Wind Turbine Analysis Application Manual

Introduction

This application is used to analyze the mechanical forces on shafts of a wind turbine. Required inputs include wind turbine geometries, design specifications, material properties, wind force histories, and external surrounding properties. With these inputs, 'turbine_analysis.py' solves for safety factors against yielding and fatigue, maximum angles of twist, and maximum service life. By comparing these values with the given design specifications, the application is able to determine whether or not sections of the wind turbine's shafts will fail—these shaft details are displayed on plots. The user is able to alter inputs (shaft section geometries, material properties, wind force history, and external properties) and observe corresponding changes in design values.

Wind Turbine Details

The wind turbine consists of a main shaft and a crankshaft interacting with each other via a geared connection. **Figure 1** depicts the system and highlights the locations of connections to the turbine casing, thrust block, walls, and between shaft gears.

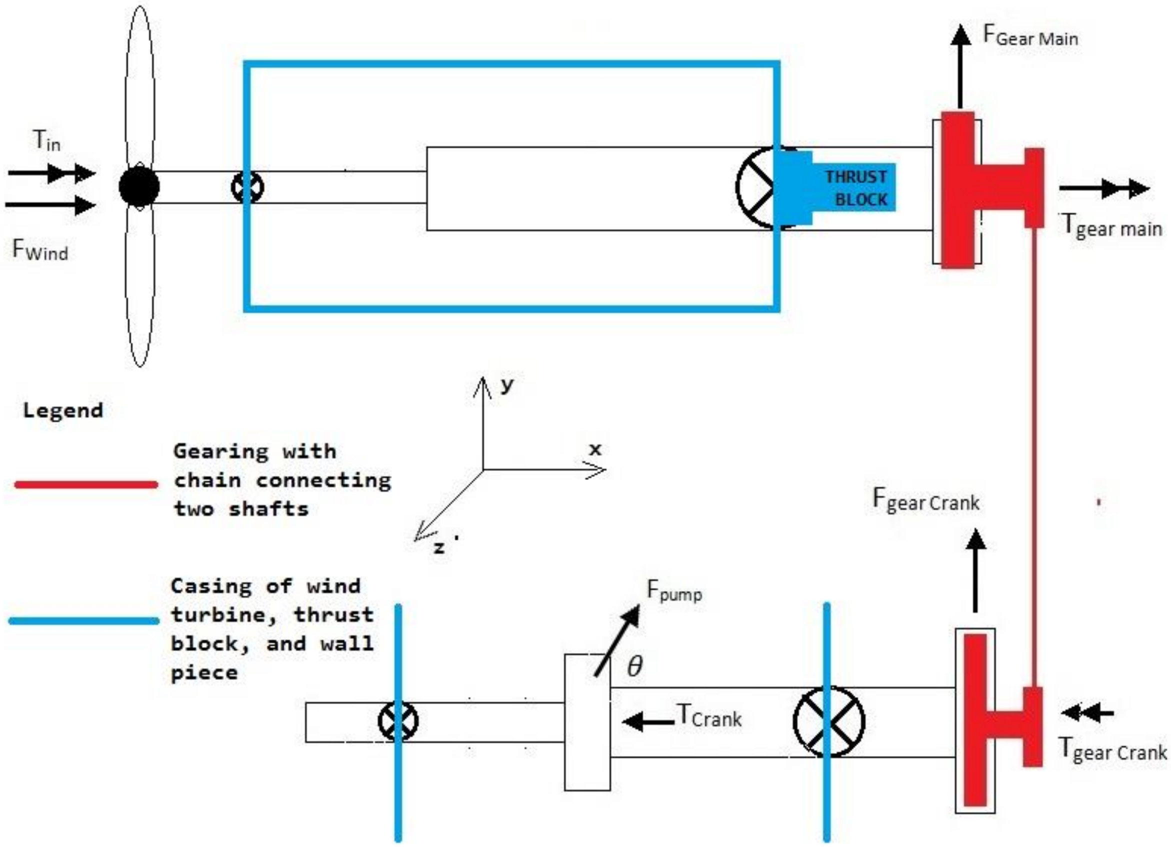

Figure 1. The wind turbine system as a whole. Wind blowing against the propeller turns the main shaft and, via a geared connection, turns the crankshaft. The rotation of the crankshaft powers an external pump or generator. The housing of the shafts, shown in blue, create reaction forces at the locations marked by an X enclosed in a circle.

