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SFFSTAB:
A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC
STABILITY OF A SELF-FORGING FRAGMENT (U)

by

C.A. Weickert

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ABSTRACT

An aerodynamic stability computer program (SFFSTAB) has been developed for calculating the spin rate required for stabilization of a self-forging fragment. An aerodynamic stability criterion which combined gyroscopic and dynamic stability was used together with a technique for calculating aerodynamic coefficients. SFFSTAB is a useful tool for conducting aerodynamic stability parameter studies for different fragment shapes. Complete documentation of the computer program including sample problem, flowchart and FORTRAN listing is provided.
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### NOMENCLATURE

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<tr>
<td>$A$</td>
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<tr>
<td>$C_D$</td>
<td>drag coefficient</td>
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<tr>
<td>$C_G$</td>
<td>center of mass</td>
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<tr>
<td>$C_{m_p}$</td>
<td>derivative of the magnus-moment coefficient</td>
</tr>
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</tr>
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<td>$C_N$</td>
<td>normal-force coefficient</td>
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<tr>
<td>$C_P$</td>
<td>center of pressure</td>
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NOMENCLATURE (cont'd)

- $d$: projectile diameter
- $d_b$: base diameter of projectile
- $d_n$: base diameter of segment
- $D$: drag force
- $I_x$: axial moment of inertia
- $I_y$: transverse moment of inertia
- $K_x$: dimensionless axial radius of gyration
- $K_y$: dimensionless transverse radius of gyration
- $l$: projectile length
- $L$: lift force or distance from the Magnus center of pressure to the center of gravity
- $s$: length of segment
- $M$: Mach number
- $m$: mass
- $N$: normal force
NOMENCLATURE (cont'd)

- **P** projectile spin rate
- **R** resultant force
- **R_1** Reynolds Number based on \( l \)
- **S** projectile cross-sectional area
- **S_d** dynamic stability factor
- **S_g** gyroscopic stability factor
- **V** velocity
- **\( \alpha \)** angle of attack
- **\( \theta \)** angle between surface tangent and free stream or flare angle
- **\( \rho \)** density
SFFSTAB: A COMPUTER PROGRAM TO CALCULATE THE 
AERODYNAMIC STABILITY OF A SELF-FORGING FRAGMENT

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C.A. Weickert

1.0 INTRODUCTION

The purpose of this report is to describe the criteria for stability and to document a program which is capable of calculating aerodynamic coefficients and spin rates required for stabilization of self-forging fragments.

The Demolitions Group at the Defence Research Establishment Suffield (DRES) is responsible for military related research in Canada on demolitions and demolition devices. DRES is developing a Self-Forging Fragment (SFF) technology base suitable for the study of the application of SFF devices to demolition problems.

One of the projects currently under study is the application of spin stabilization to self-forging fragments. The project requires both numerical and experimental capabilities to study the SFF formation and flight stability.
The ORES Flash X-ray Facility has the capability of obtaining formation, shape, stability characteristics and trajectory data for the fragments. The fragments can be monitored over a 60 m flight path by using a combination of X-ray radiographs and yaw screens. To fulfill the numerical requirements, and the requirement for a code to determine what parameters to vary, a computer program was developed to calculate the aerodynamic coefficients for a self-forging fragment and to predict its stability.

Section 2 describes self-forging devices and the fragment characteristics, including selected results from experimental tests. In Section 3 aerodynamic stability criteria are presented. Section 4 describes the computer program Self-Forging Fragment STABILITY (SFFSTAB). The results for sample problems are also described in this section.

The DATCOM [3] method for obtaining aerodynamic coefficients is documented in Appendix A, and properties of spherical segments and truncated cones are given in Appendix B. A flowchart and a FORTRAN listing of the computer program with input and output for the sample problem presented in Section 4 are contained in Appendix C.

2.0 SELF-FORGING FRAGMENT DEVICE

A typical self-forging fragment (SFF) device, as illustrated in Figure 1, consists of a body which is filled with high explosive (HE) and a metal liner. The charge is initiated by a detonator and an explosive booster. Upon initiation, the resulting detonation wave travels through the HE subjecting the metal liner to high forces causing a single fragment to be formed, and accelerating this fragment to a high velocity. Typical SFF's have initial velocities of
2-3 km/sec. These fragments can travel to distances well in excess of 1000 calibers, beyond which accuracy becomes a problem.

In many self-forging fragment designs, the objective is to produce a long rod-type fragment as opposed to a ball-type fragment since the former has, in general, greater target penetration capability. However, a long fragment is inherently unstable in flight as illustrated in Figure 2. This figure shows flash radiographs of the fragment as it deviates from the intended flight path. This instability results in a loss of accuracy and a lower target penetration capability. Current SFF designs use a flared tail fragment. This feature increases the stability of the fragment and improves its accuracy. However, the flared tail increases the aerodynamic drag on the fragment, resulting in a shorter flight path, and it also reduces the penetrating capability of the fragment since the tail does not contribute to the penetration process. If a fragment could be spin stabilized, the requirement for a flared tail would be eliminated (see Figure 3). This would result in increased performance of the self-forging fragment device. The main aim of this report is to present a computer program for calculating the requirements for aerodynamic stability and to illustrate its application to self-forging fragments with flared rod and blunt cone shapes.

3.0 AERODYNAMICS OF SELF-FORGING FRAGMENTS

Determination of the aerodynamic stability of a projectile requires a knowledge of the mass distribution within the projectile (i.e., location of the center of gravity, moments of inertia) and the aerodynamic parameters (i.e., lift, drag, etc.). For most projectiles the mass distribution can be calculated or measured from the projectile design and the aerodynamic parameters can be determined by wind tunnel
experiments. However, for self-forging fragments the actual shape of the fragment that will be formed from a liner is unknown, so that these properties cannot be determined a priori. Flash X-radiography can be used to determine the outer profile of the fragment but in general, unless very high-energy X-rays are used, the radiographs do not reveal any information about the interior of the fragment. Also, the high velocities of self-forging fragments requires that very specialized hypersonic tunnels be used to measure the aerodynamic parameters. Numerical techniques are therefore used to calculate the self-forging fragment stability. This report describes the SFFSTAB code developed for this purpose. After a review of the aerodynamic forces and moments acting on a projectile, formulas for gyroscopic and dynamic stability used in a stability criterion derived by Murphy [2] are presented. Aerodynamic coefficients required for the stability formulas are provided by the DATCOM method [3]. Results for typical fragment shapes are also presented.

The aerodynamic forces acting on a projectile are illustrated in Figures 4 and 5. The resultant (R) of the forces acting on a projectile can be decomposed into the drag force (D) and lift force (L) in the wind coordinate system, or the normal force (N) and axial force (A) in the body coordinate system. The resultant force (R) acts on the center of pressure (CP) which is the point at which the net moment is zero. An additional force which acts on a projectile is the magnus force (see Figure 5). The combination of the air flowing over the projectile and the spin of the projectile results in an asymmetric boundary layer thickness distribution. This effectively changes the aerodynamic shape of the body which results in a force normal to the angle of attack plane.

The location of the center of pressure (CP) depends on the velocity of the projectile. Therefore, it is more convenient to use
the center of gravity (CG) or center of mass which depends only on the mass distribution in the projectile. The forces acting at the center of pressure are replaced by an equivalent force and moment combination at the center of gravity. The aerodynamic forces and moments are usually non-dimensionalized. The corresponding force and moment coefficients, $C_{\text{FORCE}}$ and $C_{\text{MOMENT}}$, take the general forms:

$$C_{\text{FORCE}} = \frac{\text{FORCE}}{\rho V^2 S},$$

$$C_{\text{MOMENT}} = \frac{\text{MOMENT}}{\rho V^2 S l},$$

where $\rho$ and $V$ are the air density and velocity respectively, $S$ is the projectile cross-sectional area, and $l$ is the projectile length.

The dominant aerodynamic effect is the pitching-moment or static-moment coefficient ($C_m$). This coefficient represents the overturning or pitching moment which is a function of the distance between the centers of mass (CG) and pressure (CP). If the derivative of the pitching moment ($C_{m_{\alpha}}$) with respect to the angle of attack ($\alpha$) is negative, the CP is located behind the CG and the projectile is said to be statically stable (i.e., stable as long as it is not perturbed). Conversely, if $C_{m_{\alpha}}$ is greater than zero, then the CP is located ahead of the CG and the projectile is statically unstable. Physically, the center of gravity is the pivot point of the projectile. The resultant force ($R$) acts at the center of pressure in a direction towards the rear of the projectile. Thus, if the force acts ahead of the pivot point the projectile is statically unstable, and conversely if it acts behind the pivot point the projectile is statically stable.

Stabilization of projectiles is accomplished by two techniques, fin and spin stabilization. Fin stabilization is accomplished by
adding fins (or a flared tail in the case of a self-forging fragment) to the projectile in order to shift the center of pressure behind the center of gravity. In the second technique, the projectile is spun in order to maintain the center of pressure as close as possible to the trajectory which is the path of the center of mass. For a spinning projectile a gyroscopic stability factor \( S_g \) is defined by Murphy [2] as:

\[
S_g = \frac{2}{\rho V C_m d^2} \left( \frac{I_x}{I_y} \right) \frac{P}{I_y} \frac{1}{V} \frac{1}{C_m d^2},
\]

where \( P \) and \( V \) are the projectile spin rate and velocity, \( \rho \) is the air density, \( d \) is the projectile diameter, \( C_m \) is the derivative of the pitching-moment coefficient, and \( I_x \) and \( I_y \) are the axial and transverse moments of inertia, respectively. The dominant aerodynamic coefficient affecting the motion of a spinning projectile is the pitching-moment coefficient. In order for a statically unstable projectile to have a periodic motion (i.e., continue to spin) and not tumble, the gyroscopic stability factor \( S_g \) must be greater than one. Physically the motion in this case is the same as that of a spinning top. Gyroscopic stability, like static stability (i.e., center of pressure behind the center of gravity) is required for stable oscillatory motion, but this alone does not ensure that small perturbations acting on the projectile will not grow and result in unstable motion. In order to characterize the response to small perturbations, a dynamic stability factor \( S_d \) was derived by Murphy [2] from the equations of motion of a spinning projectile. This stability factor is:
where $K_x$ and $K_y$ are the dimensionless axial and transverse radii of gyration, respectively, the sum $(C_{mq} + C_{m_p})$ is the pitch-damping coefficient, $C_{N_a}$ and $C_{m_p}$ are the derivatives of the normal-force and magnus-moment coefficients, respectively, and $C_D$ is the drag coefficient.

The relation between the spin rate of a projectile and various types of projectile stability was characterized by Murphy [2]. His results are summarized on the stability diagram shown in Figure 6. The boundary between dynamic stability and instability is given by the equation:

$$\frac{1}{S_g} = S_d \left( 2 - S_d \right). \quad (3.5)$$

This equation can be used in conjunction with equation (3.3) to determine the stability bounds on the projectile spin rate ($P$). The following conclusions can be made by referring to Figure 6:

1. A dynamically stable projectile must be gyroscopically stable (i.e., $\frac{1}{S_g} < 1$);

2. If $S_d$ lies in the interval (0-2), a statically unstable projectile can be stabilized by spinning it at a sufficiently high rate and a statically stable projectile is always dynamically stable;
(3) If \( S_d \) lies outside this interval, a statically unstable projectile cannot be spin-stabilized. In fact, a statically stable projectile can be made dynamically unstable by spin.

It should be pointed out that the results shown in Figure 6 assume that \( S_d \) does not depend on the spin rate. If there is a strong dependence of the magnus moment on spin then the method of determining stability must be modified [2].

The effects of the various coefficients in equation (3.4) on the dynamic stability factor (\( S_d \)) have been studied by Platou [5]. He presents a series of graphs that can be used as a guide to determine the influence of projectile design changes on the dynamic stability.

In order to apply the stability criterion described above, the mass distribution (moments of inertia, radii of gyration) and the aerodynamic coefficients in equations (3.3) and (3.4) must be known. As previously mentioned, determination of the aerodynamic coefficients for self-forging fragments by experimental wind tunnel testing is difficult and therefore numerical techniques are used for this purpose. A compendium of methods (DATCOM) for determining aerodynamic coefficients for subsonic to hypersonic velocity regimes has been assembled by the US Air Force [3]. For the case of hypersonic velocities (applicable to self-forging fragments), Newtonian impact theory is used to determine the pressure coefficient for any surface element. Fluid particles that impact the surface are assumed to lose their normal component of momentum, whereas the tangential component is preserved. The impact results in a pressure coefficient (\( C_p \)) of the form

\[
C_p = 2 \sin^2 \phi
\]  

(3.6)
where $\phi$ is the angle between a tangent to the surface and the direction of the free stream of fluid particles. This pressure coefficient is then used to derive analytical expressions for the aerodynamic coefficients for a particular shape of projectile. The DATCOM method uses design charts and empirical relationships to determine the aerodynamic coefficients at hypersonic velocities for projectile shapes composed of one or more cone frustums with or without a spherical nose. As will be shown later these shapes can be used for self-forging fragments.

The method will now be illustrated for the derivative of the normal-force coefficient ($C_{Nn}$) which is given by

$$\frac{dC_{Nn}}{d\alpha} = C_{Nn} = \sum_{n=1}^{m} \left( \frac{d_n}{d_B} \right)^2 \left( C_{Nn} \right)$$

(3.7)

where $d_n$ and $d_B$ are the base diameters of the segment and projectile, respectively. To apply this equation, the body is divided into $m$ segments, the first segment being either a spherical nose or a cone frustum, and each succeeding segment being a cone frustum. The parameter $C_{Nn}$ for a spherical nose, based on its base area, is obtained from Figure 7, and $C_{Nn}$ for a cone frustum, based on the base area of the specific segment, is obtained from Figure 8. The ratio $(d_n/d_B)^2$ refers $C_{Nn}$ to the base area of the configuration. By evaluating $C_{Nn}$ for each segment and then applying equation (3.7) the derivative of the normal-force coefficient ($C_{Nn}$) for the complete projectile is obtained. The method applied to the remainder of the aerodynamic coefficients (except for the derivative of the magnus moment coefficient ($C_{m_{Nn}}$)) is given in Appendix A. The derivative of the magnus moment coefficient ($C_{m_{Nn}}$) can be determined from the following empirical equation [5]:

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\[ C_m = \frac{26.3 \ (1/d)^2 L}{\sqrt{R}} \]  

where \( l \) and \( d \) are the projectile length and diameter, respectively, \( L \) is the distance from the magnus center of pressure to the center of gravity and \( R \) is the Reynolds Number based on \( l \).

All of the information previously described in this section can be incorporated into a computer program for calculating aerodynamic stability of self-forging fragments.

4.0 **SFFSTAB: AERODYNAMIC STABILITY PROGRAM**

A computer program SFFSTAB has been developed for calculating the aerodynamic stability of a self-forging fragment. In this program, physical properties such as volume, mass, and moments of inertia are first calculated. Formulas for these properties for hollow spherical segments and hollow truncated cones have been derived and are given in Appendix B. Next, the aerodynamic coefficients are computed using the DATCOM method (Appendix A). Gyroscopic and dynamic stability are calculated and the projectile's stability characteristics are determined from the stability criteria illustrated in Figure 6. If the fragment is dynamically unstable, but can be spin stabilized, then a minimum fragment spin rate for stabilization is calculated. Since the fragment is initially formed from a saucer-shaped liner, it is necessary to translate the fragment spin rate into a spin rate for the initial device configuration. This is simply done by dividing the liner into segments and applying conservation of angular momentum (see Figure 9).

