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Flight Mechanics Technical Memorandum 408

INCORPORATION OF VORTEX LINE AND VORTEX RING HOVER
WAKE MODELS INTO A COMPREHENSIVE ROTORCRAFT
ANALYSIS CODE (U)

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S. Hill, K.R. Reddy

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by

R. TOFFOLETTO, N. E. GILBERT, S. HILL, and K. R. REDDY

SUMMARY

The incorporation of simplified hover wake models into the comprehensive rotorcraft analysis code CAMRAD is described and examples are given on their use. The axisymmetric models, in which vortices are represented by either straight lines or rings, are a more generalized form of the free wake models of R. T. Miller at MIT, with the wake geometry also able to be prescribed. Incorporation has allowed access to the tabular representation in CAMRAD of airfoil section characteristics as functions of angle of attack and Mach number, and has broadened the range of rotor wake models in the code to include a free wake hover model that does not have the convergence problems of the existing free wake model when used for hover.



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NOTATION*

c	blade chord **
c_l	blade lift coefficient **
C_T/σ	ratio of thrust coefficient to rotor solidity
d_{bv}	core burst test parameter
f	factor introducing lag in solution
f_r	empirical scale factor for concentrated vortices inboard of tip vortex
K_1, K_2	axial settling rates of tip vortex before and after passage of following blade
K_3, K_4	radial contraction parameters for tip vortex
M	number of aerodynamic segments
M_{tip}	blade tip Mach number
N	number of blades
r, z	radial and axial displacement coordinates (origin at rotor hub centre; z positive down)
$r_A[i]$	r at mid-points of aerodynamic segments, for $i = 1, \dots, M$
$r_{AE}[i]$	r at edges of aerodynamic segments (from root to tip), for $i = 1, \dots, M+1$
r_{bc}	burst vortex core radius
r_c	vortex core radius
r'_c	vortex core radius limited to a minimum of 0.005
r_{uc}	unburst vortex core radius
S	number of concentrated vortices along the blade
T	number of vortex line or ring levels in intermediate wake
u, w	net radial and axial induced velocity components [†]
u_F, w_F	radial and axial induced velocity components due to far wake [†]
u_I, w_I	radial and axial induced velocity components due to intermediate wake [†]
w_b	downwash at blade due to trailing near wake **
w_{self}	self-induced downwash at blade **
α	blade angle of attack **
Γ	blade bound circulation **
Δ	incremental change in appropriate quantity
ϵ	tolerance for induced velocity convergence
θ	blade pitch angle **
$\lambda_x, \lambda_y, \lambda_z$	longitudinal, lateral, and vertical induced velocity components (funct's of r, ψ)
ϕ	blade inflow angle **
ψ	blade azimuth angle

* All quantities are dimensionless (based on density, rotor rotational speed, and rotor radius). Quantities used only locally to simplify expressions are not included here

** Function of r

† Function of r, z

Subscripts

m,n	as for subscript (s,t) but at a source of induced velocity, i.e. when calculating induced velocity at $(r_{s,t}, z_{s,t})$, contributions are summed over (m,n)
max	maximum value
new	value at current iteration
old	value at previous iteration
s,t	value at concentrated vortex number s (from tip), where $1 \leq s \leq S$, and at vortex line or ring level number t at which induced velocity is to be calculated (i.e. object). Note: $1 \leq s \leq S$ and $1 \leq t \leq T$ in intermediate wake; $t = 0$ at blade, in which case subscript is dropped (e.g. $r_{s,0} \equiv r_s$); $t = T + 1$ for far wake

1. INTRODUCTION

In response to requests from the Australian Services to evaluate performance characteristics, especially for hover, of helicopters presently operated, as well as those being considered for procurement, Aeronautical Research Laboratory (ARL) has developed an analysis capability in the area of hovering rotor aerodynamics which includes both inhouse and acquired codes.

In 1987, Reddy and Gilbert compared predicted hover performance with flight data for four helicopters.¹ Comparisons were also made of main rotor blade loading distribution for one of the helicopters, a Sikorsky S-58 (equivalent to Westland Wessex). Predictions were obtained using three nonuniform inflow rotor wake models and a uniform inflow model based on momentum theory. The nonuniform wake models used were a

- helical vortex lattice prescribed wake model,
- vortex line prescribed wake model, and
- vortex ring free wake model.

The first of these models is incorporated in CAMRAD (Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics), a code developed by Johnson at Ames Research Center.^{2,3,4,5} The code, which was acquired in 1984 as part of a cooperative program with the US Army, uses straight-line vortex elements joined in the form of a helical vortex lattice to represent the trailed and shed vorticity. CAMRAD was also used to provide uniform inflow predictions (based on momentum theory), a preliminary process in determining the trimmed prescribed wake solution.

The second model, which uses infinite and semi-infinite straight-line vortices, was developed by Reddy^{6,7} at ARL independently of very similar work by Miller^{8,9} at Massachusetts Institute of Technology (MIT) and Beddoes (unpublished) at Westland Helicopters Limited (WHL). An acquired free wake hover code that was implemented at ARL by Hill and Reddy (unpublished) was used as the third model. The method, which generally represents infinite line vortices by rings, is based on one of the variations in Miller's method.

To investigate the consistency of these methods, the same parameters and empirical corrections were used within each model in applying to each helicopter, and where possible, consistency of appropriate quantities between models was also maintained. The major identified inconsistency between the wake models was the different representation of airfoil characteristics. In CAMRAD, the two-dimensional airfoil section characteristics are represented in tabular form as functions of angle of attack and Mach number; compressibility effects are therefore effectively incorporated. In the more simplified vortex line and vortex ring models, the characteristics are represented by a constant lift curve slope and a quadratic drag polar without corrections for compressibility. It was planned therefore to incorporate the vortex line and vortex ring models into CAMRAD, principally to allow the two-dimensional airfoil data to be available to these simpler models.

Since Miller's models are formulated in a way that allows a free wake geometry for both the vortex line and vortex ring models, it was decided to incorporate his models, but in a more generalized form, allowing the geometry to also be prescribed using the options in CAMRAD, as well as some additional features. The main purpose of this report is to document the model formulation used and to provide the information necessary to run the models.

2. WAKE MODELS

Comprehensive codes such as CAMRAD allow the analysis of a complete rotorcraft, usually allowing for two separate rotors. However, it is generally assumed sufficient to consider only the main rotor in the case of hover for a conventional helicopter with a single main rotor and anti-torque tail rotor. For performance predictions, standard estimates are then made for the power requirements of the tail rotor, accessories and transmission, and aerodynamic interference. By assuming an axisymmetric wake, the harmonics of blade motion and the shed wake can be neglected, and only collective control needs to be adjusted to trim to a specified thrust.

The helical vortex lattice model in CAMRAD follows the common approach of closely tracing the three-dimensional helical shape of both the strong tip vortex and inboard vortex sheet. Unfortunately, this apparently straight-forward approach results in a computation process that is complex and computationally demanding. This is especially so for the hover case where there is no large uniform relative wind due to the translational velocity of the helicopter. This means that the wake is not swept away from the rotor and hence more of the wake must be considered. It also means that wake induced velocities are the only velocities present, resulting in a greater sensitivity of the wake geometry to changes in induced velocity. This increased sensitivity leads to instabilities and slow wake convergence if free wake models are used.¹⁰

The simplified axisymmetric methods described here are an attempt to overcome the above problems for the hover case. The basis of these methods is that the continuously descending helix is represented by vertically separated horizontal vortex lines (for a horizontal rotor disc), which are either straight or circular. The wake is divided into three regions, which are defined as near, intermediate, and far.

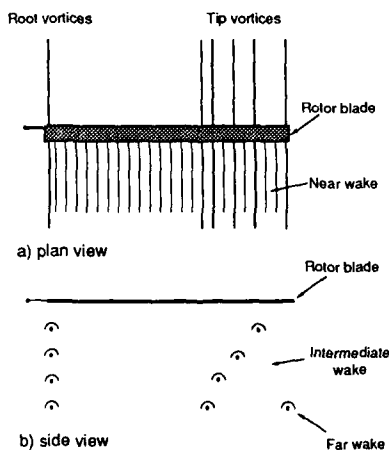


Fig. 1 Vortex Line Wake Model with Concentrated Far Wake

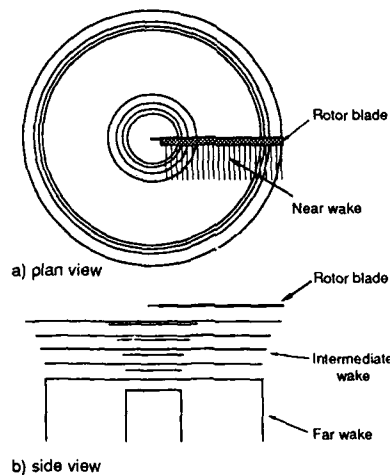


Fig. 2 Vortex Ring Wake Model with Distributed Far Wake

The three wake regions are illustrated in Figs 1 and 2 for the vortex line and vortex ring models respectively. These are first described in relation to a prescribed wake geometry using either of the options in CAMRAD, i.e. (a) Landgrebe¹¹ or (b) Kocurek and Tangler.¹² Both are based on model rotor flow visualization data.

For both vortex line and vortex ring models, the near wake is represented by semi-infinite straight lines attached to, and in the plane of, the blade, with a greater concentration towards the tip. Based on the observations in Kocurek and Tangler's experiments of four well defined tip vortices below the blade, the intermediate wake is represented at each of the corresponding four axial levels by either two straight infinite vortex lines (Fig. 1) or two vortex rings (Fig. 2). However, the generalized manner in which these methods are implemented here allows the number of these levels to be varied (up to 36). One of these 'concentrated' rolled-up vortices is located at the outside boundary of the prescribed contracted wake and represents the strong tip vortex, and the other is located directly beneath the root cutout and represents the inboard vorticity.

Below the intermediate wake region, it is believed that the wake is unstable; the tip vortices undergo viscous dissipation, resulting in wake expansion. To account for this region, which is still close enough to the rotor disc to induce significant inflow, Kocurek and Tangler proposed a vortex ring with radius equal to the rotor radius, axial location at the same level as the fourth tip vortex beneath the rotor, and strength of four times that of the tip vortex. This concept is adopted as an option for the far wake (referred to as 'concentrated far wake') in the form of either a ring for the vortex ring model, or an infinite straight line replacing the ring for the vortex line model, as shown in Fig. 1. The other option for the far wake included is the one given by Miller (referred to as 'distributed', 'sheet', or 'distributed sheet') using two semi-infinite vortex planes (for vortex line) or cylinders (for vortex ring - as in Fig. 2) with strength determined by the geometry of the intermediate wake, and positioned one wake spacing below each of the last inner and outer rings of the intermediate region. This latter option is the only one used for the free wake method. For the prescribed wake method, the far wake may be neglected.

When the wake geometry is allowed to be free in Miller's simplified models, the difficulties of convergence typical of vortex lattice models are not generally experienced. The radius and axial spacing of each concentrated vortex in the intermediate wake, with its consequent effect on the distributed far wake, is determined by the requirements for equilibrium of the velocities, this being the essence of the free wake method. In Miller's method, up to three concentrated vortices are allowed in the intermediate wake though only two are used in the prescribed intermediate wake here and in Ref. 1 by Reddy and Gilbert when using Miller's vortex ring free wake model. The generalized formulation here allows this number to be increased up to ten.

The computational procedure is outlined in Appendix A, with the prescribed wake method incorporated as part of the complete method, and expressions for the velocity components induced by wake vortex elements are given in Appendix B (see Ref. 8 for derivations). Block diagrams showing the separate structures of the free and prescribed wake methods are given in Appendices C and D respectively.

3. PROGRAM MODIFICATIONS

Modifications to the standard VAX 780 version of CAMRAD are given. Because the new axisymmetric models are intended to be used for a single rotor configuration, modifications made to Rotor 1 subprograms are not similarly made to Rotor 2 subprograms.

The following subprograms (each stored as a separate Fortran file, e.g. GEOMR1.FOR) in CAMRAD (see Ref. 5, Part II) have been modified (see Appendix E):

GEOMR1	- Calculate wake geometry distortion
INPTW1	- Read wake namelist
PRNTW1	- Print wake input data
RAMF	- Calculate rotor/airframe periodic motion and forces
TRIM	- Trim
TIMER	- Program timer

Changes to the VAX VMS operating system since 1984 have resulted in the output of null component CPU times at the end of the CAMRAD output file. Modifications to TIMER, while not necessary for implementation of the models, are therefore included in Appendix E.

The following added subprograms (all included in the file WAKER1.FOR) form the basis of the new models (see Appendix F):

WAKER1	- Determine induced velocity at rotor using vortex line or ring model
VTXIF	- Calculate induced velocity in intermediate wake due to intermediate and far wake
IVTERP	- Calculate induced velocity along blade at concentrated vortices
ILINE	- Evaluate expressions for velocity induced by vortex line in intermediate wake
IRING	- Evaluate elliptic integral expressions for velocity induced by vortex ring in intermediate wake
ELLIPCON	- Calculate constants used in elliptic integral expressions
FRING	- Evaluate elliptic integral expressions for velocity induced by semi-infinite vortex cylinder in far wake
FLINE	- Evaluate elliptic integral expressions for velocity induced by semi-infinite vortex sheet in far wake
PRESWG	- Determine prescribed wake geometry

The above modified files and added file are first compiled. After then obtaining the main program object file CAMRAD.OBJ and library object file CAMRAD.OLB containing all original compiled subprograms, the new executable file CAMRAD.EXE is given on typing

```
$LINK CAMRAD, GEOMR1, INPTW1, PRNTW1, RAMF, TRIM, TIMER, WAKER1, CAMRAD/LIB
```

Nine new input variables, all in namelist NLWAKE, have been added (see Appendix G for description and default values). Also included in Appendix G are some comments on existing CAMRAD variables.

4. TEST CASES

To demonstrate the various model options and illustrate the effect of including compressibility, comparisons are made of blade loading distribution for the S-58 using Scheiman's test data¹³ as in Ref. 1. Main rotor performance and blade loads are obtained from CAMRAD using the basic H-34 (i.e. S-58) data deck and NACA 0012 airfoil tables.

Fig. 3 shows the effect of compressibility using the vortex ring, free wake model. Since the tip Mach number is relatively low ($= 0.56$), the effect is only minimal in this example. For the 'compressible' case in Fig. 3, the command file and resulting output file (the latter in abbreviated form) are given in Appendices H and J respectively. The vortex ring, free wake model is selected by setting $OPMODL = 2$ and $LEVEL(1) = 2$. Two rolled-up vortices ($NIBV = 2$) and four vortex levels in the intermediate wake ($NIVL = 4$) are specified. The free wake model only allows the distributed sheet far wake model. The empirical factor scaling the rolled-up concentrated vortices inboard of the one at the tip is set to the default value of 0.6. By setting inputs $DEBUG(14)$ and $DEBUG(24)$ to 1, additional information on the induced velocity and free wake geometry is printed. Because the solution is independent of azimuth, the number of azimuth steps per revolution ($MPSI$ and also $MPSIR$) is set to the minimum value of 4, the number of blades.

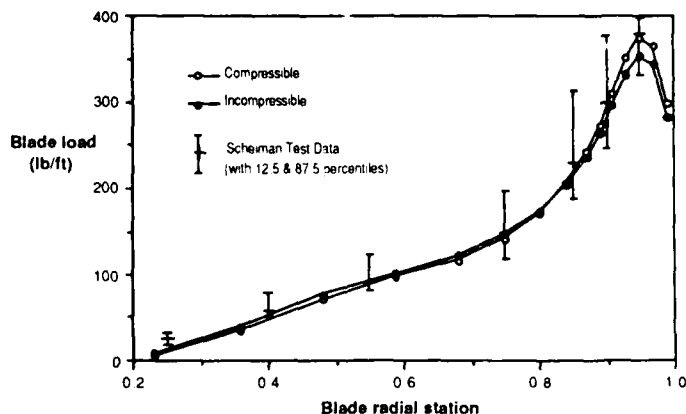


Fig. 3 Effect of Compressibility on Blade Load Distribution for S-58 using Vortex Ring, Free Wake Model ($C_T/\sigma \approx 0.0817$)

Operating conditions and main rotor data, which are common to all the test cases presented, are included in the output file listing (Appendix J). Values of the new input variables for the new models are included in the 'Main Rotor' subsection of the 'Input Data' section of this file.

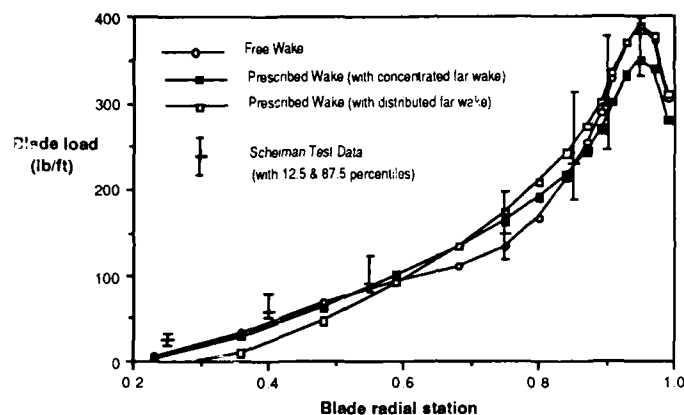


Fig. 4 Effect of Wake Model Variations on Blade Load Distribution for S-58 using Vortex Line Model ($C_T/\sigma = 0.0817$)

Figs 4 and 5 show the effect of the same wake model variations applied to the vortex line and vortex ring models respectively, each with compressibility included. In Table 1, the maximum blade loading (at a radial station of 0.95) is tabulated for these variations, but both with and without compressibility included. Each model gives reasonably similar distributions, but the maximum loading given by the vortex line, prescribed wake model with a concentrated far wake is about 10% less than that given by the other models.

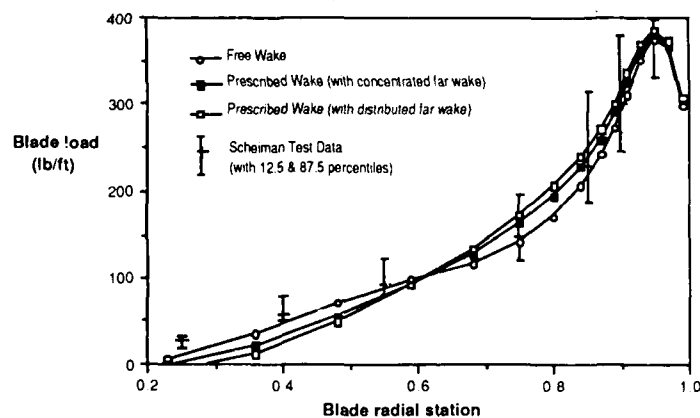


Fig. 5 Effect of Wake Model Variations on Blade Load Distribution for S-58 using Vortex Ring Model ($C_T/\sigma = 0.0317$)

TABLE 1
Effect of Wake Model Options on Maximum Blade Load for S-58

Wake Model	Compressible		Incompressible	
	Vortex Line	Vortex Ring	Vortex Line	Vortex Ring
Free	388	375	365	353
Prescribed (concentrated far wake)	349	380	316	338
Prescribed (distributed far wake)	388	385	346	346

5. CONCLUDING REMARKS

By incorporating the simplified hover wake models described here into CAMRAD, the models themselves have been enhanced by allowing access to compressibility effects included in the two-dimensional airfoil tables used by CAMRAD. In addition, the range of rotor wake models in CAMRAD has been broadened and now includes a free wake hover model (either vortex line or vortex ring) that does not have the convergence problems of the existing free wake model in CAMRAD when used for hover.

