1-1-1992

A Generic Blade-Element Simulation Library Based On The Genhel Model: Final Report On The BERMADA Rotor Model Project

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December 1992

A GENERIC BLADE -ELEMENT SIMULATION LIBRARY BASED ON THE FEN HEL MODEL (THE FINAL REPORT ON THE BERMADA ROTOR MODEL PROJECT)

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IST-TR-92-35

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Prepared for Loral
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Section I. The Reusable Library Module Routines

A main purpose of this project was to design and construct a set of reusable mathematical routines which amount to a general-purpose library to implement blade-element rotor math models for helicopters. This library is also referred to as "the low-level modules" since they form the mathematical basis of the blade-element model. The design guidelines were as follows:

- Be independent of a specific simulation data structure
- Follow the Sikorsky document for the *GenHel* (Generic Helicopter) math model.
- Be general in nature – not specific to the BlackHawk helicopter.
- Do functions using a consistent, matrix & vector algebra approach.

The intermediate states created during the execution of a single cycle of the math model are listed in Appendix A. Several exceptions to this rule are discussed in the section. Along with each state is listed the library routine number which matches the description of the routine in the design document and a unique index enumerating each state value. For example, the "rotor_filter_moments" are given the state #85 and are calculated by the library routine "1.2.14.4".

Section II. The Summation Modules

There are six modules in the design document which are not "low level" modules, but instead, sum up results from a collection of low level modules. For these operations, a data structure is required since both the pre-summed values and the summation results must be stored for later use. The delivered summation modules are in the package Loral Executive Functions and make reference to the data structure entitled Loral Data Structure.

The data structure design was created at the request of Loral as a modification of a previous data structure used in the debug phase of the project (which did not conform to their simulation approach). The Loral Data Structure design supports the abstraction of the states of major portions of the helicopter rotor. For example, a record of states exists for each blade, each hinge, and the rotor hub, among others. When possible, values common to all objects of a certain type (i.e. segment, hub) are contained in the *state* portion of the object while values unique to this particular instance of an object type are contained in the *configuration* portion of the object.

The summation modules along with their state variable number:

100 Find_Main_Rotor_Forces_In_Hub_Axis
101 Find_Aero_Shears_Per_Blade_In_Span_Axis
102 Find_Total_Aero_Shear_Forces_For_Dynamic_Twist
103 Find_Total_Aero_Shear_Forces
104 Find_Total_Aero_Moments_Wrt_Hinge_In_Blade_Span
105 Find_Rotor_Hub_Moments_In_Hub_Axis

The numbers associated with these modules may occur in other documents as their identification. The module numbers have been used in development as opposed to the module names as the names are sometimes cumbersome.

Section III. Aerodynamic Coupling Issues

After the initial specification for the library modules was completed, we investigated the issues of how the modules would be threaded in an actual, aerodynamically-correct simulation. Simply expressed, over eighty modules had been specified and then coded in Ada. These modules represented operations necessary for the implementation of almost any blade-element rotor model.

Since we based the module design on both the Sikorsky document and a working GenHel simulation written at NASA, we contacted the simulation's author. He informed us of some critical issues on which he'd spent much time:

- Sikorsky integration essential. It works much better than conventional integration routines.
- His implementation worked with integration intervals up to 36 degrees of rotor rotation. Between 6 degrees and 10 degrees was the optimal interval size.
- Quantization error and system oscillation had to be eliminated by careful hand adjustment of the equations – particularly in the lag damper model.
- The lag damper on the Blackhawk helicopter responds in a very non-linear fashion and was difficult to model. Much effort was put into the math model for the GenHel simulation. When reimplementing the model, this area will need to be "re-tuned" to eliminate oscillation.
- The delta moment terms were simplified for run-time performance. These terms are currently being reviewed by others at NASA besides the author.
- When integrations were performed (relative to the other calculations) was experimentally changed to find the best result.

Section IV. Cross-Referencing to Find The Order

Since we knew that the aerodynamics in the model were complex, we needed to have a way of determining the correct "firing order" of the modules. This could not directly follow the GenHel simulation since the library modules were general in nature – not mapping one-to-one with the GenHel simulation's equations.

A cross reference was constructed by pattern matching the names of input and output variables from each routine. The *Module Parameters* document, shown in Appendix C, provided the system-at-a-glance view – listing all the input and output parameters for each library module. The

Module Parameters document was scanned by custom-developed parsing software to create a cross reference. The result is shown in Appendix D.

Once the cross reference was complete, it was used to construct *Dependency Graphs* of the aerodynamic states. The organization of the graphs conforms to the following rules:

1. Each node corresponds to a particular state variable produced by one of the low-level modules.

2. To perform the calculations for the state variable at a particular node in the graph requires that all state variables corresponding to each of the node's children have already been calculated during this simulation step. Therefore, the graph must be calculated in a bottom-up fashion with all child nodes being calculated before their parents.

3. There is no restriction on calculation order between nodes on the same level of the graph.

Examples of several dependency graphs are included in Appendix E.

Section V. Parallel Threading of the Library Modules

At first, armed with the cross reference and the dependency graphs, we began to develop a sequential order for the modules. This quickly became overwhelming since the number of assumptions of which states had already been computed became unmanageable. Keeping track of what has been called and what has not was very tedious

The parallel threading of the library modules was proposed in response to the complexity of the interdependencies of the rotor library modules. By using a parallel threading scheme, the rotor library modules were able to be run and tested for correctness while the calling order could be changed dramatically with simple changes in the code.

The parallel execution order program was comprised of a series of Ada tasks. Each task contained:

1. Calls to the tasks responsible for any children below the current node in the dependency graph.

2. A call to the single low-level library function which calculates the state variable the task is responsible for.

Using this paradigm, a task must be created for each intermediate state of any portion of the rotor model. Once the task has run once, subsequent calls to it in the same simulation cycle do not recalculate its value. Every module that is needed is called, but those modules which have already been called are not actually recomputed. This scheme allows for the maximum parallelism with the rotor library as the degree of granularity. A simplified example is presented in the pseudocode below:

```
Task Task5 is   (task for calculating the value of State #5)
  ENTRY calc IS
      IF not called before during this cycle THEN
        – set called flag for reference in future calls this cycle
        called := TRUE;
        – calculate state value. It depends on states 6 and 7
        task6.calc;
        task7.calc;
        DataStruct.state5 := DataStruct.state6 + DataStruct.state7;
      ENDIF
  END calc
  ENTRY Reset IS
        called := FALSE;
  END Reset
END Task5;
```

In the above example, the task shown is for the computation of state #5 in the data structure. The expression for calculating state #5's value uses states #6 and #7. Therefore, a call is made to the tasks responsible for calculating their values. Task6 or Task7 may have their own dependencies, but this is abstracted from Task5. This abstraction allows all tasks in the parallel threading to consider only their immediate children in the dependency graph – yielding a very simple, consistent system implementation.

For each parallel or partially-parallel design, a tradeoff must be made in the data structure ("Are duplicate storage locations for each parallel computation needed?"). For the parallel threading developed on this project, we decided to allow the highest degree of potential parallelism. Duplicate data structure locations exist for each blade, and each data structure entry has a task to calculate it's value. If there were *NumOfBlades* number of calls required to a module (one call for each different blade), then there were *NumOfBlades* number of tasks created so that each call had its own task and each task stores results in it's separate data structure location.

Once the parallel executive was complete, it was used as a tool to to resolve the dependencies. By using the output of the parallel execution which tracked when each module was actually called, it was a simple task to generate a serial executive with an assurance that there were no conflicts of a variables being used before their associative generating module was actually called.

Section VI. Sequential Threading of the Library Modules

The sequential threading of the rotor library modules was first attempted immediately after the library modules were written. However, the complexity of the task was high and the probability of error was equally high, so the writing of a serial execution order was postponed until after the completion of the parallel execution was accomplished.

The serial execution order was determined by taking the output of the parallel execution order and finding the loops and redundancies and making them into procedure calls or for loops in the serial executive. When there was a slight change in the parallel calling order (1 module), the apparent change in the serial execution order was drastic. This was a confirmation that many different possible calling orders for the serial execution existed. Therefore, using the "firing order" from the parallel execution to determine the calling order in the serial execution proved to be a very useful technique. The serial execution order is listed in Appendix A.

Appendix A - Sequential Ordering

The following is a list of the serial execution of the rotor library routines. The underlying data structure is not given or implied, only the actual modules that, at each stage, must be called to insure a proper execution order are listed. Proper execution order is determined by the following criteria:

- For each routine in a simulation cycle, the input variables necessary for its execution have already been generated during the current time cycle.

The following is pseudo-Ada as references to objects (a particular blade and segment) actually mean that the particular data item (i.e. blade #3) must be calculated and stored for later use. Each line starting with "find_" and matching the name of a low-level module indicates simply that this low-level module must now be run. The low-level module's output will be stored in a data structure now shown in this example. Therefore, this code only indicates the proper ordering, it is not a final, compilable serial "executive" for the blade-element rotor math model.

```
procedure blade_calculations;
procedure segment_calculations;

procedure computations is
begin
  find_hub_to_body_xform_matrix ;
  find_vel_of_sound ;
  find_hub_vel_in_body_axis ;
  find_hub_vel_in_hub_axis ;
  find_centrifugal_acc_of_hub ;
  find_gust_acc_of_hub ;
  find_tangential_acc_of_hub ;
  find_hub_acc_in_body_axis ;
  for i in 1 .. Number_Of_Blades
        blade_calculations(i);
  end for;
  find_main_rotor_forces_in_hub_axis ;
  find_main_rotor_filtered_forces ;
  find_main_rotor_force_in_body_axis ;

  -- moment calculations
  for i in 1 .. Number_Of_Blades
```

```
        find_flapping_moments_due_to_flap_damper (blade_number)
        find_flapping_moments_due_to_lag_damper (blade_number)
        find_lag_damper_displacement (blade_number)
        find_lag_damper_force (blade_number)
        find_lagging_moments_due_to_flap_damper (blade_number)
        find_lagging_moments_due_to_lag_damper (blade_number)
        find_delta_moments (blade_number)
  end for;

  find_total_aero_moments_in_hub_axis ;
  find_rotor_filtered_moments ;
  find_rotor_hub_moments_in_body_axis ;

end computations;


procedure blade_calculations (blade_number:integer) is
begin
  find_rot_shaft_to_hub_xform_matrix (blade_number)
  find_blade_span_to_rot_shaft_xform_matrix (blade_number)
  find_blade_lag_angle_xform_matrix (blade_number)
  find_blade_flap_angle_xform_matrix (blade_number)
  find_vel_vector_to_segment_xform_matrix (blade_number)
  find_rot_shaft_vel (blade_number)
  find_body_vel_in_blade_span (blade_number)
  find_hub_rates_in_rot_shaft (blade_number)
  find_ang_vel_of_hinge_wrt_hub (blade_number)
  find_abs_ang_vel_of_hinge_in_rot_shaft (blade_number)
  find_hinge_vel_in_rot_shaft (blade_number)
  find_hinge_vel_in_blade_span (blade_number)
  find_hub_rates_in_blade_span (blade_number)
  for i in 1 .. Number_Of_Segments
       segment_calculations(blade_number, i)
  end for;
  find_aero_shears_per_blade_in_span_axis (blade_number)
  find_aero_shear_per_blade_in_rot_shaft (blade_number)
  find_time_drv_of_lag_xform_matrix_in_rot_shaft (blade_number)
  find_ang_acc_of_blade_wrt_hinge_in_rot_shaft (blade_number)
  find_ang_acc_of_hub_in_rot_shaft (blade_number)
  find_ang_acc_of_hinge_wrt_hub (blade_number)
  find_abs_ang_acc_of_hinge_in_rot_shaft (blade_number)
  find_ang_vel_of_blade_wrt_hinge_in_rot_shaft (blade_number)
  find_abs_ang_acc_of_blade_in_rot_shaft (blade_number)
  find_abs_ang_vel_of_blade_in_rot_shaft (blade_number)
  find_acc_of_blade_wrt_hinge_in_rot_shaft (blade_number)
  find_acc_of_hinge_wrt_hub_in_rot_shaft (blade_number)
  find_abs_acc_of_hub_in_rot_shaft (blade_number)
  find_acc_of_blade_in_rot_shaft (blade_number)
  find_inertial_shears_per_blade_in_rot_shaft (blade_number)
  find_total_blade_force_in_rot_shaft (blade_number)
end blade_calculations;

procedure segment_calculations (blade_number:integer; segment_number:integer) is
begin
  find_segment_vel_in_blade_span_due_to_hub_rates (blade_number, segment_number)
  find_segment_interference_vel (blade_number, segment_number)
  find_segment_flap_vel (blade_number, segment_number)
  find_segment_lag_vel (blade_number, segment_number)
```

```
  find_segment_vel_in_blade_span (blade_number, segment_number)
  find_segment_yaw_angle_of_flow (blade_number, segment_number)
  find_vel_vector_to_segment_xform_matrix (blade_number, segment_number)
  find_segment_mach (blade_number, segment_number)
  find_segment_dynamic_pitch (blade_number, segment_number)
  find_segment_geometric_pitch_angle (blade_number, segment_number)
  find_total_segment_pitch_angle (blade_number, segment_number)
  find_segment_angle_of_attack (blade_number, segment_number)
  find_segment_aero_coefficients (blade_number, segment_number)
  find_segment_aero_shear_forces (blade_number, segment_number)
end segment_calculations;



procedure integrations is
begin

 for i in 1 .. Number_Of_Blades
       find_abs_acc_of_hinge_in_rot_shaft (i)
       find_rot_shaft_to_blade_span_xform_matrix (i)
       find_abs_acc_of_hinge_in_blade_span (i)
       find_abs_ang_vel_of_blade_in_blade_span (i)
       find_abs_ang_acc_of_blade_in_blade_span (i)
       find_total_aero_moments_wrt_hinge_in_blade_span (i)
       find_aero_moments_wrt_hinge_in_blade_span (i)
       find_total_external_blade_moment (i)
       find_blade_flap_rate (i)
       find_blade_flap_angle (i)
       find_lag_acc_of_blade_in_rot_shaft (i)
       find_blade_lag_rate (i)
       find_blade_lag_angle (i)
       find_flap_acc_of_blade_in_rot_shaft (i)
 end for;

  find_total_aero_shear_forces_for_dynamic_twist ;
 find_total_aero_shear_forces ;

end integrations;
```

Appendix B - List of States and Their Indices

The following is a list of all of the rotor library modules with each line in the form of shorthand index, module number if applicable, and module name.