As an example of the application of the SFFSTAB computer program consider the self-forging fragment radiograph shown in Figure 10.
As illustrated a five segment model was used to represent the fragment. The objective of the calculation was to determine the stability characteristics of this fragment and to determine if it could be spin stabilized. The actual output from the SFFSTAB program is given as the sample problem in Appendix C. For the solid fragment shape shown in Figure 10, the calculated minimum spin rate for stabilization was 66280 RPM. Based on conservation of angular momentum this corresponds to an initial SFF charge spin rate of 3860 RPM.

SFFSTAB is a useful tool for conducting parametric studies for different fragment shapes. The dependence of stability on the exterior shape is illustrated in Figure 11, where the fragment spin rate required for dynamic stability as a function of the flare angle $\theta$ is shown for typical fragment shapes. The interior profile also has a significant effect on the dynamic stability. Some typical results obtained for fragments with similar exterior profiles but varying degrees of hollowness are shown in Figure 12. Notice that as the fragment shape is changed from hollow to completely solid the spin rate required for dynamic stability increases.

5.0 SUMMARY

In summary, an aerodynamic stability criterion which combined gyroscopic and dynamic stability has been presented. A technique for calculating the aerodynamic coefficients was used together with the stability criterion for calculating the stability of self-forging fragments. A computer program (SFFSTAB) was developed using this information and sample problems illustrating the effects of parameters such as interior and exterior fragment profiles have been presented. This report provides the complete documentation required to use the program SFFSTAB.
REFERENCES


Figure 2

RADIOGRAPHS OF UNSTABLE FRAGMENT

DELAY TIME (μs)
2755  740  375

TIP POSITION (m)
6.484  1.762  0.891

SFF CHARGE SPIN RATE 0 RPM
FRAGMENT VELOCITY 2366 m/s
Figure 3

TECHNIQUES FOR SELF-FORGING FRAGMENT STABILIZATION
Figure 4

AERODYNAMIC FORCES ON A BODY

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Figure 5

MAGNUS FORCE (Reference [4])

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Figure 7

DERIVATIVE OF THE NORMAL FORCE COEFFICIENT FOR SPHERICAL SEGMENTS (Reference [3])
Figure 8

DERIVATIVE OF THE NORMAL FORCE COEFFICIENT FOR CONE FRUSTUMS

(Reference [31])

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Figure 9

APPROXIMATION OF LINER GEOMETRY BY SEGMENTS
REQUIRED FRAGMENT SPIN RATE = 6940 (RAD/SEC) = 66280 (RPM)
REQUIRED CHARGE (SFF) SPIN RATE = 404 (RAD/SEC) = 3860 (RPM)

Figure 10
"SFFSTAB" RESULTS FOR EXPERIMENTALLY OBSERVED FRAGMENT
Figure 11

FRAGMENT SPIN RATE REQUIRED FOR DYNAMIC STABILITY VS FLARE ANGLE $\theta$
Figure 12

SPIN RATE REQUIRED FOR DYNAMIC STABILITY OF FRAGMENTS WITH DIFFERENT INTERIOR PROFILES
APPENDIX A - DATCOM METHOD
DATCOM METHOD FOR HYPERSONIC FLOW

The DATCOM Method [3] uses the results of Newtonian impact theory. Design charts and equations are presented in Reference 3, for determining the aerodynamic characteristics at hypersonic speeds of projectile shapes composed of one or more cone frustums with or without a spherical nose. The coefficients required for gyroscopic and dynamic stability equations are given in this Appendix. The relevant coefficients are:

i) $C_{N_{\alpha}}$: NORMAL-FORCE-CURVE SLOPE

ii) $C_{m_{\alpha}}$: PITCHING MOMENT CURVE SLOPE

iii) $C_D$: DRAG COEFFICIENT

iv) $C_{Nq}$: PITCHING DERIVATIVE

v) $C_{mq}$: PITCHING DERIVATIVE

vi) $C_{m_{\alpha}}$: BODY ACCELERATION DERIVATIVE

The information contained in this Appendix has been extracted from Reference 3.
i) $C_N\alpha$: NORMAL-FORCE-CURVE SLOPE

The normal-force-curve slope of a body composed of one or more cone frustums with or without a spherical nose, based on the body base area, is given by

$$\frac{dC_N}{d\alpha} = C_N\alpha = \sum_{n=1}^{m} (C_N\alpha)_{n} \left( \frac{d_n}{d_b} \right)^2$$ (A.1)

To apply this equation the body is divided into m segments, the first segment being either a spherical nose or a cone frustum, and each succeeding segment a cone frustum. The normal-force-curve slope of a spherical nose, based on area, is obtained from Figure A-1. The normal-force-curve slope of a cone frustum, based on the base area of the specific segment, is obtained from Figure A-2. (Note that a cylinder is considered a cone frustum with $\theta = 0$ and $a/d = 1.0$, and that $C_N\alpha = 0$ by Newtonian impact theory.) The ratio $(d_n/d_b)^2$ refers the normal-force-curve slope to the base area of the configuration.
Figure A-1

NORMAL-FORCE-CURVE SLOPE FOR SPHERICAL SEGMENTS

(Reproduced from Figure 4.2.1.1-23 of Reference [3])
Figure A-2

NORMAL-FORCE-CURVE SLOPE FOR CONE FRUSTUMS

(Reproduced from Figure 4.2.1.1-26 of Reference [3])
ii) $C_M : $ PITCHING MOMENT CURVE SLOPE

The procedure for computing the total pitching-moment-curve slope for a complex body is given in the following steps. The moment values for each individual segment of a multiple cone-frustum body with or without a spherical nose are referred to a moment axis at the front face of that particular segment, and are based on the product of the base area and base diameter of that particular segment.

Step 1: Compute $C_m'$ for each body segment about its own front face, using Figures A-3 and A-4.

Step 2: Transfer the individual moment slopes to a common reference axis by applying the following moment transfer equation to each body segment.

$$C_m = C_m' + \frac{n}{d} C_N \text{ (per radian)} \quad (A.2)$$

where

- $C_N$ is the normal-force-curve slope of the individual cone-frustum or spherical nose segment, based on its own base area, from Figures A-2 and A-1, respectively.
- $d$ is the base diameter of the individual cone-frustum or spherical nose segment.
- $n$ is the distance from the front face of a given segment to the desired moment reference axis of the configuration, positive aft.
$C_m$ is the pitching-moment-curve slope of an individual segment from Figure A-3 for cone frustums and from Figure A-4 for spherical nose segments. $C_m$ is based on the product of the base area and the base diameter of the individual segment.

$C_m$ is the pitching-moment-curve slope of an individual segment based on the product of the base area and base diameter of the individual segment and referred to a common reference axis.

Step 3: The transferred pitching-moment-curve slopes of the individual body segments are then converted to a common basis by

$$C_m = \sum_{n=1}^{m} \left( C_m \right)_n \left( \frac{d_n}{d_b} \right)^3 \text{ (per radian)} \quad \text{(A.3)}$$

where the subscript $n$ refers to an individual segment of $m$ segments, and $C_m$ is referred to a common reference axis and is based on the product of the area and diameter of the base of the configuration $S_b d_b$. 
Figure A-3

$C_{m_\alpha}$ FOR CONE FRUSTUMS

(Reproduced from Figure 4.2.2.1-25a of Reference [3])
Figure A-4

$C_{m_0}'$ FOR SPHERICAL SEGMENTS

(Reproduced from Figure 4.2.2.1-25b of Reference [3])
iii) \( C_D \): DRAG COEFFICIENT

The zero-lift drag (based on the maximum frontal area) of a body composed of one or more cone frustums with or without a spherical nose is estimated by adding the pressure-drag coefficient of each segment to the body skin-friction drag coefficient.

\[
C_D = C_D + \sum_{n=1}^{m} C_D \frac{d_n}{d_{max}}^2
\]  

(A.4)

The procedure to be followed in evaluating this equation is as follows:

Step 1: Divide the body into \( m \) segments, the first segment being either a spherical nose or a cone frustum, and each succeeding segment a cone frustum. The pressure-drag coefficient for a spherical nose or cone frustum is obtained from Figures A-5 and A-6, respectively. The pressure-drag coefficients for the remainder of the segments are obtained from Figure A-7. The pressure-drag coefficients are based on the base area of the specific segment. The ratio \((d_n/d_{max})^2\) refers the pressure-drag coefficients to the maximum body frontal area.

Step 2: Obtain the body skin-friction drag coefficient by

\[
C_D = 1.02 C_{finc} \frac{S_S}{C_f S_B}
\]  

(A.5)
where

$$C_{f_{inc}}$$ is the incompressible ($M = 0$) turbulent, flat-plate skin-friction coefficient, including roughness effects, as a function of Reynolds number based on the total length of the body $$\ell_B$$. This value is obtained from Figure A-8.

$$x$$ is the reference length in inches.

$$k$$ is the surface-roughness height in inches; it depends upon surface finish. Representative values for this parameter can be obtained from Table A-1.

The ratio $$x/k$$ is computed and Figure A-9 is used to obtain the cutoff Reynolds number. If the cutoff Reynolds number is greater than the computed Reynolds number for the specific configuration, the value of $$C_f$$ is obtained from Figure A-8 at the computed Reynolds number. If the cutoff Reynolds number is less than the computed Reynolds number, the value of $$C_f$$ is obtained from Figure A-8 at the cutoff Reynolds number.

$$\frac{C_{f_C}}{C_f}$$ is the ratio of compressible to incompressible skin-friction coefficient obtained from Figure A-10.
\[ \frac{S_S}{S_B} \] is the ratio of the body wetted area to maximum body frontal area.

If this method is applied at Mach numbers low enough so that the base drag is significant, the base drag should be added to the results obtained. Unfortunately, the only base-drag coefficient results available which are compatible with the Newtonian-theory results (restricted to bodies with forward facing slopes or cylinders, in which case the Newtonian results are equal to zero) are those for cylindrical afterbodies. The pressure-drag coefficient for cylindrical afterbodies is presented in Figure A-11 for \( M < 10 \).
Figure A-5

NEWTONIAN DRAG COEFFICIENT FOR SPHERICAL SEGMENTS
REFERRED TO BASE AREA OF SEGMENT
(Reproduced from Figure 4.2.3.1-66 of Reference [3])
Figure A-6

DRAG COEFFICIENT FOR A CONE FRUSTUM CALCULATED FROM NEWTONIAN THEORY. THE GEOMETRIC PARAMETERS ARE RELATED BY THE EQUATION \( \tan \theta = \frac{1 - \lambda}{2(\ell/d)} \)

(Reproduced from Figure 3 of Reference [6])
Figure A-7

DRAG-FORCE COEFFICIENT DUE ONLY TO THE INCLINED SIDES OF A CONE FRUSTUM CALCULATED BY NEWTONIAN THEORY. 

$C_D$ IS BASED ON BODY BASE AREA $S_b$. 
TURBULENT MEAN SKIN-FRICTION COEFFICIENT ON AN INSULATED FLAT PLATE

(Reproduced from Figure 4.1.5.1-26 of Reference [3])
Table A-1

REPRESENTATIVE VALUES OF SURFACE-ROUGHNESS HEIGHT
(Reproduced from Table 4.1.5.1-A of Reference [3])

<table>
<thead>
<tr>
<th>TYPE OF SURFACE</th>
<th>EQUIVALENT SAND ROUGHNESS k (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamically Smooth</td>
<td>0</td>
</tr>
<tr>
<td>Polished Metal or Wood</td>
<td>0.02 - 0.08 x 10^{-3}</td>
</tr>
<tr>
<td>Natural Sheet Metal</td>
<td>0.16 x 10^{-3}</td>
</tr>
<tr>
<td>Smooth Matte Paint, Carefully Applied</td>
<td>0.25 x 10^{-3}</td>
</tr>
<tr>
<td>Standard Camouflage Paint, Average Application</td>
<td>0.40 x 10^{-3}</td>
</tr>
<tr>
<td>Camouflage Paint, Mass-Production Spray</td>
<td>1.20 x 10^{-3}</td>
</tr>
<tr>
<td>Dip-Galvanized Metal Surfaces</td>
<td>6 x 10^{-3}</td>
</tr>
<tr>
<td>Natural Surface of Cast Iron</td>
<td>10 x 10^{-3}</td>
</tr>
</tbody>
</table>
Figure A.9

CUTOFF REYNOLDS NUMBER

(Reproduced from Figure 4.1.5.1-27 of Reference [3])

UNCLASSIFIED
Figure A-10

COMPRESSIBILITY EFFECT ON TURBULENT SKIN FRICTION
(ZERO HEAT TRANSFER)
(Adapted from Figure 4.2.3.1-68 of Reference [3])
Figure A-11

BASE DRAG COEFFICIENT FOR BODIES OF REVOLUTION WITH NO BOATTAIL

(Adapted from Figure 4.2.3.1-60 of Reference [3])
iv) $C_N^q$: PITCHING DERIVATIVE

Charts based on simple Newtonian theory, are presented for determining $C_N^q$ of spherical segments and cone frustums at small angles of attack.

The coefficients of these charts are referred to the body base area and base diameter and to a moment center at the forward face of the segment. By proper use of the data presented, the total $C_N^q$ may be determined for bodies composed of multiple cone frustums with or without spherically blunted noses.

The Newtonian value of the derivative $C_N^q$ for a complex body is obtained as follows:

Step 1: Compute $C_N^q$ for each body segment about its front face using Figures A-12 and A-13.

Step 2: Transfer the individual derivatives $C_N^q$ to a common reference axis by applying the following transfer equation to each body segment

$$C_N^q = C_N^q - 2 \frac{\sum_{n} (-) C_N^q d^a}{d^a}$$

(A.6)

where

$C_N^q$ is the normal-force-curve slope for each segment based on individual base areas.
\( C_{Nq} \) is the pitching derivative for each segment based on individual base areas and base diameters and referred to a moment center at the forward face of the segment, from Figures A-12 and A-13.

\( n \) is the distance from the face of a given frustum to the desired moment reference axis of the configuration, positive aft.

\( d \) is the base diameter of a given frustum.

Step 3: The transferred derivatives of the individual body segments are converted to a common reference area and diameter and added. The total derivative is given by

\[
C_{Nq} = \sum_{n=1}^{m} \left( C_{Nq} \right)_n \left( \frac{d_n}{d_b} \right)^3
\]  

(A.7)
Figure A-12

PITCHING DERIVATIVE $C'_{Nq}$ FOR CONE FRUSTUMS

(Reproduced from Figure 7.2.1.1 9a of Reference [3])
Figure A-13

PITCHING DERIVATIVE $C'_{Nq}$ FOR SPHERICAL SEGMENTS

(Reproduced from Figure 7.2.1.1-9b of Reference [3])
v) $C_m$: PITCHING DERIVATIVE

Charts based on simple Newtonian theory are presented for determining $C_m$ of spherical segments and cone frustums at small angles of attack. The coefficients of these charts are referred to the base area and the square of the base diameter and to a moment center at the forward face of the segment. By proper use of the data presented, the total $C_m$ may be determined for bodies composed of multiple cone frustums with or without spherically blunted noses.

