PROGRAMS FOR MACHINE COMPUTATION
OF
ROTOR BLADE DOWNWASH

by
Nancy Ghareeb

REPORT UNDER
U.S. Navy
Bureau of Naval Weapons
Contract N0w 62-0100-d
Technical Report 107-1

August, 1964

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OF

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This program computes the downwash at the rotor blade using Equation 15 of Ref. 1. In this program the symbol, $V_1$, is used for $w_1$ of Ref. 1 and $x$ for $\gamma$. The chord variation, $x$, of Ref. 1 is here assumed to be zero. The computational techniques involved in the solution of this equation by numerical methods are chiefly those of integration and harmonic analysis. It was decided to perform the numerical integration by Simpson's rule (an approximation of the curve by a series of second degree parabolas) since this method seemed most appropriate to the nature of the function. Expressed symbolically, this means that given a function, $y = f(x)$, then

$$\int_{a}^{b} y \, dx = \frac{\Delta x}{3} \left[ y_o + y_n + 4 \sum_{i=1}^{n-1} y_i + 2 \sum_{j=2}^{n-2} y_j \right]$$

where $y_o = f(a)$ and $y_n = f(b)$, $i$ = odd integer, $j$ = even integer

For ease in programming, a separate subroutine was written to perform the harmonic analysis. This was done as follows:

Let $g(x)$ represent the function to be analyzed, then $g(x) = a_o + \sum_{k=1}^{n} (a_k \cos kx + b_k \sin kx)$ where the $a_k$ and $b_k$ are defined in the following relations:

$$a_o = \frac{1}{2\pi} \int_{Q}^{Q+2\pi} g(x) \, dx$$

$$a_k = \frac{1}{\pi} \int_{Q}^{Q+2\pi} g(x) \cos kx \, dx$$

$$b_k = \frac{1}{\pi} \int_{Q}^{Q+2\pi} g(x) \sin kx \, dx \quad (k \neq 0)$$

This analysis is, of course, applicable only for a range of $2\pi$ ($Q \rightarrow Q + 2\pi$). The integration again was performed using Simpson's rule.

The programs are written in Fortran II and should be operable at any IBM 709 or 7090 installation with one exception. The Massachusetts Institute of Technology Computation Center at which these programs were developed assigns logical tape numbers to physical tapes as follows:

<table>
<thead>
<tr>
<th>Physical</th>
<th>Logical</th>
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</thead>
<tbody>
<tr>
<td>A1</td>
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</tr>
<tr>
<td>A2</td>
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</tr>
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</tr>
<tr>
<td>B3</td>
<td>7</td>
</tr>
<tr>
<td>B4</td>
<td>3</td>
</tr>
</tbody>
</table>

Interval sizes of $7.5^\circ$ for $\psi$ and $7.5^\circ$ and $2.5^\circ$ for $\phi$ used with an $m$ of 3 and $QT$ of $-\gamma$ have produced results of sufficient accuracy for the present purposes.

CAUTION: Care must be taken in selecting interval sizes so that an odd number of points is to be used in each integration.

The Function $V_1(\psi, x)$ - Trailing Wake

$$V_1 = \int_{\psi + \gamma}^{2\pi m + \psi + \gamma} K_1(\phi) \frac{[\ell (d + \cos \phi - x \cos (\psi - \phi)) - \mu \sin \phi]}{[\ell^2 + x^2 + \gamma^2 - 2x \ell \cos (\psi - \phi) + 2d(\ell \cos \phi - x \cos \psi)]^{3/2}} d\phi$$
where \( K_1 = K_c \cos n \phi + K_s \sin n \phi \)
\[
d = \mu \left[ (2\pi m + \psi + \gamma) - \phi \right]
\]
\[
z = \lambda \left[ (2\pi m + \psi + \gamma) - \phi \right] (1.0 + a \cos \phi) - b_o (\ell - x)
\]

This program computes the value of the function for \( K_c = K_s = 1 \) for each \( \ell - x \) pair used at from one to four values of \( \gamma \) for a given number of values of \( \psi \). A value of zero is assumed to be among the \( \gamma \)'s read into the computer for each \( \ell - x \) pair, so that if only one value of \( \gamma \) is to be used that \( \gamma \) must be zero. The integration for the \( \gamma = 0 \) case only is split into two sections and integration performed between limits of \( \psi + \gamma \rightarrow 2\pi m + \psi + \gamma + QT \)
\( 2\pi m + \psi + \gamma + QT \rightarrow 2\pi m + \psi + \gamma \). The results of the latter integration are termed \( ZAPS1 (z_a(\psi)) \) for the cos component and \( ZBPS1 (z_b(\psi)) \) for the sin component.

The results of integration for the first section and the results of integration for any other \( \gamma \)'s are termed \( YIPS1 (i = 1, 2, 3, 4, 5, 6, 7, 8) \). The odd integers are assigned to the cos components and the even integers to the sin components. The \( i \)'s will correspond to the \( \gamma \)'s in the order in which the \( \gamma \)'s were read into the computer, i.e., \( Y1PS1 \) and \( Y2PS1 \) will be assigned to the results for the first \( \gamma \) read into the computer.

Next the \( YIPS1 \) terms are summed at each \( \psi \). The sum for the cos components is called \( \text{CHI} (\chi) \) and the sum for the sin components is called \( \text{SIGMA} (\sigma) \). Harmonic analysis is then performed on each of the four functions, \( \chi \), \( \sigma \), \( z_a(\psi) \), and \( z_b(\psi) \).

The time required to obtain results from the IBM 7090 computer for one \( \ell - x \) combination with 3 \( \gamma \)'s, \( m = 3 \) and interval sizes of 7.5°, 7.5° and 2.5° is approximately two minutes.

Subroutines required with this program will be described in the following pages.

The listing of the program in Fortran II together with the subroutines is given in Appendix A.

Typical results are listed in Appendix B.
Physical Explanation of Symbols

\( \psi \)  \sim \text{rotor azimuth measured from blade downwind position} \\
\( \gamma \)  \sim \text{blade spacing (cf. \( \delta \))} \\
\( m \)  \sim \text{number of wake spirals} \\
\( V_1(\psi, x) \approx w_1(\psi, x) \) \\
\( \lambda \)  \sim \text{rotor span parameter} \\
\( \phi \)  \sim \text{azimuth of wake measured from downwind position} \\
\( x \)  \sim \text{rotor span parameter (\( \gamma \) of Ref. 1)} \\
\( n \)  \sim \text{harmonic of rotor speed} \\
\( \mu \)  \sim \text{advance ratio} \\
\( \lambda \)  \sim \frac{\lambda_o}{\lambda_1} \\
\( a \)  \sim \frac{\lambda_o}{\lambda_1} \\
\( z \) \ - \text{vertical distance travelled by rotor hub} \\
\( d \) \ - \text{horizontal distance travelled by rotor hub} \\
\( b_o \) \ - \text{coning angle}
## Input Format

<table>
<thead>
<tr>
<th>Card No.</th>
<th></th>
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<td>NP</td>
<td>I1</td>
<td>MM</td>
<td>NN</td>
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<td>E13.8</td>
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<tr>
<td>1A</td>
<td>BO</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td>EMU</td>
<td>AMBDA</td>
<td>EM</td>
<td>DEPSI</td>
<td>DELPHI</td>
<td>DELTA</td>
<td>K</td>
<td>IJ</td>
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<td>E8.3</td>
<td>E8.3</td>
<td>E13.8</td>
<td>E13.8</td>
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<tr>
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<td>A</td>
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<td></td>
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<td></td>
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</tr>
</tbody>
</table>
Explanation of Symbols

L  number of harmonics to be computed in the Fourier analysis
KL  +1 → print optional table No. 2, -1 → suppress this print out
NP  interval at which table No. 2 is printed (i.e., +1 will cause printout of integral at every ψ used, +2 at every other ψ etc.)
II  number of times card No. 2 is to be repeated
MM  +1 → print optional table No. 1, -1 → suppress this print out
NN  interval at which table No. 1 is printed (see NP)
QT  determines limits of integration for γ = 0 case (i.e., QT = -π/2 will cause integration from ψ - γ to ψ + γ + 2πm - π/2 and from ψ - γ + 2πm - π/2 to ψ - γ + 2πm)
BO  b₀
EMU  μ
AMBDA  λ
EM  m
DEPSI  interval size used for ψ
DELPHI  interval size used for ψ [in γ = 0 case, in region ψ - γ → ψ - γ + 2πm + QT]
DELTA  interval size used for ψ for γ = 0 case in region ψ - γ + 2πm + QT to ψ - γ + 2πm
K  number of points of ψ to be used in harmonic analysis
IJ  number of values of a to follow
A  a
IK  number of values of l to follow
ELK  l
IL  number of values of n to follow
EN  n
IM  number of values of x to follow
X  x
IN  number of values of γ to follow
GAMMA  γ 6
Output Format

\[ \begin{align*}
\text{MU} &= \quad \text{LAMBD}A \quad = \\
\text{M} &= \quad \text{N} \quad = \\
\text{L} &= \quad \text{A} \quad = \\
\text{X} &= \\
\text{DELTA PSI} &= \\
\text{DELTA PHI (1)} &= \\
\text{DELTA PHI (2)} &= \\
\text{CHI} &= \\
\text{A - ZERO} &= \\
\text{A - k} &= \quad \text{B - k} = \\
\downarrow & \quad \downarrow \\
\text{SIGMA} &= \\
\text{A - ZERO} &= \\
\text{A - k} &= \quad \text{B - k} = \\
\downarrow & \quad \downarrow \\
\text{ZAPSI} &= \\
\text{A - ZERO} &= \\
\text{A - k} &= \quad \text{B - k} = \\
\downarrow & \quad \downarrow \\
\text{ZBPSI} &= \\
\text{A - ZERO} &= \\
\text{A - k} &= \quad \text{B - k} = \\
\downarrow & \quad \downarrow \\
\text{[Optional Table No. 1]} &= \\
\text{CHI} & \quad \text{SIGMA} \quad \text{PSI} \quad \text{ZAPSI} \quad \text{ZBPSI} \\
\downarrow & \quad \downarrow \quad \downarrow \quad \downarrow & \\
\text{[Optional Table No. 2]} &= \\
\text{PSI} & \quad \text{Y1PSI} \quad \text{Y2PSI} \quad \text{Y3PSI} \quad \text{Y4PSI} \quad \text{etc} \\
\downarrow & \quad \downarrow \quad \downarrow \quad \downarrow & \\
\end{align*} \]
\[
\Delta \phi (1) \approx \Delta \phi 
\quad [\text{see explanation of symbols (input)}]
\Delta \phi (2) \approx \Delta^2
\]

A - ZERO \approx \text{constant term resulting from Fourier analysis}

A - k \approx \text{coefficients of the } \cos k \psi \text{ terms resulting from the Fourier analysis}

B - k \approx \text{coefficients of the } \sin k \psi \text{ terms resulting from the Fourier analysis}
Subroutine Hornol (PSI, FPSI)

This subroutine performs the actual harmonic analysis as previously described. Information is transmitted to and from this subroutine by means of a common statement.