0	1.4.1	hub_to_rot_shaft_xform_matrix
1	1.4.1.1	rot_shaft_to_hub_xform_matrix
2	1.4.2	blade_lag_angle_xform_matrix
3	1.4.3	blade_flap_angle_xform_matrix
4	1.4.5	hub_to_body_xform_matrix
5	1.4.5.1	body_to_hub_xform_matrix
6	1.4.6	vel_vector_to_segment_xform_matrix
7	1.4.7	blade_span_to_rot_shaft_xform_matrix
8	1.4.7.1	rot_shaft_to_blade_span_xform_matrix
9	1.5.1	vel_of_sound
10	1.5.2	air_density
11	1.5.3	blade_segment_area
12	1.5.4	translational_acc_of_body
13	1.5.5	body_rates
14	1.5.6	body_ang_acc
15	1.5.7	body_vel
16	1.5.8	weight_coefficients_for_torsion
17	1.5.9	hub_offsets
18	1.2.6.1	hub_vel_in_body_axis
19	1.2.6.3	hub_vel_in_hub_axis
20	1.2.6.5	rot_shaft_vel
21	1.2.6.9	hub_rates_in_hub_axis
22	1.2.6.1.4	hub_rates_in_rot_shaft
23	1.2.6.1.4.2	abs_ang_vel_of_hinge_in_rot_shaft
24	1.2.6.1.2	hinge_vel_in_blade_span
25	1.2.6.1.2.1	hinge_vel_in_rot_shaft
26	1.2.6.1.3	segment_vel_in_blade_span_due_to_hub_rates
27	1.2.6.1.3.1	hub_rates_in_blade_span
28	1.3	segment_gust_vel
29	1.3.1	segment_upwash_vel
30	1.3.2	segment_downwash_vel
31	1.3.3	segment_interference_vel
32	1.2.6.7	body_vel_in_blade_span
33	1.2.6.1.7	segment_vel_in_blade_span
34	1.2.6.1.4.1	segment_lag_vel
35	1.2.6.1.5	segment_flap_vel
36	1.2.10.3	total_segment_pitch_angle
37	1.2.10.1	segment_angle_of_attack
38	1.2.10.1.1	segment_yaw_angle_of_flow
39	1.2.10.0.5	segment_mach
40	1.2.3.3	segment_aero_coefficients
41	1.2.10.5	segment_dynamic_pitch

42	1.2.10.4	segment_geometric_pitch_angle
43	1.2.7.1	hub_acc_in_body_axis
44	1.2.7.1.1	centrifugal_acc_of_hub
45	1.2.7.1.2	gust_acc_of_hub
46	1.2.7.1.3	tangential_acc_of_hub
47	1.2.8.1	abs_ang_acc_of_blade_in_rot_shaft
48	1.2.8.2	abs_ang_acc_of_hinge_in_rot_shaft
49	1.2.8.3	ang_acc_of_blade_wrt_hinge_in_rot_shaft
50	1.2.8.3.5	ang_acc_of_hub_in_hub_axis
51	1.2.8.4	ang_acc_of_hub_in_rot_shaft
52	1.2.8.5	ang_vel_of_hinge_wrt_hub
53	1.2.8.6	ang_acc_of_hinge_wrt_hub
54	1.2.8.7	ang_vel_of_blade_wrt_hinge_in_rot_shaft
55	1.2.8.8	time_drv_of_lag_xform_matrix_in_rot_shaft
56	1.2.8.9	abs_ang_vel_of_blade_in_rot_shaft
57	1.2.8.10	abs_ang_vel_of_blade_in_blade_span
58	1.2.8.11	abs_ang_acc_of_blade_in_blade_span
59	1.2.9.1	acc_of_blade_in_rot_shaft
60	1.2.9.2	acc_of_blade_wrt_hinge_in_rot_shaft
61	1.2.9.3	acc_of_hinge_wrt_hub_in_rot_shaft
62	1.2.9.4	abs_acc_of_hub_in_rot_shaft
63	1.2.9.5	abs_acc_of_hinge_in_rot_shaft
64	1.2.9.6	abs_acc_of_hinge_in_blade_span
65	1.2.11.1	main_rotor_force_in_body_axis
66	1.2.11.2	main_rotor_filtered_forces
67	1.2.11.3	total_blade_force_in_rot_shaft
68	1.2.11.4	aero_shear_per_blade_in_rot_shaft
69	1.2.11.6.1	segment_aero_shear_forces
70	1.2.11.7	inertial_shears_per_blade_in_rot_shaft
71	1.2.12.1	flap_acc_of_blade_in_rot_shaft
72	1.2.12.2	blade_flap_rate
73	1.2.12.3	blade_flap_angle
74	1.2.13.1	lag_acc_of_blade_in_rot_shaft
75	1.2.13.2	blade_lag_rate
76	1.2.13.3	blade_lag_angle
77	1.2.13.4	lag_damper_displacement
78	1.2.13.5	lag_damper_force
79	1.2.13.6	lagging_moments_due_to_lag_damper
80	1.2.13.7	lagging_moments_due_to_flap_damper
81	1.2.13.8	flapping_moments_due_to_lag_damper
82	1.2.13.9	flapping_moments_due_to_flap_damper
83	1.2.14.1	aero_moments_wrt_hinge_in_blade_span
84	1.2.14.2	total_external_blade_moment
85	1.2.14.4	rotor_filtered_moments
86	1.2.14.5	rotor_hub_moments_in_body_axis
87	1.2.14.6	delta_moments
100	1.2.11	main_rotor_forces_in_hub_axis
101	1.2.11.5	aero_shears_per_blade_in_span_axis

102	none	total_aero_shear_forces_for_dynamic_twist
103	none	total_aero_shear_forces
104	none	total_aero_moments_wrt_hinge_in_blade_span
105	none	total_aero_moments_in_hub_axis

Appendix C -

Module Parameters Document

	A	B	C	D	E	F	G
1		Module Definition for Rotor Model Library			9/15/92		
2							
3	Module #	Module Name	IN parameters		OUT parameters		Author
4							
5	1.4.1	find_hub_to_rot_shaft_xform_matrix	blade_azimuth	F	hub_to_rot_shaft_xform_matrix	M	MJS
6							
7	1.4.1.1	find_rot_shaft_to_hub_xform_matrix	blade_azimuth	F	rot_shaft_to_hub_xform_matrix	M	MJS
8							
9	1.4.2	find_blade_lag_angle_xform_matrix	blade_lag_angle	F	blade_lag_angle_xform_matrix	M	MJS
10							
11	1.4.3	find_blade_flap_angle_xform_matrix	blade_flap_angle	F	blade_flap_angle_xform_matrix	M	MJS
12							
13	1.4.5	find_hub_to_body_xform_matrix	hub_inclination_theta	F	hub_to_body_xform_matrix	M	MJS
14			hub_inclination_phi	F			
15							
16	1.4.5.1	find_body_to_hub_xform_matrix	hub_inclination_theta	F	body_to_hub_xform_matrix	M	MJS
17			hub_inclination_phi	F			
18							
19	1.4.6	find_vel_vector_to_segment_xform_matrix	segment_vel_in_blade_span	V	vel_vector_to_segment_xform_matrix	M	MJS
20			segment_yaw_angle_of_flow	F			
21							
22	1.4.7	find_blade_span_to_rot_shaft_xform_matrix	blade_lag_angle	F	blade_span_to_rot_shaft_xform_matrix	M	MJS
23			blade_flap_angle	F			
24							
25	1.4.7.1	find_rot_shaft_to_blade_span_xform_matrix	blade_lag_angle	F	rot_shaft_to_blade_span_xform_matrix	M	MJS
26			blade_flap_angle	F			
27							
28	1.5.1	find_vel_of_sound	altitude	F	vel_of_sound	F	CRL
29			air_density	F			
30							
31	1.5.2	find_air_density	altitude	F	air_density	F	CRL
32			air_density_table	LT			
33							
34	1.5.3	find_blade_segment_area	segment_index_number	I	blade_segment_area	F	MJS
35			normalized_segment_offset	F			
36			hinge_offset	F			
37			number_of_segments	I			
38			spar_offset	F			
39			tip_radius	F			
40			segment_offset	F			
41			blade_top_chord	F			
42			blade_root_chord	F			
43							
44	1.5.4	find_translational_acc_of_body	abs_acc_of_body_in_body_axis_x	F	translational_acc_of_body	V	MJS
45			abs_acc_of_body_in_body_axis_y	F			
46			abs_acc_of_body_in_body_axis_z	F			
47							
48	1.5.5	find_body_rates	P	F	body_rates	V	MJS

	A	B	C	D	E	F	G
49			Q	F			
50			R	F			
51							
52	1.5.6	find_body_ang_acc	P_dot	F	body_ang_acc	V	MJS
53			Q_dot	F			
54			R_dot	F			
55							
56	1.5.7	find_body_vel	body_vel_x	F	body_vel	V	MJS
57			body_vel_y	F			
58			body_vel_z	F			
59							
60	1.5.8	find_weight_coefficients_for_torsion	constant1	F	weight_coefficients_for_torsion	V	MJS
61			constant2	F			
62							
63	1.5.9	find_hub_offsets	hub_offset_x	F	hub_offsets	V	MJS
64			hub_offset_y	F			
65			hub_offset_z	F			
66							
67	1.2.6.1	find_hub_vel_in_body_axis	hub_offsets	V	hub_vel_in_body_axis	V	MJS
68			body_vel	V			
69			body_rates	V			
70			segment_gust_vel	V			
71			rotor_ang_vel	F			
72			tip_radius	F			
73							
74	1.2.6.3	find_hub_vel_in_hub_axis	hub_vel_in_body_axis	V	hub_vel_in_hub_axis	V	MJS
75			body_to_hub_xform_matrix	M			
76							
77	1.2.6.5	find_rot_shaft_vel	hub_to_rot_shaft_xform_matrix	M	rot_shaft_vel	V	MJS
78			hub_vel_in_hub_axis	V			
79							
80	1.2.6.9	find_hub_rates_in_hub_axis	body_rates	V	hub_rates_in_hub_axis	V	MJS
81			body_to_hub_xform_matrix	M			
82							
83	1.2.6.1.4	find_hub_rates_in_rot_shaft	hub_rates_in_hub_axis	V	hub_rates_in_rot_shaft	V	MJS
84			hub_to_rot_shaft_xform_matrix	M			
85							
86	1.2.6.1.4.2	find_abs_ang_vel_of_hinge_in_rot_shaft	hub_rates_in_rot_shaft	V	abs_ang_vel_of_hinge_in_rot_shaft	V	CRL
87			ang_vel_of_hinge_wrt_hub	V			
88							
89	1.2.6.1.2	find_hinge_vel_in_blade_span	blade_lag_angle_xform_matrix	M	hinge_vel_in_blade_span	V	MJS
90			blade_flap_angle_xform_matrix	M			
91			hinge_vel_in_rot_shaft	V			
92							
93	1.2.6.1.2.1	find_hinge_vel_in_rot_shaft	normalized_hinge_offset	F	hinge_vel_in_rot_shaft	V	MJS
94			abs_ang_vel_of_hinge_in_rot_shaft	V			
95							
96	1.2.6.1.3	find_segment_vel_in_blade_span_due_to_hub_rat	normalized_segment_offset	F	segment_vel_in_blade_span_due_to_hub_ra	V	MJS

	A	B	C	D	E	F	G
97			hub_rates_in_blade_span	V			
98							
99	1.2.6.1.3.1	find_hub_rates_in_blade_span	blade_lag_angle_xform_matrix	M	hub_rates_in_blade_span	V	MJS
100			blade_flap_angle_xform_matrix	M			
101			abs_ang_vel_of_hinge_in_rot_shaft	V			
102							
103	1.3	find_segment_gust_vel	segment_gust_vel_x	F	segment_gust_vel	V	CRL
104			segment_gust_vel_y	F			
105			segment_gust_vel_z	F			
106							
107	1.3.1	find_segment_upwash_vel	segment_upwash_vel_x	F	segment_upwash_vel	V	CRL
108			segment_upwash_vel_y	F			
109			segment_upwash_vel_z	F			
110							
111	1.3.2	find_segment_downwash_vel	segment_downwash_vel_x	F	segment_downwash_vel	V	CRL
112			segment_downwash_vel_y	F			
113			segment_downwash_vel_z	F			
114							
115	1.3.3	find_segment_interference_vel	segment_gust_vel	V	segment_interference_vel	V	MJS
116			segment_upwash_vel	V			
117			segment_downwash_vel	V			
118							
119	1.2.6.7	find_body_vel_in_blade_span	blade_lag_angle_xform_matrix	M	body_vel_in_blade_span	V	MJS
120			blade_flap_angle_xform_matrix	M			
121			rot_shaft_vel	V			
122							
123	1.2.6.1.7	find_segment_vel_in_blade_span	body_vel_in_blade_span	V	segment_vel_in_blade_span	V	MJS
124			hinge_vel_in_blade_span	V			
125			segment_vel_in_blade_span_due_to_hub_rates	V			
126			segment_interference_vel	V			
127			segment_flap_vel	V			
128			segment_lag_vel	V			
129							
130	1.2.6.1.4.1	find_segment_lag_vel	normalized_segment_offset	F	segment_lag_vel	V	MJS
131			blade_lag_rate	F			
132			blade_flap_angle	F			
133							
134	1.2.6.1.5	find_segment_flap_vel	normalized_segment_offset	F	segment_flap_vel	V	MJS
135			blade_flap_rate	F			
136							
137	1.2.10.3	find_total_segment_pitch_angle	segment_dynamic_pitch	F	total_segment_pitch_angle	F	MJS
138			segment_geometric_pitch_angle	F			
139			normalized_segment_offset	F			
140			preformed_twist_table	LT			
141							
142	1.2.10.1	find_segment_angle_of_attack	segment_vel_in_blade_span	V	segment_angle_of_attack	F	MJS
143			total_segment_pitch_angle	F			
144			segment_yaw_angle_of_flow	F			

