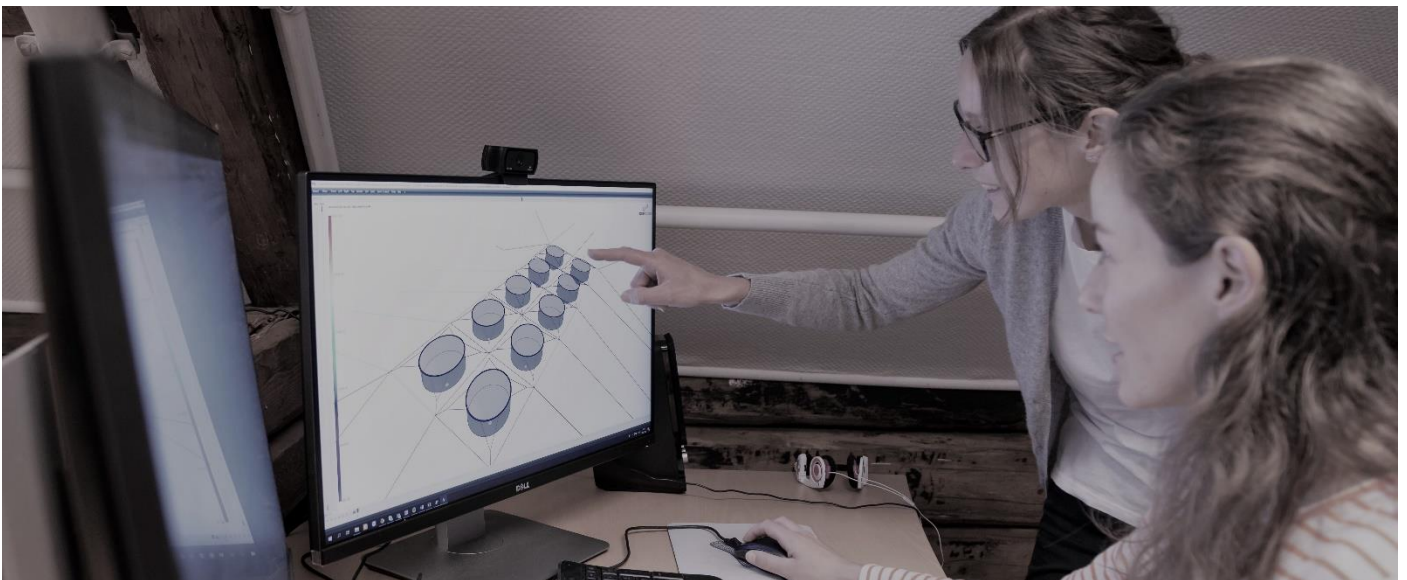


AquaSim training courses

- Wind Turbines



Revision: 1.0

AquaSim version: 2.19

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1 Prerequisites

The tutorial presents a simple case study with the purpose of demonstrating functionality in AquaSim.

It is assumed that the user is familiar with the basic principles of modelling and specifying material parameters in AquaEdit, as well as conducting analyses. If you are looking for an introduction to AquaSim we advise you to start with the Basic program tutorials.

2 Learning objectives

Upon completion of this tutorial, you will have knowledge in:

- How to model wind turbines in AquaSim
- Basic concepts for wind turbines
- How to run a dynamic analysis with a wind turbine

3 Introduction

This tutorial proposes a modelling- and analysis culture for wind turbines in AquaSim, where only the turbine is created first for validation of input parameters, then to implement this to a full coupled model, and the conduct analyses.

Wind power is one of the world's fastest growing energy sources, according to Statkraft. This is an energy source that has grown in popularity the recent years. Wind turbines are one method of exploiting the energy that wind provides. Simply put, a wind turbine system consists of three main components:

- Blades
- Generator
- Tower

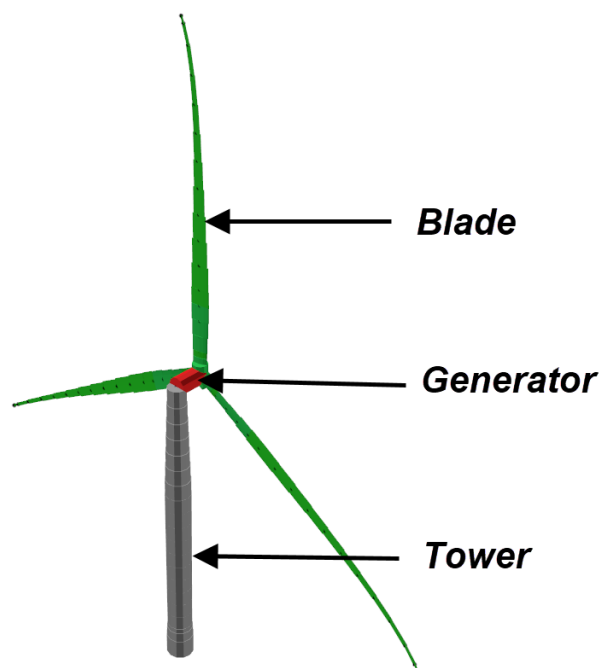


Figure 1

4 Case study – Pre-made turbine

4.1 Pre-processing (AquaEdit)

To establish a turbine, an automatic generator may be utilized in AquaEdit. To do so, you need to generate it on an existing element from the 3D window. Therefore, start with generating what we call the *Tower*. This is a vertical element, a vertical element and be can e.g. a beam component. The *Tower* supports the turbine structure and is component connecting the turbine with the foundation.

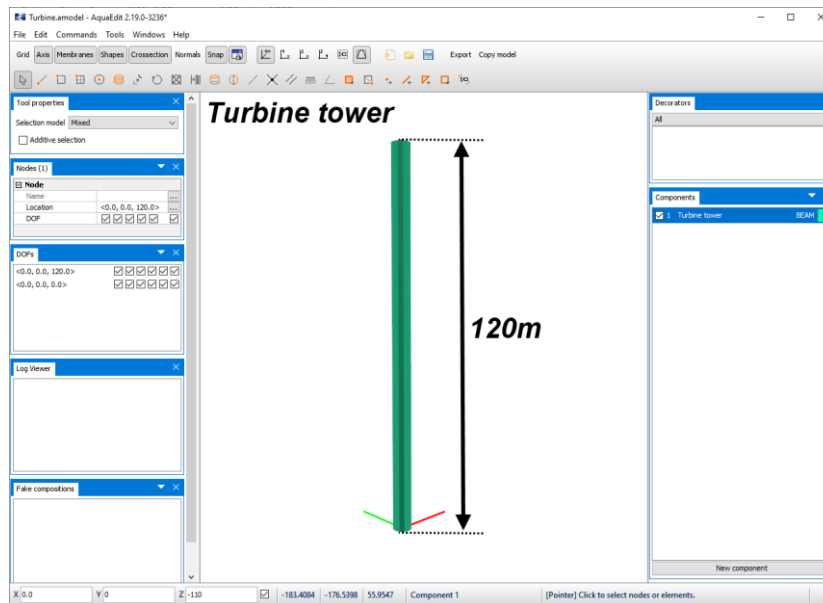


Figure 2

The beam has a diameter of 6.0 meters and is generated from the Data source type Tube in the Edit beam window. The beam is 120 meter in height and is modelled from $z=0$ m.

Since we in this section only are interested in basics of the turbine input, the two nodes representing the beam is restrained in all degrees of freedom.

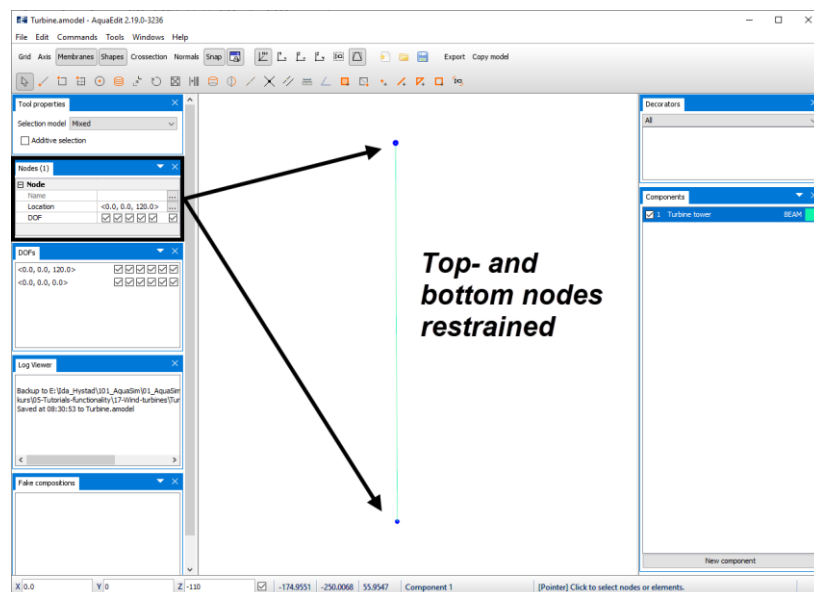


Figure 3

Click on the beam element in the 3D window and select **Elements** > **Other** > **Create turbine element**.