In deciding which of the simplified models to use, consideration should be given to maintaining a balance between the degrees of approximation used within the wake model itself. Specifically, when representing vortices by just straight lines in all wake regions, the added complexity of a free wake solution may not be warranted. The more physically accurate representation by rings would therefore seem to be more consistent with a free wake.

REFERENCES

1. Reddy, K. R. and Gilbert, N. E., "Comparison with Flight Data of Hover Performance Using Various Rotor Wake Models," *Proceedings of the Thirteenth European Rotorcraft Forum*, Arles, France, September 1987, Paper No. 2-12.
2. Johnson, W. J., "Development of a Comprehensive Analysis for Rotorcraft - I. Rotor Model and Wake Analysis," *Vertica*, Vol. 5, 1981, pp. 99-129.
3. Johnson, W. J., "Development of a Comprehensive Analysis for Rotorcraft - II. Aircraft Model Solution Procedure and Applications," *Vertica*, Vol. 5, 1981, pp. 185-216.
4. Johnson, W. J., "Assessment of Aerodynamic and Dynamic Models in a Comprehensive Analysis for Rotorcraft," *Computers & Mathematics with Applications*, Vol. 12A, No. 1, 1986, pp. 11-28.
5. Johnson, W. J., "A Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics," Parts I, II, and III, *NASA TM-81182*, 3, and 4, June/July 1980.
6. Reddy, K. R., "The Vortex Flow Field Generated by a Hovering Helicopter," *Proceedings of the 7th Australasian Conference on Hydraulics and Fluid Mechanics*, Brisbane, Australia, Aug. 1980, pp. 553-556.
7. Reddy, K. R., "The Effect of Rotor Wake Geometry Variation on Hover Induced Power Estimation for a UH-1H Iroquois Helicopter," *ARL-AERO-TM-384*, October 1986.
8. Miller, R. H., "A Simplified Approach to the Free Wake Analysis of a Hovering Rotor," *Proceedings of the Seventh European Rotorcraft and Powered Lift Aircraft Forum*, Garmisch-Partenkirchen, W. Germany, September 1981, Paper No. 2; also, *Vertica*, Vol. 6, 1982, pp. 89-95.
9. Miller, R. H., "Simplified Free Wake Analysis for Rotors," *FFA TN 1982-07*, Aeronautical Research Institute of Sweden, 1982; also, *MIT ASRL TR 194-3*.
10. Bliss, D. B., Wachspress, D. A., and Quackenbush, T. R., "A New Approach to the Free Wake Problem for Hovering Rotors," *Proceedings of the 41st Annual Forum of the American Helicopter Society*, Ft. Worth, Texas, May 1985, pp. 463-477.
11. Landgrebe, A. J., "The Wake Geometry of a Hovering Helicopter Rotor and its Influence on Rotor Performance," *Journal of the American Helicopter Society*, Vol. 17, No. 4, October 1972, pp. 3-15.
12. Kocurek, J. D. and Tangler, J. L., "A Prescribed Wake Lifting Surface Hover Performance Analysis," *Proceedings of the 32nd Annual National V/STOL Forum of the American Helicopter Society*, Washington, D.C., May 1976, Preprint No. 1001.
13. Scheiman, J., "A Tabulation of Helicopter Rotor-Blade Differential Pressures, Stresses, and Motions as Measured in Flight," *NASA TM X-952*, March 1964.

APPENDIX A

Computational Procedure

Initial Step - Free Wake only

For $r = r_A[i]$ at $i = 1, \dots, M$, set

$$w(r) = \lambda_z(r)$$

$$u(r) = 0$$

where

r = radial displacement coordinate along the blade

$r_A[i]$ = r at mid-points of aerodynamic segments

M = number of aerodynamic segments

u, w = net radial and axial induced velocity components

λ_z = vertical component of induced velocity, given by uniform inflow method based on momentum theory (from CAMRAD)

Iteration Loop

STEP 1 - Free Wake only

Calculate bound circulation distribution $\Gamma(r)$ along the blade for $r = r_A[i]$ at $i = 1, \dots, M$:

$$\Gamma(r) = \frac{1}{2} r c(r) c_l(r, \alpha, r M_{tip})$$

where

c = blade chord

c_l = blade lift coefficient

The latter is interpolated from 2-D airfoil tables as a function of angle of attack α and Mach number $r M_{tip}$, with α given by

$$\alpha(r) = \theta(r) - \phi(r)$$

where

$\theta(r)$ = blade pitch angle (specified)

$\phi(r)$ = blade inflow angle ($= w(r)/r$)

STEP 2

Representing the near wake by semi-infinite line vortices at $r = r_{AE}[i]$ for $i = 1, \dots, M+1$, calculate, using the Biot-Savart law, the induced velocity $w_b(r)$ along the blade at $r = r_A[i]$ for $i = 1, \dots, M$:

$$w_b(r) = - \sum_{i=1}^{M+1} \left[\frac{\Delta\Gamma(r_{AE}[i])}{4\pi} \left(\frac{1}{r_{AE}[i] - r} + \frac{1}{r_{AE}[i] + r} \right) \right]$$

where

$$\Delta\Gamma(r_{AE}[i]) = \Gamma(r_A[i]) - \Gamma(r_A[i-1]) \quad \text{for } i = 2, \dots, M$$

$$\Delta\Gamma(r_{AE}[1]) = \Gamma(r_A[1])$$

$$\Delta\Gamma(r_{AE}[M+1]) = -\Gamma(r_A[M])$$

The above bound circulation distribution is given in Step 1 for the free wake, and by the uniform inflow method based on momentum theory (from CAMRAD) for the prescribed wake.

STEP 3

Determine the circulation strength Γ_s and location r_s of each rolled-up, concentrated vortex along the blade for $s = 1, \dots, S$ (tip to root), where S is the total number of these vortices. The boundaries for each region to be represented by concentrated vortices are first defined as follows.

The outboard boundary of the tip vortex region is at $r_{AE}[M_0]$, where $M_0 = M + 1$, and the inboard boundary is at $r_{AE}[M_1]$, where $\Gamma(r_A[M_1])$ is the maximum of the circulation strengths (Γ_{max}) calculated in Step 1 along the blade at the aerodynamic segment mid-points.

The boundaries for the inboard regions are defined to be at the closest aerodynamic segment boundary inboard of the values defined by the user. The array indices are defined as $M_2, \dots, M_{S-1}$, corresponding to boundaries $r_{AE}[M_2], \dots, r_{AE}[M_{S-1}]$. The most inboard boundary is at the blade root, where the index is M_S , and the boundary $r_{AE}[M_S]$.

a) Free Wake

The circulation strength Γ_s and location r_s (centroid of circulation distribution over the region $r_{AE}[M_s]$ to $r_{AE}[M_{s+1}]$) are given by

$$\Gamma_s = - \sum_{i=M_s}^{M_{s+1}} \Delta\Gamma(r_{AE}[i])$$

$$r_s = \frac{1}{\Gamma_s} \sum_{i=M_s}^{M_{s+1}} r_{AE}[i] \Delta\Gamma(r_{AE}[i])$$

For $s = 2, \dots, S$, Γ_s is then scaled by an empirical factor f_r (default value of 0.6).

b) Prescribed Wake

Here $S = 2$, and the concentrated vortices are assumed to be at the boundary extremities (tip and root), with the magnitude of the circulation strength of each equal to Γ_{max} , i.e.

$$\begin{aligned}\Gamma_1 &= \Gamma_{max} & \Gamma_2 &= -\Gamma_{max} \\ r_1 &= r_{AE}[M+1] & r_2 &= r_{AE}[1]\end{aligned}$$

STEP 4 - Free Wake only

By interpolating induced velocity components along the blade calculated at the previous iteration in Step 8 (zero initially), determine values at each concentrated vortex position, for $s = 1, \dots, S$:

$$\begin{aligned}\{u_i\}_s &= u_i \quad \text{at } r = r_s \\ &= u_i(r_A[i-1]) + (u_i(r_A[i]) - u_i(r_A[i-1])) \left[\frac{r_s - r_A[i-1]}{r_A[i] - r_A[i-1]} \right] \quad \text{for } r_A[i-1] < r_s < r_A[i]\end{aligned}$$

and similarly for $\{w_i\}_s$, $\{u_F\}_s$, and $\{w_F\}_s$.

STEP 5 - Free Wake only

Set intermediate wake geometry, defining radial and axial positions of the concentrated vortices at each vortex line or ring level, i.e. $r_{s,t}$ and $z_{s,t}$, for $s = 1, \dots, S$ and $t = 1, \dots, T$, where T is the number of levels:

$$r_{s,t} = r_{s,t-1} + \Delta r_{s,t}$$

$$z_{s,t} = z_{s,t-1} + \Delta z_{s,t}$$

where the incremental displacements $\Delta r_{s,t}$ and $\Delta z_{s,t}$ are given from the previous iteration (Step 13), but are approximated initially by

$$\Delta r_{s,t} = 0$$

$$\Delta z_{s,t} = \frac{2\pi}{N} \lambda_z(r_A[M])$$

STEP 6 - Free Wake only

Calculate radial and axial components of the induced velocity at each vortex position in the intermediate wake, i.e. for $s = 1, \dots, S$ and $t = 1, \dots, T$, (a) due to the intermediate wake to give $\{u_i\}_{s,t}$ and $\{w_i\}_{s,t}$, and (b) due to the far wake to give $\{u_F\}_{s,t}$ and $\{w_F\}_{s,t}$. Only the radial components are shown below; the axial components are given by substituting w for u in all expressions:

$$\{u_I\}_{s,t} = \sum_{m=1}^S \sum_{n=1}^T \frac{1}{\Delta z_{m,n}} u_I(r_{s,t}, r_{m,n}, z_{m,n} - z_{s,t}, \Gamma_m)$$

$$\{u_F\}_{s,t} = \sum_{m=1}^S \frac{1}{\Delta z_{m,T}} u_F(r_{s,t}, r_{m,T+1}, z_{m,T+1} - z_{s,t}, \Gamma_m)$$

Expressions for the above right-hand side velocity components, together with equivalent axial components, are given in Appendix B for both vortex line and vortex ring models.

STEP 7 - Free Wake only

Using the Biot-Savart law as in Step 2, calculate the induced velocity $\{w_b\}_s$ at concentrated vortices on the blade due to the trailing near wake for $s = 1, \dots, S$:

$$\{w_b\}_s = w_b(r) \quad \text{at } r = r_s$$

$$= \sum_{m=1}^S \frac{\Gamma_m}{4\pi} \left(\frac{1}{r_m - r_s} \right) + \sum_{m=1}^S \frac{\Gamma_m}{4\pi} \left(\frac{1}{r_m + r_s} \right)$$

STEP 8 - Free Wake only

Determine net radial and axial components of the induced velocity at concentrated vortex positions on the blade (i.e. at $t = 0$) and at each vortex position in the intermediate wake:

$$u_{s,t} = \{u_I + u_F\}_s \quad \text{for } t = 0$$

$$= \{u_I + u_F\}_{s,t} \quad \text{for } t = 1, \dots, T$$

$$w_{s,t} = \{w_I + w_F + w_b\}_s + \{w_{self}\}_s \quad \text{for } t = 0$$

$$= \{w_I + w_F\}_{s,t} + \{w_{self}\}_s \quad \text{for } t = 1, \dots, T$$

The self induced velocity $\{w_{self}\}_s$ of a vortex ring of radius r_s is given by

$$\{w_{self}\}_s = \frac{\Gamma_s}{4\pi} \left[2 \ln \left(\frac{8r_s}{r_c} \right) - \frac{1}{4} \right]$$

where

r'_c = vortex core radius r_c limited to a minimum of 0.005, i.e. $\max(0.005, r_c)$

$r_c = r_{bc}$ (burst vortex core radius) if $d_{bv} \geq 0$ or $z_{1,1} < d_{bv}$

$= r_{uc}$ (unburst vortex core radius) otherwise

d_{bv} = core burst test parameter (< 0 to suppress bursting) - from CAMRAD

STEP 9

a) Free Wake

Using net induced velocity components at the blade and in the intermediate wake, determine new wake geometry for $s = 1, \dots, S$ and $t = 1, \dots, T$:

$$r_{s,t} = r_{s,t-1} + \Delta r_{s,t}$$

$$z_{s,t} = z_{s,t-1} + \Delta z_{s,t}$$

where the incremental displacements $\Delta r_{s,t}$ and $\Delta z_{s,t}$ are given by

$$\Delta r_{s,t} = \frac{\pi(u_{s,t-1} + u_{s,t})}{N}$$

$$\Delta z_{s,t} = \frac{\pi(w_{s,t-1} + w_{s,t})}{N}$$

b) Prescribed Wake

Using prescribed wake geometry based on either of the options in CAMRAD, i.e. (a) Landgrebe or (b) Kocurek and Tangler, set tip and root vortex positions (noting $S = 2$) for $t = 1, \dots, T$:

$$r_{t,t} = K_4 + (1 - K_4) e^{-2\pi K_3 t / N}$$

$$r_{2,t} = r_{AE}[1]$$

$$z_{1,t} = z_{2,t} = -\frac{2\pi}{N} [K_1 + K_2(t-1)]$$

where

K_1, K_2 = axial settling rates of tip vortex before and after passage of following blade

K_3, K_4 = radial contraction parameters for tip vortex

These parameters are given by CAMRAD on specifying the appropriate option, i.e. value of OPRWG in Namelist NLWAKE.

STEP 10

Calculate radial and axial components of the induced velocity along the blade (a) due to the intermediate wake to give $u_i(r)$ and $w_i(r)$, and (b) due to the far wake to give $u_F(r)$ and $w_F(r)$ for $r = r_A[i]$ at $i = 1, \dots, M$. As in Step 6, only the radial components are shown below, with axial components obtained by substituting w for u :

$$u_i(r) = \sum_{m=1}^S \sum_{n=1}^T u_1(r, r_{m,n}, z_{m,n}, \Gamma_m) \left(\frac{d^2}{d^2 + r_c'^2} \right)$$

$$\begin{aligned}
u_F(r) &= \sum_{m=1}^S \frac{1}{\Delta z_{m,T}} u_F(r, r_{m,T+1}, z_{m,T+1}, \Gamma_m) \quad \text{for distributed far wake} \\
&= u_1(r, r_1, z_{1,T}, 4\Gamma_1) + u_1(r, r_2, z_{2,T}, \Gamma_2) \quad \text{for concentrated far wake} \\
&\quad \text{(prescribed only)}
\end{aligned}$$

where

$$d^2 = (r_{m,n} - r)^2 + (z_{m,n} - z)^2$$

Expressions for the above right-hand side velocity components, together with the equivalent axial components, given in Appendix B are again used.

STEP 11

Determine net radial and axial components of the induced velocity along the blade to give $u(r)$ and $w(r)$ for $r = r_A[i]$ at $i = 1, \dots, M$:

$$\begin{aligned}
u(r) &= u_I(r) + u_F(r) \\
w(r) &= w_I(r) + w_F(r) + w_b(r)
\end{aligned}$$

For prescribed wake, go to Step 14.

STEP 12 - Free Wake only

Test for convergence of induced velocity; if the maximum number of iterations has been reached or

$$\frac{1}{M} \sum_{i=1}^M \left[\{w(r_A[i])\}_{\text{new}} - \{w(r_A[i])\}_{\text{old}} \right]^2 < \left[\frac{1}{2} w_{\max} \epsilon \right]^2$$

where

$$\begin{aligned}
w_{\max} &= \max |w(r_A[i])| \\
\epsilon &= \text{tolerance for induced velocity convergence}
\end{aligned}$$

and then go to Step 14.

STEP 13 - Free Wake only

To help prevent numerical instability in the iterative procedure, lag new (non-convergent) solution for (a) induced velocity $u(r)$ and $w(r)$ along the blade for $r = r_A[i]$ at $i = 1, \dots, M$, and (b) wake geometry incremental displacements $\Delta r_{s,t}$ and $\Delta z_{s,t}$ for $s = 1, \dots, S$ and $t = 1, \dots, T$:

$$\begin{aligned}
u(r) &= f \{u(r)\}_{\text{new}} + (1 - f) \{u(r)\}_{\text{old}} \\
w(r) &= f \{w(r)\}_{\text{new}} + (1 - f) \{w(r)\}_{\text{old}}
\end{aligned}$$

$$\Delta r_{s,i} = f \{ \Delta r_{s,i} \}_{\text{new}} + (1 - f) \{ \Delta r_{s,i} \}_{\text{old}}$$

$$\Delta z_{s,i} = f \{ \Delta z_{s,i} \}_{\text{new}} + (1 - f) \{ \Delta z_{s,i} \}_{\text{old}}$$

where the factor f used to introduce lag into the solution is typically 0.1.

Having completed an iterative cycle for the free wake, go back to Step 1.