	A	B	C	D	E	F	G
145							
146	1.2.10.1.1	find_segment_yaw_angle_of_flow	segment_vel_in_blade_span	V	segment_yaw_angle_of_flow	F	MJS
147							
148	1.2.10	find_total_segment_vel	all -- segment_vel_in_blade_span	V	total_segment_vel	V	CRL
149							
150	1.2.10.0.5	find_segment_mach	segment_vel_in_blade_span	V	segment_mach	F	MJS
151			rotor_ang_vel	F			
152			vel_of_sound	F			
153			tip_radius	F			
154							
155	1.2.3.3	find_segment_aero_coefficients	segment_mach	F	segment_aero_coefficients	V	MJS
156			segment_angle_of_attack	F			
157			lift_coefficient_table	BT			
158			drag_coefficient_table	BT			
159							
160	1.2.10.5	find_segment_dynamic_pitch	total_aero_shear_forces_for_dynamic_twist	V	segment_dynamic_pitch	F	S
161			weight_coefficients_for_torsion	V			
162			blade_azimuth	F			
163			blade_lag_angle	F			
164			normalized_segment_offset	F			
165			hinge_offset	F			
166							
167	1.2.10.4	find_segment_geometric_pitch_angle	blade_flap_angle	F	segment_geometric_pitch_angle	F	S
168			blade_lag_angle	F			
169			blade_azimuth	F			
170			swashplate_phase_angle	F			
171			collective_blade_pitch	F			
172			lateral_cyclic_blade_pitch	F			
173			longitudinal_cyclic_blade_pitch	F			
174			hinge_angle_coefficient	F			
175			pitch_lag_coupling_coefficient	F			
176							
177	1.2.7.1	find_hub_acc_in_body_axis	centrifugal_acc_of_hub	V	hub_acc_in_body_axis	V	S
178			gust_acc_of_hub	V			
179			tangential_acc_of_hub	V			
180			translational_acc_of_body	V			
181							
182	1.2.7.1.1	find_centrifugal_acc_of_hub	body_rates	V	centrifugal_acc_of_hub	V	S
183			hub_vel_in_body_axis	V			
184							
185	1.2.7.1.2	find_gust_acc_of_hub	gust_acc_constant	F	gust_acc_of_hub	V	S
186			hub_inclination_theta	F			
187			hub_inclination_phi	F			
188							
189	1.2.7.1.3	find_tangential_acc_of_hub	hub_offsets	V	tangential_acc_of_hub	V	S
190			body_ang_acc	V			
191							
192	1.2.8.1	find_abs_ang_acc_of_blade_in_rot_shaft	ang_acc_of_blade_wrt_hinge_in_rot_shaft	V	abs_ang_acc_of_blade_in_rot_shaft	V	S

	A	B	C	D	E	F	G
193			abs_ang_acc_of_hinge_in_rot_shaft	V			
194			abs_ang_vel_of_hinge_in_rot_shaft	V			
195			ang_vel_of_blade_wrt_hinge_in_rot_shaft	V			
196							
197	1.2.8.2	find_abs_ang_acc_of_hinge_in_rot_shaft	ang_acc_of_hub_in_rot_shaft	V	abs_ang_acc_of_hinge_in_rot_shaft	V	S
198			ang_acc_of_hinge_wrt_hub	V			
199			hub_rates_in_rot_shaft	V			
200			ang_vel_of_hinge_wrt_hub	V			
201							
202	1.2.8.3	find_ang_acc_of_blade_wrt_hinge_in_rot_shaft	lag_acc_of_blade_in_rot_shaft	F	ang_acc_of_blade_wrt_hinge_in_rot_shaft	V	S
203			flap_acc_of_blade_in_rot_shaft	F			
204			blade_lag_rate	F			
205			blade_flap_rate	F			
206			blade_lag_angle_xform_matrix	M			
207			time_drv_of_lag_xform_matrix_in_rot_shaft	M			
208							
209	1.2.8.3.5	find_ang_acc_of_hub_in_hub_axis	body_ang_acc	V	ang_acc_of_hub_in_hub_axis	V	S
210			body_to_hub_xform_matrix	M			
211							
212	1.2.8.4	find_ang_acc_of_hub_in_rot_shaft	ang_acc_of_hub_in_hub_axis	V	ang_acc_of_hub_in_rot_shaft	V	S
213			hub_to_rot_shaft_xform_matrix	M			
214							
215	1.2.8.5	find_ang_vel_of_hinge_wrt_hub	rotor_ang_vel	F	ang_vel_of_hinge_wrt_hub	V	S
216							
217	1.2.8.6	find_ang_acc_of_hinge_wrt_hub	rotor_ang_acc	F	ang_acc_of_hinge_wrt_hub	V	S
218							
219	1.2.8.7	find_ang_vel_of_blade_wrt_hinge_in_rot_shaft	blade_lag_angle_xform_matrix	M	ang_vel_of_blade_wrt_hinge_in_rot_shaft	V	S
220			blade_lag_rate	F			
221			blade_flap_rate	F			
222							
223	1.2.8.8	find_time_drv_of_lag_xform_matrix_in_rot_shaf	blade_lag_angle	F	time_drv_of_lag_xform_matrix_in_rot_sha	M	S
224			blade_lag_rate	F			
225							
226	1.2.8.9	find_abs_ang_vel_of_blade_in_rot_shaft	ang_vel_of_blade_wrt_hinge_in_rot_shaft	V	abs_ang_vel_of_blade_in_rot_shaft	V	S
227			abs_ang_vel_of_hinge_in_rot_shaft	V			
228							
229	1.2.8.10	find_abs_ang_vel_of_blade_in_blade_span	abs_ang_vel_of_blade_in_rot_shaft	V	abs_ang_vel_of_blade_in_blade_span	V	S
230			rot_shaft_to_blade_span_xform_matrix	M			
231							
232	1.2.8.11	find_abs_ang_acc_of_blade_in_blade_span	abs_ang_acc_of_blade_in_rot_shaft	V	abs_ang_acc_of_blade_in_blade_span	V	S
233			rot_shaft_to_blade_span_xform_matrix	M			
234							
235	1.2.9.1	find_acc_of_blade_in_rot_shaft	acc_of_blade_wrt_hinge_in_rot_shaft	V	acc_of_blade_in_rot_shaft	V	S
236			acc_of_hinge_wrt_hub_in_rot_shaft	V			
237			abs_acc_of_hub_in_rot_shaft	V			
238							
239	1.2.9.2	find_acc_of_blade_wrt_hinge_in_rot_shaft	abs_ang_acc_of_blade_in_rot_shaft	V	acc_of_blade_wrt_hinge_in_rot_shaft	V	S
240			abs_ang_vel_of_blade_in_rot_shaft	V			

	A	B	C	D	E	F	G
241			blade_flap_angle	F			
242			blade_lag_angle	F			
243			normalized_center_of_mass	F			
244							
245	1.2.9.3	find_acc_of_hinge_wrt_hub_in_rot_shaft	abs_ang_acc_of_hinge_in_rot_shaft	V	acc_of_hinge_wrt_hub_in_rot_shaft	V	S
246			normalized_hinge_offset	F			
247			abs_ang_vel_of_hinge_in_rot_shaft	V			
248							
249	1.2.9.4	find_abs_acc_of_hub_in_rot_shaft	hub_to_rot_shaft_xform_matrix	M	abs_acc_of_hub_in_rot_shaft	V	S
250			body_to_hub_xform_matrix	M			
251			hub_acc_in_body_axis	V			
252							
253	1.2.9.5	find_abs_acc_of_hinge_in_rot_shaft	acc_of_hinge_wrt_hub_in_rot_shaft	V	abs_acc_of_hinge_in_rot_shaft	V	S
254			abs_acc_of_hub_in_rot_shaft	V			
255							
256	1.2.9.6	find_abs_acc_of_hinge_in_blade_span	abs_acc_of_hinge_in_rot_shaft	V	abs_acc_of_hinge_in_blade_span	V	S
257			rot_shaft_to_blade_span_xform_matrix	M			
258							
259	1.2.11	find_main_rotor_forces_in_hub_axis	all -- total_blade_force_in_rot_shaft	V	main_rotor_forces_in_hub_axis	V	CRL
260			rot_shaft_to_hub_xform_matrix	M			
261							
262	1.2.11.1	find_main_rotor_force_in_body_axis	hub_to_body_xform_matrix	M	main_rotor_force_in_body_axis	V	S
263			main_rotor_filtered_forces	V			
264							
265	1.2.11.2	find_main_rotor_filtered_forces	main_rotor_forces_in_hub_axis	V	main_rotor_filtered_forces	V	OTHER
266							
267	1.2.11.3	find_total_blade_force_in_rot_shaft	aero_shear_per_blade_in_rot_shaft	V	total_blade_force_in_rot_shaft	V	S
268			inertial_shears_per_blade_in_rot_shaft	V			
269							
270	1.2.11.4	find_aero_shear_per_blade_in_rot_shaft	aero_shear_per_blade_in_span_axis	V	aero_shear_per_blade_in_rot_shaft	V	S
271			blade_span_to_rot_shaft_xform_matrix	M			
272							
273	1.2.11.5	find_aero_shear_per_blade_in_span_axis	all--segment_aero_shear_forces	V	aero_shear_per_blade_in_span_axis	V	CRL
274			segment_mach	F			
275			segment_angle_of_attack	F			
276							
277	-----	find_total_aero_shear_forces_for_dynamic_twist	all--aero_shear_per_blade_in_span	V	total_aero_shear_forces_for_dynamic_twi	V	CRL
278							
279	-----	find_total_aero_shear_forces	all--aero_shear_per_blade_in_span	V	total_aero_shear_forces	V	CRL
280							
281	-----	find_total_aero_moments_wrt_hinge_in_blade_sp	all--segment_aero_shear_forces	V	total_aero_moments_wrt_hinge_in_blade_s	V	CRL
282			segment_mach	F			
283			segment_angle_of_attack	F			
284			segment_offset				
285							
286	1.2.11.6.1	find_segment_aero_shear_forces	vel_vector_to_segment_xform_matrix	M	segment_aero_shear_forces	V	GP
287			segment_aero_coefficients	V			
288			blade_segment_area	F			

	A	B	C	D	E	F	G
289			rotor_ang_vel	F			
290			air_density	F			
291			tip_radius	F			
292							
293	1.2.11.7	find_inertial_shears_per_blade_in_rot_shaft	acc_of_blade_in_rot_shaft	V	inertial_shears_per_blade_in_rot_shaft	V	GP
294			mass_of_blade	F			
295							
296	1.2.12.1	find_flap_acc_of_blade_in_rot_shaft	mass_of_blade	F	flap_acc_of_blade_in_rot_shaft	F	GP
297			normalized_center_of_mass	F			
298			blade_moment_of_inertia_about_hinge	F			
299			abs_acc_of_hinge_in_blade_span	V			
300			abs_ang_vel_of_blade_in_blade_span	V			
301			abs_ang_acc_of_blade_in_blade_span	V			
302			total_external_blade_moment	V			
303			ang_acc_of_hub_in_hub_axis	V			
304			blade_lag_rate	F			
305			blade_lag_angle	F			
306			blade_azimuth	F			
307			rotor_ang_vel	F			
308							
309	1.2.12.2	find_blade_flap_rate	blade_flap_rate	F	blade_flap_rate	F	GP
310			delta_blade_azimuth	F			
311			rotor_ang_vel	F			
312			flap_acc_of_blade_in_rot_shaft	F			
313							
314	1.2.12.3	find_blade_flap_angle	blade_flap_rate	F	blade_flap_angle	F	GP
315			blade_flap_angle	F			
316			delta_blade_azimuth	F			
317			rotor_ang_vel	F			
318			flap_acc_of_blade_in_rot_shaft	F			
319							
320	1.2.13.1	find_lag_acc_of_blade_in_rot_shaft	mass_of_blade	F	lag_acc_of_blade_in_rot_shaft	F	GP
321			normalized_center_of_mass	F			
322			blade_moment_of_inertia_about_hinge	F			
323			abs_acc_of_hinge_in_blade_span	V			
324			abs_ang_vel_of_blade_in_blade_span	V			
325			abs_ang_acc_of_blade_in_blade_span	V			
326			total_external_blade_moment	V			
327			ang_acc_of_hub_in_hub_axis	V			
328			blade_lag_rate	F			
329			blade_lag_angle	F			
330			blade_azimuth	F			
331			rotor_ang_vel	F			
332			blade_flap_angle	F			
333			blade_flap_rate	F			
334							
335	1.2.13.2	find_blade_lag_rate	blade_lag_rate	F	blade_lag_rate	F	GP
336			lag_acc_of_blade_in_rot_shaft	F			

	A	B	C	D	E	F	G
337			delta_blade_azimuth	F			
338			rotor_ang_vel	F			
339							
340	1.2.13.3	find_blade_lag_angle	blade_lag_rate	F	blade_lag_angle	F	GP
341			lag_acc_of_blade_in_rot_shaft	F			
342			blade_lag_angle	F			
343			delta_blade_azimuth	F			
344			rotor_ang_vel	F			
345							
346	1.2.13.4	find_lag_damper_displacement	lag_damper_geom_a	F	lag_damper_displacement	V	GP
347			lag_damper_geom_b	F			
348			lag_damper_geom_c	F			
349			lag_damper_geom_d	F			
350			lag_damper_geom_r	F			
351			lag_damper_geom_theta	F			
352			lag_damper_geom_delta	F			
353			segment_geometric_pitch_angle	F			
354			blade_flap_angle	F			
355			blade_lag_angle	F			
356							
357	1.2.13.5	find_lag_damper_force	lag_damper_force_characteristics_table	LT	lag_damper_force	V	GP
358			lag_damper_displacement	V			
359			lag_damper_geom_a	F			
360			lag_damper_geom_b	F			
361			lag_damper_geom_c	F			
362			lag_damper_geom_d	F			
363			lag_damper_geom_r	F			
364			lag_damper_geom_theta	F			
365			lag_damper_rate	F			
366			lag_damper_geom_delta	F			
367			segment_geometric_pitch_angle	F			
368			blade_flap_angle	F			
369			blade_lag_angle	F			
370			blade_flap_rate	F			
371			blade_lag_rate	F			
372							
373	1.2.13.6	find_lagging_moments_due_to_lag_damper	lag_damper_force	V	lagging_moments_due_to_lag_damper	F	GP
374			segment_geometric_pitch_angle	F			
375			lag_damper_geom_theta	F			
376			blade_flap_angle	F			
377			lag_damper_displacement	V			
378			lag_damper_geom_c	F			
379			lag_damper_geom_r	F			
380							
381	1.2.13.7	find_lagging_moments_due_to_flap_damper	lag_damper_displacement	V	lagging_moments_due_to_flap_damper	F	GP
382			lag_damper_force	V			
383			lag_damper_geom_theta	F			
384			segment_geometric_pitch_angle	F			