COMMON PSI, FPSI, I, L, K, DEPSI, AQUAY, BQUAY, A-ZERO

where

PSI - variable
FPSI - a function of PSI
I - an indicator to show type of function so that excess computation is avoided, i.e., +1 → an even function, +2 → an odd function, +3 → function is neither even nor odd. This is automatically set in (MAIN)
L - number of harmonics to be computed (maximum = 20)
K - number of values of PSI to be used, must be an odd integer > 3
DEPSI - interval size used for ψ
AQUAY - output - the coefficients a-k of the cos kψ terms
BQUAY - output - the coefficients b-k of the sin kψ terms
A-ZERO - output - the constant term

It is assumed that the table of ψ will describe a range of 2π if the function is neither even nor odd and otherwise a range of π.
Subroutine Prince \((L, \text{AQUAY}, \text{BQUAY}, \text{A ZERO})\)

This subroutine prints out the results of the harmonic analysis in the following form:

\[
\begin{align*}
\text{A-ZERO} &= \quad \text{(constant term)} \\
A - 1 &= \\
A - 2 &= \\
A - L &= \\
\downarrow \\
\text{(coefficients of } \cos k\psi \text{ terms)}
\end{align*}
\]

\[
\begin{align*}
B - 1 &= \\
B - 2 &= \\
B - L &= \\
\downarrow \\
\text{(coefficients of } \sin k\psi \text{ terms)}
\end{align*}
\]

An optional version also punches these results.
Subroutine TRIP (CHI, SIGMA, PSI, ZAPSI, ZBPSI, NN, K)

This subroutine prints optional table No. 1.

Subroutine PRICK (NP)

Information is transmitted to this subroutine via COMMON. It is used to print optional table No. 2. The subroutine must conform to the number of \( \gamma \)'s used in MAIN. If 3 \( \gamma \)'s are used PRICK must output PSI and YiPSI \((i = 1 \text{ to } 6)\). The present version is written for three \( \gamma \)'s, hence some modification will be necessary if a different number of \( \gamma \)'s is to be used.
Sample Data for Program IA

Card No. 1  \( 10 \times 1 + 1 + 2 + 1 + 1 - .15707963 \times 1 + 1 \)
Card No. 1A \( + .069 \times 0 \)
Card No. 2 \(+ .100 \times 0 + .500 \times -1 + .300 \times 1 + .13089969 \times 0 + .13089969 \times 0 + .43633233 \times -1 + 49 + 1 \)
Card No. 3 \(+ .500 \times 0 + 1 \)
Card No. 4 \(+ .100 \times 1 + 1 \)
Card No. 5 \(+ .300 \times 1 + 1 \)
Card No. 6 \(+ .550 \times 0 + 3 \)
Card No. 7 \(+ .0000 \ 0000 \times 0 + 0 \)
Card No. 8 \(+ .20943950 \times 1 \)
Card No. 9 \(+ .41887901 \times 1 \)
Card No. 10 \(+ .100 \times 0 + .200 \times -1 + .300 \times 1 + .13089969 \times 0 + .13089969 \times 0 + .43633233 \times -1 + 49 + 1 \)
Card No. 11 \(+ .000 \times 0 + 1 \)
Card No. 12 \(+ .100 \times 0 + 1 \)
Card No. 13 \(+ .000 \times 0 + 1 \)
Card No. 14 \(+ .975 \times 0 + 3 \)
Card No. 15 \(+ .0000 \ 0000 \times 0 + 0 \)
Card No. 16 \(+ .20943950 \times 1 \)
Card No. 17 \(+ .41887901 \times 1 \)

Note that the data block (cards No. 3→9) following card No. 2 must be repeated (cards No. 11→17) even though some of the parameters are unchanged.
This program computes the downwash at the rotor blade using Equation 21 of Ref. 1 with the symbol, $V_2$, substituted for $w_2$ and $x$ for $\gamma$ as before.

\[
V_2 = \int_{\psi + \gamma}^{\psi + \gamma + 2\pi m} K_2(\phi) \left[ \frac{x \sin (\psi - \phi) + d \sin \phi}{z^2 + (x \sin (\psi - \phi) + d \sin \phi)^2} \right] d\phi
\]

\[
\left[ \sqrt{l^2 + x^2 + z^2 + d^2 - 2xz \cos (\psi - \phi) + 2d(l \cos \phi - x \cos \psi)} - \frac{d \cos \phi - x \cos (\psi - \phi)}{\sqrt{x^2 + z^2 + d^2 - 2xd \cos \psi}} \right] d\phi
\]

\[
d = \mu \left[ (2\pi m + \psi + \gamma) - \phi \right]
\]
\[
z = \lambda \left[ (2\pi m + \psi + \gamma) - \phi \right]
\]
\[
K_2(\phi) = K_c \cos n\phi + K_s \sin n\phi \quad (K_c \text{ and } K_s \text{ are set to } 1.0)
\]

This program evaluates the integral in two steps. For the first step (from $\psi + \gamma \rightarrow 2\pi m + \psi + \gamma + QT$) integration is performed by Simpson's rule using $K_2$ as defined above. The results of this integration are labelled $S1PSI$ for the cos component and $S2PSI$ for the sin component. For the second step $\cos n\phi$ and $\sin n\phi$ are expanded to

\[
\sin n(\psi - \phi) \sin n\psi + \cos n(\psi - \phi) \cos n\psi
\]
\[
\cos n(\psi - \phi) \sin n\psi - \sin n(\psi - \phi) \cos n\psi \quad \text{respectively.}
\]

The integration is then carried out from $(\psi + \gamma + 2\pi m + QT)$ to $(\psi + \gamma + 2\pi m)$ using $K_2 = K_c \sin n(\psi - \phi) \sin n\psi + (-K_s) \sin n(\psi - \phi) \cos n\psi$. The coefficient of $K_c$ is called $S4PSI$ and the coefficient of $(-K_s)$ is called $S3PSI$. The value of the function at the upper limit is approximated by setting $\phi = \phi - 1/2 \Delta \phi$. This gives a very good approximation when the interval size used in this region is on the order of 2.5°. Harmonic analysis is then performed on all four of these functions ($S1PSI$, $S2PSI$, $S3PSI$, $S4PSI$). This program does not consider those terms involving $\cos n(\psi - \phi)$.

The time required for one case on the IBM 7090 computer (one $x$, one $l$, one $\gamma$) is approximately .5 minutes for a 7.5° interval size and $m = 3$.  

13
Subroutines HARNAL and PRINCE are used with this program. The program used for $V_2$ is listed in Appendix C with typical results in Appendix D.

**Input Format**

Card No. 1  
L    NP    KL    IL    QT  
12  12  12  12  E13.8

Card No. 2  
EMU  AMBDA  EM  DEPSI  DELPHI  DELTA  K  IJ  
E8.3  E8.3  E8.3  E13.8  E13.8  E13.8  13  12

Card No. 3  
EN  IK  
E8.3  12

Card No. 4  
GAMMA  IL  
E13.8  12

Card No. 5  
ELK  IM  
E8.3  12

Card No. 6  
X  
E8.3
**Explanation of Symbols**

L  number of harmonics to be calculated
NP interval of printing (+1 → print integral for every ψ used, +2 for every other ψ, etc)
KL -1 → print table of SiPSI, +1 → suppress this table
II number of cards No. 2 to follow
QT determines limits of integration (QT = -π will cause integration from
ψ + γ to ψ + γ + 2πm - π/2 and from ψ + γ + 2πm - π/2 to 2πm + ψ + γ)

EMU µ
AMBDA λ
EM m
DEPSI interval size to be used for ψ
DELPHI interval size to be used for φ in region ψ + γ → 2πm + ψ + γ
DELTA interval size to be used for φ in region 2πm + ψ + γ + QT → 2πm + ψ + γ
K number of values of ψ to be used in the harmonic analysis
IJ number of values of n to follow
EN n
IK number of values of γ to follow

GAMMA γ
IL number of values of k to follow
ELK l
IM number of values of x to follow
X x
Output Format

\[
\begin{align*}
\text{MU} &= \text{LAMBDA} = M = N = \text{Gamma} = L = X = \\
(\text{optional table}) \quad \psi_1 & \quad \psi_1 & \quad \psi_1 & \quad \psi_1 & \quad \psi_1 \\
\downarrow & \quad \downarrow & \quad \downarrow & \quad \downarrow & \quad \downarrow \\
S1\psi_1 \\
A - \text{Zero} &= \quad A - k = \quad B - k = \quad \downarrow & \quad \downarrow \\
S2\psi_1 \\
A - \text{Zero} &= \quad A - k = \quad B - k = \quad \downarrow & \quad \downarrow \\
S3\psi_1 \\
A - \text{Zero} &= \quad A - k = \quad B - k = \quad \downarrow & \quad \downarrow \\
S4\psi_1 \\
A - \text{Zero} &= \quad A - k = \quad B - k = \quad \downarrow & \quad \downarrow \\
\end{align*}
\]
Sample Data for Part I, B

Card No. 1  \[ 10 + 1 - 1 + 1 - .15707963 \times 10^1 \]

Card No. 2  \[ + .100 \times 10^0 + .500 \times 10^{-1} + 300 \times 10^1 + .13089969 \times 10^0 + .13089969 \times 10^0 + .43633233 \times 10^{-1} + 49 \times 10^1 \]

Card No. 3  \[ + .300 \times 10^1 + 2 \]

Card No. 4  \[ + .0000 \times 10^0 + 0 + 1 \]

Card No. 5  \[ + .100 \times 10^1 + 1 \]

