Risø-R-Report

How 2 HAWC2, the user's manual

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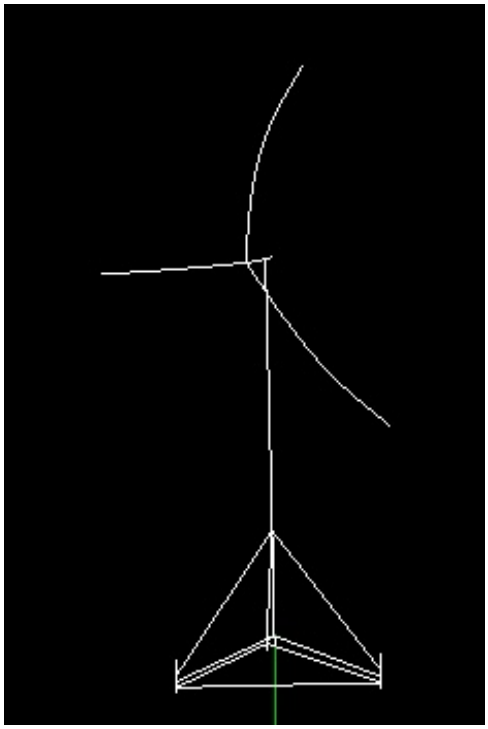
Risø-R-1597(ver. 4-1)(EN)



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Abstract (max. 2000 char.):

The report contains the user's manual for the aeroleastic code HAWC2. The code is intended for calculating wind turbine response in time domain and has a structural formulation based on multi-body dynamics. The aerodynamic part of the code is based on the blade element momentum theory, but extended from the classic approach to handle dynamic inflow, dynamic stall, skew inflow, shear effects on the induction and effects from large deflections. It has mainly been developed within the years 2003-2006 at the aeroelastic design research programme at Risoe, National laboratory Denmark, but is continously updated and improved.

This manual is updated for HAWC2 version 10.9

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Content

Preface

The HAWC2 code is a code intended for calculating wind turbine response in time domain. It has been developed within the years 2003-2006 at the aeroelastic design research programme at Risoe, National laboratory Denmark.

The structural part of the code is based on a multibody formulation where each body is an assembly of timoshenko beam elements. The formulation is general which means that quite complex structures can be handled and arbitrary large rotations of the bodies can be handled. The turbine is modeled by an assembly of bodies connected with constraint equations, where a constraint could be a rigid coupling, a bearing, a prescribed fixed bearing angle etc. The aerodynamic part of the code is based on the blade element momentum theory, but extended from the classic approach to handle dynamic inflow, dynamic stall, skew inflow, shear effects on the induction and effects from large deflections. Several turbulence formats can be used. Control of the turbine is performed through one or more DLL's (Dynamic Link Library). The format for these DLL's is also very general, which means that any possible output sensor normally used for data file output can also be used as a sensor to the DLL. This allows the same DLL format to be used whether a control of a bearing angle, an external force or moment is placed on the structure.

The code has internally at Risoe been tested against the older validated code HAWC, the CFD code Ellipsys and numerous measurements. Further on detailed verification is performed in the IEA annex 23 and annex 30 research project regarding offshore application.

During the programming of the code a lot of focus has been put in the input checking so hopefully meaningful error messages are written to the screen in case of lacking or obvious erroneous inputs. However since the code is still constantly improved we appreciate feedback from the users – both good and bad critics are welcome.

The manual is also constantly updated and improved, but should at the moment cover the description of available input commands.

Acknowledgements

The code has been developed primarly by internal funds from Risø National Laboratory – Technical University of Denmark, but the research that forms the basis of the code is mainly done under contract with the Danish Energy Authority.

The structural formulation of the model is written by Anders M. Hansen as well as the solver and the linking between external loads and structure. The aerodynamic BEM module is written by Helge A. Madsen and Torben J. Larsen. Three different stall models are implemented where the S.Ø. (Stig Øye) model is implemented by Torben J. Larsen, the mhh Beddoes model is written by Morten Hansen and Mac Gaunaa and the mhhmacg model used for trailing edge flaps is written by Mac Gaunaa and Peter Bjørn Andersen and has later been rewritten by Leonardo Bergami. The wind and turbulence module as well as the soil and DLL modules are written by Torben J. Larsen. The hydrodynamic module is written by Anders M. Hansen and Torben J. Larsen. The turbulence generator is generated by the WAsP Team and converted into a DLL by Peter

Bjørn Andersen. The dynamic wake meandering module is written by Helge A. Madsen, Gunner Larsen and Torben J. Larsen. The eigenvalue solver is implemented by Anders M. Hansen and John Hansen. General maintenance is performed by Torben J. Larsen and Anders M. Hansen.

General input layout

The HAWC 2 input format is written in a form that forces the user to write the input commands in a structured way so aerodynamic commands are kept together, structural commands the same etc.

The commands are divided into command blocks using the begin-end syntax. Each line has to be ended with a semi colon ";" which gives the possibility for writing comments and the end of each line after the semi colon. All command lines can be written with capital or small letters, but inside the code all lines are transformed into small letters. This could have importance if something case sensitive is written (e.g. the name of a subroutine within a DLL).

```
begin simulation;
  time_stop    100.0 ;
  solvertype   1 ;    (newmark)
;
  begin newmark;
    beta      0.27;
    gamma     0.51;
    deltat    0.02;
  end newmark;
end simulation;
```

In the next chapters the input commands are explaned for every part of the code. The notation is main command for a begin-end command block that is not a sub part of another begin-end block, and sub command block for a begin-end block that is included within another block. In the above written example "simulation" is a main command block and "newmark" is a sub command block.

Continue_in_file option

A feature from version 6.0 and newer is the possibility of continuing reading of the main input file into another. The command word **continue_in_file** followed by a file name causes the program to open the new file and continue reading of input until the command word **exit**. When **exit** is read the reading will continue in the previous file. An infinite number of file levels can be used.

Command name	Explanation
continue_in_file	1. File name (and path) to sublevel input file
exit	End of input file. Input reading is continued in higher level input file.

HAWC2 version handling

The HAWC2 code is still frequently updated and version handling is therefore of utmost importance to ensure quality control. For every new released version of the code a new version number is hard coded in the source. This number can be found by executing the HAWC2.exe file without any parameters. The version number is echoed to screen. The same version number is also written to every result file no matter whether ASCII or binary format is chosen. Hereby it is possible to reproduce all results at later stage and to dig in the source code for at previous version if special problems occur.