The Newtonian value of the stability derivative $C_m$ for a complex body is obtained as follows:

Step 1: Compute $C_m'$ for each body segment about its own front face using Figures A-14 and A-16 if the body has a spherically blunted nose, and Figures A-14 and A-15 if the body nose is a cone frustum.

Step 2: Transfer the individual derivatives $C_m'$ to a common moment center by applying the following axis transfer equation to each body segment:

$$C_m = C_m' - 2 - C_m' + C_N - 2\left(\frac{n}{d}\right)C_N$$

where

$C_N$ is the normal-force-curve slope for each segment based on individual base areas.
$C'_{Nq}$ is the pitching derivative for each segment based on individual base areas and base diameters and referred to a moment center at the forward face of the segment.

$C'_{m_{a}}$ is the pitching-moment-curve slope for each segment based on individual base areas and base diameters and referred to a moment center at the forward face of the segment.

$C'_{m_{q}}$ is the pitching derivative for each body segment based on individual base areas and the square of base diameters and referred to a moment center at the forward face of the segment. If a complex body consists of combinations of cone frustums, the derivative for the first frustum must be obtained from Figure A-15, which accounts for the front face being exposed to the air stream. If the body has a spherically blunted nose, the derivative of the nose is obtained from Figure A-16. For subsequent frustums the derivatives are obtained from Figure A-14.

Step 3: The transferred derivatives of the individual body segments are added after being converted to a common reference area and squared diameter. The total derivative of the individual body segments is given by

$$C_{m_{q}} = \sum_{n=1}^{m} \left( C'_{m_{q}} \right)_{n} \left( \frac{d_{n}}{d_{b}} \right)^{4}$$

(A.9)
Figure A-14

PITCHING DERIVATIVE $C_{m_q}'$ DUE TO INCLINED SIDES OF CONE FRUSTUMS

(Reproduced from Figure 7.2.1.2-12 of Reference [3])

UNCLASSIFIED
NEWTONIAN THEORY

\[ C_{m,q}' = \frac{a}{d} \]

\[ \lambda = \frac{a}{d} \]

\[ C_{m,q}' \text{ BASED ON BASE AREA AND THE SQUARE OF THE BASE DIAMETER} \]

Figure A.15

PITCHING DERIVATIVE $C_{m,q}'$ FOR CONE FRUSTUMS

(Reproduced from Figure 7.2.1.2-13a of Reference [3])
Figure A-16

PITCHING DERIVATIVE $C_{mq}'$ FOR SPHERICAL SEGMENTS

(Reproduced from Figure 7.2.1.2-13b of Reference [3])
vi) $C_{m_{a}}$: BODY ACCELERATION DERIVATIVE

The body contribution to the derivative $C_{m_{a}}$ in the hypersonic speed range is equal to zero when determined by the Newtonian Impact Theory.
APPENDIX B - SEGMENT PROPERTIES
HOLLOW SPHERICAL SEGMENT

\[
\begin{align*}
    r &= \text{INNER RADIUS OF SPHERICAL SEGMENT} \\
    R &= \text{OUTER RADIUS OF SPHERICAL SEGMENT} \\
    h &= \text{HEIGHT OF SPHERICAL SEGMENT} \\
    \bar{y} &= \text{CENTROID OF SPHERICAL SEGMENT}
\end{align*}
\]
PROPERTIES OF A SPHERICAL SEGMENT

Volume

\[ V = \pi \left[ R^2 r^2 + hR^2 - hr^2 - \frac{R^3}{3} - \frac{2r^3}{3} \right] \]

Centroid

\[ \bar{y} = \frac{3 \left( (R^2 - r^2)(4hR - 2h^2) - (R^2 - r^2)r^2 \right)}{4 \left[ 3h (R^2 - r^2) + 3Rr^2 - R^3 - 2r^3 \right]} \]

Axial Moment of Inertia (Taken about Y-axis)

\[ M \left[ \frac{8}{15} (R^5 - r^5) + (R-h)(r^n - R^n) + \frac{2}{3} (R-h)^3 (R^2 - r^2) \right] \]

\[ I_A = \frac{R^3}{2} \frac{2r^3}{3} \]

Where \( M = \text{Mass} = \text{Density} \times \text{Volume} \)
TRANSVERSE MOMENT OF INERTIA
(Taken Parallel to X-axis and Through the Centroid)

\[ I_T = \frac{M}{R^2 + hR^2 - \frac{rn^2}{3} - \frac{r^3}{3}} \]

\[ \times \frac{1}{4} (R^4 - r^4)(r-R+h) + (R^2 - r^2) \frac{1}{6} (r^3 - (r-h)^3) \]

\[ + \bar{y}^2 (r-R+h) - \bar{y} (r^2 - (R-h)^2) \]

\[ + \frac{R^4}{4} (R-r) + R^2 \frac{1}{6} (R^3 - r^3) + \bar{y}^2 (R-r) - \bar{y} (R^2 - r^2) \]

\[ - \frac{3}{20} (R^5 - r^5) + \bar{y} (R^4 - r^4) - \bar{y}^2 (R^3 - r^3) \]
HOLLOW TRUNCATED CONE

\[ r_1 = \text{INNER RADIUS AT SMALL END OF TRUNCATED CONE} \]
\[ r_2 = \text{OUTER RADIUS AT SMALL END OF TRUNCATED CONE} \]
\[ R_1 = \text{INNER RADIUS AT LARGE END OF TRUNCATED CONE} \]
\[ R_2 = \text{OUTER RADIUS AT LARGE END OF TRUNCATED CONE} \]
\[ h = \text{SEGMENT HEIGHT} \]
\[ \bar{y} = \text{CENTROID} \]
PROPERTIES OF A HOLLOW TRUNCATED CONE

Volume

\[ V = \frac{\pi h}{3} \left( R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1 \right) \]

Centroid

\[ \bar{y} = \frac{h}{4} \frac{\left( R_2^2 - R_1^2 + 3r_2^2 - 3r_1^2 + 2R_2 r_2 - 2R_1 r_1 \right)}{\left( R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1 \right)} \]

Axial Moment of Inertia (Taken about Y-axis)

\[ I_A = \frac{3M}{10} \left( R_2^4 + R_2^3 r_2 + R_2^2 r_2^2 + R_2 r_2^3 + r_2^4 \right) \]

\[ - \left( R_1^4 + R_1^3 r_1 + R_1^2 r_1^2 + R_1 r_1^3 + r_1^4 \right) \]

\[ / \left( R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1 \right) \]

Where \( M = \text{Mass} = \text{Density} \times \text{Volume} \)
TRANSVERSE MOMENT OF INERTIA
(Taken Parallel to X-axis and Through the Centroid)

\[ I_T = \frac{3M}{4} \left[ R_2^4 - 2R_2^3 (R_2 - r_2) + 2R_2^2 (R_2 - r_2)^2 - R_2 (R_2 - r_2)^3 + \frac{(R_2 - r_2)^4}{5} \right] \]

\[ - R_1^4 + 2R_1^3 (R_1 - r_1) - 2R_1^2 (R_1 - r_1)^2 + R_1 (R_1 - r_1)^3 - \frac{(R_1 - r_1)^4}{5} \]

\[ + 3M \left[ h^2 \left\{ \frac{R_2^2}{3} + \frac{(R_2 - r_2)^2}{5} - R_2 \frac{(R_2 - r_2)}{2} - \frac{R_1^2}{3} - \frac{(R_1 - r_1)^2}{5} + R_1 \frac{(R_1 - r_1)}{2} \right\} \right] \]

\[ + \bar{y}^2 \left\{ R_2^2 + \frac{(R_2 - r_2)^2}{3} - R_2 (R_2 - r_2) - R_1^2 - \frac{(R_1 - r_1)^2}{3} + R_1 (R_1 - r_1) \right\} \]

\[ + \bar{y} h \left\{ -R_2^2 - \frac{(R_2 - r_2)^2}{2} + 4R_2 \frac{(R_2 - r_2)}{3} + R_1^2 + \frac{(R_1 - r_1)^2}{2} - 4R_1 \frac{(R_1 - r_1)}{3} \right\} \]

\[ / \left[ R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1 \right] \]
APPENDIX C - FLOW CHART AND FORTRAN LISTING OF SFFSTAB
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SFFSTAB: FLOWCHART

READ AND WRITE INPUT DATA

CALCULATE PROPERTIES FOR EACH SEGMENT

- COEFF1 \( C_{N_a} \) NORMAL FORCE CURVE SLOPE FOR SPHERICAL SEGMENTS
- COEFF2 \( C_{N_a} \) NORMAL FORCE CURVE SLOPE FOR CONE FRUSTUMS
- COEFF3 \( \alpha \) PITCHING MOMENT CURVE SLOPE FOR CONE FRUSTUMS
- COEFF4 \( \alpha \) PITCHING MOMENT CURVE SLOPE FOR SPHERICAL SEGMENTS
- COEFF5 \( C_{m_a} \) COMPRESSIBILITY EFFECT ON TURBULENT SKIN FRICTION
- COEFF6 \( \frac{C_{m_a}}{C_{m_a}} \) CUTOFF REYNOLDS NUMBER
- COEFF7 \( C_{m_a} \) TURBULENT MEAN SKIN FRICTION COEFFICIENT ON AN INSULATED FLAT PLATE
- COEFF8 \( C_{m_a} \) BASE DRAG COEFFICIENT WITH NO BUATTAIL

SUBROUTINES TO GENERATE CUBIC SPLINE COEFFICIENTS FOR DATCOM GRAPHS

FIGURE C-1 SFFSTAB FLOW CHART
IHSS INERTIA PROPERTIES FOR A HOLLOW SPHERICAL SEGMENT
F421123 CALCULATE $C_{N_{\alpha}}$ FOR A GIVEN NOSE BLUNTNESS
F422125B CALCULATE $C_{m_{\alpha}}$ FOR A GIVEN NOSE BLUNTNESS

IHTC INERTIA PROPERTIES FOR A HOLLOW TRUNCATED CONE
F421126 CALCULATE $C_{N_{\alpha}}$ FOR A GIVEN SEMICONE ANGLE
F422125A CALCULATE $C_{m_{\alpha}}$ FOR A GIVEN SEMICONE ANGLE

CALCULATE DISTANCE FROM BASE OF THE BODY TO THE CENTROID OF THE SEGMENT
CALCULATE TOTAL VOLUME AND MASS OF THE BODY
CALCULATE THE CENTER OF GRAVITY OF THE BODY
CALCULATE AXIAL (POLAR) MOMENT OF INERTIA

FIGURE C-2 SFFSTAB FLOWCHART CONT'U
UNCLASSIFIED

2

CALCULATE TRANSVERSE MOMENT OF INERTIA

CALCULATE $C_{N_{\alpha}}$ FOR THE BODY

CALCULATE $C_{m_{\alpha}}$ FOR THE BODY

CALCULATE THE CENTER OF PRESSURE

GYROSCOPIC STABILITY: CALCULATE STABILITY FACTOR OR SPIN RATE

CALCULATE $C_{D_0}$ ZERO LIFT DRAG COEFFICIENT

CALCULATE $C_{D_p}$ NEWTONIAN DRAG COEFFICIENT FOR THE FIRST SEGMENT

F423166 $C_{D_p}$ FOR SPHERICAL SEGMENT

F423167T $C_{D_p}$ FOR TRUNCATED CONICAL SEGMENT

F423167S CALCULATE $C_{D_p}$ FOR THE REMAINING SEGMENTS

3

FIGURE C-3 SFFSTAB FLOW CHART CONT'D
3

F415127 CALCULATE CUTOFF REYNOLDS NUMBER

F415126 F423168 CALCULATE REYNOLDS NUMBER

CALCULATE FRONTAL AND WETTED AREAS

CALCULATED $C_D$ BODY SKIN FRICTION DRAG COEFFICIENT

CALCULATE $C_N$ PITCHING DERIVATIVE FOR A SEGMENT

F72119B $C_{n_q}$ FOR SPHERICAL SEGMENT

F72119A $C_{n_q}$ FOR TRUNCATED CONICAL SEGMENT

4

FIGURE C-4 SFFSTAB FLOWCHART CONT'D
CALCULATE $C'_m$ FOR THE FIRST SEGMENT

F721213B $C'_m$ FOR SPHERICAL SEGMENT

F721213A $C'_m$ FOR TRUNCATED CONICAL SEGMENT

F721212 CALCULATE $C'_m$ FOR THE REMAINING SEGMENTS

CALCULATE $C_m$ FOR THE BODY

MAGNUS CALCULATE $C'_m$, MAGNUS MOMENT COEFFICIENT

CALCULATE $C_m$, ACCELERATION DERIVATIVE

CALCULATE $s_d$, DYNAMIC STABILITY FACTOR

FILL CALCULATE STABILITY OF THE BODY

FIGURE C-5 SF/STAB FLOW CHART CONT'D
SERVICE SUBROUTINES

SPLINE GENERATES CUBIC SPLINE COEFFICIENTS

SEVAL EVALUATES CUBIC SPLINE FOR A GIVEN ABSCISSA

FIGURE C-6 SFFSTAB FLOWCHART CONT'D
PROGRAM TO CALCULATE GYROSCOPIC AND DYNAMIC STABILITY

DIMENSION ISEG(100),R2(100),R1(100),H(100),RR2(100),RR1(100)
DIMENSION V(100),AMASS(100),YB(100),AI(100),TI(100),CMAP(100)
DIMENSION CMAP(100),THETA(100),AD(100),DBCS(100),DCBCS(100)
DIMENSION DB(100),DBFS(100),DBFSRA(100),CMA(100),CMAL(100)
DIMENSION CDP(100),AREA(100),CNQP(100),CMQP(100),CMQ(100)
COMMON/XY1/X1(11),Y1(11)
COMMON/XY2/X2(11,10),Y2(11,10)
COMMON/XY3/X3(11,10),Y3(11,10)
COMMON/XY4/X4(13),Y4(13)
COMMON/XY5/X5(8),Y5(8)
COMMON/XY6/X6(5),Y6(5)
COMMON/XY7/X7(26),Y7(26)
COMMON/XY8/X8(8),Y8(8)
COMMON/XYB/XXB(6),YYB(6)
COMMON/BCD1/B1(11),C1(11),D1(11)
COMMON/BCD2/B2(11,10),C2(11,10),D2(11,10)
COMMON/BCD3/B3(11,10),C3(11,10),D3(11,10)
COMMON/BCD4/B4(13),C4(13),D4(13)
COMMON/BCD5/B5(8),C5(8),D5(8)
COMMON/BCD6/B6(5),C6(5),D6(5)
COMMON/BCD7/B7(26),C7(26),D7(26)
COMMON/BCD8/B8(8),C8(8),D8(8)
COMMON/BCD3B/B3B(6),C3B(6),D3B(6)
CHARACTER*6 TITLE(15)