Card No. 6  \[ + .800 \times 10^0 \]

Card No. 7  \[ + .20943950 \times 10^1 + 1 \]

Card No. 8  \[ + .100 \times 10^1 + 1 \]

Card No. 9  \[ + .800 \times 10^0 \]
PROGRAM II. ORIGINAL STRAIGHT LINE APPROXIMATION TO WAKE

This program attempts to define the trailing wake, "w", by means of the very much simplified expressions given below (see Ref. 1):

\[
w = \frac{\Gamma}{4\pi R} \cdot \frac{2(y - \eta)\cos \delta}{Z^2 + (y - \eta)^2 \cos^2 \delta}
\]

except for \( \delta = 0 \) \quad (1)

where \( y = d\cos^2 \frac{\delta}{2} - d \sin \phi \) \quad (1a)

\( d = \mu \left| S + \psi - \phi \right| \) \quad (1b)

\( Z = \lambda \left| S + \psi - \phi \right| \cdot a_0 (l - \eta) \) \quad (1c)

\( u \sin \psi = l \sin (\phi - \psi) \) \quad (1d)

\( \tan (\phi - \psi - \delta) = \frac{-\mu \cos \phi}{l + \mu \sin \phi} \) \quad (1e)

Values for \( \phi \) were found by combining equations (1b) and (1d) to give an expression of the form \( f(\phi) = 0 \). An initial guess was made for \( \phi \) and that guess improved by a Newton-Raphson iteration where the improved \( \phi \) equalled the original \( \phi \) minus \( f(\phi)/f'(\phi) \). \( f'(\phi) \) represents the derivative of \( f(\phi) \) with respect to \( \phi \).

When \( \delta = 0 \) Then \( w = \frac{\Gamma}{4\pi R} \cdot \frac{1 - \sin \delta}{(l - \eta) \cos \delta} \)

where \( \delta = \tan^{-1} \left( \frac{\mu \cos \psi}{l + \mu \sin \psi} \right) \)

since \( \phi = \psi, d = Z = 0, y = l \)

This program also performs harmonic analysis of the function as summed over the blades.

The function \( 4\pi R\omega/\Gamma \) and its harmonic coefficients are also punched out in a format suitable for input to Program III.
This program was written in FORTRAN II. It requires approximately 0.5 minute on an IBM 7094 computer to handle a case of one \( L \), one \( \gamma \), one \( \mu \), and \( \lambda \) and \( 4 \) at intervals of 15° in \( \psi \). The program was developed at the Massachusetts Institute of Technology Computation Center in Cambridge, Massachusetts.

This program requires two subroutines:

- **OUD1** - to compute \( d \) and \( \phi \)
- **HANEW** - to perform harmonic analysis

**NOTE:** INPUT AND OUTPUT are taken care of by

```
WRITE OUTPUT TAPE 2----------
READ INPUT TAPE 4 ----------
```

Therefore, it may be necessary to change an IOU table to correspond.

A list of the logical to physical tape correspondences may be found under Program IA.
EXPLANATION OF SYMBOLS

Γ = circulation
R = rotor radius
d = horizontal distance travelled by rotor hub
z = vertical distance travelled by rotor hub
η = rotor span parameter (equivalent to $x$ in program 1)
μ = advance ratio
λ = inflow normal to rotor disc
ψ = rotor azimuth
l = rotor span parameter
α = coning angle
S = blade spacing
δ = angle between vortex line and a perpendicular to the blade
ϕ = wake azimuth
**INPUT FORMAT**

<table>
<thead>
<tr>
<th>Card No. 1</th>
<th>EMU</th>
<th>AMBDA</th>
<th>IJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>I2</td>
<td>E8.3</td>
<td>E8.3</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Card No. 2</th>
<th>EL</th>
<th>ETA</th>
</tr>
</thead>
<tbody>
<tr>
<td>E8.3</td>
<td>E8.3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Card No. 3</th>
<th>DEPSI</th>
<th>AO</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 13</td>
<td>E13.8</td>
<td>E8.3</td>
</tr>
<tr>
<td>13 13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EXPLANATION OF SYMBOLS

II = a counter to be set equal to the number of times Card No. 1 is to be repeated
IK = a counter to be set equal to the number of times Card No. 2 is to be repeated
NZ = the number of blades to be considered
NH = the number of harmonics to be considered when performing harmonic analysis
K = the number of values of $\psi$ at which the function is to be computed, must be odd
DEPSI = the interval size to be used for $\psi$
AO = $a_o$
EMU = $\mu$
AMBDA = $\lambda$
IJ = counter to be set equal to the number of times Card No. 3 is to be repeated
EL = $\lambda$
ETA = $\eta$
OUTPUT FORMAT

<table>
<thead>
<tr>
<th>BLADES</th>
<th>MU =</th>
<th>LAMBD =</th>
<th>L =</th>
<th>ETA =</th>
<th>DELTA PSI =</th>
</tr>
</thead>
</table>

PSI TOTAL WAKE CONTRIBUTIONS FROM INDIVIDUAL BLADES

HARMONIC ANALYSIS

A - zero =
A - i =   B - i =

Here MU = μ, LAMBD = λ, L = L, ETA = η, PSI = Ψ, DELTA PSI = interval size used in Ψ.

CONTRIBUTIONS FROM INDIVIDUAL BLADES - These blades will be W \( \frac{4 \pi R}{\eta} \)

calculated at specific blade spacings or values of Σ in order of increasing Σ.

TOTAL WAKE - This column will be the sum of W \( \frac{4 \pi R}{\eta} \) over all blades at each Ψ.

A - zero \( \approx \) constant term resulting from harmonic analysis.
A - i \( \approx \) coefficients of the i\(^{th}\) cosine terms resulting from harmonic analysis.
B - i \( \approx \) coefficients of the i\(^{th}\) sine terms resulting from harmonic analysis.

There may also be an error message.

NO CONVERGENCE AT ZETA = . This message will be printed out if there is no convergence after repeating the iteration ten times.

In this case, the component of the trailing wake under consideration is set to zero.
PROGRAM III - ROTOR LOAD ANALYSIS

1. Description of Procedure

The nondimensionalized trailing wake, \( V_1 (\psi) \), is defined over a range of \( 0 \rightarrow 2\pi \) in the azimuth angle \( \psi \). Values of \( \psi \) generally vary by 75° or 15°. For any given configuration, "m" values of \( \eta \) and "m + 1" values of \( \ell \), where \( \ell \) and \( \eta \) are rotor span parameters, are considered so that there are "m \( \times \) m" sets of \( V_1 (\psi) \). The members of these sets are designated as \( A_{ijk} (\psi) \) where "i" refers to a specific value of \( \eta \) and "k" refers to a specific value of \( \ell \). Harmonic analysis with respect to \( \psi \) is performed on each of these sets, so that there are also "m \( \times \) m" series of "2n + 1" harmonic coefficients \( P \) and \( Q \) such that \( A_{ijk} (\psi) \propto P_{ij} + \sum_{n=1}^{\infty} Q_{ij} \) \( (P_{ij} \cos i \psi + Q_{ij} \sin i \psi) \). In the following write-up, \( i \) will always indicate a harmonic, \( \eta \) a specific value of \( \eta \), and \( k \) a specific value of \( \ell \).

A. To find the load coefficients, a system of "m" equations is set up:

\[
\lambda_{oi} = \frac{b}{2\pi} \sum_{t=1}^{m} \left[ (\eta_t \theta_t - \lambda_{o_t}) \left( P_{o_{it}} - P_{o_{it} + 1} \right) \right] - \mu \tan \psi
\]

and the \( \lambda_{oi} \) are determined. These may then be compared with the "\( \lambda \)" or "\( \lambda' \)"'s used in calculating the \( P \)'s and \( Q \)'s. If desired an iterative process may be set up, replacing the "\( \lambda \)" with the \( \lambda_{oi} \), until reasonable agreement is obtained between \( \lambda \) and the range of \( \lambda_{oi} \).

\[
V_1 (\psi) = \int_{\psi + \delta}^{\psi + \delta + 2\pi M} \frac{1}{\sqrt{\left[ 1 + d \cos \phi - \eta \cos (\psi - \phi) + \mu \sin \phi \right] \left[ 1 + d \cos \phi - \eta \cos (\psi - \phi) + 2 \eta \cos (\psi - \phi) + 2d \cos (\psi - \phi) \right]}} d\phi
\]
A \( \lambda_{ic,i} \) and a \( \lambda_{is,i} \) may also be obtained.

\[
\lambda_{ic,i} = \frac{b}{2R} \sum_{t=1}^{m} (\gamma_{t} \theta_{t} - \lambda_{o,t}) (p_{it} - p_{i,t+1})
\]

\[
\lambda_{is,i} = \frac{b}{2R} \sum_{t=1}^{m} (\gamma_{t} \theta_{t} - \lambda_{o,t})(q_{i,t} - q_{i,t+1})
\]

B. The time history of downwash \( \lambda_{i}(\psi) \) is calculated in the following manner:

\[
\lambda_{i}(\psi) = \frac{b}{2R} \left[ \sum_{t=1}^{m} (\gamma_{t} \theta_{t} - \lambda_{o,t}) (A_{it}(\psi) - A_{it+1}(\psi)) \right] - \mu \tan \psi
\]

An alternate method \( \lambda_{i}(\psi) = \lambda_{o,i} + \sum_{i=1}^{n} (\lambda_{ic,i} \cos i \psi + \lambda_{is,i} \sin i \psi) \)

was rejected, because it did not appear to give a very accurate reconstruction, unless some rather high harmonics were included.

