HAWC2 - Course

Lesson 1: Defining the Structure

Risø DTU
National Laboratory for Sustainable Energy

Agenda

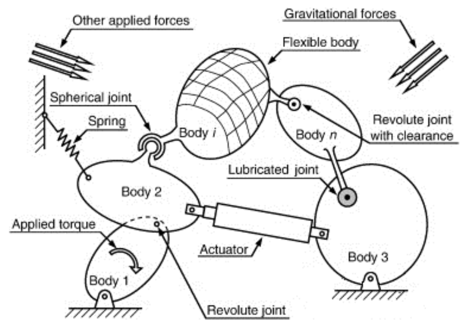
- Bit of theory: short intro to the multibody formulation

- Hawc2 blocks and the input file
    - Inputs for the structure:Main_body: defining the 'pieces':Centerline definition
        - Timoshenko beam properties
        - Damping
    - Orientation
    - Constraints
- Hawc2 output
    - Body-beam-structure output
    - Eigen analysis output

- Exercises

What is a multibody formulation?

- A general coupling method for independent structural objects (rigid or flexible). Method used also refered to as floating frame of reference.
- Large rotations and translation are accounted for in the coupling point.
- Small deflections are assumed within the objects
- Couplings are done using algebraic contraints (fixed relative position, joints, controlled position etc.)
- Every body: set of Timoshenko beams elements (6 DOF)

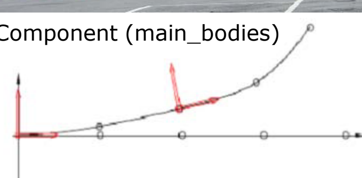


[Shabana, *"Dynamics of multibodysystems": Floating reference of frame formulation]*

Multibody Formulation

1. Full Structure (WT)

2. Component (main_bodies)



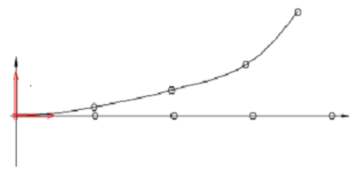
3. Bodies (reference system)

4. Body -Beam

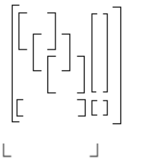
5. Beam elements (Timoshenko)

Sub-Structure Kinematics

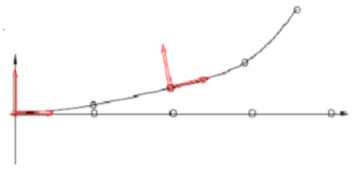
Linear



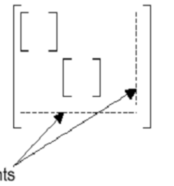
$K =$



Multibody
(2 bodies)



$K =$



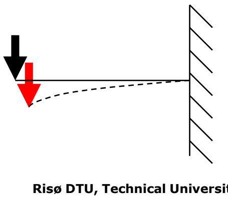
One effect of Multiple Bodies per Blade

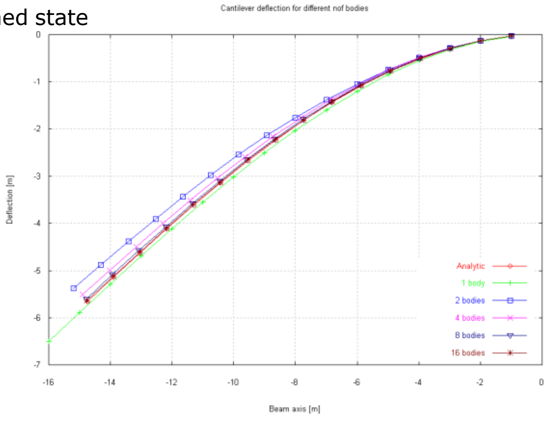
Multibody Formulation: Allows Large deflections, Linear formulation inside each body (small deflection)

- Multiple bodies allow for non linearities (large deflections & rotations): deformation states of last node passed to next body reference frame.
- Forces applied to deformed state

Example:

•Cantilevered beam loaded by end-load.





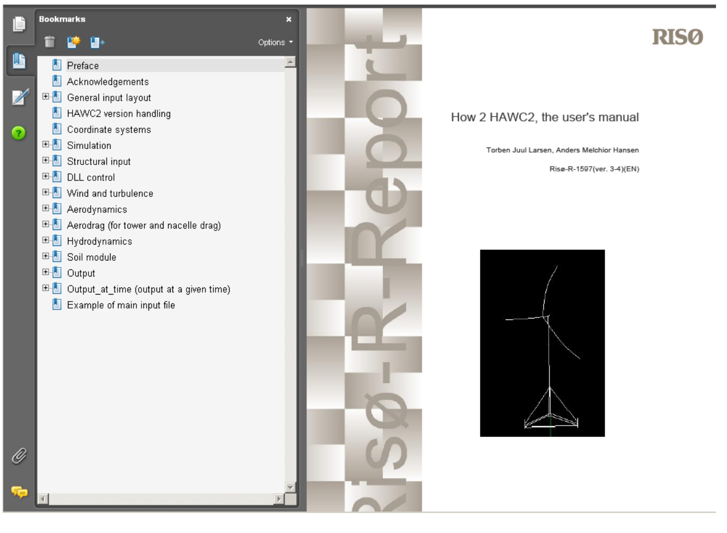
Relevance of large rotations ?

