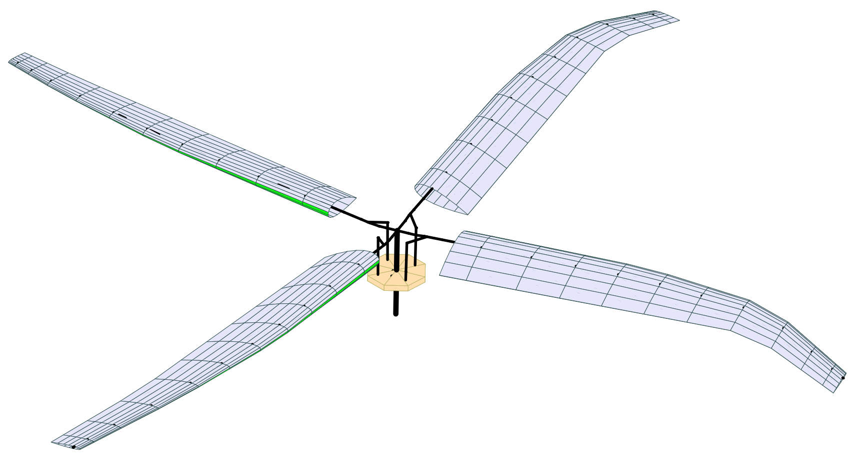
CAMRAD II

COMPREHENSIVE ANALYTICAL MODEL OF ROTORCRAFT AERODYNAMICS AND DYNAMICS

Newsletter
Issue 14, August 2008



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CAMRAD II NEWSLETTER

Issue 14, August 2008

This newsletter provides information for the users of CAMRAD II, the Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics. It is recommended that a copy be provided to each CAMRAD II user.

CAMRAD II Release 4.7 has been completed. Release 4.7 incorporates the following additions and modifications to the analysis capability.

system

a) In first-order difference evaluation of derivative matrix for Newton-Raphson trim loop, added option to calculate baseline trim quantities at end of perturbations instead of at beginning (to improve accuracy of derivative when there are problems with convergence at beginning).

b) Added calculation of modal mass to eigenvector output in flutter task.

components

a) In rotor inflow component and rotor performance component, revised momentum theory model for ducted fan.

b) In rotor performance component, revised factor of speed relating profile power to mean drag coefficient.

c) In wing wake component, added option for straightened bound vortex for near wake induced velocity calculation (for cases when induced velocity underpredicted for swept tip because of kink in bound vortex).

shell

a) Added filters so dynamic wake model can be used with blade modes in flutter task.

b) To accommodate dissimilar blades, revised use of parent mode sets; parent mode sets not used in trim or transient, only used in flutter task if trim solution is for just reference blade.

c) Extended damper model to permit joints to be at different radial station than attachment to blade element.

d) Added dimensional rotor thrust and lift to available trim targets.

documentation

a) Expanded training manual description of process for developing core input.

b) Expanded description of available stall delay options.

c) In input manuals, defined use of empirical inflow factors.

d) Clarified distinction between structural reference line and aerodynamic reference line in shell model.

Changes to Input Variables for Release 4.6

In addition to the new input variables required to implement new features, changes are required to convert Release 4.5 input to Release 4.6 input. The following variables must be changed in the namelist and command files.

input class and type	old variable	action	new variable
refined lifting line theory			
ROTOR WAKE	OPNW = 1	revised	OPNW = 2
wake component	OPNW	replaced by	OPLL
revised wake geometry update			
ROTOR WAKE	RUDWG	deleted	
rotor wake geometry component	RFWG(2)	replaced by	RFWG
	RNWG(2)	replaced by	RNWG
wing wake geometry component	RYOUNG	deleted	
	RFUPDT(2)	replaced by	RFUPDT
	RNUPDT(2)	replaced by	RNUPDT
	DQNW(2)	replaced by	DQNW

Changes to Input Variables for Release 4.4

In addition to the new input variables required to implement new features, changes are required to convert Release 4.3 input to Release 4.4 input. The following variables must be changed in the namelist and command files.

input class and type	old variable	action	new variable
prescribed control (core input)			
	OPDRVX, LENX	revised	

Changes to Input Variables for Release 4.3

In addition to the new input variables required to implement new features, changes are required to convert Release 4.2 input to Release 4.3 input. The following variables must be changed in the namelist and command files.

input class and type	old variable	action	new variable
structural dynamic sensors			
AIRFRAME STRUCTURE	QUANT = 12, 13	revised value	QUANT = 17, 18
structural dynamic component	QUANT = 12, 13, 14	revised value	QUANT = 17, 18, 19
reference frame component	QUANT = 12, 13	revised value	QUANT = 17, 18
axial flow extended far wake model			
ROTOR WAKE	WKMODL(9–11)	deleted	
	OPAX, LAX	deleted	
default values			
TRIM	TOLERT	default = 1.0	
position and mode sensors			
ROTOR STRUCTURE	DPOS, DMODE = 2, 3, 4	revised value	DPOS, DMODE = 3, 4, 5
ROTOR FLEXBEAM	DPOS, DMODE = 2, 3, 4	revised value	DPOS, DMODE = 3, 4, 5

Changes to Input Variables for Release 4.2

In addition to the new input variables required to implement new features, changes are required to convert Release 4.1 input to Release 4.2 input. The following variables must be changed in the namelist and command files.

input class and type	old variable	action	new variable
structural dynamic components (core input)			
	KELST	replaced by	KELSTD
	CELST	replaced by	CELSTD

Changes to Input Variables for Release 4.1

In addition to the new input variables required to implement new features, changes are required to convert Release 4.0 input to Release 4.1 input. The following variables must be changed in the namelist and command files.

input class and type	old variable	action	new variable
rotor inflow gradients			
ROTOR INFLOW	FMLMDA	replaced by	FMLMDA(2)
	FPLMDA	replaced by	FPLMDA(2)
	FQLMDA	replaced by	FQLMDA(2)
	FPLMDA, FQLMDA	default = 2*0.	
default values			
ROTOR STRUCTURE	NINTEG	default = 20	
ROTOR FLEXBEAM	NINTEG	default = 20	
ROTOR STRUCTURE	QUANT	default = 4	
ROTOR FLEXBEAM	QUANT	default = 4	
TRANSIENT ROTOR	OPTRAN	default = 0	

Changes to Input Variables for Release 4.0

In addition to the new input variables required to implement new features, changes are required to convert Release 3.2 input to Release 4.0 input. The following variables must be changed in the namelist and command files.

input class and type	old variable	action	new variable
plugins			
CASE		new	PLUGIN
transient circulation relaxation			
TRANSIENT	RELAXS	replaced by	RELAXS(2)
flutter period			
FLUTTER		new	FLTPER
general wake geometry			
AIRFRAME STRUCTURE structural dynamic components	OPVAX	deleted	
general wake geometry			
ROTOR WAKE	OPAFF	replaced by	OPAFWG

