# Modeling and Analysis of a Small Wind Turbine Blade

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**Abstract:** ***The purpose of this paper was to structurally analyze a smaller wind turbine blade that could potentially be used in a residential setting. The proposed blade is similar in shape to the commercial blades, but it is only 1.250 meters long as opposed to the daunting 40 meter length of larger blades. The analysis was simplified by modeling a solid aluminium blade instead of a hollow carbon fibre blade, which is commonly used. This model only works to visualize and verify the bending mode of failure, but it still provided valuable information about blade failure and the validity of residential turbine blades. The effects of stresses due to a distributed wind load acting on a simplified wind turbine blade are analyzed. The goal of this paper is to understand the structural integrity of wind turbine blades.***

**Keywords:** air-foil NACA0012, ANSYS APDL, wind turbine blade, von-Mises

## 1. Introduction

Wind turbines are becoming increasingly common as we gradually move towards cleaner energy solutions. Since wind turbines are exposed to a variety of elements and load conditions, such as wind loads, even a minor flaw in the structure can cause catastrophic failure. Thus, it is important to analyze wind turbine blades to reduce the chance of failure during operation. The investigation will aid our understanding of the stresses in turbine blades from wind loads and help us make correct design decisions to avoid catastrophic failure.

The turbine blade is designed in ANSYS APDL from NACA0012 airfoil. Then a high quality mesh is generated for the blade design. A constant distributed load across the length of the blade is applied which would accurately model a constant speed wind blowing on the turbine.

## 2. Modelling

Wind turbine blades are commonly made out of fiberglass or carbon fiber because these materials are strong, durable, and lightweight. However, it is difficult to find consistent material properties for these exotic materials. To solve this problem, our team will use aluminum as the blade material. A list of material properties is shown below in Table 1. Additionally, the generalized Hooke's law could be used to analyze the blade. The external loading conditions that will deform the turbine blade are caused by catastrophic wind speeds produced by hurricanes.The estimated force calculation is as follows:

$$F = P * A$$

Where,

$$P = 1/2 * \rho * v^2 * SF$$

The following values were used:

- ρ = density = 1.275 kg/m3
- v = velocity = 70 m/s
- SF = shape factor
- A = area = l*w

The area is estimated as a rectangular area with length of 1570 mm and width of 168 mm. The shape factor, which is a function of a copious amount of things, can initially be approximated as 0.04 which in turn yields a load condition of about 33 N which is equivalent to a pressure of 0.0002MPa.

6061-T6 Aluminum Properties are taken as yield stress (MPa)- 276, ultimate tensile strength(MPa) -310, Young's modulus(MPa) -68.9, Density(kg/m3) -2700 and Poisson's Ratio-0.33.

Finite Element Meshes: For simplicity, Shell 181 a tetrahedral mesh was used. The mesh had a global size of 15mm and used defaults for all other options. This tetrahedral mesh is an acceptable starting point for the analysis because it captures the correct blade geometry and does not take a long time to run with only 2,048 elements.

## 3. Model Assembly and Boundary Conditions

The wind turbine blade is by itself in the model, so the analysis was performed on a singular part.However, in real world applications each turbine blade is bolted to a central hub that spins togenerate electricity. A fully fixed (ALL degrees of freedom) boundary condition on the bigger end face to simulate a fastened end face. This boundary condition does not allow the end face to translate or rotate in any direction. All loading conditions were performed with only this simple boundary condition. A distributed wind load of 0.0002 MPa across the entire blade surface of one side is applied. This loading condition is different from the point loads because it attempts to model the effects of the wind hitting the entire blade, instead of just at the tip. In reality, this loading condition is very practical because the wind would not be concentrated at one point. The distributed load was generated using a traction force applied in the positive y direction on the front surface of the blade.

**Analysis of Finite Element Model**

The small point load condition uses a value of 10 N placed directly at the tip of the blade. The following contour plots illustrate the loading distribution and the response of the blade to the input load. Also, Figure 9 shows the Stress vs. X-location plot for the loading condition. The last loading condition is the distributed wind loading condition according to a wind velocity of 50 m/s. Using equations found in section 2, the wind speed was translated to a traction force and the following plots were created as a result.

