-GAMSV(J)
00003170
JMAX=J
00003180
JSTOR=20
00003190
301 IF (GAM.GT.0.0) GAM=GAM1
00003200
IF (GAM.LT.0.0) GAM=-1.0*GAM1
00003210
IF (JSTOR.EQ.20) GO TO 1000
00003220
53 CONTINUE

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.....
 AT THIS POINT ALL SHED VORTICES HAVE THEIR CORRECTED STRENGTHS
 AND SEPARATION POINTS ASSIGNED. BEGIN CALCULATIONS TO DETERMINE
 THEIR INFLUENCE ON THE CONFIGURATION OF INTEREST.

1000	JEN)=JMAX+1	0003240
	CLEAR ARRAYS	0003250
	DO 510 J=JEND,20	0003260
	GSEP(J)=0.0	0003270
	GSEP(Y(J)=0.0	0003280
	GSEP(Z(J)=0.0	0003290
610	CONTINUE	0003300
	AXL=0.0	0003310
	SEG.=ABS(FBDDYL)/VS	0003320
	DO 200 K=1,VS	0003330
	DO 260 II=1,JMAX	0003340
	GAMP(II)=0.0	0003350
	SFPC(II)=0.0	0003360
	FMP(II)=0.0	0003370
	GPDV(II)=0.0	0003380
	SFPSV(II)=0.0	0003390
	FMP(II)=0.0	0003400
	GRUTS(II)=0.0	0003410
	SFRJTS(II)=0.0	0003420
	FMBUT(II)=0.0	0003430
	GBUAS(II)=0.0	0003440
	SFRJAS(II)=0.0	0003450
	FMBAS(II)=0.0	0003460
	GRUT(II)=0.0	0003470
	SFRUT(II)=0.0	0003480
240	CONTINUE	
C	EXAMINE SEGMENT OF INTEREST TO DETERMINE NUMBER OF VORTICES	
C	SEPARATING ON OR PRIOR TO IT	
	AXL=AXL+SEG.	0003490
	DO 201 J=1,JMAX	0003500
	IF(AXL.GT.ABS(GSEP(J)))GO TO 201	0003510
	JM1=J-1	0003520
	GO TO 203	0003530
201	CONTINUE	0003540
203	IF(JM1.GT.0)GO TO 214	0003550
C	NO VORTICES SEPARATING ON OR PRIOR TO SEGMENT	
	GAM(K)=0.0	0003560
	SF(K)=0.0	0003570
	YMOD(K)=0.0	0003580
	GO TO 200	0003590
204	AXLM1=AXL-SEG.	0003600
	(START=)	0003610
	DO 205 IV=1,JM1	0003620
C	DOES VORTEX START ON OR PRIOR TO SEGMENT	
	IF(ABS(GSEP(JVS)).GT.AXLM1)GO TO 204	0003630
C	-----	
C	SEPARATED VORTICES PASSING OVER ENTIRE SEGMENT	
C	-----	
	IF(JVS.GT.2)GO TO 511	0003640
C	CIRCULATION ON SEGMENT DUE TO FIRST TWO VORTICES	
	VDSP=TAN(E)*((AXLM1+(SEG/2.))-ABS(GSEP(JVS)))	0003650
	VDC=VDSP*(D/2.)*SIN(THETA1)	0003660

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HNTSI=SMTH((VVC)**2.)*(1/(2.)*COS(THETA))**2.)) 0003670
GAMPC(JVS)=GAMSV(JVS)*COS(E) 0003680
GO TO 612 0003690
: CIRCULATION ON SEGMENT DUE TO STREET VORTICES
611 JVS42=JVS-2 0003700
DSP=(AAL4)*(SEGL/2.))-ARS(GSEP(JVS42)) 0003710
SIGMA=TAN(SMTH((1/(2.)*SURT((1/(2.))*2.)) 0003720
(1/(2.))*2.))*2.)-(1/(2.))*2.)-(1/(2.))*2. 0003730
>SIN(THETA)))/(ARS(GSEP(JVS))-ARS(GSEP(JVS42))) 0003740
XTHM=(ARS(GSEP(JVS42))*TAN(SIGMA)-ARS(GSEP(JVS))*TAN(E)) 0003750
1/(TAN(SIGMA)-TAN(E)) 0003760
XLEV=XTHM-ARS(GSEP(JVS42)) 0003770
IF (ISPA.NT.XLEV) GO TO 513 0003780
VDC=VUSP*(1/(2.))*SIN(THETA)) 0003790
VDC=VUSP*(1/(2.))*SIN(THETA)) 0003800
ROJ1=SMTH((VVC)**2.)*(1/(2.))*2.)) 0003810
C CIRCULATION ON SEGMENT DUE TO STREET VORTEX TRANSITIONING BETWEEN
C FOPPL AND THOMSON TRAJECTORIES
GAMPC(JVS)=GAMSV(JVS)*COS(SIGMA) 0003820
GO TO 612 0003830
613 VDSPTAN(E)*(AAL4*(SEGL/2.))-ARS(GSEP(JVS)) 0003840
VDC=VUSP*(1/(2.))*SIN(THETA)) 0003850
ROJ1=SMTH((VVC)**2.)*(1/(2.))*2.)) 0003860
C CIRCULATION ON SEGMENT DUE TO STREET VORTICES FOLLOWING THOMSON
C TRAJECTORY
GAMPC(JVS)=GAMSV(JVS)*COS(E) 0003870
612 RCA=ROJ1/3 0003880
IF (RCA.NT.GAALIM) GO TO 315 0003890
C ADJUSTING INDUCED CIRCULATION FOR RADIAL DECAY
GAMPC(JVS)=GAMPC(JVS)*((GAAL4-RCA)/GAALIM) 0003900
GO TO 315 0003910
315 GAMPC(JVS)=0 0003920
C SIDE FORCE AND VARIOUS ADHENT CIRCULATIONS
616 SEPC(JVS)=ARS(GAMPC(JVS))*HUIFVDCSEGL 0003930
IF (GAALC(JVS).GT.0.0) SEPC(JVS)=SEPC(JVS) 0003940
FMCPC(JVS)=SEPC(JVS)*(AAL4*(SEGL/2.)) 0003950
GO TO 215 0003960
C -----
C VORTEX SEPARATES AT 141 HOURS OF SEGMENT
C -----
206 IF (ISTAB1.EQ.0) ISTAB1=JVS 0003970
IF (JVS.GT.216) TO 514 0003980
C CIRCULATION ON REMAINING PORTION OF SEGMENT DUE TO FIRST TWO
C VORTICES
VDSPTAN(E)*(AAL4-ARS(GSEP(JVS)))/2. 0003990
VDC=VUSP*(1/(2.))*SIN(THETA)) 0004000
ROJ1=SMTH((VVC)**2.)*(1/(2.))*2.))*COS(THETA))**2.)) 0004010
GPSV(JVS)=GAMSV(JVS)*COS(E) 0004020
GO TO 515 0004030
C CIRCULATION ON REMAINING PORTION OF SEGMENT DUE TO STREET VORTICES
614 JVS42=JVS-4 0004040
DSP=(ARS(GSEP(JVS))+(AAL4-ARS(GSEP(JVS)))/2.0))-ARS(GSEP(JVS42)) 0004050
SIGMA=ATAN(SMTH((1/(2.)*SURT((1/(2.))*2.)) 0004060
(1/(2.))*2.))*2.)-(1/(2.))*2.)-(1/(2.))*2.)))/(THETA)))/
>(ARS(GSEP(JVS))-ARS(GSEP(JVS42))) 0004070
XTHM=(ARS(GSEP(JVS42))*TAN(SIGMA)-ARS(GSEP(JVS))*TAN(E)) 0004080
1/(TAN(SIGMA)-TAN(E)) 0004090
XLEV=XTHM-ARS(GSEP(JVS42)) 0004100
XLEV=XTHM-ARS(GSEP(JVS42)) 0004110

