

# Finite Element Modeling and Evaluation of Ceiling Fan Blades Using Wood as Alternative Engineering Material

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**Abstract:** Demand for metals and plastics as engineering materials for construction is on the increase leading to increase in cost compared to wood. Wood is renewable and available throughout the world. It is strong, tough and durable as a construction material. Autodesk AutoCAD, ANSYS and SOLID WORKS software were deployed in carrying out finite element modelling (FEM), development and evaluation of ceiling fan blades using wood as engineering materials. *Design of the fan blades was carried out.* Fabrication of the of blades with the above configuration was carried out in the Wood Products Engineering Workshop. *The blades were made of dimensions with lengths, 400mm, 500mm and 600mm lengths, width of 3mm and thickness of 3mm. While the weights of the blades were 2.0, 2.5 and 3kg respectively.* Each blade types were coupled to the head of a conventional fan and tested accordingly. In each speed of operation of the fan, digital anemometer was deployed in taking readings such as fan velocity and airflow rate. The results for each of the fan blade types were compared to that of a conventional fan blade. Results obtained were stress and strain concentration and blade failures. Correlation and regression analysis were done based on wood type, blade size, velocity and airflow, Von Misses stress and strain to know their relationship. Findings showed that blades A has a minimum factor of safety of 8.5364 and 8.6958 respectively, the configuration B has a minimum factor of safety of 10.773 and 10.625 respectively, while the configuration C has a minimum factor of safety of 11.419 and 11.436 respectively.

**Keywords:** wood blade, finite element model, stress, strain, airflow, fan

Fans are widely used for circulating air for the purpose of cooling in rooms, buildings, agricultural machineries, mechanical, electrical and electronic gadgets to create a more comfortable atmosphere. Air flow are created using fans in fluids - liquids and gases. Fan consists of a rotating arrangement of vanes or blades which act on the fluid by pulling or pushing it [1]. Reports have showed that the cost of metals and plastics generally are becoming higher than wood as construction materials leading to high market prices of products [2]. Utilization of available, cheap and durable wood as replacement for ceiling fan blades would definitely lead to products availability, accessibility and affordability.

Fans are specifically used in circulating air for the purpose of cooling in buildings, agricultural machineries, mechanical, electrical and electronic gadgets to create more conducive environment. Most postharvest crops processing and storage equipment utilize fans for their effective operations. Fans creates flow within a fluid such as liquids and gases. Axial flow fan creates air flow linearly along the axis rotation. Thus, forcing air to move in parallel to the shaft for cooling, compression and ventilation [3]. The rotating assembly of blades and hub is known as an impeller, a rotor, or a runner [1]. Generally, fan blades will always rotate when placed in the direction of flow of a fluid, however, such

does not produce enough airflow relevant to provide cooling system. Metals and plastic materials are readily used in the design of fan blades. Reports show that the cost of metals and plastics generally are becoming higher than wood as construction materials [2].

Wood is the oldest, cheapest and most widely used engineering materials. It is the only significant building material that is grown [4], renewable and readily available in all parts of the globe. In Nigeria, wood is available in almost all the geopolitical zones. It is durable and performs creditably well when properly treated. Wood is cheaper than other materials like metals, plastics, composites and alloys used for the design of fans and other devices [5].

ANSYS and SOLID WORKS software enables the utilization of Finite Element Analysis (FEA) for predicting how a product reacts to real-world forces [6]. Finite element modeling (FEM) makes it possible for the analysis of complex engineering problems. It allows full 3D simulation without compromising the geometrical details. Wood, the oldest and most widely used engineering materials is the only significant building material that is grown [4]. It is renewable and readily available throughout the world. In Nigeria, wood is available in almost all the geopolitical zones. Wood has high ratio of durability and performance when properly treated. It is considerably cheaper than other materials like metals, plastics, composites and alloys used for the design of fans and other devices [5]. Utilization of wood in fans development is scarce. Hence, there is great necessity in the use and application of wood in the design and production of fan blades to reduce cost and optimized production.

Finite Element Modelling (FEM) permits complex analysis of multilayered complex shape structures, including stress-strain, dynamic, thermal, or electromagnetic loading. Finite Element Analysis (FEA) is a computerized method for Predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects [6]. FEM applications include stress analysis, slope stability analysis, seepage of fluids in soils and rocks, analysis of dams, tunnels, bore holes, propagation of stress waves and dynamic soil structure interaction. ANSYS and SOLID WORKS software package based on the finite element analysis, enable 3D simulation without compromising the geometrical details [7]. ANSYS is used to determine how a product will function with different specifications, without building a prototype or conducting crash tests [8].