Tjæreborg

10 m/s

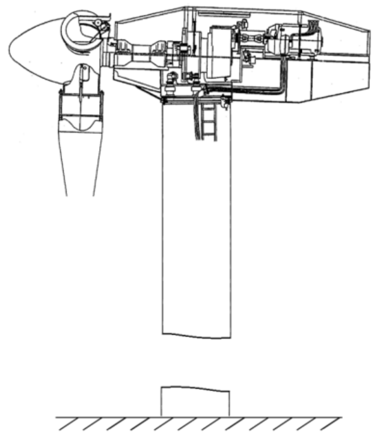
External flap/edge loads on blade causes torsion when blades deflect. Main torsion load effect on blades. This also contributes to blade twist.

The manual



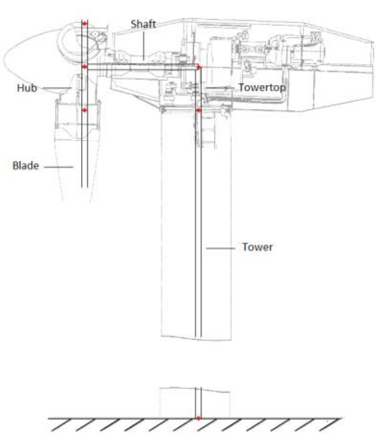
Turbine modeling with beam elements

- Division of turbine components into a HAWC2 model consisting of main bodies and beam elements

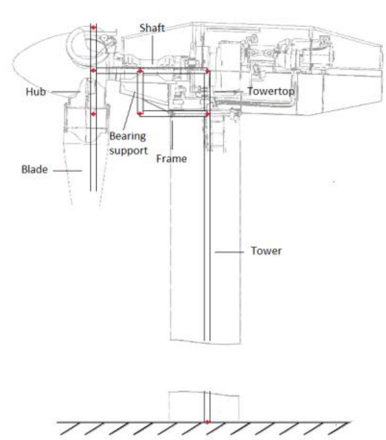


Main bodies

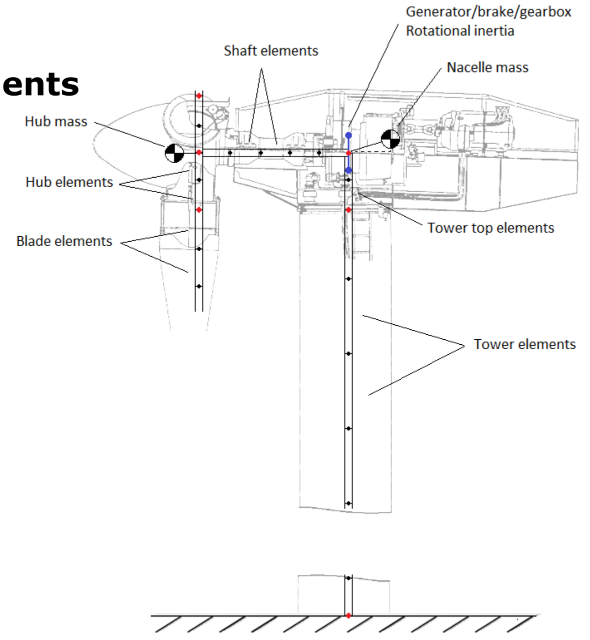
Traditional way of modeling nacelle



Alternative way of modeling nacelle

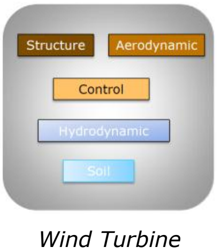


Beam elements



Hawc2 blocks

- Aim: *simulate the loads that a wind turbine might experience*

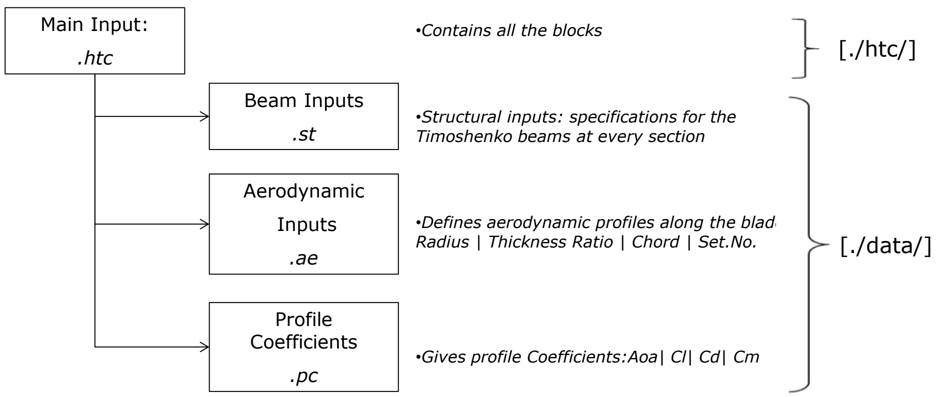


Wind Turbine

External Conditions

Hawc2 input files:

- How the input files are organized:



Main command blocks

```
begin Simulation;

end simulation;
;----------------------------------------------------------------------
   begin new_htc_structure;
  beam_output_file_name  ./log/wt_beam.dat;
  body_output_file_name  ./log/wt_body.dat;
  body_eigenanalysis_file_name ./eigenfrq/wt_body_eigen.dat;
  structure_eigenanalysis_file_name ./eigenfrq/wt_strc_eigen.dat ;
;
  begin main_body;

  end main_body;
;
  begin orientation;

  end orientation;
;
  begin constraint;

  end constraint;
;
   end new_htc_structure;
;----------------------------------------------------------------------
  begin wind ;

  end wind;
;----------------------------------------------------------------------
  begin aero ;

  end aero ;
;----------------------------------------------------------------------
  begin hydro;

  end hydro;
;----------------------------------------------------------------------
  begin dll;

  end dll;
;----------------------------------------------------------------------
  begin output;

  end output;
```

→ Set up of simulation properties

→ Definition of the structural components

→ Definition of outputs and directories

→ Definition of structural components

→ Orientation of structural components

→ Constraints of structural components

→ Definition of wind conditions

→ Definition of aerodynamic properties

→ Definition of hydrodynamic properties

→ Link to dll´s (controllers etc.)

