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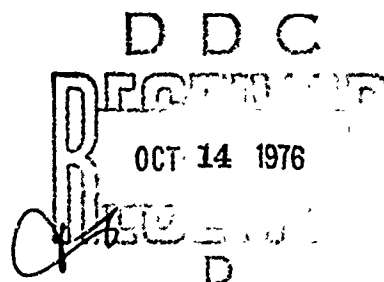
Bethesda, Md. 20084

A COMPUTER PROGRAM FOR THE PRELIMINARY DESIGN OF  
CONTRAROTATING PROPELLERS

by

E. B. Caster and T. A. LaFone

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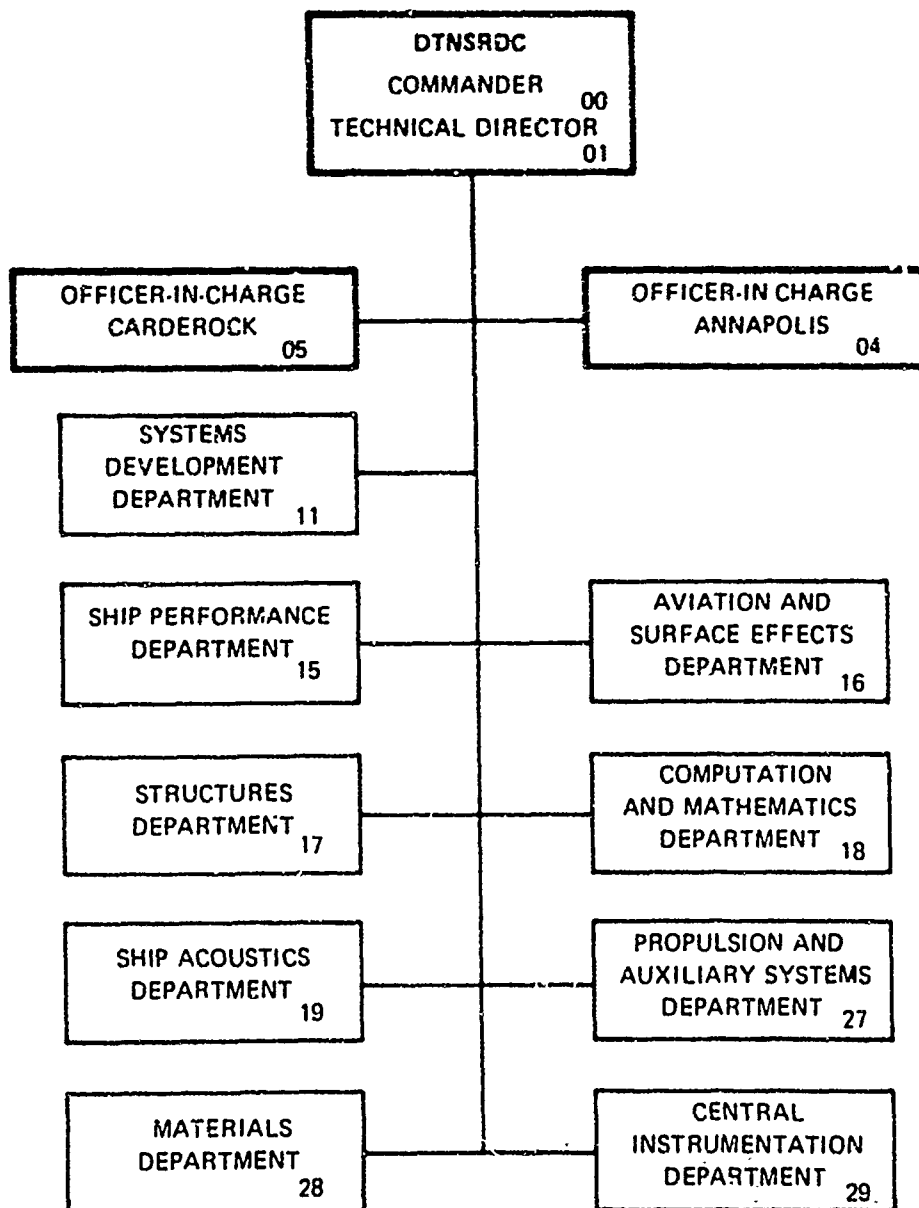
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surface theory.

An analysis of results obtained for a sample set of contrarotating propellers, designed using the new method presented, show that different design and performance predictions are obtained for the aft propellers when results are compared to those calculated using the old method. Calculations made using the new design method are considered more accurate due to the improved method of determining the propeller interaction effects.

A FORTRAN listing of the new propeller, developed to run on the computer at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) is presented as well as input and output obtained for a sample set of contrarotating propeller designs.

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# NOTATION

|                          |                                                                                                                                                             |
|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $A_E$                    | Expanded blade area, $2 \int_{r_h}^R c \, dr$                                                                                                               |
| $A_E/A_O$                | Propeller expanded area ratio, $(2Z/\pi) \int_{x_h}^1 c/D \, dx$                                                                                            |
| $(A_E/A_O)_K$            | Keller's minimum expanded area ratio for eliminating back bubble cavitation, $(2.6+0.6Z)K_T / \{ \sigma_{0.7} [J^2 + (0.7\pi)^2] \} + K$                    |
| $A_O$                    | Disc area, $\pi D^2/4$                                                                                                                                      |
| $A_P$                    | Estimated propeller projected area, $(1.067-0.229(P/D)_1) A_E$                                                                                              |
| $a(x)$                   | Area of section, $2 c(x) t(x) \int_0^1 t(x, x_\ell) \, dx$                                                                                                  |
| $B(x)$                   | Distance of CG from face, $\bar{y} \cos \phi + x \sin \phi - \theta_S \times R \tan \phi - \theta_R \times R + D_H/2$                                       |
| $(c/R)_{LE}, (c/R)_{TE}$ | Chord lengths measured from leading edge and trailing edge of blade to propeller reference line                                                             |
| $C_D$                    | Section drag coefficient                                                                                                                                    |
| $C_{FO}$                 | Frictional resistance of section                                                                                                                            |
| CG                       | Center of gravity                                                                                                                                           |
| $C_L$                    | Blade section lift coefficient                                                                                                                              |
| $C_P$                    | Power loading coefficient, $P_D / \{ (\rho/2) \pi R^2 V_A^3 \}$                                                                                             |
| $C_{PS}$                 | Power loading coefficient based on ship speed, $P_D / \{ (\rho/2) \pi R^2 V^3 \}$ ; calculated $\int_{x_h}^1 (1+\epsilon/\tan \beta_I) (dC_{PSi}/dx) \, dx$ |
| $C_{TS}$                 | Thrust loading coefficient based on ship speed, $T / \{ (\rho/2) \pi R^2 V^2 \}$ ; calculated $\int_{x_h}^1 (1-\epsilon \tan \beta_I) (dC_{TSi}/dx) \, dx$  |
| $c$                      | Propeller blade chord length, $c(x)$                                                                                                                        |
| $C_{PSi}$                | Inviscid power loading coefficient, $(4Z/\lambda_s) \times G \{ (1-w_x) + U_T/2V \}$                                                                        |
| $C_{TSi}$                | Inviscid thrust loading coefficient, $4ZG(x/\lambda_s - U_A/2V)$                                                                                            |

|                    |                                                                                                     |
|--------------------|-----------------------------------------------------------------------------------------------------|
| D                  | Propeller diameter                                                                                  |
| $d_H$              | Hub diameter                                                                                        |
| F(x)               | Parameter for calculating the fluctuating angles of attack, $1/(1+2\pi\tan(\beta_I-\beta)/C_{L_I})$ |
| $f_M$              | Camber                                                                                              |
| g                  | Acceleration due to gravity                                                                         |
| $g_a$              | Lerbs axial distance factors (Reference 1)                                                          |
| G(r)               | Nondimensional circulation about a blade section, $\Gamma/(2\pi RV)$                                |
| $G_F$              | Spacing between fillets                                                                             |
| $G_Z$              | Spacing between blades at hub                                                                       |
| H                  | Static head at propeller shaft centerline                                                           |
| $I_{x_o}, I_{y_o}$ | Moment of inertia of blade section about x and y axes                                               |
| J                  | Advance coefficient, $V(1-w_T)/(nD) = V_A/(nD)$                                                     |
| $J_V$              | Ship speed advance coefficient, $V/(nD)$                                                            |
| K                  | Kellers' constant for predicting minimum blade area of propeller (see p. 24)                        |
| $K_Q$              | Torque coefficient, $Q/(\rho n^2 D^5)$                                                              |
| $K_T$              | Thrust coefficient, $T/(\rho n^2 D^4)$                                                              |
| LI                 | Propeller lift distribution per unit span for finite element stress calculations                    |
| $M_P$              | Moment of blades (see p. 24 )                                                                       |
| $M_{Tb}, M_{Qb}$   | Moment due to thrust and torque                                                                     |
| $M_{x_o}, M_{y_o}$ | Moment parallel and perpendicular to the nose-tail line                                             |
| n                  | Propeller revolution per unit time                                                                  |

|                |                                                                                                |
|----------------|------------------------------------------------------------------------------------------------|
| $(P/D)_i$      | Estimated propeller pitch ratio at 0.7 radius, $0.7\pi\tan\beta_i$ in program                  |
| $P_D$          | Delivered power at propeller, $2\pi Qn$                                                        |
| $P_E$          | Effective power                                                                                |
| $P_S$          | Shaft power                                                                                    |
| $Q$            | Propeller torque                                                                               |
| $R$            | Propeller tip radius                                                                           |
| $r$            | Propeller local radius                                                                         |
| $r_h$          | Propeller hub radius                                                                           |
| $r_\ell$       | Local position along the section chord                                                         |
| $T$            | Propeller thrust                                                                               |
| $t$            | Propeller blade maximum thickness $t(x)$ , thrust deduction fraction                           |
| $t(x, x_\ell)$ | Chord wise distribution of section thickness (NACA 66 modified thickness form is used)         |
| $U_A/2V$       | Axial induced velocity at lifting line                                                         |
| $U_T/2V$       | Tangential induced velocity at lifting line                                                    |
| $V$            | Ship speed                                                                                     |
| $V_A$          | Speed of advance of the propeller, $V(1-w_T)$                                                  |
| $V_x$          | Local velocity along the x axis at any field point                                             |
| $V_r$          | Inflow velocity at each propeller section, $V/\sqrt{(1-w_x)+U_A/2V)^2+(x/\lambda_s-U_T/2V)^2}$ |
| $w_a/V$        | Axial velocity from sources other than the propeller wake $(1-w_x)$                            |
| $W_B$          | Weight of blades                                                                               |
| $W_H$          | Weight of hub                                                                                  |
| $W_P$          | Propeller weight                                                                               |

|                 |                                                                                                      |
|-----------------|------------------------------------------------------------------------------------------------------|
| $w_c$           | Circumferential mean wake fraction at each radius calculated from wake survey                        |
| $w_t/V$         | Tangential wake velocities from sources other than the propeller wake $(1-w_x)$                      |
| $w_T$           | Propeller effective wake fraction as determined from thrust identity from self propulsion experiment |
| $w_v$           | Volume mean wake fraction                                                                            |
| $w_x$           | Propeller wake fraction                                                                              |
| $x$             | Nondimensional radial distance, $r/R$                                                                |
| $x_h$           | Nondimensional hub radius, $(r_h/R)$                                                                 |
| $x_\ell$        | Nondimensional distance along section chord, $(r_\ell/c)$                                            |
| $z$             | Number of blades                                                                                     |
| $z_R$           | Propeller rake                                                                                       |
| $z_T$           | Total rake, rake plus induced rake                                                                   |
| $\alpha_i$      | Section ideal angle of attack, $1.54C_L$ for NACA $a=0.8$ meanline in two-dimensional flow           |
| $\alpha_{\max}$ | Maximum fluctuating angle of attack, $\alpha_i - (-\Delta\beta)F(x)$                                 |
| $\alpha_{\min}$ | Minimum fluctuating angle of attack, $\alpha_i - (+\Delta\beta)F(x)$                                 |
| $\beta$         | Advance angle of a propeller blade section                                                           |
| $\beta_I$       | Hydrodynamic flow angle of a propeller blade section                                                 |
| $\Gamma$        | Propeller circulation, $2\pi RVG$                                                                    |
| $\epsilon$      | Section drag-lift ratio, $C_D/C_L$                                                                   |
| $\eta_D$        | Propulsive efficiency, $P_E/P_D = (1-t)C_{TS}/C_{PS}$                                                |
| $\theta_R$      | Blade rake angle in degrees (see p. 15)                                                              |
| $\theta_S$      | Blade skew angle in degrees (see p. 15)                                                              |

|                |                                                                                    |
|----------------|------------------------------------------------------------------------------------|
| $\lambda_s$    | Advance ratio of propeller based on ship speed, $V/(nD)$                           |
| $\rho$         | Water density                                                                      |
| $\rho_p$       | Density of propeller material                                                      |
| $\phi$         | Pitch angle                                                                        |
| $\sigma$       | Section cavitation number, $2gH/V_r^2$                                             |
| $\sigma_{0.7}$ | Burrill cavitation number,<br>$2gH/\{(V(1-w_{x=0.7})^2 + (0.7\pi nD)^2\}$          |
| $\tau_c$       | Burrill thrust loading coefficient,<br>$2gH/\{(V(1-w_{x=0.7})^2 + (0.7\pi nD)^2\}$ |

# **ABSTRACT**

This report presents a new computer program that can be used to design and predict the performance of contrarotating propellers. The new program utilizes the latest numerical computation techniques developed for the design of contrarotating propellers. The hydrodynamic pitch angle distribution is specified as input and the design calculations are made using Lerbs' moderately loaded single screw lifting line propeller theory. The propeller interaction effects (the most important new feature of the design procedure) are obtained using Kerwin's field point velocity program developed using finite bladed lifting surface theory.

An analysis of results obtained for a sample set of contrarotating propellers, designed using the new method presented, show that different design and performance predictions are obtained for the aft propeller when results are compared to those calculated using the old method. Calculations made using the new design method are considered more accurate due to the improved method of determining the propeller interaction effects.

A FORTRAN listing of the new program, developed to run on the computers at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) is presented as well as input and output obtained for a sample set of contrarotating propeller designs.

## ADMINISTRATIVE INFORMATION

This work was sponsored by the Naval Sea Systems Command, SEA 034, and carried out under the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) Work Unit 1544-256, Task 14438.

## INTRODUCTION

The David W. Taylor Naval Ship Research and Development Center (DTNSRDC), Carderock Laboratory, was requested by the Naval Sea Systems Command (NAVSEA) to develop a computer program that can be used to better design and predict the propulsive and cavitation performance of contrarotating propellers. Contrarotating propellers have been used on naval vessels, especially torpedoes, because they offer advantages over single-screw propellers by being more efficient, having smaller optimum diameters, and being torque-balanced resulting in better stability. Unfortunately, the contrarotating propeller theory and design procedure have not kept pace with the advancement developed for single-screw propellers where the design and performance predictions can be made with a high degree of accuracy.

The old contrarotating propeller design procedure used at DTNSRDC is based on Lerbs' theory of References 1, 2, and 3. This method requires that the same hydrodynamic pitch distribution be specified as input for the forward and aft propellers and results obtained show that similar circulation distributions are computed for both propellers. The average axial and tangential propeller induced velocities used to determine the propeller interaction effects are derived using the uniformly loaded sink disc theory in this design method.

DTNSRDC is presently evaluating a package of contrarotating propeller design computer programs based on lifting line and lifting surface theories, recently developed by Nelson in Reference 4. The propeller lifting line theory used requires the circulation distribution (which must be the same for the forward and aft propellers) rather than the hydrodynamic pitch distribution, to be specified as input. The corresponding hydrodynamic pitch distribution is calculated using Lerbs' moderately loaded single screw theory

1. Lerbs, H.W., "Contra-Rotating Optimum Propellers Operating in a Radially Non-Uniform Wake," David Taylor Model Basin Report 941, May 1955
2. Morgan, William B. and Wrench, J.W., Jr., "Some Computational Aspects of Propeller Design," Methods in Computational Physics, Vol. 4, Academic Press Inc., New York, p 301-331, 1965
3. Morgan, W.B., "The Design of contrarotating Propellers Using Lerbs' Theory," Transactions of the Society of Naval Architects and Marine Engineers, vol. 68, p 6-38, 1960
4. Nelson, D.M., "A Computer Program Package for Designing Wake-Adapted Counterrotating Propellers: A Users Manual," Naval Undersea Center, Fleet Engineering Department Report NUC TP 494, December 1975

of Reference 5, which has been extended to account for finite circulation values at the propeller hub. Nelson's method for determining propeller interaction effects (average axial and tangential propeller induced velocities) are determined using the procedure developed by Hough and Ordway in Reference 6, corrected to account for finite blade number effects. Preliminary results from Nelson's computer program for making pitch and camber calculations based on contrarotating propeller lifting surface theory show that lifting surface effects due to the forward and aft propellers are small.

The new contrarotating propeller design computer program based on Lerbs moderately loaded single screw propeller theory of Reference 5 is similar to the computer program developed for single screw propellers in Reference 7 except that additional calculations are required to account for propeller interaction effects required in the contrarotating propeller design program. The average axial and tangential propeller-induced velocities needed to determine the propeller interaction

5. Lerbs, H.W., "Moderately Loaded Propellers with a Finite Number of Blades and an Arbitrary Distribution of Circulation," Transactions of the Society of Naval Architects and Marine Engineers, Vol. 60, p 73-117, 1952
6. Hough, G.R. and Ordway, D.E., "The Generalized Actuator Disk," Advanced Research Report TAR-TR-6401, Therm, Inc., January 1964
7. Caster, E.B., Diskin, J.A., and LaFone, T.A., "A Lifting Line Computer Program for the Preliminary Design of Propellers," David W. Taylor Naval Ship Research and Development Center Report SPD-595-01, November 1975

effects are derived using Kerwin's field point velocity program described by Denny in Reference 8. These calculations represent the most important new feature of the design procedure presented. Unlike the old method<sup>1,2,3</sup>, the new contrarotating propeller design computer program allows different hydrodynamic pitch distributions, wake distributions and rpm values to be specified as input for the forward and aft propellers. Nelson's lifting surface theory<sup>4</sup> for contrarotating propellers should be used to calculate the final pitch and camber for these propellers. Preliminary results using Nelson's lifting surface theory show that the lifting surface interaction effects due to the forward and aft propellers are small. As a result, lifting surface theory developed for single screw propellers (Reference 9) may be used to determine the final pitch and camber for the contrarotating propellers if Nelson's program is not available. The estimated propeller stresses are calculated based on simple beam theory<sup>10</sup> modified to account for effect of rake and skew. The propeller weight, spacing between propeller blades, chord lengths for lifting surface

pitch and camber calculations and blade load distributions

8. Denny, Stephen B., "Comparisons of Experimentally Determined and Theoretically Predicted Pressures in the Vicinity of a Marine Propeller," Naval Ship Research and Development Center Report 2349, May 1967
9. Morgan, W.B., Silovic, Vladimir, and Denny, S.B., "Propeller Lifting Surface Corrections," Transactions of the Society of Naval Architects and Marine Engineers, Vol. 76, p 309-347, 1968.
10. Eckhardt, M.K. and Morgan, W.B., "A Propeller Design Method," Transactions of the Society of Naval Architects and Marine Engineers, Vol. 63, p 325-370, 1955

for finite element stress calculations are also included in the calculations made using this method. Parameters for calculating the minimum expanded area ratio by Keller<sup>11</sup> and the methods of Burrill<sup>12</sup> and Brockett<sup>13</sup> are used to check the cavitation performance of each propeller. An input option to specify the hull radial induced velocity (not available in the program presented) would also improve the accuracy of the design calculations.

#### PROPELLER LIFTING-LINE THEORY

As mentioned in the Introduction, the new contrarotating design procedure follows closely Lerbs' moderately loaded, single-screw lifting-line propeller theory<sup>5</sup> as described in Reference 7. Kerwin's field point velocity program<sup>8</sup> is used to determine the propeller interaction effects (average axial and tangential propeller-induced velocities). The diameter of the aft propeller is based on contraction of the slip stream. These calculations are made using the continuity equation as described in Reference 1, once Lerbs' distance factors ( $g_a$ ) values, plotted in Figure 1, are specified. More exact con-

traction of the slip stream calculations can be made using

11. Keller, J. Auf'm, "Enige aspecten bij het ontwerpen van Scheepsschroeven," *Schip en Werf*, No. 24, p 658-662, 1966
12. Burrill, L.C. and Emerson, A., "Propeller Cavitation: Further Tests on 16-Inch Propeller Models in the Kings College Cavitation Tunnel," *Transactions of the North East Coast Institution of Engineers and Ship Builders*, Vol. 78, p 295-320, 1963-64
13. Brockett, Terry, "Minimum Pressure Envelopes for Modified NACA 66 Sections with NACA  $a=0.8$  Camber and BUSHIPS Type I and Type II Sections," *David Taylor Model Basin Report 1780*, 1966

the propeller-induced field point velocity program of Reference 8 if velocities are calculated at a sufficient number of points. This approach was not used in the program presented because it would result in a significant increase in the core size and running time of the computer program.

The main steps in the new contrarotating propeller design procedure presented are as follows:

1. Lerbs' moderately loaded single-screw lifting-line propeller theory<sup>5</sup> is used to make design calculations for the forward propeller. The average axial and tangential velocities induced by the aft propeller on the forward propeller are not included initially in these calculations, but must be included in subsequent calculations.
2. Lerbs' contrarotating (equivalent) propeller design procedure<sup>1</sup> is used to calculate the aft propeller diameter.
3. Kerwin's field point velocity program described in Reference 8 is used to compute the average axial and tangential velocities induced by the forward propeller on the aft propeller.

4. The aft propeller design calculations are made using Lerbs' moderately loaded single-screw lifting-line propeller theory<sup>5</sup> where the average axial and tangential velocities induced by the forward propeller on the aft propeller (step 3) are included in the aft propeller calculations. These steps (1 through 4) are repeated until the propeller-induced velocities converge.

#### DESCRIPTION OF INPUT DATA

Appendix A presents a list of dimensioned propeller design parameters required for the new computer program developed which must be in the international system of units (SI units). This list also contains conversion factors ( $K_{SI}$ ) for changing dimensioned parameters from SI units to English units. Effective power ( $P_E$ ), speed ( $V$ ), number of blades ( $Z$ ), diameter ( $D$ ), propeller wake ( $1-w_x$ ), the hydrodynamic flow angle distribution ( $\beta_I$ ) and distance factors ( $g_a$ ) from Figure 1 are required input parameters in order to make nonviscous propeller design calculations based on lifting-line theory. The radial distribution of blade chord lengths, nondimensionalized on diameter, ( $c/D$ ) and section drag coefficients ( $C_D$ ) must be specified as input if design calculations are to account for the viscous

drag effects on the blades. The radial distribution of maximum thickness nondimensionalized on chord length ( $t/c$ ), blade rake angle ( $\theta_R$ ), and skew angle ( $\theta_S$ ) parameters are input so propeller stresses based on beam theory of Reference 10 can be calculated. The static head ( $H$ ) is input so the blade section cavitation number ( $\sigma$ ) can be computed. Appendix A also gives the complete input format (card numbers, format and description of input parameters) for the computer program. A brief description of how some of these parameters can be determined will be discussed next.

#### Effective Power, Speed, and Shaft Power

Effective power and speed are normally obtained from model self-propulsion experiments. Input effective power ( $P_E$ ) and shaft power ( $P_S$ ) are defined as follows:

$$P_E = VT(1-t) \quad (1)$$

$$P_S = 2\pi nQ \quad (2)$$

where  $n$  = propeller revolutions

$P_S$  = shaft power,

$P_E$  = effective power,

$Q$  = propeller torque,

$T$  = propeller thrust,

$V$  = ship speed, and

$(1-t)$  = thrust deduction, which may vary with propeller diameter and speed.

#### Nondimensional Radial Distance ( $x$ )

This is a reference set of eleven nondimensional radial distances  $x_i$  at which all other distributions, either input or calculated by the computer, are defined as existing.

In general,  $x_i = r_i/R$ , with the restrictions

$$x_1 = r_h/R$$

$$x_{11} = R/R=1,$$

where  $r_i$  = the distance along the propeller reference line

from the shaft axis to the  $i$ th section,

$r_h$  = propeller hub radius, and

$R$  = propeller tip radius.

#### Propeller Wake

The radial distribution of the axial wake ( $1-w_x$ ) which varies with propeller diameter is also required input data. The circumferential mean of the axial velocity distribution ( $1-w_c$ ) is obtained from a wake survey without the propeller operating. However, the ( $1-w_c$ ) wake distribution must be corrected for the propeller action. No completely satisfactory method is presently available to obtain this correction, but an approximation of the radial distribution of the wake ( $1-w_x$ ) with the propeller operating is obtained as follows:

### Wake distribution

$$(1-w_x) = \{(1-w_T)(1-w_C)\}/(1-w_v) \quad (3)$$

where  $(1-w_C)$  = radial distribution of the circumferential  
mean wake from wake survey data,

$(1-w_T)$  = effective wake from self propulsion data

$(1-w_v)$  = volume mean wake,  $\{2/(1-x_h^2)\} \int_{x_h}^1 (1-w_x) x dx$ ,

$R$  = propeller radius,

$r$  = propeller local radius,

$r_h$  = propeller hub radius,

$x$  = nondimensional radial distance ( $r/R$ ), and

$x_h$  = nondimensional hub radius ( $r_h/R$ ).

The propeller wake distribution may also vary with propeller diameter depending on the hull characteristics of the vessel.

### Advance Angle Distribution Option

The advance angle distribution ( $\tan\beta$ ) defined as  $V(1-w_x)/(\pi n D x)$  is normally calculated on the computer for the case where the propeller wake  $(1-w_x)$  from Equation (3) sufficiently represents wake in the plane of the propeller being designed. For most single screw propeller designs this approach gives good performance predictions. If a propeller operates inside a duct or in the vicinity of another propeller as in the case of tandem or contrarotating propellers, the axial ( $w_a/V$ ) and tangential ( $w_t/V$ ) velocities induced by these additional sources can be accounted for using

different methods. For contrarotating propellers, the propeller interference velocities are computed using Kerwin's field point velocity program described in Reference 8 in the following manner:

$$\tan\beta = [(1-w_x) + w_a/V] / [(x/\lambda_s) - w_t/V] \quad (4)$$

where  $w_a/V$  = axial velocity induced by forward and aft propellers on each other,

$w_t/V$  = tangential velocity induced by forward and aft propeller on each other,

$\lambda_s$  = advance ratio based on ship speed,  $V/(\pi n D)$

$V$  = ship speed, and

$D$  = propeller diameter.

It can be seen from Equation (4) that for the case where  $(w_a/V)$  and  $(w_t/V)$  values are specified as zero, the advance angle  $\tan\beta$  is calculated in the usual manner when designing single screw propellers.

#### Hydrodynamic Flow Angle

The hydrodynamic flow angle distribution ( $\tan\beta_I$ ) can be specified as input. An option is included so Lerbs' optimum  $\tan\beta_I$  distribution<sup>10</sup> can be calculated by the computer as follows:

$$\tan\beta_I = (\tan\beta/\eta_i) \left( (1-w_T)/(1-w_X) \right)^{1/2} \quad (5)$$

where  $\eta_i$  = propeller ideal efficiency

$\tan\beta$  = advance angle distribution.

Lerbs' optimum  $\tan\beta_I$  distribution usually results in optimum propeller efficiency. If other factors such as cavitation, strength and vibration are considered, the input of an alternate  $\tan\beta_I$  distribution may be desired.

#### Static Head

The static head (H) at the shaft centerline is required input. This parameter (H) is defined as  $H_s + H_a - H_v$ , where  $H_s$  is the shaft submergence,  $H_a$  is the atmospheric pressure, and  $H_v$  is the vapor pressure of fluid which is normally small compared with  $H_a$  and may be neglected. The static head (H) is used to calculate the section cavitation number ( $\sigma$ ) in Equation (25) and the Burrill cavitation number  $\sigma_{0.7}$  of Equation (30).

#### Blade Outline and Expanded Area Ratio

The blade outline (c/D) and expanded area ratio ( $A_E/A_O$ ) must be input for the design. An expanded area ratio ( $A_E/A_O$ ) is calculated on the computer according to:

Expanded Area Ratio:

$$A_E/A_O = (2Z/\pi) \int_{x_h}^1 c/D \, dx \quad (6)$$

where  $c$  = chord length,

$c/D$  = nondimensional chord length

$Z$  = number of blades

The final blade outline and expanded area ratio should be chosen to give satisfactory propeller strength and cavitation characteristics.

#### Blade Thickness to Chord Ratio

The input of maximum thickness to chord ratio ( $t/c$ ) values allow an estimate of the propeller principal stresses (see The Propeller Stress Calculations Using Beam Theory section discussed later) based on beam theory<sup>10</sup> to be calculated during the preliminary design stage of the propellers. From a rough estimate of the blade outline ( $c/D$ ) for the final design and an estimate of the radial distribution of thickness ( $t/D$ ) based on fatigue strength<sup>10</sup>, the following equation can be used to obtain initial ( $t/c$ ) input values:

Blade Thickness Ratio:

$$t/c = (t/D)/(c/D) \quad (7)$$

where  $t/D$  = radial distribution of thickness (can be estimated from Reference 10).

### Rake and Skew

The rake angle at the blade tip ( $\theta_R$ ) and the skew angles ( $\theta_S$ ) for a design are specified to permit adequate predictions of principal propeller stresses using the beam theory method described in Reference 10 and discussed later in the Propeller Stress section of this report.

The rake ( $\theta_R$ ) is defined consistent with Reference 14 as the distance from the propeller plane to the generator line in the direction of the shaft axis. Aft displacement is considered positive rake.

Since the skew angles ( $\theta_S$ ) significantly affect propeller unsteady forces, a computer program based on the unsteady contrarotating propeller lifting surface theory of Reference 15 can be used to select the skew angles ( $\theta_S$ ) for the design. The input skew angles ( $\theta_S$ ) in degrees are defined as the angular displacement of points on the blade reference line from the propeller reference line in the projected view.

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14. Cumming, R.A., Dictionary of Ship Hydrodynamics - Propeller Section, 14th International Towing Tank Conference 1975, Report of Presentation Committee, Appendix VII, 1975
  15. Tsakonas, J. and Jacobs, W.R., "Counterrotating and Tandem Propellers Operating in Spatially Varying, Three-Dimensional Flow Fields," Davidson Laboratory, Stevens Institute of Technology Report 1335, September 1968

### Section Drag Coefficient

In order to account for viscous effects when predicting the performance of a propeller, the section drag coefficient ( $C_D$ ) must be specified as input. A section drag coefficient ( $C_D$ ) value of 0.0085 usually gives reasonable estimates of model propeller drag for propeller shapes normally used at DTNSRDC in the past. For propellers having very thick blades, the following equation, available as an input option on the computer, and derived as a function of maximum thickness ( $t/c$ ) values using experimental data from NACA 66 type section<sup>16,17</sup>, will give a better estimate of the section drag coefficient ( $C_D$ ):

Section Drag Coefficient:

$$C_D = C_{FO} \left[ 1 + 1.25(t/c) + 125 (t/c)^4 \right] \quad (8)$$

where  $C_{FO}$  is the frictional resistance of the section, e.g.,

$C_{FO} \approx 0.008$  for Reynolds number of approximately  $10^6$  and

$C_{FO} \approx 0.004$  for Reynolds number of approximately  $10^8$ .

Options for using alternate nonlinear  $C_D$  distributions, or a constant  $C_D$  distributions are also available.

### Lerbs Axial Distance Factors

It was noted earlier that Lerbs' axial distance factors ( $g_a$ ), rather than the use of the more correct propeller-

induced velocities from Reference 8, were used to obtain

16. Abbot, Ira H. and Von Doenhoff, Albert E., "Theory of Wing Sections Including a Summary of Airfoil Data," Dover Publication Inc., New York, Library of Congress Catalog No.: 60-1601, 1949
17. Hoerner, S.F., "Fluid-Dynamic Drag," Published by the author, Midland Park, New Jersey, 1965

contraction of the slip stream and the aft propeller diameter in order to minimize core size and running time of the computer program. The  $g_a$  values from Reference 1, plotted as a function of propeller radius and spacing between propeller blade center lines, are presented in Figure 3.

#### DESCRIPTION OF OUTPUT DATA

Lerbs' lifting line theory is used to calculate the propeller lift coefficient ( $C_L$ ), nondimensional circulation ( $G$ ), hydrodynamic flow angle ( $\beta_I$ ), axial induced velocity ( $U_A/2V$ ), and tangential induced velocity ( $U_T/2V$ ). These lifting-line calculations take into account viscous drag effects on the propeller by specifying as input in the computer program the propeller section nondimensional chord length ( $c/D$ ) and section drag coefficient ( $C_D$ ). A method for obtaining values for  $c/D$  and  $C_D$  is discussed in the Description of Input Data section of this report. With these parameters available, the necessary design and performance prediction parameters for contrarotating propellers can be obtained.

#### Thrust and Power Loading Coefficients, and Propulsive Efficiency

The new contrarotating propeller design computer program calculates the thrust ( $C_{TS}$ ) and power ( $C_{PS}$ ), loading coefficients based on ship speed and the estimated propulsive efficiency ( $\eta_D$ )

for these propellers in the following manner:

Thrust Loading Coefficient:

$$(C_{TS})_{fwd,aft} = \int_{x_h}^1 (1 - \epsilon \tan \beta_I) / (dC_{TSI}/dx) dx = T / ((\rho/2) \pi R^2 V^2) \quad (9)$$

$$(C_{TS})_{CR} = (C_{TS})_{fwd} + (R_{aft}/R_{fwd})^2 (C_{TS})_{aft} \quad (10)$$

Power Loading Coefficient:

$$(C_{PS})_{fwd,aft} = \int_{x_h}^1 (1 + \epsilon / \tan \beta_I) (dC_{PSI}/dx) dx = P_S / ((\rho/2) \pi R^2 V^3) \quad (11)$$

$$(C_{PS})_{CR} = (C_{PS})_{fwd} + (R_{aft}/R_{fwd})^2 (C_{PS})_{aft} \quad (12)$$

Propulsive Efficiency:

$$(\eta_D)_e)_{CR} = (1 - t) C_{TS} / C_{PS} = P_E / P_D \quad (13)$$

where based on ship speed

$$(C_{TS})_{DESIGN} = T / ((\rho/2) \pi R^2 V^2)$$

$$(C_{PS})_{DESIGN} = P_S / ((\rho/2) \pi R^2 V^3)$$

fwd,aft = subscripts for forward and aft propellers,  
respectively

CR = subscript for the set of contrarotating propellers

$C_{TSI}$  = nondimensional inviscid local thrust loading  
coefficient,  $4ZG(x/\lambda_S - U_A/2V)$

$C_{PSI}$  = nondimensional inviscid local power loading  
coefficient,  $(4Z/\lambda_S) x G((1 - w_x) + U_T/2V)$

G = nondimensional circulation from lifting line theory

$U_A/2V$  = axial induced velocity from lifting line theory

$U_T/2V$  = tangential induced velocity from lifting line theory

V = ship speed

$\rho$  = density of fluid

The calculated thrust (T) is obtained from Equation (9) and the shaft power ( $P_S$ ) is calculated using Equation (11) for each propeller.

Other parameters useful in designing and evaluating the performance of propellers include the advance coefficient (J), ship speed advance coefficient ( $J_V$ ), thrust coefficient ( $K_T$ ), torque coefficient ( $K_Q$ ), moment due to thrust ( $M_{Tb}$ ), moment due to torque ( $M_{Qb}$ ), moment parallel to section nose-tail line ( $M_{x_0}$ ), moment perpendicular to the nose-tail line ( $M_{y_0}$ ), and the blade loading distribution (LI). These parameters are calculated as follows:

Advance Coefficient:

$$J = V(1-w_T)/(nD) = V_A/(nD) \quad (14)$$

Ship Speed Advance Coefficient:

$$J_V = V/(nD) \quad (15)$$

Thrust Coefficient:

$$K_T = T/(\rho n^2 D^4) = (\pi C_{TS}/8) J_V^2 \quad (16)$$

Torque Coefficient:

$$K_Q = Q/(\rho n^2 D^5) = (C_{PS}/16) J_V^3 \quad (17)$$

Moment Due to Thrust:

$$M_{Tb}(x) = (\rho \pi R^3 V^2 / (2Z)) \int_{x_h}^1 (x-x_0) (1-\epsilon \tan \beta_I) (dC_{TSI}/dx) dx \quad (18)$$

Moment Due to Torque:

$$M_{Qb}(x) = (\rho \pi R^3 V^2 / (2Z)) \int_{x_h}^1 (x - x_o) (\tan \beta_I + \epsilon) (dC_{TSI} / dx) dx \quad (19)$$

Moments Parallel to Section Nose-tail Line:

$$M_{xo}(x) = M_{Tb} \cos \phi + M_{Qb} \sin \phi \quad (20)$$

Moment Perpendicular to Section Nose-tail Line:

$$M_{yo}(x) = M_{Tb} \sin \phi - M_{Qb} \cos \phi \quad (21)$$

Blade Loading Distribution:

$$LI(x) = \frac{1}{2} \rho c V_r^2 C_L \quad (22)$$

where  $x, x_o$  = propeller nondimensional radial stations,  $r/R$  and  $r_o/R$

$\phi$  = propeller pitch angle ( $\phi = \beta_I$  in computer program)

$V_r$  = section inflow velocity,  $\sqrt{[(1-w_x) + U_A/2V]^2 + [(x/\lambda_S) - U_T/2V]^2}$

#### PROPELLER STRESS CALCULATIONS USING BEAM THEORY

A propeller blade must contain enough material to keep the stresses within a blade below a certain predetermined level. This level depends on the material properties with regard to both steady-state and fatigue strength and to both mean and unsteady blade loading. The material selection controls the allowable stress level and the blade chord, thickness, rake and skew are the main parameters which control the blade stress for a given blade loading. Stresses based on beam theory<sup>10</sup> in the propeller blade are computed for each propeller. Both hydrodynamic and centrifugal loadings

are considered. Effects of rake and skew are included. In this stress calculation procedure, the propeller blade is represented as a straight cantilever beam of variable cross-section without camber. Experimental results show that the neutral axis of an airfoil section lies approximately along the mean line, so camber is not considered in the stress calculations presented. Only the maximum principal stresses calculated at the mid-chord of each section are printed as output in the computer program. Stresses for the final design should be calculated by finite element techniques if rake and skew for the propeller differ from usual propeller shapes.

#### PARAMETERS FOR MAKING BLADE SURFACE CAVITATION CHECKS

Brockett's theoretically derived incipient cavitation charts of Reference 13 can be used to predict the blade surface cavitation characteristics of each propeller once the lifting-line calculations have been completed. The two-dimensional camber-to-chord ratio ( $f_M/c$ ), ideal angle of attack in degrees ( $\alpha_i$ ), section cavitation number ( $\sigma$ ) nondimensionalized with the section inflow velocity ( $V_r$ ), and the maximum and minimum fluctuating angles of attack ( $\alpha_{max}, \alpha_{min}$ ) in degrees are parameters that must be determined before Brockett's incipient cavitation charts can be used.

