TECHNISCHE UNIVERSITÄT MÜNCHEN

LEHRSTUHL FÜR WINDENERGIE

TUM reference wind turbines

Data Structure Description

Pietro Bortolotti

Report

Garching bei München, March 2016

Introduction

This document describes the data structure **Parameters**, a `Matlab`® structure containing wind turbine data. In the following, `CpLambda` is the name of an aero-servo-elastic code used for computing the blade loads, while `ANBA` is the name of a code used for computing sectional stiffnesses, inertial properties and for recovering stresses and strains on the blade cross sections given sectional loads.

The fields of the structure **Parameters** are:

```
WTConfiguration: [1x1 struct]
Controller: [1x1 struct]
Wind: [1x1 struct]
Blade: [1x1 struct]
Tower: [1x1 struct]
Materials: [1x1 struct]
DLC: [1x1 struct]
```

which are explained in the next sections.

1 Parameters.WTConfiguration

This section collects macro data describing the wind turbine configuration:

RotorDiameter = rotor diameter $[m]$;

RatedPower = rated power $[W]$;

ConeAngle = rotor pre-cone angle $[deg]$;

HubHeight = hub height $[m]$;

Overhang = rotor overhang $[m]$;

UpTilt = nacelle uptilt angle $[deg]$;

NacelleHeight = vertical size of the nacelle $[m]$;

maxVtip = maximum allowable blade tip speed $[m/s]$;

Jrotor = rotor inertia $[kgm^2]$.

2 Parameters.Controller

This section collects data describing the wind turbine control:

OmegaRated = rated rotor rotational speed $[rad/s]$;

PitchRated = rated blade pitch angle $[deg]$;

TorqueRated = rated generator torque $[Nm]$;

maxCp = rated power coefficient $[-]$;

TSRRated = rated tip speed ratio $[-]$.

The field includes then 6 vectors where data describing the wind turbine states scheduled against wind speed are listed. These are named Cpmax, TSR, pitch, Omega, Power and Torque, while wind is present in the field Winds.

3 Parameters.Wind

This section collects data describing the wind modelling. The two most important sub-fields are Grid and Weibull. The first one includes parameters used to model the wind grid, while the second the parameters of the Weibull distribution to compute AEP and fatigue damages.

4 Parameters.Blade

This section collects data describing the blade geometry, external shape, thicknesses and structural characteristics.

During blade sizing, `CpLambda` computes loads at the Structural Design Sections (SDSs) by running Design Load Cases (DLCs). At these same span-wise locations, the degrees of freedom of the structural optimization are located (i.e., thicknesses of webs, skin and of the inter-web midsection). The number of SDSs is chosen considering accuracy, computational cost, and well posedness of the optimization problem. To provide for a better description of the blade, the blade geometry is then interpolated at the Geometrical Design Sections (GDSs), which are more closely spaced than the SDSs (see Fig. 1).

4.1 .ExternalGeometry

This field collects data describing the external blade geometry at the GDSs.

NN = number of GDSs;

Eta = non-dimensional (0 = root, 1 = blade tip) span-wise location of the GDSs;

Chord = chord at each GDS $[m]$;

Twist = twist at each GDS $[deg]$;

ACOffset = distance between the aerodynamic center and the pitch axis, positive if the aerodynamic center is aft wrt the pitch axis $[m]$;

LE = distance between the airfoil leading edge and the pitch axis $[m]$;

TE = distance between the airfoil trailing edge and the pitch axis $[m]$;

AirfoilShape = airfoil shape. Each cell contains a shape matrix, i.e. the x, y coordinates of points on the airfoil expressed in the aerodynamic reference frame x_A, y_A (see Fig. 2).

4.2 .InternalGeometry

This field collects data describing the internal geometry of the blade at the GDSs.