Changes to Input Variables for Release 3.1

In addition to the new input variables required to implement new features, changes are required to convert Release 3.0 input to Release 3.1 input. The following variables must be changed in the namelist and command files.

input class and type	old variable	action	new variable
circulation loop parameters depend on wake loop level			
TRIM	RELAXC	revised	RELAXC(4)
output harmonic analysis method			
TRIM		new	OPHRMO
	default is Fourier interpolation (previous releases used linear interpolation)		
use of quasistatic blade modes			
TRIM ROTOR TRANSIENT ROTOR FLUTTER ROTOR	DOFM	default = 12*1,28*2	
specify reference option for each wing sensor			
ROTOR AERODYNAMICS wing components (core input)	OPREF	revised	OPREF(NSEN)
identification of rolled-up trailed vortices			
ROTOR AERODYNAMICS wing components (core input)		new	OPTRU(NTRAIL+1)
ROTOR WAKE wake component (core input)	OPRUIV	replaced by	OPTRU of wing
trailing edge flap options			
ROTOR STRUCTURE		new	FEDGE
ROTOR AERODYNAMICS	FEDGE	deleted	
dynamic stall models			
dynamic stall table			XS, MUM, L0L, L0M
	new variables; included in sample table DYNAMICSTALL.2STD		
calculation of aerodynamic loads			
wing components (core input)		new revised revised	LNAME GNAME USNAME, DSNAME
	GNAME now is only component output (not component input as well) USNAME, DSNAME now are for all panels		

Changes to Input Variables for Release 3.0

In addition to the new input variables required to implement new features, changes are required to convert Release 2.0 input to Release 3.0 input. The following variables must be changed in the namelist and command files.

input class and type	old variable	action	new variable
section load by force balance method			
ROTOR STRUCTURE	OPDALD, DRDALD	delete	
wake and wake geometry			
ROTOR WAKE	OPFW	default = 0 not 1	
use of quasistatic blade modes			
TRIM ROTOR TRANSIENT ROTOR FLUTTER ROTOR	DOFM	default = 12*1,28*0 not 6*1,34*0	
dynamic stall and unsteady aerodynamics			
ROTOR AERODYNAMICS	CLAUS	replaced by	KCLAUS
wing components (core input)	OPUSLD	replaced by	USMODL
		new	OPUS, PRMUS
	DSMODL	options changed	
		new	OPDS, PRMDS
dynamic stall models require a table file (example provided with sample input)			
correction of error in use of parameter by analysis			
ROTOR AERODYNAMICS wing components (core input)	OPYAW = 0 turned feature on	corrected	OPYAW = 1 turns feature on

Changes to Input Variables for Release 2.0

In addition to the new input variables required to implement new features, changes are required to convert Release 1.2 input to Release 2.0 input. The following variables must be changed in the namelist and command files.

input class and type	old variable	action	new variable
wing trailing-edge flap model			
ROTOR STRUCTURE		new	OPTEF
		new	FGAIN
		new	flap definition
ROTOR AERODYNAMICS	OPFLAP	deleted	(replace by rotor structure input)
	FGAIN	deleted	(replace by rotor structure input)
	NTABLE, TBLFLP	deleted	
	FEDGEL, FEDGER	replaced by	FEDGE(2)
		new	XAFF, LFLAP, XHINGE, etc.

create airfoil table for wing with flap

in the extended format for C81 decks, without a trailing edge flap the header line (the first line of the file) must have two blanks after NAM (in columns 43 and 44); otherwise the INPUT program assumes that the deck includes data for flap loads

input class and type	old variable	action	new variable
blade aerodynamic sensors (changes introduced by flap model, affecting non-flap quantities as well)			
ROTOR AERODYNAMICS	QUANT	revise definition	
airfoil tables (INPUT program)			
namelist NLTABL	NREF, REF	deleted	
namelist NLEQN		new	RETBL1
blade position and blade mode sensors			
ROTOR STRUCTURE	old OPPOS, NRPOS	replaced by	new OPPOS, DPOS, NRPOS
ROTOR FLEXBEAM	old OPPOS, NRPOS	replaced by	new OPPOS, DPOS, NRPOS
removed reduced collocation point option of wing component			
ROTOR AERODYNAMICS	OPCOLL	deleted	
extended vortex core models			
ROTOR WAKE	OPCORE=0	replaced by	OPVCD=2
		new	WEXIN=1
	or wake extent Kxx	replaced by	Rxx (with WEXIN=2)
arbitrary number of rotors			
AIRFRAME STRUCTURE	RGEAR	replaced by	RGEAR(2)
AIRFRAME CONTROL	TCRnIN	replaced by	TCRIN(n)
	TCRn(i,j)	replaced by	TCR(i,j,n)
ROTOR INFLOW	KINTHR	replaced by	KINTHR(otherrotor)
	KINTFR	replaced by	KINTFR(otherrotor)

removed separate definition of number of integration points for rigid elements

ROTOR STRUCTURE	RINTEG	deleted	
ROTOR FLEXBEAM	RINTEG	deleted	

bearingless configuration, separate definition of inboard end of blade and snubber attachment to blade

ROTOR FLEXBEAM		new	EBLADE (= EROOT)

revise jobs with snubber modified using core input, since
shell now creates snubber interface at location and connection number 3 (not 1) of blade element

added extension-torsion as separate variable

ROTOR STRUCTURE		new	KT (= KP)
ROTOR FLEXBEAM		new	KT (= KP)
beam component (core input)		new	KT2 (= KP2)

simplified beam geometry definition

beam component (core input)	LPDEFN	deleted	
	JPDEFN	deleted	
	CPDEFN	deleted	

added new system piece, class = WEIGHTS (core input)

RESPONSE RIGID	WTCxxx, WTPxxx	replaced by	WTNAME
RESPONSE VARIABLE	WTCONV, WTPERT	replaced by	WTNAME, KINDWT

use defaults for weights and order reduction in variable response
(default TMRED=TNRED=FLRED=1, WTCONV=WTPERT=1.)