Wind blowing against the turbine's propeller creates a force, F_{wind}. The resulting rotation of the propeller creates a torque, T_{in}, which is transferred across the main shaft to the gear at the right end as $T_{gear\ main}$. A gear chain links the gear of the main shaft to the crankshaft (**Figure 2**). The torque is then converted to $T_{gear\ crank}$, whose magnitude depends on the ratio of the gear radii, R_2/R_1, between the main shaft and crankshaft. Because the gear chain connection is directly to the sides (z-direction) of the shafts, a vertical (y-direction) force is created. These are depicted by $F_{gear\ main}$ and $F_{gear\ crank}$. $T_{gear\ crank}$ transfers across the crankshaft to T_{crank}, the torque applied to the gear which powers a water pump or generator.

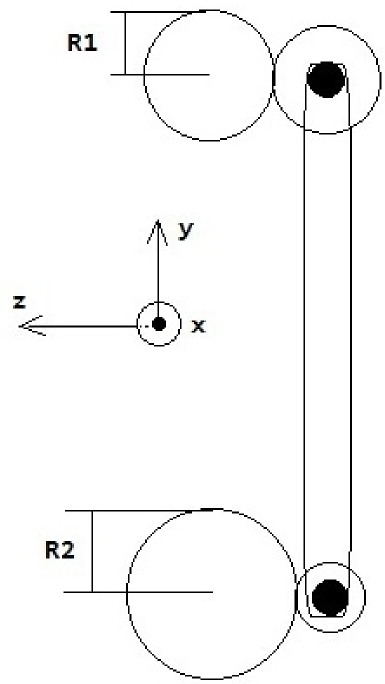

Figure 2. The back view of the wind turbine showing the geared connection between the main shaft at the top and the crankshaft at the bottom.

The housings of the main shaft and crankshaft are connected to the shafts at locations marked by an enclosed X. These connections create reaction forces on the shafts, R_{1y}, R_{1z}, R_{2y}, etc. These reaction forces are shown in **Figures 3 & 4**. Also shown are sections and their lengths and diameters.

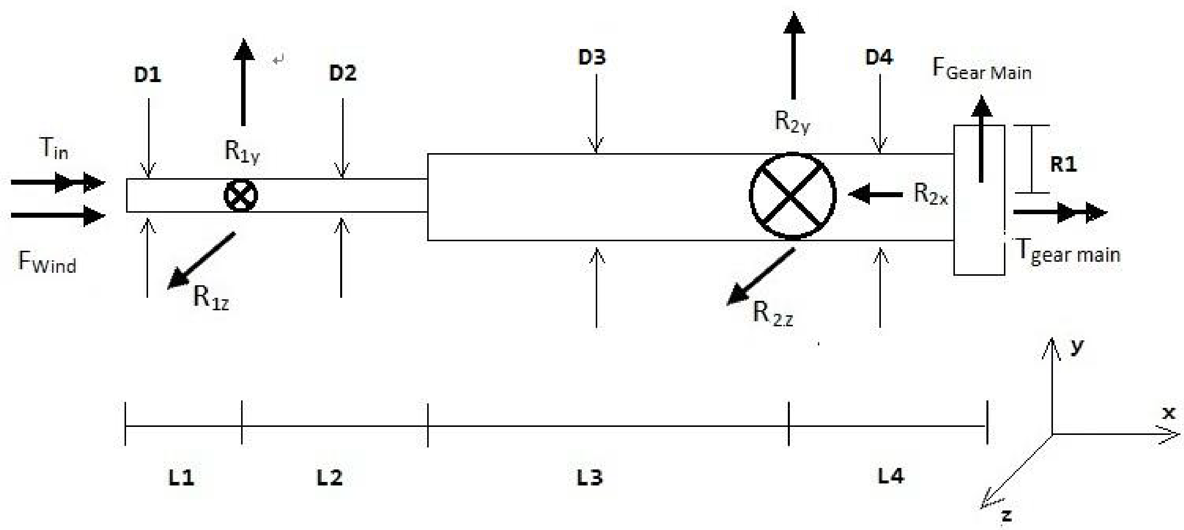

Figure 3. The main shaft and the forces acting on it. The four sections shown each have their own diameter and length.