All information covering the different code versions has been made. These data are listed on the next pages.

```
!       Version information:
!       Version name                      ! Date           Resp            Info
!-------------------------------------------------------------------------------------------------------------------------------------------
---------------
!       global%version='HAWC2MB 1.0'      ! 20.04.2006     TJUL            Version system started. Changes in so_dyn_stall model performed.
!                                         ! 24.04.2006     TJUL/ANMH       Bearing3 in topology - slight modification still needed, but now mhha
                                                                           needs a version
!       global%version='HAWC2MB 1.1'      ! 25.04.2006     TJUL            mhha laptop in MAC check, integer overflow negletec in compiler
                                                                           settings
!       global%version='HAWC2MB 1.1work'  ! 26.04.2006     TJUL            tjul stationairy pc in MAC check
!                                                                          New check regarding thicknesses in aeodynamic files
!                                         ! 28.04.2006     TJUL            ktho stationairy pc in MAC check
!       global%version='HAWC2MB 1.2'      ! 28.04.2006     TJUL            Radius non-dim in structural _st input data and aerodynamic _ae data
!       global%version='HAWC2MB 1.3'      ! 01.05.2006     TJUL            Extra check in structural files reading procedures
!                                                                          Tab characters can now be used in htc files and other input files
!                                                                          Check that c2_def structure length larger than eps
!       global%version='HAWC2MB 1.4'      ! 02.05.2006     TJUL            New check in hawc_file output that time_stop>time_start
!                                                                          Topologi_timoschenko.f90 updated related to changes in version 1.3
!       global%version='HAWC2MB 1.5'      ! 03.05.2006     TJUL            ktho laptop in MAC check
!                                                                          Get_state_rot function in body.f90
!                                                                          New mbdy state_rot output command in topologi_mainbody_output
!                                                                          Rotation velocity and acceleration in aerodynamic blade section
                                                                           variables
!                                                          MACQ/TJUL       Dynamic_stall_mhh included
!       global%version='HAWC2MB 1.6'      ! 04.05.2006     TJUL            Extension of bladelink criteria for execution stop
!       global%version='HAWC2MB 1.7'      ! 09.05.2006     TJUL            New error message in windturb_mann.f90
!                                                                          New error messages regarding matrix not definite problems
!                                                                          New MAC checks (Niels Kjølstad + students)
!       global%version='HAWC2MB 1.8'      ! 09.05.2006     TJUL            New MAC check
!       global%version='HAWC2MB 1.9'      ! 16.05.2006     TJUL            New MAC check
!       global%version='HAWC2MB 2.0'      ! 18.05.2006     TJUL            New MAC check
!       global%version='HAWC2MB 2.1'      ! 19.05.2006     TJUL            Error messages corrected in mbdy state_rot command
!                                                          MHHA/TJUL       New MAC check procedure (loop over all adresses instead of only one)
!       global%version='HAWC2MB 2.2'      ! 22.05.2006     TJUL            New ignore function in body actions
!                                         ! 30.05.2006     TJUL            Old MAC check procedure reimplemented since troubles occured with the
                                                                           new version
!       global%version='HAWC2MB 2.3'      ! 30.05.2006     TJUL            Replacement of procedure that calculates euler parameters based on
                                                                           transformation matrix
!                                                                          (only important for cases with eulerp output used)
!       global%version='HAWC2MB 2.4'      ! 31.05.2006     TJUL            General cleanup in multibodyproto.f90 file (simple generator model
                                                                           excluded, now
!                                                                          tmp_gen_speed output command is excluded)
!                                         ! 01.06.2006     TJUL            New MAC checks
!       global%version='HAWC2MB 2.5'      ! 04.06.2006     TJUL            External Licence manager DLL used. Avoids new versions of the HAWC2
                                                                           code to be build at
!                                                                          every new MAC number
!                                         !                               and and also works when the computer is not connected to a LAN
!       global%version='HAWC2MB 2.6'      ! 13.06.2006     TJUL            Newmark variables reorganized
!                                         !                               Hydrodynamic loads cut-in at 2secs, as for the aero loads. To reduce
                                                                           initial transients
!                                         !                               New acceptance criteria from License manager
!                                         !                               New input check in topologi_mainbody
!                                         !                               Order of radius of gyration input shifted for the new_htc_structure
                                                                           input. Now: 1st
!                                                                          column (Rix) is the one affected if mass center position changes on the
                                                                           chord line
!       global%version='HAWC2MB 2.7'      ! 23.06.2006     ANMH            Normalisation of vectors in utils funtions get_two_plane_vectors. Used
                                                                           for better
!                                                                          accuracy in bearing1 and bearing2 definitions
```

```
!       global%version='HAWC2MB 2.8'      ! 17.07.2006     TJUL/FRBA        Correction of bug in get_ae_data procedure in aeroload_calcforces unit. Profile sets
!                                                                           higher than one is now also usable.
!       global%version='HAWC2MB 2.9'      ! 17.07.2006     TJUL             Gravity loads cut-in at 0.5secs, same method as for the aero loads. To reduce initial transients
!                                                                           Harmonic2 function in general output (time limitid harmonic function)
!       global%version='HAWC2MB 3.0'      ! 24.07.2006     TJUL             topologi_mainbody_actions module added. New features to the actions list.
!       global%version='HAWC2MB 3.1'      ! 26.07.2006     TJUL             Mann turbulence is reused if simulation time is longer than included in turbulence box
!       global%version='HAWC2MB 3.2'      ! 28.07.2006     TJUL             Correction of bug in aerodynamic moment integration procedure (only related to aerodynamic file output)
                                          ! 31.07.2006     TJUL             Change of error message criteria regarding alowable number of bodies within a mainbody (<n elements)
                                          ! 01.08.2006     TJUL             Correction of bug in dynstall_mhh model so no division by zero occurs when a zerolift profile is used.
                                          ! 01.08.2006     ANMH             Correction of bug related to torsion of blade in the blade linker
!       global%version='HAWC2MB 3.3'      ! 04.08.2006     TJUL             Check applied on exp expressions in dynamic stall mhh model to avoid underflow errors
!       global%version='HAWC2MB 3.4'      ! 09.08.2006     TJUL             New check applied in mann turbulence unit to avoid array out of bounds during bizar startup transients
!                                         ! 11.08.2006     TJUL             Correction of exp check in dynstall_mhh model just created in version 3.2
!       global%version='HAWC2MB 3.5'      ! 28.08.2006     TJUL             Generator_rotation sensor setup for old_htc_structure format - replaces the older tmp_gen_speed sensor. Updates in hawcstructure.f90 and body_output.f90
!                                         !                                 New error message in body_output
!                                         !                                 Improvement of general command reader in genout_tools in order to accept tabulator spacings
                                          !                                 General shine up of aerodynamic calculations regarding induction and tiploss calculations rechecked against IEA rev 3 calculations
                                          !                                 Number of radial point in the induction calculation is default set to the name number as number of aero sections. Previous default of 30 stations
                                          !                                 Linear interpolation in aeroload_tools updated so no division by zero occurs when x0=x1, used in cases where extrapolation is not wanted
                                          ! 29.08.2006    ANMH/TJUL         Fix1 constraints updated in topologi_constraints_fix1.f90 and hawcstructure.f90. Ensures e.g. that constraint properties are identical for blades. Ensures that blades performs identically.
!       global%version='HAWC2MB 3.6'      ! 14.09.2006     TJUL             New acceptance criteria from license manager
!       global%version='HAWC2MB 3.7'      ! 15.09.2006     TJUL             New general load linker that replaces bladelink.f90 and wavelink.f90
                                          !                ANMH/TJUL        Pitchsensors (bearing sensor) updated during iterations too. Especially important for DLL controllers
!       global%version='HAWC2MB 3.8'      ! 06.10.2006     TJUL             Correction of bug related to aero int_force and int_moment sensors
                                          !                                 Correction of bug in DLL actions. On nodes different from nr. 1, in- and external forces and moments were placed on the node 1 number lower.
                                          !                TJUL             Pitch sensor modified. Now pitch velocity is clculated based on numerical differentiation of calculated angle. Should be less sensitive to solver inaccuracies.
                                          !                TJUL             In output of bearing sensor new options are added. (-180:180 deg output etc.)
                                          !                ANMH             Correction of bug in loadlinker. It turned out that loadfunction were only correct if an even number of calculation points were used (aero or hydro). Now OK also for odd numbers
!       global%version='HAWC2MB 3.9'      ! 06.10.2006     TJUL             Soil spring module added (soil stuff from hydro module removed)
!       global%version='HAWC2MB 4.0'      ! 02.11.2006     TJUL             Extra output commands in aero output_at
!       global%version='HAWC2MB 4.1'      ! 02.11.2006     ANMH/TJUL        Replacement of added stiffness method for soil springs. Much better and faster than previous. Still not perfect.
```

```
                                    ! 10.11.2006     ANMH/TJUL       Update of bearing3. Now it is general.
                                    ! 10.11.2006     TJUL            Output variables rearranged. Only command included in bearing outputs
                                    ! 10.11.2006     TJUL            Topologi input modified so many bases are allowable.
                                    ! 15.11.2006     ANMH/TJUL       Files synchronized with Anders. Slight update in dll_calls,dll_types
                                                                     and windturb_mann.
!       global%version='HAWC2MB 4.2'  ! 16.11.2006     TJUL            Rearrangement of output/action sensor allocation. Reduces .exe size
                                                                     from 23MB to 2.3MB
                                    !                TJUL/HAMA       Correction of sensors induc and windspeed in output_at aero. They were
                                                                     previously in a  wrong coordinate system when written to output_at.
!       global%version='HAWC2MB 4.3'  ! 17.11.2006     TJUL            New fix3 constraint. Locks a node to ground in a given rotation
                                                                     direction.
                                    ! 23.11.2006     ANMH            Update of loadlinker with respect to procedures for numerical update of
                                                                     stiffness, damping and mass terms. Improves solutions of soil spring
                                                                     systems significant.
                                    ! 27.11.2006     TJUL            Same procedure used for the hydrodynamic part => faster convergence.
!       global%version='HAWC2MB 4.4'  ! 27.11.2006     TJUL            Bug fixed related to input for action sensor: mbdy moment_int
                                    ! 04.12.2006     ANMH            index+7 -> index+6 in body_get_state_rot subroutine. Affects
                                                                     orientation of all local load elements in load linker.
!       global%version='HAWC2MB 4.5'  ! 06.12.2006     TJUL            New sensors in aero module.
                                    !                                Out of bounds bug in aero output_at corrected
                                    ! 07.12.2006     ANMH            Files used in topologi_tools are closed after use.
                                    ! 12.12.2006     TJUL            In make output command, outputs are bypassed if global time > output
                                                                     stoptime
                                    ! 13.12.2006     TJUL            In mann turbulence a new command (dont_scale) is made.
                                    ! 21.12.2006     TJUL            Update of HAWC_mann module. Important only if turbulence outside box is
                                                                     used.
                                    ! 04.01.2007     TJUL            omega vector for aerodynamic module in rotor reference coordinates. In
                                                                     aero files only rotation speed around y-axis is used. Eliminates
                                                                     influence from e.g. pitch velocity
                                    ! 04.01.2007     MHHA/TJUL       New optional relaxation parameter for solver. Extra command in
                                                                     simulation input.
!       global%version='HAWC2MB 4.6'  ! 12.01.2007     ANMH            Change of sign in forcedll.f90. Important only if an external force dll
                                                                     as coupled springs are used. Not important for hawc_dll
!       global%version='HAWC2MB 4.7'  ! 06.02.2007     ANMH/TJUL       Update of code structure, multibodyproto split into several subroutines
                                    !                                New logical variables related to simulation_input
                                    !                                New state_at in mbdy output
!       global%version='HAWC2MB 4.8'  ! 08.02.2007     TJUL            mbdy actions force/moment commands updated with sign possibility on
                                                                     force component
!       global%version='HAWC2MB 4.9'  ! 12.02.2007     TJUL            new error message in turbulence input reader
                                    ! 19.02.2007     TJUL            New potential flow tower shadow model where source is linked to tower
                                                                     motion
        global%version='HAWC2MB 5.0'  ! 26.02.2007     TJUL            New mbdy state_rot output option: orientation in euler angles defined
                                                                     through the rotation order xyz
!       global%version='HAWC2MB 5.1'  ! 27.02.2007     TJUL            Correction of method used to calculate mbdy state_rot rotation in
                                                                     general
!                                                                        New mbdy state_rot output option: orientation in euler angles defined
                                                                     through the rotation order yxz
!                                                                        Small adjustements in DLL_output to avoid array out of bounds when long
                                                                     mbdy names are used
!       global%version='HAWC2MB 5.2'  ! 02.03.2007     ANMH/TJUL       Bug fixed related to continue_on_no_convergence criteria
!                                                      TJUL            HAWC2MB version echoed to screen before input is read.
!                                                      TJUL            New licence manager compiler option
!       global%version='HAWC2MB 5.3'  ! 13.03.2007     ANMH/TJUL       Bug fixed related to bearing3. Somehow the coupling nodes was not
                                                                     defined since version 4.0 It affects the transfer of loads from
                                                                     bearing3 and further dow the tower.
!       global%version='HAWC2MB 5.4'  ! 21.03.2007     TJUL/ANMH       Eigenfrequency analysis feature added. Performs analysis on every
                                                                     individual body
!                                   !                TJUL            Some pointer nullify's are changed to deallocate(pointer).
```

```
!       global%version='HAWC2MB 5.4'      ! 21.03.2007     TJUL/ANMH        Eigenfrequency analysis feature added. Performs analysis on every
                                                                              individual body
!                                         !                TJUL             Some pointer nullify's are changed to deallocate(pointer).
!       global%version='HAWC2MB 5.5'      ! 29.03.2007     TJUL             Small change in constraint bearing2 action input. Now only 4 parameters
                                                                              nessecairy as was allways the idea.
!       global%version='HAWC2MB 5.6'      ! 10.04.2007     TJUL             Bug fix related to number of output sensors in DLL output
!                                         !                ANMH             Change in external force module force_dll.f90. Update sequence of
                                                                              affected body changed.
!                                         !                TJUL             body_update_T is called in the end of post_init in order to allow for
                                                                              added stiffness, damping etc. by the rest of the initialization
                                                                              subroutines.
!       global%version='HAWC2MB 5.7'      ! 16.04.2007     TJUL             Small update of continue on no convergence
!       global%version='HAWC2MB 5.8'      ! 18.04.2007     TJUL             Mann turbulence files is closed after every buffer read. To allow
                                                                              several simulations acces to the same turbulence files.
!                                                                             New initial buffer read so out of x-bounds errors are avoided. Uses
                                                                              periodicity of turbulence boxes. In principal this allows for
                                                                              infinitely large simulations.
!       global%version='HAWC2MB 5.9'      ! 23.04.2007     TJUL             Opening of mann turbulence boxed with loops and waits so several
                                                                              simulations can acces the same turbulence.
                                          ! 26.04.2007     TJUL             Only option in mbdy output, wind output, hydro output
                                                                              SO dynamic stall input parameters put in as default. No need for
                                                                              parameter input if not    changed.
                                          ! 23.05.2007     TJUL             Check that turbulence scale_time_start is less the total simulation
                                                                              length
!                                                                             Correction of bug related to "only" option for output for main_body,
                                                                              wind and hydro output commands
        global%version='HAWC2MB 6.0'      ! 01.06.2007     TJUL             New error check that animation can be written to. Error message if not.
                                          ! 08.06.2007     TJUL             New possibility of continuing read in masterfile in a new file with the
                                                                              command:'continue_in_file'. Infinite number of level can be made.
                                                                              Filename also written to logfile when line number is written.
                                          ! 15.06.2007     TJUL             Logfile_name command option in simulation_input. Enables file written
                                                                              logfiles. Error messages more clear with *** ERROR *** as key word
                                          ! 08.08.2007     TJUL             Aerodynamic drag forces on structures enables with the new module
                                                                              aerodrag.
!       global%version='HAWC2MB 6.1'      ! 03.09.2007     TJUL             Corrections made in continue_in_file option. End of file check removed
-                                                                             replaced with exit command.
                                          ! 03.09.2007     ANMH             New unitnumber used when turbulence files are reopened. To avoid unit
                                                                              mismatch especiall
                                          ! 05.09.2007     TJUL             Bug fixed in hydroload module. Only important when more than one hydro
                                                                              element are used.
                                          ! 06.09.2007     TJUL             Bug fixed in hydroload module. Important if hydroelements have
                                                                              different coo than global.
                                          ! 07.09.2007     TJUL             Bug fixed in hydroload module. Important if relative z_distances has
                                                                              been used as hydro element input
        global%version='HAWC2MB 6.2'      ! 20.09.2007     PBJA/TJUL        Dynamic stall module that combines the mhh Beddoes stall model with the
                                                                              MACflap model. Coded by PBJA, implemented by TJUL.
        global%version='HAWC2MB 6.3'      ! 10.10.2007     TJUL             New general output command "general stairs" for a series of step
                                                                              functions.
        global%version='HAWC2MB 6.4'      ! 29.10.2007     TJUL             Some files synchronized with HAWC2aero regarding !IFDEF compiler
                                                                              directives
                                          ! 12.11.2007     TJUL             Torque and power output sensor in aero module modified to give correct
                                                                              results also with use of hub extenders
                                          ! 27.11.2007     TJUL             Wake meandering model implemented, rearrangement of aero files to avoid
                                                                              compiler linker (circulation) errors
                                          ! 29.11.2007     ANMH             Eigenvalue solver for complete turbine at standstill, initialisation of
                                                                              aerodrag element number!
!       global%version='HAWC2MB 6.5'      ! 04.01.2008     TJUL             User defined turbulence scaling implemented. Similar in principle to
                                                                              user defined shear.
```

```
                                    ! 17.01.2008     TJUL            Bearing3 omegaS action command implemented to enable rotor speed
                                                                     control directly from external DLL
                                    ! 04.02.2008     ANMH            Bouyancy forces calculated based on external pressures
                        !                            TJUL            Prestress constraint fix4
                !                                                    DLL call to external wake kinematics dll changed. E.g. dynamic pressure
                                                                     added
!       global%version='HAWC2MB 6.6'  ! 04.02.2008     TJUL            bearing4. Cardan shaft contraint. Locked in relative translation.
                                                                     Locked in rotation around one vector
                                    ! 08.02.2008     TJUL            Bug fixed in turbulence module affecting version 5.5.
                                    ! 08.02.2008     TJUL            Bug fixed regarding turbulence scaling factors. In version 6.5 the
                                                                     turbulence was excluded for normal use - corrected.
                                    ! 08.02.2008     TJUL            Previous .dat file deleted when hawc_binary output files are written.
                                    ! 11.02.2008     TJUL            In mann and flex turbulence module: std scaling factors default to
                                                                     v=0.8 u=1.0 w=0.5
                                    ! 11.02.2008     TJUL            Bug fixed regarding IEC-gust EWS
                                    ! 13.02.2008     TJUL            New Auto distribution of hydrodynamic calculation points possible
                                    ! 13.02.2008     TJUL/ANMH       Bug fixed regarding hydrodynamic boyancy. Axial force on conical
                                                                     members changed from distributed forces to constant force contributions
                                                                     instead (to decrease sensitivity to number of hydro points)
                !                                                    F function only on external kinematics in hydro module.
                !                                                    Dynamic pressure contribution include. Also in wkin_dll calling format.
                !                                                    Coordinates in wkin_dll call changed from global to local hydro coo
                                                                     (origo in 0,0,MSL Z-dir vertical upwards, X-dir in wave direction)
                !                                                    Change in hydro output command "fm" and "fd"
                                    ! 15.02.2008     TJUL            trim commands inserted in reading of master input "begin" and "exit"
                                                                     commands.
                                    ! 15.02.2008     TJUL            Bug fixed regarding output of "free_wind_hor" command.
                                    ! 19.02.2008     TJUL            S.O. dynamic stall parameters included as default
!       global%version='HAWC2MB 6.7'  ! 26.02.2008     TJUL            Bug fixed regarding mbdy action command with "local" coordinates
                                    ! 27.02.2008     TJUL            Extra error messages for errors during aero read routines
                                    ! 29.02.2008     TJUL            Small modifications in eigenvalue solver so large eigenvalue problem
                                                                     can be solved without very large stack size
                                    ! 06.03.2008     TJUL            Dynamic pressure on conical sections also in hydroload
                                    ! 09.03.2008     TJUL            Wordlength incresed to 100 chars in general input reading.
                                    ! 11.03.2008     TJUL            Error handling for infinity cases in hawc_binary output
                                    ! 11.03.2008     ANMH/TJUL       Dynamic pressure on conical hydro sections
                                    ! 11.03.2008     TJUL            Update of mann turb reading routines for boxes where N_y<>N_z
                                    ! 11.03.2008     TJUL            Small modifications in the wake module for robustness
                                    ! 13.03.2008     TJUL            Update of mann turb reading so buffer is updated also when requested
                                                                     point is before buffer start pos (especially important for wake sim.
                                                                     with several wake sources)
!       global%version='HAWC2MB 6.8'  ! 14.03.2008     TJUL            Update of tower shadow pot2 and jet2 models, so they can handle
                                                                     multiple sources.
!       global%version='HAWC2MB 6.9'  ! 21.03.2008     TJUL            Increase of maxloops in mann turbulence reading.
        global%version='HAWC2MB 7.0'  ! 09.04.2008     TJUL            New check in license_manager
!       global%version='HAWC2MB 7.1'  ! 21.05.2008     TJUL            Bug fixed in command line interpreter (if too many command words were
                                                                     present)
                                    ! 26.05.2008     ANMH/TJUL       Concentrated masses option in main_body (no coriolis effects etc. so
                                                                     far)
                                    ! 11.06.2008     TJUL            Extra acceleration sensor including gravity
                                    ! 13.06.2008     TJUL            Minimum values of rotational speed and free wind speed in the indution
                                                                     module.
!       global%version='HAWC2MB 7.2'  ! 15.06.2008     TJUL            F startup function and relative motion in aerodrag included
                                                                     extra check on shear power law expression in wind module to avoid NAN's
!       global%version='HAWC2MB 7.3'  ! 22.07.2008     TJUL            Concentrated mass in modal calculation
                                    ! 01.08.2008     TJUL            Bug in calculation procedure of aerodynamic torque and power corrected.
                                                                     Bug in tower shaddow pot2 and jet2 models corrected. Important only if
                                                                     rotation of tower legs were present.
```

```
!       global%version='HAWC2MB 7.4'      ! 05.08.2008     ANMH            Change in output of forces/moments in general. More correct when long
                                                                             elements are used.
                                                                             Distributed external loads, inertial loads included on top of elastic
                                                                             part. Previously only elastic part used.
                          !                                  ANMH            Hydrodynamic axial drag possible
                                                                             Bearing 2 updated to allow for +-180deg rotation
                                          ! 06.08.2008     TJUL/HAMA       Update of tower shaddow 2 models. Factors multiplied instead of
                                                                             deficits added. Better when several tower shadow sources are used.
        global%version='HAWC2MB 7.5'      ! 08.08.2008     TJUL            Correction of matrix conditioning during eigenvalue calculations.
                                                                             Version 7.3 and 7.4 was not correct regarding this!
!       global%version='HAWC2MB 7.6'      ! 24.09.2008     TJUL            Bug fixed in tower pot2 model.
                                          !                                  Old LIB files for old HAWC input format read, removed form project
        global%version='HAWC2MB 7.7'      ! 01.10.2008     TJUL            Extra logfile output regarding load linking.
                                          !                                  NEED EXTRA ATTENTION -NOT COMPLETELY FIXED YET- WORK ONLY when body
                                                                             structure is defined along the body z coodinates!
                                                                             Bug fixed in aerodrag module (important if aerodrag is linked to a
                                                                             structure where local element and body coo doesn not coincide)
                                          ! 08.10.2008     PBJA/TJUL       Mann turbulence generator DLL call added
                                          ! 08.10.2008     TJUL            Warning written if a comma "," is written within a command line
        global%version='HAWC2MB 7.8'      ! 10.10.2008     TJUL            Animation files for structure eigenvalues calc placed in same directory
                                                                             as eigenvalue list
                                          ! 10.10.2008     TJUL            Limitations in orientation_relative removed. Any coupling node can now
                                                                             be chosen. Eigenvalue solver however not updated for this option yet.
        global%version='HAWC2MB 7.9'      ! 17.11.2008     TJUL            Extra subroutines in normal DLL hawc_dll call. Subroutines added: init
                                                                             and message.
                                          ! 18.11.2008     TJUL            Directories needed are now automatically created if they do not exist
                                          ! 19.11.2008     TJUL            A status sensor is added in the general outputs.
                                          ! 19.11.2008     TJUL            Solvertype is default set to 1=newmark
                                          ! 20.11.2008     TJUL            In dynamic wake model, downstream distance without offset, makes better
                                                                             agreement with measurements and FIDAP
                                          ! 20.11.2008     TJUL            In Dynamic Wake Model: Possibility of writing file with Ct and Cq data
                                          ! 21.11.2008     TJUL            Change in force DLL module. Now bodyname refers to a main_body
                                          ! 21.11.2008     ANMH            Update of initial hydrodynamic loads for added mass/stiffness
                                                                             calculation
                                          ! 21.11.2008     ANMH            Update of loadlinker and solver wrt. calculation of added
                                                                             mass/stiffness/damping.
                                                                             Asymmetric solver implemented - to improved convergence for hydrodyn.
                                                                             problems(not active in version 7.9)
        global%version='HAWC2MB 8.0'      ! 28.11.2008     TJUL            In wake meander model. User calculated deficits can be read.
                                          ! 02.12.2008     TJUL            Change in error message of tower shadow jet and jet2 model - when
                                                                             points requested is inside tower.
                                          ! 02.12.2008     TJUL            General output sensor "status" is set to -1 in last time step.
                                          ! 03.12.2008     PBJA            Near wake induction model implemented
                                          ! 03.12.2008     PBJA            Possibility of exporting wind field including shear, tower shadow, wake
                                                                             etc.
                                          ! 03.12.2008     PBJA            In normal induction model. First order time filter on induced
                                                                             velocities replaced with two indicial functions - modified filter
                                                                             approach. Better agreement with NASA AIMES experiment.
                                          ! 18.12.2008     ANMH/TJUL       Bug correction of concentrated mass indexing in eigenvalue calculation.
                                                                             Important (only) if mass is connected to body node 1
                                          ! 18.12.2008     ANMH/TJUL       Possibility of calculating structural natural frequencies without
                                                                             damping contribution. More robust calculation
        global%version='HAWC2MB 8.1'      ! 09.01.2009     TJUL            In mann model. Auto generation of missing turbulence in more general
                                                                             form.
                                          ! 09.01.2009     TJUL            In hydro module. Currents included, wave direction included.
                                          ! 16.01.2009     ANMH            Assymmetric solver option, which decreases number of iterations for
                                                                             offshore simulations considerable. Newmark-symmetric option
!       global%version='HAWC2MB 8.2'      ! 20.01.2009     TJUL            Bug found in version 8.0 regarding Dynamic wake meander model. Input
```

```
                                                                                deficits to Aislie model with wrong value in last radius point.
        global%version='HAWC2MB 8.3'      ! 21.01.2009     TJUL             Rearrangement of write procedure for final deficit in Dynamic wake
                                                                                meander model. Array-out-of-bound could occur in special cases
                                          ! 02.02.2009     TJUL             New twist angle sensor in output_at aero commands
                                          ! 27.02.2009     TJUL             Small correction of tip loss model. sin(phi) instead of phi.
                                          ! 11.03.2009     ANMH/TJUL        Update of modal solver. Now also usable for floating systems.
                                          ! 18.03.2009     HAMA/TJUL        Update of Dynamic wake meander model. Deficit are now more narrow than
                                                                                previous. Default parameters k1,k2 are changed.
                                          ! 05.05.2009     ANMH             Bug fix in mass matrix and orthogonally of local orientation matrices.
                                                                                Important (only) with prebend and mass center offset from elastic axis.
                                          ! 05.05.2009     TJUL             Small updates regarding mbdy commands instead/supplementary to old body
                                                                                commands in new_htc_structure inputs
                                          ! 05.05.2009     ANMH             Extra parameter in hydro element regarding linear axial drag
                                                                                contribution.
                                          ! 06.05.2009     TJUL             More residual information outputted in case of no convergence
!       global%version='HAWC2MB 8.4'      ! 11.05.2009     TJUL             New input check on number of mann box points. power of 2 criteria.
!                                                                               Mode shape animation files written in appropriate directories.
                                          ! 12.05.2009     ANMH             Initialization of timosection properties
                                          ! 13.05.2009     TJUL             No double eigenvalue sets are written in table of structural
                                                                                frequencies
!       global%version='HAWC2MB 8.5'      ! 14.05.2009     ANMH             Bug corrected in eigenvalue solver related to version 8.3 and 8.4
!       global%version='HAWC2MB 8.6'      ! 08.07.2009     TJUL             Bug fix related to mann turbulence look-up indexes for points just
                                                                                outside the turbulence box.
                                          ! 08.07.2009     TJUL             New updates of DWM wake model. New ainslie-15.exe and modification of
                                                                                default parameters.
        global%version='HAWC2MB 8.7'      ! 24.08.2009     TJUL             In main_body input limitation of 4 c2def points lower to 2. If less
                                                                                than 4 points, linear interpolation is used.
                                          ! 30.08.2009     TJUL             Element coordinates can now be used without limitations. Local
                                                                                coordinate system written in beam_output_file.
                                          ! 04.09.2009     ANMH             Loadlinker updated so arbitrary body coordinations systems can be used.
                                                                                Linker now follows local curved beam direction
                                          ! 04.09.2009     TJUL             Positive definite damping model originally formulated by Morten H.
                                                                                Hansen is included in HAWC2. Makes it possible to utilize the shear
                                                                                center position away from the elastic axis without problems with
                                                                                damping model.
                                          ! 05.09.2009     TJUL             Small bugfix related to aerodrag module.
!       global%version='HAWC2MB 8.8'      ! 08.10.2009     TJUL             Bug related to damping model changes in version 8.7 corrected.
!       global%version='HAWC2MB 8.9'      ! 09.10.2009     ANMH/TJUL        New structure output: Structure_inertia_file_name
        global%version='HAWC2MB 9.0'      ! 26.11.2009     TJUL             New check for input errors regarding negative diameters in aerodrag
                                                                                module
                                          ! 03.12.2009     TJUL             In wake model. Ainslie-15.exe replaced by ainslie-15.dll, to enable
                                                                                execution on linux platforms using WINE
                                          ! 21.12.2009     TJUL             In wake model. Bug fixed dealing with several neigbouring wind
                                                                                turbines. Change in turbine order for ainslie15.dll input/output
                                          ! 30.12.2009     TJUL             Flex integer format option in output.
                                          ! 04.01.2010     TJUL             Change in variables in eigenvalue module to avoid stack errors
                                          ! 05.01.2010     TJUL             Change in loadlinker merge criteria to avoid error with closely spaced
                                                                                nodes
                                          ! 31.01.2010     TJUL             New control DLL module names type2_dll
                                          ! 31.01.2010     TJUL             Possibility to input case_sensitive words using ' symbols. Especially
                                                                                related to control subroutine names.
                                          ! 15.02.2010     TJUL             Change in wind shear logarithmic format to ensure a shear of zero below
                                                                                global zero.
        global%version='HAWC2MB 9.1'      ! 29.03.2010     TJUL             New parameter possible in mbdy moment_int actions command
                                          ! 31.03.2010     ANMH             Possibility of external systems solved together with HAWC2, this goes
                                                                                for bodies and constraints
                                          ! 01.04.2010     TJUL             Small update of result file sensorlist output for hawc_ascii and
                                                                                hawc_binary
```

```
                                    ! 15.04.2010     TJUL            Updates in FORCE DLL module. New initialization option, label option.
                                    ! 17.05.2010     TJUL            Update of wind ramps to speed up simulation time
                                    ! 29.06.2010     TJUL            DLL module, type2_dll updated regarding first outputs in dll calls
                                    ! 16.07.2010     TJUL            Small change in compiler settings.
        global%version='HAWC2MB 9.2'! 13.08.2010     TJUL            Possibility for aerodynamic sections positioned according to ae_file
                                                                     input.
                                    ! 25.08.2010     TJUL            Updated procedure for hub coo which defines coo with arbitrary rotor
                                                                     orientation
                                    ! 09.09.2010     TJUL            Simulation stop enabled by external dll action.
                                    ! 13.09.2010     JOMH            Updated eigenvalue solution procedure
                                    ! 13.09.2010     JOMH            Zero-termination of all strings used for dll's
                                    ! 28.09.2010     TJUL            Bug correction from version 9.1 regarding wind steps.
!       global%version='HAWC2MB 9.3w'! 06.10.2010     TJUL            Bug correction in interpolation of profile coef when several pc sets
                                                                     are used.
                                    ! 20.10.2010     TJUL            Bug correction of predictor in newmark solver. Version 9.0 and 9.1 gave
                                                                     problems coupling in controllers
                                    ! 21.10.2010     TJUL            Eigenvalue solver from version 9.2 removed and old 9.1 version included
                                                                     instead. Not correct solutions in all cases.
                                    ! 21.10.2010     TJUL            Turbulence buffer not updated when buffer contains the full turbulence
                                                                     box.
!       global%version='HAWC2MB 9.4'! 21.10.2010     TJUL            Code updated for handling multiple aerodynamic rotors
                                    ! 26.10.2010     TJUL            Be aware that the near wake induction model is not working in this
                                                                     edition. The normal induction model works fine though.
                                    ! 26.10.2010     JOMH            Eigenvalue solver updated again, so now it should be both correct and
                                                                     robust
!       global%version='HAWC2MB 9.5'! 12.11.2010     TJUL            Bug fixed when outputting wake pos when no wake defined - code crash
                                                                     occured.
                                    ! 17.11.2010     TJUL            BEM rewritten in more structured way and to make sure local properties
                                                                     in grid points are all local. More correct for non-uniform loading
                                    ! 19.11.2010     TJUL            IN BEM, time filters are now on induced velocities instead of
                                                                     factors,same goes with azimuthal yaw correction in induction.
                                    ! 21.11.2010     TJUL            WSP lookup only performed for first iteration to save simulation time.
                                    ! 24.11.2010     TJUL            Final adjustments of BEM induction
!       global%version='HAWC2MB 9.6'! 27.11.2010     TJUL            Improvements of yaw correction in BEM calculation, comparison with
                                                                     FIDAP
                                    ! 02.12.2010     TJUL            Bugfix related to output of DWM wake position
!       global%version='HAWC2MB 9.7'! 03.12.2010     TJUL            Improvements of yaw correction in BEM calculation, comparison with
                                                                     FIDAP
                                    ! 03.12.2010     TJUL            BEM restructured for more correct local CT prediction, time constants
                                                                     on induced velocities, yaw correction on induced axial velocities
                                                                     instead of factors
                                    ! 03.12.2010     TJUL            BEM improved regarding aerodynamic yaw correction, compared with
                                                                     actuatordisc results
                                    ! 03.12.2010     TJUL            BEM improved regarding dynamic time constants, compared with
                                                                     actuatordisc results
                                    ! 03.12.2010     TJUL            Dyn. time constants reduced for first 10seconds to reduce time for
                                                                     initial equilibrium
!       global%version='HAWC2MB 9.8'! 17.12.2010     TJUL            Small bug correction. Crash occured when aero output requested when
                                                                     rotor was not defined
                                    ! 28.12.2010     MHHA            Bug fix regarding omega vector for aero module. Version9-2 to 9.7 had
                                                                     problems with rotor orientations azimthally angle more than +-90deg.
!       global%version='HAWC2MB 9.9'! 05.01.2011     TJUL            Update regarding wake meandering,lowpass filter in time instead of area
                                                                     based filter
!       global%version='HAWC2MB 10.0'! 17.01.2011     TJUL            New calibration in DWM model. Ainslie_16.dll used.
!       global%version='HAWC2MB 10.1'! 01.02.2011     TJUL            BEM bug correction regarding induction for two bladed turbines. + DWM
                                                                     model deficit k1 paprameter changed to 0.20 as default
!       global%version='HAWC2MB 10.2'! 01.02.2011     TJUL            User defined a-ct relation in BEM included
!       global%version='HAWC2MB 10.3'! 08.02.2011     TJUL            DLL action command aero bem_grid_a inserted.
```

```
!       global%version='HAWC2MB 10.4'     ! 18.03.2011     TJUL            In DWM model, k1 parameter default value changed back to 0.13 (good
                                                                             match with Egmond aa Zee measurements)
                                          ! 13.05.2011     TJUL/LEOB       Bug corrections in the maghmhh dynstall model
                                          ! 16.05.2011     ANMH            Update and general improvement of hydrodynamic mass so is it coded in
                                                                             body coordinates (time varying)
                                          ! 17.05.2011     TJUL            Small updates of modal_new.f90 to minimize stack usage
!       global%version='HAWC2MB 10.5'     ! 17.05.2011     ANMH            Concentrated hydrodynamic added masses also included in new procedure,
                                                                             which makes the solver converge faster and more stable than previous
!       global%version='HAWC2MB 10.6'     ! 15.06.2011     TJUL            Update of mbdy state_rot output
                                          ! 12.08.2011     TJUL            Small update in variable check to fullfill requirements from new
                                                                             compiler
                                          ! 30.08.2011     TJUL            Updates in hydrodynamics related to flooded members.
                                          ! 31.08.2011     HAMA/TJUL       Limitation in tangential induction changed (tangential induction was
                                                                             not correct for high loading Ct)
                                          ! 31.08.2011     LEOB            New updated model for dynamic stall of trailing edge flaps
                                          ! 05.09.2011     TJUL            Updates in buoyancy regarding point change in diameters
                                          ! 05.09.2011     TJUL            Update in structure output. Hydro added mass outputted if defined.
                                          ! 13.09.2011     LEOB            New alfadot sensor in aero output
                                          ! 19.09.2011     TJUL            Hydro added mass solver module updated for inner flodded area
                                          ! 26.09.2011     KNKR            New spinner output sensor in aeroload module
!       global%version='HAWC2MB 10.7'     ! 04.10.2011     TJUL            External forces enabled for external modules
                                          ! 18.10.2011     TJUL            In DWM model, Multiple wakes handled by choosing the decifit with
                                                                             larget wsp reduction. Previously a summation of deficits was performed
                                          ! 24.10.2011     TJUL            In boyancy part. Correction with eps at mudlevel, to improve stability
                                                                             when structure ends at mudlevel.
        global%version='HAWC2MB 10.8'     ! 02.11.2011     TJUL            Fourrier based low pass filter in DWM model instead of second order
                                                                             filter
                                          ! 09.11.2011     LEOB/TJUL       Update in dynamic induction to include the influence of trailing edge
                                                                             flaps
                                          ! 18.11.2011     TJUL            New random output sensor added to general output commands.
                                          ! 22.11.2011     ANMH/TJUL       Update in topology initial rotation velocities. Should decrease initial
                                                                             transients
                                          ! 22.11.2011     TJUL            Aerodynamic load is removed for first 5 second and then gradually put
                                                                             on structure (fully applied at 10s) to avoid convergence problems
                                                                             during initial transients.
                                          ! 05.12.2011     TJUL            Close dll's inserted to increase robustness on especially windows 7
                                                                             platforms
                                          ! 05.12.2011     ANMH            Eigenvalue solver update to account for non-coinciding nodes and free
                                                                             relative rotation
                                          ! 02.11.2011     ANMH            Orientation of node in call to FORCE_DLL is changed (back) to global
                                                                             reference
                                          ! 02.11.2011     ANMH            Disabling of constraints can now be handled - new command "disable_at"
                                                                             is introduced for constraints FIX0, FIX1, BEARING1 and BEARING2
                                          ! 02.11.2011     ANMH            "INPUT" subroutine introduced in EXTSYS which enables HAWCDLL to send
                                                                             output to EXTSYS
                                          ! 06.11.2011     LEOB            Update of dynamic stall models MHH and ATEF for correct handling of +-
                                                                             pi angle of attack crossing.
                                          ! 07.11.2011     TJUL            New aero command 'output_profile_coef_filename', enables output of
                                                                             static interpolated profile coefficients
                                          ! 07.11.2011     ANMH/TJUL       Update of initial structural velocity conditions, to reduce the initial
                                                                             transients in general
                                          ! 08.11.2011     TJUL            New aero sensor, where is is possible to ouput the local elastic
                                                                             torsion

        global%version='HAWC2MB 10.9'     ! 15.12.2011     TJUL            New procedure for calculating non-rotating hub coordinate system.
                                                                             important for free-yawing rotors.
```

Coordinate systems

The global coordinate system is located with the z-axis pointing vertical downwards. The x and y axes are horizontal to the side.

When wind is submitted, the default direction is along the global y-axes. Within the wind system meteorological u,v,w coordinates are used, where u is the mean wind speed direction, v is horizontal and w vertical upwards. When x,y,z notation is used within the wind coo. this refers directly to the u,v,w definition.

Every substructure and body (normally the same) is equipped with its own coordinate system with origo in node1 of this structure. The structure can be arbitrarily defined regarding orientation within this coordinate system. Within a body a number of structural elements are present. The orientation of coordinate systems for these elements are chosen automatically by the program. The local z axis is from node 1 to 2 on the element.

The coordinate system for the blade structures must be defined with the z axis pointing from the blade root and outwards, x axis in the tangential direction of rotation and y axis from the pressure side towards the suction side of the blade profiles. This is in order to make the linkage between aerodynamics and structure function.

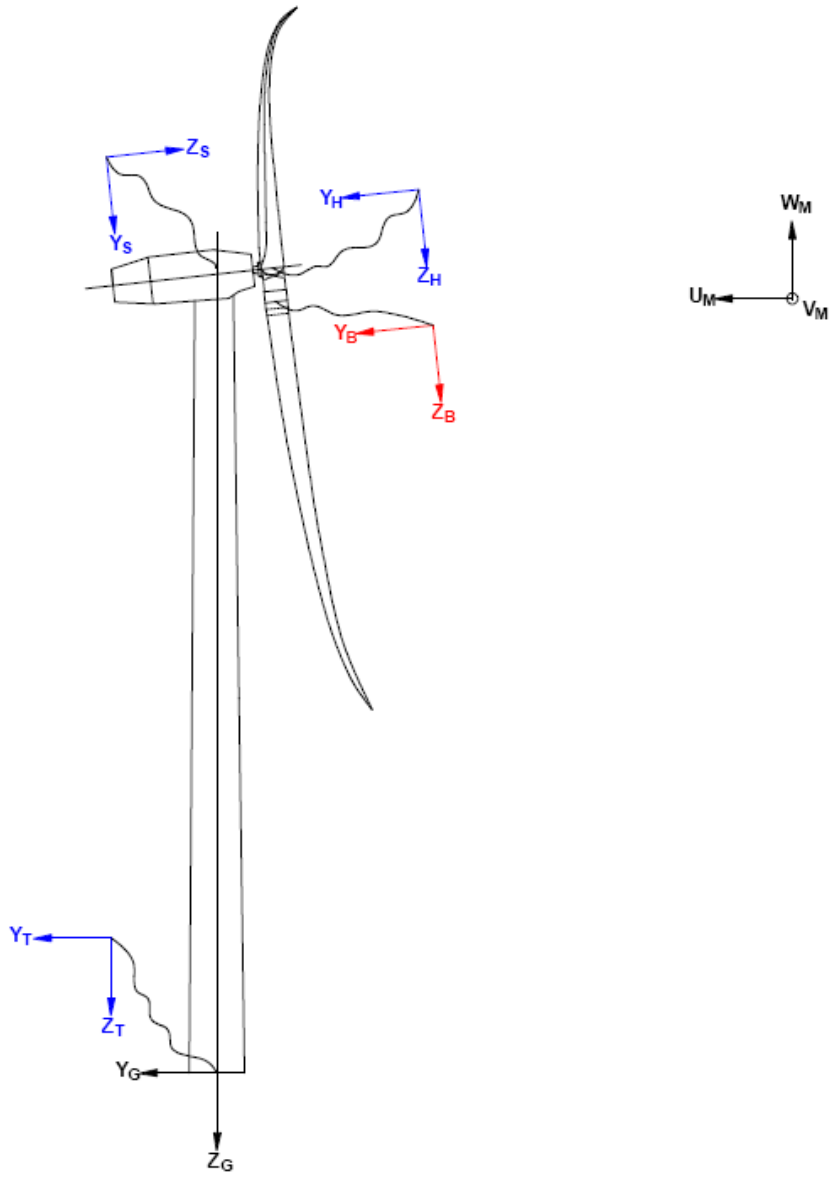


Figure 1. Illustration of coordinate system as result of user input from example in section Example of main input file at page 92. There are two coordinate systems in ***black*** *which are the default coordinate systems of global reference and default wind direction. The* ***blue*** *coordinate systems are main body coordinate systems attached to node 1 of the substructure, the orientation of these are fully determined by the user. The* ***red*** *coordinate systems are also defined by the user, but in order to make the linkage between aerodynamic forces and structure work these have to have the z from root to tip, x in chordwise direction and y towards the suction side.*

Simulation

Main command block - Simulation

This block shall be present when time simulations are requested – always.