Previous Releases

CAMRAD II Release 4.6 was completed in May 2007. Release 4.6 incorporated the following additions and modifications to the analysis capability:

system
a) In linear system analysis, added alternate print of eigenvalues if too large for standard format.
b) Added percentages to data vector statistics.

components
a) In wake geometry components, revised distortion integration algorithm for improved accuracy; and removed young/elder distinction for velocity update.
b) Refined second-order lifting-line theory (three-quarter chord collocation point). In wake geometry components, calculated collocation points at both quarter chord and three-quarter chord. In wake components, collocation points on wing set at both quarter chord and three-quarter chord. In wing components, second-order lifting-line theory use three-quarter chord induced velocity for effective angle of attack. In rotorcraft shell, induced power obtained from quarter chord induced velocity.
c) In wing components, more robust identification of airfoil zero lift angle-of-attack.
d) In wake geometry components, corrected prescribed wake geometry for negative thrust.
e) Improved use of default names and labels in linear normal modes component.

shell
a) Added blade damper model.
b) Removed governor contribution to rotor control for fixed wings.
c) Added specification of number of tilting rotors for tiltrotor configuration.
d) Order reduction based on multiblade coordinates applied to swashplate degrees of freedom.
e) Included swashplate torque in total rotor torque for performance.

documentation
a) Updated description of loose coupling with CFD codes.
b) Clarified and expanded documentation, including description of standard atmosphere; notation for description of sensors of structural dynamic components; description of use of scenarios; use of rotor solidity value; description of drive train configuration with more than two rotors.

CAMRAD II Release 4.5 was completed in April 2006. Release 4.5 incorporated the following additions and modifications to the analysis capability:

<u>system</u>
a) Added multiblade coordinate and rotating-to-nonrotating transforms to trim part solution procedure, including rotorcraft shell option.
b) For case-to-case or job-to-job initialization, added transfer of trim loop derivative matrix.
c) Revised time history printer-plot procedure, including option for separate scales for quantities in sensor vector.
d) Improved description of options in interactive extraction by INPUT program, including plot shell data, draw core geometry, and extract airfoil parameters.
e) Improved description of graphics extraction by OUTPUT program, including color definitions for Tecplot formats.
f) Revised airfoil table generation by equations, for more robust code and documentation consistent with code.

<u>components</u>
a) For CFD component, added access to component input (controls) from solution subroutine CFDSOL.
b) In rotor performance component, added option to include rotor velocity effect in mean drag coefficient calculation.
c) Extended sensors of structural dynamics components, to include reaction load measured relative frame, and power relative frame.
d) In linear normal modes component, added scale factors on mode shapes used for forces in equations, and for evaluation of matrices; permitting one-way interaction by setting factor to zero.

<u>shell</u>
a) Added options for specification of trim quantities and variables, including hub force and moment and trim quantities of all rotors.
b) Added print of control matrices constructed by shell.
c) Option to use mean circulation separately for induced velocity and for wake geometry evaluation.
d) Added individual-blade-control, as actuator on pitch link joint.
e) Extended tip-path plane sensor options to include measure of gimbal or teeter motion.
f) Added blade reaction jet control (as applied forces on blade), including sensors and performance output.
g) Added rotor shaft spring and free rotation options.
h) Added CFD position sensors as input to CFD component.

documentation

a) Clarified description of shape files for structural elements in graphics and animation (Volumes IV, V, VI, VIII, chapter 3).

b) Clarified documentation. No blank lines in table format (Volume IV, chapter 43; Volume VI, chapter 26; Volume VII, section 3-2). Height above ground (Volume VI, chapters 9 and 10). Hub node for fixed wing (Volume VI, chapter 16). Number of beam element degrees of freedom (Volume V, chapter 9; Volume VI, chapter 20). Description of section axes (Volume III, figure 7-2b; Volume VI, figure 20-3; Volume VII, figure 8-1b).

CAMRAD II Release 4.4 was completed in April 2005. Release 4.4 incorporated the following additions and modifications to the analysis capability:

components

a) For wake and wake geometry components, added option to specify vortex core radius for entire tip trailed vorticity set (instead of for individual trailers).
b) Extended prescribed control component to allow prescribed time function to be the velocity or acceleration, integrated to obtain displacement.
c) Added option to define element names for degree of freedom and output vectors in differential equation component, transfer function component (only output), and programmable component (degree of freedom and first output vector).
d) For wing performance component, revised calculation of ideal velocity and power. For rotor performance component added wing parameters, including wing L/D. For rotorcraft performance component added aircraft L/D.
e) Revised CFD component to improve interface with CFD code (tight coupling).
f) For lifting line wing and rigid body wing components, added option to use prescribed load increments (in wing frame) for interface with external aeroacoustic analysis (instead of prescribed coefficient increments).
g) For lifting line wing, rigid body wing, and CFD components, added option to discretize load as force and moment at quarter chord (instead of forces at quarter chord and three-quarter chord).

shell

a) Added construction of autopilot for transient task.
b) In blade section load calculations, deleted options for only inertial or only applied load terms in force balance.
c) Added print of blade passage frequency. Added wing parameters to output, including wing L/D. Added aircraft L/D to output.
d) Improved check of trim quantities for cases with no aerodynamics.
e) Added option to calculate solidity from chord.
f) Extended fixed wing model, accounting for blade center of gravity offset from hub when calculate airframe center of gravity, and adding option to connect root to blade element at arbitrary radial station, possibly with pitch bearing.
g) Added requirement for pitch bearing to be inboard of pitch horn, and pitch bearing with control not available with swashplate mechanism.
h) Added option to suppress nonuniform inflow interference velocity separately at other rotors or airframe collocation points.

documentation

a) Expanded description of core input preparation in training manual (Volume VII, chapter 9).

b) For wing wake geometry component, added note regarding wake geometry extrapolation with consolidation, and revised description of initial wake convection option (Volume V, chapters 28 and 29; Volume VI, chapter 24).

c) Expanded description of parameters defining gimbal, flap and lag hinge, and locked joints in rotor structure input (Volume VI, chapter 20).

d) Clarified description of airframe and drive train modal analysis (Volume VI, chapters 10, 12, and 14).

CAMRAD II Release 4.3 was completed in February 2004. Release 4.3 incorporated the following additions and modifications to the analysis capability:

system

a) For response evaluation in trim task, added option to use full interaction of periodic parts, without check for inconsistent periods.
b) For Newton-Raphson and regulator trim loops, added scale factors for print of variables and controls.
c) Revised the equations used to calculate synthesized airfoil data for airfoil table (revised stall angle for moments).
d) Developed generic programs to extract data from CAMRAD II output file.
e) In OUTPUT program, added option to extract all azimuth angles and span stations of wing sensor, for polar or two-dimensional plot.
f) In INPUT and OUTPUT programs, extended export formats to include CAMRAD standard (space, tab, or comma delimiters); Tecplot; and Rotater (draw only).
g) In OUTPUT program, added Tecplot format for extraction of graphics and animation data.
h) In OUTPUT program, added capability to identify section from compact list, or by searching for string in title.