STEP 14

Transform induced velocity components $u(r)$ and $w(r)$ along the blade to longitudinal, lateral, and vertical components $\lambda_x(r, \psi)$, $\lambda_y(r, \psi)$, and $\lambda_z(r, \psi)$ used by CAMRAD:

$$\begin{bmatrix} \lambda_x \\ \lambda_y \\ \lambda_z \end{bmatrix} = \begin{bmatrix} -u \cos \psi \\ u \sin \psi \\ w \end{bmatrix}$$

APPENDIX B

Velocity Components Induced by Wake Vortex Elements

Vortex Line

$$u_1(r, p, h, \Gamma) = \frac{\Gamma}{2\pi} \left[\frac{h}{(p+r)^2 + h^2} - \frac{h}{(p-r)^2 + h^2} \right]$$

$$w_1(r, p, h, \Gamma) = \frac{\Gamma}{2\pi} \left[\frac{p+r}{(p+r)^2 + h^2} + \frac{p-r}{(p-r)^2 + h^2} \right]$$

$$u_F(r, p, h, \Gamma) = -\frac{\Gamma}{4\pi} \ln \left(\frac{h^2 + (p+r)^2}{h^2 + (p-r)^2} \right)$$

$$w_F(r, p, h, \Gamma) = \frac{\Gamma}{2\pi} \left[\pi - \arctan\left(\frac{h}{p-r}\right) - \arctan\left(\frac{h}{p+r}\right) \right] \quad \text{for } p < r$$

$$= \frac{\Gamma}{2\pi} \left[\frac{\pi}{2} - \arctan\left(\frac{h}{p+r}\right) \right] \quad \text{for } p = r$$

$$= -\frac{\Gamma}{2\pi} \left[\arctan\left(\frac{h}{p-r}\right) + \arctan\left(\frac{h}{p+r}\right) \right] \quad \text{for } p > r$$

Vortex Ring

$$u_1(r, p, h, \Gamma) = -\frac{\Gamma}{4\pi} \frac{h}{2r} \sqrt{\frac{k^2}{pr}} \left[\frac{E(2-k^2)}{(1-k^2)} - 2K \right]$$

$$w_1(r, p, h, \Gamma) = \frac{\Gamma}{4\pi} \sqrt{\frac{k^2}{pr}} \left[K - \frac{E(1 - \frac{1}{2}k^2(1+p/r))}{(1-k^2)} \right]$$

$$u_F(r, p, h, \Gamma) = -\frac{\Gamma}{2\pi k} \sqrt{\frac{p}{r}} \left[K(2-k^2) - 2E \right]$$

$$w_F(r, p, h, \Gamma) = \frac{\Gamma}{2\pi} \int_0^\pi \left(\frac{p(p-r \cos \phi)}{r^2 + p^2 - 2pr \cos \phi} \left[1 - \frac{h}{r^2 + p^2 + h^2 - 2pr \cos \phi} \right] \right) d\phi$$

where the latter is integrated numerically, and

$$k^2 = \frac{4pr}{(p+r)^2 + h^2}$$

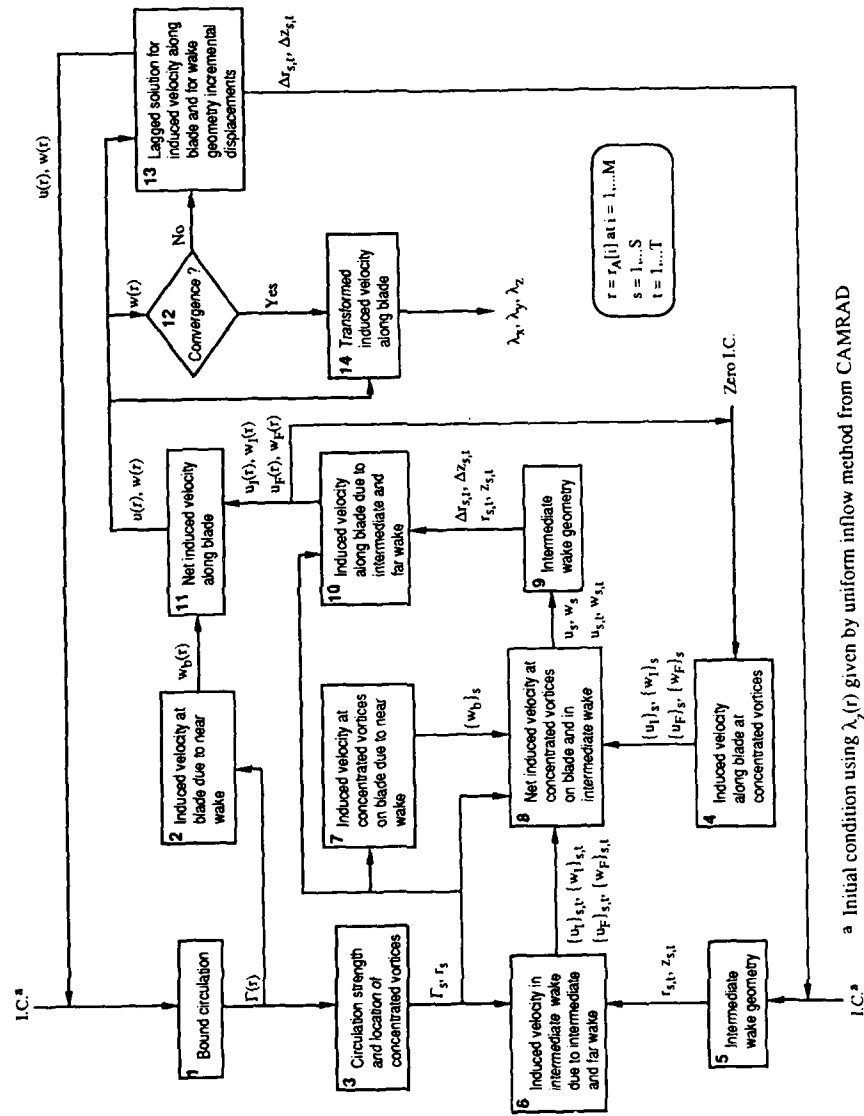
$$E = 1 + \frac{1}{2}(F - \frac{1}{2})(1-k^2) + \frac{3}{16}(F - \frac{13}{12})(1-k^2)^2$$

$$K = F + \frac{1}{4}(F-1)(1-k^2) + \frac{9}{64}(F - \frac{7}{8})(1-k^2)^2$$

$$F = \ln \left(\frac{4}{\sqrt{1-k^2}} \right)$$

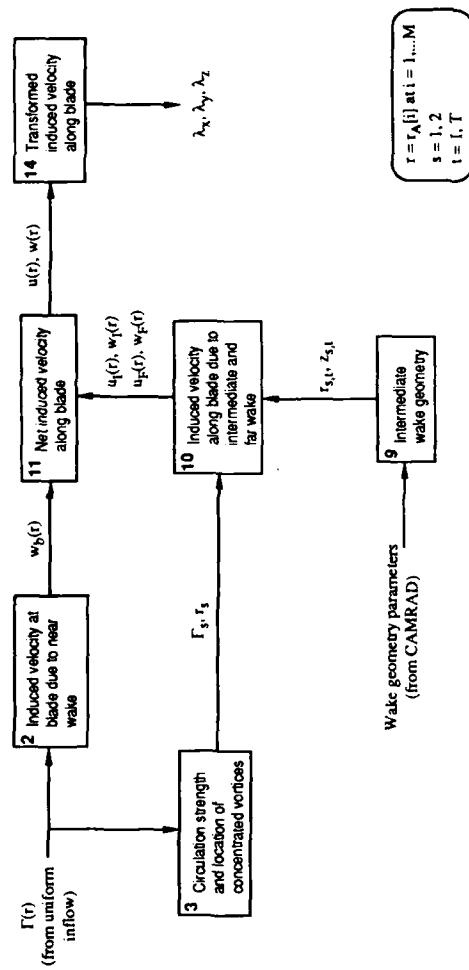
APPENDIX C

Block Diagram for Free Wake Method



a Initial condition using $\lambda_z(r)$ given by uniform inflow method from CAMRAD
 Note: Numbers in upper left corner of boxes refer to step numbers in Appendix A

APPENDIX D **Block Diagram for Prescribed Wake Method**



Note: Numbers in upper left corner of boxes refer to step numbers in Appendix A

APPENDIX E Modified CAMRAD Subprograms

```

SUBROUTINE GEOMRI(LEVEL)
...
...
COMMON /KTIP/KT                                MOD
...
...
C
C CALCULATE WAKE GEOMETRY DISTORTION
C
...
...
C
C FOR KOCUREK AND TANGLER AND LANDGREBE MODELS, FWGT(1) AND FWGT(2) MOD
C ARE USED AS FACTORS FOR KT(1) AND KT(2) MOD
C
C KOCUREK AND TANGLER
C   FB=.000729*TW
C   FC=2.3-.206*TW
C   FM=1.-.25*EXP(.04*TW)
C   FN=.5-.0172*TW
C   KT(1)=(FB+FC*(ABS(CTG)/FLOAT(NBLADE)**FN)**FM)*FWGT(1) MOD
C   KT(2)=SQRT(ABS(CTG-FLOAT(NBLADE)**FN*(ABS(-FB/FC))**(1./FM))) MOD
C   1*FWGT(2)
C   KT(3)=4.*CTH
C   KT(4)=.78
C   GO TO 17
C LANDGREBE
16 KT(1)=.25*(CTOS+.001*TW)*FWGT(1) MOD
   KT(2)=(1+.01*TW)*CTH*FWGT(2) MOD
   KT(3)=.145+27.*CTG
   KT(4)=.78
...
...
SUBROUTINE INPTW1
COMMON /W1DATA/FACTWN,OPVXVY,KNW,KRW,KFW,KDW,RRU,FRU,PRU,FNW,DVS,D
1LS,CORE(5),OPCORE(2),WKMODL(13),OPNWS(2),LHW,OPHW,OPRTS,VELB,DPHIB
2,DBV,QDEBUG,MRG,NG(30),MRL,NL(30),OPWKB(3),KRWG,OPRWG,FWGT(2),FWG
3SI(2),FWGSO(2),KWGT(4),KWGSI(4),KWGSO(4)
INTEGER OPVXVY,OPCORE,WKMODL,OPNWS,OPHW,OPRTS,OPWKB,OPRWG
1  ,NIVL,NIBV,WFMODL,OPMODL,ITERV MOD
REAL KWGT,KWGS1,KWGSO
1  ,RIBB(8),FGAMMA MOD

COMMON /G1DATA/KFWG,OPFWG,ITERWG,FACTWG,WGMODL(2),RTWG(2),COREWG(4
1),MRVBWG,LDMMWG,NDMMWG(36),IPWGDB(2),QWGDB,DQWG(2)
INTEGER OPFWG,WGMODL
COMMON /TMDATA/TMOX(182)
INTEGER DEBUG
EQUIVALENCE (TMOX(41),DEBUG)
COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
1NULIN,NUIN
COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA, MOD
1 ITERV MOD

```

```

C
C READ WAKE NAMELIST
C
  NAMELIST /NLWAKE/FACTWN,OPVXVY,KNW,KRW,KFW,KDW,RRU,FRU,PRU,FNW,DVS
1,DLS,CORE,OPCORE,WFMODL,OPNWS,LHW,OPHW,OPRTS,VELB,DPHIB,DBV,QDEBUG
2,MRG,NG,MRL,NL,OPWKBP,KRWG,OPRWG,FWGT,FWGSI,FWGSO,KWGT,KWGT,KGSI,KWGT
3,KFWG,OPFWG,ITERWG,FACTWG,WGMDL,RTWG,COREWG,MRVBWG,LDMWG,NDMWG,IP
4WGDB,QWGDB,DQWG
5,NIVL,RIBB,NIBV,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA,ITERV MOD
C MOD
C ----- DEFAULT VALUES FOR VORTEX LINE/RING ----- MOD
C MOD
  NIBV=2 MOD
  DO I=1,8 MOD
    RIBB(I)=0.0 MOD
  END DO MOD
  NIVL=4 MOD
  FACTIV=0.1 MOD
  EPIVEL=0.05 MOD
  WFMODL=2 MOD
  OPMODL=0 MOD
  FGAMMA=0.6 MOD
  ITERV=200 MOD
C ----- END ----- MOD
999 FORMAT (1X,33HREADING NAMELIST NLWAKE (ROTOR 1))
  WRITE (NUOUT,999)
  READ (NUIN,NLWAKE)
  IF (DEBUG .GE. 2) WRITE (NUDB,NLWAKE)
  RETURN
  END

  SUBROUTINE PRNTW1
...
...
  COMMON /R1DATA/R1XX(932) MOD
  EQUIVALENCE (R1XX(81),RROOT) MOD
  EQUIVALENCE (TMXX(77),MPSI),(TMXX(157),LEVEL)
  COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
1NULIN,NUIN
  REAL RIBB(8),FGAMMA MOD
  INTEGER NIVL,WFMODL,OPMODL,NIBV,ITERV MOD
  COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA, MOD
1 ITERV MOD
C
C PRINT WAKE INPUT DATA
C
...
...
C ----- VORTEX RING/LINE -----
C
991 FORMAT(/1X,'VORTEX LINE AND VORTEX RING MODELS (PRESCRIBED AND FR
IEE)'/5X,'NUMBER OF INTERMEDIATE VORTEX LEVELS, NIVL =',I3/5X,'FAR
2 WAKE MODEL (0 TO OMIT, 1 FOR CONCENTRATED, 2 FOR SHEET)', WFMODL
3=',I3/5X,'FOR FREE WAKE ONLY'/5X,'FACTOR INTRODUCING LAG IN INDU
4CED VELOCITY, FACTIV =',F10.4/5X,'TOLERANCE FOR INDUCED VELOCITY,
5 EPIVEL =',F10.4/5X,'ROLLED-UP VORTEX WEIGHTING FACTOR (EXCLUDING
6TIP), FGAMMA =',F9.4/5X,'MAXIMUM NUMBER OF INDUCED VELOCITY ITERAT
7IONS, ITERV =',I4/5X,'NUMBER OF ROLLED-UP VORTICIES, NIBV =',I3)

```

```

986  FORMAT(/5X,'INBOARD EDGE OF ROLLED-UP VORTICIES, EXCLUDING ROOT AN
      1D TIP (NIBV-2 VALUES),'//15X,'RIBB =' ,8(F9.4))
C
C ----- END -----
C
...
...
999  FORMAT (/1X,23HNONUNIFORM INFLOW MODEL/                                MOD
      *5X,'VORTEX LINE MODEL IF 1, VORTEX RING MODEL IF 2, OPMODL =' ,I3/MOD
      *                                     5X,27HEXTENT OF NEAR WAKE,MOD
      1 KRW =,I5/5X,33HEXTENT OF ROLLING UP WAKE, KRW =,I5/5X,26HEXTENT
      2 OF FAR WAKE, KFW =,I5/5X,30HEXTENT OF DISTANT WAKE, KDW =,I5/5X
      3,37HROLLUP INITIAL RADIAL STATION, RRU =,F10.4/5X,42HROLLUP INITI
      4AL TIP VORTEX FRACTION, FRU =,F10.4/5X,27HROLLUP EXTENT (DEG), P
      4RU =,F10.2/5X,37HNEAR WAKE TIP VORTEX FRACTION, FNW =,F10.4/5X,50
      5HNUMBER OF SPIRALS IN AXISYMMETRIC FAR WAKE, LHW =,I5/5X,40HAXISY
      6MMETRIC WAKE GEOMETRY IF 0, OPHW =,I3)
...
...
      WRITE (NUOUT,990) KRWG,OPRWG,(FWGT(I),FWGSI(I),FWGSO(I), I=1,2),(K
      1WGT(I),KWGSI(I),KWGSO(I), I=1,4)
      WRITE (NUOUT,991) NIVL,WFMODL,FACTIV,EPIVEL,PGAMMA,ITERV,NIBV      MOD
      IF (NIBV .GT. 2) THEN      MOD
        IF (RIBB(1) .LT. RROOT) THEN      MOD
          DRI=(0.9-RROOT)/FLOAT(NIBV-1)      MOD
          DO I=1,NIBV-2      MOD
            RIBB(I)=RROOT+I*DRI      MOD
          END DO      MOD
        END IF      MOD
        WRITE(NUOUT,986) (RIBB(I),I=1,NIBV-2)      MOD
      END IF      MOD
      IF (LEVEL .LE. 1) GO TO 1      MOD
...
...
      SUBROUTINE RAMF(LEVEL1,LEVEL2,OPLMDA)
...
...
      COMMON /RING/RIXX(16)      MOD
      INTEGER OPRTR2,DEBUG,MHARM(2),MHARMF(2)      MOD
      1,OPMODL      MOD
      EQUIVALENCE (TMXX(77),MPSI),(TMXX(179),MHARM(1)), (TM
      1XX(91),ITERM),(TMXX(92),EPMOTN),(TMXX(93),ITERC),(TMXX(94),EPCIRC)
      2,(TMXX(49),DEBUG),(TMXX(90),MREV),(TMXX(89),MPSIR),(TRIMXX(11),OPR
      3TR2),(RTR1XX(4),CMEAN1),(RTR1XX(6),NBM1),(RTR1XX(7),NTM1),(RTR1XX(
      48),NGM1),(RTR2XX(4),CMEAN2),(RTR2XX(6),NBM2),(RTR2XX(7),NTM2),(RTR
      52XX(8),NGM2),(BODYXX(254),NAM),(ENGNXX(11),NDM),(TMXX(181),MHARMF(
      61)),(R1XX(24),SIGMA1),(R2XX(24),SIGMA2)
      7 ,(RIXX(14),OPMODL)      MOD
      COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
      1NULIN,NUIN
C
C  CALCULATE ROTOR/AIRFRAME PERIODIC MOTION AND FORCES
C
...
...
C  CALCULATE INDUCED VELOCITY
C
      CALL WAKEU1

```

```

C ----- VORTEX RING/LINE ----- MOD
      IF(OPMODL.GT.0.AND.LEVEL1.NE.0) THEN MOD
        CALL WAKER1(LEVEL1) MOD
        GOTO 14 MOD
      ENDIF MOD
C ----- END ----- MOD
      CALL WAKEN1(LEVEL1) MOD
...
...
C END MOTION ITERATION
C TEST CIRCULATION CONVERGENCE
      OUT=0
      IF (LEVEL1 .EQ. 0) GO TO 53
      IF ((LEVEL1 .EQ. 2) .AND. (OPMODL .GT. 0)) GO TO 205 MOD
      GLMS=0.
...
...

      SUBROUTINE TRIM
      COMMON /TMDATA/TMXX(182)
      COMMON /TRIMCM/TRIMXX(1604)
      COMMON /CASECM/CASEXX(9)
      COMMON /RING/RIXX(16) MOD
      INTEGER RESTRT,RSWRT,OPRTR2
      1 ,OPMODL MOD
      EQUIVALENCE (TMXX(157),LEVEL1),(TMXX(158),LEVEL2),(TMXX(159),ITERU
1),(TMXX(160),ITERR),(TMXX(161),ITERF),(TMXX(162),NPRNTT),(TMXX(163
2),NPRNTP),(TMXX(164),NPRNTL),(CASEXX(1),RESTRT),(CASEXX(5),RSWRT),
3(TRIMXX(11),OPRTR2)
4 ,(RIXX(14),OPMODL) MOD
      COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
1NULIN,NUIN
C
C TRIM
C
...
...
C NONUNIFORM INFLOW AND PRESCRIBED WAKE
2 IF (LEVEL .EQ. 1) ITERR=MAX0(ITERR,1)
  IF (ITERR .LE. 0) GO TO 3
  DO 20 IT=1,ITERR
  IF (LEVEL1 .EQ. 0) GO TO 22
  LEV1=1
C ----- VORTEX LINE/RING ----- MOD
      IF(OPMODL.GT.0) THEN MOD
        CALL GEOMR1(LEV1) MOD
        GOTO 22 MOD
      END IF MOD
C ----- END ----- MOD
C
      CALL WAKEC1(LEV1)
...
...