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IF (ISP.GT.AXLEN) GO TO 315                                00004120
VDS2 = TAN(SIGMA) * ((AXL - ABS(GSEP(JVS))) / 2.)          00004130
VDC2 = VDS2 * ((D/2.) * SIN(METAT))                        00004140
RDIST = SORT((VDC2**2.) * ((M/2.1002.)) * ((M/2.1002.))  00004150
: CIRCULATION ON REMAINING PORTION OF SEGMENT DUE TO VORTICES
: TRANSITIONING BETWEEN FOMPL AND THOMSON TRAJECTORIES
GPSV(JVS) = GMSV(JVS) * COS(SIGMA)                        00004160
GO TO 615                                                    00004170
616 VDS2 = TAN(E) * ((AXL - ABS(GSEP(JVS))) / 2.)          00004180
VDC2 = VDS2 * ((D/2.) * SIN(METAT))                        00004190
RDIST = SORT((VDC2**2.) * ((M/2.1002.)) * ((M/2.1002.))  00004200
: CIRCULATION ON REMAINING PORTION OF SEGMENT DUE TO VORTICES
: FOLLOWING THOMSON TRAJECTORY
GPSV(JVS) = GMSV(JVS) * COS(E)                            00004210
615 RCL = RDIST / 2.                                        00004220
IF (RCL.GT.3*AXL(M)) GO TO 317                             00004230
: ADJUSTING INDUCED CIRCULATION TO ACCOUNT FOR RADIAL DECAY
GPSV(JVS) = GPSV(JVS) * ((3*AXL(M) - RCL) / 3*AXL(M))      00004240
GO TO 314                                                    00004250
317 GPSV(JVS) = 0.0                                         00004260
: SIDE FORCE AND YAWING MOMENT CALCULATIONS
318 SFPSV(JVS) = ABS(SFPSV(JVS)) * HUI * VCO * (AXL - ABS(GSEP(JVS))) 00004270
IF (3PSV(JVS).GT.0.0) SFPSV(JVS) = -SFPSV(JVS)            00004280
FMGPSV(JVS) = SFPSV(JVS) * ((ABS(GSEP(JVS)) * ((AXL - ABS(GSEP(JVS))) / 2.)) 00004290
205 CONTINUE                                               00004300
: GO TO 214 IF NO VORTICES SEPARATE ON SEGMENT OF INTEREST
IF (ISTART.EQ.0) GO TO 214                                00004310
: -----
: CALCULATE CIRCULATION INDUCED BY A GROWING VORTEX FROM THE
: BEGINNING OF THE SEGMENT UP TO POINT OF SEPARATION
: -----
GO TO 207 (ISTART,JM)                                     00004320
IF (N.GT.209) GO TO 209                                    00004330
IF (V.LE.2.AND.ABS(GSEP(N)).GT.NOSEL) GO TO 209           00004340
: NO CIRCULATION INDUCED BY POTENTIAL VORTICES UP TO POINT OF
: SEPARATION
GRUTS(N) = 0.0                                             00004350
SFGRUTS(N) = 0.0                                           00004360
FMGRUTS(N) = 0.0                                           00004370
GO TO 217                                                  00004380
209 IF (AXL4).LT.NOSEL) GO TO 227                          00004390
: CIRCULATION INDUCED BY FIRST TWO VORTICES SEPARATING PAST THE
: SHOULDER AND WITH THE SEGMENT LYING ENTIRELY ON THE CYLINDRICAL
: PORTION OF BODY
GAX_M1 = ((GAMP20 * VINE * PSIN(AJAR(1))) * ((AXL(M) - NOSEL) * GRATE)) 00004400
IF (AXL4).GT.AXLE) GAX_M1 = (GAMP20 * VINE * PSIN(AJAR(1))) * 00004410
1 * ((AXLE - NOSEL) * GRATE) + ((AXL(M) - AXLE) * GRATE * 0.4) 00004420
GSP = ((GAMP20 * VINE * PSIN(AJAR(1))) * ((ABS(GSEP(N)) - NOSEL) * GRATE)) 00004430
IF (ABS(GSEP(N)).GT.AXLE) GSP = (GAMP20 * VINE * PSIN(AJAR(1))) * 00004440
1 * ((AXLE - NOSEL) * GRATE) + ((ABS(GSEP(N)) - AXLE) * GRATE * 0.4) 00004450
211 GRUTS(N) = (GSP * GAX_M1) / 2.                          00004460
CAL EQUIN(CASE)                                           00004470
IF (ICASE.EQ.0) GO TO 237                                  00004480
GO TO 215                                                  00004490
629 GRUTS(N) = 0.0                                         00004500
234 GRUTS(N) = -GRUTS(N)                                    00004510
: SIDE FORCE AND YAWING MOMENT CALCULATIONS
C 237 SFGRUTS(N) = ABS(GRUTS(N)) * HUI * VCO * (ABS(GSEP(N)) - AXL(M)) 00004520

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IF (GOUTS(1),GT,0.) SEBITS(N)=SEBITS(N)
FMGOUT(N)=SEBITS(N)*(ALM1+(ABS(GSEP(N))-AXLM1)/2.0))
GO TO 207
208 IF (V,GT,4) GO TO 210
C CIRCULATION INDUCED BY GROWTH OF INITIAL TWO STREET VORTICES
C EXPERIENCING MODIFIED GROWTH RATE
NM2=N-2
DIFF=(ABS(GSEP(N))-ABS(GSEP(NM2)))
GRAD34=GRAD1/DIFF
GAXLM1=GRAD34*(AXLM1-ABS(GSEP(NM2)))
IF (ABS(GSEP(NM2)),GT,AXLE) GAXLM1=0.4*GRAD34*(AXLM1-ABS(GSEP(NM2)))
IF (AXLM1,GT,AXLE,AND,ABS(GSEP(NM2)),LT,AXLE) GAXLM1=(AXLE-
1ABS(GSEP(NM2)))*GRAD34+((AXLM1-AXLE)*GRAD34*0.4)
GSP=GRAD34*(ABS(GSEP(N))-ABS(GSEP(NM2)))
IF (ABS(GSEP(NM2)),GT,AXLE) GSP=0.4*GRAD34*(ABS(GSEP(N))-ABS(GSEP(NM2)))
12)))
IF (ABS(GSEP(N)),GT,AXLE,AND,ABS(GSEP(NM2)),LT,AXLE) GSP=(AXLE-
1ABS(GSEP(NM2)))*GRAD34+((ABS(GSEP(N))-AXLE)*GRAD34*0.4)
XPOINT = AXLM1 + ((ABS(GSEP(N)) - AXLM1)/2.0)
CAL XY7(4,0),THETA1,ABSSEP(N),GSEP(N),GSEP(NM2),XPOINT,Y,Z,A1,A2)
RDIS = SQRT((Y**2.) + (Z**2.))
RCAL = RDIS/7
IF (RCAL,GT,3*AXLTM) GO TO 620
C ADJUSTING CIRCULATION TO ACCOUNT FOR RADIAL DECAY
GAXLM1 = GAXLM1 * ((GAXLIM - RCAL)/GAXLTM)
GSP = GSP * ((GAXLIM - RCAL)/GAXLTM)
GAXLM1 = GAXLM1 * COS(A1) * COS(A2)
GSP = GSP * COS(A1) * COS(A2)
GO TO 211
210 NM2=N-2
C CIRCULATION INDUCED BY GROWTH OF STREET VORTICES HAVING NOMINAL
C GROWTH RATE
GAXLM1=GRATE*(AXLM1-ABS(GSEP(NM2)))
IF (ABS(GSEP(NM2)),GT,AXLE) GAXLM1=0.4*GRATE*(AXLM1-ABS(GSEP(NM2)))
IF (AXLM1,GT,AXLE,AND,ABS(GSEP(NM2)),LT,AXLE) GAXLM1=(AXLE-
1ABS(GSEP(NM2)))*GRATE+((AXLM1-AXLE)*GRATE*0.4)
GSP=GRATE*(ABS(GSEP(N))-ABS(GSEP(NM2)))
IF (ABS(GSEP(NM2)),GT,AXLE) GSP=0.4*GRATE*(ABS(GSEP(N))-ABS(GSEP(NM2)))
11)))
IF (ABS(GSEP(N)),GT,AXLE,AND,ABS(GSEP(NM2)),LT,AXLE) GSP=(AXLE-
1ABS(GSEP(NM2)))*GRATE+((ABS(GSEP(N))-AXLE)*GRATE*0.4)
XPOINT = AXLM1 + ((ABS(GSEP(N)) - AXLM1)/2.0)
CAL XY7(4,0),THETA1,ABSSEP(N),GSEP(N),GSEP(NM2),XPOINT,Y,Z,A1,A2)
RDIS = SQRT((Y**2.) + (Z**2.))
RCAL = RDIS/7
IF (RCAL,GT,3*AXLTM) GO TO 620
GAXLM1 = GAXLM1 * ((GAXLIM - RCAL)/GAXLTM)
C ADJUSTING CIRCULATION TO ACCOUNT FOR RADIAL DECAY
GSP = GSP * ((GAXLIM - RCAL)/GAXLTM)
GAXLM1 = GAXLM1 * COS(A1) * COS(A2)
GSP = GSP * COS(A1) * COS(A2)
GO TO 211
C CIRCULATION INDUCED BY FIRST TWO VORTICES SEPARATING PAST THE
C SHOULDER BUT WITH A PORTION OF THE SEGMENT ON THE NOSE
227 GAXLM1=0.0
GNOSEL=GAMP2*VINF*0.75*SIN(ADAR(1))
GSP=((GAMP2*VINF)*SIN(ADAR(1)))*((ABS(GSEP(N))-GNOSEL)*GRATE))
IF (ABS(GSEP(N)),GT,AXLE) GSP=(GAMP2*VINF*0.75*SIN(ADAR(1)))*