The blade has two straight (planar) shear webs, which are orthogonal to the maximum blade chord. The two webs start at a given span-wise location, and end at another given span-wise location, i.e. they do not extend form the blade root to the blade tip. The structural arrangement

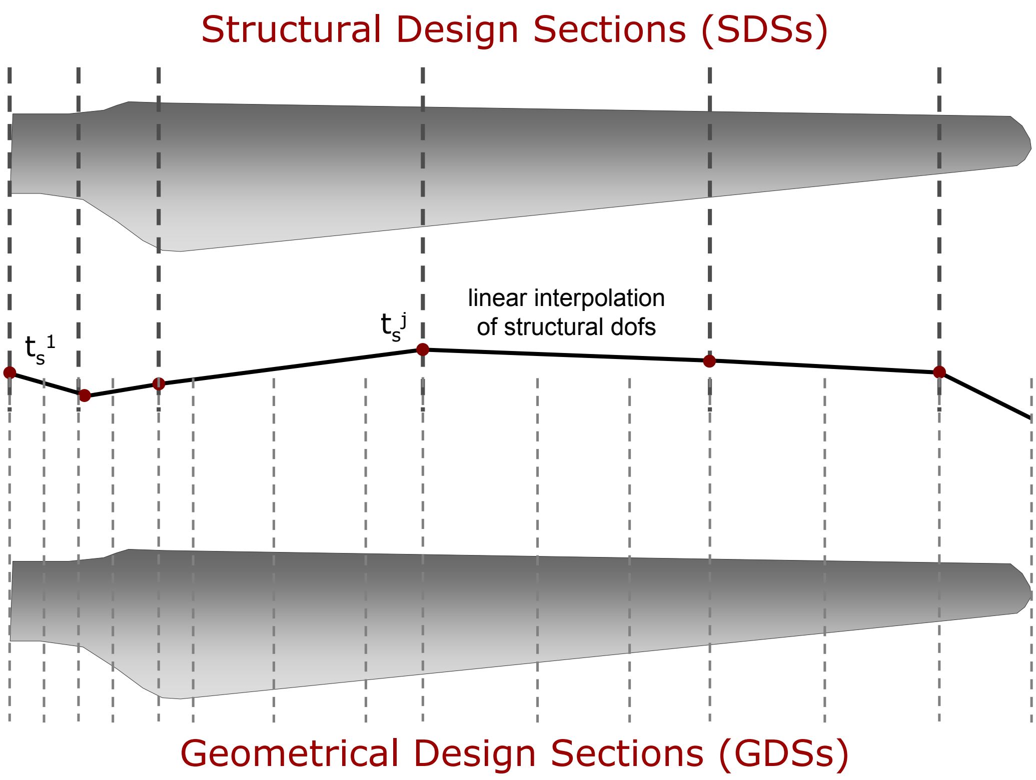

Fig. 1: Structural (SDS) and geometrical (GDS) design sections of the blade.

is of the box type, with top and bottom inter-web midsections which occupy the space between the two shear webs. The midsections, differently from the shear webs, extend all the way to the blade root. The structural arrangement is depicted in Fig. 3

ShearWebStart = non-dimensional ($\in [0, 1]$) span-wise location of beginning of shear webs;

ShearWebEnd = non-dimensional ($\in [0, 1]$) span-wise location of ending of shear webs;

FrontWebPosition = position of the first shear web (i.e., the one closest to the LE) wrt the pitch axis, for each GDS $[m]$. For the innermost GDSs, between the blade root and the beginning of the shear webs, this quantity indicates the beginning of the midsection cap;

AftWebPosition = position of the second web (i.e., the one closest to the TE) wrt the pitch axis, for each GDS $[m]$. For the innermost GDSs, between the blade root and the beginning of the shear webs, this quantity indicates the end of the midsection cap;

CapSuctStart/CapPresStart = position of the beginning of the suction and pressure spar caps wrt the pitch axis, for each GDS $[m]$. For the innermost GDSs, between the blade root and

