Final Report

Offshore Wind Turbine

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December 6, 2013

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1.0 Executive Summary

The main purpose of our design project is to design a wind turbine that can successfully operate offshore. Additionally, we have added the dimension of autonomy to the design, which will allow the floating turbine to self-navigate to its selected location and self-orient when needed. With the final design selected, the process of detailed design, component analysis, materials procurement, and construction scheduling has been completed. Each component of the final design, including the turbine blades, generator, tower, foundation, and electric motors has been designed. Note, however, that some of these components have been designed with sufficient detail to allow for their manufacture, while other, less critical components (i.e., outside the main scope of our design project) have been sufficiently designed to allow for their informed selection from the commercial market.

2.0 Acknowledgement

There were many individuals that advised and guided our group and its members throughout the design process. The efforts of these individuals not only served to guide us through the design process, but also to continue our education in the principles of math, science and engineering. Each of them routinely made time, in their busy schedules, to meet with us and provide us with substantive feedback. Our sponsor, Dr. Sungmoon Jung, not only provided us with a challenging, inspiring, and innovative design project, he made himself available for weekly "sponsor meetings". He continually provided us with positive feedback and encouragement, while asking the hard questions that pushed us to learn and improve our ideas and designs. Our mentor, Dr. Kumar, guided us through some of the more difficult aerodynamic issues, which ultimately helped shape the final design. Our Senior Design instructors, Dr. Amin and Dr. Frank, continually provided outlines and guidance regarding the deliverables and presentations. Dr. Faruque and Dr. Graber also provided valuable input that helped shape the size and shape of the final turbine design.

3.0 Project Overview

3.1 Sponsor Requirements

The energy potential of offshore wind farms is much greater than that of land based farms thanks to the reduced surface roughness of the sea. For some states the entire electricity could come from offshore wind farms. With such enormous energy potential, offshore wind turbines will contribute to the national energy security.

Although the floating offshore wind turbine has advantages, the cost is still prohibitive. The most important project objective is to reduce the cost compared to existing ideas. The approach is not limited to innovative design --you may come up with innovative construction method, logistics, or any other approach that you can think of.

3.2 Scope

The scope for the offshore wind turbine is related to location and water depth. The location should be sufficiently far from shore such that surface effects from land are immaterial leaving only those from the ocean surface. Water depth should be deep enough to be considered “deep water” (i.e., greater than or equal to 60m).

3.3 Goal

The purpose of this project is to expand a future renewable resource in the hopes of making it available for the commercial market. The largest problem facing the current development is expense. If it were able to have grid parity, the benefits from offshore wind power would grow the renewable energy market tremendously. The largest cost components, of an offshore wind turbine system, are the foundation and overall construction. The primary goal is to modify existing designs to minimize cost, while maximizing output and sustainability with the goal of reaching a levelized cost of electricity with respect to total grid production.

3.4 Constraints

Time Management: The Floating Wind Turbine must be designed, built and tested before the last week of the spring semester (as of now April 25th 2014). Time management will be necessary in order to batch and cure the concrete foundation, build the steel structure and manufacture the blades and gears before the project deadline. Proper scheduling will be essential to the overall success of the Floating Wind Turbine.

Budget: As of now our budget is 2,000 dollars that is being supplied by Dr. Jung’s research grant. Supplies will also be donated from Florida Rock and Cives Steel which will alleviate some of the financial burden from acquiring materials. Blades, gears, motors and sensors will be restricted to the 2,000 dollar budget. The team will track expenditures in order to stay on budget and provide a quality product with a marginal cost.

Team members: The team consists of seven members from three disciplines of engineering. There are three mechanical, three civil and one electrical engineering majors assigned to this project. It is imperative that the three disciplines communicate and schedule effectively amongst each other to make the Floating Wind Turbine a reality. Due to differing schedules, the team must overcome scheduling conflicts and resolve a meeting time once a week that can accommodate the team. This is critical to meet objectives and benchmarks determined by faculty and the team members.

In order to overcome scheduling conflicts, much of the work will be broken into task that will completed remotely by the team members. Proper file organization will minimize confusion and ease collaboration of report writing. Drop box and the File Exchange in the EEL4911 Blackboard Course site will be utilized to share, retain and organize documents.

Task will be tracked and benchmarks will be set using a Gantt Chart created in Microsoft Project. The specified timeline will be utilized to track progress, goals, due dates. This timeline will govern the progression of the project.

4.0 Design and Analysis

From the dynamic point of view, a wind turbine is a complex structure to design reliably for a given service lifetime. In fact, the fatigue loading of a wind turbine is more severe than that experienced by helicopters, aircraft wings and car engines. The reason is not only the magnitude of the forces but also the number of load cycles that the structure has to withstand during its lifetime of 20 or more years (Figure 3.0) (1).

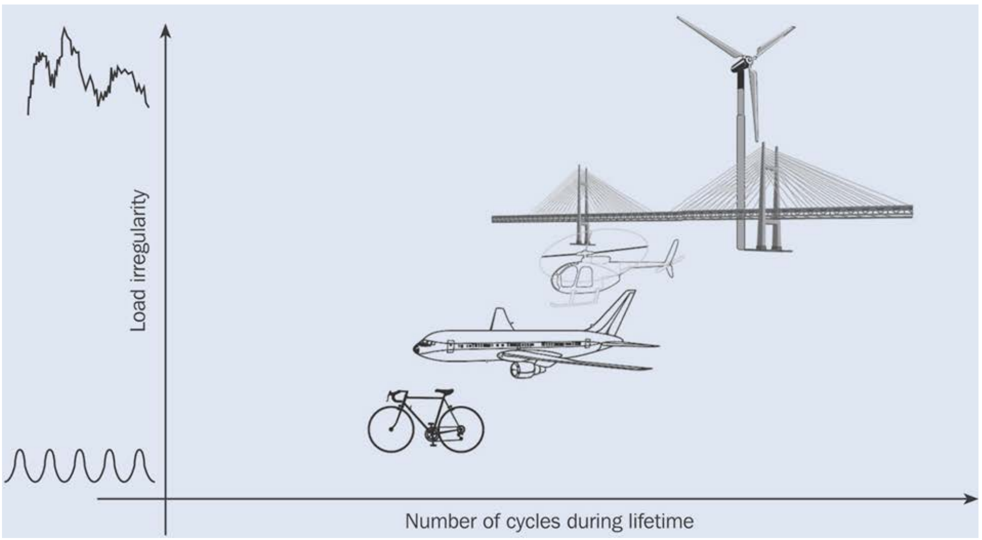


Figure 3.0: Number of cycles during a lifetime (1)

4.1 Turbine Blades

The magnitude and direction of loading play important roles in determining the design characteristics for a wind turbine's individual components. With regards to the turbine blades, much of the wind's energy is converted into rotational energy, which is then converted into electrical energy via the onboard generator. However, when the wind's direction is not normal to the blades' rotation, especially in the circumstance of a wind gust, the blades can experience additional wind loading. This additional wind loading, above what is required to rotate the blades, can cause the blades to deflect, which is known as *tip deflection*, δ (see Figure 3.1).

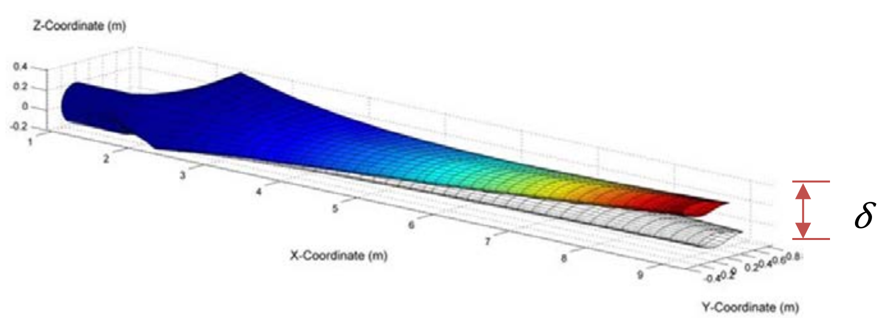


Figure 3.1: Tip deflection (1)

4.1.1 Wind Turbine Blade Geometry

The overall amount of deflection is important as it relates to the yield strength of the material used to fabricate the blade. To account for the worst case scenario (and to simplify the necessary calculations), it will be assumed that all of the wind's energy, from a gust, causes the blade to deflect (this scenario might occur when the turbine is at its maximum rotation, which would mean that the additional wind load, from a gust, could not be translated into rotational energy, but would have to be absorbed by the blades via their deflection). In this case, the following equations would be used to calculate the force of the wind and the deflection of a given blade. To further simply the calculations, the blade's cross sectional area will be approximated as a hollow ellipse. See Figures 3.2 and 3.3.

$$\delta = (FL^3)/(8EI)$$

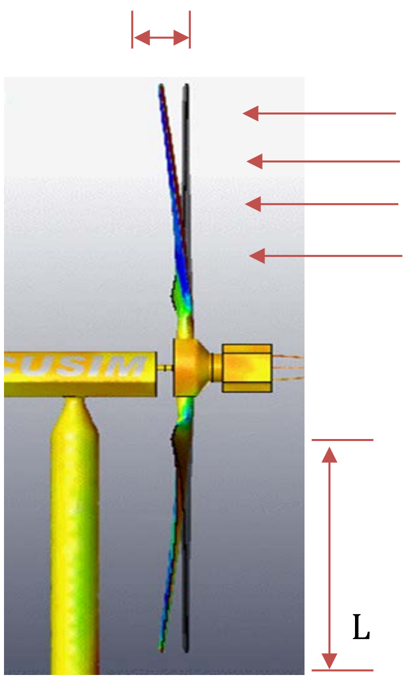


Figure 3.2: Profile view with wind loading and deflection (1).

$$F_{wind} = \tfrac{1}{2}\, p\, v^2\, C_d\, A_s$$

Where: p = Air density, 1.29 kg/m^3

V = Wind velocity

C_d = Coefficient of drag

A_s = Frontal surface area (what the wind "sees")

F_{wind} = Wind force

L = Blade length

E = Elastic modulus

I = Moment of inertia

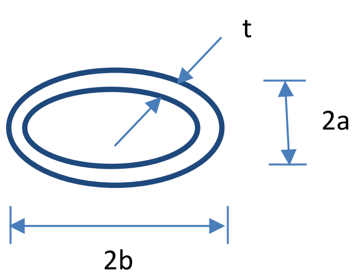


Figure 3.3: Cross-sectional view of a wind turbine blade modeled as a hollow ellipse. The cross-section affects the moment equations Z and I, along with surface area A_s, which are as follows:

$Z = \pi/4\ a^2\ t\ (1 + 3b/a)$

$I = \pi/4\ a^3\ t\ (1 + 3b/a)$

$A_s = L\ 2b$

$A_c = \pi(a + b)t$

4.1.2 Turbine Blade Design Requirements

Table 3.1 outlines the design requirements for a wind turbine blade, specifically related to resisting deflection caused by wind loading, while practically maintaining lightweight. Stiffness relates to deflection, while toughness relates to the practical consideration that a blade must be able to sustain impacts (e.g., from bird strikes) without fracturing, which will help in the final material selection.

Table 3.1 *Design Requirements (FCOFV)*

Function	Turbine Blade—meaning light, stiff beam
Constraints	Length, L specified Bending Stiffness, S specified Toughness G > 1 kJ/m^2
Objective	Minimize the Mass, m
Free Variables	Wall Thickness, t Choice of Material

4.1.3 Materials Index, M, for Turbine Blade

For a given length, *L*, the required stiffness, S^* is adjusted by altering the wall thickness, *t.* The quantities S^*, *L*, and *C* are all specified or constant; the best materials for a light, stiff beam (with a hollow, elliptical cross section) are those with the largest values of index *M*. The materials index, M will be used, in the next section, to compile a list of the best possible materials to be used for a wind turbine blade.

$$m = AL\rho$$

$$S = \frac{CEI}{L^3} \geq S^*$$

$$I = \frac{\pi}{4} a^3 t(1 + \frac{3b}{a})$$

$$t = \frac{4SL^3}{\pi a^3 \left(1 + \frac{3b}{a}\right) CE}$$

$$m = \left(\frac{4SL^3(a+b)}{a^3 \left(1 + \frac{3b}{a}\right) C}\right)(L)\left(\frac{\rho}{E}\right)$$

$$\boldsymbol{M} = \frac{\boldsymbol{E}}{\boldsymbol{\rho}}$$

4.1.4 Materials for Wind Turbine Blades

The materials in Table 3.2 came from a graph that plotted *Young's Modulus, E* against *Density, ρ* (2). Given the design requirements laid-out in Table 3.1, these are the best materials that can be used to fabricate a lightweight, stiff turbine blade.

Table 3.2 *Materials for Wind Turbine Blades*

Material	Index M (GPa/(Mg/m^3))	Comment
Wood Parallel to the Grain	11.7 – 14.7	Traditional material for airboat propellers; inexpensive; natural variability
CFRP	46.7 – 133.3	As good as good with more control over properties
Ceramics	35 - 95	Good M, but low toughness and high cost

4.1.5 Values for Turbine Blade Calculations

Based on the average value of wind velocities, from wind gusts in areas where wind farms have be constructed in the US, a value of 20 m/s (47 mph) has be selected for the following calculations (3). Also, Tables 3.3, 3.4 and 3.5 contain the material properties, design characteristics, and geometric values, respectively, for the selected materials in Table 3.2 and the given blade geometry and equations from section 3.1.1.