```

```

C   NONUNIFORM INFLOW AND FREE WAKE
      3 ITERF=MAX0(ITERF,1)
      DO 30 IT=1,ITERF
      IF (LEVEL1 .EQ. 0) GO TO 32
      LEV1=LEVEL1
C
      IF(OPMODL.GT.0) GO TO 32
C
      CALL WAKEC1(LEV1)
      ...
      ...
      SUBROUTINE TIMER(N,I,T)
      COMMON /TIMECM/TSTART(14),TSUM(14),NCALLS(14),IDBSAV(23),ICNT
      COMMON /TMDATA/TMX(182)
      EQUIVALENCE (TMX(64),DEBUG),(TMX(41),IDB(1)),(TMX(40),ITDB)
      INTEGER DEBUG,IDB(23)
      INTEGER*4 ITIME,HANDLE_ADR,CODE
      COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
      1NULIN,NUIN
C
C   PROGRAM TIMER
C
      REAL TFRAC(14),TCALL(14)
      INTEGER ID(2,14)
      DATA MT/14/
      DATA ID/4HCASE,4H      ,4HTRIM,4H      ,4HFLUT,4H      ,4HSTAB,4H      ,4H
      1TRAN,4H      ,4HSTAB,4HL      ,4HFLUT,4HL      ,4HWAKE,4HC      ,4HGEOM,4HR
      2 ,4HRAFF,4H      ,4HMODE,4H      ,4HMOTN,4HR      ,4HPERF,4H      ,4HLOAD,4
      3H      /
      999 FORMAT (1H1,17HCOMPUTATION TIMES//50X,8HCPU TIME,4X,7HPERCENT,8X,6
      1HNUMBER,3X,9HTIME/CALL/52X,5H(SEC),19X,8HOF CALLS,4X,5H(SEC)/)
      998 FORMAT (1X,6HTIME =,F12.3,4H SEC)
      997 FORMAT (1X,6HTIME =,F12.3,4H SEC,5X,7H(START ,2A4,1H))
      996 FORMAT (1X,6HTIME =,F12.3,4H SEC,5X,5H(END ,2A4,1H),5X,12H(CALL NU
      1MBER,13,18H, TIME INCREMENT =,F12.3,5H SEC))
      901 FORMAT (10X,4HCASE,31X,2F12.3,I12,F12.3)
      902 FORMAT (10X,11HTRIM (TRIM),24X,2F12.3,I12,F12.3)
      903 FORMAT (10X,14HFLUTTER (FLUT),21X,2F12.3,I12,F12.3)
      904 FORMAT (10X,22HFLIGHT DYNAMICS (STAB),13X,2F12.3,I12,F12.3)
      905 FORMAT (10X,16HTRANSIENT (TRAN),19X,2F12.3,I12,F12.3)
      906 FORMAT (10X,23HLINEAR ANALYSIS (STABL),12X,2F12.3,I12,F12.3)
      907 FORMAT (10X,23HLINEAR ANALYSIS (FLUTL),12X,2F12.3,I12,F12.3)
      908 FORMAT (10X,25HNONUNIFORM INFLOW (WAKEC),10X,2F12.3,I12,F12.3)
      909 FORMAT (10X,21HWAKE GEOMETRY (GEOMR),14X,2F12.3,I12,F12.3)
      910 FORMAT (10X,25HVIBRATORY SOLUTION (RAFF),10X,2F12.3,I12,F12.3)
      911 FORMAT (10X,18HROTOR MODES (MODE),17X,2F12.3,I12,F12.3)
      912 FORMAT (10X,23HROTOR EQUATIONS (MOTNR),12X,2F12.3,I12,F12.3)
      913 FORMAT (10X,18HPERFORMANCE (PERF),17X,2F12.3,I12,F12.3)
      914 FORMAT (10X,12HLOADS (LOAD),23X,2F12.3,I12,F12.3)
      CODE=2
      IF (N .EQ. 0) GO TO 10
      IF (N .EQ. 1) GO TO 11
      IF (N .EQ. 2) GO TO 12
      IF (N .EQ. 3) GO TO 13
C   RETURN PRESENT TIME
      IERROR=LIB$STAT_TIMER (CODE,ITIME,HANDLE_ADR)
      T=.01*FLOAT(ITIME)
      IF (DEBUG .GE. 1) WRITE (NUOUT,998) T
      RETURN
C   INITIALIZE
      10 CONTINUE
      IERROR=LIB$INIT_TIMER (HANDLE_ADR)

```

MOD

MOD

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```

DO 100 JT=1,MT
  TSUM(JT)=0.
  NCALLS(JT)=0
100 TSTART(JT)=0.
  ICNT=0
  RETURN
C  START TIMER
11 CONTINUE
  IERROR=LIB$STAT TIMER(CODE,ITIME,HANDLE_ADR)
  T=.01*FLOAT(ITIME)
  TSTART(I)=T
  IF (DEBUG .GE. 1) WRITE (NUOUT,997) T,ID(1,I),ID(2,I)
  IF (I .LE. 1) GO TO 113
  IF (ICNT .EQ. 1) GO TO 111
  DO 112 II=1,23
  IDBSAV(II)=IDB(II)
112 IDB(II)=0
  ICNT=1
111 IF (ITIME .LT. ITDB*1000) GO TO 113
  DO 114 II=1,23
114 IDB(II)=IDBSAV(II)
113 CONTINUE
  RETURN
C  STOP TIMER
12 CONTINUE
  IERROR=LIB$STAT TIMER(CODE,ITIME,HANDLE_ADR)
  T=.01*FLOAT(ITIME)
  DT=T-TSTART(I)
  TSUM(I)=TSUM(I)+DT
  NCALLS(I)=NCALLS(I)+1
  IF (DEBUG .GE. 1) WRITE (NUOUT,996) T,ID(1,I),ID(2,I),NCALLS(I),DT
  RETURN
C  PRINT TIMES
13 CONTINUE
  TCASE=TSUM(1)
  IF (TCASE .NE. 0.) TCASE=100./TCASE
  DO 130 JT=1,MT
  TFRACT(JT)=TSUM(JT)*TCASE
  TCALL(JT)=0.
  IF (NCALLS(JT) .NE. 0) TCALL(JT)=TSUM(JT)/FLOAT(NCALLS(JT))
130 CONTINUE
  WRITE (NUOUT,999)
  WRITE (NUOUT,901) TSUM(1),TFRACT(1),NCALLS(1),TCALL(1)
  WRITE (NUOUT,902) TSUM(2),TFRACT(2),NCALLS(2),TCALL(2)
  WRITE (NUOUT,903) TSUM(3),TFRACT(3),NCALLS(3),TCALL(3)
  WRITE (NUOUT,904) TSUM(4),TFRACT(4),NCALLS(4),TCALL(4)
  WRITE (NUOUT,905) TSUM(5),TFRACT(5),NCALLS(5),TCALL(5)
  WRITE (NUOUT,906) TSUM(6),TFRACT(6),NCALLS(6),TCALL(6)
  WRITE (NUOUT,907) TSUM(7),TFRACT(7),NCALLS(7),TCALL(7)
  WRITE (NUOUT,908) TSUM(8),TFRACT(8),NCALLS(8),TCALL(8)
  WRITE (NUOUT,909) TSUM(9),TFRACT(9),NCALLS(9),TCALL(9)
  WRITE (NUOUT,910) TSUM(10),TFRACT(10),NCALLS(10),TCALL(10)
  WRITE (NUOUT,911) TSUM(11),TFRACT(11),NCALLS(11),TCALL(11)
  WRITE (NUOUT,912) TSUM(12),TFRACT(12),NCALLS(12),TCALL(12)
  WRITE (NUOUT,913) TSUM(13),TFRACT(13),NCALLS(13),TCALL(13)
  WRITE (NUOUT,914) TSUM(14),TFRACT(14),NCALLS(14),TCALL(14)
  RETURN
END

```

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APPENDIX F **Added CAMRAD Subprograms**

```

SUBROUTINE WAKER1(LEVEL)
C-----
C   DETERMINE THE INDUCED VELOCITY AT THE ROTOR USING A VORTEX
C   LINE OR RING MODEL
C
C   THE WAKE MAY BE EITHER PRESCRIBED OR FREE
C
C   THE FAR WAKE MAY BE EITHER NEGLECTED OR REPRESENTED AS A
C   DISTRIBUTED OR CONCENTRATED VORTEX

    INTEGER DEBUGG,DEBUGV,I,IR,IT,J,JPSI,JR,JT,LEVEL,M,MPSI,MRA,N,
1     NBLADE,NIBV,NTM,NTM1,OPCOMP,OPMODL,S,SMAX,T,NIVL,WFMDL,
2     MS(0:10),ICOUNT,ITERV
    REAL ALPHA,AREA,BETAC,BETAS,CL,COREB,CVERT,D5,DA,DBV,DELW,DGAM,
1     DGAMR,DU,DW,E,EPIVEL,EPR,ERR,FACTIV,FACTOR,FOLD,GAMR,H,
2     LAMBDA,MACH,MTIP,PI,Q1,RMN,RROOT,T75,URES,WMAX,ZST,ANGL(30),
3     DR(10,36),DZ(10,36),GAMA(30),GS(10),R(10,36),DROLD(10,36),
4     RS(10),RUB(0:10),U(30),UIF(10,36),UNW(10,36),UOLD(30),US(10),
5     W(30),WB(30),WIF(10,36),WIFR(30),WNW(10,36),WOLD(30),WRU(10),
6     WS(10),WSELF(10),Z(10,36),DZOLD(10,36),RIBB(8),FGAMMA

    CHARACTER CHAR*2

C-----
C   CAMRAD COMMON BLOCK
C-----
    COMMON /R1DATA/R1XX(932)
    COMMON /RTR1CM/RTR1XX(1070)
    COMMON /CONTCM/CONTRX(32)
    COMMON /WKV1CM/WKV1XX(8165)
    COMMON /TMDATA/TMXX(182)
    COMMON /TRIMCM/TRIMXX(1604)
    COMMON /W1DATA/W1XX(126)
    COMMON /QR1CM/QR1XX(1139)
    COMMON /MD1CM/MD1XX(6773)
    COMMON /AEMNCM/AEMNXX(78)

    COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMDL,OPMODL,FGAMMA,
1     ITERV

    REAL RA(30),TWIST(30),CHORD(30),VIND(3,30,36),GAMOLD(30,36),
1     SINPSI(36),COSPSI(36),THETZL(36),DRA(30),RAE(31),GAM(30,36),
2     ZETA(5,30),P1(5),CRCOLD(36),CRC(36),CORE(2)

C-----
C   EQUIVALENCE (R1XX(150),MRA),(RTR1XX(20),RA(1)),(CONTRX(1),T75),
1     (R1XX(272),TWIST(1)),(R1XX(302),THETZL(1)),(W1XX(1),FACTOR),
2     (R1XX(182),CHORD(1)),(QR1XX(24),GAM(1,1)),(R1XX(81),RROOT),
3     (WKV1XX(1120),VIND(1,1,1)),(R1XX(26),NBLADE),(TMXX(77),MPSI),
4     (TRIMXX(57),SINPSI(1)),(R1XX(80),OPCOMP),(RTR1XX(7),NTM),
5     (TRIMXX(21),COSPSI(1)),(W1XX(13),CORE(1)),(W1XX(40),DBV),
6     (RTR1XX(2),MTIP),(WKV1XX(4360),LAMBDA),(QR1XX(1104),CRC(1)),
7     (QR1XX(22),BETAC),(QR1XX(23),BETAS),(RTR1XX(50),DRA(1)),
8     (R1XX(151),RAE(1)),(WKV1XX(4),GAMOLD(1,1)),(TMXX(53),DEBUGV),
9     (TMXX(63),DEBUGG),(MD1XX(6148),ZETA(1,1)),(AEMNXX(31),P1(1)),
A     (WKV1XX(1084),CRCOLD(1))

C-----
C   COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
1     INULIN,NUIN

C-----
C   END CAMRAD COMMON BLOCK
C-----

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C
COMMON /HELICOM/Q1,W,U,GAMA,RS,GS,WS,US,DZ,R,DR,Z,WIFR,SMAX

899 FORMAT(/1X,'RING/LINE LEVEL ',10(I9))
900 FORMAT(/1X,'VORTEX NO.',I4,' R=',10(F9.5))
901 FORMAT(18X,'Z=',10(F9.5))
902 FORMAT(/1X,'STRENGTH OF ROLLED UP VORTEX',F10.6)
903 FORMAT(5X,10(F9.5))
904 FORMAT(1X,A2,2X,10(F9.5))

C
C INITIALIZE VARIABLES
C
DATA PI/3.14159265/
IF (LEVEL .EQ. 1) THEN
    SMAX=2
ELSE
    SMAX=NIBV
END IF
MS(0)=MRA+1
RUB(0)=RAE(MRA+1)
MS(SMAX)=1
RUB(SMAX)=RROOT
IF (SMAX .LE. 2) GO TO 20
C TEST DATA FOR FATAL ERRORS
DO I=1,NIBV-2
    IF (I .EQ. 1) THEN
        IF (RIBB(I) .LT. RROOT) GO TO 10
    ELSE
        IF (RIBB(I) .LT. RIBB(I-1)) THEN
            WRITE(NUDB,*) 'ERROR IN DATA :LOCATION OF INBOARD VORTEX
1BOUNDARIES'
            GO TO 10
        END IF
    END IF
END DO
DO I=1,NIBV-2
    S=SMAX-I
    RUB(S)=RIBB(I)
END DO
GO TO 20
10 DRI=(0.9-RROOT)/FLOAT(NIBV-1)
DO I=0,NIBV-2
    S=SMAX-I
    RUB(S-1)=RUB(S)+DRI
END DO
20 NTM1=MAX0(1,NTM)
ICOUNT=1
CVERT=180./PI
Q1=2.0*PI/FLOAT(NBLADE)
IT=0

C
C GEOMETRIC PITCH AND INDUCED VELOCITY FROM CAMRAD
C (FREE WAKE ONLY)
C
IF (LEVEL .EQ. 2) THEN
    DO IR=1,MRA
        ANGL(IR)=T75+(TWIST(IR)+THETZL(IR))/CVERT
        W(IR)=-VIND(3,IR,1)
        DO JT=1,NTM1
            ANGL(IR)=ANGL(IR)+ZETA(JT,IR)*P1(JT)
        END DO
    END DO

```

```

      END DO
    END IF
  C
  C POSITIONS OF ROLL-UP BOUNDARIES
  C
    IF (SMAX .GT. 2) THEN
      DO I=2,SMAX-1
        S=I
        DO JR=1,MRA
          J=JR
          IF (RAE(J) .GE. (RUB(S)-1.E-4)) GO TO 101
        DO
      C
      C RUB(S) IS INBOARD LIMIT OF THE VORTEX ROLL-UP BOUNDARY
      C
        END DO
      MS(S)=J
    END DO
    END IF
    MS(0)=MRA+1
    RUB(0)=RAE(MRA+1)
    MS(SMAX)=1
    RUB(SMAX)=RROOT
  C
  C BEGINNING OF LOOP FOR NEXT ITERATION
  C
  C COMPUTE BLADE BOUND CIRCULATION
  C
  70 IF (LEVEL .EQ. 1) THEN
  C
  C FROM CAMRAD
  C
    FOLD=1.0-FACTOR
    DO JPSI=1,MPSI
      CRCOLD(JPSI)=FOLD*CRCOLD(JPSI)+FACTOR*CR(C(JPSI))
      DO IR=1,MRA
        GAMOLD(IR,JPSI)=FOLD*GAMOLD(IR,JPSI)+FACTOR
      1 *GAM(IR,JPSI)
        GAMA(IR)=GAMOLD(IR,JPSI)
      END DO
    END DO
  ELSE
  C
  C FROM INDUCED VELOCITY
  C
    DO 80 JR=1,MRA
  C
  C DETERMINE ALPHA,URES,MACH,COSL
  C
      ALPHA=(ANGL(JR)-W(JR)/RA(JR))*CVERT
      URES=W(JR)*W(JR)+RA(JR)*RA(JR)
      IF(URES.NE.0.0) URES=SQRT(ABS(URES))
      MACH=URES*MTIP
      IF(OPCOMP.EQ.0) MACH=0.0
  C
  C LIFT COEFFICIENT
  C
      CALL AEROT1(ALPHA,MACH,RA(JR),1,CL,CD,CM)
  C
  C CIRCULATION
  C
      GAMA(JR)=0.5*CL*URES*CHORD(JR)
  C

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```

80    CONTINUE
      END IF
C
C    LOOP TO FIND STATION OF MAX. CIRCULATION
C
      DO 90 JR=MRA,2,-1
        J=JR
        IF(GAMA(J) .GT. GAMA(J-1)) GO TO 100
90    CONTINUE
100   MS(1)=J      ! MS(1) IS LOCATION OF MAX. CIRCULATION ON BLADE
      RUB(1)=RAE(J)
C
C    COMPUTE INDUCED VELOCITY AT BLADE DUE TO NEAR TRAILING WAKE
C    {DUE TO SHEET}
C
105   DO 111 IR=1,MRA
      WB(IR)=0.0
      DO 110 JR=1,MRA+1
        IF (JR .EQ. 1) THEN
          DELW=-1/(4.*PI)*(GAMA(JR))*
1          (1.0/(RAE(JR)-RA(IR))+1.0/(RAE(JR)+RA(IR)))
        ELSE IF (JR .EQ. (MRA+1)) THEN
          DELW=1/(4.*PI)*(GAMA(JR-1))*
1          (1.0/(RAE(JR)-RA(IR))+1.0/(RAE(JR)+RA(IR)))
        ELSE
          DELW=-1/(4.*PI)*(GAMA(JR)-GAMA(JR-1))*
1          (1.0/(RAE(JR)-RA(IR))+1.0/(RAE(JR)+RA(IR)))
        END IF
        WB(IR)=WB(IR)+DELW
110    CONTINUE
111   CONTINUE
C
C    PRESCRIBED WAKE GEOMETRY
C
      IF(LEVEL .EQ. 1) THEN
        CALL PRESWG(MS(1))
        GO TO 306
      END IF
C
C    FIND CENTROID OF VORTEX, RS(S)
C
      DO S=1,SMAX
        GS(S)=0.0
        GAMR=0.0
        DO 120 JR=MS(S)+1,MS(S-1)
          IF (JR .EQ. 2) THEN
            DGAM=GAMA(JR)
          ELSE IF (JR .EQ. (MRA+1)) THEN
            DGAM=-GAMA(JR-1)
          ELSE
            DGAM=GAMA(JR)-GAMA(JR-1)
          END IF
          GS(S)=GS(S)-DGAM
C
C    GS(S) IS THE CIRCULATION OF THE VORTEX, S
C
          DGAMR=DGAM*RAE(JR)
          GAMR=GAMR+DGAMR
120    CONTINUE
        IF (ABS(GS(S)) .LT. 1.E-10) THEN
          RS(S)=(RUB(S)+RUB(S-1))/2.0
        ELSE

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        RS(S)=ABS(GAMR/GS(S))      ! LOCATION OF VORTEX, S
        IF (S .NE. 1) GS(S)=GS(S)*FGAMMA
    END IF
END DO
C
C FIND VELOCITIES AT RS(S), WS(S), AND US(S)
C
DO I=1,SMAX
    S=I
    DO J=MS(S),MS(S-1)
        JR=J
        IF (RS(S) .LT. RAE(JR)) GO TO 160
    END DO
C
C INDUCED VELOCITY
C
160 CALL IVTERP(S,JR)
C
    IF (IT .EQ. 0) THEN
        WS(S)=0.0
        US(S)=0.0
    END IF
END DO
IF (IT .EQ. 2) THEN
    DO S=1,SMAX
        DO T=1,TMAX
            IF (T .EQ. 1) THEN
                Z(S,T)=DZ(S,T)
                R(S,T)=RS(S)+DR(S,T)
            ELSE
                Z(S,T)=Z(S,T-1)+DZ(S,T)
                R(S,T)=R(S,T-1)+DR(S,T)
            END IF
        END DO
    END DO
ELSE
C
C ESTABLISH INITIAL WAKE GEOMETRY FROM MOMENTUM THEORY
C
    DO 221 S=1,SMAX
        DO 220 T=1,NIVL
            IR=MS(1)
219      D5=W(IR)*Q1
C CHECK TO SEE IF INFLOW AT STATION IR IS .NE. TO ZERO.
C IF INFLOW AT IR .EQ. ZERO THEN MOVE IN TO NEXT RADIAL STATION.
C THIS PREVENTS PROGRAM FROM CRASHING & HELPS CONVERGENCE.
            IF (D5 .EQ. 0.0) THEN
                IR=IR+1
                GO TO 219
            ENDIF
            DZ(S,T)=D5
            R(S,T)=RS(S)      ! INITIALISE RADIAL VORTEX POSITONS
            DR(S,T)=0.0
            IF (T .EQ. 1) THEN
                Z(S,T)=DZ(S,T) ! INITIALISE VERTICAL VORTEX POSITONS
            ELSE
                Z(S,T)=Z(S,T-1)+DZ(S,T)
            END IF
220      CONTINUE
221      CONTINUE

```