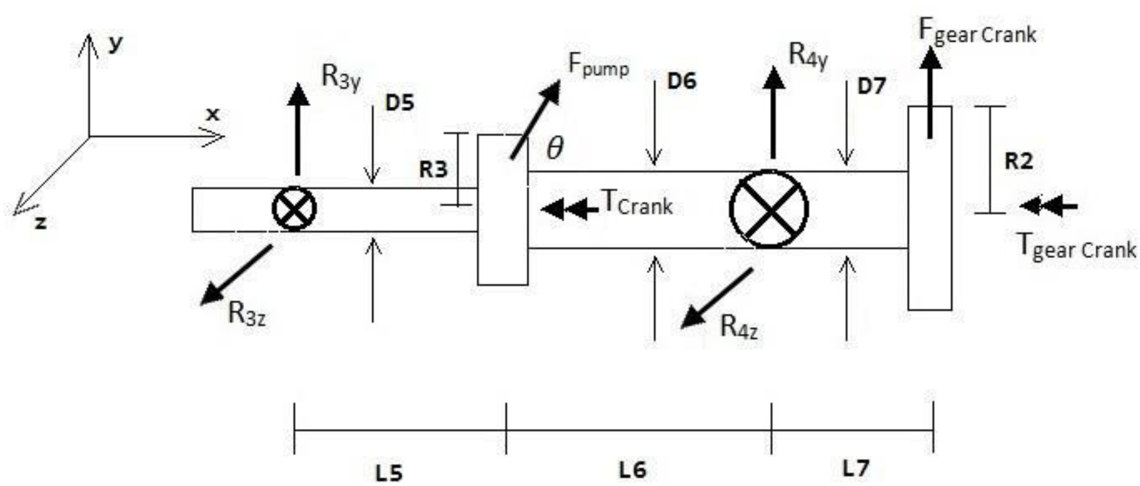

Figure 4. The crankshaft and the forces acting on it. Unlike the main shaft, which has 4 sections, the crankshaft is separated into 3 sections.

The crankshaft provides power to a pump/generator. The crank—the arm connecting the crankshaft to the pump—is shown in **Figure 5**. The force F_{pump} acts on the crankshaft at angle θ relative to a horizontal axis passing through the center of the crankshaft. The crankshaft itself rotates at an angular velocity, ω. The radius of the gear connecting the crank to the crankshaft has a radius, R_3, that determines the magnitude of F_{pump}.

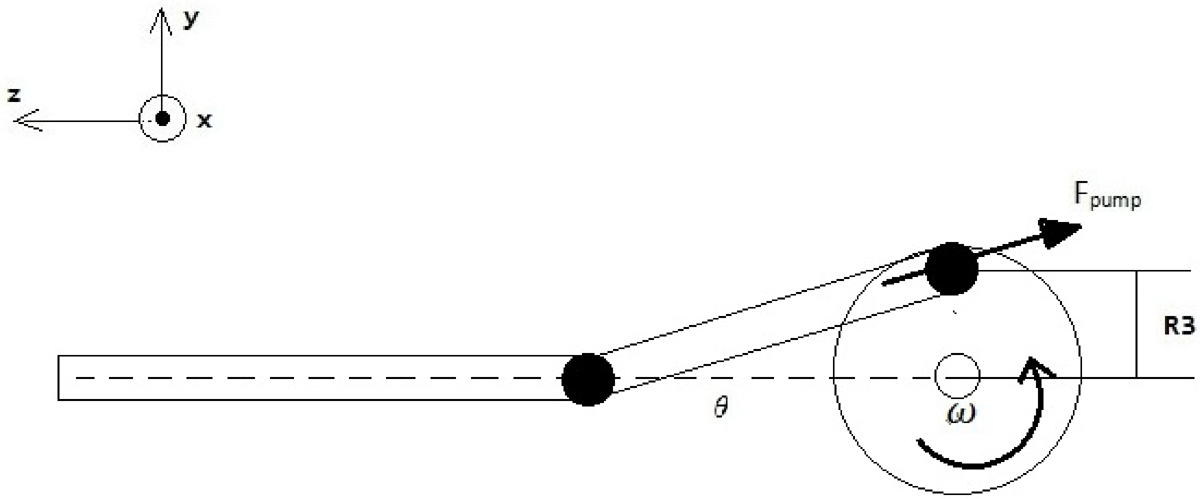

Figure 5. The crank arm as seen looking down the axis of the crankshaft. The crank itself is connected to a gear, with radius R_3, on the crankshaft. The rotation of the crankshaft is converted to a linear back-and-forth motion which can power a pump or generator.