Table 3.3 *Material Properties (average values)*

Material	E (GPa)	σ_y (MPa)	p (kg/m^3)
Wood Parallel to the Grain	13	50	700
CFRP	110	800	1550
Ceramics	86	1197	2485

Table 3.4 *Dimensions of Blade and Wind Speed (average values based on Fig. 1.2)*

2a (m)	2b (m)	L (m)	C_d (ellipse, turbulent)	v (m/s)
0.9	1.8	9	0.20	45

Table 3.5 *Geometric Values*

t (m)	A_s (m^2)	A_c (m^2)	I (m^4)	Z (m^3)
0.00079	16.2	0.003350	0.000396	0.000879
0.00159	16.2	0.006743	0.000797	0.001770

0.00635	16.2	0.026931	0.003181	0.007069

4.1.6 Final Values and Selection

Using the values from Tables 3.3, 3.4, and 3.5, along with the equations from section 2.1 (repeated here), the following calculations values can be determined. The final results are tabulated in Table 3.6.

Deflection: $\delta = (F_{wind} L^3)/(8EI)$

Wind Load: $F_{wind} = ½ \, p \, v^2 \, C_d \, A_s$

$F_{wind} = 4232$ N

Min. Yield Strength: $\sigma_{ymin} = (F_{wind} L)/(2Z)$

Table 3.6 *Final Values*

Material	δ (m)	σ min (Pa)	σy (Pa)	m (kg)
Wood Parallel to the Grain	-	-	5.00E+07	-
t1	7.50E-02	2.17E+07	-	21
t2	3.72E-02	1.08E+07	-	42
t3	9.32E-03	2.69E+06	-	170
CFRP	-	-	8.00E+08	
t1	8.86E-03	2.17E+07	-	47
t2	4.40E-03	1.08E+07	-	94
t3	1.10E-03	2.69E+06	-	376
Ceramics	-	-	1.20E+09	
t1	1.13E-02	2.17E+07	-	75
t2	5.63E-03	1.08E+07	-	151
t3	1.41E-03	2.69E+06	-	602

FINAL SELECTION: CFRP at a thickness of 0.79mm (t1)

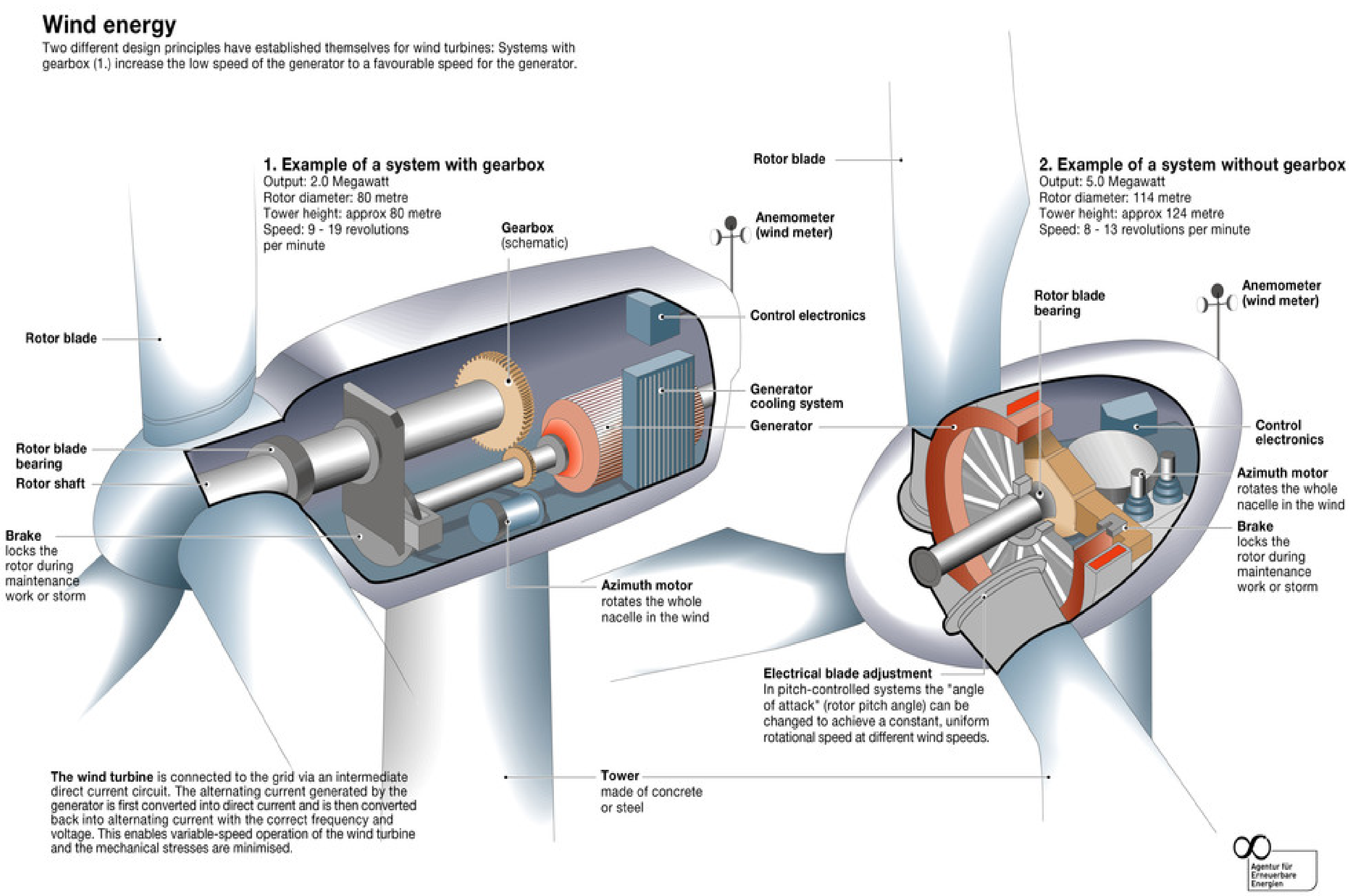
Based on a thorough analysis of the materials selected for a wind turbine blade, keeping in mind the primary objective of a light, stiff material that is also tough, **the best material available is CFRP** at a thickness of 0.79mm. CFRP, at 0.79mm thick, has a minimal deflection of 0.886cm, while allowing more control over its properties than wood and being tougher than ceramics. This selection is reinforced by the fact that CFRP is a typical and widely used material in the fabrication of today's wind turbine blades.

4.2 Generator

When looking at today's wind turbine designs we see that there are two main concepts in generating power. In both concepts they consist of a generator, the difference being uses a gearbox or direct drive. When breaking down both concepts we see many fundamental differences.

In Gearbox design, we typically see a 6 phase, 6 pole induction generator that requires 1500+ rpm synchronous speed in 50 Hz, while it requires 1800+ rpm synchronous speed in 60 Hz. These gearbox, work well in on-shore application as they are easy accessible and maintenance is not too much of a burden, however when looking at off-shore applications we see that the task is a bit more of a challenge and in return presents a higher cost. On the other hand, using gearboxes in off-shore applications isn't all bad. We see that in today's technology most applications do use gearboxes because they can produce such high voltage potential, increase the rpm up to synchronous speeds, and allow a wider range of wind speeds. Typically in induction generator with a gearbox we see a range of 1800-1860 rpm before having to put the turbine into stall phase. Although this may sound like an ideal design there are many flaws in using gearboxes and an ideal induction generator. For example, with gearboxes weight becomes an important fact which was not a problem on land. Increase weight, impacts the structure of the base which in turn increases the cost. When looking at an induction generator another burden that plays a role is a needed external excitation. This excitation roughly consumes about 20% of the power before being able to synchronous and pump out power to the grid. Another factor as mentioned above is maintenance. It costs a significant amount to have a skilled professional go out on a boat and climb up to perform maintenance or fix a problem. In all, there are positives and negatives in gearboxes that do allow the creation of power back onto the grid.

In direct drive designs, we typically see an excitation static generator, induction generator or a permanent magnet generator. In floating offshore designs it is more efficient to use a permanent magnet generator for direct drive because of its size and reliability. A permanent magnet generator is roughly 4 meters, compared to a excitation static generator which is 8 meters. When comparing an induction generator and its need for multiple poles to use such lower rpms it is inefficient to use. For example, an induction generator would need to use 80+ poles resulting in a bigger, more expensive, and less efficient generator. Therefore with the purpose of reducing the load, permanent magnet would be the ideal option in direct drive. Permanent magnet generators are relatively easy to manufacture and assembly with the rotor is cheaper compared to induction generators. Using permanent magnets also eliminate the need for brushes and external excitation sources. In direct drive permanent magnet designs, there is a 20% energy savings because of its self-excitation and losses across the gearbox are now disregarded. Permanent magnet generators allows for size reduce on the base, which reduces the cost of materials, and also is more reliable and longer lasting than most generators of equal power output. Another added benefit of direct drive is now gearbox maintenance can be ignored, resulting in further saving in commissioning, erection, and contingency. Although there are many pros for direct drive permanent magnet generators there are some down sides as well. Permanent magnet generators are more costly due to the market and its rare earth metals that create the magnetic field. Due to new innovations in the past two years, including reducing the size and efficiency, prices are slowly beginning to drop. As innovation increases and more permanent magnets generators hit the market they will drastically reduce in price. Another problem that could arise is the rotor becoming demagnetized thus resulting in a shift of the poles and lack of the creation of power. Because this technology is rather new, there is no case where this has happened yet, but it is always a small possibility. In all, there are solutions and challenges that direct drive permanent magnet generators give to the creation of power in offshore wind applications.



(4)

Power Generation	Maintenance (0.3)	Weight (0.3)	Initial Cost (0.2)	Efficiency (0.2)	Totals
Gearbox	5	4	6	6	5.1
Direct Drive	8	6	4	8	6.7

After using the decision matrix, the answer between direct drive versus using a gearbox is to go with the direct drive design. Although the direct drive route is initially more expensive, looking at the long term picture it is cheaper with only requiring two services a year. Direct drive also provides more reliability and a greater life span up to 20 years, while offering easier assembly during the erection phase of the project. Looking at the comparison of a gearbox with induction generator versus a direct drive permanent magnet generator, it is seen that permanent magnet generators offer the best solution to bring down cost with improved efficiency in the future.

When deciding what the generator would output the team used the equation $P=1/2\rho Av^3$. Calculating the area of 9 meter blades the clear choice was using two 100kW permanent magnet generators that cost's $14,240 for our two tower design. The specs of these generators are a start-up speed of 3m/s and a survival speed of 40 m/s with a weight of 2400 Kg each. These specs were designed to ensure a low start-up speed and making its survival speed was large enough that there were no safety concerns.

4.3 Tower

4.3.1 Turbine Tower

When designing an offshore wind turbine, all structural components are classified into one of three categories regarding safety. The classes are based on risk level for personal injury, pollution, economical consequences and negligible risk to human life. Because the tower can delay the entire construction of a turbine, and because it is such a large investment, it is must be designed according to the high safety class. The tower can fail due to fatigue, cracking, buckling, shearing, or stresses due to welding. A tree diagram of faults is pictured below.

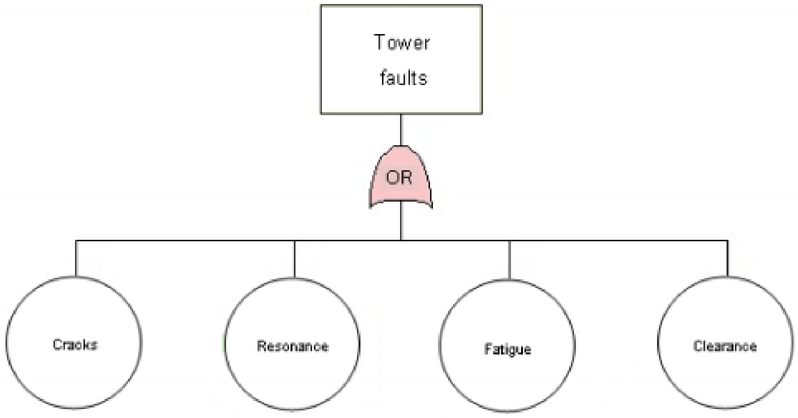


Figure 3.2.1 Tower Faults

4.3.2 Wind Turbine Tower Geometry

The most important function of the tower is to support the weight of the nacelle and the blades and carry the loads generated from the operation of the turbine. The structural components of the tower are very important and have significant effects on the systems performance and response. The general shape of any tower has a very high height to width ratio, causing this structural component to be the most sensitive to wind loading. For this project, two designs were considered: steel lattice tower and steel tubular column. These are pictured below:

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Figure 3.2.2 Photographs of lattice tower (left) and steel tubular tower (right)

Research was done on each of these designs and revealed the following. Lattice towers entail a specific assembly order to attain a specific structural strength and stiffness using the least amount of material. The steel is used most efficiently and results in a very light weight

tower. The ability to assemble this tower on site allows it to be used for extremely tall wind turbines. It has a lower initial cost than steel column towers but requires more maintenance due to its abundance of connections, which could become costly over time. Most existing wind turbines are built with steel columns. The advantages include the enclosed cavity which provides more shelter for maintenance work and electrical component housing, assembly efficiency and aesthetic impact. It has been established in the industry that the largest steel column diameter that can be transported is 4.3 meters in diameter; this would be the most significant reason to design a lattice structure over a steel tubular beam. Based on this information and the size of the turbine to be designed, the steel column was selected. The following section will explicitly depict the design process carried out for the wind turbine tower. The Design of Offshore Wind Turbine Structures OFFSHORE STANDARD DNV-OS-J101 was referenced to design the tower. According to this standard, "The design of a structural system, its components and details shall, as far as possible, satisfy the following requirements:
— resistance against relevant mechanical, physical and chemical deterioration is achieved
— fabrication and construction comply with relevant, recognized techniques and practice
— inspection, maintenance and repair are possible.
Structures and structural components shall possess ductile resistance unless the specified purpose
requires otherwise. Structural connections are, in general, to be designed with the aim to minimize stress concentrations and reduce complex stress flow patterns. As far as possible, transmission of high tensile stresses through the thickness of plates during welding, block assembly and operation shall be avoided. In cases where transmission of high tensile stresses through the thickness occurs, structural material with proven through-thickness properties shall be used." [2011 DNV pg 26]

