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A COMPUTER PROGRAM FOR
THE PREDICTION OF DUCTED
FAN PERFORMANCE

by Michael R. Mendenhall and Selden B. Spangler

Prepared by

NIELSEN ENGINEERING & RESEARCH, INC.

Mountain View, Calif.

for Ames Research Center

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SYMBOLS

A	area of duct exit plane, $\pi D^2/4$
A_n	Fourier series coefficients for the radial velocity induced on the reference cylinder by all the internal vortex cylinders, eq. (10)
A_n^*	Fourier series coefficients for the axial velocity induced on the reference cylinder by all the internal vortex cylinders, eq. (11)
A_p	propeller disk area, $\pi(R_p^2 - R_{CB}^2)$
B_n	Fourier series coefficients for the radial velocity induced on the reference cylinder by the outer trailing vortex cylinder, eq. (8)
B_n^*	Fourier series coefficients for the axial velocity induced on the reference cylinder by the outer trailing vortex cylinder, eq. (9)
b	propeller chord length, fig. 2
C_M	pitching moment coefficient, M/RAq or $M/\rho n^2 D_p^5$
C_N	normal force coefficient, N/Aq or $N/\rho n^2 D_p^4$
C_n	Glauert series coefficients for γ_D , eq. (6)
C_p	pressure coefficient, eq. (44)
C_T	thrust coefficient, T/Aq or $T/\rho n^2 D_p^4$
c	chord length of duct
c_l	lift coefficient for fan blade section
c_{l_α}	lift curve slope for fan blade section
c_n	Glauert series coefficients for γ_α , eq. (25)
D	diameter of duct in the exit plane
D_n	Fourier series coefficients for the radial velocity induced on the reference cylinder by the centerbody, eq. (12)
D_n^*	Fourier series coefficients for the axial velocity induced on the reference cylinder by the centerbody, eq. (13)

D_p	propeller diameter
E_n	Fourier series coefficients for the radial velocity induced on the reference cylinder by γ , γ_w , and the centerbody, eq. (29)
E_n^*	Fourier series coefficients for the axial velocity induced on the reference cylinder by γ_D , γ , γ_w , and the centerbody, eq. (34)
E_n'	Fourier series coefficients for the radial velocity induced on the reference cylinder by γ_D , γ , γ_w , and the centerbody, eq. (40)
F_n	Fourier series coefficients for the radial velocity induced on the reference cylinder by the duct-bound vorticity, eq. (43)
F_n^*	Fourier series coefficients for the axial velocity induced on the reference cylinder by the duct-bound vorticity, eq. (38)
$F(x)$	scaling factor
G_n^*	Fourier series coefficients for the axial velocity induced on the reference cylinder by the γ_α vorticity, eq. (37)
H_n	Fourier series coefficients for the radial velocity induced on the reference cylinder by the trailing vortex filaments associated with γ_α
h	fan blade thickness, fig. 2
i	incidence angle of fan blade section measured from the line of zero lift, fig. 2
J	advance ratio, V/nD_p
$\bar{J}$	effective advance ratio, $J \cos \alpha$
J'	advance ratio parameter, eq. (3)
$\bar{J}'$	effective advance ratio parameter, $J' \cos \alpha$
l_{CB}	length of centerbody
M	pitching moment
N	number of fan blades or normal force
n	fan rotational speed, rev/sec
$P_{k\ell}$	coefficients for velocity induced by duct-bound vorticity, eq. (16)

q	free-stream dynamic pressure, $\rho v^2/2$
R	radius of duct exit plane, $D/2$
R_{CB}	radius of fan root (nominally same as centerbody radius at fan station)
R_n	Fourier series coefficients of duct geometric camberline
R_n^*	Fourier series coefficients of the duct effective camberline, eq. (14)
R_p	radius of fan tip
$\bar{r}$	mean radius of equal area element of fan disk
r_c	radius from duct centerline to duct camberline, fig. 1
r_e	radius from duct centerline to effective duct camberline
r_{max}	maximum radius of centerbody
T	thrust force
t	duct thickness
u	induced axial velocity
u_{CB}	axial velocity induced by centerbody singularity distribution
u_{qd}	axial velocity induced by duct thickness distribution
u_s	duct surface velocity
u_γ	axial velocity induced by the vortex cylinder trailing from the duct trailing edge
u_{γ_w}	total axial velocity induced by all internal vortex cylinders trailing from the fan
u_{γ_D}	axial velocity induced by duct-bound vorticity, γ_D
V	free-stream velocity
$\bar{V}$	effective free-stream velocity, $V \cos \alpha$
v_{CB}	radial velocity induced by centerbody singularity distribution
v_γ	radial velocity induced by the vortex cylinder trailing from the duct trailing edge

v_{γ_w}	total radial velocity induced by all the internal vortex cylinders trailing from the fan
v_{γ_D}	radial velocity induced by duct-bound vorticity, γ_D
x	axial distance from leading edge of duct
x_{CB}	location of centerbody nose in duct coordinate system, fig. 1
x_p	fan location within duct
$x_{r_{max}}$	location of maximum centerbody radius in duct coordinate system
x_s	axial distance measured from $c/2$, fig. 1
z	number of equal area elements making up fan disk area
α	free-stream angle of attack
β	fan blade section pitch angle, fig. 2
Γ	circulation bound to fan blade, eq. (1)
ϵ	convergence criterion
γ	strength of outer trailing vortex cylinder
γ_D	axially symmetric component of duct-bound vorticity, eq. (6)
γ_w	strength of w^{th} inner trailing vortex cylinder
γ_α	duct-bound vorticity component due to angle of attack, eq. (25)
Δp	rise in static and total pressure across actuator disk
θ	transformed axial distance, $x = 1/2 (1 - c \cos \theta)$
ρ	free-stream density
ϕ	azimuthal angle
ω	fan rotational speed, rad/sec

Subscripts

DP	for the complete ducted propeller
D(P)	for the duct in the presence of the propeller
D(α)	for the duct at angle of attack
P(D)	for the propeller shrouded by the duct
$s/4$	at $3/4$ radius location of the fan blade
tip	at the tip of the fan blade
z	indicating the outer trailing vortex cylinder or outer fan annulus

A COMPUTER PROGRAM FOR THE PREDICTION OF DUCTED FAN PERFORMANCE

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SUMMARY

This document is a user's manual for a computer program developed to determine the performance of a ducted fan in axial flow and at angle of attack. The program is used to predict the performance at a specified advance ratio and angle of attack of a given fan-duct combination, which is specified by the radial distributions of blade pitch, chord, and thickness; the duct chord, diameter, camber, and thickness distribution; the fan location; and the centerbody geometry. The information obtained from the program is duct and fan thrust and ducted fan normal force and pitching moment coefficient. Radial distributions of fan inflow velocity and blade angle of attack are also obtained. The program calculates the duct surface pressure distribution at any specified azimuthal angle. The program is written in Fortran IV for the IBM 7094 computer and requires approximately two minutes running time per case. Included in this manual are a brief description of the theory and the calculation procedure, descriptions of input and output, program listing, sample cases, and some comparisons with data.

1. INTRODUCTION

This report is one of two documents prepared under Contract NAS2-4953 for the Ames Research Center, NASA. The work on this contract is concerned with development of methods for predicting the aerodynamic performance of ducted fans in uniform flow. This document is a user's manual for the computer program developed under the contract. The second document (ref. 1) describes the analysis on which the computer program is based.

The authors and their associates have done a considerable amount of prior work on ducted fan analysis (refs. 2-6). The final task of that work involved the preparation of a computer program for calculating the aerodynamic characteristics of a ducted fan in a uniform, axial

flow (ref. 6). The purpose of the present investigation is to make certain improvements and additions to the computer program of reference 6. The additional analysis required to make these improvements is reported in reference 1. The improvements consist of adding a capability for angle of attack flow, computing duct surface pressure distributions, adding a centerbody model, and removing certain restrictions on advance ratio and nonlinear blade lift characteristics. This report includes a brief discussion of the theoretical approach and the assumed flow model with a summary of the equations used in the program. No derivations are included, but references are given to all the derivations of interest. The actual operation of the program is discussed along with descriptions of input and output. Program listings and sample cases are also included. Some brief comparisons with data are presented to give some information on the range of usefulness of the program. This document completely supersedes reference 6.

2. THEORETICAL APPROACH AND FLOW MODEL

The discussion of this section is intended to describe the theoretical approach in sufficient detail to permit the user of the program to understand the sequence of calculations in the program. The equations in the program are given with references to the source in which each is derived.

The flow model is inviscid and is based on potential flow theory. The approach used is to decouple the axial flow and angle of attack problems, treat each individually, and superimpose the solutions.

2.1 Axial Flow

The analysis for axial flow is basically that described in reference 5 with the modifications and additions described in reference 1. Singularity distributions are used to represent the fan wake, the duct loading, the duct thickness, and the centerbody. The basic axisymmetric flow model is shown in figure 1(a). A duct reference cylinder is defined as that cylinder having the same radius as the duct trailing edge. The reference cylinder is used in conjunction with the boundary condition imposed on the duct.

The duct may have both thickness and camber, and the chord-to-diameter ratio may have any value.¹ The fan configuration is specified by the number of blades (N) and by the radial distribution of chord (b), pitch (β), and thickness (h) as shown in figure 2. The effect of blade camber is not directly considered; however, the pitch angle, β , is assumed to be the angle between the plane of rotation and the zero lift line of the local blade section. Each blade section is assumed to have a lift coefficient slope, c_{ℓ_α} , of 2π up to the point of local blade stall. This point is assumed to be a function only of the blade thickness-to-chord ratio as described in reference 1. After the blade section stalls, the section lift coefficient is assumed to be constant and equal to $c_{\ell_{\max}}$. Since blade element theory is used to determine the fan performance, use of the program is limited to ducted fans with relatively low blade solidity. The upper limit on solidity has not been estimated because of the lack of suitable data for comparing predicted and measured performance.

The fan annulus is divided into a number ($z \leq 24$) of equal area annuli in each of which blade element theory is used to describe local blade performance. The bound circulation (Γ) is constant within each annulus and a vortex cylinder with strength γ_w is assumed to be shed from each annulus and to extend downstream along the duct axis. The outer vortex cylinder is assumed to lie along the duct reference cylinder and to be shed from the duct trailing edge.

From equation (5) of reference 5, the bound circulation on the portion of the blade in the w^{th} annulus is

$$\frac{\Gamma_w}{RV} = \frac{1}{2} c_{\ell} \frac{b_w}{R} \frac{u_w}{V} \left[\left(\frac{\bar{r}_w \omega}{u_w} \right)^2 + 1 \right]^{1/2} \quad (1)$$

¹There is an upper limit on c/D of approximately 2.5 imposed by the absence of $P_{k\ell}$ values and induced camber coefficients for c/D values greater than 2. See p. 7 for further details.

and the strength of the w^{th} internal trailing vortex cylinder is

$$\frac{\gamma_w}{V} = \left[\left(1 + \sum_{m=w+1}^Z \frac{\gamma_m}{V} \right)^2 + \frac{N}{\pi J'} \left(\frac{\Gamma_w}{RV} - \frac{\Gamma_{w+1}}{RV} \right) \right]^{1/2} - \left(1 + \sum_{m=w+1}^Z \frac{\gamma_m}{V} \right) \quad (2)$$

where

$$J' = \frac{V}{R\omega} \quad (3)$$

The strength of the outer vortex cylinder is

$$\frac{\gamma_Z}{V} = \left[1 + \frac{N}{\pi J'} \left(\frac{\Gamma_Z}{RV} \right) \right]^{1/2} - 1 \quad (4)$$

In many of the following equations, γ is used as a normalizing parameter. When γ is used without a subscript it designates the strength of the outer cylinder, γ_Z .

Assuming that the inflow to the fan (u/V) is known, the radial distribution of bound circulation may be calculated using equation (1), and the strength of the vortex cylinders can be obtained from equations (2) and (4). However, the inflow to a fan in a specified duct at a given flight condition is not known a priori. The inflow is made up of the free stream plus the axial velocity components induced by all the singularity distributions. Thus, the inflow to the propeller at a given radial station is

$$\frac{u_m}{V} = 1 + \frac{u_{\gamma_D}}{V} + \frac{u_{\gamma}}{V} + \frac{u_{q_D}}{V} + \frac{u_{CB}}{V} + \frac{1}{2} \sum_{w=m}^{Z-1} \frac{\gamma_w}{V} \quad (5)$$

With the exception of the centerbody-induced flow, the components of the inflow velocity are computed in the same manner as is described in Appendix A of reference 5. The velocity (u_{CB}) induced by the centerbody is not considered in reference 5 but is computed using equation (15) of reference 1. The velocities induced by the centerbody must be corrected to account for the fact that the centerbody is submerged in a

free stream greater than V . The details of this correction are presented in reference 1. Note that the inflow profile is dependent on the duct and fan loadings which, in turn, are affected by the inflow profile; therefore, an iterative scheme is used to converge on a solution.

The trailing vortex cylinder, the fan wake vortex cylinders, the centerbody, and the free stream all induce components of flow through the duct camberline. In order to cancel this flow and cause the net flow to be tangent to the camberline, a distribution of bound vorticity (γ_D) is placed on the duct. This bound vorticity is expressed in terms of a Glauert series (eq. (17), ref. 4) as

$$\frac{\gamma_D}{\gamma} = C_0 \cot \frac{\theta}{2} + \sum_{n=1}^5 C_n \sin n\theta \quad (6)$$

and the unknown C_n coefficients are determined from the flow tangency condition on the duct reference cylinder.

The basic relation that is solved to cause the flow to be tangent to the camberline is

$$v_{\gamma_D} + v_{\gamma} + v_{\gamma_w} + v_{CB} = \frac{dr_e}{dx} \left(v + u_{\gamma_D} + u_{\gamma} + u_{\gamma_w} + u_{CB} \right) \quad (7)$$

where dr_e/dx is the effective slope of the camberline. The following procedure is used to solve equation (7) for the unknown C_n coefficients.

The radial velocity (v_{γ}) induced along the duct reference cylinder by the vortex cylinder trailing from the duct trailing edge is given by equation (C-3) of reference 5. This velocity is expressed in non-dimensional form by a six-term Fourier cosine series as

$$\frac{v_{\gamma}}{\gamma} = \sum_{n=0}^5 B_n \cos n\theta \quad (8)$$

The axial velocity (u_γ) induced by the same vortex cylinder is given by equation (23) of reference 3. This velocity is expressed in non-dimensional form by a similar six-term Fourier cosine series as

$$\frac{u_\gamma}{\gamma} = \sum_{n=0}^5 B_n^* \cos n\theta \quad (9)$$

The radial and axial velocities induced along the duct reference cylinder by all the vortex cylinders trailing from the fan are computed using equation (13) and (20), respectively, of reference 3. The sum of the radial and axial velocities induced by all the internal vortex cylinders is expressed as

$$\frac{v_{\gamma_w}}{V} = \sum_{n=0}^5 A_n \cos n\theta \quad (10)$$

$$\frac{u_{\gamma_w}}{V} = \sum_{n=0}^5 A_n^* \cos n\theta \quad (11)$$

The radial and axial velocities induced along the duct reference cylinder by the centerbody singularity distribution are computed using equations (15) and (16) of reference 1. These velocities are expressed as

$$\frac{v_{CB}}{V} = \sum_{n=0}^5 D_n \cos n\theta \quad (12)$$

$$\frac{u_{CB}}{V} = \sum_{n=0}^5 D_n^* \cos n\theta \quad (13)$$

The slope of the effective camberline is specified as

$$\frac{dr_e}{dx} = \sum_{n=0}^3 R_n^* \cos n\theta \quad (14)$$

where the effective camber is made up of a geometric camber and an induced camber as discussed in detail in section 2.3 of reference 6. The induced camber is due to the velocity induced by the source ring distribution representing the duct thickness, and the method of computing this effect is based on the work described in Chapter 2 of reference 7. The induced camber is described by a Fourier series similar to equation (14) where the first four coefficients are tabulated as a function of c/D in reference 6. These coefficients are included in the program in Subroutine CAMBER and are automatically combined with the geometric camber coefficients. The calculation of the geometric camber coefficients is described in section 4.2 of this report.

The axial velocity induced by the bound vorticity, γ_D , can be written in terms of the C_n coefficients as

$$\begin{aligned} \frac{4D}{c} \frac{u_{\gamma_D}}{\gamma} = & \left(\ln \frac{16D}{c} - 1 \right) \left(C_0 + \frac{C_1}{2} \right) + \left(\frac{2C_0 + C_2}{2} \right) \cos \theta \\ & + \left(\frac{C_3 - C_1}{4} \right) \cos 2\theta + \left(\frac{C_4 - C_2}{6} \right) \cos 3\theta + \left(\frac{C_5 - C_3}{8} \right) \cos 4\theta \end{aligned} \quad (15)$$

from equation (18) of reference 4. The radial velocity component can be found from equation (1.13) of reference 8 as

$$\frac{v_{\gamma_D}}{\gamma} = \frac{C_0}{2} - \sum_{\ell=0}^5 \frac{C_\ell}{2} P_{0\ell} + \sum_{k=1}^5 \cos k\theta \left(-\frac{C_k}{2} + \sum_{\ell=0}^5 \frac{C_\ell}{2} P_{k\ell} \right) \quad (16)$$

where the $P_{k\ell}$ coefficients are given in tables 2.1 through 2.4 of reference 9. These tables have been extended to c/D values of 2.0, and provision has been made in the program to extrapolate beyond 2.0. However, the variation of $P_{k\ell}$ with c/D is not linear, and the extrapolation should not be made much past 2.5.

Substituting equations (8) through (16) into equation (7) results in

$$\sum_{n=0}^5 \left(\frac{\gamma}{V} B_n + A_n + D_n \right) \cos n\theta + \frac{\gamma_D}{\gamma} \left(\frac{\gamma}{V} \right) = \sum_{m=0}^3 R_m^* \cos n\theta \left[\sum_{n=0}^5 \left(\frac{\gamma}{V} B_n^* + A_n^* + D_n^* \right) \cos n\theta + \frac{\gamma_D}{\gamma} \left(\frac{\gamma}{V} \right) + 1 \right] \quad (17)$$

Expanding both sides of equation (17) into Fourier cosine series and equating each of the six harmonics results in six linear algebraic equations in terms of the six unknowns, C_n . With the parameter e defined below,

$$e \equiv \frac{c}{4D} \quad (18)$$

the equation for the zeroth harmonic is

$$\begin{aligned} & \left[(1 - P_{00}) - 2R_0^* e \left(\ln \frac{4}{e} - 1 \right) - R_1^* e \right] C_0 \\ & + \left[\frac{R_2^* e}{4} - R_0^* e \left(\ln \frac{4}{e} - 1 \right) \right] C_1 + \left[\frac{R_3^* e}{6} - \frac{R_1^* e}{2} - P_{02} \right] C_2 \\ & + \left[\frac{-R_2^* e}{4} \right] C_3 + \left[-\frac{R_3^* e}{6} - P_{04} \right] C_4 + \left[0 \right] C_5 \\ & = 2R_0^* B_0^* + R_1^* B_1^* + R_2^* B_2^* + R_3^* B_3^* - 2B_0 \\ & + \frac{V}{\gamma} \left[2R_0^* (D_0^* + A_0^* + 1) + R_1^* (D_1^* + A_1^*) + R_2^* (D_2^* + A_2^*) \right. \\ & \left. + R_3^* (D_3^* + A_3^*) - 2(D_0 + A_0) \right] \quad (19) \end{aligned}$$

The equation for the first harmonic is

$$\begin{aligned}
& \left[P_{10} - 2R_O^*e - 2R_1^*e \left(\ln \frac{4}{e} - 1 \right) - R_2^*e \right] C_0 \\
& + \left[(P_{11} - 1) - R_1^*e \left(\ln \frac{4}{e} - 1 \right) + \frac{R_1^*e}{4} + \frac{R_3^*e}{4} \right] C_1 \\
& + \left[-R_O^*e - \frac{R_2^*e}{3} \right] C_2 + \left[P_{13} - \frac{R_1^*e}{4} - \frac{R_3^*e}{8} \right] C_3 \\
& + \left[-\frac{R_2^*e}{6} \right] C_4 + \left[P_{15} - \frac{R_3^*e}{8} \right] C_5 \\
& = 2R_O^*B_1^* + 2R_1^*B_O^* + R_1^*B_2^* + R_2^*(B_1^* + B_3^*) + R_3^*(B_2^* + B_4^*) - 2B_1 \\
& + \frac{V}{\gamma} \left[2R_O^*(D_1^* + A_1^*) + 2R_1^*(D_O^* + A_O^* + 1) + R_1^*(D_2^* + A_2^*) \right. \\
& + R_2^*(D_1^* + D_3^* + A_1^* + A_3^*) + R_3^*(D_2^* + D_4^* + A_2^* + A_4^*) \\
& \left. - 2(D_1 + A_1) \right] \tag{20}
\end{aligned}$$

The equation for the second harmonic is

$$\begin{aligned}
& \left[P_{20} - e(R_1^* + R_3^*) - 2R_2^*e \left(\ln \frac{4}{e} - 1 \right) \right] C_0 \\
& + \left[\frac{R_O^*e}{2} - R_2^*e \left(\ln \frac{4}{e} - 1 \right) \right] C_1 + \left[(P_{22} - 1) - \frac{R_1^*e}{3} - \frac{R_3^*e}{2} \right] C_2 \\
& + \left[\frac{R_2^*e}{8} - \frac{R_O^*e}{2} \right] C_3 + \left[P_{24} - \frac{R_1^*e}{6} + \frac{R_3^*e}{10} \right] C_4 + \left[-\frac{R_2^*e}{8} \right] C_5 \\
& = 2R_O^*B_2^* + R_1^*(B_1^* + B_3^*) + R_2^*(2B_O^* + B_4^*) + R_3^*(B_1^* + B_5^*) - 2B_2 \\
& + \frac{V}{\gamma} \left[2R_O^*(D_2^* + A_2^*) + (R_1^* + R_3^*)(D_1^* + A_1^*) + R_1^*(D_3^* + A_3^*) \right. \\
& \left. + 2R_2^*(D_O^* + A_O^* + 1) + R_2^*(D_4^* + A_4^*) + R_3^*(D_5^* + A_5^*) - 2(D_2 + A_2) \right] \tag{21}
\end{aligned}$$

The equation for the third harmonic is

$$\begin{aligned}
& \left[P_{30} - R_2^* e - 2R_3^* e \left(\ln \frac{4}{e} - 1 \right) \right] C_0 \\
& + \left[P_{31} + \frac{R_1^* e}{4} - R_3^* e \left(\ln \frac{4}{e} - 1 \right) \right] C_1 + \left[\frac{R_0^* e}{3} - \frac{R_2^* e}{2} \right] C_2 \\
& + \left[(P_{33} - 1) - \frac{R_1^* e}{8} \right] C_3 + \left[\frac{R_2^* e}{10} - \frac{R_0^* e}{3} \right] C_4 + \left[P_{35} - \frac{R_1^* e}{8} \right] C_5 \\
& = 2R_0^* B_3^* + R_1^* (B_2^* + B_4^*) + R_2^* (B_1^* + B_5^*) + 2R_3^* B_0^* - 2B_3 \\
& + \frac{V}{\gamma} \left[2R_0^* (D_3^* + A_3^*) + R_1^* (D_2^* + A_2^* + D_4^* + A_4^*) \right. \\
& \left. + R_2^* (D_1^* + A_1^* + D_5^* + A_5^*) + 2R_3^* (D_0^* + A_0^* + 1) - 2(D_3 + A_3) \right] \\
& \quad (22)
\end{aligned}$$

The equation for the fourth harmonic is

$$\begin{aligned}
& \left[P_{40} - R_3^* e \right] C_0 + \left[\frac{R_2^* e}{4} \right] C_1 + \left[P_{42} + \frac{R_1^* e}{6} - \frac{R_3^* e}{2} \right] C_2 \\
& + \left[\frac{R_0^* e}{4} - \frac{R_2^* e}{4} \right] C_3 + \left[(P_{44} - 1) - \frac{R_1^* e}{15} \right] C_4 + \left[-\frac{R_0^* e}{4} \right] C_5 \\
& = 2R_0^* B_4^* + R_1^* (B_3^* + B_5^*) + R_2^* B_2^* + R_3^* B_1^* - 2B_4 \\
& + \frac{V}{\gamma} \left[2R_0^* (D_4^* + A_4^*) + R_1^* (D_3^* + A_3^* + D_5^* + A_5^*) \right. \\
& \left. + R_2^* (D_2^* + A_2^*) + R_3^* (D_1^* + A_1^*) - 2(D_4 + A_4) \right] \\
& \quad (23)
\end{aligned}$$

The equation for the fifth harmonic is

$$\begin{aligned}
& \left[P_{50} \right] C_0 + \left[P_{51} + \frac{R_3^* e}{4} \right] C_1 + \left[\frac{R_2^* e}{6} \right] C_2 + \left[P_{53} + \frac{R_1^* e}{8} - \frac{R_3^* e}{4} \right] C_3 \\
& + \left[\frac{R_0^* e}{5} - \frac{R_2^* e}{6} \right] C_4 + \left[(P_{55} - 1) - \frac{R_1^* e}{8} \right] C_5 \\
& = 2R_0^* B_5^* + R_1^* B_4^* + R_2^* B_3^* + R_3^* B_2^* - 2B_5 + \frac{V}{\gamma} \left[2R_0^* (D_5^* + A_5^*) \right. \\
& \quad \left. + R_1^* (D_4^* + A_4^*) + R_2^* (D_3^* + A_3^*) + R_3^* (D_2^* + A_2^*) - 2(D_5 + A_5) \right]
\end{aligned} \tag{24}$$

Solution of equations (19) through (24) yields the C_n coefficients defining the duct-bound vorticity, which in turn permit a new inflow profile to be computed from equation (5).

2.2 Angle of Attack

The angle of attack solution is that for a thin, cylindrical duct in a crossflow $V \sin \alpha$. This solution is superimposed on the axial flow solution as follows. The ducted fan is considered to be in a modified axial flow in which the velocity $\bar{V}$ is $V \cos \alpha$. The axial flow analysis discussed in section 2.1 is applied to obtain the axisymmetric portion of the bound and free vorticity and source distributions. The duct is then considered to be in a flow at angle of attack. A nonaxisymmetric vorticity distribution is placed on the duct to cancel the $V \sin \alpha$ crossflow through the duct reference cylinder. The duct-bound vorticity has the form

$$\frac{\gamma_\alpha}{V} = \sin \alpha \cos \phi \left[c_0 \cot \frac{\theta}{2} + \sum_{n=1}^5 c_n \sin n\theta \right] \tag{25}$$

where the c_n coefficients are functions only of c/D and are tabulated in Table I of reference 10. There is in addition a distribution of free trailing filaments caused by the variation of strength around the γ_α rings. The forces and moments on the ducted fan are then computed by considering both the axisymmetric and nonaxisymmetric singularity distributions.

The $V \sin \alpha$ crossflow and the γ_α vorticity induce a nonaxisymmetric inflow into the fan. The resulting circumferentially varying blade loading was examined in reference 5. A solution was obtained, with a number of simplifying assumptions, that indicated two compensating effects occurring to cause the net effect of angle of attack on blade load distribution to be relatively small. On the basis of these results and the complexity of the analysis, the inclusion of angle of attack effects on fan loading in the computer program was not considered justified.

The force and moment equations are derived in references 1 and 5 by considering the force resulting from a velocity acting on a bound vorticity. The viscous drag on the duct, centerbody, and fan blades is not considered in the analysis. The forces and moments on the centerbody and the moment on the fan are small compared to the duct loading and are neglected.

The effective free stream is defined by the variables

$$\begin{aligned}\bar{J}' &= J' \cos \alpha \\ \bar{V} &= V \cos \alpha\end{aligned}\tag{26}$$

Thus, the fan thrust coefficient² is given by equation (10) of reference 5 as

$$C_{T_{P(D)}} = \frac{A_p}{A} \frac{N}{\pi \bar{J}' z} \sum_{n=1}^z \frac{\Gamma_n}{R \bar{V}} \cos^2 \alpha\tag{27}$$

The duct thrust coefficient due to the duct singularity distribution is computed using equation (36) of reference 1.

²The equations for the force and moment coefficients given in this section are based on nondimensionalizing the force or moment by q , A , and R . The alternate approach noted in the Symbols List is also provided within the program.

$$C_{T_D(P)} = -\pi \frac{C}{D} \frac{\gamma}{V} \cos^2 \alpha \left[C_0(4E_0 + 2E_1) + 2C_1E_0 + \sum_{n=1}^4 (C_{n+1}E_n - C_nE_{n+1}) \right] \quad (28)$$

where

$$E_n = \frac{\gamma}{V} B_n + A_n + D_n \quad (29)$$

In the assumed flow model, there is a discontinuity in the duct surface pressure distribution due to the pressure rise across the fan. The increased pressure acting on the inner duct surface aft of the fan causes the following duct thrust coefficient.

$$C_{T_D(P)} = \left[1 - \left(\frac{R_p}{R} \right)^2 \right] \frac{\Delta p_z}{q} \cos^2 \alpha \quad (30)$$

One component of the thrust coefficient due to the duct at angle of attack is

$$C_{T_D(\alpha)} = \pi \frac{C}{D} \sin^2 \alpha (2c_0 + c_1) \quad (31)$$

from equation (39) of reference 1. The second part of the thrust coefficient due to the duct at angle of attack is

$$C_{T_D(\alpha)} = -\frac{\pi}{2} \frac{C}{D} \sin^2 \alpha \left[c_0(4H_0 + 2H_1) + 2c_1H_0 + \sum_{n=1}^4 (c_{n+1}H_n - c_nH_{n+1}) \right] \quad (32)$$

from equation (41) of reference 1. The H_n Fourier series coefficients describe the radial velocity distribution induced at the duct by the trailing vortex filaments associated with γ_α . These Fourier coefficients are defined in equation (40) of the above reference. The total duct thrust coefficient is then the sum of equations (27), (28), (31), and (32).

The duct normal force coefficient is given by equations (48), (51), and (52) of reference 1.

$$C_{N_{DP}} = \frac{\pi}{2} \frac{C}{D} \sin \alpha \cos \alpha \left[(4c_0 + 2c_1) + f(c_n, E_n^*) + g(C_n, G_n^*) \right] \quad (33)$$

where

$$E_n^* = \frac{\gamma}{V} (B_n^* + F_n^*) + A_n^* + D_n^* \quad (34)$$

and

$$f(c_n, E_n^*) = c_0 (4E_0^* + 2E_1^*) + 2c_1 E_0^* + \sum_{n=1}^4 (c_{n+1} E_n^* - c_n E_{n+1}^*) \quad (35)$$

$$g(C_n, G_n^*) = C_0 (4G_0^* + 2G_1^*) + 2C_1 G_0^* + \sum_{n=1}^4 (C_{n+1} G_n^* - C_n G_{n+1}^*) \quad (36)$$

The G_n^* are the Fourier coefficients describing the velocity u_{γ_D} which is computed using equation (49) of reference 1.

$$\frac{u_{\gamma_D}}{V} = \sin \alpha \cos \phi \sum_0^5 G_n^* \cos n\theta \quad (37)$$

The F_n^* are the Fourier coefficients describing the velocity u_{γ_D} which is computed using equation (A-9) of reference 5.

$$\frac{u_{\gamma_D}}{\gamma} = \sum_0^5 F_n^* \cos n\theta \quad (38)$$

The duct pitching moment coefficient is given by equations (57), (59), (60), and (62) of reference 1 as

$$\begin{aligned}
c_{M_{DP}} = & \frac{\pi}{2} \sin \alpha \cos \alpha \left\{ \frac{1}{2} \frac{\gamma}{V} \left(\frac{C}{D} \right)^2 \bar{f}(c_n, G_n^*) + \left(\frac{C}{D} \right)^2 (2c_0 + c_2) \right. \\
& + \frac{1}{2} \left(\frac{C}{D} \right)^2 \bar{g}(c_n, E_n^*) - \frac{C}{D} \left[c_0 (4E_0' + 2E_1') + 2c_1 E_0' \right. \\
& \left. \left. + \sum_{n=1}^4 (c_{n+1} E_n' - c_n E_{n+1}') \right] \right\} \quad (39)
\end{aligned}$$

where

$$E_n' = \frac{\gamma}{V} (B_n + F_n) + A_n + D_n \quad (40)$$

$$\begin{aligned}
\bar{f}(c_n, G_n^*) = & c_0 (4G_0^* + 4G_1^* + 2G_2^*) + c_1 (G_1^* - G_3^*) + c_2 (2G_0^* - G_4^*) \\
& + c_3 (G_1^* - G_5^*) + c_4 G_2^* + c_5 G_3 \quad (41)
\end{aligned}$$

$$\begin{aligned}
\bar{g}(c_n, E_n^*) = & c_0 (4E_0^* + 4E_1^* + 2E_2^*) + c_1 (E_1^* - E_3^*) + c_2 (2E_0^* - E_4^*) \\
& + c_3 (E_1^* - E_5^*) + c_4 E_2^* + c_5 E_3 \quad (42)
\end{aligned}$$

The F_n are the Fourier coefficients describing the velocity v_{γ_D} which is computed using equation (16).

$$\frac{v_{\gamma_D}}{\gamma} = \sum_0^5 F_n \cos n\theta \quad (43)$$

The duct surface pressure distribution is obtained from the Bernoulli equation

$$C_p = 1 - \left(\frac{u_s}{V} \right)^2 \quad (44)$$

where u_s is the induced surface velocity distribution. The surface velocity, u_s , is made up of a continuous portion and a discontinuous portion as given by equation (67) of reference 1. The continuous

velocity is corrected for duct thickness and the discontinuous velocity is approximated near the leading edge to remove the singularity. These corrections and approximations are explained in detail in reference 1.

3. PROGRAM DESCRIPTION

3.1 Calculation Procedure

The computation proceeds as follows. An initial knowledge of the fan inflow velocity profile is required to compute blade performance, from which all other computations are made. Since the inflow is affected by the as yet undetermined duct-bound vorticity, an iterative procedure is used. An initial, uniform inflow of $2V$ is assumed, and the blade element calculations are made to determine the fan performance and the fan wake characteristics. The flow tangency condition on the duct reference cylinder is then applied to determine the duct-bound vorticity distribution. With all the singularity distributions known, the fan inflow is calculated. This is compared with the initially assumed inflow. If the two do not agree, a new inflow equal to the average between the initial and computed inflows is determined. The fan and duct-bound vorticity calculations are repeated to obtain a new inflow. The process continues until the inflow velocity in each annulus has converged to within the desired value. When convergence is obtained for all annuli, the program continues to calculate force and moment coefficients and duct surface pressure coefficients if desired.

3.2 Flow of Calculations

This section contains a discussion of the sequence of calculations within the program. The discussion describes the functions that are performed in the main program and each of the subroutines and the basic order in which they are performed. References are given for the various equations or relations used in the parts of the program.

The program consists of a main program and 20 subroutines. The cards in the source deck are identified in Columns 73 to 80 with a four-character identification indicating the number of the subroutine and a three-digit number representing the order of the card within the subroutine.

The main program is relatively short. Its basic functions are to control the flow of the program, and to perform the calculation for the local blade element performance, the calculation for the total fan inflow, the comparison of initial and computed inflows to determine convergence, and the calculation of the new inflow profile if the solution is not converged. The relationship between the main program and the subroutines is shown in figure 3.

The first operation in MAIN is a general initialization of four subroutines. ELLIPS is called to initialize tables of elliptic integrals, LAMBDA is called to initialize tables of the Heuman Lambda Function, PKL is called to initialize tables of $P_{k\ell}$ coefficients at various ratios of duct chord to diameter, and CLALF is called to initialize a table of section $c_{\ell_{\max}}$ versus thickness-to-chord ratio. The table of $c_{\ell_{\max}}$ versus t/c is determined from figure 2(b) of reference 1.

The program has several subroutines which are necessary for the operation of the program because of the service they perform, but they are not important to the understanding of the sequence of events in the program. These will be discussed here briefly and then omitted from the following program description, although they are shown on figure 3. Subroutine ELLIPS does a table look-up for the complete elliptic integrals of the first and second kind, given the argument of the elliptic integrals. Subroutine LAMBDA does a table look-up for the Heuman Lambda Function, given the two arguments of the function. Subroutine ARCSIN computes the principal value of the angle given the value of the sine of the angle. Subroutine FOURCS does a Fourier analysis of a function, given a table of values of the function. The subroutine computes an n -term cosine series ($n \leq 50$) to fit the given function. The first six terms of the series are used for the calculations in the program.