→ Definition of sensors (output)

new_htc_structureBlock

```
;----------------------------------------------------------------------
  begin new_htc_structure;
 beam_output_file_name  ./log/wt_beam.dat;
 body_output_file_name  ./log/wt_body.dat;
 body_eigenanalysis_file_name ./eigenfrq/wt_body_eigen.dat;
 structure_eigenanalysis_file_name ./eigenfrq/wt_strc_eigen.dat ;
;----------------------------------------------------------------------
 begin main_body;

 end main_body;
;----------------------------------------------------------------------
 begin orientation;

 end orientation;
;----------------------------------------------------------------------
 begin constraint;

 end constraint;
;----------------------------------------------------------------------
  end new_htc_structure;
;----------------------------------------------------------------------
```

1) Set up the *main_bodies (components)*

- Internal coordinate system
- Structural properties

2) Give the orientation of the *main_bodies(initial position and velocity)*

3) How do the main_bodiesconnect to each other

htc_structure definitions

- A body is a structural object with its own coo. system and position and orientation according to the global coo. Bodies are connected by constraints.
- To make it convenient for the user the terminology main_body is often used. This is a body or a structural component which is subdivided into bodies. Could also be understood as a sub structure (Tower, shaft, blade...)

- The main_body properties must be set up in its own coordinate system first!
- Secondly the initial position, orientation, velocity, rotation velocity must be defined.
- Last the constraints are defined.

Define Main_body

```
begin main_body;
```

- *Initialization*

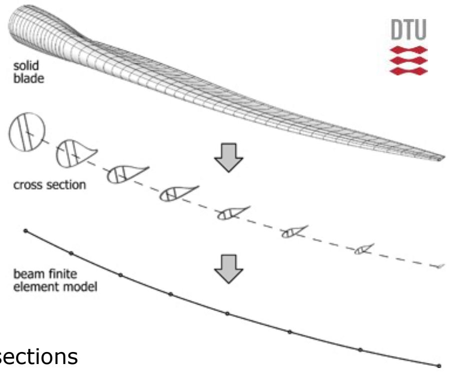
  Name, type, nbodies, distribution
- *Rayleigh Damping*
- *Assign structural properties:*

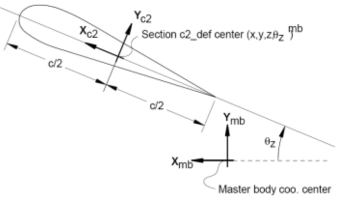
  Call to .stfile

  Properties of Timoshenko's beam sections
- *Centerline Definition:*

  Relation between the main body coordinate system (pitch axis) and the local-sections coordinate system: centerline (half-chord point), twist.

(*Concentrated mass-inertia*)






```
end main_body;
```


Main_Body example

```
begin main_body;
  name          blade1 ;
  type          timoschenko ;
  nbodies       9 ;
  node_distribution    c2_def;
  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     -0.0027      0.0006    1.367     -13.308       ;
  sec 3     -0.1057      0.0250    4.100     -13.308       ;
  sec 4     -0.2501      0.0592    6.833     -13.308       ;
  sec 5     -0.4592      0.1086    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;
```

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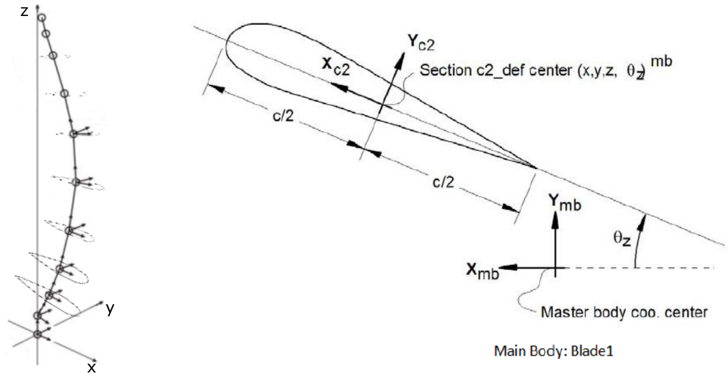
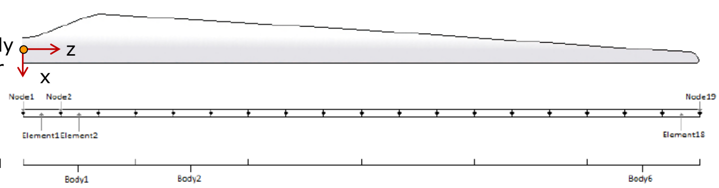
Definition of the centerline

Position and orientation of half chord point related to main body coordinate





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Structural input in data file

```
-----------------------------------
#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
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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
```
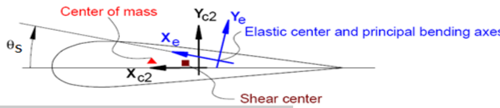

Timoshenko_inputfile (.st)

Position of structural centers related to c2_def section coo.