components

a) Extended differential equation component to include nonlinear transformation of output variables.
b) In programmable and helicopter tail boom components, allow definition of element names for degrees of freedom and output vectors.
c) Added more Euler angle sensors for structural dynamic and reference frame components.
d) Added weight (gravity force) or load factor sensor to structural dynamic components.
e) For finite element beam component, added option for section load by force balance to use just inertial or just applied loads.
f) In rigid airframe aerodynamics component, added constant terms to equations for aerodynamic loads.
g) In lifting line wing and rigid body wing components, extended prescribed coefficient increment (from external aeroacoustic analysis) to include M2c form.
h) For wing sensors, write units and additional definition to the plot file.
i) For wing wake geometry component, revised option for default of OPVCM, OPVCD, OPVCG.
j) For rotor inflow and rotor dynamic wake components, revised implementation of empirical factor for mean inflow.
k) For wing inflow and rotor inflow components, added lagged inflow model for transient and flutter tasks.
l) In rotor inflow component, added vortex ring state model, including character that leads to unstable flight dynamics in vortex ring state.

shell

a) For reference, calculate and print mean blade chord.
b) Changed default of trim tolerance.
c) Removed axial flow extended far wake model (still available using core input).
d) Calculate wake velocities off the rotor for the post trim solution.
e) Include input of swashplate mass and moment of inertia.
f) Added blade position sensors for a cfd interface.
g) Added swashplate node force and moment sensors.
h) Defined sensor for rotorcraft performance that measures all applied loads acting on the airframe component.
i) Option to use mean circulation and circulation peaks in induced velocity and wake geometry calculations, for improved circulation convergence in hover.
j) Added rotating hub frame.
k) Option to construct nonrotating wing (as rotor without rotation).
l) Option to construct rotor with unequal blade spacing.
m) Extended drive train model to include center engine configuration.
n) Extended tiltrotor configuration to symmetric or not, all rotors or just first two rotors tilt.
o) Extended symmetric transformation for flutter task to multirotor as well as tiltrotor configuration, for all rotors or just first two rotors.
p) Introduced option to obtain trim solution of rotors and airframe using common period with full interaction (not suppressing vibratory interaction at inconsistent period), specifically applicable to calculation of full main rotor and tail rotor interaction in trim.

documentation

a) Added note on positive direction of body axes for airframe aerodynamics (Volume 21, chapter 17).
b) Added note on origin of tail boom panels (Volume V, chapter 23; Volume VI, chapter 16).
c) Describe available functions of interactive INPUT and OUTPUT programs, including animation (Volumes IV, V, VI, and VIII, chapter 3; Volume VII, chapter 2).
d) Added note on use of inertial axis displacement instead of body axis velocity with airframe sensors (Volume VI, chapter 16).
e) For rigid airframe aerodynamics component, added note on dependent variables of two-dimensional tables (Volume V, chapter 21; Volume VI, chapter 17).
f) Added notes on setting OPCHLD with OPPART = 3, and about parameters required for dissimilar blades (Volume VI, chapters 10 and 24).
g) Added note on requirement for 1/rev solution in order to get nonrotating frame forces and moments acting on airframe (Volume VI, chapter 4).

h) Revised description of initialization from previous cases, using OPINIT of job namelist (Volume VI, chapter 8; Volume VII, chapters 2 and 8).
i) Notes regarding airfoil tables: Only airfoil tables prepared from source files or internally (Volume VII, chapters 2 and 3). Connection between span stations and airfoil decks (Volume VI, chapter 7). Extensions to original C81 format (Volume VI, chapter 26; Volume VII, chapter 3).
j) Revised training manual (Volume VII).

CAMRAD II Release 4.2 was completed in January 2003. Release 4.2 incorporated the following additions and modifications to the analysis capability:

system
a) Prepared Java program to create and edit CAMRAD II rotorcraft shell input. The program "CAMRADIIinput" and installation instructions are available from the Johnson Aeronautics web site.
b) Extended two-dimensional standard table format to include one-dimensional form: columns of dependent variables, with same independent variable values.
c) Revised main and machine-dependent routines for Windows or Macintosh operating system.

components
a) In wing wake geometry component, added specification of maximum number of near/far wake transitions, for reduced memory requirement.
b) In wing wake component, added option for internal calculation of influence coefficients (instead of component input/output), to reduce memory requirements.
c) For consolidation model in wing wake geometry component, added option for tip rollup at the edge rather than at the centroid (input weight to specify position between edge and centroid).
d) Added Euler angle sensor to structural dynamic components and reference frame component.
e) For structural dynamic components, extended definition of elastomeric spring/damper to include rate terms.

shell
a) Revised wake model for transient task to use internal calculation of influence coefficients, which reduces both memory requirements and computation time. Added option to use internal calculation in the trim task as well.

documentation
a) Added note regarding use of rigid wake geometry in trim with free wake geometry in transient (Volume VI, chapter 13).
b) For lifting line wing, added description of alternate stall delay method (Volume II, chapter 21).

CAMRAD II Release 4.1 was completed in February 2002. Release 4.1 incorporated the following additions and modifications to the analysis capability:

<u>system</u>
a) Added four-dimensional table.
b) For three-dimensional tables, added option for third variable to be cyclical.
c) Revised analysis of flutter equations, so residues calculated from modes rather than from zeros.
d) Added to the INPUT program the capability to extract airfoil characteristics from standard and C81 airfoil tables.

<u>components</u>
a) Created rotor dynamic wake component, implementing Peters and He unsteady, finite-state inflow model.
b) In rotor inflow component, improved calculation of inflow gradients produced by rotor velocity perturbations; added hover and forward flight values for factors in linear inflow gradient.
c) Revised wing and rotor inflow components, so in flutter or transient task with dynamic inflow, velocity direction is the instantaneous wing plane normal.
d) Added calculation of rotating rates in reference plane component. Tip plane rotation rates for linear inflow gradients included in rotor inflow component.
e) For airframe aerodynamic component, increased possible independent variables in tables, and added four-dimensional table option.
f) Added four-dimensional table option to gust component, and to gust input of wing wake geometry component.
g) In wing wake and wing wake geometry components, added option for input factor multiplying default values of sheet and near wake cores.
h) In wing components, added calculation of bound circulation centroid and radius of gyration data.
i) Added core radius term scaled with trailed vorticity moment to wing wake and wing wake geometry components.
j) Added trailed vortex line consolidation model to wing wake geometry component, as a simulation of tip vortex formation.

shell

a) Added dynamic wake option for uniform inflow (Peters and He inflow model).
b) Revised tiltrotor model to allow more than two rotors.
c) Added low speed wake scenario.
d) Revised post-trim solution of rotorcraft shell, so wake geometry frozen even with circulation loop (for improved convergence).
e) Added capability to use gust input in trim (to simulate aerodynamic interference).
f) Added simulated gimbal option for bearingless blade configurations.
g) For bearingless blade configuration, added option for snubber to connect blade (pitch-case) to flexbeam instead of to hub, allowing flexibility inboard of the snubber attachment.
h) Increased number of collocation points off rotor.

documentation

a) Added description of wake models, options, and scenarios (Volume VI, chapter 24).
b) Added notes about post trim (high resolution) calculations (Volume VI, chapter 10).
c) Added description of aerodynamic sensors (forces in section axes, wing frame axes, wing plane axes; Volume V, chapters 23 and 33, and Volume VI, chapter 22).
d) Added note about use of inertial axis displacement coordinates for rigid body degrees of freedom (Volume VI, chapter 10).
e) Improved description of radial stations for CAMRAD airfoil table, particularly for the search option (Volume IV, chapters 6 and 43; Volume VI, chapters 7 and 26).
f) Expanded description of tiltrotor geometry (Volume III, chapter 5; Volume VI, chapter 16).
g) Revised training manual (Volume VII).