Subroutine INPUT is called by the main program. The major function of subroutine INPUT is to determine all of the quantities used in the calculation that are functions only of the duct configuration, the centerbody geometry, the fan blade characteristics, or the number of fan annuli. Included in these quantities are the Fourier series coefficients for velocities and vorticities which are functions only of duct chord-to-diameter ratio or duct thickness. This subroutine also

reads in the input data, checks it for certain specific errors, and then prints out all of the input information. Now several subroutines must be called to do more specific initialization of parameters which are only dependent on the geometry of the system. Subroutine HUB is called to compute the strength and location of the point source and point sink which describe the centerbody model. ALFRNG is called to compute the G_n^* Fourier coefficients in equation (37) and the H_n Fourier coefficients in equation (32). PRESS is called to set up tables of the duct thickness correction factor and the leading-edge singularity parameter. These tables are used in the calculation of the duct surface pressure distribution. Subroutine INPUT next calls subroutine PKL to look up a table of the $P_{k\ell}$ influence coefficients. These coefficients, used in computing the radial velocity induced by a distribution of vortex rings, are functions only of c/D and are obtained from reference 9. Subroutine CAMBER is called to compute the induced camber coefficients which are combined with the geometric camber coefficients to obtain the total effective camber of the duct.

Subroutine HUB is called again by INPUT to compute the Fourier coefficients D_n and D_n^* . These coefficients are constants for a given duct and centerbody configuration; therefore, they may be computed at this time assuming a unit free stream and then correcting for the increased free stream as they are used.

Subroutine PROP divides the fan annulus into the required number of annuli (which is input), computes the inner, outer, and mean radii of the annuli and interpolates in the blade β , b/R_p , and h/b input tables to obtain values of β , b/R_p , and h/b at the mean radii of the annuli.

Certain components of the inflow to the fan are constants and can be computed at this time. Subroutine GAMCYL computes the nondimensional axial inflow velocities (in the form u/γ) induced at the mean radii of the fan annuli by a vortex cylinder trailing from the duct trailing edge. These are a function only of c/D . The equation solved is equation (A-10) of reference 5. In this equation, it is necessary to use elliptic integrals, an arcsin relation, and the Heuman Lambda Function. These are obtained, respectively, from subroutines ELLIPS, ARCSIN, and LAMBDA. Subroutine SRCRNG computes the nondimensional axial inflow velocity

(in the form u/V) induced at the mean radii of the fan annuli by the source rings representing the duct thickness distribution. The equation used is equation (A-6) of reference 5. Subroutine HUB computes the nondimensional axial inflow velocity (in the form u/V) induced at the mean radii of the fan annuli by the source-sink distribution representing the centerbody geometry. The equation used is equation (15) of reference 1. The two latter inflow velocities must be corrected for the increased local axial velocity as is discussed in reference 1.

Subroutine BNCOEF computes the Fourier cosine series coefficients (B_n) for the nondimensional radial velocity (in the form v/γ) induced along the duct reference cylinder by a vortex cylinder trailing from the duct trailing edge. The equation used is equation (C-3) of reference 5. The subroutine ANCOEF computes Fourier series coefficients for three sets of velocities on the duct reference cylinder. The coefficients B_n^* are those of the nondimensional axial velocity (u/γ) induced by a vortex cylinder from the duct trailing edge (eqs. (23) and (25) of ref. 3). The coefficients $(A_n)_w$ and $(A_n^*)_w$ are those of the nondimensional radial (v/γ_w) and axial (u/γ_w) velocities, respectively, induced by the w^{th} inner vortex cylinder trailing from the fan. The equations used are equations (13) and (16), and equations (20) and (21), respectively, of reference 3. These Fourier coefficients are obtained by fitting a 50-term Fourier cosine series to the chordwise velocity distribution and truncating after the sixth term. At this point, the coefficients for all of the velocities induced at the duct reference cylinder by the fan wake, duct thickness, and the centerbody are known, and control returns to the main program.

The blade element performance in each of the fan disk annuli is computed using the local blade lift coefficient obtained from subroutine CLALF. The section c_ℓ includes the effect of local blade stall in the manner described in reference 1. The strengths of the internal vortex cylinders are now computed. The main program calls subroutine CNCOEF. The basic purpose of this subroutine is to apply the boundary condition of no flow through the duct camberline to compute the Fourier coefficients, C_n , representing the duct-bound vorticity γ_D . The six C_n coefficients are obtained from the solution of a matrix equation involving the A_n , A_n^* , B_n , B_n^* , D_n , D_n^* coefficients, the camber

coefficients, and the vortex cylinder strengths just computed. The three dependent matrices in this equation are computed and defined in subroutine CNCOEF. The equation is then solved for the C_n through use of the matrix inversion subroutine, MATRIX. If the matrix to be inverted is singular, an error message is printed and the subroutine transfers to a STOP statement.

Now that all the singularity distributions are known, the correction factors which are applied to the duct thickness-induced velocities and the centerbody-induced velocities are computed. Both correction factors need the velocities induced by the vortex cylinder trailing from the trailing edge of the duct and the duct-bound vorticity, γ_D . These induced axial velocities are obtained from subroutines GAMCYL and VTXRNG, respectively.

Subroutine VTXRNG is called again to compute the axial inflow to the fan due to the duct-bound vorticity, γ_D . Equation (A-9) of reference 5 is used with the C_n coefficients just computed.

The main program then sums the inflow velocities in each of the fan annuli obtained from all the singularity distributions and adds to these the free-stream velocity and the discontinuous portion of the velocity difference across each vortex cylinder ($\gamma_w/2$). The resulting total inflow in each annulus is compared with the initially assumed inflow. If all velocities do not agree within the prescribed convergence limit, the new inflow is assumed to be the average between the initial and computed velocities. The program then returns to the computation of new values of the local blade performance. Subroutine CNCOEF is called, new C_n coefficients determined, new corrections for the centerbody-induced velocities and duct-thickness-induced velocities are computed, VTXRNG is called to obtain the fan inflow due to the duct-bound vorticity, and a new total fan inflow obtained. This iterative process is repeated until convergence is obtained for all the fan annuli or until 50 iterations have been completed.

After convergence is obtained, the main program calls OUTPUT which immediately prints out the fan loading and inflow parameters. The force and moment coefficients are computed and output, and if the duct surface pressure coefficients are to be computed, subroutine PRESS is called. In PRESS, the velocity induced on the duct reference cylinder by all the

singularity distributions is computed. This includes the axial velocity induced by the duct-bound vorticity, γ_α , associated with the duct at angle of attack. These induced velocities are obtained from subroutine ALFRNG which uses equation (49) of reference 1. After summing all the continuous and discontinuous velocity components, Bernoulli's equation is used to compute the duct surface pressure coefficients. Control returns to OUTPUT where the pressure coefficients are printed. This completes the series of calculations and control is returned to the main program.

The above sequence of operations is arranged such that the calculations performed by INPUT provide all the parameters dependent only on the duct and propeller configuration. Thus, if performance of a given configuration at a number of advance ratios or angles of attack is desired, an index is read from a card following completion of the calculations in OUTPUT, the next values of J and α read, and control is returned to the part of the main program just after INPUT has been called, which avoids some recomputation. If a new configuration is to be analyzed, control returns to the statement in the main program calling INPUT, where a complete new case is read in.

3.3 Use of Program

The program is written in Fortran IV for the IBM 7094 computer. No tapes other than the standard input and output tapes are required. Typical execution times are approximately two minutes for the first case and one minute for each additional run utilizing the same geometry. A complete description of the input and output is presented in sections 4 and 5 respectively, and a program listing is given in section 7.

4. DESCRIPTION OF INPUT

This section contains a description of the input for the computer program. The information required on the cards is described in section 4.1. The remainder of the subsections below describe the manner in which some of the input quantities are determined for a given ducted fan configuration.

4.1 Input Data

The format of the input cards making up a normal run is shown in figure 4. In this figure the variable is given as well as the card column in which the punching of the value of the variable is begun and the format in which it is punched. In all input the format is set up for four figures to the right of the decimal point. If more significant figures are required, the decimal point may be moved to the left some appropriate amount. As long as the number is punched in the specified field of 10 columns, the decimal point may be punched in any column.

Card No. 1 contains any alphabetic and numeric information that is desired for identification purposes. This information is printed at the top of each page of output.

Card No. 2 contains information about the geometry of the duct. The first item (c/D) is the chord-to-diameter ratio. This value should be greater than zero and less than about 2.5. This upper limit is approximate and is necessary only because some coefficients built into the program must be extrapolated for $c/D > 2$. The next items on this card are the axial location of the fan within the duct (x_p/c), the maximum thickness-to-chord ratio of the airfoil section of the duct (t/c),³ the ratio of the duct radius at the trailing edge to the fan radius (R/R_p), and the ratio of the centerbody radius at the fan station to the fan tip radius (R_{CB}/R_p) (or the fan hub-tip ratio). The last item is the convergence criterion (ϵ). The iteration will stop when the inflow profiles agree within $\epsilon \times 10^2$ percent. A suggested range for ϵ is $0.001 \leq \epsilon \leq 0.01$.

Card No. 3 contains the four Fourier coefficients (R_n) of a cosine series fit to the duct camberline. If the duct is uncambered, these four values are all zero.⁴

³The value of t/c must be within the range $0.06 \leq t/c \leq 0.24$ because of correction factors used in the calculation of duct pressure distribution. If t/c is outside this range, the pressure distribution will be slightly in error, but all other calculations will be correct.

⁴A detailed discussion of the manner of computing these four coefficients is given in section 4.2.

Card No. 4 contains the information necessary to define the centerbody. The first item is the centerbody length expressed as a fraction of the duct chord (ℓ_{CB}/c). The second item is the location of the centerbody nose in the duct coordinate system (x_{CB}/c). If the centerbody extends forward of the duct leading edge, $x_{CB}/c < 0$. The next item is the maximum radius of the centerbody expressed as a fraction of the centerbody length (r_{max}/ℓ_{CB}) and the last item on this card is the x location of r_{max} ($x_{r_{max}}$) in the duct coordinate system. Preparation of the input on this card must meet certain specifications which are discussed in detail in section 4.3.

Card No. 5 contains six quantities. The first, NBLD, is the number of fan blades. This number must be greater than zero. The second item, NZ, is the number of equal area annuli into which the fan annulus is divided. The limitation on NZ is $2 \leq NZ \leq 24$. The third item, NZP, is the number of stations in the input table of fan blade characteristics. The limitations on NZP are $2 \leq NZP \leq 24$. The next quantity is IR, the number of x -stations at which the duct surface pressure distribution is to be calculated. At a given x/c , the pressure coefficient is computed on the inside and outside surface of the duct. The value of IR must be in the range $1 \leq IR \leq 25$.⁵ The next item, NPRES, is an index which controls the form of the surface pressure coefficient. If NPRES = 1, the surface pressure coefficient is based on free-stream dynamic pressure. If NPRES = 2, the surface pressure coefficient is based on the propeller tip speed. The last quantity, NPRINT, is an output index which controls the quantity of output. For normal runs, NPRINT = 0. If NPRINT = 1, an extra page of optional output is developed which contains a table of the components of the inflow to the propeller. This optional output is described in the output section of this report. Another output option is available, but the authors recommend that it not be used, as it is useful only for diagnostic purposes. If NPRINT = 10, a page listing all of the Fourier cosine series coefficients for the u and v

⁵The input controlling the pressure distribution calculation has been set up for ease of repetitive running with the same configuration. Consequently, IR must be 1 or greater, whether or not any pressures are to be computed. An index on the last card indicates the requirement for computing pressures.

velocities induced at the duct reference cylinder is printed. If $NPRINT = 11$, both of the above optional pages are output. In most cases of interest, $NPRINT$ will be identically zero.

Card No. 6 contains the fan radii (r/R_p) at which the blade characteristics are to be input. There are NZP entries in this table, so if $NZP > 8$, the other entries in the table must be included on following cards. For example, if $NZP = 17$, three cards are required. The first two cards will have eight fields each and the third card one field. The values must be put in order of increasing radius ratio. The first entry in the table should be the value of r/R_p at the root or hub, which nominally is equal to R_{CB}/R_p , the value on Card No. 2. The last value in the table should be $r/R_p \approx 1.0$. There cannot be more than 24 entries in the table.

Card No. 7 contains values of the fan blade chord (b/R_p) at the radial stations corresponding to the values on Card No. 6. With eight fields per card, there will be as many cards here as in the r/R_p case (Card No. 6).

Card No. 8 contains the fan blade pitch angle (β) in degrees at the radial stations corresponding to the values on Card No. 6. The pitch angle is the blade twist angle measured from the plane of rotation to the zero lift line of the local blade section. The number of cards here will be the same as the number of r/R_p cards (Card No. 6).

Card No. 9 contains the blade section thickness-to-chord ratio at the radial stations corresponding to those on Card No. 6. The number of cards here will be the same as the number of r/R_p cards (Card No. 6).

Card No. 10 contains the values of x/c at which the duct surface pressure coefficients are to be calculated. This card should contain IR values, and if $IR > 8$, the ninth and succeeding values should be put on following cards in the same format as shown for Card No. 10. The values should be put in ascending order with the limitation $0 \leq x/c \leq 1.0$. Since the inner duct surface pressure distribution has a discontinuity at the fan due to the pressure jump aft of the fan, it is desirable to include x/c values just upstream and downstream of the fan. No numerical problem occurs, however, if the x/c value exactly at the fan station is input, since the program uses the total

pressure upstream of the fan to compute the inner duct pressure coefficient at the fan station.

Card No. 11 is the last card required for a particular configuration. The first item on this card is a run identification number, NRUN. The only restrictions on NRUN are that $\text{NRUN} \leq 9999$ and $\text{NRUN} \neq 0$. The second quantity is the index NPHI, which is the number of azimuth stations around the duct at which the surface pressure coefficients are to be calculated. The limitation is that $0 \leq \text{NPHI} \leq 5$. If $\text{NPHI} = 0$, no pressure calculation will be performed for this run. The next quantity is the advance ratio, J. The advance ratio must be greater than zero.⁶ The duct angle of attack, α , in degrees is the next item. The only requirement is that $\cos \alpha \neq 0$. The remaining five fields on the card should contain the azimuth angles, ϕ , in degrees, at which pressure distributions are to be calculated. There should be NPHI values of ϕ , and due to the symmetry of the flow, $0 \leq \phi \leq 180^\circ$.

If only one run is to be made, the input deck is complete with Card No. 11. If two or more runs are to be made, the card arrangement following Card No. 11 for stacking runs is as follows:

(1) If the same ducted fan configuration is to be investigated at a different advance ratio or angle of attack or if different values of ϕ are of interest, only one additional card is required to initiate the new run. This card has the same format as Card No. 11. The run number can be changed to identify the new run. Each succeeding run with the same configuration requires the one additional card, and this card can be repeated as many times as desired.

(2) If a different duct and/or fan configuration is to be investigated, the card following Card No. 11 must be blank. The new case is then loaded as a deck consisting of Card Nos. 1 through 11.

A sample set of input data illustrating the program options is shown in figure 6.

⁶A value of $J = 0$ causes numerical problems in the machine. To compute a zero advance ratio (hover) case, set $J = 0.01$.

4.2 Duct Camber and Thickness

The duct thickness and camber are required on the second and third cards. A brief discussion is given below with regard to the selection of these parameters. In order to give a reasonably wide latitude to the use of the program while at the same time not storing a great quantity of airfoil data in the program, the specifications of duct thickness and camber were separated.

The thickness distribution is taken to be the local profile thickness as measured from the camberline. For purposes of including thickness effects in the performance calculations, the thickness distribution is specified within the program as that of a symmetrical four-digit NACA airfoil which has an analytical expression for the variation of thickness with distance along the chord. This distribution is completely specified by one parameter, the ratio of maximum thickness to chord. In selecting a value for a given duct configuration, it is suggested that the $(t/c)_{\max}$ value be chosen which will yield the best fit to the actual duct shape along the inner forward portion of the duct, while still giving a reasonable fit over the other portions of the section. Tables of thickness distribution for various $(t/c)_{\max}$ can be obtained from Appendix I of reference 11.

The camber coefficients required in the third card are computed according to the methods given below. Figure 1 indicates the notation and coordinate systems. The axial coordinates are x , measured from the leading edge with the range 0 to c ; θ , measured from the leading edge with the range 0 to π ; and x_s , measured from $x = c/2$ with the range $-c/2$ to $+c/2$. The relation between θ and x_s is given by

$$\cos \theta = -2x_s/c \quad (45)$$

The local slope of the geometric camberline is

$$\frac{dr_c}{dx_s} = \sum_{n=0}^3 R_n \cos(n\theta) \quad (46)$$

This can be integrated to give the camberline shape as

$$\begin{aligned} \frac{r_c - R}{c} = & -R_0 \left(\frac{1 + \cos \theta}{2} \right) + R_1 \left(\frac{1 - \cos^2 \theta}{4} \right) \\ & + R_2 \left(\frac{1}{6} + \frac{1}{2} \cos \theta - \frac{1}{3} \cos^3 \theta \right) \\ & + R_3 \left(-\frac{1}{4} + \frac{3}{4} \cos^2 \theta - \frac{1}{2} \cos^4 \theta \right) \end{aligned} \quad (47)$$

The camberline radius at the trailing edge is identically that of the duct reference cylinder, which passes through the trailing-edge radius; that is, at $\theta = \pi$, $r_c - R = 0$. Four other points along the camberline must be selected and their r_c values put into the above equation to obtain four simultaneous equations for the four R_n coefficients. It is suggested on the basis of past experience that these points be nearly equally spaced for best results; that is, at $x/c = 0, 1/4, 1/2$, and $3/4$. If these four points are chosen, the R_n coefficients can be calculated from the following equations.

$$\begin{bmatrix} R_0 \\ R_1 \\ R_2 \\ R_3 \end{bmatrix} = \begin{bmatrix} (-1 \frac{2}{3}) & (1 \frac{1}{3}) & (0) & (-1 \frac{1}{3}) \\ (-3 \frac{1}{3}) & (5 \frac{1}{3}) & (-4) & (5 \frac{1}{3}) \\ (-2) & (4) & (0) & (-4) \\ (-1 \frac{1}{3}) & (5 \frac{1}{3}) & (-8) & (5 \frac{1}{3}) \end{bmatrix} \times \begin{bmatrix} \left(\frac{r_c - R}{c} \right)_0 \\ \left(\frac{r_c - R}{c} \right)_{1/4} \\ \left(\frac{r_c - R}{c} \right)_{1/2} \\ \left(\frac{r_c - R}{c} \right)_{3/4} \end{bmatrix} \quad (48)$$

If the camberline is not well behaved (for example, if it should have a hook near the leading edge), four other values of x/c may be necessary to give the best overall fit to the actual camberline. Several tries may be necessary to select the right combination of four points.

If the duct has no camber, all the R_n coefficients are input equal to zero.

4.3 Centerbody

The centerbody shape is approximated by a Rankine body, figure 5. Because the centerbody model is so simple, there are certain restrictions on the input. It is necessary that x_{CB}/c , r_{max}/l_{CB} , l_{CB}/c , and $x_{r_{max}}/c$ be input such that the centerbody half-length (distance between the nose and the point of maximum radius) is greater than the maximum radius; that is

$$x_{r_{max}} - x_{CB} > r_{max}$$

or in terms of the nondimensional ratios,

$$\left(\frac{x_{r_{max}}}{c}\right)\left(\frac{c}{l_{CB}}\right) - \left(\frac{x_{CB}}{c}\right)\left(\frac{c}{l_{CB}}\right) > \left(\frac{r_{max}}{l_{CB}}\right)$$

The effect of the centerbody on the ducted fan performance cannot be eliminated entirely from the program, but it can be made negligibly small by inputting the appropriate geometry. Thus, if the user wishes to remove the effect of the centerbody, the centerbody parameters should be input according to the following rules:

$$\frac{x_{CB}}{c} = \frac{x_p}{c} - 0.02$$

$$\frac{l_{CB}}{c} = 0.04$$

$$\frac{r_{max}}{l_{CB}} = 0.005$$

$$\frac{x_{r_{max}}}{c} = \frac{x_p}{c}$$

If these values are used, the area inside the fan hub radius (πR_{CB}^2) will be unloaded unless R_{CB} is set equal to zero. It should be noted that because of the formulation of the program, the leading edge of the centerbody should be forward of the fan station in order to avoid numerical problems; that is

$$\frac{x_{CB}}{c} < \frac{x_p}{c}$$

Generally, in approximating the centerbody shape, the user should try to fit the portion between the nose and the fan station best. This will give the best results for the inflow to the fan. If possible, the total length should be approximated, but if compromise is necessary, the portion ahead of the fan is more important than that aft of the fan. If the maximum centerbody radius occurs aft of the fan, some judgment must be used to decide on the position and value of the maximum radius. Remembering that the purpose of the centerbody model is to approximate the blockage effect on the inflow to the fan, the best centerbody model is a compromise to give the closest fit to both the maximum radius and the radius at the fan station.

4.4 Fan Blade Characteristics

A simple method to account for local blade stall is described in reference 1. This method involves a table of $c_{l_{\max}}$ versus t/c derived from figure 2(b) of reference 1. This table is built into Subroutine CLALF. If the user wishes to change this table, he should use the following procedure.

The local section thickness-to-chord ratio is called array TCB with 10 entries ranging from $TCB(1) = 0$ to $TCB(10) = 0.34$. The blade section $c_{l_{\max}}$ is called array CLMX, with 10 entries corresponding to the TCB array. The table is easily changed by changing corresponding entries of TCB and CLMX. It is advised that the total number of entries (10) in the table be unchanged. If the user would like to remove the effect of blade stall and assume that the blade section $c_{l_{\alpha}}$ is constant and equal to 2π at any angle of attack, every entry in the array CLMX should be set equal to some large number, for example, 10.0.

5. DESCRIPTION OF OUTPUT

The nominal output consists of three pages of data, to which can be added one additional page of optional output. The pages are numbered and each page has the run number at the top plus the identification information which is punched in the first card of the input deck.

A typical set of output including one page of optional output is shown in the sample case (figure 7).

The first page is numbered PAGE 0. It contains a listing of the input data plus a table of definitions of symbols. The input listed on the line entitled DUCT GEOMETRY is the duct chord-to-diameter ratio (C/D), the axial position of the fan station as a fraction of duct chord (XP/C), the duct maximum thickness-to-chord ratio (T/C), the ratio of the duct trailing-edge radius to fan radius (RTE/RP), and the ratio of centerbody radius in the plane of the fan to the fan radius (RCB/RP). The next line lists the geometric camber coefficients, R_n . The next group of data indicates the fan blade geometry input into the program. The number of blades is given, and a table of (nondimensional) blade chord (B/RP), blade pitch angle ($BETA$), and thickness-to-chord ratio (TH/CHD) versus nondimensional radius (R/RP) is given. This information is followed by the centerbody geometry which consists of the ratio of centerbody length to the duct chord (LCB/C), the axial location of the centerbody nose (XCB/C), the maximum radius of the centerbody in fraction of centerbody length ($RMAX/LCB$), and the axial location of the maximum radius ($X(RMAX)/C$). The next line contains the convergence criterion ($EPSILON$). This is followed by a table of symbols and their definitions.

Page 1 is optional output ($NPRINT = 1$) and is so noted at the top of the page. This page lists the inflow velocity results obtained after convergence of the iterative process. For convenience, the duct characteristics printed on the previous page are again printed here at the top of the page with the addition of the ratio of the fan disk area to the duct exit area (AP/A). The next line lists the four Fourier coefficients of the effective camber, R_n^* . Following these are the duct angle of attack in degrees ($ALPHA$), the advance ratios $J = V/nD_p$ and $J' = V/\omega R$, and the values of $J \cos \alpha$ and $J' \cos \alpha$. The following table lists the induced inflow velocity in each of the annuli (N). At the center of each of the annuli, denoted R/RP , the inflow is made up of the velocities induced by the duct thickness (UQD/V), the duct-bound vorticity (UGD/V), the vortex cylinder trailing from the fan tip (UG/V), and the centerbody (UCB/V). The final column indicates the local blade bound vorticity, Γ/RV , ($GAMMA/RV$). The numbers in parentheses above UQD/V and UCB/V are the correction factors for

the thickness distribution and the centerbody, respectively. The last output on the page is the number of iterations required for convergence, and the convergence criterion. When the duct is at angle of attack, the reference V in the table is actually $V \cos \alpha$ or $\bar{V}$.

The next page, page 2, lists the fan and duct performance. Again, the duct characteristics are listed at the top of the page, together with the angle of attack and advance ratios. The table that follows lists at each of the fan annuli centers (R/R_P) the total inflow velocity (U/V), the strength of the vortex cylinder shed from the outer radius of the annulus (GAM/V), the angle of attack of the blade, in degrees, as measured from the line of zero lift of the blade, and the total pressure rise divided by the free-stream dynamic head ($\Delta P/Q$). When the duct is at angle of attack, the nondimensional inflow results, blade bound vorticity, and fan pressure rise are based on $\bar{V} = V \cos \alpha$, rather than V . Following the table are various force and moment coefficients preceded by note (A) or (B). The thrust and normal force and moment coefficients opposite (A) are defined as

$$C_T = \frac{T}{qA}$$

$$C_N = \frac{N}{qA}$$

$$C_M = \frac{M}{qAR}$$

where the moment center is at the center of the duct ($x = c/2$, $r = 0$). The coefficients opposite (B) are defined using the fan rotational speed and tip diameter as

$$C_T = \frac{T}{\rho n^2 D_p^4}$$

$$C_N = \frac{N}{\rho n^2 D_p^4}$$

$$C_M = \frac{M}{\rho n^2 D_p^5}$$

The propeller thrust coefficient is $CTP(D)$. The duct thrust coefficient based only on the thrust on the duct-bound singularity distributions is given as $CTD(P)$. The sum of these two is $CTDP$. The duct-thrust coefficient including the pressure thrust due to the fan tip pressure rise acting on the inner duct surface aft of the propeller as well as the thrust on the singularity distributions is noted $CTD(P)'$. The sum of this duct thrust and the propeller thrust is noted $CTDP'$. The normal-force coefficient is $CNDP$ and the moment coefficient is $CMDP$.

The thrust coefficients with and without the pressure thrust added to the inner duct surface are presented in the output. The results in reference 5 show that inclusion of the pressure thrust on the duct gives better agreement with measured duct-thrust coefficients and pressure distributions on the inner duct surface. Therefore, all thrust results presented in section 9, Data Comparisons, include the pressure thrust on the duct. Both thrust results are included in the output so that the user can see the full effect of the pressure rise aft of the fan.

The last items on page 2 are several notes. Notes (A) and (B) are self-explanatory. The note denoted with an asterisk (*) corresponds to any asterisk printed in the table. This note is printed to bring attention to the fact that the blade sections are stalled in the annuli so noted.

The last page of output, page 3, contains the duct surface pressure distribution if it has been requested ($NPHI \neq 0$). Again, the duct characteristics and flow conditions are printed at the top of the page. The next line lists the azimuth angles, ϕ , in degrees. Directly under the azimuth angles are the corresponding pressure coefficients on the inside ($CP(IN)$) and outside ($CP(OUT)$) surfaces of the duct. The pressure coefficients are based on the free-stream dynamic pressure ($NPRES = 1$)

$$C_p = 1 - \left(\frac{u_s}{V} \right)^2$$

or the propeller tip speed (NPRES = 2)

$$C_p = \frac{v^2 - u_s^2}{2n^2 D_p^2}$$

according to the note printed as the last line on this page.

This completes the output for one complete run. The pages that follow depend on how runs are stacked. If the same duct and fan configuration is to be run at new values of advance ratio, angle of attack, or azimuth angles, the additional output will be the same as above starting with page 1. If some change has been made in the configuration, then the complete set of output from page 0 listing the new input data will follow.

6. DESCRIPTION OF ERROR MESSAGES AND STOPS

A number of error messages and stops are built into the program so that if certain conditions occur, the computation will stop and some indication of why it was stopped will be printed on the output.

Immediately after reading in the input data, several checks are made on specific quantities. If $NPHI > 5$, it is set equal to 5 and execution continues with no error message.

If the number of propeller blades (NBLD) is less than or equal to zero, the following message is printed:

"NUMBER OF BLADES IN ERROR, NBLD = -xx"

If the convergence criterion, ϵ , is less than or equal to zero, the following message is printed:

"CONVERGENCE CRITERION MUST BE GREATER THAN 0.0"

If the angle of attack, α , is greater than or equal to 90° , the following message is printed:

"ANGLE OF ATTACK MUST BE LESS THAN 90.0 DEGREES"

If the advance ratio, J , is less than or equal to zero, the following message is printed:

"ADVANCE RATIO MUST BE GREATER THAN 0.0"

In Subroutine CLALF the propeller blade thickness-to-chord ratios are tested. If any do not fall in the range $0.0 \leq t/c \leq 0.34$, the following message is printed:

"THE BLADE THICKNESS-TO-CHORD RATIO IS OUTSIDE THE RANGE
0.0 TO 0.34"

Two error messages associated with computation of a centerbody shape are built into Subroutine HUB. If the centerbody geometry is input such that the requirements listed in section 4.3 are not met, the following message is printed:

"INPUT CENTERBODY DIMENSIONS IN ERROR"

If Subroutine HUB is unable to converge on the source and sink locations, the following message is printed:

"SUBROUTINE HUB UNABLE TO COMPUTE CENTERBODY
GEOMETRY"

If any or all of the above messages are printed, the following message is also printed:

"ERROR - EXECUTION TERMINATED"

and the program terminates execution at a STOP statement in the Main program.

The above errors are due to errors in the input data and should be simple to correct. If the program fails to converge on the inflow profile in 50 iterations, two more iterations are made. The results of iterations number 51 and 52 are output, including the optional page showing the components of the induced inflow velocities. The following messages are then printed:

"PROGRAM DID NOT CONVERGE ON INFLOW PROFILE"

"ERROR - EXECUTION TERMINATED"

and the computation terminates at the STOP statement in the Main program.

The above error is rare and has occurred in the authors' experience only under conditions of small advance ratio, $J \cos \alpha$, and small blade pitch angles. If all the input appears correct, increase $J \cos \alpha$ by increasing J or decreasing α and rerun the same case again. Also check the convergence criterion (ϵ), and consider increasing it to relax the tolerance on convergence. Experience has shown that ϵ

should not be larger than 0.01. There is approximately 10 percent difference between force and moment coefficients computed with $\epsilon = 0.01$ and $\epsilon = 0.10$. An example of a case that consistently did not converge was the Doak ducted fan (ref. 12) with 11° pitch at advance ratios less than 0.5 in axial flow.

If the duct thickness-to-chord ratio is outside the range $0.06 \leq t/c \leq 0.24$, the following warning is printed:

"DUCT PRESSURE DISTRIBUTION CALCULATION ASSUMES
T/C = x.xxx"

7. PROGRAM LISTING

The ducted fan performance analysis program is written in Fortran IV for the IBM 7094 computer. The program consists of the main program and 20 subroutines. Each source deck is identified in columns 73-80 by a four-character identification (NExx) indicating the number of the subroutine and a three-digit number sequencing the cards within the subroutine. The program listing is given in the following pages. The table below will act as a table of contents for the program listing.

<u>Program</u>	<u>Identification</u>	<u>Page No.</u>
MAIN	NE00	37
INPUT	NE01	40
PKL	NE02	44
ELLIPS	NE03	47
LAMBDA	NE04	53
HUB	NE05	61
CAMBER	NE06	63
PROP	NE07	64
CLALF	NE08	65
ARCSIN	NE09	67
MATRIX	NE10	68
FOURCS	NE11	69
SRCRNG	NE12	71
VTXRNG	NE13	73
ALFRNG	NE14	77
GAMCYL	NE15	81

<u>Program</u>	<u>Identification</u>	<u>Page No.</u>
BNCOEF	NE16	83
ANCOEF	NE17	84
CNCOEF	NE18	87
PRESS	NE19	89
OUTPUT	NE20	93

C	DUCTED PROPELLER ANALYSIS PROGRAM	NE00 001
C		NE00 002
	DIMENSION B(6),BS(6),SA(6),SAS(6),P(6,6)	NE00 003
	DIMENSION C(6),A(25,6),AS(25,6),D(6),DS(6),SC(6),GS(6),H(6)	NE00 004
	DIMENSION RB(25),BR(25),BTA(25),TCBLD(25),RA(25),XPRES(25),PHI(5)	NE00 005
	DIMENSION UG(25),UQD(25),UGD(25),UV(25),UCB(25),VCB(25),	NE00 006
1	UGP(25,25),UGA(25),GV(25),GRV(25),CPP(5,25),CPM(5,25)	NE00 007
	DIMENSION ALPHA(25),STALL(25),JSTL(25),TALK(20)	NE00 008
C		NE00 009
	COMMON MZZZ,CD,R0,R1,R2,R3,PI,B,BS,SA,SAS,P	NE00 010
	COMMON/NEAR1/ NRUN,NBLD,NZ,MZ,NPRES,IR,NTIME,NERR,NPAG,NPHI,NPRINT	NE00 011
	COMMON/NEAR2/ C,A,AS,D,DS,SC,GS,H	NE00 012
	COMMON/NEAR3/ RRP,XP,Z,BLD,RB,BR,BTA,TCBLD,TC,RCBRP,APA,ALF,XPRES,	NE00 013
1	RA,XCB,XR,ELCBC,RMAX,PHI,CORJ,CORCB	NE00 014
	COMMON/NEAR4/ UG,UQD,UGD,UV,UCB,VCB,UGP,UGA,GV,GAM,GRV,CPP,CPM	NE00 015
	COMMON/NEAR5/ ARJ,ARJP,EPS,RAD,CL,ALPHA,STALL,JSTL,TALK	NE00 016
C		NE00 017
	120 FORMAT(2I5,7F10.6)	NE00 018
	997 FORMAT (///10X,42HPROGRAM DID NOT CONVERGE ON INFLOW PROFILE///)	NE00 019
	998 FORMAT (///10X,28HERROR - EXECUTION TERMINATED///)	NE00 020
C		NE00 021
C	INITIALIZATION OF SUBROUTINES	NE00 022
C		NE00 023
	DUM=0.0	NE00 024
	MZZZ=0	NE00 025
	CALL ELLIPS (DUM,DUM,DUM)	NE00 026
	CALL LAMBDA (DUM,DUM,DUM)	NE00 027
	CALL PKL (DUM,P)	NE00 028
	CALL CLALF (0)	NE00 029
	MZZZ=1	NE00 030
C		NE00 031
	PI=3.1415926	NE00 032
	RAD=180./PI	NE00 033
C		NE00 034
	29 NERR=0	NE00 035
	CALL INPUT	NE00 036
	IF (NERR) 28,28,999	NE00 037
C		NE00 038
	28 CSALF=COS(ALF/RAD)	NE00 039
	ARJV=ARJ	NE00 040
	ARJVP=ARJP	NE00 041
	ARJ=ARJ*CSALF	NE00 042
	ARJP=ARJP*CSALF	NE00 043
	DO 30 K=1,NZ	NE00 044
30	UV(K)= 2.0	NE00 045
	NTIME=1	NE00 046
	CORCB=2.0	NE00 047
31	DO 32 K=1,NZ	NE00 048
	BPI=RB(K)/ARJP/UV(K)	NE00 049
	ABPI=ATAN (BPI)	NE00 050
	ALPHA(K)=(ABPI-BTA(K))*RAD	NE00 051
	BPI=BPI*BPI	NE00 052
	BPI=SQRT (BPI+1.0)	NE00 053
	J=K	NE00 054
	CALL CLALF (J)	NE00 055
	IF (NERR-1) 25,999,999	NE00 056
25	CONTINUE	NE00 057
	GRV(K)=0.5*CL*BR(K)*UV(K)*BPI	NE00 058
32	CONTINUE	NE00 059