4.3.3 Design of the Tower

American Society of Civil Engineers has published ASCE 7-10 Minimum Design Loads for Buildings and other structures. This code and methodology was adopted:

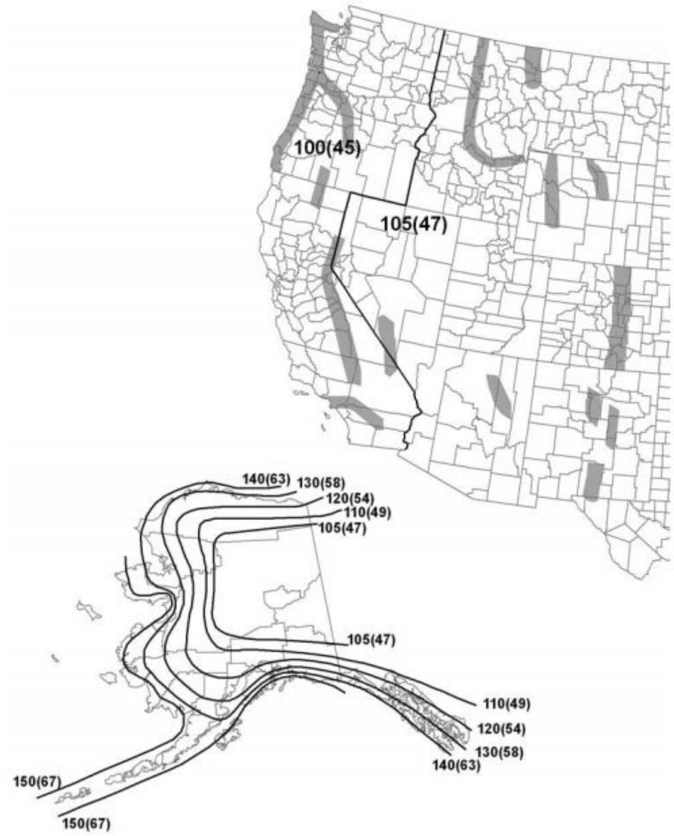
"Steps to Determine Wind Loads for Enclosed, Partially Enclosed and Open Buildings of All Heights

- **Step 1: Determine risk category of building or other structure, see Table 1.5-1**

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a] Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	IV

- **Step 2: Determine the basic wind speed, V, for the applicable risk category, see Figure**



26.5-1A, B or C

Figure 26.5-1C Basic Wind Speeds for Occupancy Category I Buildings and Other Structures.

- Step 3: Determine wind load parameters:
  - Wind directionality factor, Kd , see Section 26.6 and Table 26.6-1

Structure Type	Directionality Factor K_d*
Buildings **Main Wind Force Resisting System** **Components and Cladding**	 0.85 0.85
Arched Roofs	0.85
Chimneys, Tanks, and Similar Structures **Square** **Hexagonal** **Round**	 0.90 0.95 0.95
Solid Freestanding Walls and Solid Freestanding and Attached Signs	0.85
Open Signs and Lattice Framework	0.85
Trussed Towers **Triangular, square, rectangular** **All other cross sections**	 0.85 0.95

  - Topographic factor, Kzt, see Section 26.8 and Table 26.8-1

26.8.2 Topographic Factor

The wind speed-up effect shall be included in the calculation of design wind loads by using the factor K_{zt}:

$$K_{zt} = (1 + K_1 K_2 K_3)^2 \qquad (26.8\text{-}1)$$

where K_1, K_2, and K_3 are given in Fig. 26.8-1.

If site conditions and locations of structures do not meet all the conditions specified in Section 26.8.1 then $K_{zt} = 1.0$.

- Step 4: Determine velocity pressure exposure coefficient, Kz see Table 27.3-1

Table 27.3-1

Height above ground level, z		Exposure		
ft	(m)	B	C	D
0-15	(0-4.6)	0.57	0.85	1.03
20	(6.1)	0.62	0.90	1.08
25	(7.6)	0.66	0.94	1.12
30	(9.1)	0.70	0.98	1.16
40	(12.2)	0.76	1.04	1.22
50	(15.2)	0.81	1.09	1.27
60	(18)	0.85	1.13	1.31
70	(21.3)	0.89	1.17	1.34
80	(24.4)	0.93	1.21	1.38
90	(27.4)	0.96	1.24	1.40
100	(30.5)	0.99	1.26	1.43
120	(36.6)	1.04	1.31	1.48
140	(42.7)	1.09	1.36	1.52
160	(48.8)	1.13	1.39	1.55
180	(54.9)	1.17	1.43	1.58
200	(61.0)	1.20	1.46	1.61
250	(76.2)	1.28	1.53	1.68
300	(91.4)	1.35	1.59	1.73
350	(106.7)	1.41	1.64	1.78
400	(121.9)	1.47	1.69	1.82
450	(137.2)	1.52	1.73	1.86
500	(152.4)	1.56	1.77	1.89

Notes:

1. The velocity pressure exposure coefficient K_z may be determined from the following formula:

   For 15 ft. $\leq z \leq z_g$ — $K_z = 2.01\,(z/z_g)^{2/\alpha}$

   For $z <$ 15 ft. — $K_z = 2.01\,(15/z_g)^{2/\alpha}$

2. α and z_g are tabulated in Table 26.9.1.
3. Linear interpolation for intermediate values of height z is acceptable.
4. Exposure categories are defined in Section 26.7.

- Step 5: Determine velocity pressure qz or qh Eq. 27.3-1

Velocity pressure, q_z, evaluated at height z shall be calculated by the following equation:

$$q_z = 0.00256 K_z K_{zt} K_d V^2 \text{ (lb/ft}^2\text{)} \qquad (27.3\text{-}1)$$

[In SI: $q_z = 0.613 K_z K_{zt} K_d V^2$ (N/m²); V in m/s]

where

K_d = wind directionality factor, see Section 26.6
K_z = velocity pressure exposure coefficient, see Section 27.3.1
K_{zt} = topographic factor defined, see Section 26.8.2
V = basic wind speed, see Section 26.5

MATHCAD CALCULATIONS:

$K_d := 0.95 \quad K_{ZT} := 1 \quad Z := 66 \quad c_1 := 6.62 \quad c_2 := 1273$

$\alpha := c_1 \cdot Z^{-0.133} = 3.792 \qquad Z_g := Z^{0.125} \cdot c_2 = 2.149 \times 10^3$

$K_Z := 2.01 \left(\frac{Z}{Z_g}\right)^{\frac{2}{\alpha}} = 0.32 \qquad v := 160\text{mph} \qquad v_{up} := 50\text{mph}$

$q_{zup} := 0.00256 \cdot K_Z \cdot K_{ZT} \cdot K_d \cdot v_{up}^2 = 4.19 \frac{\text{ft}^2}{\text{s}^2}$

$q_z := 4.19 \frac{\text{lb}}{\text{ft}^2}$

4.3.4 Materials for Wind Turbine Tower

Steel Design

Due to the combined Flexural and Axial Loading, the Column and Chapter H sections were referenced in the AISC Steel Manual.

$$Axial_{load} = 1.692 \times 10^{4}\,lb$$

$$D_{Rotor} := 30ft$$

$$A_{Rotor} := \left(\frac{\pi}{4}\right)\left(D_{Rotor}^{2}\right) = 706.858\,ft^{2}$$

$$P_{Rotor} := A_{Rotor} \cdot q_z = 2.962 \times 10^{3}\,lb$$

$$D_{out} := 24in$$

$$D_{in} := 23in$$

$$t := 0.50in$$

Steel Selection

A618 Grade I

$$F_y := 50ksi$$

$$F_u := 70ksi$$

$$E := 29000ksi$$

$$1ksi = 1 \times 10^{3}\,psi$$

$$A_1 := \pi \frac{\left(D_{out}^{2} - D_{in}^{2}\right)}{4} = 0.256\,ft^{2}$$

Torsional Shear Constant

$$C1 := \pi \frac{\left(D_{out} - t\right)^2}{2} = 6.024\,ft^2$$

Polar Moment of Inertia

$$I_1 := \pi \frac{\left(D_{out}{}^4 - D_{in}{}^4\right)}{64} = 0.123\,ft^4$$

Radius of Gyration

$$r_1 := \left(\frac{I_1}{A_1}\right)^{\frac{1}{2}} = 0.693\,\text{ft}$$

Effective Length Determine using Table C-A-7.1

$$K_1 := 0.6$$

Laterally Unbraced Length

$$L_1 := 792\text{in}$$

$$\text{Slender}_{\text{Ratio1}} := K_1 \cdot \frac{L_1}{r_1} = 57.181$$

$$F_{e1} := \frac{\left(\pi^2 \cdot E\right)}{\text{Slender}_{\text{Ratio1}}{}^2} = 8.754 \times 10^4\,\text{psi}$$

$$F_{cr.Axial1} := \left(0.658^{\frac{F_y}{F_{e1}}}\right) \cdot F_y = 3.937 \times 10^4\,\text{psi}$$

$$P_{n1} := F_{cr.Axial1} \cdot A_1 = 1.453 \times 10^6\,\text{lbf}$$

Axial Load According to LRFD

$$\text{AXIAL}_{\text{LRFD}} := \text{Axial}_{\text{load}} \cdot 1.6 = 2.707 \times 10^4\,\text{lb}$$

The Critical Axial Load is greater than the required Axial load.

$M_{max} := 200 kip \cdot ft$ M.max was calculated by Hand

$$S := \pi \frac{\left(D_{out}^{4} - D_{in}^{4}\right)}{32 D_{out}} = \blacksquare$$

$$1 in^{3} = 4.329 \times 10^{-3} gal$$

$$Mn := \left[F_y + \frac{(0.021E)}{\left(\frac{D_{out}}{t}\right)}\right] \cdot 212.52 in^{3} = 3.572 \times 10^{7} \frac{ft^{2} \cdot lb}{s^{2}}$$

$$\phi M\_n = 0.9 \left[F_y + \frac{(0.021E)}{\left(\frac{D_{out}}{t}\right)}\right] \cdot 212.52 in^{3} = 1000 \text{ kip -ft}$$

<u>The designed max moment is substantially greater than the required moment.</u>

4.3.5 Final Values and Selection

The A616 Grade1steel column will be 66 feet tall with a diameter of 2 feet. The wall thickness is .5 inches, and it weighs 8,635 pounds.

4.4 Foundation

4.4.1 Deck

The metal decking used was selected for weight, cost, and usability. Not structural support. Accessibility for maintenance crews was the main concern.

4.4.2 Sub-Deck

The sub-deck rests on the truss framing and is made of W-shape beam members. This slab is continuously welded to 2.5 inch cap plate members on the truss framing. It was designed to translate the weight of the tower and the bending moment caused by wind hitting the tower to the truss frame below.

Dead Load = Weight of Wind Turbine
Design Dead Load = 200 psf which was determined using ASCE7 for Industrial Floors.
Max Moment = 403 kip-ft and was determined from the moment diagram.

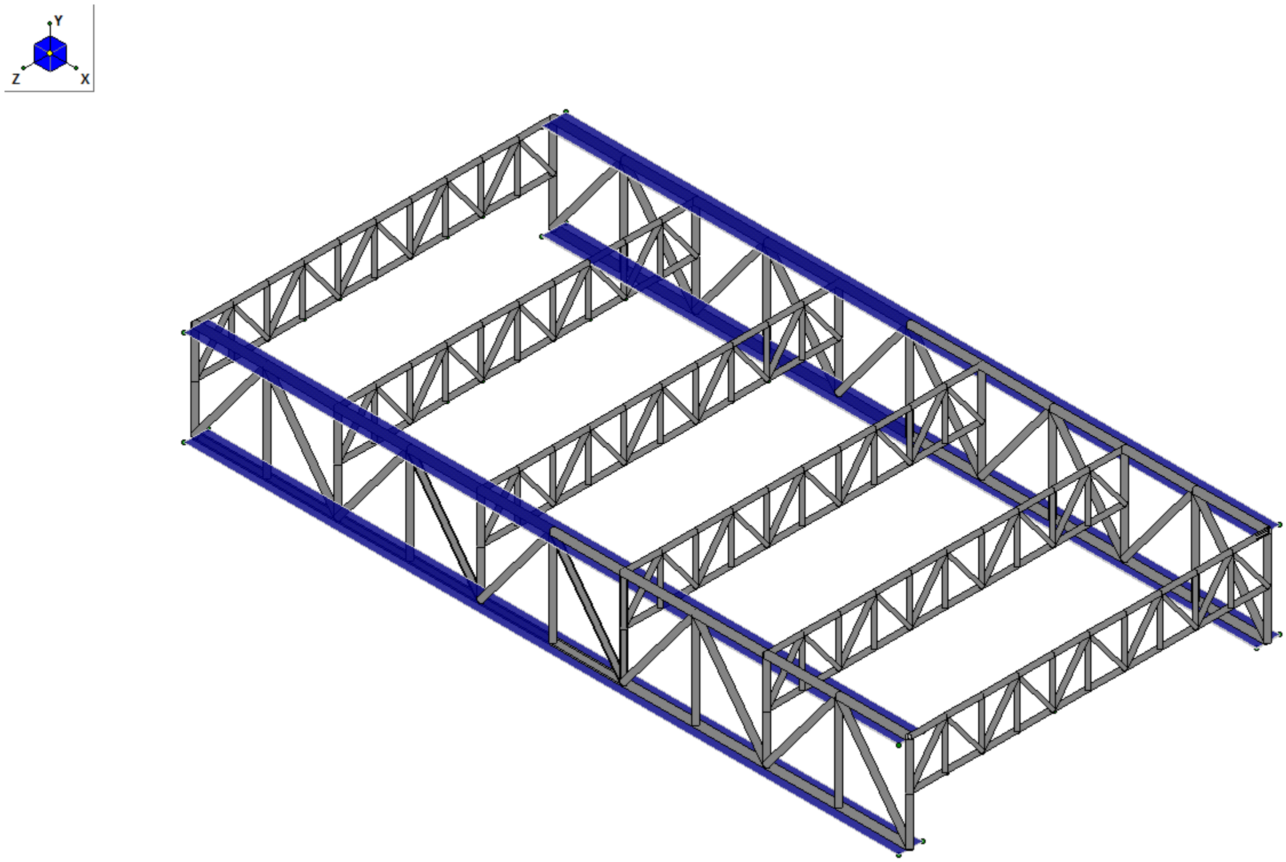
The supporting beam chosen for the deck is a W21x111. The steel chosen has a yield strength of 50 ksi. The Beam was chosen from Table 3-10 in the AISC Steel Manual. The beam is capable of holding a design load of 810 kip- ft. This provides a safety factor of 2 which is within the standard range of 1.5-3 for vessels.