ITYPE = 0 - SPHERICAL SEGMENT AND TRUNCATED CONES ARE USED
ITYPE = 1 - ONLY TRUNCATED CONES ARE USED
DEN = DENSITY OF MATERIAL (MASS/VOLUME) (LB SEC**2/IN**4)
NSEG = NUMBER OF SEGMENTS
DBCS = DISTANCE FROM BASE OF BODY TO CENTROID OF SEGMENT
TVOL = TOTAL VOLUME OF BODY (IN**3)
TMASS = TOTAL MASS OF BODY (LB SEC**2/IN)
CGOB = CENTER OF GRAVITY OF BODY (RELATIVE TO BASE)
AIB = AXIAL (POLAR) MOMENT OF INERTIA OF THE BODY (LB SEC**2 IN)
TIB = TRANSVERSE MOMENT OF INERTIA OF THE BODY (LB SEC**2 IN)
DCBCS = DISTANCE FROM CENTROID OF BODY TO CENTROID OF SEGMENT
DB = BASE DIAMETER OF THE SEGMENT
CNAT = TOTAL CNA FOR THE BODY
CMAT = TOTAL CMA FOR THE BODY (BASED ON AREA AND BASE DIAMETER)
CMATL = TOTAL CMA FOR THE BODY (BASED ON AREA AND BODY LENGTH)
RA = DISTANCE FROM MOMENT REFERENCE AXIS TO BASE OF BODY
(IF RA = 0.0 THE C OF G OF THE BODY IS USED)
DBFS = DISTANCE FROM BASE OF BODY TO FRONT FACE OF SEGMENT
DBFSRA = DISTANCE FROM FRONT FACE OF SEGMENT TO MOMENT REFERENCE AXIS
CMA = CMA FOR A SEGMENT, REFERRED TO A COMMON REFERENCE AXIS
(BASED ON AREA AND BASE DIAMETER)
CMAL = CMA FOR A SEGMENT, REFERRED TO A COMMON REFERENCE AXIS
(BASED ON AREA AND SEGMENT LENGTH)
BL = LENGTH OF BODY
C XCP = CENTER OF PRESSURE AS A FRACTION OF BODY LENGTH
C XM = MOMENT CENTER LOCATION AS A FUNCTION OF BODY LENGTH
C RHO = AIR DENSITY(LB SEC**2/IN**4)
C W = SPIN RATE (RAD/SEC)
C VEL = PROJECTILE VELOCITY(IN/SEC)
C ISG = 1 - CALCULATE W
C 0 - CALCULATE SG
C SG = GYROSCOPIC STABILITY FACTOR
C CDP = NEWTONIAN DRAG COEFFICIENT
C BLUNT = NOSE BLUNTNESS FOR A SPHERICAL SEGMENT
C ESR = EQUIVALENT SAND ROUGHNESS(IN)
C RE = REYNOLDS NUMBER (BASED ON L )
C RES = SAME AS RE
C CRE = CUTOFF REYNOLDS NUMBER
C AR = ADMISSIBLE ROUGHNESS
C U = ABSOLUTE VISCOSITY(LB SEC/IN**2)
C CF = INCOMPRESSIBLE FLAT PLATE SKIN FRICTION COEFFICIENT
C CFCCF = RATIO OF COMPRESSIBLE TO INCOMPRESSIBLE SKIN FRICTION
C CD = BODY SKIN FRICTION DRAG COEFFICIENT
C CDD = ZERO LIFT DRAG COEFFICIENT
C CDB = BASE DRAG COEFFICIENT
C AREA = SURFACE AREA OF A SEGMENT
C CNQP = PITCHING DERIVATIVE FOR A SEGMENT
C CMAP = PITCHING MOMENT CURVE SLOPE FOR A SEGMENT
C CMAP = NORMAL FORCE CURVE SLOPE FOR A SEGMENT
C CMQP = PITCHING DERIVATIVE FOR SEGMENT
C CMQP = PITCHING DERIVATIVE TRANSFERRED TO A COMMON AXIS
C CMAP = DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT
C CMD = ACCELERATION DERIVATIVE
C SD = DYNAMIC STABILITY FACTOR
C AKB = DIMENSIONLESS AXIAL RADIUS OF GYRATION
C TKB = DIMENSIONLESS TRANSVERSE RADIUS OF GYRATION
C DMCP = DISTANCE FROM MAGNUS CENTER OF PRESSURE TO CENTER OF GRAVITY
C ISPIN = 1 - READ LINER DATA
C TAM = TOTAL ANGULAR MOMENTUM (LB SEC IN)
C WL = SPIN RATE OF LINER (RAD/SEC)
C RPM = SPIN RATE OF LINER (RPM)
C NLS = NUMBER OF LINER SEGMENTS
C TLS = THICKNESS OF LINER SEGMENT
C HLS = HEIGHT OF LINER SEGMENT
C RCS = RADIUS TO CENTROID OF CROSS-SECTIONAL AREA OF LINER SEGMENT
C AMASSL = MASS OF LINER SEGMENT
C TMASSL = TOTAL MASS OF THE LINER
C
C************************************************************
C
C READ AND WRITE INPUT DATA
C
READ(5,900)(TITLE(I),I=1,15)
900 FORMAT(13A6,2A1)
WRITE(6,801)(TITLE(I),I=1,15)

801 FORMAT(1H ,///,5X,13A6,2Al,///)

READ(5,10)DEN

10 FORMAT(F10.5)

READ(5,15)IYPE,NSEG

15 FORMAT(2I5)

IF(IYPE.EQ.1)GO TO 20

READ(5,25)ISEG(1),R2(1),R1(1),H(1)

25 FORMAT(I5,5X,3F10.5)

DO 30 I=2,NSEG

READ(5,35)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)

35 FORMAT(I5,5X,5F10.5)

30 CONTINUE

GO TO 40

20 DO 45 I=1,NSEG

READ(5,35)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)

45 CONTINUE

40 WRITE(6,46)

46 FORMAT(1H1,10X

GYROSCOPIC STABILITY DATA *****',//)

WRITE(6,50)DEN,IYPE,NSEG

50 FORMAT(1H ,5X,'DENSITY = ',F15.8,5X,'IYPE = ',I5,5X,

1 'NUMBER OF SEGMENTS = ',I5)

WRITE(6,55)

55 FORMAT(1H ,7X,'ISEG',9X,'RR2',12X,'RR1',13X,'R2',13X,

1 'R1',13X,'H',//)

IF(IYPE.EQ.1)GO TO 60

WRITE(6,65)ISEG(1),R2(1),R1(1),H(1)

65 FORMAT(1H ,5X,I5,30X,3(5X,F10.5))

DO 70 I=2,NSEG

WRITE(6,75)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)

70 CONTINUE

GO TO 80

60 DO 90 I=1,NSEG

WRITE(6,75)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)

90 CONTINUE

80 READ(5,210)RA

210 FORMAT(F10.5)

READ(5,295)ISG

295 FORMAT(I5)

WRITE(6,400)RA,ISG

400 FORMAT(1H ,5X,'REFERENCE AXIS = ',F10.5,5X,'ISG = ',I5)

IF(ISG.EQ.1)GO TO 300

READ(5,305)W,RHO,VEL

305 FORMAT(3F10.5)

WRITE(6,405)W,RHO,VEL

405 FORMAT(1H ,5X,'W = ',F20.10,5X,'RHO = ',F20.15,5X,'VELOCITY = ',

1 F15.5)

GO TO 420

300 READ(5,305)SG,RHO,VEL

WRITE(6,410)SG,RHO,VEL

410 FORMAT(1H ,5X,'SG = ',F10.5,5X,'RHO = ',F20.15,5X,'VELOCITY = ',

1 F15.5)
C CALCULATE PROPERTIES FOR EACH SEGMENT

420 CALL COEFF1
   CALL COEFF2
   CALL COEFF3
   CALL COEFF4
   CALL COEFF5
   CALL COEFF6
   CALL COEFF7
   CALL COEFF8
   DO 100 I=1,NSEG
      IF(I.GT.1)GO TO 105
      IF(ITYPE.EQ.1)GO TO 105
      CALL IHSS(ISEG(I),R2(I),R1(I),H(I),DEN,V(I),AMASS(I),YB(I),
           1 B,AI(I),TI(I))
      YB(1)=B
      BLUNT=H(I)/R2(I)
      CALL F421123(BLUNT,CNAP(I))
      CALL F422125B(BLUNT,CMAP(I))
      WRITE(6,110)BLUNT,CNAP(1),CMAP(I)
   110 FORMAT(1H,5X,'NOSE BLUNTNESS=',F10.5,5X,'CNAP=',F10.5,
           1 5X,'CMAP=',F10.5,1//)
   GO TO 100
   105 CALL IHTC(ISEG(I),RR2(I),RRI(I),R2(I),R1(I),H(I),DEN,V(I),
       1 AMASS(I),YB(I),AI(I),TI(I))
      AD(I)=R2(I)/RR2(I)
      THETA(I)=ATAN((R2(I)-R2(I))/H(I))/3.14159265*180.
      CALL F421126(THETA(I),CNAP(I),AD(I))
      CALL F422125A(THETA(I),CMAP(I),AD(I))
      WRITE(6,115)THETA(I),AD(I),CNAP(I),CMAP(I)
   115 FORMAT(1H,5X,'THETA=',F10.5,5X,'A/O=',F10.5,5X,
       1 'CNAP=',F10.5,5X,'CMAP=',F10.5,1//)
   100 CONTINUE

C CALCULATE DISTANCE FROM BASE OF BODY TO CENTROID OF SEGMENT

      SUM1=H(NSEG)
      NSEG1=NSEG-1
      DBCS(NSEG)=YB(NSEG)
      DO 120 I=1,NSEG1
         DBCS(NSEG-I)=YB(NSEG-I)+SUM1
         SUM1=SUM1+H(NSEG-I)
      120 CONTINUE

C CALCULATE THE TOTAL VOLUME AND TOTAL MASS OF BODY

      TVOL=0.0
      TMASS=0.0
      DO 125 I=1,NSEG
         TVOL=TVOL+V(I)
         TMASS=TMASS+AMASS(I)
      125 CONTINUE

C CALCULATE CENTER OF GRAVITY OF BODY (RELATIVE TO BASE)
SUM2=0.0
DO 130 I=1,NSEG
   SUM2=SUM2+DBCS(I)*V(I)
130 CONTINUE
CGOB=SUM2/TVOL

C CALCULATE AXIAL (POLAR) MOMENT OF INERTIA
AIB=0.0
DO 135 I=1,NSEG
   AIB=AIB+AI(I)
135 CONTINUE

C CALCULATE DISTANCE FROM CG OF BODY CG OF SEGMENT
DO 140 I=1,NSEG
   DCBCS(I)=ABS(DBCS(I)-CGOB)
140 CONTINUE

C CALCULATE TRANSVERSE MOMENT OF INERTIA USING PARALLEL AXIS THEOREM
TIB=0.0
DO 145 I=1,NSEG
   TIB=TIB+TI(I)+AMASS(I)*DCBCS(I)**2.
145 CONTINUE

C CALCULATE BASE DIAMETER OF EACH SEGMENT
DO 195 I=1,NSEG
   IF(I.GT.1)GO TO 190
   IF(ITYPE.EQ.1)GO TO 190
   DB(1)=2.*(H(1)*(2*R2(I)-H(1)))**.5
   GO TO 195
190 DB(I)=2.*RR2(I)
195 CONTINUE
WRITE(6,150)
150 FORMAT(1H6X,'ISEG',8X,'DBCS',11X,'DCBCS',12X,'DB')
DO 155 I=1,NSEG
   WRITE(6,160)ISEG(I),DBCS(I),DCBCS(I),DB(I)
160 FORMAT(1H5X,'ISEG',12X,'DBCS',12X,'DCBCS',12X,'DB')
155 CONTINUE
WRITE(6,165)TVOL
165 FORMAT(1H5X,'TOTAL VOLUME OF BODY = ',F10.5)
WRITE(6,170)TMASS
170 FORMAT(1H5X,'TOTAL MASS OF BODY = ',F10.5)
WRITE(6,175)CGOB
175 FORMAT(1H5X,'CENTER OF GRAVITY OF BODY RELATIVE TO BASE = ',F10.5)
WRITE(6,180)AIB
180 FORMAT(1H5X,'AXIAL MOMENT OF INERTIA OF BODY = ',F10.5)
WRITE(6,185)TIB
185 FORMAT(1H5X,'TRANSVERSE MOMENT OF INERTIA OF BODY = ',F10.5)
C CALCULATE CNA FOR THE BODY
C
CNA=0.0
DO 200 I=1,NSEG
CNA=CNA+CNAP(I)*(DB(I)/DB(NSEG))**2.
200 CONTINUE
WRITE(6,205)CNAT
205 FORMAT(1H1,5X,'CNA FOR THE BODY =',F10.5)
C
C CALCULATE DISTANCE FROM BASE OF BODY TO FRONT FACE OF SEGMENT
C
SUM3=0.0
DO 215 I=1,NSEG
DBFS(NSEG+1-I )=SUM3+H(NSEG+1-I)
SUM3=SUM3+H(NSEG+1-I)
215 CONTINUE
C
C CALCULATE DISTANCE FROM SEGMENT FRONT FACE TO MOMENT REFERENCE AXIS
IF(RA.EQ.0.0)RA=CGOB
DO 220 I=1,NSEG
DBFSRA(I)=DBFS(I)-RA
220 CONTINUE
C
C CALCULATE CMA FOR EACH SEGMENT(BASED ON AREA AND BASE DIAMETER)
DO 225 I=1,NSEG
CMA(I)=CMAP(I)*DBFSRA(I)/DB(I)*CNAP(I)
225 CONTINUE
C
C CALCULATE CMA FOR EACH SEGMENT(BASED ON AREA AND SEGMENT LENGTH)
DO 510 I=1,NSEG
CMA(I)=CMAP(I)*DB(I)/H(I)+DBFSRA(I)/H(I)*CNAP(I)
510 CONTINUE
C
C CALCULATE CMA FOR THE BODY(BASED ON AREA AND BASE DIAMETER)
CMA=0.0
DO 330 I=1,NSEG
CMA=CMA+CMA(I)*CNAP(I)**3.
330 CONTINUE
C
C CALCULATE THE LENGTH OF THE BODY
BL=0.0
DO 350 I=1,NSEG
BL=BL+I
350 CONTINUE
C
C CALCULATE CMA FOR THE BODY(BASED ON AREA AND BODY LENGTH)
CMA=0.0
C
CMATL=CMATL+CMAL(I)*(DB(I)/DB(NSEG))**2.*(H(I)/BL)

500 CONTINUE

C

C CALCULATE THE CENTER OF PRESSURE

XM=(BL-RA)/BL
XCP=XM-CMATL/CNAT
WRITE (6,240)
DO 245 I=1,NSEG
WRITE(6,250) ISEG( I) ,DBFS( I) ,DBFSRA( I) ,CMA( I) ,CMAL( I)
240 FORMAT(1H ,6X,'ISEG',8X,'DBFS',10X,'DBFSRA',12X,'CMA',11X,
1 'CMAL',/)
245 CONTINUE
WRITE(6,255)CNAT
255 FORMAT(1H ,5X,'TOTAL CMA FOR THE BODY =',F10.5)
WRITE(6,260)CMAT
260 FORMAT(1H ,5X,'TOTAL CMA FOR THE BODY (BASED ON AREA AND ',
1 'BASE DIAMETER =',F10.5)
WRITE(6,265)BL
265 FORMAT(1H ,5X,'LENGTH OF THE BODY =',F10.5)
WRITE(6,270)XCP
270 FORMAT(1H ,5X,'CENTER OF PRESSURE AS A FRACTION OF BODY ',
1 'LENGTH =',F10.5)