```

      END IF
C
C   COMPUTE VELOCITIES IN WAKE DUE TO INTERMEDIATE AND FAR WAKES
C
230 DO 271 S=1,SMAX
      DO 270 T=1,NIVL
        DZOLD(S,T)=DZ(S,T)
        DROLD(S,T)=DR(S,T)
C
C   CALCULATE VELOCITIES AT R(S,T), Z(S,T) DUE TO INTERMEDIATE AND FAR WAKES
C
        CALL VTXIF(R(S,T),Z(S,T),0,WIF(S,T),UIF(S,T))
C
C
C   VELOCITY IN WAKE DUE TO ROLLED-UP NEAR WAKE
C
        H=-Z(S,T)
        IF (OPMODL .EQ. 1) GO TO 260
        WNW(S,T)=0.0
        UNW(S,T)=0.0
        DO M=1,SMAX
          RMN=RS(M)
          CALL IRING(R(S,T),RMN,H,GS(M),DU,DW)
          WNW(S,T)=WNW(S,T)+DW
          UNW(S,T)=UNW(S,T)+DU
        END DO
        GO TO 666
260   WNW(S,T)=0.0
        UNW(S,T)=0.0
        DO M=1,SMAX
          CALL ILINE(R(S,T),RS(M),H,GS(M),DU,DW)
          WNW(S,T)=WNW(S,T)+DW
          UNW(S,T)=UNW(S,T)+DU
        END DO
666   COREB=CORE(1)
        IF (DBV .GE. 0.0 .AND. Z(1,1) .LT. DBV) COREB=CORE(2)
        IF (COREB .LT. 0.005) COREB=0.005
C
C   SELF INDUCED VELOCITY
C
        WSELF(S)=1/(4.*PI)*GS(S)*(LOG(8.0*RS(S)/COREB)-0.25)
        WIF(S,T)=WIF(S,T)+WNW(S,T)*0.5+WSELF(S)
        UIF(S,T)=UIF(S,T)+UNW(S,T)*0.5
270   CONTINUE
271 CONTINUE
C
C   COMPUTE VELOCITY AT A ROLLED-UP NEAR WAKE DUE TO OTHER ROLLED-UP
C   NEAR WAKES
C
      DO 305 S=1,SMAX
        WRU(S)=0.0
        DO M=1,SMAX
          IF (RS(S) .GT. (RS(M)-1.E-4) .AND. RS(S) .LT. (RS(M)+1.E-4)
1) THEN
            DW=GS(M)/(2.0*RS(M))
          ELSE
            DW=GS(M)*(1.0/(RS(M)-RS(S))+1.0/(RS(M)+RS(S)))
          END IF
          WRU(S)=WRU(S)+DW
        END DO
C
C   COMPUTE NEW WAKE GEOMETRY

```

```

C
      Z(S,1)=(WS(S)+WIF(S,1)+WRU(S)*1/(4.*PI))*0.5+WSELF(S)*0.5)*Q1
      DR(S,1)=(US(S)+UIF(S,1))*0.5*Q1
      DZ(S,1)=Z(S,1)
      R(S,1)=DR(S,1)+RS(S)
290   DO 300 T=2,NIVL
        DZ(S,T)=Q1*(WIF(S,T)+WIF(S,T-1))*0.5
        Z(S,T)=Z(S,T-1)+DZ(S,T)
        DR(S,T)=Q1*(UIF(S,T)+UIF(S,T-1))*0.5
        R(S,T)=R(S,T-1)+DR(S,T)
300   CONTINUE
305 CONTINUE
C*****
      IF (DEBUGG .GE. 2) THEN
        WRITE(NUDB,*) ' '
        WRITE(NUDB,*) ' VORTEX LINE/RING GEOMETRY'
        WRITE(NUDB,*) ' ITERATION NUMBER',ICOUNT
        WRITE(NUDB,899) (T,T=0,NIVL)
        DO S=1,SMAX
          ZS=0.0
          WRITE(NUDB,900) S,RS(S),(R(S,T),T=1,NIVL)
          WRITE(NUDB,901) ZS,(Z(S,T),T=1,NIVL)
          WRITE(NUDB,902) GS(S)
          WRITE(NUDB,*) ' '
        END DO
      END IF
C*****
C
C   COMPUTE NEW INDUCED VELOCITIES AT ROTOR
C
      WMAX=0.0
      ERR=0.0
306   DO 330 IR=1,MRA
        ZST=0.0
        UOLD(IR)=U(IR)
        WOLD(IR)=W(IR)
        IF (IT .EQ. 0) UOLD(IR)=0.0
C
C   VELOCITIES AT RA(IR) DUE TO INTERMEDIATE AND FAR WAKES
C
        CALL VTXIF(RA(IR),ZST,LEVEL,WIFR(IR),U(IR))
C
        W(IR)=WIFR(IR)+WB(IR)
        IF ((W(IR)*W(IR)) .GT. WMAX) WMAX=(W(IR)*W(IR))
        ERR=ERR+(W(IR)-WOLD(IR))**2
330   CONTINUE
C
C   NO LOOP IF DESCRIBED WAKE
C
      IF (LEVEL .EQ. 1) THEN
        IT=3
        GO TO 380
      END IF
C
C   COUNT ITERATIONS AND CHECK CONVERGENCE
C
      ICOUNT=ICOUNT+1
      ERR=ERR/MRA/MRA
      EPR=EPIVEL*EPIVEL*WMAX/4.0
      IF (ERR .GT. EPR) GO TO 350
      IT=3
      GO TO 380

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```

C
C      WEIGHT NEW VELOCITIES AND DISPLACEMENTS FOR NEXT ITERATION
C
350 DO 360 IR=1,MRA
      FOLD=1.0-FACTIV
      W(IR)=FOLD*WOLD(IR)+FACTIV*W(IR)
      U(IR)=FOLD*UOLD(IR)+FACTIV*U(IR)
360 CONTINUE
      IT=2
      DO 375 S=1,SMAX
        DO 370 T=0,NIVL
          DZ(S,T)=FOLD*DZOLD(S,T)+FACTIV*DZ(S,T)
          DR(S,T)=FOLD*DROLD(S,T)+FACTIV*DR(S,T)
370      CONTINUE
375 CONTINUE
C
C      IT=0 :FIRST ITERATION, IT=2 :PROCEEDING ITERATIONS, IT=3 :CONVERGED
C
380 IF (IT .EQ. 3) GO TO 395

      IF (ICOUNT .GT. ITERV) GO TO 396
      GO TO 70
C
395 CONTINUE
      IF (DEBUGV .GE. 1) THEN
        WRITE(NUDB,*) ' INDUCED VELOCITIES FOR VORTEX LINE/RING MODEL'
        WRITE(NUDB,*) ' RADIAL STATIONS'
        WRITE(NUDB,903) (RA(IR),IR=1,MRA)
        WRITE(NUDB,*) ' BLADE AXES'
        WRITE(NUDB,*) ' AXIAL VELOCITY'
        WRITE(NUDB,903) (W(IR),IR=1,MRA)
        WRITE(NUDB,*) ' RADIAL VELOCITY'
        WRITE(NUDB,903) (U(IR),IR=1,MRA)
        WRITE(NUDB,*) ' '
      END IF
      DO JPSI=1,MPSI
        DO IR=1,MRA
          VIND(3,IR,JPSI)=-W(IR)
          VIND(2,IR,JPSI)=U(IR)*SINPSI(JPSI)
          VIND(1,IR,JPSI)=U(IR)*COSPSI(JPSI)
        END DO
        IF (DEBUGV .GE. 2) THEN
          WRITE(NUDB,*) ' SHAFT AXES'
          PSI=FLOAT(JPSI)*360.0/FLOAT(MPSI)
          WRITE(NUDB,*) ' PSI =',PSI
          CHAR='LX'
          WRITE(NUDB,904) CHAR,(VIND(1,IR,JPSI),IR=1,MRA)
          CHAR='LY'
          WRITE(NUDB,904) CHAR,(VIND(2,IR,JPSI),IR=1,MRA)
          CHAR='LZ'
          WRITE(NUDB,904) CHAR,(VIND(3,IR,JPSI),IR=1,MRA)
          WRITE(NUDB,*) ' '
        END IF
      END DO
      IF (DEBUGG .EQ. 1) THEN
        WRITE(NUDB,*) ' '
        WRITE(NUDB,*) ' VORTEX LINE/RING WAKE GEOMETRY'
        WRITE(NUDB,*) ' NUMBER OF ITERATIONS',ICOUNT
        WRITE(NUDB,899) (T,T=0,NIVL)
        DO S=1,SMAX
          ZS=0.0
          WRITE(NUDB,900) S,RS(S),(R(S,T),T=1,NIVL)

```

```

        WRITE(NUDB,901) ZS,(Z(S,T),T=1,NIVL)
        WRITE(NUDB,902) GS(S)
        WRITE(NUDB,*) ' '
    END DO
END IF

C  CALCULATE MEAN INDUCED VELOCITY
    LAMBDA=0.0
    AREA=0.0
    DO IR=1,MRA
        DA=RA(IR)*DRA(IR)
        AREA=AREA+DA
        DO JPSI=1,MPSI
            LAMBDA=LAMBDA-(VIND(3,IR,JPSI)-BETAC*VIND(1,IR,JPSI)
1          -BETAS*VIND(2,IR,JPSI))*DA
        END DO
    END DO
    LAMBDA=LAMBDA/(FLOAT(MPSI)*AREA)
    RETURN
396  WRITE(NUDB,*) '***** SOLUTION NOT CONVERGING (INDUCED VELOCIT
1Y) *****'
    GO TO 395

END

C-----
SUBROUTINE VTXIF(RST,ZST,LEVEL,WIF,UIF)
C
C  SUBROUTINE TO CALCULATE THE VELOCITY AT (RST,ZST) DUE TO
C  THE INTERMEDIATE AND FAR WAKES
C
    REAL UIF,WIF,UI,WI,RMN,H,DW,DU,CORE(2),KT,
1    COREB,DBV,RST,DS,FACT,W2,UF,RIBB(8)

    INTEGER M,SMAX,N,NIVL,OPMODL,WiMODL,LEVEL

    COMMON /W1DATA/W1XX(126)

    EQUIVALENCE (W1XX(13),CORE(1)),(W1XX(40),DBV)

    COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA,
1    ITERV
    COMMON /KTIP/KT(4)

    REAL Q1,W(30),GAMA(30),RS(10),GS(10),WS(10),US(10),DZ(10,36),
1    R(10,36),DR(10,36),Z(10,36),WIFR(30),U(30)

    COMMON /HELICOM/Q1,W,U,GAMA,RS,GS,WS,US,DZ,R,DR,Z,WIFR,SMAX

    UIF=0.0
    WIF=0.0
    DO M=1,SMAX
        WI=0.0
        UI=0.0
C
C  INTERMEDIATE WAKE
C
        DO N=1,NIVL
            RMN=R(M,N)
            H=Z(M,N)-ZST
            IF (OPMODL.EQ. 1) THEN
                CALL ILINE(RST,RMN,H,GS(M),DU,DW) ! VORTEX LINE
            ELSE

```

```

      CALL IRING(RST,RMN,H,GS(M),DU,DW) ! VORTEX RING
    END IF
C
C   EFFECT OF VISCOUS CORE USING APPROXIMATION BY SCULLY
C
      IF (LEVEL .GE. 1) THEN
        COREB=CORE(1)
        IF (DBV .GT. 0.0 .AND. DBV .GT. Z(1,1)) COREB=CORE(2)
        DS=(RMN-RST)**2+H*H
        FACT=DS/(DS+COREB*COREB)
      ELSE
        FACT=1.0
      END IF
      WI=WI+DW*FACT
      UI=UI+DU*FACT
    END DO
C
C   FAR WAKE
C
      H=Z(M,NIVL)-ZST+DZ(M,NIVL)
      RMN=R(M,NIVL)+DR(M,NIVL)
      IF (OPMODL .EQ. 1) THEN
        CALL FLINE(RST,RMN,H,GS(M),UF,WF) ! VORTEX LINE
      ELSE
        CALL FRING(RST,RMN,H,GS(M),UF,WF) ! VORTEX RING
      END IF
      IF (LEVEL .EQ. 1) THEN ! PRESCRIBED WAKE
        IF (WFMODL .EQ. 1) THEN ! CONCENTRATED FAR WAKE
          IF (M .EQ. 1) THEN ! TIP VORTEX
            GAMM=4.0*GS(M)
            IF (OPMODL .EQ. 1) THEN
              CALL ILINE(RST,RMN,H,GAMM,UF,WF) ! VORTEX LINE
            ELSE
              CALL IRING(RST,RMN,H,GAMM,UF,WF) ! VORTEX RING
            END IF
          ELSE ! ROOT VORTEX
            IF (OPMODL .EQ. 1) THEN
              CALL ILINE(RST,RMN,H,GS(M),UF,WF) ! VORTEX LINE
            ELSE
              CALL IRING(RST,RMN,H,GS(M),UF,WF) ! VORTEX RING
            END IF
          END IF
        END IF
      END IF
      IF (WFMODL .EQ. 0) THEN ! NO FAR WAKE
        WIF=WIF+WI
        UIF=UIF+UI
      ELSE IF (WFMODL .EQ. 1) THEN ! CONCENTRATED FAR WAKE
        WIF=WIF+(WI+WF)
        UIF=UIF+(UI+UF)
      ELSE
        WIF=WIF+(WI+WF/DZ(M,NIVL)) ! DISTRIBUTED FAR WAKE
        UIF=UIF+(UI+UF/DZ(M,NIVL))
      END IF
    ELSE
      IF (ABS(DZ(M,NIVL)) .LT. 0.0001) DZ(M,NIVL)=0.1
      WIF=WIF+(WI+WF/DZ(M,NIVL)) ! FREE WAKE
      UIF=UIF+(UI+UF/DZ(M,NIVL))
    END IF
  END DO
  RETURN
END

```

```

      SUBROUTINE IVTERP(S,I)
C
C  SUBROUTINE TO CALCULATE THE INDUCED VELOCITY AT RS(S) BY
C  INTERPOLATING THE VELOCITIES AT RA(I) (I=1,MRA)
C
      REAL RA(30),GRAD
      INTEGER S,I
      COMMON /RTR1CM/RTR1XX(1070)
      EQUIVALENCE (RTR1XX(20),RA(1))
      REAL Q1,W(30),GAMA(30),RS(10),GS(10),WS(10),US(10),DZ(10,36),
1      R(10,36),DR(10,36),Z(10,36),WIFR(30),U(30)
      COMMON /HELICOM/Q1,W,U,GAMA,RS,GS,WS,US,DZ,R,DR,Z,WIFR,SMAX

      GRAD=(RS(S)-RA(I-1))/(RA(I)-RA(I-1))
C  VERTICAL VELOCITY
      WS(S)=WIFR(I-1)+(WIFR(I)-WIFR(I-1))*GRAD
C  RADIAL VELOCITY
      US(S)=U(I-1)+(U(I)-U(I-1))*GRAD
      RETURN
      END
-----
      SUBROUTINE ILINE(R,P,H,GAMMA,UILINE,WILINE)
C
C  FUNCTION FOR RADIAL AND AXIAL COMPONENT OF VELOCITY INDUCED
C  BY VORTEX LINE
C
      REAL R,P,H,GAMMA,UILINE,WILINE
      DATA PI/3.14159265/
      IF (ABS(H) .LT. 1.E-4 .AND. ABS(P-R) .LT. 1.E-4) THEN
          UILINE=0.0
          WILINE=0.0
          RETURN
      END IF
C
      WILINE=GAMMA/(2.*PI)*((P-R)/((P-R)**2+H*H)+(P+R)/((P+R)**2+H*H))
      UILINE=-GAMMA/(2.*PI)*(H/((P-R)**2+H*H)-H/((P+R)**2+H*H))
C
      RETURN
      END
-----
      SUBROUTINE IRING(R,P,H,GAMMA,UIRING,WIRING)
C
C  FUNCTION FOR RADIAL AND AXIAL COMPONENT OF VELOCITY
C  INDUCED BY VORTEX RING
C
      REAL R,P,H,K2,E,K,TEMP2
      DATA PI/3.14159265/
      IF (ABS(H) .LT. 1.E-4 .AND. ABS(P-R) .LT. 1.E-4) THEN
          WIRING=0.0
          UIRING=0.0
          RETURN
      END IF
      CALL ELLIPCON(R,P,H,K2,E,K)

```

```

C      TEMP2=K2/(R*P)
      IF (TEMP2 .LE. 0.0 ) THEN
        WRITE(6,*) ' BAD SIGN.  MODULE IRING'
        STOP
      END IF
C AXIAL VELOCITY
      WIRING=SQRT(TEMP2)*(K-E*(1.0-.5*K2*(1.0+P/R))/(1.0-K2))
      WIRING=GAMMA/(PI*4.)*WIRING
C RADIAL VELOCITY
      UIRING=H/(2.0*R)*SQRT(TEMP2)*(E*(2.0-K2)/(1.0-K2)-2.0*K)
      UIRING=-GAMMA/(4.*PI)*UIRING
C
      RETURN
      END
C-----
      SUBROUTINE ELLIPCON(R,P,H,K2,E,K)
C
C      EVALUATE CONSTANTS USED IN INDUCED VELOCITY COMPONENTS
C      DEFINED BY ELLIPTIC INTEGRALS
C
      REAL R,P,H,K2,E,K,TEMP2,F
      K2=4.0*R*P/((R+P)**2+H*H)
      IF (K2 .GE. (1.0-2.E-8)) GO TO 100
C
      TEMP2=1.0-K2
      F=LOG(4.0/SQRT(TEMP2))
      E=1.0+.5*(F-.5)*(1.0-K2)+3./16.*(F-13./12.)*(1.0-K2)**2
      K=F+.25*(F-1.0)*(1.0-K2)+9./64.*(F-7./6.)*(1.0-K2)**2
C
      RETURN
C
100 E=1.0
      K=10.0
      K2=1.0-3.0E-8
C
      RETURN
      END
C-----
      SUBROUTINE FRING(R,P,H,GAMMA,UFRING,WFRING)
C
C      RADIAL AND AXIAL COMPONENT OF VELOCITY INDUCED BY SEMI-
C      INFINITE VORTEX CYLINDER
C
      REAL R,P,H,PI,P3,P4,X3,I4,K2,E,K,TEMP2
      DATA PI/3.14159265/
      IF(ABS(P) .LT. 1.0E-6) P=1.0E-6
C
C      AXIAL VELOCITY
C
      WFRING=0.0
      P3=0.2*PI
      DO 20 P4=P3*0.5,PI-P3*0.5,P3
        X3=P*P+R*R+H*H-2.0*R*P*COS(P4)
        I4=P3*P*(P-R*COS(P4))/(P*P+R*R-2.0*R*P*COS(P4))
        *      *(1.0-H/SQRT(X3))
C
      WFRING=WFRING+I4
20 CONTINUE

```

```

      WFRING=GAMMA/(2.*PI)*WFRING
C
C   RADIAL VELOCITY
C
      CALL ELLIPCON(R,P,H,K2,E,K)
      TEMP2=P/R/K2
      IF (TEMP2 .LE. 0.0) THEN
        WRITE(6,*) P,R,K2
        WRITE(6,*) 'BAD SIGN.  MODULE FRING'
        STOP
      END IF
      UFRING=-GAMMA/(2.*PI)*SQRT(TEMP2)*(K*(2.0-K2)-2.0*E)
      RETURN
      END
C-----
      REAL FUNCTION FLINE(R,P,H,GAMMA,UFLINE,WFLINE)
C
C   RADIAL AND AXIAL VELOCITY DUE TO VORTEX SHEET
C
      REAL R,P,H,PI,E,GAMMA,UFLINE,WFLINE