Deck Beams weigh 252 kips
Allowable Deck weight including floor is 1000 kips.

4.4.3 Truss Framing

The structural support of the turbine is comprised of a truss framing system and a sub-deck. The framing was designed, taking into account dead and live loads, for strength and fatigue. The live load due to wind hitting the blades and tower is the governing load on the framing and created a large strength requirement. Loads on the lateral bracing are due to ocean waves, thus, bracing trusses were designed for fatigue.

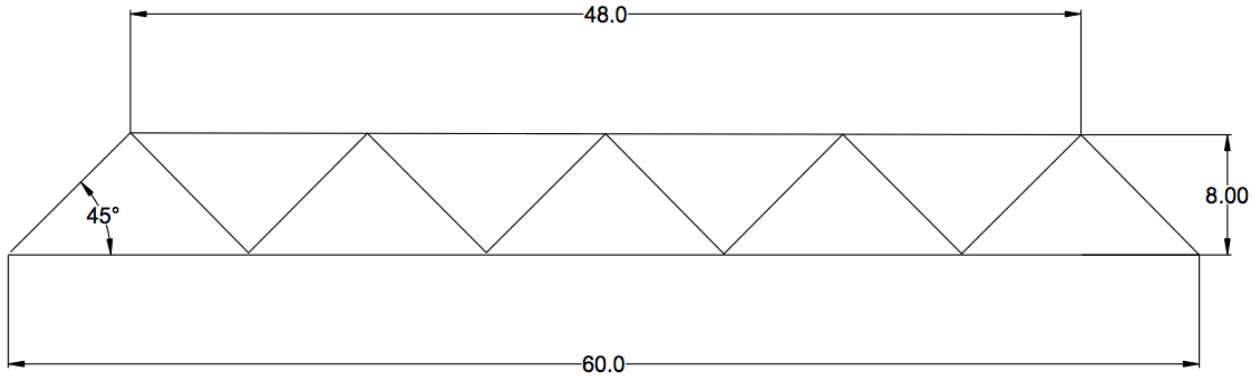
The truss frame system includes two parallel beam-trusses with six lateral bracing trusses. The trusses are comprised of circular tube structural members and are pin connected. Each Beam-Truss is capped by a 2.5 inch plate. The framing is connected to both the pontoons and deck by continuous welds with the cap plates, which are continuously welded to the sub-deck and pontoons.



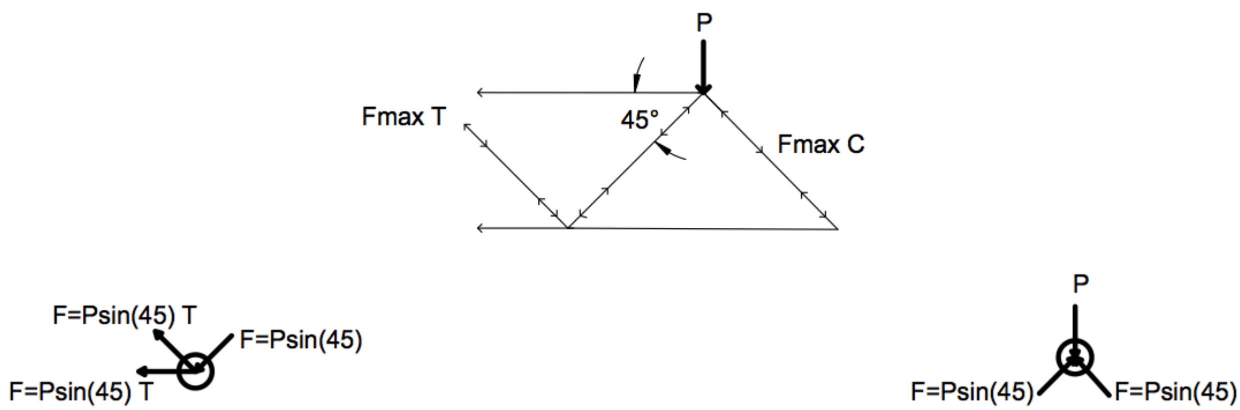
This diagram shows the support trusses and truss bracing supporting the deck and turbine. The beam-trusses rest directly on the pontoons. The bracing trusses support the structure against lateral translation and deflection. The truss design is Warren B configuration.

The beam-trusses are comprised of round HSS16x0.625 members while the truss braces are round HSS5x0.25 members. The steel used for both is A500 Grade B steel with yield stress, Fy=42ksi, and fracture stress, Fu=58ksi. The cap plates are 2.5 inches thick using A36 steel with yield stress, Fy=36ksi, and fracture stress, Fu=58ksi.

Below lies a diagram of the beam-trusses. (The bracing trusses are proportionally 1/10th the dimensions of the beam-trusses.)



Below are the free body diagram analyses accounting for the weight of the members above the support frame.



Support Framing Member Design

Design a circular HSS Shape for Mmax = 397 kip-ft Pmax = 455 kips AISC Requirements: where K=0.65 L=20ft Using A500 Grade B Steel with Fy=42ksi and Fu=58ksi

(as recommended for rectangular HSS shapes) LRFD: Mu < ϕMn *In AISC Table 3-15 Try*

HSS16x0.625

397 kip-ft < 435 kip-ft (ok)

Check For adequacy In:

Pu < ϕPn Effective Length:KL=(0.65)(26ft) = 17 ft

In AISC Table 4-17 for HSS16x0.625

455 ksi < 1240 ksi (OK)

Compression Analysis:

Slenderness ratio: KL/r=0.65(26x12)/5.46= 37.1 < 200 (OK) KL/r < 4.71(E/Fy)^1/2 37.1 < 4.71(29,000/46)^1/2 37.1 < 118.3

Fy/Fe < 2.25 42/208 < 2.25 0.20 < 2.25 (OK)

Tension Analysis:

Yielding:

Pn = Fcr Ag =(38.6)(28.1) = 1085 kips ϕPn = 0.9(1085) = 977 kips > 455 kips (OK)

Fe=208 ksi Fcr=38.6 ksi

Pn=FyAg=42ksi(28.1in^2)=1180kips ϕPn=0.9(1180kips)= 1062 kips > 455 kips (OK)

Fracture: Pn=FuAe

Pn=(58ksi)(3.275in^2) =189.95 kips

where, Ae=AgU Ae=0.625(5.24in^2)=3.275 in^2

ϕPn=0.75(189.95kips)=142.5 kips > 128 kips (OK)

U=1-0.375=0.625

Use HSS16x0.625 shape @ 103 lb/ft (self weight) For bracing Use HSS5x0.250 shape @ 12.69 lb/ft

Weight Analysis:

30members @ 26ft @ 103lb/ft + 75members @ 4ft @ 12.69lb/ft = 84.1kips

4.4.4 Pontoon Design

The Pontoons are the main component to a stable platform. In order to increase stability, the pontoons have been designed to have a buoyancy ratio of 1.5 : 1. This ratio allows the Pontoons to be able to successfully float a load equivalent to half the weight of the entire structure. This buoyancy tolerance allows for the pontoons to be ballasted. The ballast allows the pontoons to take on water as needed to adjust the overall buoyancy of the structure. For example, by taking on water, the overall structure's center of gravity will be lowered which provides a structure that is more resistant to the overturning moment. By pumping out the water and decreasing the overall weight of the structure, the structure sits higher in the water, thus reducing drag. This will allow the structure to move through the water more efficiently.

The Buoyancy equation was the controlling design parameter that must be met. The formula below indicates that a positive number results in a floating number.

Buoyancy = (Weight of displaced fluid) - (Weight of structure)

The Pontoon's Diameter were determined first by calculating the weight of the deck structure including the Wind Turbine and the allowable deck loading. Once the deck weight was determined, the amount of needed displaced water could be calculated. From this point, the method of guess and check was utilized to determine the pontoon diameter. Guess and check was chosen due to the change in pontoon weight as diameter changed. After optimization the following parameters and dimensions were defined and calculated for the pontoon using the below method.

Total Deck Weight = 1286 kips $Deck_{weight} := 1286kip$ $Deck_{weightmetric} := 590000kg$

$Water_{density} := 1000 \frac{kg}{m^3}$ $Steel_{Density} := 7800 \frac{kg}{m^3}$ $Pontoon_{Length} := 60m$

$Pontoon_{Thickness} := 0.0254m$

Volume of water needed to diplace Weight of Deck = 590 m^3

In order to displace this required volume of water the pontoon would need to have a diameter of 3.54m

Assume Diamter is 4m to determine the weight of the steel in the pontoon.

Volume of steel =9.55m^3

Weight of Steel =75000 kg

Volume of Required Displaced water =75 m^3

Total Required Displaced volume =665m3

Total Volume Displaced (For 1 Pontoon) = 745m^3

Buoyancy = (Weight of displaced fluid) - (Weight of structure)

Buoancy = (1000kg/m^3)(745m^3) - (590000kg + 75000 kg) = 230,000kg

Total Buoyancy for vessel = 1,050,000 kg

The vessel has approxiamte Buoyancy ratio of 1.5 to 1. It can be concluded that the vessel is positvely Boyant and thus will float.

One of the biggest contributors to the innovation of this turbine is the self-propelling propulsion system attached to the swath of the foundation. To start, a general understanding of the system needed to clear so a free body diagram was necessary. The figure below shows a free body diagram of how this issue was executed. Summing the forces in the horizontal direction is essential.

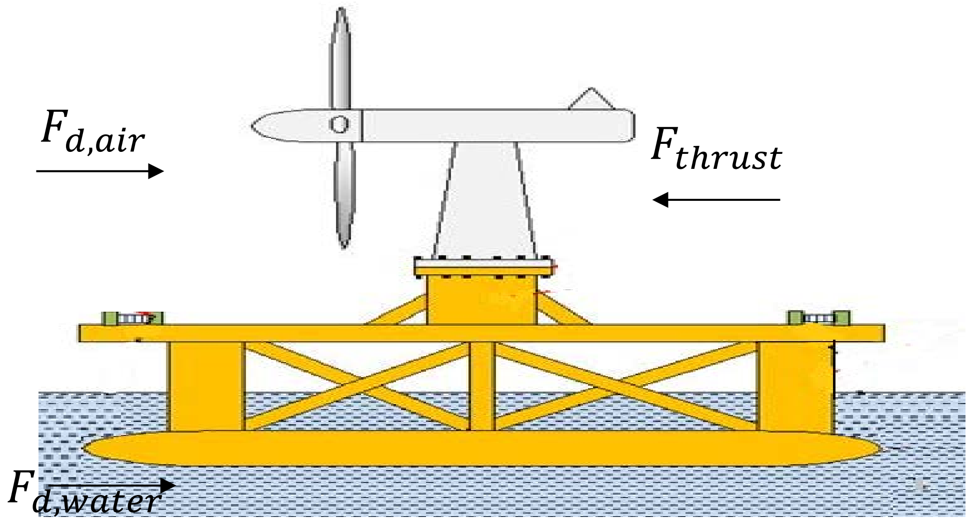


Figure 1 – Free Body Forces Breakdown

According to the figure, the amount of thrust forces needs to overcome all of the drag forces that are acting against it. Friction is another force and factor in this computation but it is so minimal that the component can be negated and assumed to be zero. From here the drag forces need to be calculated. The formula for analyzing drag forces is based on the equation:

$$F_d = \frac{1}{2} C_d v^2 A_c p \qquad \text{(Equation 1)}$$

Therefore, based on the free body diagram:

$$F_{thrust} = F_{d,total} = F_{d,air} + F_{d,water} \qquad \text{(Equation 2)}$$

Based on the final detail design for the full scale model, the following key parameters are used in order to calculate this equation. The traveling velocity of $5\ \frac{m}{s}$ was arbitrarily decided in order to perform these calculations. The speed at which the turbine travels is not a concern as long as it reaches its destination point. The table compares these parameters through thorough research or internal calculations based on the final design. Cross sectional areas were calculated based on the detail final designs of the foundation and structure, towers, hub/nacelle, and finally blades. The table is primarily set to evaluate and compare the major parameters between the air and the water. In other words, these components will reveal the most significant factors that go into the equation above.

Table 1 – Free Body Forces Breakdown

	Air	Water
Drag Coefficients	1.0	0.5
Fluid Density	$1.225\ \frac{kg}{m^3}$	$1000\ \frac{kg}{m^3}$
Cross Sectional Area	$118.2\ m^2$	$13.366\ m^2$

After researching and analyzing these parameters, it is very clear that drag force of the water is exponentially bigger than the drag force through the air. Clearly, the main contributing factor is the huge difference in the fluid density. Since the factor of the density of water is about 1000 times greater than air, this plays a huge factor in the calculations. The full calculations for this analysis are shown below using Mathcad software.