C. The distributed airloads \( L_{n}(c,s) \) for \( n > 2 \) are calculated for each \( \eta_{i} \) as follows:

Let \( Y_{ic,i} = F_{i} \lambda_{ic,i} - G_{i} \lambda_{is,i} \) where \( i = 2, 3, 4, 5, 6, 7 \) and \( F \) and \( G \) are generally but not necessarily, constant over \( i \) and \( j \).

and \( Y_{is,i} = F_{i} \lambda_{is,i} + G_{i} \lambda_{ic,i} \)

Then \( L_{ic,i} = C \left\{ \eta_{i} Y_{ic,i} + \frac{b}{2} \left[ Y_{i+1, s_{i}} - Y_{i-1, s_{i}} \right] \right\} L_{i}(c,s) \) for \( i = 3, 4, 5, 6 \)

\( L_{is,i} = C \left\{ \eta_{i} Y_{is,i} + \frac{b}{2} \left[ Y_{i-1, c_{i}} - Y_{i+1, c_{i}} \right] \right\} \)

\( C \) is a conversion factor, depending upon the dimensions of the test model under consideration.
D. The load function $L_i(\psi)$ is computed in two parts:

1. $L_{i1}(\psi) = -C(\eta_i, \mu \sin \psi) \lambda_i(\psi)$

2. $L_{G_i}(\psi) = -C\left\{\theta_i(\eta_i^2 + \mu^2/2) - \eta_i \mu a_1 + \frac{1}{2} \mu b_1 \eta_i - \frac{7}{4} a_0 \eta_i \right\} \sin \psi + \frac{1}{2} b_1 (\eta_i^2 + \mu^2/4) \cos \psi - \frac{1}{2} b_1 \cos 2 \psi - \frac{1}{2} a_1 \sin 3 \psi - \frac{1}{4} b_1 \cos 3 \psi \right\}$

$L_i(\psi) = L_{i1}(\psi) \cdot L_{G_i}(\psi)$

C is again a conversion factor, and $a_0, a_1, b_1$ are geometric parameters (blade coning angle and first harmonic flapping).

$L_i(\psi)$ is also computed with the zero-th, first, and second harmonics eliminated. (The third harmonics in $L_{G_i}(\psi)$ are considered negligible.)

$\tilde{L}_i(\psi) = C\left\{\eta_i, \mu \sin \psi\right\} \lambda_i(\psi) - \frac{1}{2} \lambda_{1s_i} - \frac{1}{2} \lambda_{2s_i} \cos \psi - \frac{1}{2} \lambda_{2c_i} \sin \psi - \frac{1}{2} \lambda_{3s_i} \cos 2 \psi - \frac{1}{2} \lambda_{3c_i} \sin 2 \psi \right\}$

NOTE: If it is desired to do a case where the number of $I$'s is not one greater than the number of $\eta$, then a different procedure must be used. Suppose Program II has been run for five values of $\eta$ and two values of $I$.

$\lambda_{i0} = \rho |P_{i0}| - \mu \tan i$

$\lambda_{ic} = \rho |P_{ic}| - \mu \tan i$

$\lambda_{is} = \rho |Q_{is}|$ and $|i| = 1 \rightarrow 5$

$\lambda_i(\psi) = \rho |A_{i1}(\psi)| - A_{i2}(\psi) - \mu \tan i$
Where \( \rho \) is an appropriate conversion factor. A rough approximation would be
\[
\frac{b}{2R} \times \text{the average (} \gamma_{1i} - \lambda \text{)}.
\]

These "\( \lambda \)" must then be put into the appropriate card format for input data to Program III C. If a small computer is available it is easy to write a simple program to do this.
2. Description of Variables

\( V_1(\psi) = \) non-dimensionalized trailing wake for
\( \psi = \) azimuth angle for rotor
\( S = \) determined by blade spacing
\( M = \) number of wake spirals
\( I, \eta = \) rotor span parameters \( (\eta \text{ is the same as } \chi \text{ in program I}) \)
\( d, z = \) horizontal and vertical distances travelled by rotor hub
\( \mu = \) advance ratio
\( \phi = \) azimuth angle for wake
\( m = \) number of values of \( \eta \) under consideration
\( n = \) number of harmonics taken in harmonic analysis of \( V_1(\psi) \)
\( i \text{ or } is = \) indicates an \( i \)th cosine or sine harmonic resulting from harmonic analysis
\( j = \) indicates a specific value of \( \eta = \eta_j \)
\( k = \) indicates a specific value of \( I = I_k \)

\( F = \) lift deficiency function - from data obtained from shed and harmonic trailing wakes.
\( G = \) lift phasing function - from data obtained from shed and harmonic trailing wakes.

3. Program Mechanics

This program is written in FORTRAN II. It requires approximately .3 minutes to handle a case involving five values of \( \eta \) on the IBM 7094. One subroutine "CROUT" is used to solve the system of simultaneous equations. A maximum of \( \eta, \theta, F \) or \( G \), a maximum of 50 values \( \psi \), and a maximum of 20 harmonics may be used. This program was developed with the aid of the facilities at the Massachusetts Institute of Technology Computation Center.
INPUT FORMAT

Card No. 1  DEPSI  BOER  TANMU  EMU  CF  II  M  KP  NH  NGP  I2P
  E13.8  E8.3  E8.3  E8.3  E8.3  I3  I3  I3  I3  I3  I3

Card No. 2  ETA (1)  THETA (1)  F(l)  G(I)
  E8.3  E8.3  E8.3  E8.3

This card format must be repeated "m" times in succession.

Card No. 3

A. If I2P = 1
   1. A(I, J, K)  5E14.7
   2. B(I, J, K)  6E12.5

These cards are to be grouped by \( \eta \) then by \( \eta \) i.e., hold \( \eta \) constant; enter 1. and 2. for \( \eta \), followed by 1 and 2 for \( \eta \), etc., up to 1. and 2. for \( \eta \). Then consider \( \eta = \eta_2 \) and repeat the process.

B. If I2P = 2
   In this case the ordering will be the same, except that each subgroup of 1 and 2 will be augmented by 3 and 4
   1. A(I, J, K)  5E14.7
   2. B(I, J, K)  6E12.5
   3. C(K)  5E14.7
   4. D(K)  6E12.5

in this case 1 and 3 are added together as are 2 and 4.

Card No. 4  AZERO  AONE  BONE
  3E8.3
Explanation of Variables

DEPSI = interval size used for $\nu$

BOER = $\frac{b}{2R}$

TANMU = $\tan \theta$

EMU = $\mu$

CF = a conversion factor depending on the geometry of the model being considered

II = number of times Card No. 1 is to be repeated

M = number of values of $\eta$

KP = number of points of $\psi$

NH = number of harmonics (a \textsuperscript{th} term + all cos coefficients + all sin coefficients)

NGP = number of card No. 4 to be input

I2P = +2 indicates C and D arrays are to be input, + 1 indicates only A and B are to be input

ETA(I) = $\eta_i$

THETA(I) = $\theta_i$

F(I) = $F_i$

G(I) = $G_i$

A(I, J, K) = harmonic coefficients resulting from the harmonic analysis of $B(I, J, K)$

B(I, J, K) = "KP" values of the trailing wake function. (If the function has been separated into near and far wakes, this will be the far wake portion)

* C(K) = harmonic coefficients resulting from the harmonic analysis of $D(K)$

* D(K) = "KP" values of the near wake portion of the trailing wake to be added on to B

* These will be omitted if I2P = +1

AZERO = $a_o$

AONE = $a_1$ Blade flapping is defined as $a_o - a_1 \cos \psi - b_1 \sin \psi$.

BONE = $b_1$
LOAD COEFFICIENTS FOR ETA = \( \eta, \eta_2, \ldots, \eta_m \)

\[ \eta = \eta_i \]

(These will follow sequentially so that the first sine harmonic will be assigned a number equal to that of the last cosine harmonic plus one)

LAMBDA (PSI) FOR ETA = \( \psi \)

ETA = \( \eta \), \( \psi \)

LOAD COEFFICIENTS = \( \lambda_0, \lambda_i, \lambda_i, \lambda_{is} \)

LAMBDA (PSI) = \( \lambda_i \)

\( L_{ci}, L_{is} \)

\( L(i) \) = \( L_{ci}(\psi) \)

\( L(G) \) = \( L_{ci}(\psi) \)