These parameters are calculated as follows:

Section Maximum Camber to Chord Ratio for NACA  $a=0.8$  Meanline:

$$f_M/c = 0.0679 C_L \quad (23)$$

Section Ideal Angle of Attack in Degrees for NACA  $a=0.8$  Meanline:

$$\alpha_i = 1.54 C_L \quad (24)$$

Section Cavitation Number:

$$\sigma = 2g(H-xR)/V_r^2 \quad (25)$$

where  $g$  = acceleration due to gravity

$H$  = static head at shaft centerline (see section on Static Head)

$V_r$  = inflow velocity of each propeller section.

The maximum and minimum fluctuating angles of attack

( $\alpha_{max}, \alpha_{min}$ ) in degrees are calculated using the method derived by Lerbs and Rader in Reference 18. These calculations can be made using the following equations:

Maximum Fluctuating Angles of Attack:

$$\alpha_{max} = \alpha_i - (-\Delta\beta)F(x) \quad (26)$$

Minimum Fluctuating Angles of Attack:

$$\alpha_{min} = \alpha_i - (+\Delta\beta)F(x) \quad (27)$$

where  $-\Delta\beta$  = maximum effective angle of attack in degrees

(from wake survey data)

$+\Delta\beta$  minimum effective angle of attack in degrees

(from wake survey data)

18. Lerbs, H.W. and Rader, H.P., "Über der Auftriebsgradienten von Profilen im Propeller Verband," Schiffstechnik, Vol. 9, No. 48, p 178-180, 1962

The parameter  $F(x)$  in Equations (26) and (27) is dependent on the hydrodynamic flow angle ( $\beta_I$ ), the advance angle ( $\beta$ ) and the lift coefficient ( $C_L$ ), and is calculated on the computer using the following equation:

$$F(x) = 1 / \{ 1 + 2\pi \tan(\beta_I - \beta) / C_L \} \quad (28)$$

The Burrill Cavitation Charts<sup>12</sup> can also be used to give an approximate check on the cavitation performance of propellers. Burrill's thrust loading coefficient ( $\tau_c$ ) and cavitation number ( $\sigma_{0.7}$ ) at 0.7 radius, defined as follows, are parameters that must be known in order to use these cavitation charts:

Burrill Loading Coefficient:

$$\tau_c = T / \{ (\rho/2) A_p \{ V(1-w_{x=0.7}) \}^2 + (0.7\pi n D)^2 \} \quad (29)$$

Burrill Cavitation Number at 0.7 Radius:

$$\sigma_{0.7} = 2gH / \{ \{ V(1-w_{x=0.7}) \}^2 + (0.7\pi n D)^2 \} \quad (30)$$

where  $A_E$  = propeller expanded area,  $2 \int_{r_h}^R c \, dr$

$A_O$  = propeller disc area,  $\pi D^2/4$

$A_P$  = propeller projected area,  $(1.067 - 0.229(P/D)_i) A_E$

$(P/D)_i$  = estimated propeller pitch ratio at 0.7 radius, estimated as  $0.7\pi \tan \beta_I$

Keller's method<sup>11</sup> of predicting the minimum expanded area ratio of the propeller is also calculated on the computer.

The minimum expanded area ratio, based on eliminating back bubble type cavitation, is computed as follows:

$$(A_E/A_O)_K = (2.5 + 0.6Z)K_T / \{\sigma_{0.7} (J^2 + (0.7\pi)^2)\} + K \quad (31)$$

where  $K = 0.2$  is used for single screw ships with manganese-bronze propellers having rake of approximately 10 degrees,  $K = 0.10$  is used for twin-screw ships with copper-aluminum-bronze propellers,  $K = 0.15$  is used for twin-screw ships with manganese-bronze propellers, and  $K = 0$  to  $K = 0.05$  is used for propellers for fast ships such as destroyers and frigates. The constant,  $K = 0.15$ , was used in developing this computer program. If a different value of  $K$  is desired, the expanded area ratio calculated in Equation (31) should be adjusted to account for changes in the value of  $K$ .

#### Chord Lengths for Lifting Surface Pitch and Camber Calculations

The final pitch and camber for each propeller can be calculated using Nelson's computer program, presented in Reference 4, based on lifting surface theory for contrarotating propellers. However, Nelson has shown that in some cases lifting-surface interaction effects of contrarotating propellers are small. If this is the case, single propeller lifting

surface theory from References 19, 20, 21, and

19. Kerwin, J.E., "The Solution of Propeller Lifting-Surface Problems by Vortex Lattice Methods," Department of Naval Architecture and Marine Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1961
20. Kerwin, J.E. and Leopold, R., "Propeller Incidence Correction Due to Blade Thickness," Journal of Ship Research, Vol. 7, No. 2, 1963, p 1, 6
21. Cheng, H.M., "Hydrodynamic Aspects of Propeller Design Based On Lifting-Surface Theory: Part I - Uniform Chordwise Load Distribution," David Taylor Model Basin Report 1802, 1964

22 can be used to calculate the final pitch and camber for each propeller. These programs require as input the section chord length,  $(c/R)_{LE}$  and  $(c/R)_{TE}$  nondimensionalized on propeller radius, in terms of the skew angle ( $\theta_s$ ), hydrodynamic flow angle ( $\beta_I$ ) and blade outline ( $c/D$ ). The parameter  $(c/R)_{LE}$  and  $(c/R)_{TE}$  measured from the leading and trailing edges to its reference line, respectively, are calculated in the following manner on the computer:

Chord Lengths Measured from Blade Leading Edge:

$$(c/R)_{LE} = x\theta_s / (57.296 \cos\beta_I) - c/D \quad (32)$$

Chord Lengths Measured from Blade Trailing Edge:

$$(c/R)_{TE} = x\theta_s / (57.296 \cos\beta_I) + c/D \quad (33)$$

#### SPACING BETWEEN BLADES AND FILLETS

Propeller designs should have enough clearance between blades at the hub so fillets can be properly applied. Hill<sup>23</sup> derived the following equation which is used in the program to estimate spacing between blades  $G_z$  at the hub without fillets:

$$G_z = (2\pi r_h) / Z - (t_h / \sin \phi) \quad (34)$$

where  $\phi$  is the propeller pitch angle ( $\phi = \beta_I$  in computer program).

Based on a number of full-scale propellers built with standard fillets, Hill's blade clearance equation was modified

the following manner to estimate spacing  $G_F$  between fillets

22. Cheng, H.M., "Hydrodynamic Aspects of Propeller Design Based On Lifting-Surface Theory: Part II - Arbitrary Chordwise Load Distribution," David Taylor Model Basin report 1803, 1965
23. Hill, J.G., "The Design of Propellers," Transactions of the Society of Naval Architects and Marine engineers, Vol. 57, 1949

at the hub during the preliminary stage of the design.

$$G_F = (2\pi r_h)/Z - (1.9t_h/\sin\phi) \quad (35)$$

A layout of blade sections is recommended as a final fillet clearance check.

#### PROPELLER WEIGHT AND CENTER OF GRAVITY

The approximate propeller weight ( $W_p$ ) and location of center of gravity (CG) from the propeller center line is also calculated for each design. In order to make these calculations, the specific weight of the material ( $\rho_p$ ) must be specified as input. The propeller hub is assumed to be a circular cylinder of equal length and diameter. The propeller center line is located at the mid length of the propeller hub and no allowance is made for the propeller bore or blade root fillets in these calculations. The weight ( $W_p$ ) for each propeller is calculated as follows:  
Propeller Weight:

$$W_p = W_B + W_H \quad (36)$$

where  $W_B$  = weight of blades,  $\rho_p Z \int_{x_h}^1 a(x) dx$

$W_H$  = weight of hub,  $\pi/4(\rho_p D_H^2)$

$D_H$  = hub diameter

$a(x)$  = area of section at radius  $x$ ,  $2c(x)t(x) \int_0^1 t(x, x_\ell) dx$

$c(x)$  = chord length of section at radius  $x$

$t(x)$  = maximum thickness of section thickness

$t(x, x_\ell)$  = chordwise distribution of section thickness

(NACA 66 modified thickness form is used in program)

$x_\ell$  = nondimensional coordinate along the section chord  
( $x_\ell/c$ )

$\rho_p$  = specific weight of material considered

The propeller center of gravity (CG) with respect to the blade center line, where plus values represent the distance ahead of the center line and negative values aft of the center line, is calculated in the following manner:

Center of Gravity:

$$CG = M_p / M_p \quad (37)$$

where  $M_p$  = moment of the propeller,  $\rho_m \int_{x_h}^1 a(x) B(x) dx$

$B(x)$  = distance of center of gravity from propeller

center line,  $\bar{y} \cos\phi + \bar{x} \sin\phi - \theta_s x R \tan\phi - \theta_R x + d_H/2$

$\bar{x}$  = longitudinal center of gravity along chord line

$\bar{y}$  = vertical center of gravity perpendicular to chord line

$\theta_R$  = rake angle in radians

$\theta_s$  = skew angle in radians

$\phi$  = pitch angle in radians, ( $\phi = \beta_I$  is used in the program)

#### COMPUTER PROGRAM

A new computer program has been derived for the preliminary design of contrarotating propellers using the CDC 6400, 6600 and 6700 computers at DTNSRDC. A core storage of approximately

128,000 octal is required for the computer program, and it takes approximately 4 minutes to compile the computer program. The actual running time per case using the design thrust option is approximately 6 minutes and when the design shaft horsepower option is used, the running time is approximately 9 minutes. A detailed description of the input and output formats for the computer program is presented in Appendix A, and a FORTRAN listing of the new computer program is shown in Appendix B.

#### PROPELLER DESIGN THRUST AND POWER OPTIONS

The thrust option can be used to make lifting line calculations for propellers required to produce a given thrust at specified values of speed and rpm (this is accomplished by adjusting the input  $\tan\beta_T$  distribution), or the power option can be used if the propeller is required to absorb a specified power at a given rpm (in which case the speed is determined).

From each calculated power, a new value of speed (assumed to vary as the cube root of the ratio of the design and calculated power) is obtained and its corresponding effective power is obtained from the effective power input curve. Design calculations again produce a new calculated power, and the process continues until the closeness criteria of design and calculated power is satisfied (two iterations are normally sufficient). Smaller increments of input speeds in general cause faster convergence.

Once the basic shape of the distribution is defined (see the Hydrodynamic Flow Angle Distribution section) the final  $\tan\beta_I$  distribution  $K_4 \tan\beta_I$  is determined using the thrust or power options, by making lifting line calculations of three nondimensional thrust loading coefficients  $(C_{TS})_1$ ,  $(C_{TS})_2$ , and  $(C_{TS})_3$  that correspond to three hydrodynamic pitch distributions,  $K_1 \tan\beta_I$ ,  $K_2 \tan\beta_I$ , and  $K_3 \tan\beta_I$  where  $K_1 = 0.975$ ,  $K_2 = 1.0$ , and  $K_3 = 1.025$ . Once these calculations are obtained, the following system of equations are set up:

$$(C_{TS})_1 = A + BK_1 + CK_1^2$$

$$(C_{TS})_2 = A + BK_2 + CK_2^2$$

$$(C_{TS})_3 = A + BK_3 + CK_3^2$$

from which values of A, B, and C are obtained. Then, values of A, B, and C are substituted in the following equation to obtain the value of  $K_4$ .

$$C_{TS} = A + BK_4 + CK_4^2$$

where  $C_{TS}$  = design thrust loading coefficient (Equation 9).

#### DESIGN CALCULATIONS OF A SAMPLE SET OF CONTRAROTATING PROPELLERS

Design calculations are shown in Table 1 for a sample set of contrarotating propellers with 7 blades and an expanded area ratio ( $A_E/A_O$ ) of 0.293 for the forward propeller, and 6 blades with  $A_E/A_O = 0.365$  for the aft propeller. These propellers were designed to operate in a wake with a thrust loading coefficient based on ship speed ( $C_{TS}$ ) of 0.265 and an advance coefficient (J) of 1.235. Both propellers had a 100 percent linear skew distribution resulting in 51.4

and 60 degree blade tip skew angles for the forward and aft propellers, respectively. Solid and dashed lines in Figures 2 through 8 show calculations obtained using the old design method<sup>1,2,3</sup> and the new computer program, respectively. These figures show that the radial distribution of the hydrodynamic pitch ( $\pi x \tan \beta_I$ ), nondimensional circulation ( $G$ ), axial ( $U_T/2V$ ) and tangential ( $U_T/2V$ ) induced velocities calculated using both methods differed significantly, especially for the aft propeller. The thrust loading coefficient ( $C_{Ts}$ ), power loading coefficient ( $C_{Ps}$ ) and propulsive efficiency ( $\eta_D$ ) calculated for the sample set of contra-rotating propellers using the old and new methods are printed in Table 2. Results in Table 2 show that the old design method predicts similar thrust ( $C_{Ts}$ ) and power ( $C_{Ps}$ ) loading coefficients for the forward and aft propellers where as the new design method predicts that the aft propeller  $C_{Ts}$  and  $C_{Ps}$  values are significantly higher than those calculated for the forward propeller. The propulsive efficiency ( $\eta_D$ ) of 0.886 predicted for the sample set of contrarotating propellers using the new method is approximately 2 percentage points lower than the  $\eta_D$  value of 0.912 calculated using the old design method. Performance predictions using the new design method should be more accurate than the predictions made using the old design method because of the improved methods of accounting for the propeller interaction effects.

## RECOMMENDATIONS

The following investigations should be carried out in the future in order to better design and predict the performance of contrarotating propellers:

1. Utilize induced velocities derived by Kerwin in Reference 8 to obtain more exact calculations for contraction of the slip stream and the aft propeller diameter. This subroutine should be reprogrammed to significantly reduce the running time presently required to make it practical for use in the contrarotating propeller design computer program.
2. Include the effects of the hull radial induced velocity as an input option in the contrarotating propeller design procedure.
3. Conduct model propulsive and cavitation experiments on a set of contrarotating propellers to validate the design procedure.
4. Options for specifying noncylindrical hubs, arbitrary propeller locations and allowances for the propeller bore should be added to the program presented to improve the predictions of propeller weight and center of gravity.

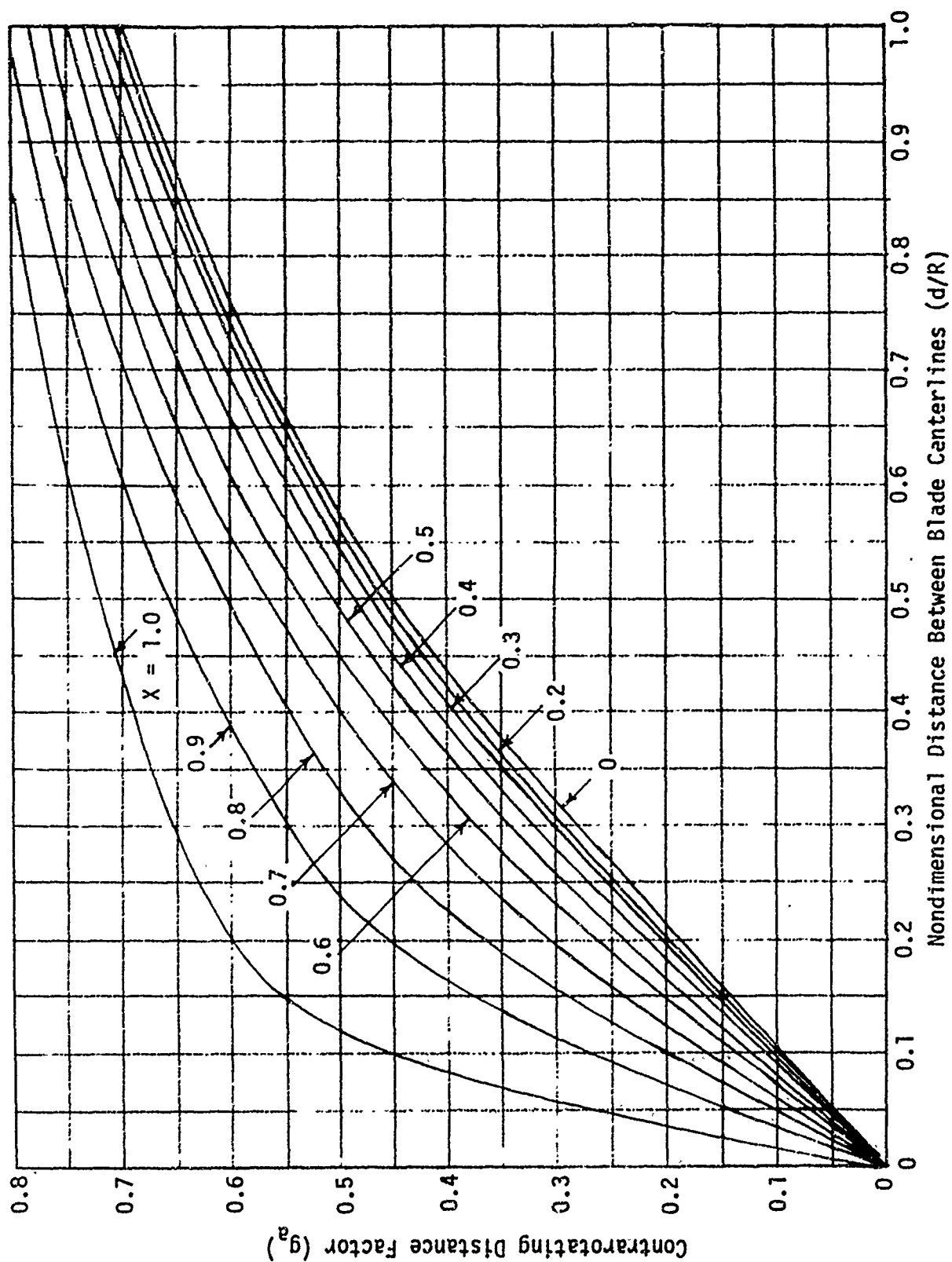


Figure 1 - Lerbs Distance Factors ( $g_a$ ) for Aft Propeller Diameter Calculations

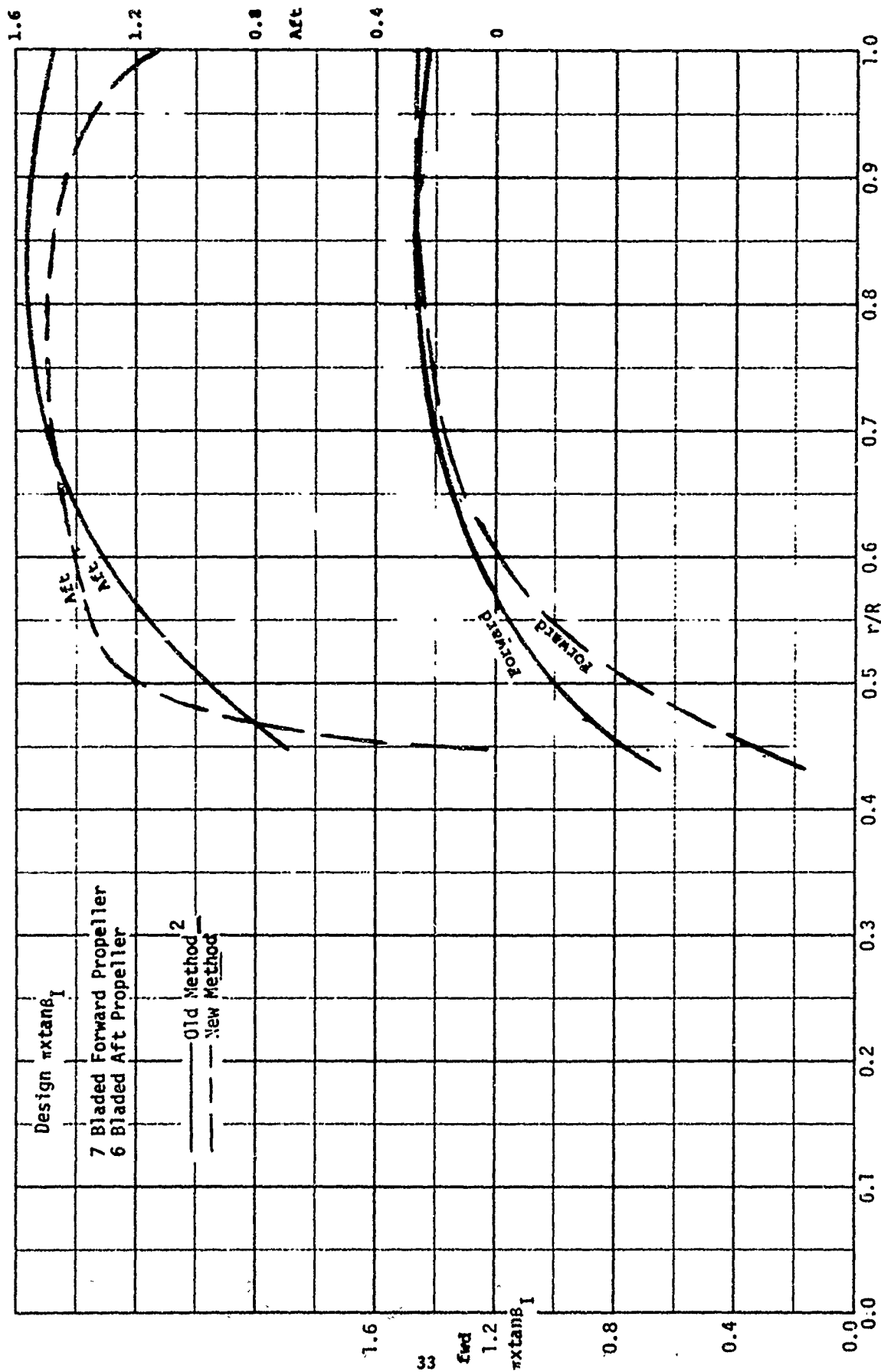


Figure 2 - Hydrodynamic Pitch Angle Distribution for Sample Set of Propellers

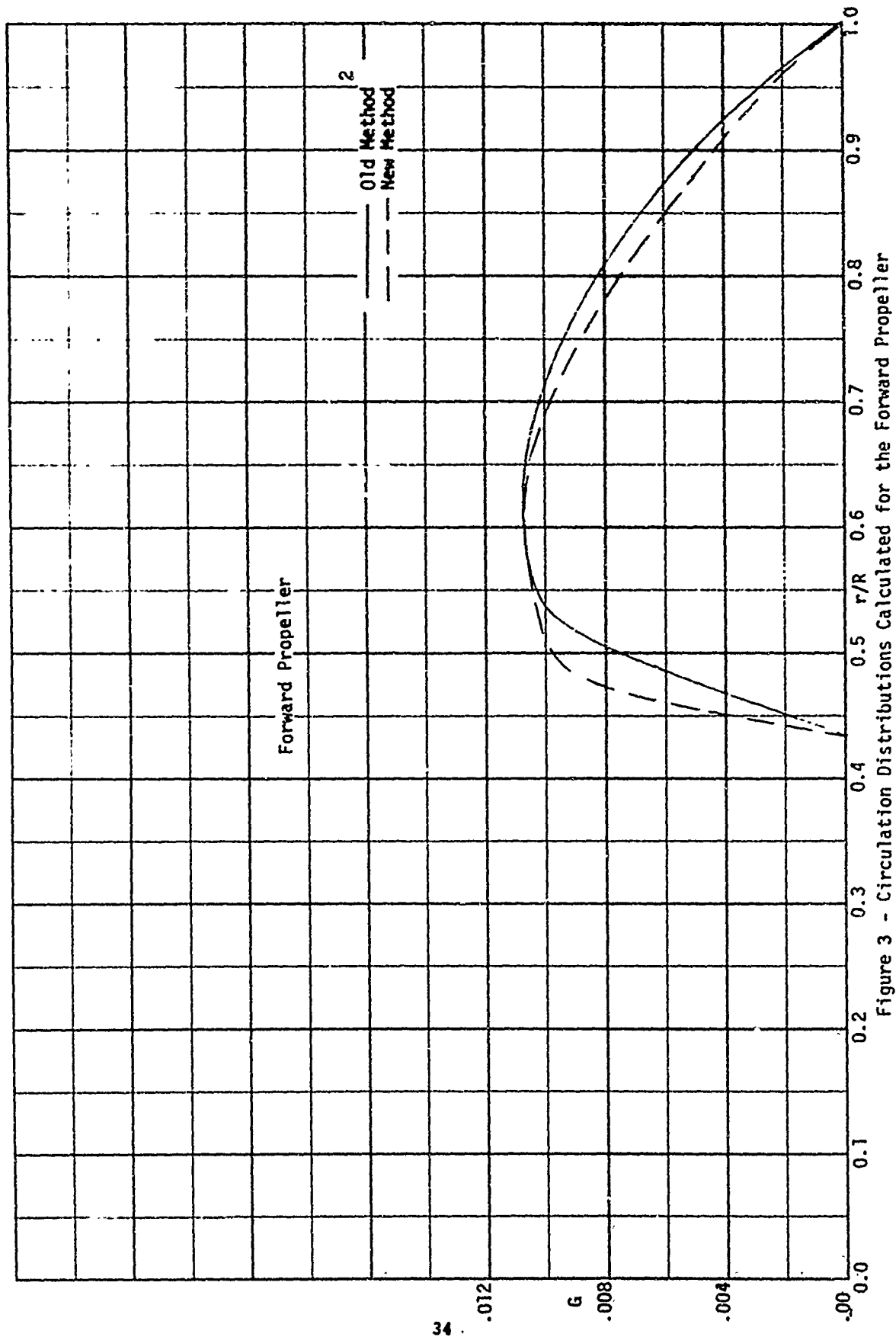


Figure 3 - Circulation Distributions Calculated for the Forward Propeller

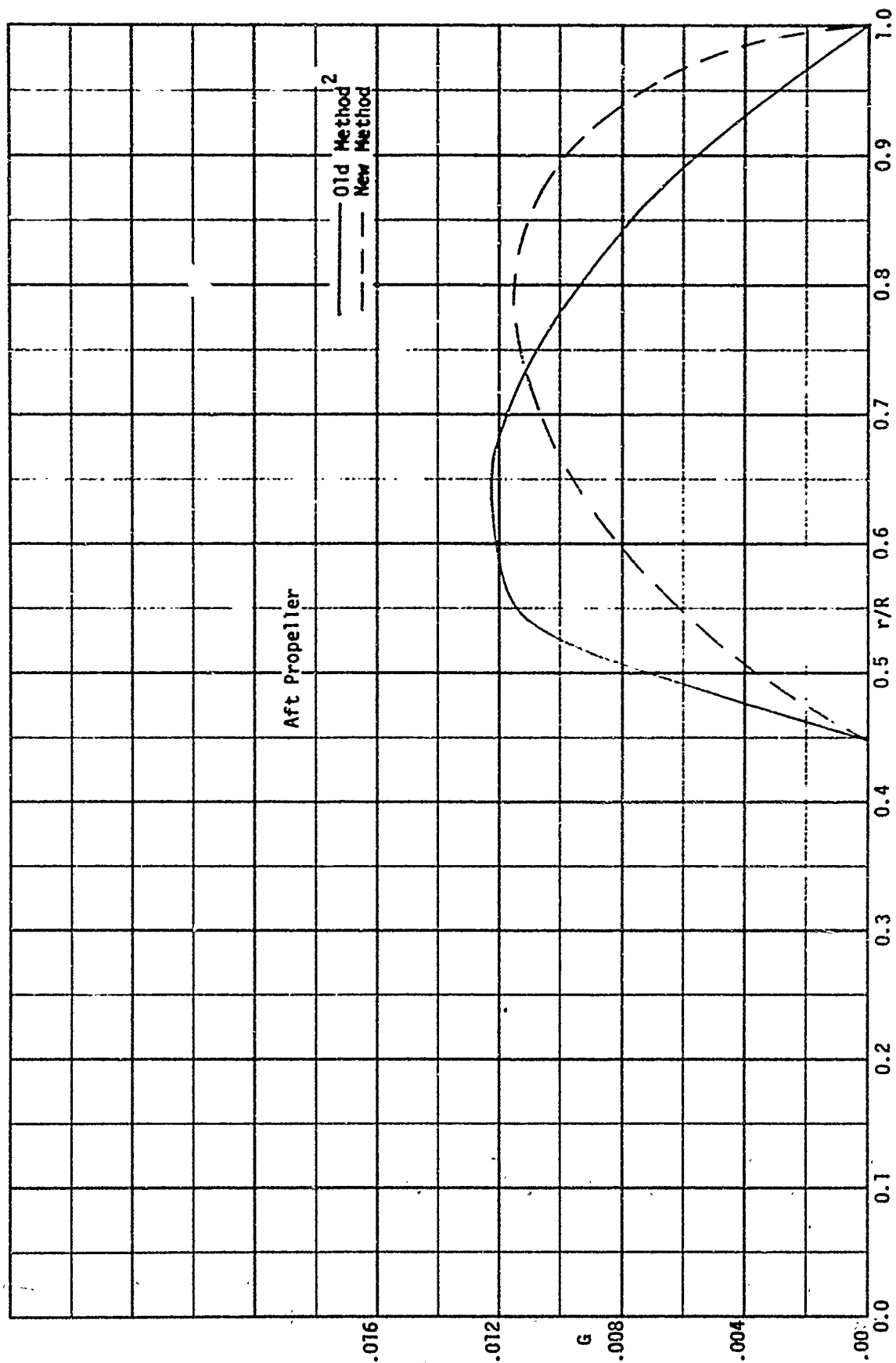


Figure 4 - Circulation Distributions Calculated for the Aft Propeller

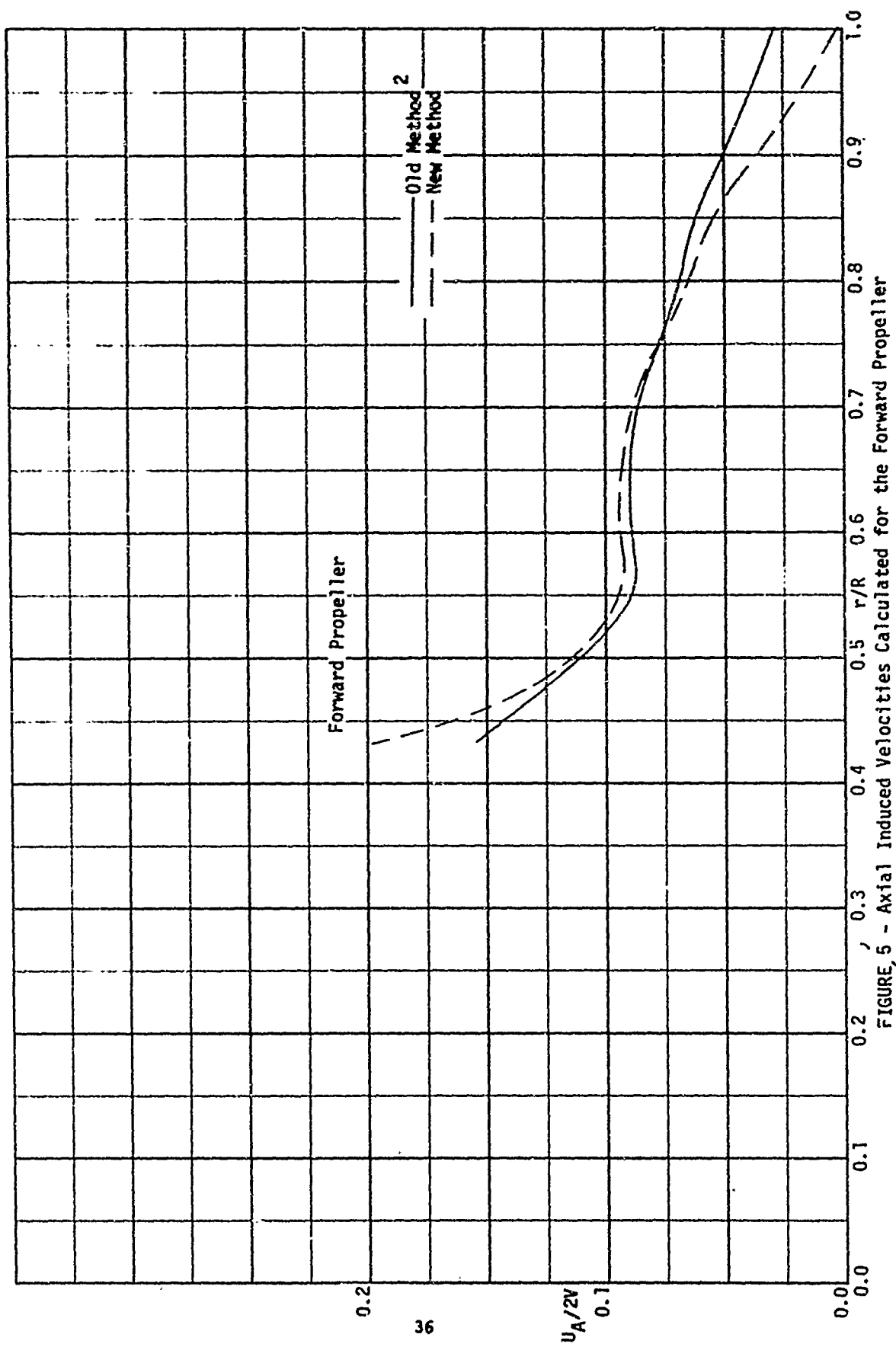
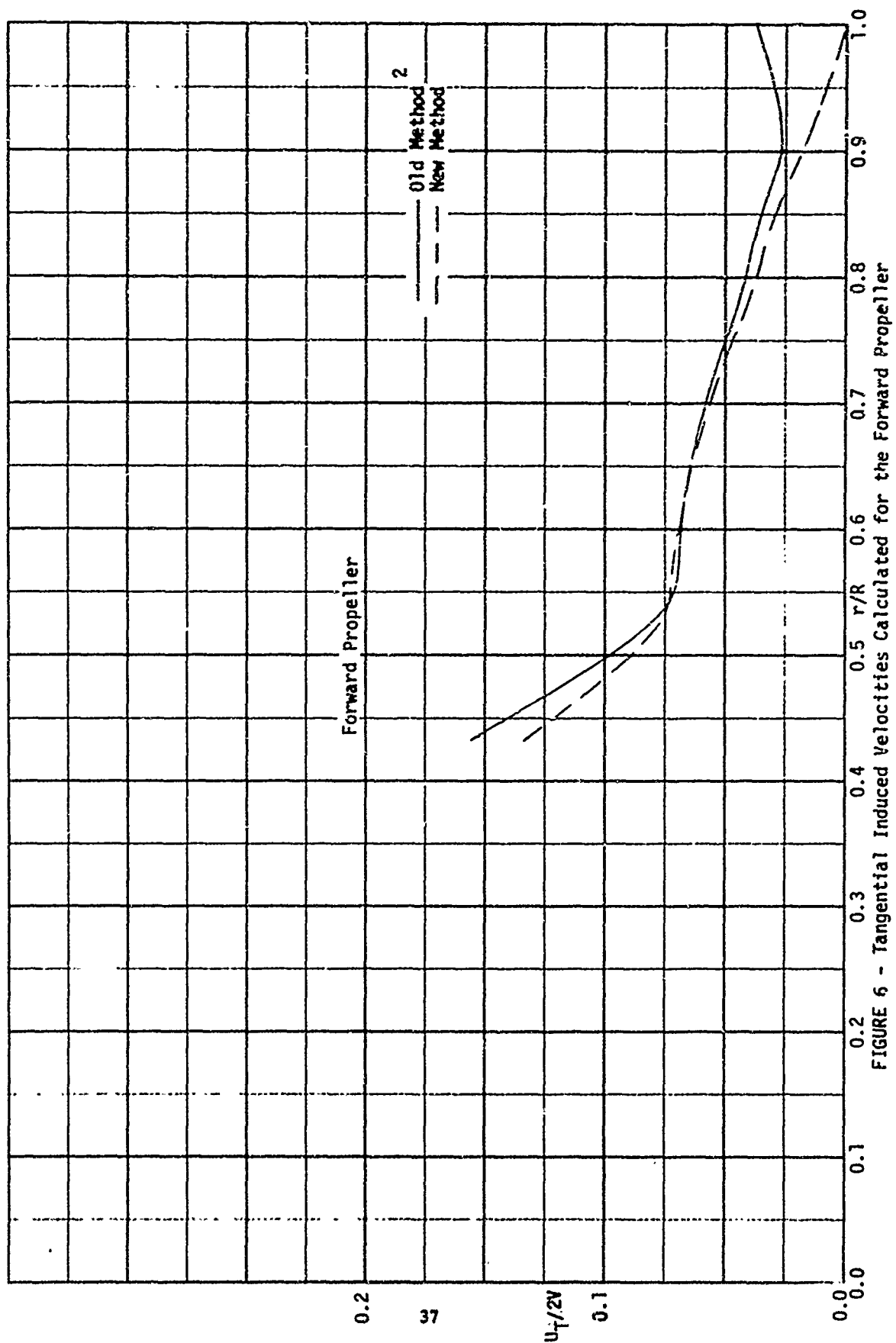