THRUST REQUIRED FOR WIND TURBINE SWATH

$F_{thrust} = F_{d\_air} + F_{d\_h20} + F_{fric}$ $V := 5\,\frac{m}{s}$ $F_{fric} := 0$

ABOVE WATERLINE

$\rho_{air} := 1.225\,\frac{kg}{m^3}$ $C_{d\_above} := 1.0$

Area 1) $t_{deck} := 1m$ $d_{tower} := 2m$ $w_{outside} := 1m$

$$\boxed{A_{1a} := t_{deck}\cdot(20m + d_{tower} + 2\cdot w_{outside}) = 24\,m^2}$$

Area 2) $h_{tower} := 20m$

$$\boxed{A_{2a} := h_{tower}\cdot d_{tower} = 40\,m^2}$$

Area 3) $r_{blade} := 9m$ $face_{blade} := 0.25m$

$$\boxed{A_{3a} := r_{blade}\cdot face_{blade} = 2.25\,m^2}$$

Area 4) $h_{above} := 4m$ $w_{above} := .1m$

$$\boxed{A_{4a} := h_{above}\cdot w_{above} = 0.4\,m^2}$$

$$A_{frontal\_above} := A_{1a} + 2\cdot A_{2a} + 6\cdot A_{3a} + 2\cdot A_{4a}$$

$$\boxed{F_{d\_air} := \frac{1}{2}\cdot\rho_{air}\cdot V^2\cdot C_{d\_above}\cdot A_{frontal\_above} = 1.811\cdot kN}$$

BELOW WATERLINE

$\rho_{h20} := 1000\,\frac{kg}{m^3}$ $C_{d1} := 0.4$ $C_{d2} := 0.1$ $C_{d\_below} := C_{d1} + C_{d2} = 0.5$

Area 1) $d_{swath} := 2m$

$$A_{1b} := 2\frac{\pi\, d_{swath}^{2}}{4} = 6.283\,m^{2}$$

Area 2) $h_{below} := 4m$ $w_{below} := .1m$

$$A_{2b} := h_{above} \cdot w_{above} = 0.4\,m^{2}$$

$$A_{frontal\_below} := 2A_{1b} + 2 \cdot A_{2b} = 13.366\,m^{2}$$

$$F_{d\_h20} := \frac{1}{2} \cdot \rho_{h20} \cdot V^{2} \cdot C_{d\_below} \cdot A_{frontal\_below} = 83.54 \cdot kN$$

TOTAL THRUST REQUIRED

$$F_{thrust} := F_{d\_air} + F_{d\_h20} + F_{fric} = 85.351 \cdot kN$$

$$F_{thrust} = 19187.732 \cdot lbf$$

TOTAL POWER REQUIRED(2 engines)

$$Power := \frac{F_{thrust}}{2} \cdot V = 286.145 \cdot hp$$

$$Power = 213.378 \cdot kW$$

After compiling and analyzing all of the calculations, it has been determined that the total amount of power that is needed to move the turbine out to its designated location is about two 286 HP motors. Knowing this, a 300HP Lincoln 1800 RPM three phase motor has been selected.

Figure 2 – Motor Selection

This motor was selected for several reasons. Most importantly, it produces the amount of power that will be needed to transport the entire system. Although the cost of this motor seems very expensive, this model in particular is much more cost effective compared to other existing 300 HP competitors. Another great aspect of this model is that it is a TEFC motor. TEFC stands for "Total Enclosed Fan Cooled" motor. The primary purpose of a TEFC is its ability to protect from environmental effects over a long period of time. It is commonly used in ordinary industrial situations. It offers tremendous protection against common hazards. The fan that is located in the back of the shaft is covered by the housing. It brings in air over the fins of the motor. At this stage, excess heat is removed and cooling occurs. This model also contains a water as well. It weighs approximately 3000 pounds by the structural design for the full scale model is able to absorb and support over a million pounds. An electric motor was a team decision to go with because of its self-sustaining power capability as well as environmentally friendly effect on its surroundings.

4.5 Autonomy

When looking at the wind turbine industry today there have been many different innovations to improve the product as a whole. From new generator concepts to the latest in blade designs, the wind power industry has accelerated faster than anyone could have imagined. Although these concepts are great improvements, there is a new idea that can revolutionize the way man-kind produces power. The future is autonomy, particularly in autonomous off-shore wind turbines.

When deciding how to control the autonomy, there are a ton of different aspects one must take into consideration, especially because of the high voltage electric motor being used. To help motel how the autonomy would be manufactured, Tesla's model of how they communicate with their motor was used.

In the autonomy package there are four main components: GPS, Power Stage, Controllers, and the filter stage. The language that is being used will be C programming and assembly to help make communication more efficient.

The first component GPS is the main way, to communicate with the wind turbine and tell it where to go. The high level model of how this will work is a communication hub on land will send a signal to the wind turbine, and the hardware onboard will interpret the signal. From here the controller gives the motor instructions and navigated the wind turbine to its desired location.

Next is the power stage, one of the more complex components. The power stage is made of large semiconductors switch arrays. The switches will be composed one square inch by a quarter inch thing silicon insulated gate bipolar transistors (IGBTs). These arrays are the connected to the grid port or the motor depending whether the wind turbine is in commissioning or operation. Within each array, there will be more switches grouped into three pairs of half bridge rectifiers. During commissioning each of these bridges form a phase, and are connected to each phase of the 3-phase permanent magnet motor. During, operation however, there will only need to be two of these bridges active because there are only two ports in the AC line. To switch between operation and commissioning phases four relays will be used. These relays allow the switches to be connected to either the grid or connected to the motor.

The second largest component is the controllers on board. There are two types of controllers used: the digital signal processor (DSP) and the safety processor (SP). These controllers turn the switches on and off, up to 32,000 times per second. In this model the DSP is the primary controller, while the SP is the secondary. The DSP controls the torque and charge behavior of the motor and grid operation, while the SP monitors the current consistency, and other issues that need to be sent back to the communication hub.

The last component is the filer stage. The filter stage helps filter out the noise created by all the electronics. For instance, a large amount of the electrical noise is created during the power stage, and if this noise was to conduct back into the power lines it could interfere with the GPS, and other signals being sent onboard. If this problem was to occur, the wind turbine would essentially not know where it is. To create the filter, inductors will be placed between the IGBTs and the different port to avoid any interference.

The language that is being used will be C programming and assembly to help make communication more efficient.

5.0 Risk, Reliability, Environmental, & Safety Assessments

Potential risks and reliabilities are one of the most important factors that were taken into account when coming up with the final design for the offshore wind turbine. One risk that needs to be accounted is making sure that the blades will be stalled upon transporting out to the desired location. Not only this, but making sure that the transport period is under safe and steady wind conditions. Strong winds such as during hurricanes and tropical storms could create a very disruptive installation period. However, this judgment is something that can easily be projected and determined ahead of time so the decision should be relatively easy. One of the biggest features that has been introduced is making this structure completely autonomous, allowing the turbine to propel itself out to the desired location in deep water and being able to return to its original dock location. Comparing to existing technologies, this idea does not exist yet and we were asked to come up with an innovative design that appeals to customers but still finds a way to reduce total lifetime costs of the turbine. By doing this, installation costs have greatly reduced since the turbine will be programmed to propel out to the desired distance and be able to stay in that particular location. Installing turbines on mainland are much cheaper than in deep waters simply because oh how convenient it allows field workers to perform their day-to-day tasks. Not only this but maintenance costs have drastically decreased as well and will allow troubleshooting and rework to become much more accessible. By implementing autonomy, manufacturing companies will not have to pay field service workers to transport out to deep water and fix this turbine on site.

Obviously, the main purpose for wind turbines is to created large power output that is environmentally sustainable. The biggest and most positive aspect about this technology is that although initial costs are very expensive, the wind turbine will more than pay off itself during it's entire estimated 25-30 year lifespan. This project is by far one of the more environmentally friendly that was offered from the FAMU-FSU College of Engineering. From a safety perspective, having an offshore wind turbine establishes a far less concern due to how far this is located off mainland. Based on the structural analysis, the foundation is able to hold an enormous amount of weight while still being able to float. Another great asset of the catamaran design is it's able to fight against strong wave loadings and currents. This greatly reduces the safety concern because the foundation is made to handle strong forces. Because of this, large boating manufactures and military and defense contractors have gone with this design because of how successful the material performs in deep water situations.

6.0 Design for Manufacturing of Prototype

It is not feasible to construct a full-scale version of our offshore wind turbine design; therefore we must scale-down the detailed designs from section 3.0, Design and Analysis, and use these scaled designs to fabricate and build a scaled-down version of the offshore wind turbine. In some cases, the materials and connections used must also change to accommodate the scaled-down version (and our budget).

6.1 Turbine Blades

The scaled-down version of the turbine blade more closely resembles the blade of a boat paddle than that of a full-scale wind turbine blade. This is due primarily to two factors: 1) the cost to fabricate, and 2) the ability to fabricate the scaled-down blades. The fabrication techniques available to us are limited and are not well equipped to manufacture a turbine blade with the intricacies and complexities of design that are found in typical full-scale blades. An alternative would be to purchase blades that could be used for a scaled-down version, such as ours, but we'd prefer to make our own. Currently, we are planning to fabricate the turbine blades with a 3D printer. See Figure 5.1 and Table 5.1 for details.

Table 5.1: Turbine blade dimensions

Length (in)	Thickness (in)	Maximum Width (in)	Material
8	1/8	5	ABS Plastic

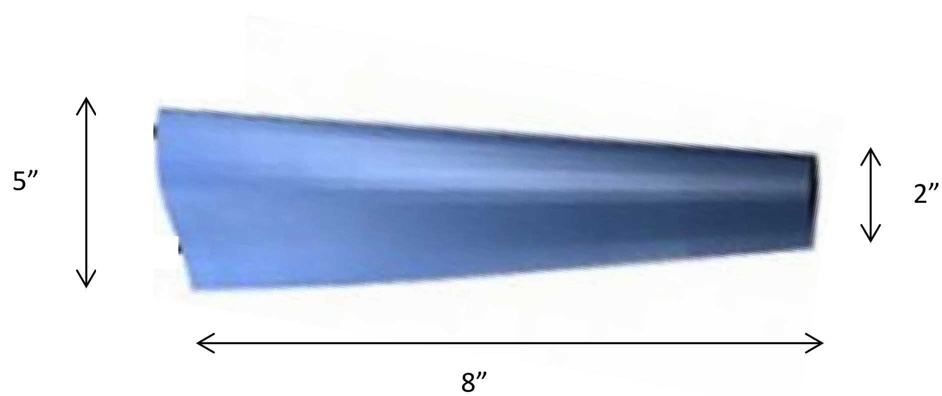


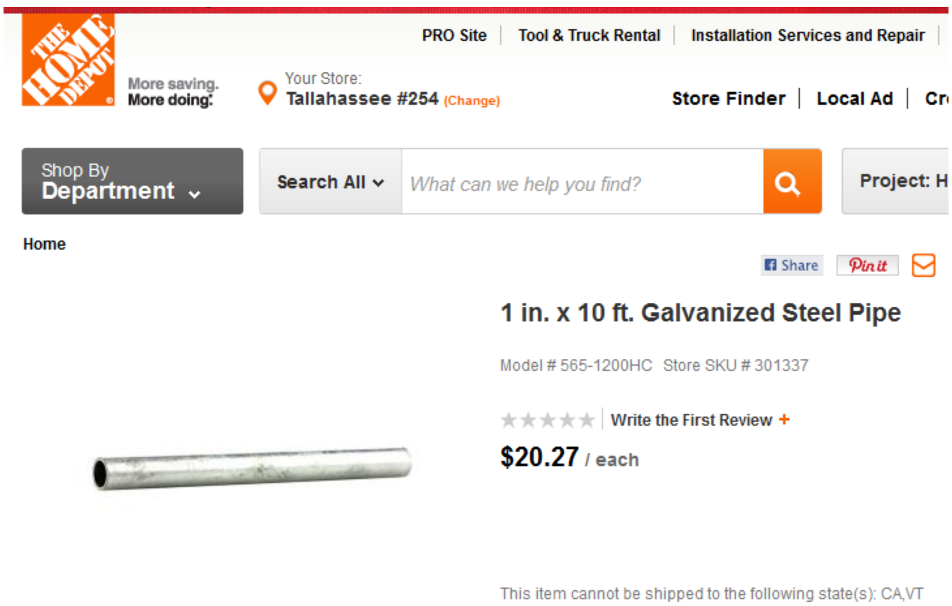
Figure 5.1: Turbine blade dimensions

6.2 Generator

Scaling factors with the production of energy will limit the ability to replicate the output of the large scale design. The prototype in this regard will use a small generator provided by the sponsor.

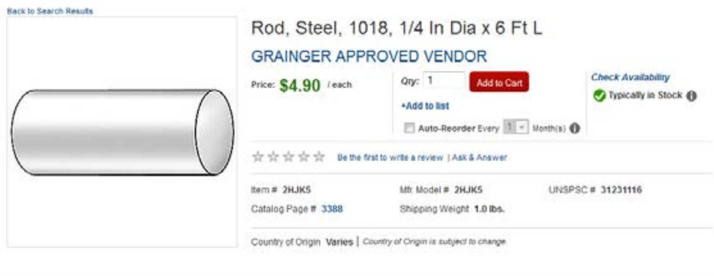
6.3 Tower

The Tower will be made utilizing the galvanized steel pipe as shown below from Home Depot. The construction of the tower will require one 10 foot galvanized pipe that cost $20.27. The pipe will be cut using the metal saw in the machine shop to the appropriate scaled dimensions. The tower will then be pinned/bolted to the deck. The overall process should take between 3-4 hours. The construction includes scheduling the shop time, cutting of material, welding pinned connection pieces and inspection of tower.



