

WhiteBox Instructions



Everett Wind Energy Team

These instructions are intended to accompany the WhiteBox instruction videos in the [Wind Energy 101](#) curriculum. They are much more detailed than the videos, and are intended as a reference guide, **not** something to be read all at once. If you need more detail on part of WhiteBox, find it in the Table of Contents and navigate straight to that section. The sections can be read independently.

If you have any questions, please feel free to reach out at EWETmedia@gmail.com.

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What is WhiteBox?

WhiteBox Learning is an online software package students can use to simulate engineering problems. Real wind turbines are massive, expensive constructions, so their performance is heavily simulated before they are built to be sure that they will be worth the investment. WhiteBox can be used to predict how small wind turbines will perform.

How do I log in?

Navigate to www.whiteboxlearning.com/login, and click on the picture of the wind turbine with the **KIDWIND 2.0** module, under **Student Login** (Figure 1).

UPDATE: This page has changed since these instructions were written. Do *not* click on the turbine that says "KidWind Challenge". There are two different versions of this software; the video and this document were both created for the original version.

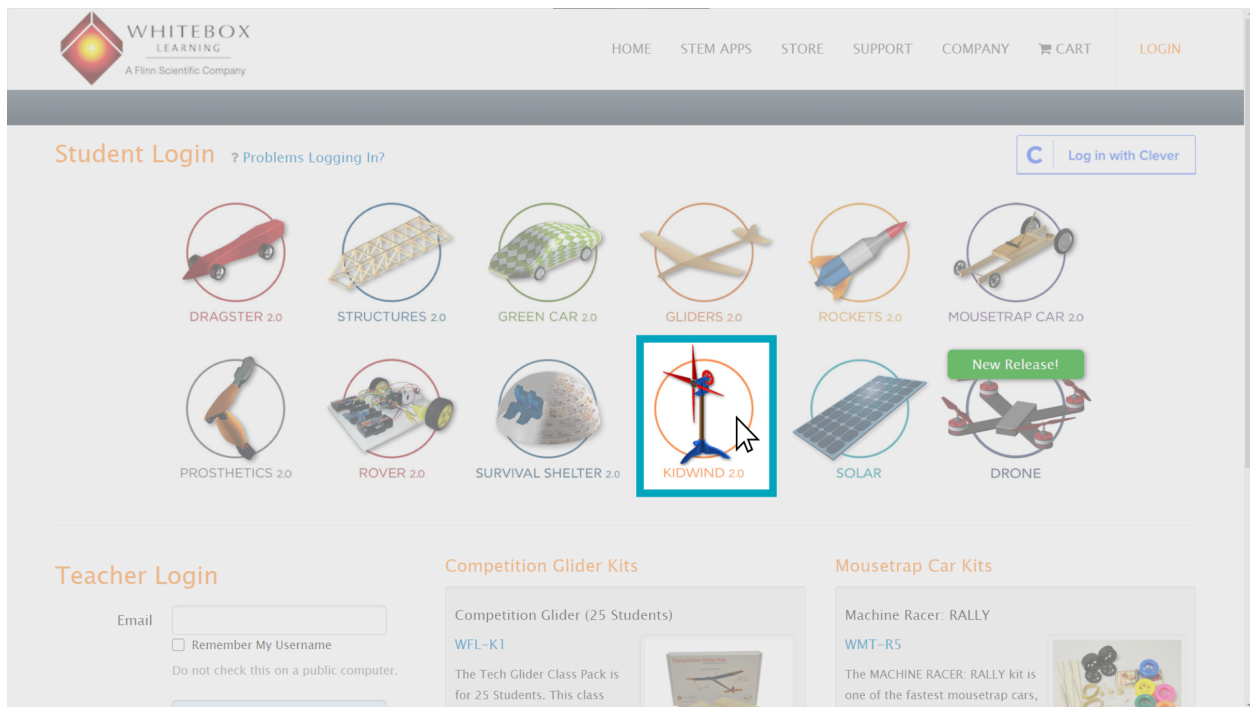


Figure 1: Click on the Kidwind 2.0 module on the login page.

Once you click the picture, enter your assigned **STUDENT ID** and **GROUP ID** in the box that appears. Click **LOGIN**. This will take you to the **Start** page (Figure 2).

The KidWind simulator has five modules, **Research**, **Engineering**, **Competition**, **Outputs**, and **Build & Test**. We will mostly be using the **Research** and **Engineering** modules.

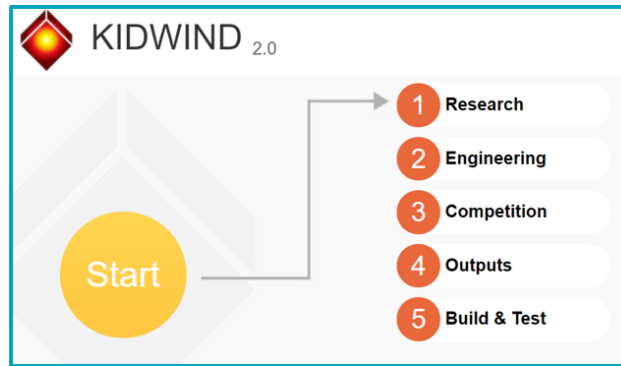



Figure 2: Start page containing the five modules of the KidWind simulator. The modules are accessible on other screens via buttons at the top of the page.


Module 1: Research


The **Research** module contains information that will be useful to have before building a turbine. It contains both informational pages and quizzes, which can be viewed on the left-hand side of the screen. Click the  icons next to each topic to view the content.