1	r, curved length distance from main_body node 1 [m]
2	m, mass per unit length [kg/m]
3	xm, xc2-coordinate from C1/2 to mass center [m]
4	ym, yc2-coordinate from C1/2 to mass center [m]
5	rix, radius of inertia related to elastic center. Corresponds to rotation about principal bending xe axis [m]
6	riy, radius of inertia related to elastic center. Corresponds to rotation about principal bending ye axis [m]
7	xs, xc2-coordinate from C1/2 to shear center [m]
8	ys, yc2-coordinate from C1/2 to shear center [m]
9	E, modulus of elasticity [N/m2]
10	G, shear modulus of elasticity [N/m2]
11	Ix, area moment of inertia with respect to principal bending xe axis [m4] This is the principal bending axis most parallel to the xc2 axis
12	Iy, area moment of inertia with respect to principal bending ye axis [m4]
13	K, torsional stiffness constant with respect to ze axis at the shear center [m4/rad]. For a circular section only this is identical to the polar moment of inertia.
14	kx shear factor for force in principal bending xe direction [-]
15	ky, shear factor for force in principal bending ye direction [-]
16	A, cross sectional area [m2]
17	Θ_s structural pitch about zc2 axis. This is the angle between the xc2 -axis defined with the c2_def command and the main principal bending axis xe.
18	xe, xc2-coordinate from C1/2 to center of elasticity [m]
19	ye, yc2-coordinate from C1/2 to center of elasticity [m]

Timoshenko_inputfile (.st)

- A small explanation about radius of gyration (also called radius of inertia) and the area moment of inertia (related to stiffness) is shown below in N.5 and N.11
  - **N.5** r_{tx} $[m]$ 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:

$$I_{xx} = \int r_{tx}^2 \mathrm{d}m \quad \rightarrow \quad r = \sqrt{\frac{I_{xx}}{m}} = \sqrt{\frac{I_x}{\mathrm{A}}}$$

  - **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:

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

$$\mathrm{Stiffn}_{\mathrm{edge}} = E \cdot I_y$$

$$\mathrm{Stiffn}_{\mathrm{tors}} = \mathbf{G} \cdot \mathbf{K}$$

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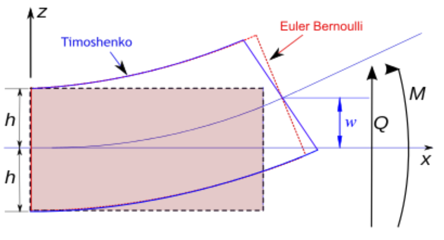
Timoshenko_inputfile (.st)

- A small explanation about shear factor N.14 and N.15. The shar factor kx, ky is implemented as $1/f_s$ where f_s is the form factor also referred to as the shear coefficient.

- Setting a very high value for kx, ky and the beam will behave as a Bernoulli Euler beam (no shear stress)

Table 10-4 Form factor f_s for shear

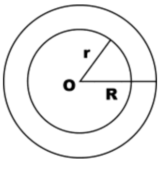
Section	f_s
Rectangle	$\frac{6}{5}$
Circle	$\frac{10}{9}$
Thin tube	2
I-section or box section	$\frac{A}{A_{web}}$



DTU

Cylinder example (Steel)

D=1 m
t=20 mm
R=0.5
r=0.48
Rho=7850 kg/m^3
N.9:E=2.10E+11 N/m^2
N.10:E=8.08E+10 N/m^2
N.16: A=pi*(R^2-r^2)=0.06158 m^2
N.2:m=rho*A=4.7350E+02 kg/m
N.11-12:Ix=Iy=pi/4*(R^4-r^4)=7.3952E-03 m^4
N.5-6:Rix=Riy=Sqrt(Ix/A)=0.34655 m
N.14-15:kx=ky=1/2=0.5
N.13:K/Ip=pi/32*(D^4-d^4)=0.01479 m^4
N.3,4,7,8,17,18,19: xm,ym,xs,ys,Θ_s,xe,ye = 0



$$I = \frac{\pi}{4}\left(r_o^4 - r_i^4\right)$$

, where:

I = Area Moment of Inertia of Cylinder (m^4)

r_o = Outer Radius (m)

r_i = Inner Radius (hole) (m), is 0 for a solid cylinder.

$$I_p = \pi \cdot (D^4 - d^4) / 32$$

Ip = Polar moment of inertia
D = Outer diameter (m)
d = Inner diameter (m)

Rayleigh damping parameters

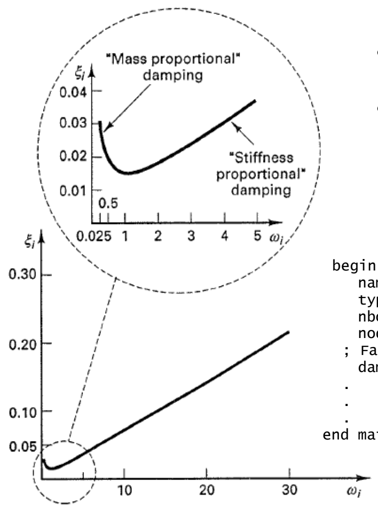


Figure E9.10 Damping as a function of frequency

- Mass and stiffness proportional damping parameters need to be given for the vibration direction around the x,y, and z direction.
- Mass proportional damping controls the mean damping level.
- Stiffness proportional damping controls the change with respect to higher frequencies.

```
begin main_body;
   name         blade1 ;
   type         timoschenko ;
   nbodies      9 ;
   node_distribution     c2_def ;
 ; Factors  Mx,    My,    Mz,    Kx,    Ky,    Kz
   damping_posdef   3.0e-2 2.2e-2 4.0e-2 5.9e-4 1.9e-3 5.0e-4 ;
  .
  .
  .
end main_body;
```


Damping with multiple bodies (blades)

- The mass proportional part of the damping matrix yields a different damping if the number of bodies is changed
- This can be handled by:

1. Set the mass proportional part of the damping to zero (damping_posdef 0.0 0.0 0.0 Kx Ky Kz) and only use the stiffness proportional part when tuning.