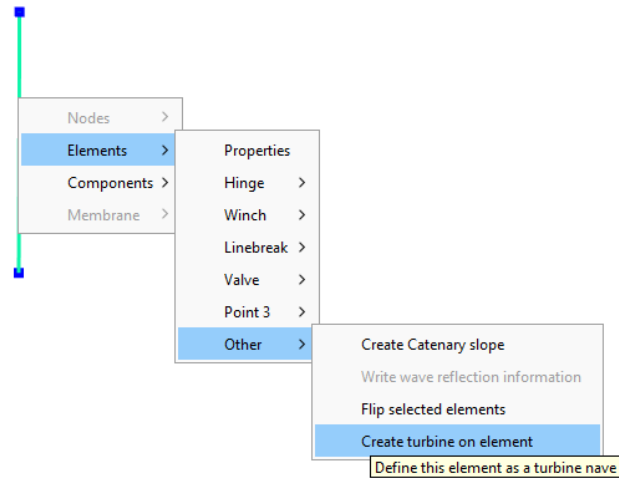


Figure 4

The interface of the built-in **Generate turbine**-tool will be loaded.

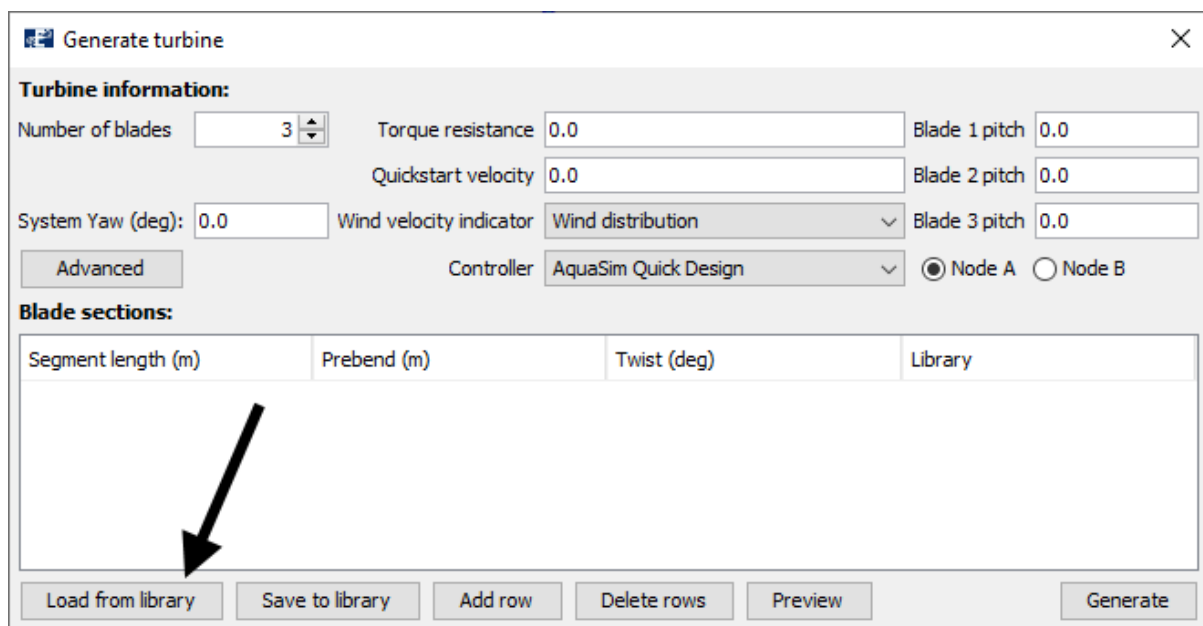


Figure 5

In this window, there is currently no turbine generated. This is seen as the **Blade sections**-area is empty. Turbines can be introduced manually or imported from a file. Once a 'new' turbine is built, this can be exported to the AquaSim library. In this way, generating will be a one-time-event.

To import an existing turbine, click on **Load from library** in the lower left corner of the window. In the file catalogue **Library** > **turbine** should be opened as seen in the figure below.

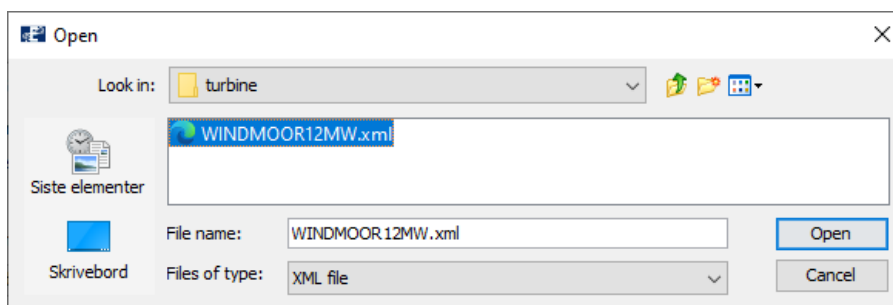
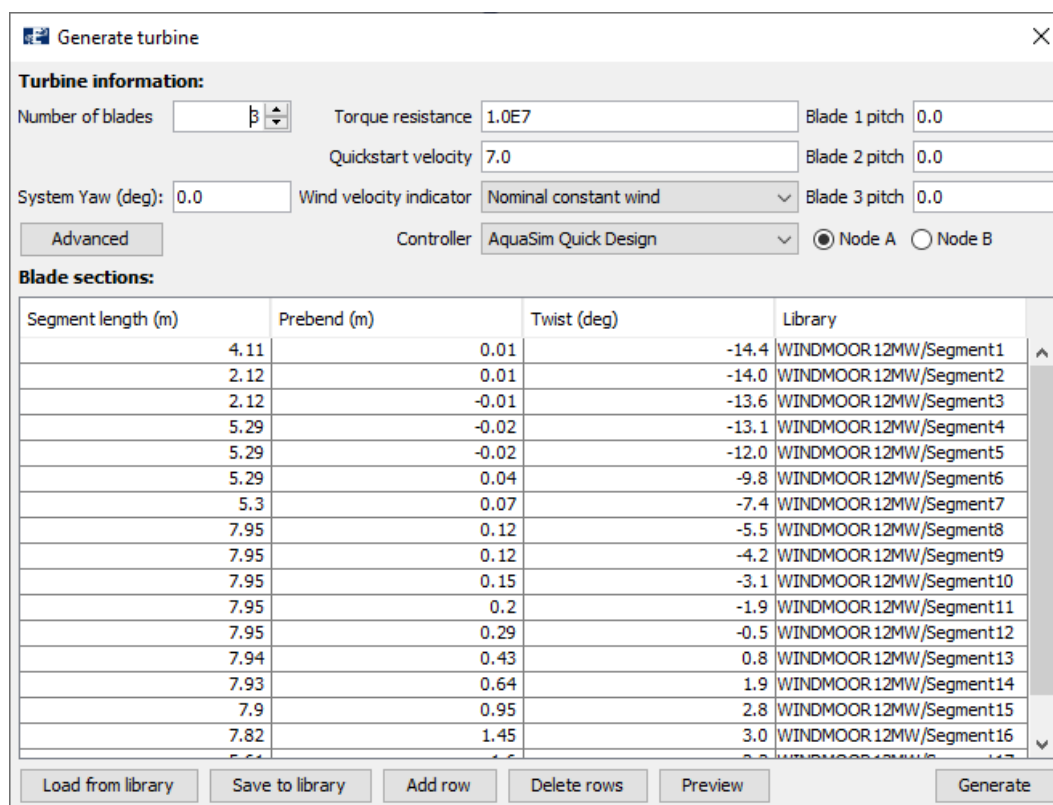


Figure 6

The turbine-folder contain the WINDMOOR12MW.xml turbine, which is included as an example when installing AquaSim. Select **Open** to load the file into AquaEdit. Then data will be loaded to the Generate turbine-tool, as shown below.



The image shows the 'Generate turbine' dialog box. It contains two main sections: 'Turbine information' and 'Blade sections'.

Turbine information:

- Number of blades: 3
- Torque resistance: 1.0E7
- Blade 1 pitch: 0.0
- Quickstart velocity: 7.0
- Blade 2 pitch: 0.0
- System Yaw (deg): 0.0
- Wind velocity indicator: Nominal constant wind
- Blade 3 pitch: 0.0
- Controller: AquaSim Quick Design
- Node A (selected) / Node B

Blade sections:

Segment length (m)	Prebend (m)	Twist (deg)	Library
4.11	0.01	-14.4	WINDMOOR12MW/Segment1
2.12	0.01	-14.0	WINDMOOR12MW/Segment2
2.12	-0.01	-13.6	WINDMOOR12MW/Segment3
5.29	-0.02	-13.1	WINDMOOR12MW/Segment4
5.29	-0.02	-12.0	WINDMOOR12MW/Segment5
5.29	0.04	-9.8	WINDMOOR12MW/Segment6
5.3	0.07	-7.4	WINDMOOR12MW/Segment7
7.95	0.12	-5.5	WINDMOOR12MW/Segment8
7.95	0.12	-4.2	WINDMOOR12MW/Segment9
7.95	0.15	-3.1	WINDMOOR12MW/Segment10
7.95	0.2	-1.9	WINDMOOR12MW/Segment11
7.95	0.29	-0.5	WINDMOOR12MW/Segment12
7.94	0.43	0.8	WINDMOOR12MW/Segment13
7.93	0.64	1.9	WINDMOOR12MW/Segment14
7.9	0.95	2.8	WINDMOOR12MW/Segment15
7.82	1.45	3.0	WINDMOOR12MW/Segment16

Buttons at the bottom: Load from library, Save to library, Add row, Delete rows, Preview, Generate.

Figure 7

Please note: the WINDMOOR12MW.xml-file from the turbine-folder, is a file that points to the beam library where you find a folder with the same name. This folder contains several xml-files which contain the cross-sectional properties of each blade segment and turbine nave. This you should have in mind when saving properties to library.