6.4 Foundation

The supporting structure of the deck will utilize 1/4" carbon steel rods obtained through Grainger. The rods have a strength capacity of 55,000psi, which will far exceed the required strength for the scale model. The truss decking and supports will need approximately 60 feet of steel rods. The 6' rod section cost $4.90. 15 rod sections will be purchased to accommodate the deck and expected welding errors. The construction process is expected to be 10 hours. The construction includes scheduling the shop time, cutting of material, welding truss connection pieces and inspection of deck and support columns.



The deck flooring which provides very little support strength will consist of steel diamond mesh obtained from Grainger at a cost of $8.30 a piece. The floor will require two pieces that will be tack welded to the support deck. The total construction time is estimated at 2-3 hours. The construction includes scheduling the shop time, cutting of material, tack welding mesh to deck and inspection of floor.

The pontoons will be constructed using PVC piping. The overall diameter will be determined once structure is built. It is pertinent to know the weight of the scaled structure before picking an appropriate pipe. The estimated diameter of the pipe is 4 inches. The pipe will come at no cost since it is being donated. The estimated time construction of the pontoons is 4-5 hours. This includes assembling the connections and inspection of the pontoon.

6.5 Motors

In terms for the prototype model next semester in the spring, similar calculations were performed. These calculations were simply scaled down to the approximate size that the prototype will be based on the scope of the project that was established in August 2013. The two main parameters that are affected by this scaling is obviously the frontal area for both above and below the waterline as well as the traveling speed that the turbine will be moving to reach its final destination. The general size of the prototype should be able to fit on a table so the frontal area was scaled down by a factor of 1/80. Similarly, the traveling velocity is to be scaled down by a factor of 1/10. By doing this, the amount of thrust needed to propel the entire turbine can be computed and evaluated. The table below shows this comparison between this full scale and prototype model:

Table 2 – Comparison from Full Scale to Prototype Parameters

	Full Scale	Prototype
A_c above waterline	13.36 m	0.167 m
A_c below waterline	118.3 m	1.478 m
Traveling Velocity	$5\ \frac{m}{s}$	$0.5\ \frac{m}{s}$
Thrust Power	Two 286 HP Motors	Two 0.036 HP Motors

Based this table, the amount of thrust need to propel this motor is determined. As a result, the following motor has been selected. This product was selected because it is a very common and excellent quality motor for RC Electric Boats. Also, in terms of procurement, this product is very common in almost every store so the lead time would be extremely minimal. The expected lead time should be no more than a 10 business days if they were to be ordered offline.

Final Selection: Stinger 20-Turn Motor

Figure 2 – Motor Selection for Prototype

Table 3 – Cost Breakdown between Full Scale and Prototype

	Cost	Quantity	Total Cost
300HP LINCOLN 1800RPM 449TS TEFC 3PH MOTOR (Full Scale)	$9,199.00	2	$18,398.00
Stinger 20-Turn Motor (Prototype Model)	$19.00	2	$38.00

7.0 Procurement & Budget

Procurement of required materials must be processed through the civil department of the FAMU-FSU College of Engineering. In order to streamline the process and stay on the specified schedule, a materials list including price quote, and distributor will be submitted to the Civil Department (Specifically Rosa Booker). This will allow the submission to be processed over the winter break. The process takes approximately three weeks. The material requested will then be available the first week of the spring semester (January 6-10, 2014). This is pertinent in order to start the construction of the wind turbine as scheduled.

The following list provides the materials requested, the material purpose, the dispenser, the unit price, and the estimated material cost.

Component	Item	Distributor	Unit Price ($)	Quantity	Cost ($)
Tower	1" Galvanized Pipe	Grainger	20.27	1	20.27
Decking	1/4" steel rod	Grainger	4.90	15	73.50
Floor	Mesh Screen	Home Depot	8.30	3	24.90
Pontoon	PVC Pipe	ASCE	Donated	1	0.00
Blades	Blade	Hobby Town	3.00	3	9.00
Electrical Components/Motor	--	Hobby Town	500.00	1	500.00
Protection/Sealant	Hydro-Dipping	Precision-Hydro	400.00	1	400.00
Generator	Generator	Sponsor	Donated	2	0.00
			Total Approximate Cost:		1027.67

From the table, an approximate total cost of $1027.67 has been budgeted for construction. This value is well within the $2000 budget provided by the sponsor. Unaccounted miscellaneous items will be purchased or obtained by donations on an as need basis.

The decking, floor and Tower will need to be welded. Once the supplies have arrived, an appointment will be setup with the machine shop to complete the welding. The machine shop will weld the trusses together according to shop drawings provided.

8.0 Communications

Communications are an essential part to working together as a group, as well as, keeping in good contact with advisors. Especially with three different disciplines, staying in touch and up to date is important. Within the group, there is a communal Dropbox, email folder, and group text, to ensure everyone is on the same page. We also meet for two hours (longer if necessary) every week. The communications with advisors include a weekly meeting with Dr. Amin, Dr. Jung, Dr. Frank, and Dr. Shih. We communicate with these professors primarily through email. Also individual meetings with advisors are scheduled as needed. The group meets with the main advisor, Dr. Jung for an hour every other week to stay on track and ensure adherence to the expected outcomes. Furthermore, despite a slow start, the offshore wind turbine group has found a productive system of communication and will continue this imperative trend.

9.0 Conclusions

In conclusion, the main purpose of the design project is to design a wind turbine that can fully function and operate offshore. The design project was composed of many different concepts, several of which innovate the wind turbine industry. The biggest contribution that was added was a dimension of autonomy. Autonomy allows the floating turbine to self-navigate to its selected location as well as self-orient when needed. With the final design selected and the process of detailed design complete, all that is left is the prototype. With the prototype it will demonstrate how the autonomy concept would work, as well as how it could function as a whole. The other main component in demonstration will be power generation. The prototype will also be built to demonstrate how power generation will be accomplished. In all this project bring a great piece of innovation to the offshore wind industry, and can be used in the future to change the way the world generates power.

10.0 Environmental and Safety Issues and Ethics

The environmental issues associated with this design are negligible as they are limited to the turbines affecting the flight path of birds. No other environmental impacts have been considered. Safety issues have been addressed by designing a safe ascension system for maintenance workers with harness line attachment points en route to the turbine. In addition, this design addresses the need for renewable turn switch power in an ethical manner.

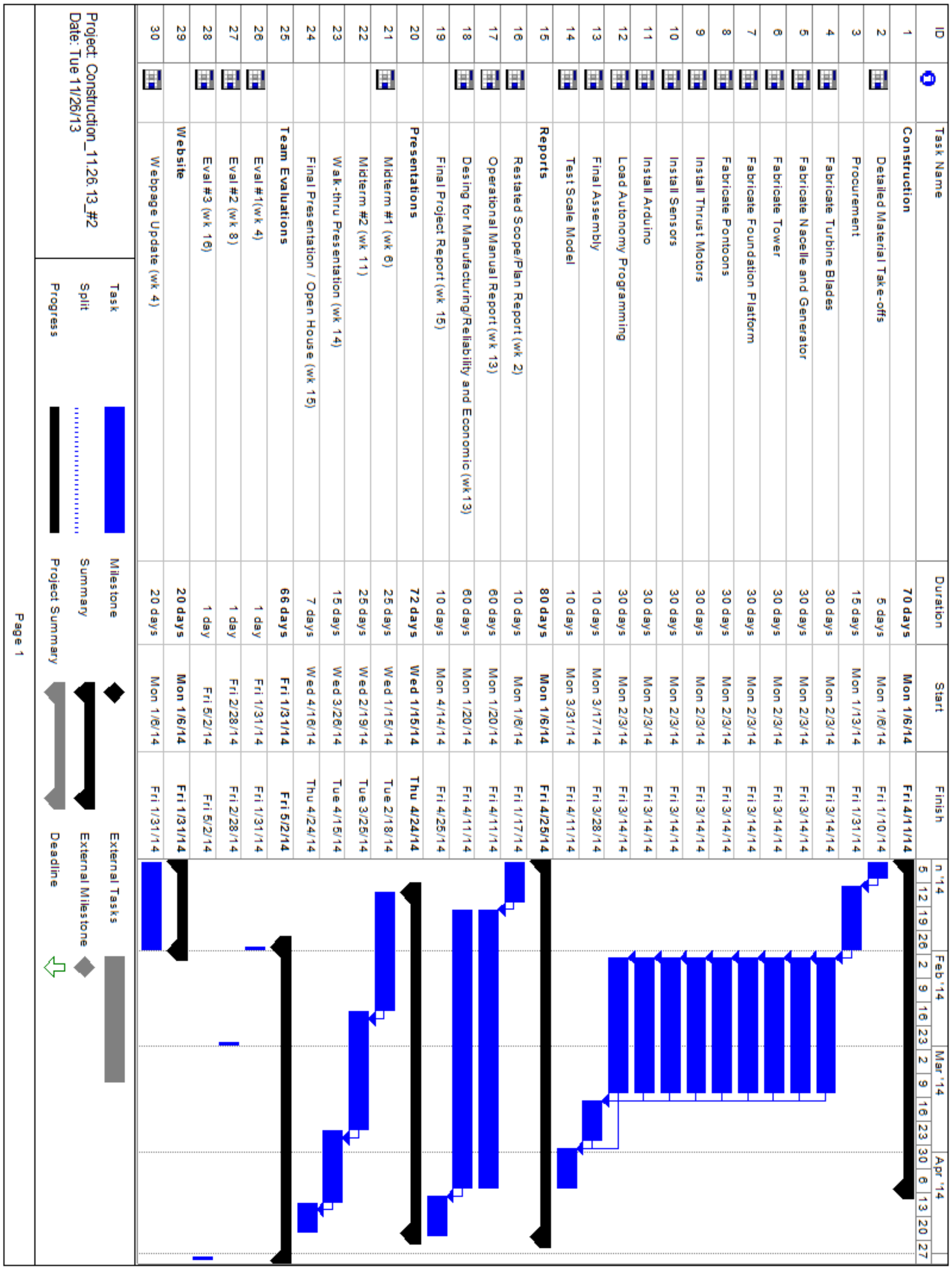
With regard to the added propulsion design, energy required was constrained to be renewable in nature. While diesel is a viable and effective method, generation of wind energy is aimed at reducing pollution to the environment thus any included operation must also follow suit.

11.0 Future Plans for Prototype

Much of the prototype will be evolving similar to the analysis. With each iteration or problem, concessions and compromises will be reached. The scope was discussed following our design presentation and many options including remote control vs. GPS, ballast of the SWATH, controllers and circuits, etc. were discussed with respect to amount of precision being expected. The prototype will represent our model while demonstrating respect to efficient engineering.

12.0 Gantt Chart, Resources, & Budget

12.1 Gantt Chart



ID	Task Name	Duration	Start	Finish
1	**Construction**	**70 days**	**Mon 1/6/14**	**Fri 4/11/14**
2	Detailed Material Take-offs	5 days	Mon 1/6/14	Fri 1/10/14
3	Procurement	15 days	Mon 1/13/14	Fri 1/31/14
4	Fabricate Turbine Blades	30 days	Mon 2/3/14	Fri 3/14/14
5	Fabricate Nacelle and Generator	30 days	Mon 2/3/14	Fri 3/14/14
6	Fabricate Tower	30 days	Mon 2/3/14	Fri 3/14/14
7	Fabricate Foundation Platform	30 days	Mon 2/3/14	Fri 3/14/14
8	Fabricate Pontoons	30 days	Mon 2/3/14	Fri 3/14/14
9	Install Thrust Motors	30 days	Mon 2/3/14	Fri 3/14/14
10	Install Sensors	30 days	Mon 2/3/14	Fri 3/14/14
11	Install Arduino	30 days	Mon 2/3/14	Fri 3/14/14
12	Load Autonomy Programming	30 days	Mon 2/3/14	Fri 3/14/14
13	Final Assembly	10 days	Mon 3/17/14	Fri 3/28/14
14	Test Scale Model	10 days	Mon 3/31/14	Fri 4/11/14
15	**Reports**	**80 days**	**Mon 1/6/14**	**Fri 4/25/14**
16	Restated Scope/Plan Report (wk 2)	10 days	Mon 1/6/14	Fri 1/17/14
17	Operational Manual Report (wk 13)	60 days	Mon 1/20/14	Fri 4/11/14
18	Desing for Manufacturing/Reliability and Economic (wk 13)	60 days	Mon 1/20/14	Fri 4/11/14
19	Final Project Report (wk 15)	10 days	Mon 4/14/14	Fri 4/25/14
20	**Presentations**	**72 days**	**Wed 1/15/14**	**Thu 4/24/14**
21	Midterm #1 (wk 6)	25 days	Wed 1/15/14	Tue 2/18/14
22	Midterm #2 (wk 11)	25 days	Wed 2/19/14	Tue 3/25/14
23	Walk-thru Presentation (wk 14)	15 days	Wed 3/26/14	Tue 4/15/14
24	Final Presentation / Open House (wk 15)	7 days	Wed 4/16/14	Thu 4/24/14
25	**Team Evaluations**	**66 days**	**Fri 1/31/14**	**Fri 5/2/14**
26	Eval #1(wk 4)	1 day	Fri 1/31/14	Fri 1/31/14
27	Eval #2 (wk 8)	1 day	Fri 2/28/14	Fri 2/28/14
28	Eval #3 (wk 16)	1 day	Fri 5/2/14	Fri 5/2/14
29	**Website**	**20 days**	**Mon 1/6/14**	**Fri 1/31/14**
30	Webpage Update (wk 4)	20 days	Mon 1/6/14	Fri 1/31/14

12.2 Resources

Our primary resources consist of computer programs, vendors, and fabricators. Fabricators often require electronic files of designed parts for manufacturing. Some of the programs we've used to meet this requirement are Pro-Engineer and AutoCAD. Many of our parts are available, on the commercial market, and can be purchased directly from such vendors as The Home Depot and RadioShack. The College of Engineering provides us with several skilled fabricators from which to choose. We will utilize the Machine Shop, operated by Jeremy, and the ME Lab, operated by Keith Larson.