2. Only tune damping by useing ” structure_eigenanalysis”

-Remember to use the same number of bodies as in the real time simulations. If it is important to look into the damping on main_body level this means that it is necessary to make a set-up for all components consisting of multiple bodies which are then cantilevered (fix0) and tuned separately. Usually it is sufficient to use ”structure_eigenanalysis” on the entire structure.

new_htc_structureBlock

```
;------------------------------------------------------------------------
  begin new_htc_structure;
 beam_output_file_name  ./log/wt_beam.dat;
 body_output_file_name  ./log/wt_body.dat;
 body_eigenanalysis_file_name ./eigenfrq/wt_body_eigen.dat;
 structure_eigenanalysis_file_name ./eigenfrq/wt_strc_eigen.dat ;
;------------------------------------------------------------------------
 begin main_body;

 end main_body;
;------------------------------------------------------------------------
 begin orientation;

 end orientation;
;------------------------------------------------------------------------
 begin constraint;

 end constraint;
;------------------------------------------------------------------------
  end new_htc_structure;
;------------------------------------------------------------------------
```

1) Set up the *main_bodies (components)*

- •Internal coordinate system
- •Structural properties

2) Give the orientation of the *main_bodies(initial position and velocity)*

3) How do the main_bodiesconnect to each other

Coordinate systems

•Each main_body defined in its coordinate system (c2_def)

•Orientation block defines:

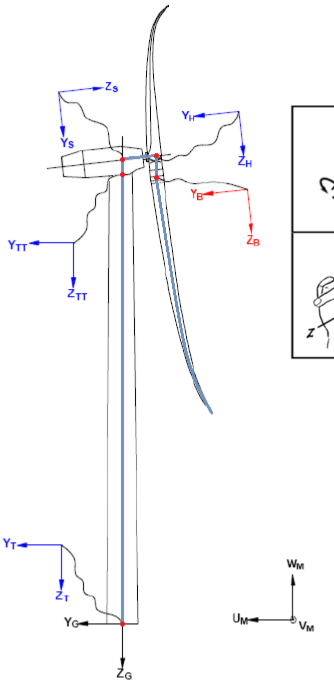
- •Relation between the main_bodies coordinate systems (how the 'pieces' assemble…)
- •Initial conditions: position and velocity (initial!)

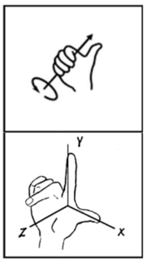
HAWC2 uses a fixed Global coordinarte system (right hand coordinate system,

Z pointing downwards, Y same direction as the on commoing wind)

Blade coordinate systems is not optional:

X towards leading edge and Y in flap!





Orientation

```
  begin orientation;
    begin base;
      body   tower;
      inipos        0.0 0.0 0.0 ;        initial position of node 1
      body_eulerang 0.0 0.0 0.0;
    end base;
;
    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
    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;
.......
    end orientation;
```

1) “feet on the ground”:

Relate to inertial coordinate system

2) Relative orientation between two main_bodies: (can be repeated)

•Body 1 (and 2): name + node

•EulerAng: (can be repeated)

Rotation of body2 coordinate system, wrt to body1.

Angles in body2 system, around c2 origo.

Good Practice: *one rotation at the time*

•ini_rotvec:

Initial rotation around the specified axis, with specified value. Axis in body2 coordinates.

new_htc_structureBlock

```
;-----------------------------------------------------------------------
   begin new_htc_structure;
  beam_output_file_name  ./log/wt_beam.dat;
  body_output_file_name  ./log/wt_body.dat;
  body_eigenanalysis_file_name ./eigenfrq/wt_body_eigen.dat;
  structure_eigenanalysis_file_name ./eigenfrq/wt_strc_eigen.dat ;
;-----------------------------------------------------------------------
  begin main_body;

  end main_body;
;-----------------------------------------------------------------------
  begin orientation;

  end orientation;
;-----------------------------------------------------------------------
  begin constraint;

  end constraint;
;-----------------------------------------------------------------------
   end new_htc_structure;
;-----------------------------------------------------------------------
```

1) Set up the *main_bodies (components)*

•Internal coordinate system

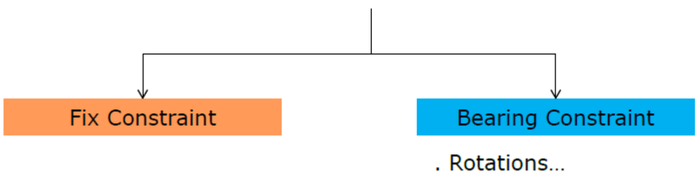
•Structural properties

2) Give the orientation of the *main_bodies(initial position and velocity)*

3) How do the main_bodiesconnect to each other

Constraints

- Constraint relation in between *main_bodies:*
- How do the pieces stick together?