	A	B	C	D	E	F	G
385			lag_damper_geom_c	F			
386			lag_damper_geom_r	F			
387							
388	1.2.13.8	find_flapping_moments_due_to_lag_damper	void	F	flapping_moments_due_to_lag_damper	F	GP
389							
390	1.2.13.9	find_flapping_moments_due_to_flap_damper	blade_flap_angle	F	flapping_moments_due_to_flap_damper	F	GP
391			blade_flap_rate	F			
392			flapping_spring_stiffness	F			
393			flapping_damper_rate	F			
394							
395							
396	1.2.14.1	find_aero_moments_wrt_hinge_in_blade_span	total_aero_moments_wrt_hinge_in_blade_span	V	aero_moments_wrt_hinge_in_blade_span	V	GP
397			tip_radius	F			
398							
399	1.2.14.2	find_total_external_blade_moment	aero_moments_wrt_hinge_in_blade_span	V	total_external_blade_moment	V	GP
400			flapping_moments_due_to_flap_damper	F			
401			flapping_moments_due_to_lag_damper	F			
402			lagging_moments_due_to_flap_damper	F			
403			lagging_moments_due_to_lag_damper	F			
404			blade_flap_rate	F			
405			blade_flap_angle	F			
406							
407	1.2.14.3	find_rotor_hub_moments_in_hub_axis	all -- total_blade_force_in_rot_shaft	V	rotor_hub_moments_in_hub_axis	V	CRL
408			rot_shaft_to_hub_xform_matrix	M			
409			delta_moments	V			
410							
411	1.2.14.4	find_rotor_filtered_moments	rotor_hub_moments_in_hub_axis	V	rotor_filtered_moments	V	OTHER
412							
413	1.2.14.5	find_rotor_hub_moments_in_body_axis	rotor_filtered_moments	V	rotor_hub_moments_in_body_axis	V	GP
414			hub_to_body_xform_matrix	M			
415			hub_offsets	V			
416			main_rotor_filtered_forces	V			
417							
418	1.2.14.6	find_delta_moments	flapping_moments_due_to_flap_damper	F	delta_moments	V	GP
419			flapping_moments_due_to_lag_damper	F			
420			lagging_moments_due_to_flap_damper	F			
421			lagging_moments_due_to_lag_damper	F			
422			blade_azimuth	F			
423			blade_lag_angle	F			
424							