FIGURE 5 - Axial Induced Velocities Calculated for the Forward Propeller



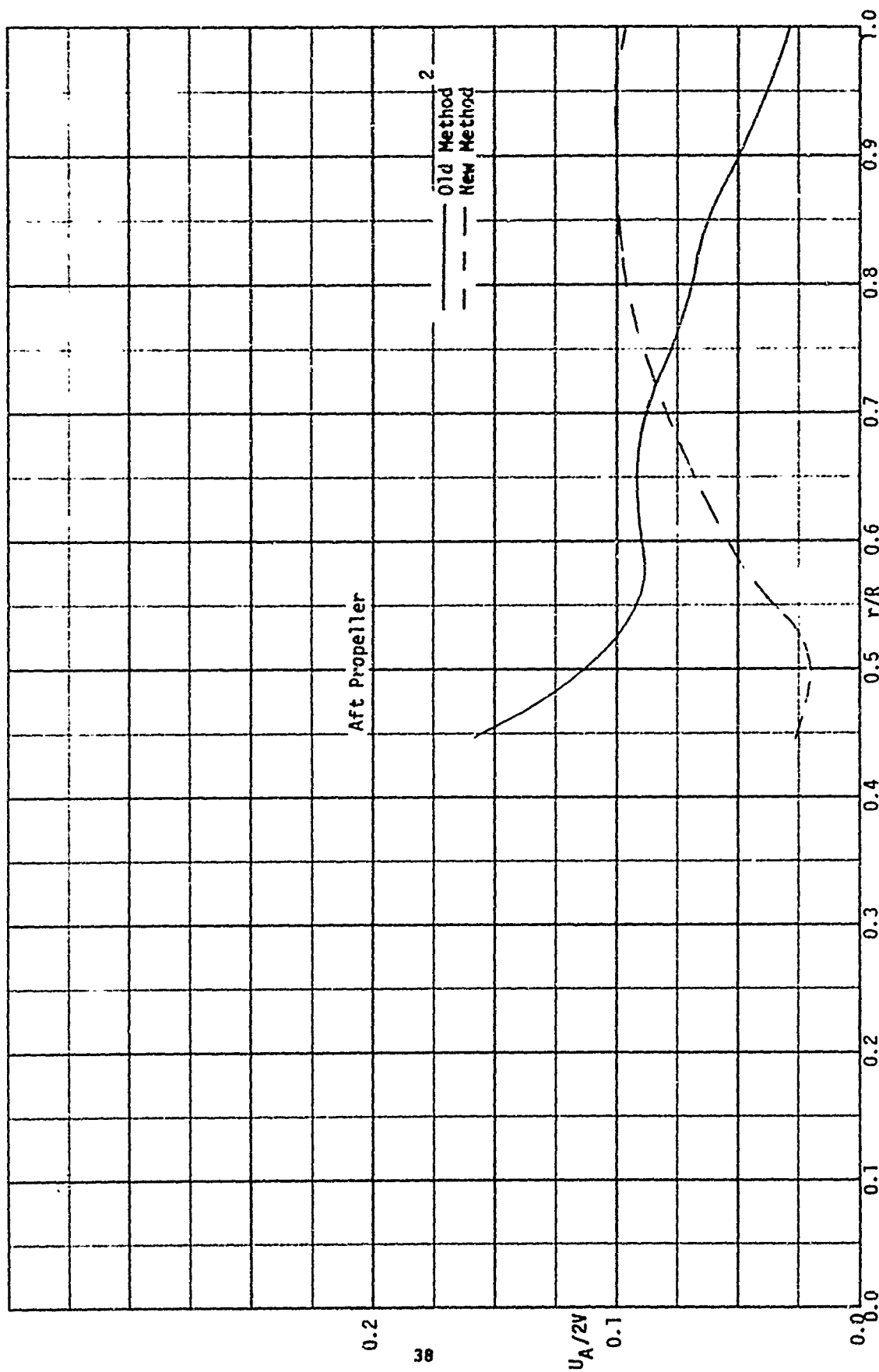


FIGURE 7 - Axial Induced Velocities Calculated for the Aft Propeller

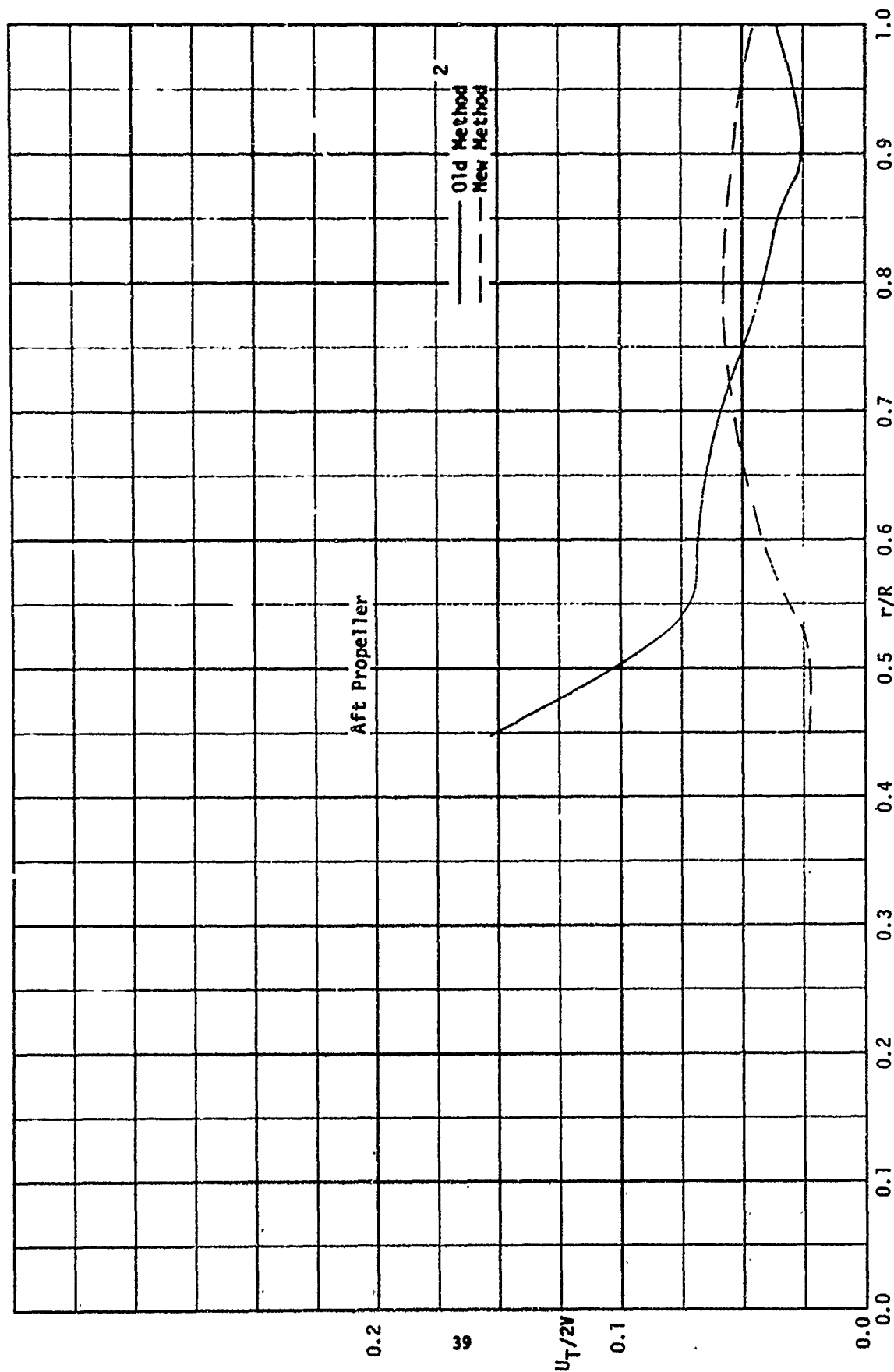


FIGURE 8 - Tangential Induced Velocities Calculated for the Aft Propeller

TABLE 1

## OUTPUT DATA FOR THE SAMPLE SET OF CONTRAROTATING PROPELLERS

|                                                                                                             |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
|-------------------------------------------------------------------------------------------------------------|------------|------------|------------|-------------|-------------|------------|------------|------------|-----------|-----------|--|--|--|--|
| FWD                                                                                                         |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| THRUST OPTION                                                                                               |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| ND OF V= 1.0 DENSITY OF PROPKG/M3)= 8303.27                                                                 |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| V(M/SEC)= 1.2450E+01                                                                                        |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| PE(KW)= 1.2040E+01                                                                                          |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| D(M)= .3911 1-MIT= .7050 1-TMD= .7660 RHO(KG/M3)= 1025.8600                                                 |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| TETS OPT= 1.000 RAKE OPT= 3.000                                                                             |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| TANBI CPT= 1.00 DRAG OPT= .0085 TANB OPT= 0.80                                                              |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| Z= 7.0000E+00                                                                                               |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| AE/A0= 2.9300E-01                                                                                           |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| N(REV/MIN)= 1.0900E+03                                                                                      |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| X= 4.3300E-01 5.0000E-01 5.5000E-01 6.0000E-01 6.5000E-01 7.0000E-01 8.0000E-01 9.0000E-01 9.0000E-01       |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| 1-WX= 1.4000E-01 2.0000E-01 2.5000E-01 3.0000E-01 3.5000E-01 4.0000E-01 4.5000E-01 5.0000E-01 7.0000E-01    |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| TANGI= 1.2500E-01 4.7100E-01 5.7300E-01 6.1500E-01 6.2500E-01 6.1100E-01 5.6000E-01 5.3300E-01 5.3300E-01   |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| C/D= 1.4140E-01 1.4140E-01 1.4140E-01 1.4140E-01 1.4140E-01 1.4140E-01 1.4140E-01 1.4140E-01 1.4140E-01     |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| T/C= 1.0400E-01 1.7610E-01 1.6470E-01 1.5420E-01 1.4360E-01 1.3300E-01 1.1430E-01 1.1090E-01 1.0800E-01     |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| D(M)=3.9115E-01 N(REV/MIN)=1.0900E+03 Z=7.0000E+00 AF/A0=2.9300E-01                                         |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| CPT=6.7993E-02 CPSI=1.0193E-01 CTSI=1.3250E+00                                                              |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| X                                                                                                           |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| TANGI                                                                                                       | TANBI      | TAN B      | G          | UT/2V       | UA/2V       | OCPSI      | VR(M/SEC)  | CAV        |           |           |  |  |  |  |
| 4.3300E-01                                                                                                  | 1.2517E-01 | 2.3117E-01 | 0.         | -7.3081E-03 | -6.1432E-02 | 0.         | 7.6951E+00 | 6.3839E+00 |           |           |  |  |  |  |
| 5.0000E-01                                                                                                  | 4.8295E-01 | 4.3633E-01 | 4.6390E-03 | 2.9553E-02  | 2.4695E-02  | 1.0877E-01 | 1.1103E+01 | 2.9642E+00 |           |           |  |  |  |  |
| 5.5000E-01                                                                                                  | 5.7333E-01 | 5.1939E-01 | 7.2712E-03 | 4.6221E-02  | 5.0595E-02  | 1.0265E-01 | 1.2956E+01 | 2.2052E+00 |           |           |  |  |  |  |
| 6.0000E-01                                                                                                  | 6.3060E-01 | 5.1939E-01 | 9.0566E-03 | 5.9033E-02  | 8.9045E-02  | 2.5033E-01 | 1.4514E+01 | 1.7723E+00 |           |           |  |  |  |  |
| 6.5000E-01                                                                                                  | 6.4177E-01 | 5.1939E-01 | 1.0159E-02 | 6.7168E-02  | 9.7133E-02  | 3.0615E-01 | 1.5924E+01 | 1.4805E+00 |           |           |  |  |  |  |
| 7.0000E-01                                                                                                  | 6.2663E-01 | 5.1716E-01 | 1.0310E-02 | 6.3028E-02  | 9.6226E-02  | 3.4310E-01 | 1.7311E+01 | 1.5558E+00 |           |           |  |  |  |  |
| 8.0000E-01                                                                                                  | 5.7502E-01 | 5.0031E-01 | 8.6762E-03 | 4.6332E-02  | 5.3225E-02  | 3.4431E-01 | 1.9328E+01 | 9.4939E-01 |           |           |  |  |  |  |
| 8.5000E-01                                                                                                  | 5.4734E-01 | 4.4503E-01 | 7.6439E-03 | 4.0317E-02  | 7.1255E-02  | 3.1879E-01 | 2.1143E+01 | 8.4323E-01 |           |           |  |  |  |  |
| 9.0000E-01                                                                                                  | 5.1955E-01 | 4.7438E-01 | 5.9235E-03 | 2.9503E-02  | 5.7069E-02  | 2.6470E-01 | 2.2394E+01 | 7.5147E-01 |           |           |  |  |  |  |
| 9.5000E-01                                                                                                  | 4.9105E-01 | 4.6203E-01 | 3.6433E-03 | 1.9748E-02  | 4.3285E-02  | 1.8305E-01 | 2.3596E+01 | 6.7648E-01 |           |           |  |  |  |  |
| 1.0000E+00                                                                                                  | 4.6613E-01 | 4.4781E-01 | 0.         | 1.2728E-02  | 2.7330E-02  | 0.         | 2.4769E+01 | 6.1360E-01 |           |           |  |  |  |  |
| CPT=6.6254E-02 CPSI=1.0827E-01 CTSI=1.3246E+00                                                              |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| X                                                                                                           | CL         | ALI(DEC)   | FM/C       | CD/CL       | F(X)        | LI(N/H)    | TETS(DEC)  | (C/RD)LE   | (C/RD)TE  | T/RD      |  |  |  |  |
| 4.330E-01                                                                                                   | 0.         | 3.714E-01  | 1.630E-02  | 3.524E-02   | 0.          | 0.         | 0.         | -1.414E-01 | 1.414E-01 | 5.486E-02 |  |  |  |  |
| 5.000E-01                                                                                                   | 2.412E-01  | 4.782E-01  | 2.108E-02  | 2.371E-02   | 4.185E-01   | 1.479E+03  | 1.061E+00  | -8.251E-02 | 2.003E-01 | 4.980E-02 |  |  |  |  |
| 5.500E-01                                                                                                   | 3.195E-01  | 5.317E-01  | 2.344E-02  | 2.462E-02   | 3.339E-01   | 2.539E+03  | 1.515E+01  | -2.355E-02 | 2.596E-01 | 4.658E-02 |  |  |  |  |
| 6.000E-01                                                                                                   | 3.453E-01  | 5.436E-01  | 2.397E-02  | 2.408E-02   | 3.791E-01   | 2.639E+03  | 1.965E+01  | 4.613E-02  | 3.289E-01 | 4.361E-02 |  |  |  |  |
| 6.500E-01                                                                                                   | 3.203E-01  | 5.075E-01  | 2.210E-02  | 2.579E-02   | 3.332E-01   | 2.801E+03  | 2.422E+01  | 2.074E-01  | 4.057E-01 | 4.061E-02 |  |  |  |  |
| 7.000E-01                                                                                                   | 2.522E-01  | 3.884E-01  | 1.712E-02  | 3.370E-02   | 4.039E-01   | 2.777E+03  | 3.329E+01  | 2.074E-01  | 4.906E-01 | 3.761E-02 |  |  |  |  |
| 8.000E-01                                                                                                   | 2.193E-01  | 3.377E-01  | 1.489E-02  | 3.877E-02   | 4.149E-01   | 2.537E+03  | 3.782E+01  | 3.980E-01  | 6.744E-01 | 3.159E-02 |  |  |  |  |
| 8.500E-01                                                                                                   | 1.760E-01  | 2.710E-01  | 1.195E-02  | 4.830E-02   | 4.333E-01   | 2.302E+03  | 4.236E+01  | 5.107E-01  | 7.637E-01 | 2.561E-02 |  |  |  |  |
| 9.000E-01                                                                                                   | 1.370E-01  | 2.110E-01  | 9.303E-03  | 6.204E-02   | 4.795E-01   | 1.423E+03  | 4.683E+01  | 6.322E-01  | 9.674E-01 | 2.543E-02 |  |  |  |  |
| 1.000E+00                                                                                                   | 0.         | 0.         | 0.         | 0.          | 0.          | 0.         | 5.143E+01  | 7.722E-01  | 9.532E-01 | 2.239E-02 |  |  |  |  |
| ETA0=9.3467E-01 PS(KW)=1.7275E+01 1-TMD=7.6400E-01 1-MIT=7.0500E-01 V(KNOTS)=2.4204E+01 V(M/SEC)=2.2451E+01 |            |            |            |             |             |            |            |            |           |           |  |  |  |  |
| DESIGN TM(N)=1.2659E+03 CALCULATED TM(N)=1.2658E+03                                                         |            |            |            |             |             |            |            |            |           |           |  |  |  |  |

TABLE 1 CONTINUED

| X         | AREA(M2)  | XBAR(M)   | YBAR(M) | IXO(M4)   | IYO(M4)   | MXO(M-M)  | MYO(M-M)  | MTB(M-M)  | MQB(M-M)  | MAXSTRESS(PA) |
|-----------|-----------|-----------|---------|-----------|-----------|-----------|-----------|-----------|-----------|---------------|
| 4.330E-01 | 4.268E-04 | 2.813E-02 | 0.      | 2.896E-09 | 5.750E-08 | 1.162E+01 | 3.504E+01 | 1.085E+01 | 6.711E+00 | 3.357E+07     |
| 5.500E-01 | 3.624E-04 | 2.813E-02 | 0.      | 1.772E-09 | 4.841E-08 | 7.703E+00 | 5.707E+01 | 6.817E+00 | 4.182E+00 | 3.166E+07     |
| 6.000E-01 | 3.393E-04 | 2.813E-02 | 0.      | 1.454E-09 | 4.578E-08 | 6.025E+00 | 3.368E+01 | 5.263E+00 | 3.203E+00 | 2.772E+07     |
| 6.500E-01 | 3.160E-04 | 2.813E-02 | 0.      | 1.175E-09 | 4.256E-08 | 4.463E+00 | 2.529E+01 | 3.869E+00 | 2.329E+00 | 2.366E+07     |
| 7.000E-01 | 2.926E-04 | 2.813E-02 | 0.      | 9.332E-10 | 3.942E-09 | 3.136E+00 | 1.842E+01 | 2.787E+00 | 1.611E+00 | 1.929E+07     |
| 8.000E-01 | 2.402E-04 | 2.750E-02 | 0.      | 5.605E-10 | 3.091E-08 | 1.133E+00 | 6.525E+00 | 9.812E-01 | 5.703E-01 | 1.832E+07     |
| 8.500E-01 | 2.031E-04 | 2.567E-02 | 0.      | 3.748E-10 | 2.277E-08 | 5.403E-01 | 3.829E+00 | 4.684E-01 | 2.693E-01 | 6.497E+06     |

| X         | PAKE | PI XTANBI | PI XTANS  |
|-----------|------|-----------|-----------|
| 4.330E-01 | 0.   | 1.744E-01 | 2.145E-01 |
| 5.500E-01 | 0.   | 7.586E-01 | 6.851E-01 |
| 5.588E-01 | 0.   | 1.815E+00 | 8.618E-01 |
| 6.000E-01 | 0.   | 1.189E+00 | 9.771E-01 |
| 6.500E-01 | 0.   | 1.311E+00 | 1.068E+00 |
| 7.000E-01 | 0.   | 1.373E+00 | 1.137E+00 |
| 8.000E-01 | 0.   | 1.445E+00 | 1.257E+00 |
| 8.500E-01 | 0.   | 1.462E+00 | 1.295E+00 |
| 9.000E-01 | 0.   | 1.469E+00 | 1.343E+00 |
| 9.500E-01 | 0.   | 1.466E+00 | 1.379E+00 |
| 1.000E+00 | 0.   | 1.464E+00 | 1.407E+00 |

WEIGHT OF BLADES(M) = 16.9281

WEIGHT OF PROP(BLADES+CYLINDRICAL HUB)(M) = 327.6586

CENTER OF GRAVITY OF PROP REFERENCED FROM MICHORD OF ROOT SECTION (- FWD, + AFT)/D = .883728

CENTER OF GRAVITY OF BLADES REFERENCED FROM MICHORD OF ROOT SECTION (- FWD, + AFT)/D = .872175

HUB DIMENSIONS/D

HUB DIAM = .43388

HUB LENGTH = .4338

MICHORD OF ROOT SECTION TO AFT END OF HUB = .2165

KELLERS MINIMUM EAR = .2953E+00

SPEED COEFF V/(MD) JS = .1752E+01

ADVANCE COEFF V(1-WTT)/(MD) JA = .1235E+01

DESIGN THRUST COEFF KT = .1597E+00

TORQUE COEFF KQ = .3641E-01

PROPULSIVE EFFICIENCY ETAD = .9347E+00

BURRILL THRUST COEFF TC = .2782E+00

BURRILL CAVITATION COEFF SIGMA(0.7) = .1175E+01

CLEARANCE AT HUB BETWEEN BLADES/D = -.0027637

CLEARANCE AT HUB BETWEEN FILLETS/D = -.02741481

TABLE 1 CONTINUED

## AFT PROP OF CONTRAROTATING SET

| AFT                                                                                     |            |                         |            |             |             |            |            |             |            |
|-----------------------------------------------------------------------------------------|------------|-------------------------|------------|-------------|-------------|------------|------------|-------------|------------|
| THRUST OPTION                                                                           |            |                         |            |             |             |            |            |             |            |
| NO OF V=                                                                                | 1.0        | DENSITY OF PROP(KG/M3)= | 8303.97    |             |             |            |            |             |            |
| V(I/SEC)=                                                                               | 1.2450E+01 |                         |            |             |             |            |            |             |            |
| PE(KN)=                                                                                 | 1.2540E+01 |                         |            |             |             |            |            |             |            |
| O(MN)=                                                                                  | .3792      | 1-MIT=                  | .7050      | 1-THO=      | .7643       | H(MN)=     | 19.4000    | RHO(KG/M3)= | 1025.8600  |
| TETS OPT=                                                                               | 1.300      | RAME OPT=               | 0.000      |             |             |            |            |             |            |
| TANBI OPT=                                                                              | 1.00       | ORAC OPT=               | .0005      | TANB OPT=   | 0.00        |            |            |             |            |
| Z=                                                                                      | 6.0000E+00 |                         |            |             |             |            |            |             |            |
| AE/A0=                                                                                  | 3.550E-01  |                         |            |             |             |            |            |             |            |
| N(REV/MIN)=                                                                             | 1.0900E+03 |                         |            |             |             |            |            |             |            |
| X=                                                                                      | 4.4700E-01 | 5.1700E-01              | 5.6000E-01 | 6.0600E-01  | 6.5300E-01  | 7.0000E-01 | 7.4700E-01 | 8.9680E-01  |            |
| 1-MX=                                                                                   | 9.4700E-01 | 1.0000E-01              | 5.8300E-01 | 6.7400E-01  | 5.7300E-01  | 7.3430E-01 | 7.5300E-01 | 7.9430E-01  |            |
| TANBI=                                                                                  | 0.0900E-01 | 6.1900E-01              | 9.9500E-01 | 0.5000E-01  | 0.2000E-01  | 7.8000E-01 | 6.9500E-01 | 5.9500E-01  |            |
| C/D=                                                                                    | 1.6530E-01 | 1.6530E-01              | 1.6530E-01 | 1.6530E-01  | 1.6530E-01  | 1.6530E-01 | 1.6530E-01 | 1.3000E-01  |            |
| T/C=                                                                                    | 1.1130E-01 | 1.4300E-01              | 1.3900E-01 | 1.3100E-01  | 1.2700E-01  | 1.1500E-01 | 9.8080E-02 | 9.3000E-02  |            |
|                                                                                         | 1.0130E-01 | C.                      |            |             |             |            |            |             |            |
| J(MN)=3.7922E-01 N(EV/MIN)=1.0900E+03 Z=6.0000E+00 AE/A0=3.5500E-01                     |            |                         |            |             |             |            |            |             |            |
| CPTI=9.9649E-02 CPSI=1.2073E-01 CTSI=1.4394E-01 CT /CPSI=1.1922E+00                     |            |                         |            |             |             |            |            |             |            |
| X                                                                                       |            |                         |            |             |             |            |            |             |            |
| TANBI                                                                                   | TANBI      | TAN B                   | C          | UT/2V       | UA/2V       | CCPSI      | DCPSI      | VR(M/SEC)   | CAVV       |
| 4.4700E-01                                                                              | 2.5455E-02 | 4.2552E-01              | 0.         | -5.189E-02  | -3.5277E-01 | 0.         | 0.7045E-01 | 1.1674E+01  | 3.0455E+00 |
| 5.1700E-01                                                                              | 7.9720E-01 | 5.2576E-01              | 1.3766E-02 | 1.3126E-01  | 1.5978E-01  | 2.1669E-01 | 1.7045E-01 | 1.3478E+01  | 2.0711E+00 |
| 5.6000E-01                                                                              | 7.7397E-01 | 5.4707E-01              | 1.3311E-02 | 1.1992E-01  | 1.2345E-01  | 3.0166E-01 | 2.5036E-01 | 1.4910E+01  | 1.7037E+00 |
| 6.0600E-01                                                                              | 7.3256E-01 | 5.9131E-01              | 1.3235E-02 | 7.9548E-02  | 1.0735E-01  | 3.2131E-01 | 2.5671E-01 | 1.5014E+01  | 1.5493E+00 |
| 6.5330E-01                                                                              | 7.0571E-01 | 5.7231E-01              | 1.3030E-02 | 7.3593E-02  | 1.0637E-01  | 3.4607E-01 | 2.6750E-01 | 1.6030E+01  | 1.3395E+00 |
| 7.0000E-01                                                                              | 6.7224E-01 | 5.5725E-01              | 1.2586E-02 | 6.5235E-02  | 1.0175E-01  | 3.6307E-01 | 3.0575E-01 | 1.7955E+01  | 1.1723E+00 |
| 7.9700E-01                                                                              | 5.9699E-01 | 5.1636E-01              | 1.0386E-02 | 5.0314E-02  | 3.0495E-02  | 3.4337E-01 | 3.0475E-01 | 2.2132E+01  | 9.5629E-01 |
| 8.4700E-01                                                                              | 5.5599E-01 | 4.9116E-01              | 8.4491E-03 | 3.9377E-02  | 7.6435E-02  | 3.1335E-01 | 2.7114E-01 | 2.3562E+01  | 7.9420E-01 |
| 8.9600E-01                                                                              | 5.1279E-01 | 4.6995E-01              | 6.0972E-03 | 2.7276E-02  | 5.8335E-02  | 2.4324E-01 | 2.1074E-01 | 2.3562E+01  | 6.9449E-01 |
| 9.4700E-01                                                                              | 4.5678E-01 | 4.4419E-01              | 2.8496E-03 | 5.3906E-03  | 2.0436E-02  | 1.2404E-01 | 1.0306E-01 | 2.4827E+01  | 6.1344E-01 |
| 1.0000E+00                                                                              | 3.5335E-01 | 4.1762E-01              | 0.         | -4.2195E-02 | -1.1097E-01 | 3.         | 0.         | 2.6424E+01  | 5.4375E-01 |
| CPT=9.7507E-02 CPS=1.2072E-01 CTS=1.4093E-01 CTS/CPS=1.1021E+00                         |            |                         |            |             |             |            |            |             |            |
| X                                                                                       |            |                         |            |             |             |            |            |             |            |
| GL                                                                                      | GL         | FM/C                    | CD/CL      | F(X)        | LI(H/M)     | TETS(OEG)  | (C/RD)LE   | (C/RD)YE    | T/RD       |
| 4.4700E-01                                                                              | 0.         | 0.                      | 0.         | 0.          | 0.          | 0.         | -1.653E-01 | 1.653E-01   | 5.323E-02  |
| 5.1700E-01                                                                              | 3.780E-01  | 5.822E-01               | 2.567E-02  | 2.401E-01   | 2.208E+03   | 7.595E+00  | -7.766E-02 | 2.529E-01   | 4.893E-02  |
| 5.6000E-01                                                                              | 4.225E-01  | 6.507E-01               | 2.669E-02  | 2.012E-02   | 3.023E+03   | 1.226E+01  | -1.333E-02 | 3.173E-01   | 4.595E-02  |
| 6.0600E-01                                                                              | 4.012E-01  | 6.173E-01               | 2.724E-02  | 3.757E-01   | 3.145E+03   | 1.725E+01  | 6.708E-02  | 3.315E-01   | 4.331E-02  |
| 6.5330E-01                                                                              | 3.633E-01  | 5.672E-01               | 2.501E-02  | 3.799E-01   | 3.346E+03   | 2.235E+01  | 1.456E-01  | 4.772E-01   | 4.031E-02  |
| 7.0000E-01                                                                              | 3.299E-01  | 5.081E-01               | 2.240E-02  | 2.576E-02   | 3.425E+03   | 2.745E+01  | 2.368E-01  | 5.694E-01   | 3.032E-02  |
| 7.9700E-01                                                                              | 2.643E-01  | 3.762E-01               | 1.659E-02  | 3.479E-02   | 3.208E+03   | 3.797E+01  | 4.542E-01  | 7.772E-01   | 3.155E-02  |
| 8.4700E-01                                                                              | 1.978E-01  | 3.047E-01               | 1.343E-02  | 3.971E-01   | 2.804E+03   | 4.740E+01  | 5.61E-01   | 8.975E-01   | 2.375E-02  |
| 8.9600E-01                                                                              | 1.436E-01  | 2.259E-01               | 1.009E-02  | 5.720E-02   | 2.153E+03   | 4.972E+01  | 7.192E-01  | 9.942E-01   | 2.567E-02  |
| 9.4700E-01                                                                              | 8.090E-02  | 1.246E-01               | 5.493E-03  | 4.066E-01   | 1.577E+03   | 5.425E+01  | 8.748E-01  | 1.097E+00   | 2.242E-02  |
| 1.0000E+00                                                                              | 0.         | 0.                      | 0.         | 5.516E-01   | 0.          | 6.303E+01  | 1.111E+00  | 1.111E+00   | 0.         |
| ETAD=8.4198E-01 PS(KN)=1.9176E+01 1-THO=7.6400E-01 1-MIT=7.0500E-01 V(KNOTS)=2.4204E+01 |            |                         |            |             |             |            |            |             |            |
| DESIGN THIN=1.2658E+03 CALCULATED THIN=1.2656E+03                                       |            |                         |            |             |             |            |            |             |            |

TABLE 1 CONTINUED

| X         | AREA(M2)  | XOAR(M)   | YBAR(M) | IXO(M4)   | IYO(M4)   | MXO(M-M)  | MYO(M-M)  | MTB(M-M)  | HQB(M-M)  | MAXSTRESS(MPA) |
|-----------|-----------|-----------|---------|-----------|-----------|-----------|-----------|-----------|-----------|----------------|
| 4.470E-01 | 4.558E-04 | 3.202E-02 | 0.      | 2.731E-09 | 7.821E-08 | 1.100E+01 | 3.548E+01 | 1.082E+01 | 7.238E+00 | 3.739E+07      |
| 5.690E-01 | 3.924E-04 | 3.202E-02 | 0.      | 1.758E-09 | 6.752E-08 | 7.837E+00 | 7.563E+01 | 6.498E+00 | 4.136E+00 | 3.134E+07      |
| 6.860E-01 | 3.792E-04 | 3.202E-02 | 0.      | 1.471E-09 | 6.364E-08 | 5.809E+00 | 4.749E+01 | 4.911E+00 | 3.124E+00 | 2.697E+07      |
| 6.538E-01 | 3.448E-04 | 3.202E-02 | 0.      | 1.168E-09 | 5.927E-08 | 4.146E+00 | 2.921E+01 | 3.576E+00 | 2.239E+00 | 2.239E+07      |
| 7.888E-01 | 3.250E-04 | 3.202E-02 | 0.      | 9.954E-10 | 5.587E-08 | 2.901E+00 | 2.083E+01 | 2.486E+00 | 1.531E+00 | 1.744E+07      |
| 7.978E-01 | 2.644E-04 | 3.128E-02 | 8.      | 5.613E-10 | 4.338E-08 | 7.348E+00 | 7.348E+00 | 8.502E-01 | 5.078E-01 | 1.826E+07      |
| 8.478E-01 | 2.276E-04 | 2.963E-02 | 0.      | 3.990E-10 | 3.352E-08 | 4.416E-01 | 3.416E+00 | 3.885E-01 | 2.241E-01 | 5.898E+06      |

| X         | RAKE | PI XTANG1 | PI XTANG  |
|-----------|------|-----------|-----------|
| 4.470E-01 | 0.   | 3.631E-02 | 5.976E-01 |
| 5.178E-01 | 0.   | 1.295E+00 | 8.556E-01 |
| 5.688E-01 | 0.   | 1.372E+00 | 9.639E-01 |
| 6.868E-01 | 0.   | 1.398E+00 | 1.107E+00 |
| 6.538E-01 | 0.   | 1.450E+00 | 1.174E+00 |
| 7.888E-01 | 0.   | 1.479E+00 | 1.229E+00 |
| 7.978E-01 | 0.   | 1.588E+00 | 1.292E+00 |
| 8.478E-01 | 0.   | 1.479E+00 | 1.312E+00 |
| 8.968E-01 | 0.   | 1.443E+00 | 1.323E+00 |
| 9.478E-01 | 0.   | 1.359E+00 | 1.321E+00 |
| 1.088E+00 | 0.   | 1.110E+00 | 1.312E+00 |

WEIGHT OF BLADES(M)= 14.6988

WEIGHT OF PROPELLER CYLINDRICAL HUB(M)= 326.4885

CENTER OF GRAVITY OF PROP REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D= .884111

CENTER OF GRAVITY OF BLADES REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D= .898187

HUB DIMENSIONS/D

HUB DIAM = .447880

HUB LENGTH = .4470

MIDCHORD OF ROOT SECTION TO AFT END OF HUB = .2235

KELLERS MINIMUM EAR= .2946E+00

SPEED COEFF V/(ND) JS= .1887E+01

ADVANCE COEFF V(1-WTT)/(ND) JA= .1274E+01

DESIGN THRUST COEFF KT= .1888E+00

TORQUE COEFF KQ= .4719E-01

PROPULSIVE EFFICIENCY ETAD= .8420E+00

BURRILL THRUST COEFF TC= .2464E+00

BURRILL CAVITATION COEFF SIGMA(8.7)= .1280E+01

CLEARANCE AT HUB BETWEEN BLADES/D= -.82856395

CLEARANCE AT HUB BETWEEN FILLETS/D= -.84451592

TABLE 1 CONTINUED

PERFORMANCE OF SET OF CONTRAROTATING PROPELLERS

|       |        |
|-------|--------|
| CTS=  | .26492 |
| CPS=  | .22867 |
| ETA0= | .88591 |

TABLE 2

THRUST AND POWER LOADING COEFFICIENTS AND PROPULSIVE EFFICIENCY  
CALCULATED USING THE OLD AND NEW DESIGN METHODS

| Performance Predictions                        | Old Method <sup>1,2,3</sup> | New Method |
|------------------------------------------------|-----------------------------|------------|
| Thrust Loading Coefficient<br>( $C_{TS}$ ) fwd | 0.137                       | 0.133      |
| Thrust Loading Coefficient<br>( $C_{TS}$ ) aft | 0.137                       | 0.141      |
| Thrust Loading Coefficient<br>( $C_{TS}$ ) CR  | 0.265                       | 0.265      |
| Power Loading Coefficient<br>( $C_{PS}$ ) fwd  | 0.113                       | 0.108      |
| Power Loading Coefficient<br>( $C_{PS}$ ) aft  | 0.116                       | 0.128      |
| Power Loading Coefficient<br>( $C_{PS}$ ) CR   | 0.222                       | 0.229      |
| Propulsive Efficiency ( $\eta_D$ ) CR          | 0.912                       | 0.886      |

APPENDIX A

INPUT AND OUTPUT FORMATS FOR THE COMPUTER PROGRAM DEVELOPED

TABLE 1

List of dimensioned input and output parameters used by computer program based on English and SI units

| <u>Parameter</u>                | <u>English Units</u>                  | <u>SI Units</u>        | <u>KSI<sup>(1)</sup></u> |
|---------------------------------|---------------------------------------|------------------------|--------------------------|
| Shaft power ( $P_S$ )           | hp                                    | KW                     | 0.7457                   |
| Effective power ( $P_E$ )       | hp                                    | KW                     | 0.7457                   |
| $\rho_p$                        | lbm/ft <sup>3</sup>                   | kg/m <sup>3</sup>      | 16.01846                 |
| V                               | knots <sup>(2)</sup>                  | m/s                    | 0.514444                 |
| V                               | ft/sec                                | knots <sup>(2)</sup>   | 0.5924                   |
| D                               | ft                                    | m                      | 0.3048                   |
| H                               | ft                                    | m                      | 0.3048                   |
| $\rho$                          | lbf sec <sup>2</sup> /ft <sup>4</sup> | kg/m <sup>3</sup>      | 515.3788                 |
| n                               | rev/min                               | rev/min <sup>(3)</sup> | 1.0                      |
| T, weight                       | lbf                                   | N                      | 4.44822                  |
| $V_r$                           | ft/sec                                | m/s                    | 0.3048                   |
| LI                              | lbf/ft                                | N/m                    | 14.5939                  |
| $M_{Tb}$                        | in lbf                                | Nn                     | 0.112985                 |
| $M_{Qb}$                        | in lbf                                | Nn                     | 0.112985                 |
| $M_{xo}$                        | in lbf                                | Nn                     | 0.112985                 |
| $M_{yo}$                        | in lbf                                | Nn                     | 0.112985                 |
| Max Stress                      | lbf/in <sup>2</sup>                   | Pa                     | 6894.757                 |
| SKEW                            | deg                                   | deg <sup>(3)</sup>     | 1.0                      |
| RAKE                            | deg                                   | deg <sup>(3)</sup>     | 1.0                      |
| Mass polar moment<br>of INERTIA | lbm in <sup>2</sup>                   | kgm <sup>2</sup>       | 0.00029264               |

(1) Multiply English Units by KSI to get SI Units.

(2) Computer program uses knots in both English Units option and SI Units option.

(3) These are not SI Units but are permitted to be used in the SI system according to International Standards Organization (ISO) Standard No. 1000.