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64

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RCA_ = RDIS/7
IF (RCA_.GT.3AMLM) 37 1) 621
C ADJUSTING INDUCED CIRCULATION TO ACCOUNT FOR RADIAL DECAY
GAXL = GAXL*((GAMLI4-RCA)/3AMLM)
GAXL = GAXL * COS(A1) * COS(A2)
GO TO 216
C CIRCULATION INDUCED BY STREET VORTEX EXPERIENCING NOMINAL GROWTH
C RATE
214 GAXL=GRATE*(AXL-ABS(GSEP(L)))
LP2=L+2
IF (ABS(GSEP(L)).GT.AXLE) GAXL=0.4*GRATE*(AXL-ABS(GSEP(L)))
IF (ABS(GSEP(L)).LT.AXLE.AND.AXL.GT.AXLE) GAXL=((AXLE-ABS(GSEP(L)))*
1)GRATE)+(0.4*GRATE*(AXL-AXLE))
GSP=0.0
XPOINT = ABS(GSEP(L)) + ((AXL-ABS(GSEP(L)))/2.)
CALL XYZ(H.),THETA(.45SEP(LP2),GSEP(LP2),GSEP(L),XPOINT,Y,Z,A1,A2)
RDIS = SQRT((Y**2.)+(Z**2.))
RCA_ = RDIS/7
IF (RCA_.GT.3AMLM) 37 1) 621
GAXL = GAXL*((GAMLI4-RCA)/3AMLM)
GAXL = GAXL * COS(A1) * COS(A2)
GO TO 216
212 CONTINUE
C *****
C IF ISTART DOES NOT EQUAL JN1 THIS MEANS THAT NO GROWING VORTICES
C CAN PASS OVER THE FULL LENGTH OF THE SEGMENT. THEREFORE ALL
C CIRCULATION CALCULATIONS FOR THE SEGMENT ARE COMPLETE. GO TO 221
C *****
C IF (ISTART.NE.JN1) GO TO 221
C -----
C CALCULATE GROWTH OVER SEGMENT DUE TO A SINGLE VORTEX GROWING
C OVER THE ENTIRE SEGMENT LENGTH
C -----
JNEXT=ISTART+1
IF (JNEXT.EQ.2) GO TO 213
IF (JNEXT.GT.2) GO TO 221
219 IF (AXL.GT.NOSEL.AND.AXLE.NE.NOSEL) GO TO 221
IF (AXL.GT.NOSEL) GO TO 226
SEGMENT ENTIRELY ON NOSE
GRU(JNEXT)=0.0
GO TO 224
C CIRCULATION INDUCED ON SEGMENT BY GROWTH OF SECOND VORTEX WITH
C THE SEGMENT STARTING ON THE NOSE
224 GAXL=0.0
GNOSL=3AMP2*VINF*POSIN(ADAR(1))
GAXL=((3AMP2*VINF*POSIN(ADAR(1)))+(AXL-NOSEL)*GRATE)
IF (AXL.GT.AXLE) GAXL=(3AMP2*VINF*POSIN(ADAR(1)))+
1) (AXLE-NOSEL)*GRATE)+(AXL-AXLE)*GRATE*0.4)
GRU(JNEXT)=(GAXL*NOSEL)/2.
CALL FORU(JNEXT,ICASE)
IF (ICASE.EQ.0) GO TO 246
247 GRU(JNEXT)=-GRU(JNEXT)
C SIDE FORCE AND YAWING MOMENT CALCULATIONS
246 SFGU(JNEXT)=ABS(S4(JNEXT))*RMOVF*VC*(AXL-NOSEL)
IF (GRU(JNEXT).GT.0.) SFGU(JNEXT)=-SFGU(JNEXT)
FMGJU(JNEXT)=SFGU(JNEXT)*(NOSEL+((AXL-NOSEL)/2.))
GO TO 221
C CIRCULATION INDUCED ON SEGMENT BY GROWTH OF SECOND VORTEX WITH

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THE ENTIRE SEGMENT LIVING ON THE CYLINDRICAL BODY SECTION

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223 GAXLM1=((GAMP2*VINF*DSIN(ANAR(I)))+(AXLM1-NOSEL)*GRATE) 00005930
IF (AXLM1.GT.AXLF) GAXLM1=(GAMP2*VINF*DSIN(ANAR(I)))+ 00005940
1((AXLE-NOSEL)*GRATE)+(AXLM1-AXLF)*GRATE*0.4) 00005950
GAXLM=((GAMP2*VINF*DSIN(ANAR(I)))+(AXLM1-NOSEL)*GRATE) 00005960
IF (AXLM.GT.AXLE) GAXLM=(GAMP2*VINF*DSIN(ANAR(I)))+ 00005970
1((AXLE-NOSEL)*GRATE)+(AXLM-AXLE)*GRATE*0.4) 00005980
225 GRU(JNEXT)=(GAXL+GAXLM1)/2. 00005990
CALL EURU(JNEXT,ICASE) 00006000
IF (ICASE.EQ.0) GO TO 224 00006010
GO TO 245 00006020
622 GRU(JNEXT)=0.0 00006030
245 GRU(JNEXT)=-GRU(JNEXT) 00006040
224 SFGHU(JNEXT)=ABS(SHU(JNEXT))*RHO*V*VC*SEGL 00006050
IF (SHU(JNEXT).GT.0.0) SFGHU(JNEXT)=-SFGHU(JNEXT) 00006060
FMGRU(JNEXT)=SFGHU(JNEXT)*(AXLM1+(SEGL/2.)) 00006070
GO TO 221 00006080
220 IF (JNEXT.GT.4) GO TO 222 00006090
CIRCULATION INDUCED BY INITIAL TWO STREET VORTICES HAVING A
MODIFIED GROWTH RATE
JNM2=JNEXT-2 00006100
IF (ABS(GSEP(JNM2)).GT.NOSEL) GO TO 222 00006110
DIFF=ABS(GSEP(JNEXT))-ABS(GSEP(JNM2)) 00006120
GRAD34=GRAD/DIFF 00006130
GAXLM1=GRAD34*(AXLM1-ABS(GSEP(JNM2))) 00006140
IF (ABS(GSEP(JNM2)).GT.AXLE) GAXLM1=0.4*GRAD34*(AXLM1-ABS(GSEP(JNM2))) 00006150
1) 00006160
IF (AXLM1.GT.AXLF.AND).ABS(GSEP(JNM2)).LT.AXLF) GAXLM1=((AXLE- 00006170
1-ABS(GSEP(JNM2)))*GRAD34)+(AXLM1-AXLF)*GRAD34*0.4) 00006180
GAXLM=GRAD34*(AXLM1-ABS(GSEP(JNM2))) 00006190
IF (ABS(GSEP(JNM2)).GT.AXLE) GAXLM=0.4*GRAD34*(AXLM1-ABS(GSEP(JNM2))) 00006200
IF (AXLM.GT.AXLE.AND).ABS(GSEP(JNM2)).LT.AXLF) GAXLM=((AXLE- 00006210
1ABS(GSEP(JNM2)))*GRAD34)+(AXLM-AXLE)*GRAD34*0.4) 00006220
XPOINT = AXLM1 + (SEGL/2.) 00006230
CALL X77(1+JNEXT,THETAT,4*GSEP(JNEXT),GSEP(JNEXT),GSEP(JNM2),XPOINT,Y,Z) 00006240
1,A1,A2) 00006250
RDIS1 = SINT((Y**2.)/(Z**2.)) 00006260
RCAL = RDIS1/7 00006270
IF (RCAL.GT.GAMLTM) GO TO 622 00006280
GAXLM1 = GAXLM1 * ((GAMLIM - RCAL)/GAMLIM) 00006290
ADJUSTING CIRCULATION TO ACCOUNT FOR RADIAL DECAY
GAXL = GAXL * ((GAMLIM - RCAL)/GAMLIM) 00006300
GAXLM1 = GAXLM1 * COS(A1) * COS(A2) 00006310
GAXL = GAXL * COS(A1) * COS(A2) 00006320
GO TO 225 00006330
222 JNM2=JNEXT-2 00006340
CIRCULATION INDUCED BY STREET VORTICES HAVING REGULAR GROWTH RATE
GAXLM1=GRATE*(AXLM1-ABS(GSEP(JNM2))) 00006350
IF (ABS(GSEP(JNM2)).GT.AXLE) GAXLM1=0.4*GRATE*(AXLM1-ABS(GSEP(JNM2))) 00006360
1) 00006370
IF (AXLM1.GT.AXLF.AND).ABS(GSEP(JNM2)).LT.AXLF) GAXLM1=((AXLE- 00006380
1ABS(GSEP(JNM2)))*GRATE)+(AXLM1-AXLF)*GRATE*0.4) 00006390
GAXLM=GRATE*(AXLM1-ABS(GSEP(JNM2))) 00006400
IF (ABS(GSEP(JNM2)).GT.AXLE) GAXLM=0.4*GRATE*(AXLM1-ABS(GSEP(JNM2))) 00006410
IF (AXLM.GT.AXLE.AND).ABS(GSEP(JNM2)).LT.AXLF) GAXLM=((AXLE- 00006420
1ABS(GSEP(JNM2)))*GRATE)+(AXLM-AXLE)*GRATE*0.4) 00006430
XPOINT = AXLM1 + (SEGL/2.) 00006440