\( L(G + 1) \) = HARMONICS EXTRACTED - \( \tilde{L}_i(\psi) \)
APPENDIX A

Program for $V_1$ - Trailing Wake

DIMENSION Y(PS1(361),Y2PS1(361),Y3PS1(361),Y4PS1(361),Y5PS1(361)),
1 Y6PS1(361),Y7PS1(361),Y8PS1(361),Y9PS1(361),Y10PS1(361),ZPS1(361),PS1(361),
2 (X1361,J1361,ALPHAY20),ALPHAY12C
COMMON PS1,YPS1,ILK,PS1Y,PS1Y2,PS1Y3,PS1Y4,PS1Y5,PS1Y6,PS1Y7,PS1Y8,
1 PS1Y9,PS1Y10,PS1Z1,PS1Z2,PS1Z3,PS1Z4,PS1Z5,PS1Z6,PS1Z7,
2 PS1Z8,PS1Z9,PS1Z10,PS1Z11,PS1Z12,PS1Z13,PS1Z14,PS1Z15,PS1Z16,
3 PS1Z17,PS1Z18,PS1Z19,PS1Z20,PS1Z21,PS1Z22,PS1Z23,PS1Z24,
4 PS1Z25,PS1Z26,PS1Z27,PS1Z28,PS1Z29,PS1Z30,PS1Z31,PS1Z32,
5 PS1Z33,PS1Z34,PS1Z35,PS1Z36,PS1Z37,PS1Z38,PS1Z39,PS1Z40,
6 PS1Z41,PS1Z42,PS1Z43,PS1Z44,PS1Z45,PS1Z46,PS1Z47,PS1Z48,
7 PS1Z49,PS1Z50,PS1Z51,PS1Z52,PS1Z53,PS1Z54,PS1Z55,PS1Z56,
8 PS1Z57,PS1Z58,PS1Z59,PS1Z60,PS1Z61,PS1Z62,PS1Z63,PS1Z64,
9 PS1Z65,PS1Z66,PS1Z67,PS1Z68,PS1Z69,PS1Z70,PS1Z71,PS1Z72,
10 PS1Z73,PS1Z74,PS1Z75,PS1Z76,PS1Z77,PS1Z78,PS1Z79,PS1Z80,
11 PS1Z81,PS1Z82,PS1Z83,PS1Z84,PS1Z85,PS1Z86,PS1Z87,PS1Z88,
12 PS1Z89,PS1Z90,PS1Z91,PS1Z92,PS1Z93,PS1Z94,PS1Z95,PS1Z96,
13 PS1Z97,PS1Z98,PS1Z99,PS1Z100,PS1Z101,PS1Z102,PS1Z103,
14 PS1Z104,PS1Z105,PS1Z106,PS1Z107,PS1Z108,PS1Z109,PS1Z110,
15 PS1Z111,PS1Z112,PS1Z113,PS1Z114,PS1Z115,PS1Z116,PS1Z117,
16 PS1Z118,PS1Z119,PS1Z120,PS1Z121,PS1Z122,PS1Z123,PS1Z124,
17 PS1Z125,PS1Z126,PS1Z127,PS1Z128,PS1Z129,PS1Z130,PS1Z131,
18 PS1Z132,PS1Z133,PS1Z134,PS1Z135,PS1Z136,PS1Z137,PS1Z138,
19 PS1Z139,PS1Z140,PS1Z141,PS1Z142,PS1Z143,PS1Z144,PS1Z145,
20 PS1Z146,PS1Z147,PS1Z148,PS1Z149,PS1Z150,PS1Z151,PS1Z152,
21 PS1Z153,PS1Z154,PS1Z155,PS1Z156,PS1Z157,PS1Z158,PS1Z159,
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23 PS1Z167,PS1Z168,PS1Z169,PS1Z170,PS1Z171,PS1Z172,PS1Z173,
24 PS1Z174,PS1Z175,PS1Z176,PS1Z177,PS1Z178,PS1Z179,PS1Z180,
25 PS1Z181,PS1Z182,PS1Z183,PS1Z184,PS1Z185,PS1Z186,PS1Z187,
26 PS1Z188,PS1Z189,PS1Z190,PS1Z191,PS1Z192,PS1Z193,PS1Z194,
27 PS1Z195,PS1Z196,PS1Z197,PS1Z198,PS1Z199,PS1Z200,PS1Z201,
28 PS1Z202,PS1Z203,PS1Z204,PS1Z205,PS1Z206,PS1Z207,PS1Z208,
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30 PS1Z216,PS1Z217,PS1Z218,PS1Z219,PS1Z220,PS1Z221,PS1Z222,
31 PS1Z223,PS1Z224,PS1Z225,PS1Z226,PS1Z227,PS1Z228,PS1Z229,
32 PS1Z230,PS1Z231,PS1Z232,PS1Z233,PS1Z234,PS1Z235,PS1Z236,
33 PS1Z237,PS1Z238,PS1Z239,PS1Z240,PS1Z241,PS1Z242,PS1Z243,
34 PS1Z244,PS1Z245,PS1Z246,PS1Z247,PS1Z248,PS1Z249,PS1Z250,
35 PS1Z251,PS1Z252,PS1Z253,PS1Z254,PS1Z255,PS1Z256,PS1Z257,
36 PS1Z258,PS1Z259,PS1Z260,PS1Z261,PS1Z262,PS1Z263,PS1Z264,
35 IF (GAMMA = 0.0001) 37, 37, 36
36 ASSIGN 40 TO JK
GO TO 20
37 IF (PHI + 0.5*DELPHI - SPHI - QT) 36, 36, 19
40 ALPHA = ALPHA + 2.0*TAU*COSF(EN*PHI)
OMEGA = OMEGA + 2.0*TAU*SINF(EN*PHI)
PHI = PHI + DELPHI
ASSIGN 33 TO JK
GO TO 20
43 IF (PHI - SPHI) 30, 30, 45
45 GO TO (71, 69, 67, 65), M
50 PHI - PHI - DELPHI
51 BETA = BETA + TAU*COSF(EN*PHI)
ZETA = ZETA + TAU*SINF(EN*PHI)
PHI = PHI + DELTA
IF (PHI - SPHI) 52, 52, 63
52 ASSIGN 55 TO JK
GO TO 20
55 BETA = BETA + 4.0*TAU*COSF(EN*PHI)
ZETA = ZETA + 4.0*TAU*SINF(EN*PHI)
PHI = PHI + DELTA
IF (PHI + 0.5*DELTA - SPHI) 57, 57, 58
57 ASSIGN 59 TO JK
GO TO 20
58 ASSIGN 51 TO JK
GO TO 20
59 BETA = BETA + 2.0*TAU*COSF(EN*PHI)
ZETA = ZETA + 2.0*TAU*SINF(EN*PHI)
PHI = PHI + DELTA
ASSIGN 55 TO JK
GO TO 20
63 ZAPSI(J) = (DELTA*BETA)/3.0
ZAPSI(J) = (DELTA*ZETA)/3.0
GO TO 45
65 Y1PSI(J) = (DELPHI*ALPHA)/3.0
Y2PSI(J) = (DELPHI*OMEGA)/3.0
CHI(J) = CHI(J) + Y1PSI(J)
SIGMA(J) = SIGMA(J) + Y2PSI(J)
GO TO 73
67 Y3PSI(J) = (DELPHI*ALPHA)/3.0
Y4PSI(J) = (DELPHI*OMEGA)/3.0
CHI(J) = CHI(J) + Y3PSI(J)
SIGMA(J) = SIGMA(J) + Y4PSI(J)
GO TO 73
69 Y5PSI(J) = (DELPHI*ALPHA)/3.0
Y6PSI(J) = (DELPHI*OMEGA)/3.0
CHI(J) = CHI(J) + Y5PSI(J)
SIGMA(J) = SIGMA(J) + Y6PSI(J)
GO TO 73
71 Y7PSI(J) = (DELPHI*ALPHA)/3.0
Y8PSI(J) = (DELPHI*OMEGA)/3.0
CHI(J) = CHI(J) + Y7PSI(J)
SIGMA(J) = SIGMA(J) + Y8PSI(J)
73 PSI(J+1) = PSI(J) + DEPSI
74 CONTINUE
IN = IN - 1
IF(IN) 77,77,13

77      L = 3

79      CALL HARNAL (PSI,CHI)
      WRITE OUTPUT TAPE 2,80

80      FORMAT (1HO///4H CHI////
      CALL PRINCE(L,AQUAY,BQUAY,AZERO)
      CALL HARNAL (PSI,SIGMA)
      WRITE OUTPUT TAPE 2,82

82      FORMAT (1HO///6H SIGMA////
      CALL PRINCE(L,AQUAY,BQUAY,AZERO)
      CALL HARNAL (PSI,ZAPSI)
      WRITE OUTPUT TAPE 2,84

84      FORMAT (1HO///6H ZAPSI////
      CALL PRINCE(L,AQUAY,BQUAY,AZERO)
      CALL HARNAL (PSI,ZBPSI)
      WRITE OUTPUT TAPE 2,85

85      FORMAT (1HO///6H ZBPSI////
      CALL PRINCE(L,AQUAY,BQUAY,AZERO)
      IF (MM) 88,88,87

87      CALL TRIP (CHI,SIGMA,PSI,ZAPSI,ZBPSI,NN,K)

88      IF (KL) 90,90,89

89      CALL PRICK (NP)

90      IM = IM - 1
      IF (IM) 92,92,9

92      IL = IL - 1
      IF (IL) 94,94,8

94      IK = IK - 1
      IF (IK) 96,96,7

96      IJ = IJ - 1
      IF (IJ) 98,98,5

98      II = II - 1
      IF (II) 101,101,3

99      WRITE OUTPUT TAPE 2,100,PSI(,),PHI

100     FORMAT (3SH ISINGULARITY OCCURS AT PSI OF E16.8,8H ,PHI = E16.8)
      GO TO 90

101     CALL EXIT

END(1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)
SUBROUTINE HARNAL (PSI, FPSI)
DIMENSION PSI(361), FPSI(361), AQUAY(20), BQUAY(20)
COMMON PSI, FPSI, I, L, K, DEPSI, AQUAY, BQUAY, AZERO
KN*K-3
R=1.0
GO TO (5,35,5), I
5  GRAL = FPSI(1) + FPSI(K) + 4.0*FPSI(K-1)
   DO 12 M=2,KN,2
12  GRAL = GRAL + 4.0*FPSI(M) + 2.0*FPSI(M+1)
   AZERO = (DEPSI*GRAL)/9.4247778
   Q=0.0
   DO 25 J=1,L
      Q=Q + 1.0
      GRAND = FPSI(1)*COSF(Q*PSI(1)) + FPSI(K)*COSF(Q*PSI(K))
   1 + 4.0*FPSI(K-1)*COSF(Q*PSI(K-1))
   DO 20 M=2,KN,2
20   GRAND = GRAND + 4.0*COSF(Q*PSI(M))*FPSI(M)
      1 + 2.0*FPSI(M+1)*COSF(Q*PSI(M+1))
   AQUAY(J) = ((2.0*DEPSI)/9.4247778)*GRAND
   IF (I-3) 25,32,22
22   AQUAY(J) = AQUAY(J)/2.0
25   CONTINUE
   IF (I-3) 34,34,34
34   AZERO = AZERO/2.0
   R = 0.5
35   P = 0.0
   DO 43 J = 1, L
      P = P + 1.0
      TGRAL = FPSI(1)*SINF(P*PSI(1)) + FPSI(K)*SINF(P*PSI(K))
   1 + 4.0*FPSI(K-1)*SINF(P*PSI(K-1))
   DO 42 K = 2, KN, 2
42   TGRAL = TGRAL + 4.0*FPSI(M)*SINF(P*PSI(M))
      1 + 2.0*FPSI(M+1)*SINF(P*PSI(M+1))
   BQUAY(J) = ((2.0*DEPSI)/9.4247778)*TGRAL*R
43   CONTINUE
49   RETURN
   ENC(1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)