HOME RESEARCH ENGINEERING COMPETITION OUTPUTS BUILD AND TEST JOURNAL FILE HELP LOGOUT


RESEARCH


Engineering Design Process

The Engineering Design Process 


Design Challenge 


Background


Background 


Background Quiz 


Knowledge At Work


Blade Terminology 


Power in the Wind 


Quiz: Power in the Wind 


Turbine Power Output 


Quiz: Turbine Power 


Blades in Motion 


Quiz: Blades in Motion 


Blade Pitch 

Quiz: Blade Pitch 

Blade Span and Chord 

Quiz: Blade Span and Chord 

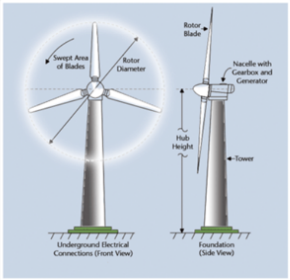
Other Variables 

Wind Farm Siting 

Prev Next

Power in the Wind

Wind is the fuel that powers a wind turbine. The more wind, the more power that is available for the wind turbine to convert.



Drawing of the rotor and blades of a wind turbine, courtesy of ESN

Rotor and Blades
Image courtesy of The European Commission

A simple equation for the power available in a column of wind is described below. *This is not how much power the turbine is generating -- this is how much power is in the wind!*

$$\text{Power in the Wind (watts)} = \frac{1}{2} \rho (\pi r^2) \times V^3$$

where:

ρ = Density of the Air (kg/m³)
 r = Radius of the column of air (m)
 V = Wind Velocity (m/s)

Figure 3: The Research module

Quizzes

The research module contains several quizzes, which test your knowledge of the previous section in the series. You can only complete each quiz once, but if you get an answer incorrect, you can guess again. Once the quiz is completed, you can view your score and the correct answers.

Module 2: Engineering

The **Engineering** module is where you can design your turbine. Figure 4 shows the layout of the module. The screen when you first open the module will have the side panel, file manager, and view controls. The docking station and viewscreen content are controlled by buttons on the side panel.

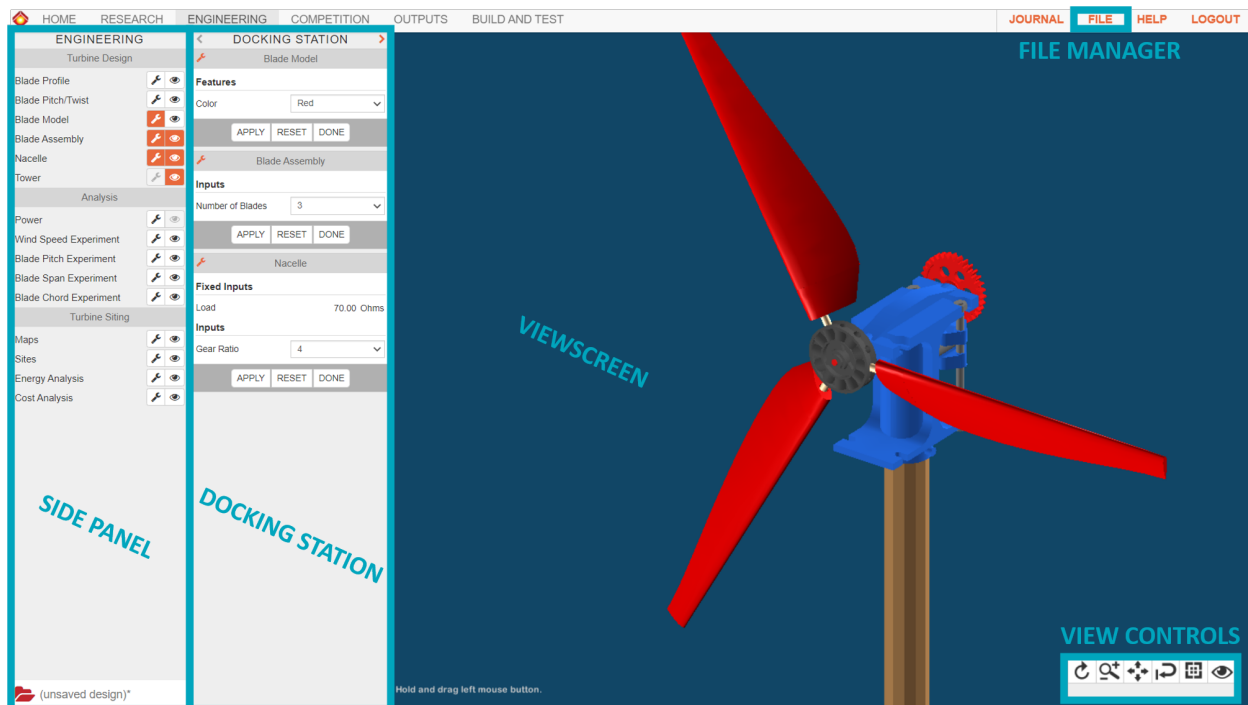


Figure 4: The Engineering module

The Side Panel

There are many different things you can edit from the side panel. Clicking the **setup** (🔧) icon next to any item makes controls for that item appear in the docking station, and clicking the **view** (👁️) displays the item in the viewscreen. In general, when you are editing something, make sure that the **setup** (🔧) and **view** (👁️) icons for the thing you're editing are both turned on, and the buttons for all other rows are deactivated.

The Docking Station

The docking station is where you can edit different fields. Any item in the side panel with the setup (🔧) icon highlighted will appear in the docking station.

Important: Whenever you change something in the docking station, you must hit **APPLY** for anything to happen.

To remove something from the docking station, click the **DONE** button under it. (Clicking the setup (⚙️) icon again won't do anything.)

The File Manager

The file manager is where you can open and save turbine designs. Click **FILE** → **Save** to save your current turbine. Once you have saved your turbine, the file name will appear in the bottom of the side panel. A green icon next to the file name indicates that your turbine is saved; a red icon means you have unsaved changes. Always make sure your turbine is saved before closing WhiteBox.

The View Controls

The toolbar in the bottom right-hand corner of the screen is used to move your turbine around the screen. Table 1 shows the different icons in the toolbar.