4.1.1 Generate turbine-tool

The different options from the top-lines in the Generate turbine-tool are:

- **Number of blades [-]:** the number of turbine blades that is distributed around the nave. Usually, three blades are applied.

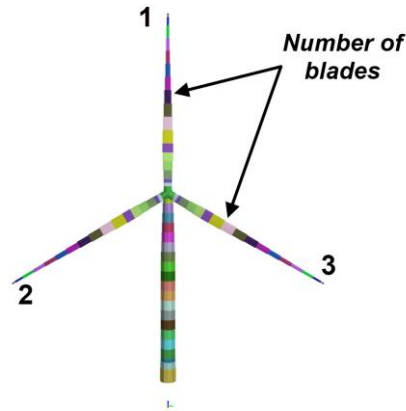


Figure 8

- **System Yaw [deg]:** orientation of the nave and system at the start of the analysis. 0 degrees means that the nave is pointing along the positive x-axis. 90 degrees mean the nave is pointing along the positive y-axis.

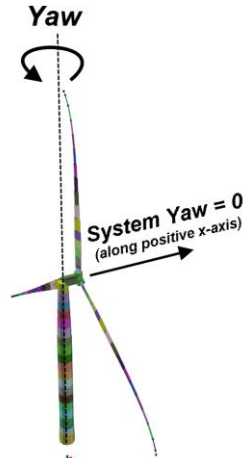


Figure 9

- **Torque resistance [Nm/(rad/s)]:** this is a resistance that is proportional with the rotational velocity of the nave. This parameter interacts with the controller.

- **Quick start velocity [RPM]:** velocity chosen for quick start in the analysis. When the dynamic part of the AquaSim analysis starts, the turbine blades will have this rotational velocity.

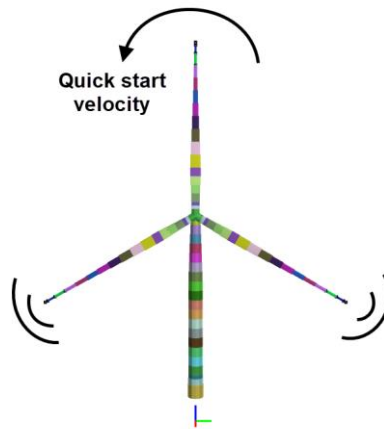


Figure 10

Leave this equal to + 7.0.

- **Wind velocity indicator [-]:**
 - Wind distribution: wind flow predicted by wind distribution (i.e. a wind profile).
 - Nominal constant wind: wind flow is flat (constant) fixed wind speed.

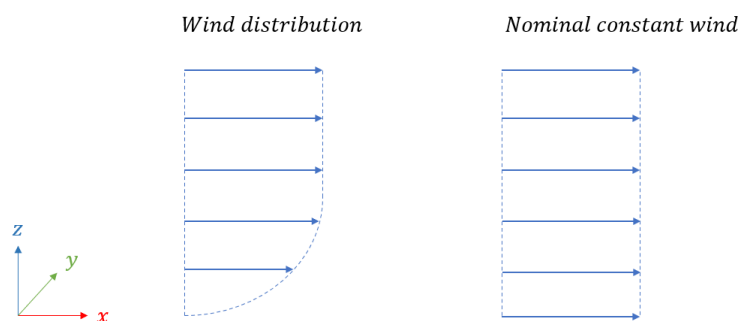


Figure 11

We choose to apply the **Nominal constant wind** in our case study.

- **Controller:** the type of controller that should be applied. The controller regulates the torque resistance, system yaw and blade pitch as the blades rotate. Three options are available:
 - AquaSim Quick Design
 - Internal
 - ROSCO (Python integration)

We choose to apply the **AquaSim Quick Design** in our case study.

- **Blade 1-3 pitch:** regulates the pitch of the blades.

Blade pitch

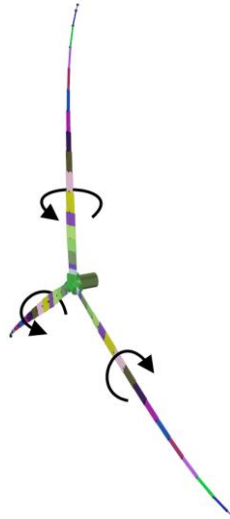


Figure 12

- **Node A / Node B:** which node on the *Tower* the turbine should be attached to. Node A is the first node that was defined when the *Tower*-element was drawn in the 3D window. Node B is then the second.

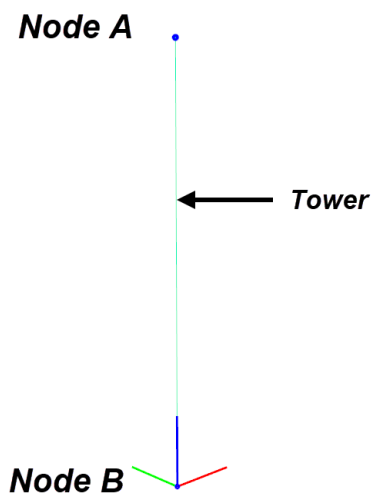


Figure 13

- **Advanced:** gives you access to advanced settings for the wind turbine. You can read more detailed information about this in the [AquaEdit User Manual \(link\)](#), or the report [TR-FOU-100004-5\(link\)](#).

Blade sections:

Segment length (m)	Prebend (m)	Twist (deg)	Library
4.11	0.01	-14.4	WINDMOOR 12MW/Segment1
2.12	0.01	-14.0	WINDMOOR 12MW/Segment2
2.12	-0.01	-13.6	WINDMOOR 12MW/Segment3

Figure 14

Each blade is divided into sections, and for each section the following information is given in **Blade sections**:

- **Segment length (m):** radial length of each blade segment, in meters.

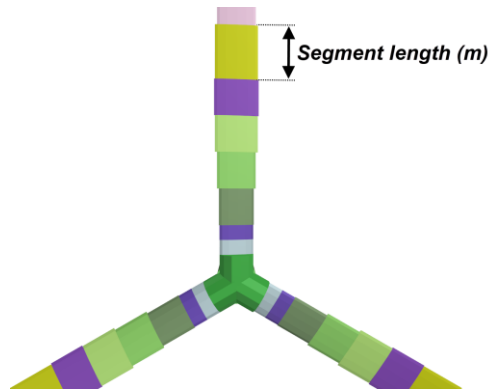


Figure 15

- **Prebend (m):** how much the element is directed towards the wind (if positive values) over the element length. That is, how much more upwards to the wind the outer node of the segment is relative to the inner node.

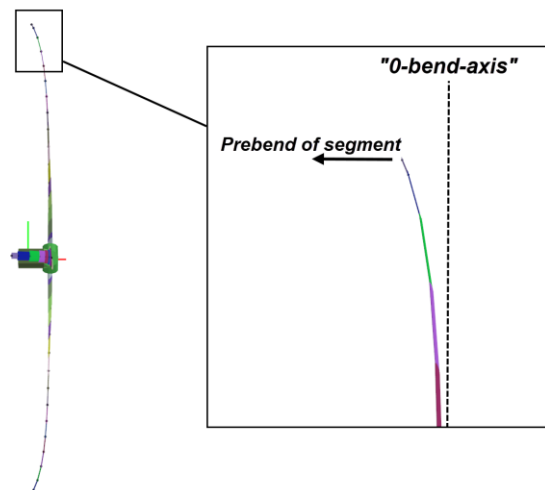


Figure 16

- **Twist (deg):** twist of each segment. This can be viewed as local pitch of each segment in the blade.

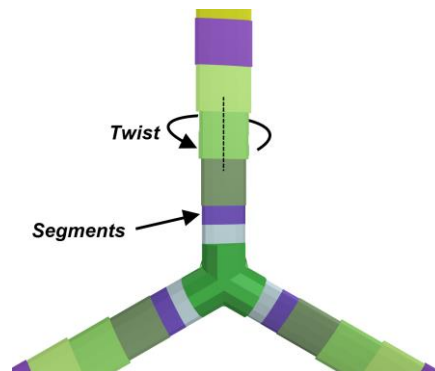


Figure 17

- **Library:** the path to where the cross-section properties to each segment is located. This coded to point to *AquaSim\Library\beam*-folder.

The lower part of the window gives you the options to **load a turbine from the library** or **save to the library**. The **Add row** and **Delete rows** regulates the number of rows in the Blade sections-part of this window. Selecting **Preview** gives you the option of seeing the turbine without generating it. This is useful in cases where you want to check certain parameters in this window. **Generate**, generates the turbine. Elements and components needed for the turbine will be generated in AquaEdit.

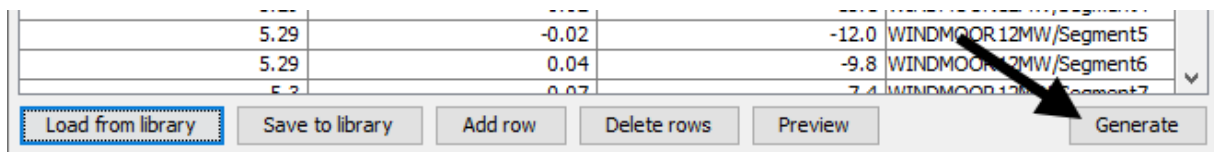


Figure 18

Let us generate this turbine by **selecting Generate**.