[9] studied experimental and CFD/FEA simulation of large axial fan effect on flow. The flow pattern is changed by adding a radiator in front of axial fan. However, it produces around 10 to 20 percent stresses on the blade surface. [10] made an effort to find

the best thermal comfort level with the combination of air-conditioners and ceiling fans. A two dimensional steady state problem was solved using CFD simulation. Fourteen different simulation cases were run for different locations of inlet diffuser and the position of the fan. Momoi and Sagara et al. (2004) studied the velocity profile of a ceiling fan in an air-conditioned room. CFD results show greater value of velocity profile near the rotational centre of the ceiling fan. [11] developed a new approach for installation of ceiling fans that have an enclosed housing and is hidden inside the ceiling floor. Using experimental and numerical methodology, the flow behaviour is predicted with different operating conditions and geometric housing. Conclusions revealed that as air moves towards the floor, different flow patterns are generated and demonstrate “inhale-return” phenomenon only when housing comprises of anomalous shaped high ring-plate and outlet-inlet ratio. [12] experimentally compared the composite materials fan blades with aluminium fan blades. Results show that composite blade save 34% fabrication cost and 30% power because of 28% weight reduction.

Analysis and experiments have been carried out by several researchers to investigate the behaviour of both stress and fracture mechanics [13]; [14]. Finite element methods (FEM) was used in the analysis of stress, strain, fatigue and sheet metal during forming [15]; [16]; [17]. [3] conducted a finite element analysis and optimization of aluminium axial fan blade. Von Mises stress criterion under pressure, 500 Pa was utilized using length of 84, 92, 102, 110 and 130 mm; and twisting angle of 10, 20, 30 and 40°. Result showed that lower stress was delivered compared to other models. [18] (2019) evaluated the performance of Gmalina arborea, Zebrawood and Plywood as replacement for standing fan blades. Thus blade diameters of 240 mm, 242.5 mm, 247.5 mm, and 282.5 mm produced an average airflow of 3.65 cms, 3.24 cms, 3.94 cms and 4.41 cms respectively. Fan velocity and airflow had positive correlation with blade area and negative correlation with density of blade. Regression equation with coefficient of linearity,  $R^2$  of 0.999 was obtained, showing effectiveness of wood as engineering material in fans production

### 1.1 Problem Statement/Justification

Most fan blades in use today utilize aluminium, plastics and composites metals. Reports show that the cost of metals and plastics generally are becoming higher than wood as construction materials [2]. Wood is renewable and readily available throughout the world and in Nigeria, wood is available in almost all the geopolitical zones, especially in the South-South. It has high ratio of durability and performance when properly treated and it is cheaper than other materials like metals,

plastics, composite materials and alloys used for the design of fans and other devices [5]. Wood can be utilized in the production of fan blades.

## 1.2 Objectives of the study

The objectives of the study are: (1) Design ceiling fan wooden blades using finite element analysis by deploying Autodesk AutoCAD, ANSYS and SOLIDWORKS, (2) Fabricate ceiling fan wooden blades for replacement of conventional ones and (3) Evaluate the performance of the blades in terms of Von Mises stress, strain, velocity, air flow and efficiency.

## 1.0 Methodology

### 2.1 Design Considerations of Ceiling Fan Wooden Blades

Finite Element Modelling and evaluation of ceiling fan wooden blades considered a number of factors such as: Type of wood, dimension of blades, Strength of materials for the fabrication, Von Mises stress, strain, durability of the blades, moisture content of wood, cost, required lifespan, maintenance cost, speed of rotor, vibration, noise and airflow from blades.

### 2.2 Materials Consideration for the Design of Ceiling Fan Wooden Blades

Materials selection is crucial to the design of the fan blades. Purchase of three (3) conventional fans, three types of hard wood were considered among the following: (i) Honduras mahogany, (ii) Birch Veneer and (iii) Zebra.

### 2.3 Design of Blades

*Design of the fan blades was carried out. Three (3) dimensional considerations were considered. these were 400mm, 500mm and 600mm lengths, with width of 3mm and thickness of 3mm. While the weight of the blades was be restricted to 2.0, 2.5 and 3kg respectively for optimum operation [19].*

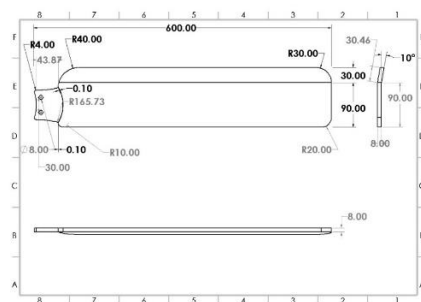


Fig. 1. Design drawing of 600mm fan blade (A)