Table 1: *View controls icons*

Icon	Name	Description
🔄	Rotate	Rotate the model clicking and dragging it
🔍	Zoom	Click the left mouse button to zoom in, and the right one to zoom out
✚	Pan	Click and drag to move the model around the viewscreen
🔄	Reset	Resets view to the default position
📺	Cycle Views	Clicking cycles through left, front, right, top, and isographic views
👁️	Clear	Clears the viewscreen by turning off all the show buttons in the side panel

Turbine Design

The first subset of items in the side panel are the turbine design ones. These items are for designing the turbine blades, deciding how many blades you want, and picking your gears.

Blade Profile

The first turbine design item is **Blade Profile**. This is where you decide the shape of the blade. The basic blade measurements are shown below.

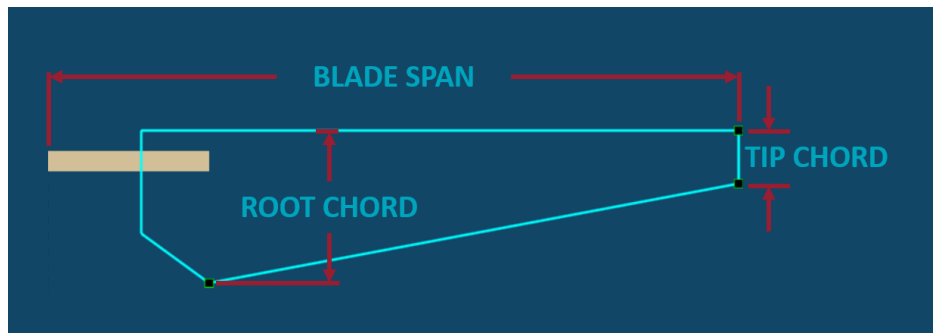


Figure 5: *Blade profile dimensions*

You can change the blade by changing the numbers in the docking station (don't forget to hit **APPLY**), or by dragging the black and green squares on the viewscreen.

You can also switch between simple and complex blade types via the drop-down in the docking station. Using a complex blade type lets you make one of the edges curved (Figure 6) by dragging the black and green circles that appear on the viewscreen.

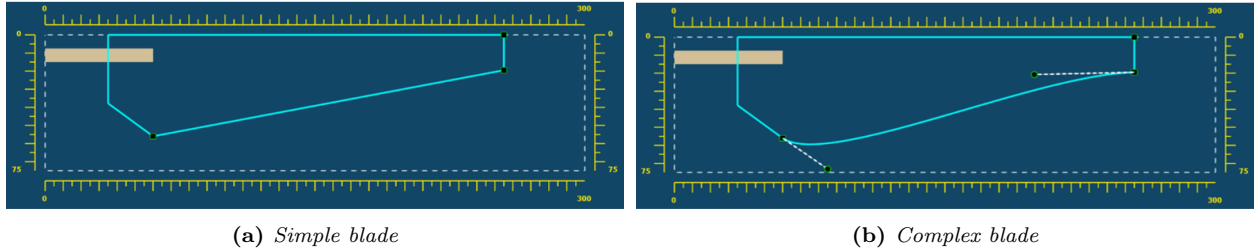


Figure 6: Simple vs complex blade types. Use a complex blade type to get curved edges.

When you are finished editing your blade profile, don't forget to click the **DONE** button in the docking station, and hit the orange show/hide (👁) icon in the side panel to clear the viewscreen.

Blade Pitch/Twist

After the blade profile is created, the next step is to set the blade pitch and twist. Figure 7 shows how pitch and twist are measured. You can adjust the blade pitch by dragging the black and green circle in the viewscreen. The black and yellow circle controls the twist.

The view in Figure 7 is looking down the end of the blade. The yellow profile represents the tip of the blade, and the green profile shows the blade root.

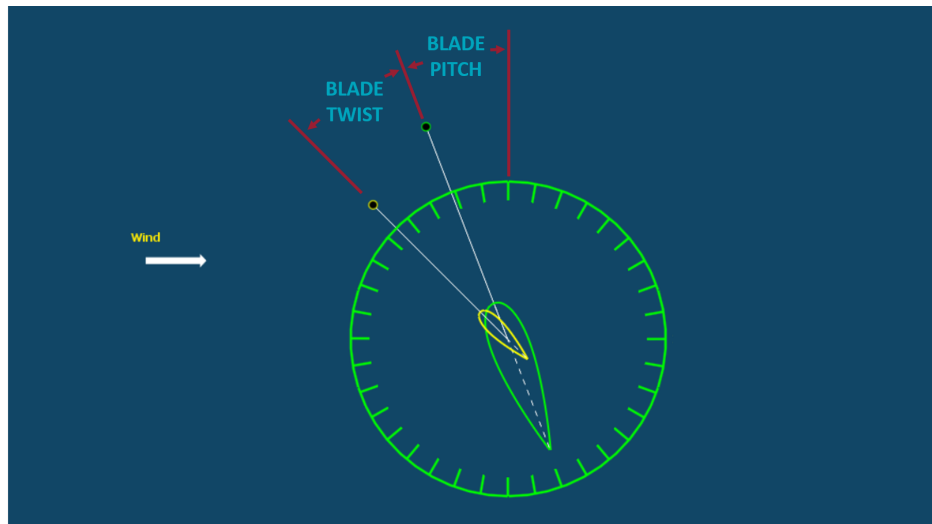
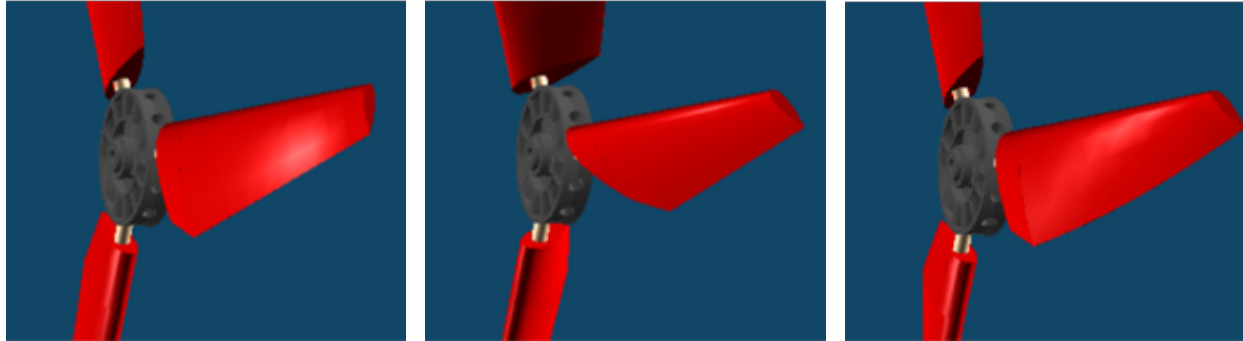


Figure 7: Blade twist and blade pitch. Blade pitch is measured from the vertical direction, while blade twist is measured from the blade pitch angle.