Obl.	Command name	Explanation
*	time_stop	1. Simulation length [s]
	solvertype	1. Choice of available solver method (1=newmark)
	solver_relax	1. Relaxation parameter on increment within a timestep. Can be used to make difficult simulation run through solver when parameter is decreased, however on the cost of simulation speed. Default=1.0
	on_no_convergence	Parameter that informs solver of what to do if convergence is not obtained in a time step. 1. 'stop': simulation stops – default. 'continue': simulation continues, error message is written.
	convergence_limits	Convergence limits that must be obtained at every time step. 1. epsresq, residual on internal-external forces, default=10.0 2. epsresd, residual on increment, default=1.0 3. epsresg, residual on constraint equations, default=0.7
	max_iterations	1. Number of maximum iterations within a time step.
	animation	Included if animation file is requested 1. Animation file name incl. relative path. E.g. ./animation/animation1.dat
	logfile	Included if a logfile is requested internally from the htc command file. 1. Logfile name incl. relative path. E.g. ./logfiles/log1.txt

Sub command block – newmark

This block shall be present when the solvertype is set to the newmark method.

Obl.	Command name	Explanation
	beta	1. beta value (default=0.27)
	gamma	1. gamma value (default=0.51)
*	deltat	1. time increment [s]
	symmetry	1. Solver assumtion regarding mass, damping and stiffness matrices (1=symmetric (default), 2=assymetric (recommended for offshore structures). When hydrodynamic loading is applyed this parameter will automatically change to 2.)

Structural input

Main command block – new_htc_structure

Obl.	Command name	Explanation
	beam_output_file_name	1. Filename incl. relative path to file where the beam data are listed (output) (example ./info/beam.dat)
	body_output_file_name	1. Filename incl. relative path to file where the body data are listed (output) (example ./info/body.dat)
	struct_inertia_output_file_name	1. Filename incl. relative path to file where the global inertia information data are listed (output) (example ./info/inertia.dat)
	body_eigenanalysis_file_name	1. Filename incl. relative path to file where the results of an eigenanalysis are written. (output) (example ./info/eigenfreq.dat)
	constraint_output_file_name	1. Filename incl. relative path to file where the constraint data are listed (output). (example ./info/constraint.dat)
	structure_eigenanalysis_file_name	1. Filename incl. relative path to file where the results of an complete turbine eigenanalysis are listed (example ./info/eigen_all.dat). Animation files of the first modes are places in same directory as the HAWC2 executable. In the analysis the assumption of rigidly connected bodies in the coupling points are assumed. 2. Optional parameter determining if structural damping is included in the eigenvalue calculation or not. (0=damping not included, most robust method, 1=damping included default)

Sub command block – main_body

This block can be repeated as many times as needed. For every block a new body is added to the structure. A main body is a collection of normal bodies which are grouped together for bookkeeping purposes related to input output. When a main body consist of several bodies the spacing the name of each body inherits the name of the master body and is given an additional name of '_#', where # is the body number. An example could be a main body called 'blade1' which consist of two bodies. These are then called 'blade1_1' and blade1_2' internally in the code. The internal names are only important if (output) commands are used that refers to the specific body name and not the main body name.

Obl.	Command name	Explanation
*	name	1. Main_body identification name (must be unique)
*	type	1. Element type used (options are: timoschenko)
*	nbodies	1. Number of bodies the main_body is divided into (especially used for blades when large deformation effetcs needs attention). Equal number of elements on each body, eventually extra elements are placed on the first body.

Obl.	Command name	Explanation
*	node_distribution	1. Distribution method of nodes and elements. Options are: • "uniform" nnodes. Where uniform ensures equal element length and nnodes are the node numbers. • "c2_def", which ensures a node a every station defined with the sub command block c2_def.
	damping	Original damping model that can only be used when the shear center location equals the elastic center to ensure a positive definite damping matrix. It is recommended to use the **damping_posdef** command instead. Rayleigh damping parameters containing factors that are multiplied to the mass and stiffness matrix respectfully. 1. M_x 2. M_y 3. M_z 4. K_x 5. K_y 6. K_z
	damping_posdef	Rayleigh damping parameters containing factors. M_x, M_y, M_z are constants multiplied on the mass matrix diagonal and inserted in the damping matrix. K_x, K_y, K_z are factors multiplied on the moment of inertia I_x, I_y, I_z in the stiffness matrix and inserted in the damping matrix. Parameters are in size approximately the same as the parameters used with the original damping model written above. 1. M_x 2. M_y 3. M_z 4. K_x 5. K_y 6. K_z
	copy_main_body	Command that can be used if properties from a previously defined body shall be copied. The name command still have to be present, all other data are overwritten. 1. Main_body identification name of main_body that is copied.
	gravity	1. Specification of gravity (directed towards z_G). NB! this gravity command only affects the present main body. Default=9.81 [m/s^2]
	concentrated_mass	Concentrated masses and inertias can be attached to the structure. The offset distance as well as the moments and products of inertia is related to the body's coordinates system. 1. Node number to which the inertia is attached. 2. Offset distance x-direction [m] 3. Offset distance y-direction [m] 4. Offset distance z-direction [m] 5. Mass [kg] 6. I_{xx} [kg m^2] 7. I_{yy} [kg m^2] 8. I_{zz} [kg m^2] 9. I_{xy} [kg m^2] – optional 10. I_{xz} [kg m^2] – optional 11. I_{yz} [kg m^2] – optional

Sub sub command block – timoschenko_input

Block containing information about location of the file containing distributed beam property data and the data set requested.

Obl.	Command name	Explanation
*	filename	1. Filename incl. relative path to file where the distributed beam input data are listed (example ./data/hawc2_st.dat)
*	set	1. Set number 2. Sub set number

Sub sub command block – c2_def

In this command block the definition of the centerline of the main_body is described (position of the half chord, when the main_body is a blade). The input data given with the sec commands below is used to define a continous differentiable line in space using akima spline functions. This centerline is used as basis for local coordinate system definitions for sections along the structure. If two input sections are given it is assumed that all points are on a straight line. If three input sections are given points are assumed to be on the line consisted of two straight lines. If four or more input sections are given points are assumed to be on an akima interpolated spline. This spline will include a straight line if a minimum of three points on this line is defined.

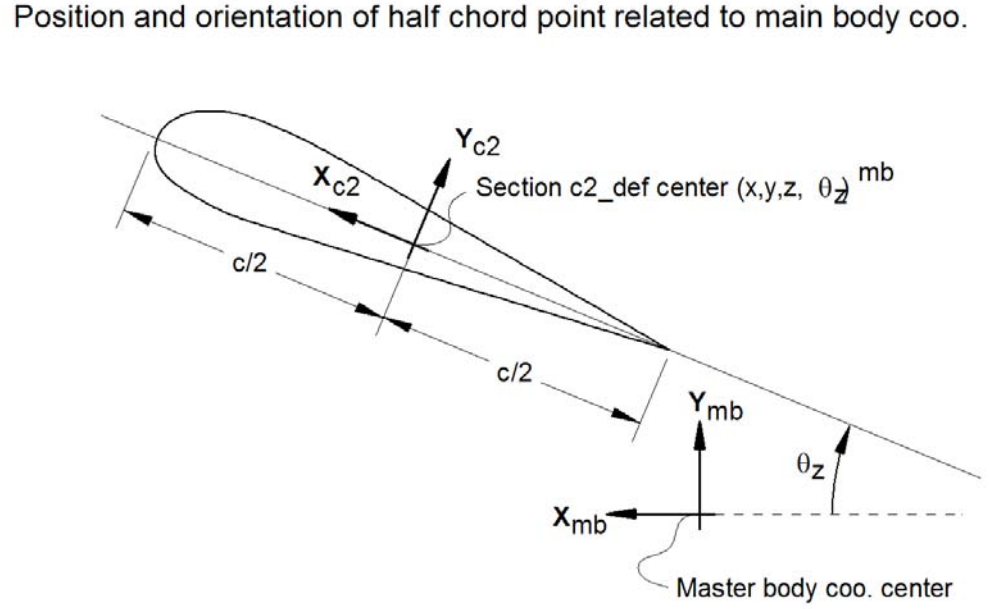
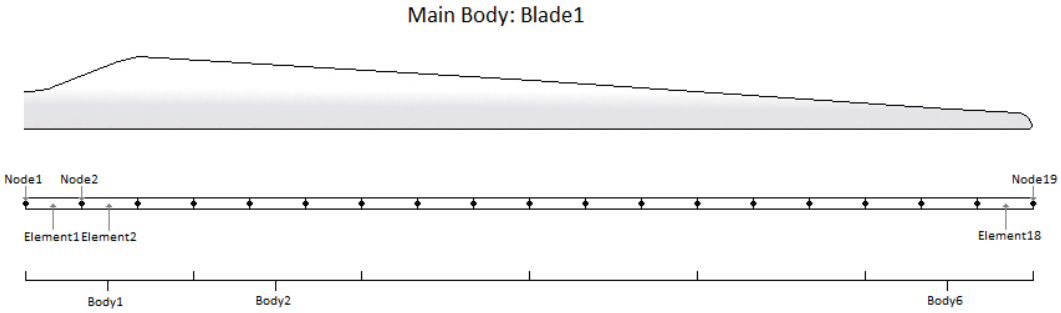


Figure 2: Illustration of c2_def coordinate system related to main body coordinates.

Obl.	Command name	Explanation
*	nsec	Must be the present before a “sec” command. 1. Number of section commands given below
*	sec	Command that must be repeated “nsec” times. Minimum 4 times. 1. Number 2. x-pos [m] 3. y-pos [m] 4. z-pos [m] 5. θ_z [deg]. Angle between local x-axis and main_body x-axis in the main_body x-y coordinate plane. For a straight blade this angle is the aerodynamic twist. Note that the sign is positive around the z-axis, which is opposite to traditional notation for etc. a pitch angle.

Here is an illustration of how a blade can be defined with respect to discretisation of bodies, nodes and elements.



Here is an example of this written into the htc-input file.

```
begin main_body;
name        blade1 ;
type        timoschenko ;
nbodies     6 ;
node_distribution    c2_def;
damping_posdef   1.17e-4 5.77e-5 6.6e-6 6.6e-4 5.2e-4 6.5e-4 ;
begin timoschenko_input ;
filename ./data/st_file.txt ;
  set 1 1 ;                set subset
end timoschenko_input;
begin c2_def;              Definition of centerline (main_body coordinates)
  nsec 19 ;
sec 1          -0.0000        0.0000        0.000          0.000         ;
sec 2          -0.0041        0.0010        3.278        -13.590         ;
sec 3          -0.1048        0.0250        6.556        -13.568         ;
sec 4          -0.2582        0.0492        9.833        -13.564         ;
sec 5          -0.4694        0.0587       13.111        -13.546         ;
sec 6          -0.5689        0.0957       16.389        -11.406         ;
sec 7          -0.5455        0.0883       19.667        -10.145         ;
sec 8          -0.5246        0.0732       22.944         -9.043         ;
sec 9          -0.4362        0.0669       26.222         -7.843         ;
sec 10         -0.4644        0.0554       29.500         -6.589         ;
sec 11         -0.4358        0.0449       32.778         -5.447         ;
sec 12         -0.4859        0.0347       36.056         -4.234         ;
sec 13         -0.3759        0.0265       39.333         -3.545         ;
sec 14         -0.3453        0.0130       42.611         -2.223         ;
sec 15         -0.3156        0.0084       45.889         -1.553         ;
sec 16         -0.2791        0.0044       49.167         -0.934         ;
sec 17         -0.2675        0.0017       52.444         -0.454         ;
sec 18         -0.1785        0.0003       55.722         -0.121         ;
sec 19         -0.1213        0.0000       59.000         -0.000         ;
 end c2_def ;
end main_body;
```

Format definition of file including distributed beam properties

The format of this file which in the old HAWC code was known as the hawc_st file is changed slightly for the HAWC2 new_htc_structure format.
In the file (which is a text file) two different datasets exist. There is a main set and a sub set. The main set is located after a "#" sign followed by the main set number. Within a main there can be as many subsets as desired. They are located after a "$" sign followed by the local set number. The next sign of the local set number is the number of lines in the following rows that belong to this sub set.

The content of the columns in a data row is specified in the table below. In general all centers are given according to the $C_{1/2}$ center location and all other are related to the principal bending axes.

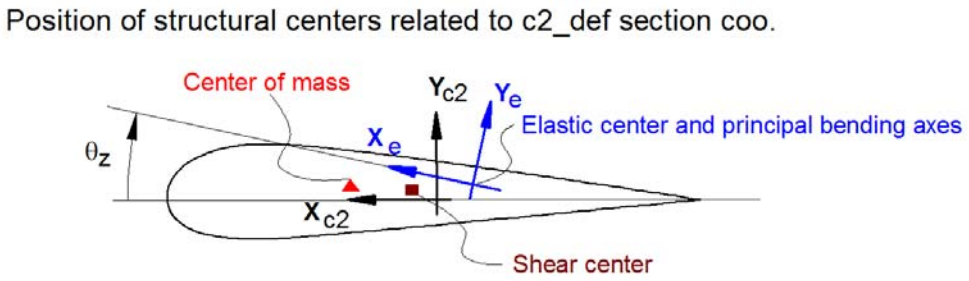


Figure 3: Illustration of structural properties that in the input files are related to the c2 coordinate system

Table 1 Structural data

Column	Parameter
1	**r, curved length distance from main_body node 1 [m]**
2	**m, mass per unit length [kg/m]**
3	**x_m, x_{c2}-coordinate from $C_{1/2}$ to mass center [m]**
4	**y_m, y_{c2}-coordinate from $C_{1/2}$ to mass center [m]**
5	**r_{ix}, radius of inertia related to elastic center. Corresponds to rotation about principal bending x_e axis [m]**
6	**r_{iy}, radius of inertia related to elastic center. Corresponds to rotation about principal bending y_e axis [m]**
7	**x_s, x_{c2}-coordinate from $C_{1/2}$ to shear center [m]**
8	**y_s, y_{c2}-coordinate from $C_{1/2}$ to shear center [m]**
9	**E, modulus of elasticity [N/m^2]**
10	**G, shear modulus of elasticity [N/m^2]**
11	**I_x, area moment of inertia with respect to principal bending x_e axis [m^4]**
12	**I_y, area moment of inertia with respect to principal bending y_e axis [m^4]**
13	**K, torsional stiffness constant with respect to z_e axis at the shear center [m^4/rad]. For a circular section only this is identical to the polar moment of inertia.**
14	**k_x shear factor for force in principal bending x_e direction [-]**
15	**k_y, shear factor for force in principal bending y_e direction [-]**
16	**A, cross sectional area [m^2]**
17	**θ_s, structural pitch about z_{c2} axis. This is the angle between the x_{c2} -axis defined with the c2_def command and the 1st main principal bending axis x_e.**
18	**x_e, x_{c2}-coordinate from $C_{1/2}$ to center of elasticity [m]**
19	**y_e, y_{c2}-coordinate from $C_{1/2}$ to center of elasticity [m]**

An example of an inputfile can be seen on the next page. The most important features to be aware of are colored with red.

```
1 main data sets available
-----------------------------------
Here is space for comments etc
.
.
.
-----------------------------------
#1 Main data set number 1 - an example of a shaft structure
-----------------------------------
More comments space
```

r	m	x_cg	y_cg	ri_x	ri_y	x_sh	y_sh	E	G	I_x	I_y	K	k_x	k_y	A	theta_s	x_e	y_e
[m]	[kg/m]	[m]	[m]	[m]	[m]	[m]	[m]	[N/m^2]	[N/m^2]	[N/m^4]	[N/m^4]	[N/m^4]	[-]	[-]	[m^2]	[deg]	[m]	[m]
$1 10 Sub set number 1 with 10 data rows																		
0.00	100	0	0	224.18	224.18	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
0.10	100	0	0	224.18	224.18	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
0.1001	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
1.00	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
1.90	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
2.00	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
3.00	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
3.20	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
4.00	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
5.0191	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0

```
-----------------------------------
More comments space
```

r	m	x_cg	y_cg	ri_x	ri_y	x_sh	y_sh	E	G	I_x	I_y	K	k_x	k_y	A	theta_s	x_e	y_e
[m]	[kg/m]	[m]	[m]	[m]	[m]	[m]	[m]	[N/m^2]	[N/m^2]	[N/m^4]	[N/m^4]	[N/m^4]	[-]	[-]	[m^2]	[deg]	[m]	[m]
$2 10 As dataset 1, but stiff																		
0.00	100	0	0	224.18	224.18	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
0.10	100	0	0	224.18	224.18	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
0.1001	1	0	0	0.2	0.2	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
1.00	1	0	0	0.2	0.2	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
1.90	1	0	0	0.2	0.2	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
2.00	1	0	0	0.2	0.2	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
3.00	1	0	0	0.2	0.2	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
3.20	1	0	0	0.2	0.2	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
4.00	1	0	0	0.2	0.2	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
5.0191	1	0	0	0.2	0.2	0	0	2.10E+16	8.10E+15	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0

```
-----------------------------------
More comments space
```

r	m	x_cg	y_cg	ri_x	ri_y	x_sh	y_sh	E	G	I_x	I_y	K	k_x	k_y	A	theta_s	x_e	y_e
[m]	[kg/m]	[m]	[m]	[m]	[m]	[m]	[m]	[N/m^2]	[N/m^2]	[N/m^4]	[N/m^4]	[N/m^4]	[-]	[-]	[m^2]	[deg]	[m]	[m]
$3 10 as data set 1 but changed mass properties																		
0.00	1000	0	0	2.2418	2.2418	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
0.10	1000	0	0	2.2418	2.2418	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
0.1001	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
1.00	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
1.90	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
2.00	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
3.00	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
3.20	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
4.00	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0
5.0191	1	0	0	0.2	0.2	0	0	2.10E+11	8.10E+10	1.00E+02	1.00E+02	0.05376	0.52	0.52	0.59	0	0.0	0.0

- **N.5** r_{ix} $[m]$ Radius of inertia. Related to the Moment of Inertia I_{xx} $[kg\ m^2]$, which gives the rotation inertia, resistance to change in rotation rate:

$$I_{xx} = \int r_{ix}^2 \mathrm{d}m \quad \rightarrow \quad r = \sqrt{\frac{I_{xx}}{m}} \tag{1}$$

  Steiner's parallel axis theorem applies (for concentrated inertia):
  $I_{xx} = I_{cg} + M * r^2$

- **N.11** I_x $[m^4]$ Area moment of inertia with respect to x_e. It's the second moment of area $I_x = \int y^2 \mathrm{d}A$. Multiplied by Young's modulus E gives the flapwise bending stiffness:

$$\mathrm{Stiffn}_{\mathrm{flap}} = E \cdot I_x = \frac{M}{\mathrm{d}^2 w / \mathrm{d}^2 x} \tag{2}$$

Sub command - orientation

In this command block the orientation (regarding position and rotation) of every main_body are specified.

Sub sub command - base

The orientation of a main_body to which all other bodies are linked – directly or indirectly.

Obl.	Command name	Explanation
*	mbdy (old command name **body** still usable)	1. Main_body name that is declared to be the base of all bodies (normally the tower or foundation)
*	inipos	Initial position in global coordinates. 1. x-pos [m] 2. y-pos [m] 3. z-pos [m]
♣	mbdy_eulerang (old command name **body_eulerang** still usable)	Command that can be repeated as many times as needed. All following rotation are given as a sequence of euler angle rotations. All angle can be filled in (rotation order x,y,z), but it is recommended only to give a value different from zero on one of the angles and reuse the command if several rotations are needed. 1. θ_x [deg] 2. θ_y [deg] 3. θ_z [deg]
♣	body_eulerpar	The rotation is given as euler parameters (quaternions) directly (global coo). 1. r_0 2. $\mathbf{r}_1$ 3. $\mathbf{r}_2$ 4. $\mathbf{r}_3$
♣	mbdy_axisangle (old command name **body_axisangle** still usable)	Command that can be repeated as many times as needed. A version of the euler parameters where the input is a rotation vector and the rotation angle of this vector. 1. x-value 2. y-value 3. z-value 4. angle [deg]

♣ One of these commands must be present.

Sub sub command - relative

This command block can be repeated as many times as needed. However the orientation of every main_body should be described.

Obl.	Command name	Explanation
*	mbdy1 (old command name **body1** still usable)	1. Main_body name to which the next main_body is attached. 2. Node number of body1 that is used for connection. ("last" can be specified which ensures that the last node on the main_body is used).
*	mbdy2 (old command name **body2** still usable)	1. Main_body name of the main_body that is positioned in space by the relative command. 2. Node number of body2 that is used for connection. ("last" can be specified which ensures that the last node on the main_body is used).
♣	mbdy2_eulerang (old command name **body2_eulerang** still usable)	Command that can be repeated as many times as needed. All following rotation are given as a sequence of euler angle rotations. All angle can be filled in (rotation order x,y,z), but it is recommended only to give a value different from zero on one of the angles and reuse the command if several rotations are needed. Until a rotation command is specified body2 has same coo. as body1. Rotations are performed in the present body2 coo. system. 1. θ_x [deg] 2. θ_y [deg] 3. θ_z [deg]
♣	mbdy2_eulerpar (old command name **body2_eulerpar** still usable)	The rotation is given as euler parameters (quaternions) directly (global coo). 1. r_0 2. $\mathbf{r}_1$ 3. $\mathbf{r}_2$ 4. $\mathbf{r}_3$
♣	mbdy2_axisangle (old command name **body2_axisangle** still usable)	Command that can be repeated as many times as needed. A version of the euler parameters where the input is a rotation vector and the rotation angle of this vector. Until a rotation command is specified main_body2 has same coo. as main_body1. Rotations are performed in the present main_body2 coo. system. 1. x-value 2. y-value 3. z-value 4. angle [deg]
	mbdy2_ini_rotvec_d1 (old command name **body2_ini_rotvec_d1** still usable)	Initial rotation velocity of main body and all subsequent attached bodies. A rotation vector is set up and the size of vector (the rotational speed) is given. The coordinate system used is main_body2 coo. 1. x-value 2. y-value 3. z-value 4. Vector size (rotational speed [rad/s])

Sub command - constraint

In this block constraints between the main_bodies and to the global coordinate system are defined.

Sub sub command – fix0

This constraint fix node number 1 of a given main_body to ground.

Obl.	Command name	Explanation
*	mbdy (old command name **body** still usable)	Name of main body that is fixed to ground at node 1
	disable_at	Time to which constraint can be disabled 1. t_0

Sub sub command – fix1

This constraint fix a given node on one main_body to another main_body's node.

Obl.	Command name	Explanation
*	mbdy1 (old command name **body1** still usable)	1. Main_body name to which the next main_body is fixed. 2. Node number of main_body1 that is used for the constraint. ("last" can be specified which ensures that the last node on the main_body is used).
*	mbdy2 (old command name **body2** still usable)	1. Main_body name of the main_body that is fixed to main_body1. 2. Node number of main_body2 that is used for the constraint. ("last" can be specified which ensures that the last node on the main_body is used).
	disable_at	Time to which constraint can be disabled 1. t_0

Sub sub command – fix2

This constraint fix a node 1 on a main_body to ground in x,y,z direction. The direction that is free or fixed is optional.

Obl.	Command name	Explanation
*	mbdy (old command name **body** still usable)	1. Main_body name to which node 1 is fixed.
*	dof	Direction in global coo that is fixed in translation 1. x-direction (0=free, 1=fixed) 2. y-direction (0=free, 1=fixed) 3. z-direction (0=free, 1=fixed)

Sub sub command – fix3

This constraint fix a node to ground in tx,ty,tz rotation direction. The rotation direction that is free or fixed is optional.

Obl.	Command name	Explanation
*	mbdy (old command name **body** still usable)	1. Main_body name to which node 1 is fixed. 2. Node number
*	dof	Direction in global coo that is fixed in rotation

		1. tx-rot.direction (0=free, 1=fixed) 2. ty-rot.direction (0=free, 1=fixed) 3. tz-rot.direction (0=free, 1=fixed)

Sub sub command – fix4

Constraint that locks a node on a body to another node in translation but not rotation with a pre-stress feature. The two nodes will start at the defined positions to begin with but narrow the distance until fully attached at time T.

Obl.	Command name	Explanation
*	mbdy1 (old command name **body1** still usable)	1. Main_body name to which the next main_body is fixed. 2. Node number of main_body1 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	mbdy2 (old command name **body2** still usable)	1. Main_body name of the main_body that is fixed to body1. 2. Node number of main_body2 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
	time	3. Time for the pre-stress process. Default=2sec

Sub sub command – bearing1

Constraint with properties as a bearing without friction. A sensor with same identification name as the constraint is set up for output purpose.

Obl.	Command name	Explanation
*	name	1. Identification name
*	mbdy1 (old command name **body1** still usable)	1. Main_body name to which the next main_body is fixed with bearing1 properties. 2. Node number of main_body1 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	mbdy2 (old command name **body2** still usable)	1. Main_body name of the main_body that is fixed to body1 with bearing1 properties. 2. Node number of main_body2 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	bearing_vector	Vector to which the free rotation is possible. The direction of this vector also defines the coo to which the output angle is defined. 1. Coo. system used for vector definition (0=global,1=mbdy1,2=mbdy2) 2. x-axis 3. y-axis 4. z-axis
	disable_at	Time to which constraint can be disabled 1. t_0

Sub sub command – bearing2

This constraint allows a rotation where the angle is directly specified by an external dll action command.

Obl.	Command name	Explanation
*	name	1. Identification name
*	mbdy1 (old command name **body1** still usable)	1. Main_body name to which the next main_body is fixed with bearing2 properties. 2. Node number of main_body1 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	mbdy2 (old command name **body2** still usable)	1. Main_body name of the main_body that is fixed to main_body1 with bearing1 properties. 2. Node number of main_body2 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	bearing_vector	Vector to which the rotation occur. The direction of this vector also defines the coo to which the output angle is defined. 1. Coo. system used for vector definition (0=global,1=mbdy1, 2=mbdy2) 2. x-axis 3. y-axis 4. z-axis
	disable_at	Time to which constraint can be disabled 1. t_0

Sub sub command – bearing3

This constraint allows a rotation where the angle velocity is kept constant throughout the simulation.