Appendix D -

Module Cross Reference

```
0 1.4.1 hub_to_rot_shaft_xform_matrix
 --- IN  PARAMS:
 --- CALLS ME:
  <--  20      1.2.6.5          rot_shaft_vel
  <--  22      1.2.6.1.4        hub_rates_in_rot_shaft
  <--  51      1.2.8.4          ang_acc_of_hub_in_rot_shaft
  <--  62      1.2.9.4          abs_acc_of_hub_in_rot_shaft

  1      1.4.1.1         rot_shaft_to_hub_xform_matrix
 --- IN  PARAMS:
 --- CALLS ME:

  2      1.4.2           blade_lag_angle_xform_matrix
 --- IN  PARAMS:
  -->  76      1.2.13.3         blade_lag_angle
 --- CALLS ME:
  <--  24      1.2.6.1.2        hinge_vel_in_blade_span
  <--  27      1.2.6.1.3.1      hub_rates_in_blade_span
  <--  32      1.2.6.7          body_vel_in_blade_span
  <--  49      1.2.8.3          ang_acc_of_blade_wrt_hinge_in_rot_shaft
  <--  54      1.2.8.7          ang_vel_of_blade_wrt_hinge_in_rot_shaft

  3      1.4.3           blade_flap_angle_xform_matrix
 --- IN  PARAMS:
  -->  73      1.2.12.3         blade_flap_angle
 --- CALLS ME:
  <--  24      1.2.6.1.2        hinge_vel_in_blade_span
  <--  27      1.2.6.1.3.1      hub_rates_in_blade_span
  <--  32      1.2.6.7          body_vel_in_blade_span

  4      1.4.5           hub_to_body_xform_matrix
 --- IN  PARAMS:
 --- CALLS ME:
  <--  65      1.2.11.1         main_rotor_force_in_body_axis
  <--  86      1.2.14.5         rotor_hub_moments_in_body_axis

  5      1.4.5.1         body_to_hub_xform_matrix
 --- IN  PARAMS:
 --- CALLS ME:
  <--  19      1.2.6.3          hub_vel_in_hub_axis
  <--  21      1.2.6.9          hub_rates_in_hub_axis
  <--  50      1.2.8.3.5        ang_acc_of_hub_in_hub_axis
  <--  62      1.2.9.4          abs_acc_of_hub_in_rot_shaft

  6      1.4.6           vel_vector_to_segment_xform_matrix
 --- IN  PARAMS:
  -->  33      1.2.6.1.7        segment_vel_in_blade_span
  -->  38      1.2.10.1.1       segment_yaw_angle_of_flow
 --- CALLS ME:
  <--  69      1.2.11.6.1       segment_aero_shear_forces

  7      1.4.7           blade_span_to_rot_shaft_xform_matrix
 --- IN  PARAMS:
  -->  76      1.2.13.3         blade_lag_angle
```

```
 --> 73      1.2.12.3        blade_flap_angle
--- CALLS ME:
 <-- 68      1.2.11.4        aero_shear_per_blade_in_rot_shaft

 8      1.4.7.1         rot_shaft_to_blade_span_xform_matrix
--- IN  PARAMS:
 --> 76      1.2.13.3        blade_lag_angle
 --> 73      1.2.12.3        blade_flap_angle
--- CALLS ME:
 <-- 57      1.2.8.10        abs_ang_vel_of_blade_in_blade_span
 <-- 58      1.2.8.11        abs_ang_acc_of_blade_in_blade_span
 <-- 64      1.2.9.6         abs_acc_of_hinge_in_blade_span

 9      1.5.1           vel_of_sound
--- IN  PARAMS:
 --> 10      1.5.2           air_density
--- CALLS ME:
 <-- 39      1.2.10.0.5      segment_mach

 10     1.5.2           air_density
--- IN  PARAMS:
--- CALLS ME:
 <-- 9       1.5.1           vel_of_sound
 <-- 69      1.2.11.6.1      segment_aero_shear_forces

 11     1.5.3           blade_segment_area
--- IN  PARAMS:
--- CALLS ME:
 <-- 69      1.2.11.6.1      segment_aero_shear_forces

 12     1.5.4           translational_acc_of_body
--- IN  PARAMS:
--- CALLS ME:
 <-- 43      1.2.7.1         hub_acc_in_body_axis

 13     1.5.5           body_rates
--- IN  PARAMS:
--- CALLS ME:
 <-- 18      1.2.6.1         hub_vel_in_body_axis
 <-- 21      1.2.6.9         hub_rates_in_hub_axis
 <-- 44      1.2.7.1.1       centrifugal_acc_of_hub

 14     1.5.6           body_ang_acc
--- IN  PARAMS:
--- CALLS ME:
 <-- 46      1.2.7.1.3       tangential_acc_of_hub
 <-- 50      1.2.8.3.5       ang_acc_of_hub_in_hub_axis

 15     1.5.7           body_vel
--- IN  PARAMS:
--- CALLS ME:
 <-- 18      1.2.6.1         hub_vel_in_body_axis

 16     1.5.8           weight_coefficients_for_torsion
```

```
--- IN  PARAMS:
--- CALLS ME:
 <--  41     1.2.10.5       segment_dynamic_pitch

 17     1.5.9          hub_offsets
--- IN  PARAMS:
--- CALLS ME:
 <--  18     1.2.6.1        hub_vel_in_body_axis
 <--  46     1.2.7.1.3      tangential_acc_of_hub
 <--  86     1.2.14.5       rotor_hub_moments_in_body_axis

 18     1.2.6.1        hub_vel_in_body_axis
--- IN  PARAMS:
 -->  17     1.5.9          hub_offsets
 -->  15     1.5.7          body_vel
 -->  13     1.5.5          body_rates
 -->  28     1.3            segment_gust_vel
--- CALLS ME:
 <--  19     1.2.6.3        hub_vel_in_hub_axis
 <--  44     1.2.7.1.1      centrifugal_acc_of_hub

 19     1.2.6.3        hub_vel_in_hub_axis
--- IN  PARAMS:
 -->  18     1.2.6.1        hub_vel_in_body_axis
 -->  5      1.4.5.1        body_to_hub_xform_matrix
--- CALLS ME:
 <--  20     1.2.6.5        rot_shaft_vel

 20     1.2.6.5        rot_shaft_vel
--- IN  PARAMS:
 -->  0      1.4.1          hub_to_rot_shaft_xform_matrix
 -->  19     1.2.6.3        hub_vel_in_hub_axis
--- CALLS ME:
 <--  32     1.2.6.7        body_vel_in_blade_span

 21     1.2.6.9        hub_rates_in_hub_axis
--- IN  PARAMS:
 -->  13     1.5.5          body_rates
 -->  5      1.4.5.1        body_to_hub_xform_matrix
--- CALLS ME:
 <--  22     1.2.6.1.4      hub_rates_in_rot_shaft

 22     1.2.6.1.4      hub_rates_in_rot_shaft
--- IN  PARAMS:
 -->  21     1.2.6.9        hub_rates_in_hub_axis
 -->  0      1.4.1          hub_to_rot_shaft_xform_matrix
--- CALLS ME:
 <--  23     1.2.6.1.4.2    abs_ang_vel_of_hinge_in_rot_shaft
 <--  48     1.2.8.2        abs_ang_acc_of_hinge_in_rot_shaft

 23     1.2.6.1.4.2    abs_ang_vel_of_hinge_in_rot_shaft
--- IN  PARAMS:
 -->  22     1.2.6.1.4      hub_rates_in_rot_shaft
 -->  52     1.2.8.5        ang_vel_of_hinge_wrt_hub
```

```
--- CALLS ME:
 <--  25     1.2.6.1.2.1     hinge_vel_in_rot_shaft
 <--  27     1.2.6.1.3.1     hub_rates_in_blade_span
 <--  47     1.2.8.1         abs_ang_acc_of_blade_in_rot_shaft
 <--  56     1.2.8.9         abs_ang_vel_of_blade_in_rot_shaft
 <--  61     1.2.9.3         acc_of_hinge_wrt_hub_in_rot_shaft

 24     1.2.6.1.2      hinge_vel_in_blade_span
--- IN  PARAMS:
 -->  2      1.4.2           blade_lag_angle_xform_matrix
 -->  3      1.4.3           blade_flap_angle_xform_matrix
 -->  25     1.2.6.1.2.1     hinge_vel_in_rot_shaft
--- CALLS ME:
 <--  33     1.2.6.1.7       segment_vel_in_blade_span

 25     1.2.6.1.2.1    hinge_vel_in_rot_shaft
--- IN  PARAMS:
 -->  23     1.2.6.1.4.2     abs_ang_vel_of_hinge_in_rot_shaft
--- CALLS ME:
 <--  24     1.2.6.1.2       hinge_vel_in_blade_span

 26     1.2.6.1.3      segment_vel_in_blade_span_due_to_hub_rates
--- IN  PARAMS:
 -->  27     1.2.6.1.3.1     hub_rates_in_blade_span
--- CALLS ME:
 <--  33     1.2.6.1.7       segment_vel_in_blade_span

 27     1.2.6.1.3.1    hub_rates_in_blade_span
--- IN  PARAMS:
 -->  2      1.4.2           blade_lag_angle_xform_matrix
 -->  3      1.4.3           blade_flap_angle_xform_matrix
 -->  23     1.2.6.1.4.2     abs_ang_vel_of_hinge_in_rot_shaft
--- CALLS ME:
 <--  26     1.2.6.1.3       segment_vel_in_blade_span_due_to_hub_rates

 28     1.3            segment_gust_vel
--- IN  PARAMS:
--- CALLS ME:
 <--  18     1.2.6.1         hub_vel_in_body_axis
 <--  31     1.3.3           segment_interference_vel

 29     1.3.1          segment_upwash_vel
--- IN  PARAMS:
--- CALLS ME:
 <--  31     1.3.3           segment_interference_vel

 30     1.3.2          segment_downwash_vel
--- IN  PARAMS:
--- CALLS ME:
 <--  31     1.3.3           segment_interference_vel

 31     1.3.3          segment_interference_vel
--- IN  PARAMS:
 -->  28     1.3             segment_gust_vel
```

```
  -->  29      1.3.1           segment_upwash_vel
  -->  30      1.3.2           segment_downwash_vel
--- CALLS ME:
  <--  33      1.2.6.1.7       segment_vel_in_blade_span

 32      1.2.6.7         body_vel_in_blade_span
--- IN  PARAMS:
  -->  2       1.4.2           blade_lag_angle_xform_matrix
  -->  3       1.4.3           blade_flap_angle_xform_matrix
  -->  20      1.2.6.5         rot_shaft_vel
--- CALLS ME:
  <--  33      1.2.6.1.7       segment_vel_in_blade_span

 33      1.2.6.1.7       segment_vel_in_blade_span
--- IN  PARAMS:
  -->  32      1.2.6.7         body_vel_in_blade_span
  -->  24      1.2.6.1.2       hinge_vel_in_blade_span
  -->  26      1.2.6.1.3       segment_vel_in_blade_span_due_to_hub_rates
  -->  31      1.3.3           segment_interference_vel
  -->  35      1.2.6.1.5       segment_flap_vel
  -->  34      1.2.6.1.4.1     segment_lag_vel
--- CALLS ME:
  <--  6       1.4.6           vel_vector_to_segment_xform_matrix
  <--  37      1.2.10.1        segment_angle_of_attack
  <--  38      1.2.10.1.1      segment_yaw_angle_of_flow
  <--  39      1.2.10.0.5      segment_mach

 34      1.2.6.1.4.1     segment_lag_vel
--- IN  PARAMS:
  -->  75      1.2.13.2        blade_lag_rate
  -->  73      1.2.12.3        blade_flap_angle
--- CALLS ME:
  <--  33      1.2.6.1.7       segment_vel_in_blade_span

 35      1.2.6.1.5       segment_flap_vel
--- IN  PARAMS:
  -->  72      1.2.12.2        blade_flap_rate
--- CALLS ME:
  <--  33      1.2.6.1.7       segment_vel_in_blade_span

 36      1.2.10.3        total_segment_pitch_angle
--- IN  PARAMS:
  -->  41      1.2.10.5        segment_dynamic_pitch
  -->  42      1.2.10.4        segment_geometric_pitch_angle
--- CALLS ME:
  <--  37      1.2.10.1        segment_angle_of_attack

 37      1.2.10.1        segment_angle_of_attack
--- IN  PARAMS:
  -->  33      1.2.6.1.7       segment_vel_in_blade_span
  -->  36      1.2.10.3        total_segment_pitch_angle
  -->  38      1.2.10.1.1      segment_yaw_angle_of_flow
--- CALLS ME:
  <--  40      1.2.3.3         segment_aero_coefficients
```

```
 38     1.2.10.1.1      segment_yaw_angle_of_flow
--- IN  PARAMS:
 -->  33      1.2.6.1.7       segment_vel_in_blade_span
--- CALLS ME:
 <--  6       1.4.6           vel_vector_to_segment_xform_matrix
 <--  37      1.2.10.1        segment_angle_of_attack

 39     1.2.10.0.5      segment_mach
--- IN  PARAMS:
 -->  33      1.2.6.1.7       segment_vel_in_blade_span
 -->  9       1.5.1           vel_of_sound
--- CALLS ME:
 <--  40      1.2.3.3         segment_aero_coefficients

 40     1.2.3.3         segment_aero_coefficients
--- IN  PARAMS:
 -->  39      1.2.10.0.5      segment_mach
 -->  37      1.2.10.1        segment_angle_of_attack
--- CALLS ME:
 <--  69      1.2.11.6.1      segment_aero_shear_forces

 41     1.2.10.5        segment_dynamic_pitch
--- IN  PARAMS:
 -->  16      1.5.8           weight_coefficients_for_torsion
 -->  76      1.2.13.3        blade_lag_angle
--- CALLS ME:
 <--  36      1.2.10.3        total_segment_pitch_angle

 42     1.2.10.4        segment_geometric_pitch_angle
--- IN  PARAMS:
 -->  73      1.2.12.3        blade_flap_angle
 -->  76      1.2.13.3        blade_lag_angle
--- CALLS ME:
 <--  36      1.2.10.3        total_segment_pitch_angle
 <--  77      1.2.13.4        lag_damper_displacement
 <--  78      1.2.13.5        lag_damper_force
 <--  79      1.2.13.6        lagging_moments_due_to_lag_damper
 <--  80      1.2.13.7        lagging_moments_due_to_flap_damper

 43     1.2.7.1         hub_acc_in_body_axis
--- IN  PARAMS:
 -->  44      1.2.7.1.1       centrifugal_acc_of_hub
 -->  45      1.2.7.1.2       gust_acc_of_hub
 -->  46      1.2.7.1.3       tangential_acc_of_hub
 -->  12      1.5.4           translational_acc_of_body
--- CALLS ME:
 <--  62      1.2.9.4         abs_acc_of_hub_in_rot_shaft

 44     1.2.7.1.1       centrifugal_acc_of_hub
--- IN  PARAMS:
 -->  13      1.5.5           body_rates
 -->  18      1.2.6.1         hub_vel_in_body_axis
--- CALLS ME:
```

```
 <--  43     1.2.7.1        hub_acc_in_body_axis

 45     1.2.7.1.2      gust_acc_of_hub
--- IN  PARAMS:
--- CALLS ME:
 <--  43     1.2.7.1        hub_acc_in_body_axis

 46     1.2.7.1.3      tangential_acc_of_hub
--- IN  PARAMS:
 -->  17     1.5.9          hub_offsets
 -->  14     1.5.6          body_ang_acc
--- CALLS ME:
 <--  43     1.2.7.1        hub_acc_in_body_axis

 47     1.2.8.1        abs_ang_acc_of_blade_in_rot_shaft
--- IN  PARAMS:
 -->  49     1.2.8.3        ang_acc_of_blade_wrt_hinge_in_rot_shaft
 -->  48     1.2.8.2        abs_ang_acc_of_hinge_in_rot_shaft
 -->  23     1.2.6.1.4.2    abs_ang_vel_of_hinge_in_rot_shaft
 -->  54     1.2.8.7        ang_vel_of_blade_wrt_hinge_in_rot_shaft
--- CALLS ME:
 <--  58     1.2.8.11       abs_ang_acc_of_blade_in_blade_span
 <--  60     1.2.9.2        acc_of_blade_wrt_hinge_in_rot_shaft

 48     1.2.8.2        abs_ang_acc_of_hinge_in_rot_shaft
--- IN  PARAMS:
 -->  51     1.2.8.4        ang_acc_of_hub_in_rot_shaft
 -->  53     1.2.8.6        ang_acc_of_hinge_wrt_hub
 -->  22     1.2.6.1.4      hub_rates_in_rot_shaft
 -->  52     1.2.8.5        ang_vel_of_hinge_wrt_hub
--- CALLS ME:
 <--  47     1.2.8.1        abs_ang_acc_of_blade_in_rot_shaft
 <--  61     1.2.9.3        acc_of_hinge_wrt_hub_in_rot_shaft

 49     1.2.8.3        ang_acc_of_blade_wrt_hinge_in_rot_shaft
--- IN  PARAMS:
 -->  74     1.2.13.1       lag_acc_of_blade_in_rot_shaft
 -->  71     1.2.12.1       flap_acc_of_blade_in_rot_shaft
 -->  75     1.2.13.2       blade_lag_rate
 -->  72     1.2.12.2       blade_flap_rate
 -->  2      1.4.2          blade_lag_angle_xform_matrix
 -->  55     1.2.8.8        time_drv_of_lag_xform_matrix_in_rot_shaft
--- CALLS ME:
 <--  47     1.2.8.1        abs_ang_acc_of_blade_in_rot_shaft

 50     1.2.8.3.5      ang_acc_of_hub_in_hub_axis
--- IN  PARAMS:
 -->  14     1.5.6          body_ang_acc
 -->  5      1.4.5.1        body_to_hub_xform_matrix
--- CALLS ME:
 <--  51     1.2.8.4        ang_acc_of_hub_in_rot_shaft
 <--  71     1.2.12.1       flap_acc_of_blade_in_rot_shaft
 <--  74     1.2.13.1       lag_acc_of_blade_in_rot_shaft
```

```
 51      1.2.8.4          ang_acc_of_hub_in_rot_shaft
--- IN  PARAMS:
 -->  50      1.2.8.3.5       ang_acc_of_hub_in_hub_axis
 -->  0       1.4.1           hub_to_rot_shaft_xform_matrix
--- CALLS ME:
 <--  48      1.2.8.2         abs_ang_acc_of_hinge_in_rot_shaft

 52      1.2.8.5          ang_vel_of_hinge_wrt_hub
--- IN  PARAMS:
--- CALLS ME:
 <--  23      1.2.6.1.4.2     abs_ang_vel_of_hinge_in_rot_shaft
 <--  48      1.2.8.2         abs_ang_acc_of_hinge_in_rot_shaft

 53      1.2.8.6          ang_acc_of_hinge_wrt_hub
--- IN  PARAMS:
--- CALLS ME:
 <--  48      1.2.8.2         abs_ang_acc_of_hinge_in_rot_shaft

 54      1.2.8.7          ang_vel_of_blade_wrt_hinge_in_rot_shaft
--- IN  PARAMS:
 -->  2       1.4.2           blade_lag_angle_xform_matrix
 -->  75      1.2.13.2        blade_lag_rate
 -->  72      1.2.12.2        blade_flap_rate
--- CALLS ME:
 <--  47      1.2.8.1         abs_ang_acc_of_blade_in_rot_shaft
 <--  56      1.2.8.9         abs_ang_vel_of_blade_in_rot_shaft

 55      1.2.8.8          time_drv_of_lag_xform_matrix_in_rot_shaft
--- IN  PARAMS:
 -->  76      1.2.13.3        blade_lag_angle
 -->  75      1.2.13.2        blade_lag_rate
--- CALLS ME:
 <--  49      1.2.8.3         ang_acc_of_blade_wrt_hinge_in_rot_shaft

 56      1.2.8.9          abs_ang_vel_of_blade_in_rot_shaft
--- IN  PARAMS:
 -->  54      1.2.8.7         ang_vel_of_blade_wrt_hinge_in_rot_shaft
 -->  23      1.2.6.1.4.2     abs_ang_vel_of_hinge_in_rot_shaft
--- CALLS ME:
 <--  57      1.2.8.10        abs_ang_vel_of_blade_in_blade_span
 <--  60      1.2.9.2         acc_of_blade_wrt_hinge_in_rot_shaft

 57      1.2.8.10         abs_ang_vel_of_blade_in_blade_span
--- IN  PARAMS:
 -->  56      1.2.8.9         abs_ang_vel_of_blade_in_rot_shaft
 -->  8       1.4.7.1         rot_shaft_to_blade_span_xform_matrix
--- CALLS ME:
 <--  71      1.2.12.1        flap_acc_of_blade_in_rot_shaft
 <--  74      1.2.13.1        lag_acc_of_blade_in_rot_shaft

 58      1.2.8.11         abs_ang_acc_of_blade_in_blade_span
--- IN  PARAMS:
 -->  47      1.2.8.1         abs_ang_acc_of_blade_in_rot_shaft
 -->  8       1.4.7.1         rot_shaft_to_blade_span_xform_matrix
```

```
--- CALLS ME:
 <--  71     1.2.12.1       flap_acc_of_blade_in_rot_shaft
 <--  74     1.2.13.1       lag_acc_of_blade_in_rot_shaft

 59     1.2.9.1        acc_of_blade_in_rot_shaft
--- IN  PARAMS:
 -->  60     1.2.9.2        acc_of_blade_wrt_hinge_in_rot_shaft
 -->  61     1.2.9.3        acc_of_hinge_wrt_hub_in_rot_shaft
 -->  62     1.2.9.4        abs_acc_of_hub_in_rot_shaft
--- CALLS ME:
 <--  70     1.2.11.7       inertial_shears_per_blade_in_rot_shaft

 60     1.2.9.2        acc_of_blade_wrt_hinge_in_rot_shaft
--- IN  PARAMS:
 -->  47     1.2.8.1        abs_ang_acc_of_blade_in_rot_shaft
 -->  56     1.2.8.9        abs_ang_vel_of_blade_in_rot_shaft
 -->  73     1.2.12.3       blade_flap_angle
 -->  76     1.2.13.3       blade_lag_angle
--- CALLS ME:
 <--  59     1.2.9.1        acc_of_blade_in_rot_shaft

 61     1.2.9.3        acc_of_hinge_wrt_hub_in_rot_shaft
--- IN  PARAMS:
 -->  48     1.2.8.2        abs_ang_acc_of_hinge_in_rot_shaft
 -->  23     1.2.6.1.4.2    abs_ang_vel_of_hinge_in_rot_shaft
--- CALLS ME:
 <--  59     1.2.9.1        acc_of_blade_in_rot_shaft
 <--  63     1.2.9.5        abs_acc_of_hinge_in_rot_shaft

 62     1.2.9.4        abs_acc_of_hub_in_rot_shaft
--- IN  PARAMS:
 -->  0      1.4.1          hub_to_rot_shaft_xform_matrix
 -->  5      1.4.5.1        body_to_hub_xform_matrix
 -->  43     1.2.7.1        hub_acc_in_body_axis
--- CALLS ME:
 <--  59     1.2.9.1        acc_of_blade_in_rot_shaft
 <--  63     1.2.9.5        abs_acc_of_hinge_in_rot_shaft

 63     1.2.9.5        abs_acc_of_hinge_in_rot_shaft
--- IN  PARAMS:
 -->  61     1.2.9.3        acc_of_hinge_wrt_hub_in_rot_shaft
 -->  62     1.2.9.4        abs_acc_of_hub_in_rot_shaft
--- CALLS ME:
 <--  64     1.2.9.6        abs_acc_of_hinge_in_blade_span

 64     1.2.9.6        abs_acc_of_hinge_in_blade_span
--- IN  PARAMS:
 -->  63     1.2.9.5        abs_acc_of_hinge_in_rot_shaft
 -->  8      1.4.7.1        rot_shaft_to_blade_span_xform_matrix
--- CALLS ME:
 <--  71     1.2.12.1       flap_acc_of_blade_in_rot_shaft
 <--  74     1.2.13.1       lag_acc_of_blade_in_rot_shaft

 65     1.2.11.1       main_rotor_force_in_body_axis
```

```
--- IN  PARAMS:
 -->  4       1.4.5         hub_to_body_xform_matrix
 -->  66      1.2.11.2      main_rotor_filtered_forces
--- CALLS ME:

 66      1.2.11.2      main_rotor_filtered_forces
--- IN  PARAMS:
--- CALLS ME:
 <--  65      1.2.11.1      main_rotor_force_in_body_axis
 <--  86      1.2.14.5      rotor_hub_moments_in_body_axis

 67      1.2.11.3      total_blade_force_in_rot_shaft
--- IN  PARAMS:
 -->  68      1.2.11.4      aero_shear_per_blade_in_rot_shaft
 -->  70      1.2.11.7      inertial_shears_per_blade_in_rot_shaft
--- CALLS ME:

 68      1.2.11.4      aero_shear_per_blade_in_rot_shaft
--- IN  PARAMS:
 -->  7       1.4.7         blade_span_to_rot_shaft_xform_matrix
--- CALLS ME:
 <--  67      1.2.11.3      total_blade_force_in_rot_shaft

 69      1.2.11.6.1    segment_aero_shear_forces
--- IN  PARAMS:
 -->  6       1.4.6         vel_vector_to_segment_xform_matrix
 -->  40      1.2.3.3       segment_aero_coefficients
 -->  11      1.5.3         blade_segment_area
 -->  10      1.5.2         air_density
--- CALLS ME:

 70      1.2.11.7      inertial_shears_per_blade_in_rot_shaft
--- IN  PARAMS:
 -->  59      1.2.9.1       acc_of_blade_in_rot_shaft
--- CALLS ME:
 <--  67      1.2.11.3      total_blade_force_in_rot_shaft

 71      1.2.12.1      flap_acc_of_blade_in_rot_shaft
--- IN  PARAMS:
 -->  64      1.2.9.6       abs_acc_of_hinge_in_blade_span
 -->  57      1.2.8.10      abs_ang_vel_of_blade_in_blade_span
 -->  58      1.2.8.11      abs_ang_acc_of_blade_in_blade_span
 -->  84      1.2.14.2      total_external_blade_moment
 -->  50      1.2.8.3.5     ang_acc_of_hub_in_hub_axis
 -->  75      1.2.13.2      blade_lag_rate
 -->  76      1.2.13.3      blade_lag_angle
--- CALLS ME:
 <--  49      1.2.8.3       ang_acc_of_blade_wrt_hinge_in_rot_shaft
 <--  72      1.2.12.2      blade_flap_rate
 <--  73      1.2.12.3      blade_flap_angle

 72      1.2.12.2      blade_flap_rate
--- IN  PARAMS:
 -->  72      1.2.12.2      blade_flap_rate
```

```
 --> 71     1.2.12.1       flap_acc_of_blade_in_rot_shaft
--- CALLS ME:
 <-- 35     1.2.6.1.5      segment_flap_vel
 <-- 49     1.2.8.3        ang_acc_of_blade_wrt_hinge_in_rot_shaft
 <-- 54     1.2.8.7        ang_vel_of_blade_wrt_hinge_in_rot_shaft
 <-- 72     1.2.12.2       blade_flap_rate
 <-- 73     1.2.12.3       blade_flap_angle
 <-- 74     1.2.13.1       lag_acc_of_blade_in_rot_shaft
 <-- 78     1.2.13.5       lag_damper_force
 <-- 82     1.2.13.9       flapping_moments_due_to_flap_damper
 <-- 84     1.2.14.2       total_external_blade_moment

 73     1.2.12.3       blade_flap_angle
--- IN  PARAMS:
 --> 72     1.2.12.2       blade_flap_rate
 --> 73     1.2.12.3       blade_flap_angle
 --> 71     1.2.12.1       flap_acc_of_blade_in_rot_shaft
--- CALLS ME:
 <-- 3      1.4.3          blade_flap_angle_xform_matrix
 <-- 7      1.4.7          blade_span_to_rot_shaft_xform_matrix
 <-- 8      1.4.7.1        rot_shaft_to_blade_span_xform_matrix
 <-- 34     1.2.6.1.4.1    segment_lag_vel
 <-- 42     1.2.10.4       segment_geometric_pitch_angle
 <-- 60     1.2.9.2        acc_of_blade_wrt_hinge_in_rot_shaft
 <-- 73     1.2.12.3       blade_flap_angle
 <-- 74     1.2.13.1       lag_acc_of_blade_in_rot_shaft
 <-- 77     1.2.13.4       lag_damper_displacement
 <-- 78     1.2.13.5       lag_damper_force
 <-- 79     1.2.13.6       lagging_moments_due_to_lag_damper
 <-- 82     1.2.13.9       flapping_moments_due_to_flap_damper
 <-- 84     1.2.14.2       total_external_blade_moment

 74     1.2.13.1       lag_acc_of_blade_in_rot_shaft
--- IN  PARAMS:
 --> 64     1.2.9.6        abs_acc_of_hinge_in_blade_span
 --> 57     1.2.8.10       abs_ang_vel_of_blade_in_blade_span
 --> 58     1.2.8.11       abs_ang_acc_of_blade_in_blade_span
 --> 84     1.2.14.2       total_external_blade_moment
 --> 50     1.2.8.3.5      ang_acc_of_hub_in_hub_axis
 --> 75     1.2.13.2       blade_lag_rate
 --> 76     1.2.13.3       blade_lag_angle
 --> 73     1.2.12.3       blade_flap_angle
 --> 72     1.2.12.2       blade_flap_rate
--- CALLS ME:
 <-- 49     1.2.8.3        ang_acc_of_blade_wrt_hinge_in_rot_shaft
 <-- 75     1.2.13.2       blade_lag_rate
 <-- 76     1.2.13.3       blade_lag_angle

 75     1.2.13.2       blade_lag_rate
--- IN  PARAMS:
 --> 75     1.2.13.2       blade_lag_rate
 --> 74     1.2.13.1       lag_acc_of_blade_in_rot_shaft
--- CALLS ME:
 <-- 34     1.2.6.1.4.1    segment_lag_vel
```

```
 <--  49      1.2.8.3        ang_acc_of_blade_wrt_hinge_in_rot_shaft
 <--  54      1.2.8.7        ang_vel_of_blade_wrt_hinge_in_rot_shaft
 <--  55      1.2.8.8        time_drv_of_lag_xform_matrix_in_rot_shaft
 <--  71      1.2.12.1       flap_acc_of_blade_in_rot_shaft
 <--  74      1.2.13.1       lag_acc_of_blade_in_rot_shaft
 <--  75      1.2.13.2       blade_lag_rate
 <--  76      1.2.13.3       blade_lag_angle
 <--  78      1.2.13.5       lag_damper_force

 76     1.2.13.3        blade_lag_angle
--- IN  PARAMS:
 -->  75      1.2.13.2       blade_lag_rate
 -->  74      1.2.13.1       lag_acc_of_blade_in_rot_shaft
 -->  76      1.2.13.3       blade_lag_angle
--- CALLS ME:
 <--  2       1.4.2          blade_lag_angle_xform_matrix
 <--  7       1.4.7          blade_span_to_rot_shaft_xform_matrix
 <--  8       1.4.7.1        rot_shaft_to_blade_span_xform_matrix
 <--  41      1.2.10.5       segment_dynamic_pitch
 <--  42      1.2.10.4       segment_geometric_pitch_angle
 <--  55      1.2.8.8        time_drv_of_lag_xform_matrix_in_rot_shaft
 <--  60      1.2.9.2        acc_of_blade_wrt_hinge_in_rot_shaft
 <--  71      1.2.12.1       flap_acc_of_blade_in_rot_shaft
 <--  74      1.2.13.1       lag_acc_of_blade_in_rot_shaft
 <--  76      1.2.13.3       blade_lag_angle
 <--  77      1.2.13.4       lag_damper_displacement
 <--  78      1.2.13.5       lag_damper_force
 <--  87      1.2.14.6       delta_moments

 77     1.2.13.4        lag_damper_displacement
--- IN  PARAMS:
 -->  42      1.2.10.4       segment_geometric_pitch_angle
 -->  73      1.2.12.3       blade_flap_angle
 -->  76      1.2.13.3       blade_lag_angle
--- CALLS ME:
 <--  78      1.2.13.5       lag_damper_force
 <--  79      1.2.13.6       lagging_moments_due_to_lag_damper
 <--  80      1.2.13.7       lagging_moments_due_to_flap_damper

 78     1.2.13.5        lag_damper_force
--- IN  PARAMS:
 -->  77      1.2.13.4       lag_damper_displacement
 -->  42      1.2.10.4       segment_geometric_pitch_angle
 -->  73      1.2.12.3       blade_flap_angle
 -->  76      1.2.13.3       blade_lag_angle
 -->  72      1.2.12.2       blade_flap_rate
 -->  75      1.2.13.2       blade_lag_rate
--- CALLS ME:
 <--  79      1.2.13.6       lagging_moments_due_to_lag_damper
 <--  80      1.2.13.7       lagging_moments_due_to_flap_damper

 79     1.2.13.6        lagging_moments_due_to_lag_damper
--- IN  PARAMS:
 -->  78      1.2.13.5       lag_damper_force
```

```
  -->  42      1.2.10.4        segment_geometric_pitch_angle
  -->  73      1.2.12.3        blade_flap_angle
  -->  77      1.2.13.4        lag_damper_displacement
--- CALLS ME:
  <--  84      1.2.14.2        total_external_blade_moment
  <--  87      1.2.14.6        delta_moments

 80      1.2.13.7        lagging_moments_due_to_flap_damper
--- IN  PARAMS:
  -->  77      1.2.13.4        lag_damper_displacement
  -->  78      1.2.13.5        lag_damper_force
  -->  42      1.2.10.4        segment_geometric_pitch_angle
--- CALLS ME:
  <--  84      1.2.14.2        total_external_blade_moment
  <--  87      1.2.14.6        delta_moments

 81      1.2.13.8        flapping_moments_due_to_lag_damper
--- IN  PARAMS:
--- CALLS ME:
  <--  84      1.2.14.2        total_external_blade_moment
  <--  87      1.2.14.6        delta_moments

 82      1.2.13.9        flapping_moments_due_to_flap_damper
--- IN  PARAMS:
  -->  73      1.2.12.3        blade_flap_angle
  -->  72      1.2.12.2        blade_flap_rate
--- CALLS ME:
  <--  84      1.2.14.2        total_external_blade_moment
  <--  87      1.2.14.6        delta_moments

 83      1.2.14.1        aero_moments_wrt_hinge_in_blade_span
--- IN  PARAMS:
--- CALLS ME:
  <--  84      1.2.14.2        total_external_blade_moment

 84      1.2.14.2        total_external_blade_moment
--- IN  PARAMS:
  -->  83      1.2.14.1        aero_moments_wrt_hinge_in_blade_span
  -->  82      1.2.13.9        flapping_moments_due_to_flap_damper
  -->  81      1.2.13.8        flapping_moments_due_to_lag_damper
  -->  80      1.2.13.7        lagging_moments_due_to_flap_damper
  -->  79      1.2.13.6        lagging_moments_due_to_lag_damper
  -->  72      1.2.12.2        blade_flap_rate
  -->  73      1.2.12.3        blade_flap_angle
--- CALLS ME:
  <--  71      1.2.12.1        flap_acc_of_blade_in_rot_shaft
  <--  74      1.2.13.1        lag_acc_of_blade_in_rot_shaft

 85      1.2.14.4        rotor_filtered_moments
--- IN  PARAMS:
--- CALLS ME:
  <--  86      1.2.14.5        rotor_hub_moments_in_body_axis

 86      1.2.14.5        rotor_hub_moments_in_body_axis
```