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CAL_ XY/(H*2)*THETA1*ADSEP(JNEXT),RSEP(INEVT)*RSEP(JNM2),XPOINT,V,Z0000450
1041,A2) 00004460
RDIST = SQRT((Y**2.)+(Z**2.)) 00004470
RCAL = RDIST/7 00004480
IF(RCAL.GT.3*WMLIM)GO TO 622 00004490
GAX_M1 = GAXL_M1 * ((GAXLIM - RCAL)/WMLIM) 00004500
GAXL = GAXL * ((GAXLIM - RCAL)/WMLIM) 00004510
GAX_M1 = GAXL_M1 * COS(A1) * COS(A2) 00004520
GAXL = GAXL * COS(A1) * COS(A2) 00004530
GO TO 225 00004540
C *****
C COME TO 219 WHEN NO VORTICES SEPARATE WITHIN BOUNDS OF SEGMENT
C OF INTEREST. TWO GROWING VORTICES PASS OVER THE ENTIRE SEGMENT.
C *****
218 JP1=J+1 00004550
DO 228 J1=J,J+1 00004560
IF(J1.EQ.2)GO TO 229 00004570
IF(J1.GT.2)GO TO 231 00004580
229 IF(AXL.GT.NOSEL.AND.AXL_M1.GE.NOSEL)GO TO 231 00004590
IF(AXL.GT.NOSEL)GO TO 232 00004600
C SEGMENT ENTIRELY ON NOSE
GBU(J1)=0.0 00004610
GO TO 233 00004620
C CIRCULATION INDUCED BY SECOND VORTEX WHEN SEGMENT STARTS ON NOSE
232 GAX_M1=0.0 00004630
GNOSL=GAMP2*VINF*0.5*SIN(AOAR(I)) 00004640
GAX_F((GAMP2*VINF*0.5*SIN(AOAR(I)))+(AXL-NOSL)*GRATE)) 00004650
IF(AXL.GT.AXLE)GAXL=((GAMP2*VINF*0.5*SIN(AOAR(I)))+(AXLE-NOSEL)* 00004660
GRATE)+(AXL-AXLE)*0.4*GRATE) 00004670
GBU(J1)=(GAXL*GNOSL)/2. 00004680
CAL_ FORD(J1,ICASE) 00004690
IF(ICASE.EQ.0)GO TO 233 00004700
249 GBU(J1)=-GBU(J1) 00004710
C SIDE FORCE AND YAWING MOMENT CALCULATIONS
233 SFGBU(J1)=ABS(GBU(J1))*RHUINF*VC*(AXL-NOSL) 00004720
IF(SBU(J1).GT.0.0)SFGBU(J1)=-SFGBU(J1) 00004730
FMGBU(J1)=SFGBU(J1)*(NOSEL*(AXL-NOSL)/2.) 00004740
GO TO 228 00004750
C CIRCULATION INDUCED BY SECOND VORTEX WHEN ENTIRE SEGMENT IS ON
C CYLINDRICAL PORTION OF BODY
231 GAX_M1=((GAMP2*VINF*0.5*SIN(AOAR(I)))+(AXL_M1-NOSL)*GRATE)) 00004760
IF(AXL_M1.GT.AXLE)GAXL_M1=((GAMP2*VINF*0.5*SIN(AOAR(I)))+( 00004770
((AXLE-NOSL)*GRATE)+(AXL_M1-AXL)*GRATE*0.4) 00004780
GAX_F((GAMP2*VINF*0.5*SIN(AOAR(I)))+(AXL-NOSL)*GRATE)) 00004790
IF(AXL.GT.AXLE)GAXL=((GAMP2*VINF*0.5*SIN(AOAR(I)))+( 00004800
((AXLE-NOSL)*GRATE)+(AXL-AXLE)*GRATE*0.4) 00004810
236 GBU(J1)=(GAXL*GAXL_M1)/2. 00004820
CAL_ EORD(J1,ICASE) 00004830
IF(ICASE.EQ.0)GO TO 233 00004840
GO TO 251 00004850
623 GBU(J1)=0.0 00004860
251 GBU(J1)=-GBU(J1) 00004870
C SIDE FORCE AND YAWING MOMENT CALCULATIONS
250 SFGBU(J1)=ABS(GBU(J1))*RHUINF*VC*SEGL 00004880
IF(SBU(J1).GT.0.0)SFGBU(J1)=-SFGBU(J1) 00004890
FMGBU(J1)=SFGBU(J1)*(AXL_M1*(SEGL/2.)) 00004900
GO TO 228 00004910
230 IF(J1.GT.4)GO TO 234 00004920