33	GV(NZ)=GRV(NZ)*BLD/PI/ARJP+1.0	NE00 060
	AGV= 1.	NE00 061
	IF (GV(NZ))133,233,233	NE00 062
133	GV(NZ)=-GV(NZ)	NE00 063
	AGV=-1.	NE00 064
233	GV(NZ)=AGV*SQRT (GV(NZ))-1.	NE00 065
	AGV= 1.	NE00 066
	SGV=1.0	NE00 067
34	DO 35 J=1,MZ	NE00 068
	K=NZ-J	NE00 069
	L=K+1	NE00 070
	SGV=SGV+GV(L)	NE00 071
	SGV2=SGV*SGV	NE00 072
	GRVD=GRV(K)-GRV(L)	NE00 073
	GRVD=GRVD*BLD/PI/ARJP	NE00 074
	DUM=SGV2+GRVD	NE00 075
	AGV=1.0	NE00 076
	IF (DUM.LT.0.0) AGV=-1.0	NE00 077
	GV(K)=AGV*SQRT(AGV*DUM)-SGV	NE00 078
35	CONTINUE	NE00 079
	DO 38 N=1,6	NE00 080
	SA(N)=0.	NE00 081
38	SAS(N)=0.	NE00 082
	DO 40 N=1,6	NE00 083
	DO 39 M=1,MZ	NE00 084
	SA(N)=SA(N)+A(M,N)*GV(M)	NE00 085
39	SAS(N)=SAS(N)+AS(M,N)*GV(M)	NE00 086
40	CONTINUE	NE00 087
C		NE00 088
	DO 41 N=1,6	NE00 089
	SA(N)=SA(N) + D(N)*CORCB	NE00 090
41	SAS(N)=SAS(N) + DS(N)*CORCB	NE00 091
	GAM=GV(NZ)	NE00 092
97	CALL CNCOEF (GAM,C)	NE00 093
	DO 141 N=1,6	NE00 094
	SA(N)=SA(N) - D(N)*CORCB	NE00 095
141	SAS(N)=SAS(N) - DS(N)*CORCB	NE00 096
C		NE00 097
C	COMPUTE CORRECTION FOR LOW ADVANCE RATIOS (CORJ)	NE00 098
C		NE00 099
	DUM=XPRES(1)	NE00 100
	DUMM=RA(1)	NE00 101
	XPRES(1)=XP	NE00 102
	RA(1)=1.0	NE00 103
	CALL GAMCYL (CD,XP,1,RB,UG,1,XPRES,UGP,RRP,RA)	NE00 104
	IRC=-1	NE00 105
	CALL VTXRNG (CD,XP,IRC,RB,C,UGD,XPRES,P)	NE00 106
	CORJ=UGD(1)*GAM + UGP(1,1)*GAM + 1.0	NE00 107
	IF (CORJ.LT.1.0) CORJ=1.0	NE00 108
C		NE00 109
C	COMPUTE CORRECTION FOR CENTERBODY INDUCED VELOCITIES (CORCB)	NE00 110
C		NE00 111
	RA(1)=0.0	NE00 112
	CALL GAMCYL (CD,XP,1,RA,UG,0,XPRES,UGP,RRP,RA)	NE00 113
	IRC=1	NE00 114
	CALL VTXRNG (CD,XP,IRC,RA,C,UGD,XPRES,P)	NE00 115
	CORCB=UGD(1)*GAM+UGP(1,1)*GAM+1.0	NE00 116
	DO 142 J=1,MZ	NE00 117
142	CORCB=CORCB+GV(J)/2.0	NE00 118

IF (CORCB.LT.1.0) CORCB=1.0	NE00 119
XPRES(1)=DUM	NE00 120
RA(1)=DUMM	NE00 121
C	NE00 122
CDP=CD*RRP	NE00 123
CALL VTXRNG (CDP,XP,NZ,RB,C,UGD,XPRES,P)	NE00 124
98 IRT=0	NE00 125
SUMG=0.	NE00 126
DO 42 J=1,MZ	NE00 127
42 SUMG=SUMG+GV(J)	NE00 128
DO 45 J=1,MZ	NE00 129
UNV=1.+(UG(J)*GAM)+(UGD(J)*GAM)+UQD(J)*CORJ+UCB(J)*CORCB+SUMG/2.0	NE00 130
SUMG=SUMG-GV(J)	NE00 131
DELV=UV(J)-UNV	NE00 132
DELV=DELV/UNV	NE00 133
DELV=ABS (DELV)	NE00 134
IF(DELV-EPS) 45,45,44	NE00 135
44 IRT=IRT+1	NE00 136
45 UV(J)=(UV(J)+UNV)/2.	NE00 137
J=NZ	NE00 138
UNV=1.+(UG(J)*GAM)+(UGD(J)*GAM)+UQD(J)*CORJ+UCB(J)*CORCB	NE00 139
DELV=UV(NZ)-UNV	NE00 140
DELV=DELV/UNV	NE00 141
DELV=ABS (DELV)	NE00 142
UV(NZ)=(UV(NZ)+UNV)/2.	NE00 143
IF(DELV-EPS) 46,46,47	NE00 144
47 IRT=IRT+1	NE00 145
46 IF(IRT) 50,60,50	NE00 146
50 NTIME=NTIME+1	NE00 147
IF (NTIME-51) 31,60,60	NE00 148
60 CALL OUTPUT	NE00 149
IF (NTIME-51) 68,69,68	NE00 150
69 NERR=0	NE00 151
GO TO 31	NE00 152
68 IF (NERR) 70,70,996	NE00 153
70 READ (5,120) NRUN,NPHI,ARJ,ALF,(PHI(J),J=1,5)	NE00 154
ARJP=ARJ/PI/RRP	NE00 155
NPAG=0	NE00 156
IF (NPHI.GT.5) NPHI=5	NE00 157
IF (NRUN) 28,29,28	NE00 158
C	NE00 159
C ERROR STOP	NE00 160
996 WRITE (6,997)	NE00 161
999 WRITE (6,998)	NE00 162
STOP	NE00 163
C	NE00 164
END	NE00 165

	SUBROUTINE INPUT	NE01 001
C		NE01 002
	DIMENSION B(6),BS(6),SA(6),SAS(6),P(6,6)	NE01 003
	DIMENSION C(6),A(25,6),AS(25,6),D(6),DS(6),SC(6),GS(6),H(6)	NE01 004
	DIMENSION RB(25),BR(25),BTA(25),TCBLD(25),RA(25),XPRES(25),PHI(5)	NE01 005
	DIMENSION UG(25),UQD(25),UGD(25),UV(25),UCB(25),VCB(25),	NE01 006
1	UGP(25,25),UGA(25),GV(25),GRV(25),CPP(5,25),CPM(5,25)	NE01 007
	DIMENSION ALPHA(25),STALL(25),JSTL(25),TALK(20)	NE01 008
	DIMENSION RE(4)	NE01 009
C		NE01 010
	COMMON MZZZ,CD,R0,R1,R2,R3,PI,B,BS,SA,SAS,P	NE01 011
	COMMON/NEAR1/ NRUN,NBLD,NZ,MZ,NPRES,IR,NTIME,NERR,NPAG,NPHI,NPRINT	NE01 012
	COMMON/NEAR2/ C,A,AS,D,DS,SC,GS,H	NE01 013
	COMMON/NEAR3/ RRP,XP,Z,BLD,RB,BR,BTA,TCBLD,TC,RCBRP,APA,ALF,XPRES,	NE01 014
1	RA,XCB,XR,ELCBC,RMAX,PHI,CORJ,CORCB	NE01 015
	COMMON/NEAR4/ UG,UQD,UGD,UV,UCB,VCB,UGP,UGA,GV,GAM,GRV,CPP,CPM	NE01 016
	COMMON/NEAR5/ ARJ,ARJP,EPS,RAD,CL,ALPHA,STALL,JSTL,TALK	NE01 017
C		NE01 018
101	FORMAT(15H1 RUN NUMBER,15,49X,4HPAGE,13//)	NE01 019
102	FORMAT(12H INPUT/5X,65HDUCT GEOMETRY... C/D XP/C	NE01 020
1	T/C RTE/RP RCB/RP)	NE01 021
103	FORMAT(10X,20HCAMBER COEFFICIENTS,,4F10.6//)	NE01 022
104	FORMAT(5X,22HPROPELLER GEOMETRY... ,13,1X,6HBLADES//)	NE01 023
105	FORMAT(25X,34HR/RP B/RP BETA TH/CHD)	NE01 024
106	FORMAT (/5X,47HDEFINITION OF SYMBOLS USED IN TABULAR OUTPUT...//)	NE01 025
107	FORMAT(10X,66HR/RP RADIAL PROPELLER STATION IN FRACTION OF PR	NE01 026
	1OPELLER RADIUS)	NE01 027
108	FORMAT(10X,57HB/RP PROPELLER CHORD IN FRACTION OF PROPELLER R	NE01 028
	1ADIUS)	NE01 029
109	FORMAT(10X,36HBETA PROPELLER PITCH IN DEGREES)	NE01 030
110	FORMAT (10X,50HTH/CHD PROPELLER BLADE THICKNESS-TO-CHORD RATIO)	NE01 031
111	FORMAT (/5X,22HCENTERBODY GEOMETRY...2X5HLCB/C,5X5HXCB/C,3X8HRMAX/	NE01 032
	1LCB,2X9HX(RMAX)/C/25X,4F10.5)	NE01 033
112	FORMAT (/5X,35HCONVERGENCE CRITERION... EPSILON =,F7.5)	NE01 034
114	FORMAT (10X1HV9X20HFREE STREAM VELOCITY)	NE01 035
122	FORMAT(10X,31HU TOTAL INFLOW VELOCITY)	NE01 036
124	FORMAT(10X,48HGAM/V STRENGTH OF INTERNAL VORTEX CYLINDER N)	NE01 037
125	FORMAT(10X,34HALPHA ANGLE OF ATTACK, DEGREES)	NE01 038
126	FORMAT(10X,60HDELTA P/Q RISE IN TOTAL PRESSURE ACROSS PROPELLER	NE01 039
	1RMALIZED/25X,31HON FREE STREAM DYNAMIC PRESSURE)	NE01 040
127	FORMAT(10X,53HCTP(D) THRUST COEFFICIENT ON PROPELLER IN THE DUC	NE01 041
	1T)	NE01 042
128	FORMAT(10X,40HCTD(P) THRUST COEFFICIENT ON THE DUCT)	NE01 043
129	FORMAT(10X,34HCTDP TOTAL THRUST COEFFICIENT)	NE01 044
130	FORMAT(10X,65HCTD(P)' THRUST COEFFICIENT ON DUCT INCLUDING PRESS	NE01 045
	1URE THRUST ON/25X,29HTHE DUCT AFT OF THE PROPELLER)	NE01 046
131	FORMAT (10X,60HCTDP' TOTAL THRUST COEFFICIENT INCLUDING PRESS	NE01 047
	1RE THRUST)	NE01 048
132	FORMAT (10X,40HCNDP TOTAL NORMAL FORCE COEFFICIENT)	NE01 049
133	FORMAT (10X,43HCM DP TOTAL PITCHING MOMENT COEFFICIENT)	NE01 050
134	FORMAT (10X,23HJ ADVANCE RATIO)	NE01 051
135	FORMAT (10X,43HJ' RATIO OF V TO PROPELLER TIP SPEED)	NE01 052
148	FORMAT(20A4)	NE01 053
149	FORMAT(10X,20A4//)	NE01 054
C		NE01 055
240	FORMAT (F10.3,F8.3,F10.4,F8.3,F8.4,2(2X,1PE12.5))	NE01 056
241	FORMAT (I10,6F10.6)	NE01 057
244	FORMAT (5X,6(1PE13.6))	NE01 058
250	FORMAT(20X,5F10.6//)	NE01 059

251	FORMAT(20X,2F10.6,F10.3,F10.5)	NE01 060
520	FORMAT (215,7F10.4)	NE01 061
521	FORMAT (8F10.4)	NE01 062
522	FORMAT (10I5)	NE01 063
C		NE01 064
750	FORMAT (///10X,33HNUMBER OF BLADES IN ERROR, NBLD =,I5)	NE01 065
751	FORMAT (///10X,46HCONVERGENCE CRITERION MUST BE GREATER THAN 0.0)	NE01 066
752	FORMAT (///10X,46HANGLE OF ATTACK MUST BE LESS THAN 90.0 DEGREES)	NE01 067
753	FORMAT (///10X,38HADVANCE RATIO MUST BE GREATER THAN 0.0)	NE01 068
C		NE01 069
20	READ (5,148) TALK	NE01 070
	READ (5,521) CD,XP,TC,RRP,RCBRP,EPS	NE01 071
	READ (5,521) RO,R1,R2,R3	NE01 072
	READ (5,521) ELCBC,XCB,RMAX,XR	NE01 073
	READ (5,522) NBLD,NZ,NZP,IR,NPRES,NPRINT	NE01 074
	READ (5,521) (RB(J),J=1,NZP)	NE01 075
	READ (5,521) (BR(J),J=1,NZP)	NE01 076
	READ (5,521) (BTA(J),J=1,NZP)	NE01 077
	READ (5,521) (TCBLD(J),J=1,NZP)	NE01 078
	READ (5,521) (XPRES(N),N=1,IR)	NE01 079
	READ (5,520) NRUN,NPHI,ARJ,ALF,(PHI(J),J=1,5)	NE01 080
C		NE01 081
C	CHECK INPUT DATA	NE01 082
C		NE01 083
	IF (NPHI.GT.5) NPHI=5	NE01 084
	IF (NBLD) 700,700,701	NE01 085
700	WRITE (6,750) NBLD	NE01 086
	NERR=1	NE01 087
701	IF (EPS) 702,702,703	NE01 088
702	WRITE (6,751)	NE01 089
	NERR=1	NE01 090
703	IF (ALF-90.0) 704,705,705	NE01 091
705	WRITE (6,752)	NE01 092
	NERR=1	NE01 093
704	IF (ARJ) 706,706,707	NE01 094
706	WRITE (6,753)	NE01 095
	NERR=1	NE01 096
707	IF (NERR) 708,708,999	NE01 097
708	CONTINUE	NE01 098
	NPAG=0	NE01 099
	WRITE (6,101) NRUN,NPAG	NE01 100
	WRITE (6,149) TALK	NE01 101
C		NE01 102
C	INITIALIZATION OF SUBROUTINES	NE01 103
C		NE01 104
	MZZZ=0	NE01 105
	CALL HUB (CD,XR,XCB,ELCBC,RMAX,IR,XPRES,RB,RRP,UCB,VCB)	NE01 106
	IF (NERR.GE.1) GO TO 999	NE01 107
	CALL ALFRNG (CD,50,SC,UGA,XPRES)	NE01 108
	DO 22 J=1,6	NE01 109
	H(J)=UGA(J+6)	NE01 110
22	GS(J)=UGA(J)	NE01 111
	CALL PRESS	NE01 112
	MZZZ=1	NE01 113
	Z=NZ	NE01 114
	MZ=NZ-1	NE01 115
	CALL PKL (CD,P)	NE01 116
	ARJP=ARJ/PI/RRP	NE01 117
	BLD=NBLD	NE01 118

	APA=1./ (RRP*RRP)-(RCBRP*RCBRP/RRP/RRP)	NE01 119
	WRITE (6,102)	NE01 120
	WRITE (6,250) CD,XP,TC,RRP,RCBRP	NE01 121
	WRITE (6,103) R0,R1,R2,R3	NE01 122
	WRITE (6,104) NBLD	NE01 123
	WRITE (6,105)	NE01 124
	DO 21 J=1,NZP	NE01 125
21	WRITE (6,251) RB(J),BR(J),BTA(J),TCBLD(J)	NE01 126
	WRITE (6,111) ELCBC,XCB,RMAX,XR	NE01 127
	WRITE (6,112) EPS	NE01 128
C		NE01 129
C	COMPUTE INDUCED CAMBER COEFFICIENTS	NE01 130
C		NE01 131
	CALL CAMBER (CD,TC,RE)	NE01 132
	R0=R0-RE(1)	NE01 133
	R1=R1-RE(2)	NE01 134
	R2=R2-RE(3)	NE01 135
	R3=R3-RE(4)	NE01 136
C		NE01 137
	WRITE (6,106)	NE01 138
	WRITE (6,107)	NE01 139
	WRITE (6,108)	NE01 140
	WRITE (6,109)	NE01 141
	WRITE (6,110)	NE01 142
	WRITE (6,114)	NE01 143
	WRITE (6,122)	NE01 144
	WRITE (6,134)	NE01 145
	WRITE (6,135)	NE01 146
	WRITE (6,124)	NE01 147
	WRITE (6,125)	NE01 148
	WRITE (6,126)	NE01 149
	WRITE (6,127)	NE01 150
	WRITE (6,128)	NE01 151
	WRITE (6,129)	NE01 152
	WRITE (6,130)	NE01 153
	WRITE (6,131)	NE01 154
	WRITE (6,132)	NE01 155
	WRITE (6,133)	NE01 156
C		NE01 157
C	COMPUTE THE FOURIER COEFFICIENTS DUE TO THE CENTERBODY	NE01 158
C		NE01 159
	MZZZ=-1	NE01 160
	N=50	NE01 161
	CALL HUB (CD,XP,XCB,ELCBC,RMAX,N,XPRES,RB,RRP,UCB,VCB)	NE01 162
	MZZZ=1	NE01 163
	DO 40 K=1,6	NE01 164
	D(K)=VCB(K)	NE01 165
40	DS(K)=UCB(K)	NE01 166
C		NE01 167
	CALL PROP (NZP,RB,BR,BTA,TCBLD,RRP,RCBRP,NZ,RA)	NE01 168
C		NE01 169
C	COMPUTE THE CONSTANT PORTION OF THE INFLOW PROFILE	NE01 170
C		NE01 171
	CDP=CD*RRP	NE01 172
	CALL GAMCYL (CDP,XP,NZ,RB,UG,O,XPRES,UGP,RRP,RA)	NE01 173
	CALL SRCRNG (CD,XP,TC,NZ,RB,UQD)	NE01 174
	CALL HUB (CD,XP,XCB,ELCBC,RMAX,NZ,XPRES,RB,RRP,UCB,VCB)	NE01 175
C		NE01 176
C	COMPUTE THE FOURIER COEFFICIENTS DUE TO THE TRAILING VORTICITY	NE01 177

C

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CRBN=CD*2.
CALL BNCOEF (CRBN,B)
NOUT=6
N=50
NCYL=NZ-1
CALL ANCOEF (NCYL,N,RA,XP,CD,RRP,NRUN,O,BS,A,AS)
DO 30 K=1,NZ
BR(K)=BR(K)/RRP
RB(K)=RB(K)/RRP
BTA(K)=90.0-BTA(K)
30 BTA(K)=BTA(K)/RAD
999 RETURN
END

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NE01 178
NE01 179
NE01 180
NE01 181
NE01 182
NE01 183
NE01 184
NE01 185
NE01 186
NE01 187
NE01 188
NE01 189
NE01 190
NE01 191

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C      SUBROUTINE PKL (CD,P)
C      DIMENSION P(6,6),A(6,6,7),C(7)
C      COMMON MZZZ
C      IF (MZZZ) 1,2,1
2 DO 10 K=1,6
  DO 10 L=1,6
  DO 10 M=1,7
10 A(K,L,M)=0.0
C
  A(1,1,2) = .02683
  A(1,3,2) = .01343
  A(1,5,2) = -.00001
  A(2,1,2) = .05366
  A(2,2,2) = .02987
  A(2,4,2) = -.00304
  A(3,1,2) = .00608
  A(3,3,2) = .00403
  A(3,5,2) = -.00099
  A(4,1,2) = -.00005
  A(4,2,2) = -.00101
  A(4,4,2) = .00148
  A(4,6,2) = -.00049
  A(5,1,2) = -.00001
  A(5,3,2) = -.00049
  A(5,5,2) = .00079
  A(6,4,2) = -.00029
  A(6,6,2) = .00049
C
  A(1,1,3) = .07281
  A(1,3,3) = .03644
  A(1,5,3) = -.00004
  A(2,1,3) = .14561
  A(2,2,3) = .08526
  A(2,4,3) = -.01252
  A(2,6,3) = .00006
  A(3,1,3) = .02491
  A(3,3,3) = .01655
  A(3,5,3) = -.00411
  A(4,1,3) = -.00016
  A(4,2,3) = -.00417
  A(4,4,3) = .00609
  A(4,6,3) = -.00200
  A(5,1,3) = -.00013
  A(5,3,3) = -.00206
  A(5,5,3) = .00318
  A(6,2,3) = .00002
  A(6,4,3) = -.00120
  A(6,6,3) = .00197
C
  A(1,1,4) = .11925
  A(1,3,4) = .05945
  A(1,5,4) = .00019
  A(2,1,4) = .23849
  A(2,2,4) = .14668
  A(2,4,4) = -.02765
  A(2,6,4) = .00021

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```

NE02 001
NE02 002
NE02 003
NE02 004
NE02 005
NE02 006
NE02 007
NE02 008
NE02 009
NE02 010
NE02 011
NE02 012
NE02 013
NE02 014
NE02 015
NE02 016
NE02 017
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NE02 051
NE02 052
NE02 053
NE02 054
NE02 055
NE02 056
NE02 057
NE02 058
NE02 059

```

A(3,1,4) = .05488
 A(3,3,4) = .03702
 A(3,5,4) = -.00965
 A(4,1,4) = .00071
 A(4,2,4) = -.00922
 A(4,4,4) = .01418
 A(4,6,4) = -.00463
 A(5,1,4) = -.00042
 A(5,3,4) = -.00482
 A(5,5,4) = .00732
 A(6,1,4) = -.00005
 A(6,2,4) = .00005
 A(6,4,4) = -.00278
 A(6,6,4) = .00450

C

A(1,1,5) = .16016
 A(1,3,5) = .07907
 A(1,5,5) = .00107
 A(2,1,5) = .32032
 A(2,2,5) = .20609
 A(2,4,5) = -.04629
 A(2,6,5) = .00035
 A(3,1,5) = .09186
 A(3,3,5) = .06338
 A(3,5,5) = -.01766
 A(4,1,5) = .00402
 A(4,2,5) = -.01544
 A(4,4,5) = .02592
 A(4,6,5) = -.00855
 A(5,1,5) = -.00072
 A(5,3,5) = -.00883
 A(5,5,5) = .01338
 A(6,1,5) = -.00025
 A(6,2,5) = .00008
 A(6,4,5) = -.00512
 A(6,6,5) = .00814

C

A(1,1,6) = .22278
 A(1,3,6) = .10634
 A(1,5,6) = .00536
 A(2,1,6) = .44556
 A(2,2,6) = .30830
 A(2,4,6) = -.08513
 A(2,6,6) = -.00059
 A(3,1,6) = .17105
 A(3,3,6) = .12346
 A(3,5,6) = -.03845
 A(4,1,6) = .02020
 A(4,2,6) = -.02784
 A(4,4,6) = .05692
 A(4,6,6) = -.01932
 A(5,1,6) = .00079
 A(5,3,6) = -.01858
 A(5,5,6) = .02935
 A(6,1,6) = -.00123
 A(6,2,6) = -.00011
 A(6,4,6) = -.01087
 A(6,6,6) = .01620

C

NE02 060
 NE02 061
 NE02 062
 NE02 063
 NE02 064
 NE02 065
 NE02 066
 NE02 067
 NE02 068
 NE02 069
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 NE02 104
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 NE02 107
 NE02 108
 NE02 109
 NE02 110
 NE02 111
 NE02 112
 NE02 113
 NE02 114
 NE02 115
 NE02 116
 NE02 117
 NE02 118

A(1,1,7) = .26624	NE02 119
A(1,3,7) = .12146	NE02 120
A(1,5,7) = .01214	NE02 121
A(2,1,7) = .53248	NE02 122
A(2,2,7) = .38891	NE02 123
A(2,4,7) = -.11898	NE02 124
A(2,6,7) = -.00429	NE02 125
A(3,1,7) = .24533	NE02 126
A(3,3,7) = .18468	NE02 127
A(3,5,7) = -.06210	NE02 128
A(4,1,7) = .04662	NE02 129
A(4,2,7) = -.03871	NE02 130
A(4,4,7) = .09563	NE02 131
A(4,6,7) = -.03416	NE02 132
A(5,1,7) = .00738	NE02 133
A(5,3,7) = -.02992	NE02 134
A(5,5,7) = .05270	NE02 135
A(6,1,7) = -.00194	NE02 136
A(6,2,7) = -.00088	NE02 137
A(6,4,7) = -.01918	NE02 138
A(6,6,7) = .02998	NE02 139
C	NE02 140
C(1)=0.0	NE02 141
C(2)=0.25	NE02 142
C(3)=0.50	NE02 143
C(4)=0.75	NE02 144
C(5)=1.00	NE02 145
C(6)=1.50	NE02 146
C(7)=2.00	NE02 147
GO TO 71	NE02 148
C	NE02 149
1 DO 20 J=1,7	NE02 150
IF(C(J)-CD) 20,19,21	NE02 151
20 CONTINUE	NE02 152
GO TO 21	NE02 153
19 M=J	NE02 154
GO TO 100	NE02 155
21 M=J-1	NE02 156
N=J	NE02 157
DELT=C(N)-C(M)	NE02 158
DIFF=CD-C(M)	NE02 159
DELTA=DIFF/DELT	NE02 160
DO 30 K=1,6	NE02 161
DO 30 L=1,6	NE02 162
P(K,L)=A(K,L,M)+(DELTA*(A(K,L,N)-A(K,L,M)))	NE02 163
30 CONTINUE	NE02 164
GO TO 71	NE02 165
100 DO 40 K=1,6	NE02 166
DO 40 L=1,6	NE02 167
P(K,L)=A(K,L,M)	NE02 168
40 CONTINUE	NE02 169
71 RETURN	NE02 170
END	NE02 171

C	SUBROUTINE ELLIPS (AKSQ,TK,TE)	NE03 001
C	SUB. ELLIPS -- TABLE LOOK-UP OF ELLIPTIC INTEGRALS	NE03 002
C		NE03 003
	DIMENSION CKK(100),CK(100),CE(100)	NE03 004
	COMMON MZZZ	NE03 005
	IF (MZZZ) 73,10,3	NE03 006
	10 CONTINUE	NE03 007
C		NE03 008
C	CKK = ARGUMENT OF ELLIPTIC INTEGRALS	NE03 009
C		NE03 010
	CKK(1) = 0.00	NE03 011
	CKK(2) = .01	NE03 012
	CKK(3) = .02	NE03 013
	CKK(4) = .03	NE03 014
	CKK(5) = .04	NE03 015
	CKK(6) = .05	NE03 016
	CKK(7) = .06	NE03 017
	CKK(8) = .07	NE03 018
	CKK(9) = .08	NE03 019
	CKK(10) = .09	NE03 020
	CKK(11) = .10	NE03 021
	CKK(12) = .11	NE03 022
	CKK(13) = .12	NE03 023
	CKK(14) = .13	NE03 024
	CKK(15) = .14	NE03 025
	CKK(16) = .15	NE03 026
	CKK(17) = .16	NE03 027
	CKK(18) = .17	NE03 028
	CKK(19) = .18	NE03 029
	CKK(20) = .19	NE03 030
	CKK(21) = .20	NE03 031
	CKK(22) = .21	NE03 032
	CKK(23) = .22	NE03 033
	CKK(24) = .23	NE03 034
	CKK(25) = .24	NE03 035
	CKK(26) = .25	NE03 036
	CKK(27) = .26	NE03 037
	CKK(28) = .27	NE03 038
	CKK(29) = .28	NE03 039
	CKK(30) = .29	NE03 040
	CKK(31) = .30	NE03 041
	CKK(32) = .31	NE03 042
	CKK(33) = .32	NE03 043
	CKK(34) = .33	NE03 044
	CKK(35) = .34	NE03 045
	CKK(36) = .35	NE03 046
	CKK(37) = .36	NE03 047
	CKK(38) = .37	NE03 048
	CKK(39) = .38	NE03 049
	CKK(40) = .39	NE03 050
	CKK(41) = .40	NE03 051
	CKK(42) = .41	NE03 052
	CKK(43) = .42	NE03 053
	CKK(44) = .43	NE03 054
	CKK(45) = .44	NE03 055
	CKK(46) = .45	NE03 056
	CKK(47) = .46	NE03 057
	CKK(48) = .47	NE03 058
		NE03 059

CKK(49) = .48
 CKK(50) = .49
 CKK(51) = .50
 CKK(52) = .51
 CKK(53) = .52
 CKK(54) = .53
 CKK(55) = .54
 CKK(56) = .55
 CKK(57) = .56
 CKK(58) = .57
 CKK(59) = .58
 CKK(60) = .59
 CKK(61) = .60
 CKK(62) = .61
 CKK(63) = .62
 CKK(64) = .63
 CKK(65) = .64
 CKK(66) = .65
 CKK(67) = .66
 CKK(68) = .67
 CKK(69) = .68
 CKK(70) = .69
 CKK(71) = .70
 CKK(72) = .71
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 CKK(74) = .73
 CKK(75) = .74
 CKK(76) = .75
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 CKK(78) = .77
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 CKK(81) = .80
 CKK(82) = .81
 CKK(83) = .82
 CKK(84) = .83
 CKK(85) = .84
 CKK(86) = .85
 CKK(87) = .86
 CKK(88) = .87
 CKK(89) = .88
 CKK(90) = .89
 CKK(91) = .90
 CKK(92) = .91
 CKK(93) = .92
 CKK(94) = .93
 CKK(95) = .94
 CKK(96) = .95
 CKK(97) = .96
 CKK(98) = .97
 CKK(99) = .98
 CKK(100) = .99

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CK = COMPLETE ELLIPTIC INTEGRALS OF FIRST KIND

CK(1) = 1.570796
 CK(2) = 1.574746
 CK(3) = 1.578740
 CK(4) = 1.582780

CK(5) = 1.586868
 CK(6) = 1.591003
 CK(7) = 1.595188
 CK(8) = 1.599423
 CK(9) = 1.603710
 CK(10) = 1.608049
 CK(11) = 1.612441
 CK(12) = 1.616889
 CK(13) = 1.621393
 CK(14) = 1.625955
 CK(15) = 1.630576
 CK(16) = 1.635257
 CK(17) = 1.640000
 CK(18) = 1.644806
 CK(19) = 1.649678
 CK(20) = 1.654617
 CK(21) = 1.659624
 CK(22) = 1.664701
 CK(23) = 1.669850
 CK(24) = 1.675073
 CK(25) = 1.680373
 CK(26) = 1.685750
 CK(27) = 1.691208
 CK(28) = 1.696749
 CK(29) = 1.702374
 CK(30) = 1.708087
 CK(31) = 1.713889
 CK(32) = 1.719785
 CK(33) = 1.725776
 CK(34) = 1.731865
 CK(35) = 1.738055
 CK(36) = 1.744351
 CK(37) = 1.750754
 CK(38) = 1.757269
 CK(39) = 1.763898
 CK(40) = 1.770647
 CK(41) = 1.777519
 CK(42) = 1.784519
 CK(43) = 1.791650
 CK(44) = 1.798918
 CK(45) = 1.806328
 CK(46) = 1.813884
 CK(47) = 1.821593
 CK(48) = 1.829460
 CK(49) = 1.837491
 CK(50) = 1.845694
 CK(51) = 1.854075
 CK(52) = 1.862641
 CK(53) = 1.871400
 CK(54) = 1.880361
 CK(55) = 1.889533
 CK(56) = 1.898925
 CK(57) = 1.908547
 CK(58) = 1.918410
 CK(59) = 1.928526
 CK(60) = 1.938908
 CK(61) = 1.949568
 CK(62) = 1.960521
 CK(63) = 1.971783

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CK(64) = 1.983371
 CK(65) = 1.995303
 CK(66) = 2.007598
 CK(67) = 2.020279
 CK(68) = 2.033369
 CK(69) = 2.046894
 CK(70) = 2.060882
 CK(71) = 2.075363
 CK(72) = 2.090373
 CK(73) = 2.105948
 CK(74) = 2.122132
 CK(75) = 2.138970
 CK(76) = 2.156516
 CK(77) = 2.174827
 CK(78) = 2.193971
 CK(79) = 2.214022
 CK(80) = 2.235068
 CK(81) = 2.257205
 CK(82) = 2.280549
 CK(83) = 2.305232
 CK(84) = 2.331409
 CK(85) = 2.359264
 CK(86) = 2.389016
 CK(87) = 2.420933
 CK(88) = 2.455338
 CK(89) = 2.492635
 CK(90) = 2.533335
 CK(91) = 2.578092
 CK(92) = 2.627773
 CK(93) = 2.683551
 CK(94) = 2.747073
 CK(95) = 2.820752
 CK(96) = 2.908337
 CK(97) = 3.016112
 CK(98) = 3.155875
 CK(99) = 3.354141
 CK(100) = 3.695637

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CE = COMPLETE ELLIPTIC INTEGRALS OF SECOND KIND

CE(1) = 1.570796
 CE(2) = 1.566862
 CE(3) = 1.562913
 CE(4) = 1.558948
 CE(5) = 1.554969
 CE(6) = 1.550973
 CE(7) = 1.546963
 CE(8) = 1.542936
 CE(9) = 1.538893
 CE(10) = 1.534833
 CE(11) = 1.530758
 CE(12) = 1.526665
 CE(13) = 1.522555
 CE(14) = 1.518428
 CE(15) = 1.514284
 CE(16) = 1.510122
 CE(17) = 1.505942
 CE(18) = 1.501743
 CE(19) = 1.497526

CE(20) = 1.493290
 CE(21) = 1.489035
 CE(22) = 1.484761
 CE(23) = 1.480466
 CE(24) = 1.476152
 CE(25) = 1.471818
 CE(26) = 1.467462
 CE(27) = 1.463086
 CE(28) = 1.458688
 CE(29) = 1.454269
 CE(30) = 1.449827
 CE(31) = 1.445363
 CE(32) = 1.440876
 CE(33) = 1.436366
 CE(34) = 1.431832
 CE(35) = 1.427274
 CE(36) = 1.422691
 CE(37) = 1.418083
 CE(38) = 1.413450
 CE(39) = 1.408791
 CE(40) = 1.404105
 CE(41) = 1.399392
 CE(42) = 1.394652
 CE(43) = 1.389883
 CE(44) = 1.385086
 CE(45) = 1.380259
 CE(46) = 1.375402
 CE(47) = 1.370515
 CE(48) = 1.365596
 CE(49) = 1.360645
 CE(50) = 1.355661
 CE(51) = 1.350644
 CE(52) = 1.345592
 CE(53) = 1.340505
 CE(54) = 1.335382
 CE(55) = 1.330223
 CE(56) = 1.325024
 CE(57) = 1.319788
 CE(58) = 1.314511
 CE(59) = 1.309192
 CE(60) = 1.303832
 CE(61) = 1.298428
 CE(62) = 1.292979
 CE(63) = 1.287484
 CE(64) = 1.281942
 CE(65) = 1.276350
 CE(66) = 1.270707
 CE(67) = 1.265013
 CE(68) = 1.259263
 CE(69) = 1.253458
 CE(70) = 1.247595
 CE(71) = 1.241671
 CE(72) = 1.235684
 CE(73) = 1.229632
 CE(74) = 1.223512
 CE(75) = 1.217321
 CE(76) = 1.211056
 CE(77) = 1.204714
 CE(78) = 1.198290

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CE(79) = 1.191781
 CE(80) = 1.185183
 CE(81) = 1.178490
 CE(82) = 1.171697
 CE(83) = 1.164798
 CE(84) = 1.157787
 CE(85) = 1.150656
 CE(86) = 1.143396
 CE(87) = 1.135998
 CE(88) = 1.128451
 CE(89) = 1.120742
 CE(90) = 1.112856
 CE(91) = 1.104775
 CE(92) = 1.096478
 CE(93) = 1.087938
 CE(94) = 1.079121
 CE(95) = 1.069986
 CE(96) = 1.060474
 CE(97) = 1.050502
 CE(98) = 1.039947
 CE(99) = 1.028595
 CE(100) = 1.015994

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C

GO TO 30
 3 IF(AKSQ-.99)20,20,21
 21 PARA=0.25*(1.0-AKSQ)
 700 TEST = 1.00E-07
 IF(PARA-TEST)701,702,702
 701 PARA=TEST
 702 ZLP=ALOG(4./PARA)
 TK=ZLP*0.5*(1.+PARA)-PARA
 TE=1.0+(ZLP*PARA)-PARA
 GO TO 30
 20 JA=100.0*AKSQ
 JA=1+JA
 IF(CKK(JA)-AKSQ)22,23,22
 23 TK=CK(JA)
 TE=CE(JA)
 GO TO 30
 22 CON=(AKSQ-CKK(JA))/(CKK(JA+1)-CKK(JA))
 TK=CK(JA)+CON*(CK(JA+1)-CK(JA))
 TE=CE(JA)+CON*(CE(JA+1)-CE(JA))
 GO TO 30
 73 IF(AKSQ-.01)721,721,720
 721 PARA=.25*AKSQ
 GO TO 700
 720 AKSQ=1.-AKSQ
 GO TO 20
 30 CONTINUE
 RETURN
 END

SUBROUTINE LAMBDA (XP,ZP,YP)

TABLE LOOK-UP OF HEUMAN LAMBDA FUNCTION

DIMENSION Y(19,19),X(19),Z(19)

COMMON MZZZ

IF (MZZZ) 20,10,20

10 CONTINUE

X = ARCSIN K (DEGREES)

X(1)= 0.000000
X(2)= 5.000000
X(3)= 10.000000
X(4)= 15.000000
X(5)= 20.000000
X(6)= 25.000000
X(7)= 30.000000
X(8)= 35.000000
X(9)= 40.000000
X(10)= 45.000000
X(11)= 50.000000
X(12)= 55.000000
X(13)= 60.000000
X(14)= 65.000000
X(15)= 70.000000
X(16)= 75.000000
X(17)= 80.000000
X(18)= 85.000000
X(19)= 90.000000

Z = BETA (DEGREES)

Z(1)= 0.000000
Z(2)= 5.000000
Z(3)= 10.000000
Z(4)= 15.000000
Z(5)= 20.000000
Z(6)= 25.000000
Z(7)= 30.000000
Z(8)= 35.000000
Z(9)= 40.000000
Z(10)= 45.000000
Z(11)= 50.000000
Z(12)= 55.000000
Z(13)= 60.000000
Z(14)= 65.000000
Z(15)= 70.000000
Z(16)= 75.000000
Z(17)= 80.000000
Z(18)= 85.000000
Z(19)= 90.000000

Y = HEUMAN LAMBDA FUNCTION

Y(1, 1)= 0.000000
Y(1, 2)= .087156
Y(1, 3)= .173648
Y(1, 4)= .258819

NE04 001
NE04 002
NE04 003
NE04 004
NE04 005
NE04 006
NE04 007
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Y(1, 5)= .342020
 Y(1, 6)= .422618
 Y(1, 7)= .500000
 Y(1, 8)= .573576
 Y(1, 9)= .642788
 Y(1,10)= .707107
 Y(1,11)= .766044
 Y(1,12)= .819152
 Y(1,13)= .866025
 Y(1,14)= .906308
 Y(1,15)= .939693
 Y(1,16)= .965926
 Y(1,17)= .984808
 Y(1,18)= .996195
 Y(1,19)= 1.000000
 Y(2, 1)= 0.000000
 Y(2, 2)= .086990
 Y(2, 3)= .173318
 Y(2, 4)= .258327
 Y(2, 5)= .341370
 Y(2, 6)= .421815
 Y(2, 7)= .499050
 Y(2, 8)= .572487
 Y(2, 9)= .641567
 Y(2,10)= .705765
 Y(2,11)= .764592
 Y(2,12)= .817600
 Y(2,13)= .864388
 Y(2,14)= .904599
 Y(2,15)= .937930
 Y(2,16)= .964135
 Y(2,17)= .983037
 Y(2,18)= .994624
 Y(2,19)= 1.000000
 Y(3, 1)= 0.000000
 Y(3, 2)= .086495
 Y(3, 3)= .172332
 Y(3, 4)= .256858
 Y(3, 5)= .339430
 Y(3, 6)= .419419
 Y(3, 7)= .496219
 Y(3, 8)= .569244
 Y(3, 9)= .637940
 Y(3,10)= .701786
 Y(3,11)= .760298
 Y(3,12)= .813034
 Y(3,13)= .859602
 Y(3,14)= .899660
 Y(3,15)= .932934
 Y(3,16)= .959244
 Y(3,17)= .978597
 Y(3,18)= .991511
 Y(3,19)= 1.000000
 Y(4, 1)= 0.000000
 Y(4, 2)= .085677
 Y(4, 3)= .170704
 Y(4, 4)= .254434
 Y(4, 5)= .336231
 Y(4, 6)= .415475

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Y(4, 7)= .491565
 Y(4, 8)= .563926
 Y(4, 9)= .632010
 Y(4,10)= .695307
 Y(4,11)= .753346
 Y(4,12)= .805703
 Y(4,13)= .852010
 Y(4,14)= .891969
 Y(4,15)= .925384
 Y(4,16)= .952226
 Y(4,17)= .972787
 Y(4,18)= .988015
 Y(4,19)= 1.000000
 Y(5, 1)= 0.000000
 Y(5, 2)= .084549
 Y(5, 3)= .168458
 Y(5, 4)= .251092
 Y(5, 5)= .331827
 Y(5, 6)= .410054
 Y(5, 7)= .485184
 Y(5, 8)= .556657
 Y(5, 9)= .623939
 Y(5,10)= .686540
 Y(5,11)= .744012
 Y(5,12)= .795963
 Y(5,13)= .842073
 Y(5,14)= .882119
 Y(5,15)= .916018
 Y(5,16)= .943918
 Y(5,17)= .966343
 Y(5,18)= .984410
 Y(5,19)= 1.000000
 Y(6, 1)= 0.000000
 Y(6, 2)= .083124
 Y(6, 3)= .165625
 Y(6, 4)= .246882
 Y(6, 5)= .326288
 Y(6, 6)= .403252
 Y(6, 7)= .477203
 Y(6, 8)= .547600
 Y(6, 9)= .613936
 Y(6,10)= .675748
 Y(6,11)= .732623
 Y(6,12)= .784220
 Y(6,13)= .830282
 Y(6,14)= .870676
 Y(6,15)= .905441
 Y(6,16)= .934867
 Y(6,17)= .959607
 Y(6,18)= .980779
 Y(6,19)= 1.000000
 Y(7, 1)= 0.000000
 Y(7, 2)= .081425
 Y(7, 3)= .162247
 Y(7, 4)= .241870
 Y(7, 5)= .319707
 Y(7, 6)= .395191
 Y(7, 7)= .467777
 Y(7, 8)= .536953

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Y(7, 9)= .602244
 Y(7,10)= .663225
 Y(7,11)= .719533
 Y(7,12)= .770883
 Y(7,13)= .817093
 Y(7,14)= .858117
 Y(7,15)= .894095
 Y(7,16)= .925409
 Y(7,17)= .952751
 Y(7,18)= .977159
 Y(7,19)= 1.000000
 Y(8, 1)= 0.000000
 Y(8, 2)= .079476
 Y(8, 3)= .158377
 Y(8, 4)= .236134
 Y(8, 5)= .312192
 Y(8, 6)= .386013
 Y(8, 7)= .457086
 Y(8, 8)= .524935
 Y(8, 9)= .589127
 Y(8,10)= .649283
 Y(8,11)= .705094
 Y(8,12)= .756337
 Y(8,13)= .802903
 Y(8,14)= .844820
 Y(8,15)= .882297
 Y(8,16)= .915757
 Y(8,17)= .945873
 Y(8,18)= .973573
 Y(8,19)= 1.000000
 Y(9, 1)= 0.000000
 Y(9, 2)= .077307
 Y(9, 3)= .154073
 Y(9, 4)= .229767
 Y(9, 5)= .303869
 Y(9, 6)= .375880
 Y(9, 7)= .445330
 Y(9, 8)= .511786
 Y(9, 9)= .574862
 Y(9,10)= .634231
 Y(9,11)= .689642
 Y(9,12)= .740932
 Y(9,13)= .788051
 Y(9,14)= .831085
 Y(9,15)= .870277
 Y(9,16)= .906056
 Y(9,17)= .939042
 Y(9,18)= .970039
 Y(9,19)= 1.000000
 Y(10, 1)= 0.000000
 Y(10, 2)= .074953
 Y(10, 3)= .149408
 Y(10, 4)= .222878
 Y(10, 5)= .294884
 Y(10, 6)= .364976
 Y(10, 7)= .432729
 Y(10, 8)= .497760
 Y(10, 9)= .559735
 Y(10,10)= .618381

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Y(10,11)= .673501
 Y(10,12)= .724985
 Y(10,13)= .772830
 Y(10,14)= .817155
 Y(10,15)= .858217
 Y(10,16)= .896419
 Y(10,17)= .932311
 Y(10,18)= .966576
 Y(10,19)= 1.000000
 Y(11, 1)= 0.000000
 Y(11, 2)= .072455
 Y(11, 3)= .144464
 Y(11, 4)= .215587
 Y(11, 5)= .285399
 Y(11, 6)= .353500
 Y(11, 7)= .419519
 Y(11, 8)= .483125
 Y(11, 9)= .544038
 Y(11,10)= .602038
 Y(11,11)= .656976
 Y(11,12)= .708785
 Y(11,13)= .757496
 Y(11,14)= .803241
 Y(11,15)= .846269
 Y(11,16)= .886942
 Y(11,17)= .925731
 Y(11,18)= .963204
 Y(11,19)= 1.000000
 Y(12, 1)= 0.000000
 Y(12, 2)= .069861
 Y(12, 3)= .139334
 Y(12, 4)= .208034
 Y(12, 5)= .275597
 Y(12, 6)= .341676
 Y(12, 7)= .405958
 Y(12, 8)= .468167
 Y(12, 9)= .528076
 Y(12,10)= .585512
 Y(12,11)= .640369
 Y(12,12)= .692612
 Y(12,13)= .742291
 Y(12,14)= .789537
 Y(12,15)= .834576
 Y(12,16)= .877717
 Y(12,17)= .919353
 Y(12,18)= .959944
 Y(12,19)= 1.000000
 Y(13, 1)= 0.000000
 Y(13, 2)= .067226
 Y(13, 3)= .134126
 Y(13, 4)= .200380
 Y(13, 5)= .265684
 Y(13, 6)= .329751
 Y(13, 7)= .392328
 Y(13, 8)= .453192
 Y(13, 9)= .512167
 Y(13,10)= .569122
 Y(13,11)= .623985
 Y(13,12)= .676745

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Y(13,13)= .727455
Y(13,14)= .776237
Y(13,15)= .823283
Y(13,16)= .868846
Y(13,17)= .913240
Y(13,18)= .956826
Y(13,19)= 1.000000
Y(14, 1)= 0.000000
Y(14, 2)= .064614
Y(14, 3)= .128968
Y(14, 4)= .192809
Y(14, 5)= .255897
Y(14, 6)= .318009
Y(14, 7)= .378946
Y(14, 8)= .438541
Y(14, 9)= .496661
Y(14,10)= .553214
Y(14,11)= .608153
Y(14,12)= .661480
Y(14,13)= .713246
Y(14,14)= .763552
Y(14,15)= .812552
Y(14,16)= .860443
Y(14,17)= .907464
Y(14,18)= .953885
Y(14,19)= 1.000000
Y(15, 1)= 0.000000
Y(15, 2)= .062100
Y(15, 3)= .124009
Y(15, 4)= .185540
Y(15, 5)= .246517
Y(15, 6)= .306778
Y(15, 7)= .366180
Y(15, 8)= .424604
Y(15, 9)= .481959
Y(15,10)= .538183
Y(15,11)= .593247
Y(15,12)= .647159
Y(15,13)= .699961
Y(15,14)= .751731
Y(15,15)= .802581
Y(15,16)= .852654
Y(15,17)= .902119
Y(15,18)= .951166
Y(15,19)= 1.000000
Y(16, 1)= 0.000000
Y(16, 2)= .059779
Y(16, 3)= .119433
Y(16, 4)= .178839
Y(16, 5)= .237883
Y(16, 6)= .296459
Y(16, 7)= .354475
Y(16, 8)= .411857
Y(16, 9)= .468546
Y(16,10)= .524506
Y(16,11)= .579721
Y(16,12)= .634200
Y(16,13)= .687972
Y(16,14)= .741089

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Y(16,15)= .793624
 Y(16,16)= .845669
 Y(16,17)= .897332
 Y(16,18)= .948733
 Y(16,19)= 1.000000
 Y(17, 1)= 0.000000
 Y(17, 2)= .057773
 Y(17, 3)= .115479
 Y(17, 4)= .173054
 Y(17, 5)= .230436
 Y(17, 6)= .287571
 Y(17, 7)= .344410
 Y(17, 8)= .400915
 Y(17, 9)= .457055
 Y(17,10)= .512813
 Y(17,11)= .568181
 Y(17,12)= .623166
 Y(17,13)= .677782
 Y(17,14)= .732059
 Y(17,15)= .786036
 Y(17,16)= .839759
 Y(17,17)= .893286
 Y(17,18)= .946677
 Y(17,19)= 1.000000
 Y(18, 1)= 0.000000
 Y(18, 2)= .056256
 Y(18, 3)= .112490
 Y(18, 4)= .168682
 Y(18, 5)= .224814
 Y(18, 6)= .280867
 Y(18, 7)= .336826
 Y(18, 8)= .392679
 Y(18, 9)= .448417
 Y(18,10)= .504034
 Y(18,11)= .559529
 Y(18,12)= .614903
 Y(18,13)= .670162
 Y(18,14)= .725315
 Y(18,15)= .780373
 Y(18,16)= .835352
 Y(18,17)= .890270
 Y(18,18)= .945145
 Y(18,19)= 1.000000
 Y(19, 1)= 0.000000
 Y(19, 2)= .055556
 Y(19, 3)= .111111
 Y(19, 4)= .166667
 Y(19, 5)= .222222
 Y(19, 6)= .277778
 Y(19, 7)= .333333
 Y(19, 8)= .388889
 Y(19, 9)= .444444
 Y(19,10)= .500000
 Y(19,11)= .555556
 Y(19,12)= .611111
 Y(19,13)= .666667
 Y(19,14)= .722222
 Y(19,15)= .777778
 Y(19,16)= .833333

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Y(19,17)= .888889
Y(19,18)= .944444
Y(19,19)= 1.000000

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C

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GO TO 90
20 DX = 5.0
DZ = 5.0
FNX=XP/DX
N=FNX
N=N+1
FNZ=ZP/DZ
M=FNZ
M=M+1
C1=(ZP-Z(M))/DZ
C2=(XP-X(N))/DX
A=(Y(N,M+1)-Y(N,M))*C1
B=(Y(N+1,M)-Y(N,M))*C2
D=C1*C2*(Y(N+1,M+1)-Y(N+1,M)+Y(N,M)-Y(N,M+1))
YP=Y(N,M)+A+B+D
90 RETURN
END