      DATA PI/3.1415927/
C   AXIAL VELOCITY
      WFLINE=PI/2.-ATAN(H/(R+P))
      IF(P .GT. (R+1.0E-8)) WFLINE=PI-ATAN(H/(P-R))-ATAN(H/(P+R))
      IF(P .LT. (R-1.0E-8)) WFLINE=ATAN(H/(R-P))-ATAN(H/(R+P))
      WFLINE=GAMMA/(2.*PI)*WFLINE
C   RADIAL VELOCITY
      UFLINE=-GAMMA/(4.*PI)*LOG((H*H+(R+P)**2)/(H*H+(P-R)**2))

      RETURN
      END
C-----
      SUBROUTINE PRESWG(I)
C
C   DETERMINES PESCIBED WAKE GEOMETRY FOR VORTEX RING AND LINE METHODS
C
      REAL HV,RT,RROOT,KT(4),RIBB(8)
      INTEGER IR,NIVL,WFMODL
C   -----  CAMRAD COMMON BLOCKS  -----
      COMMON /R1DATA/R1XX(932)
      COMMON /KTIP/KT
      EQUIVALENCE (R1XX(81),RROOT)
C   -----  END  -----
      COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA,
1      ITERV
      REAL Q1,W(30),GAMA(30),RS(10),GS(10),WS(10),US(10),DZ(10,36),
1      R(10,36),DR(10,36),Z(10,36),WIFR(30),U(30)

      COMMON /HELICOM/Q1,W,U,GAMA,RS,GS,WS,US,DZ,R,DR,Z,WIFR,SMAX

      RS(1)=1.0
      GS(1)=GAMA(I)
      RS(2)=RROOT
      GS(2)=-GS(1)
      DO IR=1,NIVL+1
        HV=KT(1)*Q1+KT(2)*(Q1*IR-Q1)
        RT=KT(4)+(1-KT(4))*(1.0/EXP(Q1*IR*KT(3)))
        R(1,IR)=RT
        R(2,IR)=RROOT
        Z(1,IR)=HV

```

```

      Z(2,IR)=HV
    END DO
    DZ(1,NIVL)=Z(1,NIVL+1)-Z(1,NIVL)
    DZ(2,NIVL)=DZ(1,NIVL)
    DR(1,NIVL)=R(1,NIVL+1)-R(1,NIVL)
    IF (WFMODL .EQ. 1) THEN
      DR(1,NIVL)=1.0-R(1,NIVL)
      DR(2,NIVL)=0.0
      DZ(1,NIVL)=0.0
      DZ(2,NIVL)=0.0
    END IF
    RETURN
  END

```

APPENDIX G

Input Description

New Variables in Namelist NLWAKE

Variable	Default	Description
OPMODL	0	Inflow model 0 vortex lattice (existing CAMRAD model) 1 vortex line 2 vortex ring
NIVL	4	Number of vortex levels in intermediate wake; maximum 36
WFMODL	2	Far wake model in prescribed wake vortex line and ring models 0 no far wake 1 concentrated 2 distributed sheet
FACTIV	0.1	Factor introducing lag in induced velocity iteration
EPIVEL	0.05	Tolerance for induced velocity
FGAMMA	0.6	Roll-up weighting factor
ITERV	200	Maximum number of induced velocity iterations
NIBV	2	Number of rolled-up vortices; minimum 2, maximum 10
RIBB(NIBV-2)		Inboard edge of rolled-up vortices from root to tip, excluding root and tip; must be between root and 0.9 (default: evenly distributed)

Comments on Important Existing CAMRAD Variables

Namelist	Variable(s)	Comment
NLTRIM	MPSI, MPSIR	Because solutions are independent of azimuth, can be as low as number of blades
NLTRIM	DEBUG(14),(24)	Additional debug information for new models
		Prescribed wake Free wake
NLTRIM	LEVEL(1)	1 2
NLTRIM	ITERU	1 0 or 1
NLTRIM	ITERR	1 0 or 1
NLTRIM	ITERF	N/A 1
NLWAKE	OPRWG	Defines prescribed wake geometry, as with existing vortex lattice model in CAMRAD
NLWAKE	CORE(1),(2), DBV	As with existing vortex lattice model in CAMRAD
NLWAKE	FWGT(1),(2)	For Kocurek & Tangler ($8 \leq \text{OPRWG} \leq 11$) and Landgrebe ($8 \leq \text{OPRWG} \leq 11$) models, factors for vortex settling rates KT(1) and KT(2); equal 1 for unchanged experimental rates

APPENDIX H

Test Case Command File

```
$ASSIGN [USERNAME.CAMRAD.AIRFOIL]NACA0012.TAB AFTABLE1
$ASSIGN [USERNAME.CAMRAD.INPUT]H34.DAT INPUTFILE
$DEFINE/USER_MODE SYS$OUTPUT [USERNAME.CAMRAD]H34.OUT
$RUN [USERNAME.CAMRAD]CAMRAD
  &NLCASE NCASES=1,BLKDAT=0,NFRS=-1,NFEIG=-1,NFAF2=41,&END
  &NLTRIM MPSI=4,MPSIR=4,DEBUG(24)=1,DEBUG(14)=1,
  VKTS=0.0,FACTOR=0.5,ITERC=40,ITERM=40,FACTM=0.5,MTRIM=80,
  LEVEL(1)=1,ITERR=1,ITERF=0,DELTA=0.5,ITERU=1,
  OPDENS=3,TEMP=56.0,DENSE=0.00232,
  OPTRIM=11,EPTRIM=0.001,CTTRIM=0.0817,MHARM=0,NROTOR=1,
  COLL=9.1,
  DOF=54*0,DOFT=8*0,
  NPRNTP=0,NPRNTL=0,NPRNTT=1,NPRNTI=1,
  OPREAD=1,1,2*0,1,1,
  &END
  &NLRTR VTIPN=621.6,BTIP=1.00,KHLMDB=1.15,
  KFLMDA=1.0,FXLMDA=1.0,FMLMDA=0.,FACTWU=0.5,OPCOMP=1,
  &END
  &NLWAKE KFW=120,OPHW=0,OPRWG=8,FACTWN=0.1,
  WKMODL(2)=0,WKMODL(4)=0,WKMODL(6)=0,WKMODL(8)=0,WKMODL(12)=0,
  CORE(1)=0.05,CORE(2)=0.05,DBV=-1.,
  FWGT(1)=1.0,FWGT(2)=1.0,
  EPIVEL=0.02,WFMDL=2,OPMODL=1,NIBV=2,FGAMMA=0.7,
  FACTIV=0.1,ITERV=200,
  &END
  &NLBODY CONFIG=0,ASHAFT(1)=0,
  &END
  &NLLOAD MALOAD=1,NWKGMP=4*0,MWKGMP=0,
  NPLOT=75*0,
  &END
```

APPENDIX J Test Case Output File

```

.....
* COMPREHENSIVE ANALYTICAL MODEL OF ROTORCRAFT AERODYNAMICS AND DYNAMICS
* RELEASE ONE, JANUARY 1980
* .....

READING NAMELIST NLCASE

NEW JOB, NUMBER OF CASES = 1
RESTART FILE NOT WRITTEN (RSWRT = 0)
INPUT SOURCE IS FILE (BLKDAT = 0)
INPUT FILE READ EVERY CASE (RDFILE = 1)

UNIT NUMBERS
INPUT FILE, NFDAT = 40
AIRFOIL 1 FILE, NFAF1 = 41
AIRFOIL 2 FILE, NFAF2 = 41
RESTART FILE, NFRS = -1
EIGENVALUE FILE, NFEIG = -1
SCRATCH FILE, NFSCH = 50
NAMELIST INPUT, NUIN = 5
PRINTED OUTPUT, NUOUT = 6
DEBUG OUTPUT, NUDB = 6
PRINTER PLOTS, NUPP = 6
LINEAR SYSTEMS, NULIN = 6

INPUT FILE, NAME = (AER213.CANRAD.INPUT)H34.DAT
AIRFOIL 1 FILE, NAME = (AER213.CANRAD.AIRFOIL)NACA0012.TAB

READING INPUT FILE
READING NAMELIST NLTRIM
READING NAMELIST NLTRM ROTOR 1
READING NAMELIST NLTRM ROTOP 1
READING NAMELIST NLBODI
READING NAMELIST NLBODI
READING NAMELIST NLLOAE ROTOP 1
READING AIRFOIL TABLES
COMPREHENSIVE ANALYTICAL MODEL OF ROTORCRAFT AERODYNAMICS AND DYNAMICS
.....
CASE NUMBER 1 NEW JOB, IDENTIFICATION = 5 5 22 1.00012 CODE = ..... ENGLISH UNITS (FT, SLUG, SEC)

TITLE = H-34 HELICOPTER
ROTOR 1 = H-34 HELICOPTER MAIN ROTOR
AIRFOIL 1 = NACA 0012 AIRFOIL STANDARD C2, TABLES
AIRFRAME = H-34 HELICOPTER AIRFRAME