Obl.	Command name	Explanation
*	name	1. Identification name
*	mbdy1 (old command name **body1** still usable)	1. Main_body name to which the next main_body is fixed with bearing3 properties. 2. Node number of main_body1 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	mbdy2 (old command name **body2** still usable)	1. Main_body name of the main_body that is fixed to body1 with bearing3 properties. 2. Node number of main_body2 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	bearing_vector	Vector to which the rotation occur. The direction of this vector also defines the coo to which the output angle is defined. 1. Coo. system used for vector definition (0=global,1=body1,2=body2) 2. x-axis 3. y-axis 4. z-axis
*	omegas	1. Rotational speed [rad/sec]

Sub sub command – bearing4

This constraint is a cardan shaft constraint. Locked in relative translation. Locked in rotation around one vector and allows rotation about the two other directions.

Obl.	Command name	Explanation
*	name	1. Identification name
*	mbdy1 (old command name **body1** still usable)	1. Main_body name to which the next main_body is fixed with bearing3 properties. 2. Node number of main_body1 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	mbdy2 (old command name **body2** still usable)	1. Main_body name of the main_body that is fixed to body1 with bearing3 properties. 2. Node number of main_body2 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	bearing_vector	Vector to which the rotation is locked. The rotation angle and velocity can be outputted around the two perpendicular directions. 1. Coo. system used for vector definition (0=global,1=mbdy1, 2=mbdy2) 2. x-axis 3. y-axis 4. z-axis

Sub sub command – bearing5

This constraint is a spherical constraint. Locked in relative translation. Free in rotation around all three axis, but only sensor on the main rotation direction.

Obl.	Command name	Explanation
*	name	1. Identification name
*	mbdy1 (old command name **body1** still usable)	1. Main_body name to which the next main_body is fixed with bearing3 properties. 2. Node number of main_body1 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	mbdy2 (old command name **body2** still usable)	1. Main_body name of the main_body that is fixed to body1 with bearing3 properties. 2. Node number of main_body2 that is used for the constraint. (“last” can be specified which ensures that the last node on the main_body is used).
*	bearing_vector	Vector to which the rotation is locked. The rotation angle and velocity can be outputted around the two perpendicular directions. 1. Coo. system used for vector definition (0=global,1=mbdy1, 2=mbdy2) 2. x-axis 3. y-axis 4. z-axis

DLL control

This block contains the possible Dynamic Link Library formats accessible for the user. The Dll's are mainly used to control the turbine speed and pitch, but since the DLL format is very general, other use is possible too e.g. external loading of the turbine. Since the HAWC2 core has no information about external stiffness or inertia we have experienced some issues with the solver if the DLL includes high stiffness terms or especially large inertia terms. The new type2_dll interface is slightly more stable related to the solver than the hawc_dll interface.

Main command block – dll

So far only one DLL format is available, which is the hawc_dll format listed below.

Sub command block – hawc_dll

In the HAWC_DLL format a subroutine within an externally written DLL is setup. In this subroutine call two one-dimensional arrays are transferred between the HAWC2 core and the DLL procedure. The first contains data going from the HAWC2 core to the DLL and the other contains data going from the DLL to the core. It is very important to notice that the data are transferred between HAWC2 and the DLL in every timestep and every iteration. The user should handle the iteration inside the DLL.

Two more subroutines are called if they are present:

The first is an initialisation call including a text string written in the init_string in the commands below. This could be the name of a file holding local input parameters to the data transfer subroutine. This call is only performed once. The name of this subroutine is the same name as the data transfer subroutine defined with the command *dll_subroutine* below with the extra name '_init', hence is the data transfer subroutine is called 'test', the initialisation subroutine will be 'test_init'.

The second subroutine is a message exchange subroutine, where messages written in the DLL can be send to the HAWC2 core for logfile writing. The name of this subroutine is the same name as the data transfer subroutine defined with the command *dll_subroutine* below with the extra name '_message', hence is the data transfer subroutine is called 'test', the initialisation subroutine will be 'test_message'.

The command block can be repeated as many times as desired. Reference number to DLL is same order as listed, starting with number 1. However it is recommended to refer the DLL using the name feature which in many cases can avoid confusion.

Obl.	Command name	Explanation
	name	1. Reference name of this DLL (to be used with DLL output commands)
*	filename	1. Filename incl. relative path of the DLL (example ./DLL/control.dll)
*	dll_subroutine	1. Name of subroutine in DLL that is addressed (remember to specify the name in the DLL with small letters!)
*	arraysizes	1. size of array with outgoing data 2. size of array with ingoing data
	deltat	1. Time between dll calls. Must correspond to the simulation sample frequency or be a multiple of the time step size. If deltat=0.0 or the deltat command line is omitted the HAWC2 code calls the dll subroutine at every time step.
	init_string	1. Text string (max 256 characters) that will be transferred to the DLL through the subroutine '*subroutine*_init'. *Subroutine* is the name given in in the command dll_subroutine. No blanks can be included.

Sub command block – type2_dll

This dll interface is an updated slightly modified version of the hawc_dll interface. In the TYPE2_DLL format a subroutine within an externally written DLL is setup. In this subroutine call two one-dimensional arrays are transferred between the HAWC2 core and the DLL procedure. The first contains data going from the HAWC2 core to the DLL and the other contains data going from the DLL to the core. It is very important to notice that the data are transferred between HAWC2 and the DLL in the first call of every timestep where the out-going variables are based on last iterated values from previous time step. The sub command **output** and **actions** are identical for both the hawc_dll and the type2_dll interfaces.

In the dll connected with using the type2_dll interface two subroutines should be present. An *initialization* routine called only once before the time simulation begins, and an *update* routine called in every time step. The format in the calling of these two subroutines are identical where two arrays of double precision is exchanged. The subroutine uses the **cdecl** calling convention.

Obl.	Command name	Explanation
	name	1. Reference name of this DLL (to be used with DLL output commands)
*	filename	1. Filename incl. relative path of the DLL (example ./DLL/control.dll)
*	dll_subroutine_init	1. Name of initialization subroutine in DLL that is addressed (remember to specify the name in the DLL with small letters!)
*	dll_subroutine_update	1. Name of subroutine in DLL that is addressed at every time step (remember to specify the name in the DLL with small letters!)
*	arraysizes_init	1. size of array with outgoing data in the initialization call 2. size of array with ingoing data in the initialization

		call
*	arraysizes_update	1. size of array with outgoing data in the update call 2. size of array with ingoing data in the update call
	deltat	1. Time between dll calls. Must correspond to the simulation sample frequency or be a multiple of the time step size. If deltat=0.0 or the deltat command line is omitted the HAWC2 code calls the dll subroutine at every time step.

when using the type2_dll interface the values transferred to the DLL in the initialization phase is done using a sub command block called **init**. The commands for this subcommand block is identical to the **output** subcommand explained below, but only has the option of having the *constant* output sensor available. An example is given for a small dll that is used for converting rotational speed between high speed and low speed side of a gearbox.:

```
begin dll;
  begin type2_dll;
    name hss_convert;
    filename  ./control/hss_convert.dll ;
    arraysizes_init  3 1 ;
    arraysizes_update  2 2 ;
    begin init;
      constant 1 2.0 ;     number of used sensors - in this case only 1
      constant 2 35.110;   gearbox ratio
      constant 3 35.110;   gearbox ratio
    end init;
    begin output;
      constraint bearing1 shaft_rot 2 only 2 ;   rotor speed in rpm
      constraint bearing1 shaft_rot 3 only 2 ;   rotor speed in rad/s
    end output;
;
    begin actions;
;      rotor speed in rpm * gear_ratio
;      rotor speed in rad/s * gear_ratio
    end actions;
  end type2_dll;
end dll;
```

Sub command block - output

In this block the same sensors are available as when data results are written to a file with the main block command **output**. The order of the sensors in the data array is continuously increased as more sensors are added.

Sub command block - actions

In this command block variables inside the HAWC2 code is changed depending of the specifications. This command block can be used for the hawc_dll interface as well as the type2_dll interface. An action commands creates a handle to the HAWC2 model to which a variable in the input array from the DLL is linked.

!NB in the command name two separate words are present.

Obl.	Command name	Explanation
	aero beta	The flap angle beta is set for a trailing edge flap section (is the mhhmagf stall model is used). The angle is positive towards the pressure side of the profile. Unit is [deg] 1. Blade number 2. Flap section number
	body force_ext	An external force is placed on the structure. Unit is [N]. 1. body name 2. node number 3. composant (1 = F_x, 2 = F_y, 3 = F_z)

Obl.	Command name	Explanation
	body moment_ext	An external moment is placed on the structure. Unit is [Nm]. 1. body name 2. node number 3. composant (1 = M_x, 2 = M_y, 3 = M_z)
	body force_int	An external force with a reaction component is placed on the structure. Unit is [N]. 1. body name for action force 2. node number 3. composant (1 = F_x, 2 = F_y, 3 = F_z) 4. body name for reaction force 5. Node number
	body moment_int	An external moment with a reaction component is placed on the structure. Unit is [N]. 1. body name for action moment 2. node number 3. composant (1 = M_x, 2 = M_y, 3 = M_z) 4. body name for reaction moment 5. Node number
	body bearing_angle	A bearing either defined through the new structure format through bearing2 or through the old structure format (spitch1=pitch angle for blade 1, spitch2=pitch angle for blade 2,...). The angle limits are so far [0-90deg]. 1. Bearing name
	mbdy force_ext	An external force is placed on the structure. Unit is [N]. 1. main body name 2. node number on main body 3. composant (1 = F_x, 2 = F_y, 3 = F_z) , if negative number the force is inserted with opposite sign. 4. coordinate system (possible options are: mbdy name,"global","local"). "local" means local element coo on the inner element (on the element indexed 1 lower that the node number). One exception if node number =1 then the element nr. also equals 1.
	mbdy moment_ext	An external moment is placed on the structure. Unit is [Nm]. 1. main body name 2. node number on main body 3. composant (1 = M_x, 2 = M_y, 3 = M_z) , if negative number the moment is inserted with opposite sign. 4. coordinate system (possible options are: mbdy name,"global","local"). "local" means local element coo on the inner element (on the element indexed 1 lower that the node number). One exception if node number =1 then the element nr. also equals 1.

Obl.	Command name	Explanation
	mbdy force_int	An internal force with a reaction component is placed on the structure. Unit is [N]. 1. main body name for action force 2. node number on main body 3. composant (1 = F_x, 2 = F_y, 3 = F_z) , if negative number the force is inserted with opposite sign. 4. coordinate system (possible options are: mbdy name,"global","local"). "local" means local element coo on the inner element (on the element indexed 1 lower that the node number). One exception if node number =1 then the element nr. also equals 1. 5. main body name for reaction force 6. Node number on this main body
	mbdy moment_int	An internal force with a reaction component is placed on the structure. Unit is [Nm]. 1. main body name for action moment 2. node number on main body 3. composant (1 = M_x, 2 = M_y, 3 = M_z) , if negative number the moment is inserted with opposite sign. 4. coordinate system (possible options are: mbdy name,"global","local"). "local" means local element coo on the inner element (on the element indexed 1 lower that the node number). One exception if node number =1 then the element nr. also equals 1. 5. main body name for reaction moment 6. Node number on this main body
	constraint bearing2 angle	The angle of a bearing2 constraint is set. The angle limits are so far [+/-90deg]. 1. Bearing name
	body printvar	Variable is just echoed on the screen. No parameters.
	body ignore	1. Number of consecutive array spaces that will be ignored
	mbdy printvar	Variable is just echoed on the screen. No parameters.
	mbdy ignore	1. Number of consecutive array spaces that will be ignored
	general printvar	Variable is just echoed on the screen. No parameters.
	general ignore	1. Number of consecutive array spaces that will be ignored
	stop_simulation	Logical switch. If value is 1 the simulation will be stopped and output written.

HAWC_DLL format example written in FORTRAN 90

```
subroutine test(n1,array1,n2,array2)
implicit none
!DEC$ ATTRIBUTES DLLEXPORT, ALIAS:'test'::test
integer*4           :: n1, &    ! Dummy integer value containing the array size of array1
                       n2       ! Dummy integer value containing the array size of array2
real*4,dimension(10) :: array1  ! fixed-length array, data from HAWC2 to DLL
                                ! - in this case with length 10
real*4,dimension(5)  :: array2  ! fixed-length array, data from DLL to HAWC2
                                ! - in this case with length 5

! Code is written here

end subroutine test

!-------------------------------------------------------

Subroutine test_init(string256)
Implicit none
!DEC$ ATTRIBUTES DLLEXPORT, ALIAS:'test_init'::test_init
Character*256 :: string256

! Code is written here

End subroutine test_init

!-------------------------------------------------------

Subroutine test_message(string256)
Implicit none
!DEC$ ATTRIBUTES DLLEXPORT, ALIAS:'test_message'::test_message
Character*256 :: string256

! Code is written here

End subroutine test_message
```

HAWC_DLL format example written in Delphi

```
library test_dll;

type
  array_10 = array[1..10] of single;
  array_5  = array[1..5] of single;
  ts       = array[0..255] of char;

Procedure test(var n1:integer;var array1 : array_10;
               var n2:integer;var array2 : array_5);stdcall;
// n1 is a dummy integer value containing the size of array1
// n2 is a dummy integer value containing the size of array2
begin
  // Code is written here

end;

//-------------------------------------------------------

Procedure test_init(var string256:ts; length:integer);stdcall;
var
  init_str:string[255]
begin
  init_str=strpas(string256);
  // Code is written here
  writeln(init_str);
end;

//-------------------------------------------------------

Procedure test_message(var string256:ts; length:integer);stdcall;
var
  message_str:string;
begin
  // Code is written here
  message_str:='This is a test message';
  strPCopy(string256,message_str);
end;

exports test,test_init,test_message;

begin
  writeln('The DLL pitchservo.dll is loaded with succes');

  // Initialization of variables can be performed here
end;

end.
```

HAWC_DLL format example written in C

```
extern "C" void __declspec(dllexport) __cdecl test(int &size_of_Data_in, float Data_in[],
int                 &size_of_Data_out,                 float                  Data_out[])
{
 for        (int        i=0;        i<size_of_Data_out;        i++)        Data_out[i]=0.0;
//
 printf("size_of_Data_in                     %d:                     \n",size_of_Data_in);
 printf("Data_in                                %g:                          \n",Data_in[0]);
 printf("size_of_Data_out                    %d:                    \n",size_of_Data_out);
 printf("Data_out         %g: \n",Data_out[0]);

}

extern "C" void __declspec(dllexport) __cdecl test_init(char* pString, int length)
{
        // Define buffer (make room for NULL-char)
        const int max_length = 256;
        char buffer[max_length+1];
        //
        // Print the length of pString
        printf("test_init::length = %d\n",length);
        //
        // Transfer string
        int nchar = min(max_length, length);
        memcpy(buffer, pString, nchar);
        //
        // Add NULL-char
        buffer[nchar] = '\0';
        //
        // Print it...
        printf("%s\n",buffer);
}

extern "C" void __declspec(dllexport) __cdecl test_message(char* pString, int max_length)
{
        // test message (larger than max_length)
        char pmessage[] = "This is a test message "
                          "and it continues and it continues and it continues "
                          "and it continues and it continues and it continues "
                          "and it continues and it continues and it continues "
                          "and it continues and it continues and it continues "
                          "and it continues and it continues and it continues "
                          "and it continues and it continues and it continues ";

        // Check max length  -  transfer only up to max_length number of chars
        int nchar = min((size_t)max_length, strlen(pmessage));  // nof chars to transfer
(<= max_length)
        memcpy(pString, pmessage, nchar);
        //
        // Add NULL-char if string space allows it (FORTRAN interprets a NULL-char as
the end of the string)
        if (nchar < max_length) pString[nchar] = '\0';
}
```

TYPE2_dll written in Delphi

```
library hss_convert;

uses
  SysUtils,
  Classes,
  Dialogs;

Type
  array_1000 = array[0..999] of double;
Var
  factor : array of double;
  nr : integer;
{$R *.res}

procedure initialize(var InputSignals: array_1000;var OutputSignals: array_1000); cdecl;
var
  i : integer;
begin
  nr:=trunc(inputsignals[0]);
  if nr>0 then begin
    setlength(factor,nr);
    for i:=1 to nr do
      factor[i-1]:=Inputsignals[i];
    outputsignals[0]:=1.0;
  end else outputsignals[0]:=0.0;
end;

procedure update(var InputSignals: array_1000;var OutputSignals: array_1000); cdecl;
var
  i : integer;
begin
  for i:=0 to nr-1 do begin
    OutputSignals[i] := InputSignals[i]*factor[i];
  end;
end;

exports Initialize,Update;

begin
  // Main body

end.
```

TYPE2_dll written in C

```
extern "C" void __declspec(dllexport) __cdecl initialize(dfloat *Data_in, dfloat
*Data_out)
{ for (int i=0; i<8; i++) Data_out[0]+=Data_in[i];
}

extern "C" void __declspec(dllexport) __cdecl update(dfloat *Data_in, dfloat *Data_out)
{ for (int i=0; i<25; i++) Data_out[0]+=Data_in[i];
Data_out[8]=123;
}
```

TYPE2_DLL format example written in FORTRAN 90

```
subroutine initialize(array1,array2)
implicit none
!DEC$ ATTRIBUTES DLLEXPORT, C, ALIAS:'initialize'::initialize
real*8,dimension(1000) :: array1  ! fixed-length array, data from HAWC2 to DLL
                                  ! - in this case with length 1000
real*8,dimension(1)    :: array2  ! fixed-length array, data from DLL to HAWC2
                                  ! - in this case with length 1

! Code is written here

end subroutine initialize

!-------------------------------------------------------

subroutine update(array1,array2)
implicit none
!DEC$ ATTRIBUTES DLLEXPORT, C, ALIAS:'update'::update
real*8,dimension(1000) :: array1  ! fixed-length array, data from HAWC2 to DLL
                                  ! - in this case with length 1000
real*8,dimension(100)    :: array2  ! fixed-length array, data from DLL to HAWC2
                                  ! - in this case with length 100

! Code is written here

end subroutine initialize
```

Wind and turbulence

Main command block -wind

Obl.	Command name	Explanation
*	wsp	1. Mean wind speed in center [m/s]
*	density	1. Density of the wind [kg/m^3]
*	tint	Turbulence intensity [-].
*	horizontal_input	This command determines whether the commands above should be understood as defined in the global coordinate system (with horizontal axes) or the meteorological coordinates system (u,v,w) witch can be tilted etc. 1. (0=meteorological – default, 1=horizontal)
*	center_pos0	Global coordinates for the center start point of the turbulence box, meteorological coordinate system etc. (default should the hub center) 1. x_G [m] 2. y_G [m] 3. z_G [m]
*	windfield_rotations	Orientation of the wind field. The rotations of the field are performed as a series of 3 rotations in the order yaw, tilt and roll. When all angles are zero the flow direction is identical to the global y direction. 1. Wind yaw angle [deg], positive when the wind comes from the right, seen from the turbine looking in the -y_G direction. 2. Terrain slope angle [deg], positive when the wind comes from below. 3. Roll of wind field [deg], positive when the wind field is rotated according to the turbulence u-component.
*	shear_format	Definition of the mean wind shear 1. Shear type 0=none $\bar{u}(z) = 0$, 1=constant $\bar{u}(z) = c$, 2=logarithmic $\bar{u}(z) = u_0 \frac{\log \frac{-z_0^G + z^M}{r_0}}{\log \frac{-z_0^G}{r_0}}$, 3=power law $\bar{u}(z) = u_0 \frac{\left(-z_0^G + z^M\right)^\alpha}{-z_0^G}$, 4=linear $\bar{u}(z) = u_0 \frac{\partial u}{\partial z}$ 2. Parameter used together with shear type (case of shear type: 0=dummy, 1=c, 2=r_0, 3= α, 4=du/dz at center)
*	turb_format	1. Turbulence format (0=none, 1=mann, 2=flex)
*	tower_shadow_method	1. Tower shadow model (0=none, 1=potential flow – default, 2=jet model, 3=potential_2 (flow where shadow source is moved and rotated with tower coordinates system)

Obl.	Command name	Explanation
	scale_time_start	1. Starting time for turbulence scaling [s]. Stop time is determined by simulation length.
	wind_ramp_factor	Command that can be repeated as many times as needed. The wind_ramp_factor is used to calculate a factor that is multiplied to the wind speed vectors. Can be used to make troublefree cut-in situations. Linear interpolation is performed between t_0 and t_{stop}. 1. time start, t_0 2. time stop, t_{stop} 3. factor at t_0 4. factor at t_{stop}
	wind_ramp_abs	Command that can be repeated as many times as needed. The wind_ramp_abs is used to calculate a wind speed that is added to the wind speed u-composant. Can be used to make wind steps etc. Linear interpolation is performed between t_0 and t_{stop}. 1. time start, t_0 2. time stop, t_{stop} 3. wind speed at t_0 4. wind speed at t_{stop}
	user_defined_shear	1. Filename incl. relative path to file containing user defined shear factors (example ./data/shear.dat)
	user_defined_shear_turbulence	1. Filename incl. relative path to file containing user defined shear turbulence factors (example ./data/shearturb.dat)
	iec_gust	Gust generator according to IEC 61400-1 1. Gust type 'eog' = extreme operating gust $u(z,t)=u(z,t)-0.37A\sin\left(\frac{3\pi(t-t_0)}{T}\right)\left(1-\cos\frac{2\pi(t-t_0)}{T}\right)$ 'edc' = extreme direction change $\theta(t)=0.5\varphi_0\left(1-\cos\left(\frac{\pi(t-t_0)}{T}\right)\right)$ 'ecg' = extreme coherent gust $u(z,t)=u(z,t)+0.5A\left(1-\cos\left(\frac{\pi(t-t_0)}{T}\right)\right)$ 'ecd' = extreme coherent gust with dir. change $u(z,t)=u(z,t)+0.5A\left(1-\cos\left(\frac{\pi(t-t_0)}{T}\right)\right)$ $\theta(t)=0.5\varphi_0\left(1-\cos\left(\frac{\pi(t-t_0)}{T}\right)\right)$ 'ews' = extreme wind shear $d=\frac{\sqrt{y_M^2+z_M^2}}{D}$ $u(z,t)=u(z,t)+\frac{d}{D}A\left(1-\cos\left(\frac{\pi(t-t_0)}{T}\right)\right)\cos\left(\arctan 2\left(y^M,-z^M\right)-\varphi_0\right)$ even though the 'ews' expressions do not match the expressions in the standard completely, it gives identical results provided a mutual power law shear is used and the A parameter is set to $A=2.5+0.2\beta\sigma_1\left(\frac{D}{\Lambda_1}\right)^{\frac{1}{4}}$ and the parameter φ_0 is set to 0, 90, 180, 270 [deg] respectively. 2. Amplitude A [m/s] 3. Angle φ_0 [deg] 4. Time start, t_0 [m/s] 5. Duration T [m/s]

Sub command block - mann

Block that must be included if the mann turbulence format is chosen. Normal practice is to use all three turbulence components (u,v,w) but only the specified components are used. In 2008 the turbulence generator was linked to the code so mannturbulence can be created without using external software. The command create_turb_parameters will search for turbulence files with names given below, but if these are not found the turbulence will be created.

A short explanation of the parameters L and $\alpha\varepsilon^{2/3}$ and its relation to the IEC61400-1 ed. 3 standard is given:

The fundamentals of the Mann model is isotropic turbulence in neutral atmospheric conditions. The energy spectrum is given based on the Von Karman spectrum (1). In isotropic turbulence, the properties of turbulence like variance and turbulent length scale is identical for all three direction corresponding to vortex structures being circular.

$$E(k) = \alpha\varepsilon^{\frac{2}{3}} L^{\frac{5}{3}} \frac{(Lk)^4}{\left(1+(Lk)^2\right)^{\frac{17}{6}}} \qquad (1)$$

The relation between wave number k and frequency f is related through the mean wind speed $\overline{U}$.

$$k = \frac{2\pi f}{\overline{U}} \qquad (2)$$

However, atmospheric conditions are <u>not</u> isotropic and the vortex structures become more elliptic in shape with longer length scale and higher variance level in the u direction. In the Mann model, this is accounted for using rapid distortion theory quantified through a shear blocking factor Γ. A Γ parameter of 1 corresponds to isotropic turbulence, whereas a higher Γ value is used for non-isotropic turbulence. The relation between non-isotropic and isotropic properties as function of Γ can be seen in Figure 4. It is normally recommended to use $\Gamma = 3.9$ for normal atmospheric conditions. A length scale of $L = 0.7\Lambda_1$ is recommended for normal conditions. Λ_1 is defined as the wavelength where the longitudinal power spectral density is equal to 0.05. According to the IEC61400-1 the wavelength Λ_1 shall be considered as a constant of 42m (above a height of 60m).