```

	SUBROUTINE HUB (CD,XR,XCB,ELCBC,H,IR,X,RB,RRP,U,V)	NE05 001
C		NE05 002
C	CALCULATION OF VELOCITIES INDUCED BY THE CENTERBODY	NE05 003
C	** CENTERBODY IS REPRESENTED AS A RANKINE BODY **	NE05 004
C		NE05 005
	DIMENSION X(25),RB(25),U(25),V(25),FU(50),FV(50),D(6),DS(6)	NE05 006
	COMMON MZZZ	NE05 007
C		NE05 008
	700 FORMAT (///10X,36HINPUT CENTERBODY DIMENSIONS IN ERROR///)	NE05 009
	701 FORMAT (///10X,52HSUBROUTINE HUB UNABLE TO COMPUTE CENTERBODY GEOM	NE05 010
	1ETRY///)	NE05 011
C		NE05 012
	IF (MZZZ) 3,1,2	NE05 013
	1 XIZ=(XR-XCB)/ELCBC	NE05 014
C		NE05 015
C	COMPUTE LOCATION OF POINT SOURCE	NE05 016
C		NE05 017
	IF (XIZ=H) 10,10,11	NE05 018
	10 NERR=1	NE05 019
C		NE05 020
C	ERROR MESSAGE	NE05 021
	WRITE (6,700)	NE05 022
	RETURN	NE05 023
	11 H2=H*H	NE05 024
	XIZ2=XIZ*XIZ	NE05 025
	A=XIZ-H	NE05 026
	DO 20 J=1,20	NE05 027
	AA=XIZ*H2*SQRT(A*A + H2)	NE05 028
	AA=XIZ2-SQRT(AA)	NE05 029
	AA=SQRT(AA)	NE05 030
	DEL=ABS(AA-A)/AA	NE05 031
	IF (DEL-.001) 30,30,19	NE05 032
	19 A=(AA+A)/2.	NE05 033
	20 CONTINUE	NE05 034
C		NE05 035
C	ERROR MESSAGE	NE05 036
C		NE05 037
	WRITE (6,701)	NE05 038
	NERR=1	NE05 039
	RETURN	NE05 040
	30 A=AA	NE05 041
	EMV=((XIZ2-A*A)**2)/(4.*XIZ*A)	NE05 042
	RETURN	NE05 043
	2 IF (IR) 100,100,200	NE05 044
C		NE05 045
C	COMPUTE VELOCITIES INDUCED AT THE DUCT REFERENCE CYLINDER	NE05 046
C		NE05 047
	100 W=0.5/CD/ELCBC	NE05 048
	NX=-IR	NE05 049
	DO 40 J=1,NX	NE05 050
	XI=X(J)-XCB-XIZ*ELCBC	NE05 051
	XI=XI/ELCBC	NE05 052
	35 XPA=XI+A	NE05 053
	XMA=XI-A	NE05 054
	34 RXPA=SQRT(XPA*XPA + W*W)	NE05 055
	RXMA=SQRT(XMA*XMA + W*W)	NE05 056
	RXPA3=RXPA**3	NE05 057
	RXMA3=RXMA**3	NE05 058
	U(J)=EMV*(XPA/RXPA3 - XMA/RXMA3)	NE05 059

	V(J)=EMV*W*(1./RXPA3 - 1./RXMA3)	NE05 060
40	CONTINUE	NE05 061
	RETURN	NE05 062
C		NE05 063
C	COMPUTE INFLOW VELOCITIES	NE05 064
C		NE05 065
200	XI=XR-XCB-XIZ*ELCBC	NE05 066
	XI=XI/ELCBC	NE05 067
	DO 60 J=1,IR	NE05 068
	W=RB(J)*.5/CD/ELCBC/RRP	NE05 069
65	XPA=XI+A	NE05 070
	XMA=XI-A	NE05 071
64	RXPA=SQRT(XPA*XPA + W*W)	NE05 072
	RXMA=SQRT(XMA*XMA + W*W)	NE05 073
	RXPA3=RXPA**3	NE05 074
	RXMA3=RXMA**3	NE05 075
	U(J)=EMV*(XPA/RXPA3 - XMA/RXMA3)	NE05 076
	V(J)=EMV*W*(1./RXPA3 - 1./RXMA3)	NE05 077
	PSI=W*W/2. - EMV*(XPA/RXPA - XMA/RXMA)	NE05 078
60	CONTINUE	NE05 079
	RETURN	NE05 080
C		NE05 081
C	COMPUTE D(N) AND D-STAR(N) FOURIER COEFFICIENTS	NE05 082
C		NE05 083
	3 W=0.5/CD/ELCBC	NE05 084
	N=IR	NE05 085
	CN=N	NE05 086
	PI=3.1415926	NE05 087
	DTH=PI/(CN-1.)	NE05 088
	TH=-DTH	NE05 089
	DO 80 J=1,N	NE05 090
	TH=TH+DTH	NE05 091
	CSTH=COS(TH)	NE05 092
	XG=0.5*(1.-CSTH)	NE05 093
	XI=XG-XCB-XIZ*ELCBC	NE05 094
	XI=XI/ELCBC	NE05 095
	XPA=XI+A	NE05 096
	XMA=XI-A	NE05 097
	RXPA=SQRT(XPA*XPA+W*W)	NE05 098
	RXMA=SQRT(XMA*XMA+W*W)	NE05 099
	RXPA3=RXPA**3	NE05 100
	RXMA3=RXMA**3	NE05 101
	FU(J)=EMV*(XPA/RXPA3-XMA/RXMA3)	NE05 102
	FV(J)=EMV*W*(1./RXPA3-1./RXMA3)	NE05 103
80	CONTINUE	NE05 104
	NOUT=6	NE05 105
	CALL FOURCS (FU,FU,N,NOUT,0)	NE05 106
	CALL FOURCS (FV,FV,N,NOUT,0)	NE05 107
	DO 81 J=1,NOUT	NE05 108
	D(J)=FV(J)	NE05 109
	DS(J)=FU(J)	NE05 110
	U(J)=DS(J)	NE05 111
81	V(J)=D(J)	NE05 112
	RETURN	NE05 113
	END	NE05 114

C	SUBROUTINE CAMBER (CD,TC,RP)	NE06 001
C	SUBROUTINE TO COMPUTE INDUCED CAMBER COEFFICIENTS	NE06 002
C	DIMENSION CDRAT(5),DCD(4,5),RP(4)	NE06 003
C	DATA CDRAT/0.0,0.25,0.50,0.75,1.0/	NE06 004
	DATA (DCD(1,J),J=1,5)/0.0,0.00149,0.00316,0.00505,0.00696/	NE06 005
	DATA (DCD(2,J),J=1,5)/0.0,0.10897,0.22236,0.33414,0.43940/	NE06 006
	DATA (DCD(3,J),J=1,5)/0.0,0.03558,0.07223,0.11022,0.14928/	NE06 007
	DATA (DCD(4,J),J=1,5)/0.0,-0.00203,-0.00539,-0.00948,-0.01375/	NE06 008
C	DO 2 J=1,5	NE06 009
	N=J	NE06 010
	IF (CDRAT(J)-CD) 2,3,4	NE06 011
2	CONTINUE	NE06 012
4	M=N-1	NE06 013
	DEL=CDRAT(N)-CDRAT(M)	NE06 014
	DIF=CD-CDRAT(M)	NE06 015
	DELTA=DIF/DEL	NE06 016
	DO 10 K=1,4	NE06 017
	RP(K)=DCD(K,M) + DELTA*(DCD(K,N)-DCD(K,M))	NE06 018
10	CONTINUE	NE06 019
	GO TO 20	NE06 020
3	M=N	NE06 021
	DO 6 K=1,4	NE06 022
6	RP(K)=DCD(K,M)	NE06 023
20	DO 21 K=1,4	NE06 024
21	RP(K)=RP(K)*TC	NE06 025
	RETURN	NE06 026
	END	NE06 027
		NE06 028
		NE06 029
		NE06 030
		NE06 031

C	SUBROUTINE PROP (NZP, RB, BR, BTA, TCBLD, RRP, RCBRP, NZ, RA)	NE07 001
C	SUBROUTINE TO COMPUTE PROPELLER GEOMETRY PARAMETERS	NE07 002
C		NE07 003
	DIMENSION RB(25), BR(25), TCBLD(25), X(25), Y(25), Z(25), ZZ(25), BTA(25)	NE07 004
	1 RA(25)	NE07 005
C	P=RCBRP*RCBRP	NE07 006
	D=1.-P	NE07 007
	X(1)=RCBRP	NE07 008
	ZN=NZ	NE07 009
	MZ=MZ+1	NE07 010
	DO 20 J=2,MZ	NE07 011
	K=J-1	NE07 012
	AK=K	NE07 013
	E=AK/ZN*D+P	NE07 014
20	X(J)=SQRT (E)	NE07 015
	DO 21 J=1,NZ	NE07 016
21	RA(J)=X(J+1)	NE07 017
	X(1)=(RCBRP+RA(1))/2.0	NE07 018
	DO 22 J=2,NZ	NE07 019
22	X(J)=(RA(J)+RA(J-1))/2.0	NE07 020
	K=1	NE07 021
	RB(NZP+1)=RB(NZP)	NE07 022
	BR(NZP+1)=BR(NZP)	NE07 023
	BTA(NZP+1)=BTA(NZP)	NE07 024
	TCBLD(NZP+1)=TCBLD(NZP)	NE07 025
	DO 39 J=1,NZ	NE07 026
30	IF (RB(K)-X(J)) 31,32,33	NE07 027
32	Y(J)=BR(K)	NE07 028
	Z(J)=BTA(K)	NE07 029
	ZZ(J)=TCBLD(K)	NE07 030
	GO TO 39	NE07 031
31	K=K+1	NE07 032
	GO TO 30	NE07 033
33	DEL=X(J)-RB(K-1)	NE07 034
	DEL=DEL/(RB(K)-RB(K-1))	NE07 035
	Y(J)=DEL*(BR(K)-BR(K-1))	NE07 036
	Y(J)=Y(J)+BR(K-1)	NE07 037
	Z(J)=DEL*(BTA(K)-BTA(K-1))	NE07 038
	Z(J)=Z(J)+BTA(K-1)	NE07 039
	ZZ(J)=DEL*(TCBLD(K)-TCBLD(K-1))	NE07 040
	ZZ(J)=ZZ(J)+TCBLD(K-1)	NE07 041
39	CONTINUE	NE07 042
	DO 40 J=1,NZ	NE07 043
	RB(J)=X(J)	NE07 044
	BR(J)=Y(J)	NE07 045
	BTA(J)=Z(J)	NE07 046
	TCBLD(J)=ZZ(J)	NE07 047
40	CONTINUE	NE07 048
	RETURN	NE07 049
	END	NE07 050
		NE07 051
		NE07 052

C	SUBROUTINE CLALF (J)	NE08 001
C	COMPUTATION OF BLADE SECTION LIFT COEFFICIENT	NE08 002
C		NE08 003
C	DIMENSION TCB(10),CLMX(10)	NE08 004
C		NE08 005
C	DIMENSION B(6),BS(6),SA(6),SAS(6),P(6,6)	NE08 006
C	DIMENSION RB(25),BR(25),BTA(25),TCBLD(25),RA(25),XPRES(25),PHI(5)	NE08 007
C	DIMENSION ALPHA(25),STALL(25),JSTL(25),TALK(20)	NE08 008
C		NE08 009
C	COMMON MZZZ,CD,R0,R1,R2,R3,PI,B,BS,SA,SAS,P	NE08 010
C	COMMON/NEAR1/ NRUN,NBLD,NZ,MZ,NPRES,IR,NTIME,NERR,NPAG,NPHI,NPRINT	NE08 011
C	COMMON/NEAR3/ RRP,XP,Z,BLD,RB,BR,BTA,TCBLD,TC,RCBRP,APA,ALF,XPRES,	NE08 012
C	1 RA,XCB,XR,ELCBC,RMAX,PHI,CORJ,CORCB	NE08 013
C	COMMON/NEAR5/ ARJ,ARJP,EPS,RAD,CL,ALPHA,STALL,JSTL,TALK	NE08 014
C		NE08 015
C	101 FORMAT (//////////70H THE BLADE THICKNESS-TO-CHORD RATIO IS OUT	NE08 016
C	1SIDE THE RANGE 0.0 TO .34)	NE08 017
C	IF (MZZZ) 2,1,2	NE08 018
C	1 CONTINUE	NE08 019
C		NE08 020
C	TABLE OF VALUES OF CLMAX VERSUS BLADE THICKNESS-TO-CHORD RATIO	NE08 021
C		NE08 022
C	TCB(1)=0.0	NE08 023
C	TCB(2)=.06	NE08 024
C	TCB(3)=.08	NE08 025
C	TCB(4)=.10	NE08 026
C	TCB(5)=.12	NE08 027
C	TCB(6)=.15	NE08 028
C	TCB(7)=.18	NE08 029
C	TCB(8)=.21	NE08 030
C	TCB(9)=.24	NE08 031
C	TCB(10)=.34	NE08 032
C		NE08 033
C	CLMX(1)=0.9	NE08 034
C	CLMX(2)=0.9	NE08 035
C	CLMX(3)=1.2	NE08 036
C	CLMX(4)=1.45	NE08 037
C	CLMX(5)=1.6	NE08 038
C	CLMX(6)=1.5	NE08 039
C	CLMX(7)=1.35	NE08 040
C	CLMX(8)=1.3	NE08 041
C	CLMX(9)=1.25	NE08 042
C	CLMX(10)=1.1	NE08 043
C	RETURN	NE08 044
C		NE08 045
C	2 CONTINUE	NE08 046
C	19 IF (TCB(10)-TCBLD(J)) 21,20,20	NE08 047
C	20 IF (TCB(1)-TCBLD(J)) 22,22,21	NE08 048
C	21 WRITE (6,101)	NE08 049
C	NERR=1	NE08 050
C	RETURN	NE08 051
C	22 N=1	NE08 052
C	23 IF (TCB(N)-TCBLD(J)) 24,25,26	NE08 053
C	24 N=N+1	NE08 054
C	GO TO 23	NE08 055
C	25 CLMAX=CLMX(N)	NE08 056
C	GO TO 27	NE08 057
C	26 DEL=(TCBLD(J)-TCB(N-1))/(TCB(N)-TCB(N-1))	NE08 058
C		NE08 059

```
      CLMAX=CLMX(N-1)+DEL*(CLMX(N)-CLMX(N-1))
27  CONTINUE
      CL=2.*PI*ALPHA(J)/RAD
      STALL(J)=0.0
28  IF (CL-CLMAX) 29,30,30
30  CL=CLMAX
      STALL(J)=1.0
29  CONTINUE
      RETURN
      END
```

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NE08 060
NE08 061
NE08 062
NE08 063
NE08 064
NE08 065
NE08 066
NE08 067
NE08 068
NE08 069
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	SUBROUTINE ARCSIN(ARG,PHI,INDEX)	NE09 001
C		NE09 002
C	SUBROUTINE FOR COMPUTING ARC SINE	NE09 003
C		NE09 004
C		NE09 005
C	ARG IS THE SINE OF THE ANGLE.	NE09 006
C	PHI IS THE ANGLE (PRINCIPAL VALUE, $-\pi/2$ TO $\pi/2$)	NE09 007
C	OUTPUT FROM SUBROUTINE.	NE09 008
C	INDEX IS 1 IF ANGLE IS TO BE IN RADIANS.	NE09 009
C	INDEX IS 0 IF ANGLE IS TO BE IN DEGREES.	NE09 010
C		NE09 011
	HPI=1.5707963	NE09 012
	A=1.0-ARG*ARG	NE09 013
	IF (A) 5,2,1	NE09 014
2	IF (ARG) 4,3,3	NE09 015
3	PHI=HPI	NE09 016
	GO TO 6	NE09 017
4	PHI=-HPI	NE09 018
	GO TO 6	NE09 019
1	PHI=ATAN (ARG/SQRT (A))	NE09 020
	GO TO 6	NE09 021
5	WRITE (6,100)	NE09 022
100	FORMAT(/5X30HERROR...SIN X GREATER THAN 1.0//)	NE09 023
	GO TO 2	NE09 024
6	IF(INDEX) 7,7,8	NE09 025
7	PHI=90.*PHI/HPI	NE09 026
8	RETURN	NE09 027
	END	NE09 028

SUBROUTINE MATRIX (A,NR)	NE10 001
DIMENSION A(6, 7),B(19,19),N(12)	NE10 002
NC=NR+1	NE10 003
DO 1 J=1,NR	NE10 004
1 N(J)=0	NE10 005
DO 2 I=1,NR	NE10 006
CON=0.0	NE10 007
II=I-1	NE10 008
DO 3 J=1,NR	NE10 009
JJ=J-1	NE10 010
IF (II) 4,4,5	NE10 011
5 DO 6 K=1,II	NE10 012
IF (J-N(K)) 6,3,6	NE10 013
6 CONTINUE	NE10 014
4 CONA=A(J,1)	NE10 015
IF (CONA) 8,9,9	NE10 016
8 CONA=-CONA	NE10 017
9 IF (CONA-CON) 3,3,11	NE10 018
11 CON=CONA	NE10 019
N(I)=J	NE10 020
3 CONTINUE	NE10 021
IF(CON) 500,600,500	NE10 022
600 WRITE (6,601) I	NE10 023
601 FORMAT(13H SINGULAR, I=,I3)	NE10 024
STOP	NE10 025
500 NN=N(I)	NE10 026
DO 12 J=1,NR	NE10 027
12 A(J,NC)=0.0	NE10 028
A(NN,NC)=1.0	NE10 029
DIV=A(NN,1)	NE10 030
DO 13 L=1,NC	NE10 031
13 A(NN,L)=A(NN,L)/DIV	NE10 032
DO 14 L=1,NR	NE10 033
IF (L-NN) 15,14,15	NE10 034
15 CMULT=A(L,1)	NE10 035
DO 16 J=1,NC	NE10 036
16 A(L,J)=A(L,J)-CMULT*A(NN,J)	NE10 037
14 CONTINUE	NE10 038
DO 17 L=1,NR	NE10 039
DO 18 J=1,NR	NE10 040
18 A(L,J)=A(L,J+1)	NE10 041
17 CONTINUE	NE10 042
2 CONTINUE	NE10 043
DO 19 J=1,NR	NE10 044
DO 20 L=1,NR	NE10 045
NN=N(J)	NE10 046
20 B(J,L)=A(NN,L)	NE10 047
19 CONTINUE	NE10 048
DO 21 J=1,NR	NE10 049
DO 22 L=1,NR	NE10 050
NN=N(J)	NE10 051
22 A(L,NN)=B(L,J)	NE10 052
21 CONTINUE	NE10 053
RETURN	NE10 054
END	NE10 055

C	SUBROUTINE FOURCS (F,B,N,NOUT,NPRINT)	NE11 001
C		NE11 002
C	SUB. FOURCS -- FOURIER COSINE SERIES DETERMINATION	NE11 003
C	FROM RALSTON AND WILF -- MATH. METHODS FOR DIGITAL COMPUTERS	NE11 004
C	CHAPT. 24 BY G. GOERTZEL	NE11 005
C		NE11 006
	DIMENSION F(50),FF(50),B(50)	NE11 007
	COMMON MZZZ	NE11 008
700	FORMAT (1H /)	NE11 009
701	FORMAT (4E15.7)	NE11 010
702	FORMAT(5X5HTHETA6X10HFOURIER FN6X11HORIGINAL FN4X12HFOURIER COEF/)	NE11 011
	PI=3.1415927	NE11 012
	IF(NOUT-N)10,10,11	NE11 013
11	NOUT=N	NE11 014
10	ZRO=0.	NE11 015
	ONE=1.0	NE11 016
	TWO=2.0	NE11 017
	IZRO=0	NE11 018
	IONE=1	NE11 019
	ITWO=2	NE11 020
	HPI=1.5707963	NE11 021
	NH=N	NE11 022
	NS=ITWO*(NH-IONE)	NE11 023
	FNS=NS	NE11 024
	FR=TWO/FNS	NE11 025
	PIN=PI*FR	NE11 026
	DO 201 I=1,NH	NE11 027
	CJ=I-IONE	NE11 028
	CSI=COS (PIN*CJ)	NE11 029
	CCSI=CSI+CSI	NE11 030
	CA=ZRO	NE11 031
	CB=ZRO	NE11 032
	DO 202 J=2,NS	NE11 033
	JK=NS-J+ITWO	NE11 034
	IF(JK-NH) 220,220,221	NE11 035
221	JK=ITWO*NH-JK	NE11 036
220	CC=F(JK)+CA*CCSI-CB	NE11 037
	CB=CA	NE11 038
202	CA=CC	NE11 039
	FF(I)=FR*(F(1)+CA*CSI-CB)	NE11 040
	IF(I-IONE) 290,291,290	NE11 041
291	FF(I)=FF(I)/TWO	NE11 042
290	JN=NS-I-I+IONE	NE11 043
	IF(JN) 203,204,204	NE11 044
203	FF(I)=FF(I)/TWO	NE11 045
204	CONTINUE	NE11 046
201	CONTINUE	NE11 047
	IF (NPRINT-1)2,6,7	NE11 048
6	M=N	NE11 049
	GO TO 1	NE11 050
7	M=NOUT	NE11 051
1	CN=N	NE11 052
	WRITE (6,700)	NE11 053
	WRITE (6,702)	NE11 054
	DTH=PI/(CN-1.0)	NE11 055
	TH=-DTH	NE11 056
	DO 3 I=1,N	NE11 057
	TH=TH+DTH	NE11 058
	SUM=0.0	NE11 059

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DO 4 J=1,M
  CJ=J-1
4 SUM=SUM+ FF(J)*COS (CJ*TH)
3 WRITE (6,701) TH, SUM,F(I), FF(I)
2 DO 8 K=1,NOUT
8 B(K)=FF(K)
  RETURN
END
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NE11 060
NE11 061
NE11 062
NE11 063
NE11 064
NE11 065
NE11 066
NE11 067
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	SUBROUTINE SRCRNG (CD,XSC,TC,NRP,RP,UQD)	NE12 001
C		NE12 002
C	VELOCITY INDUCED BY DISTRIBUTION OF SOURCE RINGS	NE12 003
C		NE12 004
	DIMENSION TH(205),QD(205),DI(3),A(6),RP(25),UQD(25)	NE12 005
	COMMON MZ	NE12 006
	PI=3.1415926	NE12 007
	A(1)=TC* 2.969	NE12 008
	A(2)=-TC*1.26	NE12 009
	A(3)=-TC*3.516	NE12 010
	A(4)=TC* 2.843	NE12 011
	A(5)=-TC*1.015	NE12 012
	DQ =200.	NE12 013
	DTI=200.	NE12 014
14	DT=PI/DQ	NE12 015
	XS=XSC-.5	NE12 016
	N=DQ	NE12 017
	NM=N	NE12 018
	N=N+1	NE12 019
	K=N+4	NE12 020
	DO 15 J=1,K	NE12 021
	TH(J)=0.	NE12 022
15	QD(J)=0.	NE12 023
	DO 19 J=2,N	NE12 024
	TH(J)=TH(J-1)+DT	NE12 025
120	T=TH(J)	NE12 026
	ST=SIN (T)	NE12 027
	SN2=SIN (T/2.)	NE12 028
	QD(J)=A(1)/2./SN2	NE12 029
	DO 18 I=2,5	NE12 030
	IN=I-1	NE12 031
	EN=IN	NE12 032
	INX=IN+IN-2	NE12 033
	ENX=INX	NE12 034
	QD(J)=QD(J)+EN*A(I)*(SN2**ENX)	NE12 035
18	CONTINUE	NE12 036
	QD(J)=QD(J)*ST	NE12 037
19	CONTINUE	NE12 038
	TH(N+1)=PI+1.	NE12 039
	QD(N+1)=QD(N)	NE12 040
22	QD(1)=A(1)	NE12 041
	TH(1)=0.	NE12 042
31	DTP=PI/DTI	NE12 043
	TP=0.	NE12 044
	H=DTP/3.	NE12 045
	UI=0.	NE12 046
	CST=-2.*XS	NE12 047
	CST2=CST*CST	NE12 048
40	DO 69 JR=1,NRP	NE12 049
	R=RP(JR)	NE12 050
50	K=1	NE12 051
	NT=1	NE12 052
51	DO 60 J=K,3	NE12 053
	CTP=COS (TP)	NE12 054
	ZWP=CD*(CTP-CST)	NE12 055
	PP=(ZWP*ZWP)+((R+1.)*(R+1.))	NE12 056
	PM=(ZWP*ZWP)+((R-1.)*(R-1.))	NE12 057
	AK2=4.*R/PP	NE12 058
	CALL ELLIPS (AK2,ZK,ZE)	NE12 059