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MAIN

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CIRCULATION INDUCED BY INITIAL STRENGTH VORTICES HAVING MODIFIED
GROWTH RATE
JIM2=J1-2
DIFF=ABS(GSEP(J1))-ABS(GSEP(JIM2))
GRAD34=GAM1/DIFF
GAXLM1=GRAD34*(AXLM1-ABS(GSEP(JIM2)))
IF(ABS(GSEP(JIM2)).GT.AXLE)GAXLM1=0.4*GRAD34*(AXLM1-ABS(GSEP(J1+2)
1)
IF(AXLM1.GT.AXLE.AND).ABS(GSEP(JIM2)).LT.AXLE)GAXLM1=((AXLE
1-ABS(GSEP(JIM2)))*GRAD34)+((AXLM1-AXLE)*GRAD34*0.4)
GAXLM=GRAD34*(AXL-ABS(GSEP(JIM2)))
IF(ABS(GSEP(JIM2)).GT.AXLE)GAXLM=0.4*GRAD34*(AXL-ABS(GSEP(J1+2)))
IF(AXL.GT.AXLE.AND).ABS(GSEP(JIM2)).LT.AXLE)GAXLM=((AXLE
1-ABS(GSEP(JIM2)))*GRAD34)+((AXL-AXLE)*GRAD34*0.4)
XPOINT = AXLM1 + (SEG-V2.)
CALL XYZ(M+J).THETA1,ABSSEP(J1),GSEP(J1),GSEP(JIM2),XPOINT,Y,7+41,42
1)
RDIST=SQRT((Y**2.)+(Z**2.))
RCAL = RDIST/7
IF(RCAL.GT.GAMLM1)GO TO 623
ADJUSTING CIRCULATION TO ACCOUNT FOR RADIAL DECAY
GAXLM1 = GAXLM1 * ((GAMLM1 - RCAL)/GAMLM1)
GAXL1 = GAXL * ((GAMLM1 - RCAL)/GAMLM1)
GAXLM1 = GAXLM1 * COS(A1) * COS(A2)
GAXL = GAXL * COS(A1) * COS(A2)
GO TO 236
234 JIM2=J1-2
CIRCULATION INDUCED BY SEGMENT BY STRENGTH VORTICES HAVING NOMINAL
GROWTH RATE
GAXLM1=GRATE*(AXLM1-ABS(GSEP(JIM2)))
IF(ABS(GSEP(JIM2)).GT.AXLE)GAXLM1=0.4*GRATE*(AXLM1-ABS(GSEP(JIM2)
1)
IF(AXLM1.GT.AXLE.AND).ABS(GSEP(JIM2)).LT.AXLE)GAXLM1=((AXLE-
1-ABS(GSEP(J1+2)))*GRATE)+((AXLM1-AXLE)*GRATE*0.4)
GAXLM=GRATE*(AXL-ABS(GSEP(JIM2)))
IF(ABS(GSEP(JIM2)).GT.AXLE)GAXLM=0.4*GRATE*(AXL-ABS(GSEP(JIM2)))
IF(AXL.GT.AXLE.AND).ABS(GSEP(JIM2)).LT.AXLE)GAXLM=((AXLE-
1-ABS(GSEP(J1+2)))*GRATE)+((AXL-AXLE)*GRATE*0.4)
XPOINT = AXLM1 + (SEG-V2.)
CALL XYZ(M+J).THETA1,ABSSEP(J1),GSEP(J1),GSEP(JIM2),XPOINT,Y,7+41,42
1)
RDIST=SQRT((Y**2.)+(Z**2.))
RCAL = RDIST/7
IF(RCAL.GT.GAMLM1)GO TO 623
ADJUSTING CIRCULATION TO ACCOUNT FOR RADIAL DECAY
GAXLM1 = GAXLM1 * ((GAMLM1 - RCAL)/GAMLM1)
GAXL1 = GAXL * ((GAMLM1 - RCAL)/GAMLM1)
GAXLM1 = GAXLM1 * COS(A1) * COS(A2)
GAXL = GAXL * COS(A1) * COS(A2)
GO TO 236
228 CONTINUE
221 SF(K)=0.0
FMT(K)=0.0
ZERGING OUT CONTRIBUTIONS FROM SFD VORTICES
GO 239 JT=1,JMAX
SFPC(JT)=0.0
FMGPC(JT)=0.0
SFPSV(JT)=0.0

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FMGDSV(JT)=0.0 00007440

C SUM CONTRIBUTIONS TO SIDE FORCE AND YAWING MOMENT ON EACH SEGMENT
 $SF(K) = SF(K) + SFPC(JT) + SFPSV(JT) + SFPTS(JT) + SFBUAS(IT) + SF3BU(IT)$ 00007450
 $FMT(K) = FMT(K) + FMGPC(JT) + FMGPSV(IT) + FMGRIT(JT) + FMHIAc(JT)$ 00007460
 $+ FM3HU(JT)$ 00007470

239 CONTINUE 00007480

C CALCULATE SEGMENT CENTER OF PRESSURE
 $XARM = ABS(FMT(K)) / ABS(SF(K))$ 00007490
 $YMOY(K) = SF(K) * XARM$ 00007500

C GO TO NEXT SEGMENT AND REPEAT CALCULATIONS

200 CONTINUE 00007510
 $TSF = 0.0$ 00007520
 $TYMOM = 0.0$ 00007530

C SUM SIDE FORCE AND YAWING MOMENT CONTRIBUTIONS FROM ALL SEGMENTS
 $NO 112 \leq 1.05$ 00007540
 $TSF = TSF + SF(K)$ 00007550
 $TYMOM = TYMOM + YMOY(K)$ 00007560

312 CONTINUE 00007570

C GO TO 54 IF ISOLATED BODY
 $IF(1000NF.EQ.1) GO TO 54$ 00007580
 $JMAX1 = JMAX$ 00007590
 $DO 350 K=1, JMAX$ 00007600
 $IF(ABS(RSEP(K)) .LE. ABS(EMOYL)) GO TO 350$
 $JMAX1 = K-1$
 $GO TO 352$ 00007620

350 CONTINUE 00007630
 $352 NFF1=0$ 00007640
 $JMAX = JMAX1$
 $FNF1(I)=0.0$ 00007650
 $SRO_M(I)=0.0$ 00007660

C CAL. FINCAL TO CARRY OUT VORTEX/FIN INTERACTION CALCULATIONS
 $351 CAL. FINCAL(JMAX, SARMV(1), XFM, YFM, ZFM, XCMAX, XF, ZFMAY, ZF, LAM,$ 00007670
 $IGSEP1(I), GSEP7(I), H.E.PI, D.VINFA, SREFT, RMAINF, GSEP(I), RVFY, 1STO,$ 00007680
 $2RNF, MYCP, ROLM)$ 00007690

C $IF(1STOP.EQ.1) 1SKIP(I)=1$ 00007700

C $IF(1STOP=1)$ A VORTEX PASSES WITHIN 1/4 BODY RADIUS OF FIN.

C DISCONTINUE CALCULATIONS, GO TO NEXT ANGLE OF ATTACK
 $IF(1STOP.EQ.1) GO TO 56$ 00007710
 $SRO_M(I) = SROLM(I) + ROLM$ 00007720

C SUM SIDE FORCE AND YAWING MOMENT
 $TSF = TSF + RVFY$ 00007730
 $TYMOM = TYMOM + ((ABS(EMOYL) + (ABS(XCMAX - XF) / 2.)) * RVFY)$ 00007740

C $IF(LAM.EQ.0.0) NFF1=1$ 00007750
 $IF(LAM.EQ.0.0) FNF1(I)=4VF$ 00007760
 $NORA = NORA + 1$ 00007770

C GO TO 58 WHEN CONTRIBUTIONS FROM ALL FINS HAVE BEEN CALCULATED
 $IF(NORA.GT. NLAM) GO TO 58$ 00007780
 $LAM = NA(NORA)$ 00007790
 $LAM = LAM$ 00007800
 $LAM = LAM / 57.29577$ 00007810

C CALCULATE COORDINATES OF FIN ROOT CHORD LEADING EDGE
 $XFP = XF$ 00007820
 $YFR = -1. * (D/2.) * SIN(LAM)$ 00007830
 $ZFR = (D/2.) * COS(LAM)$ 00007840
 $GO TO 351$ 00007850