4.1.2 Turbine components

Your model should now resemble the figure below, where you have a full turbine with shaft, nave and turbine blades.

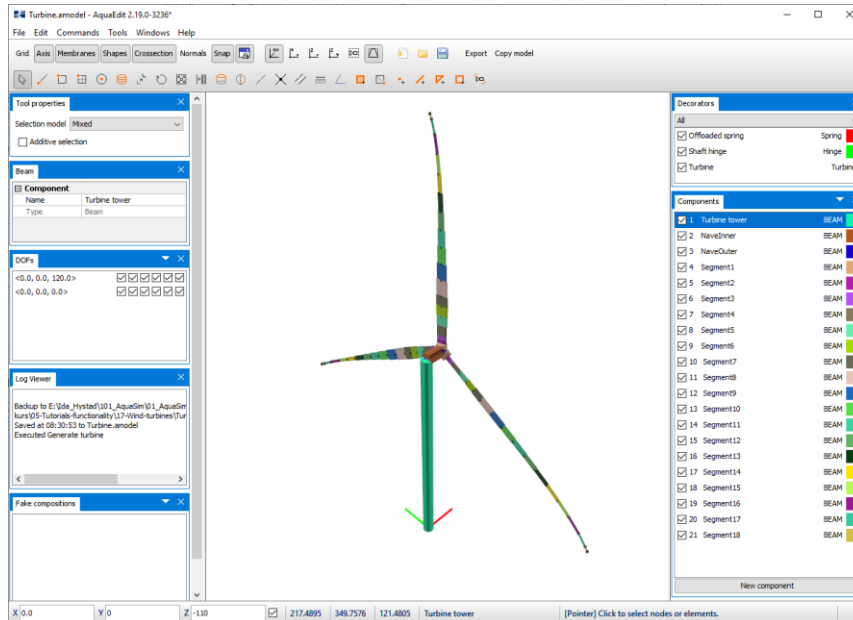


Figure 19

For the WINDMOOR12MW, a total of 18 blade *Segments* are generated. They are automatically modelled as Beam components and are found in the Components- window. The nave is connecting the *Tower* to the turbine blades. Node decorators representing the generator, and more is also added.

4.1.3 Blade segments

Double click on one of the segments from the Components-window to view its properties. We have selected *Segment3*.

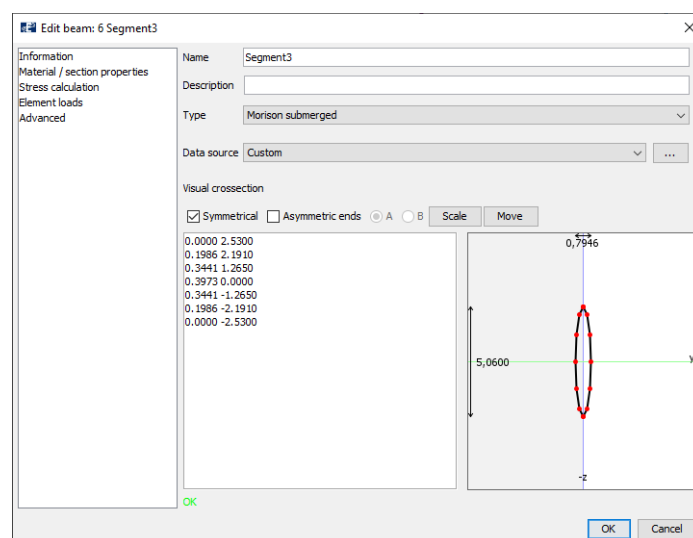


Figure 20

The cross section of the blade is presented in the Information-tab. As default, the beam type is Morison submerged. Meaning forces are calculated based on Morison equation.

Select **Advanced** to view tables for drag, lift, and yaw for the individual cross-section.

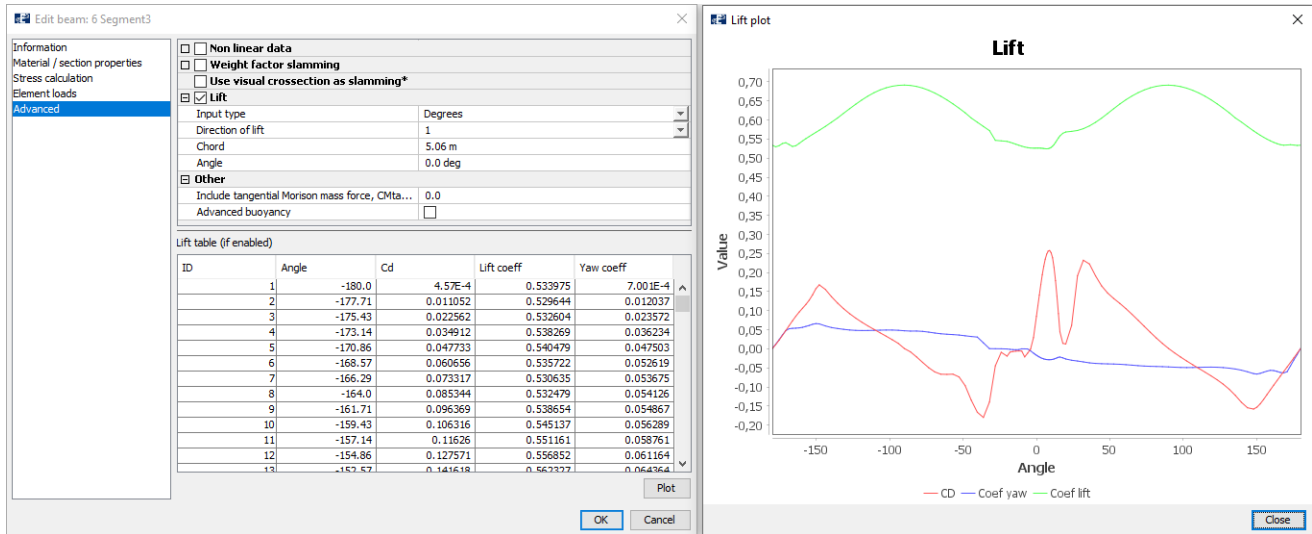


Figure 21

The drag and lift are given as a function of the inflow angle. And by selecting Plot, you may see how the drag coefficient (**CD**), yaw coefficient (**Coef yaw**) and lift coefficient (**Coef lift**) is distributed around the blade cross section from -180 degrees to +180 degrees. To exit these windows, select **Close** on the Plot and **Cancel** in the Edit beam-window.

4.1.4 Nave and node decorators

The turbine nave is divided into two sections:

- **NaveInner**: a static beam element that connects the Tower to the generator (Shaft hinge).
- **NaveOuter**: a rotating beam element that connects the blades to the generator.

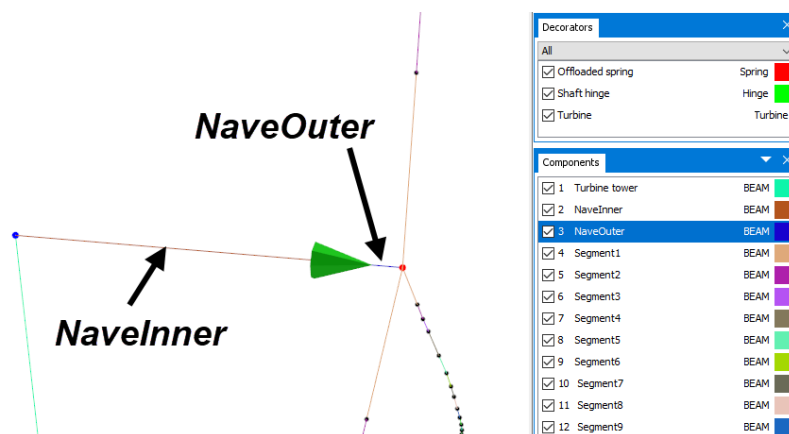


Figure 22

Further, we have three node decorators that are generated. These are:

- **Offloaded spring**
- **Shaft hinge**
- **Turbine**

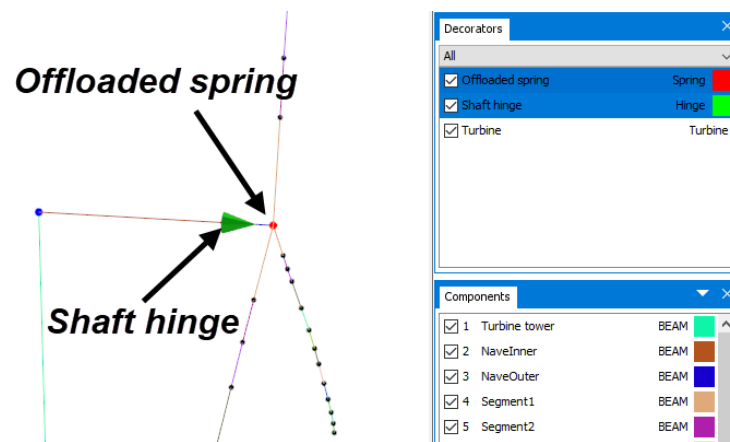


Figure 23

4.1.5 Offloaded spring

Double click on *Offloaded spring* from the Decorators-window to view the properties. This is a spring that is applied to stabilize the turbine blades in the initial static part of the analysis, prior to the dynamic analysis.