In the Mann generation of turbulence a length scale L has to be used. This is the length scale of the Von Karman spectrum (1) and therefore different than the length scale used in the Kaimal formulation (3). The energy spectrum of Kaimal is formulated

$$E(f) = \sigma^2 \frac{4L/\overline{U}}{\left(1+6fL/\overline{U}\right)^{\frac{5}{3}}} \qquad (3)$$

where the input parameters are given based on the table values in

	Velocity component index (k)		
	1	2	3
Standard deviation σ_k	σ_1	0,8 σ_1	0,5 σ_1
Integral scale, L_k	8,1 Λ_1	2,7 Λ_1	0,66 Λ_1

Table 2: Information about Kaimal length scales and standard deviation ratio from the IEC61400-1

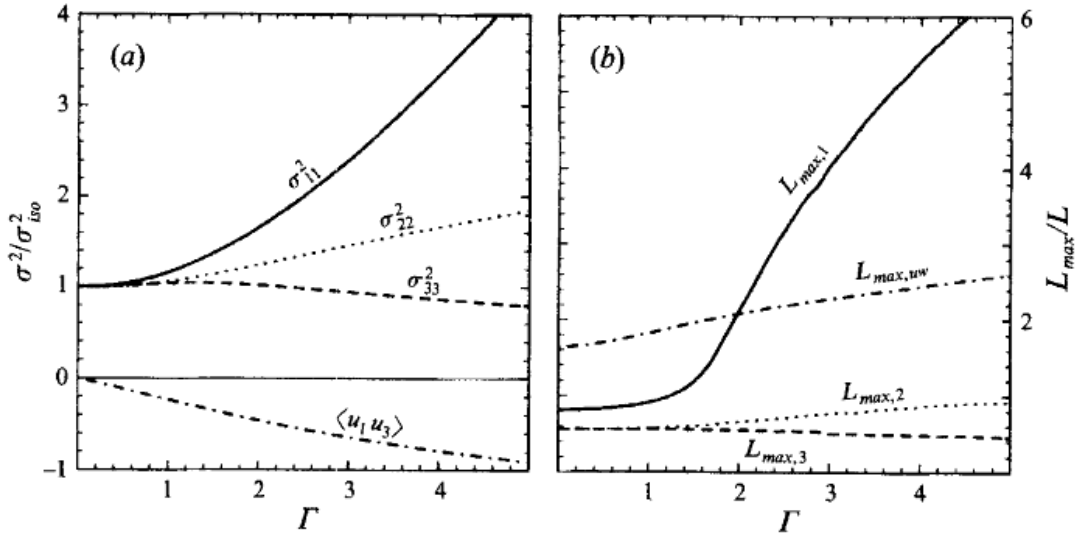


Figure 4:Turbulence characteristics compared to isotropic conditions as function of gamma parameter, Mann.. Left: Relation between variance is changed for higher shear distortions. Right: The relation between length scales are also changed for non-isotropic turbulence. It is recommended to use $\Gamma = 3.9$ *for normal atmospheric conditions. This is also the requirement in the IEC61400-1 standard. Isotropic conditions are obtained using* Γ *=1.*

The result of using $\Gamma = 3.9$ is that the structure of the turbulence corresponds the normal atmospheric conditions, but the actual level of turbulence is also affected as seen in *Figure 4*. It is not straight forward to give the exact analytical relationship between the input parameter $\alpha\varepsilon^{\frac{2}{3}}$ and the final longitudinal variance and it is therefore very practical to introduce a turbulence scaling factor SF. This turbulence scaling factor is calculated based on the actual variance level in the box (normally extracted in the center of the box of longitudinal turbulence) and the target variance σ^2_{target} based on the requested turbulence intensity $\sigma = Ti\,\overline{U}$.

$$SF = \sqrt{\frac{\sigma^2_{\text{target}}}{\sigma^2}} \qquad (4)$$

The scale factor is to be multiplied to every values in the turbulence box for all the u,v and w directions. This is done automatically inside HAWC2.

Obl.	Command name	Explanation
	create_turb_parameters	With this command, the code will search for turbulence files with names given below, but if these are not found the turbulence will be created based on the given parameters. 1. Length scale L 2. $\alpha\varepsilon^{2/3}$ 3. γ 4. Seed number (any integer will do) 5. High frequency compensation (1=point velocity only represent local value which is closest to anemometer measurements, recommended in

Obl.	Command name	Explanation
		most cases, 0=point velocity represents average velocity in grid volume)
	filename_u	1. Filename incl. relative path to file containing mann turbulence u-composant (example ./turb/mann-u.bin)
	filename_v	1. Filename incl. relative path to file containing mann turbulence v-composant (example ./turb/mann-v.bin)
	filename_w	1. Filename incl. relative path to file containing mann turbulence w-composant (example ./turb/mann-w.bin)
*	box_dim_u	1. Number of grid points i u-direction 2. Length between grid points in u-direction
*	box_dim_v	1. Number of grid points i v-direction 2. Length between grid points in v-direction
*	box_dim_w	1. Number of grid points i w-direction 2. Length between grid points in w-direction
	std_scaling	Ratio between standard deviation for specified component related to turbulence intensity input specified in main wind command block. 1. Ratio to u-direction (default=1.0) 2. Ratio to v-direction (default=0.8) 3. Ratio to w-direction (default=0.5)
	dont_scale	If this command is used the normal scaling to ensure the specified turbulence intensity is bypassed. 1. (0=scaling according to specified inputs – default, 1=raw turbulence field used without any scaling)

Sub command block - flex

Block that must be included if the mann turbulence format is chosen.

Obl.	Command name	Explanation
*	filename_u	1. Filename incl. relative path to file containing flex turbulence u-composant (example ./turb/flex-u.int)
*	filename_v	1. Filename incl. relative path to file containing flex turbulence v-composant (example ./turb/flex-v.int)
*	filename_w	1. Filename incl. relative path to file containing flex turbulence w-composant (example ./turb/flex-w.int)
	std_scaling	Ratio between standard deviation for specified composant related to turbulence intensity input specified in main wind command block. 1. Ratio to u-direction (default=1.0) 2. Ratio to v-direction (default=0.7) 3. Ratio to w-direction (default=0.5)

File description of user defined shear

In this file a user defined shear used instead, or in combination with one of the default shear types (logarithmic, exponential...). When the user defined shear is used the name and location of the datafile must be specified with the *wind – user_defined_shear* command. This command specifies the location of the file and activates the user defined shear. If this shear is replacing the original default shear the command *wind – shear_format* must be set to zero!

Only one shear can be present in a single file. The shear describes the mean wind profile of the u, v and w component of a vertical cross section at the rotor. The wind speeds are normalized with the mean wind speed defined with the command *wind – wsp*.

Line number	Description
1	Headline (not used by HAWC2)
2	Information of shear v-component. #1 is the number of columns, NC #2 is the number of rows, NR
3	Headline (not used by HAWC2)
4..+NR	Wind speed in v-direction, normalized with u-mean. # NC columns
+1	Headline (not used by HAWC2)
+1..+NR	Wind speed in u-direction, normalized with u-mean. # NC columns.
+1	Headline (not used by HAWC2)
+1..+NR	Wind speed in w-direction, normalized with u-mean. # NC columns
+1	Headline (not used by HAWC2)
+1..+NC	Horizontal position of grid points (meteorological coo)
+1	Headline (not used by HAWC2)
+1..+NR	Vertical position of grid points (meteorological coo)

Example of user defined shear file

```
# User defined shear file
3 5  # nr_v, nr_w     array sizes
# shear_v component, normalized with U_mean
0.0 0.0 0.0
0.0 0.0 0.0
0.0 0.0 0.0
0.0 0.0 0.0
# shear_u component, normalized with U_mean
1.0 1.0 1.0
1.0 1.0 1.0
1.0 1.0 1.0
1.0 1.0 1.0
# shear_w component, normalized with U_mean
0.0 0.0 0.0
0.0 0.0 0.0
0.0 0.0 0.0
0.0 0.0 0.0
# v coordinates
-50.0
0.0
50.0
# w coordinates
0.0
60.0
100.0
200.0
```

File description of user defined shear turbulence

In this file a set of factors are defined to scale the turbulence as function of vertical and lateral postion. When the user defined shear is used, the name and location of the datafile must be specified with the *wind – user_defined_shear_turbulence* command. This command specifies the location of the file and activates the user defined shear.

Only one set of turbulence factors can be present in a single file. The set describes the factors that are multiplied to the turbulence components directly. There are no procedures inside the code to ensure that the actual standard deviation is the same as specified. To be sure of this, the simulation length must fit the length of the turbulence box. The factors in the datafile are still applied even when the dont_scale command is activated in the main turbulence block.

Line number	Description
1	Headline (not used by HAWC2)
2	Information of shear #1 is the number of columns, NC #2 is the number of rows, NR
3	Headline (not used by HAWC2)
4..+NR	Scale factors in v-direction # NC columns
+1	Headline (not used by HAWC2)
+1..+NR	Wind speed in u-direction. # NC columns.
+1	Headline (not used by HAWC2)
+1..+NR	Wind speed in w-direction. # NC columns
+1	Headline (not used by HAWC2)
+1..+NC	Horizontal position of grid points (meteorological coo)
+1	Headline (not used by HAWC2)
+1..+NR	Vertical position of grid points (meteorological coo)

Example of user defined shear turbulence file

```
# User defined shear turbulence file
3 5  # nr_v, nr_w     array sizes
# factors v component
1.0 1.0 1.0
1.0 1.0 1.0
1.0 1.0 1.0
1.0 1.0 1.0
# factors u component
1.0 1.0 1.0
1.0 1.0 1.0
0.8 0.8 0.8
0.5 0.5 0.5
# factors w component
1.0 1.0 1.0
1.0 1.0 1.0
1.0 1.0 1.0
1.0 1.0 1.0
# v coordinates
-50.0
0.0
50.0
# w coordinates
0.0
60.0
100.0
200.0
```

Sub command block - wakes

Block that must be included if the Dynamic Wake Meandering model is used to model the wind flow from one or more upstream turbines.
In order to make the model function, two Mann turbulence boxes must be used. One for the meandering turbulence – which is a box containing atmospheric turbulence, but generated with a course resolution in the v,w plane (grid size of 1 rotor diameter). It is important that the turbulence vectors at the individual grid points represent a mean value covering a grid cube. It is also important that the total size of the box is large enough to cover the different wake sources including their meandering path. The resolution in the u-direction should be as fine a possible. The used length scale should correspond to normal turbulence condition. The other turbulence box that is needed is a box representing the micro scale turbulence from the wake of the upstream turbine itself. The resolution of this box should be fine (e.g. 128x128 points) in the v,w plane which should only cover 1 rotor diameter. The resolution in the u direction should also be fine, but a short length of the box (e.g. 2.5Diameter) is OK, since the turbulence box is reused. The length scale for this turbulence is significantly shorter than for the other boxes since it represents turbulence from tip and root vortices mainly. A length scale of 1/16 rotor diameter seems appropriate.

The two turbulence boxed are included by the following sub commands

```
begin mann_meanderturb;
       (parameters are identical to the normal Mann turbulence box, see
       above)
end mann_meanderturb;

begin mann_microturb;
       (parameters are identical to the normal Mann turbulence box, see
       above)
end mann_microturb;
```

The rest of the wake commands are given in the following table.

Obl.	Command name	Explanation
*	nsource	1. Number of wake sources. If 0 is used the wake module is by-passed (no source positions can be given in this case).
*	source_pos	Command that must be repeated *nsource* times. This gives the position of the wake source (hub position) in global coordinates. Wake source position given for down stream turbines are however not used in the simulations since they don't affect the target turbine. 1. x-pos [m] 2. y-pos [m] 3. z-pos [m]
*	op_data	Operational conditions for the wake sources. 1. Rotational speed [rad/s] 2. Collective pitch angle [deg]. Defined positive according to the blade root coo, with z-axis from root towards tip.
	ble_parameters	Parameters used for the BLE model used for developing the wake deficit due to turbulent mixing. 1. k_1 [-], default=0.10 2. k_2 [-], default=0.008 3. clean-up parameter (0=intermediate files are kept, 1=intermediate files are deleted), default=1
	microturb_factors	Parameters used for scaling the added wake turbulence according to the deficit depth and depth derivative. 1. k_{m1} [-], factor on deficit depth, default=0.60 2. k_{m2} [-], factor on depth derivative, default=0.25
	tint_meander	Turbulence intensity of the meander turbulence box. If this command is not used then the default turbulence intensity from the general wind commands is used (normal use) 1. Turbulence intensity [-]
	write_ct_cq_file	File including the local axial and tangential forces (non-dim) as function of blade radius is written. 1. Filename incl. path (e.g. ./res/ct_cq.data)
	write_final_deficits	File with the deficits used in the correct downstream distance is written. The windspeed deficits are non-dim with the mean wind speed. 1. Filename incl. path (e.g. ./res/ct_cq.data)

Sub command block – tower_shadow_potential

Block that must be included if the potential flow tower shadow model is chosen.

Obl.	Command name	Explanation
*	tower_offset	The tower shadow has its source at the global coordinate z axis. The offset is the base point for section 1 1. Offset value (default=0.0)
*	nsec	Command that needs to present before the radius commands. 1. Number of datasets specified by the radius command.
*	radius	Command that needs to be listed nsec times. 1. z coordinate [m] 2. Tower radius at z coordinate [m]

Sub command block – tower_shadow_jet

Block that must be included if the model based on the boundary layer equations for a jet is chosen. This model is especially suited for downwind simulations.

Obl.	Command name	Explanation
*	tower_offset	The tower shadow has its source at the global coordinate z axis. The offset is the base point for section 1 1. Offset value (default=0.0)
*	nsec	Command that needs to present before the radius commands. 1. Number of datasets specified be the radius command.
*	radius	Command that needs to be listed nsec times. 1. z coordinate [m] 2. Tower radius at z coordinate [m] 3. C_d drag coefficient of tower section (normally 1.0 for circular section, but this depends heavily on the reynold number)

Sub command block – tower_shadow_potential_2

Block that must be included if the tower shadow method 3 is chosen. This potential model is principally similar to the potential flow model described previously but differs in the way that the shadow source is moved and rotated in space as the tower coordinate system is moving and rotating. It is also possible to define several tower sources e.g. if the tower is a kind of tripod or quattropod. Just include more tower_shadow_potential_2 blocks if more sources are required.

The coordinate system that the shadow method is linked to is specified by the user, e.g. the mbdy coordinate from the tower main body. To make sure that the tower source model is always linked in the same way as the tower (could be tricky since the tower is fully free to be specified along the x,y or z axis or a combination) the base coordinate system for the shadow model is identical to the coordinates system obtained by the local element coordinates, where the z axis is always pointing from node 1 towards node 2. This is the reason that the tower radius input has to specified with positive z-values, see below.

Obl.	Command name	Explanation
*	tower_mbdy_link	Name of the main body to which the shadow source is linked. 1. mbdy name
*	nsec	Command that needs to present before the radius commands. 1. Number of datasets specified by the radius command.
*	radius	Command that needs to be listed nsec times. 1. z coordinate [m] (allways positive!) 2. Tower radius at z coordinate [m]

Sub command block – tower_shadow_jet_2

Block that must be included if the tower shadow method 4 is chosen. This jet model is principally similar to the jet model described previously but differs in the way that the shadow source is moved and rotated in space as the tower coordinate system is moving and rotating. It is also possible to define several tower sources e.g. if the tower is a kind of tripod or quattropod. Just include more tower_shadow_jet_2 blocks if more sources are required.

The coordinate system that the shadow method is linked to is specified by the user, e.g. the mbdy coordinate from the tower main body. To make sure that the tower source model is always linked in the same way as the tower (could be tricky since the tower is fully free to be specified along the x,y or z axis or a combination) the base coordinate system for the shadow model is identical to the coordinates system obtained by the local element coordinates, where the z axis is always pointing from node 1 towards node 2. This is the reason that the tower radius input has to specified with positive z-values, see below.

Obl.	Command name	Explanation
*	tower_mbdy_link	Name of the main body to which the shadow source is linked. 1. mbdy name
*	nsec	Command that needs to present before the radius commands. 1. Number of datasets specified by the radius command.
*	radius	Command that needs to be listed nsec times. 1. z coordinate [m] (allways positive!) 2. Tower radius at z coordinate [m]

Sub command block – turb_export

With this sub command block, a mann format turbulence box including information from shear, wakes, tower shadow etc. is written. Same data point positions are used as specified in the turbulence module including the parameters specifyed for the originally used mann turbulence box.

Obl.	Command name	Explanation
*	filename_u	Filename of turbulence box with axial turbulence 1. File name
*	filename_v	Filename of turbulence box with lateral turbulence 1. File name
*	filename_w	Filename of turbulence box with vertical turbulence 1. File name

Aerodynamics

Main command block - aero

This module set up parameters for the aerodynamic specification of the rotor. It is also possible to submit aerodynamic forces to other structures as example the tower or nacelle, but see chapter (Aerodrag) regarding this. The module can ba added as many times as requested if multiple aerodynamic rotors are needed.

Obl.	Command name	Explanation
	name	Name o rotor (in case of multiple rotors defined)
*	nblades	Must be the first line in aero commands! 1. Number of blades
*	hub_vec	Link to main-body vector that points downwind from the rotor under normal conditions. This corresponds to the direction from the pressure side of the rotor towards the suction side where the coordinate system is normally taken from the main shaft system.. 1. mbdy name or 'old_input' if old_htc_structure format is applied. 2. mbdy coo. component (1=x, 2=y, 3=z). If negative the opposite direction used. Not used together with old_htc_structure input (specify a dummy number).
*	link	Linker between structural blades and aerodynamic blades. There must be same number of link commands as nblades! 1. blade number 2. link chooser – options are • mbdy_c2_def (used with new structure format) • blade_c2_def (used with old structure format, see description below in this chapter) 3. mbdy name (with new structure format), not used to anything with old structure format.
*	ae_filename	1. Filename incl. relative path to file containing aerodynamic layout data (example ./data/hawc2_ae.dat)
*	pc_filename	1. Filename incl. relative path to file containing profile coefficients (example ./data/hawc2_pc.dat)
*	induction_method	1. Choice between which induction method that shall be used (0=none, 1=normal BEM dynamic

Obl.	Command name	Explanation
	name	Name o rotor (in case of multiple rotors defined)
		induction, 2= Near Wake induction method)
*	aerocalc_method	1. Choice between which aerodynamic load calculation method that shall be used. (0=none, 1=normal)
	aerosections	Number of aerodynamic calculation points at a blade. The distribution is performed automatically using a cosinus transformation which gives closest spacing at root and tip. 1. Number of points at each blade.
	aero_distribution	1. Distribution method of aerodynamic calculation points. Options are: • "default" number. The distribution is performed automatically using npoints position with a cosinus transformation which givest closest spacing at root and tip. • "ae_file" set. The distribution is given with same spacing as values in the ae_file with set number set..
*	ae_sets	Set number from ae_filename that is linked to blade 1,2,...,nblades 1. set for blade number 1 2. set for blade number 2 . . . nblades. set for blade number nblades
*	tiploss_method	1. Choice between which tip-loss model that shall be used (0=none, 1=prandtl (default))
*	dynstall_method	1. Choice between which dynamic stall model that shall be used (0=none, 1=Stig Øye method, 2=MHH Beddoes method, 3=Gaunaa-Andersen method with Deformable Trailing Edge Flap's)

Sub command block – dynstall_so

Block that may be included if the Stig Øye dynamic stall method is chosen. If not included defaults parameters are automatically used.

Obl.	Command name	Explanation
	dclda	1. Linear slope coefficient for unseparated flow (default=6.28)
	dcldas	1. Linear slope coefficient for fully separated flow (default=3.14)
	alfs	1. Angle of attack [deg] where profile flow is fully separated. (default=40)
	alrund	1. Factor used to generate synthetic separated flow Cl values (default=40)
	taufak	1. Time constant factor in first order filter for F function (default=10.0). Internally used as tau=taufak*chord*vrel

Sub command block – dynstall_mhh

Block that may be included if the MHH Beddoes dynamic stall method is chosen. If not included defaults parameters are automatically used.

Obl.	Command name	Explanation
	a1	1. Coefficients of the exponential potential flow step response approximation: Phi(s)=1-A1*exp(-b1*s)-

		A2*exp(-b2*s). (default= 0.165)
	a2	1. Coefficients of the exponential potential flow step response approximation: Phi(s)=1-A1*exp(-b1*s)-A2*exp(-b2*s). (default= 0.335)
	b1	1. Coefficients of the exponential potential flow step response approximation: Phi(s)=1-A1*exp(-b1*s)-A2*exp(-b2*s). (default= 0.0455)
	b2	1. Coefficients of the exponential potential flow step response approximation: Phi(s)=1-A1*exp(-b1*s)-A2*exp(-b2*s). (default= b2=0.300)
	update	Choice between update methods: 1. 1 (default)=>update aerodynamics all iterations all timesteps; 0=>only update aerodynamics first iteration each new timestep
	taupre	1. Non-dimensional time-lag parameters modeling pressure time-lag. Default value =1.5
	taubly	1. Non-dimensional time-lag parameters modeling boundary layer time-lag. Default value=6.0
	only_potential_model	1. 0(default)=>run full MHH beddoes model; 1=>Potential flow model dynamics superposed to steady force coefficients;

Sub command block – dynstall_mhhmagf

Block that may be included if the MHHMAGF Beddoes dynamic stall method is chosen. The stall model is the MHH Beddoes dynamic stall model expanded with dynamic effects of trailing edge flap motion.

Obl.	Command name	Explanation
*	flap	Command that must be repeated for each flap section defined 1. Non-dim radius r/R of flap section start, from blade root. 2. Non-dim radius r/R of flap section end, from blade root. 3. Filename incl. relative path to file containing α-delta C_l static profile coefficients. Fileformat is ASCII – two colums. The delta C_l marks the delta for one degree positive flap angle at various angles of attack.
	ais	Coefficients of the exponential potential flow step response approximation: 1. A1 (default= 0.0821) 2. A2 (default=0.1429) 3. A3 (default=0.3939) Default coefficients is derived for the Risø-B1-18 profile
	bis	Coefficients of the exponential potential flow step response approximation: 1. B1 2. B2 3. B3
	ti1	Camberline coefficients 1. TI1_a (default=0.01095889075152) 2. TI1_b (default=-0.00097224060418)
	ti2	Camberline coefficients 1. TI2_a (default=-0.00105409494045) 2. TI2_b (default=-0.00000964520546) 3. TI2_c (default=0.00011409945431) 4. TI2_d (default=-0.00000096469297)

Obl.	Command name	Explanation
	ti3	Camberline coefficients 1. TI3_a (default=-0.01823405820608) 2. TI3_b (default=-0.00043120871058) 3. TI3_c (default=-0.00042628415385) 4. TI3_d (default=-0.00004009691664)
	ti4	Camberline coefficients 1. TI4_a (default=-0.04288996443976) 2. TI4_b (default=-0.00090740475877)
	ti5	Camberline coefficients 1. TI5_a (default=-0.17732761097554) 2. TI5_b (default=0.00050518296019)
	ti6	Camberline coefficients 1. TI6_a (default=0.15479786740119) 2. TI6_b (default=0.00144695790428)
	ti7	Camberline coefficients 1. TI7_a (default=-0.20821609838649) 2. TI7_b (default=-0.01746039372665)
	ti8	Camberline coefficients 1. TI8_a (default=0.01329688411426) 2. TI8_b (default=0.00088185679919) 3. TI8_c (default=0.00737988450743) 4. TI8_d (default=0.00054605607792)
	ti9	Camberline coefficients 1. TI9_a (default=-0.02960508187800) 2. TI9_b (default=0.00001446048395) 3. TI9_c (default=-0.00211611339069) 4. TI9_d (default=0.00001171165409)
	hdydx	1. Camberline coef. (default=-0.07106384522900)
	hy	1. Camberline coef. (default=-0.00199404265933)
	fdydxle	1. Camberline coef. (default=0.00619732559359)
	gdydxle	1. Camberline coef. (default=0.00288436419056)
	gyle	1. Camberline coef. (default=0.00006407600471)
	update	Choice between update methods: 1. 1 (default)=>update aerodynamics all iterations all timesteps; 0=>only update aerodynamics first iteration each new timestep
	taupre	1. Non-dimensional time-lag parameters modeling pressure time-lag. Default value =1.5
	taubly	1. Non-dimensional time-lag parameters modeling boundary layer time-lag. Default value=6.0

Camberline coefficients used to specify the dynamics of the flap. These coefficients are given by the Gaunaa model. Default vales used are for the Risø B1-18 profile with a 10% chord length flap mounted.

Sub command block – bemwake_method

Dynamic inflow settings used to calculate the dynamic induction. If not included defaults parameters are automatically used.

Obl.	Command name	Explanation
	nazi	1. Number of azimuthal points in the induction grid. A high number increased accuracy but slow down the simulation time. Default is 16.
	fw	Dynamic time constants and mixing ratio contribution for the far wake part of the induction. 1. Mixing ratio, default is 0.4 2. k3 (poly. coef. for r/R sensitivity) default=0.0 3. k2 (poly. coef. for r/R sensitivity) default=-0.4751 4. k1 (poly. coef. for r/R sensitivity) default=0.4101 5. k0 (poly. coef. for r/R sensitivity) default=1.921
	nw	Dynamic time constants and mixing ratio contribution for the near wake part of the induction. 6. Mixing ratio, default is 0.6 7. k3 (poly. coef. for r/R sensitivity) default=0.0 8. k2 (poly. coef. for r/R sensitivity) default=-0.4783 9. k1 (poly. coef. for r/R sensitivity) default=0.1025 10. k0 (poly. coef. for r/R sensitivity) default=0.6125
	a-ct-filename	Filename for userdefined relation bewteen a and ct.

Data format for the aerodynamic layout

The format of this file which in the old HAWC code was known as the hawc_ae file is changed slightly for the HAWC2 input format. The position of the aerodynamic center is no longer an input value, since the definition is that the center is located in $C_{1/4}$ with calculated velocities in $C_{3/4}$.

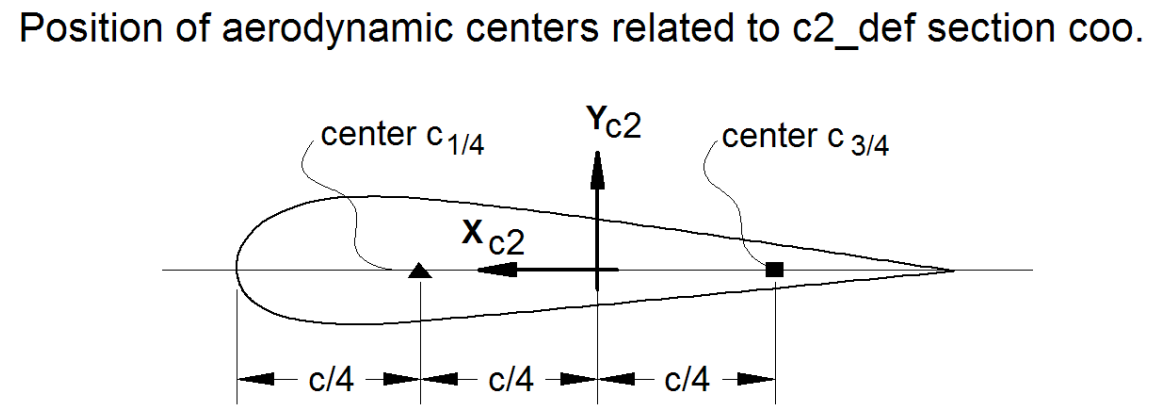


Figure 5: Illustration of aerodynamic centers c1/4 and c3/4

The format of the file is specified in the following two tables

Line number	Description
1	#1: Nset, Number of datasets present in the file. The format of ecah data set can be read below. The datasets are repated without blank lines etc.
2	#1: Set number. #2: Nrows, Number of data rows for this set
3..2+Nrows	Data row according to Table 4

Table 3: Format of main data structure for the aerodynamic blade layout file

The content of the colums in a data row is specified in the table below.