TRIM ANALYSIS
WIND TUNNEL TRIM, OPTIM = 11
SINGLE ROTOR CONFIGURATION, ROTOR = 1

```

OPERATING CONDITIONS
 VELOCITY (KNOTS) = 0.00
 V/(OMEGA*R) = 0.0000
 ROTATIONAL SPEED (RPM) = 211.99
 TIP SPEED = 621.60
 TIP MACH NUMBER = 0.5584

OUT OF GROUND EFFECT
 AIRCRAFT ENVIRONMENT (1 FOR ALT AND STD DAY, 2 FOR ALT AND TEMP, 3 FOR DENSITY AND TEMP), OPDENS = 3
 WING FLAP SETTING, AFLAP = 0.00 DEG
 ENGINE STATE (1 FOR AUTOROTATION, 2 FOR ENGINE OUT), OPENG = 0
 GOVERNOR TRIM (0 TO TRIM COLL, 1 TO TRIM ROTOR-1 GOV, 2 TO TRIM ROTOR-2 GOV, 3 TO TRIM BOTH GOVERNORS), OPGOVT = 0

ALTITUDE MSL = 841.3
 DENSITY = 0.002320
 DENSITY RATIO = 0.9756
 DENSITY ALTITUDE = 841.4
 SOUND SPEED = 1113.22
 TEMPERATURE = 56.00

MAIN ROTOR PARAMETERS
 RADIUS = 28.000
 NUMBER OF BLADES = 4
 LOCK NUMBER = 3.6976
 SOLIDITY = 0.06220
 IB = 1146.491
 MEAN CHORD/RADIUS = 0.04885

V/(OMEGA*R) = 0.0000
 TIP SPEED = 621.60
 ROTATIONAL SPEED (RPM) = 211.99
 OMEGA (RAD/SEC) = 22.200
 TIP MACH NUMBER = 0.5584
 OPSTLL = 1
 OPYAW = 0
 OPCOMP = 1
 OPUSLD = 2
 INFLOW = 1 0 0 0 0
 OPHVIB = 1 0 1

COUNTER-CLOCKWISE ROTATION DIRECTION
 HINGED BLADE (HINGE = 0, EFLAP = 0.0357, FLAG = 0.0357)
 NONUNIFORM INFLOW WITH FREE WAKE GEOMETRY (LEVEL = 2)

DEGREES OF FREEDOM
 DOF = Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9,Q10
 Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9,Q10
 PHIF,THETAF,PSIF,XF,YF,ZF
 PSIS,PSII,PSIE TGOVT,TGOVI,TGOV2
 F0,P1,P2,P3,P4 BG
 F0,P1,P2,P3,P4 BG
 QF1,QF2,QF3,QF4,QF5,QF6,QF7,QF8,QF9,QF10
 (ROTOR-1)
 (ROTOR-2)
 (AIRFRAME)
 (DRIVE TRAIN)

DOF = 0000000000 00000 0 INBM = 0, NTM = 0, NGM = 0
 0000000000 00000 0 INBM = 0, NTM = 0, NGM = 0
 000000 0000000000 INAM = 0
 000 000 INDM = 0

DOFT = TRIM Q1,Q2,Q3,Q4 (ROTOR-1)
 DOFT = 0000 (NBNT = 0) 0000 (NBNT = 0)

ANALYSIS PARAMETERS
 NUMBER OF AZIMUTH STATIONS = 4
 AZIMUTH INCREMENT (DEG) = 30.000
 NUMBER OF HARMONICS FOR ROTOR = 0 (ROTOR-1) 0 (ROTOR-2)
 NUMBER OF HARMONICS FOR AIRFRAME = 0 (ROTOR-1) 0 (ROTOR-2)

TRIM ITERATION

	DELO THETA-FT TGOVR1	DELG PHI-FT TGOVR2	DELS THETA-PP THETA-T	DELP PSI-PP	CT/S
TARGETS					
N = 0	0.15882	0.00000	0.00000	0.00000	0.081700
	0.00000	0.00000	0.00000	0.00000	0.082627
	0.00000	0.00000	0.00000	0.00000	
I=1	0.15446	0.00000	0.00000	0.00000	0.079228
	0.00000	0.00000	0.00000	0.00000	
	0.00000	0.00000	0.00000	0.00000	
N = 1	0.15823	0.00000	0.00000	0.00000	0.082076
	0.00000	0.00000	0.00000	0.00000	
	0.00000	0.00000	0.00000	0.00000	
N = 2	0.15799	0.00000	0.00000	0.00000	0.081750
	0.00000	0.00000	0.00000	0.00000	
	0.00000	0.00000	0.00000	0.00000	

AIRCRAFT TRIM					

UNIFORM INFLOW

WAKE/TRIM ITERATION NUMBER 1 MAXIMUM = 1

NUMBER OF TRIM ITERATION = 2 MAXIMUM = 30 TOLERANCE = 0.00100

WIND TUNNEL TRIM OPTION NUMBER 11

FORCES

	TRIMMED	TARGET	ERROR	CONTROL	TRIMMED	INPUT
** CT/S	0.0817501	0.0817000	0.0000501	** DELG	9.05	9.10 **
CP/S	0.0059571	0.0000000	0.0000000	DELC	0.00	0.00
CL/S	0.0817501	0.0000000	0.0000000	DELS	0.00	0.00
CX/S	0.0000000	0.0000000	0.0000000	THETA-T	0.00	0.30
CY/S	0.0000000	0.0000000	0.0000000	PSI-T	0.00	0.30
BETAS	0.0000	0.0000	0.0000000	AYAW	0.00	0.30
BETAS	0.0000	0.0000	0.0000000			

COLLECTIVE CONTROLS

THROTTLE CONTROLS	DELO =	9.05	TGOVR1 =	0.00
AIRCRAFT CONTROLS	DELT =	0.00	C-T =	0.00
ROTOR CONTROLS	DELF =	0.00	DELE =	0.00
	T75 =	9.05	TIC =	0.00

INDUCED VELOCITIES FOR VORTEX LINE/RING MODEL

RADIAL STATIONS	0.23000	0.36000	0.43000	0.50000	0.68000	0.75000	0.80000	0.81000	0.87000	0.89000
0.91000	0.93000	0.95000	0.97000	0.99000						

BLADE AXES
 AXIAL VELOCITY
 0.04604 0.05129 0.05631 0.06487 0.07229 0.07325 0.07065 0.06554 0.05952 0.05364
 0.04643 0.03878 0.03527 0.04011 0.05821
 RADIAL VELOCITY
 -0.00428 -0.00627 -0.00758 -0.01063 -0.02342 -0.03661 -0.04681 -0.05471 -0.05844 -0.05929
 -0.05904 -0.05675 -0.05123 -0.04448 -0.03871

VORTEX LINE/RING WAKE GEOMETRY NUMBER OF ITERATIONS 18

RING/LINE LEVEL	0	1	2	3	4
VORTEX NO. 1	R= 0.99505	0.93178	0.87272	0.83788	0.81971
	Z= 0.00000	0.01452	0.08148	0.17569	0.27666

STRENGTH OF ROLLED UP VORTEX 0.014695

VORTEX NO. 2	R= 0.62525	0.60237	0.57525	0.54890	0.52590
	Z= 0.00000	0.11749	0.25421	0.39994	0.55391

STRENGTH OF ROLLED UP VORTEX -0.008817

TRAIN ITERATION

	DELO	DELG	DELS	DELG	DELG	CT/S
	THETA-FT	PHI-FT	THETA-FT	PHI-FT	THETA-T	
TARGETS	TGOVR1	TGOVR2	TGOVR2	TGOVR2	TGOVR2	0.081700
N = 0	0.15799	0.00000	0.00000	0.00000	0.00000	0.080704
	0.00000	0.00000	0.00000	0.00000	0.00000	
	0.00000	0.00000	0.00000	0.00000	0.00000	

INDUCED VELOCITIES FOR VORTEX LINE/RING MODEL

RADIAL STATIONS
 0.23000 0.36000 0.48000 0.59000 0.68000 0.75000 0.80000 0.84000 0.87000 0.89000
 0.91000 0.93000 0.95000 0.97000 0.99000
 BLADE AXES
 AXIAL VELOCITY
 0.04640 0.05170 0.05676 0.06536 0.07279 0.07377 0.07115 0.06604 0.06001 0.05410
 0.04680 0.03909 0.03563 0.04060 0.05901
 RADIAL VELOCITY
 -0.00432 -0.00633 -0.00767 -0.01080 -0.02366 -0.03692 -0.04719 -0.05511 -0.05884 -0.05976
 -0.05959 -0.05732 -0.05170 -0.04486 -0.03902

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VORTEX LINE/RING WAKE GEOMETRY
NUMBER OF ITERATIONS      18
RING/LINE LEVEL           0      1      2      3      4
VORTEX NO.   1   R= 0.99502 0.93140 0.87218 0.83734 0.81923
                Z= 0.00000 0.01483 0.08248 0.17743 0.27907
STRENGTH OF ROLLED UP VORTEX 0.01899
VORTEX NO.   2   R= 0.92546 0.60224 0.57487 0.54834 0.52516
                Z= 0.00000 0.11845 0.25638 0.40349 0.55887
STRENGTH OF ROLLED UP VORTEX -0.008939
N = 4
    0.15952 0.00000 0.00000 0.00000 0.00000 0.081664
    0.00000 0.00000 0.00000 0.00000 0.00000
    0.00000 0.00000 0.00000 0.00000
...
*****
INPUT DATA
*****

TITLE = H-31 HELICOPTER
JOB OR CASE IDENTIFICATION. CODE =
UNITS 1 FOR ENGLISH, 2 FOR METRIC. OPUNIT = 1
ANALYSIS TASKS 0 TO SUPPRESS.
    ANTYPE1 = 0          FLUTTER
    ANTYPE2 = 0          FLIGHT DYNAMICS
    ANTYPE3 = 0          TRANSIENT
NAMELIST READ CONTROL. OPREAD = 0 1 1 0 0 1 1 0 0 0 0
DEBUG PRINT CONTROL. DEBUG = 0 0 1 0 0 0 0 0 0 0 0 1 0
INPUT PRINT CONTROL 0 FOR SHORT FORM, 1 FOR LONG FORM. NPRINT = 1

OPERATING CONDITIONS
AIRCRAFT SPEED (KNOTS). VKTS = 0.00
V/(OMEGA*R). VEL = 0.0000
ROTOR-1 TIE SPEED. WTIP = 21.00
ROTOR-1 ROTATIONAL SPEED (RPM). PRN = 211.99
AIRCRAFT ENVIRONMENT 1 FOR ALT AND STD DAY, 2 FOR ALT AND TEMP, 3 FOR DENSITY AND TEMP, OPDENS = 3
ALTITUDE ABOVE MSL. ALTMSL = 811.3
AIR TEMPERATURE. TEMP = 51.60
AIR DENSITY. DENSE = 0.002320
NUMBER OF ROTORS. NPOTOR = 1
GROUND EFFECT 0 FOR OGE, OPGE = 0

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ALTITUDE CG ABOVE GROUND, HAGL = 0.00
 ENGINE STATE (1 FOR AUTOROTATION, 2 FOR ENGINE OUT), OPENGN = 0
 WING FLAP ANGLE (DEG), AFLAP = 0.00
 DEGREE OF FREEDOM VECTOR, DOF = 00000000000000000000 00000000000000000000 00000000000000000000
 TRIM BENDING DEGREE OF FREEDOM VECTOR, DOFT = 0000 0000

MOTION ANALYSIS

NUMBER OF AZIMUTH STEPS, MPSI = 4
 NUMBER OF HARMONICS IN ROTOR MOTION, MHARM = 0 0
 NUMBER OF HARMONICS IN AIRFRAME MOTION, MHARMF = 0 0
 NUMBER OF ROTOR AZIMUTH STEPS BETWEEN UPDATE OF AIRFRAME VIBRATION, MPSIR = 4
 NUMBER OF REVOLUTIONS BETWEEN TEST OF MOTION CONVERGENCE, MREV = 1
 MAXIMUM NUMBER OF MOTION ITERATIONS, ITERM = 40
 TOLERANCE FOR MOTION CONVERGENCE (DEG), EPMOTN = 0.02000
 MAXIMUM NUMBER OF CIRCULATION ITERATIONS, ITERC = 40
 TOLERANCE FOR CIRCULATION CONVERGENCE (CT/S), EPCIRC = 0.001000
 LAG TO IMPROVE CONVERGENCE OF MOTION ITERATION, FACTM = 0.500

WAKE ANALYSIS

INFLOW MODEL (0 FOR UNIFORM, 1 FOR PRESCRIBED WAKE, 2 FOR FREE WAKE), LEVEL = 2 0
 WAKE/TRIM ITERATIONS (0 TO SKIP),
 ITERU = 1 UNIFORM INFLOW LEVEL
 ITERR = 0 NONUNIFORM INFLOW AND PRESCRIBED WAKE GEOMETRY LEVEL
 ITERF = 1 NONUNIFORM INFLOW AND FREE WAKE GEOMETRY LEVEL

TRIM ANALYSIS

FREE FLIGHT TRIM (0-9) OR WIND TUNNEL TRIM (10-29), OPTRIM = 11
 MAXIMUM NUMBER OF ITERATIONS ON CONTROL TO ACHIEVE TRIM, MTRIM = 30
 NUMBER OF TRIM ITERATIONS BETWEEN UPDATE OF TRIM DERIVATIVE MATRIX, MTRIND = 20
 CONTROL STEP IN TRIM DERIVATIVE CALCULATION (DEG), DELTA = 0.5000
 FACTOR REDUCING CONTROL INCREMENT, FACTOR = 0.5000
 TOLERANCE ON TRIM CONVERGENCE, EPTRM = 0.00100
 GOVERNOR TRIM (0 TO TRIM COLL, 1 TO TRIM ROTOR-1 GOV, 2 TO TRIM ROTOR-2 GOV, 3 TO TRIM BOTH GOVERNORS), OPGOV = 0

INITIAL CONTROL SETTINGS

COLL = 9.10 COLLECTIVE STICK DISPLACEMENT
 LATCYC = 0.00 LATERAL CYCLIC STICK DISPLACEMENT
 LONGCYC = 0.00 LONGITUDINAL CYCLIC STICK DISPLACEMENT
 PEDAL = 0.00 PEDAL DISPLACEMENT
 APITCH = 0.00 PITCH ANGLE THETA-FT OR THETA-1
 AROLL = 0.00 ROLL ANGLE PHI-FT
 ACLIMB = 0.00 CLIMB ANGLE THETA-FP
 AYAW = 0.00 YAW ANGLE PSI-FP OR PSI-T
 RTURN = 0.00 TRIM TURN RATE

TARGETS FOR WIND TUNNEL TRIM

CTTRIM = 0.001700 (CT/S OR CL/S)
 CPTRIM = 0.000000 (CP/S)
 CXTRIM = 0.000000 (CX/S)
 XTRIM = 0.000 (X/Q)
 CYTRIM = 0.000000 (CY/S)
 BCTRIM = 0.000 (BETA-C)
 BSTRIM = 0.000 (BETA-S)

DYNAMIC MODEL

ENDING MODE TYPE = 0 FOR HINGED, 1 FOR CANTILEVER, 2 FOR ARTICULATED, HINGE = 0
 NO PITCH BEARING IF 1, NOPB = 0
 STRUCTURAL COUPLING, RCPL = 1.0000
 HINGE OFFSET, RFLAP = 0.0357, ELAP = 0.0357
 HINGE SPRING, RFLAP = 0.0000, KLAG = 0.0000
 HINGE SPRING PITCH (DEG), TSFRNG+RCPLS*T75 = 0.00 + 0.0000 * T75
 COLLECTIVE CONTROL SYSTEM DAMPING, TDAMP0 = 0.0000
 CYCLIC CONTROL SYSTEM DAMPING, TDAMP1 = 0.0000
 ROTATING CONTROL SYSTEM DAMPING, TDAMP2 = 0.0000
 LINEAR LAG DAMPER COEFFICIENT, LDAMP1 = 1700.0000
 NONLINEAR LAG DAMPER MAXIMUM MOMENT (0. FOR LINEAR, LDAMP2 = 900.0000
 NONLINEAR LAG DAMPER, LAG RATE AT MAXIMUM MOMENT, LDAMP3 = 0.0400
 PITCH BENDING COUPLING (1 FOR INPUT, 2 TO CALCULATE, NEGATIVE FOR NO COS FACTOR), KPIN = 1
 PHIPB = 0.00, PHIPL = 0.00, RPB = 0.05000, RPH = 0.05000, XPH = 0.05000
 BLADE MASS (IF LE 0, INTEGRAL OF SECTION MASS USED), MBLADE = -1.0000
 TIP MASS, MAST = 0.0000
 TIP MASS CG OFFSET, XIT = 0.00000
 FEATHERING AXIS RADIAL LOCATION, RFA = 0.08000
 GIMBAL UNDERSLING, ZFA = 0.00000
 TORQUE OFFSET, XFA = 0.00000
 PRECONE (DEG), CONE = 0.00
 DROOP AT T75=0. (DEG), DROOP = 0.00
 SWEEP AT T75=0. (DEG), SWEEP = 0.00
 FEATHERING AXIS DROOP (DEG), FORDROP = 0.00
 FEATHERING AXIS SWEEP (DEG), FSWEEP = 0.00
 CONTROL SYSTEM STIFFNESS INPUT (1 FOR SPRING, 2 FOR FREQUENCIES AT VTIPN), WFIN = 2

FREQUENCY SPRING
 1.500 0.0000
 1.500 0.0000
 1.500 0.0000

NUMBER OF RADIAL STATIONS IN BLADE MODE CALCULATION, MRB = 40
 TOLERANCE ON COLLECTIVE (DEG) FOR NUMERICAL INTEGRATION OF INERTIAL COEFFICIENTS, MRM = 50
 CALCULATE NONROTATING BENDING FREQUENCIES IF NE 0, EPMODE = 0.50000
 NUMBER OF BENDING MODE COLLOCATION FUNCTIONS, NCOLB = 4
 NUMBER OF TORSION MODE COLLOCATION FUNCTIONS, NCOLT = 2
 HUB VIBRATION COMPONENTS (0 TO SUPPRESS)
 OPHVIB(1) = 1 VIBRATION DUE TO THIS ROTOR
 OPHVIB(2) = 0 VIBRATION DUE TO OTHER ROTOR
 OPHVIB(3) = 1 STATIC ELASTIC DEFLECTION

SECTION AERODYNAMIC CHARACTERISTICS
 NUMBER OF AERODYNAMIC SEGMENTS, MRA = 15
 EDGES OF SEGMENTS, R = 0.1600 0.3000 0.4200 0.5400 0.6400 0.7200 0.7800 0.8200 0.8600 0.8800
 0.9000 0.9200 0.9400 0.9600 0.9800 1.0000

DRA	C/R	TWIST (DEG)	THETA-ZL (DEG)	XA/R	XAC/R	M-CORR LIFT	M-CORR DRAG	M-CORR MOMENT	TIP LOSS
RA = 0.2300	0.1400	0.04880	4.160	0.0000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.3600	0.1200	0.04880	3.120	0.0000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.4800	0.1200	0.04880	2.160	0.0000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.5900	0.1000	0.04880	1.280	0.0000	0.00000	1.0000	1.0000	1.0000	1.0000

RA = 0.6300 0.0300 0.04880 0.560 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.7500 0.0400 0.04880 0.000 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.8000 0.0400 0.04880 -0.100 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.8400 0.0400 0.04880 -0.720 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.8700 0.0300 0.04880 -0.960 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.9000 0.0300 0.04880 -1.120 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.9100 0.0200 0.04880 -1.280 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.9300 0.0200 0.04880 -1.440 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.9500 0.0200 0.04880 -1.600 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.9700 0.0200 0.04880 -1.760 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000
 RA = 0.9900 0.0200 0.04880 -1.920 0.00000 0.00000 1.0000 1.0000 1.0000 1.0000

SECTION INERTIAL AND STRUCTURAL CHARACTERISTICS

NUMBER OF INERTIAL STATIONS, NRI = 14

	TWIST	MASS	MI/R	KC/R	KMP/R**2	EI-ZZ	EI-XX	I-THETA	GJ
RI = 0.0000	0.00	2.05000	0.00000	0.00000	0.000110	0.54000E+06	0.65000E+07	0.12900	0.83000E+06
RI = 0.0310	5.74	2.05000	0.00000	0.00000	0.000110	0.54000E+06	0.65000E+07	0.12900	0.83000E+06
RI = 0.0620	5.79	2.05000	0.00000	0.00000	0.000110	0.54000E+06	0.65000E+07	0.12900	0.83000E+06
RI = 0.0930	5.61	2.05000	0.00000	0.00000	0.000110	0.54000E+06	0.65000E+07	0.12900	0.83000E+06
RI = 0.1240	5.45	1.77000	0.00000	0.00000	0.000110	0.34700E+07	0.32100E+07	0.12900	0.83000E+06
RI = 0.1550	5.34	0.61200	0.00000	0.00000	0.000110	0.22300E+07	0.64000E+06	0.04800	0.31000E+06
RI = 0.1860	5.26	0.39900	0.00000	0.00000	0.000110	0.21000E+07	0.23600E+07	0.02300	0.13000E+06
RI = 0.2170	5.13	0.13100	0.00000	0.00000	0.000110	0.21000E+06	0.13900E+07	0.00600	0.13000E+06
RI = 0.2480	4.80	0.13100	0.00000	0.00000	0.000110	0.11900E+06	0.11900E+07	0.01200	0.14600E+06
RI = 0.2790	4.41	0.15700	0.00000	0.00000	0.000110	0.10200E+06	0.11100E+07	0.01600	0.13900E+06
RI = 0.3100	4.25	0.20500	0.00000	0.00000	0.000110	0.10200E+06	0.11100E+07	0.01750	0.12500E+06
RI = 0.3410	-0.84	0.20500	0.00000	0.00000	0.000110	0.10200E+06	0.11100E+07	0.01750	0.12500E+06
RI = 0.3720	-1.03	0.35400	0.00000	0.00000	0.000110	0.10200E+06	0.11100E+07	0.01750	0.12500E+06
RI = 0.4030	-2.00	0.35400	0.00000	0.00000	0.000110	0.10200E+06	0.11100E+07	0.01750	0.12500E+06

NONLINEAR INFLOW MODEL

VOXTEL LINE MODEL IF 1, VOXTEL PING MODEL IF 2, OPXMDL = 2

ORIENT OF NEAR WAKE, FNM = 12

ORIENT OF POLLING ON WAKE, FPM = 12

ORIENT OF FAR WAKE, FFW = 100

ORIENT OF CIRCULAR WAKE, FCM = 0

POLLUP INITIAL RAZIAL STATION, PRU = 0.8000

POLLUP INITIAL HIP CENTER FRACTION, PRF = 0.8000

POLLUP EXTENT DES, PRY = 0.00

NEAR WAKE CIL VOXTEL FRACTION, FNM = 0.3000

NUMBER OF SPIRALS IN ASYMMETRIC FAR WAKE, LHM = 30

ASYMMETRIC WAKE GEOMETRT IF 0, OPW = 0

NUMBER OF CIRCULATION POINTS, MCP = 15

CIRCULATION POINTS (AERODYNAMIC SEGMENT NUMBER), NS = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

NUMBER OF INFLOW POINTS, NRI = 15

INFLOW POINTS (AERODYNAMIC SEGMENT NUMBER), NI = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

VORTEX CORE RADII
 CORE(1) = 0.05000 TIP VORTICES
 CORE(2) = 0.05000 BURST TIP VORTICES
 CORE(3) = 0.01000 DISTANT WAKE TIP VORTICES
 CORE(4) = -1.00000 INBOARD TRAILED LINES
 CORE(5) = -1.00000 INBOARD SHED LINES
 VORTEX CORE TYPE 0 FOR DISTRIBUTED VORTICITY, 1 FOR CONCENTRATED VORTICITY
 OPCORE(1) = 0 TIP VORTICES
 OPCORE(2) = 0 INBOARD WAKE

WAKE MODEL 0 TO OMIT, 1 FOR STEPPED LINE, 2 FOR LINEAR LINE, 3 FOR SHEET
 WNMDEL(1) = 2 TIP VORTICES
 WNMDEL(2) = 0 NEAR WAKE SHED
 WNMDEL(3) = 2 NEAR WAKE TRAILED
 WNMDEL(4) = 0 ROLLING UP WAKE SHED
 WNMDEL(5) = 2 ROLLING UP WAKE TRAILED
 WNMDEL(6) = 0 FAR WAKE SHED
 WNMDEL(7) = 2 FAR WAKE TRAILED
 WNMDEL(8) = 0 DISTANT WAKE SHED
 WNMDEL(9) = 2 DISTANT WAKE TRAILED
 WNMDEL(10) = 2 BOUND VORTICES
 WNMDEL(11) = 3 HOVER WAKE AXIAL
 WNMDEL(12) = 0 HOVER WAKE SHED
 WNMDEL(13) = 3 HOVER WAKE RING

CORE BURST PROPAGATION RATE, VELB = 0.3330
 CORE BURST AGE INCREMENT, DPHB = 0.000
 SHEET EDGE TEST CRITERION (LT 0. TO SUPPRESS), DBV = -1.000000
 LIFTING SURFACE CORRECTION CRITERION (LT 0. TO SUPPRESS), DVS = 0.100000
 FACTOR INTRODUCING LAG IN CIRCULATION FOR INDUCED VELOCITY, DELS = 0.500000
 SUPPRESS X AND Y COMPONENTS OF INFLOW AT ROTORS IF 0, OPVXT = 1