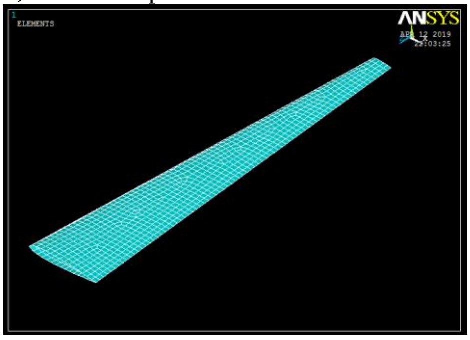


**Figure 1:** Meshed model

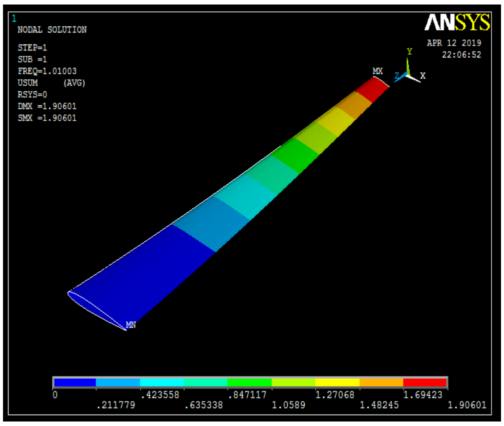


**Figure 2:** First natural frequency 1.01Hz mode shape

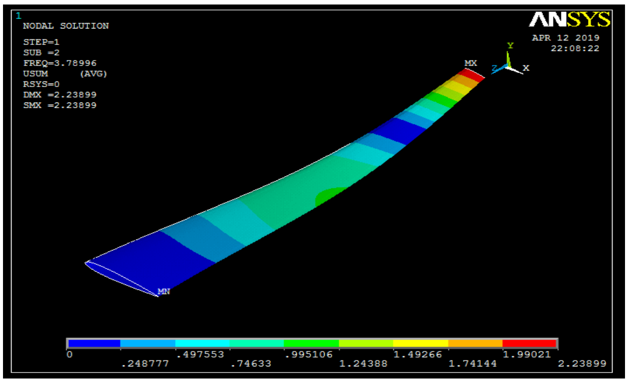


**Figure 3:** Second natural frequency 3.78 Hz mode shape

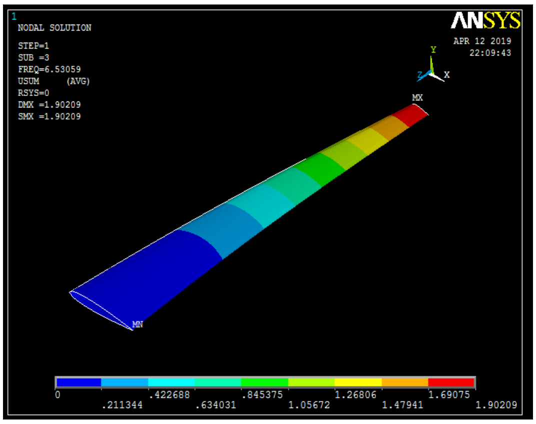


**Figure 4:** Third natural frequency 6.53Hz mode shape

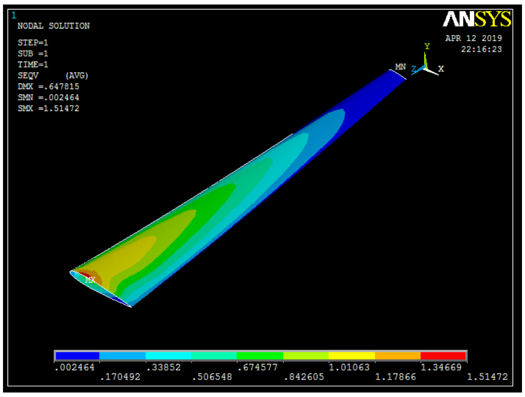


**Figure 5:** pressure 0.0002MPa 1.5 MPa

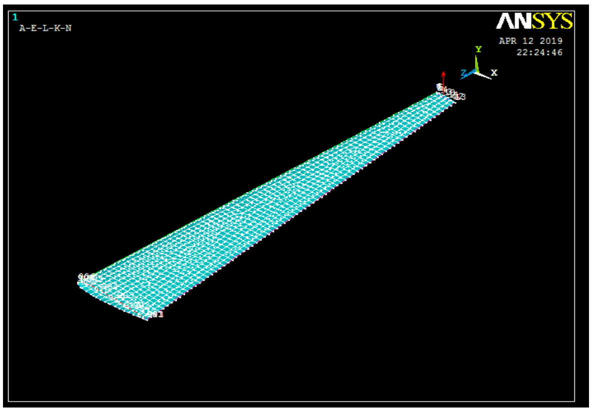


**Figure 6:** Load 10 N at tip

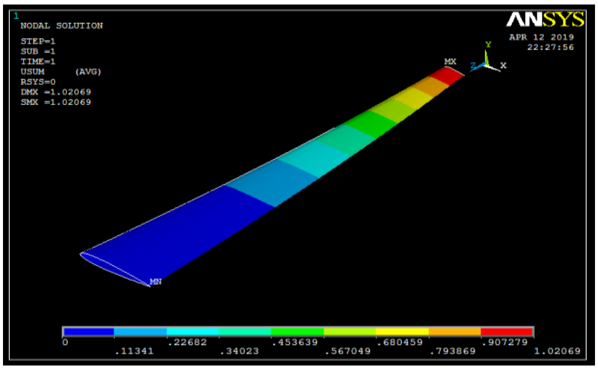


**Figure 7:** Deformation for 10N load 1.02 mm

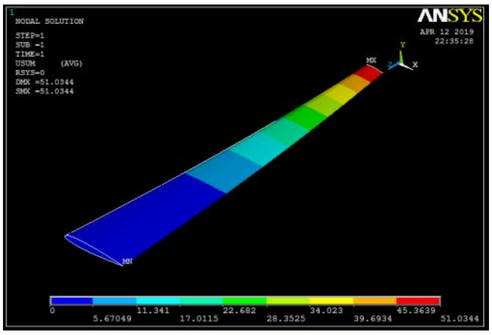


**Figure 8:** Deformation for 500N load 51.03mm

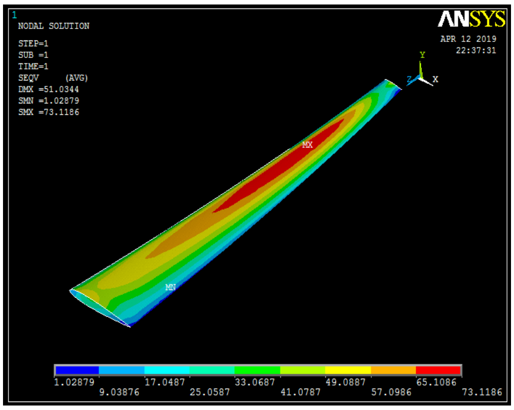


**Figure 9:** Von-Mises stress for 500N load at tip 73MPa

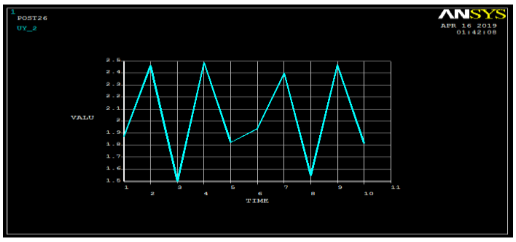


**Figure 10:** Transient analysis at 10 N

## 4. Conclusion

The response of four different loading conditions on the blade were analysed: a small point loading condition of 10 N, a large point loading condition of 500 N, a frequency loading condition, and a wind distributed load on the entirety of the blade. At this loading condition, a maximum stress of 73.1186 MPa is experienced at a slightly lower location than the tip of the blade. This maximum stress is lower than the yield stress of 276 MPa provided in Table 1, which would allow for the blade to return to its original shape as it does not enter the plastic region. A maximum deflection of 51.03 mm is experienced at the tip of the blade. These results show that for a residential turbine, a load of 10 N creates minimal deflection on the blade, about 1.6 % of length of blade.

The large force caused a maximum stress of 73.11 MPa inside the blade. Again referencing to properties of material this stress is smaller than the yield and ultimate tensile strength showing that if the blade was subjected to this much strong force it would not fail catastrophically.

The frequency loading condition was to check the resonance frequencies of the blade. The blade had only two resonances at 30 Hz and 50 Hz. These two frequencies are so high that no naturally occurring wind pattern would ever hit these frequencies. It shows that the blade's designer worked to insure that the resonance frequencies would be very large so that the blade would never be subjected to them.