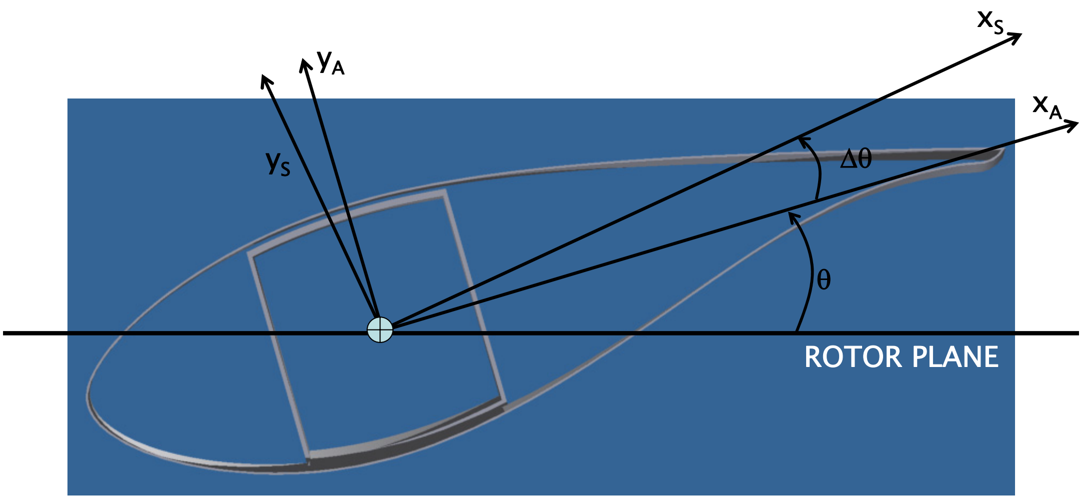

Fig. 2: Sectional references frames. Aerodynamic: x_A, y_A; structural: x_S, y_S.

the beginning of the shear webs, this quantity indicates the end of the midsection cap;

CapSuctEnd/CapPresEnd = position of the end of the suction and pressure spar caps wrt the pitch axis, for each GDS $[m]$. For the innermost GDSs, between the blade root and the beginning of the shear webs, this quantity indicates the end of the midsection cap;

CapSuctWidth/CapPresWidth = width of inter-web midsection (same as distance between the start and the end of the spar caps), for each GDS $[m]$;

Shell_TE_SS/Shell_LE_SS/Shell_LE_PS/Shell_TE_PS = thickness of external shell skin in $[m]$ for each GDS, potentially differentiating between 4 sectors, namely trailing edge vs leading edge and suction side vs pressure side;

StripThicknessAtLE/StripThicknessAtTE = thickness of leading and trailing edge reinforcements, for each GDS $[m]$;

StripAtLE/StripAtTE = position of leading and trailing edge reinforcements wrt the pitch axis, for each GDS $[m]$;

SuctCapThickness/PresCapThickness = thickness of suction and pressure spar caps, for each GDS $[m]$;

FrontWebThickness = thickness of first shear web, for each GDS $[m]$;

AftWebThickness = thickness of second shear web, for each GDS $[m]$;

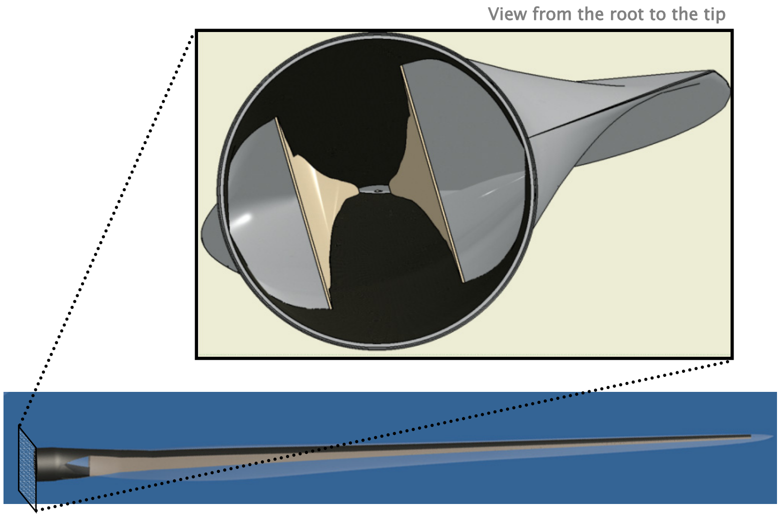

Fig. 3: Structural arrangement of the blade.

WeightProportionalNonStructuralMass = additional non-structural masses (i.e fillers such as PVC and wood), expressed in per cent of the blade sectional structural mass, for each GDS.

ChordProportionalNonStructuralMass = additional non-structural masses, expressed as a weight for unit span, for each GDS $[kg/m]$.