<u>References</u>

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Appendix

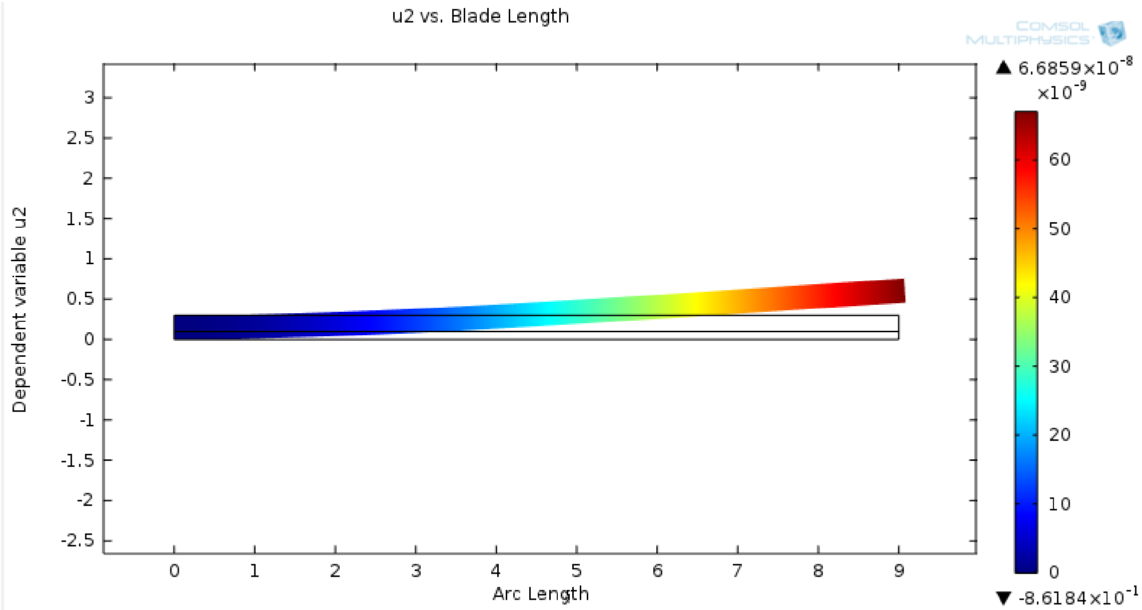


Figure x – COMSOL Model Displacement Breakdown for Typical Cantilevers

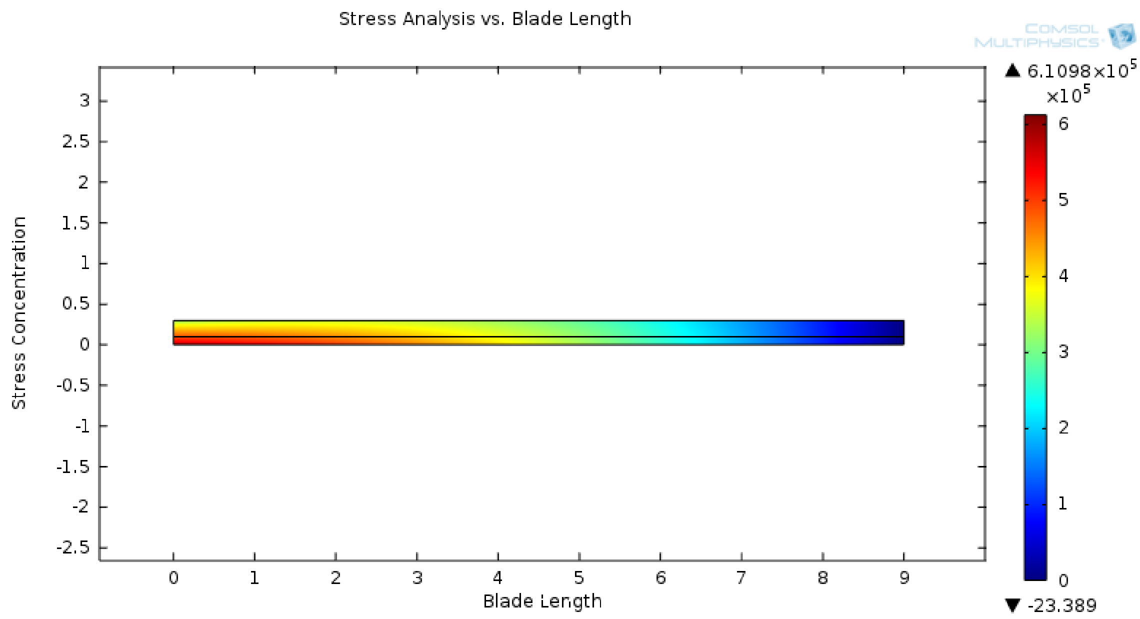


Figure xx – COMSOL Model Stress Concentration for Typical Cantilevers

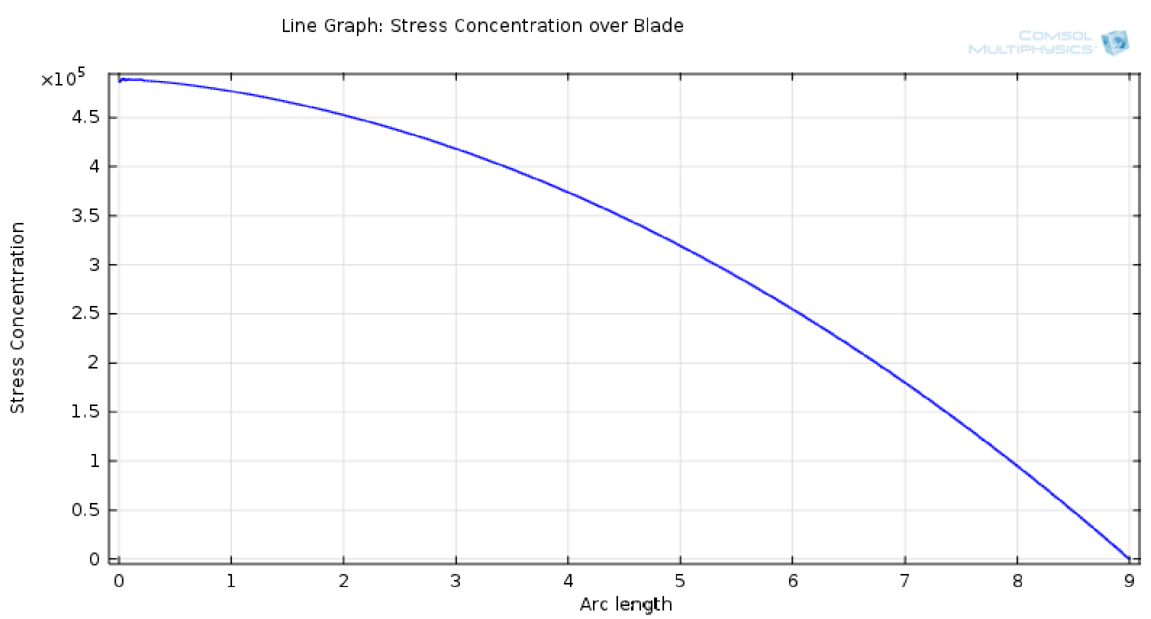


Figure xx – COMSOL Line Graph Stress Concentration for Typical Cantilevers

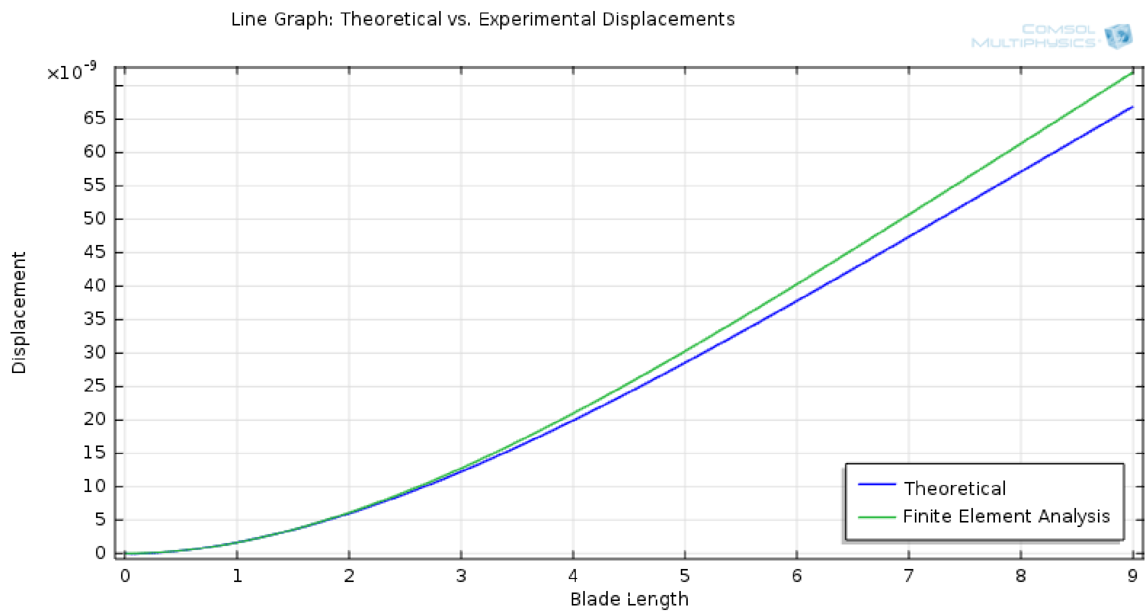
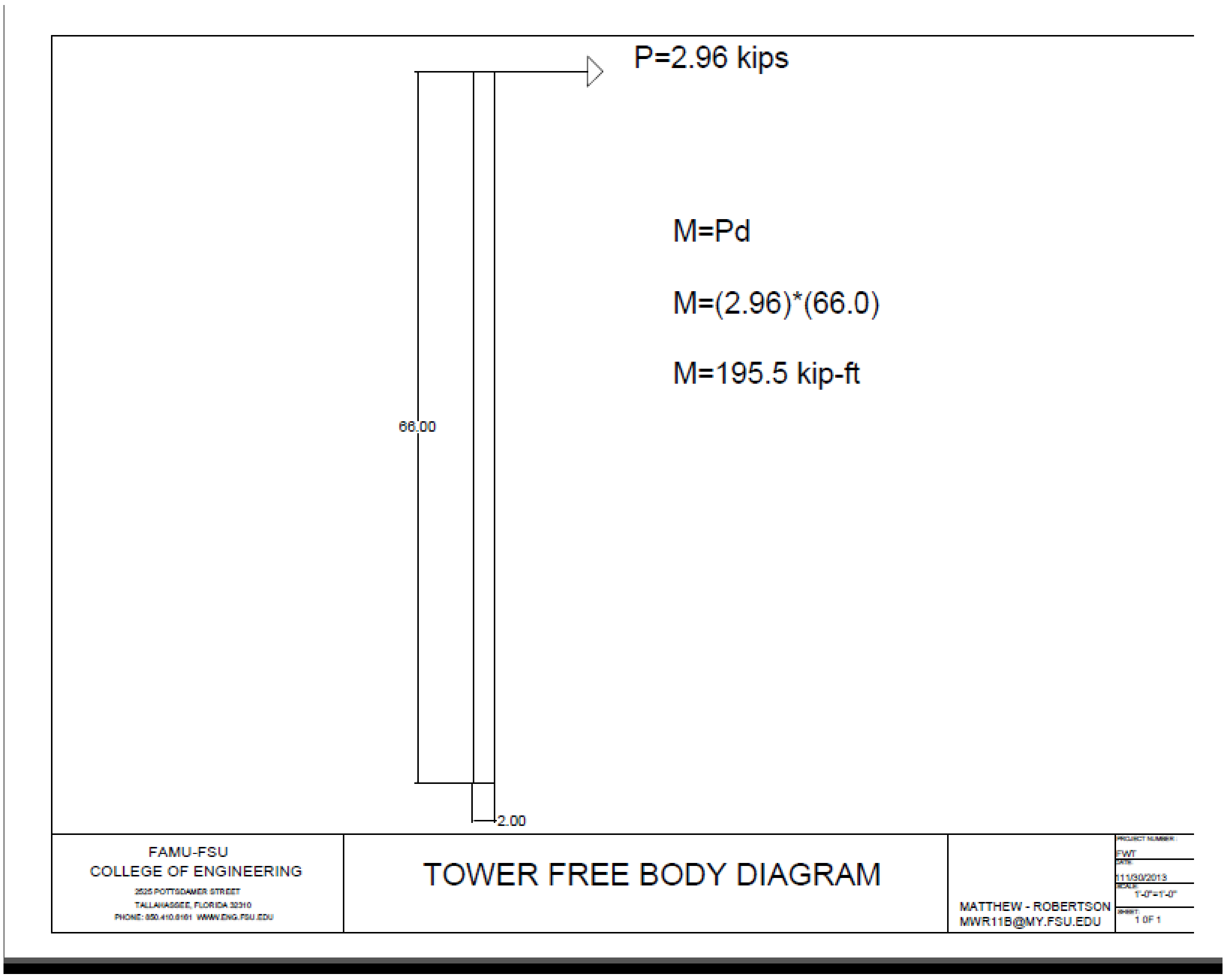
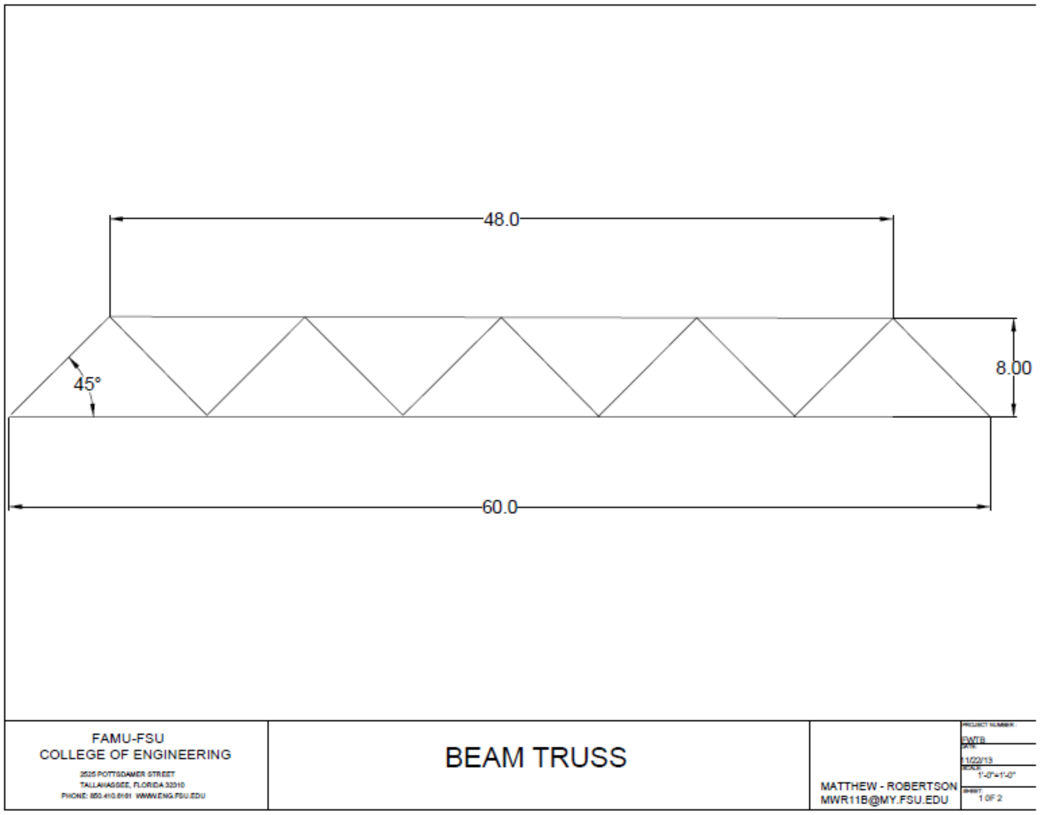
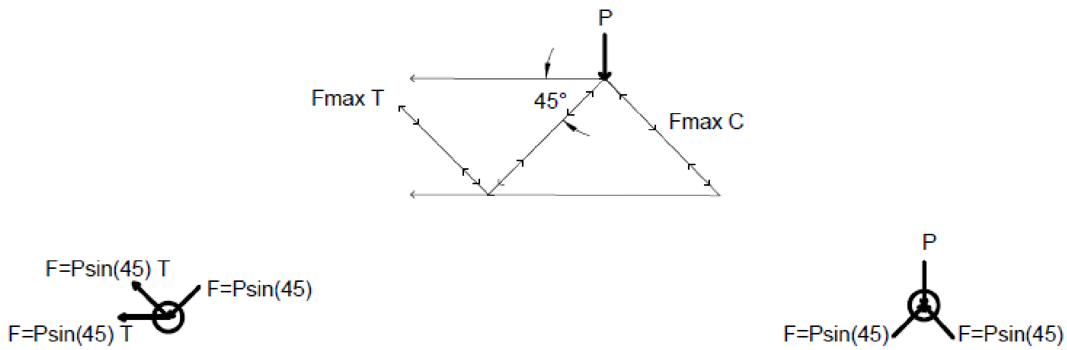