35
SUBROUTINE PRICK(NP)
DIMENSION Y1PSI(361),Y2PSI(361),Y3PSI(361),Y4PSI(361),Y5PSI(361),
1 Y6PSI(361),Y7PSI(361),Y8PSI(361),PSI(361),AQUAY(20),BQUAY(20)
COMMON PSI,Y1PSI,Y2PSI,Y3PSI,Y4PSI,Y5PSI,Y6PSI,Y7PSI,Y8PSI,
1 Y4PSI,Y5PSI,Y6PSI,Y7PSI,Y8PSI
WRITE OUTPUT TAPE 2,3
1 FORMAT(102H1PSI Y1PSI Y2PSI Y3PSI)
15 FORMAT(102H1PSI Y4PSI Y5PSI Y6PSI)
WRITE OUTPUT TAPE 2,6,PSI(J),Y1PSI(J),Y2PSI(J),Y3PSI(J),
1 Y4PSI(J),Y5PSI(J),Y6PSI(J),
6 FORMAT (E13.5,5E16.5)
9 CONTINUE
RETURN
END
SUBROUTINE TRIP(CHI, SIGMA, PSI, ZAPSI, BPSI, NN, K)
DIMENSION CHI(361), SIGMA(361), PSI(361), ZAPSI(361), BPSI(361)
WRITE OUTPUT TAPE 2,1
1 FORMAT (78H1CHI SIGMA PSI
1 ZAPSI ZBPSI//)
DO 9 J = 1,K,NN
   WRITE OUTPUT TAPE 2,5,CHI(J),SIGMA(J),PSI(J),ZAPSI(J),BPSI(J)
5 FORMAT (E13.5,E18.5)
9 CONTINUE
RETURN
END(1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)
SUBROUTINE PRINCFL(AQUAY,BQUAY,AZERC)
DIMENSION AQUAY(20),BQUAY(20)
WRITE OUTPUT TAPE 2,5,AZERC
FORMAT(1H0/10HCA-ZERO = E18.8)
CO 9 J = 1,L
WRITE OUTPUT TAPE 2,7,J,AQUAY(J),J,BQUAY(J)
FORMAT (3HQA-12,3H = E18.8,10H B-12,3H = E18.8)
CONTINUE
RETURN
END(1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)

38


APPENDIX B

Typical Results from Program of Appendix A

\[ \mu = 0.100 \quad \lambda = 0.0500 \quad k = 3.000 \quad n = 3.000 \quad l = 1.000 \quad a = 0.500 \quad x = 0.550 \]

\[ \Delta \psi_1 = 0.13000 \quad \Delta \psi_{1(1)} = 0.13000 \quad \Delta \psi_{1(2)} = 0.04363 \]

\[ \chi_1 \]

\[
\begin{array}{c|c|c}
A-ZENC & 0.2818441E+01 \\
A & \begin{array}{l}
C \cdot 23537176-00 \\
-0.4422728E+01 \\
-0.21407055E+01 \\
-0.32869507E-00 \\
C \cdot 79406596-01 \\
C \cdot 77531750E-01 \\
-0.2372786E-00 \\
C \cdot 31351981E-00 \\
-0.33793276E-00 \\
C \cdot 32846637E-00 \\
A-1 & 0.4901446E-00 \\
A & \begin{array}{l}
-0.44811134E-00 \\
0.8173908E-00 \\
-0.18497241E-00 \\
0.33456618E-00 \\
-0.4501490E-00 \\
A-2 & 0.322408E+01 \\
A & \begin{array}{l}
-0.26339015E+01 \\
0.34310731E+01 \\
-0.16649285E+01 \\
A-4 & 0.4901446E+00 \\
\end{array}
\end{array}
\end{array}
\]

\[ \Sigma \]

\[
\begin{array}{c|c|c}
A-ZENG & 0.2818441E+01 \\
A & \begin{array}{l}
C \cdot 23537176-00 \\
-0.4422728E+01 \\
-0.21407055E+01 \\
-0.32869507E-00 \\
C \cdot 79406596-01 \\
C \cdot 77531750E-01 \\
-0.2372786E-00 \\
C \cdot 31351981E-00 \\
-0.33793276E-00 \\
C \cdot 32846637E-00 \\
A-10 & 0.324808*E+00 \\
A-1 & 0.16649285E+00 \\
A & \begin{array}{l}
-0.26339015E+01 \\
0.34310731E+01 \\
-0.16649285E+01 \\
A-4 & 0.4901446E+00 \\
\end{array}
\end{array}
\end{array}
\]

39
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**ZBPSI**

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\[ \mu = 0.200 \quad \lambda = 0.0250 \quad \kappa = 3.000 \quad \eta = 0. \quad L = 0.500 \quad A = 0. \quad \delta = 0.030 \]

\[ \Delta \psi_1 = 0.26180 \quad \Delta \phi_1 = 0.76180 \quad \Delta \phi_2 = 0.04363 \]

\[
\begin{array}{ll}
A-\text{ZERO} & = 0.248968500 \quad 01 \\
A-1 & = 0.7673818 \quad 01 \\
A-2 & = 0.9597169 \quad 01 \\
A-3 & = 0.9227449 \quad 01 \\
A-4 & = 0.7061440 \quad 01 \\
A-5 & = 0.3809358 \quad 01 \\
A-6 & = 0.3546547 \quad 00 \\
A-7 & = 0.2075118 \quad 01 \\
A-8 & = 0.3705075 \quad 01 \\
A-9 & = 0.4223138 \quad 01 \\
A-10 & = 0.3726328 \quad 01 \\
\end{array}
\]

\[
\begin{array}{ll}
\Sigma \text{ZERO} & = 0. \\
\Sigma-1 & = 0. \\
\Sigma-2 & = 0. \\
\Sigma-3 & = 0. \\
\Sigma-4 & = 0. \\
\end{array}
\]
| A- 5 | -0.00 | B- 5 | 0.00 |
| A- 6 | 0.00  | B- 6 | 0.00 |
| A- 7 | 0.00  | B- 7 | 0.00 |
| A- 8 | 0.00  | B- 8 | -0.00|
| A- 9 | 0.00  | B- 9 | -0.00|
| A-10 | 0.00  | B-10 | -0.00|

**ZAPS1**

| A-ZERC | -0.14611866E 01 |
| A- 1   | -0.50505327E 00 | B- 1 | -0.56519654E 00 |
| A- 2   | -0.14080133E-00  | B- 2 | -0.58095719E-01 |
| A- 3   | -0.35664590E-01  | B- 3 | 0.40008912E-02 |
| A- 4   | -0.73993352E-02  | B- 4 | 0.54272138E-02 |
| A- 5   | -0.10136589E-02  | B- 5 | 0.23007582E-02 |
| A- 6   | 0.55484471E-04   | B- 6 | 0.89713659E-03 |
| A- 7   | 0.44217125E-03   | B- 7 | 0.90215145E-03 |
| A- 8   | 0.25120047E-02   | B- 8 | 0.18273765E-02 |
| A- 9   | 0.11903889E-01   | B- 9 | 0.13314038E-02 |
| A-10  | 0.46938109E-01   | B-10 | -0.19368302E-01|

**ZDPS1**

| A-ZERC | -0.00 |

45
<p>| A-1 = -0. | B-1 = 0. |
| A-2 = 0. | B-2 = 0. |
| A-3 = 0. | B-3 = 0. |
| A-4 = 0. | B-4 = -0. |
| A-5 = 0. | B-5 = -0. |
| A-6 = -0. | B-6 = -0. |
| A-7 = -0. | B-7 = -0. |
| A-8 = -0. | B-8 = 0. |
| A-9 = -0. | B-9 = 0. |
| A-10 = 0. | B-10 = 0. |</p>
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APPENDIX C

Program for V<sub>2</sub> - Shed Wake

```
DIMENSION PSI(361), S1PSI(361), S2PSI(361), S3PSI(361), S4PSI(361), AQUAY(20), BQUAY(20)
COMMON PSI, S1PSI, L, K, DEPSI, AQUAY, BQUAY, AZERO
READ INPUT TAPE 4, 3, L, NP, KL, II, QT
FORMAT (I12, E13.8)
READ INPUT TAPE 4, 5, EMU, AMBDA, EM, DEPSI, DELPHI, DELTA, K, I, J
FORMAT (3F8.3, 3E13.8, 13, 12)
READ INPUT TAPE 4, 7, EN, IK
FORMAT (E8.3, 12)
READ INPUT TAPE 4, 9, GAMMA, IL
READ INPUT TAPE 4, 12, X
FORMAT (E8.3, I2)
READ INPUT TAPE 4, 13, ELK, IM
READ INPUT TAPE 4, 1, K
FORMAT (F8.3)
PSI(1) = 0.0
WRITE OUTPUT TAPE 2, 15, EMU, AMBDA, EM, EN, GAMMA, ELK, X
FORMAT (6H1MU - F6.3, 12M LAMBDA « F6.3, 7H M « F6.3, 7H N « F6.3/)
DO 53 J = 1, K
ALPHA = 0.0
ETA = 0.0
ETA = 0.0
SPHI = 6.2831852*EM*PSI(J) + GAMMA
EPHI = SPHI + QT
PHI = PSI(J) + GAMMA
ASSIGN 22 TO JJ
D = EMU*(SPHI - PHI)
I = AMBDA*(SPHI - PHI)
PI = 2**2*(X*SINF(PSI(J) - PHI) + D*SINF(PHI))**2
IF (PI) 90, 90, 70
RHO = X**2*Z**2*D**2-2.0*EM*X*SINF(PSI(J))
SIGMA = RHO*ELK**2-2.0*EM*ELK*X*SINF(PHI)*PI+2.0*EM*ELK*X*SINF(PHI)
THETA = (D*COSF(PHI) - X*COSF(PSI(J) - PHI))
TAU = ((X*SINF(PSI(J) - PHI) + D*SINF(PHI))/PI)*((ELK*THETA)/SQRTF(SIGMA))
GO TO JJ, (22, 25, 30, 35, 40, 45)
ASSIGN 25 TO JJ
IF (PHI - EPMI) 18, 23, 23
ASSIGN 35 TO JJ
GO TO 18
ASSIGN 25 TO JJ
IF (PHI - DELPHI) 18, 23, 23
ASSIGN 35 TO JJ
GO TO 18
ASSIGN 25 TO JJ
GO TO 18
ASSIGN 25 TO JJ
GO TO 18
```