C

C CALCULATE GYROSCOPIC STABILITY AND SPIN RATE

PI=3.14159265
IF(ISG.EQ.0)GO TO 275
W=(SG*PI*RHO*TIB*ABS(CMAT)*DB(NSEG)**3.)/(2.*AIB**2.)**.5*VEL
RPM=W*30/PI
WRITE(6,280)W,RPM
280 FORMAT(1H ,5X,'SPIN RATE (RAD/SEC) =',F15.5,5X,
1 'SPIN RATE (RPM) =',F15.5)
GO TO 285
275 SG=2.*AIB**2.***(W/VEL)**2.//(PI*RHO*TIB*CMAT**DB(NSEG)**3.)
WRITE(6,290)SG
290 FORMAT(1H ,5X,'GYROSCOPIC STABILITY FACTOR =',F10.5)
WRITE(6,310)RHO,VEL
310 FORMAT(1H ,5X,'AIR DENSITY =',F10.5,5X,'PROJECTILE VELOCITY =',
1 'F10.5)

C

C CALCULATE CDP FOR THE FIRST SEGMENT

SPHERICAL FIRST SEGMENT

35 IF(ITYPE.EQ.1)GO TO 600
CALL F423166(BLUNT,CDP(1))
GO TO 605

TALL (TRUNCATED) FIRST SEGMENT
$\Pi=3.141592\times10^6$

\[
SB=\Pi^2 DB(NSEG)^4/4
\]

IF I TYPE EQ 1 GO TO 620
AREA(I) = \Pi * (R2(I) - R1(I))^2 + (H(I) * H(I))^2 * 5 * (R2(I) * R2(I))

625 AREA(I) = \Pi * ((R2(I) - R1(I))^2 + (H(I) * H(I))^2 * 5 * (R2(I) * R2(I))

CONTINUE
SS = 0
DO 635 I = 1, NSEG
SS = SS + AREA(I)
CONTINUE

C CALCULATE CDF, BODY SKIN FRICTION DRAG COEFFICIENT
CDF = 1.02 * CF * CCFCF * SS / SB

C CALCULATE CDO, ZERO LIFT DRAG COEFFICIENT
SUMD = 0.0
DO 640 I = 1, NSEG
SUMD = SUMD + CD(I) * (DB(I) / DB(NSEG))^2
CONTINUE
CALL F423160(VEL, CDB)
CDO = CDF + SUMD + CDB

C CALCULATE CNQP, PITCHING DERIVATIVE FOR SEGMENT

UNCLASSIFIED
BASED ON BASE AREA AND BASE DIAMETERS REFERRED TO FORWARD F-A TAIL SEGMENT

- UNCLASSIFIED

C

UNCLASSIFIED

CALCULATE THE MAGNUS MOMENT COEFFICIENT

CALL MAGNUS(BL,DB(NSEG),RES,CGOB,CMPA)

CALCULATE CMAD. THE ACCELERATION DERIVATIVE CMAD IN THE HYPERSONIC SPEED RANGE IS EQUAL TO ZERO WHEN DETERMINED BY NEWTONIAN THEORY

CMAD=0.0

CALCULATE SD, DYNAMIC STABILITY FACTOR

AKB=(AIB/(TMASS*DB(NSEG)**2.))**.5
TKB=(TIB/(TMASS*DB(NSEG)**2.))**.5
SD=(2.*(CNAT-CDO)+2.*AKB**(-2.)*CMAP)/(CNAT-2.*CMAP-2.*TKB**(-2.)*CMAD)

UNCLASSIFIED
C WRITE DYNAMIC STABILITY DATA
C
WRITE(6,700)
700 FORMAT(1H,10X,'****** DYNAMIC STABILITY DATA *****',/)
WRITE(6,705)ESR,AR
705 FORMAT(1H,5X,'EQUIVALENT SAND ROUGHNESS = ',E12.6,5X,
1 'ADMISSIBLE ROUGHNESS = ',E12.6)
WRITE(6,710)RES,U
710 FORMAT(1H,5X,'REYNOLDS NUMBER = ',E12.6,5X,
1 'ABSOLUTE VISCOSITY = ',E12.6)
WRITE(6,810)CRE
810 FORMAT(1H,5X,'CUTOFF REYNOLDS NUMBER = ',E12.6)
WRITE(6,715)SB,SS
715 FORMAT(1H,5X,'BODY MAXIMUM FRONTAL AREA = ',F10.5,5X,
1 'BODY WETTED AREA = ',F10.5)
WRITE(6,720)AKB,TKB
720 FORMAT(1H,5X,'DIMENSIONLESS AXIAL RADIUS OF GYRATION = ',F10.5,
1 5X,'DIMENSIONLESS TRANSVERSE RADIUS OF GYRATION = ',F10.5,/) DO 725 I=1,NSEG
WRITE(6,800)I
800 FORMAT(1H,5X,'PROPERTIES FOR SEGMENT NUMBER ',I5)
WRITE(6,730)CDP(I),CNQP(I)
730 FORMAT(1H,5X,'CDP = ',F10.5,5X,'CNQP = ',F10.5)
WRITE(6,735)CMQP(I),CMQ(I)
735 FORMAT(1H,5X,'CMQP = ',F10.5,5X,'CMQ = ',F10.5,/) CONTINUE
WRITE(6,740)CF
740 FORMAT(1H,5X,'INCOMPRESSIBLE FLAT PLATE SKIN FRICTION ',
1 'COEFFICIENT (CF) = ',F10.5)
WRITE(6,745)CFCCF
745 FORMAT(1H,5X,'COMPRESSIBLE/INCOMPRESSIBLE SKIN FRICTION ',
1 'COEFFICIENT (CFCCF) = ',F10.5)
WRITE(6,750)CDF
750 FORMAT(1H,5X,'BODY SKIN FRICTION DRAG COEFFICIENT (CDF) = ',
1 F10.5)
WRITE(6,755)CDB
755 FORMAT(1H,5X,'BODY BASE DRAG COEFFICIENT (CDB) = ',F10.5)
WRITE(6,760)CDO
760 FORMAT(1H,5X,'BODY ZERO LIFT DRAG COEFFICIENT (CDO) = ',F10.5)
WRITE(6,765)CMQT
765 FORMAT(1H,5X,'BODY PITCHING DERIVATIVE (CMQT) = ',F10.5)
WRITE(6,780)CMPA
780 FORMAT(1H,5X,'DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT ',
1 '(CMPA) = ',F10.5)
WRITE(6,785)CMD
785 FORMAT(1H,5X,'BODY ACCELERATION DERIVATIVE (CMPA) = ',F10.5)
WRITE(6,790)SD
790 FORMAT(1H,5X,'DYNAMIC STABILITY FACTOR (SD) = ',F10.5)
C C CALCULATE STABILITY OF THE BODY C
CALL F611 (CMAT,SD,RHO,TIB,AIB,Db(NSEG),VEL,DEN)
STOP
END
SUBROUTINE IHSS(ISEG,R2,R1,H,DEN,V,AMASS,YB,B,AL,TI)

CALCULATE THE INERTIA PROPERTIES FOR A HOLLOW SPHERICAL SEGMENT

ISEG = SEGMENT NUMBER
R2 = OUTER RADIUS
R1 = INNER RADIUS
H = HEIGHT OF SEGMENT
DEN = DENSITY OF MATERIAL (MASS/VOLUME)
V = VOLUME
AMASS = MASS
YB = DISTANCE FROM REFERENCE AXIS TO CENTROID
B = DISTANCE FROM BASE OF SEGMENT TO CENTROID
AI = AXIAL (POLAR) MOMENT OF INERTIA
TI = TRANSVERSE MOMENT OF INERTIA

PI=3.1415926
V=PI*(R2**2*R1+H*R2**2-R2**2+H*R1-R1**2)**3./3.-2.*R1**3./3.
YB=3.*((R2**2-R1**2)*(4.*H*R2-2.*H**2)-(R2**2-R1**2)**2.)/(4.*((R2**2-R1**2)*(3.*H)+3.*R2**2*R1-R1**2)-2.*R1**3.))
AMASS=DEN*V
B=YB-R2+H
AI=DEN*PI/2.*(8./15.*(R2**5.-R1**5.)*(R2-H)*(R1**4.-R2**4.))
1+2./3.*(R2-H)**3.*(R2**2-R1**2)
RR1=R2-R1
RR2=(R2**2-R1**2)
RR3=(R2**3.-R1**3.)
RR4=(R2**4.-R1**4.)
RR5=(R2**5.-R1**5.)
TI=DEN*PI/2*(.25*RR4*(R1-R2+H)+RR2*(1./6.*(R1**3.-(R2-H)**3.))
1+YB*YB*(R1-R2-H)*(R1**2-(R2-H)**2.))+.25*RR**4.*RR1
2+R2*R2*(1./6.*RR3+YB*YB*RR1-RR2).3/20.*RR5+.5*YB*RR4
3-RR**2/3.*RR3)
WRITE(6,300)ISEG
300 FORMAT(1H,5X, 'PROPERTIES FOR SEGMENT NUMBER ',I5)
WRITE(6,301)
301 FORMAT(1H,10X,'HOLLOW SPHERICAL SEGMENT')
WRITE(6,302)R2,R1,H
302 FORMAT(1H,5X,'OUTER RADIUS = ',F10.5,5X,'INNER RADIUS = ',F10.5,5X,'HEIGHT = ',F10.5)
WRITE(6,303)DEN,V,AMASS
303 FORMAT(1H,5X,'DENSITY = ',F15.8,5X,'VOLUME = ',F15.8,5X,
1 'MASS = ',F15.8)
WRITE(6,304)YB
304 FORMAT(1H,5X,'DISTANCE FROM REFERENCE AXIS TO CENTROID = ',
1 F15.8)
WRITE(6,305)B
305 FORMAT(1H,5X,'DISTANCE FROM BASE OF SEGMENT TO CENTROID = ',
1 F15.8)
WRITE(6,306)AI
306 FORMAT(1H,5X,'AXIAL MOMENT OF INERTIA = ',F15.8)
WRITE(6,307)TI
307 FORMAT(1H ,5X,'TRANSVERSE MOMENT OF INERTIA = ',F15.8)
RETURN
END

C******************************************************************************
C
C SUBROUTINE IHTC(ISEG,RR2,RR1,R2,R1,H,DEN,V,AMASS,YB,AI,TI)
C
C CALCULATE THE INERTIA PROPERTIES FOR A HOLLOW TRUNCATED CONE
C
C ISEG = SEGMENT NUMBER
C RR2 = OUTER RADIUS AT LARGE END
C RR1 = INNER RADIUS AT LARGE END
C R2 = OUTER RADIUS AT SMALL END
C R1 = INNER RADIUS AT SMALL END
C H = HEIGHT OF TRUNCATED CONE
C DEN = DENSITY OF MATERIAL (MASS/VOLUME)
C V = VOLUME
C AMASS = MASS
C YB = DISTANCE FROM CONE BASE TO CENTROID
C AI = AXIAL(POLAR) MOMENT OF INERTIA
C TI = TRANSVERSE MOMENT OF INERTIA
C
PI=3.1415926
DUMB=(RR2**2-RR1**2)*RR1+R2**2-R1**2+RR2**2-RR1**2)
V=PI*H/3.*DUMB
YB=.25*H*(RR2**2-RR1**2+R2**2-3.*R1**2+2.*RR2**2-R1**2)/DUMB
AMASS=DEN*V
A1=den*PI*H/10.*((RR2**4.+RR2**3.*R2-RR2**2*R2**2+1
RR2**2*R2**3.+R2**4.)-(RR1**4.+RR1**3.*R1+RR1**2*R1**2+2
RR1**3.+R1**4.))
A1=RR1-R1
A2=(RR1-R1)**2.
A3=(RR1-R1)**3.
A4=(RR1-R1)**4.
A1=(RR2-R2)**2.
B2=(RR2-R2)**2.
B3=(RR2-R2)**3.
B4=(RR2-R2)**4.
TI=(.75*AMASS*(RR2**2-RR1**2-2.*RR2**3.*B1+2.*RR2**2*B2-RR2*B3
+ B4/5.-RR1**4.+2.*RR1**3.*A1-2.*RR1**2.*A2+RR1*A3-A4/5.)
- A2/5.+RR1**A1/2.)+YB*YB*(RR2**2+B2/3.-RR2*B1-RR1**B1
5 +RR1**A1-A2/2.-4.*RR1*A1/3.))/DUMB
WRITE(6,310)ISEG
310 FORMAT(1H ,5X,'PROPERTIES FOR SEGMENT NUMBER ',I5)
WRITE(6,311)
311 FORMAT(1H ,10X,'HOLLOW TRUNCATED CONE')
WRITE(6,312)RR2,RR1
312 FORMAT(1H ,5X,'OUTER RADIUS AT LARGE END = ',F10.5,5X,
1 'INNER RADIUS AT LARGE END = ',F10.5)
SUBROUTINE COEFF1
C
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.1.1-23
C NORMAL-FORCE-CURVE SLOPE FOR SPHERICAL SEGMENTS
C
COMMON/X1/Y1(X1),Y1(Y1)
COMMON/BCD1/B1(11),C1(11),D1(11)
DATA(X1(I),I=1,11)/0.0000,0.1000,0.2000,0.3000,0.4000,
1 0.5000,0.6000,0.7000,0.8000,0.9000,
2 1.0000/
DATA(Y1(I),I=1,11)/0.0000,0.1748,0.3497,0.5070,0.6399,
1 0.7517,0.8392,0.9091,0.9580,0.9895,
2 1.0000/
N=11
CALL SPLINE(N,X1,Y1,B1,C1,D1)
RETURN
END