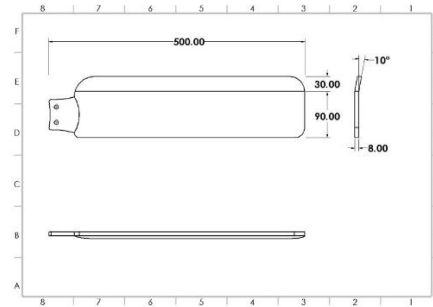


Fig. 2. Design drawing of 500mm fan blade (B)

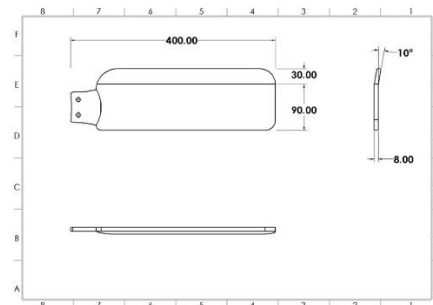


Fig. 3. Design drawing of 400mm fan blade (C)

### 2.4 Fabrication of the blades

Fabrication of the of blades with the above configuration was carried out in the Wood Products Engineering Workshop using the following machines: Circular Saw, Band Saw, Drilling machine, Plane, Sander sealant vanish and spar vanish for wood finishing, Sand paper 320 and 250 grit - for improving the smoothness of the wood.

### 2.5 Performance Evaluation of the designed and fabricated wooden fan blades

Finite element analysis of the different blades was carried out using ANSYS 2021 and SOLIDWORKS 2021. Structural analysis was conducted to find out the minimum and maximum values of stress, strain, displacement and the factor of safety acting on different configurations of a wooden fan blade. Performance evaluation of the constructed wooden blades was carried out by replacing conventional fan blades with the constructed blades of different configurations one at a time. The experimental design considered 3 types of wooden fan blade lengths – 600mm, 500mm and 400mm, tagged as A, B and C respectively. All the blades have thickness of 3mm. Each blade types were coupled to the head of a conventional fan and tested

accordingly. In each speed of operation of the fan, digital anemometer was deployed in taking readings such as speed of fan and airflow rate. Fan noise and smoothness during operation was also taken note of in each case. The results for each of the fan blade types were compared to that of a conventional fan blades.

### 3.0 Results and Discussion

#### 3.1 Stress Distribution of the Blades

After exerting a load of 360rpm on each configuration of the fan blade, results of the minimum and maximum stress, strain, displacement and factor of safety were determined. The results are presented below with corresponding images. The force distribution on the Blades can be determined by matching the colours on the blades to that of the rectangular tab beside it to get the corresponding values. The images below showing the results have been scaled to help the observer visualize how the blade is expected to deform after years of usage.

Considering that the fan blades are all subjected to the same rotational speed, the results obtained from this analysis indicates that fan blade configuration C performed better than the configurations A and B [20]. This conclusion was drawn based on the values obtained from the factor of safety. The configuration A has a minimum factor of safety of 8.5364 and 8.6958 respectively, the configuration B has a minimum factor of safety of 10.773 and 10.625 respectively, while the configuration C has a minimum factor of safety of 11.419 and 11.436 respectively.

