HAWC2 - Course

Lesson 1: Defining the Structure

Risø DTU
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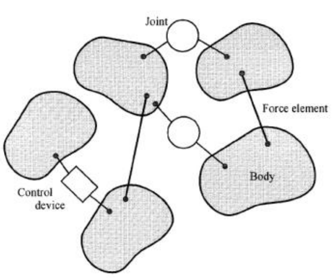
What is a multibody formulation?

- 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.)



Position of a point on an object *i*

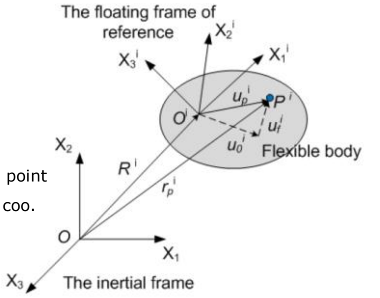
$$r_p^i = R^i + A^i \overline{u}_p^i$$

vector in local ref. from local origo to point

Orientation matrix of local coo related to global coo.

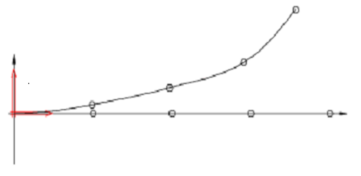
Vector in global ref. from origo to object origo

vector in global ref. from origo to point

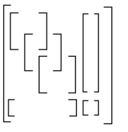


Sub-Structure Kinematics

Linear

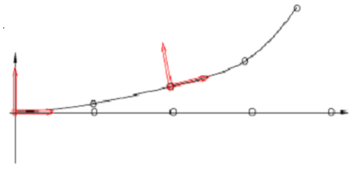


$K =$

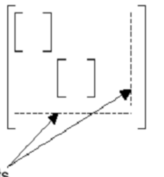


Multibody

(2 bodies)



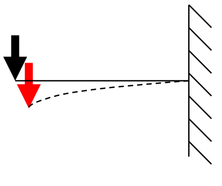
$K =$

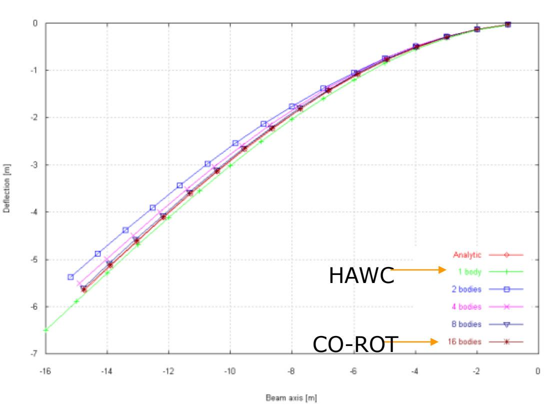


One effect of Multiple Bodies per Blade

Example:

•Bernouilli-Euler cantilever beam loaded by end-load.





Relevance of large rotations ?

Tjæreborg

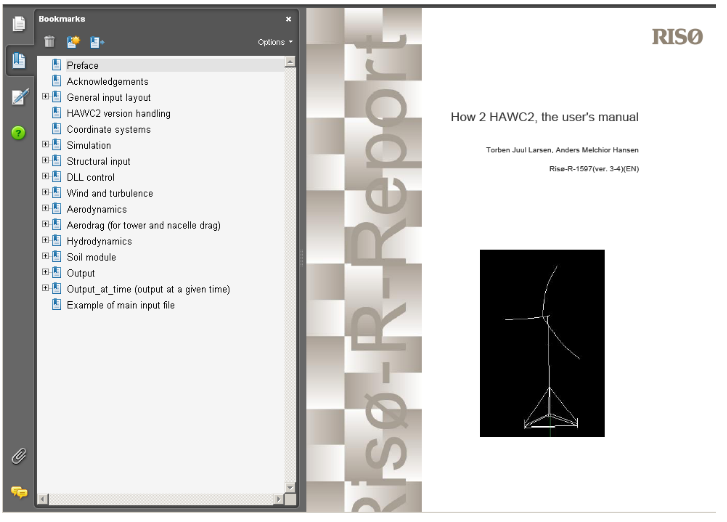
10 m/s

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

Main command blocks

```
begin simulation;
…
end simulation;
;
begin  main_body;
…
end  main_body;
;
begin orientation;
…
end orientation;
;
begin constraint;
…
end constraint;
;
begin wind;
…
end wind;
;
begin aero;
…
end aero;
;
begin dll;
…
end dll;
;
begin output;
…
end output;
```

The manual

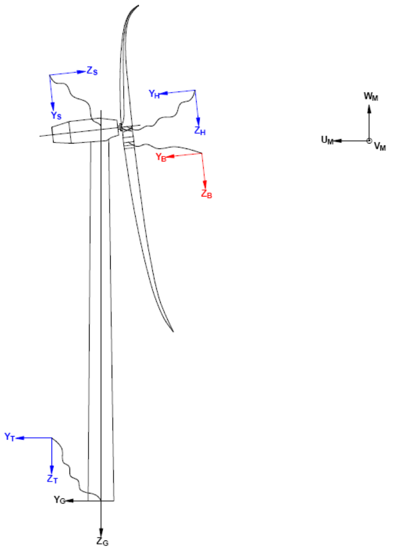


Definitions

- 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.