C CALCULATE FREE STREAM DYNAMIC PRESSURE
 $58 Q = .5 * RHOINF * (VINFA**2.)$ 00007860

C CALCULATE SIDE FORCE AND YAWING MOMENT COEFFICIENTS

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	CY(I)=TSF/(J*SREF)	00007870
	CETA(I)=TYMOM/(J*SREF*J)	00007880
C	TRANSFER OF YAWING MOMENT	
	CETAMC(I)=(CETA(I)/CY(I))-(XMC/D))*CY(I)	00007890
52	CONTINUE	00007900
	IF(IDCONF.EQ.0)GO TO 23	00007910
C	PRINT BODY PLIS TAIL OUTPUT	
	IF(VFF1.NE.0)WRITE(5,9)XMC	00007920
8	FORMAT(3X,15HANGLE OF ATTACK,4X,24CY,6X,64CETAMC,7X,9HROLL MOM.,	
	24X,12HNORMAL FORCE,/,	
	36X,9H(DEGREES),14X,3HCG=F5,2,2HFT,5X,7H(FT-LB),4X,	
	416H(FIN NO. 1 (LB)))	
	IF(VFF1.EQ.0)WRITE(5,10)XMC	00007970
10	FORMAT(3X,15HANGLE OF ATTACK,4X,24CY,6X,64CETAMC,7X,9HROLL MOM.,/,	
	2,6X,9H(DEGREES),14X,3HCG=F5,2,2HFT,5X,7H(FT-LB))	
	DO 313 I=1,NAVA	00008000
	IF(ISKIP(I).NE.0)GO TO 313	00008010
	IF(VFF1.NE.0)WRITE(5,7)AOAD(I),CY(I),CETAMC(I),SHOLL(I),FNF(I)	00008020
9	FORMAT(7X,F5,2,6X,F7,3,5X,F7,3,6X,F7,3,7X,FA,3)	00008030
	IF(VFF1.EQ.0)WRITE(5,11)AOAD(I),CY(I),CETAMC(I),SQRM(I)	00008040
11	FORMAT(7X,F6,2,6X,F7,3,5X,F7,3,6X,F7,3)	00008050
313	CONTINUE	00008060
	GO TO 24	00008070
C	PRINT ISOLATED BODY OUTPUT	
23	WRITE(6,25)XMC	00008080
25	FORMAT(3X,15HANGLE OF ATTACK,4X,24CY,6X,64CETAMC,/,	
	26X,9H(DEGREES),14X,3HCG=F5,2,2HFT)	
	DO 26 I=1,NAOA	00008110
	WRITE(6,27)AOAD(I),CY(I),CETAMC(I)	00008120
27	FORMAT(7X,F6,2,6X,F7,3,5X,F7,3)	00008130
26	CONTINUE	00008140
	IF(IOPT.NE.1)GO TO 24	00008150
C	IF IOPT=1 SCALE ISOLATED BODY OUTPUT FOR NOSE FINENESS RATIO AND	
C	BLUNTNESS RATIO EFFECTS	
	CALL IOPT1(FSMN,NOSE,24,4H,XMC,CY(I),CETA(I),CETAMC(I),	00008160
	2IPASS,NAOA)	00008161
	IF(IPASS.EQ.0)GO TO 24	00008170
	WRITE(6,800)	00008180
800	FORMAT(1X,12H=ICKS OPT(ON)	
	WRITE(6,25)XMC	00008200
	DO 801 I=1,NAJA	00008210
	WRITE(6,27)AOAD(I),CY(I),CETAMC(I)	00008220
801	CONTINUE	00008230
24	READ(5,4)IRUN	00008270
C	CHECK TO SEE IF ANOTHER RUN IS TO BE MADE	
	IF(IRUN.EQ.1)GO TO 41	00008280
	CALL EXIT	00008290
	END	00008300

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XYZ

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SUBROUTINE XYZ(M, THETA, AJ, XJ, XJ2, X, Y, Z, PI, DELTA) 0000310
*****
C SUBROUTINE XYZ CALCULATES COORDINATES OF POINTS ALONG VORTEX
C GROWTH TRAJECTORY
C *****
C IF (ABS(AJ), ST, ARS(XJ)) GO TO 100 0000320
C CALCULATE COORDINATES OF POINTS ALONG GROWTH TRAJECTORY OF A
C NORMAL STREET VORTEX
PI = ATAN(((H/2.) - ((D/2.) * COS(THETA)))) / (ARS(XJ) - ARS(XJ2)) 0000330
CEBAR = (ABS(XJ) - X) / COS(PI) 0000340
ACBAR = SQRT(((H/2.) - ((D/2.) * COS(THETA)))) * 2. 0000350
1 ((ABS(AJ) - ARS(XJ2)) * 2.) 0000360
Z = (H/2.) - ((ABS(XJ) - X) * TAN(PI)) 0000370
101 DELTA = ATAN((SQRT(((H/2.) + SQRT(((H/2.) * 2. + ((D/2.) * 2.))) * 2. 0000380
1 - ((H/2.) * 2.)) - ((D/2.) * SIN(THETA))) / ACBAR) 0000390
Y = ((ACBAR - CEBAR) * TAN(DELTA)) + ((D/2.) * COS(THETA)) 0000400
GO TO 102 0000410
C CALCULATE COORDINATES OF POINTS ALONG GROWTH TRAJECTORY OF A
C VORTEX FORCED TO SEPARATE AT THE REAR OF THE BODY
100 PI = ATAN(((H/2.) - ((D/2.) * COS(THETA)))) / (ARS(AJ) - ARS(XJ2)) 0000420
CEBAR = (ABS(AJ) - X) / COS(PI) 0000430
ACBAR = SQRT(((H/2.) - ((D/2.) * COS(THETA)))) * 2. 0000440
1 ((ABS(AJ) - ARS(XJ2)) * 2.) 0000450
Z = (H/2.) - ((ABS(AJ) - X) * TAN(PI)) 0000460
GO TO 101 0000470
102 RETURN 0000480
END 0000490

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EOAO

SUBROUTINE EOAO(INT,IEO)

0000A500

.....
SUBROUTINE EOAO DETERMINES IF A VORTEX IS NUMBERED EVEN OR ODD.
THIS DETERMINES THE SIGN APPLIED TO THE CIRCULATION
.....

INTD2=INT/2

0000A510

INP1=INT+1

0000A520

INP102=INP1/2

0000A530

IEO=1

0000A540

IF (INP102.GT.INTD2) IEO=0

0000A550

ODD IEO=0

0000A560

EVEN IEO=1

0000A570

REIJRN

0000A580

END

0000A590

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FINCAL

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SUBROUTINE FINCAL(JMAX,GAMSV,XF0,YF0,ZF0,XFMAX,XF,ZFMAX,ZF,IA4,
1USEPT,USEPZ,H,E,PHI,D,VINFA,SREF,PHINF,GCEP,RNFF,ICTOP,
2RNF,RYCP,ROLM)
REAL LAM
DIMENSION GAMSV(1),GSEPT(1),GSEPZ(1),GSEP(1),X(10),Y(10),Z(10),
1VNT(10),VT(10),A0A05(10),VNVAR(20),CN(20)
DIMENSION YCP(20)
SUBROUTINE FINCAL CALCULATES THE NORMAL FORCE INDUCED ON FINS BY
SHED VORTICES IN THE BODY LEE SIDE WAKE
*****
JSTART=JMAX-1
DO 53 J=JSTART, JMAX
    SHED VORTEX STRENGTH
    GAM=GAMSV(J)
    CALCULATION OF COORDINATES ON FIN LEADING EDGE WHERE CALCULATIONS
    ARE TO BE MADE
    X(1)=XF0
    Y(1)=YF0
    Z(1)=ZF0
    FLES=(XFMAX-XF)/(ZFMAX-ZF)
    DELZ=(ZFMAX-ZF)/10.
    DO 51 I=1,10
        IF(I.GT.1)GO TO 55
        X(I)=FLES*(DE_Z/2.)*X(1)
        Z(I)=Z(1)+(DE_Z/2.)*COS(LAM)
        Y(I)=Y(1)-(DE_Z/2.)*SIN(LAM)
        GO TO 57
56 K=I-1
        X(I)=FLES*DELZ*Y(K)
        Z(I)=Z(K)+DELZ*COS(LAM)
        Y(I)=Y(K)-DELZ*SIN(LAM)
        AXIAL DISTANCE FROM POINT OF VORTEX SEPARATION TO POINT ON FIN
57 DELX=ABS(X(I)-GSEPT(J))
        DEFINITION OF VORTEX LATERAL DISPLACEMENT
        IF(GAM.GT.0.0.AND.J.LE.2)YVCL=-GSEPZ(J)
        IF(GAM.GT.0.0.AND.J.GT.2)YVCL=-H/2.
        IF(GAM.GT.0.0.AND.J.EJ.JSTART,UP,J.FD,JMAX)YVCL=-GSEPZ(J)
        IF(GAM.LT.0.0.AND.J.LE.2)YVCL=GSEPZ(J)
        IF(GAM.LT.0.0.AND.J.GT.2)YVCL=H/2.
        IF(GAM.LT.0.0.AND.J.EJ.JSTART,UP,J.FD,JMAX)YVCL=GSEPZ(J)
        A1=(ABS(Z(I)-DELX*TAN(E)))*COS(E)
        B1=ABS(YVCL-Y(I))
        ANG_E=ATAN(A1/B1)
        BBAR=DELX/COS(E)
        DBBAR=(ABS(DELX*TAN(E)-Z(I)))*SIN(E)
        BRAR=BBAR-DBBAR
        ZADJ=BBAR*SIN(E)
        PHI1=ANGLE
        RADIAL DISTANCE FROM VORTEX CORE TO POINT ON FIN MEASURED ALONG
        A LINE PERPENDICULAR TO THE VORTEX CORE
67 R1=(ABS(Z(I)-DELX*TAN(E)))*COS(E)/SIN(PHI1)
        R10=R1/(0/2.)
        IF VORTEX PASSES WITHIN 1/4 BODY RADIUS OF POINT ON FIN
        DISCONTINUE CALCULATIONS
        IF(R10.LE.0.25)GO TO 21
        VELOCITY INDUCED AT POINT ON FIN BY VORTEX
        VT1=0.44/(2.*PI*R1)
        COMPONENTS OF VELOCITY