Column	Parameter
1	r, distance from main_body node 1 along z-coordinate [m]
2	chord length [m]
3	thickness ratio between profile height and chord [%]
4	Profile coefficient set number

Table 4 Format of the data rows for the aerodynamic blade layout file

Example of an aerodynamic blade layout file

```
1       Number of datasets in the file.
1 25  Set nr, nrows.
0       2.42    100     1  Radius [m]  chord[m]       thick[%]       PC [-]
1.239   2.42    100     1
1.24    2.42    99.9    1
3.12    2.48    96.4    1
5.24    2.65    80.5    1
7.24    2.81    65.0    1
9.24    2.98    51.6    1
11.24   3.14    40.3    1
13.24   3.17    32.5    1
15.24   2.99    28.4    1
17.24   2.79    25.6    1
19.24   2.58    23.7    1
20.44   2.46    22.8    1
23.24   2.21    20.9    1
25.24   2.06    20.0    1
27.24   1.92    19.4    1
29.24   1.8     19.0    1
31.24   1.68    18.7    1
33.24   1.55    18.6    1
35.24   1.41    18.3    1
37.24   1.18    17.9    1
38.24   0.98    17.3    1
39.24   0.62    16.3    1
39.64   0.48    15.7    1
40.00   0.07    14.8    1
```

Data format for the profile coefficients file

The format of this file which in the old HAWC code was known as the hawc_pc file has not been changed for the HAWC2 code.

The format of the file is specified in the following two tables

Line number	Description
1	#1: Nset, Number of datasets present in the file. The format of ecah data set can be read below. The datasets are repated without blank lines etc.
2	#1: Nprofiles. Number of profiles included in the data set.
3	#1: Set number. #2: Nrows. #3: Thickness in percent of chord length
4..3+Nrows	Data row according to Table 6

Table 5: Format of main data structure for the profile coefficients file

The content of the colums in a data row is specified in table below.

Column	Parameter
1	α, angle of attack [deg]. Starting with -180.0, ending with +180.0
2	C_l lift coefficient [-]
3	C_d drag coefficient [-]
4	C_m moment coefficient [-]

Table 6 Format of the data rows for the profile coefficients file

Example of the profile coefficients file

```
1 Airfoil data for the nrel 5 mw turbine
8
1   127  17 DU17 airfoil with an aspect ratio of 17.  Original -180 to 180deg
-180.00    0.000   0.0198   0.0000
-175.00    0.374   0.0341   0.1880
```

```
-170.00    0.749   0.0955   0.3770
-160.00    0.659   0.2807   0.2747
-155.00    0.736   0.3919   0.3130
-150.00    0.783   0.5086   0.3428
-145.00    0.803   0.6267   0.3654
-140.00    0.798   0.7427   0.3820
-135.00    0.771   0.8537   0.3935
-130.00    0.724   0.9574   0.4007
-125.00    0.660   1.0519   0.4042
-120.00    0.581   1.1355   0.4047
-115.00    0.491   1.2070   0.4025
-110.00    0.390   1.2656   0.3981
-105.00    0.282   1.3104   0.3918
-100.00    0.169   1.3410   0.3838
 -95.00    0.052   1.3572   0.3743
 -90.00   -0.067   1.3587   0.3636
 -85.00   -0.184   1.3456   0.3517
 -80.00   -0.299   1.3181   0.3388
 -75.00   -0.409   1.2765   0.3248
 -70.00   -0.512   1.2212   0.3099
 -65.00   -0.606   1.1532   0.2940
 -60.00   -0.689   1.0731   0.2772
 -55.00   -0.759   0.9822   0.2595
```

Data format for the user defined a-ct relation

The format of the file is specified in the following two tables

Line number	Description
1	Nset interpolationmethod. Nset is number of data row present in the file. The format of ecah data set can be read below. Interpolationmethod can either be “linear” or “akima”
2..Nset	Data row according to Table 6

Table 7: Format of main data structure for the profile coefficients file

The content of the colums in a data row is specified in table below.

Column	Parameter
1	non-dim radius r/R
2	k1 polynomium coef
3	k2 polynomium coef
4	k3 polynomium coef
5	k4 polynomium coef

Table 8 Format of the data rows for the profile coefficients file

Main command block – blade_c2_def (for use with old_htc_structure format)

In this command block the definition of the centerline of the main_body is described (position of the half chord). This command shall be used as a main command even though it is only used together with the aerodynamic module. The reason for this is that it used to submit information that is usually given in the new_htc_structure format, which is also a main command block. The input data given with the sec commands below is used to define a continuous differentiable line in space using akima spline functions. This centerline is used as basis for local coordinate system definitions for sections along the structure. If a straight line is requested a minimum of three points of this line must be present.

Obl.	Command name	Explanation
*	nsec	Must be the present before a "sec" command. 1. Number of section commands given below
*	sec	Command that must be repeated "nsec" times 1. Number 2. x-pos [m] 3. y-pos [m] 4. z-pos [m] 5. θ_z [deg]. Angle between local x-axis and main_body x-axis in the main_body x-y coordinate plane. For a straight blade this angle is the aerodynamic twist. Note that the sign is positive around the z-axis, which is opposite to traditional notation for etc. a pitch angle.

Aerodrag (for tower and nacelle drag)

Main command aerodrag

With this module it is possible to apply aerodynamic drag forces at a given number of structures.

Subcommand aerodrag_element

Command block that can be repeated as many times as needed. In this command block aerodynamic drag calculation points are set up for a given main body.

Obl.	Command name	Explanation
*	body_name mbdy_name	1. Main_body name to which the hydrodynamic calculation points are linked.
*	aerodrag_sections	1. Distribution method: ("uniform" only possibility) 2. Number of calculation points (min. 2).
	nsec	This command must be present before the sec commands 1. Number of sections given below
	sec	This command must be repeated nsec times 1. Distance in [m] along the main_body c2_def line. Positive directed from node 1 to node "last". 2. C_d drag coefficient (default=1.0) 3. Width of structure (diameter)
	update_states	Logical parameter that determines whethe the movement of the structure is included or not. 1. parameter (1=states are updated (default), 0=not updated)

*) Input commands that must be present

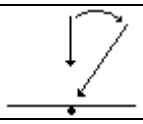
Hydrodynamics

Main command block - hydro

In this command block hydrodynamic forces calculated using Morison's formula is set up.

Sub command block – water_properties

Obl.	Command name	Explanation
*	gravity	1. Gravity acceleration (used for calculation of buoyancy forces). Default = 9.81 m/s^2
*	mudlevel	1. Mud level [m] in global z coordinates.
*	mwl	1. Mean water level [m] in global z coordinates.
*	rho	1. Density of the water [kg/m^3]. Default=1027
	wave_direction	1. Wave direction [deg]. Direction is positive when the waves come forward from the right when looking towards the wind at default conditions. V_0 Wave direction

		
	current	1. Current type (0=none (default), 1=constant, 2=power law U(z)=U0((z+mudlevel-mwl)/(mudlevel-mwl))^alfa 2. Current velocity at mwl, u0 3. type parameter. If type=2 then parameter is alfa 4. Current direction relative to wave direction [deg]. Positive direction if current comes from the right looking towards the incoming waves.
	water_kinematics_dll	1. Filename incl. relative path to file containing water kinematics dll (example ./hydro/water_kin.dll) 2. String sent to initialization of dll. This is typical the name of a local inputfile of the dll.

Sub command block – hydro_element

Command block that can be repeated as many times as needed. This command block set up hydrodynamic calculation points and link them to a main_body.

Obl.	Command name	Explanation
*	body_name mbdy_name	1. Main_body name to which the hydrodynamic calculation points are linked.
*	hydrosections	1. Distribution method of hydrodynamic calculation points. Options are: • "uniform" nnodes. Where uniform ensures equal distance of the calculation points. nnodes are number of calculation points. • "auto" nint. Here calculations points are chosen as the postions of the structural nodes and the hydro dynamic input section given by the sec command. The parameter *nint* is a refinement parameter given *nint* extra calculation points in between the other points.
*	nsec	This command must be present before the sec commands 1. Number of sections given below

Obl.	Command name	Explanation
*	sec	This command must be repeated nsec times 1. Relative distance along the main_body c2_def line. Positive directed from node 1 to node "last". 2. C_m inertia coefficient (default=1.0) 3. C_d drag coefficient (default=1.0) 4. Cross sectional area [m^2] 5. Cross sectional area to which C_m is related. (default=area for circular sections) [m^2] 6. Width of construction perpendicular to flow direction [m] 7. drdz gradient(optional). For calculating the buoyancy also for conical sections the gradient expressing the change in radius with change of distance along the main_body c2_def line. Only important when buoyancy forces are included. 8. Axial drag C_d coefficient for concentrated force contribution (optional). Drag area is circular area defined by the local width. Contribution is quadratic regarding water velocity. 9. Axial inertia C_m coefficient for concentrated force contribution (optional). Inertia volume is a sphere defined by the local width as diameter. 10. Axial drag C_d coefficient for concentrated force contribution (optional). Drag area is circular area defined by the local width. Contribution is linear regarding water velocity. 11. Internal cross sectional area for flooded members [m^2]. 0=member is not flooded.
	buoyancy	1. Specification whether buoyancy forces are included or not. 0=off (default), 1=on (remember to define the 7th parameter in the *sec* input line.
	update_states	1. Specification whether the hydrodynamic sections are updated in time with respect to pos, vel, acc and orientations, or simply considered to remain fixed. 0=not updated, 1=updated (default)
	update_kinematics	1. Specification whether the water kinematics are updated during iterations or only once per time step. 0=only updated once per time step, 1=full update (default).

Here is an example of this written into the htc-input file.

```
  begin HYDRO_ELEMENT ;
   mbdy_name cylinder ;
   buoyancy 1 ;
   update_states  1 ; (0: no dynamic interaction, 1: fully coupled solution
   hydrosections auto 4 ; dist, of hydro calculation points from 1 to nsec
   nsec 2; z    Cm Cd A      Aref   width dr/dz Cd_a_(quad) Cm_a Cd_a_lin Aif
   sec       0.0   1   1   3.404   3.404   2.082 0.0    0.0            0.0   0.0
3.023;
   sec       5.0   1   1   3.404   3.404   2.082 0.0    0.0            0.0   0.0
3.023;
  end HYDRO_ELEMENT ;
```

This example shows a flooded cylindrical element (l=5 m, d= 2,082 m and t=60mm).

Description of the water_kinematics_dll format.

```
subroutine init(inputfile,t0,t1,dt) implicit none
character*(*) :: inputfile
real*8                :: t0   ! start time for simulation
real*8                :: t1   ! stop time for simulation
real*8                :: dt   ! time increment
!DEC$ ATTRIBUTES DLLEXPORT, ALIAS:'init'::init
end subroutine init

!-------------------------------------------------------------------------
subroutine set_new_time(time)
implicit none
```

```
!DEC$ ATTRIBUTES DLLEXPORT, ALIAS:'set_new_time'::set_new_time
real*8                :: time

end subroutine set_new_time

!-------------------------------------------------------------------------
subroutine get_sea_elevation(posxy_h,elevation)
implicit none
!DEC$ ATTRIBUTES DLLEXPORT, ALIAS:'get_sea_elevation'::get_sea_elevation
real*8,dimension(2) :: posxy_h         ! horizontal position coordinates
real*8            :: elevation              ! water height above mean water
                                            ! level, positive upwards
end subroutine get_sea_elevation

!-------------------------------------------------------------------------
!DEC$ ATTRIBUTES DLLEXPORT, ALIAS:'get_kinematics'::get_kinematics
real*8,dimension(3)           ::      pos_h,&
                                      vel_h,&
                                      acc_h
real*8                        ::      pres
end subroutine get_kinematics
```

User manual to the standard wkin.dll version 1.4.

The wkin.dll which is delivered along with the HAWC2 code needs a separate inputfile. The format for these inputs are the same as the HAWC2 main inputfile with usage of begin..end clauses, semi colon separators, exit command etc. Command words are described below.

All command words written below has to be included in an begin .. end clause called wkin_input:

begin wkin_input;
...
end wkin_input;
exit;

Main commands in the wkin.dll:

Obl.	Command name	Explanation
*	wavetype	1. Type of wave used. (0=regular airy, 1=irregular airy, 2=deterministic irregular airy, 3=regular stream function)
*	wdepth	1. Water depth [m]. Positive value.

Sub command *reg_airy:*
Command that need to be present if the wavetype equals 0 in the main command.

Obl.	Command name	Explanation
*	stretching	1. Wheeler stretching of waves. (0=off, 1=on)
*	wave	1. Significant wave height H_s [m] 2. Wave period T [s]

Sub command *ireg_airy:*
Command that need to be present if the wavetype equals 1 in the main command.

Obl.	Command name	Explanation
*	stretching	1. Wheeler stretching of waves. (0=off, 1=on)
*	spectrum	1. Base spectrum used. (1=jonswap, 2= Pierson Moscowitz)
	jonswap	1. Significant wave height H_s [m] 2. Wave period T_p [s] 3. γ parameter [-]. A typical value is 3.3
	pm	1. Significant wave height H_s [m] 2. Wave period T_p [s]

Obl.	Command name	Explanation
*	coef	1. Number of coefficients. Normally 200 are used even though higher values are recommended in general. A speed issue... 2. Seed number. A positive integer value.
	spreading	1. Spreading model. (0=none, 1=K_{2s} model also referred to as K_n model) 2. Spreading parameter. If model=1 the parameter is s, a positive integer. The higher value, the less spreading.
	pregen	Pre-generation of a wave field (default is on). Using this option the irregular wave field is calculated during initialization phase and only table look-up is done during the time simulation phase. Very fast and still accurate. 1. Pregen option. (0=traditional approach (slow), 1=pregenerated wave field used)

Sub sub command *pregen_field:*

Optional command input to the use of pre-generated wave fields.

Obl.	Command name	Explanation
	t_resolution	1. Time increment in wave field (default is 10points for highest frequency in spectrum)
	z_resolution	1. Number of point along the water height. (default=15)
	y_resolution	1. Number of lateral points. (default=1). It has to be an uneven number. 2. Distance between points.
	xrange	1. Maximum requested distance from x=0 that will be requested during look up [m]. X is in hydrodynamic coordinates (in direction of the waves). (default=100m)

Sub command *det_airy:*

Command that need to be present if the wavetype equals 2 in the main command. This command is used when water kinematics needs to be calculated based on a measured elevation time series.

Obl.	Command name	Explanation
*	file	1. File name for measured wave elevation.
*	nsamples	1. Number of lines present in wave elevation file
*	nskip	1. Number of lines to skip before reading of wave elevation file
*	colums	1. Colum number for time sensor in file. 2. Colum number for wave elevation in file.
	stretching	1. Wheeler stretching of waves. (0=off, 1=on (default))
	cutoff_frac	1. Fraction of total energy which is discarded in the low and high frequency ranges. Default 1E-5

Wkin.dll example file

```
begin wkin_input ;
  wavetype 1 ;       0=regular, 1=irregular, 2=deterministic
  wdepth  220.0 ;
;
  begin reg_airy ;
    stretching 0;    0=none, 1=wheeler
    wave 9 12.6;     Hs,T
  end;
;
  begin ireg_airy ;
    stretching 0;     0=none, 1=wheeler
    spectrum   1;    (1=jonswap)
    jonswap 9 12.6 3.3 ; (Hs, Tp, gamma)
    coef 200 1 ;      (coefnr, seed)
    spreading 1 2;      (type(0=off 1=on), s parameter (pos. integer min 1)
  end;
;
  begin det_airy ;
    stretching 0;     0=none, 1=wheeler
    file ..\waves\elevation.dat ;
    nsamples 32768 ;
    nskip 1 ;
    columns 1 5 ;     time column, elevation column
  end;
;
end;
;
exit ;
```

Soil module

Main command block - soil

In this command block soil spring/damper forces can be attached to a main body. The formulation is performed so it can be used for other external distributed spring/damper systems than soil.

Sub command block – soil_element

Command block that can be repeated as many times as needed. In this command block the distributed soil spring/damper system is set up for a given main body.

Obl.	Command name	Explanation
*	body_name	1. Main_body name to which the soil calculation points are linked.
*	datafile	1. Filename incl. relative path to file containing soil spring properties (example ./soil/soildata.dat)
*	soilsections	1. Distribution method: ("uniform" only possibility) 2. Number of section (min. 2).
	damping_k_factor	1. Rayleigh kind of damping. Factor the linear stiffness coefficients are multiplied with to obtain the damping coefficients. When the factor is 1.0 the vibration is critically damped for the rigid mainbody connected to the spring and dampers.
♣	set	1. Set number in datafile that is used.

*) Input commands that must be present

♣) Command can be repeated as many times as desired.

Data format of the soil spring datafile

In the file (which is a text file) different distributed springs can be defined. Each set is located after the "#" sign followed by the set number. Within a set the following data needs to be present.

line 1	"spring type"	(can be "axial", "lateral" or "rotation_z")
line 2:	"nrow ndefl"	(nrow is number of rows, ndefl is number of deflections (colums)
line 3..3+nrow	"z_global F(1) F(2),..., F(ndefl)"	First colum is the spring location (global z coordinate). The following colums are Force/length at the different deflection stations. First deflection must be zero. The forces are assumed symmetrical around the zero deflection.

An example is given below:

```
This is a nonlinear soil spring demonstration file
#1
lateral               (axial/lateral)
5 4                    nrow ndefl
        0.0     0.1     0.2     1.0   x1 x2 x3 .....   [m]
0.0     0       15      20      500   Z_G  F_1 F_2 F_3 .... F_ndefl [kN/m]
10.0    0       15      20      500
20.0    0       15      20      500
30.0    0       15      20      500
40.0    0       15      20      500
#2
axial                 (axial/lateral)
5 4                    nrow ndefl
        0.0     0.1     0.2     1.0   x1 x2 x3 .....   [m]
0.0     0       150     200     5000  Z_G  F_1 F_2 F_3 .... F_ndefl [kN/m]
10.0    0       150     200     5000
20.0    0       150     200     5000
30.0    0       150     200     5000
40.0    0       150     200     5000
#3
rotation_z            (axial/lateral/rotation_z)
5 4                    nrow ndefl
        0.0     0.1     0.2     1.0   x1 x2 x3 .....   [rad]
0.0     0       150     200     5000  Z_G M_1 M_2 M_3 .... M_ndefl [kNm/m]
10.0    0       150     200     5000
20.0    0       150     200     5000
30.0    0       150     200     5000
40.0    0       150     200     5000
```

External forces through DLL

Main command block – Force

Sub command - DLL

This command block can be used when a user defined external force is applied to the structure. The main difference between this DLL format and the normal DLL control interface (used with external controllers) is that added stiffness is calculated initially leading to a more robust a fast solution of the coupled system. This force module can with good results be applied for external equivalent soil-springs or hydrodynamic forces for floating constructions or mooring lines.

Obl.	Command name	Explanation and parameters
	dll	1. Filename incl. relative path to the external DLL (example ./dll/force.dll)
	update	1. Name of subroutine in the DLL.
	mbdy	1. Name of main body to which force dll is coupled.
	node	1. Node number of main body to which force dll is couple

```
Example of a  DLL interface written in fortran90
!
! Demonstration of force DLL
!
SUBROUTINE DemoForceDLL(time,x,xdot,xdot2,amat,omega,omegadot,F,M)
!DEC$ ATTRIBUTES DLLEXPORT::DemoForceDLL
!DEC$ ATTRIBUTES ALIAS:'demoforcedll' :: DemoForceDLL
! input
DOUBLE PRECISION                 :: time    ! time
DOUBLE PRECISION ,DIMENSION(3)   :: x       ! global pos. of reference node
DOUBLE PRECISION ,DIMENSION(3)   :: xdot    ! global vel. of reference node
DOUBLE PRECISION ,DIMENSION(3)   :: xdot2   ! global acc. of reference node
DOUBLE PRECISION ,DIMENSION(3)   :: omega   ! angular vel. of ref. node
                                            ! (global base)
DOUBLE PRECISION ,DIMENSION(3)   :: omegadot ! angular acc. of ref. node
                                             ! (global base)
DOUBLE PRECISION ,DIMENSION(3,3) :: amat     ! rotation matrix (body ->
                                             !                  global)
! output
DOUBLE PRECISION ,DIMENSION(3)   :: F        ! External force in reference
                                             ! node (global base)
DOUBLE PRECISION ,DIMENSION(3)   :: M        ! External moment in reference
                                             ! node (global base)
! locals
LOGICAL, SAVE                    :: bInit = .FALSE. ! Initialization flag
DOUBLE PRECISION                 :: mass  = 0.d0    ! Point mass
!
! Initialise on first call
IF (.NOT.bInit) THEN
  bInit = .TRUE.
  ! Open file and read mass
  OPEN(10,FILE="DemoForceDLL_mass.dat")
  READ(10,*) mass
  CLOSE(10)
ENDIF
!
! Calc. force
F = mass*((/0.d0,0.d0,9.81d0/) - xdot2)
M = 0.d0
!
END SUBROUTINE DemoForceDLL
```

Output

This command **output** can either be a main command block or a sub command block within the hawc_dll command block. In the tables below two special columns are introduced. One is *only option* and the other *label option*. When the check mark is 'yes' in *only option* it is possible to use only one of the fields if mre than one sensor was defined through the command. The sensor that is used is determined by the number following the *only* command word, see example below.

```
constraint bearing1 shaft_rot 2 only 2;
```

If the *only* command (and the following number) was omitted two sensors was defined; one for the angle and one for the velocity. With the *only* command only the velocity sensor is used in the output since the following number is 2.

With the label option it is possible to make a user defined label of the sensor which is written in the sensor list file. The label command is the # symbol. Everything after the # symbol is used as a label. An example of this could be

```
dll inpvec 1 1 # This is a dummy label ;
```

Commands used with results file writing

When the output command is used for output files (the most normal purpose) some information regarding file name and format needs to be give

Obl	Command	Explanation
*	filename	1. Filename incl. relative path to outputfile without extension (example ./res/output)
	data_format	ASCII or compressed binary output can be chosen. Default is the ASCII format if nothing is specified. 1. format ('hawc_ascii'=ASCII format, 'hawc_binary'=compressed binary format, 'flex_binary'=compressed binary format)
	buffer	Buffer size in terms of time steps. When the buffer is full the data are written to data file. Only used togeter with the ASCII format. 1. buffer size
	time	Time start t_0 and stop t_1 for output is defined. Defult is the entire simulation length if nothing is specified. 1. t_0 2. t_1

File format of HAWC_ASCII files

Results are written to an ascii formatted data file with the name assigned to the filename variable (eg. filename ./res/resfil). The data file will have the extension .dat as a standard. The description of the sensors in the data file is given in another textfile with same filename as the data file but the extension .sel. An example could be: ./res/resfil.dat and ./res/resfil.sel.

In the .sel-file, line numer 9 specifies the following parameters: Number of scans, Number of sensors, Duration of output file, Data format (ASCII/BINARY). Example:

```
10 96 20.000 ASCII
```

From line number 13 and onwards, the sensors are specified with the following information:
Sensor number, Variable description, unit, Long description. Example:

```
5      bea1 angle_speed              rad/s      pitch1 angle speed
```

Full example of the .sel file:

```
  Version ID : HAWC2MB 4.3w
                                                          Time : 14:23:28
                                                          Date : 22:11.2006
  Result file : ./res2_rev0/case41c_nohydro.dat
   Scans    Channels    Time [sec]      Format
     4500       199         90.000      ASCII

  Channel   Variable Description

     1      Time                           s          Time
     2      bea1 angle                     deg        shaft_rot angle
     3      bea1 angle_speed               rpm        shaft_rot angle speed
     4      bea1 angle                     deg        pitch1 angle
     5      bea1 angle_speed               rad/s      pitch1 angle speed
     6      bea1 angle                     deg        pitch2 angle
     7      bea1 angle_speed               rad/s      pitch2 angle speed
     8      bea1 angle                     deg        pitch3 angle
     9      bea1 angle_speed               rad/s      pitch3 angle speed
```

File format of HAWC_BINARY files

In this file format results are written to a binary unformatted data file with the name assigned to the filename variable (eg. filename ./res/resfil). The data file will have the extension .dat as a standard. The description of the sensors in the data file is given in another textfile with same filename as the data file but the extension .sel. An example could be: ./res/resfil.dat and ./res/resfil.sel.

The data are scaled to standard 2-byte integers, with a range of 32000 using a scalefactor. The scalefactor is determined for each output sensor

$$s = \frac{MAX\,(abs(\max), abs(\min))}{32000}$$

where *max* and *min* are the largest and lowest number in the original data for the sensor. These scale factors are written in the end of the accompanying .sel file. When

converting a binary number to the actual number its just a matter of multiplying the binary numbers of a sensor with the corresponding scalefactor.

In the accompanying text file, which has the extension .sel-file, information of the content in the datafile is stored. In line number 9 the following parameters are specified: Number of scans, Number of sensors, Duration of output file, Data format (ASCII/BINARY). Example:

```
10 96 20.000 ASCII
```

From line number 13 and onwards, the sensors are specified with the following information:
Sensor number, Variable description, unit, Long description. Example:

```
5      bea1 angle_speed               rad/s      pitch1 angle speed
```

From line number 9+nsensors+5 and upwards the scalefactors are written.