PP=SQRT (PP)	NE12 060
U=ZWP*ZE/PP/PM	NE12 061
52 IF(TP=TH(NT))55,54,53	NE12 062
53 NT=NT+1	NE12 063
GO TO 52	NE12 064
54 Q=QD(NT)	NE12 065
GO TO 56	NE12 066
55 Q=QD(NT-1)+(TP-TH(NT-1))*(QD(NT)-QD(NT-1))/(TH(NT)-TH(NT-1))	NE12 067
56 DI(J)=Q*U	NE12 068
60 TP=TP+DTP	NE12 069
K=2	NE12 070
UI=UI+H*(DI(1)+4.*DI(2)+DI(3))	NE12 071
DI(1)=DI(3)	NE12 072
IF(TP=PI)51,51,61	NE12 073
61 UV=UI*CD/PI	NE12 074
UQD(JR)=UV	NE12 075
TP=0.	NE12 076
UI=0.	NE12 077
69 CONTINUE	NE12 078
RETURN	NE12 079
END	NE12 080

C	SUBROUTINE VTXRNG (CD,XSC,IR,RP,CN,UG,XPRES,P)	NE13 001
C	VELOCITY INDUCED BY DISTRIBUTION OF VORTEX RINGS	NE13 002
C	DIMENSION TH(205),GD(205),DI(3),RP(25),UG(25),CN(6),XPRES(25)	NE13 003
C	DIMENSION FU(50),FV(50),CP(6),P(6,6)	NE13 004
C	COMMON MZZZ	NE13 005
C	C0=CN(1)	NE13 006
	C1=CN(2)	NE13 007
	C2=CN(3)	NE13 008
	C3=CN(4)	NE13 009
	C4=CN(5)	NE13 010
	C5=CN(6)	NE13 011
C	SET UP A TABLE OF GAMMA D/GAMMA * SIN(THETA) VERSUS THETA	NE13 012
C	DG=100.	NE13 013
	DTI=200.	NE13 014
	PI=3.1415926	NE13 015
13	DT=PI/DG	NE13 016
	N=DG	NE13 017
	NM=N	NE13 018
	N=N+1	NE13 019
	K=N+4	NE13 020
	DO 12 J=1,K	NE13 021
	TH(J)=0.	NE13 022
	ST=0.0	NE13 023
12	GD(J)=0.	NE13 024
	DO 19 J=2,N	NE13 025
	TH(J)=TH(J-1)+DT	NE13 026
120	T=TH(J)	NE13 027
	CT=COS (T/2.)	NE13 028
	CT=CT/SIN (T/2.)	NE13 029
	A=C0*CT	NE13 030
	ST=SIN (T)	NE13 031
	B=C1*ST	NE13 032
	C=C2*SIN (2.*T)	NE13 033
	D=C3*SIN (3.*T)	NE13 034
	E=C4*SIN (4.*T)	NE13 035
	F=C5*SIN (5.*T)	NE13 036
	GD(J)=A+B+C+D+E+F	NE13 037
	GD(J)=GD(J)*ST	NE13 038
19	CONTINUE	NE13 039
	TH(N+1)=PI+1.	NE13 040
	GD(N+1)=GD(N)	NE13 041
22	GD(1)=2.*C0	NE13 042
	TH(1)=0.	NE13 043
31	DTP=PI/DTI	NE13 044
	TP=0.	NE13 045
	H=DTP/3.	NE13 046
	UI=0.	NE13 047
C	IF (MZZZ) 200,10,10	NE13 048
C	10 IF (IR) 70,11,11	NE13 049
C	11 XS=XSC-.5	NE13 050
	CST=-2.*XS	NE13 051
		NE13 052
		NE13 053
		NE13 054
		NE13 055
		NE13 056
		NE13 057
		NE13 058
		NE13 059

C	CST2=CST*CST	NE13 060
C	COMPUTE INFLOW VELOCITIES	NE13 061
C		NE13 062
	40 DO 69 JR=1,IR	NE13 063
	R=RP(JR)	NE13 064
	50 K=1	NE13 065
	NT=1	NE13 066
	51 DO 60 J=K,3	NE13 067
	STP=SIN (TP)	NE13 068
	CTP=COS (TP)	NE13 069
	CTP2=CTP*CTP	NE13 070
	X2=CST2-(2.*CST*CTP)+CTP2	NE13 071
	X2=X2*CD*CD	NE13 072
	PP=X2+((R+1.)*(R+1.))	NE13 073
	PM=X2+((R-1.)*(R-1.))	NE13 074
	AK2=4.*R/PP	NE13 075
	CALL ELLIPS (AK2,ZK,ZE)	NE13 076
	PM=2.*(R-1.)/PM	NE13 077
	PP=1./SQRT (PP)	NE13 078
	U=ZK-ZE*(1.+PM)	NE13 079
	U=U*PP	NE13 080
	52 IF (TP-TH(NT))55,54,53	NE13 081
	53 NT=NT+1	NE13 082
	GO TO 52	NE13 083
	54 G=GD(NT)	NE13 084
	GO TO 56	NE13 085
	55 G=GD(NT-1)+(TP-TH(NT-1))*(GD(NT)-GD(NT-1))/(TH(NT)-TH(NT-1))	NE13 086
	56 DI(J)=G*U	NE13 087
	60 TP=TP+DTP	NE13 088
	K=2	NE13 089
	UI=UI+H*(DI(1)+4.*DI(2)+DI(3))	NE13 090
	DI(1)=DI(3)	NE13 091
	IF (TP-PI)51,51,61	NE13 092
	61 UG(JR)=CD/2./PI*UI	NE13 093
	TP=0.	NE13 094
	UI=0.	NE13 095
	69 CONTINUE	NE13 096
	GO TO 999	NE13 097
C		NE13 098
C	COMPUTE VELOCITIES INDUCED AT THE DUCT REFERENCE CYLINDER	NE13 099
C		NE13 100
	70 IR=-IR	NE13 101
	DO 99 JR=1,IR	NE13 102
	X=XPRES(JR)	NE13 103
	K=1	NE13 104
	NT=1	NE13 105
	XS=X-.5	NE13 106
	CST=-2.*XS	NE13 107
	CST2=CST*CST	NE13 108
	77 DO 71 J=K,3	NE13 109
	CTP=COS (TP)	NE13 110
	CTP2=CTP*CTP	NE13 111
	X2=CST2-(2.*CST*CTP)+CTP2	NE13 112
	X2=X2*CD*CD	NE13 113
	PP=X2+4.	NE13 114
	AK2=4./PP	NE13 115
	CALL ELLIPS (AK2,ZK,ZE)	NE13 116
	PP=1./SQRT (PP)	NE13 117
		NE13 118

U=(ZK-ZE)*PP	NE13 119
72 IF (TP=TH(NT)) 75,74,73	NE13 120
73 NT=NT+1	NE13 121
GO TO 72	NE13 122
74 G=GD(NT)	NE13 123
GO TO 76	NE13 124
75 G=GD(NT-1)+(TP-TH(NT-1))*(GD(NT)-GD(NT-1))/(TH(NT)-TH(NT-1))	NE13 125
76 DI(J)=G*U	NE13 126
71 TP=TP+DTP	NE13 127
K=2	NE13 128
UI=UI+H*(DI(1)+4.*DI(2)+DI(3))	NE13 129
DI(1)=DI(3)	NE13 130
IF (TP=PI) 77,77,78	NE13 131
78 UG(JR)=CD/2./PI*UI	NE13 132
TP=0.	NE13 133
UI=0.	NE13 134
99 CONTINUE	NE13 135
GO TO 999	NE13 136
C	NE13 137
C COMPUTE F(N) AND F-STAR(N) FOURIER COEFFICIENTS	NE13 138
C	NE13 139
200 MZZ=MZZZ	NE13 140
MZZZ=1	NE13 141
DO 210 J=1,6	NE13 142
210 CP(J)=0.0	NE13 143
DUM=0.0	NE13 144
DO 211 L=1,6	NE13 145
211 DUM=DUM + CN(L)*P(1,L)	NE13 146
CP(1)=(CN(1)-DUM)/2.0	NE13 147
DO 212 K=2,6	NE13 148
DO 213 L=1,6	NE13 149
213 CP(K)=CP(K) + CN(L)*P(K,L)	NE13 150
212 CP(K)=(CP(K)-CN(K))/2.0	NE13 151
N=IR	NE13 152
EN=N	NE13 153
DTA=PI/(EN-1.)	NE13 154
TA=-DTA	NE13 155
DO 220 JR=1,N	NE13 156
TA=TA+DTA	NE13 157
CSTA=COS(TA)	NE13 158
CSTA2=CSTA*CSTA	NE13 159
DUM=0.0	NE13 160
DO 215 K=2,6	NE13 161
J=K-1	NE13 162
TJ=J	NE13 163
215 DUM=DUM+CP(K)*COS(TJ*TA)	NE13 164
FV(JR)=CP(1)+DUM	NE13 165
K=1	NE13 166
NT=1	NE13 167
207 DO 201 J=K,3	NE13 168
CTP=COS(TP)	NE13 169
CTP2=CTP*CTP	NE13 170
X2=CSTA2-(2.*CSTA*CTP)+CTP2	NE13 171
X2=X2*CD*CD	NE13 172
PP=X2+4.0	NE13 173
AK2=4./PP	NE13 174
CALL ELLIPS (AK2,ZK,ZE)	NE13 175
PP=1./SQRT(PP)	NE13 176
U=(ZK-ZE)*PP	NE13 177

202 IF (TP-TH(NT)) 205,204,203	NE13 178
203 NT=NT+1	NE13 179
GO TO 202	NE13 180
204 G=GD(NT)	NE13 181
GO TO 206	NE13 182
205 G=GD(NT-1)+(TP-TH(NT-1))*(GD(NT)-GD(NT-1))/(TH(NT)-TH(NT-1))	NE13 183
206 DI(J)=G*U	NE13 184
201 TP=TP+DTP	NE13 185
K=2	NE13 186
UI=UI+H*(DI(1)+4.*DI(2)+DI(3))	NE13 187
DI(1)=DI(3)	NE13 188
IF (TP-PI) 207,207,208	NE13 189
208 FU(JR)=CD/2./PI*UI	NE13 190
TP=0.0	NE13 191
UI=0.0	NE13 192
220 CONTINUE	NE13 193
NOUT=6	NE13 194
NPR=0	NE13 195
CALL FOURCS (FU,FU,N,NOUT,NPR)	NE13 196
DO 216 J=1,6	NE13 197
UG(J)=FU(J)	NE13 198
216 UG(J+6)=CP(J)	NE13 199
MZZZ=MZZ	NE13 200
C	NE13 201
999 RETURN	NE13 202
END	NE13 203

	SUBROUTINE ALFRNG (CD,IR,SC,UGA,XPRES)	NE14 001
C	AXIAL VELOCITY INDUCED BY A DISTRIBUTION OF ALPHA VORTEX RINGS	NE14 002
C		NE14 003
	DIMENSION TH(205),GA(205),DI(3),XPRES(25),SC(6),UGA(25),ST(6)	NE14 004
	DIMENSION TCD(7),TSC(6,7)	NE14 005
	DIMENSION GS(6),F(50),HF(6),FH(50),DVT(3)	NE14 006
C		NE14 007
	COMMON MZZZ	NE14 008
C		NE14 009
	DATA TCD/ 0.,0.5,0.75,1.0,1.5,2.0,5.0/	NE14 010
	DATA (TSC(I,1),I=1,6)/1.7,0.,0.,0.,0.,0./	NE14 011
	DATA (TSC(I,2),I=1,6)/1.0978,-0.2382,-0.0175,0.,0.,0./	NE14 012
	DATA (TSC(I,3),I=1,6)/0.92,-0.345,-0.042,0.,0.,0./	NE14 013
	DATA (TSC(I,4),I=1,6)/0.7955,-0.4151,-0.0680,0.,0.,0./	NE14 014
	DATA (TSC(I,5),I=1,6)/0.5611,-0.4834,-0.1230,-0.0121,0.,0./	NE14 015
	DATA (TSC(I,6),I=1,6)/0.5640,-0.5045,-0.1666,-0.0317,0.0035,0./	NE14 016
	DATA (TSC(I,7),I=1,6)/0.3566,-0.4590,-0.2607,-0.1246,-0.0494,0./	NE14 017
C		NE14 018
	IF (MZZZ) 2,1,2	NE14 019
	1 CONTINUE	NE14 020
C		NE14 021
C	COMPUTE SC(N) COEFFICIENTS	NE14 022
C		NE14 023
	DO 11 J=1,7	NE14 024
	JSC=J	NE14 025
	IF (CD-TCD(J)) 4,3,11	NE14 026
	11 CONTINUE	NE14 027
	3 DO 5 N=1,6	NE14 028
	5 SC(N)=TSC(N,JSC)	NE14 029
	GO TO 10	NE14 030
	4 IF (JSC-1) 6,6,7	NE14 031
	6 RETURN	NE14 032
	7 DELSC=(TCD(JSC)-TCD(JSC-1))/(TCD(JSC)-CD)	NE14 033
	J=JSC	NE14 034
	DO 8 N=1,6	NE14 035
	8 SC(N)=(TSC(N,J-1)-TSC(N,J))/DELS + TSC(N,J)	NE14 036
C		NE14 037
C	SET UP A TABLE OF GAMMA ALPHA/V*SIN(THETA) VERSUS THETA	NE14 038
C		NE14 039
	10 PI=3.1415926	NE14 040
	DG=200.	NE14 041
	DT=PI/DG	NE14 042
	K=201	NE14 043
	DO 12 J=1,K	NE14 044
	TH(J)=0.0	NE14 045
	12 GA(J)=0.0	NE14 046
	DO 20 J=2,K	NE14 047
	TH(J)=TH(J-1)+DT	NE14 048
	T=TH(J)	NE14 049
	CTN=COS(T/2.)/SIN(T/2.)	NE14 050
	CT=COS(T)	NE14 051
	ST(1)=SIN(T)	NE14 052
	ST(2)=2.*ST(1)*CT	NE14 053
	DO 13 N=3,5	NE14 054
	NM=N-1	NE14 055
	NMM=N-2	NE14 056
	13 ST(N)=2.*ST(NM)*CT-ST(NMM)	NE14 057
	GA(J)=SC(1)*CTN	NE14 058
	DO 14 N=2,6	NE14 059

14	GA(J)=GA(J)+SC(N)*ST(N-1)	NE14	060
	GA(J)=GA(J)*ST(1)	NE14	061
20	CONTINUE	NE14	062
	GA(1)=2.*SC(1)	NE14	063
	TH(K+1)=PI+1.	NE14	064
	GA(K+1)=GA(K)	NE14	065
C		NE14	066
C	COMPUTE G-STAR(N) AND H(N) FOURIER COEFFICIENTS	NE14	067
C		NE14	068
	MZZZ=1	NE14	069
	DTI=200.	NE14	070
	DTP=PI/DTI	NE14	071
	H=DTP/3.	NE14	072
	TP=0.0	NE14	073
	UI=0.0	NE14	074
	VIT=0.0	NE14	075
	R=1.0	NE14	076
	R32=R**1.5	NE14	077
	RP2=(R+1.)**2	NE14	078
	N=IR	NE14	079
	CN=N	NE14	080
	DTA=PI/(CN-1.)	NE14	081
	TA=-DTA	NE14	082
	DO 50 JR=1,N	NE14	083
	TA=TA+DTA	NE14	084
	CSTA=COS(TA)	NE14	085
	K=1	NE14	086
	NT=1	NE14	087
47	DO 41 J=K,3	NE14	088
	CTP=COS(TP)	NE14	089
	XI=(CTP-CSTA)*CD	NE14	090
	X2=XI*XI	NE14	091
	DEN=X2+RP2	NE14	092
	AK2=4.*R/DEN	NE14	093
C		NE14	094
C	CALL ELLIPSE(AK2,ZK,ZE)	NE14	095
		NE14	096
	AKP=1.0-AK2	NE14	097
	AKQ=2.0-AK2	NE14	098
	AK4=AK2*AK2	NE14	099
	AYE=((8.0*R*AKQ/AK4) + (2.*R) + 2.0 - 4./AK2*(2.*R+1.))*ZE	NE14	100
	AYE=AYE + AKP/AK2*(8.*R + 4. - 16.*R/AK2)*ZK	NE14	101
	U=AYE/SQRT(DEN)/(X2+(R-1.)*(R-1.))	NE14	102
	AK=SQRT(AK2)	NE14	103
	AKZ=4.*R/RP2	NE14	104
	SBETA=SQRT((1.-AKZ)/(1.-AK2))	NE14	105
C		NE14	106
	CALL ARCSIN (SBETA,BETA,0)	NE14	107
	CALL ARCSIN (AK,ASK,0)	NE14	108
	CALL LAMBDA (ASK,BETA,HLMB)	NE14	109
C		NE14	110
	EPSR=1.	NE14	111
	AVT=4.*((ZK-ZE)/AK+2.*PI*AK/SQRT(AKZ)*(1.-HLMB)*SQRT((1.-AKZ)/(AKZ	NE14	112
1	-AK2))	NE14	113
	AVT=AVT*XI/(8.*PI*R32) + EPSR/4.	NE14	114
42	IF (TP-TH(NT)) 45,44,43	NE14	115
43	NT=NT+1	NE14	116
	GO TO 42	NE14	117
44	G=GA(NT)	NE14	118

GO TO 46	NE14 119
45 G=GA(NT-1)+(TP-TH(NT-1))*(GA(NT)-GA(NT-1))/(TH(NT)-TH(NT-1))	NE14 120
46 DI(J)=G*U	NE14 121
DVT(J)=G*AVT	NE14 122
41 TP=TP+DTP	NE14 123
K=2	NE14 124
UI=UI+H*(DI(1)+4.*DI(2)+DI(3))	NE14 125
DI(1)=DI(3)	NE14 126
VIT=VIT+H*(DVT(1)+4.*DVT(2)+DVT(3))	NE14 127
DVT(1)=DVT(3)	NE14 128
IF (TP-PI) 47,47,48	NE14 129
48 F(JR)=-CD*UI/2./PI	NE14 130
FH(JR)=CD*VIT	NE14 131
TP=0.0	NE14 132
UI=0.0	NE14 133
VIT=0.0	NE14 134
50 CONTINUE	NE14 135
NOUT=6	NE14 136
NPR=0	NE14 137
CALL FOURCS (F,F,N,NOUT,NPR)	NE14 138
CALL FOURCS (FH,FH,N,NOUT,NPR)	NE14 139
DO 51 J=1,NOUT	NE14 140
GS(J)=F(J)	NE14 141
HF(J)=FH(J)	NE14 142
UGA(J+6)=HF(J)	NE14 143
51 UGA(J)=GS(J)	NE14 144
MZZZ=0	NE14 145
RETURN	NE14 146
2 CONTINUE	NE14 147
TP=0.0	NE14 148
UI=0.0	NE14 149
	NE14 150
CALCULATE THE AXIAL VELOCITY INDUCED BY THE ABOVE VORTEX DISTRIBUTION	NE14 151
	NE14 152
70 DO 99 JR=1,IR	NE14 153
X=XPRES(JR)	NE14 154
K=1	NE14 155
NT=1	NE14 156
XS=X-.5	NE14 157
CST=-2.*XS	NE14 158
R=1.0	NE14 159
77 DO 71 J=K,3	NE14 160
CTP=COS(TP)	NE14 161
X2=(CTP-CST)*CD	NE14 162
X2=X2*X2	NE14 163
DEN=X2+(R+1.)*(R+1.)	NE14 164
AK2=4.*R/DEN	NE14 165
CALL ELLIPS (AK2,ZK,ZE)	NE14 166
AKP=1.0-AK2	NE14 167
AKQ=2.0-AK2	NE14 168
AK4=AK2*AK2	NE14 169
AYE=((8.0*R*AKQ/AK4) + (2.*R) + 2.0 - 4./AK2*(2.*R+1.))*ZE	NE14 170
AYE=AYE + AKP/AK2*(8.*R + 4. - 16.*R/AK2)*ZK	NE14 171
U=AYE/SQRT(DEN)/(X2+(R-1.)*(R-1.))	NE14 172
72 IF (TP-TH(NT)) 75,74,73	NE14 173
73 NT=NT+1	NE14 174
GO TO 72	NE14 175
74 G=GA(NT)	NE14 176
GO TO 76	NE14 177

75	G=GA(NT-1)+(TP-TH(NT-1))*(GA(NT)-GA(NT-1))/(TH(NT)-TH(NT-1))	NE14	178
76	DI(J)=G*U	NE14	179
71	TP=TP+DTP	NE14	180
	K=2	NE14	181
	UI=UI+H*(DI(1)+4.*DI(2)+DI(3))	NE14	182
	DI(1)=DI(3)	NE14	183
	IF (TP-PI) 77,77,78	NE14	184
78	UGA(JR)=-CD*UI/2./PI	NE14	185
	TP=0.0	NE14	186
	UI=0.0	NE14	187
99	CONTINUE	NE14	188
999	RETURN	NE14	189
	END	NE14	190

C	SUBROUTINE GAMCYL (CD,XC,N,RP,UG,IR,XPRES,UGP,RRP,RA)	NE15 001
C		NE15 002
C	SUBROUTINE TO COMPUTE THE AXIAL VELOCITIES INDUCED BY CONSTANT	NE15 003
C	STRENGTH VORTEX CYLINDERS	NE15 004
C		NE15 005
	DIMENSION RP(25),UG(25),XPRES(25),UGP(25,25),RA(25)	NE15 006
	COMMON MZ	NE15 007
C		NE15 008
	PI=3.1415926	NE15 009
	NR=N	NE15 010
	CR=CD*2.	NE15 011
	IF (IR) 2,1,2	NE15 012
	1 XG=(XC-1.)*CR	NE15 013
C		NE15 014
C	COMPUTE THE VELOCITY INDUCED AT THE PROPELLER STATION	NE15 015
C		NE15 016
	20 DO 30 J=1,NR	NE15 017
	R=RP(J)	NE15 018
	IF(R) 22,21,22	NE15 019
	21 U=SQRT ((XG*XG)+1.)	NE15 020
	U=XG/U+1.0	NE15 021
	U=0.5*U	NE15 022
	GO TO 30	NE15 023
	22 XG2=XG*XG	NE15 024
	RP1=(R+1.)*(R+1.)	NE15 025
	RM1=(R-1.)*(R-1.)	NE15 026
	SNB=SQRT (XG2+RM1)	NE15 027
	SNB=XG/SNB	NE15 028
	SKG2=4.*R/(XG2+RP1)	NE15 029
	CALL ELLIPS(SKG2,ZK,ZE)	NE15 030
	SKG=SQRT (SKG2)	NE15 031
	CALL ARCSIN(SKG,ASKG,0)	NE15 032
	CALL ARCSIN(SNB,BETA,0)	NE15 033
	NDEX=0	NE15 034
	IF (BETA) 23,24,24	NE15 035
	23 BETA=-BETA	NE15 036
	NDEX=1	NE15 037
	24 CALL LAMBDA(ASKG,BETA,HLMB)	NE15 038
	IF(NDEX) 25,26,25	NE15 039
	25 HLMB=-HLMB	NE15 040
	NDEX=0	NE15 041
	26 CONTINUE	NE15 042
	U=.25*HLMB+.5	NE15 043
	TM=SKG*XG*ZK/(4.*PI)	NE15 044
	TM=TM/SQRT (R)	NE15 045
	U=U+TM	NE15 046
	30 UG(J)=U	NE15 047
	GO TO 99	NE15 048
	2 NCYL=N	NE15 049
C		NE15 050
C	COMPUTE THE VELOCITY INDUCED AT THE REFERENCE CYLINDER BY	NE15 051
C	THE TRAILING VORTEX CYLINDERS	NE15 052
C		NE15 053
	DO 60 J=1,NCYL	NE15 054
	RGR=RA(J)/RRP	NE15 055
	RGR2=(RGR+1.)*(RGR+1.)	NE15 056
	RGRM=(RGR-1.)*(RGR-1.)	NE15 057
	RTRGR=SQRT(RGR)	NE15 058
	IF (J-NCYL) 31,32,32	NE15 059

32	XP=1.0	NE15	060
	RGR=1.0	NE15	061
	RGR2=4.0	NE15	062
	RGRM=0.0	NE15	063
	GO TO 33	NE15	064
31	XP=XC	NE15	065
33	DO 60 JR=1,IR	NE15	066
	X=XPRES(JR)	NE15	067
	XG=X-XP	NE15	068
	XGR=XG*CR	NE15	069
	XGR2=XGR*XGR	NE15	070
	IF (XGR) 38,42,38	NE15	071
42	IF (RGR-1.0) 142,242,342	NE15	072
142	UG=0.0	NE15	073
	GO TO 60	NE15	074
242	UG=0.25	NE15	075
	GO TO 60	NE15	076
342	UG=0.50	NE15	077
	GO TO 60	NE15	078
38	CONTINUE	NE15	079
	GKSQ=4.*RGR/(XGR2+RGR2)	NE15	080
	GK=SQRT(GKSQ)	NE15	081
	CALL ELLIPS (GKSQ,ZK,ZE)	NE15	082
	NDEX=0	NE15	083
	SNB=XGR/SQRT(XGR2+RGRM)	NE15	084
	CALL ARCSIN (SNB,BETA,0)	NE15	085
	CALL ARCSIN (GK,ASK,0)	NE15	086
	IF (BETA) 34,35,35	NE15	087
34	BETA=-BETA	NE15	088
	NDEX=-1	NE15	089
35	CALL LAMBDA (ASK,BETA,HLMB)	NE15	090
	IF (NDEX) 36,37,37	NE15	091
36	HLMB=-HLMB	NE15	092
	BETA=-BETA	NE15	093
	NDEX=0	NE15	094
37	CONTINUE	NE15	095
	IF (XGR) 41,42,43	NE15	096
43	NDEX=-1	NE15	097
	HLMB=-HLMB	NE15	098
	XGR=-XGR	NE15	099
41	IF (RGR-1.0) 141,241,241	NE15	100
141	UG=GK*XGR*ZK/(4.*PI*RTRGR)-.25*HLMB	NE15	101
	GO TO 45	NE15	102
241	UG=GK*XGR*ZK/(4.*PI*RTRGR)+0.50+.25*HLMB	NE15	103
45	IF (NDEX) 46,60,60	NE15	104
46	XGR=-XGR	NE15	105
	NDEX=0	NE15	106
	HLMB=-HLMB	NE15	107
47	IF (RGR-1.0) 147,247,347	NE15	108
147	UG=-UG	NE15	109
	GO TO 60	NE15	110
247	UG=-UG+0.5	NE15	111
	GO TO 60	NE15	112
347	UG=-UG+1.0	NE15	113
60	UGP(J,JR)=UG	NE15	114
99	RETURN	NE15	115
	END	NE15	116

C
C
C

SUBROUTINE BNCOEF (C,BGI)

FOURIER ANALYSIS OF RADIAL VELOCITY INDUCED BY AN
ACTUATOR DISK IN THE EXIT PLANE -- B(N)

```

DIMENSION BG( 6,2),BGI(6),BGO( 6)
COMMON MZZZ
PI=3.1415927
MZZZ=-10
N=100
KMAX=6
DO 10 K=1,KMAX
10 BGI(K)=0.0
EPS=PI/180.
PIM=PI-EPS
CN=N
DELTH=.5*PIM/CN
NP=N+1
DO 6 I=1,NP
DO 3 J=1,2
FI=I-2
FJ=J
TH=FI*PIM/CN+FJ*DELTH
STH=SIN (TH)
CTH=COS (TH)
72 XG=-.5*C*(1.+CTH)
73 XGSQ=XG*XG
GKSQ=XGSQ/(4.+XGSQ)
GK=SQRT (4./(4.+XGSQ))
CALL ELLIPS (GKSQ,ZKG,ZCG)
BGC=.5/PI*((GK-2./GK)*ZKG+2./GK*ZCG)
STHK=0.
CTHK=1.
DO 2 K=1,KMAX
BG(K,J)=BGC*CTHK
CON=STHK*CTH+CTHK*STH
CTHK=CTHK*CTH-STHK*STH
2 STHK=CON
3 CONTINUE
DO 5 K=1,KMAX
IF(I-1)4,5,4
4 BGI(K)=BGI(K)+DELTH*(BG(K,1)+(BGO(K)+BG(K,1)+BG(K,2))/3.)
5 BGO(K)=BG(K,2)
6 CONTINUE
EXTRA=-EPS/PI*ALOG(4./EPS*SQRT (2./C))
SI=-1
DO 7 K=1,KMAX
SI=-SI
7 BGI(K)=2.*(BGI(K)+SI*EXTRA)/PI
BGI(1)=.5*BGI(1)
MZZZ=1
RETURN
END

```

NE16 001
NE16 002
NE16 003
NE16 004
NE16 005
NE16 006
NE16 007
NE16 008
NE16 009
NE16 010
NE16 011
NE16 012
NE16 013
NE16 014
NE16 015
NE16 016
NE16 017
NE16 018
NE16 019
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NE16 048
NE16 049
NE16 050
NE16 051
NE16 052
NE16 053

SUBROUTINE ANCOEF(NCYL,N,RA,XP,CD,RRP,NRUN,NPRINT,BS,A,AS)	NE17 001
DIMENSION F(50),BS(6),A(25,6),AS(25,6),RA(25)	NE17 002
COMMON MZZZ	NE17 003
142 FORMAT (1H1,4X10HRUN NUMBER,I5,49X4HPAGE,I3,2H-F,//)	NE17 004
242 FORMAT (10X55HFOURIER COSINE SERIES COEFFICIENTS --- OUTPUT INDEN	NE17 005
1X =,I3)	NE17 006
NPAGE = 0	NE17 007
NOUT = 6	NE17 008
20 CR=CD*2.0	NE17 009
PI=3.1415927	NE17 010
21 CN=N	NE17 011
DTH=PI/(CN-1.)	NE17 012
TH=-DTH	NE17 013
C	NE17 014
C	NE17 015
C	NE17 016
22 DO 30 J=1,N	NE17 017
TH=TH+DTH	NE17 018
CSTH=COS (TH)	NE17 019
XG=-.5*CR*(1.+CSTH)	NE17 020
GKSQ=XG*XG	NE17 021
GKSQ=4.0+GKSQ	NE17 022
GKSQ=4.0/GKSQ	NE17 023
CALL ELLIPS (GKSQ,ZK,ZE)	NE17 024
GK=SQRT (GKSQ)	NE17 025
30 F(J)=0.25+(GK*XG/4.*ZK/PI)	NE17 026
IF(NPRINT) 171,171,170	NE17 027
170 NPAGE = NPAGE + 1	NE17 028
WRITE (6,142) NRUN,NPAGE	NE17 029
WRITE (6,242) NPRINT	NE17 030
171 CALL FOURCS (F,F ,N,NOUT,NPRINT)	NE17 031
DO 31 J=1,NOUT	NE17 032
31 BS(J)=F(J)	NE17 033
C	NE17 034
C	NE17 035
C	NE17 036
32 DO 40 J=1,NCYL	NE17 037
RRR=RRP/RA(J)	NE17 038
RRAP=RRR+1.0	NE17 039
RRAP=RRAP*RRAP	NE17 040
RRR4=4.0*RRR	NE17 041
RASQT=SQRT (RRR)	NE17 042
TH=-DTH	NE17 043
33 DO 38 K=1,N	NE17 044
TH=TH+DTH	NE17 045
CSTH=COS (TH)	NE17 046
XR=CR*(1.-CSTH)*.5	NE17 047
XG=XR-(XP*CR)	NE17 048
XG=XG*RRR	NE17 049
XGSQ=XG*XG	NE17 050
GKSQ=RRAP+XGSQ	NE17 051
GKSQ=RRR4/GKSQ	NE17 052
GK=SQRT (GKSQ)	NE17 053
CALL ELLIPS(GKSQ,ZK,ZE)	NE17 054
F(K)=((ZE-ZK)/GK+(GK*ZK/2.))/PI/RASQT	NE17 055
38 CONTINUE	NE17 056
IF(NPRINT) 173,173,172	NE17 057
172 NPAGE = NPAGE + 1	NE17 058
WRITE (6,142) NRUN,NPAGE	NE17 059

```

WRITE (6,242) NPRINT
173 CALL FOURCS (F,F,N,NOUT,NPRINT)
DO 39 K=1,NOUT
39 A(J,K)=F(K)
40 CONTINUE

```

C
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C

COMPUTE A-STAR(N) FOURIER COEFFICIENTS

```

42 DO 50 J=1,NCYL
  RRA=RRP/RA(J)
  RPRIM=1.0/RRA
  RRAP=RRA+1.0
  RRAP=RRAP*RRAP
  RRA4=4.0*RRA
  RASQT=SQRT (RRA)
  TH=-DTH
43 DO 48 K=1,N
  TH=TH+DTH
  Csth=cos (TH)
  XR=CR*(1.0-Csth)*.5
  XG=XR-(XP*CR)
  XG=XG*RRAP
  XGSQ=XG*XG
  GKSQ=RRAP+XGSQ
  GKSQ=RRA4/GKSQ
  GK=SQRT (GKSQ)
  CALL ELLIPS (GKSQ,ZK,ZE)
  NDEX=0
  SNB=RRA-1.0
  SNB=SNB*SNB
  SNB=XGSQ+SNB
  SNB=1.0/SQRT (SNB)
  SNB=XG*SNB
  CALL ARCSIN (SNB,BETA,0)
  CALL ARCSIN (GK,ASK,0)
  XG=XG*RPRIM
  IF(BETA) 62,63,63
62 BETA=-BETA
  NDEX=-1
63 CALL LAMBDA (ASK,BETA,HLMB)
  IF(NDEX) 64,65,65
64 HLMB=-HLMB
  NDEX=0
  BETA=-BETA
65 CONTINUE
  IF(XG) 71,72,73
72 IF(RPRIM-1.0) 74,75,76
74 F(K)=0.0
  GO TO 48
75 F(K)=-.25
  GO TO 48
76 F(K)=-.50
  GO TO 48
73 NDEX=-1
  HLMB=-HLMB
  XG=-XG
71 IF(RPRIM-1.0) 77,78,78
77 F(K)=-GK*XG*ZK/4.0/PI*RASQT
  F(K)=F(K)+(.25*HLMB)

```

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NE17 060
NE17 061
NE17 062
NE17 063
NE17 064
NE17 065
NE17 066
NE17 067
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NE17 115
NE17 116
NE17 117
NE17 118

```

GO TO 79	NE17 119
78 F(K)=-GK*XG*2K/4.0/PI*RASQT	NE17 120
F(K)=F(K)-.5-(.25*HLMB)	NE17 121
79 IF(NDEX) 80,48,48	NE17 122
80 XG=-XG	NE17 123
NDEX=0	NE17 124
IF(RPRIM-1.) 81,82,83	NE17 125
81 F(K)=-F(K)	NE17 126
GO TO 48	NE17 127
82 F(K)=-F(K)-0.5	NE17 128
GO TO 48	NE17 129
83 F(K)=-F(K)-1.0	NE17 130
48 F(K)=-F(K)	NE17 131
IF(NPRINT) 175,175,174	NE17 132
174 NPAGE = NPAGE + 1	NE17 133
WRITE (6,142) NRUN,NPAGE	NE17 134
WRITE (6,242) NPRINT	NE17 135
175 CALL FOURCS (F,F,N,NOUT,NPRINT)	NE17 136
DO 49 K=1,NOUT	NE17 137
49 AS(J,K)=F(K)	NE17 138
50 CONTINUE	NE17 139
RETURN	NE17 140
END	NE17 141

```

SUBROUTINE CNCOEF (GV,XC)
DIMENSION A(6),B(6),AS(6),BS(6),CN1(6),CN2(6),Q(6,7),P(6,6),XC(6)
DIMENSION CVG(6)
COMMON MZZZ,CD,R0,R1,R2,R3,PI,B,BS,A,AS,P
VG=1.0/GV
C=2.*CD

```

CALCULATE COEFFICIENT MATRIX