Figure xx – COMSOL Displacement Theoretical vs. Finite Element Analysis



P=2.96 kips
M=Pd
M=(2.96)*(66.0)
M=195.5 kip-ft
66.00
2.00
FAMU-FSU
COLLEGE OF ENGINEERING
2525 POTTSDAMER STREET
TALLAHASSEE, FLORIDA 32310
PHONE: 850.410.6161 WWW.ENG.FSU.EDU
TOWER FREE BODY DIAGRAM
MATTHEW - ROBERTSON
MWR11B@MY.FSU.EDU
PROJECT NUMBER:
FWT
DATE:
11/30/2013
SCALE:
1'-0"=1'-0"
SHEET:
1 OF 1


48.0
45°
8.00
60.0
FAMU-FSU
COLLEGE OF ENGINEERING
2525 POTTSDAMER STREET
TALLAHASSEE, FLORIDA 32310
BEAM TRUSS
MATTHEW - ROBERTSON
MWR11B@MY.FSU.EDU
FWTB
11/22/13
1'-0"=1'-0"
1 OF 2



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PHONE: 850.410.6161 WWW.ENG.FSU.EDU

ANALYSIS OF BEAM TRUSS

MATTHEW - ROBERTSON
MWR11B@MY.FSU.EDU

PROJECT NUMBER: FWTB
DATE: 11/22/13
SCALE: 1'-0"=1'-0"
SHEET: 2 OF 2

Use HSS16x0.625 shape @103 lb/ft (self weight)
For bracing Use HSS5x0.250 shape @12.69 lb/ft
Weight Analysis:
30 members @ 26 ft @ 103 lb/ft + 75 members @ 4 ft @ 12.69 lb/ft = 84.1 kips

Axial Load

$Nacelle_{weight} := 9000lb$

$Blade_{weight} := 7920lb$

$Axial_{load} := Nacelle_{weight} + Blade_{weight} = 1.692\times 10^{4}\,lb$

Wind Load Determined using ASCE 7

Directioanlity factor (K_d) - Determined from Table 26.6.1

Design Velocity (v) - Determined from graphic 26.5-1C

Topographic factor (K_{ZT}) - Determined from 26.8-1

Velocity Pressure Coefficient (K_z) - Determined from Table 26.6.1

Velocity Pressure (q_Z) -Determined by Equation 27.3-1

$K_d := 0.95 \quad K_{ZT} := 1 \quad Z := 66 \quad c_1 := 6.62 \quad c_2 := 1273$

$\alpha := c_1 \cdot Z^{-0.133} = 3.792 \qquad Z_g := Z^{0.125} \cdot c_2 = 2.149\times 10^{3}$

$K_Z := 2.01\left(\frac{Z}{Z_g}\right)^{\frac{2}{\alpha}} = 0.32 \qquad v := 160mph \qquad v_{up} := 50mph$

$q_{zup} := 0.00256K_Z \cdot K_{ZT} \cdot K_d \cdot v_{up}{}^{2} = 4.19\frac{ft^2}{s^2}$

$q_z := 4.19\frac{lb}{ft^2}$

Steel Design

Due to the combined Flexural and Axial Loading, the Column and Chapter H sections were referenced in the AISC Steel Manual.

$$Axial_{load} = 1.692 \times 10^{4}\ lb$$

$$D_{Rotor} := 30ft$$

$$A_{Rotor} := \left(\frac{\pi}{4}\right)\left(D_{Rotor}{}^{2}\right) = 706.858\ ft^{2}$$

$$P_{Rotor} := A_{Rotor} \cdot q_z = 2.962 \times 10^{3}\ lb$$

$$D_{out} := 24in$$

$$D_{in} := 23in$$

$$t := 0.50in$$

<u>Steel Selection</u>

A618 Grade I

$$F_y := 50ksi$$

$$F_u := 70ksi$$

$$E := 29000ksi$$

$$1ksi = 1 \times 10^{3}\ psi$$

$$A_1 := \pi \frac{\left(D_{out}{}^{2} - D_{in}{}^{2}\right)}{4} = 0.256\ ft^{2}$$

Torsional Shear Constant

$$C1 := \pi \frac{\left(D_{out} - t\right)^{2}}{2} = 6.024\ ft^{2}$$

Polar Moment of Inertia

$$I_1 := \pi \frac{\left(D_{out}{}^{4} - D_{in}{}^{4}\right)}{64} = 0.123\ ft^{4}$$

Radius of Gyration

$$r_1 := \left(\frac{I_1}{A_1}\right)^{\frac{1}{2}} = 0.693\,\text{ft}$$

Effective Length Determine using Table C-A-7.1

$K_1 := 0.6$

Laterally Unbraced Length

$L_1 := 792\text{in}$

$$\text{Slender}_{\text{Ratio1}} := K_1 \cdot \frac{L_1}{r_1} = 57.181$$

$$F_{e1} := \frac{\left(\pi^2 \cdot E\right)}{\text{Slender}_{\text{Ratio1}}{}^2} = 8.754 \times 10^4\,\text{psi}$$

$$F_{cr.Axial1} := \left(0.658^{\frac{F_y}{F_{e1}}}\right) \cdot F_y = 3.937 \times 10^4\,\text{psi}$$

$$P_{n1} := F_{cr.Axial1} \cdot A_1 = 1.453 \times 10^6\,\text{lbf}$$

Axial Load According to LRFD

$$\text{AXIAL}_{\text{LRFD}} := \text{Axial}_{\text{load}} \cdot 1.6 = 2.707 \times 10^4\,\text{lb}$$

The Critical Axial Load is greater than the required Axial load.

$M_{max} := 200\text{kip}\cdot\text{ft}$ M.max was calculated by Hand

$$S := \pi \frac{\left(D_{out}{}^4 - D_{in}{}^4\right)}{32 D_{out}} = \blacksquare$$

$$1\text{in}^3 = 4.329 \times 10^{-3}\,\text{gal}$$

$$Mn := \left[F_y + \frac{(0.021E)}{\left(\frac{D_{out}}{t}\right)}\right] \cdot 212.52\text{in}^3 = 3.572 \times 10^7\,\frac{\text{ft}^2\cdot\text{lb}}{\text{s}^2}$$

$$\phi M\_n = 0.9\left[F_y + \frac{(0.021E)}{\left(\frac{D_{out}}{t}\right)}\right]\cdot 212.52\,in^3 = 1000\ kip\text{-}ft$$

The designed max moment is substantially greater than the required moment.

Final Column Selection

Column Height= 66 ft
Diameter = 2 ft
Wall Thickness = 0.5 in
Steel Grade: A616 Gr. I

Weight of Column= 8635 lb

Boat Deck Design

Dead Load = Weight of Wind Turbine

Design Dead Load = 200 psf which was dtermined using ASCE7 for Industrial Floors.

Max Moment = 403kip-ft and was determined from the moment diagram

The supporting beam chosen for the deck is a W21x111. The steel chosen has a yield strength of 50 ksi. The Beam was chosen from Table 3-10 in the AISC Steel Manual. The beam is capable of holding a design load of 810 kip- ft. This provides a safety factor of 2 which is within the standard range of 1.5-3 for vessels.

Deck Beams weigh 252 kips

Allowable Deck weight including floor is 1000 kips.

Deck Support Design

Design a circular HSS Shape for Mmax = 397 kip-ft Pmax = 455 kips

AISC Requirements:

where K=0.65 L=20ft Using A500 Grade B Steel with Fy=42ksi and Fu=58ksi
(as recommended for rectangular HSS shapes)

LRFD: Mu < ϕMn *In AISC Table 3-15 Try HSS16x0.625*
397 kip-ft < 435 kip-ft (ok)

Check For adequacy In:

Pu < ϕPn Effective Length:KL=(0.65)(26ft) = 17 ft

In AISC Table 4-17 for HSS16x0.625

455 ksi < 1240 ksi (OK)

Compression Analysis:

Slenderness ratio: KL/r=0.65(26x12)/5.46= 37.1 < 200 (OK)
KL/r < 4.71(E/Fy)^1/2
37.1 < 4.71(29,000/46)^1/2
37.1 < 118.3

Fe=208 ksi
Fcr=38.6 ksi

Fy/Fe < 2.25
42/208 < 2.25
0.20 < 2.25 (OK)

Pn = Fcr Ag =(38.6)(28.1) = 1085 kips
ϕPn = 0.9(1085) = 977 kips > 455 kips (OK)

Tension Analysis:

Yielding:

Pn=FyAg=42ksi(28.1in^2)=1180kips
ϕPn=0.9(1180kips)= 1062 kips > 455 kips (OK)

Fracture:

Pn=FuAe

where, Ae=AgU U=1-0.375=0.625
Ae=0.625(5.24in^2)=3.275 in^2

Pn=(58ksi)(3.275in^2)
=189.95 kips

ϕPn=0.75(189.95kips)=142.5 kips > 128 kips (OK)

Use HSS16x0.625 shape @103 lb/ft (self weight)
For bracing Use HSS5x0.250 shape @12.69 lb/ft

Weight Analysis:

30 members @ 26 ft @ 103 lb/ft + 75 members @ 4 ft @ 12.69 lb/ft = 84.1 kips

Pontoon Dimensions

Pontoons will be modeled as cylinders for calculations to provide a factor of safety for thrust. Once required thrust is etablished, the pontoon will be optimized for optimal performance

Total Deck Weight = 1286 kips

$Deck_{weight} := 1286kip$

$Deck_{weightmetric} := 590000kg$

$Water_{density} := 1000\frac{kg}{m^3}$

$Steel_{Density} := 7800\frac{kg}{m^3}$

$Pontoon_{Thickness} := 0.0254m$

$Pontoon_{Length} := 60m$

Volume of water needed to diplace Weight of Deck = 590 m^3

In order to displace this required volume of water the pontoon would need to have a diameter of 3.54m

Assume Diamter is 4m to determine the weight of the steel in the pontoon.

Volume of steel =9.55m^3

Weight of Steel =75000 kg

Volume of Required Displaced water =75 m^3

Total Required Displaced volume =665m3

Total Volume Displaced (For 1 Pontoon) = 745m^3

Buoyancy = (Weight of displaced fluid) - (Weight of structure)

Buoancy = (1000kg/m3)(745m3) - (590000kg + 75000 kg) = 230,000kg

Total Buoyancy for vessel = 1,050,000 kg

The vessel has approxiamte Buoyancy ratio of 1.5 to 1. It can be concluded that the vessel is positvely Boyant and thus will float.