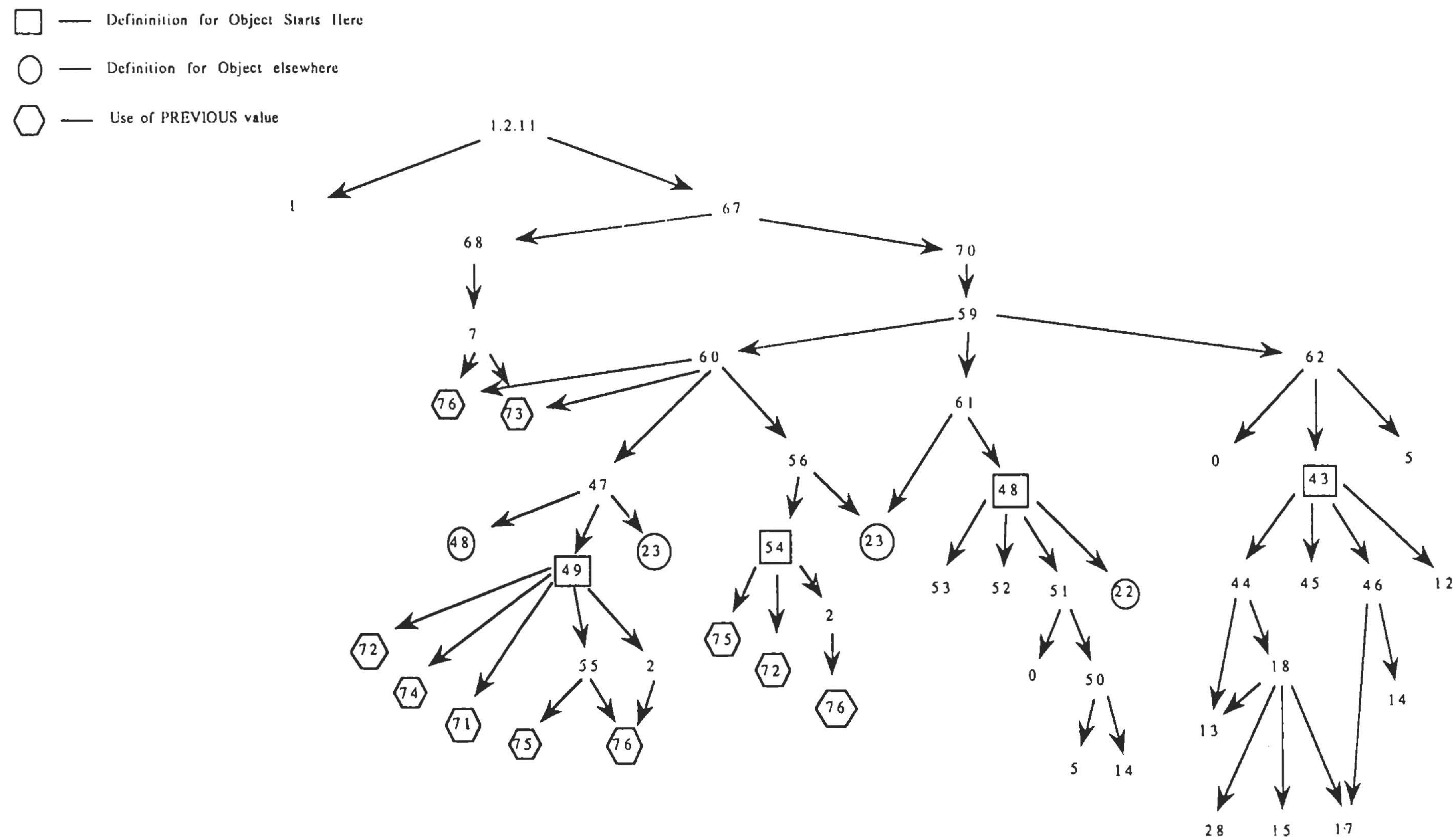
```
--- IN  PARAMS:
 -->  85      1.2.14.4        rotor_filtered_moments
 -->  4       1.4.5           hub_to_body_xform_matrix
 -->  17      1.5.9           hub_offsets
 -->  66      1.2.11.2        main_rotor_filtered_forces
--- CALLS ME:

 87     1.2.14.6        delta_moments
--- IN  PARAMS:
 -->  82      1.2.13.9        flapping_moments_due_to_flap_damper
 -->  81      1.2.13.8        flapping_moments_due_to_lag_damper
 -->  80      1.2.13.7        lagging_moments_due_to_flap_damper
 -->  79      1.2.13.6        lagging_moments_due_to_lag_damper
 -->  76      1.2.13.3        blade_lag_angle
--- CALLS ME:
```