The meaning of the geometric parameters is illustrated Fig. 4

4.3 .Structure

This field collects the structural data computed by `ANBA` at the GDSs. The structural characteristics are expressed in the structural reference frame (see Fig. 2), whose axes are twisted wrt the aerodynamic axes of the angle **DeltaTheta**.

T11 = edge-wise shear stiffnesses $[N]$ along the x_S axis;

T22 = flap-wise shear stiffnesses $[N]$ along the y_S axis;

EA = axial stiffnesses $[N]$;

E11 = flap-wise stiffnesses $[Nm^2]$;

E22 = edge-wise stiffnesses $[Nm^2]$;

GJ = torsional stiffnesses $[Nm^2]$;

Centroid = coordinates of the centroid wrt the structural reference frame $[m]$;

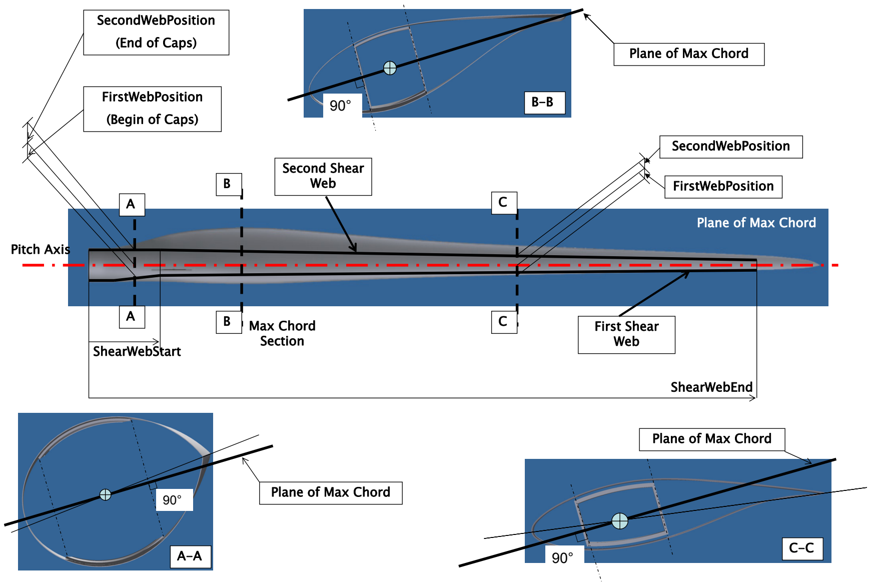

Fig. 4: View of the blade in the plane of maximum chord, and illustration of the main geometric parameters.

DeltaTheta = angle between the aerodynamic and the structural reference frames $[deg]$;

ShearCenter = coordinates of the shear center wrt the structural reference frame $[m]$;

Mass = masses $[kg/m]$;

I = moments of inertia $[kgm^2/m]$, along the axis normal to the section (i.e. polar inertia) and the two x_S and y_S axes, respectively;

CenterOfMass = coordinates of the center of gravity wrt the structural reference frame $[m]$;

4.4 .Root

RootRadius = distance of blade root from hub center $[m]$;

RootMass = additional root mass $[kg]$ (not included in the blade mass);

RootMassCog = distance between blade root and **RootMass** center of gravity $[m]$.

4.5 .Sensor

N = number of SDSs at which loads are provided;

Eta = non-dimensional (0 = root, 1 = blade tip) span-wise locations of the SDSs.

5 Parameters.CompositeMaterials

This field contains the mechanical properties of the materials used in the blade sectional analysis.

WebAndShellMaterial = mechanical proprieties of materials used for the external shell and the shear webs:

- E11 : longitudinal Young's modulus $[MPa]$;
- E22 : lateral Young's modulus $[MPa]$;
- v12 : Poisson ratio;
- G : shear modulus $[MPa]$;
- Density : density $[kg/m^3]$;
- SigmaMax : maximum allowable stress in the longitudinal direction $[MPa]$;
- TauMax : maximum allowable shear stress $[MPa]$;
- LayerThickness : thickness of one layer $[m]$;

CapMaterial = mechanical proprieties of materials used for the inter-web midsections:

- E11 : longitudinal Young's modulus $[MPa]$;
- E22 : lateral Young's modulus $[MPa]$;
- v12 : Poisson ratio;
- G : shear modulus $[MPa]$;
- Density : density $[kg/m^3]$;
- SigmaMax : maximum allowable stress in the longitudinal direction $[MPa]$;
- TauMax : maximum allowable shear stress $[MPa]$;
- LayerThickness : thickness of one layer $[m]$;

6 Parameters.Tower

This field includes data about tower design. The tower is made of **NumberSectors** conical sectors, each described by a bottom and a top point. These data points are located following the field **Height** along the tower, and each point is described by the following data values:

WallThickness = sector wall thickness $[mm]$;

Diameter = sector diameter $[m]$;

Area = sector section area $[m^2]$;

AxialStiffness = axial stiffness $[Nm]$;

BendingStiffness = bending stiffness $[Nm^2]$;

TorsionalStiffness = torsional stiffness $[Nm^2]$;

ShearStiffness = shear stiffness $[N]$;

MassUnitLength = mass per unit length $[kg/m]$;

PolarMomentInertia = polar moment of inertia [m^4];

The field also includes the subfield **MaterialProp**, which includes the properties of the material of the tower. The tower may be composed of several different materials. For each material the following properties are listed:

- Emodulus : Young's modulus for an isotropic material [GPa];
- Poisson_coeff : Poisson ratio [$-$];
- Density : density [kg/m^3];
- YieldStrength : yield strength [MPa];
- UltimateStrength : ultimate strength [MPa];

7 Parameters.DLC

This field contains data pertaining to the Design Load Cases (DLCs) used to design the wind turbine, including time histories and load envelope matrices. Four subfields are present: rotor, hub, tower top and tower root.

7.1 .Rotor

This field includes the envelopes from the rotor sensors.

DLCName = list of DLCs;

DynamicSimulationNb = number of simulations (some DLCs account for more than one simulation);

SafetyFactor = safety factors as defined by IEC 61400, for each DLC;

InitialTime = use blade loads starting at **InitialTime** seconds;

FinalTime = use blade loads ending at **FinalTime** seconds;

Envelope = array of dimension **Parameters.Blade.Sensor.N**, containing the load envelope matrix at each SDSs. Each matrix is of size 12 by 6. Each row contains the six load components in the order Fx, Fy, Fz, Mx, My, Mz (see below); the 12 rows represent the max and min values for each load component, in the same order. The envelopes are computed by finding maximum and minimum loads on all three blades. NOTICE: the envelope loads already include the safety factors (defined in variable **SafetyFactor**), hence they should not be multiplied by the safety factors;

LoadCase = array of dimension **Parameters.Blade.Sensor.N**, containing the blade *id*, the DLC and the time associated to the envelope matrix loads.

TimeHistories = variable of dimension **DynamicSimulationNb** with the following data:

- Time : time values;
- RotorSpeed : rotor speed time history;
- Pitch1 : blade 1 pitch time history;

- Blade : for each blade and each SDS, sectional load components in the structural reference frame:
  - Fx : edge-wise shear $[N]$;
  - Fy : flap-wise shear $[N]$;
  - Fz : axial force $[N]$;
  - Mx : flap-wise bending $[Nm]$;
  - My : edge-wise bending $[Nm]$.
  - Mz : torsional moment $[Nm]$;

  NOTICE: the loads above do not include the safety factors.

7.2 .Hub

This field includes the envelopes from the a sensor placed at the centre of the hub. The components of the forces follow a reference system placed at rotor center and oriented as described below:

- x axis : rotor thrust, measured along the shaft in wind direction;
- y axis : side force;
- z axis : vertical component, upwards;

7.3 .TowerTop

This field includes the envelopes from the a sensor placed on top of the tower. The components of the forces follow a reference system placed at tower top and oriented as described below:

- x axis : parallel to the ground towards wind direction;
- y axis : side direction parallel to the ground and perpendicular to the main wind direction;
- z axis : vertical component, upwards;

7.4 .TowerRoot

This field includes the envelopes from the a sensor placed at the root of the tower. The components of the forces follow a reference system placed at tower bottom and oriented as the reference system of tower top.