Full example of the .sel file:

```
_____________________________________________________________________________
  Version ID : HAWC2MB 4.3
                                                          Time : 14:23:28
                                                          Date : 22:11.2006
_____________________________________________________________________________
  Result file : ./res2_rev0/case41c_nohydro.dat
_____________________________________________________________________________
   Scans    Channels    Time [sec]      Format
     4500        9         90.000       ASCII

  Channel   Variable Description

     1      Time                           s          Time
     2      bea1 angle                     deg        shaft_rot angle
     3      bea1 angle_speed               rpm        shaft_rot angle speed
     4      bea1 angle                     deg        pitch1 angle
     5      bea1 angle_speed               rad/s      pitch1 angle speed
     6      bea1 angle                     deg        pitch2 angle
     7      bea1 angle_speed               rad/s      pitch2 angle speed
     8      bea1 angle                     deg        pitch3 angle
     9      bea1 angle_speed               rad/s      pitch3 angle speed
_____________________________________________________________________________
Scale factors:
  1.56250E-04
  5.61731E-03
  4.41991E-04
  1.00000E+00
  1.00000E+00
  1.00000E+00
  1.00000E+00
  1.00000E+00
  1.00000E+00
```

An important thing to notice is that in the binary data file all sensors are stored sequentially, i.e. all data for sensor 1, all data for sensor 2, etc. This way of storing the data makes later reading of a sensor extra fast since all data for a sensor can be read without reading any data for the other sensor.

A small matlab code for reading the binary HAWC2 format can be seen below.

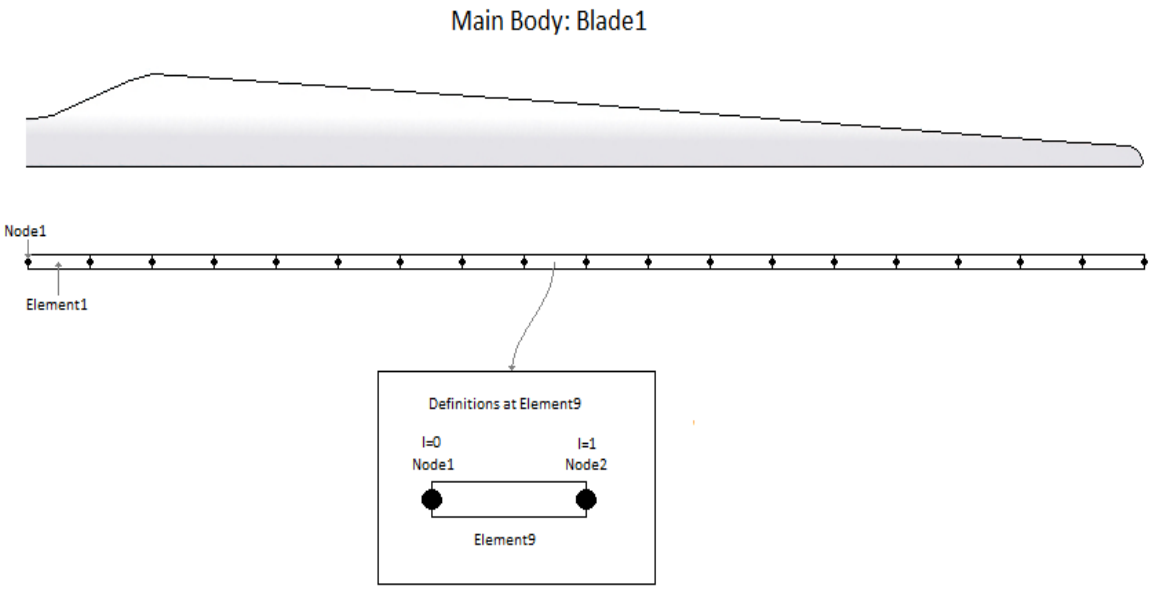
```
function sig = ReadHawc2Bin(FileName,path);
% Reads binary HAWC2 results file
% -------------------------------------
% [t,sig] = ReadFlex4(FileName,Ch);
% filename should be without extension
% -------------------------------------
% BSKA 26/2-2008
% -------------------------------------
ThisPath = pwd; cd(path(1,:))



% reading scale factors from *.sel file
fid = fopen([FileName,'.sel'], 'r'); fgets(fid); fgets(fid);
fgets(fid); fgets(fid); fgets(fid); fgets(fid); fgets(fid);
fgets(fid);
tline = fscanf(fid,'%d');
N = tline(1); Nch = tline(2); Time = tline(3); fclose(fid);
ScaleFactor = dlmread([FileName,'.sel'],'',[9+Nch+5 0 9+2*Nch+4
0]);

% reading binary data file
fid = fopen([FileName,'.dat'], 'r'); sig =
fread(fid,[N,Nch],'int16')*diag(ScaleFactor); fclose(fid);

cd(ThisPath)
```

mbdy (main body output commands)

Command 1	Command 2	Explanation	Only option	Label option
mbdy	forcevec	F_x, F_y, F_z shear force vector defined to output. 1. Main_body name 2. Element number 3. Node number on element 4. Main_body name of which coordinate system is used for output. "global" and "local" can also be used. Local is around local beam main bending directions.	yes	yes
mbdy	momentvec	M_x, M_y, M_z moment vector defined to output. 1. Main_body name 2. Element number 3. Node number on element 4. Main_body name of which coordinate system is used for output. "global" and "local" can also be used. Local is around local beam main bending directions.	yes	yes

Command 1	Command 2	Explanation	Only option	Label option
mbdy	state	Vector with 3 components of either position, velocity or acceleration of a point on an element defined to output. If 'acg' is used, the acceleration including the gravity contribution is written. 1. State: 'pos', 'vel', 'acc','acg' ("pos"=position, "vel"=velocity, "acc"=acceleration) 2. Main_body name 3. Element number 4. Relative distance from node 1 to node 2 on element 5. Main_body name of which coordinate system is used for output. "global" can also be used.	yes	yes
mbdy	state_at	Vector with 3 components of either position, velocity or acceleration of a point on an element defined to output. The point is offset from the element z axis by an x and y distance. 1. State: 'pos', 'vel' or 'acc' 2. Main_body name 3. Element number 4. Relative distance from node 1 to node 2 on element 5. Main_body name of which coordinate system is used for output. "global" can also be used. 6. x-coordinate offset [m] 7. y-coordinate offset [m]	yes	Yes
mbdy	state_rot	Vector with components of either axis and angle (angle [rad], r_1,r_2,r_3), euler parameters (quaternions r_0,r_1,r_2,r_3), euler angles, rotation velocity (ω-vector) or rotation acceleration ($\dot{\omega}$-vector) of a point on an element defined to output. For the sensor eulerang_xyx a set of euler angles are created based on the orientation matrix. Be aware that the method used is only valid for rotations in the intervals ($\theta_x \pm 180°$, $\theta_y \pm 90°$, $\theta_x \pm 180°$) 1. State : 'axisangle', 'eulerp', 'eulerang_xyz', 'omega' or 'omegadot' 2. Main_body name 3. Element number 4. Relative distance from node 1 to node 2 on element 5. Main_body name of which coordinate system is used for output. "global" can also be used.	yes	Yes

This illustration shows how the sensors are placed on an element in terms of local nodes and relative distance.



Constraint (constraint output commands)

bearing1

Command 1	Command 2	Explanation	Only option	Label option
constraint	bearing1	Bearing angle and angle velocity defined to output 1. bearing1 name 2. unit of output (1:angle [unit=rad, range -π:π], vel [rad/s]; 2:angle [unit=deg, range 0:360], vel [rpm]; 3:angle [unit=deg, range 0:360], vel [rad/s]); 4:angle [unit=deg, range -180:180], vel [rad/s]; 5:angle [unit=deg, range -180:180], vel [deg/s])	Yes	No

bearing2

Command 1	Command 2	Explanation	Only option	Label option
constraint	bearing2	Bearing angle and angle velocity defined to output 1. bearing1 name 2. unit of output (1:angle [unit=rad, range -π:π], vel [rad/s]; 2:angle [unit=deg, range 0:360], vel [rpm]; 3:angle [unit=deg, range 0:360], vel [rad/s]); 4:angle [unit=deg, range -180:180], vel [rad/s]; 5:angle [unit=deg, range -180:180], vel [deg/s])	Yes	No

bearing3

Command 1	Command 2	Explanation	Only option	Label option
constraint	bearing3	Bearing angle and angle velocity defined to output 1. bearing1 name 2. unit of output (1:angle [unit=rad, range -π:π], vel [rad/s]; 2:angle [unit=deg, range 0:360], vel [rpm]; 3:angle [unit=deg, range 0:360], vel [rad/s]); 4:angle [unit=deg, range -180:180], vel [rad/s]; 5:angle [unit=deg, range -180:180], vel [deg/s])	Yes	No

bearing4

Rotation angle and velocity of the two axis perpendicular to the cardan shaft torsion axis are outputted.

Command 1	Command 2	Explanation	Only option	Label option
constraint	bearing4	Bearing angle and angle velocity defined to output 1. bearing1 name 2. unit of output (1:angle [unit=rad, range -π:π], vel [rad/s]; 2:angle [unit=deg, range 0:360], vel [rpm]; 3:angle [unit=deg, range 0:360], vel [rad/s]); 4:angle [unit=deg, range -180:180], vel [rad/s]; 5:angle [unit=deg, range -180:180], vel [deg/s])	Yes	No

body (old body output commands)

These commands are still part of the code but should be seen as obsolete since they refer to an internal body naming insted of the main_body names. Please refer to the *mbdy* output commands.

Command 1	Command 2	Explanation	Label option
body	forcevec	F_x, F_y, F_z shear force vector defined to output. Unit [kN] 1. body number 2. Element number 3. Node number on element 4. coordinate system (1=body, 2=global, 3=element)	No
body	momentvec	M_x, M_y, M_z moment vector defined to output. Unit [kNm] 1. body number 2. Element number 3. Node number on element 4. coordinate system (1=body, 2=global, 3=element)	No
body	node_defl	x,y,z deflection vector (within a body) defined to output. Unit [m] 1. body number 2. Element number 3. Node number on element 4. coordinate system (1=body, 2=global, 3=element)	No
body	node_rot	θ_x, θ_y, θ_z, rotations (within a body) define to output. Unit [rad] 1. body number 2. Element number 3. Node number on element 4. coordinate system (1=body, 2=global, 3=element)	No
body	pitchangle	Pitchangle of pitch bearing defined with the old_htc_structure is defined to output. 1. Unit (1=[rad], 2=[deg] 2. Pitch bearing number	No
body	pitchspeed	Pitch velocity of pitch bearing defined with the old_htc_structure is defined to output. 1. Unit (1=[rad/s], 2=[deg/s] 2. Pitch bearing number	No
body	node_state	State vector (position, velocity or accelertion) of a given on an element is defined to output. 1. state (“pos”=position, “vel”=velocity, “acc”=acceleration) 2. body name 3. element number 4. z_{rel} (distance between node 1 and 2 divided by element length) 5. coordinate system (1=global)	No

aero (aerodynamic related commands)

Command 1	Command 2	Explanation	Label option
aero	time	Simulation time to output. No parameters.	No
aero	azimuth	Azimuth angle of selected blade. Zero is vertical downwards. Positive clockwise around blade root y-axis. Unit [deg] 1. Blade number	No
aero	omega	Rotational speed of rotor. Unit [rad/s]	No
aero	vrel	Relative velocity in x-y local aerodynamic plane. Unit [m/s] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	alfa	Angle of attack in x-y local aerodynamic plane. Unit [deg] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	alfadot	Pitch rate term (z-axis rotation) in local aerodynamic plane, as used for non-circulatory contributions. Unit [rad/s] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	beta	Flap deflection angle (matching the deflection specified by the flap control .dll): 1. Blade number 2. Flap number, according to the order defined in the dynstall_ateflap sub-command block.	No
aero	cl	Instantaneous lift coefficient. Unit [-] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	cd	Instantaneous drag coefficient. Unit [-] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	cm	Instantaneous moment coefficient. Unit [-] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	lift	Lift force at calculation point. Unit [kN/m] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	drag	Drag force at calculation point. Unit [kN/m] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	moment	Aerodynamic moment at calculation point. Unit [kNm/m] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No

Command 1	Command 2	Explanation	Label option
aero	secforce	Aerodynamic force at calculation point. Local aero coo. Unit [kN/m] 1. Blade number 2. Dof number (1=F_x, 2=F_y, 3=F_z) 3. Radius [m] (nearest inner calculation point is used)	No
aero	secmoment	Aerodynamic moment at calculation point. Local aero coo. Unit [kN/m] 1. Blade number 2. Dof number (1=M_x, 2=M_y, 3=M_z) 3. Radius [m] (nearest inner calculation point is used)	No
aero	int_force	Integrated aerodynamic forces from tip to calculational point. NB the integration is performed around the $C_{3/4}$ location. Unit [kN] 1. Coordinates system (1=local aero coo, 2=blade ref. system, 3=global, 4=rotor polar) 2. Blade number 3. Dof number (1=M_x, 2=M_y, 3=M_z) 4. Radius [m] (nearest inner calculation point is used)	No
aero	int_moment	Integrated aerodynamic moment from tip to calculational point. NB the integration is performed around the $C_{3/4}$ location. Unit [kN] 1. Coordinates system (1=local aero coo, 2=blade ref. system, 3=global, 4=rotor polar) 2. Blade number 3. Dof number (1=M_x, 2=M_y, 3=M_z) 4. Radius [m] (nearest inner calculation point is used)	No
aero	torque	Integrated aerodynamic forces of all blades to rotor torsion. Unit [kNm]. No parameters	No
aero	thrust	Integrated aerodynamic forces of all blades to rotor thrust. Unit [kN]. No parameters	No
aero	position	Position of calculation point. Unit [m]. 1. Coordinates system (1=local aero coo, 2=blade ref. system, 3=global, 4=rotor polar) 2. Blade number 3. Dof number (1=M_x, 2=M_y, 3=M_z) 4. Radius [m] (nearest inner calculation point is used)	No
aero	rotation	Orientation of calculation point. Unit [deg]. 1. Blade number 2. Dof number (1=θ_x, 2=θ_y, 3=θ_z) 3. Radius [m] (nearest inner calculation point is used) 4. Coordinates system (1=blade_ref. coo, 2=rotor polar coo.)	No

Command 1	Command 2	Explanation	Label option
aero	velocity	Velocity of calculation point. Unit [m/s]. 1. Coordinates system (1=local aero coo, 2=blade ref. system, 3=global, 4=rotor polar) 2. Blade number 3. Dof number (1= V_x, 2=V_y, 3=V_z) 4. Radius [m] (nearest inner calculation point is used)	No
aero	acceleration	Acceleration of calculation point. Unit [m/s^2]. 1. Coordinates system (1=local aero coo, 2=blade ref. system, 3=global, 4=rotor polar) 2. Blade number 3. Dof number (1= V_x, 2=V_y, 3=V_z) 4. Radius [m] (nearest inner calculation point is used)	No
aero	windspeed	Free wind speed seen from the blade. Unit [m/s] 1. Coordinates system (1=local aero coo, 2=blade ref. system, 3=global, 4=rotor polar) 2. Blade number 3. Dof number (1= V_x, 2=V_y, 3=V_z) 4. Radius [m] (nearest inner calculation point is used)	No
aero	induc	Local induced velocity at calculation point. Unit [m/s] 1. Coordinates system (1=local aero coo, 2=blade ref. system, 3=global, 4=rotor polar) 2. Blade number 3. Dof number (1= V_x, 2=V_y, 3=V_z) 4. Radius [m] (nearest inner calculation point is used)	No
aero	induc_sector_ct	Thrust coefficient at a position on the rotor. Unit [-] 1. Radius [m/s] 2. Azimuth angle (zero downwards) [deg]	No
aero	induc_sector_cq	Torque coefficient at a position on the rotor. Unit [-] 1. Radius [m/s] 2. Azimuth angle (zero downwards) [deg]	No
aero	induc_sector_a	Axial induction coefficient at a position on the rotor. Unit [-] 1. Radius [m/s] 2. Azimuth angle (zero downwards) [deg]	No
aero	induc_sector_am	Tangential induction coefficient at a position on the rotor. Unit [-] 1. Radius [m/s] 2. Azimuth angle (zero downwards) [deg]	No
aero	induc_a_norm	Axial velocity used in normalization expression of rotor thrust coefficients. The average axial wind velocity incl. induction. Unit [m/s]. No parameters.	No

Command 1	Command 2	Explanation	Label option
aero	induc_am_norm	Tangential velocity used in normalization expression of torque coefficient. Average tangential velocity at a given radius. Unit [m/s]. 1. Radius [m]	No
aero	inflow_angle	Angle of attack + rotation angle of profile related to polar coordinates (not pitching). Unit [deg] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	dcldalfa	Gradient $dCl/d\alpha$. Unit [deg^{-1}] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	dcddalfa	Gradient $dCd/d\alpha$. Unit [deg^{-1}] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	gamma	Circulation strength at calculation point. Unit [m^2/s] 1. Blade number 2. Radius [m] (nearest inner calculation point is used)	No
aero	kfw	BEM Dynamic Induction scaling factor, as default kfw=number of blades (eg.3), but when running the Near Wake model the far wake has to be scaled, kfw is the scaling coefficient usually around 2.7. Unit []	No
aero	lambda	Tip speed rato, Unit []	No
aero	windspeed_boom	Free wind speed seen by a boom mounted on a blade section. Coordinate system used “blade ref. system”. Unit [m/s]. 1. Blade number 2. Radius [m] (nearest inner calculation point is used) 3. Boom-length X, measured from half chord point positive towards LE [m] 4. Boom-length Y, measured from half chord point positive towards pressureside [m]	No
aero	actuatordiskload	Actuator disk load provide normalized load export for the Actuator Disk Model. 1. DOF (1=Ft, 2=Fa, 3=Fr) 2. Radius [m] (nearest inner calculation point is used)	No

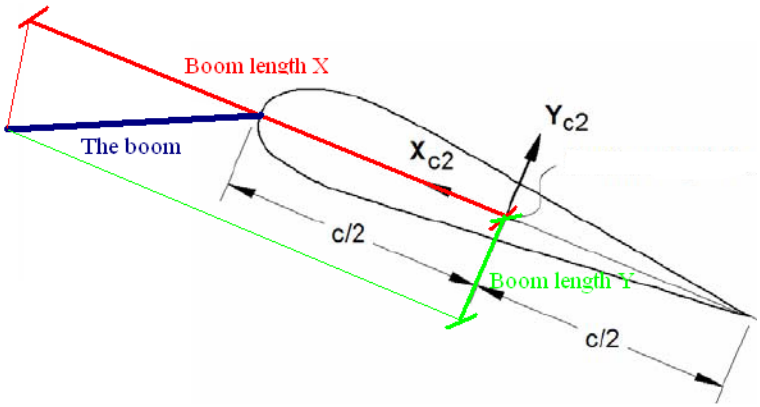


Illustration of the boom coordinates used by the "windspeed_boom" command.

wind (wind output commands)

Command 1	Command 2	Explanation	Only option	Label option
wind	free_wind	Wind vector V_x, V_y, V_z, (wind as if the turbine didn't exist). 1. Coordinate system (1=global, 2=non rotating rotor coordinates (x always horizontal, y always out-of-plane)) 2. x-pos (global coo) 3. y-pos (global coo) 4. z-pos (global coo)	Yes	No
wind	free_wind_hor	Horizontal wind component velocity [m/s] and direction [deg] defined to output. Dir=0 when wind equals y-dir. 1. Coordinate system (1=global, 2=non rotating rotor coordinates (x always horizontal, y always out-of-plane)) 2. x-pos (global coo) 3. y-pos (global coo) 4. z-pos (global coo)	Yes	No

wind_wake (wind wake output commands)

Command 1	Command 2	Explanation	Only option	Label option
wind_wake	wake_pos	Position of the wake deficit center after the meandering proces to the downstream end position. x,y and z position is written in meteorological coordinates $(x,y,z)_M=(u,v,w)$ with origo in the position defined with center_pos0 in the general wind commands. 1. wake source number	Yes	No

dll (DLL output commands)

Command 1	Command 2	Explanation	Label option
dll	inpvec	Value from DLL input vector is defined to output 1. DLL number 2. array index number	yes
dll	outvec	Value from DLL output vector is defined to output 1. DLL number 2. array index number	yes

hydro (hydrodynamic output commands)

Command 1	Command 2	Explanation	Only option	Label option
hydro	water_surface	Water surface level at a given horizontal location is defined to output (global coordinates). Unit [m] 1. x-pos 2. y-pos	No	No
hydro	water_vel_acc	Water velocity V_x, V_y, V_z, and acceleration A_x, A_y, A_z vectors defined to output. Unit [m/s] and [m/s^2]. 1. x-pos 2. y-pos 3. z-pos	Yes	No
hydro	fm	Inertia force F_x, F_y, F_z contribution from Morisons formula in a given calculation point. Unit [kN] 1. hydro element number 2. sec number 3. coordinate system (1=global)	Yes	No
hydro	fd	Drag force F_x, F_y, F_z contribution from Morisons formula in a given calculation point. Unit [kN] 1. hydro element number 2. sec number 3. coordinate system (1=global)	Yes	No

general (general output commands)

Command 1	Command 2	Explanation	Label option
general	constant	A constant value is send to output 1. constant value	No
general	step	A step function is created. This function changes from f_0 to f_1 at time t_0. 1. t_0 [sec] 2. f_0 3. f_1	No
general	time	The time is send to output. No parameters	No
general	deltat	The time increment is send to output. No parameters	No
general	harmonic	A harmonic function is send to output $F(t) = A\sin(2\pi f_0 t) + k$ 1. A 2. f_0 3. k	No
general	harmonic2	A harmonic function is send to output $F(t) = \begin{cases} 0 & t < t_0 \\ A\sin(2\pi f_0 (t - t_0)) + k & t_0 \le t \le t_1 \\ 0 & t > t_1 \end{cases}$ 1. A 2. f_0 3. k 4. t_0 5. t_1	No
general	stairs	A series of steps resulting in a staircase signal is created. 1. f_0 start value of function 2. t_0 time for first step change [s] 3. Step size 4. Step duration [s] 5. Number of steps	No
general	status	A status flag (mainly for controller purpose) is written. A first time step and first iteration the output value is 0. During the rest of the simulation the value is 1 until last time step where the value is -1.	No

Output_at_time (output at a given time)

This command is especially usefull if a snapshot of loads or other properties are required at a specific time. This is mostly used for writing calculated aerodynamic properties as function of blade location. The command block can be repeated as many times as needed (e.g. if outputs at more than one time is needed)

The command must be written with the following syntax
`output_at_time` *`keyword time`*
where *`keyword`* is a command listed in the subsections below. Sofar only the command `aero` is present. The last command word *`time`* is the time in seconds from simulation start to which the output are written.

aero (aerodynamic output commands)

The first line in the output_at block must be the information regarding which file the outputs are written (the filename command listed in the table below)

Command 1	Explanation	Label option
filename	Filename incl. relative path to output file (example ./output/output_at.dat). 1. filename	No
alfa	Angle of attack [deg]. 1. Blade number	No
alfadot	Pitch rate term (z-axis rotation) in local aerodynamic plane, as used for non-circulatory contributions. Unit [rad/s]. 1. Blade number	No
vrel	Relative velocity [m/s] 1. Blade number	No
cl	Lift coefficient [-] 1. Blade number	No
cd	Drag coefficient [-] 1. Blade number	No
cm	Moment coefficient [-] 1. Blade number	No
lift	Lift force L [N] 1. Blade number	No
drag	Drag force D [N] 1. Blade number	No
moment	Moment force M [Nm] 1. Blade number	No
secforce	Aerodynamic forces [N] 1. Blade number 2. DOF number (1=x,2=y,3=z) 3. Coordinate system (1=aero, 2=blade, 3=global, 4=rotor polar)	No
secmoment	Aerodynamic moments [Nm] 1. Blade number 2. DOF number (1=x,2=y,3=z) 3. Coordinate system (1=aero, 2=blade, 3=global, 4=rotor polar)	No
int_force	Aerodynamic forces integrated from tip to given radius [N] 1. Blade number 2. DOF number (1=x,2=y,3=z) 3. Coordinate system (1=aero, 2=blade, 3=global, 4=rotor polar)	No
int_moment	Aerodynamic moment integrated from tip to given radius [N] 1. Blade number 2. DOF number (1=x,2=y,3=z) 3. Coordinate system (1=aero, 2=blade, 3=global, 4=rotor polar)	No
inipos	Initial position of sections in blade coo [m] 1. Blade number 2. DOF number (1=x,2=y,3=z)	No
position	Actual position of section [m] 1. Blade number 2. DOF number (1=x,2=y,3=z) 3. Coordinate system (1=aero, 2=blade, 3=global, 4=rotor polar)	No

Command 1	Explanation	Label option
velocity	Actual velocity of section [m/s] 1. Blade number 2. DOF number (1=x,2=y,3=z) 3. Coordinate system (1=aero, 2=blade, 3=global, 4=rotor polar)	No
acceleration	Actual acceleration of section [m/s] 1. Blade number 2. DOF number (1=x,2=y,3=z) 3. Coordinate system (1=aero, 2=blade, 3=global, 4=rotor polar)	No
ct_local	Local thrust coefficient [-]. Calculated based on the expression $C_t = \frac{F_{axial}\, B}{\frac{1}{2}\rho 2\pi r V_{\inf}^2}$ 1. Blade number	No
cq_local	Local tangential force coefficient [-]. Calculated based on the expression $C_q = \frac{F_{\tan}\, B}{\frac{1}{2}\rho 2\pi r V_{\inf}^2}$ 1. Blade number	No
chord	Chord length [m] 1. Blade number	No
induc	Induced velocity [m/s] 1. Blade number 2. DOF number (1=x,2=y,3=z) 3. Coordinate system (1=aero, 2=blade, 3=global, 4=rotor polar)	No
windspeed	Free windspeed (without induction but incl. tower shadow effects if used) [m/s] 1. Blade number 2. DOF number (1=x,2=y,3=z) 3. Coordinate system (1=aero, 2=blade, 3=global, 4=rotor polar)	No
inflow_angle	Angle of attack + rotation angle of profile related to polar coordinates (not pitching). Unit [deg] 1. Blade number	No
dcldalfa	Gradient $dCl/d\alpha$. Unit [deg^{-1}] 1. Blade number	No
dcddalfa	Gradient $dCd/d\alpha$. Unit [deg^{-1}] 1. Blade number	No