The pitch and the twist are both limited to certain values, so some values cannot be input into WhiteBox. If you enter an illegal value, the blade will just jump back to the previous value.

Figure 8 shows different values of pitch and twist on a 3D model of a blade. Figure 8a shows both the pitch and twist at their lowest values. Figures 8b and 8c show what increasing the pitch and twist values does to the shape of the blade.



(a) Blade with low pitch and no twist

(b) Blade displaying high pitch

(c) Blade displaying high twist

Figure 8: Different pitches and twists of blades.

Blade Model

The blade model menu lets you select the color of your blades, and clicking the show/hide icon (👁) will show a single 3D model of a blade. Make sure to hide this once you are done, since this 3D model will overlap later ones.

Blade Assembly

This blade assembly menu lets you set the number of blades you want. Once you are happy with the number of blades, click **DONE** on the docking station menu, but leave the blade assembly visible if you are moving onto the next item in the side menu. The next two items are meant to be displayed with the blade assembly.

Nacelle

This is where you can set your gear ratio. Once you are done, click **DONE**, but leave it visible if you are proceeding onto the **Tower** item.

Tower

There are no variables to set here, this just toggles the tower visibility. See Figure 9 for an example of a turbine with the tower, nacelle, and blade assembly all visible.

NOTE: This is the last item in the Turbine Design section of the side panel. This is a good time to save your turbine design. Use the file manager in the upper right-hand side of the screen.

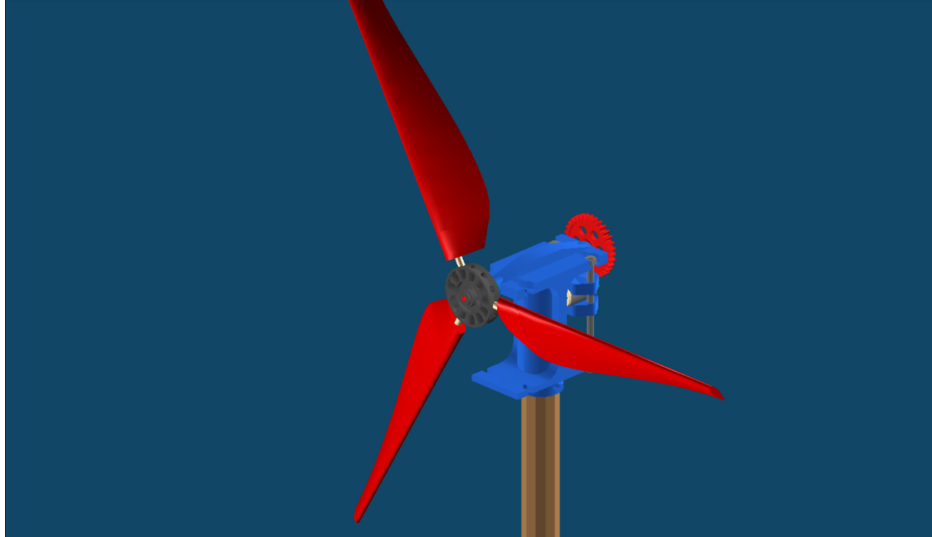


Figure 9: Completed turbine with blade assembly, nacelle, and tower all visible.

Analysis

The analysis section of the side panel is where you see how well your turbine design performs. Before using the analysis section, clear the viewscreen by using the hide/show buttons in the side panel, or with the clear button (👁) in the view controls.

Power

This is where WhiteBox calculates how much power your turbine produces at a given wind speed. From the docking station, you can select a wind speed from a drop-down, hit **APPLY**, and the power the turbine is generating will appear in the bottom of the docking station menu. You can also view the speed of the blade tips, the turbine rotational speed, the generator rotational speed, the torque produced by the turbine, and the voltage and current the generator is generating.

The menu needs to be visible for the other items in the analysis section, so don't click **DONE** unless you're done with the analysis section.

Wind Speed Experiment

This menu shows the effect of wind speed on power production. There are two columns in this menu: **Wind Speed (m/s)** and **Power (Watts)**. To run this experiment, you use the **Power** menu to find the power output for different wind speeds and record them manually in the table in the **Wind Speed Experiment** menu. Follow the procedure below.

1. Ensure that both the **Power** and **Wind Speed Experiment** menus are present in the docking station by clicking their setup (🔧) buttons in the side panel. If there are numbers other than 0.00 in the **Power (Watts)** column of the **Wind Speed Experiment** menu, click **RESET**.
2. Set the drop-down in the **Power** menu to 2 m/s, and click **APPLY** in the **Power** menu.
3. Read the power reading from the bottom of the **Power** menu, and record it in the 2 m/s row in the **Wind Speed Experiment** menu. If you receive a "No Solution" message, skip this wind speed and

leave the power at 0.00 Watts. Click **APPLY** on the **Wind Speed Experiment** menu.

4. Repeat steps 2-3 for the other wind speeds until you have tested all of them. Make sure the **Wind Speed Experiment** item in the side menu is set to visible. You should have a graph similar to the one in Figure 10.