CAMRAD II Release 4.0 was completed in November 2000. Release 4.0 incorporated the following additions and modifications to the analysis capability:

<u>system</u>
a) Developed plugin capability, allowing developers and users to add to the functionality of both the shell and components.
b) Defined limited edition, intended for university users and plugin developers.
c) Added relaxation of implicit equations to transient integration part.
d) Extended graphics and animation capability to include definition of solid shapes for wings and structural elements.
e) Added new table formats: class = UNSTRUCTURED, type = REAL or INTEGER.
f) Increased maximum size of standard airfoil table independent variables.
g) Added option to use tab as delimiter in all tables.
h) Added option to include stall delay in airfoil data extracted by INPUT program.

<u>components</u>
a) Extended wing wake geometry component ("general method" of shell) to include convection by gust velocities.
b) Extended sensor calculation of structural dynamic components, so motion and reaction loads are available in axes of a component frame or parent frame.

<u>shell</u>
a) Added relaxation of circulation to rotorcraft shell transient task (with no loops), which allows a converged solution to be obtained with nonuniform inflow (prescribed or free wake geometry). The solution procedure with wake and circulation loops (requiring much more computation time) need not be used now in most cases.
b) Revised rotor structural input so sign of STU, SVU, SVW, SWT in anisotropic beam model changed for core input of clockwise rotating rotor; thus shell input of identical counter-clockwise and clockwise rotating rotors does not require sign changes.
c) Revised use of the general free wake geometry so the solution can be obtained for just a subset of all rotors.
d) Revised so trim solution for airframe and drive train parts (time-invariant) obtained only for unique periods. Hence the rotors always see vibratory input from all other rotors of the same period.
e) Generalized the definition of the flutter period.

<u>documentation</u>
a) Added description of VTIPN usage by rotorcraft shell.
b) Added note about changing time step for graphics and animation output.

CAMRAD II Release 3.2 was completed in October 1999. Release 3.2 incorporated the following additions and modifications to the analysis capability:

system

a) Added graphics and animation capability, with the OUTPUT program reading data from the plot file and generating Mathematica® input files.
b) Added transient restart capability, with break/print/resume at specified time in integration part or specified iteration and level in loop; allowing review of progress of transient solution (transient calculation entirely specified by initial job).
c) Extended aerodynamic environment to include stratosphere; and added option to input density, speed of sound, and viscosity (for easier modelling of fluids other than air).
d) Revised constraint equation for cantilever interfaces with forces in connection axes (to improve convergence for rotors with a gimbal or teeter hinge).
e) Added to modes piece a default for structural damping of higher modes.
f) Added capability in harmonic trim part to filter degrees of freedom, by ignoring equations and setting harmonics of degrees of freedom to zero when solve equations (used for simulated gimbal/teeter hinge).
g) Added capability in harmonic and time finite element trim parts to identify child degrees of freedom; setting child motion to parent motion, with a phase shift, after solve dynamic degrees of freedom (used for shell solution of all blades).

components

a) To improve handling of sideward flight, revised rigid airframe aerodynamics component so forces can be in body axes, and a pitch-then-yaw definition of angle-of-attack and sideslip angle can be used (wind axes and yaw-then-pitch are the conventional definitions).
b) Deleted residual option of linear normal modes component (led to recursive subroutine calls).
c) Extended spring/damper model of structural dynamic components, so table can depend on switch parameter (element of component input, or time); allowing more complex behavior, including change of properties during transient.
d) Added option for finite element beam component to calculate force balance load at beam axis as well as at tension center.

wing components

a) Added static stall delay factors (useful for wind turbines and tiltrotors).
b) Added separate lift-curve slope factor for flap terms in unsteady loads.
c) Added separate tip loss factors for steady, unsteady, and dynamic stall terms of lift and moment (core input only).

wing wake geometry component
a) Extended wing wake geometry component ("general method" of shell) to include airframe flow field influence, using simple model (wings and bodies) of airframe flow field component.

shell
a) Added option for simulated gimbal/teeter hinge; consisting of flap hinge at center of rotation, filtered in trim solution so only pN±1 harmonics are nonzero, and only teeter or tip-path plane tilt degrees of freedom in flutter solution; approximate model for better convergence and computation time.
b) Added option to enforce identical motion of blades, including filtering the harmonics of the gimbal/teeter motion, when solve all blades together; for better convergence.
c) Added option to calculate blade torsion moments at beam axis (instead of at tension center) for nodal reaction or force balance; new default is torsion moments at beam axis.
d) Added option for position and mode sensors on reference line as well as on beam axis.
e) Added specification of maximum span station for peak bound circulation.
f) Included gimbal motion in position sensors for flutter task.
g) Revised INPUT program to extract aerodynamic geometry at input radial stations.
h) Added power sensor for trailing-edge flap.
i) Added specification of dimensional flight and wind speed.
j) Added pitch angle of flap and lag hinges.
k) Added check that solve all blades when gimbal or teeter hinge used.
l) Added option for tip-path plane sensor to be on flexbeam for bearingless configuration.
m) Revised modal structural damping so last value used for all higher modes.
n) Deleted transient solution procedure option with motion loop and separate airframe and rotor integration parts.
o) Corrected errors in definition of prescribed trailing-edge flap motion; and construction of hinges at zero radial station.

documentation
a) Added table describing input conventions for rotor geometry (Volume VI, chapter 20).
b) Added figure describing cfd interface (Volume II, chapter 33).
c) Added note on sign convention of flap airfoil coefficients (Volume I, chapter 24).
d) Added description of shell transient solution procedure without wake and circulation loops, applied to cases with vortex wake model (Volume III, chapter 10; Volume VI, chapter 12).