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VY1=VT1*SIN(P411)
VZ1=VT1*COS(P411)*COS(E)
IF(ZADJ.LT.Z(I))GO TO 86
IF(YVCL.LT.Y(I))GO TO 87
VY1=-1.*VY1
GO TO 69
87 VY1=-1.*VY1
VZ1=-1.*VZ1
GO TO 69
86 IF(YVCL.LT.Y(I))VZ1=-1.*VZ1
69 VYN1=VY1*COS(LAM)
VZN1=VZ1*SIN(LAM)
NORMAL COMPONENT OF VELOCITY INDUCED ON FIN BY VORTEX
VN1=VYN1+VZN1
A2=ABS(Z(I)-DELX*TAN(E))
B2=ABS(YVCL-Y(I))
ANGLE2=ATAN(A2/B2)
ZADJ2=DELX*TAN(E)
PHI2=ANGLE2
70 R2=(ABS(Z(I)-DELX*TAN(E))/SIN(PHI2)
IF(YVCL.GT.Y(I).AND.ZADJ2.GT.Z(I))GO TO 88
IF(YVCL.LT.Y(I).AND.ZADJ2.GT.Z(I))GO TO 88
IF(YVCL.GT.Y(I).AND.ZADJ2.LT.Z(I))GO TO 88
IF(YVCL.LT.Y(I).AND.ZADJ2.LT.Z(I))GO TO 88
DEFINITION OF EQUIVALENT VORTEX STRENGTH
88 GAM2=VN1*(2.*PHI*R2)/(COS(PHI2)*SIN(LAM)-SIN(PHI2)*COS(LAM))
GO TO 73
89 GAM2=-1.*VN1*(2.*PHI*R2)/(SIN(PHI2)*COS(LAM)+COS(PHI2)*SIN(LAM))
GO TO 73
90 GAM2=VN1*(2.*PHI*R2)/(SIN(PHI2)*COS(LAM)+COS(PHI2)*SIN(LAM))
GO TO 73
91 GAM2=VN1*(2.*PHI*R2)/(SIN(PHI2)*COS(LAM)-COS(PHI2)*SIN(LAM))
LOCATION OF IMAGE VORTEX
73 F=SQRT((ABS(YVCL))**2.+(DELX*TAN(E))**2.)
GI=((D/2.)*F
THETA=ATAN(ABS(YVCL)/(DELX*TAN(E)))
IF(GAM2.GT.0.)THETA=-1.*THETA
YI=GI*SIN(THETA)
ZI=GI*COS(THETA)
RI=SQRT((ABS(Y(I)-YI))**2.+(ABS(Z(I)-ZI))**2.)
GAM1=-1.*GAM2
CALCULATE VELOCITY INDUCED AT POINT ON FIN BY IMAGE VORTEX
VTI=GAM1/(2.*PHI*RI)
A2I=ABS(Z(I)-ZI)
B2I=ABS(YI-Y(I))
ANGLEI=ATAN(A2I/B2I)
PHI2I=ANGLEI
VYI=VTI*SIN(P4I2I)
VZI=VTI*COS(P4I2I)
IF(ZI.LT.Z(I))GO TO 92
IF(YI.LT.Y(I))GO TO 93
VYI=-1.*VYI
GO TO 76
93 VYI=-1.*VYI
VZI=-1.*VZI
GO TO 76
92 IF(YI.LT.Y(I))VZI=-1.*VZI
76 VYN1=VYI*COS(LAM)

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FINCAL

	VZNI=VZI*SIN(AM)	0n00958n
C	NORMAL COMPONENT OF VELOCITY INDUCED AT POINT ON FIN BY IMAGE	
C	VORTEX	
	VNI=VYNI+VZNI	0n00959n
	RC=SQRT(ABS(Y(I))**2.+ABS(Z(I))**2.)	0n00960n
C	CALCULATION OF NORMAL COMPONENT OF VELOCITY INDUCED AT POINT	
C	ON FIN BY CENTRAL VORTEX	
	VNC=GAM2/(2.*PHI*RC)	0n00961n
C	SUMMATION OF NORMAL VELOCITY COMPONENTS FOR ALL SEGMENTS	
	VNT(I)=VNI+VNI+VNC	0n00962n
51	CONTINUE	0n00963n
	VT(J)=0.0	0n00964n
	DO 52 I=1.10	0n00965n
	VT(I)=VT(J)+VNT(I)	0n00966n
52	CONTINUE	0n00967n
	DO 53 I=1.10	0n00968n
C	EFFECTIVE ANGLE OF ATTACK INDUCED AT POINT ON FIN	
	AOA(J)=ATAN(ABS(VNT(I))/VINFA)	0n00969n
	IF(VNT(I).GT.0.)AOA(J)=1.*AOA(J)	0n00970n
A3	CONTINUE	0n00971n
	SYADY=0.0	0n00972n
	SADY=0.0	0n00973n
	DO 54 I=1.10	0n00974n
	IF(I.EQ.1)YCPY=7/2.*DELZ/2.	0n00975n
	IF(I.GT.1)YCPY=YCPY+DELZ	0n00976n
	SYADY=AOA(J)*YCPY+DELZ*SYADY	0n00977n
	SADY=AOA(J)*DELZ+SADY	0n00978n
54	CONTINUE	0n00979n
C	FIN SPANWISE CENTER OF PRESSURE	
	YCP(J)=SYADY/SADY	0n00980n
C	AVERAGE VELOCITY INDUCED AT FIN LEADING EDGE	
	VNHAR(J)=ABS(VT(J)/1.1)	0n00981n
	AIN=ATAN(VNHAR(J)/VINFA)	0n00982n
	VEL=SQRT((VINFA**2.)+(VNHAR(J)**2.))	0n00983n
	AR=2.*(ZFMAX-ZF)**2./5REF	0n00984n
	CNA=PHI*AR/2.	0n00985n
	Q=0.5*RHUINF*(VEL**2.)	0n00986n
C	NORMAL FORCE INDUCED ON FIN BY A VORTEX	
	FN(J)=CNA*AIN**2.*5REF	0n00987n
	AIN=AIN*57.29	0n00988n
	IF(VT(J).LT.0.0)FN(J)=-1.*FN(J)	0n00989n
C	LOOP AND CALCULATE NORMAL FORCE INDUCED BY ALL OTHER VORTICES IN	
C	WAKE	
53	CONTINUE	0n00990n
	RNF=0.0	0n00991n
C	RESILIENT FIN NORMAL FORCE	
	DO 54 I=JSTART,JMAX	0n00992n
	RNF=RNF+FN(I)	0n00993n
54	CONTINUE	0n00994n
	RNFY=RNF*COS(AM)	0n00995n
	RNFZ=RNF*SIN(AM)	0n00996n
	RM=0.0	0n00997n
C	CALCULATE ROLLING MOMENT	
	DO 55 I=JSTART,JMAX	0n00998n
	RM=RM+YCP(I)*FN(I)	0n00999n
55	CONTINUE	0n01000n
	RYCP=ABS(RM)/ABS(RNF)	0n01001n
	ROL=-1.*RNF**2*YCP	0n01002n