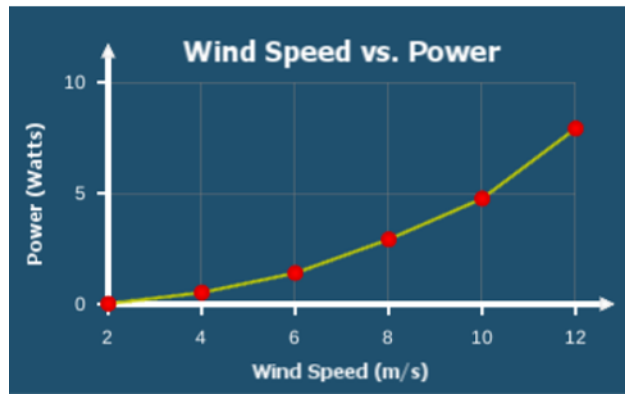


Figure 10: Wind speed experiment graph

Blade Pitch Experiment

This experiment shows the effect of different blade pitches on power production. Follow the procedure below.

1. Ensure that the **Blade Pitch/Twist**, **Power**, and **Blade Pitch Experiment** menus are all present in the docking station by clicking their setup (⚙️) buttons in the side panel. If there are numbers other than 0.00 in the **Power (Watts)** column of the **Blade Pitch Experiment** menu, click **RESET**.
Recall that not all pitch or twist values are legal. To run this experiment, ensure that your blade twist value is between -1.00 deg and 30.00 deg. If this is not true, running this experiment will change the blade twist value partway through as the blade reaches a pitch that cannot be calculated by the solver. To avoid "No Solution" errors, pick a lower wind speed in the **Power** menu. Don't forget to hit "APPLY". Try to run the experiment at the highest wind speed you can without getting errors.
2. In the **Blade Pitch/Twist** menu, change the blade pitch to 1.00 deg. Click **APPLY**. The rows in the **Power** menu should update automatically, flashing yellow.
3. Record the power reading from the **Power** menu in the 1 degree row of the **Blade Pitch Experiment** menu. If you got a "No Solution" error, leave the value at 0.00 Watts. Hit **APPLY** in that menu.
4. Repeat steps 2-3 until you have tested all the blade pitches listed. You should have a graph something like the one in Figure 11.

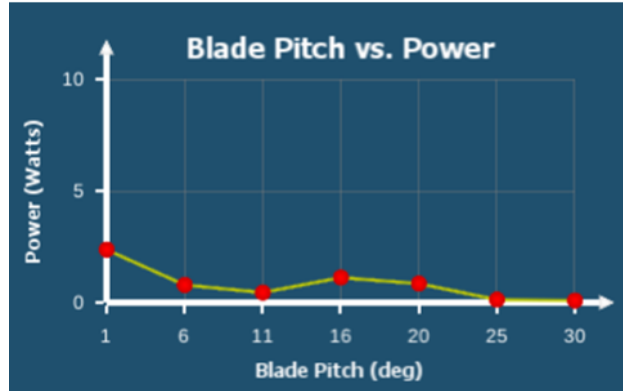


Figure 11: Blade pitch experiment graph

Blade Span Experiment

This experiment shows how blade length (span) affects power production. Follow the procedure below to run the experiment.

1. Ensure that the **Blade Profile**, **Power**, and **Blade Span Experiment** menus are all present in the docking station by clicking their setup (⚙️) buttons in the side panel. If there are numbers other than 0.00 in the **Power (Watts)** column of the **Blade Span Experiment** menu, click **RESET**.
To avoid "No Solution" errors, pick a lower wind speed in the **Power** menu. Don't forget to hit "APPLY". Try to run the experiment at the highest wind speed you can without getting errors.
2. In the **Blade Profile** menu, change the blade span to 140.00 mm. Click **APPLY**. The rows in the **Power** menu should update automatically, flashing yellow.
3. Record the power reading from the **Power** menu in the 140 millimeter row of the **Blade Span Experiment** menu. If you got a "No Solution" error, leave the value at 0.00 Watts. Hit **APPLY** in that menu.
4. Repeat steps 2-3 until you have tested all the blade spans listed. You should have a graph something like the one in Figure 12.

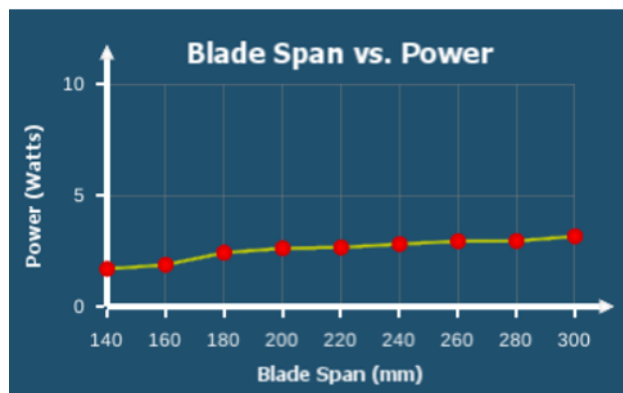


Figure 12: Blade span experiment graph

Blade Chord Experiment

This experiment shows how the chord length of the blade tips affect power production. Follow the procedure below to run the experiment.

NOTE: The name "Blade Chord Experiment" refers to the chord of the *tip* of the blade. Leave the root chord at a single value throughout this experiment.

1. Ensure that the **Blade Profile**, **Power**, and **Blade Chord Experiment** menus are all present in the docking station by clicking their setup (🔧) buttons in the side panel. If there are numbers other than 0.00 in the **Power (Watts)** column of the **Blade Span Experiment** menu, click **RESET**.
To avoid "No Solution" errors, pick a lower wind speed in the **Power** menu. Don't forget to hit "APPLY". Try to run the experiment at the highest wind speed you can without getting errors.
2. In the **Blade Profile** menu, change the tip chord to 15.00 mm. Click **APPLY**. The rows in the **Power** menu should update automatically, flashing yellow with any changes.
3. Record the power reading from the **Power** menu in the 15 millimeter row of the **Blade Chord Experiment** menu. If you got a "No Solution" error, leave the value at 0.00 Watts. Hit **APPLY** in that menu.
4. Repeat steps 2-3 until you have tested all the blade spans listed. You should have a graph something like the one in Figure 13.