# APPENDIX A

## INPUT FORMAT (FORWARD PROPELLER)

| Card No. | Format | Parameter    | Description of Input                                                                                                                                                                        |
|----------|--------|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1        | F8.6   | d/R          | Axial distance between the forward and aft propeller planes nondimensionalized on forward propeller radius.                                                                                 |
| 2        | 12A6   | ----         | Identification of design input data.                                                                                                                                                        |
| 3        | F8.4   | $P_S$ or 0.0 | Input the design shaft power if the power option is used. Input 0.0 if the design thrust option is used (see the section on the propeller design thrust and power options).                 |
| 4        | F8.4   | 1.0 or 5.0   | Number of different speeds (V) and effective power values to be punched on Cards 5 and 6, respectively. Input 1.0 for the thrust option and 5.0 for the power option.                       |
|          |        | $\rho_p$     | Specific weight of propeller material ( $\rho_p$ ) for weight calculations.                                                                                                                 |
| 5        | F8.4   | V            | Design speed (V). For the power option, input five different speeds in increasing order with the third speed being the best estimate of final speed. Input one speed for the thrust option. |
| 6        | F8.4   | $P_E$        | Design effective power values corresponding to input speeds on Card 5. (See Equation (1)).                                                                                                  |

| Card No. | Format | Parameter                         | Description of Input                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------|--------|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7        | F8.6   | D                                 | Propeller diameter (D)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|          |        | $(1-w_T)$                         | Effective wake $(1-w_T)$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|          |        | $(1-t)$                           | Thrust deduction $(1-t)$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|          |        | H                                 | Static head (H) at shaft centerline. (See section on Static Head).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|          |        | $\rho$                            | Density of water ( $\rho$ )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|          |        | Skew Angle<br>$(\theta_s)$ Option | For a linear skew angle distribution input percent of skew in decimal form. For nonlinear skew input -1.0 and the skew angles in degrees $(\theta_s)$ must be punched on Cards 22 and 23.                                                                                                                                                                                                                                                                                                                                                                                                                        |
|          |        | $\theta_R$                        | Rake angle at blade tip in degrees. Use $+\theta_R$ value for blades raked aft and $-\theta_R$ for forward rake.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|          |        |                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| 8        | F8.6   | 1.0                               | Input 1.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|          |        | $C_D$                             | Use $CD \geq 10$ to input the radial distribution of drag coefficients (CD); $0 < CD < 10$ to input a constant drag $C_D = CD$ at all radial stations; $CD = 0$ causes the computer program to calculate the radial distribution of drag coefficients using the equation $C_D = 0.008(1 + 1.25(t/c) + 125(t/c)^4)$ ; $-10 < CD < 0$ causes the computer program to use a constant frictional resistance $C_{FO} = ABS(C_{FO})$ in Equation 8, $C_D = C_{FO}(1 + 1.25(t/c) + 125(t/c)^4)$ ; $CD \leq -10$ to input the radial distribution of frictional resistance ( $C_{FO}$ ) values to be used in Equation 8. |
|          |        | $\tan\beta$ Option<br>0.0 or 1.0  | Input 0.0 if $\tan\beta$ is calculated on the computer in the normal manner. Input 1.0 if $\tan\beta$ distribution is arbitrary and punched on Cards 26 and 27.                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

| Card No. | Format | Parameter           | Description of Input                                                                                                                                                                                   |
|----------|--------|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9        | F8.6   | $z$                 | Number of blades                                                                                                                                                                                       |
| 10       | F8.6   | $A_E/A_O$           | Expanded area ratio                                                                                                                                                                                    |
| 11       | F8.6   | $n$                 | Revolutions per unit time                                                                                                                                                                              |
| 12-13    | F8.6   | $x$                 | Nondimensional radial station<br>(eleven values arbitrary<br>spaced from propeller hub<br>to tip)                                                                                                      |
| 14-15    | F8.6   | $(1-w_x)$           | Propeller wake $(1-w_x)$ cor-<br>responding to input $x$ values                                                                                                                                        |
| 16-17    | F8.6   | $\tan\beta_I$       | Tangent of hydrodynamic<br>flow angle $(\tan\beta_I)$ corresponding<br>to input $x$ values. If Lerbs<br>optimum $\tan\beta_I$ distribution<br>is desired, 0.0 values must<br>be punched in these cards |
| 18-19    | F8.6   | $c/D$               | Section chord lengths correspond-<br>ing to input $x$ values                                                                                                                                           |
| 20-21    | F8.6   | $t/c$               | Thickness-chord ratios<br>corresponding to input $x$<br>values                                                                                                                                         |
| 22-23    | F8.6   | $\theta_s$ Optional | Blade skew angles corresponding<br>to input $x$ values to be<br>input only if -1.0 for skew<br>option is punched in Card<br>7. Otherwise Cards 22 and<br>23 must not be used as input<br>cards.        |
| 24-25    | F8.6   | $C_D$ Optional      | Section drag coefficient cor-<br>responding to input values if<br>$CD > 10$ on Card 8; frictional re-<br>sistance of section if $CD \leq 10$ .                                                         |

| Card No. | Format | Parameter            | Description of Input                                                                                                                                                                 |
|----------|--------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 26-27    | F8.6   | $\tan\beta$ Optional | Tangent of advance angle corresponding to input $x$ values to be input only if 1.0 for $\tan\beta$ option is punched on Card 8. Otherwise Cards 26 and 27 must not be used as input. |
| 28-29    | F8.6   | $g_a$                | Distance factors ( $g_a$ ) corresponding to input $x$ values from Reference 1 and Figure 1.                                                                                          |

# INPUT FORMAT (AFT PROPELLER)

| Card No. | Format | Parameter    | Description of Input                                                                                                                                                                                   |
|----------|--------|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 30       | 12A6   |              | Identification of design input data.                                                                                                                                                                   |
| 31       | F8.4   | $P_S$ or 0.0 | Input the design shaft power delivered at the propeller if the power option is used. Input 0.0 if the design thrust option is used (see the section on the propeller design thrust and power options). |
| 32       | F8.4   | 1.0 or 5.0   | Number of different speeds (V) and effective power values to be punched on Cards 33 and 34, respectively. Input 1.0 for the thrust option and 5.0 for the power option.                                |
|          |        | $\rho_P$     | Specific weight of propeller material ( $\rho_M$ ) for weight calculations.                                                                                                                            |
| 33       | F8.4   | V            | Design speed (V). For the power option. Input five different speeds in increasing order with the third speed being the best estimate of final speed. Input one speed for the thrust option.            |
| 34       | F8.4   | $P_E$        | Design effective power values corresponding to input speeds on Card 33. (See Equation (1)).                                                                                                            |
| 35       | F8.6   | 0.0          | Input 0.0 for aft propeller diameter which is calculated on the computer.                                                                                                                              |
|          |        | $(1-w_T)$    | Effective wake $(1-w_T)$                                                                                                                                                                               |
|          |        | $(1-w_T)$    | Thrust deduction $(1-t)$                                                                                                                                                                               |

| Card No. | Format | Parameter                           | Description of Input                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------|--------|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|          |        | H                                   | Static Head (H) at shaft centerline. (See section on Static Head).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|          |        | $\rho$                              | Density of water ( $\rho$ ).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|          |        | Skew Angle<br>( $\theta_s$ ) Option | For a linear skew angle distribution input percent of skew in decimal form. For nonlinear skew input -1.0 and the skew angles in degrees ( $\theta_s$ ) must be punched in Cards 50 and 51.                                                                                                                                                                                                                                                                                                                                                                                                                        |
|          |        | $\theta_R$                          | Rake angle at blade tip in degrees. Use $+\theta_R$ value for blades raked aft and $-\theta_R$ for forward rake.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 36       | F8.6   | 1.0                                 | Input 1.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|          |        | $C_D$                               | Use $CD \geq 10$ to input the radial distribution of drag coefficients (CD); $0 < CD < 10$ to input a constant drag $C_D = CD$ at all radial stations; $CD = 0$ causes the computer program to calculate the radial distribution of drag coefficients using the equation $C_D = 0.008(1 + 1.25((t/c) + 125(t/c)^4))$ ; $-10 < CD < 0$ causes the computer program to use a constant frictional resistance $C_{FO} = ABS(C_{FO})$ in Equation 8, $C_D = C_{FO}(1 + 1.25(t/c) + 125(t/c)^4)$ ; $CD \leq -10$ to input the radial distribution of frictional resistance ( $C_{FO}$ ) values to be used in Equation 8. |
|          |        | $\tan\beta$ Option<br>0.0 or 1.0    | Input 0.0 if $\tan\beta$ is calculated on the computer in the normal manner. Input 1.0 if $\tan\beta$ distribution is arbitrary and punched on Cards 54 and 55.                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 37       | F8.6   | Z                                   | Number of blades                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 38       | F8.6   | $A_E/A_O$                           | Expanded area ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

| Card No. | Format | Parameters           | Description of Input                                                                                                                                                                       |
|----------|--------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 39       | F8.6   | $n$                  | Revolutions per unit time                                                                                                                                                                  |
| 40-41    | F8.6   | $x$                  | Nondimensional radial station (eleven values arbitrarily spaced from propeller hub to tip).                                                                                                |
| 42-43    | F8.6   | $(1-w_x)$            | Propeller wake $(1-w_x)$ corresponding to input $x$ values.                                                                                                                                |
| 44-45    | F8.6   | $\tan\beta_I$        | Tangent of hydrodynamic flow angle ( $\tan\beta_I$ ) corresponding to input $x$ values. If Lerbs optimum $\tan\beta_I$ distribution is desired, 0.0 values must be punched in these cards. |
| 46-47    | F8.6   | $c/D$                | Section chord lengths corresponding to input $x$ values.                                                                                                                                   |
| 48-49    | F8.6   | $t/c$                | Thickness-chord ratios corresponding to input $x$ values.                                                                                                                                  |
| 50-51    | F8.6   | $\theta_s$ Optional  | Blade skew angles corresponding to input $x$ values to be input only if -1.0 for skew option is punched in Card 35. Otherwise Cards 50 and 51 must not be used as input cards.             |
| 52-53    | F8.6   | $C_D$ Optional       | Section drag coefficient corresponding to input values if $CD > 10$ on Card 8; frictional resistance of section if $CD \leq 10$ .                                                          |
| 54-55    | F8.6   | $\tan\beta$ Optional | Tangent of advance angle corresponding to input $x$ values to be input only if 1.0 for $\tan\beta$ option is punched on Card 8. Otherwise Cards 54 and 55 must not be used as input.       |

TABLE 1

## A DESCRIPTION OF THE OUTPUT PARAMETERS

| Computer<br>Parameter | Parameter     | Description of Output                                              |
|-----------------------|---------------|--------------------------------------------------------------------|
| V                     | V             | Speed (input)                                                      |
| PE                    | $P_E$         | Effective power (input)                                            |
| D                     | D             | Diameter (input)                                                   |
| Z                     | Z             | Number of blades (input)                                           |
| H                     | H             | Static head (input)                                                |
| RHO                   | $\rho$        | Density of fluid (input)                                           |
| AE/AO                 | $A_E/A_O$     | Expanded area ratio (input or Equation (6))                        |
| CPSI                  | -----         | Nonviscous power coefficient<br>(Equation (11) when $\epsilon=0$ ) |
| CTSI                  | -----         | Nonviscous thrust coefficient<br>(Equation (9) when $\epsilon=0$ ) |
| XI                    | x             | Nondimensional radii (x)                                           |
| DCTSI                 | $dC_{Tsi}$    | Local nonviscous thrust coefficient<br>(Defined in Equation (9))   |
| DCPSI                 | $dC_{Psi}$    | Local nonviscous power coefficient<br>(Defined in Equation (11))   |
| CPS                   | $C_{PS}$      | Power loading coefficient (Equation (11))                          |
| CTS                   | $C_{TS}$      | Thrust loading coefficient (Equation (9))                          |
| TANBI                 | $\tan\beta_I$ | Tangent of hydrodynamic flow angle                                 |
| TANB                  | $\tan\beta$   | Tangent of advance angle                                           |
| G                     | G             | Nondimensional circulation                                         |
| UT/2V                 | $U_T/2V$      | Tangential velocity induced at<br>lifting line                     |
| UA/2V                 | $U_A/2V$      | Axial velocity induced at lifting<br>line                          |

| Computer<br>Parameter | Parameter    | Description of Output                                                                           |
|-----------------------|--------------|-------------------------------------------------------------------------------------------------|
| VR                    | $V_r$        | Section inflow velocity, Equation (22)                                                          |
| SIGMAX                | $\sigma$     | Section cavitation number, Equation (25)                                                        |
| CL                    | $C_L$        | Section lift coefficient                                                                        |
| ALI                   | $\alpha_i$   | Section two-dimensional ideal angle of attack in degrees for NACA a=0.8 meanline, Equation (24) |
| FM/C                  | $f_M/c$      | Section two-dimensional maximum camber ratio for NACA a=0.8 meanline, Equation (23)             |
| CD/CL                 | $\epsilon$   | Section drag-lift ratio ( $=C_D/C_L$ )                                                          |
| F(X)                  | $F(x)$       | Parameter for calculations section fluctuating angles of attack, Equation (28)                  |
| LI                    | $L I$        | Propeller load distribution for finite element stress calculations, Equation (22)               |
| SKEW ANGLE            | $\theta_s$   | Propeller skew angle in degrees                                                                 |
| (C/R) LE              | $(c/R)_{LE}$ | Chord lengths for lifting surface pitch and camber calculations, Equation (32)                  |
| (C/R) TE              | $(c/R)_{TE}$ | Chord lengths for lifting surface pitch and camber calculations, Equation (33)                  |
| T/R                   | $t/R$        | Ratio of section thickness to radius                                                            |
| PC                    | $\eta_D$     | Estimated propulsive efficiency, Equation (13)                                                  |
| PS                    | -----        | calculated shaft power delivered at the propeller, Equation (13)                                |
| 1-T                   | $(1-t)$      | Propeller thrust deduction                                                                      |
| 1-WT                  | $(1-w_T)$    | Propeller effective wake.                                                                       |

| Computer<br>Parameter | Parameter          | Description of Output                                                              |
|-----------------------|--------------------|------------------------------------------------------------------------------------|
| TH(N)                 | T                  | Design thrust, Equation (9)                                                        |
| TH(N)                 | T                  | Calculated thrust, Equation (9)                                                    |
| A                     | -----              | Area of section                                                                    |
| XBAR                  | -----              | Longitudinal position about x axis<br>parallel to nose-tail line from<br>centroid  |
| YBAR                  | -----              | Vertical distance about y axis<br>perpendicular to nose-tail line<br>from centroid |
| IXO                   | -----              | Moment of inertia about x axis<br>parallel to nose-tail line                       |
| IYO                   | -----              | Moment of inertia about y axis<br>perpendicular to nose-tail line                  |
| MTB                   | $M_{Tb}$           | Bending moment due to thrust,<br>Equation (18)                                     |
| MQB                   | $M_{Qb}$           | Bending moment due to torque,<br>Equation (19)                                     |
| MXO                   | $M_{xo}$           | Bending moment about the x axis,<br>Equation (20)                                  |
| MYO                   | $M_{yo}$           | Bending moment about the y axis,<br>Equation (21)                                  |
| MAX STRESS            | -----              | Maximum stress, Reference 10                                                       |
| RAKE ANGLE            | $\theta_R$         | Rake angle in degrees                                                              |
| PIXTANBI              | $\pi \tan \beta_I$ | Hydrodynamic pitch angle                                                           |
| PIXTANB               | $\pi \tan \beta$   | Advance angle                                                                      |
| WEIGHT OF<br>BLADES   | $(W_B)$            | Equation (36), $W_H=0$                                                             |

| <u>Computer<br/>Parameter</u>                      | <u>Parameter</u> | <u>Description of Output</u> |
|----------------------------------------------------|------------------|------------------------------|
| WEIGHT OF<br>PROP (BLADES<br>+ CYLINDRICAL<br>HUB) | $(W_p)$          | Equation (36)                |
| CENTER OF<br>GRAVITY OF<br>PROP                    | CG               | Equation (37)                |
| CENTER OF<br>GRAVITY OF<br>BLADES                  | -----            | Equation (37), $M_H=0$       |
| KELLERS<br>MINIMUM EAR                             | $(A_E/A_O)_K$    | Equation (31)                |
| SPEED<br>COEFF (JV)                                | $J_V$            | Equation (15)                |
| ADVANCE<br>COEFF (JA)                              | J                | Equation (14)                |
| THRUST<br>COEFF (KT)                               | $K_T$            | Equation (16)                |
| TORQUE<br>COEFF (KQ)                               | $K_Q$            | Equation (17)                |
| PROPULSIVE<br>EFFICIENCY<br>ETAD                   | $\eta_D$         | Equation (13)                |
| BURRILL<br>THRUST<br>COEFF (TC)                    | $\tau_C$         | Equation (29)                |
| BURRILL<br>CAVITATION<br>COEFF                     | $\sigma_{0.7}$   | Equation (30)                |
| CLEARANCE<br>AT HUB<br>BETWEEN<br>BLADES           | $G_Z$            | Equation (34)                |

| Computer<br>Parameter                  | Parameter       | Description of Output                                                          |
|----------------------------------------|-----------------|--------------------------------------------------------------------------------|
| CLEARANCE AT<br>HUB BETWEEN<br>FILLETs | $G_F$           | Equation (35)                                                                  |
| CTS                                    | $(C_{TS})_{CR}$ | Thrust loading coefficient for set of contra-rotating propellers (Equation 10) |
| CPS                                    | $(C_{P3})_{CR}$ | Power loading coefficient for set of contra-rotating propellers (Equation 12)  |
| ETAD                                   | $(\eta_D)_{CR}$ | Propulsive efficiency for set of contra-rotating propellers (Equation 13)      |

APPENDIX B

FORTRAN LISTING OF COMPUTER PROGRAM

```

PROGRAM GMAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
COMMON/CWEIGHT/X,CHORD,THICKNS,CAMBER,PITCH,SKFWR,DIAM,ZZ,DEN,WAKE
1,ST
1,PI,PP7,PP8,PP9,PP11,EWAKE,VS,FPS,SIGMA,EAR,BT
DIMENSION B(38,38),B1(181),B2(181),B3(181),B4(362),B5(362),B6(362)
1,B7(181),B8(181),B9(181),B10(181),B11(181),B12(181),B13(181),B14(
2181),B15(181),AZ(38,38),BH(38,38),C(38,38),CC(38,38),INDEX(38,3)
3,A(38,72),PB(38,72)
COMMON B,B1,B2,B3,B4,B5,B6,B7,B8,B9,B10,B11,B12,B13,B14,B15,AZ,BH,
1C,CC,INDFX,A,B9
COMMON ID,JB,JC,JD,JDD,JFF
COMMON CL1(11)
DIMENSION CHORD(38),THICKNS(38),CAMBER(38),PITCH(38),SKFWR(38)
1,X(38),BETA1(38),BT(11)
DIMENSION X3(38),X4(38),X5(38),X6(38),VEL(9),EHP(9),BLA(9),EXX(9)
DIMENSION AZZ(38,38)
DIMENSION ASHP(9)
DIMENSION XMM(9)
DIMENSION CAV(9),CAF(9)
DIMENSION FX(11),FP(11)
DIMENSION VEL1(9),FHP1(9)
DIMENSION L(11,14,2)
DIMENSION CONST(11),G(11),H(11)
DIMENSION SVL(9),SPE(9)
DIMENSION UA(11),UT(11),WV(11),UR(11),UA1(11,2),UT1(11,2),UR1(11,2
1)
DIMENSION AEL(11,9)
DIMENSION DEX(11,3,2),COM(12,2)
DIMENSION FWDHP(3),AFTHP(3)
DIMENSION BZ(111)
DIMENSION AX(11),PAK(11)
DIMENSION VSUB,SO(11),VSUBF(11),PLFT(11),AV(11),BV(11)
COMMON CCONE(11),CLTWO(11),CCTHR(11),CCFOR(11)
DIMENSION ARFA(7),YBAR(7),YBAR(7),AYEXO(7),AYEYO(7),EMXC(7),EMYO(7
1),FMTB(7),EMOB(7),STPMAX(7)
DIMENSION FXTBI(11),PXTB(11)
DIMENSION SX(7)
COMMON PP1,PP2,PP3,PP4,PP5,PP6,PP10
DIMENSION GA11(11)
DIMENSION HUBDIM(6,2)
DIMENSION CPT(2),CPS(2),CTS(2)
COMMON /WRT/ JPR
READ(5,406) DFX(1,2,1)
406 FORMAT(F8.4)
JPR=0
IPO=1
IOCR=0
XDD=4.0
IOC=XDD
PI=3.14159265358979
OSI=16.01846
PWR=.7456999
VSI=.5144444
ELF=.3048
ELI=.0254
EL2=ELI*ELI
EL4=EL2*EL2

```

```

SIM=.1129848
SMX=6894.757
SWT=4.44822
RHOSI=515.3788
IPR=C
JG=0
DO 813 K=1,2
XRPM=1.0
XZZ=1.0
XEA=1.0
JG=JG+1
READ(5,830) (COM(I,K),I=1,12)
933 FORMAT(12A6)
    READ(5,10000) SPWR
    SHP=SPWR/PWR
    READ(5,10009) XVV,DSN
    HUB=0.
    DEN=DSN/DSI
    IRPM=XPPM
    IVV=XVV
    READ(5,10009) (SVL(I),I=1,IVV)
    READ(5,10009) (SPE(I),I=1,IVV)
    READ(5,10009) SDM,EWAKE,ETHRUS,SHD,SRO,XPS,RAKE
    DO 409 I=1,IVV
    VEL(I)=SVL(I)/VSI
409 EHP(I)=SPE(I)/PWR
    DIA=SDM/ELF
    HEAD=SHD/ELF
    RHO=SPO/RHOSI
    IF(SHP) 103,102,103
103 SHP=SHP/2.0
    NXVV=XVV
102 CONTINUE
    READ(5,10009) TANBI,CO,TANB
    B(2,1)=CO
    JC=11
    IZZ=XZZ
    IEA=XEA
    READ(5,10009) (BLA(I),I=1,IZZ)
    BLAS=BLA(1)
    READ(5,10009) (EXX(I),I=1,IEA)
    EXXS=EXX(1)
    READ(5,10009) (XMM(I),I=1,IRPM)
    READ(5,10009) (X3(I),I=1,JC)
    READ(5,10009) (X4(I),I=1,JC)
    READ(5,10009) (X5(I),I=1,JC)
    READ(5,10009) (X6(I),I=1,JC)
    READ(5,10009) (AZZ(I,25),I=1,JC)
    IF(XPS) 6,7,7
    6 READ(5,10009) (A7Z(I,24),I=1,JC)
    DO 26 I=1,JC
    AZZ(I,38)=AZZ(I,24)
26 CONTINUE
7 CONTINUE
    IF(ABS(CD).GE.10.) READ(5,10009) (B(I,7),I=1,JC)
    IF(CD.GE.10.) GO TO 10010
    TM=P(2,1)

```

```

      CFO=.008
      IF(CO.GT.0.) CFO=1.
      IF(CO.GT.-10. .AND.CO.LT.0.) CFO=-CO
      DO 10007 I=1,JC
      IF(CO.LE.0.) TM=1.+1.25*AZZ(I,25)+125.*AZZ(I,25)**4
      IF(CO.LE.-10.) CFP=B(I,7)
10007  B(I,7)=CFO*TM
10008  FORMAT(72H
1
10000  FORMAT(F8.4)
10009  FORMAT(9F8.4)
10010  IF(TANB.LE.0.) READ(5,10009) (R(I,8),I=1,JC)
      IF(IOCP.NE.0) GO TO 57
      IF(K.NE.1) GO TO 57
      READ(5,10009) (GA11(I),I=1,11)
57  CONTINUE
      IF(HUR.NE.0.) READ(5,10009) (MURDIM(I,K),I=1,6)
      D(10,1,K)=XVV
      D(11,1,K)=XRPM
      DO 802 I=1,IVV
      D(I,1,K)=VEL(I)
802  D(I,2,K)=EHP(I)
      D(11,2,K)=EWAKE
      D(1,3,K)=ETHRUS
      D(6,3,K)=XPS
      D(7,3,K)=SHP
      D(9,3,K)=CO
      D(10,3,K)=TANB
      D(10,2,K)=DIA
      D(2,3,K)=HEAC
      D(3,3,K)=RHO
      D(4,3,K)=XZ7
      D(5,3,K)=XEA
      D(8,3,K)=TANBI
      D(11,3,K)=DEN
      D(11,4,K)=HUR
      DO 803 I=1,I27
803  D(I,4,K)=BLA(I)
      DO 804 I=1,IFA
804  D(I,5,K)=EXX(I)
      DO 805 I=1,I2PM
805  D(I,6,K)=XMM(I)
      DO 808 I=1,JC
      D(I,7,K)=X3(I)
      D(I,8,K)=X4(I)
      D(I,9,K)=X5(I)
      D(I,10,K)=X6(I)
808  D(I,11,K)=AZZ(I,25)
      IF(XPS) 806,807,807
806  DO 125 I=1,JC
125  D(I,12,K)=AZZ(I,24)
807  CONTINUE
      DO 809 I=1,JC
809  D(I,13,K)=B(I,7)
810  IF(TANB) 812,812,811
811  DO 126 I=1,JC
126  D(I,14,K)=B(I,8)

```

```

812 CONTINUE
DEX(1,1,K)=4.0
DEX(2,1,K)=11.0
DEX(3,1,K)=1.0
DEX(1,2,2)=-DEX(1,2,1)
JT=11
813 CONTINUE
IC=-2
JN=0
JQ=0
IK=1
NF=0
NTT=0
IF(SHP) 90,91,90
91 NXVV=1
90 DO 10073 NK=1,NXVV
105 CONTINUE
NT=0
NTT=NTT+1
IF(NK.GT.1) IDO=2
DO 10072 NIT=1,IDO
NT=NT+1
XVV=D(10,1,IK)
IV9=XVV
XRP4=D(11,1,IK)
IF(SHP) 152,152,153
153 IF(NTT.EQ.NXVV+1) GO TO 151
152 CONTINUE
DO 520 I=1,IVV
VEL(I)=D(I,1,IK)
520 EMP(I)=D(I,2,IK)
151 CONTINUE
DO 1 I=1,IVV
CAV(I)=VEL(I)
1 CAE(I)=EMP(I)
DIA=D(10,2,IK)
EWAKE=D(11,2,IK)
ETHRUS=D(1,3,IK)
HEAD=D(2,3,IK)
RHO=D(3,3,IK)
XZZ=D(4,3,IK)
XEA=D(5,3,IK)
XPS=D(6,3,IK)
SHP=D(7,3,IK)
TAN9I=D(8,3,IK)
CD=D(9,3,IK)
TAN8=D(10,3,IK)
DEN=D(11,3,IK)
HUR=D(11,4,IK)
DO 821 I=1,IZZ
BLA(I)=D(I,4,IK)
821 BLAS=BLA(1)
DO 822 I=1,IEA
EXX(I)=D(I,5,IK)
822 EXXS=EXX(1)
DO 823 I=1,IRPP
823 XMM(I)=D(I,6,IK)

```

```

      DO 824 I=1,JC
      X3(I)=O(I,7,IK)
      X4(I)=O(I,8,IK)
      X5(I)=O(I,9,IK)
      X6(I)=O(I,10,IK)
824  AZZ(I,25)=O(I,11,IK)
      IF(XPS) 825,826,826
825  DO 127 I=1,JL
      AZZ(I,24)=O(I,12,IK)
826  CONTINUE
827  DO 128 I=1,JC
      B(I,7)=O(I,13,IK)
828  IF(TANB) 831,831,829
829  DO 129 I=1,JC
      B(I,8)=O(I,14,IK)
831  CONTINUE
      DO 15 I=1,JC
      15  AZZ(I,23)=X3(I)
      JC1=JC-1
      DO 16 I=2,JC1
      16  AZZ(I,19)=X3(I+1)
      AZZ(I,19)=X3(I)
      DO 4 I=1,11
      AZZ(I,36)=AZZ(I,25)
      AZZ(I,37)=AZZ(I,23)
      DO 10072 IF=1,IZZ
      B(9,2)=BLA(IE)
      XSX=XPS*(360.0/B(9,2))
      AS1=XSX/(1.0-X3(I))
      AS2=XSX-AS1
      DO 10072 KE=1,IEA
      DO 10072 IMP=1,IRPM
      RPY=XPM(IMP)
      EAR=EXX(KE)
      DO 100 I=1,JC
      B(I,3)=X3(I)
      B(I,4)=X4(I)
      B(I,5)=X5(I)
      IF(YFS) 14,17,13
      13  CONTINUE
      AZZ(I,24)=AS1*X3(I)+AS2
      AZZ(I,24)=0.0
      GO TO 166
      14  AZZ(I,24)=AZZ(I,34)
      166  CONTINUE
      AZZ(I,38)=AZZ(I,24)
      177  CONTINUE
      DO 10051 LF=1,JC
      10051 B(LE,6)=(BLAS*EAR*X6(LE))/(B(9,2)*EXXS)
      DO 10052 LF=1,JC
      10052 AZZ(LE,25)=AZZ(LE,36)*B(LE,6)
      DO 30 I=1,9
      VEL(I)=CAV(I)
      30  FHP(I)=CAE(I)
      B(5,2)=XMM(IMP)/60.0
      IVV=XVV
      IVA=1

```

```

10046 IF(SHP) 51,52,51
      52 DO 53 IG=1,IVV
        VEL1(IG)=VEL(IG)
      53 EHP1(IG)=EHP(IG)
        IV=1
        GO TO 54
      51 CONTINUE
        IV=1
        IF(NTT.EQ.NXVV+1) GO TO 155
        VEL1(1)=VEL(NK)
        EHP1(1)=EHP(NK)
        GO TO 54
      155 VEL1(1)=VEL(1)
        EHP1(1)=EHP(1)
      54 CONTINUE
      21 DO 5 I=1,11
        AZZ(I,25)=AZZ(I,36)
      5  AZZ(I,23)=AZZ(I,37)
        B(6,2)=(325.86*EHP1(IV))/(VEL1(IV)*ETHRUS)
        B(7,2)=1.688*VEL1(IV)
        AJJ=1.0
        NN=0
      10001 BJ=1.0
        JB=9J
      10002 FORMAT( 3I3)
      10003 CONTINUE
        DDJ=1.0
        JEE=TANBI
        JOD=DDJ
        B6(361)=1.0
        JD=.666667*FLOAT(JC)
        B(1,1)=0.0
        B(2,1)=CD
        B(3,1)=TANB
        B(4,1)=0.6
        B(6,1)=0.0
        B(7,1)=0.0
        B(8,1)=0.0
        B(9,1)=0.0
        B(1,2)=1.0
        B(2,2)=1.0
        B(3,2)=RHO
        B(5,1)=EWAKE
        B(3,2)=DIA
        B(4,2)=HEAD
        RSL=B(7,2)/(3.14159265*B(5,2)*B(3,2))
      10012 IF(B(1,5)) 10017,10017,10019
      10017 CONTINUE
        IF(B(5,1)) 800,800,801
      800  B(5,1)=B(JC,4)
      801  CONTINUE
        DO 10018 I=1,JC
      10018 B(I,5)=(RSL*SQR(B(5,1))*SQR(B(I,4)))/(B(I,3)*B(4,1))
      10019 NN=NN+1
        HUGL=X3(1)*DIA/2.0
        ADJS=(X3(11)*DIA/2.0)-HUGL
        DO 35 I=1,11

```

```

35 RAK(I) = ((X3(I)*DIA/2.0) - HUBL)*RAKE/ADJS
   IPR = IPR + 1
   IF(JPP.NE.2) GO TO 10087
   SUM = DIA*ELF
   WRITE(6,130)
130 FORMAT(1H1)
   IF(IK-1) 115,115,116
115 WRITE(6,117)
117 FORMAT(43X,*FORWARD PROP OF CONTRAPOTATING SET*)
   GO TO 118
118 WRITE(6,119)
119 FORMAT(45X,*AFT PROP OF CONTRAPOTATING SET*)
118 CONTINUE
   WRITE(6,830) (COM(I,IK),I=1,12)
   TSHP = 2.*SFWR
   IF(SHF.LO.0.) WRITE(6,410)
   IF(SHF.NE.0.) WRITE(6,10020) TSHP
410 FORMAT(2X,*THRUST OPTION*)
10020 FORMAT(2X,*PS(KW)=*,1X,1P9E12.4)
   WRITE(6,10026) XVV,DSN
10026 FORMAT(2X,*NO OF V=*,F5.1,4X,
1(KG/M3)=*,F10.2,4X)
   WRITE(6,10027) (SVL(I),I=1,IV9)
10027 FORMAT(2X,*V(M/SEC)=*,1P9E12.4)
   WRITE(6,10045) (SPE(I),I=1,IV9)
10045 FORMAT(2X,*PE(KW)=*,2X,1P9E12.4)
   WRITE(6,10025) SUM,ETAKE,ETHRUS,SHD,SRO,XPS,RAKE
10025 FORMAT(2X,*U(M)=*F3.4,4X,*1-WTT=*F3.4,4X,*1-THD=*F8.4,4X,*H(M)=*
2 F9.4,4X,*RHO(KG/M3)=*F10.4/2X,*TETS OPT=*,F6.3,3X,*RAKE OPT=*,
3 F6.3)
   WRITE(6,10029) TANGI,CO,TANB
10029 FORMAT(2X,*TANGI OPT=*,F4.2,4X,*DRAG OPT=*,F7.4,4X,*TANB OPT=*,
1F4.2)
   WRITE(6,10030) (BLA(I),I=1,IZZ)
10030 FORMAT(2X,*Z=*,10X,1P9E12.4)
   WRITE(6,10031) (EXX(I),I=1,IEA)
10031 FORMAT(2X,*AE/A0=*6X,1P9E12.4)
   WRITE(6,10032) (XMM(I),I=1,IRFM)
10032 FORMAT(2X,*N(REV/MIN)=*,1P9E12.4)
   WRITE(6,10042)
   WRITE(6,10033) (X3(I),I=1,JC), (X4(I),I=1,JC), (X5(I),I=1,JC), (X6(I),
1I=1,JC), (AZZ(I,25),I=1,JC)
10033 FORMAT(2X,*X=*,1P9E12.4/10X,1P2E12.4/2X,*1-WX=*,1P9E12.4/
110X,1P2E12.4/2X,*TANGI=*,1P9E12.4/10X,1P2E12.4/2X,*C/D=*,1P9
2E12.4/10X,1P2E12.4/2X,*T/C=*,1P9E12.4/10X,1P2E12.4)
   IF(XPS) 22,23,23
22 WRITE(6,10036) (AZZ(I,24),I=1,JC)
10036 FORMAT(2X,*TETS=*,1P9E12.4/10X,1P2E12.4)
23 CONTINUE
   IF(CD) 24,24,25
24 WRITE(6,10037) (R(I,7),I=1,JC)
10037 FORMAT(2X,*CD=*,1P9E12.4/10X,1P2E12.4)
25 CONTINUE
10043 FORMAT(4X,*D(M)=*1PE10.4,* N(REV/MIN)=*1PE10.4,* Z=*,1PE10.4,
2 * AE/A0=*1PE10.4)
10044 FORMAT(3X,*ETAD=*,
2 1PE10.4,2X,*PS(KW)=*,1PE10.4,3X,*1-THD=*,1PE10.4,

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```

2   TX,*1-WTT=*,1PE10.4,3X,
2   *V(KNOTS)=*1PE10.4,3X,*   DESIGN TH(N)=*,1PE10.4,
3   /,78X,*V(M/SEC)=*,1PE10.4,3X,*CALCULATED TH(N)=*,1PE10.4)
    WRITE(6,10042)
    WRITE(6,10043) SOM,RPM,B(9,2),EAR
10087 VK=B(7,2)/1.6878
     VMS=B(7,2)*ELF
     DO 10090 I=1,JC
     AZZ(I,25)=AZZ(I,25)*B(I,6)
10090 B(I,30)=B(I,5)
10024 FORMAT(1P9E12.4)
     IF(JN) 65,65,66
     65 CONTINUE
     XMM1=RPM/60.0
     IF(TANR) 10034,10034,101
10034 DO 10035 I=1,JC
10035 B(I,8)=RSL/B(I,3)*B(I,4)
     CW1=B(7,8)
     101 CONTINUE
     GO TO 67
66   CONTINUE
     DO 68 I=1,JC
     CONST(I)=PI*XMM1*DIA*X3(I)/B(7,2)
     G(I)=UA(I)+X4(I)
     H(I)=CONST(I)-UT(I)
     68 B(I,8)=G(I)/H(I)
     CW2=B(7,8)
     DO 31 I=1,11
31   B(I,8)=CW1/CW2*B(I,9)
     IF(IK-2) 33,32,33
32   DO 34 I=1,11
34   B(I,8)=D(10,2,1)*B(I,8)/D(10,2,2)
33   CONTINUE
     67 CONTINUE
     IF(SHP) 85,85,86
     85 JN=JN+1
     86 CONTINUE
     ALPHA=6.2831853/72.
     DO 12 I=1,36
     DO 12 J=1,72
     AC=ALPHA*FLOAT((J-1)*I)
     A(I,J)=SIN(AC)
     12 BB(I,J)=COS(AC)
     AJJ=1.0
20003 IF(JEE)2,2,3
2   AJJ=1.
     GO TO 47
3   DO 209 IDC=1,2
     DO 201 I=1,JC
201  B(I,30)=B(I,30)*AJJ
     B14(41)=.975
     B14(42)=1.000
     B14(43)=1.025
     DO 215 IJ=41,43
     IJT=IJ+4
     IJP=IJ+8
     DO 216 I=1,JC

```

```

216  B(I,5)=B(I,30)*B14(IJ)
      CALL SUB
      B14(IJT)=B5(362)
      B14(IJP)=B6(362)
215  CONTINUE
      B15(41)=1.0
      B15(44)=1.0
      B15(47)=1.0
      B15(42)=B14(41)
      B15(45)=B14(42)
      B15(48)=B14(43)
      B15(43)=B14(41)**2
      B15(46)=B14(42)**2
      B15(49)=B14(43)**2
      IF(B(1,2)) 8,8,9
9     CC(1,1)=B14(45)
      CC(2,1)=B14(46)
      CC(3,1)=B14(47)
      TTT=B(6,2)/((B(8,2)*3(3,2)**2*3.1415927*B(7,2)**2)/3.)
      GO TO 18
8     CC(1,1)=B14(49)
      CC(2,1)=B14(50)
      CC(3,1)=B14(51)
      TTT=55.*B(6,2)/((B(8,2)*B(3,2)**2*3.1415927*B(7,2)**2)/8.)
19    DO 11 I=1,3
      DO 11 J=1,3
      K=7*(J-1)+I
11    C(J,I)=B15(K+40)
      B10(191)=3
      CALL SIMEQ(3,C,C)
10043 AJJ=(-CC(2,1)+SQRT(CC(2,1)**2-4.*CC(3,1)*(CC(1,1)-TTT)))/(2.*CC(3,
11))
209  CONTINUE
50    B5(361)=-1.0
      JEE=0
48    DO 49 I=1,JC
49    B(I,5)=B(I,30)*AJJ
47    CONTINUE
      CALL SUB
      PP11=B15(161)*ETHRUS
      PP12=EHP1(IV)/PP11
      THP=B(6,2)
      ATHR=B(8,2)/3.0*3.14159*(B(3,2)**2)*(B(7,2)**2)*PP7
      ASHP(IV)=PP12
      IF(SHP) 55,56,55
55    IVV=1
56    IV=IV+1
      IF(IVV-IV) 10050,21,21
10050 CONTINUE
      DO 10049 IX=1,IV
      EHP(IX)=EHP1(IX)
10049 VEL(IX)=VEL1(IX)
      DO 40050 I=1,JC
      AZZ(I,26)=B(I,14)
      AZZ(I,27)=B(I,5)
      BII=ATAN(AZZ(I,27))
      CII=(AZZ(I,24)*B(I,3))/(57.2958*COS(BII))