SUBROUTINE COEFF2
C
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.1.1-26
C NORMAL-FORCE-CURVE SLOPE FOR CONE FRUSTRUMS
C
COMMON/X2/Y2(X2),Y2(Y2)
COMMON/BCD2/B2(11,10),C2(11,10),D2(11,10)
DIMENSION B(10),C(10),D(10),XXX(10),YYY(10)
DATA(X2(I,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1 50.000,60.000,70.000,80.000,90.000/
DATA(Y2(I,I),I=1,10)/2.0000,1.9406,1.7727,1.5140,1.1818,
1 0.8287,0.5035,0.2448,0.0664,0.0000/
DATA(X2(2,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
DATA(Y2(2,1),I=1,10)/9.8251, 9.1611, 1.7448, 1.4790, 1.1678, 0.8287, 0.5035, 0.2448, 0.0664, 0.0000/
DATA(X2(3,1),I=1,10)/0.0000, 10.0000, 20.0000, 30.0000, 40.0000, 50.0000, 60.0000, 70.0000, 80.0000, 90.0000/
DATA(Y2(3,1),I=1,10)/1.9196, 1.8601, 1.6853, 1.4371, 1.1224, 0.7867, 0.4755, 0.2448, 0.0664, 0.0000/
DATA(X2(4,1),I=1,10)/0.0000, 10.0000, 20.0000, 30.0000, 40.0000, 50.0000, 60.0000, 70.0000, 80.0000, 90.0000/
DATA(Y2(4,1),I=1,10)/1.8217, 1.7622, 1.6119, 1.3601, 1.0664, 0.7517, 0.4510, 0.2203, 0.0629, 0.0000/
DATA(X2(5,1),I=1,10)/0.0000, 10.0000, 20.0000, 30.0000, 40.0000, 50.0000, 60.0000, 70.0000, 80.0000, 90.0000/
DATA(Y2(5,1),I=1,10)/1.6853, 1.6329, 1.4755, 1.2587, 0.9825, 0.6923, 0.4231, 0.1958, 0.0594, 0.0000/
DATA(X2(6,1),I=1,10)/0.0000, 10.0000, 20.0000, 30.0000, 40.0000, 50.0000, 60.0000, 70.0000, 80.0000, 90.0000/
DATA(Y2(6,1),I=1,10)/1.5070, 1.4510, 1.3217, 1.1259, 0.8811, 0.6259, 0.3706, 0.1783, 0.0559, 0.0000/
DATA(X2(7,1),I=1,10)/0.0000, 10.0000, 20.0000, 30.0000, 40.0000, 50.0000, 60.0000, 70.0000, 80.0000, 90.0000/
DATA(Y2(7,1),I=1,10)/1.2867, 1.2413, 1.1259, 0.9580, 0.7552, 0.5315, 0.3252, 0.1538, 0.0455, 0.0000/
DATA(X2(8,1),I=1,10)/0.0000, 10.0000, 20.0000, 30.0000, 40.0000, 50.0000, 60.0000, 70.0000, 80.0000, 90.0000/
DATA(Y2(8,1),I=1,10)/1.0210, 0.9895, 0.9865, 0.7622, 0.5909, 0.4161, 0.2552, 0.1224, 0.0315, 0.0000/
DATA(X2(9,1),I=1,10)/0.0000, 10.0000, 20.0000, 30.0000, 40.0000, 50.0000, 60.0000, 70.0000, 80.0000, 90.0000/
DATA(Y2(9,1),I=1,10)/0.7168, 0.6923, 0.6224, 0.5350, 0.4196, 0.2937, 0.1748, 0.0804, 0.0210, 0.0000/
DATA(X2(10,1),I=1,10)/0.0000, 10.0000, 20.0000, 30.0000, 40.0000, 50.0000, 60.0000, 70.0000, 80.0000, 90.0000/
DATA(Y2(10,1),I=1,10)/0.3671, 0.3566, 0.3287, 0.2797, 0.2203, 0.1503, 0.0909, 0.0420, 0.0105, 0.0000/
DATA(X2(11,1),I=1,10)/0.0000, 10.0000, 20.0000, 30.0000, 40.0000, 50.0000, 60.0000, 70.0000, 80.0000, 90.0000/
DATA(Y2(11,1),I=1,10)/0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000/

N=10
DO 200 J=1,11
DO 210 K=1,10
XXX(K)=X2(J,K)
YYY(K)=Y2(J,K)
210 CONTINUE
 CALL SPLINE(N,XXX,YYY,B,C,D)
DO 220 K=1,10
 B2(J,K)=B(K)
 C2(J,K)=C(K)
 D2(J,K)=D(K)
220 CONTINUE
200 CONTINUE
 RETURN
END
SUBROUTINE COEFF3

GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.2.1-25A
C MAP FOR CONE FRUSTRUMS

COMMON/XY3/X3(11,10),Y3(11,10)
COMMON/XYB/XXB(6),YYB(6)
COMMON/BCD3/B3(11,10),C3(11,10),D3(11,10)
COMMON/BCD3B/B3B(6),C3B(6),D3B(6)

DIMENSION B(10),C(10),D(10),XXX(10),YYY(10)

DATA(X3(1,I),I=1,10)/15.279,20.000,25.000,30.000,40.000,
1 50.000,60.000,70.000,80.000,90.000/
DATA(Y3(1,I),I=1,10)/-2.400,-1.800,-1.398,-1.149,-0.796,
1 -0.564,-0.388,-0.249,-0.125,0.0000/
DATA(X3(2,I),I=1,10)/13.219,15.000,20.000,25.000,30.000,
1 40.000,50.000,60.000,75.000,90.000/
DATA(Y3(2,I),I=1,10)/-2.400,-2.114,-1.599,-1.249,-1.017,
1 -0.723,-0.526,-0.367,-0.183,0.0000/
DATA(X3(3,I),I=1,10)/11.159,15.000,20.000,25.000,30.000,
1 40.000,50.000,60.000,75.000,90.000/
DATA(Y3(3,I),I=1,10)/-2.400,-1.807,-1.353,-1.083,-0.900,
1 -0.658,-0.485,-0.350,-0.183,0.0000/
DATA(X3(4,I),I=1,10)/9.0990,10.000,15.000,20.000,25.000,
1 35.000,45.000,60.000,75.000,90.000/
DATA(Y3(4,I),I=1,10)/-2.400,-2.118,-1.453,-1.100,-0.903,
1 -0.661,-0.516,-0.339,-0.170,0.0000/
DATA(X3(5,I),I=1,10)/6.8670,10.000,15.000,20.000,25.000,
1 35.000,45.000,60.000,75.000,90.000/
DATA(Y3(5,I),I=1,10)/-2.400,-1.668,-1.159,-0.893,-0.737,
1 -0.564,-0.460,-0.315,-0.159,0.0000/
DATA(X3(6,I),I=1,10)/5.0000,10.000,15.000,20.000,25.000,
1 35.000,45.000,60.000,75.000,90.000/
DATA(Y3(6,I),I=1,10)/-2.400,-1.239,-0.862,-0.685,-0.588,
1 -0.471,-0.398,-0.287,-0.149,0.0000/
DATA(X3(7,I),I=1,10)/5.0000,10.000,15.000,20.000,30.000,
1 40.000,50.000,60.000,75.000,90.000/
DATA(Y3(7,I),I=1,10)/-1.595,-0.845,-0.613,-0.498,-0.402,
1 -0.350,-0.308,-0.246,-0.138,0.0000/
DATA(X3(8,I),I=1,10)/5.0000,10.000,15.000,20.000,30.000,
1 40.000,50.000,60.000,75.000,90.000/
DATA(Y3(8,I),I=1,10)/-0.900,-0.519,-0.395,-0.298,-0.204,
1 -0.184,-0.163,-0.128,-0.083,0.0000/
DATA(X3(9,I),I=1,10)/5.0000,10.000,15.000,25.000,35.000,
1 45.000,55.000,65.000,75.000,90.000/
DATA(Y3(9,I),I=1,10)/-0.436,-0.260,-0.218,-0.194,-0.190,
1 -0.180,-0.163,-0.128,-0.083,0.0000/
DATA(X3(10,I),I=1,10)/-0.118,-0.090,-0.080,-0.083,-0.097,
1 -0.100,-0.093,-0.080,-0.055,0.0000/
DATA(X3(11,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1 50.000,60.000,70.000,80.000,90.000/
DATA(Y3(11,I),I=1,10)/0.0000,0.0000,0.0000,0.0000,0.0000,
1 0.0000,0.0000,0.0000,0.0000,0.0000/
DATA(XXB(I),I=1,6)/5.0000,6.8670,9.0990,11.159,13.219,15.279/
DATA(Y4B(I),I=1,6)/0.5000,0.4000,0.3000,0.2000,0.1000,0.0000/
N=10
DO 200 J=1,11
  DO 210 K=1,10
    XXX(K)=X3(J,K)
    YYY(K)=Y3(J,K)
210 CONTINUE
  CALL SPLINE(N,XXX,YYY,B,C,D)
200 CONTINUE
C C GENERATE THE CUBIC SPLINE COEFFICIENTS FOR THE BOTTOM OF THE
C GRAPH WHERE CMAP = -2.4 AND A/D IS .5 TO 0
C
N=6
  CALL SPLINE(N,XXB,YYB,B3B,C3B,D3B)
  RETURN
END
C***********************************************************************
C SUBROUTINE COEFF4
C C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.2.1-25B
C CMAP FOR SPHERICAL SEGMENTS
C
COMMON/X4/X4(13),Y4(13)
COMMON/BCD4/B4(13),C4(13),D4(13)
DATA(X4(I),I=1,13)/0.0000,0.0250,0.0500,0.1000,0.2000,
1 0.3000,0.4000,0.5000,0.6000,0.7000,
2 0.8000,0.9000,1.0000/
DATA(Y4(I),I=1,13)/0.0000,-.0918,-.1482,-.2188,-.3000,
1 -.3600,-.3988,-.4341,-.4588,-.4800,
2 -.4941,-.5012,-.5012/
N=13
  CALL SPLINE(N,X4,Y4,B4,C4,D4)
  RETURN
END
C***********************************************************************
C SUBROUTINE F421123(BLUNT,CNAP)
C C CALCULATES CNAP FOR A GIVEN NOSE BLUNTNESS
C NORMAL-FORCE-CURVE SLOPE FOR SPHERICAL SEGMENTS
C
SUBROUTINE F421126(THETA,CNAP,AD)

C CALCULATES CNAP FOR A GIVEN SEMICONE ANGLE
C NORMAL-FORCE-CURVE SLOPE FOR CONE FRUSTUMS

COMMON/XY2/X2(11,10),Y2(11,10)
COMMON/BCD2/B2(11,10),C2(11,10),D2(11,10)
DIMENSION CNA(11),XXX(10),YYY(10),B(10),C(10),D(10)
DIMENSION XX(11),BB(11),CC(11),DD(11)
DATA(XX(I),I=1,11)/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,1.0/1.0
DO 200 J=1,11
DO 210 K=1,10
XXX(K)=X2(J,K)
YYY(K)=Y2(J,K)
210 CONTINUE
DO 220 K=1,10
B(K)=B2(J,K)
C(K)=C2(J,K)
D(K)=D2(J,K)
220 CONTINUE
CALL SEVAL(THETA,DUMB,01Y0,D2YO,D3YO,XXX,YYY,B,C,D,10)
CNA(J)=DUMB
200 CONTINUE
CALL SPLINE(11,XX,CNA,BB,CC,DD)
CALL SEVAL(AD,CNAP,D1YO,D2YO,D3YO,XX,CNA,BB,CC,DD,11)
RETURN
END

SUBROUTINE F422125A(THETA,CMAP,AD)

C CALCULATES CMAP FOR A GIVEN SEMICONE ANGLE
C CMAP FOR CONE FRUSTUMS

COMMON/XY3/X3(11,10),Y3(11,10)
COMMON/XYB/XXB(6),YYB(6)
COMMON/BCD3/B3(11,10),C3(11,10),D3(11,10)
COMMON/BCD3B/B3B(6),C3B(6),D3B(6)
DIMENSION XX1(11),XX2(11),XX3(10),XX4(9),XX5(8),XX6(7)
DIMENSION XXX(10),YYY(10),B(10),C(10),D(10)
DIMENSION CMA1(11),BB1(11),CC1(11),DD1(11)
DIMENSION CMA2(11),BB2(11),CC2(11),DD2(11)
DIMENSION CMA3(10),BB3(10),CC3(10),DD3(10)
DIMENSION CMA4(9),BB4(9),CC4(9),DD4(9)
DIMENSION CMA5(8),BB5(8),CC5(8),DD5(8)
DIMENSION CMA6(7),BB6(7),CC6(7),DD6(7)
DATA(XX1(I),I=1,11)/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,1
     0.9,1.0/

C  REGION 1 ( THETA .GE. 15.279)

   IF(THETA.LT.15.279)GO TO 10
   DO 200 J=1,11
   DO 210 K=1,10
      XXX(K)=X3(J,K)
      YYY(K)=Y3(J,K)
   210 CONTINUE
   DO 220 K=1,10
      B(K)=B3(J,K)
      C(K)=C3(J,K)
      D(K)=D3(J,K)
   220 CONTINUE
   CALL SEVAL(THETA,DUMB,D1YO,D2YO,D3YO,XXX,YYY,B,C,D,10)
   CMA1(J)=DUMB
   200 CONTINUE
   CALL SPLINE(11,XX1.,CMA1,BB1,CC1,DD1)
   CALL SEVAL(AD,CMAP,D1YO,D2YO,D3YO,XX1,CMAP1,BB1,CC1,DD1,11)
   GO TO 1000

C  REGION 2 ( THETA .LT. 15.279 BUT .GE. 13.219)

10 IF(THETA.LT.13.219)GO TO 20
   DO 201 J=2,11
   DO 211 K=1,10
      XXX(K)=X3(J,K)
      YYY(K)=Y3(J,K)
   211 CONTINUE
   DO 221 K=1,10
      B(K)=B3(J,K)
      C(K)=C3(J,K)
      D(K)=D3(J,K)
   221 CONTINUE
   CALL SEVAL(THETA,DUMB,D1YO,D2YO,D3YO,XXX,YYY,B,C,D,10)
   CMA2(J)=DUMB
   XX2(J)=XX1(J)
   201 CONTINUE
   CALL SEVAL(THETA,DUMB,D1YO,D2YO,D3YO,XXX,YYY,B,C,D,10)
   CMA2(J)=DUMB
   XX2(J)=XX1(J)
   201 CONTINUE
   CALL SEVAL(THETA,DUMB,D1YO,D2YO,D3YO,XXX,YYY,B,C,D,10)
   CMA2(J)=DUMB
   XX2(J)=XX1(J)
   201 CONTINUE
   CALL SPLINE(11,XX2,CMA2,BB2,CC2,DD2)
   CALL SEVAL(AD,CMAP,D1YO,D2YO,D3YO,XX2,CMAP2,BB2,CC2,DD2,11)
   GO TO 1000

C  REGION 3 ( THETA .LT. 13.219 BUT .GE. 11.159)

20 IF(THETA.LT.11.159)GO TO 30

UNCLASSIFIED
DO 202 J=1,11
DO 212 K=1,10
XXX(K)=X3(J,K)
YYY(K)=Y3(J,K)
212 CONTINUE
DO 222 K=1,11
B(K)=B3(J,K)
C(K)=C3(J,K)
D(K)=D3(J,K)
222 CONTINUE
CALL SEVAL( THETA,DUMB,01Y0,02Y0,03Y0,XXX,YYY,B,C,D,10)
CMA4(J-2)=DUMB
XX4(J-2)=XX1(J)
202 CONTINUE
DO 203 J=4,11
DO 213 K=1,10
XXX(K)=X3(J,K)
YYY(K)=Y3(J,K)
213 CONTINUE
DO 223 K=1,10
B(K)=B3(J,K)
C(K)=C3(J,K)
D(K)=D3(J,K)
223 CONTINUE
CALL SEVAL( THETA,DUMB,01Y0,02Y0,03Y0,XXX,YYY,B,C,D,10)
CMA4(J-2)=DUMB
XX4(J-2)=XX1(J)
203 CONTINUE
DO 204 J=5,11
DO 214 K=1,10
XXX(K)=X3(J,K)
YYY(K)=Y3(J,K)
40 IF(THETA.LT.6.867)GO TO 50
UNCLASSIFIED
C14 CONTINUE
     DO 224 K=1,10
     B(K)=B3(J,K)
     C(K)=C3(J,K)
     D(K)=D3(J,K)
224 CONTINUE
     CALL SEVAL(THETA,DUMB,D1YO,D2YO,D3YO,XXX,YYY,B,C,D,10)
     CMA5(J-3)=DUMB
     XX5(J-3)=XX1(J)
204 CONTINUE
     CALL SEVAL(THETA,DUMB,D1YO,D2YO,D3YO,XXX,YYY,B3B,C3B,D3B,6)
     CMA5(J)=DUMB
     XX5(J)=XX1(J)
     IF(AD.LT.DUMB)GO TO 2000
     CALL SPLINE(8,XX5,CMA5,BB5,CC5,DD5)
     CALL SEVAL(AD,CMAP,D1YO,D2YO,D3YO,XXX,YYY,B3B,C3B,D3B,6)
     GO TO 1000