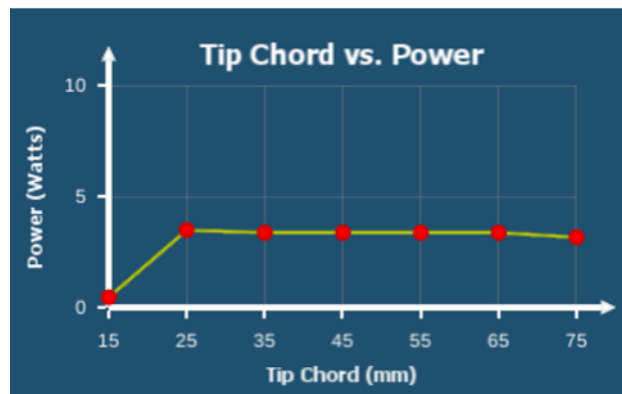


Figure 13: Blade chord experiment graph

Turbine Siting

The turbine siting section is where you design a turbine layout. There are four items in this portion of the side panel: **Maps**, **Sites**, **Energy Analysis**, and **Cost Analysis**. Unlike previous sections, all four of these should be put in the docking station and displayed in the viewscreen with the setup (🔧) and show/hide (👁️) icons. (See Figure 14.)

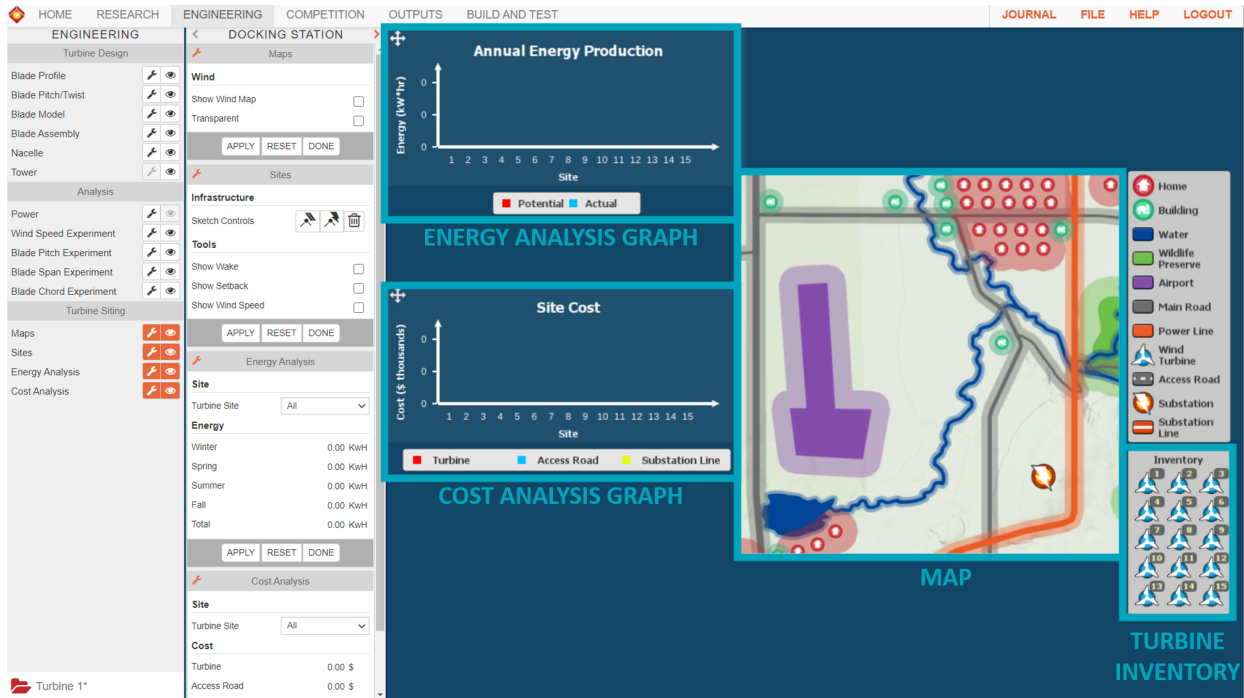


Figure 14: Turbine siting screen

Maps

The **Maps** menu gives you several options for your site map. Before we look at those, note the default map in Figure 15a. The map shows roads, buildings, power lines, and wildlife preserves. Note that each item is surrounded by a lighter-colored outline; this is called the *setback*, and it will be important in the next section.

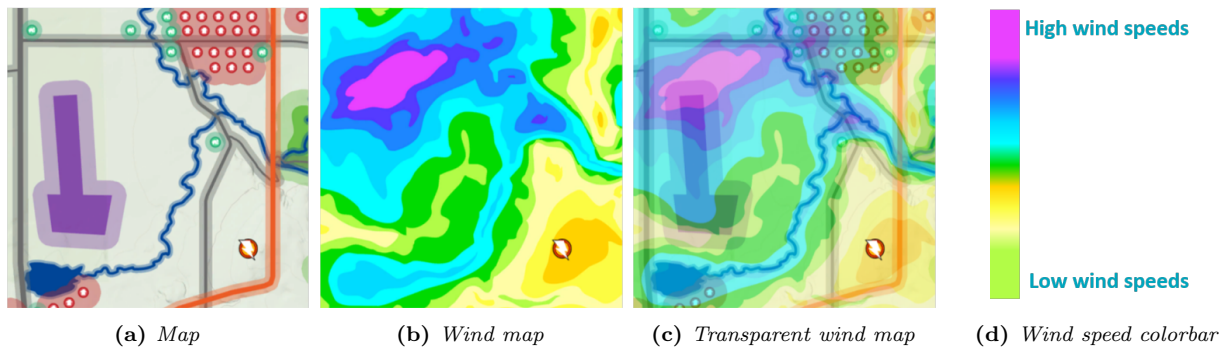


Figure 15: Wind map display and transparency.