Constraints

- Fix0: This constraint fix node number 1 of a given main_body to ground.
- Fix1: This constraint fix a given node on one main_body to another main_body's node.
- Fix 2: 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.
- Fix 3: This constraint fix a node to ground in tx,ty,tz rotation direction. The rotation direction that is free or fixed is optional.
- Fix 4: Constraint that locks a node on a body to a another node in translation but not rotation with a prestress feature. The two nodes will start at the defined positions to begin with but narrow the distance until fully attached at time T.
  - Disable at a time option for fix 1 and 2

Constraints

- Bearing 1: Constraint with properties as a bearing without friction. A sensor with same identification name as the constraint is set up for output purpose.

- Bearing 2: This constraint allows a rotation where the angle is directly specified by an external dll action command.

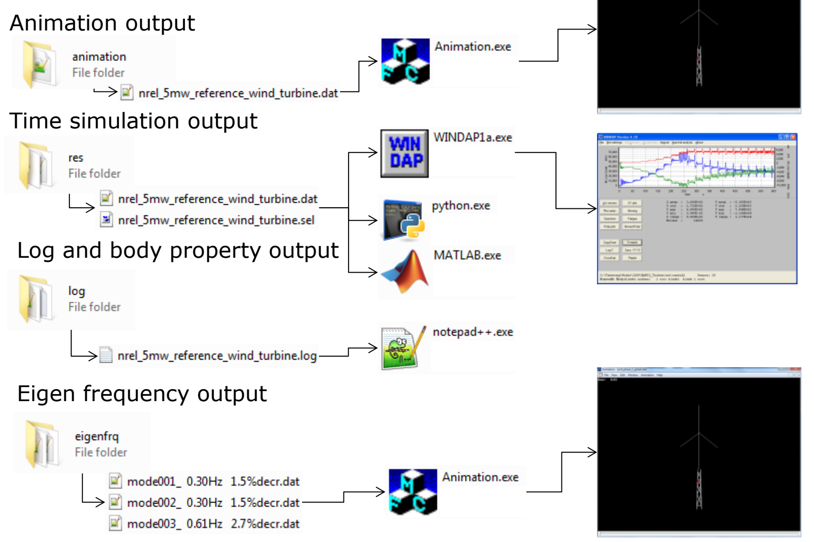
- Bearing 3: This constraint allows a rotation where the angle velocity is kept constant throughout the simulation.

- Bearing 4: This constraint is a cardan shaft contraint. Locked in relative translation. Locked in rotation around one vector and allows rotation about the two other directions.

Constraints

```
 begin constraint;
   begin fix0;  fixed to ground in translation and rotation of node 1
      body tower;
    end fix0;
;
    begin bearing1;                       free bearing
      name  shaft_rot ;
      body1 tower last;
      body2 shaft 1;
      bearing_vector 2 0.0 0.0 -1.0;        x=coo (0=global,1=body1,2=body2)
    end bearing1;
;
    begin fix1;
      body1 shaft last;
      body2 hub1 1;
    end fix1;
;
    begin bearing2;                       forced bearing
      name pitch1;
      body1 hub1 last;
      body2 blade1 1;
      bearing_vector 2 0.0 0.0 -1.0;        x=coo (0=global,1=body1,2=body2)
    end bearing2;
;
…
End constraint;
```

Output



Output – Animation,log,body & eigen freq.

```
begin Simulation;
  time_stop    0.1;
  solvertype   1 ;     (newmark)
  on_no_convergence continue ;
  convergence_limits 1E3 1.0 0.7 ;
  logfile ./logfiles/structure.log ;
  animation ./animation/NREL_5MW_blade_eig.dat;
  begin newmark;
    deltat    0.02;
  end newmark;
end simulation;
;
begin new_htc_structure;
  beam_output_file_name  ./logfiles/structure_beam.dat;
  body_output_file_name  ./logfiles/structure_body.dat;
  body_eigenanalysis_file_name ./eigenfrq/structure_body_eigen.dat;
  structure_eigenanalysis_file_name ./eigenfrq/structure_strc_eigen.dat;
  struct_inertia_output_file_name ./logfiles/structure_struct.dat;
```

Logfile

Animation

Beam and body properties

Body eigen freq.

Full system eigen freq.

Body list properties

Beam – body – structure output

- Commands written in the **new_htc_structure** command block

beam_output_file_name ./logfiles/caseid_beam.dat;

➢ Calculated beam properties of the bodies are written to this file

body_output_file_name ./logfiles/caseid_body.dat

➢Body initial position and orientation are written to this file

struct_inertia_output_file_name ./logfiles/caseid_struct.dat;

➢Body mass, center og gravity and added mass are written to this file

Natural frequencies

- Commands written in the **new_htc_structure** command block

body_eigenanalysis_file_name ./eigenfrq/caseid_body_eigen.dat;

➢ Eigenfrequencies of local body written to this file

structure_eigenanalysis_file_name ./eigenfrq/caseid_strc_eigen.dat;

➢Eigenfrequencies and animation files for full turbine modeshapes at stand still are written

Output - Time simulation output

```
begin output;
  filename ./res/NREL_5MW_blade_eig ;
;  time 50.0 650.0 ;
  buffer 1 ;
  general time;
  data_format  hawc_binary;
;
  constraint bearing1 shaft_rot 1; angle and angle velocity
  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 (1=global,2=non-rotation rotor coo.), pos x, pos y, pos z
;
  mbdy momentvec towertop 1 2 towertop # yaw bearing ;
  mbdy forcevec  towertop 1 2 towertop # yaw bering ;
end output;
```


Exercises – structure.htc

1. Make a sketch of the modeled turbine including the local main_body coordinate systems and global coordinates and bearing rotation vectors. Use e.g. the beam_output_file_name and body_output_file_name to help with the overview.