Required Inputs

This program requires the input of 4 text files: Design, Material Properties, Load Factors, and Wind History. Each of these files are described below along with required formats and definitions of variables used.

- **Design** - a file of shaft geometries and design constraints.

Format

$L_1 \quad L_2 \quad L_3 \quad L_4 \quad L_5 \quad L_6 \quad L_7$

$D_1 \quad D_2 \quad D_3 \quad D_4 \quad D_5 \quad D_6 \quad D_7$

$X_o \quad X_s \quad life \quad \phi_{max} \quad R_1 \quad R_2 \quad R_3$

Variable Definitions

L_1	length of shaft section 1 (m).
D_1	diameter of shaft section 1 (m)
R_1	radius of gear 1 (m)
X_o	required safety factor against yielding
X_s	required safety factor against fatigue
$life$	desired service life (days)
ϕ_{max}	maximum allowable angle of twist (radians)

- **Material Properties** - a file of a material's properties.

  Format

  $\rho \quad E \quad \nu \quad \sigma_{max} \quad c_B \quad e_B$

  Variable Definitions

ρ	mass density (kg/m^3)
E	Young's modulus (MPa)
ν	Poisson's ratio
σ_{max}	yield strength (MPa)
c_B	Basquin coefficient (MPa)
e_B	Basquin exponent

- **Load Factors** - a file containing values to describe and calculate wind turbine efficiency.

  Format

  $\lambda \quad \rho_{air} \quad C_p \quad \theta$

  Variable Definitions

λ	ratio of propeller tip speed (m/s) to wind speed (m/s)
ρ_{air}	density of the surrounding air (kg/m^3)
C_p	coefficient of power— the ratio of electric power divided by total wind power
θ	angle (relative to the horizontal) of force acting on the crankshaft from a pump (degrees)

- **Wind History** - a file containing the different wind speeds experienced throughout the day and their respective durations. The wind is measured as blowing towards the turbine blades, i.e. in the direction of the shaft axis.

  Format

  $WIND\_SPEED\_1$ (m/s) $DURATION\_1$ (hours)
  $WIND\_SPEED\_2$ (m/s) $DURATION\_2$ (hours)
  … …
  $WIND\_SPEED\_final$ (m/s) $DURATION\_final$ (hours)

Running the Application

When you run the application, a window with a blank canvas appears (**Figure 6**). Looking towards the bottom of the window at the status bar, you will see that the 4 text files mentioned in the preceding section are required: Design, Material Properties, Load Factors, and Wind History.