```

```

      AZZ(I,28)=CII-B(I,6)
      AZZ(I,29)=CII+B(I,6)
      AZZ(I,30)=B(I,6)
      AZZ(I,31)=B(I,4)
      AZZ(I,32)=B(I,12)
      AZZ(I,33)=B(I,13)
40050 AZZ(I,34)=AZZ(I,25)*2.0
      DO 36 I=1,JC
    36 AX(I)=AZZ(I,34)
      IF(AZZ(11,25).NE.0.) GO TO 5555
      SLP=(AZZ(9,34)-AZZ(6,34))/(AZZ(9,23)-AZZ(6,23))
      YINT=AZZ(9,34)-(AZZ(9,23)*SLP)
      AZZ(10,34)=(SLP*AZZ(10,23))+YINT
      AZZ(11,34)=(SLP*AZZ(11,23))+YINT
5555 CONTINUE
      DO 40052 K=26,34
      DO 40051 J=1,11
        B11(J)=B(J,3)
40051 B3(J)=AZZ(J,K)
      DO 40052 I=1,11
        S1=AZZ(I,23)
        CALL DISCOT(S1,S1,B11,B3,B3,-120,JC,0,S2)
40052 AZZ(I,K)=S2
40056 FORMAT(1PE10.3,1P10F11.3)
      DO 5050 I=1,JC
        AZZ(I,2)=B(I,2)
        B(I,20)=B(I,15)
        B(I,21)=B(I,5)
        RII=ATAN(B(I,21))
        B(I,22)=B(I,38)
        B(I,23)=B(I,6)
        B(I,24)=AZZ(I,24)
        B(I,25)=AZZ(I,25)
5050 B(I,24)=(B(I,24)*B(I,3))/(57.2958*COS(RII))
        BT(11)=B(11,5)
      DO 5001 I=1,10
5001 B1(I)=AZZ(I,19)
      DO 50030 K=20,24
      DO 50020 J=1,11
        B11(J)=B(J,3)
50020 B3(J)=B(J,K)
      DO 50030 I=1,10
        S1=B1(I)
        CALL DISCOT(S1,S1,B11,B3,B3,-120,JC,0,S2)
50030 B(I,K)=S2
      DO 50040 K=20,24
      DO 50040 I=1,10
50040 AZZ(I,K)=B(I,K)
      CALL STRESS(AZZ,AREA,XBAR,YBAR,AYEXO,AYEYO,EMXO,EMYO,EMTB,EMQB,STR
1MAX)

C      THE FOLLOWING STATEMENTS HAVE BEEN ADDED IN ORDER TO SEND THE R
C      VALUES TO SUBROUTINE WEIGHT. CHORD, THICKNESS, AND CAMBER ARE I
C      PITCH AND SKEWR ARE IN RADIAN.
      DO 999 I=1,JC
      VS=VK*1.6878
      X(I)=B(I,3)

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```

      IF (X(I).NE.0.7) GO TO 6001
      SIGMA=R(I,19)
      GO TO 6000
6001 IF (X(I).LE.0.65) GO TO 6000
      IF (X(I).GE.0.75) GO TO 6000
      SIGMA=R(I,19)
6002 CONTINUE
      CHORD(I)=B(I,6)*DIAM
      THICKNS(I)=A7Z(I,34)*DIAM/2.
      PITCH(I)=ATAN(R(I,5))
      BBJ(I)=ATAN(B(I,8))
      IF (CL1(I)) 28,27,28
27  FX(I)=C.0
      GO TO 29
28  CONTINUE
      FX(I)=1.0/(1.0+(6.2832*TAN(PITCH(I)-BBJ(I))/CL1(I)))
29  CONTINUE
      RETAI(I)=PITCH(I)*57.2958
      SKEWR(I)=A7Z(I,38)/57.2958
      AZZ(I,34)=AX(I)
      AV(I)=(B(I,4)+B(I,12))*2
      RV(I)=(B(I,4)/B(I,8)-R(I,13))*2
      VSUBPSQ(I)=VS**2*(AV(I)+RV(I))
      VSUBR(I)=SQRT(VSUBPSQ(I))
      PLFT(I)      =.5*RHO*VSUBPSQ(I)*CL1(I)* R(I,6)*DIA*14.5939
999  CAMBER(I)=.0679*R(I,18)*DIAM
      RPS=RPM/60.
      DO 996 I=1,JC
      PXTBI(I)=PI*B(I,3)*R(I,5)
      PXTB(I)=PI*B(I,3)*R(I,8)
996  CONTINUE
      EA1=(EAR*3.14159*DIA**2)/4.0
      AL=3.14159*0.7*B(7,5)
      AP=EA1*(1.067-0.229*AL)
      VA=VS*R(7,4)
      VR=SQRT(VA**2+(0.7*3.14159*RPS*DIA)**2)
      TC=2.3*B(6,2)/(RHO*AP*VR**2)
      SIGMA7=(64.4*HEAD)/VR**2
      IF (JPR.NE.2) GO TO 400
10042 FORMAT(1H)
      WRITE(6,77) PP1,PP3,PP2,PP5
77  FORMAT(4X,*CPTI=*,1PE10.4,4X,*CPSI=*,1PE10.4,4X,*CTSI=*,1PE10.4,
2   4X,*CTSI/CPSI=*,1PE10.4)
      WRITE(6,10042)
      WRITE(6,78)
78  FORMAT(6X,* X*,8X,*TANBI*,7X,*TAN B*,9X,*G*,9X,*UT/2V*,7X,
2   *UA/2V*,7X,*DCTSI*,7X,*DCPSI*,6X,*VR (M/SEC)*,5X,*CAVV*)
      DO 79 I=1,11
      VRSI=VSUBR(I)*ELF
79  WRITE(6,6010) B(I,3),B(I,5),B(I,8),B(I,14),B(I,13),B(I,12),B(I,15)
1   ,B(I,17),VRSI,B(I,19)
6010 FORMAT(1P10E12.4)
      WRITE(6,10042)
      WRITE(6,6011) PP6,PP8,PP7,PP10
6011 FORMAT(5X*CPT=*,1PE10.4,5X*CPS=*,1PE10.4,5X*CTS=*,1PE10.4,6X,
2   *CTS/CPS=*,1PE10.4)

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WRITE(6,10042)
WRITE(6,76)
76  FORMAT(5X,* X*,6X,*CL*,6X,*ALI(DEG)*5X,*FM/C*,7X,*CD/CL*,7X,
2    *F(X)*,5X,*LI(N/M)*,3X,*TETS(DEG)*,2X,* (C/RD)LE*,
3    3X,* (C/RD)TE*,5X,*T/RD* )
DO 6002 I=1,11
6002 WRITE(6,20046) B(I,3),CCONE(I),CCTWO(I),CCTHR(I),CCFOR(I),FX(I),PLF
1T(I),AZZ(I,38),AZZ(I,28),AZZ(I,29),AZZ(I,34)
20046 FORMAT(1PE10.3,1P10E11.3)
WRITE(6,10042)
SHR=THR*SMT
STHR=ATHR*SMT
WRITE(6,10044) PP11,PP12,ETHRUS,EWAKE,VK,SHR,VHS,STHR
WRITE(6,6003)
6003  FORMAT(1H1,4X,*X*,7X,*AREA(M2)*,4X,*XBAR(M)*,2X,*YBAR(M)*,5X,
2    *IXO(M4)*,4X,*IYO(M4)*,4X,*MXO(N-M)*3X,*MYO(N-M)*,3X,*MTB(N-M)*,
3    3X,*MOB(N-M)*,3X,*MAXSTRESS(PA)* )
400  CONTINUE
DO 122 I=1,7
IF(I-1) 120,121,120
121  SX(I)=B(I,3)
GO TO 122
120  SX(I)=B(I+1,3)
122  CONTINUE
IF(JPR.NE.2) GO TO 10091
DO 124 I=1,7
APR=EL2*AREA(I)
XPR=EL1*XBAR(I)
YPR=EL1*YBAR(I)
XOI=EL4*AYEXO(I)
YOI=EL4*AYEYO(I)
XOM=SIM*EMXO(I)
YOM=SIM*EMYO(I)
TBM=SIM*EMTB(I)
QBM=SIM*EMOB(I)
STRM=SMX*STRMAX(I)
124  WRITE(6,20046) SX(I),APR,XPR,YPR,XOI,YOI,XOM,YOM,TBM,QBM,STRM
WRITE(6,10042)
WRITE(6,10042)
WRITE(6,6004)
6004  FORMAT(5X*X*8X*RAKE*5X*PI XTANBI*3X*PI XTANB*)
DO 6005 I=1,11
6005  WRITE(6,6006) B(I,3),RAK(I),PXTBI(I),PXTB(I)
6006  FORMAT(1PE10.3,1P3E11.3)
10091 CONTINUE
CTS(IK)=PP7
CPS(IK)=PP8
CPT(IK)=PP6
CALL HEIGHT(JC,SIGMA7,IPO,IPR,HUBDIM,IK,HUB)
HUBSPAC=2.0*PI*X(1)*DIA*6.0*SIN(PITCH(1))/D(1,4,IK)
BLASPAC=HUBSPAC-AX(1)*DIA*6.0
FILSPAC=HUBSPAC-AX(1)*DIA*6.0*1.9
IF(JPR.NE.2) GO TO 6902
WRITE(6,998) TC,SIGMA7
SBL=BLASPAC/DIA/12.
SFI=FILSPAC/DIA/12.
WRITE(6,994) SBL,SFI

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998 FORMAT(/20X,*BURRILL THRUST COEFF TC=*,E10.4//20X,*BURR:
1TATION COEFF SIGMA(0.7)=*,E10.4)
994 FORMAT(/20X,*CLEARANCE AT HUB BETWEEN BLADES/D=*,F13.8//,
2 20X,*CLEARANCE AT HUB BETWEEN FILLETS/D=*,F13.8)
6902 CONTINUE
      IF(JPR.EQ.1) JPR=2
      DO 64 I=1,11
      A27(I,23)=A22(I,37)
      A3C(I,1)=B(I,3)
      A3C(I,2)=B(I,14)
      A3C(I,3)=A22(I,27)
      A3C(I,4)=A22(I,28)
      A3C(I,5)=A22(I,29)
      A3C(I,6)=A22(I,31)
      A3C(I,7)=B(I,12)
64  A3C(I,8)=A22(I,34)
      A3C(2,9)=B(9,2)
      IF(IOPK.NE.3) GO TO 62
      IF(IK.NE.1) GO TO 62
      IF(NK.EQ.1) GO TO 63
      GO TO 62
62  IF(NIT.EQ.1) GO TO 61
      GO TO 62
61  BZ(1)=1.0
      BZ(2)=PIA
      BZ(3)=WFA0
      BZ(4)=YPM(1)/63.3
      BZ(5)=0.931
      BZ(6)=THR*2.0
      BZ(7)=VEL(1)*1.6878
      BZ(8)=PHO
      BZ(9)=EWAKF
      BZ(10)=9LA(1)
      BZ(11)=BZ(10)
      BZ(15)=CO
      BZ(16)=C.0
      BZ(17)=0.0
      BZ(18)=0.0
      DO 300 I=1,12
300  BZ(I+99)=COM(I,1)
      IN1=6
      DO 301 IN=18,90,18
      IN1=IN1+1
      IF(IN.FQ.90) IN1=13
      DO 301 I=1,9
      IF(I-1) 302,303,302
303  J=I
      GO TO 306
302  IF(I-9) 305,304,305
304  J=I+2
      GO TO 306
305  J=I+1
306  BZ(IN+I)=O(J,IN1,1)
301  CONTINUE
      DO 307 IN=27,81,18
      IN9=IN+9
      DO 307 I=1,9

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      BZ(IN+I)=BZ(IN+I)
307 CONTINUE
      BZ(10)=0(1,4,1)
      BZ(11)=0(1,4,2)
      DO 308 I=1,9
      IN=I+72
      IF(I-1) 309,310,309
310 J=I
      GO TO 311
309 IF(I-9) 312,313,312
313 J=I+2
      GO TO 311
312 J=I+1
311 BZ(IN)=0(J,10,2)
308 CONTINUE
      DO 5000 J=1,9
      IF(J.GT.1) GO TO 5010
      BZ(J+45)=GA11(J)
      GO TO 5000
5010 IF(J.EC.9) GO TO 5002
      BZ(J+45)=GA11(J+1)
      GO TO 5000
5002 BZ(J+45)=GA11(J+2)
5000 CONTINUE
      CALL OLD(BZ,IPO)
62 CONTINUE
      D(10,2,2)=BZ(16)
      FAR=D(10,2,2)/D(10,2,1)
      AFR=D(10,2,1)/D(10,2,2)
      DO 320 I=1,JT
      DEX(I,3,1)=FAR*D(I,7,2)
      DEX(I,3,2)=AFR*D(I,7,1)
320 CONTINUE
      IC=IC+1
      IF(IC) 17,17,20
17 CONTINUE
      CALL FIELD(ABC,UA,UT,UR,IK,DEX,COM,IPO)
      IF(IC) 18,18,20
18 DO 19 I=1,11
      UA1(I,IK)=UA(I)
      UT1(I,IK)=UT(I)
19 UR1(I,IK)=UR(I)
      DO 326 I=1,11
      IF(DEX(I,3,1)-0(1,7,1)) 325,325,20
325 UA1(I,1)=0.0
      UT1(I,1)=0.0
      UR1(I,1)=0.0
326 CONTINUE
20 CONTINUE
      UA1(I,1)=0.0
      UT1(I,1)=0.0
      UR1(I,1)=0.0
      IF(JPR.NE.3) GO TO 46
      IF(IC)46,95,46
95 WRITE(6,106)
106 FORMAT(1H1////50X,*INDUCED VELOCITIES*///33X,*R*,13X,*UA/VS*,11X,*
      1UR/VS*,11X,*UT/VS*/22X,*ON AFT*)

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DO 107 I=1,11
WRITE(6,106) DEX(I,3,1),UA1(I,1),UR1(I,1),UT1(I,1)
106 FORMAT(23X,4F16.4)
107 CONTINUE
WRITE(6,109)
109 FORMAT(//22X,*ON FW*)
DO 110 I=1,11
WRITE(6,108) DFX(I,1,2),UA1(I,2),UR1(I,2),UT1(I,2)
110 CONTINUE
5007 CONTINUE
46 IF(JPA.FQ.0) JPA=1
DO 111 I=1,11
UA(I)=UA1(I,IK)
UR(I)=UR1(I,IK)
111 UT(I)=UT1(I,IK)
IF(SHP) 51,81,69
51 IVA=IVA+1
IF(IVV-IVA) 96,70,70
70 GO TO 10346
69 IF(NTT.EQ.NXVV+1) GO TO 96
IF(NT.NE.IDU-1) GO TO 97
96 NF=NF+1
IF(IK-1) 93,93,94
93 FWDSP(NF)=PP12
GO TO 96
94 NF=NF-1
AFTSP(NF)=PP12
GO TO 96
97 IF(NT.FQ.IDU) GO TO 38
96 JN=1
IF(J0) 71,72,71
72 IK=2
GO TO 73
71 IK=1
73 CONTINUE
IF(J0) 74,75,74
75 J0=1
GO TO 90
74 J0=0
90 CONTINUE
10072 CONTINUE
IF(SHP.FQ.0.0) GO TO 10073
IF(NTT.NF.NXVV) GO TO 10073
DO 99 I=1,NXVV
B11(I)=(FWDSP(I)+AFTSP(I))/2.0
VEL(I)=G(I,1,IK)
99 B3(I)=VEL(I)
S1=SHP
CALL DISCOT (S1,C1,B11,B3,B3,-120,NXVV,0,S2)
VEL1(I)=S2
DO 154 I=1,NXVV
B11(I)=VEL(I)
EHP(I)=G(I,2,IK)
154 B3(I)=EHP(I)
S1=VEL1(1)
CALL DISCOT (S1,S1,B11,B3,B3,-120,NXVV,0,S2)
EHP(1)=S2

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```

VEL(1)=VEL1(1)
IVV=1
IK=1
GO TO 105
10073 CONTINUE
OR=(D(10,2,2)/D(10,2,1))*2
CTST=CTS(1)+OR*CTS(2)
CPST=CPS(1)+OR*CPS(2)
CPTT=CPT(1)+OR*CPT(2)
ETAP=CPTT/CPST
ETAD=D(1,3,1)*CTST/CPST
WRITE(6,992) CTST,CPST,ETAD
992 FORMAT(1H1,10X,*PERFORMANCE OF SET OF CONTRAROTATING PROPELLERS*//
1//2X,*CTS= *,F8.5//2X,*CPS= *,F8.5//2X,*ETAD= *,F8.5)
STOP
END

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SUBROUTINE SUB
  DIMENSION CHORD(38),THICKNS(38),CAMBER(38),PITCH(38),SKEWR(38)
  1,XI(38)
  COMMON/CWEIGHT/XI,CHORD,THICKNS,CAMBER,PITCH,SKEWR,DIAM,ZZ,DEM
  1,RAKF,SI,PI,PP7,PP8,PP9,PP11,FWAKE,VS,RPS,SIGMA,FAR,BT
  DIMENSION B(38,38),B1(181),B2(181),B3(181),B4(362),B5(362),B6(362)
  1,B7(131),B8(181),B9(181),B10(181),B11(181),B12(131),B13(181),B14(
  2181),B15(181),AZ(38,38),BH(38,38),C(38,38),CC(38,38),INDEX(38,3)
  3,A(38,72),BR(38,72)
  COMMON B,B1,B2,B3,B4,B5,B6,B7,B8,B9,B10,B11,B12,B13,B14,B15,AZ,BH,
  1C,CC,INDEX,X,A,BR
  COMMON IU,JU,JC,JD,JDD,JFF
  COMMON CL1(11)
  COMMON CCONE(11),CLTWO(11),CLTHR(11),CCFUR(11)
  COMMON PP1,PP2,PP3,PP4,PP5,PP6,PP10
10052 DO 10025 N=1,JC
      DO 20021 I=1,JC
          AAG=1./B(I,5)
          AAH=B(N,7)/B(I,3)*AAG
          AAJ=ATAN(B(I,5))
          IF(AAH-AAG)10019,10018,10019
10019 B2(I)=COS(AAJ)
          B3(I)=SIN(AAJ)
          GO TO 20021
10018 S=1.+AAH**2
          T=SQRT(S)
          V=1.+AAG**2
          W=SQRT(V)
          AF=T-W
          U=EXP(AJ)
          R=((T-1.)/AAH*(AAG/(W-1.)))*U)**3(9,2)
          AC=1.5
          AJ=.25
          X=(1./(2.*B(9,2)*AAG))*((V/S)**AJ)
          Y=((9.*AAG**2)+2.)/(V**AL)+((3.*AAH**2-2.)/(S**AC))
          Z=1./(24.*B(9,2))*Y
          IF(AAH-AAG)10021,10021,10020
10020 AF=1.+1./(R-1.)
          AA=Y*(1./(R-1.)-Z*ALOG(AF))
          B2(I)=2.*B(9,2)**2*AAG*AAH*(1.-AAG/AAH)*AA
          B3(I)=3(9,2)*(1.-AAG/AAH)*(1.+2.*B(9,2)*AAG*AA)
          GO TO 20021
10021 AG=1.+1./(1./R-1.)
          AJ=-X*(1./(1./R-1.))+7*ALOG(AG)
          B2(I)=3(9,2)*AAG*(1.-AAH/AAG)*(1.-2.*B(9,2)*AAG*AB)
          B3(I)=2.*B(9,2)**2*AAG*(1.-AAG/AAH)*AB
20021 CONTINUE
20024 FORMAT(9F12.4)
      IN=0
      DO 1 I=1,181,5
          IN=IN+1
1          B1(IN)=.5*(1.+B(1,3))-.5*(1.-B(1,3))*COS((FLOAT(I-1)/57.2957))
          DO 2 I=1,JC
              B11(I)=B(I,3)
              B12(I)=B2(I)
2          B13(I)=B3(I)
          DO 3 I=1,37

```

```

S1=B1(I)
CALL DISCOT(S1,S1,B11,B13,B13,-120,JC,0,S3)
3  B15(I)=S3
   DO 5 I=1,37
   S1=B1(I)
   CALL DISCOT(S1,S1,B11,B12,B12,-120,JC,0,S2)
5  B14(I)=S2
   DO 4 I=1,37
   B2(I)=B14(I)
4  B3(I)=B15(I)
   DO 10022 L=1,35
   N1=37+L
   N2=37-L
   B2(N1)=B2(N2)
10022 B3(N1)=B3(N2)
      C2=2./72.
      NP=72
      NH=36
      XNP=NP
      S=0.0
      SL=0.0
      DO 20 I=1,NP
      S=S+B2(I)
20  SL=SL+B3(I)
      B4(1)=S/XNP
      B5(1)=SL/XNP
      DO 40 I=1,NH
      S=J.0
      SL=0.0
      S1=0.0
      SL1=0.0
      DO 30 J=1,NP
      S=S+B2(J)*BB(I,J)
      SL=SL+B3(J)*BB(I,J)
      S1=S1+B2(J)*A(I,J)
30  SL1=SL1+B3(J)*A(I,J)
      I1=5*I+1
      B4(I1)=S*C2
      B5(I1)=SL*C2
      B4(I1+1)=S1*C2
40  B5(I1+1)=SL1*C2
      B(1,9)=B4(1)
      B(1,10)=B5(1)
      JCM1=JC-1
      DO 10023 LK=1,35
      L=LK+1
      K=5*LK
      R(L,9)=B4(K+1)
10023 B(L,10)=B5(K+1)
      B(37,9)=B4(181)
      B(37,10)=B5(181)
      CPHI=((1.+B(1,3))-2.*B(N,3))/(1.-B(1,3))
      IF (ABS(CPHI)-1.) 20051,20051,20050
20050 CPHI=1.
20051 B(N,11)=ACOS(CPHI)
      B(1,11)=.0
      B(JC,11)=3.1415927

```

```

CON3=3.1415927
DO 10025 I=1,JC
SMP=SIN(FLOAT(I)*B(N,11))
CMP=COS(FLOAT(I)*B(N,11))
IF(N-1)10027,10026,10027
10027 IF(N-JC)10028,10029,10028
10026 AZN=.0
      BZN=.0
      N2=I+1
      DO 20026 K=1,N2
      IF(K-JC)10070,10070,20026
10070 AZN=AZN+CON3*FLOAT(I)*B(K,9)
      BZN=BZN+CON3*FLOAT(I)*B(K,10)
20026 CONTINUE
      AZL=.0
      BZL=.0
      IF(N2-JC)10060,10030,10030
10060 N1=N2+1
      DO 20036 M=N1,JC
      L=M-1
      AZL=AZL+FLOAT(L)*B(M,9)*CON3
20036 BZL=BZL+FLOAT(L)*B(M,10)*CON3
      GO TO 10030
10029 AZN=.0
      BZN=.0
      N2=I+1
      DO 20029 K=1,N2
      CKP=COS(FLOAT(K-1)*B(N,11))
      IF(K-JC)10071,10071,20029
10071 AZN=AZN-CON3*CKP*FLOAT(I)*B(K,9)*CKP
      BZN=BZN-CON3*CKP*FLOAT(I)*B(K,10)*CKP
20029 CONTINUE
      AZL=.0
      BZL=.0
      IF(N2-JC)10061,10030,10030
10061 N1=N2+1
      DO 20039 M=N1,JC
      L=M-1
      CKP=COS(FLOAT(L)*B(N,11))
      AZL=AZL-CON3*CKP*FLOAT(L)*B(M,9)*CKP
20039 BZL=BZL-CON3*CKP*FLOAT(L)*B(M,10)*CKP
      GO TO 10030
10028 AZN=.0
      BZN=.0
      CON1=3.1415927/SIN(B(N,11))
      N2=I+1
      DO 20028 K=1,N2
      CKP=COS(FLOAT(K-1)*B(N,11))
      IF(K-JC)10072,10072,20028
10072 AZN=AZN+CON1*SMP*B(K,9)*CKP
      BZN=BZN+CON1*SMP*B(K,10)*CKP
20028 CONTINUE
      AZL=.0
      BZL=.0
      IF(N2-JC)10062,10030,10030
10062 N1=N2+1
      DO 20038 M=N1,JC

```

```

L=M-1
SKP=SIN(FLOAT(L)*B(N,11))
AZL=AZL+CON1*CHP*B(M,9)*SKP
20038 BZL=BZL+CON1*CHP*B(M,10)*SKP
10039 AZ(I,N)=AZN+AZL
      BH(I,N)=BZN+BZL
10025 CONTINUE
      IF(9(1,1))20043,20043,10034
20043 CONTINUE
      DO 10031 I=1,JC
        CC(I,1)=(1.-B(1,3))*(B(I,5)/B(I,8)-1.)*B(I,4)
      DO 10031 J=1,JC
10031 C(I,J)=FLOAT(J)*(AZ(J,I)+B(I,5)*BH(J,I))
      B10(181)=JC
      CALL SINEQ(JC,C,CC)
10034 DO 10035 I=1,JC
      B(I,12)=.0
      B(I,13)=.0
      B(I,14)=.0
      DO 10035 J=1,JC
        IF(9(1,1))10036,10036,10037
10036 B(I,12)=B(I,12)+FLOAT(J)*CC(J,1)*AZ(J,I)/B(I,4)*(1./(1.-B(1,3)))
      B(I,13)=B(I,13)+FLOAT(J)*CC(J,1)*BH(J,I)/B(I,4)*(1./(1.-B(1,3)))
      B(I,14)=CC(J,1)*SIN(FLOAT(J)*B(I,11))/B(I,4)+B(I,14)
      GO TO 10035
10037 B(I,12)=B(I,12)+FLOAT(J)*B6(J)*AZ(J,I)/B(I,4)*(1./(1.-B(1,3)))
      B(I,13)=B(I,13)+FLOAT(J)*B6(J)*BH(J,I)/B(I,4)*(1./(1.-B(1,3)))
      B(I,14)=B(I,14)+B6(J)*SIN(FLOAT(J)*B(I,11))/B(I,4)
10035 CONTINUE
      B(JC,14)=.0
20091 DO 10038 I=1,JC
      B(I,15)=(B(I,14)*9(I,4)*(B(I,4)/B(I,3)-B(I,13)*B(I,4)))*4.*9(9,
12)
      B(I,16)=B(I,15)*B(I,4)
      B(I,17)=(B(I,4)/B(I,8)*B(I,14)*B(I,4)*(B(I,4)+B(I,12)*B(I,4)))*4.
1*9(9,2)
      BTT=ATAN(B(I,8))
      BTI=ATAN(B(I,5))
      R(I,18)=2.*3.1415927*B(I,14)*COS(BTI)/(1./B(I,8)-B(I,13))
      B(I,19)=64.31*(B(4,2)-B(I,3)*B(3,2)/2.)*(SIN(BTT)/(B(I,4)*B(7,2)
1*10S(BTI-BTT)))*2
      IF(I-1)9,9,6
6      IF(I-JC)10,9,9
9      B(I,20)=.0
      B(I,21)=.0
      GO TO 11
10     CONTINUE
      B(I,20)=(1.-B(I,7)*B(I,6)/B(I,18)*B(I,5))*B(I,15)
      B(I,21)=(1.+B(I,7)*B(I,6)/B(I,18)/B(I,5))*B(I,17)
11     CONTINUE
      B(I,22)=B(I,20)*B(I,4)
      B1(I)=B(I,3)
      B2(I)=B(I,15)
      B3(I)=B(I,16)
      B4(I)=B(I,17)
      B5(I)=B(I,18)
      B7(I)=9(I,19)

```

```

      B8(I)=B(I,20)
      B9(I)=B(I,21)
      B10(I)=B(I,22)
10039 CONTINUE
      PP1=SIMPUN(B1,93,JC)
      PP2=SIMPUN(B1,82,JC)
      PP3=SIMPUN(B1,84,JC)
      PP4=PP1/PP3
      PP5=PP2/PP3
      PP6=SIMPUN(B1,810,JC)
      PP7=SIMPUN(B1,88,JC)
      PP8=SIMPUN(B1,89,JC)
      PP9=PP6/PP8
      PP10=PP7/PP8
      DO 10039 I=1,JC
      JCI=JC+1-I
      DO 10040 L=1,JC
      X0=B(L,3)-B(I,3)
      IF(X0) 860,860,871
560   X0=0.0
      GO TO 861
871   CONTINUE
      X0=B(L,3)-B(I,3)
561   CONTINUE
      B2(L)=X0*B(L,2)
10040 B3(L)=X0/B(L,3)*B(L,21)
      IF(JCI-2)10041,10041,10059
10041 B(I,25)=.0
      B(I,26)=.0
      B(I,27)=.0
      B(I,29)=.0
      GO TO 10039
10059 B(I,25)=SIMPUN(B1,82,JC )      *(B(1,2)*B(3,2)**3*3.1415927*B(7,2
      1)**2)/(16.*B(9,2))
      B(I,26)=SIMPUN(B1,83,JC )      *(B(8,2)*B(3,2)**2*B(7,2)**3/(16.*B
      1(5,2)*B(9,2))
      BTI=ATAN(B(I,5))
      SBI=SIN(BTI)
      CBI=COS(BTI)
      B(I,27)=B(I,25)*CBI+B(I,26)*SBI
      B(I,28)=B(I,25)*SBI-B(I,26)*CBI
10039 CONTINUE
      DO 206 I=1,JC
      B(I,12)=B(I,4)*B(I,12)
      B(I,13)=B(I,4)*B(I,13)
206   B(I,14)=B(I,4)*B(I,14)
20080 IF(JEF)20082,20082,10081
20082 B6(361)=-1.0
20081 CONTINUE
      IF(B6(361)) 10080,10080,10081
10080 CONTINUE
      B15(181)=PP10
      DO 10049 I=1,JC
      IF(B(I,6)) 702,702,703
702   CC1=0.0
      GO TO 704
703   CC1=B(I,18)/B(I,6)

```

```

704  CONTINUE
      CL1(I)=CC1
      CC2=1.54*CC1
      CC3=.0679*CC1
      IF(CC1) 701,700,701
700  CC4=0.0
      B(I,38)=CC4
      GO TO 52
701  CC4=B(I,7)/CC1
      B(I,38)=CC4
      52 CCONE(I)=CC1
      CCTWO(I)=CC2
      CCTHR(I)=CC3
10049 CCFOR(I)=CC4
10081 CONTINUE
      R5(362)=PP7
      R6(362)=PP8
20041 RETURN
      END

```

```

      SUBROUTINE SIMED(JC,C,CC)
      DIMENSION BH(30,30),A(30,30),B15(30),C(30,30),CC(30,30)
      MP1=JC
      MPC=MP1+1
      MP2=MP1
      DO 90 I=1,MP1
00    C(I,MPC)=-CC(I,1)
      DO 91 I=1,MP1
      DO 91 J=1,MPC
01    BH(I,J)=0.0
      DO 90 I=1,MP1
02    BH(I,1)=-C(1,I+1)/C(1,1)
      DO 21 I=1,MP1
      J=I+1
01    BH(I,J)=1.0
      K=2
03    IF(K-MP1) 92,92,94
02    CONTINUE
      DO 36 I=1,MPC
      DO 36 J=1,MPC
06    A(I,J)=C(K,J)*BH(I,J)
      DO 35 I=1,MPC
      AN=0.0
      DO 37 J=1,MPC
07    AN=AN+A(I,J)
08    B15(I)=AN
      MP2=MP2+1
      DO 49 I=1,MP2
      DO 49 J=1,MPC
09    CC(I,J)=-B15(I+1)/B15(1)*BH(1,J)+BH(I+1,J)
      DO 90 I=1,MP2
      DO 90 J=1,MPC
09    BH(I,J)=CC(I,J)
      K=K+1
      GO TO 93
04    CONTINUE
      DO 99 J=1,MPC
09    CC(J,1)=CC(1,J)
01    FORMAT(1P6E12.4)
02    FORMAT(6F8.4)
      RETURN
      END

```

```

SUBROUTINE DISCOT (XA,ZA,TABX,TABY,TABZ,NC,NY,NZ,ANS)
DIMENSION TABX(1),TABY(1),TABZ(1),NPX(37),NPY(37),YY(37)
CALL UNS (NC,IA,IDX,IDZ,IMS)
IF (NZ-1) 5,5,10
5 CALL DISSER (XA,TABX,1,NY,IDX,NN)
NNN=IDX+1
CALL LAGRAN (XA,TABX(NN),TABY(NN),NNN,ANS)
GOTO 70
10 ZARG=ZA
IP1X=IDX+1
IP1Z=IDZ+1
IF (IA) 15,25,15
15 IF (ZARG-TABZ(NZ)) 25,25,20
20 ZARG=TABZ(NZ)
25 CALL DISSER (ZARG,TABZ,1,NZ,IDZ,NPZ)
NX=NY/NZ
NPZL=NPZ+IDZ
I=1
IF (IMS) 30,30,40
30 CALL DISSER (XA,TABX,1,NX,IDX,NPX)
DO 35 JJ=NPZ,NPZL
NPY(I)=(JJ-1)*NX+NPX(1)
NPX(I)=NPX(1)
35 I=I+1
GOTO 50
40 DO 45 JJ=NPZ,NPZL
IS=(JJ-1)*NX+1
CALL DISSER (XA,TABX,IS,NX,IDX,NPX(I))
NPY(I)=NPX(I)
45 I=I+1
50 DO 55 I=1,IP1Z
NLCC=NPX(I)
NLOCY=NPY(I)
55 CALL LAGRAN (XA,TABX(NLOC),TABY(NLOCY),IP1X,YY(I))
CALL LAGRAN (ZARG,TABZ(NPZ),YY,IP1Z,ANS)
70 RETURN
END

```

```

SUBROUTINE UNS (IC,IA,IDX,IDZ,IMS)
  IF (IC) 5,5,10
5  IMS=1
  NC=-IC
  GOTO 15
10 IMS=0
  NC=IC
15 IF (NC-100) 20,25,25
20 IA=0
  GOTO 30
25 IA=1
  NC=NC-100
30 IDX=NC/10
  IDZ=NC-IDX*10
  RETURN
  END

```

```

SUBROUTINE LAGRAM (XA,X,Y,N,ANS)
  DIMENSION X(1),Y(1)
  SUM=0.0
  DO 3 I=1,N
    PROD=Y(I)
    DO 2 J=1,N
      A=X(I)-X(J)
      IF (A) 1,2,1
1    B=(XA-Y(J))/A
      PROD=PROD*B
2    CONTINUE
3    SUM=SUM+PROD
  ANS=SUM
  RETURN
  END

```

```

SUBROUTINE DISSER (XA,TAB,I,NX,IO,NPX)
DIMENSION TAB(1)
NPT=IO+1
NPB=NPT/2
NPU=NPT-NPB
IF (NX-NPT) 10,5,10
5 NPX=I
RETURN
10 NLOW=I+NPB
NUPP=I+NX-(NPU+1)
DO 15 II=NLOW,NUPP
NL0C=II
IF (TAB(II)-XA) 15,20,20
15 CONTINUE
NPX=NUPP-NPB+1
RETURN
20 NL=NL0C-NPB
NU=NL+IO
DO 25 JJ=NL,NU
NDIS=JJ
IF (TAB(JJ)-TAB(JJ+1)) 25,30,25
25 CONTINUE
NPX=NL
RETURN
30 IF (TAB(NDIS)-XA) 40,35,35
35 NPX=NDIS-ID
RETURN
40 NPX=NDIS+1
RETURN
END

```

```

      FUNCTION SIMPUN(X,Y,N)
C      FORTRAN IV FUNCTION FOR SIMPSONS RULE INTEGRATION
C      ARBITRARY NO. AND LENGTH INTERVALS K. MEALS NSRDC CODE 842 10-5-67
      DIMENSION X( 2),Y( 2)
      IF(N-2) 7, 5,4
5     S=(Y(1)+Y(2))*(X(2)-X(1))/2.
      GO TO 6
      4 M=N-1
      8 IF(M-2) 9,10,11
      11 M=M-2
      GO TO 8
      9 S=(X(2)-X(1))/6.*(Y(1)*(3.-(X(2)-X(1))/(X(3)-X(1)))+Y(2)*(3.+(X(2)
      1-X(1))/(X(3)-X(2)))-Y(3)*((X(2)-X(1))*2)/((X(3)-X(1))*(X(3)-X(2)
      2))))
      L=3
      GO TO 12
      10 S=0.
      L=2
      12 M=M-1
      DO 1 K=L,M,2
      IF(ABS(X(K-1)-X(1)).GE.ABS(X(K)-X(1))) GO TO 3
      IF(ABS(X(K+1)-X(1)).GT.ABS(X(K)-X(1))) GO TO 1
      3 WRITE (6,2) K, X(K)
      2 FORMAT(23HNON MONOTONE X SIMPUN I4,1PE12.4)
      7 S=0.
      GO TO 6
      1 S=S+(X(K+1)-X(K-1))/6.*(Y(K+1)*(3.-(X(K+1)-X(K-1))/(X(K)-X(K-1)))+
      1(Y(K)*(1.+(X(K+1)-X(K-1))/(X(K)-X(K-1)))+(X(K)-X(K-1))/(X(K+1)-X(K)
      1)))+(Y(K+1)*(2.-(X(K)-X(K-1))/(X(K+1)-X(K))))))
      6 SIMPUN=S
      RETURN
      END

```

```

SUBROUTINE STRESS(AZZ,AREA,XBAR,YBAR,AYEXO,AYEYO,EMXO,EMYO,ENTB,EM
109,STRMAX)
  DIMENSION CHORD(38),THICKNS(38),CAMBER(38),PITCH(38),SKEWR(38)
  1,XI(38),BT(11)
  COMMON/CWEIGHT/XI,CHORD,THICKNS,CAMBER,PITCH,SKEWR,DIAM,ZZ,DEM
  1,RAKE,SI,PI,PP7,PP8,PP9,PP11,ENAKE,VS,RPS,SIGMA,EAR,BT
  DIMENSION AZZ(38,33)
  DIMENSION AREA(7),XBAR(7),YBAR(7),AYEXO(7),AYEYO(7),EMXO(7),EMYO(7
  1),ENTB(7),ENQB(7),STRMAX(7)
C * * * * * ALL PROGRAM CONVERTING WAS DONE BY BOB MCCALLEY
C * * * * * JOHN METZ, AT GLENN ENGINEERING SERVICES, INC.
C * * * * * ROCKVILLE, MARYLAND 20856 PHONE 427-3830
C
C * * * * * VERSION VA20 IS A MODIFICATION OF HY-74
CC * * * * * WHICH APPROXIMATES THE EFFECT OF SKEW.
C * * * * * MODIFICATION BY D.T. VALENTINE
C * * * * * CODE 544 AUGUST, 1970.
C
C PROPELLER STRESS CALCULATION PROGRAM VA20
C
C * * * * * SIMPLE BEAM APPROXIMATION INCLUDING
C * * * * * BENDING, CENTRIFUGAL AND TORSIONAL FORCES.
C
C * * * * * PROGRAM TYPE A * * * * *
C * * * * * THIS PROGRAM READS IN THE NEW TYPE DATA CARDS. * * * *
C THIS AREA RESERVES COMPUTER STORAGE FOR ALL ARRAYS USED IN THE PROGRA
  DIMENSION XE(20)
  DIMENSION HA(20),HA1(20),PHI(20),PHI2(20),XU1(20),T1(20),Q1(20),CP
  1HI(20),SPHI(20),X4(20),AE(20),BF(20),PE(20)
  DIMENSION A(13),B(13),C(13),D(13),E(13),F(13),G(13),H(13),O(13),
  XP(13),Q(13),R(13),S(13),T(13),U(13),V(13),W(13),X(13),Y(13),Z(13)
  DIMENSION R1(7,16),S1(7,16)
  DIMENSION CENTST(7),CENTHO(7)
  DIMENSION FMX(7),TX(7),FMX(13),VTX(13),SKEW(13),XU(10)
  DIMENSION VOL(7),CENT4(7),A1(7),A2(7),X2BAR(7),CENTS2(7),B2(13),
  X F5(13),P2(13),O2(13),AA(10),BB(10),CENT42(7),CENTHS(7),
  X TSKEW1(7),TSKEW2(7),ASKEW1(7),ASKEW2(7)
  DIMENSION V2(13),D2(13),E2(13)
  DIMENSION ALPHA(7)
  DIMENSION XMT(10),XL(10),XM(10),XT(10),STM(10),STLT(10)
C SET UP CONSTANTS USED IN PROGRAM COMPUTATIONS.
  W( 1)=1.
  W( 2)=4.
  W( 3)=3.
  W( 4)=8.
  W( 5)=4.
  W( 6)=8.
  W( 7)=4.
  W( 8)=8.
  W( 9)=4.
  W(10)=8.
  W(11)=3.
  W(12)=4.
  W(13)=1.
  GRAV = 32.14
C - - - - - INPUT DATA DESCRIPTIONS - - - - -
C M = TOTAL NUMBER OF PROPELLER RUNS TO BE MADE IN THIS BAT

```

C PUNCHED IN COL. 1 AND 2 OF INPUT CARD.  
 C PR, ID = PROPELLER ID CODE. ANY ALPHNUMERIC CHARACTERS.  
 C PUNCHED IN COL. 1 THRU 12 OF CARD.  
 C DA, TE = DATE OF RUN. ANY ORDER. PUNCHED IN COL. 13 THRU  
 C ZZ= NUMBER OF PROPELLER BLADES. PUNCHED IN COL. 25 THRU 2  
 C YOU MUST PUNCH A DECIMAL POINT WITH THE VALUE.  
 C VS = SPEED ADVANCE IN FEET PER SECOND. PUNCHED IN COL. 29  
 C 36. A DECIMAL POINT MUST ALSO BE PUNCHED WITH VALUE  
 C DEN = DENSITY OF PROP. IN LBS. PER CUBIC FEET.  
 C PUNCHED IN COL. 37 THRU 41 INCLUDING DECIMAL POINT.  
 C DIAM = DIAMETER OF PROP. IN FEET. PUNCHED IN COL. 42  
 C INCLUDING A DECIMAL POINT.  
 C RAKE = RAKE OF THE PROP. IN DEGREES. PUNCHED IN COL. 46  
 C 49 INCLUDING A DECIMAL POINT.  
 C VEL = VELOCITY OF PROP. IN REVOLUTIONS PER MIN.  
 C PUNCHED IN COL. 50 THRU 56 INCLUDING DECIMAL POINT.  
 C D(I) = LOCAL NONVISCOS THRUST COEFFICIENT AT XU(I).  
 C PUNCHED IN COL. 1 THRU 9 INCLUDING DECIMAL POINT.  
 C T(I) = TANGENT OF THE HYDRODYNAMIC PITCH ANGLE AT XU(I).  
 C PUNCHED IN COL. 10 THRU 18 INCLUDING DECIMAL POINT  
 C E(I) = DRAG-LIFT RATIO AT XU(I). PUNCHED IN COL. 19 THRU  
 C INCLUDING A DECIMAL POINT.  
 C P(I) = PITCH TO DIAMETER RATIO AT XU(I).  
 C PUNCHED IN COL. 29 THRU 36 INCLUDING DECIMAL POINT  
 C C(I) = CORD LENGTH IN INCHES. PUNCHED IN COL. 37 THRU 45  
 C INCLUDING A DECIMAL POINT.  
 C SKEW(I) = SKEW VALUE IN INCHES FROM LEADING EDGE TO THE  
 C REFERENCE EDGE . ALONG THE HELIX.  
 C PUNCHED IN COL. 46 THRU 52. PO  
 C XU(I) = VALUE OF -X- AS WE USE IT IN PROP REFERENCES.  
 C PUNCHED IN COL. 55 THRU 61 , INCLUDING DECIMAL PO  
 C FMX(I) = MAX CAMBER AT VALUE OF U(I).  
 C PUNCHED IN COL. 1 THRU 7 INCLUDING DECIMAL POINT  
 C TX(I) = MAX THICKNESS AT VALUE OF U(I).  
 C PUNCHED IN COL. 8 THRU 16 INCLUDING DECIMAL POINT  
 C FMMX(I) = CAMBER / MAX CAMBER VALUE AT U(I).  
 C PUNCHED IN COL. 28 THRU 34 INCLUDING DECIMAL PO  
 C YTX(I) = ONE HALF THICKNESS / MAX THICKNESS AT VALUE OF U  
 C PUNCHED IN COL. 37 THRU 43 INCLUDING DECIMAL POI  
 C U(I) = VALUE OF X SUB L USED IN PROP REFERENCES.  
 C PUNCHED IN COL. 50 THRU 56 INCLUDING DECIMAL POINT  
 C \*\*\*\*\* PROGRAM NAMES DEFINED BELOW \*\*\*\*\*  
 C CENTST = STRESS DUE TO CENTRIFUGAL FORCE.  
 C CENTM0 = MOMENT DUE TO RAKE , THAT IS ASKEW2 - ASKEW1.  
 C CENTMS = MOMENT DUE TO SKEW THAT IS TSKEW2 - TSKEW1 .  
 C CENT42 = COMPONENT OF CENT4.  
 C CENT4 = CENTRIFUGAL FORCE.  
 C X2BAR = CENTROID IN FEET.  
 C TSKEW1 = TRANSVERSE SKEW AT POINT OF INTERESTS. 0.2,0.3  
 C TSKEW2 = TRANSVERSE SKEW AT CENTROID, X2BAR, IN INCHES.  
 C ASKEW1 = LONGITUDIAL SKEW AT POINT OF INTERESTS. (RAKE+  
 C ASKEW2 = LONGITUDIAL SKEW AT CENTROID, X2BAR, IN INCHES  
 C ( RAKE + SKEW ).  
 C VOL = VOLUME IN CUBIC FEET.  
 C \*\*\*\*\*  
 C DURING THE TIME OF PROGRAM CONVERSION WE USED VARIABLE NAMES THAT WE

C TOO LONG FOR USE ON THE IBM 7090 FORTRAN SYSTEM, THEREFORE WE HAD TO  
 C SHORTEN THEM TO NO MORE THAN SIX CHARACTERS LONG. THE FOLLOWING IS  
 C OF THSES SHORTENED NAMES .....