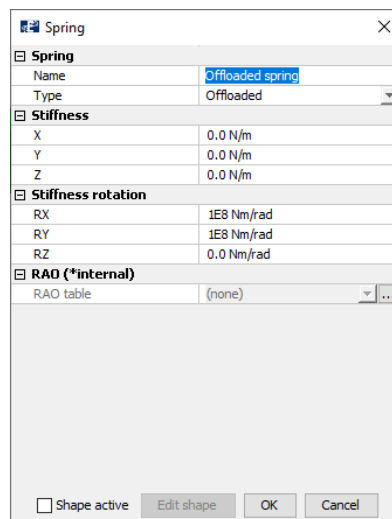


Figure 24

The spring works according to the global coordinate system, and rotational stiffness is given for both x- and y-direction. An offloaded spring has constant spring stiffness in the initial static part of the analysis and is offloaded when the dynamic part starts.

4.1.6 Shaft hinge

Shaft hinge is the generator. In AquaSim this is modelled as a hinge that is free to rotate about the axis that goes through the nave. Rotational damping is added to the hinge, which should be interpreted as the torque resistance. **Double click** on *Shaft hinge* from the Decorators-window to view the generator properties.

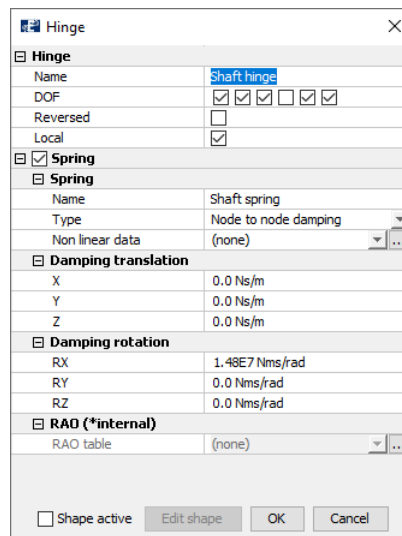


Figure 25

The generator has been given the **name** *Shaft hinge*. The section **DOF** indicates which degrees of freedom that should be restrained; selecting a checkbox means that the DOF is restrained. The three first checkboxes are translations along x-, y- and z-direction respectively. The three last checkboxes are rotations about the same axes. **Local** indicated whether DOF-restrictions should be related to the global coordinate system of the model, or the element's local coordinate system. When this checkbox is selected, it means that the references are with respect to the element's local coordinate system. This is indicated in the figure below.

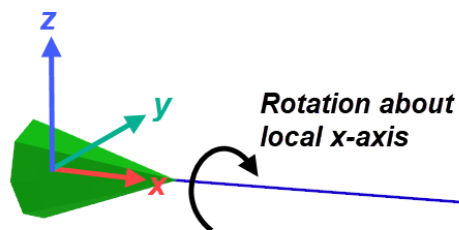


Figure 26

Rotational damping about this x-axis, **RX**, is added in the section **Damping rotations**. Select OK or Cancel to exit the Shaft hinge window.

4.1.7 Turbine

By double click on this you re-enter the **Generate turbine**-tool window.

4.2 Analysis

When conducting coupled analyses in AquaSim, one can find response and forces from combined effects such as:

- Environmental loads such as wind, waves and current.
- Loads from mooring systems.
- Loads from motions of the whole system.

From this, the coupled response is included from all load-contributions that will be present on a wind turbine that could be situated on land, offshore with fixed foundation or floating with a mooring system.

In this case study we will run an analysis to demonstrate the results options available for turbines in AquaView.

Select the Export-option from the top menu in AquaEdit to enter the window for inserting load conditions and to specify analysis settings.

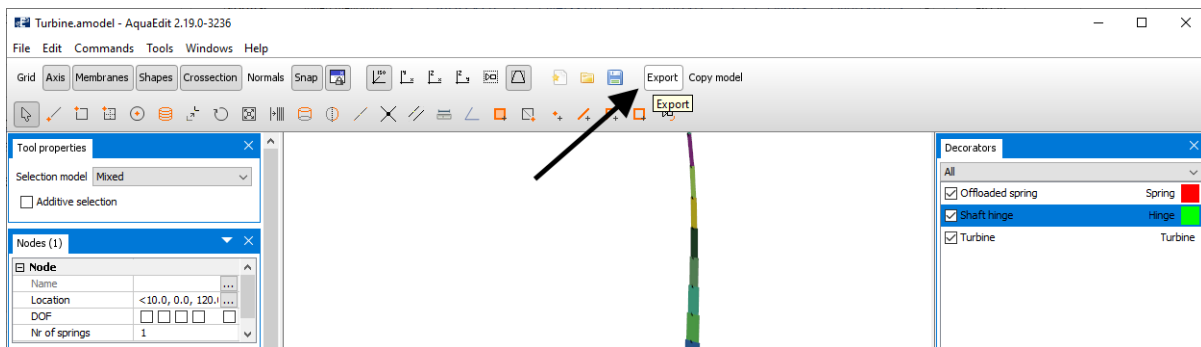


Figure 27

Select the tab named **Normal** and apply regular constant wind of 8 m/s along x-direction. Set **Num steps for waves** equal to **400**. Having **20 steps for one wave**, this will result in an analysis of 20 seconds. This should be sufficient in to see the blades rotate about 1.5 times about the nave.

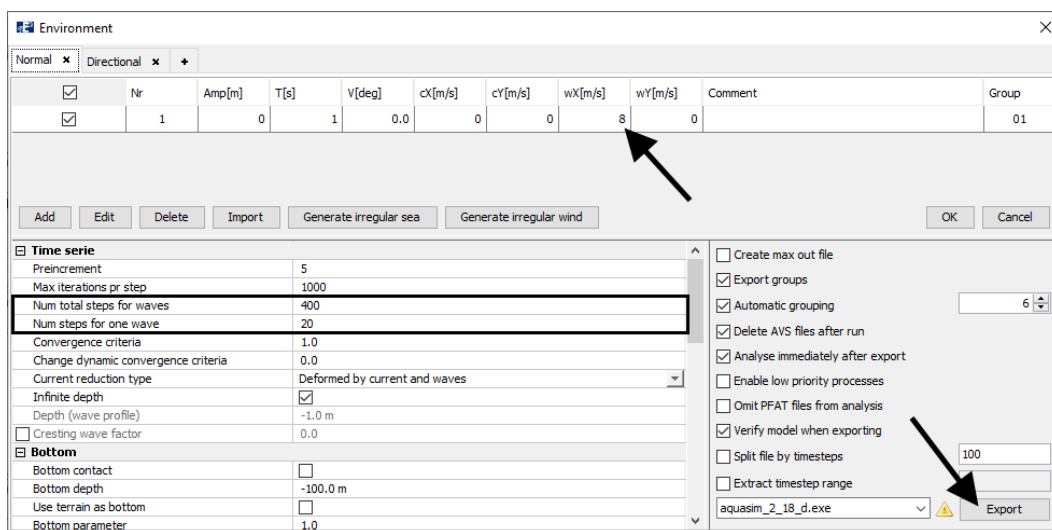


Figure 28

Select **Export** to export your model. Save the analysis an appropriate place on your computer. We named the analysis *turbine_*.

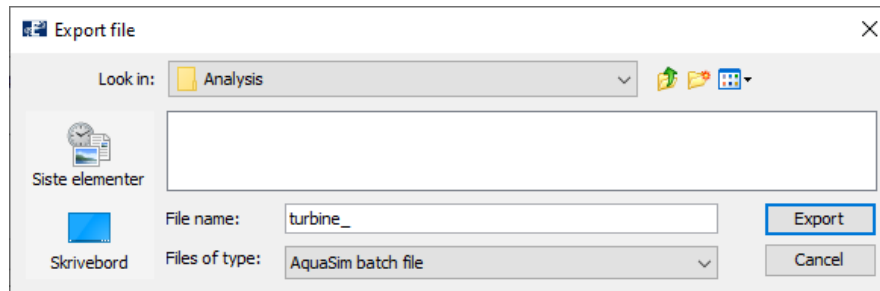


Figure 29

4.3 Post-processing (AquaView)

Once the analysis is finished you can load the avz-result file in AquaView. If you have not completed your own analysis, you may open the *turbine_01.avz* associated with this tutorial.

Results specially adapted to wind turbines are found from the top menu bar **Result** > **Turbine environment** and **Turbine results**.