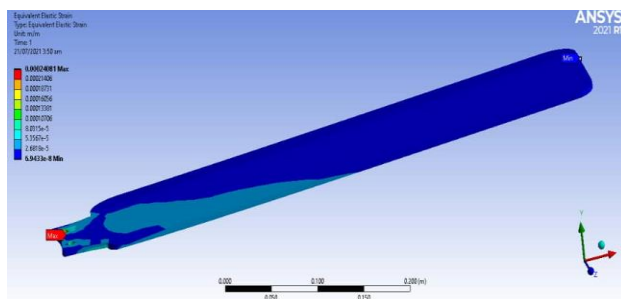


Fig. 4. Minimum and maximum stresses distribution of blade A

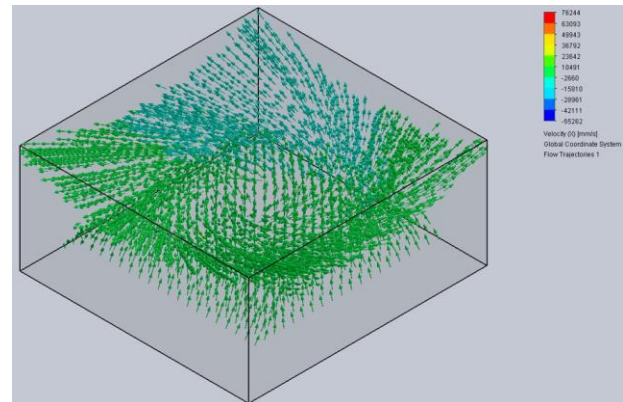


Fig. 5. Flow Trajectory for Fan blade A

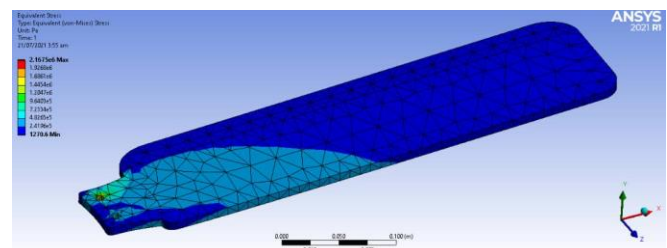


Fig. 6. Minimum and maximum stresses distribution of blade B

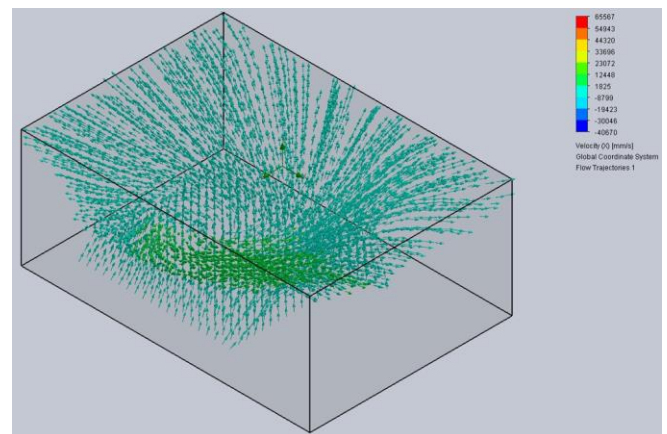


Fig. 7. Flow Trajectory for Fan blade B

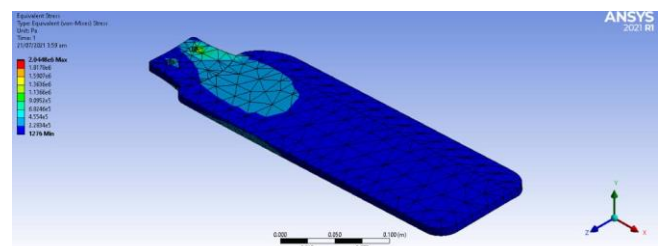


Fig. 8. Minimum and maximum stresses distribution of blade C

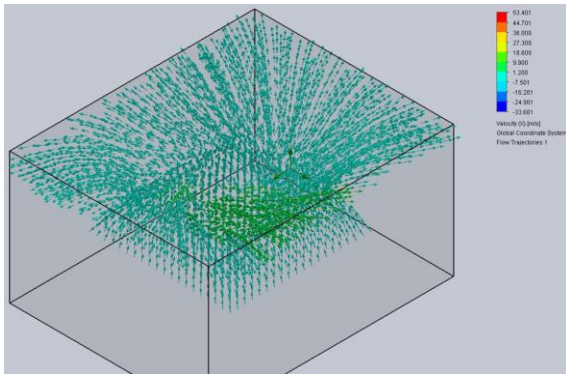


Fig. 9. Flow Trajectory for Fan blade C



Fig. 10 Fan blade A



Fig. 11. Fan blade B



Fig. 12. Fan blade C

**Table 1. Summary of fan blades performance**

<b>Blade length (mm)</b>	<b>Thick- ness (mm)</b>	<b>Weight (g)</b>	<b>Area (mm)<sup>2</sup></b>	<b>Volume mm<sup>3</sup></b>	<b>Density g/mm<sup>3</sup></b>	<b>Average Velocity m/s</b>	<b>Average Airflow Q</b>
600	3	22.221	45244.8	184350.4	0.0031640	3.15	3.48
500	3	22.743	46192.3	176332.5	0.0021641	3.12	3.52
400	3	22.771	48116.8	158440.4	0.0012577	3.54	3.63
Conventional Fan 600mm	2	22.873	47126.7	135734.4	0.0031534	3.42	3.54

Table 1 shows the results of the evaluation of the fan blades. Among the results obtained were, operational blades lengths, blade thickness (mm), weight (g), area (mm)<sup>2</sup>, volume (mm)<sup>3</sup>, density (g/mm<sup>3</sup>), fan velocity (m/s) and airflow (m<sup>3</sup>/s) and efficiency (%).

#### 4.0 Conclusion

The results obtained, one can conclude that a reduction in the blade total length leads to better structural performance. A change in the thickness of the blade also affects the structural strength but since the change in thickness of the blades for this analysis is small, the increase in structural performance is negligible when compared to the performance gotten when the total length of the blade is changed. Hence, replacement of fan blades with wood in ceiling fan is effective in the production of fans for economic viability.

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