2. Run "structure.htc" Calculate natural frequencies of individual bodies and turbine in general. Animate with the animation.exe program.

3. Run "sim_windap.htc" the time simulation and evaluate results in windap.

4. Tune the damping of the blades to a desired value

5. Correct the output sensors in "sim_windap.htc"

Exercise 1 Draw the turbine

```
begin main_body;

  name        tower ;
  sec 1 0.0 0.0 0.0     0.0 ;  x,y,z,twist
  sec 8 0.0 0.0 -87.6 0.0 ;

  name        towertop ;
  sec 1 0.0 0.0 0.0       0.0 ; x,y,z,twist
  sec 2 0.0 0.0 -1.96256  0.0 ;

  name        shaft ;
  sec 1 0.0 0.0 0.0     0.0 ;  x,y,z,twist
  sec 5 0.0 0.0 5.0191  0.0 ;

  name        hub1 ;
  sec 1 0.0 0.0 0.0     0.0 ;  x,y,z,twist
  sec 2 0.0 0.0 1.5    0.0 ; ;

  name        blade1 ;
  sec 1 0.0 0.0 0.0      0.0 ;  x,y,z,twist
  sec 19  -0.1201  0.0000 61.500 -0.000 ;
end main_body;
```

```
begin orientation;

  body   tower;
  inipos        0.0 0.0 0.0 ;
  body_eulerang 0.0 0.0 0.0;

  body1  tower last;
  body2  towertop 1;
  body2_eulerang 0.0 0.0 0.0;

  body1  towertop last;
  body2  shaft 1;
  body2_eulerang 90.0 0.0 0.0;
  body2_eulerang 5.0 0.0 0.0;
  body2_ini_rotvec_d1 0.0 0.0 -1.0 0.2

  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;

  body1  hub1 last;
  body2  blade1 1;
  body2_eulerang 0.0 0.0 0;
end orientation;
```

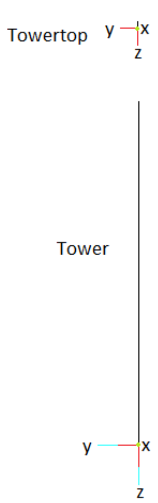
```
begin constraint;

  begin fix0;  fixed to ground
    body tower;
  end fix0;

  begin fix1;
      body1 tower last ;
      body2 towertop 1;
    end fix1;

  begin bearing1;
    name  shaft_rot;
    body1 towertop last;
    body2 shaft 1;
    bearing_vector 2 0.0 0.0 -1.0;
  end bearing1;

  begin fix1;
      body1 shaft last ;
      body2 hub1 1;
    end fix1;

  begin bearing2;
    name pitch1;
    body1 hub1 last;
   body2 blade1 1;
        bearing_vector 2 0.0 0.0 -1.0;
  end bearing2;
end constraint;
```


1 Draw the turbine

```
begin main_body;

  name        tower ;
  sec 1 0.0 0.0 0.0     0.0 ;  x,y,z,twist
  sec 8 0.0 0.0 -87.6 0.0 ;

  name        towertop ;
  sec 1 0.0 0.0 0.0       0.0 ; x,y,z,twist
  sec 2 0.0 0.0 -1.96256  0.0 ;
```

```
begin orientation;

  body   tower;
  inipos        0.0 0.0 0.0 ;
  body_eulerang 0.0 0.0 0.0;

  body1  tower last;
  body2  towertop 1;
  body2_eulerang 0.0 0.0 0.0;
```

```
begin constraint;

  begin fix0;  fixed to ground
    body tower;
  end fix0;

  begin fix1;
      body1 tower last ;
      body2 towertop 1;
    end fix1;
```



1 Draw the turbine

```
name        towertop ;
sec 1 0.0 0.0 0.0       0.0 ; x,y,z,twist
sec 2 0.0 0.0 -1.96256  0.0 ;
```

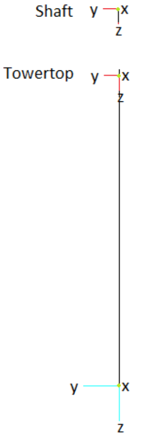
```
body1  tower last;
body2  towertop 1;
body2_eulerang 0.0 0.0 0.0;
```

```
begin fix1;
      body1 tower last ;
      body2 towertop 1;
  end fix1;
```

```
name        shaft ;
sec 1 0.0 0.0 0.0      0.0 ;  x,y,z,twist
sec 5 0.0 0.0 5.0191  0.0 ;
```

```
body1  towertop last;
body2  shaft 1;
body2_eulerang 90.0 0.0 0.0;
body2_eulerang 5.0 0.0 0.0;
body2_ini_rotvec_d1 0.0 0.0 -1.0 0.2
```

```
begin bearing1;
 name  shaft_rot;
  body1 towertop last;
  body2 shaft 1;
  bearing_vector 2 0.0 0.0 -1.0;
end bearing1;
```