REGION 6 (THETA .LT. 6.867 BUT .GE. 5.000)

50 IF(THETA.LT.5.000)GO TO 60
     DO 205 J=6,11
     DO 215 K=1,10
     XXX(K)=X3(J,K)
     YYY(K)=Y3(J,K)
215 CONTINUE
     DO 225 K=1,10
     B(K)=B3(J,K)
     C(K)=C3(J,K)
     D(K)=D3(J,K)
225 CONTINUE
     CALL SEVAL(THETA,DUMB,D1YO,D2YO,D3YO,XXX,YYY,B,C,D,10)
     CMA5(J-4)=DUMB
     XX6(J-4)=XX1(J)
205 CONTINUE
     CALL SEVAL(THETA,DUMB,D1YO,D2YO,D3YO,XXX,YYY,B3B,C3B,D3B,6)
     CMA6(J)=DUMB
     XX6(J)=XX1(J)
     IF(AD.LT.DUMB)GO TO 2000
     CALL SPLINE(7,XX6,CMA6,BB6,CC6,DD6)
     CALL SEVAL(AD,CMAP,D1YO,D2YO,D3YO,XXX,YYY,B3B,C3B,D3B,6)
     GO TO 1000
60 CMAP=0.0
     WRITE(6,4000)THETA
4000 FORMAT(1H ,5X,'THETA = ',F10.5,5X,'OUT OF THETA RANGE')
     GO TO 1000
2000 WRITE(6,3000)AD,THETA
3000 FORMAT(1H ,5X,'A/D = ',F10.5,5X,'WHICH IS OUT OF RANGE:
1 ' FOR THETA = ',F10.5)
     CMAP=999.99
1000 RETURN
END
A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC STABILITY OF A SE (U) DEFENCE RESEARCH ESTABLISHMENT SUFFIELD RALSTON (ALBERTA) C A WEICKERT MAR 87
SUBROUTINE F422125B(BLUNT, CMAP)
C
C CALCULATES CMAP FOR A GIVEN NOSE BLUNTNESS
C CMAP FOR SPHERICAL SEGMENTS
C
COMMON/XY4/X4(13), Y4(13)
COMMON/BCD4/B4(13), C4(13), D4(13)
N=13
CALL SEVAL(BLUNT, CMAP, D1YO, D2YO, D3YO, X4, Y4, B4, C4, D4, N)
RETURN
END

******************************************************************************

SUBROUTINE F423166(BLUNT, CDP)
C
C CALCULATE CDP, NEWTONIAN DRAG COEFFICIENT FOR SPHERICAL
C SEGMENTS REFERRED TO BASE AREA OF SEGMENT
C
CDP=BLUNT**2. - 2.*BLUNT + 2.
RETURN
END

******************************************************************************

SUBROUTINE F721213B(CMQP)
C
C CALCULATE CMQP, PITCHING DERIVATIVE FOR SPHERICAL SEGMENTS
C BASED ON THE BASE AREA AND THE SQUARE OF THE BASE DIAMETER
C
CMQP=-.5
RETURN
END

******************************************************************************

SUBROUTINE F721212(THETA, AD, CMQP)
C
C CALCULATE THE PITCHING DERIVATIVE CMQP DUE TO INCLINED SIDES
C OF CONE FRUSTRUMS
C
PI=3.1415926
RAD=THETA*PI/180.
A=6.*AD*AD*(1.-AD*AD)
B=-8.*AD*(1.-AD**3.)
C=3.*(1.-AD**4.)
CMQP=1./(6.*(SIN(RAD))**2.)*(A*(COS(RAD))**4.+B*(COS(RAD))**2.
1 +C)
IF(THETA.GE.5.0)GO TO 100
CMQP=0.0
WRITE(6, 105)
105 FORMAT(1H1,5X,'OUT OF THETA RANGE')
100 IF(CMQP.GE.-4.8)GO TO 200
WRITE(6,110)
110 FORMAT(1H ,5X,'OUT OF CMQP RANGE')
200 RETURN
END

C*****************************************************************************
C
SUBROUTINE F721213A(THETA,AD,CMQP)
C
C CALCULATE THE PITCHING DERIVATIVE CMQP FOR THE TOTAL CONE FRUSTRUM
C
CALL F721212(THETA,AD,CMQP)
IF(CMQP.EQ.0.0)GO TO 100
CMQP=CMQP-(AD**4.)/2.
100 RETURN
END

C*****************************************************************************
C
SUBROUTINE F423167S(THETA,AD,CDP)
C
C CALCULATE CDP, DRAG-FORCE COEFFICIENT DUE ONLY TO THE INCLINED
C SIDES OF A CONE FRUSTRUM, BASED ON BODY BASE AREA
C
PI=3.1415926
RAD=THETA*PI/180.
CDP=2.*((SIN(RAD))**2.*(1.-AD*AD)
RETURN
END

C*****************************************************************************
C
SUBROUTINE F423167T(THETA,AD,CDP)
C
C CALCULATE CDP, DRAG-FORCE COEFFICIENT FOR THE TOTAL CONE FRUSTRUM
C
PI=3.1415926
RAD=THETA*PI/180.
CDP=2.*((SIN(RAD))**2.*(1.-AD*AD)+AD*AD)
RETURN
END

C*****************************************************************************
C
SUBROUTINE COEFF5
C
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.3.1.-68
C COMPRESSIBILITY EFFECT ON TURBULENT SKIN FRICTION
C
COMMON/XY5/X5(8),Y5(8)
COMMON/BCD5/B5(8),C5(8),D5(8)
DATA(X5(I),I=1,8)/0.0000,1.0000,2.0000,3.0000,4.0000,5.0000,6.0000,10.0000/
DATA(Y5(I),I=1,8)/1.0000,0.9271,0.7708,0.6146,
1.0000,0.3958,0.3333,0.1289/
CALL SPLINE(8,X5,Y5,B5,C5,D5)
RETURN
END

C*******************************************************************************
C SUBROUTINE F423168(VEL,CFCF)
C CALCULATES CFC/CF, COMPRESSIBILITY EFFECT ON TURBULENT
C SKIN FRICTION
C
COMMON/X5(8),Y5(8)
COMMON/B5(8),C5(8),D5(8)
C
VEL = PROJECTILE VELOCITY(IN/SEC)
A = SPEED OF SOUND IN AIR(1116.4 FT/SEC)
AMACH = PROJECTILE VELOCITY (MACH NUMBER)

A=1116.4
AMACH=VEL/(12.*A)
IF(AMACH.GT.10.)GO TO 100
CALL SEVAL(AMACH,CFCF,D1YO,D2Y0,D3YO,X5,Y5,B5,C5,D5,8)
GO TO 200
100 WRITE(6,300)AMACH
300 FORMAT(1H ,10X,'MACH NUMBER=',F10.5,5X,'WHICH IS OUT OF RANGE')
200 RETURN
END

C*******************************************************************************
C SUBROUTINE COEFF6
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.1.5.1-27
C CUTOFF REYNOLDS NUMBER
C
COMMON/X6(5),Y6(5)
COMMON/B6(5),C6(5),D6(5)
DATA(X6(I),I=1,5)/1.80E03,1.65E04,1.47E05,1.30E06,1.00E07/
DATA(Y6(I),I=1,5)/1.00E05,1.00E06,1.00E07,1.00E08,8.50E08/
CALL SPLINE(5,X6,Y6,B6,C6,D6)
RETURN
END

C*******************************************************************************
C SUBROUTINE F415127(AR,CRE)
C CALCULATES CUTOFF REYNOLDS NUMBER
C
COMMON/X6(5),Y6(5)
COMMON/B6(5),C6(5),D6(5)
UNCLASSIFIED

C AR = ADMISSIBLE ROUGHNESS
C CRE = CUTOFF REYNOLDS NUMBER
C
CALL SEVAL(AR,CRE,D1YO,D2Y0,D3Y0,X6,Y6,B6,C6,D6,5)
RETURN
END

C*************************************************************
C
SUBROUTINE COEFF7
C
GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.1.5.1-26
TURBULENT MEAN SKIN FRICTION COEFFICIENT ON AN INSULATED
FLAT PLATE
C
COMMON/XY7/X7(26),Y7(26)
COMMON/BCD7/B7(26),C7(26),D7(26)
DATA(X7(I),I=1,26)/3.3E05,5.0E05,7.0E05,9.0E05,1.0E06,
1 1.5E06,2.0E06,3.0E06,5.0E06,7.0E06,
2 9.0E06,1.0E07,1.5E07,2.0E07,3.0E07,
3 5.0E07,7.0E07,9.0E07,1.0E08,1.5E08,
4 2.0E08,3.0E08,5.0E08,7.0E08,9.0E08,
5 1.0E09/
DATA(Y7(I),I=1,26)/.00550,.00505,.00474,.00454,.00445,
1 .00415,.00395,.00369,.00338,.00320,
2 .00306,.00300,.00283,.00270,.00254,
3 .00235,.00223,.00215,.00212,.00199,
4 .00191,.00182,.00170,.00164,.00160,
5 .00158/
CALL SPLINE(26,X7,Y7,B7,C7,D7)
RETURN
END

C*************************************************************
C
SUBROUTINE F415126(RE,CF)
C
CALCULATE TURBULENT MEAN SKIN FRICTION COEFFICIENT ON AN
INSULATED FLAT PLATE
C
COMMON/XY7/X7(26),Y7(26)
COMMON/BCD7/B7(26),C7(26),D7(26)
C
RE = REYNOLDS NUMBER
CF = SKIN FRICTION COEFFICIENT
C
CALL SEVAL(RE,CF,D1YO,D2Y0,D3Y0,X7,Y7,B7,C7,D7,26)
RETURN
END

C*************************************************************
C
SUBROUTINE COEFF8
C
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.3.1-60
C BASE DRAG COEFFICIENT WITH NO BOATTAIL
C
COMMON/XY8/X8(8),Y8(8)
COMMON/BCD8/B8(8),C8(8),D8(8)
DATA(X8(I),I=1,8)/1.5000,2.0000,2.5000,3.5000,1.5000,6.0000,7.0000,10.0000/
DATA(Y8(I),I=1,8)/0.1776,0.1440,0.1168,0.0800,0.0560,0.0352,0.0272,0.0110/
CALL SPLINE(8,X8,Y8,B8,C8,D8)
RETURN
END

C******************************************************************************

C SUBROUTINE F423160(VEL,CDB)
C CALCULATES CDB, BASE DRAG COEFFICIENT(WITH NO BOATTAIL)
C
COMMON /XY8/X8(8),Y8(8)
COMMON /BCD8/B8(8),C8(8),D8(8)

C VEL = PROJECTILE VELOCITY (IN/SEC)
C A = SPEED OF SOUND IN AIR (1116.4 FT/SEC)
C AMACH = PROJECTILE VELOCITY (MACH NUMBER)
C CDB = BASE DRAG COEFFICIENT
C
A=1116.4
AMACH=VEL/(12.*A)
CALL SEVAL(AMACH,CDB,01Y0,D2YO,D3YO,X8,Y8,B8,C8,D8,8)
RETURN
END

C******************************************************************************

C SUBROUTINE F72119A(THETA,AD,CNQP)
C CALCULATE CNQP, PITCHING DERIVATIVE FOR CONE FRUSDRUMS
C
PI=3.1415926
RAD=THETA*PI/180.
CNQP=2./(3.*TAN(RAD))*(2.*(1-AD**3.)-3.*AD*(COS(RAD)**2.)*1.*(1-AD*AD))
IF(THETA.GE.5.0)GO TO 100
CNQP=0.0
WRITE(6,105)
105 FORMAT(1H5X,'OUT OF THETA RANGE')
100 IF(CNQP.LE.4.4)GO TO 200
WRITE(6,110)
110 FORMAT(1H5X,'OUT OF CNQP RANGE')
200 RETURN
END

C******************************************************************************
SUBROUTINE F72119B(BLUNT,CNQP)

CALCULATE CNQP, PITCHING DERIVATIVE FOR SPHERICAL SEGMENTS

CNQP=(BLUNT*(2.-BLUNT))**.5
RETURN
END

SUBROUTINE MAGNUS(BL,DB,RES,CGOB,CMPA)

CALCULATE THE DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT

DMCP=ABS(CGOB-.333*BL)
CMPA=26.3*(BL/DB)**2.*DMCP/(RES**.5)
RETURN
END

SUBROUTINE F611 (CMAT,SD,RHO,TIB,AIB,DB,VEL,DEN)

SUBROUTINE TO DETERMINE BODY STABILITY

DIMENSION TLS(25),HLS(25),RCS(25),AMASSL(25)
PI=3.1415926
IF(SD.LT.0.0.OR.SD.GT.2.0)GO TO 10
IF(CMAT.GT.0.0)GO TO 20
WRITE(6,25)CMAT
25 FORMAT(1H5X,'CMAT=',F10.5,5X,'(NEGATIVE)')
WRITE(6,30)SD
30 FORMAT(1H5X,'SD=',F10.5,5X,'(IN THE RANGE 0-2)')
WRITE(6,35)
35 FORMAT(1H5X,'BODY IS DYNAMICALLY STABLE AT ANY SPIN RATE')
GO TO 500
20 SGI=SD*(2.-SD)
SG=1./SGI
W=(SG*PI*RHO*TIB*CMAT*DB**3.)/(2.*AIB**2.)*VEL
RPM=W**30./PI
WRITE(6,40)CMAT
40 FORMAT(1H5X,'CMAT=',F10.5,5X,'(POSITIVE)')
WRITE(6,30)SD
WRITE(6,65)SGI,SG
65 FORMAT(1H5X,'SGI=',F10.5,5X,'SG=',F10.5,5X,'(VALUES ON ' ,1 'DYNAMIC STABLE/UNSTABLE CURVE)')
WRITE(6,45)W,RPM
45 FORMAT(1H5X,'BODY IS DYNAMICALLY STABLE AT SPIN RATES ',1 'GREATER THAN ',E12.6,3X,'(RAD/SEC)',5X,E12.6,3X,'(RPM)')