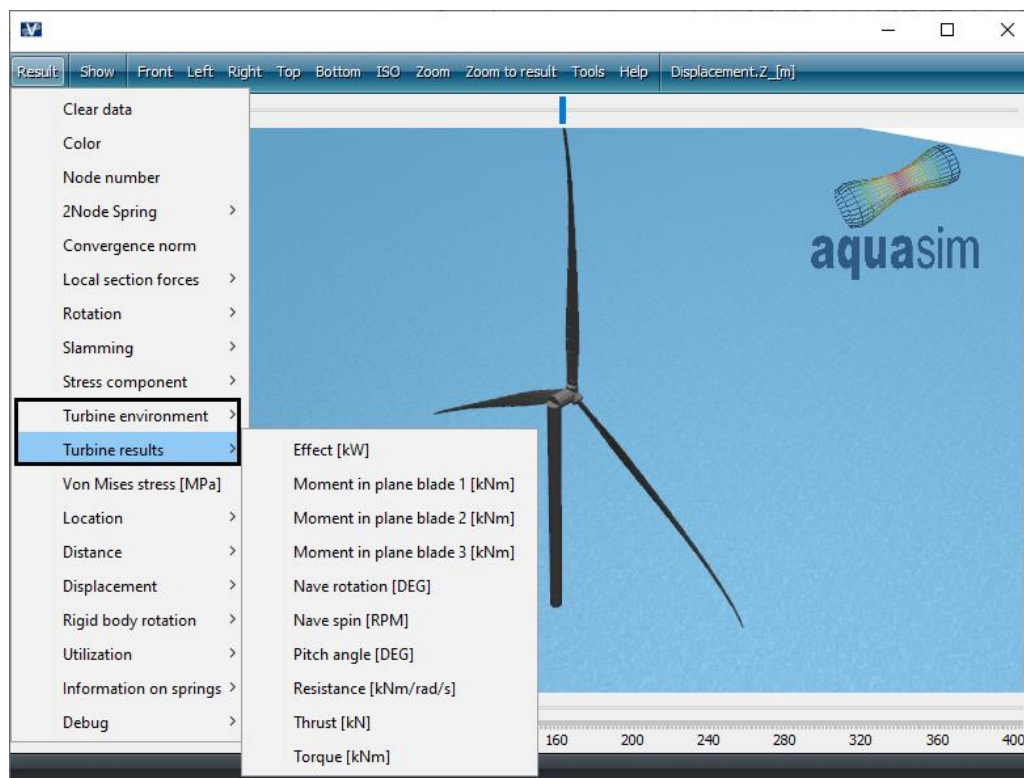


Figure 30

We should investigate some of the result options found under Turbine results. Let us start with **Nave spin [RMP]**, this is the calculated velocity of the turbine blades. **Right-click** on one of the segments in the turbine blade to view the velocity as a function of analysis-steps.

During the analysis, the nave spin stabilize around 6.65 RPM, as seen in the figure below.

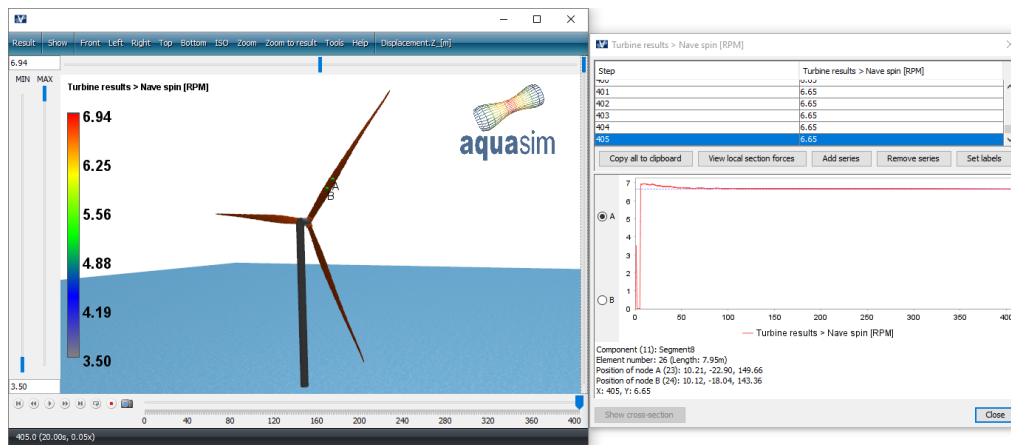


Figure 31

Another parameter that is interesting is the calculated torque. This is found from **Result > Turbine results > Torque [kNm]**.

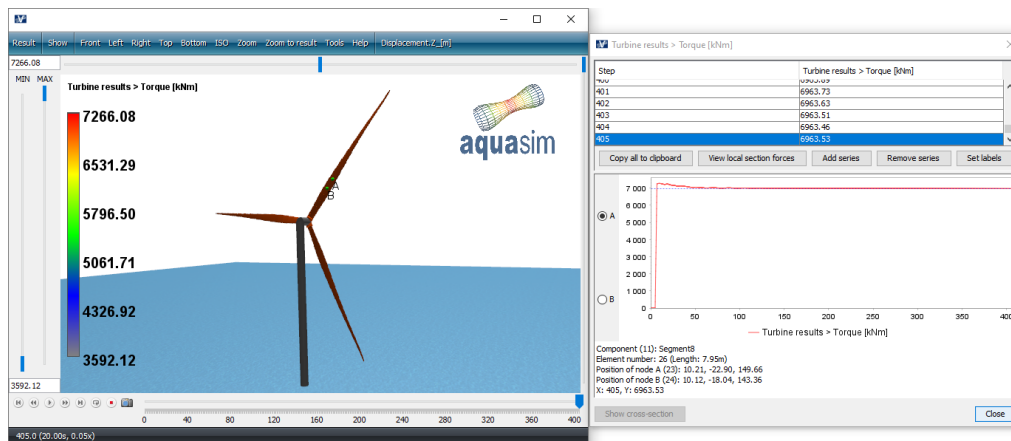


Figure 32

The torque shows the same trend as the velocity, it stabilizes around a certain level. In our analysis set-up we chose a wind velocity profile that was 'flat' and constant both in time and in space. So, the trend in the result plots correspond well with this.

Thrust is the axial force applied from the wind on the blades.

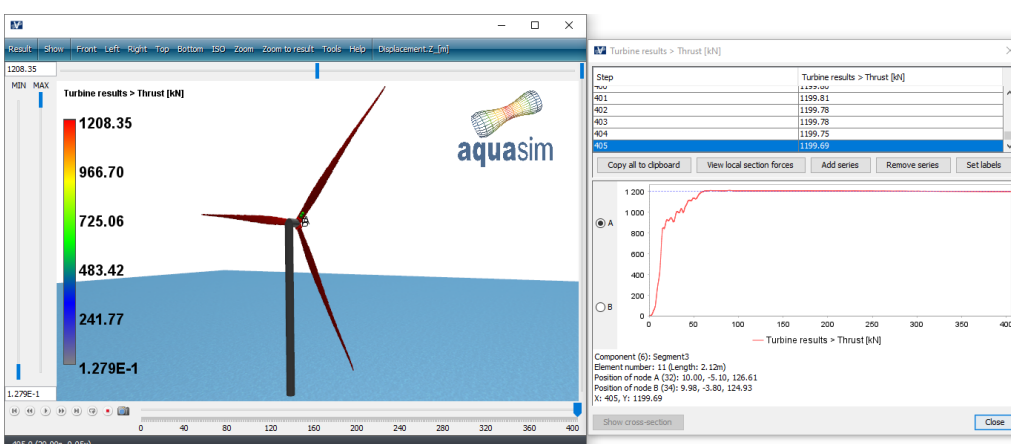


Figure 33

Options found under Turbine environment are useful to check when validating your model and input-parameters. Details of these are found in the AquaView User Manual.

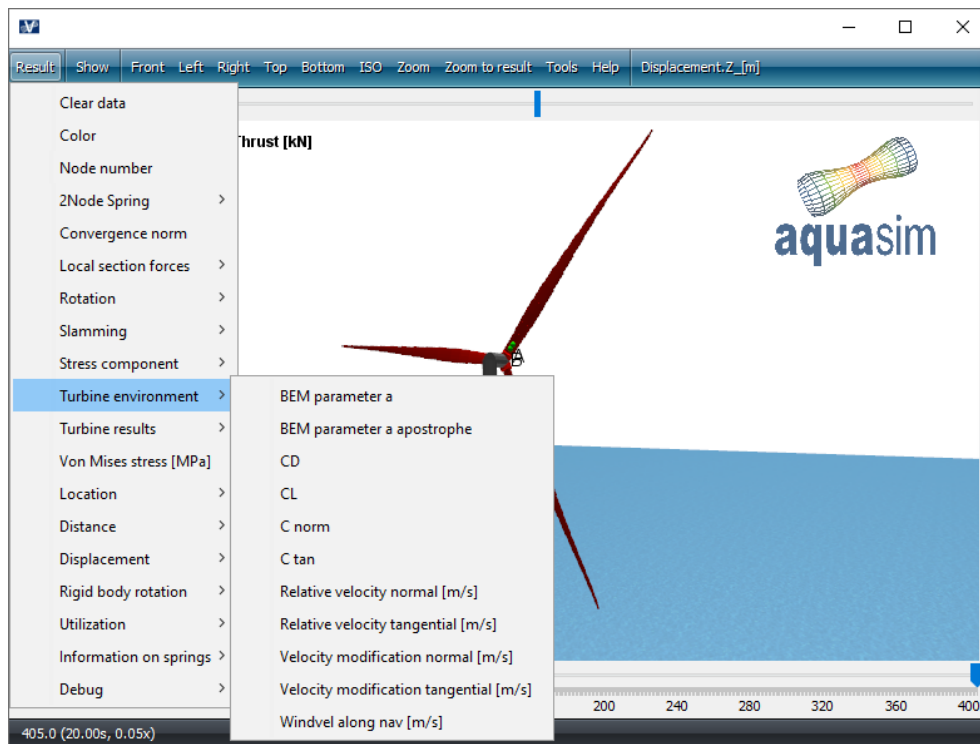


Figure 34

5 Case study – Save turbine to library

In this section, some routines for saving to library is presented. In order to create a turbine in AquaSim from the Generate turbine-tool, you will need three sets of xml-files describing the following:

- Blade segment cross-section properties (E-modulus, area, weight, drag, lift etc.),
- Blade sections (segment length, prebend, twist),
- Nave- Inner- and Outer (E-modulus, area, weight, drag).

5.1 Save segment cross-section properties to library

Saving to library is quite simple in AquaEdit. We start with the model from the previous case study.