CAMRAD II Release 3.1 was completed in August 1998. Release 3.1 incorporated the following additions and modifications to the analysis capability:

system
a) Added option in transient integration part to set acceleration to zero for first-order states (states with no mass).
b) For successive substitution iteration (trim loop or transient loop), added option for parameters to depend on level of another loop; and option to skip any level except last. Extended rotorcraft shell so relaxation factor of circulation loop depends on wake loop level; and so wake loop can skip any level except last.

components
a) Added option for strictly proper output equations (output depend only on degrees of freedom, not on control) for differential equation and programmable components.
b) Created computational fluid dynamics component. Added cfd level to rotorcraft shell. To provide initialization of the cfd solution, added to trim differential equation parts the option to evaluate implicit equations before the solution starts. This component will allow user-supplied cfd analyses to be directly coupled with the structural dynamic analyses of CAMRAD II.

wing components
a) Revised, updated, and corrected the dynamic stall models.
For the Johnson model, improved the initial calculation of the time since dynamic stall occurred, t_{DS}.
For the Leishman-Beddoes model, improved the initial calculation of the time since dynamic stall occurred, t_{DS}; and added the magnitude of Δc_{mDS} as an input (new variable x_s in the dynamic stall table).
For the ONERA EDLIN model, revised the implementation of the stall delay; and added an extra moment term for the refined transition model (new variable μ in the dynamic stall table).
For the ONERA BH model, added lift and moment terms from first-order differential equations (new variables λ_{0L} and λ_{0M} in the dynamic stall table).
b) Added parameters to directly change drag and maximum lift (useful for tiltrotor hover analysis).
c) Revised swept flow correction.
d) Revised reference option so specified separately for each sensor.

wake and wake geometry components

a) Added identification of primary ("tip") and secondary trailed vortices; for use in distortion calculation, core size, and vortex formation (initial radial station and initial vertical convection).

b) Improved free wake geometry calculation, with emphasis on hover. Revised hover wake scenarios.

c) Added capability to specify the initial tip vortex span station in the wake geometry (input; or Betz rollup for wing wake geometry component).

d) Revised wing wake geometry component so use distorted geometry of each structure to determine its convection velocity for extrapolation (instead of using the average convection velocity of all structures).

e) Added option in wing wake geometry component for wings of a subset (e.g. wings of one rotor) to have identical distortion in trim (with phase shift).

shell

a) Extended options for trailing-edge flap, to include multiple flaps per blade, and prescribed flap motion with or without inertial reactions.

b) Added output harmonic analysis option.

c) Added trim part harmonic analysis option.

d) Extended conventions to allow arbitrary tip radial station (blade radius then just a reference length).

CAMRAD II Release 3.0 was completed in August 1997. Release 3.0 incorporated the following additions and modifications to the analysis capability:

<u>system</u>
a) extended specification of gravity direction and magnitude
b) extended specification of ground plane orientation
c) revised system to allow transient or flutter task execution to follow trim initialization (trim solution initialized from previous case or job)

<u>components</u>
a) airframe flow field: added planetary ellipsoid
b) rotor inflow: added effect of rotor disk pitch and roll rates
c) structural dynamic: added rotational displacement sensor (used now for blade pitch position sensor)
d) beam: improved calculation of section load by force balance method

<u>lifting line wing</u>
a) revised yawed flow correction
b) extended models for unsteady loads: incompressible, ONERA EDLIN, Leishman-Beddoes
c) extended dynamic stall models: Johnson, Boeing, Leishman-Beddoes, ONERA EDLIN, ONERA BH (all models still use airfoil tables for static loads)
d) input program identifies some dynamic stall parameters from static airfoil tables

<u>wake and wake geometry</u>
a) hover free wake geometry
b) added initial convection and rotor prescribed model to wing wake geometry component (and to Johnson model of rotor wake geometry component)
c) revised extrapolation in free wake, for improved convergence
d) ground effect
e) revised calculation of velocity from vortex line, for better accuracy with small segments

<u>shell</u>
a) slung loads
b) option to suppress nonuniform inflow calculation of rotor-to-airframe interference
c) default wake model changed to single peak case, using maximum circulation
d) lumped masses (noncompact) on blade and flexbeam, as well as point masses
e) option for bearingless rotor snubber axes to rotate with blade, instead of fixed to hub

CAMRAD II Release 2.0 was completed in August 1996. Release 2.0 incorporated the following additions and modifications to the analysis capability:

<u>error handling</u>
a) improved error messages
b) when using the INPUT program interactively, no error messages about tables not present
c) improved error handling for tables identified and read by analysis
d) always exit when run out of space in data vector, with better error message
e) always exit on most batch file open errors
f) check names of shell input blocks
g) changed some error messages to warnings

<u>rotorcraft shell</u>
a) arbitrary number of rotors
b) increased maximum number of point masses
c) added specification of range of rigid structure for blade and flexbeam
d) removed separate definition of number of integration points for rigid elements
e) option to specify wake extent in terms of wake revs
f) for blade modes, option to exclude joints and flexbeam from mode set
g) added shaft torque and power, and rotor speed, to hub load sensors
h) when solve for all blades, get aerodynamic sensors for all blades
i) extended definition of radial stations for blade position and blade mode sensors, including common definition and user-defined stations
j) added drive train motion and loads sensors
k) implemented modal analysis for airframe and for drive train, with modal sensors

<u>bearingless configuration:</u>
l) separate definition of inboard end of blade and snubber attachment to blade
m) revised blade load calculation from nodal reaction at flexbeam node, so load outboard of node is sum of blade and flexbeam loads inboard of node
n) point masses on flexbeam

<u>for improved convergence of bearingless rotor:</u>
o) revised identification of "pitch" degree of freedom eliminated by pitch-horn/pitch-link constraint, so find elastic torsion degree of freedom of softest element inboard of pitch horn (single load path) or of softest element of flexbeam (bearingless); print "pitch" degree of freedom identified

system
a) deliverable version without low level error tests; for sample cases, 15.5% less cpu time than development version
b) added variable identifying modification or revision within a release; defined by analysis administrator in main programs; printed in header
c) added print of total number of iterations for each loop and part
d) added new system piece, class = WEIGHTS, to generate standard weights for perturbation and convergence of response; shell defines WEIGHTS pieces for each rotor (so second rotor has appropriate weights); added defaults in response input data for weights and order reduction
e) plot and draw in INPUT and OUTPUT programs handle arbitrary number of points
f) corrected response and solution procedures for consistent use of negative rotational speed value from period; revised shell to include option for negative tip speed
g) added capability to initialize trim solution from previous job; revised shell to allow only one level in wake loop
h) for better numerical conditioning of structural dynamic problems: double precision in mathematical utilities for matrix inversion, eigenanalysis, and modal analysis; introduced second eigenanalysis method

transient task
a) implementation of integration algorithm revised for better numerical precision
b) option to use double precision
c) improved convergence by allowing update of matrices relative current transient solution