To place turbines, it will be helpful to know what the wind speeds are on your site. The **Maps** menu lets you display a wind speed map, where different colors represent different wind speeds. (See Figure 15d.) Click **Show Wind Map** and hit **APPLY** to see the wind map, which should look like Figure 15b.

Later, you will need to know where buildings and roads are, so it is helpful to turn the wind map transparent,

so you can see the original map underneath. Check the box by **Transparent**, and hit **APPLY**. Your map should look like Figure 15c.

Sites

The **Sites** menu is where you place your turbines, access roads, and substation lines. For a turbine to generate power, it must meet the following three requirements:

1. The turbine must be connected to the substation via substation lines.
2. The turbine must have an access road that connects it to a road on the map.
3. The turbine must not be placed on any setbacks, either from other turbines or from items on the the map.

The **Sites** menu contains road and substation line drawing tools in the **Infrastructure** section, and tools for displaying information while placing turbines in the **Tools** section.

To place your first turbine, check the boxes by **Show Wake**, **Show Setback**, and **Show Wind Speed**, and hit **APPLY**. This isn't necessary to place turbines, but gives helpful information while you're placing your turbines (Figure 16). Drag and drop turbines from the **Inventory** onto the map to place turbines.

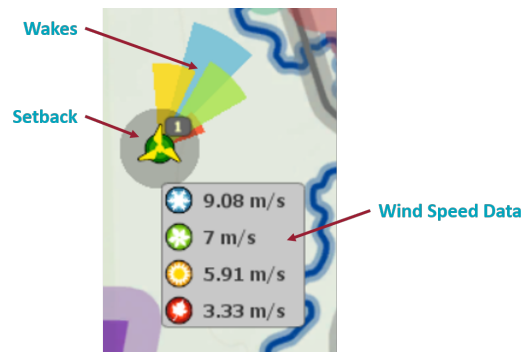










Figure 16: Turbine data visible when placing turbines while *Show Wake*, *Show Setback*, and *Show Wind Speed* boxes are checked.

When placing turbines, be careful not to place turbines on any setbacks, including those of any turbines. The gray outline around each turbine indicates it's setback (Figure 16). If you place one turbine within the setback of another, neither will generate power.

While placing turbines, information is displayed according to season. (Figure 16, Table 2.) Try to place your turbines in the highest wind speed possible without putting them in the wakes of other turbines.

Table 2: Season Icons

Icon	Definition	Wake Color
	Winter data	
	Spring data	
	Summer data	
	Fall data	

Once you have placed your turbine, you need to add access roads and substation lines.

You can add substation lines by clicking the **Create/Edit Substation Line** button (🔗) under **Infrastructure**. To add a line, click the button, then click one of your turbines and link it to either another turbine or the substation. To terminate a line while drawing, right-click. If a line does not connect a turbine to the substation, either directly or indirectly, it will turn red.

Similarly, you can add roads by clicking the **Create/Edit Road** button (🔗). You must begin drawing your road at a turbine, and all road networks must eventually lead to a road on a map. To terminate an access road at the map road, right-click while drawing an access road. If an access road is not connected to a main road, it will highlight red.

NOTE: Once a turbine has a line connected to it (either a road or a substation line), you cannot *start* another line of the same type on that turbine again. For this reason, it is a good idea to add your lines in *last*.

To delete roads and substation lines, use the Delete icon (🗑️).

NOTE: This will delete the entire chain of lines which were drawn together.

Energy Analysis

The **Energy Analysis** menu tells you how much energy your wind farm is producing. In the docking station, you can click a drop-down menu and select individual turbines to view their energy production. You can also select "All", and see information for the whole site. Once a turbine is selected, the menu in the docking station will display how much energy was produced in each season, as well as over the entire year.

There is a graph which displays the **Energy Analysis** information on the viewscreen. (Figure 17.)

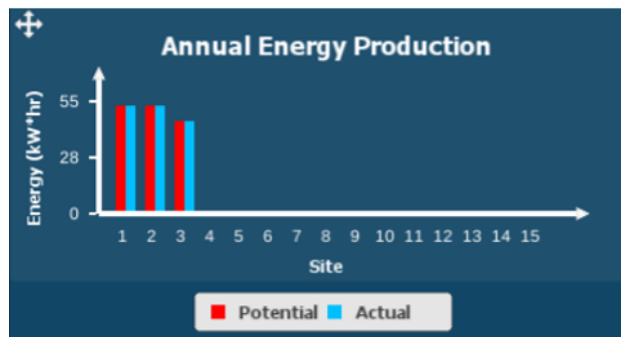


Figure 17: Annual Energy Production graph from viewscreen. The red bars indicate how much energy each turbine you have placed could be producing, and the blue bars indicate how much it is producing.

This graph is extremely helpful to watch when placing your turbines, as it shows which turbines are producing power. You can use the graph to compare how much energy you're producing with how much energy you *could be* producing. If the **Potential** and **Actual** bars are the same height, your turbine is producing the maximum amount of energy for its location. If you are producing some energy, but less than the potential, that indicates that your turbine is in the wake of another. If you are producing no energy (i.e. the blue bars are completely absent), that means that your turbine is not fulfilling one of the three requirements for power production outlined in the previous section. Check that these turbines are not on any setbacks, and ensure that they are connected to both the substation and the main roads.

Cost Analysis

The **Cost Analysis** menu gives information about how much each turbine installation costs. Like the **Energy Analysis** menu, there is a drop-down in the docking station where you can choose which turbine you want to see information about.

There is also a cost analysis graph on the viewscreen. (Figure 18.)



Figure 18: *Site Cost graph from viewscreen. For each turbine, the red bars indicate the cost of the turbine, the blue bars the cost of the access roads, and the yellow bars the cost of the substation lines.*

The data in the Site Cost graph is not accurate for the small turbines you designed; it is only meant to show how substation line and access road lengths influence the cost of your site. Each turbine has a fixed cost, but you can shorten your roads and substation lines to reduce their cost, and therefore, the cost of the whole site.