0	1.4.1	hub_to_rot_shaft_xform_matrix
1	1.4.1.1	rot_shaft_to_hub_xform_matrix
2	1.4.2	blade_lag_angle_xform_matrix
3	1.4.3	blade_flap_angle_xform_matrix
4	1.4.5	hub_to_body_xform_matrix
5	1.4.5.1	body_to_hub_xform_matrix
6	1.4.6	vel_vector_to_segment_xform_matrix
7	1.4.7	blade_span_to_rot_shaft_xform_matrix
8	1.4.7.1	rot_shaft_to_blade_span_xform_matrix
9	1.5.1	vel_of_sound
10	1.5.2	air_density
11	1.5.3	blade_segment_area
12	1.5.4	translational_acc_of_body
13	1.5.5	body_rates
14	1.5.6	body_ang_acc
15	1.5.7	body_vel
16	1.5.8	weight_coefficients_for_torsion
17	1.5.9	hub_offsets
18	1.2.6.1	hub_vel_in_body_axis
19	1.2.6.3	hub_vel_in_hub_axis
20	1.2.6.5	rot_shaft_vel
21	1.2.6.9	hub_rates_in_hub_axis
22	1.2.6.1.4	hub_rates_in_rot_shaft
23	1.2.6.1.4.2	abs_ang_vel_of_hinge_in_rot_shaft
24	1.2.6.1.2	hinge_vel_in_blade_span
25	1.2.6.1.2.1	hinge_vel_in_rot_shaft
26	1.2.6.1.3	segment_vel_in_blade_span_due_to_hub_rates
27	1.2.6.1.3.1	hub_rates_in_blade_span
28	1.3	segment_gust_vel
29	1.3.1	segment_upwash_vel
30	1.3.2	segment_downwash_vel
31	1.3.3	segment_interference_vel
32	1.2.6.7	body_vel_in_blade_span
33	1.2.6.1.7	segment_vel_in_blade_span
34	1.2.6.1.4.1	segment_lag_vel
35	1.2.6.1.5	segment_flap_vel
36	1.2.10.3	total_segment_pitch_angle
37	1.2.10.1	segment_angle_of_attack
38	1.2.10.1.1	segment_yaw_angle_of_flow
39	1.2.10.0.5	segment_mach
40	1.2.3.3	segment_aero_coefficients
41	1.2.10.5	segment_dynamic_pitch
42	1.2.10.4	segment_geometric_pitch_angle
43	1.2.7.1	hub_acc_in_body_axis
44	1.2.7.1.1	centrifugal_acc_of_hub
45	1.2.7.1.2	gust_acc_of_hub
46	1.2.7.1.3	tangential_acc_of_hub
47	1.2.8.1	abs_ang_acc_of_blade_in_rot_shaft
48	1.2.8.2	abs_ang_acc_of_hinge_in_rot_shaft
49	1.2.8.3	ang_acc_of_blade_wrt_hinge_in_rot_shaft
50	1.2.8.3.5	ang_acc_of_hub_in_hub_axis
51	1.2.8.4	ang_acc_of_hub_in_rot_shaft
52	1.2.8.5	ang_vel_of_hinge_wrt_hub

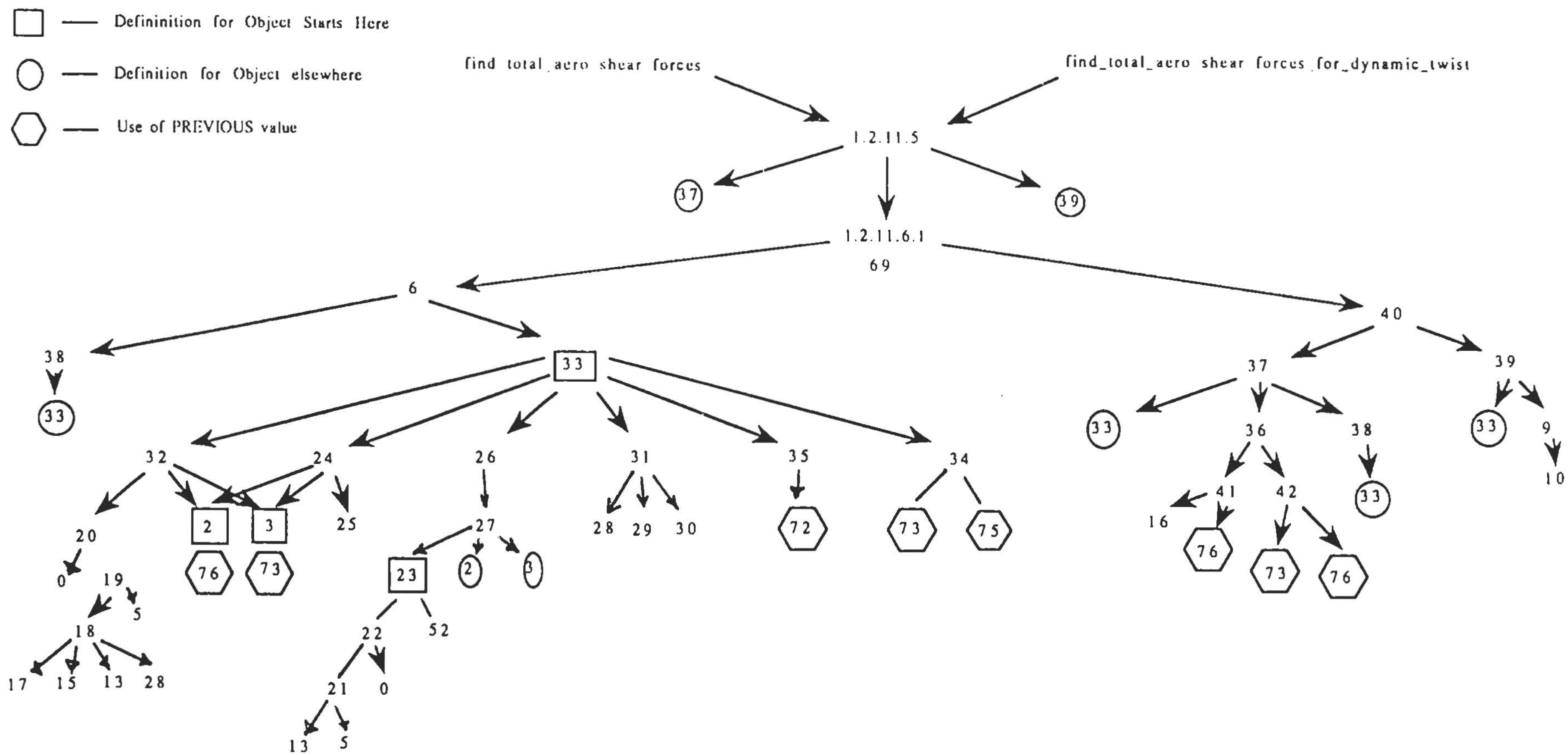
53	1.2.8.6	ang_acc_of_hinge_wrt_hub
54	1.2.8.7	ang_vel_of_blade_wrt_hinge_in_rot_shaft
55	1.2.8.8	time_drv_of_lag_xform_matrix_in_rot_shaft
56	1.2.8.9	abs_ang_vel_of_blade_in_rot_shaft
57	1.2.8.10	abs_ang_vel_of_blade_in_blade_span
58	1.2.8.11	abs_ang_acc_of_blade_in_blade_span
59	1.2.9.1	acc_of_blade_in_rot_shaft
60	1.2.9.2	acc_of_blade_wrt_hinge_in_rot_shaft
61	1.2.9.3	acc_of_hinge_wrt_hub_in_rot_shaft
62	1.2.9.4	abs_acc_of_hub_in_rot_shaft
63	1.2.9.5	abs_acc_of_hinge_in_rot_shaft
64	1.2.9.6	abs_acc_of_hinge_in_blade_span
65	1.2.11.1	main_rotor_force_in_body_axis
66	1.2.11.2	main_rotor_filtered_forces
67	1.2.11.3	total_blade_force_in_rot_shaft
68	1.2.11.4	aero_shear_per_blade_in_rot_shaft
69	1.2.11.6.1	segment_aero_shear_forces
70	1.2.11.7	inertial_shears_per_blade_in_rot_shaft
71	1.2.12.1	flap_acc_of_blade_in_rot_shaft
72	1.2.12.2	blade_flap_rate
73	1.2.12.3	blade_flap_angle
74	1.2.13.1	lag_acc_of_blade_in_rot_shaft
75	1.2.13.2	blade_lag_rate
76	1.2.13.3	blade_lag_angle
77	1.2.13.4	lag_damper_displacement
78	1.2.13.5	lag_damper_force
79	1.2.13.6	lagging_moments_due_to_lag_damper
80	1.2.13.7	lagging_moments_due_to_flap_damper
81	1.2.13.8	flapping_moments_due_to_lag_damper
82	1.2.13.9	flapping_moments_due_to_flap_damper
83	1.2.14.1	aero_moments_wrt_hinge_in_blade_span
84	1.2.14.2	total_external_blade_moment
85	1.2.14.4	rotor_filtered_moments
86	1.2.14.5	rotor_hub_moments_in_body_axis
87	1.2.14.6	delta_moments

Appendix E -

Module Dependency Graphs



Defininition for Object Starts Here
Definition for Object elsewhere
Use of PREVIOUS value
1.2.11
1
67
68
70
7
59
60
61
62
76
73
47
56
48
0
43
5
48
49
23
54
23
53
52
51
22
44
45
46
12
72
74
71
55
2
75
72
2
76
0
50
18
13
14
75
76
5
14
28
15
17


Defininition for Object Starts Here
Definition for Object elsewhere
Use of PREVIOUS value
find total aero shear forces
find_total_aero shear forces for_dynamic_twist
1.2.11.5
37
39
1.2.11.6.1
69
6
40
38
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32
24
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35
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5

Appendix F -

Rotor Object Test Inputs

The following pages contain the input values necessary for a complete calculation of the rotor object. The input data is divided into three categories:

- Input_List data: These are the values which are passed during each simulation cycle by the Helicopter object during its invocation of the rotor object. A record has been created which contains all the data needed by the rotor simulation.

- Initial Values: These values are calculated during normal rotor object execution, but if the modules are being run one-at-a-time for unit test, these values must be specifically initialized.

- Constants: These are values which are would be initialized in the configuration package for the rotor object. They are listed here since the library modules weren't set up with a configuration package.

```
-- pass in unit test initial data
        Input_List.Body_Ang_Acc := Make_Vector (0.0, 0.0, 0.0);
        Input_List.Body_Rates := Make_Vector (0.0, 2.618E-3, 0.0);
        Input_List.Body_Vel := Make_Vector (0.0, 0.0, 0.0);

        Input_List.Collective_Blade_Pitch := 0.28448; -- radians

        Input_List.Delta_Blade_Azimuth := 6.276897E-01; --radians
        Input_List.Rotor_Ang_Vel := 27.0; -- 2.827433367;  --radians/sec
        Input_List.Rotor_Ang_Acc := 0.000000E+00;  --radians/sec^2

        Input_List.Lateral_Cyclic_Blade_Pitch := 0.0;
        Input_List.Logitudinal_Cyclic_Blade_Pitch := 0.0;

        Input_List.Blade (1).Blade_Azimuth := 0.0;

        Input_List.Blade (2).Blade_Azimuth := Pi / 2.0;

        Input_List.Blade (3).Blade_Azimuth := Pi;

        Input_List.Blade (4).Blade_Azimuth := 3.0 * Pi / 2.0;
```

```
-- initial time variables that relate to the integration steps

      Main_Rotor.Blade (1).Blade_Flap_Angle := 7.247000E-03;
      Main_Rotor.Blade (1).Blade_Flap_Rate := -6.530000E-01;
      Main_Rotor.Blade (1).Blade_Lag_Angle := -6.544000E-02;
      Main_Rotor.Blade (1).Blade_Lag_Rate := -5.784000E-02;
      Main_Rotor.Blade (2).Blade_Flap_Angle := 2.250000E-02;
      Main_Rotor.Blade (2).Blade_Flap_Rate := 1.059000E+00;
      Main_Rotor.Blade (2).Blade_Lag_Angle := -6.513000E-02;
      Main_Rotor.Blade (2).Blade_Lag_Rate := 3.785000E-02;
      Main_Rotor.Blade (3).Blade_Flap_Angle := 8.315000E-02;
      Main_Rotor.Blade (3).Blade_Flap_Rate := 5.815000E-01;
      Main_Rotor.Blade (3).Blade_Lag_Angle := -6.176000E-02;
      Main_Rotor.Blade (3).Blade_Lag_Rate := 7.888000E-02;
      Main_Rotor.Blade (4).Blade_Flap_Angle := 6.821000E-02;
      Main_Rotor.Blade (4).Blade_Flap_Rate := -9.880000E-01;
      Main_Rotor.Blade (4).Blade_Lag_Angle := -6.004000E-02;
      Main_Rotor.Blade (4).Blade_Lag_Rate := -6.004000E-02;

      -- Constants for the rotor based on characteristics

      Main_Rotor.Constants.Segment_Geom_Pitch_Vel := 0.001; -- needs to be
      -- determined

      Main_Rotor.Constants.Blade_Root_Chord := 1.73;
      Main_Rotor.Constants.Blade_Top_Chord := 1.73;
      Main_Rotor.Constants.Blade_Moment_Of_Inertia_About_Hinge := 1512.6;

      Main_Rotor.Constants.Flapping_Damper_Rate := 0.0; --
      Main_Rotor.Constants.Flapping_Spring_Stiffness := 0.0;
      Main_Rotor.Constants.Gravitational_Acc := 32.2;
      Main_Rotor.Constants.Hinge_Angle_Coefficient := 0.0;
      Main_Rotor.Constants.Hinge_Offset := 1.25;

      Main_Rotor.Constants.Hub_Inclination_Phi := 0.0;
      Main_Rotor.Constants.Hub_Inclination_Theta := -0.0524; -- rad


      Main_Rotor.Constants.Hub_Offsets :=
         Make_Vector (2.061094, 0.0, -5.559615);

      Main_Rotor.Constants.Lag_Damper_Connection_Segment := 3;
      Main_Rotor.Constants.Lag_Damper_Geom_A := 0.227;
      Main_Rotor.Constants.Lag_Damper_Geom_B := 3.242;
      Main_Rotor.Constants.Lag_Damper_Geom_C := 12.040;
      Main_Rotor.Constants.Lag_Damper_Geom_D := 10.0102;
      Main_Rotor.Constants.Lag_Damper_Geom_Delta := 0.12217; --rad (7.0 deg)
      Main_Rotor.Constants.Lag_Damper_Geom_R := 6.898;
      Main_Rotor.Constants.Lag_Damper_Geom_Theta :=
         0.30510; --rad (17.481 deg)
      Main_Rotor.Constants.Mass_Of_Blade := 86.7;
      Main_Rotor.Constants.Blade_Center_Of_Mass := 10.4;

      Main_Rotor.Constants.Pitch_Lag_Coupling_Coefficient := 0.0;
```

```
Main_Rotor.Constants.Tip_Radius := 26.83;
Main_Rotor.Constants.Spar_Offset := 3.83;

Main_Rotor.Swashplate_Phase_Angle := -0.15707; -- rad (-9 deg)

Main_Rotor.Weight_Coefficients_For_Torsion :=
   Make_Vector (-0.0004, 0.0, 0.0);
```