Navigate to the **Components**-window and **left-click** on one of the segments. In the figure below, we have chosen *Segment 6*. Then **right-click** and select **Library**.

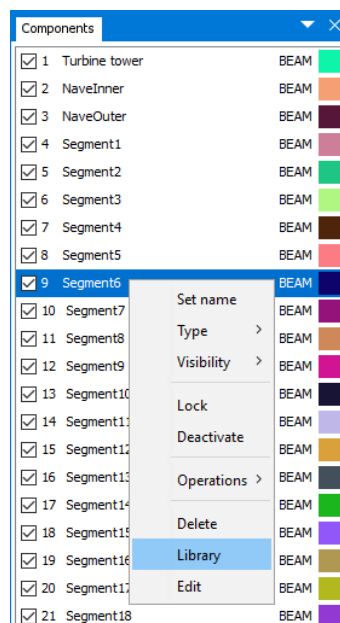


Figure 35

In order to use these cross-sectional data on turbines on a later occasion, they must be stored in the folder *AquaSim\Library\beam*. In this case, the sub-folder *WINDEXAMPLE* has been established in advance, see the figure below.

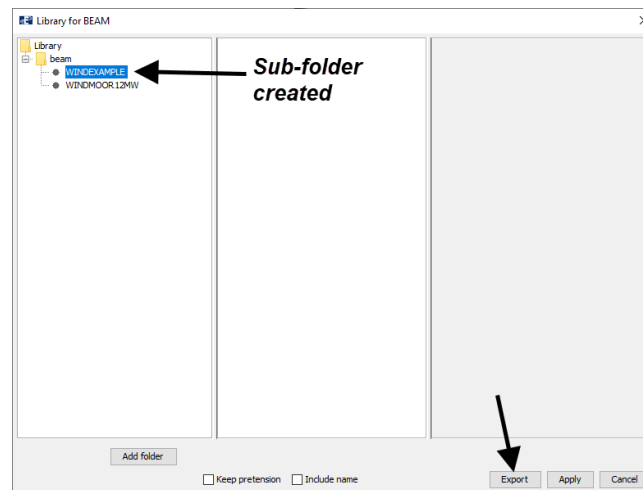


Figure 36

To be able to store *Segment 6* within the *WINDEXAMPLE*-folder, select this and then press **Export** in the lower right corner. You can then give the beam a new name or keep what is suggested. Default is that AquaEdit suggest the same as the component name. We accept this and select **OK**.

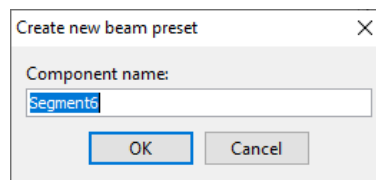


Figure 37

The Edit beam-window will automatically be opened, allowing you to adjust or change input before saving to the library. We do not want to change anything, hence select **OK**.

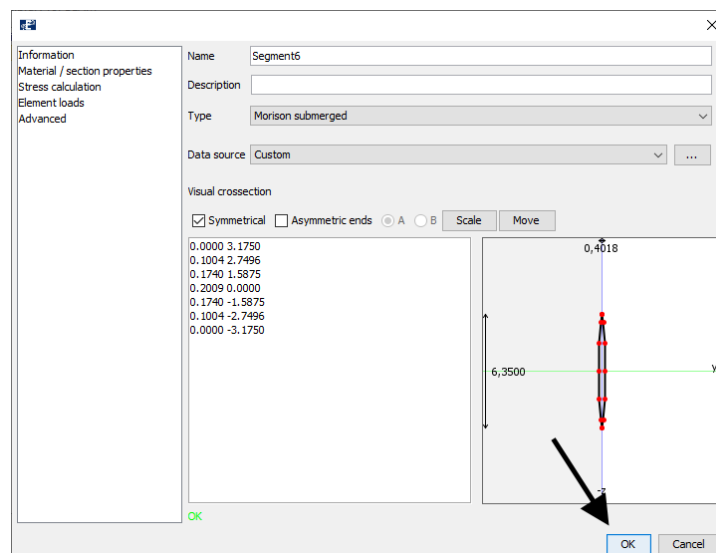


Figure 38

You are asked if you want to save the change, select **Yes** to this. *Segment 6* is successfully stored to the library and will be visible from the middle section.

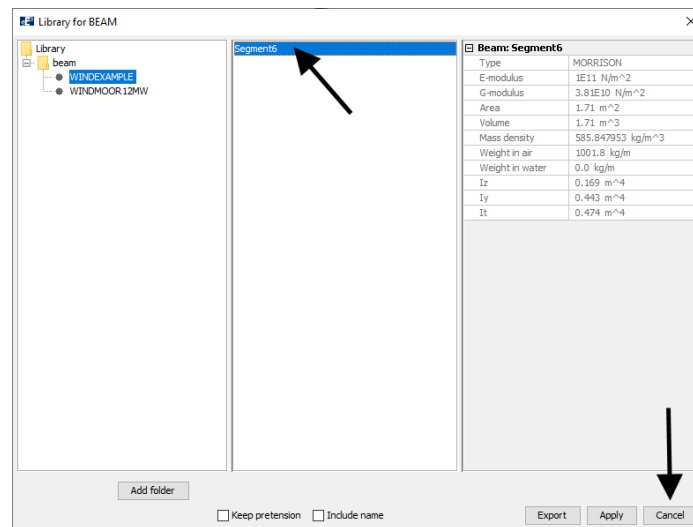


Figure 39

The cross-sectional properties are now stored as an xml-file in the following folder *AquaSim\Library\beam\WINDEXAMPLE*. Remember this for the next sections, where we are going to save both blade section and nave cross-sectional properties.

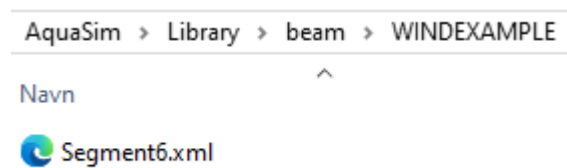


Figure 40

Saving of segment cross-sectional properties are now finished. You may exit the **Library for BEAM**-window by selecting **Cancel**.

5.2 Save nave to library

As per AquaSim version 2.19.0, there must exist xml-files describing the components *NaveInner* and *NaveOuter* in order to generate a wind turbine from a library. The nave can be saved in two ways:

1. If you do not have any established components for *NaveInner* or *NaveOuter* you may copy the xml-files from *AquaSim\Library\beam\WINDMOOR12MW* to *WINDEXAMPLE*.

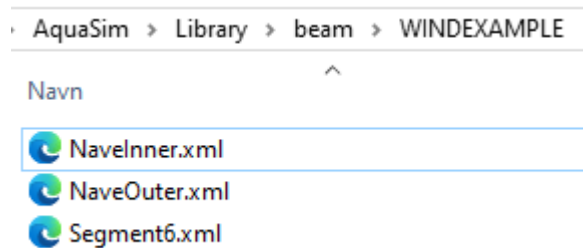


Figure 41

2. If you have established components for *NaveInner* and *NaveOuter* in AquaEdit, you may follow the same procedure as described in the previous section Save segment cross-section properties to library. The xml-files should be stored in the *WINDEXAMPLE*-folder.

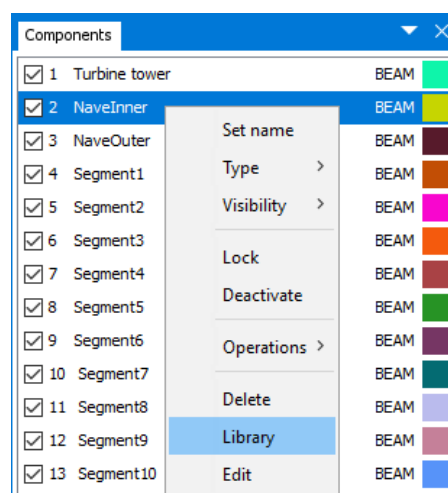
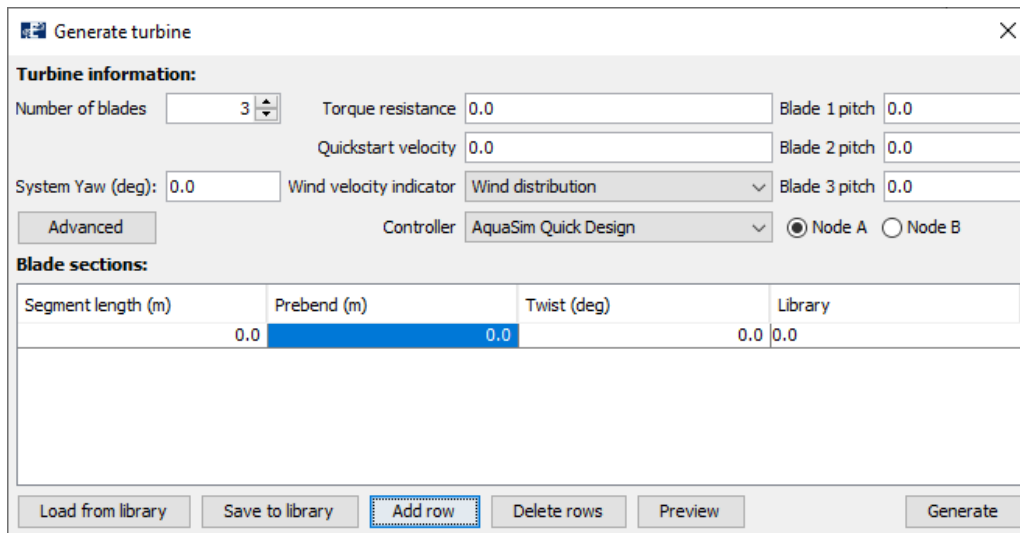


Figure 42

5.3 Save blade sections to library

Blade sections defined in the Generate turbine-tool may also be saved to library. Open AquaEdit and draw vertical beam element in the 3D window. **Right click** the element select **Elements > Other > Create turbine on element**. Then select **Add row**, as shown in the figure below.