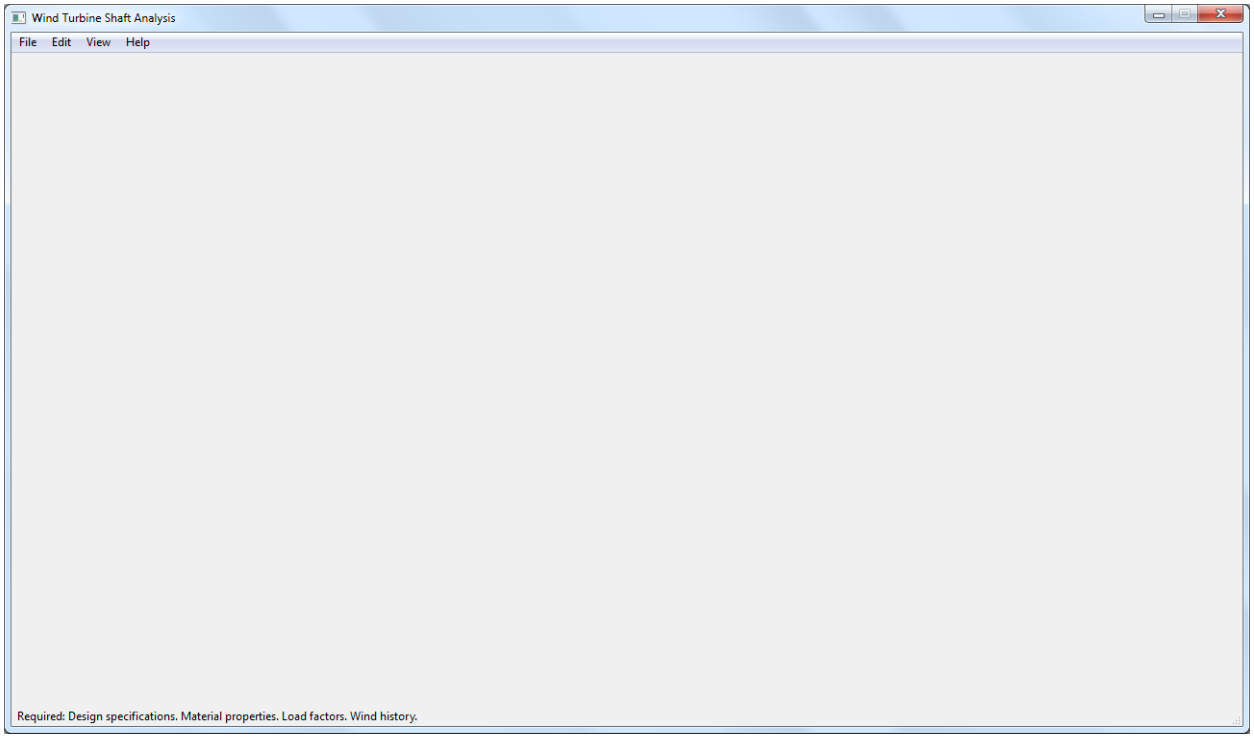

Figure 6. The application window upon starting. The display is blank because, as shown in the status bar at the bottom, 4 files are required: Design, Material Properties, Load Factors, and Wind History.

The menu bar at the top left of the window has 4 tabs: File, Edit, View, and Help. All tabs show actions you can take—each action is also bound to a keyboard shortcut. The **File** tab allows you to load the required inputs, save designs, or quit the application (**Figure 7**). Saved designs are in the same format as inputted design files.

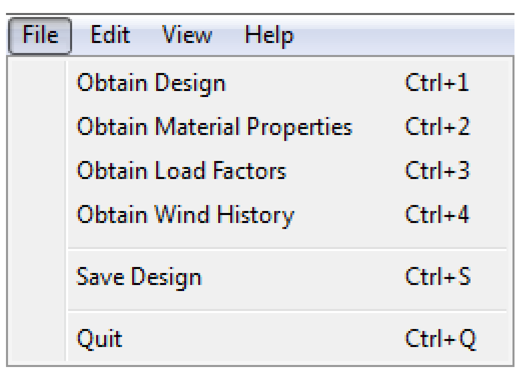

Figure 7. File tab actions. The user can load files, save the design, or quit the application.

Upon loading all required files, the program calculates and displays for each shaft its mass and, as dictated in the inputted design file, required safety factors against yielding and fatigue, maximum allowable angle of twist, and desired service. If a section of a shaft fails to meet any requirements, both it and the corresponding failing factor will be displayed in red (**Figure 8**).