```

TR0=2.*R0
35 C4D=C/8.0
36 CLN=ALOG(32.0/C)-1.0
Q(1,1)=1.0-P(1,1)-TR0*C4D*CLN-R1*C4D
Q(1,2)=R2/4.0*C4D-TR0*C4D*0.5*CLN
Q(1,3)=-P(1,3)-R1*0.5*C4D+R3*C4D/6.0
Q(1,4)=-R2*C4D/4.0
Q(1,5)=-P(1,5)-R3*C4D/6.0
Q(1,6)=0.0
Q(2,1)=P(2,1)-TR0*C4D-2.*R1*C4D*CLN-R2*C4D
Q(2,2)=P(2,2)-1.0-R1*C4D*CLN+(R1+R3)*C4D/4.0
Q(2,3)=C4D*(-R0-R2/3.)
Q(2,4)=P(2,4)-C4D*(R3+R1+R1)/8.0
Q(2,5)=-R2*C4D/6.0
Q(2,6)=P(2,6)-R3*C4D/8.0
Q(3,1)=P(3,1)-C4D*(R1+R3)-2.*R2*C4D*CLN
Q(3,2)=R0*C4D/2.0-R2*C4D*CLN
Q(3,3)=P(3,3)-1.0-C4D*(R1/3.+R3/2.)
Q(3,4)=C4D*(R2/8.-R0/2.)
Q(3,5)=P(3,5)+C4D*(R3/10.-R1/6.)
Q(3,6)=-R2*C4D/8.0
Q(4,1)=P(4,1)-C4D*(R2+2.*R3*CLN)
Q(4,2)=P(4,2)+C4D*(R1/4.-R3*CLN)
Q(4,3)=C4D*(R0/3.-R2/2.)
Q(4,4)=P(4,4)-1.0-R1*C4D/8.0
Q(4,5)=C4D*(R2/10.-R0/3.)
Q(4,6)=P(4,6)-R1*C4D/8.0
Q(5,1)=P(5,1)-R3*C4D
Q(5,2)=R2*C4D/4.0
Q(5,3)=P(5,3)+C4D*(R1/6.-R3/2.)
Q(5,4)=C4D*(R0/4.-R2/4.)
Q(5,5)=P(5,5)-1.0-C4D*R1/15.
Q(5,6)=-R0*C4D/4.0
Q(6,1)=P(6,1)
Q(6,2)=P(6,2)+R3*C4D/4.
Q(6,3)=C4D*R2/6.0
Q(6,4)=P(6,4)+C4D*(R1/8.-R3/4.)
Q(6,5)=C4D*(R0/5.-R2/6.)
Q(6,6)=P(6,6)-1.0-C4D*R1/8.

```

CALCULATE CONSTANTS

```

DO 40 I=1,6
CN1(I)=TR0*BS(I)-(2.*B(I))
GO TO (41,42,43,44,45,46),I
41 CN1(I)=CN1(I)+(R1*BS(2))+(R2*BS(3))+(R3*BS(4))
GO TO 40
42 CN1(I)=CN1(I)+R1*(BS(3)+(2.*BS(1)))+R2*(BS(2)+BS(4))+R3*(BS(3)+BS
1(5))
GO TO 40

```

```

NE18 001
NE18 002
NE18 003
NE18 004
NE18 005
NE18 006
NE18 007
NE18 008
NE18 009
NE18 010
NE18 011
NE18 012
NE18 013
NE18 014
NE18 015
NE18 016
NE18 017
NE18 018
NE18 019
NE18 020
NE18 021
NE18 022
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NE18 025
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NE18 036
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NE18 041
NE18 042
NE18 043
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NE18 045
NE18 046
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NE18 048
NE18 049
NE18 050
NE18 051
NE18 052
NE18 053
NE18 054
NE18 055
NE18 056
NE18 057
NE18 058
NE18 059

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43	CN1(I)=CN1(I)+R1*(BS(2)+BS(4))+R2*(BS(5)+(2.*BS(1)))+R3*(BS(2)+BS	NE18	060
	1(6))	NE18	061
	GO TO 40	NE18	062
44	CN1(I)=CN1(I)+R1*(BS(3)+BS(5))+R2*(BS(2)+BS(6))+2.*R3*BS(1)	NE18	063
	GO TO 40	NE18	064
45	CN1(I)=CN1(I)+R1*(BS(4)+BS(6))+R2*BS(3)+R3*BS(2)	NE18	065
	GO TO 40	NE18	066
46	CN1(I)=CN1(I)+R1*BS(5)+R2*BS(4)+R3*BS(3)	NE18	067
40	CONTINUE	NE18	068
	AS(1)=AS(1)+1.0	NE18	069
	DO 50 I=1,6	NE18	070
	CN2(I)=-2.*(A(I))+(TRO*(AS(I)))	NE18	071
	GO TO (51,52,53,54,55,56),I	NE18	072
51	CN2(I)=CN2(I)+R1*(AS(2))+R2*(AS(3))+R3*(AS(4))	NE18	073
	GO TO 50	NE18	074
52	CN2(I)=CN2(I)+R1*(2.*(AS(1))+AS(3))+R2*(AS(2)+AS(4))+R3*(AS(3)+AS	NE18	075
	15))	NE18	076
	GO TO 50	NE18	077
53	CN2(I)=CN2(I)+R1*(AS(2)+AS(4))+R2*(2.*(AS(1))+AS(5))+R3*(AS(2)+AS	NE18	078
	16))	NE18	079
	GO TO 50	NE18	080
54	CN2(I)=CN2(I)+R1*(AS(3)+AS(5))+R2*(AS(2)+AS(6))+R3*2.*(AS(1))	NE18	081
	GO TO 50	NE18	082
55	CN2(I)=CN2(I)+R1*(AS(4)+AS(6))+R2*(AS(3))+R3*(AS(2))	NE18	083
	GO TO 50	NE18	084
56	CN2(I)=CN2(I)+R1*(AS(5))+R2*(AS(4))+R3*(AS(3))	NE18	085
50	CONTINUE	NE18	086
	AS(1)=AS(1)-1.0	NE18	087
		NE18	088
	CALL MATRIX(Q,6)	NE18	089
59	DO 60 I=1,6	NE18	090
	XC(I)=0.0	NE18	091
60	CVG(I)=CN1(I)+CN2(I)/GV	NE18	092
	DO 61 I=1,6	NE18	093
	DO 61 J=1,6	NE18	094
61	XC(I)=XC(I)+Q(I,J)*CVG(J)	NE18	095
	RETURN	NE18	096
	END	NE18	097

C

```

SUBROUTINE PRESS
C
DIMENSION TCRAT(7),XV(19),DVA(8,7),F(8,19),UP(25),UM(25),SUMU(25)
DIMENSION ST(5),UCBP(25),VCBP(25),CST(5),SAVU(25),FX(25)
C
DIMENSION B(6),BS(6),SA(6),SAS(6),P(6,6)
DIMENSION C(6),A(25,6),AS(25,6),D(6),DS(6),SC(6),GS(6),H(6)
DIMENSION RB(25),BR(25),BTA(25),TCBLD(25),RA(25),XPRES(25),PHI(5)
DIMENSION UG(25),UQD(25),UGD(25),UV(25),UCB(25),VCB(25),
1 UGP(25,25),UGA(25),GV(25),GRV(25),CPP(5,25),CPM(5,25)
DIMENSION ALPHA(25),STALL(25),JSTL(25),TALK(20)
C
COMMON MZZZ,CD,R0,R1,R2,R3,PI,B,BS,SA,SAS,P
COMMON/NEAR1/ NRUN,NBLD,NZ,MZ,NPRES,IR,NTIME,NERR,NPAG,NPHI,NPRINT
COMMON/NEAR2/ C,A,AS,D,DS,SC,GS,H
COMMON/NEAR3/ RRP,XP,Z,BLD,RB,BR,BTA,TCBLD,TC,RCBRP,APA,ALF,XPRES,
1 RA,XCB,XR,ELCBC,RMAX,PHI,CORJ,CORCB
COMMON/NEAR4/ UG,UQD,UGD,UV,UCB,VCB,UGP,UGA,GV,GAM,GRV,CPP,CPM
COMMON/NEAR5/ ARJ,ARJP,EPS,RAD,CL,ALPHA,STALL,JSTL,TALK
C
DATA TCRAT/0.06,0.08,0.12,0.15,0.18,0.21,0.24/
DATA XV/0.0,0.005,0.0125,0.025,0.05,0.075,0.1,0.15,0.2,0.25,0.3,
1 0.4,0.5,0.6,0.7,0.8,0.9,0.95,1.0/
DATA (DVA(1,I),I=1,7)/3.992,2.015,1.364,0.984,0.696,0.462,0.478/
DATA (DVA(2,I),I=1,7)/2.90,1.795,1.31,0.971,0.694,0.561,0.478/
DATA (DVA(3,I),I=1,7)/1.988,1.475,1.199,0.934,0.685,0.558,0.478/
DATA (DVA(4,I),I=1,7)/1.60,1.312,1.112,0.90,0.675,0.557,0.478/
DATA (DVA(5,I),I=1,7)/1.342,1.178,1.028,0.861,0.662,0.555,0.478/
DATA (DVA(6,I),I=1,7)/1.167,1.065,0.946,0.818,0.648,0.550,0.478/
DATA (DVA(7,I),I=1,7)/1.050,0.964,0.870,0.771,0.632,0.542,0.478/
DATA (F(1,I),I=1,19)/0.,0.938,1.057,1.089,1.103,1.107,1.101,1.098,
1 1.091,1.086,1.078,1.066,1.053,1.042,1.028,1.013,0.990,0.974,0./
DATA (F(2,I),I=1,19)/0.,0.890,1.050,1.105,1.128,1.133,1.130,1.128,
1 1.122,1.114,1.106,1.089,1.072,1.054,1.039,1.017,0.984,0.969,0./
DATA (F(3,I),I=1,19)/0.,0.800,1.005,1.114,1.174,1.184,1.188,1.188,
1 1.183,1.174,1.162,1.135,1.108,1.080,1.053,1.022,0.978,0.952,0./
DATA (F(4,I),I=1,19)/0.,0.739,0.966,1.112,1.204,1.224,1.233,1.233,
1 1.229,1.218,1.204,1.170,1.131,1.098,1.064,1.024,0.972,0.934,0./
DATA (F(5,I),I=1,19)/0.,0.682,0.926,1.103,1.228,1.264,1.276,1.278,
1 1.275,1.262,1.247,1.205,1.154,1.116,1.074,1.025,0.966,0.914,0./
DATA (F(6,I),I=1,19)/0.,0.630,0.887,1.087,1.242,1.297,1.317,1.325,
1 1.320,1.306,1.290,1.240,1.178,1.133,1.085,1.027,0.957,0.895,0./
DATA (F(7,I),I=1,19)/0.,0.579,0.848,1.063,1.244,1.322,1.354,1.374,
1 1.368,1.350,1.333,1.277,1.204,1.151,1.097,1.032,0.944,0.879,0./
C
700 FORMAT (///10X,53HDUCT PRESSURE DISTRIBUTION CALCULATION ASSUMES
1/C = ,F5.3//)
C
IF (MZZZ) 2,1,2
1 CONTINUE
C
SET UP A TABLE OF CONTINUOUS VELOCITY CORRECTION FACTORS
C
DO 31 J=1,7
TCP=TCRAT(J)
JTC=J
IF (TC=TCRAT(J)) 32,33,31
32 IF (J=1) 132,132,34
31 CONTINUE

```

132	WRITE (6,700) TCP	NE19 060
33	DO 38 N=1,19	NE19 061
	IF (N-7) 37,37,38	NE19 062
37	DVA(8,N)=DVA(JTC,N)	NE19 063
38	F(8,N)=F(JTC,N)	NE19 064
	GO TO 39	NE19 065
34	DELTC=(TCRAT(JTC)-TCRAT(JTC-1))/(TCRAT(JTC)-TC)	NE19 066
	J=JTC	NE19 067
	DO 35 N=1,19	NE19 068
35	F(8,N)=(F(J-1,N)-F(J,N))/DELTC + F(J,N)	NE19 069
C		NE19 070
C	SET UP A TABLE OF THE DISCONTINUOUS VELOCITY CORRECTION FACTORS	NE19 071
C		NE19 072
	DO 36 N=1,7	NE19 073
36	DVA(8,N)=(DVA(J-1,N)-DVA(J,N))/DELTC + DVA(J,N)	NE19 074
39	CONTINUE	NE19 075
	RETURN	NE19 076
C		NE19 077
	2 CONTINUE	NE19 078
C		NE19 079
C	LOOK UP CONTINUOUS VELOCITY CORRECTION FACTOR	NE19 080
C		NE19 081
	DO 49 N=1,IR	NE19 082
	DO 42 J=1,19	NE19 083
	JK=J	NE19 084
	IF (XPRES(N)-XV(J)) 41,47,42	NE19 085
42	CONTINUE	NE19 086
41	DELX=(XV(JK)-XV(JK-1))/(XV(JK)-XPRES(N))	NE19 087
	FX(N)=(F(8,JK-1)-F(8,JK))/DELX + F(8,JK)	NE19 088
	GO TO 49	NE19 089
47	FX(N)=F(8,JK)	NE19 090
49	CONTINUE	NE19 091
	SNALF=SIN(ALF/RAD)	NE19 092
	CSALF=COS(ALF/RAD)	NE19 093
C		NE19 094
C	COMPUTE VELOCITY INDUCED BY TRAILING VORTEX CYLINDERS	NE19 095
C		NE19 096
	CALL GAMCYL (CD,XP,NZ,RB,UG,IR,XPRES,UGP,RRP,RA)	NE19 097
	DO 10 J=1,IR	NE19 098
10	SUMU(J)=1.0	NE19 099
	DO 12 J=1,IR	NE19 100
	DO 12 N=1,NZ	NE19 101
12	SUMU(J)=SUMU(J) + UGP(N,J)*GV(N)	NE19 102
C		NE19 103
C	COMPUTE VELOCITY INDUCED BY DUCT-BOUND VORTICITY	NE19 104
C		NE19 105
	IRC=-IR	NE19 106
	CALL VTXRNG (CD,XP,IRC,RB,C,UGD,XPRES,P)	NE19 107
	DO 14 J=1,IR	NE19 108
14	SUMU(J)=SUMU(J) + UGD(J)*GV(NZ)	NE19 109
C		NE19 110
C	COMPUTE VELOCITY INDUCED BY THE CENTERBODY	NE19 111
C		NE19 112
	IRC=-IR	NE19 113
	CALL HUB (CD,XR,XCB,ELCBC,RMAX,IRC,XPRES,RB,RRP,UCBP,VCBP)	NE19 114
	DO 16 J=1,IR	NE19 115
	SUMU(J)=SUMU(J) + UCBP(J)*CORCB	NE19 116
	SUMU(J)=SUMU(J)*CSALF	NE19 117
16	SAVU(J)=SUMU(J)	NE19 118

C	IF (SNALF) 20,21,20	NE19 119
C	COMPUTE VELOCITY INDUCED BY ALPHA VORTEX RINGS	NE19 120
C	20 CALL ALFRNG (CD,IR,SC,UGA,XPRES)	NE19 121
	GO TO 23	NE19 122
C	21 DO 22 J=1,IR	NE19 123
	22 UGA(J)=0.0	NE19 124
	23 DO 99 M=1,NPHI	NE19 125
	CSPHI=COS(PHI(M)/RAD)	NE19 126
	SNPHI=SIN(PHI(M)/RAD)	NE19 127
	DO 90 J=1,IR	NE19 128
	90 SUMU(J)=SAVU(J)	NE19 129
	DO 25 J=1,IR	NE19 130
	25 SUMU(J)=SUMU(J) + UGA(J)*SNALF*CSPHI	NE19 131
	30 CONTINUE	NE19 132
C		NE19 133
C	CORRECT CONTINUOUS INDUCED VELOCITY	NE19 134
C	DO 48 N=1,IR	NE19 135
	48 SUMU(N)=SUMU(N)*FX(N)	NE19 136
C		NE19 137
C	COMPUTE DISCONTINUOUS PORTION OF SURFACE VELOCITY	NE19 138
C	DO 59 N=1,IR	NE19 139
	CT=1.-2.*XPRES(N)	NE19 140
	ST(1)=SQRT(1.-CT*CT)	NE19 141
	ST(2)=2.*ST(1)*CT	NE19 142
	DO 50 K=3,5	NE19 143
	KM=K-1	NE19 144
	KMM=K-2	NE19 145
	50 ST(K)=2.*ST(KM)*CT-ST(KMM)	NE19 146
	IF (XPRES(N)-0.10) 51,57,57	NE19 147
	51 DO 52 J=1,7	NE19 148
	JK=J	NE19 149
	IF (XPRES(N)-XV(J)) 54,53,52	NE19 150
	52 CONTINUE	NE19 151
	53 DVAX=DVA(8,JK)	NE19 152
	GO TO 55	NE19 153
	54 DELX=(XV(JK)-XV(JK-1))/(XV(JK)-XPRES(N))	NE19 154
	DVAX=(DVA(8,JK-1)-DVA(8,JK))/DELX + DVA(8,JK)	NE19 155
	55 CTN=DVAX*2.0*PI	NE19 156
	GO TO 56	NE19 157
	57 CT2=SQRT((1.+CT)/2.)	NE19 158
	CTN=CT2/SQRT(1.-CT2*CT2)	NE19 159
	56 GD=C(1)*CTN	NE19 160
	GA=SC(1)*CTN	NE19 161
	DO 58 J=1,5	NE19 162
	GD=GD+C(J+1)*ST(J)	NE19 163
	58 GA=GA+SC(J+1)*ST(J)	NE19 164
	GD=GD*GV(NZ)*CSALF	NE19 165
	GA=GA*SNALF*CSPHI	NE19 166
	UM(N)=SUMU(N)-GD/2.-GA/2.	NE19 167
	59 UP(N)=SUMU(N)+GD/2.+GA/2.	NE19 168
	UT=SNALF*SNPHI	NE19 169
C		NE19 170
C	COMPUTE PRESSURE COEFFICIENT INSIDE AND OUTSIDE DUCT SURFACE	NE19 171
C		NE19 172
		NE19 173
		NE19 174
		NE19 175
		NE19 176
		NE19 177

```

DO 60 N=1,IR
UTT=UT*FX(N)
UTT=UTT*UTT
CPP(M,N)=1.-UP(N)*UP(N) + UTT
60 CPM(M,N)=1.-UM(N)*UM(N) + UTT
99 CONTINUE
RETURN
END

```

```

NE19 178
NE19 179
NE19 180
NE19 181
NE19 182
NE19 183
NE19 184
NE19 185

```


251	FORMAT (/5X4HX/C ,1(3X6HCP(IN),4X7HCP(OUT),1X))	NE20 060
252	FORMAT (/5X4HX/C ,2(3X6HCP(IN),4X7HCP(OUT),1X))	NE20 061
253	FORMAT (/5X4HX/C ,3(3X6HCP(IN),4X7HCP(OUT),1X))	NE20 062
254	FORMAT (/5X4HX/C ,4(3X6HCP(IN),4X7HCP(OUT),1X))	NE20 063
255	FORMAT (/5X4HX/C ,5(3X6HCP(IN),4X7HCP(OUT),1X))	NE20 064
256	FORMAT(///9X50HPRESSURE COEFFICIENTS BASED ON PROPELLER TIP SPEED)	NE20 065
257	FORMAT(///9X51HPRESSURE COEFFICIENTS BASED ON FREE STREAM VELOCITY)	NE20 066
260	FORMAT (I6,F9.5,5(1PE12.5))	NE20 067
261	FORMAT (2X1H*I3,F9.5,5(1PE12.5))	NE20 068
C		NE20 069
	IF (NTIME=50) 930,930,931	NE20 070
931	NERR=1	NE20 071
	NPRINT=NPRINT+1	NE20 072
930	SNALF=SIN(ALF/RAD)	NE20 073
	CSALF=COS(ALF/RAD)	NE20 074
	ARJV=ARJ/CSALF	NE20 075
	ARJVP=ARJP/CSALF	NE20 076
	NCYL=MZ	NE20 077
C		NE20 078
	IF (NPRINT.EQ.1.OR.NPRINT.GE.11) GO TO 900	NE20 079
	GO TO 901	NE20 080
900	NPAG=NPAG+1	NE20 081
	WRITE (6,701) NRUN,NPAG	NE20 082
	WRITE (6,102) TALK	NE20 083
	WRITE (6,148) CD,XP,TC,RRP,RCBRP,APA	NE20 084
	WRITE (6,124) R0,R1,R2,R3	NE20 085
	WRITE (6,149) ALF,ARJV,ARJVP,ARJ,ARJP	NE20 086
	WRITE (6,702) CORJ,CORCB	NE20 087
	WRITE (6,150)	NE20 088
	DO 61 J=1,NZ	NE20 089
	X=UG(J)*GAM	NE20 090
	Y=UGD(J)*GAM	NE20 091
	R=RB(J)*RRP	NE20 092
	XQ=UQD(J)*CORJ	NE20 093
	XY=UCB(J)*CORCB	NE20 094
61	WRITE (6,260) J,R,XQ,Y,X,XY,GRV(J)	NE20 095
	WRITE (6,151) NTIME,EPS	NE20 096
901	IF (NPRINT.GE.10) GO TO 902	NE20 097
	GO TO 903	NE20 098
902	NPAG=NPAG+1	NE20 099
	WRITE (6,701) NRUN,NPAG	NE20 100
	WRITE (6,102) TALK	NE20 101
	WRITE (6,148) CD,XP,TC,RRP,RCBRP,APA	NE20 102
	WRITE (6,149) ALF,ARJV,ARJVP,ARJ,ARJP	NE20 103
	WRITE (6,143) NCYL	NE20 104
	WRITE (6,115)	NE20 105
	WRITE (6,244) (C(J),J=1,6)	NE20 106
	IF (ALF) 904,905,904	NE20 107
904	WRITE (6,114)	NE20 108
	WRITE (6,244) (SC(J),J=1,6)	NE20 109
905	CONTINUE	NE20 110
	WRITE (6,116)	NE20 111
	WRITE (6,244) (B(K),K=1,6)	NE20 112
	WRITE (6,117)	NE20 113
	WRITE (6,244) (BS(K),K=1,6)	NE20 114
	WRITE (6,118)	NE20 115
	WRITE (6,244) (SA(J),J=1,6)	NE20 116
	WRITE (6,119)	NE20 117
	WRITE (6,244) (SAS(J),J=1,6)	NE20 118

WRITE (6,120)	NE20 119
WRITE (6,244) (D(N),N=1,6)	NE20 120
WRITE (6,121)	NE20 121
WRITE (6,244) (DS(N),N=1,6)	NE20 122
WRITE (6,113)	NE20 123
WRITE (6,244) (H(N),N=1,6)	NE20 124
WRITE (6,122)	NE20 125
DO 924 M=1,NCYL	NE20 126
924 WRITE (6,244) (A(M,N),N=1,6)	NE20 127
WRITE (6,123)	NE20 128
DO 925 M=1,NCYL	NE20 129
925 WRITE (6,244) (AS(M,N),N=1,6)	NE20 130
C	NE20 131
903 NPAG=NPAG+1	NE20 132
WRITE (6,101) NRUN,NPAG	NE20 133
WRITE (6,102) TALK	NE20 134
WRITE (6,148) CD,XP,TC,RRP,RCBRP,APA	NE20 135
WRITE (6,149) ALF,ARJV,ARJVP,ARJ,ARJP	NE20 136
WRITE (6,152)	NE20 137
X=0.	NE20 138
Y=0.	NE20 139
DO 63 J=1,NZ	NE20 140
X=GRV(J)/PI/ARJP*BLD/Z	NE20 141
Y=Y+X	NE20 142
R=RB(J)*RRP	NE20 143
DELP=GRV(J)*BLD/PI/ARJP	NE20 144
IF (STALL(J)) 62,64,62	NE20 145
64 WRITE (6,260) J,R,UV(J),GV(J),ALPHA(J),DELP	NE20 146
GO TO 63	NE20 147
62 WRITE (6,261) J,R,UV(J),GV(J),ALPHA(J),DELP	NE20 148
63 CONTINUE	NE20 149
X=0.0	NE20 150
C	NE20 151
C	NE20 152
C	NE20 153
COMPUTE DUCTED PROPELLER THRUST COEFFICIENTS	NE20 154
CTCF=ARJ*ARJ*PI/APA/8.0/CSALF/CSALF	NE20 155
CTDP(1)=Y*APA*CSALF*CSALF	NE20 156
DO 20 J=1,6	NE20 157
20 E(J)=SA(J) + D(J)*CORCB + B(J)*GAM	NE20 158
CON=-CD*PI*GAM*CSALF*CSALF	NE20 159
CTDP(2)=C(1)*(4.*E(1)+2.*E(2)) + 2.*C(2)*E(1)	NE20 160
CTALF=SC(1)*(4.*H(1)+2.*H(2)) + 2.*SC(2)*H(1)	NE20 161
DO 21 N=2,5	NE20 162
CTALF=CTALF + SC(N+1)*H(N) - SC(N)*H(N+1)	NE20 163
21 CTDP(2)=CTDP(2) + C(N+1)*E(N) - C(N)*E(N+1)	NE20 164
CTDP(2)=CTDP(2)*CON + PI*CD*(2.*SC(1)+SC(2))*SNALF*SNALF	NE20 165
CTALF=-PI*CD/2.*SNALF*SNALF*CTALF	NE20 166
CTDP(2)=CTDP(2) + CTALF	NE20 167
X=RRP*RRP	NE20 168
X=1.0-(1.0/X)	NE20 169
X=X*DELP*CSALF*CSALF	NE20 170
CTDP(3)=CTDP(2) + X	NE20 171
CTDP(4)=CTDP(1) + CTDP(2)	NE20 172
CTDP(5)=CTDP(1) + CTDP(3)	NE20 173
DO 22 J=1,5	NE20 174
22 CTDP(J+5)=CTDP(J)*CTCF	NE20 175
C	NE20 176
C	NE20 177
C	
COMPUTE DUCT NORMAL FORCE COEFFICIENTS	

DO 30 J=1,5	NE20 178
CMDP(J)=0.0	NE20 179
30 CNDP(J)=0.0	NE20 180
SACA=SNALF*CSALF	NE20 181
IF (SACA) 31,23,31	NE20 182
31 MZZZ=-1	NE20 183
C	NE20 184
COMPUTE F(N) AND F-STAR(N) FOURIER COEFFICIENTS	NE20 185
C	NE20 186
NF=50	NE20 187
CALL VTXRNG (CD,XP,NF,RB,C,UGD,XPRES,P)	NE20 188
MZZZ=1	NE20 189
DO 32 J=1,6	NE20 190
FS(J)=UGD(J)	NE20 191
32 F(J)=UGD(J+6)	NE20 192
DO 33 J=1,6	NE20 193
33 ES(J)=SAS(J) + DS(J)*CORCB + (BS(J)+FS(J))*GAM	NE20 194
CNDP(2)=SC(1)*(4.*ES(1)+2.*ES(2)) + 2.*SC(2)*ES(1)	NE20 195
DUM=0.0	NE20 196
DO 34 J=2,5	NE20 197
34 DUM=DUM + SC(J+1)*ES(J) - SC(J)*ES(J+1)	NE20 198
CNDP(2)=(CNDP(2)+DUM)*PI*CD*SACA/2.	NE20 199
CNDP(3)=C(1)*(4.*GS(1)+2.*GS(2)) + 2.*C(2)*GS(1)	NE20 200
DUM=0.0	NE20 201
DO 35 J=2,5	NE20 202
35 DUM=DUM + C(J+1)*GS(J) - C(J)*GS(J+1)	NE20 203
CNDP(3)=(CNDP(3)+DUM)*PI*CD*SACA/2.*GAM	NE20 204
CNDP(4)=PI*CD*SACA*(2.*SC(1)+SC(2))	NE20 205
CNDP(1)=CNDP(2) + CNDP(3) + CNDP(4)	NE20 206
C	NE20 207
COMPUTE DUCT MOMENT COEFFICIENTS	NE20 208
C	NE20 209
CMDP(2)=C(1)*(4.*GS(1)+4.*GS(2)+2.*GS(3)) + C(2)*(GS(2)-GS(4))	NE20 210
1 + C(3)*(2.*GS(1)-GS(5)) + C(4)*(GS(2)-GS(6)) + C(5)*GS(3)	NE20 211
2 + C(6)*GS(4)	NE20 212
CMDP(2)=CMDP(2)*PI/4.*GAM*SACA*CD*CD	NE20 213
CMDP(3)=PI/2.*CD*CD*SACA*(2.*SC(1)+SC(3))	NE20 214
CMDP(4)=SC(1)*(4.*ES(1)+4.*ES(2)+2.*ES(3)) + SC(2)*(ES(2)-ES(4))	NE20 215
1 + SC(3)*(2.*ES(1)-ES(5)) + SC(4)*(ES(2)-ES(6))	NE20 216
2 + SC(5)*ES(3) + SC(6)*ES(4)	NE20 217
CMDP(4)=CMDP(4)*PI/4.*SACA*CD*CD	NE20 218
DO 36 J=1,6	NE20 219
36 E(J)=E(J) + F(J)*GAM	NE20 220
CMDP(5)=SC(1)*(4.*E(1)+2.*E(2)) + 2.*SC(2)*E(1)	NE20 221
DUM=0.0	NE20 222
DO 37 J=2,5	NE20 223
37 DUM=DUM + SC(J+1)*E(J) - SC(J)*E(J+1)	NE20 224
CMDP(5)=-(CMDP(5)+DUM)*PI/2.*SACA*CD	NE20 225
DO 38 J=2,5	NE20 226
38 CMDP(1)=CMDP(1) + CMDP(J)	NE20 227
23 CONTINUE	NE20 228
WRITE (6,153)	NE20 229
WRITE (6,154) (CTDP(N),N=1,5) ,CNDP(1),CMDP(1)	NE20 230
CNDP(1)=CNDP(1)*CTCF	NE20 231
CMDP(1)=CMDP(1)*CTCF*RRP/2.0	NE20 232
WRITE (6,155) (CTDP(N),N=6,10),CNDP(1),CMDP(1)	NE20 233
WRITE (6,156)	NE20 234
N=0	NE20 235
NTOT=0	NE20 236

70 DO 71 J=1,NZ	NE20 237
IF (STALL(J)) 71, 71, 72	NE20 238
72 N=N+1	NE20 239
JSTL(N)=J	NE20 240
NTOT=N	NE20 241
71 CONTINUE	NE20 242
73 IF (NTOT) 75, 75, 74	NE20 243
74 WRITE (6,157) (JSTL(N),N=1,NTOT)	NE20 244
75 CONTINUE	NE20 245
IF (NPHI) 99,99,80	NE20 246
	NE20 247
COMPUTE DUCT SURFACE PRESSURE COEFFICIENTS	NE20 248
	NE20 249
80 CALL PRESS	NE20 250
DO 81 I=1,NPHI	NE20 251
DO 81 J=1,IR	NE20 252
IF (XPRES(J)=XP) 81,82,82	NE20 253
82 CPP(I,J)=CPP(I,J) + DELP*CSALF*CSALF	NE20 254
81 CONTINUE	NE20 255
IF (NPRES.LE.1) GO TO 85	NE20 256
DO 83 I=1,NPHI	NE20 257
DO 83 J=1,IR	NE20 258
CPP(I,J)=CPP(I,J)*ARJV*ARJV/2.0	NE20 259
83 CPM(I,J)=CPM(I,J)*ARJV*ARJV/2.0	NE20 260
85 NPAG=NPAG+1	NE20 261
WRITE (6,703) NRUN,NPAG	NE20 262
WRITE (6,102) TALK	NE20 263
WRITE (6,148) CD,XP,TC,RRP,RCBRP,APA	NE20 264
WRITE (6,149) ALF,ARJV,ARJVP,ARJ,ARJP	NE20 265
WRITE (6,250) (PHI(J),J=1,NPHI)	NE20 266
GO TO (1,2,3,4,5),NPHI	NE20 267
1 WRITE (6,251)	NE20 268
GO TO 6	NE20 269
2 WRITE (6,252)	NE20 270
GO TO 6	NE20 271
3 WRITE (6,253)	NE20 272
GO TO 6	NE20 273
4 WRITE (6,254)	NE20 274
GO TO 6	NE20 275
5 WRITE (6,255)	NE20 276
6 CONTINUE	NE20 277
DO 86 J=1,IR	NE20 278
86 WRITE (6,245) XPRES(J), (CPP(I,J),CPM(I,J) ,I=1,NPHI)	NE20 279
IF (NPRES.LE.1) GO TO 8	NE20 280
WRITE (6,256)	NE20 281
GO TO 99	NE20 282
8 WRITE (6,257)	NE20 283
99 RETURN	NE20 284
END	NE20 285

8. SAMPLE CASES

In this section, the input and output for several sample cases are described. The input decks are shown in figure 6 and illustrate both methods of stacking runs discussed in section 4.1. The first case considers the ducted propeller on the Bell X-22A aircraft (ref. 13). This input deck for this case is followed by a blank card, since a different configuration follows. The second and succeeding cases consider the ducted fan used on the Doak VZ-4DA aircraft (refs. 12 and 14). There are four cases illustrated in figure 6. The first of these four, which follows the blank card, has a complete input deck. The remaining three cases, which have run numbers of 2010, 2020, and 2030, use only a single card, since only the advance ratio or the angle of attack is changed. The quantities required as input were obtained from references 12-14. The only areas in which questions might arise are the geometric camber coefficients and the centerbody configuration, both of which are discussed below.

The Bell duct has an unusual camberline shape, and the coefficients resulting from equation (48) do not yield a shape that matches the actual camberline well. A better fit to the camberline was obtained by solving equation (47) at $x/c = 0, 0.15, 0.45, \text{ and } 0.7$. These are the coefficients shown on the third card of the input deck. The centerbody model is determined by placing the maximum centerbody radius at its true location aft of the fan. The Rankine body results in a centerbody which is larger and more blunt than the true centerbody. The shapes are compared in figure 3 of reference 1.

The camberline of the Doak duct was best fit by solving equation (47) at $x/c = 0, 0.25, 0.55, \text{ and } 0.8$; and these are the coefficients on the third card of the input deck for the second case. The centerbody model is determined by assuming the maximum centerbody radius to be at the propeller station. The resulting shape fits the centerbody nose very well but it is shorter in length than the true centerbody as is shown in figure 4 of reference 1.

Two runs making up the sample case output are shown in figure 7. They are the first two runs obtained from the stacked input decks shown in figure 6. Since the output was described in detail in section 5, no further comments will be given here.

9. DATA COMPARISONS

In order to give the program user some indication of the nature of the results obtained from the computer program, some comparisons with experimental data are presented. The comparisons included herein are brief because of the similarity between the current results and those included in reference 4.

Comparison between the measured and predicted total thrust coefficient on the Bell X-22A ducted propeller in axial flow (ref. 13) is shown in figure 8. These results illustrate the effect of advance ratio and fan blade pitch angle. The agreement is good until comparisons are made in regions of possible blade stall; that is, low advance ratio and high blade pitch angles. Note that the program predicts the correct trend due to blade stall when $\beta_{3/4} = 49^\circ$ even though the total thrust is overpredicted.

The total thrust coefficients presented in this report include the pressure thrust due to the increased pressure aft of the fan acting on the duct. The pressure thrust is included to give better agreement between measured and predicted duct thrust as is shown in reference 5. Thus the overprediction of the total thrust coefficient is due primarily to the predicted fan thrust as discussed in the above reference. The fan thrust is very dependent on the fan blade characteristics, and an error of 2° in the blade pitch angle can cause large differences in fan thrust.

In figure 9, the effect of angle of attack and advance ratio on the thrust, normal force, and pitching moment on the Doak ducted fan (ref. 14) are shown. The thrust and normal force agree generally with the results in reference 5; that is, the thrust is well predicted at high advance ratios and at low angles of attack, and the normal force is well predicted at high advance ratios. The major difference in results occurs with pitching moments. Reference 5 showed good prediction of pitching moments, but figure 9(c) shows poor agreement with experiment. In the early work described in references 2 and 4, some simplifying assumptions were necessary in order to compute duct pitching moments. The analysis of reference 1 removed these assumptions and showed some of them to be incorrect. Unexplainably, the more exact analysis results in poor agreement with experiment.

Comparison of predicted and measured duct surface pressure coefficients on the Doak ducted fan are shown in figures 10, 11, and 12. The present results are nearly the same as those shown in reference 4 where a larger range of conditions was investigated. Although $\alpha = 20^\circ$ is the highest angle of attack shown in figures 11 and 12, the nature of the agreement on duct pressure coefficients is the same for angles of attack as large as $\alpha = 80^\circ$.