Example of main input file

```
begin Simulation;
  time_stop    100;
  solvertype   1 ;    (newmark)
  on_no_convergence continue ;
  logfile ./log/oc3_monopile_phase_1.log ;
  animation ./animation/oc3_monopile_phase_1.dat;
;
  begin newmark;
    deltat    0.02;
  end newmark;
end simulation;
;
begin new_htc_structure;
  beam_output_file_name  ./log/oc3_monopile_phase_1_beam.dat;                   Optional - Calculated
beam properties of the bodies are written to file
  body_output_file_name  ./log/oc3_monopile_phase_1_body.dat;                   Optional - Body initial
position and orientation are written to file
;  body_eigenanalysis_file_name ./eigenfrq/oc3_monopile_phase_1_body_eigen.dat;
;  structure_eigenanalysis_file_name ./eigenfrq/oc3_monopile_phase_1_strc_eigen.dat ;
;-------------------------------------------------------------------------------------------------------------
-----------------------
;
  begin main_body;          monopile 30m
    name        monopile ;
    type        timoschenko ;
    nbodies     1 ;
    node_distribution     c2_def ;
    damping   4.5E-02 4.5E-02 8.0E-01 1.2E-03 1.2E-03 4.5E-04 ;
    begin timoschenko_input;
      filename ./data/Monopile.txt ;
      set 1 1 ;                 set subset   1=flexible,2=stiff
    end timoschenko_input;
    begin c2_def;               Definition of centerline (main_body coordinates)
      nsec 7;
      sec 1 0.0 0.0 0.0    0.0 ;  x,y,z,twist      Mudline
      sec 2 0.0 0.0 -0.1    0.0 ;  x,y,z,twist
      sec 3 0.0 0.0 -10.0    0.0 ;  x,y,z,twist    50% between mudline and MSL
      sec 4 0.0 0.0 -15.0    0.0 ;  x,y,z,twist
      sec 5 0.0 0.0 -20.0    0.0 ;  x,y,z,twist    MWL
      sec 6 0.0 0.0 -25.0  0.0 ;
      sec 7 0.0 0.0 -30.0 0.0 ;                          Monopile flange
    end c2_def ;
  end main_body;
;
  begin main_body;          tower 80m
    name        tower ;
    type        timoschenko ;
    nbodies     1 ;
    node_distribution     c2_def ;
     damping_posdef   6.456E-4 6.45E-4 1.25E-3 1.4E-3 1.4E-3 1.25E-3 ; Mx My Mz Kx Ky Kz , M´s raises
overall level, K´s raises high freguency level
    begin timoschenko_input;
      filename ./data/NREL_5MW_st.txt ;
      set 1 1 ;
    end timoschenko_input;
    begin c2_def;               Definition of centerline (main_body coordinates)
      nsec 8;
      sec 1 0.0 0.0 0.0    0.0 ;  x,y,z,twist
      sec 2 0.0 0.0 -10.0  0.0 ;
      sec 3 0.0 0.0 -20.0  0.0 ;
      sec 4 0.0 0.0 -30.0  0.0 ;
      sec 5 0.0 0.0 -40.0  0.0 ;
      sec 6 0.0 0.0 -50.0  0.0 ;
      sec 7 0.0 0.0 -60.0 0.0 ;
      sec 8 0.0 0.0 -77.6 0.0 ;
     end c2_def ;
    end main_body;
;
  begin main_body;
    name        towertop ;
    type        timoschenko ;
    nbodies     1 ;
    node_distribution     c2_def ;
;    damping_posdef   9.025E-06 9.025E-06 8.0E-05 8.3E-06 8.3E-06 8.5E-05 ;
    damping  2.50E-04  1.40E-04  2.00E-03  3.00E-05  3.00E-05  2.00E-04  ;
    concentrated_mass 2 0.0  1.9 0.21256 2.4E5 1741490.0  1.7E5 1741490.0 ;  Nacelle mass and inertia

          begin timoschenko_input;
      filename ./data/NREL_5MW_st.txt ;
      set 2 1 ;
    end timoschenko_input;
    begin c2_def;               Definition of centerline (main_body coordinates)
      nsec 2;
      sec 1 0.0 0.0 0.0       0.0 ; x,y,z,twist
      sec 2 0.0 0.0 -1.96256  0.0 ;
    end c2_def ;
  end main_body;
;
  begin main_body;
    name        shaft ;
    type        timoschenko ;
    nbodies     1 ;
    node_distribution     c2_def ;
;   damping_posdef  7.00E-3  7.00E-03  7.00E-02  3.48E-04  3.48E-04  1.156E-03 ;
   damping_posdef  7.00E-3  7.00E-03  7.00E-02  6.5E-04  6.5E-04  1.84E-02 ;
          concentrated_mass 1 0.0 0.0 0.0 0.0 0.0 0.0 5025497.444 ;generator equivalent slow shaft
    concentrated_mass 5 0.0 0.0 0.0 56780 0.0 0.0 115926 ; hub mass and inertia;
```

```
        begin timoschenko_input;
      filename ./data/NREL_5MW_st.txt ;
      set 3 1 ;
    end timoschenko_input;
    begin c2_def;              Definition of centerline (main_body coordinates)
      nsec 5;
      sec 1 0.0 0.0 0.0     0.0 ; Tower top x,y,z,twist
      sec 2 0.0 0.0 1.0     0.0 ;
      sec 3 0.0 0.0 2.0     0.0 ;
      sec 4 0.0 0.0 3.1071  0.0 ; Main bearing
      sec 5 0.0 0.0 5.0191  0.0 ; Rotor centre
    end c2_def ;
  end main_body;
;
  begin main_body;
    name        hub1 ;
    type        timoschenko ;
    nbodies     1 ;
    node_distribution     c2_def ;
    damping_posdef  2.00E-05  2.00E-05  2.00E-04  3.00E-06  3.00E-06  2.00E-05;
        begin timoschenko_input;
      filename ./data/NREL_5MW_st.txt ;
      set 4 1 ;
    end timoschenko_input;
    begin c2_def;              Definition of centerline (main_body coordinates)
      nsec 2;
      sec 1 0.0 0.0 0.0     0.0 ; x,y,z,twist
      sec 2 0.0 0.0 1.5   0.0 ;
    end c2_def ;
  end main_body;
;
  begin main_body;
    name           hub2 ;
    copy_main_body hub1;
  end main_body;
;
  begin main_body;
    name           hub3 ;
    copy_main_body hub1 ;
  end main_body;
;
  begin main_body;
    name        blade1 ;
    type        timoschenko ;
    nbodies     9 ;
    node_distribution    c2_def;
;   damping   3.5e-2 5.5e-4 5.0e-4 3.0e-4 0.5e-3 5.5e-3  ;
    damping_posdef   1.16e-4 5.75e-5 6.1e-6 6.5e-4 5.1e-4 6.4e-4 ;
   begin timoschenko_input ;
      filename ./data/NREL_5MW_st.txt ;
      set 5 1 ;                set subset
    end timoschenko_input;
    begin c2_def;              Definition of centerline (main_body coordinates)
      nsec 19 ;
          sec 1                0.0000            0.0000            0.000             0.000
          ;         x.y.z. twist
          sec 2                -0.0041           0.0010            1.367             -13.308
          ;
          sec 3                -0.1058           0.0250            4.100             -13.308
          ;
          sec 4                -0.2502           0.0592            6.833             -13.308
          ;
          sec 5                -0.4594           0.1087            10.250            -13.308
          ;
          sec 6                -0.5699           0.1157            14.350            -11.480
          ;
          sec 7                -0.5485           0.0983            18.450            -10.162
          ;
          sec 8                -0.5246           0.0832            22.550            -9.011
          ;
          sec 9                -0.4962           0.0679            26.650            -7.795
          ;
          sec 10               -0.4654           0.0534            30.750            -6.544
          ;         50% blade radius
          sec 11               -0.4358           0.0409            34.850            -5.361
          ;
          sec 12               -0.4059           0.0297            38.950            -4.188
          ;
          sec 13               -0.3757           0.0205            43.050            -3.125
          ;
          sec 14               -0.3452           0.0140            47.150            -2.319
          ;
          sec 15               -0.3146           0.0084            51.250            -1.526
          ;
          sec 16               -0.2891           0.0044            54.667            -0.863
          ;
          sec 17               -0.2607           0.0017            57.400            -0.370
          ;
          sec 18               -0.1774           0.0003            60.133            -0.106
          ;
          sec 19               -0.1201           0.0000            61.500            -0.000
          ;
   end c2_def ;
  end main_body;
;
  begin main_body;
    name           blade2 ;
    copy_main_body blade1;
  end main_body;
;
  begin main_body;
    name           blade3 ;
    copy_main_body blade1 ;
  end main_body;
```

```
;-------------------------------------------------------------------------------------------------------------
-----------------------
;
  begin orientation;
    begin base;
      body   monopile;
      inipos        0.0 0.0 20.0 ;         initial position of node 1
      body_eulerang 0.0 0.0 0.0;
    end base;
;
    begin relative;
      body1  monopile last;         indtil videre antages der internt i programmet at der altid kobles
mellen sidste knude body1 og første knude body 2
      body2  tower 1;
      body2_eulerang 0.0 0.0 0.0;
    end relative;
;
    begin relative;
      body1  tower last;
      body2  towertop 1;
      body2_eulerang 0.0 0.0 0.0;
    end relative;
;
    begin relative;
      body1  towertop last;
      body2  shaft 1;
      body2_eulerang 90.0 0.0 0.0;
      body2_eulerang 5.0 0.0 0.0;    5 deg tilt angle
      body2_ini_rotvec_d1 0.0 0.0 -1.0 0.5 ; body initial rotation velocity x.y.z.angle velocity[rad/s]
(body 2 coordinates)
;      body2_ini_rotvec_d1 0.0 0.0 -1.0 0.9424 ; body initial rotation velocity x.y.z.angle
velocity[rad/s]  (body 2 coordinates)
    end relative;
;
    begin relative;
      body1  shaft last;
      body2  hub1 1;
      body2_eulerang -90.0 0.0 0.0;
      body2_eulerang 0.0 180.0 0.0;
      body2_eulerang 2.5 0.0 0.0;      2.5deg cone angle
    end relative;
;
    begin relative;
      body1  shaft last;
      body2  hub2 1;
      body2_eulerang -90.0 0.0 0.0;
      body2_eulerang 0.0 60.0 0.0;
      body2_eulerang 2.5 0.0 0.0;      2.5deg cone angle
    end relative;
;
    begin relative;
      body1  shaft last;
      body2  hub3 1;
      body2_eulerang -90.0 0.0 0.0;
      body2_eulerang 0.0 -60.0 0.0;
      body2_eulerang 2.5 0.0 0.0;      2.5deg cone angle
    end relative;
;
    begin relative;
      body1  hub1 last;
      body2  blade1 1;
      body2_eulerang 0.0 0.0 0;
    end relative;
;
    begin relative;
      body1  hub2 last;
      body2  blade2 1;
      body2_eulerang 0.0 0.0 0.0;
    end relative;
;
    begin relative;
      body1  hub3 last;
      body2  blade3 1;
      body2_eulerang 0.0 0.0 0.0;
    end relative;
;
         end orientation;
;-------------------------------------------------------------------------------------------------------------
-----------------------
begin constraint;
;
    begin fix0;  fixed to ground in translation and rotation of node 1
      body monopile;
    end fix0;
;
    begin fix1;  fixed relative to other body in translation and rotation
      body1 monopile last;
      body2 tower 1;
    end fix1;
;
     begin fix1;
                      body1 tower last ;
                      body2 towertop 1;
                    end fix1;
;
    begin bearing1;                       free bearing
     name  shaft_rot;
      body1 towertop last;
      body2 shaft 1;
      bearing_vector 2 0.0 0.0 -1.0;        x=coo (0=global.1=body1.2=body2) vector in body2 coordinates
where the free rotation is present
   end bearing1;
;
     begin fix1;
                      body1 shaft last ;
```

```
                      body2 hub1 1;
                    end fix1;
;
     begin fix1;
                      body1 shaft last ;
                      body2 hub2 1;
                    end fix1;
;
     begin fix1;
                      body1 shaft last ;
                      body2 hub3 1;
                    end fix1;
;
    begin bearing2;
      name pitch1;
      body1 hub1 last;
     body2 blade1 1;
                              bearing_vector 2 0.0 0.0 -1.0;
   end bearing2;
;
    begin bearing2;
      name pitch2;
      body1 hub2 last;
      body2 blade2 1;
                              bearing_vector 2 0.0 0.0 -1.0;
    end bearing2;
;
    begin bearing2;
      name pitch3;
      body1 hub3 last;
      body2 blade3 1;
                              bearing_vector 2 0.0 0.0 -1.0;
    end bearing2;
end constraint;
;
end new_htc_structure;
;-------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------
begin wind ;
  density                 1.25;
  wsp                     8  ;
  horizontal_input        1;
  windfield_rotations     0.0  0.0  0.0 ;    yaw, tilt, rotation
  center_pos0             0.0 0.0 -90.00;      hub_height
  shear_format            3 0.12;
  turb_format             1     ;  0=none, 1=mann,2=flex
  tower_shadow_method     1;
  tint                    0.06 ;
  scale_time_start        200;
  wind_ramp_factor   0.0 200 0.5 1.0 ;
  ;------------------------------------------------------------------
  begin tower_shadow_potential;
    tower_offset 0.0;
    nsec  2;
    radius      0.0   2.10;
    radius     -68.10 1.15;
  end tower_shadow_potential;
  ;------------------------------------------------------------------
  ; This next part is only to be include in case of wake effects being studied
  begin wakes;
    nsource 35;
    source_pos      2548      -2900     -90       ;
    source_pos      2123      -2417     -90       ;
    source_pos      1706      -1942     -90       ;
    source_pos      1281      -1458     -90       ;
    source_pos      857       975       -90       ;         WT5
    source_pos      432       491       -90       ;         WT6
    source_pos      -425      -484      -90       ;         WT8
    source_pos      -850      -968      -90       ;         WT9
    source_pos      -1267     1458      -90       ;
    source_pos      -1700     1935      -90       ;
    source_pos      -2125     2419      -90       ;
    source_pos      3556      -2533     -90       ;
    source_pos      3131      -2049     -90       ;
    source_pos      2706      -1565     -90       ;
    source_pos      2281      1081      -90       ;         WT16
    source_pos      1602      308       -90       ;         WT17
    source_pos      1176      -176      -90       ;         WT18
    source_pos      751       -660      -90       ;         WT19
    source_pos      326       -1144     -90       ;         WT20
    source_pos      -99       -1627     -90       ;         WT21
    source_pos      3915      -1427     -90       ;
    source_pos      3486      -943      -90       ;
    source_pos      3062      -455      -90       ;
    source_pos      2405      -292      -90       ;         WT25
    source_pos      1927      -836      -90       ;         WT26
    source_pos      1502      -1319     -90       ;         WT27
    source_pos      1077      -1803     -90       ;         WT28
    source_pos      652       -2287     -90       ;         WT29
    source_pos      4235      -283      -90       ;
    source_pos      3813      205       -90       ;
    source_pos      3163      944       -90       ;
    source_pos      2679      1495      -90       ;
    source_pos      2254      1979      -90       ;
    source_pos      1829      2463      -90       ;
    source_pos      1404      2947      -90       ;
    op_data      1.4252392 2 ; 1.8 -23.1 ;1.87 0.0 rad/sec, pitch [grader] opstrøms;
    ble_parameters 0.10 0.008 0;
    begin mann_meanderturb ;
      create_turb_parameters 33.6 1 3.7 508 0.0 ;      L, alfaeps,gamma,seed, highfrq compensation
      filename_v    ./free_sector_monopile/wake-meander/wake_meand_turb_wsp8_s508_t1800v.bin ;
      filename_w    ./free_sector_monopile/wake-meander/wake_meand_turb_wsp8_s508_t1800w.bin ;
      box_dim_u   16384 1.7578125 ;
      box_dim_v     32 90 ;
      box_dim_w     32 90 ;
```

```
      std_scaling   1.0 0.8 0.5 ;
    end mann_meanderturb;
;
    begin mann_microturb ;
      create_turb_parameters 8.0 1.0 1.0 508 1.0 ;      L, alfaeps,gamma,seed, highfrq compensation
      filename_u    ./free_sector_monopile/wake-micro/wake_turb_wsp8_s508_t1800u.bin ;
      filename_v    ./free_sector_monopile/wake-micro/wake_turb_wsp8_s508_t1800v.bin ;
      filename_w    ./free_sector_monopile/wake-micro/wake_turb_wsp8_s508_t1800w.bin ;
      box_dim_u   128 1.0 ;
      box_dim_v     128 1.0 ;
      box_dim_w     128 1.0 ;
      std_scaling   1.0 1.0 1.0 ;
    end mann_microturb;
  end wakes;
  ;-----------------------------------------------------------------
  begin mann;
    create_turb_parameters 33.6 1 3.7 508 1.0 ;      L, alfaeps,gamma,seed, highfrq compensation
    filename_u    ./free_sector_monopile/turb/turb_wsp8_s508_t1800u.bin ;
    filename_v    ./free_sector_monopile/turb/turb_wsp8_s508_t1800v.bin ;
    filename_w    ./free_sector_monopile/turb/turb_wsp8_s508_t1800w.bin ;
    box_dim_u    16384 1.7578125 ;
    box_dim_v    32 3.75;
    box_dim_w    32 3.75;
    std_scaling   1.0 0.8 0.5 ;
  end mann;
end wind;;
begin aero ;
  nblades  3;
  hub_vec shaft -3 ;         rotor rotation vector (normally shaft composant directed from pressure to
;                            sustion side)
  link 1 mbdy_c2_def blade1;
  link 2 mbdy_c2_def blade2;
  link 3 mbdy_c2_def blade3;
  ae_filename         ./data/NREL_5MW_ae.txt;
  pc_filename         ./data/NREL_5MW_pc.txt;
  induction_method   1 ;     0=none, 1=normal
  aerocalc_method    1 ;     0=ingen aerodynamic, 1=med aerodynamic
  aerosections       30 ;
  ae_sets            1 1 1;
  tiploss_method     1 ;     0=none, 1=prandtl
  dynstall_method    2 ;     0=none, 1=stig øye method,2=mhh method
end aero ;
;
;-------------------------------------------------------------------------------------------------
 begin hydro;
   begin water_properties;
     rho 1027 ; kg/m^3
     gravity 9.81 ; m/s^2
     mwl 0.0 ;
     mudlevel 20.0 ;
     water_kinematics_dll ./wkin_dll.dll   ./htc_hydro/reg_airy_h6_t10.inp ;
 end water_properties;
;
   begin hydro_element;
     body_name monopile ;
     hydrosections uniform 50 ; distribution of hydro calculation points from sec 1 to nsec
     nsec 2;
     sec 0.0 1.0 1.0 28.27 28.27 6.0 ;  nr z Cm Cd V Vr width
     sec 30.0 1.0 1.0 28.27 28.27 6.0 ;  nr z Cm Cd V Vr width
   end hydro_element;
 end hydro;
;
;-------------------------------------------------------------------------------------------------
begin dll;
  begin hawc_dll;
    filename  ./control/bladed2hawc.dll ;
    dll_subroutine regulation ;
    arraysizes  15 15 ;
    deltat  0.02;
    begin output;
      general time ;
      constraint bearing2 pitch1 1;  angle and angle velocity written to dll
      constraint bearing2 pitch2 1;  angle and angle velocity written to dll
      constraint bearing2 pitch3 1;  angle and angle velocity written to dll
      constraint bearing2 shaft_rot 1; angle and angle velocity written to dll  (slow speed shaft)
      wind free_wind 1 0.0 0.0 -90.55; local wind at fixed position: coo
      general constant 97.0 ;                  generator exchange ratio
    end output;
;
    begin actions;
      body moment_int shaft 1 3 towertop 2 ;
    end actions;
  end hawc_dll;
;
  begin hawc_dll;
    filename  ./control/pitchservo_pos.dll ;
    dll_subroutine servo ;
    arraysizes  15 15 ;
    deltat    0.02 ;
    begin output;
      general time ;                                                                  1
      dll inpvec 1 2;                                                                2
      dll inpvec 1 3;                                                                3
      dll inpvec 1 4;                                                                4
      constraint bearing2 pitch1 1;  angle and angle velocity written to dll         5,6
      constraint bearing2 pitch2 1;  angle and angle velocity written to dll         7,8
      constraint bearing2 pitch3 1;  angle and angle velocity written to dll         9,10
    end output;
;
    begin actions;
      body bearing_angle pitch1;
      body bearing_angle pitch2;
      body bearing_angle pitch3;
    end actions;
  end hawc_dll;
```

```
;
   begin hawc_dll;
    filename  ./control/damper.dll ;
    dll_subroutine damp ;
    arraysizes  15 15 ;
    begin output;
      general time ;                                                                    1
      general constant 5.0;
      general constant 10.0;
      general constant -1.0E1 ;
      mbdy state vel towertop 1 1.0 tower;
   end output;
;
    begin actions;
       mbdy force_ext towertop 2 1 towertop;
              mbdy force_ext towertop 2 2 towertop;
    end actions;
  end hawc_dll;
end dll;
;
;-------------------------------------------------------------------------------------------------------------
-----------------------------------------------------
;
begin output;
  filename ./res/oc3_monopile_phase_1 ;
;  time 390.0 450.0 ;
  buffer 1 ;
  general time;
  data_format  hawc_binary;
;
  constraint bearing1 shaft_rot 2; angle and angle velocity
  constraint bearing2 pitch1 5;    angle and angle velocity
  constraint bearing2 pitch2 5;    angle and angle velocity
  constraint bearing2 pitch3 5;    angle and angle velocity
  aero omega ;
  aero torque;
  aero power;
  aero thrust;
  wind free_wind 1 0.0 0.0 -90.0; local wind at fixed position: coo
  hydro water_surface 0.0 0.0 ;        x,y   gl. pos
  mbdy momentvec towertop 1 2 towertop # yaw bearing ;
  mbdy forcevec  towertop 1 2 towertop # yaw bering ;
  mbdy momentvec shaft 4 1  shaft # main bearing ;
  mbdy momentvec blade1 3  1 blade1 # blade 1 root ;
  mbdy momentvec blade1 10 1 local # blade 1 50% local e coo ;
  mbdy momentvec hub1 1  2 hub1 # blade 1 root ;
  mbdy momentvec hub2 1  2 hub2 # blade 2 root ;
  mbdy momentvec hub3 1  2 hub3 # blade 3 root ;
  mbdy state pos towertop   1 1.0 global # tower top flange position ;
  mbdy state pos tower   1 0.0 global # tower MSL position ;
  mbdy state pos blade1  18 1.0 blade1 # blade 1 tip pos ;
  mbdy state pos blade2  18 1.0 blade2 # blade 2 tip pos ;
  mbdy state pos blade3  18 1.0 blade3 # blade 3 tip pos ;
  mbdy state pos blade1  18 1.0 global # blade 1 tip pos ;
  aero windspeed 3 1 1 63.0;   wind seen from the blade: coo(1=local ae,2=blade,3=global,4=rotor polar),
  aero windspeed 3 1 2 63.0;
  aero windspeed 3 1 3 63.0;
  aero alfa 1 45.0;
  aero alfa 2 45.0;
  aero alfa 3 45.0;
  mbdy momentvec towertop 1 1 tower # tower top -1: below top mass ;
  mbdy forcevec  towertop 1 1 tower # tower top -1: below top mass ;
  mbdy momentvec tower  1 1 tower # tower MSL ;
  mbdy forcevec  tower  1 1 tower # tower MSL ;
;
  dll outvec 1 1 # time;
  dll outvec 1 2 # pitch angle 1;
  dll outvec 1 3 # pitch vel 1;
  dll outvec 1 4 # pitch angle 2;
  dll outvec 1 5 # pitch vel 2;
  dll outvec 1 6 # pitch angle 3;
  dll outvec 1 7 # pitch vel 3;
  dll outvec 1 8 # gen. azi slow;
  dll outvec 1 9 # gen. speed slow;
  dll outvec 1 10 # free wind x;
  dll outvec 1 11 # free wind y;
  dll outvec 1 12 # free wind z;
  dll outvec 1 13 # gear ratio;
  dll inpvec 1 1 # Mgen slow;
  dll inpvec 1 2 # pitchref 1;
  dll inpvec 1 3 # pitchref 2;
  dll inpvec 1 4 # pitchref 3;
  dll inpvec 1 7 # F;
  dll inpvec 1 8 # Mechanical power generator [kW];
  dll inpvec 1 10 # Pitch rate [rad/s];
  dll inpvec 2 1 # pitch 1;
  dll inpvec 2 2 # pitch 2;
  dll inpvec 2 3 # pitch 3;
  dll outvec 2 1 # time;
  dll outvec 2 2 # pitchref 1;
  dll outvec 2 3 # pitchref 2;
  dll outvec 2 4 # pitchref 3;
  dll outvec 2 5 # pitch angle 1;
  dll outvec 2 6 # pitch speed 1;
  dll outvec 2 7 # pitch angle 2;
  dll outvec 2 8 # pitch speed 2;
  dll outvec 2 9 # pitch angle 3;
  dll outvec 2 10 # pitch speed 3;
end output;
;
exit;
```

Risø's research is aimed at solving concrete problems in the society.

Research targets are set through continuous dialogue with business, the political system and researchers.

The effects of our research are sustainable energy supply and new technology for the health sector.