CALCULATE THE EQUIVALENT SPIN RATE OF THE SFF LINER
BASED ON THE CONSERVATION OF ANGULAR MOMENTUM
C

READ(5,100)ISPIN
100 FORMAT(I5)
   IF(ISPIN.NE.1)GO TO 500
   WRITE(6,200)
200 FORMAT(1H ,//,15X,'LINER DATA',//)
   WRITE(6,205)
205 FORMAT(1H ,8X,'TLS',13X,'HLS',12X,'RCS',10X,'AMASSL',5X,
1 'SEGMENT',//)
   TAM=AIB*W
   READ(5,100)NLS
   TMASSL=0.0
   SUM1=0.0
   DO 105 I=1,NLS
      READ(5,110)TLS(I),HLS(I),RCS(I)
   110 FORMAT(3F10.5)
      AMASSL(I)=DEN*TLS(I)*HS(I)*RCS(I)*2.*PI
      TMASSL=TMASSL+AMASSL(I)
   WRITE(6,210)TLS(I),HLS(I),RCS(I)
   210 FORMAT(1H ,3(5X,F10.5),E12.5,I5)
   SUM1=SUM1+AMASSL(I)*RCS(I)**2.
105 CONTINUE
   WL=TAM/SUM1
   RPML=WL*30./PI
   WRITE(6,215)TMASSL
215 FORMAT(1H ,5X,'TOTAL MASS OF THE LINER = ',E15.6,//)
   WRITE(6,220)WL,RPML
220 FORMAT(1H ,5X,'SFF IS DYNAMICALLY STABLE AT CHARGE SPIN ',
1 'RATES GREATER THAN ',E12.6,3X,'(RAD/SEC)','E12.6,3X,'(RPM)')
   GO TO 500
10 IF(CMAT.LT.0.0)GO TO 50
   WRITE(6,40)CMAT
   WRITE(6,55)SD
55 FORMAT(1H ,5X,'SD = ',F10.5,5X,'(NOT IN THE RANGE 0-2)')
   WRITE(6,60)
60 FORMAT(1H ,5X,'BODY IS DYNAMICALLY UNSTABLE AT ANY SPINRATE')
   GO TO 500
50 SGI=SD*(2.-SD)
   SG=1./SGI
   SGA=ABS(SG)
   W=(SGA*PI*RHO*TIB*ABS(CMAT)*DB**3./(2.*AIB**2.))*5*VEL
   RPM=W*30./PI
   WRITE(6,25)CMAT
   WRITE(6,55)SD
   WRITE(6,65)SGI,SG
   WRITE(6,70)W,RPM
70 FORMAT(1H ,5X,'BODY IS DYNAMICALLY STABLE AT SPIN RATES ',
1 'LESS THAN ',E12.6,3X,'(RAD/SEC)','E12.6,3X,'(RPM)')
500 RETURN

END

C

C*************************************************************************
C*************************************************************************
C
C
SUBROUTINE SPLINE ( N , X , Y , B , C , D )
C C GENERATES CUBIC SPLINE COEFFICIENTS C
REAL X(101) , Y(101) , B(101) , C(101) , D(101)
NM1 = N - 1
IF(N-2)60,50,1
1 D(1) = X(2) - X(1)
 C(2) = (Y(2) - Y(1))/D(1)
 DO 10 I=2,NM1
 C(I) = X(I+1) - X(I)
 D(I) = X(I+1) - X(I)
 B(I) = 2.*(D(I-1) + D(I))
 C(I+1) = (Y(I+1) - Y(I))/D(I)
 C(I) = C(I+1) - C(I)
10 CONTINUE
 B(1) = -D(1)
 B(N) = -D(N-1)
 C(1) = 0.0
 C(N) = 0.0
 IF(N-3)11,15,11
11 C(1) = C(3)/(X(4)-X(2)) - C(2)/(X(3)-X(1))
 C(N) = C(N-1)/(X(N)-X(N-2)) - C(N-2)/(X(N-1)-X(N-3))
 C(1) = C(1)*D(1)*D(1)/(X(4)-X(1))
 C(N) = -C(N)*D(N-1)*D(N-1)/(X(N)-X(N-3))
15 DO 20 I=2,N
 T = D(I-1)/B(I-1)
 B(I) = B(I) - T*D(I-1)
 C(I) = C(I) - T*C(I-1)
20 CONTINUE
 C(N) = C(N)/B(N)
 DO 30 IB = 1,NM1
 I = N - IB
 C(I) = (C(I) - D(I)*C(I+1))/B(I)
30 CONTINUE
 B(N) = (Y(N) - Y(NM1))/D(NM1) + D(NM1)*(C(NM1) + 2.*C(N))
 DO 40 I = 1,NM1
 B(I) = (Y(I+1) - Y(I))/D(I) - D(I)*(C(I+1) + 2.*C(I))
 D(I) = (C(I+1) - C(I))/D(I)
 C(I) = 3.*C(I)
40 CONTINUE
 C(N) = 3.*C(N)
 D(N) = D(N-1)
 RETURN
50 B(1) = (Y(2)-Y(1))/(X(2)-X(1))
 C(1) = 0.0
 D(1) = 0.0
 B(2) = B(1)
 C(2) = 0.0
 D(2) = 0.0
60 RETURN
END
C C************************************************************************************************************************
C
SUBROUTINE SEVAL(XO,YO,D1YO,D2YO,D3YO, X,Y,B,C,D,N)
C 
C EVALUATES CUBIC SPLINE FOR A GIVEN ABSCISSA 
C 
REAL X(100), Y(100), B(100), C(100), D(100)
DATA I/1/
  IF(I-N)2,1,1
  1 I = 1
  2 IF(XO-X(I)) 10,3,3
  3 IF(XO-X(I+1)) 30,30,10
 10 I = 1
   J = N + 1
 20 K = (I+J)/2
   IF(XO-X(K)) 21,22,22
 21 J = K
   GO TO 23
 22 I = K
 23 IF(J - (I+1))30,30,20
 30 DX = XO - X(I)
   YO = Y(I) + DX*(B(I) + DX*(C(I) + DX*D(I)))
   D1YO = B(I) + DX*(2.*C(I) + 3.*D(I)*DX)
   D2YO = 2.*C(I) + 6.*D(I)*DX
   D3YO = 6.*D(I)
RETURN
END
UNCLASSIFIED
SFFSTAB INPUT

TITLE CARD (13A6, 2A1)

BODY MATERIAL DENSITY (F10.5)

SEGMENT CARD (2I5)

ITYPE = 0 - spherical segments and truncated cones are used
1 - only truncated cones are used
NSEG = number of segments

INDIVIDUAL SEGMENT CARDS - AS REQUIRED

SPHERICAL SEGMENT CARD (I5, 5X, 3F10.5) - AS REQUIRED

TRUNCATED CONE SEGMENT CARD (I5, 5X, 5F10.5) - AS REQUIRED
REFERENCE AXIS (F10.5) \[ RA = 0.0 \text{ if C of G is to be used} \]

**GYROSCOPIC STABILITY CARD (I5)**

- **ISG**
  - \( ISG = 0 \) - calculate \( SG \)
  - \( ISG = 1 \) - calculate \( W \)

**CARD FOR ISG = 0** (3F10.5) - AS REQUIRED

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<th>VEL</th>
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- \( W \) = spin rate (RAD/SEC)
- \( RHO \) = air density (lb sec\(^2\)/in\(^4\))
- \( VEL \) = body velocity (in/sec)

**CARD FOR ISG = 1** (3F10.5) - AS REQUIRED

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- \( SG \) = gyroscopic stability factor

**DRAG PARAMETERS CARD (2E10.5)**

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- \( U \) = absolute viscosity (lb sec/in\(^2\))
- \( ESR \) = equivalent sand roughness (in)
ISPIN = 1 + calculates charge spin rate

NLS = number of liner segments

TLS = thickness of segment
HLS = height of segment
RCS = radius of centroid of crosssectional area of liner segment
### BASELINE DESIGN SHOT #01

**SAMPLE PROBLEM INPUT**

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### Baseline Design Shot 01

#### Gyroscopic Stability Data

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**Reference Axis** = .00000  **SEG = 1**  
**SG = 1.00000**  **RHO = .00000011499999**  **Velocity = 92262.00000**

### Properties for Segment Number 1

**Hollow Spherical Segment**  
**Outer Radius** = .35640  **Inner Radius** = .00000  **Height** = .21520  
**Density** = .00083700  **Volume** = .03846823  **Mass** = .00003220  
**Distance from Reference Axis to Centroid** = .22600125  
**Distance from Base of Segment to Centroid** = .08480125  
**Axial Moment of Inertia** = .00000115  
**Transverse Moment of Inertia** = .00000073  
**Nose Bluntness** = .60382  **CMA** = .84218  **CMAP = -.45965**

### Properties for Segment Number 2

**Hollow Truncated Cone**  
**Outer Radius at Large End** = .40480  **Inner Radius at Large End** = .00000  
**Outer Radius at Small End** = .31930  **Inner Radius at Small End** = .00000  
**Height** = .20240  
**Density** = .00083700  **Volume** = .08373579  **Mass** = .00007009  
**Distance from Cone Base to Centroid** = .09327055  
**Axial Moment of Inertia** = .00000470  
**Transverse Moment of Inertia** = .00000259  
**Theta = 22.90069**  **A/D = .78878  **CMA = .62997  **CMAP = -.21029**

### Properties for Segment Number 3

**Hollow Truncated Cone**  
**Outer Radius at Large End** = .45760  **Inner Radius at Large End** = .00000  
**Outer Radius at Small End** = .40480  **Inner Radius at Small End** = .00000  
**Height** = .31070  
**Density** = .00083700  **Volume** = .18171506  **Mass** = .00015210  
**Distance from Cone Base to Centroid** = .14901710  
**Axial Moment of Inertia** = .00001423  
**Transverse Moment of Inertia** = .00000833  
**Theta = 9.64464**  **A/D = .88462  **CMA = .41093  **CMAP = -.11247**
## Properties for Segment Number 4

**Hollow Truncated Cone**

- **Outer Radius at Large End**: 0.47040
- **Inner Radius at Large End**: 0.00000
- **Outer Radius at Small End**: 0.45760
- **Inner Radius at Small End**: 0.00000
- **Height**: 1.17170
- **Density**: 0.00083700
- **Volume**: 0.79255570
- **Mass**: 0.00663370
- **Distance from Cone Base to Centroid**: 0.58046321
- **Axial Moment of Inertia**: 0.00007143
- **Transverse Moment of Inertia**: 0.00111590
- **Theta**: 0.62589
- **Theta**: 0.62589
- **A/D**: 0.97279
- **CNA P**: 0.09950
- **CMA**: 0.00000

## Properties for Segment Number 5

**Hollow Truncated Cone**

- **Outer Radius at Large End**: 0.54880
- **Inner Radius at Large End**: 0.00000
- **Outer Radius at Small End**: 0.47040
- **Inner Radius at Small End**: 0.00000
- **Height**: 0.69420
- **Density**: 0.00083700
- **Volume**: 0.56747804
- **Mass**: 0.00047498
- **Distance from Cone Base to Centroid**: 0.32933503
- **Axial Moment of Inertia**: 0.00006228
- **Transverse Moment of Inertia**: 0.00005010
- **Theta**: 6.44344
- **A/D**: 0.85714
- **CNA**: 0.51445
- **CMA**: -0.2005

## Table

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**Total Volume of Body**: 1.66395

**Total Mass of Body**: 0.00139

**Center of Gravity of Body (Relative to Base)**: 1.11068

**Axial Moment of Inertia of Body**: 0.00015

**Transverse Moment of Inertia of Body**: 0.00076

**CNA for the Body**: 1.51543

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TOTAL CMA FOR THE BODY = 1.51543
TOTAL CMA FOR THE BODY (BASED ON AREA AND BASE DIAMETER) = .48424
TOTAL CMA FOR THE BODY (BASED ON AREA AND BODY LENGTH) = .20488
LENGTH OF THE BODY = 2.59420
CENTER OF PRESSURE AS A FRACTION OF BODY LENGTH = .43666
SPIN RATE (RAD/SEC) = 5612.35498 SPIN RATE (RPM) = 53594.04440
OUT OF THE RANGE
OUT OF THE RANGE
***** DYNAMIC STABILITY DATA *****
EQUIVALENT SAND ROUGHNESS = .160000E-03 ADMISSIBLE ROUGHNESS = .162137E+05
REYNOLDS NUMBER = .106142E+08 ABSOLUTE VISCOSITY = .259320E-08
CUTOFF REYNOLDS NUMBER = .982166E+06
BODY MAXIMUM FRONTAL AREA = .94619 BODY WETTED AREA = 7.48865
DIMENSIONLESS AXIAL RADIUS OF GYRATION = .30295 DIMENSIONLESS TRANSVERSE RADIUS OF GYRATION = .67242

PROPERTIES FOR SEGMENT NUMBER 1
CDP = 1.15696 CMQP = .91817
CMQP = -.50000 CMQ = -.98937

PROPERTIES FOR SEGMENT NUMBER 2
CDP = .11442 CMQP = .41000
CMQP = -.14031 CMQ = -.93131

PROPERTIES FOR SEGMENT NUMBER 3
CDP = .01221 CMQP = .21421
CMQP = -.06286 CMQ = -.66824

PROPERTIES FOR SEGMENT NUMBER 4
CDP = .00001 CMQP = .00000
CMQP = .00000 CMQ = -.12824

PROPERTIES FOR SEGMENT NUMBER 5
CDP = .00688 CMQP = .39492
CMQP = -.18495 CMQ = -.63591
**INCOMPRESSIBLE FLAT PLATE SKIN FRICTION COEFFICIENT (CF) = .00447**
**COMPRESSIBLE/INCOMPRESSIBLE SKIN FRICTION COEFFICIENT (CFCCF) = .29972**

**BODY SKIN FRICTION DRAG COEFFICIENT (CDP) = .01080**
**BODY BASE DRAG COEFFICIENT (CDB) = .02795**
**BODY ZERO LIFT DRAG COEFFICIENT (CDL) = .52754**
**BODY PITCHING DERIVATIVE (CMQ) = -.22958**
**DERIVATIVE OF THE MUSKUS MOMENT COEFFICIENT (CMPA) = .01113**
**BODY ACCELERATION DERIVATIVE (CMPA) = .00000**

**DYNAMIC STABILITY FACTOR (SD) = .41145**
**CMA = .46424 (POSITIVE)**
**SD = .41145 (IN THE RANGE 0-2)**
**SGI = .65361 SG = 1.62996 (VALUES ON DYNAMIC STABLE/UNSTABLE CURVE)**

**BODY IS DYNAMICALLY STABLE AT SPIN RATES GREATER THAN .694200E+04 (RAD/SEC) \* .662912E+05 (RPM)**

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### LINER DATA

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**TOTAL MASS OF THE LINER = .133343E-02**

**SFF IS DYNAMICALLY STABLE AT CHARGE SPIN RATES GREATER THAN .404143E+03 (RAD/SEC) \* .385928E+04 (RPM)**
An aerodynamic stability computer program (SFFSTAB) has been developed for calculating the spin rate required for stabilization of a self-forging fragment. An aerodynamic stability criterion which combined gyroscopic and dynamic stability was used together with a technique for calculating aerodynamic coefficients. SFFSTAB is a useful tool for conducting aerodynamic stability parameter studies for different fragment shapes. Complete documentation of the computer program including sample problem, flowchart and FORTRAN listing is provided.
END 6 - 81 DTC