49
35  ZETA = ZETA + TAU * SIN(EN * (PSI(J) - PHI)) * COS(EN * PSI(J))
    ETA = ETA + TAU * SIN(EN * (PSI(J) - PHI)) * SIN(EN * PSI(J))
    PHI = PHI + DELTA
    ASSIGN 40 TO JJ
    IF (PHI - SPII) 18, 50, 50
40  ZETA = ZETA + 4.0 * TAU * SIN(EN * (PSI(J) - PHI)) * COS(EN * PSI(J))
    ETA = ETA + 4.0 * TAU * SIN(EN * (PSI(J) - PHI)) * SIN(EN * PSI(J))
    PHI = PHI + DELTA
    IF (SPII - (PHI + 0.5 * DELTA)) 44, 44, 43
44  PHI = PHI - 0.5 * DELTA
    ASSIGN 35 TO JJ
    GO TO 10
45  ZETA = ZETA + 2.0 * TAU * SIN(EN * (PSI(J) - PHI)) * COS(EN * PSI(J))
    ETA = ETA + 2.0 * TAU * SIN(EN * (PSI(J) - PHI)) * SIN(EN * PSI(J))
    PHI = PHI + DELTA
    ASSIGN 40 TO JJ
    GO TO 10
50  S1PSI(J) = (DELPHI/3.0) * ALPHA
    S2PSI(J) = (DELPHI/3.0) * ETA
    S3PSI(J) = (DELTA/3.0) * ZETA
    S4PSI(J) = (DELTA/3.0) * ETA
    PSI(J+1) = PSI(J) + DEPSI
53  CONTINUE
    IF (KL) 55, 60, 60
55  WRITE OUTPUT TAPE 2, 56
56  FORMAT (220) S1PSI, S2PSI, S3PSI, S4PSI
    DO 59 J = 1, K, NP
    WRITE OUTPUT TAPE 2, 57, PSI(J), S1PSI(J), S2PSI(J), S3PSI(J), S4PSI(J)
    CONTINUE
57  FORMAT (36, 7E14.6, 4E18.6)
60  I = 3
    CALL HARNAL (PSI, S1PSI)
    WRITE OUTPUT TAPE 2, 61
61  FORMAT (1HO///6H0S1PSI///////)
    CALL PRINCE (L, AQUAY, BQUAY, AZERO)
    CALL HARNAL (PSI, S2PSI)
    WRITE OUTPUT TAPE 2, 63
63  FORMAT (1HO///6H0S2PSI///////)
    CALL PRINCE (L, AQUAY, BQUAY, AZERO)
    CALL HARNAL (PSI, S3PSI)
    WRITE OUTPUT TAPE 2, 65
65  FORMAT (1HO///6H0S3PSI///////)
    CALL PRINCE (L, AQUAY, BQUAY, AZERO)
    CALL HARNAL (PSI, S4PSI)
    WRITE OUTPUT TAPE 2, 67
67  FORMAT (1HO///6H0S4PSI///////)
    CALL PRINCE (L, AQUAY, BQUAY, AZERO)
80  IM = IM - 1
    IF (IM) 82, 82, 11
82  IL = IL - 1
    IF (IL) 84, 84, 10
84  IK = IK - 1
    IF (IK) 86, 86, 8
86  IJ = IJ - 1
    IF (IJ)  88,88,6
88  II = II - 1
    IC (II)  92,92,4
90  WRITE OUTPUT TAPE 2,91,PHI,PSI(J)
91  FORMAT(1H0/22H SINGULARITY AT PHI = E15.6,10H PSI(J) = E15.6)
    GO TO 80
92  CALL EXIT
       END(1,0,0,0,0,0,0,0,1,0,0,0,0,0,0)
SUBROUTINE PRINCE(L, AQUAY, BQUAY, AZERO)
DIMENSION AQUAY(20), BQUAY(20)
WRITE OUTPUT TAPE 2,5,AZERO
5 FORMAT(1HO///10HOA-ZERO = E18.8)
DO 9 J = 1,L
WRITE OUTPUT TAPE 2,7,J,AQUAY(J),J,BQUAY(J)
7 FORMAT(3HOA-I2,3ME18.8,10HB-I2,3HE18.8)
9 CONTINUE
RETURN
END(1,0,0,0,0,0,0,0,1,0,0,0,0,0)
SUBROUTINE HARNAL (PSI, FPSI)
DIMENSION PSI(361), FPSI(361), AQUAY(20), BQUAY(20)
COMMON PSI, FPSI, I, L, K, DEPSI, AQUAY, BQUAY, AZERO

KN=K-3
R=1.0
GO TO (5, 35, 51, 15)

5 GRAL = FPSI(1) + FPSI(K) + 4.0*FPSI(K-1)
DO 12 M=2, KN, 2

12 GRAL = GRAL + 4.0*FPSI(M) + 2.0*FPSI(M+1)
AZERO = (DEPSI*GRAL)/9.4247778
Q=0.0
DO 25 J=1, L
Q=Q + 1.0
GRAND = FPSI(1)*COS(Q*PSI(1)) + FPSI(K)*COS(Q*PSI(K))
1 + 4.0*FPSI(K-1)*COS(Q*PSI(K-1))
DO 20 M=2, KN, 2

20 GRAND=GRAND + 4.0*COS(Q*PSI(M))*FPSI(M)
1 + 2.0*FPSI(M+1)*COS(Q*PSI(M+1))
AQUAY(J) = ((2.0*DEPSI)/9.4247778)*GRAND
IF (I-3) 25, 22, 22

22 AQUAY(J)=AQUAY(J)/2.0
CONTINUE
IF (I-3) 49, 34, 34

34 AZERO = AZERO/2.0
R = 0.5
35 P = 0.0
DO 43 J=1, L
P = P + 1.0
TGRAL = FPSI(1)*SINF(P*PSI(1)) + FPSI(K)*SINF(P*PSI(K))
1 + 4.0*FPSI(K-1)*SINF(P*PSI(K-1))
DO 42 M=2, KN, 2

42 TGRAL = TGRAL + 4.0*FPSI(M)*SINF(P*PSI(M))
1 + 2.0*FPSI(M+1)*SINF(P*PSI(M+1))
BQUAY(J) = ((2.0*DEPSI)/9.4247778)*TGRAL*R
CONTINUE
43 CONTINUE
49 RETURN
END(1, 0, 0, 0, 0, 0, 0, 1, 0, 0, 3, 0, 0, 0)
APPENDIX D

Typical Results from Program of Appendix C

\[ \mu = 0.100 \quad \lambda = 0.050 \quad M = 3.000 \quad N = 3.000 \quad \Gamma = 0.0 \quad \Lambda = 1.000 \quad X = 0.0 \]

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APPENDIX E

Program II with Typical Results

```
DIMENSION PSI(50), ANG(50), ZETA(6), TW(50), T(6,50), CO(50), SI(50), 1A(20), 0(20)

COMMON CL, EMU, AMBDA, ETA

1 FORMAT(3I2, 2I13, E13.0, E8.3)
   ZN = NZ
   CON = 6.2831852/ZN
   ZETA(1) = 0.0
   DO 10 I = 2, NZ
   10 CON = 6.2831852/ZN
   ZETA(I) = ZETA(I-1) + CON
   PSI(I) = 0.0
   DO 3 J = 1, NZ
   3 PSI(J+1) = PSI(J) * DEPSI

2 READ INPUT TAPE 4, 5, EMU, AMBDA, ETA

3 FORMAT(2E6.3, 12)

4 READ INPUT TAPE 4, 5, EMU, AMBDA, ETA

5 WRITE OUTPUT TAPE 2, 61, ZETA(I)

6 FORMAT(25H0, CONVERGENCE AT ETA = F10.7)
   GO TO 22
   CALL OUDKL(IS(I), PSI(J), PZA, KER, PHI)

7 PZA = PSI(J) + ZETA(I)
   IF(I-1) 13, 13, 16

8 THNU = EMU * CO(J)
   THDE = EMU * SI(J)
   IF(ABS(SIN(THDE) - 0.00001) 20, 14, 14

9 DELTA = ABS(TAN(SIN(THNU/THDE)))
   IF(THDE) 15, 115, 115

10 DELTA = 3.1415926 - DELTA
   IF(THNU) 116, 117, 117

11 DELTA = - DELTA
   IF(THDE) 118, 119, 119

12 T(I,J) = (1.0 - SIN(DELTA)) / (EL - ETA) * COSF(DELTA)
   GO TO 22

13 CALL OUDKL(IS(I), PSI(J), PZA, KER, PHI)
   PZA = PZA - PHI
   IF(KER) 17, 60, 17

14 WRITE OUTPUT TAPE 2, 61, ZETA(I)
   GO TO 20

15 D = EMU * PZA
   Z = (AMRDA * PZA - BLE)**2
   ERM = (EL - 2 - D * SI(J))**2
   IF(ERM) 20, 21, 21

16 T(I,J) = 0.0
   GO TO 22

17 ERM = SQRF(ERM)
   YE = D * SI(J) + ERM
   THNU = EMU * COSF(PHI)
   THDE = EL + ENU * SINF(PHI)
   IF(ABS(SIN(THDE) - 0.00001) 20, 70, 70

20 WRITE OUTPUT TAPE 2, 61, ZETA(I)
   GO TO 20

21 D = EMU * PZA
   Z = (AMRDA * PZA - BLE)**2
   ERM = (EL - 2 - D * SI(J))**2
   IF(ERM) 20, 21, 21
```

62
70  PSD=ABSF(ATANF(THNU/THDE))
    IF(THDE) 71,72,72
71  PSD=3.1415926-PSD
72  IF(THNU) 73,74,74
73  PSD=-PSD
74  DELTA=PHI-PSI(J)-PSD
     UTT=YE*COSF(DELTA)
     T(I,J)=2.0*UTT/(Z+UTT**2)
22  TW(J)=T(I,J)+TW(J)
25  CONTINUE
30  WRITE OUTPUT TAPE 2,33,ANG(J),TW(J),(T(I,J),I=1,NZ)
33  FORMAT(1H F8.1,F13.5,F15.5,F12.5)
     CALL HANEW(PSI,TW,K,NH,DEPSI,AZERO,A,B)
     WRITE OUTPUT TAPE 2,44,AZERO,(N,A(N),N,B(N),N=1,NH)
44  FORMAT(18H1HARMONIC ANALYSIS/1HO/9HOA-ZERO =E12.5/(3HOA-12,1H=E
     112.5,5X,3H B-12,1H= E12.5))
     PUNCH 101,AZERO,(A(J),J=1,NH),(B(I),I=1,NH)
     PUNCH 100,(TW(J),J=1,K)
100  FORMAT(6E12.5)
101  FORMAT(5E14.7)
     IJ = IJ - 1
     IF(IJ) 53,53,6
53  IK = IK - 1
     IF(IK) 54,54,4
54  II = II - 1
     IF(II) 56,56,1
56  CALL EXIT
END(1,0,0,0,0,0,0,0,1,0,0,0,0,0)
SUBROUTINE OUD1(SI, PSI, PZA, KER, PHI)
COMMON EL, FMU
NC = 1
KER = 1
C1 = EMU * SI
PHI = PSI
2 FFOD = C1 * (PHI - PZA) + EL * SINF(PHI - PSI)
EFPOD = C1 + EL * COSF(PHI - PSI)
AD = EFOD / EFPOD
IF (ABS(AD(141,516))< 0.00001) 10, 10, 4
4 NC = NC + 1
IF (NC - 10) 8, 8, 6
6 KER = 2
GO TO 10
9 PHI = PHI - AD
GO TO 2
10 RETURN
END(1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0)
SUBROUTINE HANEWtPS(I,T,K,NU,DEPSI,AZERO,A,R)
DIMENSION PSI(50),T(50),A(20),B(20),W(50)
Q = DEPSI/9.4247778
AZERO = T(1)+T(K)+4.0*T(2)
DO 2 II = 1,NH
A(II) = 0.0
2 B(II) = 0.0
W(1) = 1.0
W(K) = 1.0
W(2) = 4.0
KKK = K - 1
DO 4 JJ = 3,KKK,2
W(JJ) = 2.0
W(JJ+1) = 4.0
AZERO = AZERO + 2.0*T(JJ) + 4.0*T(JJ+1)
4 CONTINUE
AZERO = 0.5*Q*AZERO
DO 8 II = 1,NH
FLL = II
DO 10 NB = 1,K
A(II) = A(II) + W(NB)*T(NB)*COS(FLL*PSI(NB))
10 B(II) = B(II) + W(NB)*T(NB)*SINF(FLL*PSI(NB))
A(II) = Q*A(II)
B(II) = Q*B(II)
8 CONTINUE
RETURN
END(1,0,0,0,0,0,0,0,0,1,0,0,0,0,0)
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240.0 6.36870 22.56473 -10.91124 -5.28480 0.