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FINCA-I

GO TO 23
21 ISTOP=1
23 RETJRN
END

00010030
00010040
00010050
00010060

0321

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OPT1

F2=3HK3(I4,I31)-(RAT10*(3HK3(I4,I31)-3R43(I41,I3R)))	00010610
F1=F1-(F1-F2)*((T3R(I3R)-3R43)/(T42(I4R)-T4R(I3R)))	00010620
IF(FRN.GE.3.0.AND.FRN.LE.4.0)GO TO 10	00010630
G1=3R42(I4,I31)-(RAT10*(3R42(I4,I31)-3R42(I41,I3R)))	00010640
G2=3R42(I4,I31)-(RAT10*(3R42(I4,I31)-3R42(I41,I3R)))	00010650
RAT10=(2.0-FRN)/(2.0-3.0)	00010660
GO TO 11	00010670
10 G1=3R44(I4,I31)-(RAT10*(3R44(I4,I31)-3R44(I41,I3R)))	00010680
G2=3R44(I4,I31)-(RAT10*(3R44(I4,I31)-3R44(I41,I3R)))	00010690
RAT10=(4.0-FRN)/(4.0-3.0)	00010700
11 G1=G1-(G1-G2)*((T3R(I3R)-3R44)/(T42(I4R)-T4R(I3R)))	00010710
BRK1=G1-(G1-F1)*RAT10	00010720
GO TO 12	00010730
9 BRK1=1.0	00010740
12 DO 13 I=1,NA0A	00010750
CY(I)=CY(I)*F4R1*3R41	00010760
CETA(I)=CETA(I)*F4R1*3R41	00010770
CETAMC(I)=(CETA(I)/CY(I))-(X4C/D))*CY(I)	00010780
13 CONTINUE	00010790
GO TO 14	00010800
1 IPASS=0	00010810
14 RETJRN	00010820
END	00010830

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6.4 Sample Inputs/Outputs

Isolated Bodies

Input:

VINF = 890.0 ft/sec
FSMN = 0.8
RHOINF = 0.000642 lb sec²/ft⁴
ANU = 0.000575 ft²/sec
D = 0.312 ft
SREF = 0.0768 ft²
NOSEL = 0.936 ft
BODYL = 3.12 ft
XMC = 2.0 ft
DELTA = 9.45 deg
NS = 50
IDCONF = 0

NAOA = 15
NTYPE = 2
NLAM = 1

AOAD = 24., 25., 26., 28., 30., 32., 34., 36.,
38., 40., 42., 44., 46., 48., 50.

RA = 0.0
GAMLIM = 100.
IOPT1 = 1
BRN = 0.0
IRUN = 0

Output:

ANGLE OF ATTACK (DEGREES)	CY	CETAMC CG= 2.00FT
24.00	0.486	1.209
25.00	0.342	0.891
26.00	0.155	0.537
28.00	-0.287	-0.255
30.00	-0.791	-0.909
32.00	-0.705	0.308
34.00	-0.241	2.254
36.00	0.251	3.872
38.00	-0.069	2.334
40.00	-0.693	0.319
42.00	-1.137	-0.774
44.00	-0.389	2.218
46.00	0.455	4.772
48.00	-0.324	1.495
50.00	-1.163	-1.341

PICKS OPTION

ANGLE OF ATTACK (DEGREES))	CY	CETAMC CG= 2.00FT
24.00	0.694	1.728
25.00	0.489	1.273
26.00	0.222	0.767
28.00	-0.410	-0.365
30.00	-1.130	-1.299
32.00	-1.008	0.441
34.00	-0.344	3.221
36.00	0.358	5.575
38.00	-0.099	3.336
40.00	-0.991	0.456
42.00	-1.625	-1.105
44.00	-0.556	3.169
46.00	0.651	6.819
48.00	-0.463	2.136
50.00	-1.662	-1.916

Body Plus Tail

Input:

VINF	=	921.0	ft/sec
FSMN	=	0.8	
RHOINF	=	0.00059	lb sec ² /ft ⁴
ANU	=	0.000574	ft ² /sec
D	=	0.312	ft
SREF	=	0.0768	ft ²
NOSEL	=	0.938	ft
BODYL	=	3.12	ft
XMC	=	2.0	ft
DELTA	=	9.45	deg
NS	=	50	
IDCONF	=	1	
XF	=	-2.709	ft
YF	=	0.0	ft
ZF	=	0.1561	ft
XFMAX	=	-2.917	ft
YFMAX	=	0.0	ft
ZFMAX	=	0.312	ft
SREFT	=	0.049	ft ²
NAOA	=	18	
NTYPE	=	2	
NLAM	=	4	
AOAD	=	25., 27., 29., 31., 33., 35., 37., 39., 41., 43., 45., 47., 49., 51., 53., 55., 57., 59.	
RA	=	0.0, 90., 180., 270.	
GAMLIN	=	100.	
IOPT1	=	0	
BRN	=	0	
IRUN	=	0	

OUTPUT

ANGLE OF ATTACK (DEGREES)	CY	CETANG CG= 2.00 FT	ROLL MOM. (FT-LB)	NORMAL FORCE FIN NO. 1 (LB)
25.00	0.355	-0.820	-0.607	0.939
29.00	0.353	-1.026	-0.797	1.767
31.00	0.490	-0.484	0.301	1.120
33.00	0.767	0.376	0.116	1.208
35.00	1.013	1.171	0.487	0.594
37.00	1.190	1.856	1.199	-0.964
39.00	1.285	2.314	2.215	-3.388
43.00	0.651	2.669	-0.155	-1.884
45.00	-0.096	1.650	-0.839	-0.640
47.00	-0.804	1.111	-2.174	2.498
51.00	-1.315	1.445	0.374	1.705
53.00	-0.522	3.404	2.680	-0.899
55.00	0.176	4.468	3.296	-5.729
57.00	-0.238	3.576	-0.470	-1.280
59.00	-0.538	1.324	-2.087	2.631

The results of these two sample outputs, are compared against experimental data in Figures 12a and b and 13a and b

6.5 Program Limitations

There are certain limits which apply to the application of the procedures and program described in this document. Following is a list of the program limitations which the user must be familiar with before trying to use the program.

- a. The program is crossflow Mach number limited to values between 0.15 and 0.8.
- b. Due to the large side wash velocities and correspondingly large fin normal forces produced when a vortex core passes close to a fin, the program has been set up to discontinue calculations at angles of attack when a vortex core passes within 1/4 body radius of a fin and proceed to the next angle of attack. The 1/4 body radius limitation was selected after comparing the results of numerous runs against experimental data.

A potential vortex model is used in the program. The velocity produced by such a vortex at a radius R is given by the following equation:

$$v_t = \frac{\Gamma}{2\pi r}$$

It is because of this that the induced side wash velocities becomes so large when a vortex core passes close to a fin. In actuality a vortex has a viscous core beyond which the vortex can be modeled by a potential vortex. In the viscous core the velocity goes to zero at the center. In order to retain as simple a model as possible, it was decided to place the limitation described above on the program.

- c. The program should only be applied to configurations which have $\beta = 0^\circ$ or 45° . This is because the program only calculates fin forces induced by the presence of an asymmetric vortex system. Only at these roll angles do the forces on the fins produced by flow conditions other than vortices cancel themselves out due to opposite senses of direction.

d. Physically it is logical that the side force induced on the finless portion of a body is contributed to by both feeding sheets and shed vortices. However, comparisons between predictions and experimental data have indicated that the best results will be obtained when the contributions from shed vortices are neglected. The program logic predicts both contributions but prior to the point at which total side force is calculated the contributions from shed vortices are set equal to zero. This is accomplished by inserting the following

SFPC (JT) = 0.0	}	Side force and yawing moment induced by a shed vortex passing over a complete segment
FMPCG (JT) = 0.0		
SFPSV (JT) = 0.0	}	Side force and yawing moment induced by a vortex shedding within the bounds of a segment
FMGPSV (JT) = 0.0		

within the do-loop ending with statement 239.

These cards may be removed at anytime in order to study the effects of shed vortices on body side forces.

e. Caution is advised when employing the option to correct for nose fineness and bluntness ratios. The reason for this being that the scaling factors were derived from data showing considerable scatter. Also due to the unsteady nature of the vortex phenomenon, it is possible that considerably different scaling factors could be derived using other data sources.

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