components
a) rotor inflow component: revised inflow model in turbulent wake/vortex ring states, and with ducted fan; added print of inflow state data
b) wing wake and wing wake geometry components: extended vortex core models (vorticity distribution and radius growth)
c) improved programmable and helicopter tail boom components, including definition of variables and error handling
d) lifting line wing component: removed reduced collocation point option

lifting line wing component
a) extended trailing-edge flap model for full coupling with structural dynamics; including flap lift, drag, and moment loads; and unsteady aerodynamic loads produced by flap motion
b) shell defines structural dynamic component for flap (with control, inertia, stiffness)
c) trailing-edge flap added to airfoil tables

finite element beam component

a) added extension-torsion coupling as separate variable
b) composite/anisotropic materials as well as isotropic
c) geometrically exact elastic motion (large motion, small strain) as well as second order; and almost exact (extension and torsion produced by bending still second order); rigid motion always exact
d) section load by force balance method as well as displacement method and nodal reaction

documentation

a) added figures showing geometry of blade input parameters
b) revised input and training manuals to include recent experience
c) added more information on modifying the system using core input

graphics

a) CAMRAD Plot and CAMRAD Draw programs have been developed: 2D and 3D plot capability, for Macintosh

CAMRAD II Release 1.2 was completed in December 1994. Release 1.2 incorporated the following additions and modifications to the analysis capability:

a) Wing wake geometry model: general free distortion calculation.
b) Wing wake model: multiple far wake rollup; entrainment and stretching model in tip vortex rollup process.
c) Two-sided perturbation identification of derivative matrices in trim loops and parts that utilize Newton-Raphson iteration.
d) Differential momentum theory added to rotor inflow model.
e) More general gust models, including gust field from tables.
f) Include ground boundary layer in wind.
g) Random time history and general time history from table added to prescribed control.
h) Structural dynamic components: spring/damper reaction from table.
i) Added autogyro and wind turbine performance indices.
j) Improved interactive input program.
k) Improved initialization of solution from previous case.
l) Revised tables for arbitrary size of arrays, arbitrary length and uniform increments of independent variables.
m) Variable added to namelists for use as comment among input data.

CAMRAD II Release 1.1 was completed in February 1994. Release 1.1 incorporated the following additions and modifications to the analysis capability:

a) Extended use of 3D tables in rigid airframe aerodynamic component.
b) Improved analysis of linear differential equations for flutter task.
c) Constructed programmable component.
d) Constructed helicopter tail boom component.
e) Extended uniform inflow model to include ducted fan.
f) Wing model: generalized wing reference line.
g) Wing model: trailing edge flap characteristics from tables.
h) Wing model: table of prescribed coefficient increments from external aeroacoustic analysis.
i) Wake model: partial induced velocity calculation for external aeroacoustic analysis.
j) Wake model: additional trim loop for high-resolution aerodynamics and partial angle-of-attack.
k) Extended recursive identification in trim loops.
l) HHT numerical integration in transient part.
m) Improved initialization at start of transient.
n) Constructed trim part for time-domain finite element solution (harmonic shape functions).

CAMRAD II Release 1.0 was completed in July 1993.

CAMRAD II Customer Support

Support of CAMRAD II use and applications is provided by Johnson Aeronautics. Contact Wayne Johnson at:

voice: 650-325-3944
email: JohnsonAer@aol.com

Support for installation of CAMRAD II is provided by Analytical Methods, Inc. Contact Osamu Yamamoto at:

voice: 425-643-9090
fax: 425-746-1299
email: osamu@amiwest.com

Applications of CAMRAD II to specific customer projects are available by special arrangement from Analytical Methods, Inc.

CAMRAD II Web Site

Information regarding CAMRAD II can be obtained from the Johnson Aeronautics web site: www.Johnson-Aeronautics.com or www.CAMRAD.com. This site includes a description of the CAMRAD II software, images from calculations (QuickTime movies), and papers written about the CAMRAD II models and applications.

A page at the Johnson Aeronautics web site (/CAMRADIIcustomers.html) provides information intended solely for CAMRAD II customers, including:

printable, searchable copies of the documentation (Volumes I through XI, in pdf form)

the input for the sample cases

the documentation and input for the demonstrations of core input, and other examples

the Java program to create and edit rotorcraft shell input

this newsletter

Source Code for All Customers

The following files contain CAMRAD II source code that is available to all customers.

Main Programs: CAMRADII, INPUT, OUTPUT.

Draw/Plot Utilities: FILEXD, FILEXP, FILEXA (interactive write of extracted draw and plot data to a file).

Programmable Component: UPGMxx.

Helicopter Tail Boom Component: UHTBxx.

Computation Fluid Dynamics Component: CFDxxx in file UCAD.

Plugin Component: YPLGxx.

Source code for the entire system is available under license.

CAMRAD II Sample Input

CAMRAD II sample cases include the following files: namelist input, input command procedures, airfoil command procedures, and command procedures for the sample jobs. The command procedures are available for UNIX/LINUX and for HP OpenVMS. The following files of namelist input provide typical input:

ZFREQUENCY.LIST: Blade frequency calculation.

ZHOVER.LIST: Hover Analysis.

ZSIMPLE.LIST: Simplified models.

ZTEMPLATE.LIST: Template for preparation of CAMRAD II input.

ZWINDTUNNEL.LIST: Conversion of forward flight case to single rotor in wind tunnel.

These files are documented in the training manual. In addition, a script to use the INPUT program to extract the blade planform from a shell input file is provided in the file ZPLANFORM.COM.

The sample cases provide a basis for comparing computation time on different computers. The eleven jobs require a total of 0.25 hours on the fastest system at Johnson Aeronautics (CAMRAD II deliverable version).

CAMRAD II Examples

A number of examples of CAMRAD II tasks are provided in the "extras" folder, including the following files.

AEROACOUSTIC.COM
External aeroacoustic analysis, using post-trim and partial angle of attack. First CAMRAD II is run to generate partial angle of attack in post-trim analysis, perhaps with higher azimuth resolution. Then an external aeroacoustic analysis is run (input = partial angle of attack, output = airloads); a prescribed lift coefficient increment is obtained from these airloads. Then run CAMRAD II with prescribed lift coefficient increment. Uses file AEROACOUSTIC_PRESC_COEFF.2STD as simulated output from external aeroacoustic analysis.

ANIMATE.COM, ANIMATE_EXTRACT_M.COM, ANIMATE_EXTRACT_T.COM
Demonstration of graphics generation. First a plot file is produced, then the output program extracts the data from the plot file and produces input files for Mathematica® or Tecplot.

EXTRACT.FOR, EXTRACT_SUB.FOR
Generic programs to extract data from the CAMRAD II output file.

FIXEDWING.COM
Nonrotating lifting-line wing.

FROZENWAKEGEOM.TXT
Freeze the wake geometry for a second case or second job.