C CENTFOR - CUT TO - CENT4  
 C CENTST2 - CUT TO - CENTS2  
 C CENTFOR2 - CUT TO - CENT42  
 C CENTMOS - CUT TO - CENT4S  
 C LSKFW1 - TO - ASKEW1  
 C LSKFW2 - TO - ASKEW2  
 C

C \*\*\*\*\*

C READ INPUT

C ONE CARD IS READ TO SET UP MAIN LOOP AS TO THE NUMBER OF PROP STUDIES  
 NM=1

18 FORMAT(8F9.6)  
 ZZ=AZZ(9,2)  
 VS=AZZ(7,2)  
 DIAM=AZZ(3,2)  
 DIA=DIAM  
 VEL=60.0\*AZZ(5,2)  
 ISEC=0  
 AZZ(10,20)=0.0  
 AZZ(10,21)=BT(11)  
 AZZ(10,22)=0.0  
 DO 1000 I=1,10  
 D(I)=AZZ(I,20)  
 T(I)=AZZ(I,21)  
 E(I)=AZZ(I,22)  
 P(I)=0.0  
 C(I)=AZZ(I,23)\*DIA\*12.0  
 SKEW(I)=C(I)/2.0-AZZ(I,24)\*DIA\*12.0/2.0  
 1000 XU(I)=AZZ(I,19)  
 DO 30 J=2,7  
 30 AZZ(J,25)=AZZ(J+1,25)  
 DO 1001 I=1,7  
 FMX(I)=0.0  
 1001 TX(I)=AZZ(I,25)\*DIA\*12.0  
 FMMX(1)=.0000  
 FMMX(2)=.2712  
 FMMX(3)=.4482  
 FMMX(4)=.6993  
 FMMX(5)=.8635  
 FMMX(6)=.9615  
 FMMX(7)=1.000  
 FMMX(8)=.9786  
 FMMX(9)=.8592  
 FMMX(10)=.7027  
 FMMX(11)=.3586  
 FMMX(12)=.1713  
 FMMX(13)=.0000  
 YTX(1)=.0000  
 YTX(2)=.2066  
 YTX(3)=.2907  
 YTX(4)=.4000  
 YTX(5)=.4637  
 YTX(6)=.4952

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YTX(7)=.4962
YTX(8)=.4653
YTX(9)=.4035
YTX(10)=.3110
YTX(11)=.1877
YTX(12)=.1143
YTX(13)=.0333
IN=0
U(1)=0.3
U(2)=0.05
DO 1002 I=3,11
IN=IN+1
1002 U(I)=0.1*FLOAT(IN)
U(12)=0.95
U(13)=1.0
25 DO 50 I=1,7
DO 60 J=1,13
R1(I,J) = (FMMX(J)*FMX(I)-YTX(J)*TX(I)) /C(I)
S1(I,J) = (FMMX(J)*FMX(I)+YTX(J)*TX(I)) /C(I)
60 CONTINUE
50 CONTINUE
C CALCULATE THE VALUE OF F1 FROM INPUT VALUES.
26 F1=1.9905*(DIAM/2.0)**3*VS**2*PI*6.0/ZZ
FF1=F1
DO 215 I=1,10
52 P(I) = T(I)*PI*XU(I)
215 CONTINUE
C ***** COMPUTE *****
C CALCULATIONS FOR CONSTANTS USED IN DETERMINATION OF TORQUE AND THRUST
C CALCULATIONS OF BENDING MOMENTS FROM THRUST AND TORQUE,
DO 360 I5=1,2
F1=FF1
RAD1=DIAM*0.5*12.0
IF(I5-2)55,56,56
55 DO 21 I=1,10
PE(I)=P(I)
A(I)=D(I)*(1.-E(I)*T(I))
AE(I)=A(I)
B(I)=D(I)*(E(I)+T(I))
BE(I)=B(I)
PHI(I)=ATAN(T(I))
CPHI(I)=COS(PHI(I))
SPHI(I)=SIN(PHI(I))
HA(I)=(SKEW(I))*(CPHI(I)/(RAD1*XU(I)))
XU1(I)=XU(I)*COS(HA(I))
HA1(I)=C(I)/2.
210 IF(SKEW(I).EQ.HA1(I)) XU1(I)=XU(I)
GO TO 58
56 DO 57 I=1,10
P(I)=PF(I)
A(I)=AE(I)
57 B(I)=BE(I)
58 F1=F1/68.0
DO 69 I=1,7
I1=I
IF(I5-2)62,63,63
62 X0=XU1(I)

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      GO TO 64
63  X0=XU(I)
64  I3=8
      DO 68 I2=I1,18
      I3=I3+1
      IF(I5-2)65,66,66
65  X4(I3)=(XU(I2)-X0)
      XE(I3)=XU(I2)
      GO TO 67
66  X4(I3)=(XU(I2)-X0)
      XE(I3)=XU(I2)
67  T1(I3)=X4(I3)*A(I2)
68  Q1(I3)=X4(I3)*B(I2)
      T(I)=SIMPUN(XE,T1,I3)
      Q(I)=SIMPUN(XE,Q1,I3)
      T(I)=T(I)*FF1
69  Q(I)=Q(I)*FF1

C
C  LOOP WHICH APPROXIMATES STRESS DUE TO TORSION RESULTING
C  FROM SKEW
C  XT(I) = LIFT FORCE , XMT(I) = MOMENT DUE TO LIFT
C
      DO 111 I=1,7
      IF(I5-2)820,830,830
820  XMT(I)=0.00
      XK=1.9905*(DIAM/2.0)**2.*VS**2.*PI/(2.0*ZZ)
      XA=C(I)/2.0
      XB=TX(I)/2.0
      DO 222 J=1,9
      XL(J)=ABS(SKEW(J)-.45*C(J))
      XL(J)=XL(J)-ABS(SKEW(I)-.5*C(I))
      XT(J)=(A(J)*0.1*XK)/(COS(PHI(J)+E(J)))
      XM(J)=XT(J)*XL(J)
      XMT(I)=XMT(I)+XM(J)
222  CONTINUE
      STM(I)=XMT(I)*2.0/(PI*XA*XB**2.)
      STLT(I)=XMT(I)*2.0/(PI*XB*XA**2.0)
      GO TO 840
830  STM(I)=0.00
      STLT(I)=0.00
840  CONTINUE
111  CONTINUE
550  FORMAT(1H0,29X,1HX,10X,4HTAUM,12X,5HTAULE,10X,7HM SUB T)
500  FORMAT(1H,20X,4F18.6)
600  FORMAT(1H1,50X,32HSHEARING STRESSES DUE TO TORSION)

C
C
C  LOOP WHICH CALCULATES AREA (A) OF SECTIONS:
      DO 230 I=1,7
      A(I)=0.0
      DO 230 J=1,13
      R(J)=R1(I,J)
      S(J)=S1(I,J)
230  A(I)=A(I)+C(I)**2*(S(J)-R(J))*H(U) / 60.
C  LOOP WHICH CALCULATES VOL: OF SECTIONS.
      VOLTOT=0.0
      DO 241 I=1,6

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      IF(I.EQ.1) U(I+3)=XU(I)
238 VOL(I)=A(I)*((U(I+4)-U(I+3))*DIAM/288.0
241 VOLTOT=VOLTOT+VOL(I)
242 VOL(7)=A(7)*((1.0-U(10))*DIAM/ 576.0
243 VOLTOT=VOLTOT+VOL(7)
C   LOOP WHICH CALCULATES CENTRIFUGAL FORCE AND STRESS.
      IF(I5-2)244,246,246
244 DO 245 I=1,6
245 A1(I)=XU1(I)+((XU1(I+1)-XU1(I))/2.0)
      A1(7)=XU1(7)+((XU1(10)-XU1(7))/2.0)
      GO TO 248
246 DO 247 I=1,6
247 A1(I)=XU(I)+((XU(I+1)-XU(I))/2.0)
      A1(7)=XU(7)+((XU(10)-XU(7))/2.0)
C   LOOP TO TRANSFER CONSTANTS FOR DETERMINING X2BAR.
248 DO 236 I=1,7
      X2BAR(I) = 0.0
236 A2(I) = A1(I) * VOL(I)
C   LOOP TO CALCULATE RADIAL CENTROID ( X2BAR ).
      DO 251 I=1,7
      X2BAR(I) = ( (A2(1)+A2(2)+A2(3)+A2(4)+A2(5)+A2(6)+A2(7)) / VOLTOT )
      X          * (DIAM/2.0)
      A2(I) = 0.0
C   UNCORRECTED FORCE AND STRESS FOR OUTPUT OF ANSWERS WITHOUT THE EFFECT
C   RAKE AND SKEW TAKEN INTO CONSIDERATION.
254 CENT4(I) = DEN*4.0*PI**2*VEL**2*VOLTOT*X2BAR(I)/(3600.0*GRAV)
      CENTST(I) = CENT4(I) / I(I)
251 VOLTOT = VOLTOT - VOL(I)
C   LOOKING AT THE EFFECTS OF RAKE AND SKEW IN THE PROPELLER.
      DO 263 I=1,10
      IF(I.EQ.1) U(I+3)=XU(I)
      AA(I) = PI*U(I+3)
263 BB(I) = SQRT(AA(I)**2+P(I)**2)
      DO 267 I=1,7
      TSKEW1(I) = (C(I)/2.0 - SKEW(I)) * AA(I)/BB(I)
      KK = 1
146 IF(X2BAR(I)-U(KK+3)*DIAM/2.0) 149,149,151
151 KK= KK+1
      IF(KK-10)146,149,149
149 TSKEW2(I) = (C(KK)/2.0 - SKEW(KK)) * AA(KK)/BB(KK)
      ALPHA(I)=ATAN(TSKEW2(I)/(X2BAR(I) * 12.0) )
      CENT42(I) = CENT4(I)*COS(ALPHA(I))
      CENTMS(I) = CENT42(I)*TSKEW2(I) - TSKEW1(I)
      CENTS2(I) = CENT42(I) / A(I)
      ASKEW1(I)=(TSKEW1(I)*P(I)/AA(I)) + (U(I+3)*DIAM*6.0*
      X          TAN(RAKE*PI/180.0))
      ASKEW2(I)=(TSKEW2(I)*P(I)/AA(I)) + (U(KK+3)*DIAM*6.0*
      X          TAN(RAKE*PI/180.0))
267 CENTMO(I) = CENT42(I) * ( ASKEW2(I) - ASKEW1(I) )
C   LOOP TO CALCULATE RESULT AND MOMENTS FOR BOTH ANSWER PAGES.
      DO 281 I=1,7
      D(I) = ((T(I)+CENTMO(I))*AA(I)+(Q(I)-CENTMS(I))*P(I))/BB(I)
      E(I)=((T(I)+CENTMO(I))*P(I)-(Q(I)-CENTMS(I))*AA(I))/BB(I)
      D2(I)=(T(I)*AA(I)+Q(I)*P(I)) / BB(I)
281 E2(I)=(T(I)*P(I)-Q(I)*AA(I)) / BB(I)
C   PROGRAM CONTINUES.
      DO 350 I=1,7

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```

X(I)=0.0
Y(I)=0.0
DO 240 J=1,13
R(J) = R1(I,J)
S(J) = S1(I,J)
X(I)=X(I)+C(I)**3*(S(J) -R(J) )*W(J)*U(J) / 60./A(I)
240 Y(I)=Y(I)+C(I)**3*(S(J)**2-R(J)**2)*W(J) /120./A(I)
G(I)=0.0
H(I)=0.0
DO 250 J=1,13
G(I)=G(I)+C(I)**4*(S(J)**3-R(J)**3)*W(J)/180.
250 H(I)=H(I)+C(I)**4*(S(J) -R(J) )*W(J)*U(J)**2/ 60.
G(I)=G(I)-ABS(A(I))*Y(I)**2
H(I)=H(I)-ABS(A(I))*X(I)**2
F2=S(1)
DO 270 J=2,13
IF (F2-S(J)) 260, 270, 270
260 F2=S(J)
270 K=0
DO 290 J=1,13
IF (F2-S(J)) 330, 280, 290
280 K=K+1
Z(K)=U(J)
290 K=K
DO 300 L=1,K
B(L)=((C(I)*Z(L)-X(I))*E(I))/H(I)-((C(I)*F2-Y(I))*D(I))/G(I)
X+CENTS2(I)
B2(L)=((C(I)*Z(L)-X(I))*F2(I))/H(I)-((C(I)*F2-Y(I))*D2(I))/G(I)+
X CENTST(I)
V2(L)=ABS(B2(L))
300 V(L)=ABS(B(L))
F3=V(1)
F4 = V2(1)
F(I)=B(1)
F5(I) = B2(1)
DO 320 L=1,K
F(I)=V(L)
320 F5(I)=V2(L)
GO TO 340
330 F(I)=0.0
F5(I) = 0.0
340 P(I)=-X(I)*E(I)/H(I)-(C(I)*S(1)-Y(I))*D(I)/G(I)+CENTS2 (I)
P2(I)=-X(I)*E2(I)/H(I)-(C(I)*S(1)-Y(I))*D2(I)/G(I)+CENTST(I)
O2(I)=(C(I)-X(I))*E2(I)/H(I)-(-Y(I))*D2(I)/G(I)+CENTST(I)
350 O(I)=(C(I)-X(I))*E(I)/H(I)-(-Y(I))*D(I)/G(I)+CENTS2 (I)
DO 100 I=1,7
AREA(I)=A(I)
XBAR(I)=X(I)
YBAR(I)=Y(I)
AVFXO(I)=G(I)
AVEYO(I)=H(I)
EMXO(I)=O(I)
EMYO(I)=E(I)
STRMAX(I)=AZZ(I,11)
ENTB(I)=T(I)
100 EMQB(I)=Q(I)
IF(I5-2) 351,352,352

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```

351 CONTINUE
    CALL PFASTR (F,P,O,STM,STLT,AZZ)
    GO TO 360
352 DUMMY=DUMMY
    NN = NN+1
360 NN=NN+1
    RETURN
    END

```

```

SUBROUTINE PRNSTR (XX,YY,ZZ,S1,S2,AZZ)
DIMENSION AZZ(38,78)
DIMENSION XX(10),YY(10),ZZ(10),S1(10),S2(10)
C
C CALCULATION OF PRINCIPLE STRESSES
C DUE TO TORSION AND BENDING.
C
    DIMENSION XI2(10),XI3(10)
    DO 333 K=1,7
        XI2(K)=-S1(K)*S1(K)
        XI3(K)=-S2(K)*S2(K)
333 CONTINUE
    XXX=0.1
    DO 444 L=1,7
        XXX=XXX+0.1
        DO 555 M=1,3
            IF(M-2) 72,22,33
72 XI1=XX(L)
            DD=(ABS(XI1))**.2
            XD=DD-4.*XI2(L)
            CC=(ABS(XD))**.5
            GO TO 44
22 XI1=YY(L)
            GO TO 66
33 XI1=ZZ(L)
66 DD=(ABS(XI1))**.2
            XD=DD-4.*XI3(L)
            CC=(ABS(XD))**.5
44 SIGMA1=(XI1+CC)/2.0
            SIGMA2=(XI1-CC)/2.0
            AZZ(L,M)=XXX
            AZZ(L,M+10)=SIGMA1
555 AZZ(L,M+20)=SIGMA2
444 CONTINUE
700 FORMAT(1H,20X,F12.2,6X,2F20.6)
850 FORMAT(1H0,33X,1HX,12X,6HSIGMA1,10X,6HSIGMA2)
860 FORMAT(1H0,2X,99HSTRESSES AT EACH X STATION ARE GIVEN IN THE FOLLO
XWING ORDER* MIDCHORD, LEADING EDGE, TRAILING EDGE. )
    RETURN
    END

```

```

C      SUBROUTINE WEIGHT(JC,SIGMA7,IPO,IPR,HUBDIM,IK,HUB)
C      WEIGHT COMPUTES THE WEIGHT AND CENTER OF GRAVITY. THE VALUES F
C      CHORD, THICKNS, CAMBER, PITCH AND SKEWR COME FROM GHAZIN. DIAM,
C      DEN, RAKE AND PI ARE SET IN STRESS. OTHER VALUES ARE COMPUTED
C      MAKING CERTAIN ASSUMPTIONS.

```

```

      COMMON /WRT/ JPR
      COMMON/CHEIGHT/X,CHORD,THICKNS,CAMBER,PITCH,SKEWR,DIAM,ZZ,DEN,RAKE
1,SI
      1,PI,CTS,CPS,EP,PC,WAKE,VS,RPS,SIGMA,EAR
      DIMENSION CHORD(38),THICKNS(38),CAMBER(38),PITCH(38),SKEWR(38)
1,X(38)
      DIMENSION DISTHF(38),A(38)
      DIMENSION R(9),PMT(9)
      DIMENSION HUBDIM(6,2)
      DATA CNSTNT1,CNSTNT2,CNSTNT3/.3581,.8071,.0238/

```

```

C      ****VALUES COMPUTED AND DATA OUTPUT****
C      THE HUB DIAMETER IS ASSUMED TO BE THE DIAMETER TO THE FIRST RAD
C      RATIO TO BE CONSIDERED AND THE HUB ASSUMED TO BE CYLINDRICAL.
      HUBDIAM=X(1)*DIAM
C      THE HUB LENGTH IS ASSUMED TO EQUAL THE HUB DIAMETER AND THE DIS
C      THE REFERENCE LINE FROM THE HUB FACE IS TAKEN AS HALF THE HUB L
      DISREFL=HUBDIAM/2.
C      INPUT DATA AND ASSUMED DATA WRITTEN OUT.
      HUBLEN=HUBDIAM
      IF(HUB.EQ.0.) GO TO 50
      FWDIAM=HUBDIM(1,IK)
      AFTDIAM=HUBDIM(2,IK)
      HUBLEN=HUBDIM(3,IK)
      FDBORE=HUBDIM(4,IK)
      ADBORE=HUBDIM(5,IK)
      DISREFL=HUBDIM(6,IK)
      FWDRAD=FWDIAM/2.0
      AFTRAD=AFTDIAM/2.0
      HUBDIAM=X(1)*DIAM
      HUBRAD=HUBDIAM/2.0
      FRBORE=FDBORE/2.
      ARBORE=ADBORE/2.
      GO TO 270
50  CENGRVH=HUBLEN/2.
270  CONTINUE

```

```

C      ****WEIGHT CALCULATION****
      DO 10 I=1,JC
10  A(I)=CHORD(I)*THICKNS(I)
C      WEIGHT OF THE BLADES
      BSA1=SIMPUN(X,A,JC)
      WEIGHTB=CNSTNT1*DIAM*DEN*ZZ*BSA1
C      WEIGHT OF THE HUB
      IF(HUB.EQ.0.) GO TO 200
      IF(FWDIAM-AFTDIAM) 201,200,201
201  WEIGHHT=DEN*PI*HUBLEN/4.*((FWDRAD+AFTRAD)**2+((FWDRAD-AFTRAD)**2/3
1.0))
      WEIGHBR=DEN*PI*HUBLEN/4.*((FRBORE+ARBORE)**2+((FRBORE-ARBORE)**2/3
1.0))
      WEIGHTH=WEIGHHT+WEIGHBR

```

```

      CENGRVH=HUBLEN- (((HUBLEN*(FWRAD**2+2.*FWRAD*AFRAD+3.*AFRAD**2
1)/(4.*(FWRAD**2+FWRAD*AFRAD+AFRAD**2)))*WEIGHTH-(HUBLEN*(FRBOR
2E**2+2.*FRBORE*ARBORE+3.*ARBORE**2)/(4.*(FRBORE**2+FRBORE*ARBORE+A
3RBORE**2)))*WEIGHBR)/WEIGHTH)
      GO TO 282
200 WEIGHTH=PI*HUBDIAM**2*HUBLEN*DEN/4.
202 CONTINUE
C      WEIGHT OF THE PROPELLER
      WEIGHTP=WEIGHTB+WEIGHTH

C      ****CENTER OF GRAVITY CALCULATION****
      DO 20 I=1,JC
20 DISTHF(I)=CNSTNT2*CAMBER(I)*COS(PITCH(I))+CNSTNT3*CHORD(I)
      1*SIN(PITCH(I))+DISREFL

C      THE EFFECT OF RAKE AND SKEW ARE ADDED TO THE DISTANCE OF THE CE
C      GRAVITY FROM THE HUB FACE FOR EACH SECTION.
      DO 30 I=1,JC
      DISTHF(I)=DISTHF(I)-SKEWR(I)*X(I)/2.*DIAM*TAN(PITCH(I))-TAN(RAKE*
1PI/180.)*DIAM/2.*(X(11)-X(1))
30 A(I)=CHORD(I)*THICKNS(I)*DISTHF(I)
      BSA2=SIMPUN(X,A,JC)
      CENGRV3=BSA2/BSA1
      CENGRV8=DISREFL-CENGRV3

C      CENTER OF GRAVITY CONSIDERING RAKE AND SKEW
      CENGRV1=(WEIGHTB*CENGRV3+WEIGHTH*CENGRVH)/WEIGHTP
      CENGRVF=DISREFL-CENGRV1

      IF(JPR.NE.2) GO TO 53
      SWT=4.44822
      UB=WEIGHTB*SWT
      UP=WEIGHTP*SWT
      CFL=CENGRVF/DIAM
      CBL=CENGRV8/DIAM
      BA=HUBLEN/DIAM
      BB=FWRDIAM/DIAM
      BC=AFTDIAM/DIAM
      BD=DISREFL/DIAM
      BE=HUBDIAM/DIAM
      BF=FRBORE/DIAM
      BG=ADBORE/DIAM

C      ****RESULTS OUTPUT****
      IF(HUB.EQ.0.) GO TO 55
      PRINT 107, UB,UP,CFL,CBL
      PRINT 108, BA,BB,BC,BD,BE,BF,BG
      GO TO 53
55 CONTINUE
      PRINT 104, UB,UP,CFL,CBL
      PRINT 110, BE,BA,BD
53 CONTINUE

C      MINIMUM EXPANDED AREA RATIO CALCULATIONS:
      AJS=VS/(RPS*DIAM)
      AJA=WAKE*AJS
      AKT=PI*CTS*AJS**2/8.
      AKQ=CPS*AJS**3/16.
      EARMIN=(2.6+0.6*ZZ)*AKT/(SIGMA7*(AJA**2*(.7*PI)**2))+.15

```

IF(JPR.NE.2) RETURN  
PRINT 105,EARHIN,AJS,AJA,AKT,AKQ, PC

```

104 FORMAT( //20X,*WEIGHT OF BLADES(N)=*,F15.4//20X,*WEIGHT OF PROP(B
  1LADES+CYLINDRICAL HUB)(N)=*,F15.4//20X,*CENTER OF GRA
  2VITY OF PROP REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AF
  3T)/D=*,F9.6//20X,*CENTER OF GRAVITY OF BLADES REFERENCED FROM
  4 MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D=*,F9.6)
105 FORMAT(/20X,*KELLERS MINIMUM EAR=*,E10.4
  1//20X,*SPEED COEFF V/(ND) JS=*,E10.4//20X,*ADVANCE COEFF V(
  21-WTT)/(ND) JA=*,E10.4//20X,*DESIGN THRUST COEFF KT=*,E
  310.4//20X,*TORQUE COEFF KQ=*,E10.4//
  4 20X,*PROPULSIVE EFFICIENCY ETAD=*,E10.4)
110 FORMAT(/20X,*HUB DIMENSIONS/D* 11X,*HUB DIAM =*F9.6/47X, *HUB L
  1LENGTH =*,F9.4/47X,*MIDCHORD OF ROOT SECTION TO AFT END OF HUB =*,F
  29.4)
109 FORMAT(6F8.4)
107 FORMAT( //20X,*WEIGHT OF BLADES(N)=*,F15.4//20X,*WEIGHT OF PROP(B
  1LADES+TAPERED HUB)(N)=*,F15.4//20X,*CENTER OF GRA
  2VITY OF PROP REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AF
  3T)/D=*,F9.6//20X,*CENTER OF GRAVITY OF BLADES REFERENCED FROM
  4 MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D=*,F9.6)
108 FORMAT(/20X,*HUB DIMENSIONS/D* 11X,*LENGTH=*,F9.4/47X,*FWD DIA
  14=*,F9.4/47X,*AFT DIAM=*,F9.4/47X,*MIDCHORD OF ROOT SECTION TO AFT
  2 END OF HUB=*,F9.4/47X,*HUB DIAM AT MIDCHORD OF ROOT SECTION=*,F9.
  34/47X,*FWD DIAM OF BORE=*,F9.4/47X,*AFT DIAM OF BORE=*,F9.4)
  END

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SUBROUTINE FIELD(ABC,UA,UT,UR,IK,DEX,COM,IPO)
C *** MAIN *** FPV-7 FIELD POINT VELOCITIES AUG 28, 1969
DIMENSION A1(792),KB(20,41),S1(792),U1(792),XR(11),XG(11),XTB(11),
1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),P(36)
DIMENSION ABC(11,9)
COMMON /WRT/ JPR
DIMENSION DEX(11,3,2),COM(12,2)
DIMENSION UA(11),UT(11),KV(11),UR(11)
COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
142,2),SINKN(20,24),XSTAR(11
1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
2MA(100),GLT(20),GT(20,42),GTL(20),MHUB(17),NLE(20),NTE(20),NUM(41
3,PHI(42),REMARK(18),R(20),RVLAN(20,11),RV(11),RVSQ(11),RZLAN(20),R
3ZRV
42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
5,SL(20),SHA(42),SOLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),HEIGHT
6(5),X(42),XGL(11),XMAP(11),AY,AM,AA,AB,AC,AD,AE,AF,AG,AH,AI
7,AL,BUG,BLADD,BLAD,LBL,BB,BOG,BUB,CHOR,COSIKN,COSY,CCA,CCL,C,DEGR
8EE,DELT,DET,D2,D516,D75,D8,DELM,D,DELTA,DU,DV,DW,EX,E,EXGNU,GMU1,G
9NU,GLMAX,GLMIN,GHU2,H,IMAX,JT,KT,LINE,MAX,HOUSE,MT,MIN
1,NT,NX2,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NCOSE,NOGO
2,PP,QQ,Q,RH,RRBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TP,V,XL,XP,A
3NGLE(33),P,Z
DIMENSION CN(4,3)
EQUIVALENCE (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
3(XTZ,XINPUT(78))
NOGO=10
MHUB(1)=0
MHUB(2)=4
MHUB(3)=12
MHUB(4)=30
MHUB(5)=60
MHUB(6)=120
MHUB(7)=240
MHUB(8)=360
MHUB(9)=720
MHUB(10)=4320
DO 51 N=1,NOGO
J=N+NOGO-1
M=NOGO-N+1
ANGLE(J)=FLOAT(MHUB(N))*1.7453293E-01
51 ANGLE(M)=-ANGLE(J)
NOGO=2*NOGO-1
IX=0
NSTOP=DEX(1,1,IK)
NEX=DEX(3,1,IK)
1 CONTINUE
100 FORMAT(I4)
IF(NSTOP) 2,90,3
99 RETURN
109 FORMAT(18A4)
3 CONTINUE
NX=11
KT=ABC(2,9)
LINE=1

```

```

MT=12
NT=12
MTHICK=23
AY=0.8
BU3=6.0
TTHICK=.1
DO 87 I=1,11
DO 87 J=1,8
87 XINPUT(I,J)=ABC(I,J)
XINPUT(1,9)=0.0
XINPUT(2,9)=0.5
XINPUT(3,9)=1.25
XINPUT(4,9)=5.0
XINPUT(5,9)=10.0
XINPUT(6,9)=15.0
XINPUT(7,9)=20.0
XINPUT(8,9)=25.0
XINPUT(9,9)=30.0
XINPUT(1,10)=35.0
XINPUT(2,10)=40.0
XINPUT(3,10)=45.0
XINPUT(4,10)=50.0
XINPUT(5,10)=55.0
XINPUT(6,10)=60.0
XINPUT(7,10)=65.0
XINPUT(8,10)=70.0
XINPUT(9,10)=75.0
XINPUT(1,11)=80.0
XINPUT(2,11)=85.0
XINPUT(3,11)=90.0
XINPUT(4,11)=95.0

XINPUT(5,11)=100.0
DO 93 I=6,9
93 XINPUT(I,11)=0.0
DO 94 I=1,9
94 XINPUT(I,12)=0.0
XINPUT(1,13)=0.0
XINPUT(2,13)=.9120
XINPUT(3,13)=1.004
XINPUT(4,13)=1.0611
XINPUT(5,13)=1.0818
XINPUT(6,13)=1.0927
XINPUT(7,13)=1.1004
XINPUT(8,13)=1.1060
XINPUT(9,13)=1.1095
XINPUT(1,14)=1.1120
XINPUT(2,14)=1.1142
XINPUT(3,14)=1.1153
XINPUT(4,14)=1.1139
XINPUT(5,14)=1.1102
XINPUT(6,14)=1.1046
XINPUT(7,14)=1.0970
XINPUT(8,14)=1.0868
XINPUT(9,14)=1.0740
XINPUT(1,15)=1.0579
XINPUT(2,15)=1.03636

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```

XINPUT(3,15)=1.01020
XINPUT(4,15)=1.143
XINPUT(5,15)=0.0
DO 88 I=6,9
88 XINPUT(I,15)=0.0
DO 89 I=1,9
89 XINPUT(I,16)=0.0
DO 15 I=1,9
Z(I)=XINPUT(I,9)
Z(I+9)=XINPUT(I,10)
Z(I+18)=XINPUT(I,11)
Z(I+27)=XINPUT(I,12)
P(I)=XINPUT(I,13)
P(I+9)=XINPUT(I,14)
P(I+18)=XINPUT(I,15)
15 P(I+27)=XINPUT(I,16)
IF(NT) 52,99,53
52 NT=-NT
NHELIX=-1
GO TO 54
53 NHELIX=1
54 RH=XR(1)
DELT=.17453293E-01*BUG
IF(XTB(2)) 99,32,33
32 BUG=XTB(1)
DO 34 N=1,NX
34 XTB(N)=BUG/XR(N)
33 IF(XVX(1)) 99,35,36
35 DO 37 N=1,NX
37 XVX(N)=1.0
36 IF(XUA(2)) 99,38,39
38 BUG=XUA(1)
DO 40 N=1,NX
40 XUA(N)=(XTB(N)*XR(N)/BUG-XVX(N))/(1.3+XTB(N)**2)
39 IF(XTZ(2)) 99,41,42
41 BUG=XTZ(1)
DO 43 N=1,NX
43 XTZ(N)=BUG*(1.0-XR(N))
42 DO 4 N=1,NX
XMAP(N)=COMAP(XR(N),RH)
XGL(N)=XR(N)*XTB(N)
BUG=XGL(N)*(XST(N)-XSL(N))
IF(BUG.GT.0.0001) GO TO 55
XSTAR(N)=2.0*XSTAR(N-1)-XSTAR(N-2)
GO TO 4
55 XSTAR(N)=XTZ(N)*DELT*(X(L(N)**2+XR(N)**2)*(XVX(N)+XUA(N))/
1 (XGL(N)*(XST(N)-XSL(N)))
4 CONTINUE
NX2=NX-2
DO 5 I=1,NX2
B(I,1)=XG(I+1)
DO 5 J=1,NX2
5 A(I,J)=SIN(FLOAT(J)*XMAP(I+1))
IF(XG(1)) 99,6,7
6 DET=1.0
CALL MATINV(A,NX2,B,1,DET,MOUSE)
GO TO (8,99),MOUSE

```

```

5      CONTINUE
      R(NX2+1,1)=0.0
      B(NX,1)=0.0
      GO TO 11
7      XG(1)=0.0
      XG(NX)=8.0
      DO 9      I=1,NX2
      XG(I+1)=0.0
      DO 9      J=1,NX2
9      XG(I+1)=XG(I+1)+A(I,J)*B(J,1)
11     IF(JPR.NE.3) GO TO 60
300    FORMAT(1H1)
      WRITE(6,300)
      WRITE(6,102) (CON(N,IK),N=1,12),NX,LINE,MT,BUB,KT,AY
      WRITE(6,104) NT,NTHICK,(XR(N),XTB(N),XGL(N),XSL(N),XST(N),XG(N),B
1(N,1),XVX(N),XUA(N),XTZ(N),N=1,NX)
      WRITE(6,103) TTHICK,(Z(N),P(N),N=1,NTHICK)
102    FORMAT(///38X,32H***** HIT-EPV-7 *****/38X,32HPROPELLE
1R FIELD POINT VELOCITIES/25X,12A6/11X,21HNUMBER OF INPUT RADII,8X,
2I2,29X,18HTYPE OF CHORD LOAD,5X,I1/11X,19HLATTICE ARRANGEMENT,32X,
3I7H(1=NACA A-SERIES)/13X,26HNO.OF FULL RADIAL SPACES I2,21X,17H(2
4=ELLIPTICAL )/13X,26HANGULAR SPACING -DEGREES- F4.1,19X,17H(3=FL
5AT PLATE )/11X,16HNUMBER OF BLADES,12X,I2,21X,16HHA-DESIGNATION O
6F/11X,19HNO.OF FIELD POINTS,33X,17HTYPE 1 CHORD LOAD,6X,F4.2)
104    FORMAT(11X,14H8FTMEEN BLADES,13X,I3,21X,25HNO.OF POINTS IN THICKNE
1SS/11X,34H(NEGATIVE FOR HELICAL COORDINATES),17X,16HFORM INPUT TAB
2LE,6X,I2///13X,1HR,6X,22HTAN BI LAMEDA I SL,7X,2HST,7X,1HG,8X,
375HC(N) VA/VS UA*/VS TO//17X,6F9.4,F11.6,F8.3,F8.4,F9.4))
103    FORMAT(///24X,54HVELOCITY DISTRIBUTION OF 2-D THICKNESS FORM WITH
1T)/L=F6.4//29X,51HPERCENT CHORD VELOCITY PERCENT CHORD VELOC
2ITY//133X,F6.2,6X,F5.3,11X,F6.2,6X,F5.3))
50     CONTINUE
      DO 44      N=1,NTHICK
44      P(N)=(P(N)-1.0)/TTHICK
      MAX=MT+3
      MIN=MT+2
      DELM=(1.0-RH)/FLOAT(MT)
      D8=DELM*0.125
      D2=DELM*0.5
      D516=DELM*0.3125
      D75=DELM*0.75
      RZ(1)=RH+D8
      RZ(MAX)=1.0-D8
      RZ(2)=RH+D2
      P7(MIN)=1.0-D2
      RZ(3)=RH+DELM
      R(1)=RH+D516
      R(MIN)=1.0-D516
      R(2)=RH+D75
      R(MT+1)=1.0-D75
      RBASE=RH-D2
      DO 12      M=3,MT
      AM=M-1
      RZ(M+1)=RH+AM*DELM
12      R(M)=RBASE+AM*DELM
      DO 13      M=1,MIN
      RHAP=COMAP(R(M),RH)

```