Coordinate systems

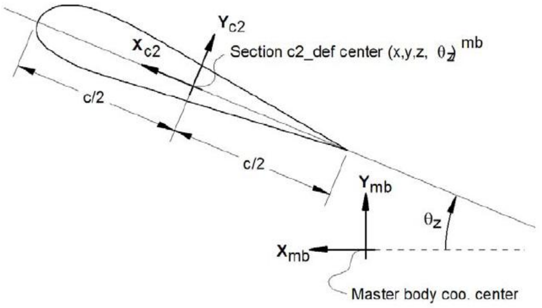


Main_Body example

```
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;
```

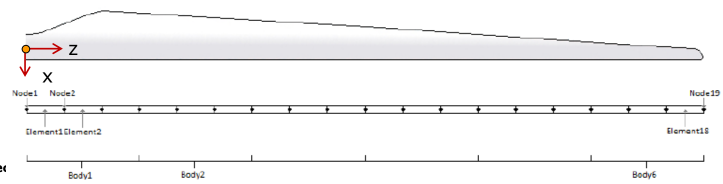
Definition of the centerline

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



Main Body: Blade1

Master body
coo. center



Structural input in data file

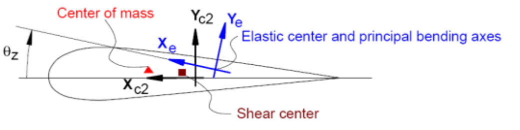
```
-----------------------------------
#1 Main data set number 1 - an example of a shaft structure
-----------------------------------
More comments space
r         m      x_cg  y_cgri_x  ri_y  x_sh  y_sh  E          G          I_x        I_y        K          k_x   k_y   A     theta_s x_e   y_e
[m]       [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_cgri_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_cgri_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
```

Input colums in data file

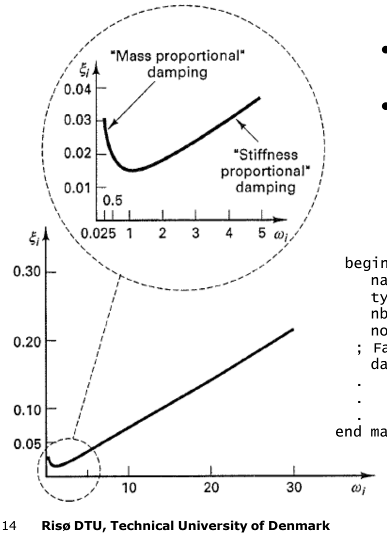
Position of structural centers related to c2_def section coo.



1	r, curved length distance from main_body nc
2	m, mass per unit length [kg/m]
3	xm, xc2-coordinate from C1/2 to mass cente
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 [N/m4]
12	Iy, area moment of inertia with respect to principal bending ye axis [N/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	structural pitch about zc2 axis. This is the angle between the xc2 -axis defined with the c2_def command and the 1st 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]

Rayleigh damping parameters

- 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   3.0e-2 2.2e-2 4.0e-2 5.9e-4 1.9e-3 5.0e-4 ;
  .
  .
  .
end main_body;
```

Figure E9.10 Damping as a function of frequency

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  shaft 1;
      body2_eulerang 90.0 0.0 0.0;
      body2_eulerang 5.0 0.0 0.0;    5 deg tilt
      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)
    end relative;
;
    begin relative;
      body1  shaft last;
      body2  hub1 1;
      body2_eulerang -90.0 0.0 0.0;
      body2_eulerang 2.5 0.0 0.0;      2.5deg cone
    end relative;
…
End orientation;
```


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.

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;
```

Natural frequencies

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

; Calculated beam properties of the bodies are written to file

beam_output_file_name ./logfiles/caseid_beam.dat;

; Body initial position and orientation are written to file

body_output_file_name ./logfiles/caseid_body.dat;

; Eigenfrequencies of local body written to file

body_eigenanalysis_file_name ./eigenfrq/caseid_body_eigen.dat;

; Eigenfrequencies and animation files for full turbine modeshapes at

; stand still are written

structure_eigenanalysis_file_name ./eigenfrq/caseid_strc_eigen.dat;

Exercise – structure.htc

- 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.

- Calculate natural frequencies of individual bodies and turbine in general. Animate with the animation.exe program.

- Does the frequencies and dampings fit? Tune for better damping.