1 Draw the turbine

```
name        shaft ;
sec 1 0.0 0.0 0.0      0.0 ;  x,y,z,twist
sec 5 0.0 0.0 5.0191  0.0 ;
```

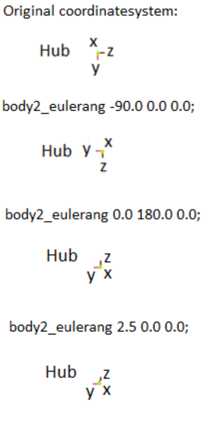
```
body1  towertop last;
body2  shaft 1;
body2_eulerang 90.0 0.0 0.0;
body2_eulerang 5.0 0.0 0.0;
body2_ini_rotvec_d1 0.0 0.0 -1.0 0.2
```

```
begin bearing1;
 name  shaft_rot;
  body1 towertop last;
  body2 shaft 1;
  bearing_vector 2 0.0 0.0 -1.0;
end bearing1;
```

```
name        hub1 ;
sec 1 0.0 0.0 0.0     0.0 ;  x,y,z,twist
sec 2 0.0 0.0 1.5     0.0 ; ;
```

```
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;
```

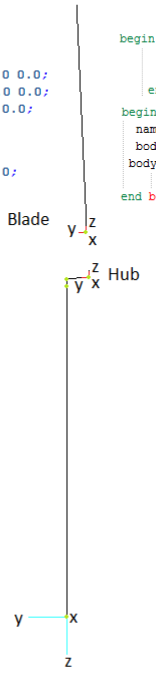
```
begin fix1;
      body1 shaft last ;
      body2 hub1 1;
  end fix1;
```



1 Draw the turbine

```
name        hub1 ;
sec 1 0.0 0.0 0.0     0.0 ;  x,y,z,twist
sec 2 0.0 0.0 1.5    0.0 ; ;

name        blade1 ;
sec 1 0.0 0.0 0.0     0.0 ;  x,y,z,twist
sec 19  -0.1201  0.0000  61.500  -0.000 ;
```

```
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;

body1  hub1 last;
body2  blade1 1;
body2_eulerang 0.0 0.0 0;
```

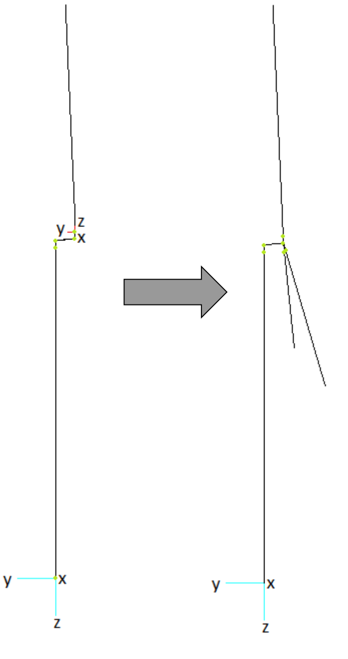



```
begin fix1;
      body1 shaft last ;
      body2 hub1 1;
    end fix1;
begin bearing2;
   name pitch1;
   body1 hub1 last;
  body2 blade1 1;
         bearing_vector 2 0.0 0.0 -1.0;
end bearing2;
```


1 Draw the turbine

blade 2, hub 2, blade 3, hub 3

Copied and attached



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Exercise 2 Run " structure.htc"

How to start HAWC2

- 1) start dos -> start_dos.bat
- 2) write: hawc2mb htc\"name of htc input file"

Evaluate results

- 1) Run " structure.htc"
- 2) Run Animation.exe
- 3) Open results in ../eigenfreq/

Exercise 2 Output

- Simulation results of "structure.htc" with a fixed shaft and a bearing at the shaft

	HAWC2 10.4 fixed shaft	HAWC2 10.4 bearing shaft
Description	[Hz]	[Hz]
1st tower transverse	0.3139	0.3166
1st tower longitudinal	0.3166	0.3223
1st rotor torsion (fixed-free)	0.5943	
1st asymmetric rotor flap/yaw	0.6157	0.6149
1st asymmetric rotor flap/tilt	0.6447	0.6437
1st symmetric rotor flap	0.6804	0.6751
1st rotor edge 1	1.0010	1.0011
1st rotor edge 2	1.0145	1.0144
2nd asymmetric rotor flap/yaw	1.6124	1.6122
1st rotor torsion (free-free)		1.6612
2nd asymmetric rotor flap/tilt	1.7343	1.7343
2nd symmetric rotor edge	1.8374	1.8373
2nd symmetric rotor flap	2.4243	2.6778
3rd asymmetric flap tilt	2.7171	2.7173
3rd asymmetric flap yaw	2.7932	2.8234

Exercise 3 Run a time simulation and evaluate results

- 1) Run ”sim_windap.htc” (start dos -> write: hawc2mb htc\sim_windap.htc)
- 2) Check the log file for error when running in ../logfiles/
- 3) Run 

- 4) Open the resultfile ”sim_windap.sel” in ../res/
- 5) Evaluate results

Exercise 4 Tune the damping of the blade

- 1) Open ” blade_eig.htc”
- 2) Change the number of bodies to a approiate number (2-3 elements pr. body -> 9 bodies)
- 3) Change the damping parameters
- 4) Run ” blade_eig.htc”
- 5) Redo step 4-5 until the damping is correct

Aim for 3% log.decr for the first 2 modes!

Exercise 5 Correct the sensors

- 1) Open "sim_windap.htc"
- 2) Add extra sensors (described in the end of the htc-File):
  - Position sensor in 50% blade span in hub coordinate system of blade 1
  - Shear force sensor in 50% blade span in hub coordinate system of blade 1
  - Position sensor to output blade twist in node 12 in blade coordinate system of blade 1
- 3) Look into the manual (page 76->) to see how the sensors are defined