Module 3: Competition

The **Competition** module is not included as part of the **Wind Energy 101** course, but this is where different students can compete against each other. In the **Engineering** section, if you go to the file manager and click **Save and Enter Competition**, your design from this section will be put into the competition. Students can select designs they want to compete against each other, click **Start**, and compare results.

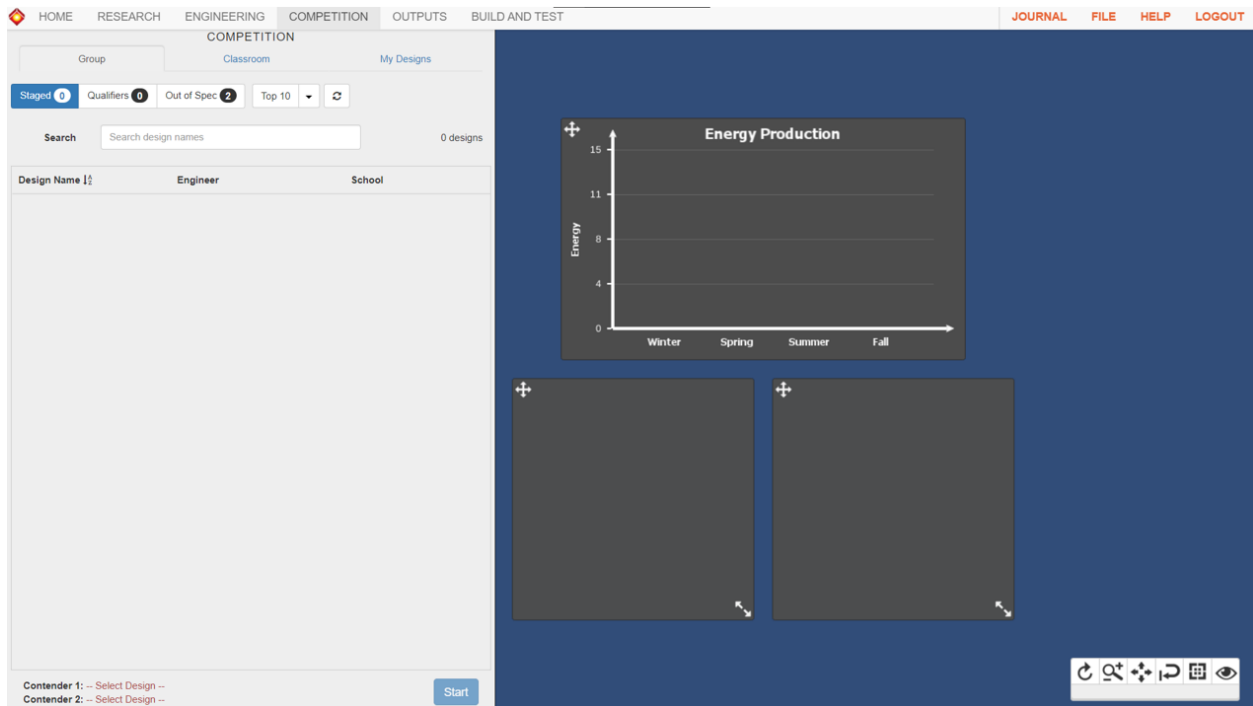


Figure 19: The Competition module.

Module 4: Outputs

The **Outputs** module is not included as part of the **Wind Energy 101** course, but this is where you can retrieve information about your design. There are print templates you can use to cut your blades out of paper, as well as downloadable STL (3D printer) files.

The screenshot displays the 'Outputs' module interface. The top navigation bar includes 'HOME', 'RESEARCH', 'ENGINEERING', 'COMPETITION', 'OUTPUTS', and 'BUILD AND TEST'. The 'OUTPUTS' section is active, showing a sidebar with options like 'Design Specifications (PDF)', 'Design Specifications (HTML)', 'Print Templates', 'Legal Size', 'Letter Size', '3D Printer Output', and 'Download STL Files'. The main content area shows a PDF viewer for 'pdf-report.pdf' at 125% zoom. The document title is 'Design Specifications' and the filename is 'Not Saved'. The content includes two tables:

Energy/Budget	Minimum	Maximum	Designed
Minimum Energy Level	250.0 kWh	--	147.87 kWh
Total Cost	--	--	\$ 1686352.55

Turbine Blades	Minimum	Maximum	Designed
Span	150.0 mm	295.0 mm	300.0 mm
Root Chord	5.0 mm	55.0 mm	60.0 mm
Tip Chord	5.0 mm	55.0 mm	75.0 mm
Pitch	1.0 deg	20.0 deg	1.0 deg
Twist	-15.0 deg	15.0 deg	10.0 deg
Number of Blades	3.0	8.0	3
Number of Sites	5.0	15.0	3

At the bottom left, there is a status indicator '(unsaved design)'.

Figure 20: The Outputs module.

Module 5: Build & Test

The **Build & Test** module is not included as part of the **Wind Energy 101** course, but this is where you can find information about how to test your turbine.

HOME RESEARCH ENGINEERING COMPETITION OUTPUTS **BUILD AND TEST** JOURNAL FILE HELP LOGOUT

BUILD AND TEST

Fabrication

Blade Construction

Assembly & Adjustments

Test Setup

Wind Turbine Test Setup

When testing your wind turbine it is important to have a clean and safe area to work in. Below are some basic tips on how to set up your testing environment.

Set up the tower with one leg facing away from the fan. For extra stability when you're using big blades or high speed wind, tape the base to the floor or desk.

Plane of rotation: don't stand here!

Stand behind or in front of the plane of rotation.

Keep your rotor diameter inside the fan diameter, or the tips will only add drag.

Use a large box or circular fan, for strong, consistent wind. A hairdryer or desk fan won't do it!

Measuring Voltage and Current

Using a multimeter, you can quantify the voltage and/or current your turbine is producing.

Measuring Voltage

Attach the wires from the generator to the multimeter. Polarity is not relevant at this point. To check the voltage, select DC volt (V) and set the number to 20.

1.5

1.8

Figure 21: The Build & Test module.