NO CONVERGENCE AT ZETA = 4.7123889

NO CONVERGENCE AT ZETA = 4.7123889
300.0 38.60082 17.72678 10.64250 10.23955 0.
315.0 35.21124 16.97518 7.17173 5.05356 6.01077
330.0 28.38611 16.51800 5.84963 3.37712 2.64136
345.0 26.71420 16.33622 5.43521 2.92165 2.02112
360.0 26.93724 16.39608 5.94507 2.96902 2.02708

NO CONVERGENCE AT ZETA = 4.7123889
## Harmonic Analysis

\[ A - \text{ZERO} = 0.18087E \ 02 \]

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# Harmonic Analysis

A-ZERO = -.73798E 01

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APPENDIX F

Program III with Typical Results

```
DIMENSION ETA(10), THETA(10), F(I), G(I), PSI(I), ANG(I), SI(I), CO(I), CT(I), ST(I), C(TT(I)), D(I), A(I,10,21), B(I,10,2), Q(O,20,71), Z(20), TIMES(I,10), ELAM(I,71), PL(I,50,10), GC(I,10), GS(I,10), 3FLC(8), EL5(H)

READ INPUT TAPE 4,2,DEPSI,BOER,IANMU,EMU,CF,II,M,KP,NH,NGP;12P
2 FORMAT(13,8,4F8.3,6I3)
N2= NH/2
ROH = 1.0/BOER
DEMU = 0.5*EMU
12EMV=0.5*EMU*EMU
READ INPUT TAPE 4,4,ETA(I),THETA(I),F(I),G(I),I=1,M
4 FORMAT(4E8.3)
PSI(I)=0.0
DO 6 J = 1,KP
ANG(J)=57.2*81*PSI(J)
CO(J) = COSF(PSI(J))
SI(J) = SINF(PSI(J))
CT(J) = COSF(2.0*PSI(J))
ST(J) = SINF(2.0*PSI(J))
CTT(J)=COSF(3.0*PSI(J))
PSI(J)=PSI(J) + DEPSI
6 STT(J)=SINF(3.0*PSI(J))
DO 7 J= 1,M
7 TIMES(J)= ETA(J)*THETA(J)
DO 20 I = 1,M
DO 13 J = 1,KP
READ INPUT TAPE 4,8,(A(I,J,K),K=1,NH)
READ INPUT TAPE 4,9,(B(I,J,K),K=1,KP)
8 FORMAT(5E14.7)
GO TO (13,10),12P
10 READ INPUT TAPE 4,8,(C(L),L=1,NH)
READ INPUT TAPE 4,9,(D(L),L=1,KP)
DO 11 K = 1,NH
11 A(I,J,K) = A(I,J,K) + C(K)
DO 12 L = 1,KP
12 B(I,J,L) = B(I,J,L) + D(L)
13 CONTINUE
Q(I,MN)=ROB*IANMU
DO 18 N = 1,M
DO 15 K = 1,NH
A(I,N,K) = A(I,N,K) - V(I,N+1,K)
DO 16 L = 1,KP
16 B(I,N,L)= B(I,N,L)-B(I,N+1,L)
Q(I,M)=A(I,N,1)
18 IF(N) 18,17,18
17 Q(I,N)=Q(I,N)+ROB
18 Q(I,MN)=Q(I,MN)+A(I,N,1)*TIMES(N)
20 CONTINUE
CALL CRNUT(JJ,M,Q,Z)
1F(JJ) 24,24,22
WRITE OUTPUT TAPE 2,23
22 FORMAT(36HNO SOLUTION --DIAGONAL ELEMENT = ZER0,1)
GO TO 64
```

WRITE OUTPUT TAPE 2, 25, (ETA(I), I = 1, M)
FORMAT(28HLOAD COEFFICIENTS FOR ETA = F6.3, 1H, 1//)
WRITE OUTPUT TAPE 2, 26, ID, (Z(I), I = 1, M)
FORMAT(13HOMAKMAGNC NO., 12, 9F13.5)
DO 28 K = 1, M
28 TIMES(K) = HGCR*(TIMES(K) - Z(K))
DO 35 J = 2, MN
   ID = J - 1
   ELAM(I, J) = 0.0
   DO 30 K = 1, M
      ELAM(I, J) = ELAM(I, J) + TIMES(K)*A(I, K, J)
  35 WRITE OUTPUT TAPE 2, 26, ID, (ELAM(N, J), N = 1, M)
DO 41 I = 1, M
41 CONTINUE
WRITE OUTPUT TAPE 2, 42, ETA(I)
FORMAT(22HLOAD ETA(PS1) FOR ETA = F6.3//)
DO 41 J = 1, KP
   PL(I, J) = TANMU
   DO 43 K = 1, M
      PL(I, J) = PL(I, J) + TIMES(K)*R(I, K, J)
  44 WRITE OUTPUT TAPE 2, 44, ANG(J), PL(I, J)
45 CONTINUE
WRITE OUTPUT TAPE 2, 45
DO 50 J = 1, M
   NZ = J - 1
   GC(I) = F(J)*ELAM(J, NZ) - G(J)*ELAM(J, NNN)
51 CONTINUE
WRITE OUTPUT TAPE 2, 56, ETA(I)
FORMAT(3ER.3)
DO 63 I = 1, M
56 WRITE OUTPUT TAPE 2, 56, ETA(I)
63 CONTINUE
WRITE OUTPUT TAPE 2, 56, ETA(I)
FORMAT(6HITAL ETA = F6.3/4HOPS1, 11X, 4HL(I), 12X, 4HL(G), 10X, 9HL(I) + L(G), 15X, 26HL(G + I)-HARMONICS EXTRACTED//)
C = ETA(I)*2
C1 = ETA(I)*(C+E2M)-ETA(I)*EMU*AZERO
C2 = 2.0*EMU*ETA(I)*ETA(I)-AZERO*(C+1.5+F2M)
C3 = BONE*(C+1.5+E2M)-EMU*AZERO*ETA(I)
C4 = EMU*AZERO*ETA(I)-AZERO*E2M
C5 = EMU*AZERO*ETA(I)-THETA(I)*L7
C6 = 0.5*EMU*AZERO
C7 = -0.5*EMU*BONE
B1 = ETA(I)*Z(I)+DMU*ELAM(1, N21)
B2 = ETA(I)*ELAM(I, 2)+DMU*ELAM(I, N22)
B3 = ETA(I)+ELAM(1, N21)+DMU*Z(I)-DMU*ELAM(I, 3)
B4 = ETA(I)+ELAM(1, 3)-DMU*(ELAM(1, N21)+ELAM(1, N22))
B5 = ETA(I)+ELAM(I, N22)+DMU*(ELAM(I, 2)-ELAM(1, 4))
DO 63 J = 1, KP
   R = CF*(ETA(I)*EMU*SI(J))
   ELEYE = -K*PL(I, J)
   ELG = CF*(C1*C2*SI(J) + C3*CO(J) + C4*ST(J) + C5*CT(J) + C6*ST(J) + C7*CT(J))
   SUML = ELG + ELEYE
   HEL = ELEYE + CF*(B1 + B2*CO(J) + B3*SI(J) + B4*CT(J) + B5*ST(J))
WRITE OUTPUT TAPE 2, 58, ANG(J), ELEYE, ELG, SUML, HEL
58 FORMAT(1H F7.2, 4E16.6)
63 CONTINUE
64 NGP = NGP - 1
IF(NGP) 66, 66, 52
66 II = II - 1
IF(II) 68, 68, 1
68 CALL EXIT
END(1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0)
SUBROUTINE GROUT(JJ,M,A,Z)
DIMENSION A(20,21),Z(20)
JJ=-2
MN=M+1
DO 27 I = 1,M
NN = 1
DO 25 J = 1,MN
SUMA = 0.0

IF(J-I) 25,25,9
9
IF (I-I) 19,19,12
12
DO 15 K = 1,NN
SUMA = SUMA+A(I,K)*A(K,J)
CONTINUE
17
A(I,J)=A(I,J)-SUMA
IF (I-I) 19,26,26
19
IF (A(I,1)) 23,21,23
21
JJ = 4
CO TO 35
23
A(I,J) = A(I,J)/A(I,1)
26
IF(I-I-NN) 25,25,24
24
NN = NN +1
25
CONTINUE
27
CONTINUE
IN = M
Z(IN) = A(M,MN)
28
IN = IN -1
IF(IN-I) 35,29,29
29
SUMB = 0.0
KK = IN + 1
DO 31 K = KK,M
SUMB = SUMB + Z(K)*A(IN,K)
31
CONTINUE
Z(IN) = A(IN,MN) - SUMB
GO TO 28
35
RETURN
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