 NEAR WAKE OPTION WHEN CIRC INFLOW PT COINCIDE 0 FOR TWO SHEETS, 1 FOR LINES, 2 FOR SINGLE SHEET
 OPNWS(1) = 1 SHED WAKE
 OPNWS(2) = 1 TRAILED WAKE
 INCLUDE ROTATION MATRICES IN INFLUENCE COEFFICIENTS IF 1, OPRTS = 0
 BLADE POSITION MODEL FOR WAKE GEOMETRY
 OPWEP(1) = 0 SUPPRESS IMPLAVE MOTION IF 0
 OPWEP(2) = 0 SUPPRESS ALL HARMONICS EXCEPT MEAN IF 0
 OPWEP(3) = 1 LINEAR FROM ROOT TO TIP IF 0
 CORUS PRINT CRITERION, QDBUE = 1000.000000

PRESCRIBED WAKE GEOMETRY
 EXTENT OF RIGID WAKE GEOMETRY, KRWG = 96
 RIGID WAKE GEOMETRY MODEL, OPRWG = 8
 PRESCRIBED WAKE GEOMETRY PARAMETERS

TIP VORTEX		INSIDE SHEET EDGE	OUTSIDE SHEET EDGE
F1	1.000000	1.000000	1.000000
F2	1.000000	1.000000	1.000000
K1	1.000000	1.000000	1.000000
K2	1.000000	1.000000	1.000000
K3	1.000000	1.000000	1.000000
K4	1.000000	1.000000	1.000000

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VORTEX LINE AND VORTEX RING MODELS (PRESCRIBED AND FREE)
NUMBER OF INTERMEDIATE VORTEX LEVELS, NIVL = 4
FAR WAKE MODEL (0 TO OMIT, 1 FOR CONCENTRATED, 2 FOR SHEET), WFMODL= 2

FOR FREE WAKE ONLY

FACTOR INTRODUCING LAG IN INDUCED VELOCITY, FACTIV = 0.1000
TOLERANCE FOR INDUCED VELOCITY, EPIVEL = 0.0200
ROLLED-UP VORTEX WEIGHTING FACTOR (EXCLUDING TIP), FGAMMA = 0.6000
MAXIMUM NUMBER OF INDUCED VELOCITY ITERATIONS, ITERV = 200
NUMBER OF ROLLED-UP VORTICES, NIBV = 2

FREE WAKE GEOMETRY
EXTENT OF FREE WAKE GEOMETRY, KFWG = 90
FREE WAKE GEOMETRY MODEL, OPFWG = 1
WAKE MODEL (0 TO OMIT, 1 FOR LINE, 2 FOR SHEET)
  WGMODL(1) = 1 INBOARD TRAILED WAKE
  WGMODL(2) = 1 SHED WAKE

VORTEX CORE RADII
COREWG(1) = 0.00250 TIP VORTICES
COREWG(2) = 0.10000 BURST TIP VORTICES
COREWG(3) = -1.00000 INBOARD TRAILED LINES
COREWG(4) = -1.00000 INBOARD SHED LINES

RADIAL STATIONS FOR TRAILED VORTICITY
RTWG(1) = 0.1000 INSIDE SHEET EDGE
RTWG(2) = 0.4000 OUTSIDE SHEET EDGE OR TRAILED LINE
NUMBER OF REVOLUTIONS OF WAKE BELOW POINT CALCULATING VELOCITY, MRVBWG = 2
GENERAL UPDATE, LDMWG = 12
BOUNDARY UPDATE, NDWMG = 6 6 6 3
WAKE VELOCITY CRITERIA
  DQWG(1) = 0.000500 NEAR WAKE ELEMENTS
  DQWG(2) = 0.000500 BOUND VORTEX
NUMBER OF WAKE GEOMETRY ITERATIONS, ITERWG = 2
FACTOR INTRODUCING LAG IN DISTORTION, FACTWG = 0.50000
DEBUG PRINT CRITERIA
  IPWGDB(1) = 4 PRINT BEFORE GENERAL UPDATE
  IPWGDB(2) = 6 PRINT AFTER EACH ITERATION
  QWGDB = 0.100000 PRINT VELOCITY CONTRIBUTION

AIRFRAME DATA
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..
..
.....
AIRCRAFT TRIM
.....

NONUNIFORM INFLOW WITH FREE WAKE GEOMETRY
WAKE/TRIM ITERATION NUMBER 2 (MAXIMUM = 2)
NUMBER OF TRIM ITERATION = 4 (MAXIMUM = 80, TOLERANCE = 0.00100)
WIND TUNNEL, TRIM OPTION NUMBER 11

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FORCES

TRIMMED	TARGET	ERROR	CONTROL	TRIMMED	INPUT
** CT/S	0.0816636	0.0004450	** DELO	9.14	9.10 **
CP/S	0.0059463	0.0000000	DEL	0.00	0.00
CL/S	0.0816636	0.0000000	DELC	0.00	0.00
CX/S	0.0000000	0.0000000	DELS	0.00	0.00
CY/S	0.0000000	0.0000000	THETA-T	0.00	0.00
BETAC	0.0000	0.0000000	PSI-T	0.00	0.00
BETAS	0.0000	0.0000000			

COLLECTIVE CONTROLS -- DELO = 9.14 TGOVR1= 0.00 TGOVR2= 0.00

THROTTLE CONTROLS -- DELT = 0.00 C-T = 0.00

AIRCRAFT CONTROLS -- DELF = 0.00 DELE = 0.00

ROTOR CONTROLS -- T75 = 9.14 TIC = 0.00 DELR = 0.00

PERFORMANCE

VEL	Q	DPHI-F	DTHETA-F	DPSI-F	DX-F	DY-F	DZ-F	DDZ-F	DOMEGA	THETA-FT	PHI-FT	T75-R1	T1C-R1	T1S-R1	T75-R2	T1C-R2	T1S-R2	DELF	DELE	DELA	DELT
0.00000	0.00000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00000	0.00000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00000	0.00000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00000	0.00000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00000	0.00000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00000	0.00000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00000	0.00000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CIRCULATION ITERATIONS = 1 (MAXIMUM = 40, TOLERANCE = 0.00100)

ROTOR-1 CG/S-RMS = 0.0003262 G/E = 0.3262

BLADE MOTION ITERATIONS = 1 (MAXIMUM = 40, TOLERANCE = 0.02000)

AIRFRAME PERFORMANCE

MAIN ROTOR PERFORMANCE

MUX	MUY	MUZ	L	MUX-TPP	MUY-TPP	MUZ-TPP	L-INT	ALF-HP	ALF-TPP	ALF-CP	MTIP	MAT	P-HP	T75	B0	T1S	B1C-HP	B1C-CP	TIC	B1S-HP	B1S-CP
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

ROTOR FORCES
 SHAFT AXES
 THRUST T = 11214.890
 DRAG FORCE H = 0.000
 SIDE FORCE Y = 0.000
 ROLL MOMENT MX = -0.010
 PITCH MOMENT MY = -0.004
 TORQUE MZ = 22865.182
 TIP-PATH PLANE AXES
 THRUST T = 11214.890
 DRAG FORCE H = 0.000
 SIDE FORCE Y = 0.000
 WIND AXES
 LIFT L = 11214.890
 DRAG X = 0.000
 FORCE ANGLES
 SHAFT AXES
 TIP-PATH PLANE AXES
 WIND AXES
 PITCH = 0.00
 ROLL = 0.00
 PITCH = 0.00
 ROLL = 0.00
 PITCH = 0.00
 ROLL = 0.00

ROTOR POWER
 TOTAL P = 922.922
 CLIMB + PARASITE PC+PP = 0.000
 PROFILE + INDUCED PO+PI = 922.922
 INDUCED PI = 728.688
 INTERFERENCE PINT = 0.000
 PROFILE PO = 194.234
 NON-IDEAL PN = 284.162
 CP/S = 0.0059463
 CPC/S+CPP/S = 0.0000000
 CPO/S+CPI/S = 0.0059463
 CPI/S = 0.0046949
 CPINT/S = 0.0000000
 CPO/S = 0.0012514
 CPN/S = 0.0018308

PERFORMANCE INDICES
 N = 0.6921
 CQ = 0.01001
 CQV = 0.01105
 CFI CT = 0.0575
 CFI CT = 0.0000
 K-INDUCED = 1.1402
 L-INDUCED = 0.0592
 L-INTERP = 0.0000
 L-IDEAL = 0.0500
 D-ROTOR = 0.000
 D/Q-ROTOR = 0.000
 L/D-ROTOR = 0.000
 D-TOTAL = 0.000
 D/Q-TOTAL = 0.000
 L/D-TOTAL = 0.000

ANGLE OF ATTACK DEG. AND MAXIMUM BOUND CIRCULATION
 PA = 0.230 0.360 0.480 0.590 0.680 0.750 0.800 0.840 0.870 0.890 0.910 0.930 0.950 0.970 0.990
 GMAX
 PSI = 90. 0.01570 1.9 4.1 4.0 4.1 3.6 3.5 3.7 3.9 4.2 4.5 4.8 5.3 5.4 5.0 3.8
 PSI = 180. 0.01570 1.9 4.1 4.6 4.1 3.6 3.5 3.7 3.9 4.2 4.5 4.9 5.3 5.4 5.0 3.8
 PSI = 270. 0.01570 1.9 4.1 4.6 4.1 3.6 3.5 3.7 3.9 4.2 4.5 4.9 5.3 5.4 5.0 3.8
 PSI = 360. 0.01570 1.9 4.1 4.6 4.1 3.6 3.5 3.7 3.9 4.2 4.5 4.9 5.3 5.4 5.0 3.8

AIRCRAFT PERFORMANCE

CLIMB + PARASITE POWER	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)
INDUCED POWER	728.688 (78.95)	0.000 (0.00)	728.688 (78.95)
INTERFERENCE POWER	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)
PROFILE POWER	194.234 (21.05)	0.000 (0.00)	194.234 (21.05)
CLIMB POWER			
PARASITE POWER			
NON-IDEAL POWER	284.162 (30.79)	0.000 (0.00)	284.162 (30.79)
TOTAL POWER	922.922	0.000	922.922

GROSS WEIGHT =	11900.00
DRAG-ROTOR =	0.00
DRAG-TOTAL =	0.00
FIGURE OF MERIT =	0.6921

LOADS, VIBRATION, AND NOISE
.....

MAIN ROTOR LOADS

BLADE AND HUB MOTION

..

..

MAIN ROTOR LOADS

AERODYNAMIC LOADING, RADIAL STATION = 0.2300

SECTION COEFFICIENTS		VELOCITIES AND MOTION		CIRCULATION		G-MAX	
PSI	ALPHA	UR	UP	CD	CM	CDR	G-MAX
PSI = 90.0	1.895	-0.0043	0.0464	0.00848	0.00000	0.00848	0.01570
PSI = 180.0	1.895	-0.0043	0.0464	0.00848	0.00000	0.00848	0.01570
PSI = 270.0	1.895	-0.0043	0.0464	0.00848	0.00000	0.00848	0.01570
PSI = 360.0	1.895	-0.0043	0.0464	0.00848	0.00000	0.00848	0.01570

VELOCITIES AND MOTION		CIRCULATION		G-MAX	
PSI	UT	PHI	THETA	FLAP	G-MAX
PSI = 90.0	0.2300	11.405	13.300	0.000	0.01570
PSI = 180.0	0.2300	11.405	13.300	0.000	0.01570
PSI = 270.0	0.2300	11.405	13.300	0.000	0.01570
PSI = 360.0	0.2300	11.405	13.300	0.000	0.01570

ANGLE-OF-ATTACK AND MACH NUMBER

	ALPHA-L	ALPHA-D	ALPHA-M	MACH-L	MACH-D	MACH-M	DALPHA-C/V	COSYAW
PSI = 90.0	1.894	1.894	1.894	0.1310	0.1310	0.1310	0.0000	0.9998
PSI = 180.0	1.894	1.894	1.894	0.1310	0.1310	0.1310	0.0000	0.9998
PSI = 270.0	1.894	1.894	1.894	0.1310	0.1310	0.1310	0.0000	0.9998
PSI = 360.0	1.894	1.894	1.894	0.1310	0.1310	0.1310	0.0000	0.9998

INDUCED VELOCITY AND GUST

	LX	LY	LZ	LIX	LIY	LIZ	UG	VG	WG
PSI = 90.0	0.00000	0.00432	0.04640	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 180.0	0.00000	0.00000	0.04640	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 270.0	0.00000	-0.00432	0.04640	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 360.0	-0.00432	0.00000	0.04640	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MEAN			0.05921						

SECTION LOADING

	L/C	D/C	M/C	DR/C	FZ=CCT/S	FX/C	MA/C	FR/C	FRT/C
PSI = 90.0	0.00550	0.00023	0.00000	0.00023	0.00534	0.00132	0.00000	0.00000	0.00000
PSI = 180.0	0.00550	0.00023	0.00000	0.00023	0.00534	0.00132	0.00000	0.00000	0.00000
PSI = 270.0	0.00550	0.00023	0.00000	0.00023	0.00534	0.00132	0.00000	0.00000	0.00000
PSI = 360.0	0.00550	0.00023	0.00000	0.00023	0.00534	0.00132	0.00000	0.00000	0.00000

SECTION LOADING

	L	D	M	DR	FZ=T	FX	MA	FR	FRT
PSI = 90.0	6.740	0.286	0.000	0.286	6.550	1.613	0.000	-0.005	-0.005
PSI = 180.0	6.740	0.286	0.000	0.286	6.550	1.613	0.000	-0.005	-0.005
PSI = 270.0	6.740	0.286	0.000	0.286	6.550	1.613	0.000	-0.005	-0.005
PSI = 360.0	6.740	0.286	0.000	0.286	6.550	1.613	0.000	-0.005	-0.005

SECTION POWER

	CP/S	CP/S	CP/S	CP/S	P	PI	PINT	PO
PSI = 90.0	0.000303	0.000248	0.000000	0.000000	0.4193	0.3435	0.0000	0.0758
PSI = 180.0	0.000303	0.000248	0.000000	0.000000	0.4193	0.3435	0.0000	0.0758
PSI = 270.0	0.000303	0.000248	0.000000	0.000000	0.4193	0.3435	0.0000	0.0758
PSI = 360.0	0.000303	0.000248	0.000000	0.000000	0.4193	0.3435	0.0000	0.0758

MAIN ROTOR LOADS

AERODYNAMIC LOADING, RADIAL STATION = 0.7500

SECTION COEFFICIENTS

	ALPHA	MACH	YAW	CL	CD	CM	CDR	CIRCULATION	G-MAX
PSI = 90.0	3.523	0.4208	2.805	0.40853	0.00908	0.00000	0.00908	0.00751	0.01570
PSI = 180.0	3.523	0.4208	2.805	0.40853	0.00908	0.00000	0.00908	0.00751	0.01570
PSI = 270.0	3.523	0.4208	2.805	0.40853	0.00908	0.00000	0.00908	0.00751	0.01570
PSI = 360.0	3.523	0.4208	2.805	0.40853	0.00908	0.00000	0.00908	0.00751	0.01570

VELOCITIES AND MOTION

	PSI	90.0	UT	UR	UP	U	PHI	THETA	LAG	FLAP
			0.7500	-0.0369	0.0738	0.7536	5.618	9.140	0.000	0.000
			0.7500	-0.0369	0.0738	0.7536	5.618	9.140	0.000	0.000
			0.7500	-0.0369	0.0738	0.7536	5.618	9.140	0.000	0.000
			0.7500	-0.0369	0.0738	0.7536	5.618	9.140	0.000	0.000

ANGLE-OF-ATTACK AND MACH NUMBER

	PSI	90.0	ALPHA-L	ALPHA-D	ALPHA-M	MACH-L	MACH-D	MACH-M	DALPHA*/C/V	COSYAW
			3.514	3.518	3.514	0.4208	0.4208	0.4208	0.0000	0.9988
			3.514	3.518	3.514	0.4208	0.4208	0.4208	0.0000	0.9988
			3.514	3.518	3.514	0.4208	0.4208	0.4208	0.0000	0.9988
			3.514	3.518	3.514	0.4208	0.4208	0.4208	0.0000	0.9988

INDUCED VELOCITY AND GUST

	PSI	90.0	LX	LY	LZ	LIX	LIY	LIZ	UG	VG	WG
			0.00000	0.03692	0.07377	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
			0.03692	0.00000	0.07377	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
			0.00000	-0.03692	0.07377	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
			-0.03692	0.00000	0.07377	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MEAN					0.05921			0.00000			

SECTION LOADING

	PSI	90.0	L/C	D/C	M/C	DR/C	FZ/C-CT/S	FX/C	MA/C	FR/C	FRT/C
			0.11589	0.00258	0.00000	0.00258	0.11508	0.01391	0.00000	-0.00013	-0.00013
			0.11589	0.00258	0.00000	0.00258	0.11508	0.01391	0.00000	-0.00013	-0.00013
			0.11589	0.00258	0.00000	0.00258	0.11508	0.01391	0.00000	-0.00013	-0.00013
			0.11589	0.00258	0.00000	0.00258	0.11508	0.01391	0.00000	-0.00013	-0.00013

SECTION LOADING

	PSI	90.0	L	D	M	DR	FZ=T	FX	MA	FR	FRT
			142.098	3.160	0.000	3.160	141.106	17.054	0.000	-0.155	-0.155
			142.098	3.160	0.000	3.160	141.106	17.054	0.000	-0.155	-0.155
			142.098	3.160	0.000	3.160	141.106	17.054	0.000	-0.155	-0.155
			142.098	3.160	0.000	3.160	141.106	17.054	0.000	-0.155	-0.155

SECTION POWER

	PSI	90.0	CP/S	CPI/S	CPINT/S	CPO/S	P	PI	PINT	PO
			0.010431	0.008489	0.000000	0.001947	14.4555	11.7645	0.0000	2.6975
			0.010431	0.008489	0.000000	0.001947	14.4555	11.7645	0.0000	2.6975
			0.010431	0.008489	0.000000	0.001947	14.4555	11.7645	0.0000	2.6975
			0.010431	0.008489	0.000000	0.001947	14.4555	11.7645	0.0000	2.6975

MAIN ROTOR LOADS

AERODYNAMIC LOADING, RADIAL STATION = 0.9900

SECTION COEFFICIENTS

	ALPHA	MACH	YAW	CL	CD	THETA	LAG	CIRCULATION	G-MAX
PSI = 90.0	3.809	0.5538	2.253	0.49599	0.00953	0.00000	0.00953	0.01200	0.01570
PSI = 180.0	3.809	0.5538	2.253	0.49599	0.00953	0.00000	0.00953	0.01200	0.01570
PSI = 270.0	3.809	0.5538	2.253	0.49599	0.00953	0.00000	0.00953	0.01200	0.01570
PSI = 360.0	3.809	0.5538	2.253	0.49599	0.00953	0.00000	0.00953	0.01200	0.01570

VELOCITIES AND MOTION

	UT	UR	UP	U	PHI	THETA	FLAP
PSI = 90.0	0.9900	-0.0390	0.0590	0.9918	3.411	7.220	0.000
PSI = 180.0	0.9900	-0.0390	0.0590	0.9918	3.411	7.220	0.000
PSI = 270.0	0.9900	-0.0390	0.0590	0.9918	3.411	7.220	0.000
PSI = 360.0	0.9900	-0.0390	0.0590	0.9918	3.411	7.220	0.000

ANGLE-OF-ATTACK AND MACH NUMBER

	ALPHA-L	ALPHA-D	ALPHA-M	MACH-L	MACH-D	MACH-M	DALPHA-C/V	COSYAW
PSI = 90.0	3.803	3.806	3.803	0.5538	0.5538	0.5538	0.0000	0.9992
PSI = 180.0	3.803	3.806	3.803	0.5538	0.5538	0.5538	0.0000	0.9992
PSI = 270.0	3.803	3.806	3.803	0.5538	0.5538	0.5538	0.0000	0.9992
PSI = 360.0	3.803	3.806	3.803	0.5538	0.5538	0.5538	0.0000	0.9992

INDUCED VELOCITY AND GUST

	LX	LZ	LIX	LIY	LIZ	UG	VG	WG
PSI = 90.0	0.00000	0.03902	0.05901	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 180.0	0.00000	0.00000	0.05901	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 270.0	0.00000	-0.03902	0.05901	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 360.0	-0.03902	0.00000	0.05901	0.00000	0.00000	0.00000	0.00000	0.00000
MEAN			0.05921					

SECTION LOADING

	LX	D/C	M/C	DR/C	FZ/C=CT/S	FX/C	MA/C	FP/C	FRT/C
PSI = 90.0	0.24367	0.00168	0.00000	0.00168	0.24296	0.01917	0.00000	-0.00018	-0.00018
PSI = 180.0	0.24367	0.00168	0.00000	0.00168	0.24296	0.01917	0.00000	-0.00018	-0.00018
PSI = 270.0	0.24367	0.00168	0.00000	0.00168	0.24296	0.01917	0.00000	-0.00018	-0.00018
PSI = 360.0	0.24367	0.00168	0.00000	0.00168	0.24296	0.01917	0.00000	-0.00018	-0.00018

SECTION LOADING

	L	D	M	DP	FZ=T	FX	MA	FR	FRT
PSI = 90.0	298.774	5.739	0.000	5.739	297.903	23.507	0.000	-0.226	-0.226
PSI = 180.0	298.774	5.739	0.000	5.739	297.903	23.507	0.000	-0.226	-0.226
PSI = 270.0	298.774	5.739	0.000	5.739	297.903	23.507	0.000	-0.226	-0.226
PSI = 360.0	298.774	5.739	0.000	5.739	297.903	23.507	0.000	-0.226	-0.226

SECTION POWER		CP/S	CPI/S	CPINT/S	CPO/S	P	PI	PINT	PO
PSI =	90.0	0.018980	0.014337	0.000000	0.004649	26.3016	19.8684	0.0000	6.4431
PSI =	180.0	0.018980	0.014337	0.000000	0.004649	26.3016	19.8684	0.0000	6.4431
PSI =	270.0	0.018980	0.014337	0.000000	0.004649	26.3016	19.8684	0.0000	6.4431
PSI =	360.0	0.018980	0.014337	0.000000	0.004649	26.3016	19.8684	0.0000	6.4431

COMPUTATION TIMES

	CPU TIME (SEC)	PERCENT	NUMBER OF CALLS	TIME/CALL (SEC)
CASE	24.540	100.000	1	24.540
TRIM (TRIM)	22.710	92.543	1	22.710
FLUTTER (FLUT)	0.000	0.000	0	0.000
FLIGHT DYNAMICS (STAB)	0.000	0.000	0	0.000
TRANSIENT (TRAN)	0.000	0.000	0	0.000
LINEAR ANALYSIS (STABL)	0.000	0.000	0	0.000
LINEAR ANALYSIS (FLUTL)	0.000	0.000	0	0.000
NONUNIFORM INFLOW (WAKEC)	0.000	0.000	0	0.000
WAKE GEOMETRY (GEOMR)	0.000	0.000	0	0.000
VIBRATORY SOLUTION (RAMF)	16.930	68.989	0	0.000
ROTOR MODES (MODE)	0.110	0.448	10	1.693
ROTOR EQUATIONS (MOTNR)	3.040	12.388	10	0.011
PERFORMANCE (PERF)	0.420	1.711	16	0.190
LOADS (LOAD)	3.770	15.363	1	0.420
			1	3.770

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14. DESCRIPTORS Helicopter wakes CAMRAD (mathematical model) Hovering Vortices Rotor Aerodynamics		15. DRDA SUBJECT CATEGORIES 0051A	
16. ABSTRACT The incorporation of simplified hover wake models into the comprehensive rotorcraft analysis code CAMRAD is described and examples are given on their use. The axisymmetric models, in which vortices are represented by either straight lines or rings, are a more generalized form of the free wake models of R.T. Miller at MIT, with the wake geometry also able to be prescribed. Incorporation has allowed access to the tabular representation in CAMRAD of airfoil section characteristics as functions of angle of attack and Mach number, and has broadened the range of rotor wake models in the code to include a free wake hover model that does not have the convergence problems of the existing free wake model when used for hover.			

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