```

SL(M)=FILLIN(RHAP,XMAP,XSL,NX)
ST(M)=FILLIN(RHAP,XMAP,XST,NX)
GLR(M)=FILLIN(R(M),XR,XGL,NX)
STAR(M)=FILLIN(R(M),XR,XSTAR,NX)
GLRZ(M)=FILLIN(RZ(M),XR,XGL,NX)
G(4)=0.0
DO 13      J=1,NX2
13  G(M)=G(M)+B(J,1)*SIN(FLOAT(J)*RHAP)
    GLRZ(MAX)=FILLIN(RZ(MAX),XR,XGL,NX)
DO 17      N=1,41
DO 17      M=1,20
    GB(M,N)=0.0
    GT(M,N)=0.0
17  SB(M,N)=0.0
    CALL FAN
DO 14      N=1,41
    NUM(N)=N
DO 14      M=1,19
14  KB(M,N)=100000.0*GB(M,N)
DO 45      N=1,41
DO 45      M=1,19
45  KB(M,N)=100000.0*GT(M,N)
DO 46      N=1,41
DO 46      M=1,19
46  KB(M,N)=100000.0*SB(M,N)
2  JT=DEX(2,1,IK)
    NEX=NEX-1
    IX=IX+1
    EX=DEX(IX,2,IK)
DO 105 J=1,JT
105 RV(J)=DEX(J,3,IK)
    BUG=0.0
    IF(NHELIX) 47,48,48
47  BUG=-EX/XGL(NX)
48  BLADD=6.2831853/FLOAT(KT)
    BUG=BLADD/FLOAT(NT)
    BLADE=BUG
DO 49      N=1,NT
    T(N,1)=-BUG/.17453293E-01
DO 50      K=1,KT
    COSKN(K,N)=COS(BUG)
    SINKN(K,N)=SIN(BUG)
50  BUG=BUG+BLADD
    BUG=BLADE-BUG
49  BLADE=BUG
DO 18      M=1,MAX
    RZSQ(M)=RZ(M)**2
    RZLAM(M)=RZ(M)*GLRZ(M)
DO 18      J=1,JT
    RZRV(M,J)=PZ(M)*RV(J)
18  RZRV2(M,J)=2.0*RZRV(M,J)
DO 19      J=1,JT
    RVSQ(J)=RV(J)**2
DO 19      M=1,MAX
19  RVLAM(M,J)=RV(J)*GLRZ(M)
    BUG=EX/(.17453293E-01*XGL(NX))
DO 31      N=1,NT

```

```

31  T(N,2)=T(N,1)-BUG
    D8=XGL(NX)/((1.0+XGL(NX)*2)*XUA(NX)+1.0)
    D2=9.8696044*D8/XVX(NX)
    BLADE=FLOAT(KT)
    NSTOP=IABS(NSTOP)
    GO TO (20,21,21,20),NST(P
20  CALL LTRAIL
    DO 23 J=1,JT
    23 CALL SUMOUT(EX,RV(J),T,S,S,NT,J,REMARK,1,D2,D8,BLADE,CN)
21  GO TO (1,24,25,24),NSTOP
24  CALL VORCES
    DO 26 J=1,JT
    26 CALL SUMOUT(EX,RV(J),T,U,S,NT,J,REMARK,2,D2,D8,BLADE,CN)
    DO 22 J=1,JT
    22 CALL SUMOUT(EX,RV(J),T,A3,S,NT,J,REMARK,3,D2,D8,BLADE,CN)
25  GO TO (1,1,27,27),NSTOP
27  CALL 97RAIL
    DO 28 J=1,JT
    28 CALL SUMOUT(EX,PV(J),T,U,S,NT,J,REMARK,4,D2,D8,BLADE,CN)
    GO TO (1,1,1,29),NSTOP
29  DO 30 J=1,JT
    CALL SUMOUT(EX,RV(J),T,S,S,NT,J,REMARK,5,D2,D8,BLADE,CN)
    UA(J)=CN(1,1)
    UR(J)=CN(1,2)
    30 UT(J)=CN(1,3)
    IF(NEX) 200,201,200
200 NSTOP=4
    GO TO 1
201 NSTOP=0
    GO TO 1
    END

```

```

C    *** FAN ***    FPV-7    FIELD POINT VELOCITIES AUG 20, 1969
SUBROUTINE FAN
  DIMENSION A1(792),KB(20,41),S1(792),U1(792),XR(11),XG(11),XTB(11),
  1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),P(36)
  COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
  142,2),SINKN(20,24),XSTAR(11
  1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
  2MA(100),GLT(20),GT(20,42),GTL(20),MHUB(17),NLE(20),NTE(20),NUH(41)
  3,PHI(42),REMARK(18),R(20),RVLAN(20,11),RV(11),RVSQ(11),RZLAN(20),R
  3ZRV
  42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
  5,SL(20),SMA(42),SQLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),HEIGHT
  6(5),X(42),XGL(11),XMAP(11),AY,AM,AA,AB,AC,AD,AE,AF,AG,AH,AI
  7,AL,BUG,BLADD,BLADE,BBL,BB,BOG,BUB,CHOR,COSIKN,COSY,CCA,CCL,C,DEGR
  8EE,DELT,DET,D2,D516,D75,D8,DELM,D,DELTA,DU,DV,DW,EX,E,EXGNU,GHU1,G
  9NU,GLMAX,GLMIN,GHU2,H,IMAX,IT,KT,LINZ,MAX,HOUSE,NT,NIN
  1,NT,NX2,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NCOSE,NOGO
  2,PP,QO,Q,RH,RBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TP,V,XL,XP,A
  3NGLF(33),P,Z
  EQUIVALENCE (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
  1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
  2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
  3(XTZ,XINPUT(78))
  DO 30 N=1,20
    BUG=FLCAT(N)*DFLT
    PHI(N+21)=BUG
    MOUSE=21-N
    PHI(MOUSE)=-BUG
    SINI(N+21)=SIN(BUG)
    SINI(MOUSE)=-SINI(N+21)
    COSI(N+21)=COS(BUG)
30  COSI(MOUSE)=COSI(N+21)
    PHI(21)=0.0
    SINI(21)=0.0
    COSI(21)=1.0
    DO 1 M=1,MIN
      ROOT=SQRT(R(M)**2+GLR(M)**2)
      D=DELT*ROOT
      SLM=SL(M)/ROOT-0.25*DELT
      STM=ST(M)/ROOT+0.25*DELT
      DO 2 N=1,41
        NLFM=N
        IF (PHI(N)-SLM)2,2,4
2      CONTINUE
      DO 5 N=NLEM,41
        NTEM=N-1
        IF (STM-PHI(N))3,3,5
5      CONTINUE
      NVV=NTEM-NLEM+1
      XL=-SL(M)+ROOT*PHI(NLEM)
      CHOR=ST(M)-SL(M)
      IF(NVV-1) 99,33,34
33  GMA(1)=1.0
      SMA(1)=0.0
      GO TO 35
34  CALL CHORD
35  NLE(M)=NLEM

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```

NTE(M)=NTEM
K=1
DO 1 N=NL2M,NTEM
  GT(M,N)=G(M)*GMA(K)
  ST(M,N)=STAR(M)*SMA(K)
1  K=K+1
  BUG=0.0
  DO 17 N=1,20
    CT(1,N)=-GB(1,N)+BUG
17  BUG=GT(1,N)
    BUG=BUG+G(1)
    GTL(1)=-G(1)
    NTFM=MAX0(21,NTF(1)-1)
    DO 18 N=21,NTEM
      GT(1,N)=-GB(1,N)+BUG
18  BUG=GT(1,N)
      DO 21 M=2,MIN
        BUG=0.0
        DO 20 N=1,20
          GT(M,N)=GB(M-1,N)-GB(M,N)+BUG
20  BUG=GT(M,N)
          GTL(M)=G(M-1)-G(M)
          BUG=BUG-GTL(M)
          NTFM=MAX0(21,NTF(M-1)-1,NTF(M)-1)
          DO 21 N=21,NTEM
            GT(M,N)=GB(M-1,N)-GB(M,N)+BUG
21  BUG=GT(M,N)
          BUG=0.0
          DO 22 N=1,20
            GT(MAX,N)=GB(MIN,N)+BUG
22  BUG=GT(MAX,N)
          BUG=BUG-G(MIN)
          GTL(MAX)=G(MIN)
          NTFM=MAX0(21,NTF(MIN)-1)
          DO 23 N=21,NTEM
            GT(MAX,N)=GB(MIN,N)+BUG
23  BUG=GT(MAX,N)
  RETURN
99 STOP
END

```

```

C *** CHORD *** FPV-7 FIELD POINT VELOCITIES AUG 28, 1969
SUBROUTINE CHORD
DIMENSION A1(792), K8(20,41), S1(792), U1(792), XR(11), XG(11), XT8(11),
1XSL(11), XST(11), XVX(11), XUA(11), XTZ(11), Z(36), P(36)
COMMON A(42,42), A3(24,11,3), S(24,11,3), U(24,11,3), XINPUT(11,16), B(
142,2), SINKN(20,24), XSTAR(11
1), COSI(42), COEX(5), COSKN(20,24), GB(20,42), GLR(20), GLRZ(20), G(20), G
2HA(100), GLT(20), GT(20,42), GTL(20), MHUB(17), NLE(20), NTE(20), NUM(41)
3, PHI(42), REMARK(18), R(20), RVLAM(20,11), RV(11), RVSQ(11), RZLAM(20), R
3ZRV
42(20,11), RZRV(20,11), PZ(20), RZSO(20), SB(20,42), SINI(42)
5, SL(20), SHA(42), SOLAM(20), STAR(20), ST(20), SPACE(42), T(24,2), WEIGHT
6(5), X(42), XGL(11), XMAP(11), AY, AH, AA, AB, AC, AD, AE, AF, AG, AH, AI
7, AL, BUG, BLADD, BLADE, BBL, BB, BOG, SUB, CHOR, COSIKN, COSY, CCA, CCL, C, DEGR
8EE, DELT, DET, Q2, Q516, Q75, Q8, DELM, D, DELTA, DU, DV, DW, EX, E, EXGNU, GMU1, G
9NU, GLMAX, GLMIN, GHU2, H, IMAX, JT, KT, LINE, MAX, MOUSE, MT, MIN
1, NT, NX2, NSTOP, NTHICK, NX, NIN, NMAX, NMIN, NLEM, NLL, NTEM, NVV, NCOSE, NOGO
2, PP, QQ, Q, RH, RBASE, RMAP, SLH, STM, SINIKN, SINY, SSL, TTHICK, TP, V, XL, XP, A
3NGLF(33), P, Z
EQUIVALENCE (A, K8), (A3, A1), (S1, S), (U1, U), (XR, XINPUT),
1(XG, XINPUT(12)), (XT8, XINPUT(23)), (XSL, XINPUT(34)),
2(XST, XINPUT(45)), (XVX, XINPUT(56)), (XUA, XINPUT(67)),
3(XTZ, XINPUT(78))
B(1,1)=1.0
B(1,2)=0.0
DO 1 N=1, NVV
A(1,N)=1.0
DO 1 M=2, NVV
1 A(M,N)=1.0/(FLOAT(N-M)+0.5)
NMIN=NVV-1
BUB=100.0/CHOR
DO 2 M=1, NMIN
X(M)=XL+(FLOAT(M)-0.5)*D
AG=X(M)*BUB
2 B(M+1,2)=FILLIN(AG,Z,P,NTHICK)
GO TO (3,5,6), LINE
3 IF(AY-0.99) 4,4,17
C CASE 1 CONSTANT LOAD
17 DO 7 M=2, NVV
7 B(M,1)=0*(ALOG(1.0-X(M-1)/CHOR)-ALOG(X(M-1)/CHOR))/CHOR
GO TO 11
C CASE 2 A SERIES MEAN LINE
4 E=1.0-AY
DO 8 M=2, NVV
V=1.0-X(M-1)/CHOR
Q=AY-X(M-1)/CHOR
IF(ABS(Q)-0.0001) 14,14,15
14 QQ=0.0
GO TO 16
15 QQ=Q*ALOG(ABS(Q))
16 PP=V*ALOG(V)
8 B(M,1)=2.0*D*((PP-QQ)/E-ALOG(X(M-1)/CHOR)-1.0)/((AY+1.0)*CHOR)
GO TO 11
C CASE 3 ELLIPTICAL LOADING
5 DO 9 M=2, NVV
9 B(M,1)=4.0*D*(1.0-2.0*X(M-1)/CHOR)/CHOR
GO TO 11

```

```

C *** LTRAIL *** FPV-7 FIELD POINT VELOCITIES AUG 20, 1969
SUBROUTINE LTRAIL
DIMENSION A1(792), KB(20,41), S1(792), U1(792), XR(11), XG(11), XT(11),
1 XSL(11), XST(11), XVX(11), XUA(11), XTZ(11), Z(36), P(36)
COMMON A(42,42), A3(24,11,3), S(24,11,3), U(24,11,3), XINPUT(11,16), B(
142,2), SINKN(20,24), XSTAR(11
1), COSI(42), COEX(5), COSKN(20,24), GB(20,42), GLR(20), GLRZ(20), G(20), G
2 MA(100), GLT(20), GT(20,42), GTL(20), MHUB(17), NLE(20), NTE(20), NUH(41)
3, PHI(42), REMARK(18), R(20), RVLAM(20,11), RV(11), RVSQ(11), RZLAM(20), R
3 ZRV
42(20,11), RZRV(20,11), RZ(20), RZSQ(20), SB(20,42), SINI(42)
5, SL(20), SHA(42), SQLAM(20), STAR(20), ST(20), SPACE(42), T(24,2), WEIGHT
6(5), X(42), XGL(11), XMAP(11), AY, AH, AA, AB, AC, AD, AE, AF, AG, AH, AI
7, AL, BUG, BLADD, BLADE, BBL, BB, BOG, BU3, CHOP, COSIKN, COSY, CCA, CCL, C, DEGR
8 EE, DELT, DFT, D2, D516, D75, D8, DELM, D, DELTA, DU, DV, DW, EX, E, EXGNU, GMU1, G
9 NU, GLMAX, GLMIN, GMU2, H, IMAX, JT, KT, LINE, MAX, HOUSE, MT, MIN
1, NT, NX2, NSTOP, NTHICK, NX, NIN, NMAX, NMIN, NLEM, NLL, NTEM, NVV, NCOSE, NOGO
2, PP, QQ, Q, RH, RBASE, RMAP, SLH, STM, SINIKN, SINY, SSL, TTHICK, TP, V, XL, XP, A
3 NGLF(33), P, Z
EQUIVALENCE (A,KB), (A3,A1), (S1,S), (U1,U), (XR,XINPUT),
1(XG,XINPUT(12)), (XT, XINPUT(23)), (XSL,XINPUT(34)),
2(XST,XINPUT(45)), (XVX,XINPUT(56)), (XUA,XINPUT(67)),
3(XTZ,XINPUT(78))
DO 5 N=1,792
5 S1(N)=0.0
BUG=40.0
DO 1 J=1,JT
DO 1 M=1,MAX
BOG=ABS(-V(J)-RZ(M))
IF(BOG-BUG) 2,1,1
2 BUG=BOG
TP=EX/GLPZ(M)
1 CONTINUE
IF(TP-ANGLE(1)) 3,3,4
4 DO 7 M=1,NOGO
NLOW=M
IF(ANGLE(M)+TP) 7,7,8
7 CONTINUE
8 IF(NLOW-1) 10,10,11
10 GMA(1)=TP+ANGLE(1)
GO TO 12
11 GMA(1)=0.0
12 N=?
DO 9 M=NLOW,NOGO
GMA(N)=TP+ANGLE(M)
9 N=N+1
NCODE=NOGO-NLOW+1
DO 6 I=1,NCODE
DELTA=GMA(I+1)-GMA(I)
COEX(1)=.046910*DELTA
COEX(2)=.230765*DELTA
COEX(3)=.5*DELTA
COEX(4)=.769235*DELTA
COEX(5)=.953090*DELTA
WEIGHT(1)=.059232*DELTA
WEIGHT(5)=WEIGHT(1)
WEIGHT(2)=.119657*DELTA

```

```

WEIGHT(4)=WEIGHT(2)
WEIGHT(3)=.142222*DELTA
DO 6      L=1,5
GNU=GHA(I)+COEX(L)
COSY=COS(GNU)
SINY=SIN(GNU)
DO 6      K=1,KI
DO 6      N=1,NT
COSIKN=COSY*COSKN(K,N)-SINY*SINKN(K,N)
SINIKN=SINY*COSKN(K,N)+COSY*SINKN(K,N)
DO 6      J=1,JT
DO 6      M=1,MAX
BOG=SQRT(((EX-GLPZ(M)*GNU)**2+RVSQ(J)+RZSQ(M)-RZRV2(M,J)*COSIKN)*
1*3)
BOG=WEIGHT(L)*GTL(M)/BOG
EXGNU=(EX-GLRZ(M)*GNU)*RZ(M)
S(N,J,1)=S(N,J,1)+(RZSQ(M)-RZRV(M,J)*COSIKN)*BOG
S(N,J,2)=S(N,J,2)+(RZLAH(M)*SINIKN+EXGNU*COSIKN)*BOG
S(N,J,3)=S(N,J,3)+(RVLAH(M,J)-RZLAH(M)*COSIKN+EXGNU*SINIKN)*BOG
6  CONTINUE
3  RETURN
FN)

```

```

C *** VORCES *** FPV-7 FIELD POINT VELOCITIES AUG 20,1969
SUBROUTINE VORCES
  DIMENSION A1(792),KB(20,41),S1(792),U1(792),XR(11),XG(11),XTB(11),
  1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),F(36)
  COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
  142,2),SINKN(20,24),XSTAR(11
  1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
  2MA(100),GLT(20),GT(20,42),GTL(20),MHUB(17),NLE(20),NTE(20),NUM(41)
  3,PHI(42),REMARK(18),R(20),RVLAM(20,11),RV(11),RVSQ(11),RZLAM(20),R
  3ZPV
  42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
  5,SL(20),SMA(42),SQLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),WEIGHT
  6(5),X(42),XGL(11),XMAP(11),AY,AM,AA,AB,AC,AD,AE,AF,AG,AH,AI
  7,AL,BUG,BLADD,BLADE,BBL,BB,BBG,BUB,CHOR,COSIKN,COSY,CCA,CCL,C,D,GR
  8EE,DELT,DET,D2,D516,D75,D8,DELM,D,DFLTA,DU,DV,DW,EX,E,EXGHU,GHU1,G
  9NU,GLMAX,GLMIN,GHU2,H,IMAX,JT,KT,LINE,MAX,MOUSE,MT,MIN
  1,NT,NX?,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NCOSE,NOGO
  2,PP,QQ,Q,RH,RBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TF,V,XL,XP,A
  3NGLE(33),P,Z
  EQUIVALENC (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
  1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
  2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
  3(XTZ,XINPUT(78))
  DO 3 N=1,792
    U1(N)=0.0
  3 A1(N)=0.0
    DO 5 I=1,41
      DO 1 K=1,KT
        DO 1 N=1,NT
          COSIKN=COSI(I)*COSKN(K,N)-SINI(I)*SINKN(K,N)
          SINIKN=SINI(I)*COSKN(K,N)+COSI(I)*SINKN(K,N)
          DO 1 J=1,JT
            BB=-2.0*RV(J)*COSIKN
            DO 1 MC=1,MIN
              IF(GB(MC,I).EQ.0.0) GO TO 1
              AA=EX-GLR(MC)*PHI(I)
              AB=AA**2+RVSQ(J)
              AC=4.0*(AA**2+RVSQ(J)*SINIKN**2)
              MD=MC+1
              BUG=-1.0
              AG=0.0
              AH=0.0
              AI=0.0
              DO 8 M=MC,MD
                IF(ABS(AC)-0.00001) 4,4,6
              4 AE=0.5*BB+RZ(M)
                AD=-0.25/AE**2
                AF=-0.5/AE+0.125*BB/AF**2
                GO TO 7
              6 AE=AC*SQRT(RZSQ(M)+RZ(M)*BB+AB)
                AD=(2.0*RZ(M)+BB)/AE
                AF=-(BB*RZ(M)+2.0*AB)/AE
              7 AG=AG+BUG*AD*GB(MC,I)
                AH=AH+BUG*AD*SB(MC,I)
                AI=AI+BUG*AF*SB(MC,I)
              8 BUG=-BUG
                U(N,J,1)=U(N,J,1)-RV(J)*SINIKN*AG

```

```
U(N,J,2)=U(N,J,2)+AA*SINIKN*AG
U(N,J,3)=U(N,J,3)-AA*COSIKN*AG
A3(N,J,1)=A3(N,J,1)+AA*AH
A3(N,J,2)=A3(N,J,2)+(RV(J)*AH-COSIKN*AI)
A3(N,J,3)=A3(N,J,3)-SINIKN*AI
1  CONTINUE
5  CONTINUE
   RETURN
   END
```

C

\*\*\* BTRAIL \*\*\* FPV-7 FIELD POINT VELOCITIES AUG 20, 1969

SUBROUTINE BTRAIL

```

DIMENSION A1(792),KB(20,41),S1(792),U1(792),XR(11),XG(11),XTB(11),
1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),P(36)

```

```

COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
142,2),SINKN(20,24),XSTAR(11

```

```

1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
2HA(100),GLT(20),GT(20,42),GYL(20),MHUB(17),NLE(20),NTE(20),NUM(41)
3,PHI(42),REMARK(18),R(20),RVLAM(20,11),RV(11),RVSQ(11),RZLAM(20),R
3ZRV

```

```

42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
5,SL(20),SHA(42),SQLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),WEIGHT
6(5),X(42),XGL(11),XMAP(11),AY,AH,AA,AB,AC,AD,AE,AF,AG,AH,AI
7,AL,BUG,BLADD,BLADDE,BBL,BB,BOG,BUB,CHOR,COSIKN,COSY,CCA,CCL,C,DEGR
8EE,DELT,DET,D2,D516,D75,D8,DELM,D,DELTA,DU,DV,DW,EX,E,EXGNU,GMU1,G
9NU,GLMAX,GLMIN,GMU2,H,IMAX,JT,KT,LINE,MAX,MOUSE,MT,MIN
1,NT,NX?,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NOOSE,NOGO
2,PP,QQ,Q,RH,RBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TP,V,XL,XP,A
3NGLE(3?),P,Z

```

```

EQUIVALENCE (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
3(XTZ,XINPUT(78))

```

```

DO 3 N=1,792

```

```

3 U1(N)=0.0

```

```

DO 1 L=1,49

```

```

GMU1=PHI(L)

```

```

DELTA=PHI(L+1)-GMU1

```

```

COEX(1)=0.211325*DELTA

```

```

COEX(2)=0.789675*DELTA

```

```

WEIGHT(1)=0.25*DELTA

```

```

WFIGHT(2)=WEIGHT(1)

```

```

DO 4 I=1,2

```

```

GNU=GMU1+COEX(I)

```

```

COSY=COS(GNU)

```

```

SINY=SIN(GNU)

```

```

DO 4 K=1,KT

```

```

DO 4 N=1,NT

```

```

COSIKN=COSY*COSKN(K,N)-SINY*SINKN(K,N)

```

```

SINIKN=SINY*COSKN(K,N)+COSY*SINKN(K,N)

```

```

DO 4 J=1,JT

```

```

DO 4 M=1,MAX

```

```

IF(GT(M,L).EQ.0.0) GO TO 4

```

```

BUG=SQRT(((EX-GLRZ(M)*GNU)**2+RVSQ(J)+RZSQ(M)-RZRV2(M,J)*COSIKN)
1**3)

```

```

BUG=WEIGHT(I)*GT(M,L)/BUG

```

```

EXGNU=(EX-GLRZ(M)*GNU)*RZ(M)

```

```

U(N,J,1)=U(N,J,1)+(RZSQ(M)-RZRV(M,J)*COSIKN)*BUG

```

```

U(N,J,2)=U(N,J,2)+(PZLAM(M)*SINIKN+EXGNU*COSIKN)*BUG

```

```

U(N,J,3)=U(N,J,3)+(RVLAM(M,J)-RZLAM(M)*COSIKN+EXGNU*SINIKN)*BUG

```

```

4 CONTINUE

```

```

1 CONTINUE

```

```

RETURN

```

```

END

```

```

C   *** SUMOUT ***   FPV-7   FIELD POINT VELOCITIES AUG 20, 1969
SUBROUTINE SUMOUT(X,R,T,U,S,NT,J,REMARK,KODE,A,B,C,CN)
DIMENSION T(24,2),U(24,11,3),S(24,11,3),REMARK(18),SN(4,3)
DIMENSION CN(4,3)
GO TO (1,2,3,4,5),KODE
1 GO TO 28
2 GO TO 28
3 GO TO 20
4 GO TO 20
5 CONTINUE
20 DO 12 I=1,3
    L=J*I-1
12  CALL HARMAN(U(1,J,I),T,CN(1,I),SN(1,I),NT,L)
    SP=A*(B*SN(1,1)+R*SN(1,3))
    CP=A*(B*CN(2,1)+R*CN(2,3))
    PM=SQRT(SP**2+CP**2)
    IF(ABS(SP)-0.00001) 13,15,16
13  PT=90.0*(1.0-SIGN(1.0,CP))/C
    GO TO 15
14  IF(ABS(CP)-0.00001) 16,15,17
16  PT=90.0*(2.0-SIGN(1.0,SP))/C
    GO TO 15
17  PT=(90.0-ATAN(CP/SP)/.17453293E-01)/C
    IF(SP) 18,18,15
18  PT=PT+180.0/C
15 CONTINUE
    GO TO (9,8,8,8,9),KODE
8   DO 7 N=1,NT
    DO 7 K=1,3
        S(N,J,K)=S(N,J,K)+U(N,J,K)
7   CONTINUE
9   RETURN
END

```

```

C   *** COMAP ***   FPV-7   FIELD POINT VELOCITIES AUG 20, 1969
FUNCTION COMAP(TEMP,RH)
IF(TEMP-.999) 1,1,2
2   COMAP=3.1415926
GO TO 19
1   CN=(1.0+RH-2.0*TEMP)/(1.0-RH)
IF(ABS(CN)-.00001) 17,17,18
17  COMAP=1.5707963

GO TO 19
18  CTN=SQRT(1.0-CN**2)/CN
    COMAP=ATAN(CTN)
    IF(CTN) 20,19,19
20  COMAP=COMAP+3.1415926
19  RETURN
C   END OF   *** COMAP ***
END

```

```

C   *** FILLIN ***   FV-7   FIELD POINT VELOCITIES AUG 20, 1969
C   FIND'S Y(X) FROM TABLE OF
C   AB(N) AND OR(N) CONTAINING NO POINTS.
C   FUNCTION FILLIN(X,AB,Q000FL,NO)
C   DIMENSION AB(3),Q000FL(3)
C   DIMENSION AB(3),OR(3)
C   ANTRA(Q001FL,Q002FL,Q003FL,Q004FL,Q005FL,Q006FL,Q007FL)=Q005FL*(Q0
104FL-Q002FL)*(Q004FL-Q003FL)/((Q001FL-Q002FL)*(Q001FL-Q003FL))+ Q0
206FL*(Q004FL-Q001FL)*(Q004FL-Q003FL)/((Q002FL-Q001FL)*(Q002FL-Q003
3FL))+Q007FL*(Q004FL-Q001FL)*(Q004FL-Q002FL)/((Q003FL-Q001FL)*(Q00
43FL-Q002FL))
C   IF(X-AB(1)) 1,3,2
3   Y=Q000FL(1)
C   GO TO 99
1   Y=ANTRA(AB(1),AB(2),AB(3),X,Q000FL(1),Q000FL(2),Q000FL(3))
C   GO TO 99
2   IF(X-AB(2))1,6,5
6   Y=Q000FL(2)
C   GO TO 99
5   DO 7 I=3,NO
C   M=I
C   IF(X-AB(I))8,9,7
9   Y=Q000FL(I)
C   GO TO 99
7   CONTINUE
8   Y=ANTRA(AB(M-2),AB(M-1),AB(M),X,Q000FL(M-2),Q000FL(M-1),Q000FL(M))
99  FILLIN=Y
C   RETURN
C   END

```

```

C   *** HARMAN ***   FV-7   FIELD POINT VELOCITIES AUG 20, 1969
C   SUBROUTINE HARMAN(X,T,A,B,NT,JUMP)
C   DIMENSION C(24,3),S(24,3),T(24),A(4),B(4),X(24)
C   IF(JUMP) 2,1,2
1   D=NT
C   DO 3 N=1,NT
C   ANGL=FLCAT(N-1)*360.0/D
C   DO 3 K=1,3
C   E=FLOAT(K)*ANGL*.17453293E-01
C   C(N,K)=2.0*COS(E)/D
3   S(N,K)=2.0*SIN(E)/D
2   DO 4 K=1,4
C   A(K)=0.0
4   B(K)=0.0
C   DO 5 N=1,NT
C   A(1)=A(1)+X(N)
C   DO 5 K=1,3
C   A(K+1)=A(K+1)+X(N)*C(N,K)
5   B(K)=B(K)+X(N)*S(N,K)
C   A(1)=A(1)/D
C   RETURN
C   END

```

```

C   MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C   NOVEMBER 1992   S GOOD   DAVID TAYLOR MODEL BASIN   AM MAT1
C
C   SUBROUTINE MATINV(A,N1,B,M1,DETERM,I0)
C
C   GENERAL FORM OF DIMENSION STATEMENT
C   DIMENSION   A( , ),B( , ),INDEX( ,3)
C
C   DIMENSION A(42,42),B(42,2),INDEX(42,3)
C   EQUIVALENCE (IROW,JROW), (ICOLU,JCOLU), (AMAX, T, SWAP)
C
C   INITIALIZATION
C
C   M=M1
C   N=N1
10  DETERM=1.0
15  DO 20 J=1,N
20  INDEX(J,3) = 0
30  DO 550 I=1,N
C
C   SEARCH FOR PIVOT ELEMENT
C
40  AMAX=0.0
45  DO 105 J=1,N
    IF(INDEX(J,3)-1) 60, 105, 60
60  DO 100 K=1,N
    IF(INDEX(K,3)-1) 80, 100, 715
80  IF (    AMAX -ABS (A(J,K))) 85, 100, 100
85  IROW=J
90  ICOLU=K
    AMAX = ABS (A(J,K))
100 CONTINUE
105 CONTINUE
    INDEX(ICOLU,3)=INDEX(ICOLU,3)+1
260 INDEX(T,1)=IROW
270 INDEX(I,2)=ICOLU
C
C   INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
130 IF (IROW-ICOLU) 140, 310, 140
140 DETERM=-DETERM
150 DO 200 L=1,N
160 SWAP=A(IROW,L)
170 A(IROW,L)=A(ICOLU,L)
200 A(ICOLU,L)=SWAP
    IF(M) 310, 310, 210
210 DO 250 L=1, M
220 SWAP=B(IROW,L)
230 B(IROW,L)=B(ICOLU,L)
250 B(ICOLU,L)=SWAP
C
C   DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
310 PIVOT   =A(ICOLU,ICOLU)
    DETERM=DETERM*PIVOT
330 A(ICOLU,ICOLU)=1.0
340 DO 350 L=1,N

```

```

350 A(ICOLU, L) = A(ICOLU, L) / PIVOT
355 IF (M) 380, 380, 360
360 DO 370 L=1, M
370 B(ICOLU, L) = B(ICOLU, L) / PIVOT

```

```

C
C      REDUCE NON-PIVOT ROWS
C

```

```

380 DO 550 L1=1, N
390 IF (L1-ICOLU) 400, 550, 400
400 T = A(L1, ICOLU)
420 A(L1, ICOLU) = 0.0
430 DO 450 L=1, N
450 A(L1, L) = A(L1, L) - A(ICOLU, L) * T
455 IF (M) 550, 550, 460
460 DO 500 L=1, M
500 B(L1, L) = B(L1, L) - B(ICOLU, L) * T
550 CONTINUE

```

```

C
C      INTERCHANGE COLUMNS
C

```

```

600 DO 710 I=1, N
610 L = N+1-I
620 IF (INDEX(L, 1) - INDEX(L, 2)) 630, 710, 630
630 JROW = INDEX(L, 1)
640 JCOLUM = INDEX(L, 2)
650 DO 705 K=1, N
660 SWAP = A(K, JROW)
670 A(K, JROW) = A(K, JCOLUM)
700 A(K, JCOLUM) = SWAP
705 CONTINUE
710 CONTINUE
      DO 730 K = 1, N
      IF (INDEX(K, 3) - 1) 715, 720, 715
720 CONTINUE
730 CONTINUE
      ID = 1
740 RETURN
715 IC = 2
      GO TO 740
      END

```

```

SUBROUTINE OLD(BZ, IPO)
DIMENSION AZZ(38,38)
DIMENSION BZ(111)
DIMENSION CZ(108), TL(12), B(99), AP(9,3), AQ(9,9), AU(9,9), AV(9,9), AX(
19,9), AY(9,9), QA(9,9), FT(9), CG(9,1)
DIMENSION EA(9,8), EB(9,8), EC(9,8), ED(9,8), PA(8), PE(3,3), PG(3,3), PH
1(3,1), PI(3,1), PF(3), XZ(9,9), WA(9,9), XA(9,9)
DIMENSION FLD(9), ALD(9), FDC(9), ADC(9), FDCP(9), ADGP(9), FDCPT(9), AD
1PT(9), FDCPT(36), AGHT(36), FDCPT(36), ADMQ(36), FHTB(9), AMTB(9), FMQB(9),
2AMQB(9), FMXB(9), AMXB(9), FMXB(9), AMXB(9)
COMMON /HRT/ JPR
DIMENSION INDEX(3,3)
COMMON CZ      , TL      , S      , AP      , AQ      , AU
COMMON AM      , AX      , AY      , QA      , FT      , CG
COMMON BO      , BY      , KO      , M3      , CMP , WA, XA
DO 30 I=1,12
30 TL(I)=BZ(I+99)
KO=1
1 KOUNT=0
KT=0
CMP = 0.0
CA = 0.0
DO 5 I=1,9
3(I+80)=BZ(I+81)
5 B(I+90)=BZ(I+90)
GO TO 5
6 DO 7 I=1,9
3(I+80)=BZ(15)
7 B(I+90)=BZ(15)
8 DO 9 I=1,14
9 B(I)=BZ(I)
DO 10 I=1,45
10 B(I+14)=BZ(I+18)
B(60)=BZ(15)
DO 11 I=1,9
3(I+60)=BZ(I+63)
11 B(I+70)=BZ(I+72)
DO 12 I=1,10
12 B(I)=BZ(10)
IF(JPR.NE.2) GO TO 100
WRITE (6,12)
12 FORMAT(1H1,44X,32HCONTRA-ROTATING PROPELLER DESIGN//)
WRITE (6,13)KO
13 FORMAT (110X,5HPAGE I2)
WRITE (6,14)
14 FORMAT(55X,10HINPUT DATA//)
WRITE (6, 15) (BZ(I), I=1,81)
15 FORMAT (6X,9F12.4)
IF (BZ(15))17,16,17
16 WRITE (6, 15) (BZ(I), I=82,99)
100 KO=KO+1
17 ECC=B(10)
B(12)=.95
B(13)=1.0
B(14)=1.05
PM=B(12)
KK=0
BI=3.0

```

```

      BJ=0.0
      9J1=0.0
      8J2=0.0
      J1=0
      RSL=B(7)/(3.1415927*B(4)*B(2))
      NZ1=B(18)
      NZ2=B(11)
      DO 380 KI=1,2
      IF(KI-2) 201,202,202
201    KJ=3
      GO TO 203
202    KJ=1
203    CONTINUE
      DO 208 KC=1,KJ
      ECC=NZ1
      R(10)=NZ1
      CALL SUB1
19 DO 20 MO=1,9
      WA(MO,1)=AW(MO,1)
      XA(MO,1)=AX(MO,1)
20 QA(MO,1)=CG(MO,1)
21 K2=MB
      GO TO (25,22),K2
22 N=9
      JP=9
23 FORMAT(I1)
      K1=JP-N
      IF(K1)1,24,1
24 GO TO *2
25 DO 26 J=1,9
      KK=4
      EA(J,KK)=AU(J,1)
      FB(J,KK)=AW(J,1)
      FC(J,KK)=AX(J,1)
26 ED(J,KK)=AY(J,1)
      B(10)=NZ?
      CALL SUB1
      KK=5
      DO 226 J=1,9
      EA(J,KK)=AU(J,1)
      EB(J,KK)=AW(J,1)
      EC(J,KK)=AX(J,1)
226 ED(J,KK)=AY(J,1)
      57 CALL SUB2(ECC,EB,EC,ED,HR,IPO)
      BZ(16)=HR
      PAT=PA(4)+(1.0-FT(9))*2*PA(8)
      DO 58 I=1,9
      IF(I-1) 400,400,401
401 IF(I-9) 402,400,402
400 FL0(I)=.0
      AL0(I)=.0
      GO TO 403
402 CONTINUE
      FLO(I)=CZ(I+9)/B(I+60)
      FLO(I)=B(I+80)/FLO(I)
      ALD(I)=CZ(I+63)/B(I+70)
      ALD(I)=B(I+90)/ALD(I)

```