Generate turbine

Turbine information:

Number of blades: 3 Torque resistance: 0.0 Blade 1 pitch: 0.0

Quickstart velocity: 0.0 Blade 2 pitch: 0.0

System Yaw (deg): 0.0 Wind velocity indicator: Wind distribution Blade 3 pitch: 0.0

Advanced Controller: AquaSim Quick Design ☒ Node A ☐ Node B

Blade sections:

Segment length (m)	Prebend (m)	Twist (deg)	Library
0.0	0.0	0.0	0.0

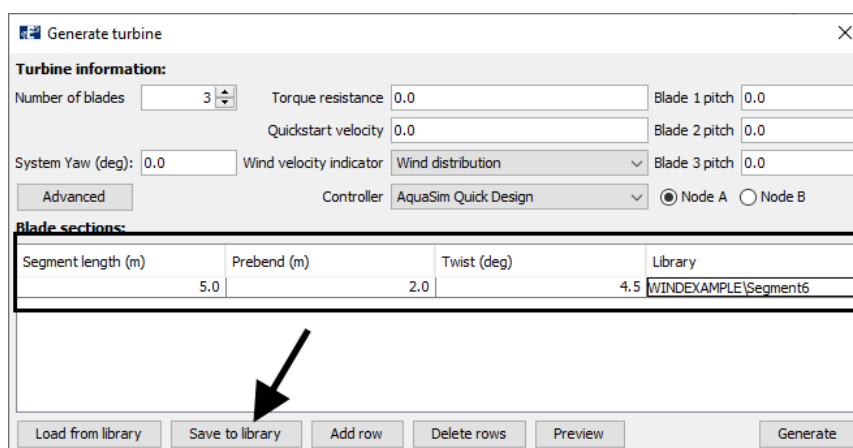
Load from library Save to library **Add row** Delete rows Preview Generate

Figure 43

Let us say you have data for **Segment length**, **Prebend** and **Twist** for *Segment6* that you saved earlier. Type in the data as given in the table below.

Segment length (m)	Prebend (m)	Twist (deg)
5	2	1.5

Remember that we earlier in this tutorial said that the **Library**-column is coded to point to the folder *AquaSim\Library\beam*. We have saved the cross-sectional data for *Segment6* in *WINDEXAMPLE*. Therefore, in the Library column, you should type *WINDEXAMPLE\Segment6*.



Generate turbine

Turbine information:

Number of blades: 3 Torque resistance: 0.0 Blade 1 pitch: 0.0

Quickstart velocity: 0.0 Blade 2 pitch: 0.0

System Yaw (deg): 0.0 Wind velocity indicator: Wind distribution Blade 3 pitch: 0.0

Advanced Controller: AquaSim Quick Design ☒ Node A ☐ Node B

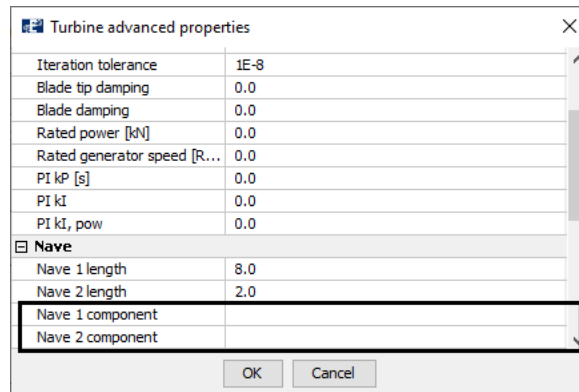
Blade sections:

Segment length (m)	Prebend (m)	Twist (deg)	Library
5.0	2.0	4.5	WINDEXAMPLE\Segment6

Load from library **Save to library** Add row Delete rows Preview Generate

Figure 44

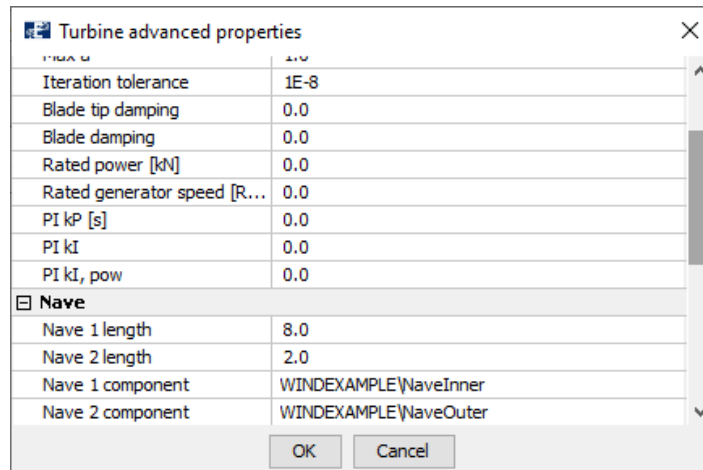
To make the turbine model complete, you must also include the path for *NaveInner* and *NaveOuter*. Select the **Advanced**-option and navigate down to the **Nave**-section.



Turbine advanced properties	
Iteration tolerance	1E-8
Blade tip damping	0.0
Blade damping	0.0
Rated power [kN]	0.0
Rated generator speed [R...	0.0
PI kP [s]	0.0
PI kI	0.0
PI kI, pow	0.0
Nave	
Nave 1 length	8.0
Nave 2 length	2.0
Nave 1 component	
Nave 2 component	

Figure 45

In the section, **Nave 1 component** will correspond to *NaveInner* and **Nave 2 component** is the *NaveOuter*. In the empty sections, the path to where the xml-files for the naves should be entered. As for Library, this part is coded to point to the folder *AquaSim\Library\beam*. We should then type what is shown in the figure below.



Turbine advanced properties	
Iteration tolerance	1E-8
Blade tip damping	0.0
Blade damping	0.0
Rated power [kN]	0.0
Rated generator speed [R...	0.0
PI kP [s]	0.0
PI kI	0.0
PI kI, pow	0.0
Nave	
Nave 1 length	8.0
Nave 2 length	2.0
Nave 1 component	WINDEXAMPLE\NaveInner
Nave 2 component	WINDEXAMPLE\NaveOuter

Figure 46

In the **Advanced**-window, select **OK**.

5.4 Save turbine to library

The information can now be saved to library. In the Generate turbine-tool window select Save to library. This will automatically point to the folder *AquaSim\Library\Turbine*. Type an appropriate name, we chose *WINDEXAMPLE*.

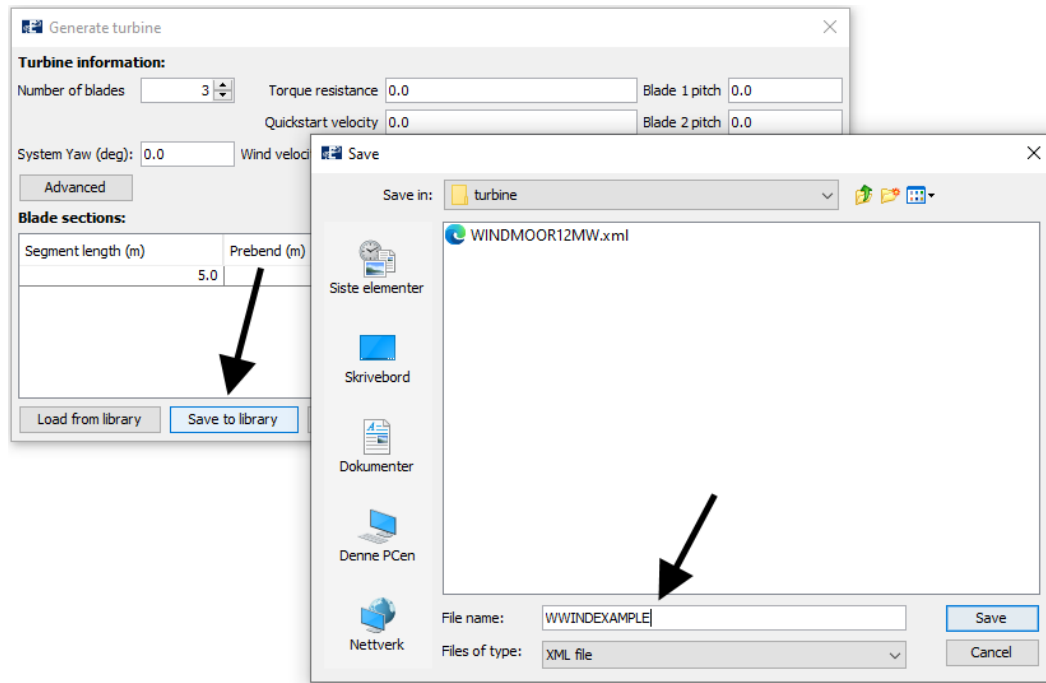


Figure 47

Now, this turbine is complete and *WINDEXAMPLE* can be implemented to a new model by following the procedures described in the first case study.

6 Revision comments

Revision no.	Comment
1.0	First publication

--- End of document ---