GENERICWT.LIST, GENERICWT.COM
Generic wind turbine input, frequency calculation, and performance calculation.

IBC.COM
Individual blade control, with and without swashplate model.

INTERBLADE.COM
Interblade damper. Uses input files EXINPUT.COM, EXAIRFRAME.LIST, EXMAINROTOR.LIST, EXTAILROTOR.LIST.

LAGDAMPER.COM
Linear lag damper; true load path, replacing angular damper about hinge.

TEFLAP.COM
Demonstration of trailing-edge flap. Cases include no flap (reference); one flap, with structural dynamics of flap; two flaps, with and without structural dynamics of flap. Uses NACA0012_ZEROFLAP.COM for airfoil file.

TEFLAPBEAM.COM
Elastic beams for flap structure.

TPP_SENSOR.COM
Tip-path plane sensors for bearingless rotor (flap bending moment on flexbeam); hingeless rotor (flap bending moment at blade root); teetering rotor (teeter hinge angle); gimballed rotor (gimbal hinge angle).

TRAN_AUTOPILOT.COM
Autopilot for transient task.

TRAN_PRESCRIBED.LIST
Prescribed airframe motion for transient task in wind tunnel.

TRIMOPTIONS.COM
Core input to revise trim loop: trim to C_T/σ and flapping (shell option); trim to thrust and hub moment; input derivative matrix.

Demonstrations of Core Input

The following documents are available, illustrating the use of core input to modify the model constructed by the rotorcraft shell. The namelist and command files required to perform the examples in these documents are provided with the software.

Demonstration of Tiltrotor Analysis Using CAMRAD II (January 1996). The construction of an elastic cantilever wing using core components is demonstrated, replacing the normal modes representation of the rotor support that is used by the rotorcraft shell.

namelist files: YTRINPUT.COM, YTRINPUT1.LIST, YTRINPUTW.LIST
job file: YTILTROTOR.COM

Demonstration of Bearingless Rotor Analysis Using CAMRAD II (January 1996). The use of core components to construct a snubber-damper with axes following the blade pitch is demonstrated, replacing the snubber with axes fixed to the hub that is used by the rotorcraft shell.

namelist files: YBINPUT.COM, YBINPUT.LIST, YBINPUTMODA.LIST, YBINPUTMODB.LIST
job file: YBEARINGLESS.COM

Demonstration of Closed-Loop HHC Analysis Using CAMRAD II (January 1996). The completion of the regulator using core input is demonstrated, including construction of filters to obtain harmonic loads for the feedback system.

namelist files: YHHCINPUT.COM, YHHCINPUT.LIST
job files: YHHC.COM, YFLAPCON.COM, YHUBCON.COM

Demonstration of Pendulum Absorber Analysis using CAMRAD II (January 1996). The use of core components to construct a flapwise pendulum absorber is demonstrated.

namelist files: YPENINPUT.COM, YPENINPUT.LIST
job file: YPENDULUM.COM

Papers on CAMRAD II

The following papers describing the CAMRAD II models and applications have been published. An extensive list of papers that have been written by various authors on CAMRAD II, CAMRAD/JA, and CAMRAD is available from the Johnson Aeronautics web site.

"Technology Drivers in the Development of CAMRAD II," by Wayne Johnson. Presented at the American Helicopter Society Aeromechanics Specialists Conference, San Francisco, California, January 1994.

Abstract: Technology drivers in the development of the comprehensive helicopter analysis CAMRAD II are reviewed. The issues discussed include flexibility of configuration model and solution procedure; expandability; mathematical model of kinematics, dynamics, and response; transportability; ease of use and productivity; and demonstrated capability.

"Rotorcraft Aeromechanics Applications of a Comprehensive Analysis," by Wayne Johnson. Presented at Heli Japan 98: AHS International Meeting on Advanced Rotorcraft Technology and Disaster Relief, Japan, April 1998.

Results from the comprehensive analysis CAMRAD II are presented, illustrating recent developments in the aerodynamics and dynamics models, and demonstrating the technology that is needed for an adequate calculation of rotorcraft behavior. Calculations of rotor performance, airloads, structural loads, and stability are presented, including comparisons with experimental data.

"A General Free Wake Geometry Calculation For Wings and Rotors," by Wayne Johnson. Presented at the American Helicopter Society Forum, Fort Worth, Texas, May 1995.

Abstract: A general free wake geometry calculation for wings and rotors is presented. The method, which has been implemented in CAMRAD II, gives good performance and airloads correlation at advance ratios of 0.05 and above, with reasonable computation speed. The wake geometry distortion can be calculated for multiple wings, multiple rotors, and non-identical blades; for all wake structures, including multiple rolled-up trailed vorticity and inboard sheets as well as tip vortices; using the same wake model as the induced velocity calculations; for transients as well as the trim solution. The theoretical

approach is described. Results are presented for rotor airloads, flapping, and performance, including comparisons with a common wake geometry method and with measured data. Calculated wake geometries are shown for a nonrotating wing, a single rotor, multiple main rotors, and a wind turbine.

"Rotorcraft Dynamics Models for a Comprehensive Analysis," by Wayne Johnson. Presented at the American Helicopter Society Forum, Washington, D.C., May 1998.

Recent developments of the dynamics models for the comprehensive analysis CAMRAD II are described, specifically advanced models of the geometry and material for the beam component, and a force balance method for calculating section loads. Calculations are compared with measurements for beams undergoing large deflection. Bearingless rotor stability and bending loads calculations are compared with the results from a full-scale wind tunnel test. With a reasonable number of beam elements representing the rotor blade, any large deflection effects are captured by the rigid body motion (which is always exact), and a second-order model of the beam element elastic motion is adequate. The deflection method gives unacceptable results for the structural loads in practical cases, and even with uniform blade properties. The force balance method described here gives good results for blade load, without requiring a large number of nodes.

"Rotorcraft Aerodynamics Models for a Comprehensive Analysis," by Wayne Johnson. Presented at the American Helicopter Society Forum, Washington, D.C., May 1998.

Recent developments of the aerodynamics models for the comprehensive analysis CAMRAD II are described, particularly the unsteady aerodynamic models and dynamic stall models, and the free wake geometry calculation. Three models for the unsteady aerodynamic loads in attached flow are implemented: from incompressible thin-airfoil theory, from ONERA EDLIN, and from Leishman-Beddoes. Five dynamic stall models are implemented: from Johnson, Boeing, Leishman-Beddoes, ONERA EDLIN, and ONERA BH. A key feature of the implementation of these models is revisions allowing the retention of airfoil tables for static loads in all cases. Results are presented for a two-dimensional airfoil, a three-dimensional wing, and rotors. Extensions of the CAMRAD II free wake method to include hover and ground effect are described, including hover performance correlation.