```

483  CONTINUE
      FDCT(I)=(1.0-FLD(I)*CZ(I))*CZ(I+18)
      ADCT(I)=(1.0-ALD(I)*CZ(I+54))*CZ(I+72)
      FDCP(I)=(1.0+FLD(I)/CZ(I))*CZ(I+27)
      ADCP(I)=(1.0+ALD(I)/CZ(I+54))*CZ(I+81)
      FDPT(I)=R(I+23)*FDCT(I)
58  ADPT(I)=R(I+32)*ADCT(I)
      FCT=SIMPUN(B(15),FDCT,9)
      ACT=SIMPUN(CZ(46),ADCT,9)
      FCP=SIMPUN(B(15),FDCP,9)
      ACP=SIMPUN(CZ(46),ADCP,9)
      FCPT=SIMPUN(B(15),FDPT,9)
      ACPT=SIMPUN(CZ(46),ADPT,9)
      FFE=FCPT/FCP
      AFE=ACPT/ACP
      FCOC=FCT/FCP
      ACOC=ACT/ACP
      TFCT=FCT+(1.0-FT(9))*2*ACT
      J1=J1+1
      K=J1+12
      B(12)=R(K)
      BY=TFCT
200  PA(KC)=3Y
      IF(KI-2)204,67,67
204  CONTINUE
      DO 31J=1,3
      PE(J,1)=1.0
31  PG(J,1)=1.0
      DO 32J=1,3
      PN(J,1)=PA(J)**2
      PE(J,3)=PN(J,1)
      PG(J,3)=PE(J,3)
      PE(J,2)=PA(J)
32  PG(J,2)=PE(J,2)
      PI(1,1)=FM
      PI(2,1)=B(13)
      PI(3,1)=B(14)
      CALL MATINS(PE,3,3,PI,1,1,DETERM,ID,INDEX)
      IF(ID-1)33,35,33
33  PRINT 34
      GO TO 82
34  FORMAT(18H CTS1* IS SINGULAR)
35  PK=BQ
      PL=PK**2
      PR=PI(1,1)+PK*PI(2,1)+PL*PI(3,1)
      IF(CA)37,36,37
36  A4=PR
      CA=1.0
37  B(12)=PR
60  CMP=1.0
      DO 61 I=1,9
      B(I+23)=BZ(I+27)
61  B(I+60)=BZ(I+63)
62  DO 63 I=1,9
63  B(I+50)=A4*B(I+50)
64  CMP=1.0
      B(12)=1.

```

300 CONTINUE

```

67 TFCP = FCP + (1.0 - FT(9)) ** 2 * ACP
TCPT = FCPT + (1.0 - FT(9)) ** 2 * ACPT
TFCE = TCPT / TFCP
TCOC = TFCT / TFCP
FNMT = B(8) * B(2) ** 3 * 3.14159265 * B(7) ** 2 / (16.0 * B(10))
ANMT = FNMT * B(10) / B(11)
FNMQ = (B(8) * B(2) ** 2 * B(7) ** 3) / (16.0 * B(4) * B(10))
ANMQ = FNMQ * B(10) / B(11)
M=0
DO 68 J=1,4
DO 68 I=1,9
M=M+1
K=J*2
FDMT(M) = (B(I+14) - B(K+13)) * FDCI(I)
ADMN(M) = (CZ(I+45) - CZ(K+44)) * ADCI(I)
FDMQ(M) = (B(I+14) - B(K+13)) / B(I+14) * FDCI(I)
68 ADMQ(M) = (CZ(I+45) - CZ(K+44)) / CZ(I+45) * ADCI(I)
DO 69 I=1,9
FMTB(I) = 0.0
AMTB(I) = 0.0
FMQB(I) = 0.0
69 AMQB(I) = 0.0
FMTB(1) = SIMPUN(B(15), FDMT(1), 9)
AMTB(1) = SIMPUN(CZ(46), ADMN(1), 9)
FMQB(1) = SIMPUN(B(15), FDMQ(1), 9)
AMCB(1) = SIMPUN(CZ(46), ADMQ(1), 9)
FMTB(3) = SIMPUN(B(17), FDMT(12), 7)
AMTB(3) = SIMPUN(CZ(48), ADMN(12), 7)
FMQB(3) = SIMPUN(B(17), FDMQ(12), 7)
AMCB(3) = SIMPUN(CZ(48), ADMQ(12), 7)
FMTB(5) = SIMPUN(B(19), FDMT(23), 5)
AMTB(5) = SIMPUN(CZ(50), ADMN(23), 5)
FMQB(5) = SIMPUN(B(19), FDMQ(23), 5)
AMCB(5) = SIMPUN(CZ(50), ADMQ(23), 5)
FMTB(7) = SIMPUN(B(21), FDMT(34), 3)
AMTB(7) = SIMPUN(CZ(52), ADMN(34), 3)
FMQB(7) = SIMPUN(B(21), FDMQ(34), 3)
AMCB(7) = SIMPUN(CZ(52), ADMQ(34), 3)
DO 70 I=1,9
FMTB(I) = FNMT * FMTB(I)
AMTB(I) = ANMT * AMTB(I)
FMQB(I) = FNMQ * FMQB(I)
70 AMQB(I) = ANMQ * AMQB(I)
DO 71 I=1,9
FMXB(I) = FMTB(I) * COS(CZ(I+36)) + FMQB(I) * SIN(CZ(I+36))
AMXB(I) = AMTB(I) * COS(CZ(I+90)) + AMQB(I) * SIN(CZ(I+90))
FMYO(I) = FMTB(I) * SIN(CZ(I+36)) - FMQB(I) * COS(CZ(I+36))
71 AMYO(I) = AMTB(I) * SIN(CZ(I+90)) - AMQB(I) * COS(CZ(I+90))
IF(JPR.EQ.2) GO TO 91
WRITE (6,12)
WRITE (6,13) K0
WRITE (6,72)
72 FORMAT(52X,14HFOE PROPELLER//)
WRITE (6,73) FCT,FCP,FCPT,FFE,FCOC
73 FORMAT(9H CTS=1PE10.4,9H CPS=1PE10.4,9H CTP=1PE10.4,9H
1 LF=1PE10.4,13H CTS/CPS=1PE10.4)

```

```

WRITE (6,74)
74 FORMAT(1H )
WRITE (6,74)
WRITE (6,75)
75 FORMAT (17X,2HXI,8X,7HEPSILON,7X,3HMTB,9X,3HMQB,9X,3HMXO,9X,3HMYO,
110X,1HM,9X,4HG(H))
WRITE (6,74)
91 KO=KO+1
DO 92 I=1,9
92 QA(I,1)=QA(I,1)/0000FL
IF(JPR.NE.2) GO TO 94
DO 76 I=1,9
76 WRITE (6,77 )B(I+14),FLC(I),FMTB(I),FMQB(I),FMXO(I),FMYO(I),I,QA(I
1,1)
77 FORMAT(12X,1P6E12.4,6X,I1,5X,E12.4)
WRITE (6,74)
WRITE (6,74)
WRITE (6,74)
WRITE (6,78)
78 FORMAT(53X,13HAFT PROPELLER//)
WRITE (6,73 )ACT,ACP,ACPT,AFE,ACOG
WRITE (6,74)
WRITE (6,75)
WRITE (6,74)
94 DO 93 I=1,9
93 CG(I,1)=CG(I,1)/B(11)
IF(JPR.NE.2) GO TO 22
DO 79 I=1,9
79 WRITE (6,77 )CZ(I+45),ALD(I),AMTB(I),AMQB(I),AMXO(I),AMYO(I),I,CG(
1I,1)
WRITE (6,80)
80 FORMAT(1H //////////)
WRITE (6,81)
81 FORMAT(57X,5HTOTAL///)
WRITE (6,73 )TFCT,TFCP,TCTP,IFFE,TCOC
82 CONTINUE
RETURN
END

```

```

SUBROUTINE SUB1
  DIMENSION CZ(108), TL(12), B(99), AP(9,9), AQ(9,9), AU(9,9), AW(9,9), AX(
19,9), AY(9,9), QA(9,9), FT(9), CG(9,1)
  DIMENSION P(81), AH(10,9)
  DIMENSION AJ(9,9), AL(9), AO(9,9), AR(9,9), AS(9,9), AT(9,9), AV(9,9), AZ
1(9,9), C(9), E(9), F(9), G(9), H(81), BA(9,9), BB(9,9), BC(9,9), BD(9,9), BE
2(9,9), BF(9,9), BG(9,9), BH(9,9), HA(9,9), XA(9,9)
  DIMENSION CF(9,1), CH(9,9), CI(9,1)
  DIMENSION BK(9), BS(9), CD(10,9), Q(9), O(81)
  DIMENSION INDEX(9,3)
  COMMON CZ      , TL      , B      , AP      , AO      , AU
  COMMON AW      , AX      , AY      , QA      , FT      , CG
  COMMON BQ      , BY      , KO      , H3      , CMP      , HA, XA
  CA=4.0
  DO 4 I=1,9
    C(I)=((1.0+B(15))-2.0*B(I+14))/(1.0-B(15))
    AH(2,I)=C(I)
    CF=C(I)**2
    ABC=(1.0-CF)
    IF(ABC)1,2,3
1  ABC=-ABC
    GO TO 3
2  ABC=.0001
3  C7(?,I)=SQRT(ABC)
    AH(1,I)=1.0
4  CD(1,I)=0.0
    AH(2,1)=1.0
    AH(?,9)=-1.0
    CD(2,1)=0.0
    CD(2,9)=0.0
    DO 5 J=3,10
      L=J-1
      DO 5 K=1,9
        AH(J,K)=(AH(L,K)*AH(2,K))-(CD(L,K)*CD(2,K))
5      C7(J,K)=(CD(L,K)*AH(2,K))+(AH(L,K)*CD(2,K))
      DO 6 I=2,8
6      E(I)=3.1415927/CD(2,I)
      RSL=B(7)/(3.1415927*B(4)*B(2))
      IF (B(51)-0.0) 9,7,9
7      DO 8 J=1,9
8      B(J+50)=RSL/(B(J+14)*B(5))*SQRT(B(9)*B(J+23))
9      DO 10 J=1,9
10     F(J)=B(12)*B(J+50)
11     DO 12 J=1,9
12     G(J)=1.0/F(J)
      DO 13 I=1,9
        JNO=I-1
        DO 13 J=1,9
          K=9*JNO+J
13     H(K)=B(I+14)/B(J+14)*G(J)
      DO 14 J=1,9
14     Q(J)=ATAN(F(J))
      DO 25 N=1,9
        KNO=N-1
        LNO=N-1
        MNO=N-1

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```

DO 25 I=1,9
J=9*MNO+I
IF(H(J)-G(I)) 16,15,16
15 K=9*KNO+I
L=9*LNO+I
O(K)=COS(Q(I))
P(L)=SIN(Q(I))
GO TO 25
16 S=1.0+H(J)**2
T=SQRT(S)
V=1.0+G(I)**2
W=SQRT(W)
AE=T-W
U=EXP(AE)
R=((T-1.0)/H(J)*(G(I)/(W-1.0)))*U)**B(10)
AC=1.5
AD=.25
X=(1.0/(2.0*B(10)*G(I)))*(V/S)**AD
Y=((9.0*G(I)**2)+2.0)/(V**AC)+((3.0*H(J)**2-2.0)/(S**AC))
Z=1.0/(24.0*B(10))*Y
IF(H(J)-G(I)) 21,21,17
17 AF=1.0+1.0/(R-1.0)
IF(AF)18,19,20
18 AF=-AF
GO TO 20
19 AF=.0001
20 AA=X*(1.0/(R-1.0)-Z*ALOG(AF))
K=9*KNO+I
L=9*LNO+I
O(K)=2.0*B(10)**2*G(I)*H(J)*(1.0-G(I)/H(J))*AA
P(L)=B(10)*(1.0-G(I)/H(J))*(1.0+2.0*B(10)*G(I)*AA)
GO TO 25
21 AG=1.0+1.0/(1.0/R-1.0)
IF(AG)22,23,24
22 AG=-AG
GO TO 24
23 AG=.0001
24 AB=-X*(1.0/(1.0/R-1.0)+Z*ALOG(AG))
K=9*KNO+I
L=9*LNO+I
O(K)=B(10)*G(I)*(1.0-H(J)/G(I))*(1.0-2.0*B(10)*G(I)*AB)
P(L)=2.0*B(10)**2*G(I)*(1.0-G(I)/H(J))*AB
25 CONTINUE
DO 26 I=1,9
IMO=I-1
DO 26 L=1,9
K=9*IMO+L
26 AP(L,I)=O(K)
DO 27 I=1,9
JMO=I-1
DO 27 L=1,9
K=9*JMO+L
27 AQ(L,I)=P(K)
DO 28 I=1,9
DO 28 L=1,9
28 AJ(L,I)=AH(I,L)
DO 29 I=1,9

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```

      DO 29 L=1,9
29  A0(L,I)=AH(I,L)
      CALL MATINS(AJ,9,9,AP,9,9,DETERM,IO,INDEX)
      IF(ID-1)30,32,30
30  PRINT 31
      GO TO 110
31  FORMAT (26H I(A) IS SINGULAR FOR Z(F))
32  CALL MATINS(A0,9,9,A0,9,9,DETERM,IO,INDEX)
      IF(ID-1)33,35,33
33  PRINT 34
      GO TO 110
34  FORMAT (25H I(T) IS SINGULAR OF Z(F))
35  AS(1,1)=AP(1,1)+AP(2,1)
      DO 36 J=7,8
36  AS(J,1)=AS(J-1,1)+AP(J+1,1)
      AS(9,1)=AS(8,1)
      DO 37 L=1,9
37  AH(L,1)=FLOAT(L)*AS(L,1)
      DO 38 L=2,9
      K=L-1
38  AU(K,1)=AP(L,1)*FLOAT(K)
      AU(9,1)=0.0
      AV(9,1)=0.0
      DO 39 L=2,9
      J=10-L
39  AV(J,1)=AV(J+1,1)+AU(J+1,1)
      DO 40 L=1,9
40  AZ(L,1)=(AH(L,1)+AV(L,1))*3.1415927
      DO 41 I=2,8
      DO 41 L=2,9
      K=L-1
41  AR(K,I)=AP(L,I)*AH(L,I)
      DO 43 I=2,8
      AS(1,I)=AP(1,I)*AH(1,I)+AR(1,I)
      DO 42 J=2,9
      K=J-1
42  AS(J,I)=AS(K,I)+AR(J,I)
43  AS(9,I)=AS(8,I)
      DO 44 I=2,8
      DO 44 L=1,9
      J=L+1
44  AH(L,I)=CD(J,I)*AS(L,I)
      DO 46 I=2,8
      DO 45 L=2,9
      K=L-1
45  AU(K,I)=AP(L,I)*CD(L,I)
46  AU(9,I)=0.0
      DO 47 I=2,8
      AV(9,I)=0.0
      DO 47 L=2,9
      J=10-L
47  AV(J,I)=AV(J+1,I)+AU(J+1,I)
      DO 48 I=2,8
      DO 48 L=1,9
      J=L+1
48  AX(L,I)=AH(J,I)*AV(L,I)
      DO 49 I=2,8

```

```

DO 49 L=1,9
49 AZ(L,I)=(AH(L,I)+AX(L,I))*F(I)
DO 50 L=1,4
J=2*L
50 AP(J,9)=-1.0*AP(J,9)
AR(1,9)=AP(1,9)+AP(2,9)
DO 51 L=2,8
51 AR(L,9)=AR(L-1,9)+AP(L+1,9)
AR(9,9)=AR(8,9)
DO 52 L=1,9
52 AS(L,9)=FLOAT(L)*AR(L,9)
DO 53 L=2,9
K=L-1
53 AU(K,9)=FLOAT(K)*AP(L,9)
AU(9,9)=0.0
AV(9,9)=0.0
DO 54 L=2,9
J=10-L
54 AV(J,9)=AV(J+1,9)+AU(J+1,9)
DO 55 L=1,9
55 AZ(L,9)=(AS(L,9)+AV(L,9))*3.1415927
DO 56 L=1,4
J=2*L
56 AZ(J,9)=-1.0*AZ(J,9)
QA(1,1)=AQ(1,1)+AQ(2,1)
DO 57 J=2,8
57 BA(J,1)=BA(J-1,1)+AQ(J+1,1)
BA(9,1)=BA(8,1)
DO 58 L=1,9
58 BB(L,1)=FLOAT(L)*BA(L,1)
DO 59 L=2,9
K=L-1
59 BC(K,1)=AQ(L,1)*FLOAT(K)
BC(9,1)=0.0
BD(9,1)=0.0
DO 60 L=2,9
J=10-L
60 BD(J,1)=BD(J+1,1)+BC(J+1,1)
DO 61 L=1,9
61 BH(L,1)=(BB(L,1)+BD(L,1))*3.1415927
DO 62 I=2,8
DO 62 L=2,9
K=L-1
62 BA(K,I)=AQ(L,I)*AH(L,I)
DO 64 I=2,8
BB(1,I)=AQ(1,I)*AH(1,I)+BA(1,I)
DO 63 J=2,9
K=J-1
63 BB(J,I)=BB(K,I)+BA(J,I)
64 BB(9,I)=BB(8,I)
DO 65 I=2,8
DO 65 L=1,9
J=L+1
65 BC(L,I)=CD(J,I)*BB(L,I)
DO 67 I=2,8
DO 66 L=2,9
K=L-1

```

```

66 BD(K,I)=AQ(L,I)*CD(L,I)
67 BD(9,I)=0.0
   DO 68 I=2,8
   BE(9,I)=0.0
   DO 68 L=2,9
   J=10-L
68 BE(J,I)=BE(J+1,I)+BD(J+1,I)
   DO 69 I=2,8
   DO 69 L=1,9
   J=L+1
69 BF(L,I)=AH(J,I)*BE(L,I)
   DO 70 I=2,8
   DO 70 L=1,9
70 BH(L,I)=(BC(L,I)+BF(L,I))*E(I)
   DO 71 L=1,4
   J=2*L
71 AQ(J,9)=-1.0*AQ(J,9)
   BA(1,9)=AQ(1,9)+AQ(2,9)
   DO 72 L=2,8
72 BA(L,9)=BA(L-1,9)+AQ(L+1,9)
   BA(9,9)=BA(8,9)
   DO 73 L=1,9
73 BB(L,9)=FLOAT(L)*BA(L,9)
   DO 74 L=2,9
   K=L-1
74 BC(K,9)=FLOAT(K)*AQ(L,9)
   BC(9,9)=0.0
   BD(9,9)=0.0
   DO 75 L=2,9
   J=10-L
75 BD(J,9)=BD(J+1,9)+BC(J+1,9)
   DO 76 L=1,9
76 BH(L,9)=(BB(L,9)+BD(L,9))*3.1415927
   DO 77 L=1,4
   J=2*L
77 BH(J,9)=-1.0*BH(J,9)
   T=3.0
   DO 78 J=1,9
78 CF(J,1)=(B(J+23)-(B(J+14)/RSL*F(J)))*(1.0-B(15))
   DO 79 J=1,9
79 H(J)=CF(J,1)*RSL/((1.0-B(15))*B(J+14))-F(J)
   DO 80 M=1,9
   DO 80 I=1,9
80 AT(I,M)=(H(I)*BH(M,I)-AZ(M,I))*(FLOAT(M)/B(10))
81 DO 82 J=1,9
82 Q(J)=(G(J)+H(J))/B(J+14)*((1.0-B(15))/2.0)
   DO 83 J=1,9
83 CG(J,1)=CF(J,1)
   DO 84 M=1,9
   L=M+1
   DO 84 I=1,9
84 AP(I,M)=CD(L,I)*Q(I)
   DO 85 I=1,9
   DO 85 J=1,9
85 AQ(J,I)=AT(J,I)-AP(J,I)
   DO 86 J=1,9
   DO 86 K=1,9

```

```

86 CH(K,J)=AQ(K,J)
   CALL MATINS(AQ,9,9,CG,1,1,DETERM,IO,INDEX)
   IF(ID-1)87,89,87
87 PRINT 88
   GO TO 110
88 FORMAT (27H G(MX) IS SINGULAR FOR Z(F))
89 DO 91 J=1,9
   SUMUA=0.0
   SUMAU=0.0
   DO 90 L=1,9
   SUMUA=SUMUA+FLOAT(L)*CG(L,1)*AZ(L,J)
90 SUMAU=SUMAU+FLOAT(L)*CG(L,1)*BH(L,J)
91 AU(J,1)=SUMUA/SUMAU
   S=.005
   DO 94 J=1,9
   CI(J,1)=AU(J,1)-G(J)
   IF(CI(J,1))92,93,93
92 CI(J,1)=-1.0*CI(J,1)
93 BW=S-CI(J,1)
   IF(BW)95,94,94
94 CONTINUE
   GO TO 101
95 T=T-1.0
   IF(T)98,96,96
96 DO 97 J=1,9
97 G(J)=AU(J,1)
   GO TO *1
98 CONTINUE
200 FORMAT(9F12.4)
99 FORMAT (20H TOO MANY ITERATIONS)
100 FORMAT (12A6)
101 DO 103 J=1,9
   SUMUT=0.0
   DO 102 K=1,9
102 SUMUT=SUMUT+FLOAT(K)*CG(K,1)*BH(K,J)
103 AW(J,1)=SUMUT/(B(10)*(1.0-B(15)))
   DO 105 J=1,9
   SUMUA=0.0
   DO 104 K=1,9
104 SUMUA=SUMUA+FLOAT(K)*CG(K,1)*AZ(K,J)
105 AX(J,1)=SUMUA/(B(10)*(1.0-B(15)))
   DO 107 J=1,9
   SUMG=0.0
   DO 106 K=1,9
   L=K+1
106 SUMG=SUMG+CG(K,1)*CD(L,J)
107 AY(J,1)=SUMG
   AY(1,1)=0.0
   AY(9,1)=0.0
   DO 108 I=1,9
   BO=AY(I,1)**2/(2.0*B(I+14))
   BV=B(I+14)/RSL
108 BK(I)=((RV-AW(I,1))*AY(I,1)+BO)*0.0
   BL=SIMPUN(B(15),BK(1),9)
   BY=BL
   BM=B(2)**2
   BP=B(7)**2

```

$BQ = (8.0 * B(6) / (B(8) * BM * 3.1415927 * BP))$   
109 MS=1  
GO TO 111  
110 MS=2  
111 RETURN  
END

```

SUBROUTINE SUB2(CC,FB,FC,FD,HR,IPO)
  DIMENSION CZ(108),TL(12),B(99),AP(9,9),AQ(9,9),AU(9,9),AH(9,9),AX(
19,9),AY(9,9),QA(9,9),FT(9),CG(9,1)
  DIMENSION TABX(9),TABY(9),FB(9,8),FC(9,8),FD(9,8),FU(9),FV(9),FW(9
1),HA(9,9),XA(9,9)
  DIMENSION FE(9),FF(9),FI(9),FP(9),FQ(9),FR(9),FS(9)
  DIMENSION FX(9),FY(9),GA(9),GB(9),GC(9),GD(9),GF(9),GG(9),GH(9),HV
1(9),GI(9),GX(9),GL(9),GN(9),HE(9),HK(9),HL(9),HP(9),HQ(9),HS
2(9)
  COMMON /WRT/ JPR
  DIMENSION HE1(9),GC1(9)
  COMMON CZ      , TL      , B      , AP      , AQ      , AU
  COMMON AH      , AX      , AY      , QA      , FT      , CG
  COMMON BO      , BY      , KO      , MB      , CMP      , HA, XA
1 RSL=B(7)/(3.1415927*B(4)*B(2))
2 GU=3.0
  DO 4 J=1,9
4 FE(J)=FD(J,4)/(2.0*B(J+14)*FB(J,4))
  DO 6 J=1,9
6 FF(J)=FD(J,8)/(2.0*B(J+14)*FB(J,8))
  FI=0.0
  FJ=0.0
  FK=1.0
7 DO 12 J=1,9
8 FG=FC(J,4)*FE(J)
9 FH=FC(J,8)*FF(J)
10 FL=(FH*(1.0-B(J+41)))*FJ
12 FY(J)=B(J+23)+FG+FL
  DO 16 J=1,9
13 FN=FK*FC(J,8)*FF(J)
14 FO=FC(J,4)*FE(J)*(1.0+B(J+41))
16 FP(J)=B(J+32)+FN+FO
  DO 18 J=2,9
18 FQ(J)=1.0-(FH(J)/FP(J))
  FQ(1)=0.0
19 GO=(B(16)-B(15))/2.0
  FR(1)=0.0
  DO 21 J=2,9
  GO=(B(J+14)-B(J+13))/2.0
21 FR(J)=(FO(J-1)+FQ(J))*B(J+14)*GO
  FS(1)=0.0
  DO 23 J=2,9
23 FS(J)=FS(J-1)+FR(J)
  FT(1)=0.0
  DO 25 J=2,9
25 FT(J)=FS(J)/(B(J+14)**2)
  GV=0.0
  DO 27 J=2,9
27 GV=GV+FT(J)
  FI=GV/9.0
28 FK=(1.0+FI)*(1.0+FJ)
  DO 30 J=1,9
30 FU(J)=FK*FC(J,8)*FF(J)*(1.0-B(J+41))
  DO 32 J=1,9
32 FV(J)=B(J+23)+FC(J,4)+FU(J)
  DO 34 J=1,9

```

```

      GQ=FK*FC(J,8)
      GR=FC(J,4)*FE(J)*(1.0+B(J+41))
34  FW(J)=B(J+32)+GQ+GR
      DO 37 J=1,9
35  GS=FW(J)/FP(J)
37  FX(J)=(FV(J)/(FW(J)*GS))-1.0
      GT=0.0
      DO 39 J=1,9
39  GT=GT+FX(J)
      FJ=GT/9.0
      GU=GU-1.0
40  IF (GU) 42,41,41
41  FK=(1.0+FI)*(1.0+FJ)
      GO TO 7
42  DO 46 J=1,9
43  FY(J)=B(J+14)/RSL
44  FZ=FV(J)-FC(J,4)
46  GA(J)=FZ/FY(J)
      DO 48 J=1,9
48  GB(J)=FV(J)/(FY(J)-FB(J,4))
      DO 50 J=1,9
49  GC(J)=ATAN(GB(J))
50  GC1(J)=ATAN(GB(J))*57.2957795
      DO 53 J=1,9
51  H0=2.0*3.1415927/GC
53  G0(J)=H0*(FD(J,4)/FV(J))*SIN(GC(J))
      DO 55 J=1,9
55  GF(J)=FD(J,4)/GC
      DO 60 J=1,9
56  GW=(FV(J)/SIN(GC(J)))*2
57  GY=2.0*GC/3.1415927
58  GG(J)=GY*G0(J)*GW*COS(GC(J))
60  GH(J)=GY/RSL*G0(J)*GW*SIN(GC(J))*B(J+14)
      DO 64 J=1,9
61  HU=B(3)-(B(J+14)*B(2)/2.0)
62  HW=(SIN(GC(J))/(B(7)*FV(J)))*2
64  HV(J)=64.31*HU*HW
      DO 66 J=1,9
66  GI(J)=((1.0-FT(J))/(1.0-FT(9)))*B(J+14)
      DO 68 J=1,9
68  GK(J)=GI(J)*(1.0-FT(9))/RSL
      DO 72 J=1,9
69  GL(J)=2.0*FB(J,4)*FE(J)*(1.0+FT(J))
70  GZ=B(J+32)+FC(J,4)*FE(J)*(1.0+B(J+41))
72  GM(J)=GZ/(GK(J)+GL(J))
      DO 74 J=1,9
74  GN(J)=FW(J)/(GK(J)-FK*FB(J,8)+GL(J))
      DO 76 J=1,9
75  HE(J)=ATAN(GN(J))
76  HE1(J)=ATAN(GN(J))*57.2957795
      DO 81 J=1,9
77  HF=2.0*3.1415927/B(11)
78  HI=FD(J,8)/FW(J)
79  HJ=(1.0+FX(J))/(1.0-FT(9))
81  HK(J)=HF*HI*HJ*SIN(HE(J))
      DO 84 J=1,9
82  HM=B(11)*B(J+32)*(1.0-FT(9))

```

```

84 HL(J)=(FD(J,8)*(1.0+FX(J)))/HM*B(J+32)
   DO 85 J=1,9
   HN=2.0*B(11)/3.1415927
   HO=(FW(J)/SIN(HE(J)))**2
   HP(J)=HN*HK(J)*HO*COS(HE(J))
85 HQ(J)=HN/RSL*HK(J)*HO*SIN(HE(J))*GI(J)*(1.0-FT(9))
86 HR=(1.0-FT(9))*B(2)
   DO 90 J=1,9
87 HT=B(3)-GI(J)*HR/2.0
88 HW=(SIN(HE(J)))/(B(7)*FW(J))**2
   CTSIF=SIMPUN(B(15),GG,9)
   CPSIF=SIMPUN(B(15),GH,9)
   CTSIA=SIMPUN(GI,HP,9)
   CPSIA=SIMPUN(GI,HQ,9)
   B(80)=CTSIF+(1.0-FT(9))**2*CTSIA
90 HS(J)=64.31*HT*HW
   IF(JPR.NE.2) GO TO 120
   IF(OMP)107,107,91
91 WRITE (6,92)
92 FORMAT(1H1)
   WRITE (6, 93)TL
93 FORMAT (12A6)
   WRITE (6, 94)KO
94 FORMAT (110X,5HPAGE 12)
   WRITE (6, 95)HR
95 FORMAT(60H
1 1PE12.4)
   WRITE (6, 96)FI
96 FORMAT(60H
1B4R 1PE12.4)
   WRITE (6, 97)FT(9)
97 FORMAT(60H
10F 11PE12.4)
   WRITE (6, 98)FJ
98 FORMAT(60H
1B4R 1PE12.4)
   WRITE (6, 99)
   WRITE (6, 99)
99 FORMAT (5H0 )
   WRITE (6, 100)
100 FORMAT(53X,13HFW PROPELLER//)
   WRITE (6, 101)B(70),CTSIF,CPSIF
101 FORMAT(8H K=1PE10.4,8H CTSI=1PE10.4,8H CPSI=1PE10.4)
   WRITE (6, 99)
   WRITE (6,102)
102 FORMAT(5X,4HX(F),5X,10HTAN BETA-I,3X,8HTAN BETA,5X,5HCLL/D,8X,4HG(
1S),6X,6HUT/2VS,6X,6HUA/2VS,7X,5HDCSTI,7X,5HDCPSI,6X,7HSIGMA X//)
   DO 103J=1,9
103 WRITE (6,104)B(J+14),GB(J),GA(J),GD(J),GF(J),FB(J,4),FC(J,4),GG(J)
1,GH(J),HV(J)
104 FORMAT(10(1PE12.4))
   WRITE (6, 99)
   WRITE (6, 99)
   WRITE (6, 105)
   WRITE (6, 101)CZ(100),CTSIA,CPSIA
   WRITE (6, 99)
105 FORMAT(53X,13HAFT PROPELLER//)

```

D-A

DELTA

DELTA X

ZETA

```

        WRITE (6,102)
        DO 106 J=1,9
106     WRITE (6,104) GI(J),GN(J),GH(J),HK(J),HL(J),FB(J,8),FC(J,8),HP(J),H
        10(J),HS(J)
120     KO=KO+1
107     DO 108 I=1,9
        CZ(I)=GB(I)
        CZ(I+9)=GD(I)
        CZ(I+18)=GG(I)
        CZ(I+27)=GH(I)
        CZ(I+36)=GC1(I)
        CZ(I+45)=GI(I)
        CZ(I+54)=GN(I)
        CZ(I+63)=HK(I)
        CZ(I+72)=HP(I)
        CZ(I+81)=HO(I)
108     CZ(I+90)=HE1(I)
        DO 109 I=1,9
        TABX(I)=B(I+14)
109     TABY(I)=B(I+70)
        DO 110 I=1,9
        X=GI(I)
        CALL DISCOT (X,X,TABX,TABY,TABY,30,9,0,Y)
110     B(I+70)=Y
        GO TO 111
111     RETURN
        END

```

```

SUBROUTINE MATINS(A,NR,N1,B,NC,M1,DETERM,ID,INDEX)
EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX,T,SWAP)
      DIMENSION A(NR,NR), B(NR,NC), INDEX(NR,3)

C
C   INITIALIZATION
C
      N=N1
      M=M1
      DETERM = 1.0
      DO 20 J=1,N
20    INDEX(J,3) = 0
      DO 550 I=1,N

C
C   SEARCH FOR PIVOT ELEMENT
C
      AMAX = 0.0
      DO 105 J=1,N
      IF(INDEX(J,3)-1) 60, 105, 60
60    DO 100 K=1,N
      IF(INDEX(K,3)-1) 80, 100, 715
80    IF (      AMAX -ABS (A(J,K))) 85, 100, 100
85    IROW=J
      ICOLUM =K
      AMAX = ABS (A(J,K))
100   CONTINUE
105   CONTINUE
      INDEX(ICOLUM,3) = INDEX(ICOLUM,3) +1
      INDEX(I,1)=IROW
      INDEX(I,2)=ICOLUM

C
C   INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
      IF (IROW-ICOLUM) 140, 310, 140
140   DETERM=-DETERM
      DO 200 L=1,N
      SWAP=A(IROW,L)
      A(IROW,L)=A(ICOLUM,L)
200   A(ICOLUM,L)=SWAP
      IF(M) 310, 310, 210
210   DO 250 L=1, M
      SWAP=B(IROW,L)
      B(IROW,L)=B(ICOLUM,L)
250   B(ICOLUM,L)=SWAP

C
C   DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
310   PIVOT  =A(ICOLUM,ICOLUM)
      DETERM=DETERM*PIVOT
330   A(ICOLUM,ICOLUM)=1.0
      DO 350 L=1,N
350   A(ICOLUM,L)=A(ICOLUM,L)/PIVOT
      IF(M) 380, 380, 360
360   DO 370 L=1,M
370   B(ICOLUM,L)=B(ICOLUM,L)/PIVOT

C
C   REDUCE NON-PIVOT ROWS
C

```

```

380 DO 550 L1=1,N
    IF(L1-ICOLUM) 400, 550, 400
400 T=A(L1,ICOLUM)
    A(L1,ICOLUM)=0.0
    DO 450 L=1,N
450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
    IF(M) 550, 550, 460
460 DO 500 L=1,M
500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
550 CONTINUE

C
C   INTERCHANGE COLUMNS
C
    DO 710 I=1,N
    L=N+1-I
    IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
630 JROW=INDEX(L,1)
    JCOLUM=INDEX(L,2)
    DO 705 K=1,N
    SWAP=A(K,JROW)
    A(K,JROW)=A(K,JCOLUM)
    A(K,JCOLUM)=SWAP
705 CONTINUE
710 CONTINUE
    DO 730 K = 1,N
    IF(INDEX(K,3) -1) 715,720,715
720 CONTINUE
730 CONTINUE
    ID = 1
810 RETURN
715 ID = 2
    GO TO 810
    END

```

SUBROUTINE GMHAS(NP,NH,Y,R)

GMHAS, A FORTRAN IV VERSION OF SHARE SUBROUTINE AM GMHAS,  
PROGRAMMED FOR IBM 360 CONVERSION.

PROGRAMMER - M. GOLDEN, CODE 892, 8-20-68.

----- ALGORITHM -----

FOR A SET OF Y(I) POINTS (0.LE.I.LE.K-1), WHICH CORRESPOND TO A  
SET OF EQUALLY SPACED X(I) POINTS, COMPUTE THE A(J), B(J), C(J),  
AND PHI(J) TERMS OF THE FOLLOWING SERIES, WHERE H IS THE NUMBER  
OF HARMONICS DESIRED.

$$Y = A(0) + \sum_{J=1}^H (A(J) \cdot \cos(J \cdot X) + B(J) \cdot \sin(J \cdot X))$$

OR

$$Y = A(0) + \sum_{J=1}^H (C(J) \cdot \sin(J \cdot X + \text{PHI}(J)))$$

WHERE C(J) IS THE AMPLITUDE AND PHI(J) IS THE PHASE ANGLE OF THE  
JTH. HARMONIC. THE FUNCTION IS ASSUMED PERIODIC WITH Y(0)=Y(K).

----- ARGUMENT DEFINITION -----

1. NP - THE NUMBER OF INPUT POINTS ( K ABOVE ).
2. NH - THE NUMBER OF HARMONICS DESIRED ( H ABOVE ).
3. Y - THE SET OF INPUT POINTS DESCRIBED ABOVE.
4. R - THE OUTPUT ARRAY, WHICH CONTAINS A(0), B(0), C(0), PHI(0),  
C(0)/C(MAX), A(1), ..., A(NH), B(NH), C(NH), PHI(NH), C(NH)/C(MAX).

----- RESTRICTIONS -----

1. R MUST BE DIMENSIONED AT LEAST 5\*(NH+1)+2 IN THE CALLING  
PROGRAM.
2. Y MUST BE DIMENSIONED AT LEAST NP IN THE CALLING PROGRAM.

----- NOTES -----

1. R(5\*NH+6) CONTAINS THE CHECKSUM

$$Y(0) = A(0) + \sum_{J=1}^{K/2} A(J) \quad \text{FOR H EVEN}$$

OR

$$Y(0) = A(0) + \sum_{J=1}^{(K-1)/2} A(J) \quad \text{FOR H ODD.}$$

2. R(5\*NH+7) CONTAINS THE CHECKSUM



```

R(I1)=S*C2
R(I1+1)=S1*C2
C=R(I1)**2+R(I1+1)**2
R(I1+2)=DSORT(C)
R(I1+4)=R(I1+2)

C
C
C
DO NOT COMPUTE PHI(I) IF A(I)=B(I)=0.

IF(R(I1).NE.0..OF.R(I1+1).NE.0.)GO TO 32
WRITE(6,31)I,I
31 FORMAT(///16H TO COMPUTE PHI( I4,46H),IT WOULD BE NECESSARY TO COM
1PUT ATAN2(0,0)./48H THESE ARGUMENTS WILL NOT BE ACCEPTABLE, SO PH
2I( I4,23H) WILL NOT BE COMPUTED.///)
GO TO 40
32 R(I1+3)=C1*ATAN2(R(I1),R(I1+1))
40 CONTINUE

C
C
C
C
COMPUTE A(K/2), B(K/2)=0, C(K/2), PHI(K/2) IF H IS EVEN.
DO NOT COMPUTE THEM IF H IS ODD OR A FULL-POINT ANALYSIS IS
NOT COMPUTED.

IF(MOD(NP,2).NE.0)GO TO 60
IF((2*NH).NE.(2*(NP/2)))GO TO 60
AI=-1.
S=1.
DO 50 I=1,NP
AI=-AI
50 S=S+AI*Y(I)
NH1=5*NH+1
R(NH1)=S/XNP
R(NH1+2)=ABS(R(NH1))
R(NH1+4)=R(NH1+2)
R(NH1+1)=0.
R(NH1+3)=SIGN(90.,R(NH1))

C
C
C
COMPUTE CMAX.

60 C=0.
NH1=NH+1
DO 70 I=1,NH1
70 C=JMAX1(C,DBLE(R(5*I)))

C
C
C
COMPUTE C(I)/CMAX FOR 0.LE.I.LE.NH.

DO 80 I=1,NH1
I1=5*I
80 R(I1)=R(I1)/C

C
C
C
COMPUTE THE CHECKSUMS IF A FULL-POINT ANALYSIS WAS COMPUTED.

IF((2*NH).NE.(2*(NP/2)))RETURN
I1=5*NH1+1
DO 90 I=1,NH1
90 R(I1)=R(I1)+R(5*I-4)
I1=I1+1
IF(MOD(NP,2).EQ.0)NH1=NH1-1
DO 100 I=2,NH1

```

```
100 R(I1)=R(I1)+R(5*I-3)*DSIN(FLOAT(I-1)*ALPHA)  
R(I1)=2.*R(I1)  
RETURN  
END
```

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**(3) TECHNICAL MEMORANDA, AN INFORMAL SERIES, USUALLY INTERNAL WORKING PAPERS OR DIRECT REPORTS TO SPONSORS, NUMBERED AS TM SERIES REPORTS, NOT FOR GENERAL DISTRIBUTION.**