The wind load was to simulate the effects of high speed wind impacting the blade. The wind speed used was 50 m/s which is near high strength winds. The resulting load caused a maximum stress of 1.51 MPa which is below the yield stress of the blade material. In the wind load it is interesting to note that the major stress point is at the base of the blade whereas the major stress point in the point loads was near the tip at the smallest cross sectional area.

In conclusion the blade was well designed to survive most real scenarios.

## References

[1] Joel Crawmer, Edward Miller, and Eros Linarez. "The Development and Analysis of Wind turbine blade". Department of Mechanical and Nuclear Engineering, Penn State College of Engineering, University park, PA

APPENDIX A

Air-foil key points used are NACA0012(values are in mm)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| K | , | 1 | , | 58.8 | , | 0.074088 | , | 125 |
| K | , | 2 | , | 46.9705572 | , | 1.5503208 | , | 125 |
| K | , | 3 | , | 33.7406748 | , | 2.8064064 | , | 125 |
| K | , | 4 | , | 20.6381532 | , | 3.4963656 | , | 125 |
| K | , | 5 | , | 8.1056976 | , | 3.0657144 | , | 125 |
| K | , | 6 | , | 0.9038148 | , | 1.2272148 | , | 125 |
| K | , | 7 | , | 0.0525672 | , | -0.303114 | , | 125 |
| K | , | 8 | , | 2.5996068 | , | -1.9825596 | , | 125 |
| K | , | 9 | , | 13.1850768 | , | -3.4434456 | , | 125 |
| K | , | 10 | , | 26.0652756 | , | -3.3012672 | , | 125 |
| K | , | 11 | , | 39.2491176 | , | -2.3360064 | , | 125 |
| K | , | 12 | , | 52.4714736 | , | -0.906696 | , | 125 |
| K | , | 13 | , | 58.8 | , | -0.074088 | , | 125 |
| K | , | 101 | , | 64.7 | , | 0.081522 | , | 250 |
| K | , | 107 | , | 0.0578418 | , | -0.3335285 | , | 250 |
| K | , | 201 | , | 72.22 | , | 0.0909972 | , | 375 |
| K | , | 207 | , | 0.06456468 | , | -0.3722941 | , | 375 |
| K | , | 301 | , | 81.84 | , | 0.1031184 | , | 500 |
| K | , | 307 | , | 0.07316496 | , | -0.4218852 | , | 500 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| K | , | 401 | , | 94.26 | , | 0.1187676 | , | 625 |
| K | , | 407 | , | 0.08426844 | , | -0.4859103 | , | 625 |
| K | , | 501 | , | 110.6 | , | 0.139356 | , | 750 |
| K | , | 507 | , | 0.0988764 | , | -0.570143 | , | 750 |
| K | , | 601 | , | 132.8 | , | 0.167328 | , | 875 |
| K | , | 607 | , | 0.1187232 | , | -0.684584 | , | 875 |
| K | , | 701 | , | 163.9 | , | 0.206514 | , | 1000 |
| K | , | 707 | , | 0.1465266 | , | -0.8449045 | , | 1000 |
| K | , | 801 | , | 203.4 | , | 0.256284 | , | 1125 |
| K | , | 807 | , | 0.1818396 | , | -1.048527 | , | 1125 |
| K | , | 901 | , | 218.97 | , | 0.2759022 | , | 1250 |
| K | , | 902 | , | 174.9173964 | , | 5.77336302 | , | 1250 |
| K | , | 903 | , | 125.6495844 | , | 10.45100016 | , | 1250 |
| K | , | 904 | , | 76.85606133 | , | 13.02039414 | , | 1250 |
| K | , | 905 | , | 30.18545244 | , | 11.41665786 | , | 1250 |
| K | , | 906 | , | 3.36578787 | , | 4.57012287 | , | 1250 |
| K | , | 907 | , | 0.19575918 | , | -1.12879035 | , | 1250 |
| K | , | 908 | , | 9.68088267 | , | -7.38301149 | , | 1250 |
| K | , | 909 | , | 97.06655439 | , | -12.29385168 | , | 1250 |
| K | , | 910 | , | 49.10095692 | , | -12.82332114 | , | 1250 |
| K | , | 911 | , | 146.1629129 | , | -8.69924016 | , | 1250 |
| K | , | 912 | , | 195.4026968 | , | -3.3765174 | , | 1250 |
| K | , | 913 | , | 218.97 | , | -0.2759022 | , | 1250 |