Appendix G

Rotor Object Test Output

Two separate listings follow. The first listing is the output file created by the unit test procedure. It names output states only by their state number (i.e. "27" instead of "hub_rates_in_blade_span"). The second listing was generated by processing the first listing with a *lex* program (Lex is a Unix parser-building tool). When the lex program ran, it looked for entries like "27<=" and replaced them with the actual variable name (like "hub_rates_in_blade_span :="). The lex tool was used to make output listings easier to understand.

```
4<=
 9.9863E-01,  0.0000E+00, -5.2376E-02,
 0.0000E+00,  1.0000E+00,  5.2376E-02,
 5.2376E-02,  0.0000E+00,  9.9863E-01,

1<=
 1.1795E-08, -1.0000E+00,  0.0000E+00,
 1.0000E+00,  1.1795E-08,  0.0000E+00,
 0.0000E+00,  0.0000E+00,  1.0000E+00,

7<=
 9.9786E-01, -6.5392E-02, -4.7390E-04,
 6.5393E-02,  9.9783E-01,  7.2314E-03,
 0.0000E+00, -7.2469E-03,  9.9997E-01,

2<=
 9.9786E-01,  6.5393E-02,  0.0000E+00,
-6.5393E-02,  9.9786E-01,  0.0000E+00,
 0.0000E+00,  0.0000E+00,  1.0000E+00,

3<=
 1.0000E+00,  0.0000E+00,  0.0000E+00,
 0.0000E+00,  9.9997E-01, -7.2469E-03,
 0.0000E+00,  7.2469E-03,  9.9997E-01,

0<=
 1.1795E-08,  1.0000E+00,  0.0000E+00,
-1.0000E+00,  1.1795E-08,  0.0000E+00,
 0.0000E+00,  0.0000E+00,  1.0000E+00,

18<= (-2.0092E-05,  0.0000E+00, -7.4487E-06 )
5<=
 9.9863E-01,  0.0000E+00,  5.2376E-02,
 0.0000E+00,  1.0000E+00,  0.0000E+00,
-5.2376E-02,  5.2376E-02,  9.9863E-01,

19<= (-2.0455E-05,  0.0000E+00, -6.3862E-06 )
20<= (-2.4126E-13,  2.0455E-05, -6.3862E-06 )
32<= ( 1.3406E-06,  2.0457E-05, -6.2378E-06 )
21<=  ( 0.0000E+00,  2.6180E-03,  1.3712E-04 )
22<=  ( 2.6180E-03,  3.0879E-11,  1.3712E-04 )
52<= ( 0.0000E+00,  0.0000E+00, -2.7000E+01 )
23<=  ( 2.6180E-03,  3.0879E-11, -2.7000E+01 )
25<= ( 4.6589E-02,  0.0000E+00,  4.5175E-06 )
24<= ( 4.6490E-02, -3.0467E-03,  4.5174E-06 )
27<= ( 2.6124E-03,  1.9550E-01, -2.6999E+01 )
26<= ( 3.1708E-01,  0.0000E+00,  3.0680E-05 )
31<= ( 0.0000E+00,  0.0000E+00,  0.0000E+00 )
35<= ( 0.0000E+00,  0.0000E+00, -2.2980E-03 )
```

```
34<= (-1.8340E-02,  0.0000E+00,  0.0000E+00 )
33<= ( 3.4523E-01, -3.0262E-03, -2.2690E-03 )
38<= 9.9996E-01
6<=
 1.1919E-01,  0.0000E+00,  7.8336E-04,
-1.0448E-03,  0.0000E+00, -6.8667E-06,
-7.8339E-04,  0.0000E+00,  1.1920E-01,

9<= 2.3640E-03 1.1157E+03
39<= 2.2417E-01
41<= 0.0000E+00
42<= 2.8495E-01 /* CRL ooops */
36<= 2.4787E-01
37<= 2.4129E-01
40<= ( 1.3458E-01,  0.0000E+00,  1.1131E+00 )
69<= ( 1.1406E+04, -9.9982E+01,  8.9410E+04 )
26<= ( 5.2356E-01,  0.0000E+00,  5.0659E-05 )
31<= ( 0.0000E+00,  0.0000E+00,  0.0000E+00 )
35<= ( 0.0000E+00,  0.0000E+00, -3.7944E-03 )
34<= (-3.0283E-02,  0.0000E+00,  0.0000E+00 )
33<= ( 5.3977E-01, -3.0262E-03, -3.7455E-03 )
38<= 9.9998E-01
39<= 3.5049E-01
41<= 0.0000E+00
42<= 2.8495E-01
36<= 1.8546E-01

100<= ( 5.1537E+04, -2.4481E+04,  2.3749E+06 )
66<= ( 5.1537E+04, -2.4481E+04,  2.3749E+06 )
65<= (-7.2922E+04,  9.9907E+04,  2.3743E+06 )
82<= 0.0000E+00
77<= ( 1.5846E+01,  2.9137E+00,  3.3838E-01 )
78<= ( 0.0000E+00,  3.6600E+03,  0.0000E+00 )
81<=-4.2521E+02
80<= 0.0000E+00
79<=-3.2792E+04
87<= ( 2.7806E+01,  2.7806E+01, -3.2792E+04 )
82<= 0.0000E+00
105<= ( 6.4342E+04, -3.0668E+04,  2.8376E+06 )
85<= ( 6.4342E+04, -3.0668E+04,  2.8376E+06 )
86<= (-2.2047E+05, -5.0635E+06,  2.7866E+06 )
63<= (-3.9803E-08,  3.3684E+00, -3.2023E+01 )
8<=
 9.9786E-01,  6.5393E-02,  0.0000E+00,
-6.5392E-02,  9.9783E-01, -7.2469E-03,
-4.7390E-04,  7.2314E-03,  9.9997E-01,

64<= ( 2.2027E-01,  3.5932E+00, -3.1998E+01 )
571<= (-6.4480E-01,  2.8113E-01, -2.7056E+01 )
58<= ( 2.3056E+00,  1.7550E+01,  1.2730E-01 )
104<= ( 3.7014E+05, -1.9919E+03,  1.2772E+07 )
84<= (-1.2772E+07,  0.0000E+00,  4.0294E+05 )
72<=-5.2853E-01
73<=-4.2778E-01
```

```
74<= 2.6621E+02
75<= 5.7436E+00
76<= 1.0439E+01
71<=-8.4337E+03
102<= ( 5.9845E+05, -3.1032E+05, -7.5022E+05 )
103<= ( 1.4367E+05, -7.4565E+02,  2.3887E+06 )

final result:
(-7.2922E+04,  9.9907E+04,  2.3743E+06 )
```

```
---------------------------------------------------------------------------
!USERS.BHAWK.EXEC_FUNCTIONS % MAIN                        STARTED 4:03:07 PM
---------------------------------------------------------------------------

hub_to_body_xform_matrix :=
 9.9863E-01,  0.0000E+00, -5.2376E-02,
 0.0000E+00,  1.0000E+00,  5.2376E-02,
 5.2376E-02,  0.0000E+00,  9.9863E-01,

rot_shaft_to_hub_xform_matrix :=
 1.1795E-08, -1.0000E+00,  0.0000E+00,
 1.0000E+00,  1.1795E-08,  0.0000E+00,
 0.0000E+00,  0.0000E+00,  1.0000E+00,

blade_span_to_rot_shaft_xform_matrix :=
 9.9786E-01, -6.5392E-02, -4.7390E-04,
 6.5393E-02,  9.9783E-01,  7.2314E-03,
 0.0000E+00, -7.2469E-03,  9.9997E-01,

blade_lag_angle_xform_matrix :=
 9.9786E-01,  6.5393E-02,  0.0000E+00,
-6.5393E-02,  9.9786E-01,  0.0000E+00,
 0.0000E+00,  0.0000E+00,  1.0000E+00,

blade_flap_angle_xform_matrix :=
 1.0000E+00,  0.0000E+00,  0.0000E+00,
 0.0000E+00,  9.9997E-01, -7.2469E-03,
 0.0000E+00,  7.2469E-03,  9.9997E-01,

hub_to_rot_shaft_xform_matrix :=
 1.1795E-08,  1.0000E+00,  0.0000E+00,
-1.0000E+00,  1.1795E-08,  0.0000E+00,
 0.0000E+00,  0.0000E+00,  1.0000E+00,

hub_vel_in_body_axis :=  (-2.0092E-05,  0.0000E+00, -7.4487E-06 )
body_to_hub_xform_matrix :=
 9.9863E-01,  0.0000E+00,  5.2376E-02,
 0.0000E+00,  1.0000E+00,  0.0000E+00,
-5.2376E-02,  5.2376E-02,  9.9863E-01,

hub_vel_in_hub_axis :=  (-2.0455E-05,  0.0000E+00, -6.3862E-06 )
rot_shaft_vel :=  (-2.4126E-13,  2.0455E-05, -6.3862E-06 )
body_vel_in_blade_span :=  ( 1.3406E-06,  2.0457E-05, -6.2378E-06 )
hub_rates_in_hub_axis :=   ( 0.0000E+00,  2.6180E-03,  1.3712E-04 )
hub_rates_in_rot_shaft :=   ( 2.6180E-03,  3.0879E-11,  1.3712E-04 )
ang_vel_of_hinge_wrt_hub :=  ( 0.0000E+00,  0.0000E+00, -2.7000E+01 )
abs_ang_vel_of_hinge_in_rot_shaft :=   ( 2.6180E-03,  3.0879E-11, -2.7000E+01 )
hinge_vel_in_rot_shaft :=  ( 4.6589E-02,  0.0000E+00,  4.5175E-06 )
hinge_vel_in_blade_span :=  ( 4.6490E-02, -3.0467E-03,  4.5174E-06 )
hub_rates_in_blade_span :=  ( 2.6124E-03,  1.9550E-01, -2.6999E+01 )
segment_vel_in_blade_span_due_to_hub_rates :=  ( 3.1708E-01,  0.0000E+00,  3.068
0E-05 )
segment_interference_vel :=  ( 0.0000E+00,  0.0000E+00,  0.0000E+00 )
segment_flap_vel :=  ( 0.0000E+00,  0.0000E+00, -2.2980E-03 )
segment_lag_vel :=  (-1.8340E-02,  0.0000E+00,  0.0000E+00 )
segment_vel_in_blade_span :=  ( 3.4523E-01, -3.0262E-03, -2.2690E-03 )
segment_yaw_angle_of_flow :=  9.9996E-01
vel_vector_to_segment_xform_matrix :=
 1.1919E-01,  0.0000E+00,  7.8336E-04,
```

```
-1.0448E-03,  0.0000E+00, -6.8667E-06,
-7.8339E-04,  0.0000E+00,  1.1920E-01,

vel_of_sound :=  2.3640E-03 1.1157E+03
segment_mach :=  2.2417E-01
segment_dynamic_pitch :=  0.0000E+00
segment_geometric_pitch_angle :=  2.8495E-01    /* CRL ooops */
total_segment_pitch_angle :=  2.4787E-01
segment_angle_of_attack :=  2.4129E-01
segment_aero_coefficients :=  ( 1.3458E-01,  0.0000E+00,  1.1131E+00 )
segment_aero_shear_forces :=  ( 1.1406E+04, -9.9982E+01,  8.9410E+04 )
segment_vel_in_blade_span_due_to_hub_rates :=  ( 5.2356E-01,  0.0000E+00,  5.065
9E-05 )
segment_interference_vel :=  ( 0.0000E+00,  0.0000E+00,  0.0000E+00 )
segment_flap_vel :=  ( 0.0000E+00,  0.0000E+00, -3.7944E-03 )
segment_lag_vel :=  (-3.0283E-02,  0.0000E+00,  0.0000E+00 )
segment_vel_in_blade_span :=  ( 5.3977E-01, -3.0262E-03, -3.7455E-03 )
segment_yaw_angle_of_flow :=  9.9998E-01
segment_mach :=  3.5049E-01
segment_dynamic_pitch :=  0.0000E+00
segment_geometric_pitch_angle :=  2.8495E-01
total_segment_pitch_angle :=  1.8546E-01

10hub_to_rot_shaft_xform_matrix :=  ( 5.1537E+04, -2.4481E+04,  2.3749E+06 )
main_rotor_filtered_forces :=  ( 5.1537E+04, -2.4481E+04,  2.3749E+06 )
main_rotor_force_in_body_axis :=  (-7.2922E+04,  9.9907E+04,  2.3743E+06 )
flapping_moments_due_to_flap_damper :=  0.0000E+00
lag_damper_displacement :=  ( 1.5846E+01,  2.9137E+00,  3.3838E-01 )
lag_damper_force :=  ( 0.0000E+00,  3.6600E+03,  0.0000E+00 )
flapping_moments_due_to_lag_damper := -4.2521E+02
lagging_moments_due_to_flap_damper :=  0.0000E+00
lagging_moments_due_to_lag_damper := -3.2792E+04
delta_moments :=  ( 2.7806E+01,  2.7806E+01, -3.2792E+04 )
flapping_moments_due_to_flap_damper :=  0.0000E+00
10body_to_hub_xform_matrix :=  ( 6.4342E+04, -3.0668E+04,  2.8376E+06 )
rotor_filtered_moments :=  ( 6.4342E+04, -3.0668E+04,  2.8376E+06 )
rotor_hub_moments_in_body_axis :=  (-2.2047E+05, -5.0635E+06,  2.7866E+06 )
abs_acc_of_hinge_in_rot_shaft :=  (-3.9803E-08,  3.3684E+00, -3.2023E+01 )
rot_shaft_to_blade_span_xform_matrix :=
 9.9786E-01,  6.5393E-02,  0.0000E+00,
-6.5392E-02,  9.9783E-01, -7.2469E-03,
-4.7390E-04,  7.2314E-03,  9.9997E-01,

abs_acc_of_hinge_in_blade_span :=  ( 2.2027E-01,  3.5932E+00, -3.1998E+01 )
5flap_acc_of_blade_in_rot_shaft :=  (-6.4480E-01,  2.8113E-01, -2.7056E+01 )
abs_ang_acc_of_blade_in_blade_span :=  ( 2.3056E+00,  1.7550E+01,  1.2730E-01 )
10hub_to_body_xform_matrix :=  ( 3.7014E+05, -1.9919E+03,  1.2772E+07 )
total_external_blade_moment :=  (-1.2772E+07,  0.0000E+00,  4.0294E+05 )
blade_flap_rate := -5.2853E-01
blade_flap_angle := -4.2778E-01
lag_acc_of_blade_in_rot_shaft :=  2.6621E+02
blade_lag_rate :=  5.7436E+00
blade_lag_angle :=  1.0439E+01
flap_acc_of_blade_in_rot_shaft := -8.4337E+03
10blade_lag_angle_xform_matrix :=  ( 5.9845E+05, -3.1032E+05, -7.5022E+05 )
10blade_flap_angle_xform_matrix :=  ( 1.4367E+05, -7.4565E+02,  2.3887E+06 )

final result:
(-7.2922E+04,  9.9907E+04,  2.3743E+06 )
```