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Palo Alto, Calif.
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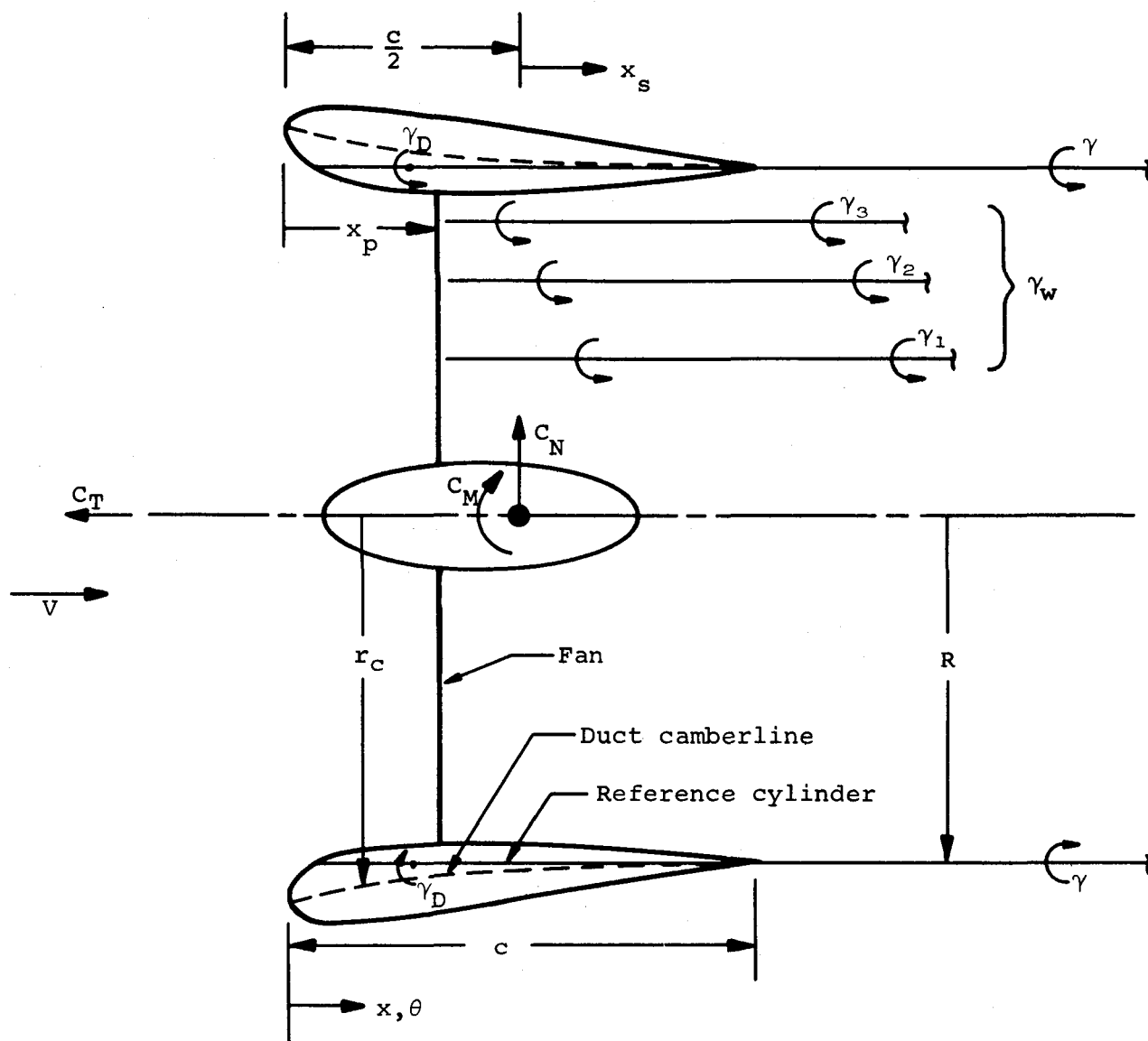


Figure 1.- Theoretical model of ducted fan in axial flow.

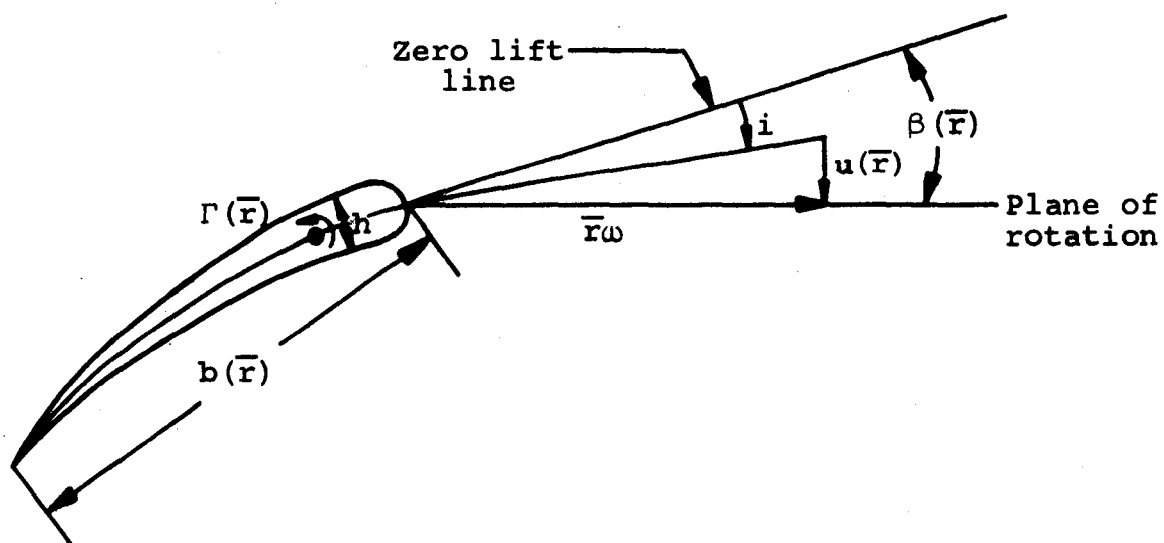
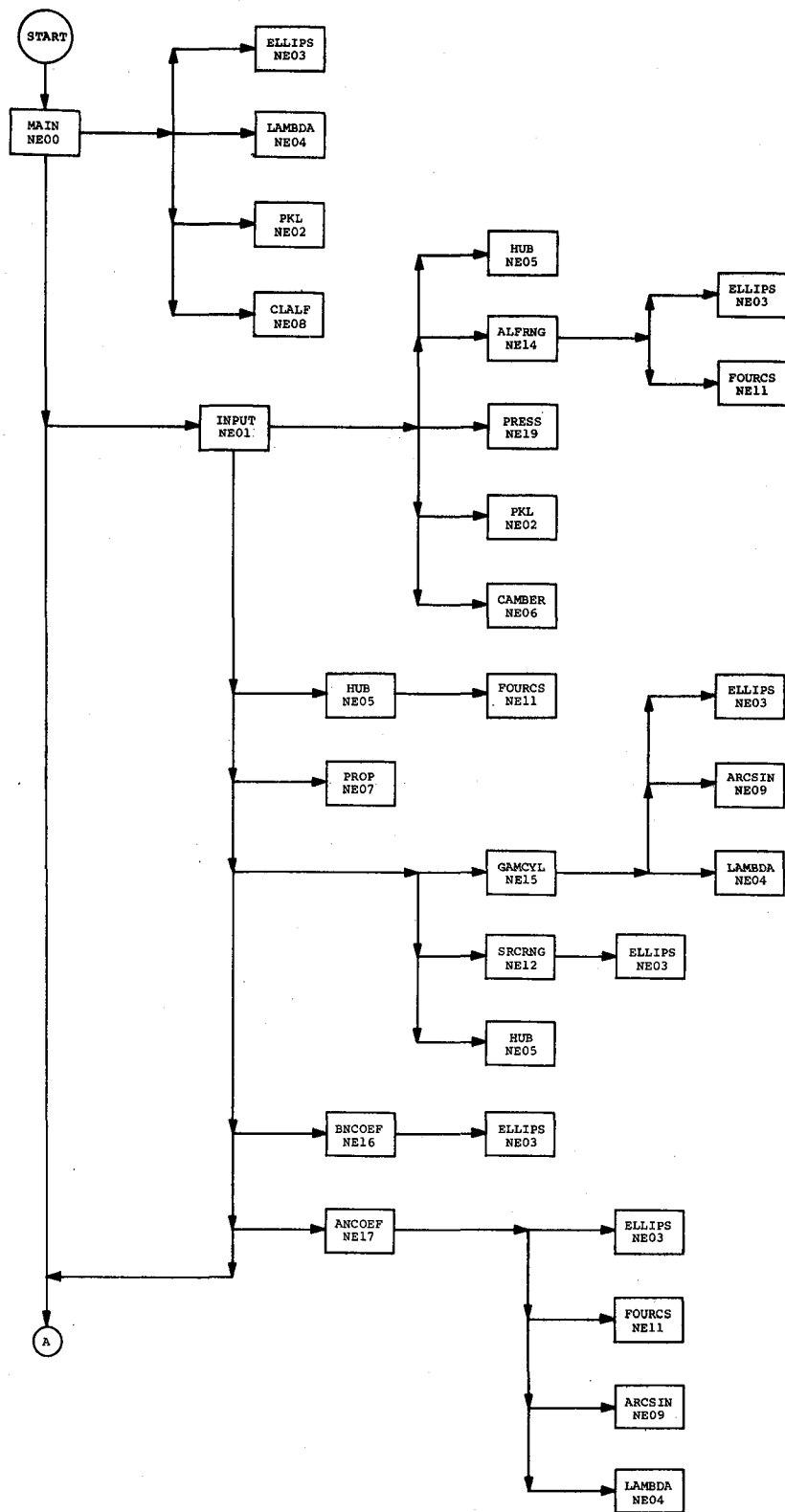


Figure 2.- Blade section flow characteristics.



(a) Initialization section.

Figure 3.- Relationship between subprograms.

Card No. 1

Variable	Title
Description	Any alphabetic or numeric identification information
Units	None
Card Column	1-80
Format	None
Value	

Card No. 2

Variable	c/D	x_p/c	t/c	R/R_p	R_{CB}/R_p	ϵ
Description	Duct chord-to-diameter ratio	Propeller location in fraction of duct chord	Duct maximum thickness-to-chord ratio	Ratio of duct trailing edge radius to propeller radius	Ratio of centerbody radius to propeller radius	Convergence criterion
Units	None	None	None	None	None	None
Card Column	5	15	25	35	45	55
Format	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x
Value						

Card No. 3

Variable	R_0	R_1	R_2	R_3
Description	Fourier coefficients of the duct geometric camberline			
Units	None	None	None	None
Card Column	5	15	25	35
Format	+ x . x x x x	+ x . x x x x	+ x . x x x x	+ x . x x x x
Value				

Figure 4.- Format of input data.

Card No. 4

Variable	ℓ_{CB}/c	x_{CB}/c	r_{max}/ℓ_{CB}	$(x/c)_{r_{max}}$
Description	Ratio of centerbody length to duct chord	Location of centerbody nose in fraction of duct chord	Ratio of maximum radius to length of centerbody	Location of maximum centerbody radius
Units	None	None	None	None
Card Column	5	15	25	35
Format	+x.xxxxx	+x.xxxxx	+x.xxxxx	+x.xxxxx
Value				

Card No. 5

Variable	NBLD	NZ	NZP	IR	NPRES	NPRINT
Description	Number of propeller blades	Number of equal area annuli on propeller	Number of stations in propeller table	Number of x-stations on duct surface	Output option for pressure coefficient	Output index
Units	None	None	None	None	None	None
Card Column	4	9	14	19	25	29
Format	x.x	x.x	x.x	x.x	x	x.x
Value						

Card No. 6(a)

Variable	r/R_p							
Description	Propeller radii at which blade characteristics are to be input, specified as a fraction of propeller radius							
Units	None	None	None	None	None	None	None	None
Card Column	5	15	25	35	45	55	65	75
Format	x.xxxxx	x.xxxxx	x.xxxxx	x.xxxxx	x.xxxxx	x.xxxxx	x.xxxxx	x.xxxxx
Value								

(a) The number of 10 column fields will be equal to NZP (Card No. 5). Each card will accommodate 8 fields; therefore, if $NZP > 8$, the remaining fields are included on following cards having the same format as Card No. 6.

Figure 4.- Continued.

Card No. 7^(b)

Variable	b/R_p							
Description	The propeller blade chord at stations corresponding to radii on Card No. 6, specified as a fraction of propeller radius.							
Units	None	None	None	None	None	None	None	None
Card Column	5	15	25	35	45	55	65	75
Format	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x
Value								

Card No. 8^(b)

Variable	β							
Description	Propeller blade pitch angle at stations corresponding to radii on Card No. 6.							
Units	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees
Card Column	5	15	25	35	45	55	65	75
Format	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x
Value								

Card No. 9^(b)

Variable	t/b							
Description	Propeller thickness-to-chord ratio at stations corresponding to radii on Card No. 6.							
Units	None	None	None	None	None	None	None	None
Card Column	5	15	25	35	45	55	65	75
Format	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x	x . x x x x
Value								

^(b) The same number of cards are required for b/R_p , β , and t/b as are required for r/R_p .

Figure 4.- Continued.

Card No. 10^(c)

Variable	x/c																							
Description	Location on duct at which pressure coefficients will be calculated, specified as a fraction of duct chord.																							
Units	None				None				None				None				None				None			
Card Column	5				15				25				35				45				55			
Format	x . x x x x				x . x x x x				x . x x x x				x . x x x x				x . x x x x				x . x x x x			
Value																								

Card No. 11

Variable	NRUN	NPHI	J	α	ϕ									
Description	Run number $\neq 0$	Number of azimuth angles ≤ 5	Advance ratio ($J \neq 0$)	Angle of attack ($ \alpha < 90^\circ$)	Azimuth angles at which duct pressure distributions will be calculated.									
Units	None	None	None	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees
Card Column	2	10	15	25	35	45	55	65	75	85	95	105	115	125
Format	x x x x	x	x . x x x x	x . x x x x	x x x . x x	x x x . x x	x x x . x x	x x x . x x	x x x . x x	x x x . x x	x x x . x x	x x x . x x	x x x . x x	x x x . x x
Value														

(c) The number of 10 column fields will be equal to IR (Card No. 5).

Figure 4.- Concluded.

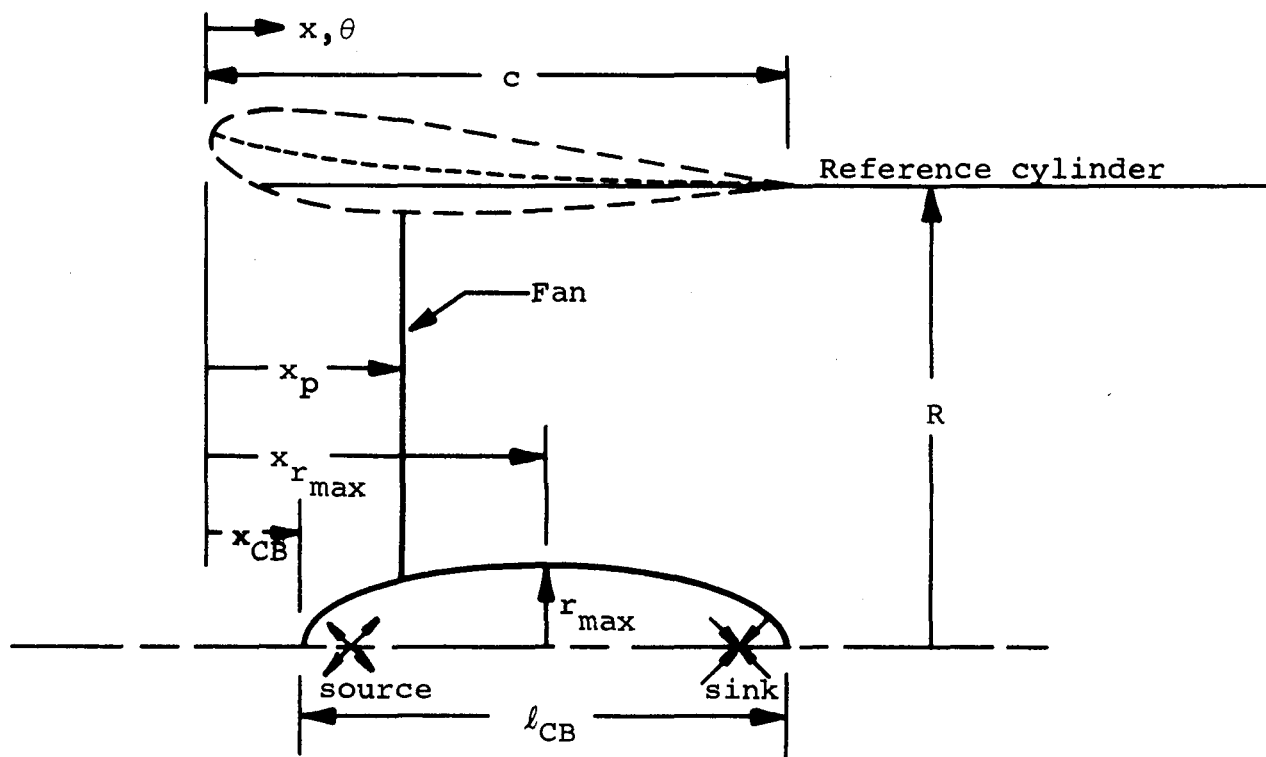


Figure 5.- Centerbody geometry.

SAMPLE CASE I ... BELL X-22A DUCTED PROPELLER ... BETA(3/4)=29 DEGREES

0.525	0.286	0.170	1.102	0.175	0.01		
-.039985	-.083845	-.062813	-.027351				
0.890	-0.067	0.202	0.467				
3 20	12 23	1 1					
0.175	0.250	0.30	0.40	0.45	0.50	0.55	0.60
0.65	0.75	0.85	1.00				
0.333	0.309	0.293	0.260	0.246	0.235	0.228	0.224
0.222	0.217	0.212	0.204				
64.0	58.5	55.0	48.0	44.4	41.0	37.7	34.8
32.5	29.0	26.5	23.5				
0.320	0.280	0.255	0.210	0.190	0.180	0.160	0.145
0.130	0.100	0.070	0.030				
0.0	0.0025	0.0050	0.010	0.020	0.030	0.040	0.050
0.10	0.15	0.20	0.25	0.285	0.287	0.30	0.40
0.50	0.60	0.70	0.80	0.90	0.95	1.00	
1000 1	0.10	0.0	0.0				

SAMPLE CASE II ... DOAK VZ-4DA DUCTED FAN ... BETA(TIP)= 15 DEGREES

0.608	0.293	0.160	1.131	0.332	0.01		
-.002748	-.029679	-.032916	.006403				
2.16	-0.561	0.115	0.293				
8 20	8 23	1					
0.332	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.156	0.155	0.152	0.144	0.131	0.117	0.104	0.091
48.0	43.0	36.0	30.0	25.0	20.8	17.5	15.0
0.190	0.154	0.120	0.100	0.084	0.072	0.062	0.054
0.0	0.0025	0.0050	0.01	0.02	0.03	0.04	0.05
0.10	0.15	0.20	0.25	0.292	0.294	0.30	0.40
0.50	0.60	0.70	0.80	0.90	0.95	1.00	
2000 5	0.178	20.0	0.0	45.0	90.0	135.0	180.0
2010 5	0.178	10.0	0.0	45.0	90.0	135.0	180.0
2020 1	0.178	0.0	0.0				
2030 5	0.342	20.0	0.0	45.0	90.0	135.0	180.0

Figure 6.- Sample input data.

SAMPLE CASE I ... BELL X-22A DUCTED PROPELLER ... BETA(3/4)=29 DEGREES

INPUT

DUCT GEOMETRY... C/D XP/C T/C RTE/RP RCB/RP
 0.525000 0.286000 0.170000 1.102000 0.175000

CAMBER COEFFICIENTS, -0.039985 -0.083845 -0.062813 -0.027351

PROPELLER GEOMETRY... 3 BLADES

R/RP	B/RP	BETA	TH/CHD
0.175000	0.333000	64.000	0.32000
0.250000	0.309000	58.500	0.28000
0.300000	0.293000	55.000	0.25500
0.400000	0.260000	48.000	0.21000
0.450000	0.246000	44.400	0.19000
0.500000	0.235000	41.000	0.18000
0.550000	0.228000	37.700	0.16000
0.600000	0.224000	34.800	0.14500
0.650000	0.222000	32.500	0.13000
0.750000	0.217000	29.000	0.10000
0.850000	0.212000	26.500	0.07000
1.000000	0.204000	23.500	0.03000

CENTERBODY GEOMETRY... LCB/C XCB/C RMAX/LCB X(RMAX)/C
 0.89000 -0.06700 0.20200 0.46700

CONVERGENCE CRITERION... EPSILON =0.01000

DEFINITION OF SYMBOLS USED IN TABULAR OUTPUT...

R/RP	RADIAL PROPELLER STATION IN FRACTION OF PROPELLER RADIUS
B/RP	PROPELLER CHORD IN FRACTION OF PROPELLER RADIUS
BETA	PROPELLER PITCH IN DEGREES
TH/CHD	PROPELLER BLADE THICKNESS-TO-CHORD RATIO
V	FREE STREAM VELOCITY
U	TOTAL INFLOW VELOCITY
J	ADVANCE RATIO
J'	RATIO OF V TO PROPELLER TIP SPEED
GAM/V	STRENGTH OF INTERNAL VORTEX CYLINDER N
ALPHA	ANGLE OF ATTACK, DEGREES
DELTA P/Q	RISE IN TOTAL PRESSURE ACROSS PROPELLER NORMALIZED ON FREE STREAM DYNAMIC PRESSURE
CTP(D)	THRUST COEFFICIENT ON PROPELLER IN THE DUCT
CTD(P)	THRUST COEFFICIENT ON THE DUCT
CTDP	TOTAL THRUST COEFFICIENT
CTD(P)'	THRUST COEFFICIENT ON DUCT INCLUDING PRESSURE THRUST ON THE DUCT AFT OF THE PROPELLER
CTDP'	TOTAL THRUST COEFFICIENT INCLUDING PRESSURE THRUST
CNDP	TOTAL NORMAL FORCE COEFFICIENT
CM DP	TOTAL PITCHING MOMENT COEFFICIENT

(a) Bell X-22A ducted propeller.

Figure 7.- Sample output.

SAMPLE CASE I ... BELL X-22A DUCTED PROPELLER ... BETA(3/4)=29 DEGREES

DUCT...	C/D	XP/C	T/C	RTE/RP	RCB/RP	AP/A
	0.525000	0.286000	0.170000	1.102000	0.175000	0.798231

EFFECTIVE CAMBER -0.040554 -0.123546 -0.075738 -0.026365

ALPHA	J	J'	J COS(A)	J' COS(A)
0.000	0.10000	0.02888	0.10000	0.02888

N	R/RP	(4.08)	UGD/V	UG/V	(6.37)	GAMMA/RV
		UQD/V			UCB/V	
1	0.22812	2.08706E-01	5.23663E 00	1.42872E 00	5.40376E-01	1.82966E 00
2	0.31920	2.24891E-01	5.33044E 00	1.23518E 00	3.75017E-01	2.09227E 00
3	0.38836	2.42306E-01	5.42540E 00	1.20587E 00	2.86758E-01	2.29096E 00
4	0.44669	2.61317E-01	5.52278E 00	1.17636E 00	2.31453E-01	2.45454E 00
5	0.49814	2.82151E-01	5.62282E 00	1.14719E 00	1.93476E-01	2.50681E 00
6	0.54471	3.05032E-01	5.72554E 00	1.11808E 00	1.65756E-01	2.40893E 00
7	0.58758	3.30190E-01	5.83089E 00	1.08937E 00	1.44616E-01	2.32899E 00
8	0.62751	3.57869E-01	5.93876E 00	1.06077E 00	1.27958E-01	2.27892E 00
9	0.66504	3.88313E-01	6.04889E 00	1.03272E 00	1.14493E-01	2.24979E 00
10	0.70056	4.21754E-01	6.16098E 00	1.00454E 00	1.03385E-01	2.23391E 00
11	0.73435	4.58395E-01	6.27481E 00	9.77391E-01	9.40685E-02	2.19695E 00
12	0.76666	4.98375E-01	6.39017E 00	9.50348E-01	8.61464E-02	2.17241E 00
13	0.79766	5.41744E-01	6.50594E 00	9.23912E-01	7.93312E-02	2.16097E 00
14	0.82749	5.88411E-01	6.62078E 00	8.97986E-01	7.34095E-02	2.13735E 00
15	0.85628	6.38125E-01	6.73757E 00	8.72429E-01	6.82195E-02	2.10810E 00
16	0.88414	6.90406E-01	6.85087E 00	8.47518E-01	6.36364E-02	2.09190E 00
17	0.91114	7.44598E-01	6.95638E 00	8.23243E-01	5.95621E-02	2.07000E 00
18	0.93737	7.99848E-01	7.05912E 00	7.99407E-01	5.59186E-02	2.04197E 00
19	0.96288	8.55179E-01	7.15662E 00	7.76403E-01	5.26428E-02	2.00963E 00
20	0.98773	9.09743E-01	7.24777E 00	7.53845E-01	4.96836E-02	1.97441E 00

8 ITERATIONS, EPSILON = 0.010000

(a) Continued.

Figure 7.- Continued.

SAMPLE CASE I ... BELL X-22A DUCTED PROPELLER ... BETA(3/4)=29 DEGREES

DUCT... C/D XP/C T/C RTE/RP RCB/RP AP/A
0.525000 0.286000 0.170000 1.102000 0.175000 0.798231

ALPHA J J' J COS(A) J' COS(A)
0.000 0.10000 0.02888 0.10000 0.02888

N	R/RP	INFLOW U/V	GAM/V	BLADE ALPHA	DELTA P/Q
* 1	0.22812	8.22806E	00-5.35298E-01	1.12870E 01	6.04887E 01
* 2	0.31920	8.25299E	00-3.83307E-01	1.43056E 01	6.91703E 01
* 3	0.38836	8.44199E	00-3.03430E-01	1.42232E 01	7.57390E 01
* 4	0.44669	8.62658E	00-9.48361E-02	1.31372E 01	8.11472E 01
5	0.49814	8.74799E	00 1.78412E-01	1.19394E 01	8.28753E 01
6	0.54471	8.73259E	00 1.48369E-01	1.10174E 01	7.96392E 01
7	0.58758	8.73975E	00 9.42183E-02	1.01865E 01	7.69965E 01
8	0.62751	8.78313E	00 5.52901E-02	9.52116E 00	7.53412E 01
9	0.66504	8.85469E	00 3.02945E-02	9.00640E 00	7.43781E 01
10	0.70056	8.94585E	00 7.09063E-02	8.61084E 00	7.38530E 01
11	0.73435	9.02441E	00 4.74073E-02	8.18429E 00	7.26311E 01
12	0.76666	9.12106E	00 2.21891E-02	7.84249E 00	7.18197E 01
13	0.79766	9.23580E	00 4.59868E-02	7.57733E 00	7.14415E 01
14	0.82749	9.34240E	00 5.73186E-02	7.29640E 00	7.06608E 01
15	0.85628	9.44943E	00 3.18934E-02	7.02046E 00	6.96937E 01
16	0.88414	9.56927E	00 4.33428E-02	6.80902E 00	6.91584E 01
17	0.91114	9.67902E	00 5.57921E-02	6.59597E 00	6.84342E 01
18	0.93737	9.78178E	00 6.48346E-02	6.37873E 00	6.75075E 01
19	0.96288	9.87603E	00 7.12116E-02	6.16215E 00	6.64384E 01
20	0.98773	9.96066E	00 7.14088E 00	5.94959E 00	6.52739E 01

	CTP(D)	CTD(P)	CTD(P)'	CTDP	CTDP'	CNDP	CMDP
(A)	5.7580E 01	5.1231E 01	6.2755E 01	1.0881E 02	1.2034E 02	0.0000E-39	0.0000E-39
(B)	2.8327E-01	2.5204E-01	3.0873E-01	5.3531E-01	5.9200E-01	0.0000E-39	0.0000E-39

NOTES...

(A) COEFFICIENTS BASED ON FREE STREAM DYNAMIC PRESSURE

(B) COEFFICIENTS BASED ON PROPELLER TIP SPEED

* BLADE SECTION LIFT COEFFICIENT HAS EXCEEDED CLMAX
IN ANNULI NOS. 1 2 3 4

(a) Continued.

Figure 7.- Continued.

SAMPLE CASE I ... BELL X-22A DUCTED PROPELLER ... BETA(3/4)=29 DEGREES

DUCT...	C/D	XP/C	T/C	RTE/RP	RCB/RP	AP/A
	0.525000	0.286000	0.170000	1.102000	0.175000	0.798231

ALPHA	J	J'	J COS(A)	J' COS(A)
0.000	0.10000	0.02888	0.10000	0.02888

AZIMUTH

PHI = /--- 0.00 ---/---

X/C	CP(IN)	CP(OUT)
0.0000	-2.536E 02	-2.536E 02
0.0025	-2.735E 02	-1.905E 02
0.0050	-2.861E 02	-1.307E 02
0.0100	-2.724E 02	-9.522E 01
0.0200	-2.444E 02	-5.532E 01
0.0300	-2.214E 02	-3.528E 01
0.0400	-2.033E 02	-2.414E 01
0.0500	-1.851E 02	-1.480E 01
0.1000	-1.425E 02	-2.476E 00
0.1500	-1.218E 02	2.554E-01
0.2000	-1.117E 02	8.872E-01
0.2500	-1.059E 02	9.914E-01
0.2850	-1.031E 02	9.998E-01
0.2870	-3.768E 01	9.999E-01
0.3000	-3.685E 01	9.998E-01
0.4000	-2.998E 01	9.861E-01
0.5000	-1.931E 01	9.005E-01
0.6000	-7.510E 00	5.112E-01
0.7000	1.453E 00	1.531E-01
0.8000	2.062E 00	5.952E-01
0.9000	-2.995E 00	9.926E-01
0.9500	3.679E 00	9.944E-01
1.0000	6.627E 01	1.000E 00

PRESSURE COEFFICIENTS BASED ON FREE STREAM VELOCITY

(a) Concluded.

Figure 7.- Continued.

SAMPLE CASE II ... DOAK VZ-4DA DUCTED FAN ... BETA(TIP)= 15 DEGREES

INPUT

DUCT GEOMETRY... C/D XP/C T/C RTE/RP RCB/RP
0.608000 0.293000 0.160000 1.131000 0.332000

CAMBER COEFFICIENTS, -0.002748 -0.029679 -0.032916 0.006403

PROPELLER GEOMETRY... 8 BLADES

R/RP	B/RP	BETA	TH/CHD
0.332000	0.156000	48.000	0.19000
0.400000	0.155000	43.000	0.15400
0.500000	0.152000	36.000	0.12000
0.600000	0.144000	30.000	0.10000
0.700000	0.131000	25.000	0.08400
0.800000	0.117000	20.800	0.07200
0.900000	0.104000	17.500	0.06200
1.000000	0.091000	15.000	0.05400

CENTERBODY GEOMETRY... LCB/C XCB/C RMAX/LCB X(RMAX)/C
2.16000 -0.56100 0.11500 0.29300

CONVERGENCE CRITERION... EPSILON =0.01000

DEFINITION OF SYMBOLS USED IN TABULAR OUTPUT...

R/RP	RADIAL PROPELLER STATION IN FRACTION OF PROPELLER RADIUS
B/RP	PROPELLER CHORD IN FRACTION OF PROPELLER RADIUS
BETA	PROPELLER PITCH IN DEGREES
TH/CHD	PROPELLER BLADE THICKNESS-TO-CHORD RATIO
V	FREE STREAM VELOCITY
U	TOTAL INFLOW VELOCITY
J	ADVANCE RATIO
J'	RATIO OF V TO PROPELLER TIP SPEED
GAM/V	STRENGTH OF INTERNAL VORTEX CYLINDER N
ALPHA	ANGLE OF ATTACK, DEGREES
DELTA P/Q	RISE IN TOTAL PRESSURE ACROSS PROPELLER NORMALIZED ON FREE STREAM DYNAMIC PRESSURE
CTP(D)	THRUST COEFFICIENT ON PROPELLER IN THE DUCT
CTD(P)	THRUST COEFFICIENT ON THE DUCT
CTDP	TOTAL THRUST COEFFICIENT
CTD(P)'	THRUST COEFFICIENT ON DUCT INCLUDING PRESSURE THRUST ON THE DUCT AFT OF THE PROPELLER
CTDP'	TOTAL THRUST COEFFICIENT INCLUDING PRESSURE THRUST
CNDP	TOTAL NORMAL FORCE COEFFICIENT
CMDP	TOTAL PITCHING MOMENT COEFFICIENT

(b) Doak VZ-4DA ducted fan.

Figure 7.- Continued.

SAMPLE CASE II ... DOAK VZ-40A DUCTED FAN ... BETA(TIP)= 15 DEGREES

DUCT...	C/D	XP/C	T/C	RTE/RP	RCB/RP	AP/A
	0.608000	0.293000	0.160000	1.131000	0.332000	0.695593

ALPHA	J	J'	J COS(A)	J' COS(A)
20.000	0.17800	0.05010	0.16727	0.04708

N	R/RP	INFLOW		GAM/V	BLADE		DELTA P/Q
		U/V	ALPHA				
1	0.36267	5.23679E	00	-1.35218E-01	8.25662E	00	2.89134E 01
2	0.41983	5.26777E	00	3.17357E-02	7.92511E	00	3.04108E 01
3	0.46999	5.27579E	00	9.98359E-02	7.29327E	00	3.00561E 01
4	0.51524	5.25198E	00	1.19916E-01	6.65377E	00	2.89533E 01
5	0.55680	5.22034E	00	1.72383E-01	6.12156E	00	2.76551E 01
6	0.59545	5.16455E	00	1.52069E-01	5.54300E	00	2.58393E 01
7	0.63174	5.12088E	00	1.76659E-01	5.12549E	00	2.42868E 01
8	0.66604	5.06680E	00	2.05082E-01	4.70483E	00	2.25413E 01
9	0.69866	5.00018E	00	1.67460E-01	4.26461E	00	2.05933E 01
10	0.72982	4.95392E	00	1.84996E-01	3.93421E	00	1.90650E 01
11	0.75970	4.90020E	00	2.03283E-01	3.59579E	00	1.74419E 01
12	0.78845	4.83857E	00	1.74513E-01	3.24839E	00	1.57372E 01
13	0.81618	4.79220E	00	1.56123E-01	2.96404E	00	1.43398E 01
14	0.84300	4.75555E	00	1.68195E-01	2.72148E	00	1.31412E 01
15	0.86899	4.71342E	00	1.79273E-01	2.47416E	00	1.19045E 01
16	0.89423	4.66602E	00	1.36541E-01	2.22443E	00	1.06487E 01
17	0.91877	4.63838E	00	1.27250E-01	2.04616E	00	9.73527E 00
18	0.94268	4.61378E	00	1.33504E-01	1.88825E	00	8.91761E 00
19	0.96599	4.58513E	00	1.38477E-01	1.72899E	00	8.09456E 00
20	0.98875	4.55222E	00	1.87724E 00	1.57029E	00	7.27852E 00

	CTP(D)	CTD(P)	CTD(P)'	CTDP	CTDP'	CNDP	CMOP
(A)	1.1534E 01	8.9945E 00	1.0397E 01	2.0528E 01	2.1931E 01	2.7529E 00	1.1474E 00
(B)	2.0631E-01	1.6089E-01	1.8598E-01	3.6719E-01	3.9228E-01	4.9241E-02	1.1606E-02

NOTES...

(A) COEFFICIENTS BASED ON FREE STREAM DYNAMIC PRESSURE

(B) COEFFICIENTS BASED ON PROPELLER TIP SPEED

(b) Continued.

Figure 7.- Continued.