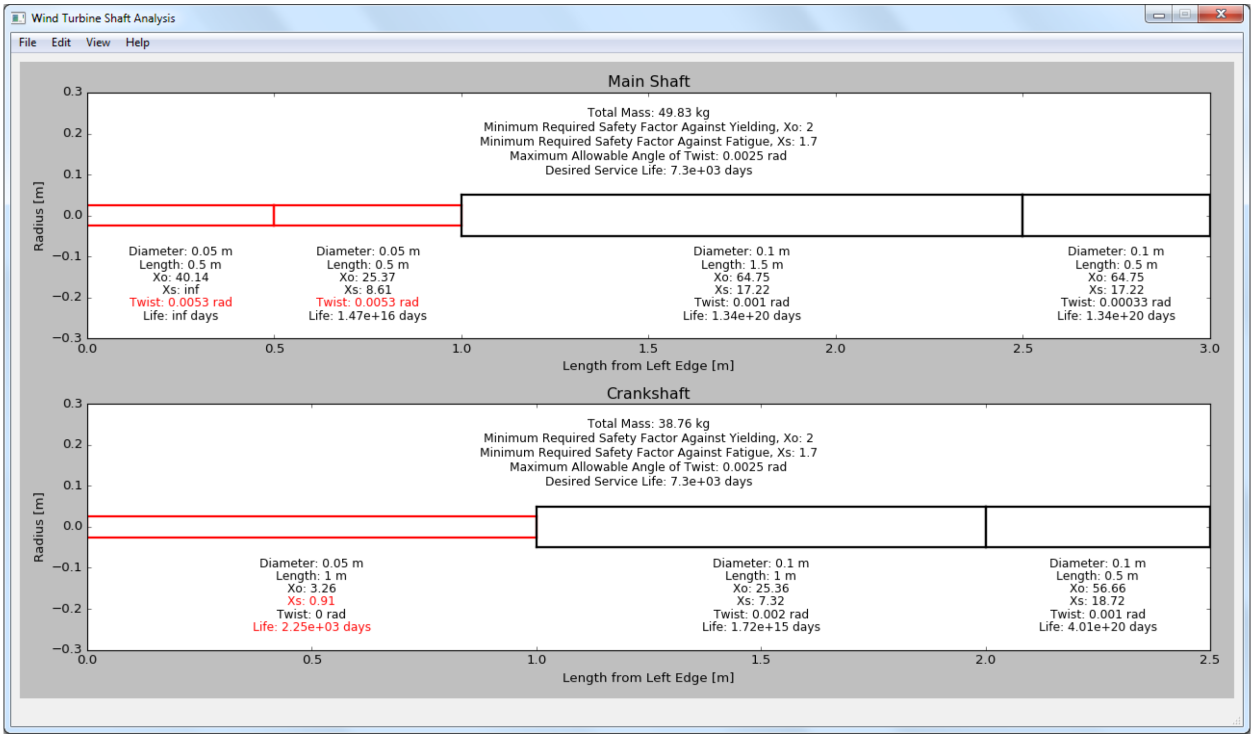

Figure 8. A display of details for the main shaft, crankshaft, and their sections. Here, shaft sections 1 and 2 (main shaft) fail due to exceeding the maximum allowable angle of twist. Shaft section 5 (crankshaft) fails due to do not meeting the minimum safety factor against fatigue or the desired service life.

When design specifications are not met, you can try inputting different materials or edit the section lengths or diameters by going to the **Edit** tab and clicking ‘Edit Design’ (**Figure 9**). This prompts the edit window to appear, as shown in **Figure 10**. You can alter dimensions and update the design and shaft plots.

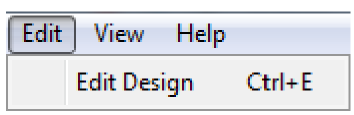

Figure 9. The **Edit** tab and its action.

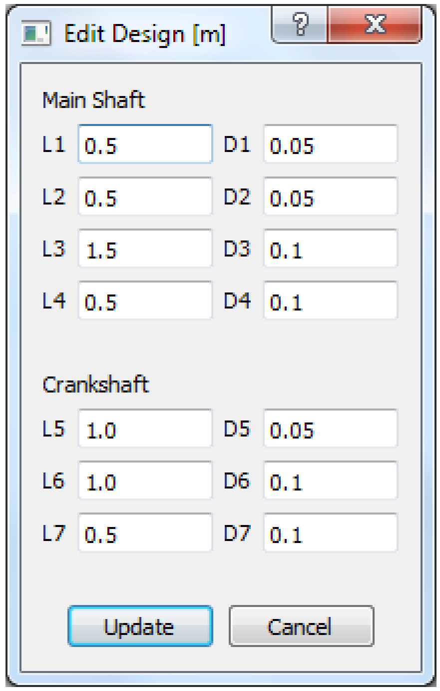

Figure 10. The edit window. Lengths and diameters for the main shaft and crankshaft can be changed. Dimensions are in meters. When the 'Update' button is pressed, the application recalculates all mechanical values and updates the display.

In the **View** tab (**Figure 11**), you can make the display of shaft section details uniform. This action is used to prevent the text of sections from overlapping or overstepping the plot boundaries. This occurs when one or more section lengths are relatively smaller than the other section lengths. The use of 'Normalize View' is depicted in **Figure 12**. Note that section details are depicted in order, i.e. the first set of text corresponding to the first section of the shaft, the second corresponds to the second section of the shaft, etc.

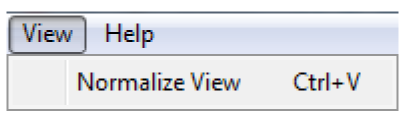

Figure 11. The **View** tab and its action.

Figure 12. The display when 'Normalize View' is checked. Shaft section details are uniformly spread across the plot. The first set of details corresponds to the first section of the respective shaft, the second corresponds to the second section, etc.

In the **Help** tab (**Figure 13**), you can read about the application's use and its origins.

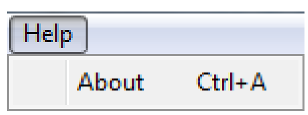

Figure 13. The **Help** tab and its action.

*Images for the section 'Wind Turbine Details' are from Cornell's Professor Hernandez's Spring 2013 MAE 2120 class project specifications.