RUN NUMBER 2900

DUCT SURFACE PRESSURE DISTRIBUTION

PAGE 2

SAMPLE CASE II ... DOAK VZ-4DA DUCTED FAN ... BETA(TIP)= 15 DEGREES

DUCT...	C/D	XP/C	T/C	RTE/RP	RCB/RP	AP/A
0.608000	0.293000	0.160000	1.131000	0.332000	0.695593	

ALPHA	J	J'	J COS(A)	J' COS(A)
20.000	0.17800	0.05010	0.16727	0.04708

AZIMUTH

PHI =	/---	0.00	---/---	45.00	---/---	90.00	---/---	135.00	---/---	180.00	---
-------	------	------	---------	-------	---------	-------	---------	--------	---------	--------	-----

X/C	CP(IN)	CP(OUT)	CP(IN)	CP(OUT)	CP(IN)	CP(OUT)	CP(IN)	CP(OUT)	CP(IN)	CP(OUT)
0.0000	-7.151E 01	-7.151E 01	-6.346E 01	-6.346E 01	-4.598E 01	-4.598E 01	-3.126E 01	-3.126E 01	-2.597E 01	-2.597E 01
0.0025	-7.547E 01	-4.980E 01	-6.775E 01	-4.375E 01	-5.081E 01	-3.072E 01	-3.628E 01	-1.994E 01	-3.096E 01	-1.613E 01
0.0050	-7.831E 01	-3.116E 01	-7.098E 01	-2.685E 01	-5.479E 01	-1.776E 01	-4.071E 01	-1.051E 01	-3.550E 01	-8.037E 00
0.0100	-7.351E 01	-2.101E 01	-6.700E 01	-1.784E 01	-5.256E 01	-1.123E 01	-3.991E 01	-6.107E 00	-3.520E 01	-4.420E 00
0.0200	-6.440E 01	-1.039E 01	-5.916E 01	-8.491E 00	-4.747E 01	-4.655E 00	-3.715E 01	-1.889E 00	-3.328E 01	-1.057E 00
0.0300	-5.740E 01	-5.510E 00	-5.309E 01	-4.257E 00	-4.317E 01	-1.823E 00	-3.446E 01	-2.230E 01	-3.118E 01	1.957E 01
0.0400	-5.210E 01	-3.038E 00	-4.830E 01	-2.146E 00	-3.978E 01	-4.817E 01	-3.222E 01	4.923E 01	-2.936E 01	6.936E 01
0.0500	-4.693E 01	-1.128E 00	-4.369E 01	-5.382E 01	-3.642E 01	4.839E 01	-2.995E 01	9.381E 01	-2.750E 01	9.600E 01
0.1000	-3.484E 01	8.448E 01	-3.281E 01	1.017E 00	-2.826E 01	1.181E 00	-2.421E 01	9.874E 01	-2.267E 01	8.022E 01
0.1500	-2.883E 01	9.920E 01	-2.734E 01	1.059E 00	-2.401E 01	1.023E 00	-2.106E 01	7.083E 01	-1.995E 01	4.967E 01
0.2000	-2.525E 01	8.816E 01	-2.408E 01	9.170E 01	-2.147E 01	8.311E 01	-1.918E 01	5.029E 01	-1.832E 01	2.967E 01
0.2500	-2.247E 01	7.867E 01	-2.152E 01	8.165E 01	-1.941E 01	7.329E 01	-1.758E 01	4.296E 01	-1.690E 01	2.396E 01
0.2920	-2.053E 01	7.407E 01	-1.972E 01	7.718E 01	-1.793E 01	7.008E 01	-1.639E 01	4.236E 01	-1.582E 01	2.484E 01
0.2940	-1.403E 01	7.372E 01	-1.323E 01	7.679E 01	-1.146E 01	6.962E 01	-9.936E 00	4.185E 01	-9.377E 00	2.431E 01
0.3000	-1.375E 01	7.353E 01	-1.297E 01	7.668E 01	-1.123E 01	6.987E 01	-9.742E 00	4.264E 01	-9.196E 00	2.538E 01
0.4000	-9.965E 00	6.813E 01	-9.407E 00	7.177E 01	-8.203E 00	6.777E 01	-7.200E 00	4.569E 01	-6.844E 00	3.124E 01
0.5000	-6.710E 00	5.929E 01	-6.312E 00	6.286E 01	-5.474E 00	5.996E 01	-4.810E 00	4.080E 01	-4.585E 00	2.809E 01
0.6000	-4.091E 00	4.139E 01	-3.800E 00	4.476E 01	-3.207E 00	4.232E 01	-2.769E 00	2.493E 01	-2.633E 00	1.336E 01
0.7000	-2.156E 00	2.850E 01	-1.943E 00	3.189E 01	-1.527E 00	3.034E 01	-1.252E 00	1.503E 01	-1.178E 00	4.663E 02
0.8000	-1.196E 00	3.668E 01	-1.039E 00	4.046E 01	-7.485E 01	4.072E 01	-5.840E 01	2.845E 01	-5.527E 01	1.970E 01
0.9000	-7.532E 01	5.950E 01	-6.440E 01	6.370E 01	-4.589E 01	6.595E 01	-3.849E 01	5.707E 01	-3.867E 01	5.014E 01
0.9500	2.597E 01	5.884E 01	3.413E 01	6.292E 01	4.671E 01	6.560E 01	4.920E 01	5.816E 01	4.727E 01	5.211E 01
1.0000	7.427E 00	1.000E 00	7.427E 00	1.000E 00	7.427E 00	1.000E 00	7.427E 00	1.000E 00	7.427E 00	1.000E 00

PRESSURE COEFFICIENTS BASED ON FREE STREAM VELOCITY

(b) Concluded.

Figure 7.- Concluded.

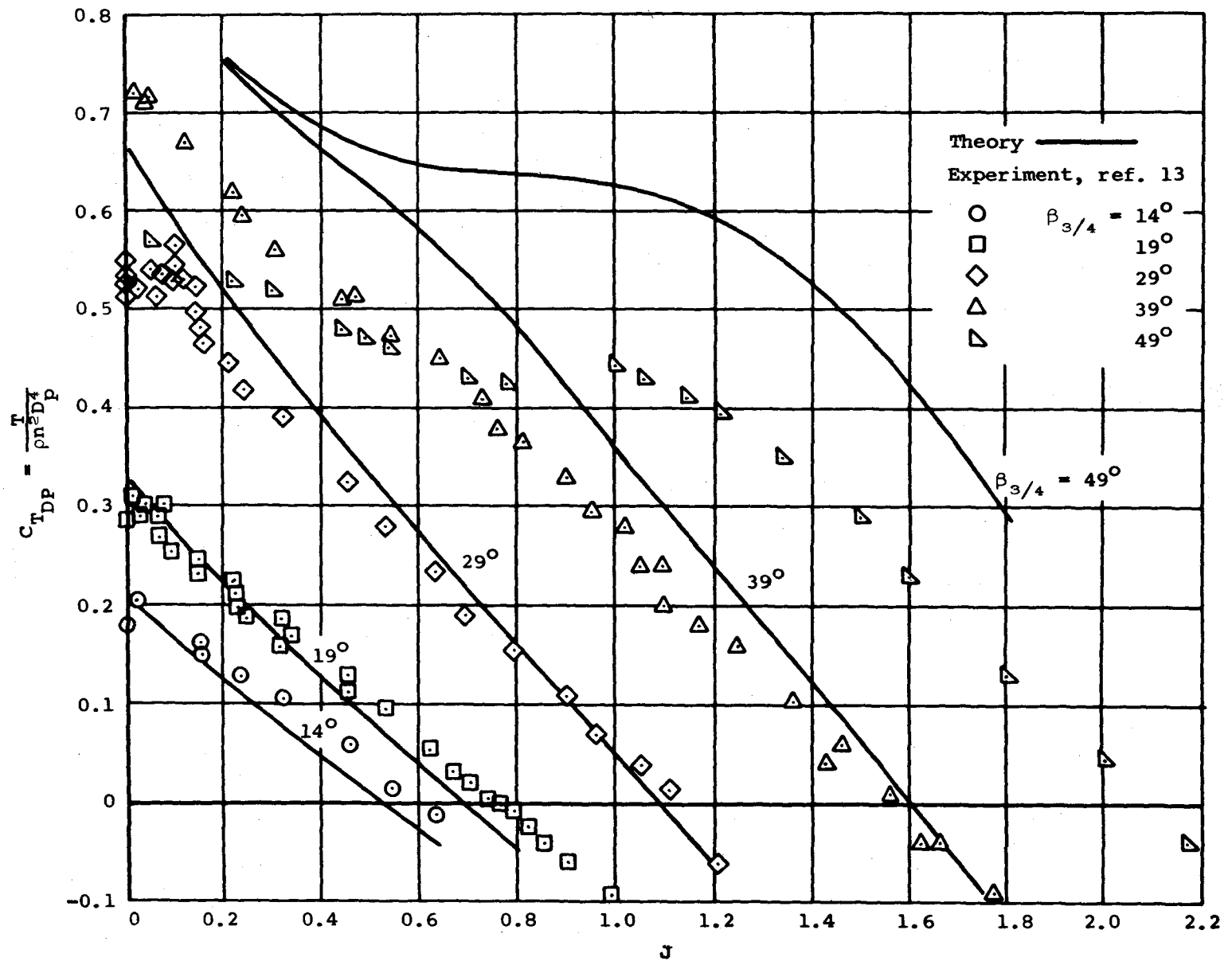
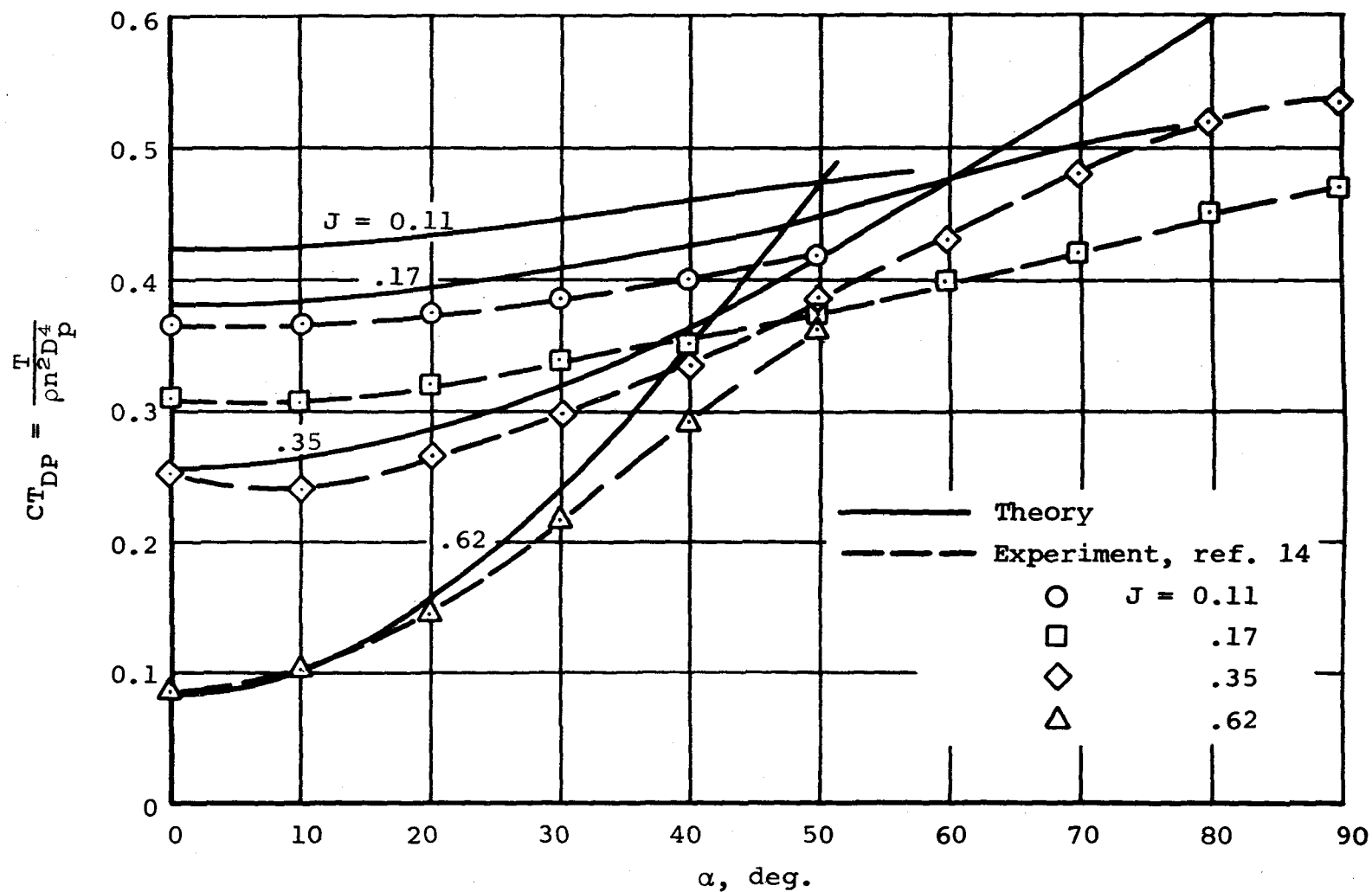
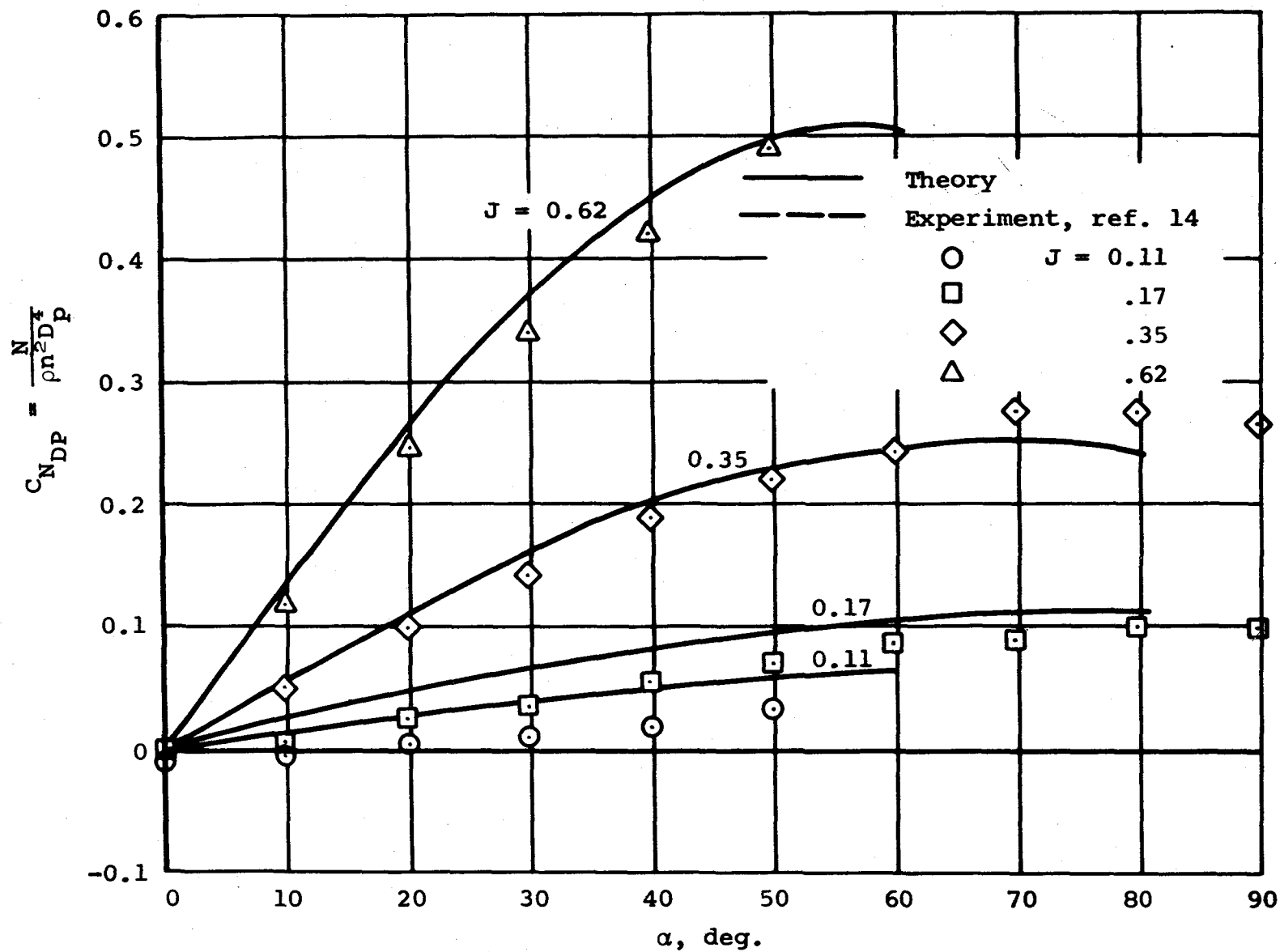


Figure 8.- Measured and predicted total thrust coefficient on the Bell X-22A ducted propeller in axial flow.



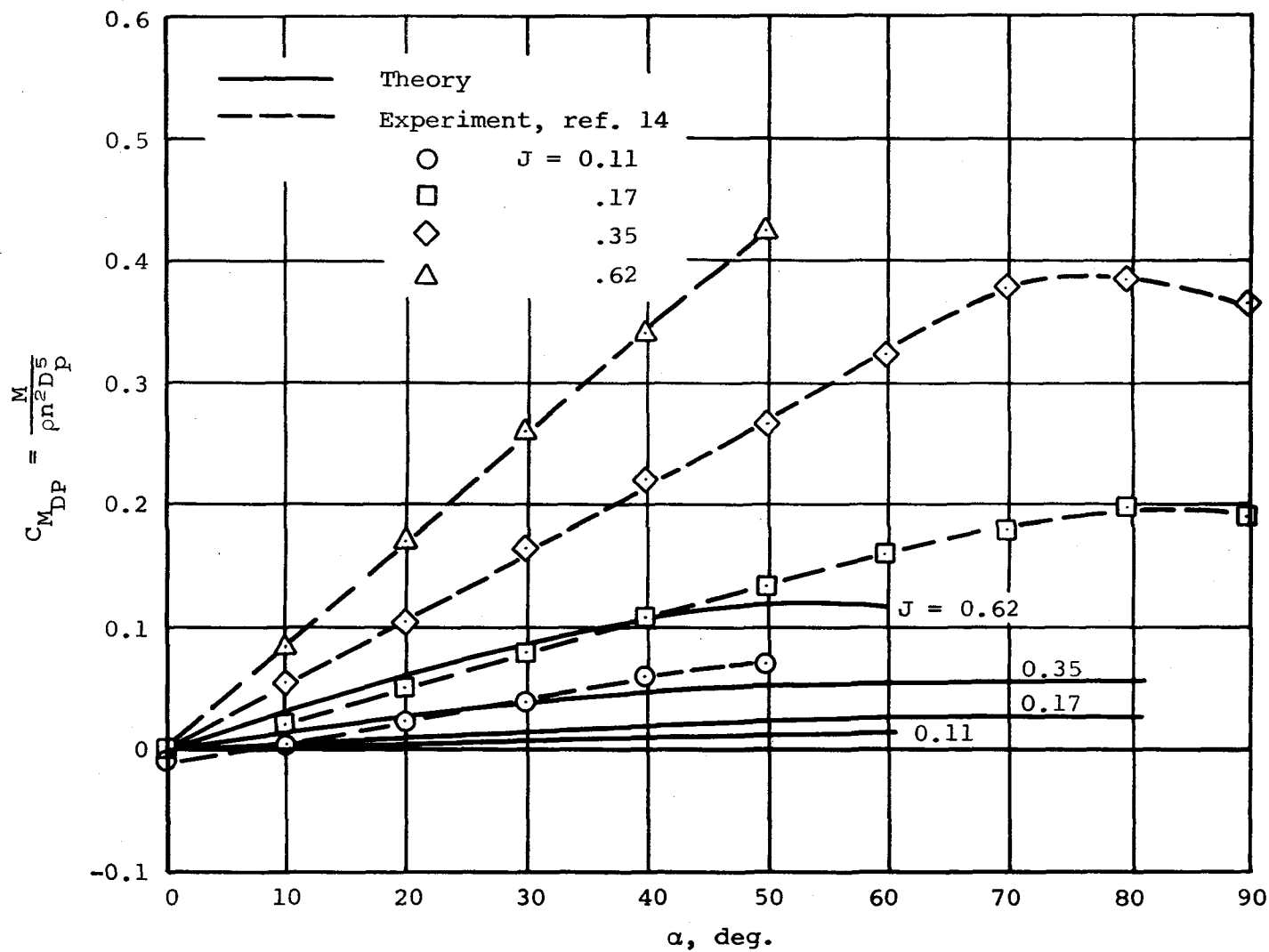
(a) Total thrust coefficient.

Figure 9.- Measured and predicted aerodynamic coefficients on the Doak VZ-4DA ducted fan, $\beta_{\text{tip}} = 15^\circ$.



(b) Normal force coefficient.

Figure 9.- Continued.



(c) Pitching moment coefficient.

Figure 9.- Concluded.

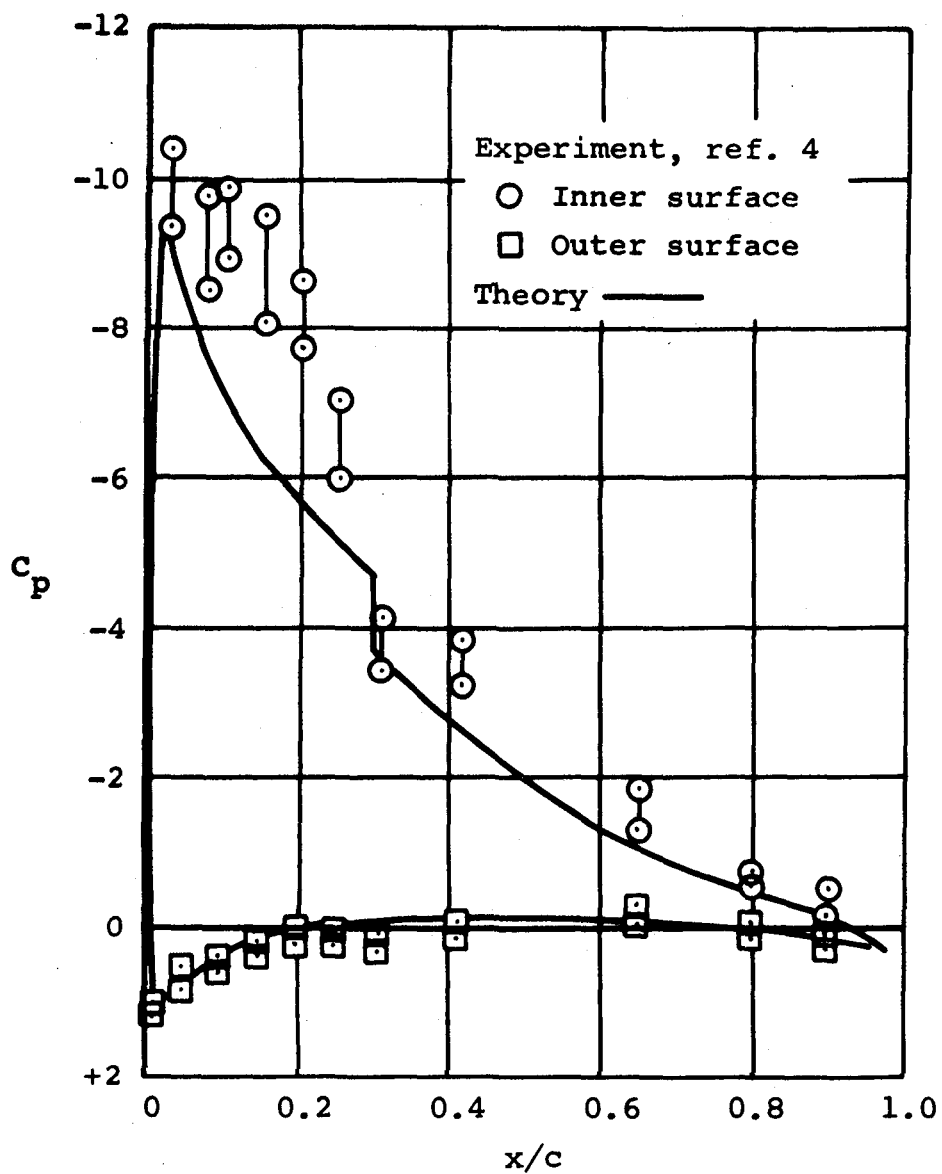
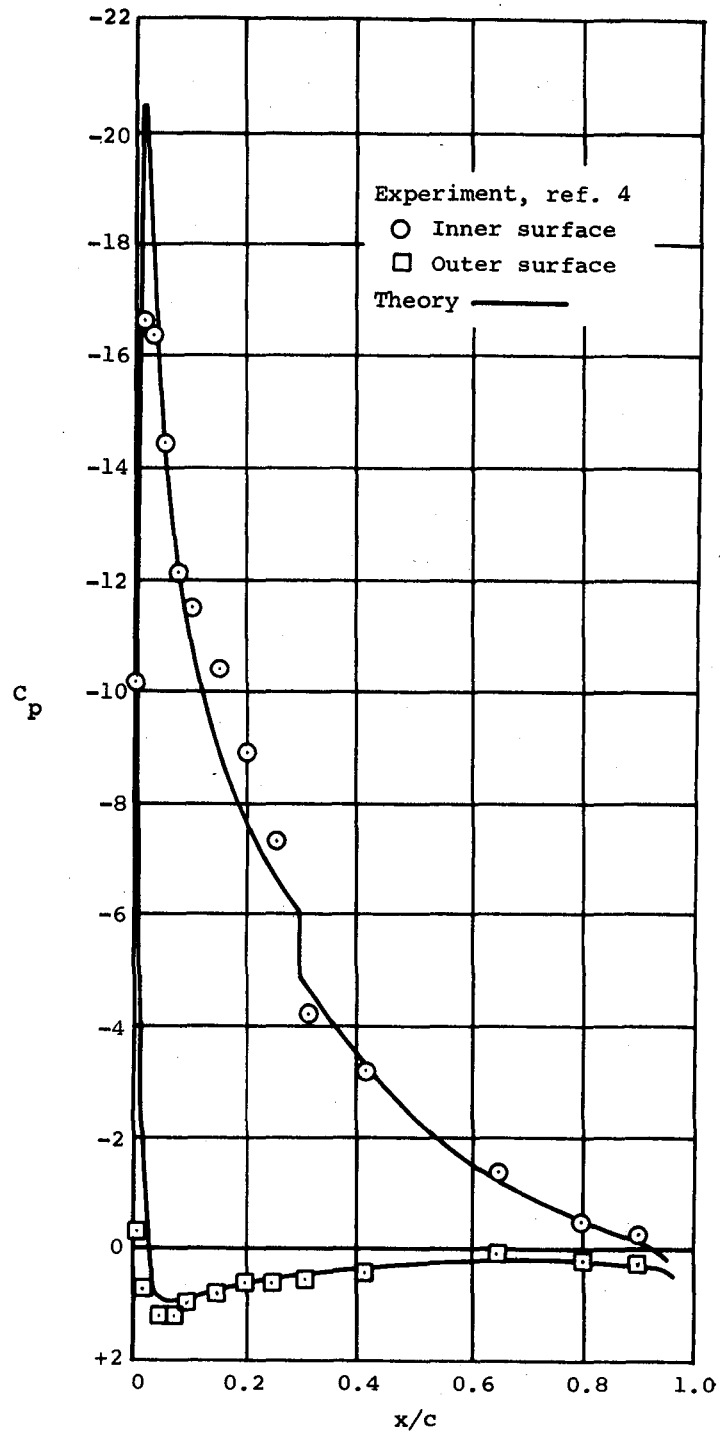
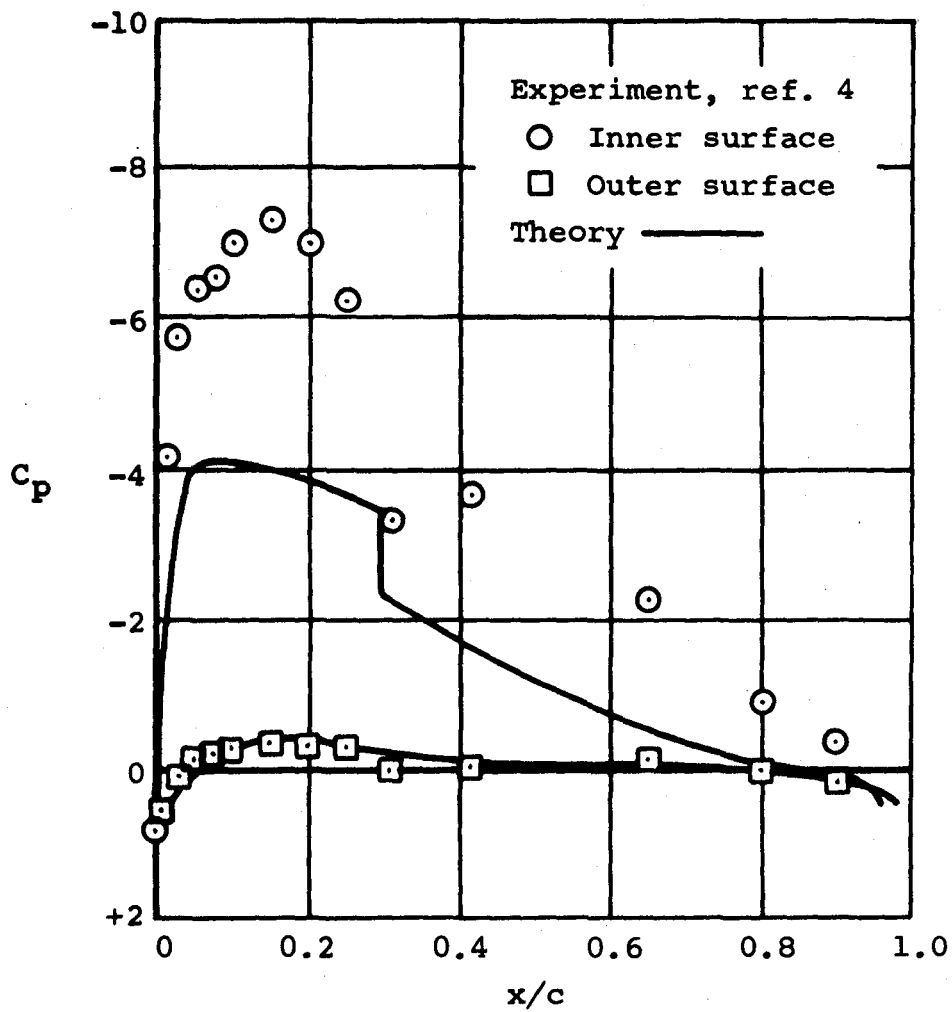


Figure 10.- Measured and predicted pressure distribution on the Doak duct at $\alpha = 0^\circ$, $J = 0.342$.



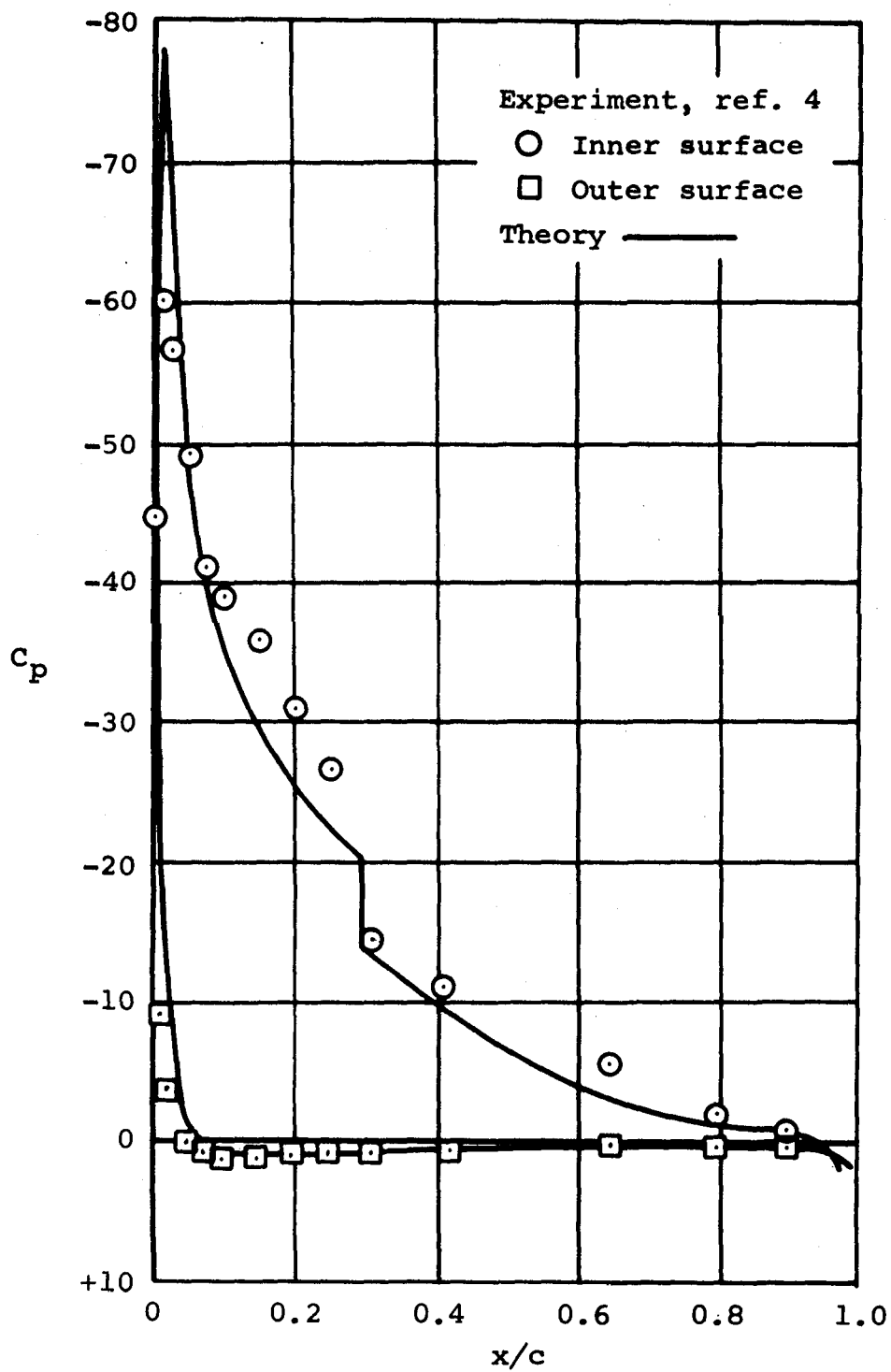
(a) $\phi = 0^\circ$.

Figure 11.- Measured and predicted pressure distribution on the Doak duct at $\alpha = 20^\circ$, $J = 0.342$.



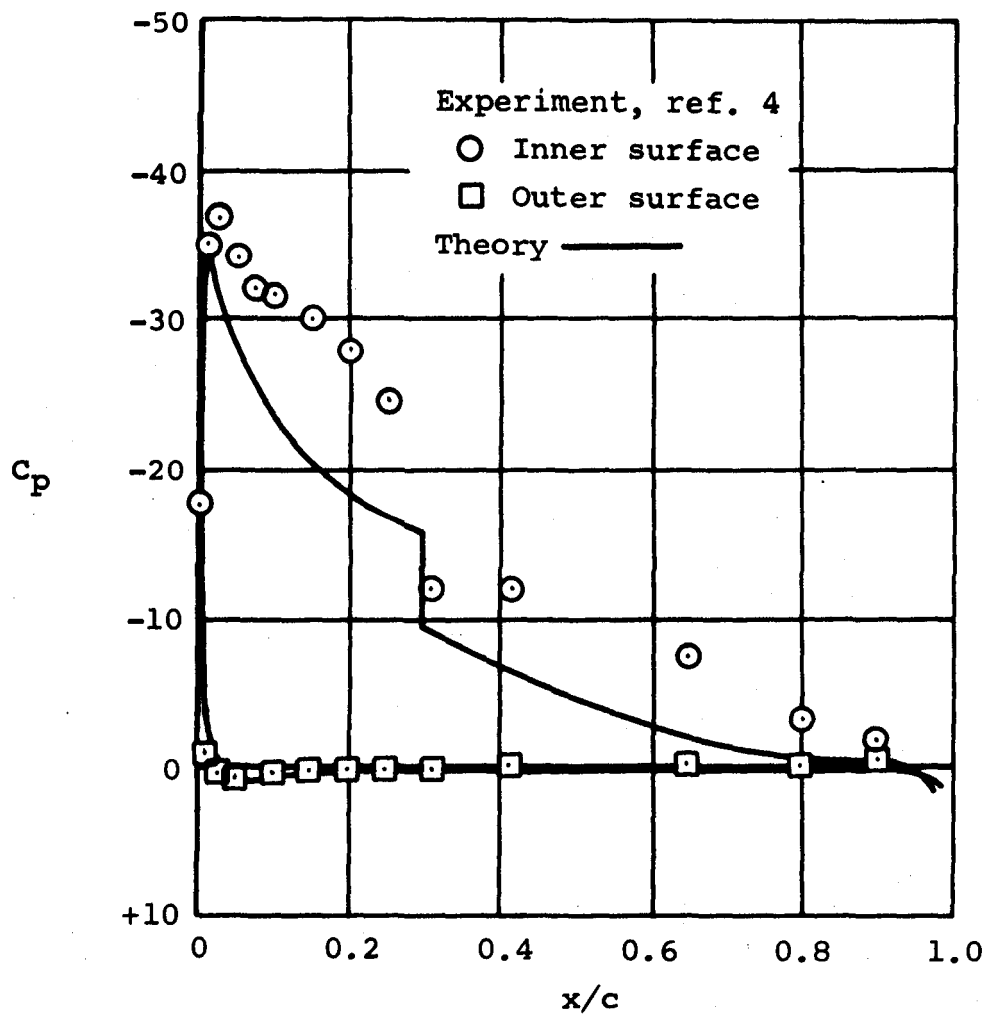
(b) $\phi = 180^\circ$.

Figure 11.- Concluded.



(a) $\phi = 0^\circ$.

Figure 12.- Measured and predicted pressure distribution on the Doak duct at $\alpha = 20^\circ$, $J = 0.178$.



(b) $\phi = 180^\circ$.

Figure 12.- Concluded.