## DEVELOPMENT AND PERFORMANCE EVALUATION OF WOOD COMPONENTS IN STANDING FAN

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## ABSTRACT

Gmalina arborea, Zebrawood and Plywood were utilized in the design, fabrication, replacement of component parts and testing of fan. Plywood, Gmalina arborea and Zebrawood were used for the construction of the blades, fan's root plate cover, stand and base respectively. The four blade sizes of diameters, 240 mm, 242.5 mm, 247.5 mm, and 282.5 mm were each coupled to the fan Hub and then mounted on the rotating shaft and tested. The various fabricated parts of the fan were coupled. The fan was tested for velocity, airflow and efficiency. Digital Anemometer was used in taking readings. Correlation and regression analysis were carried out on the data. Results showed that blades with the 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. Comparing the wooden fan blade of 282.5 mm diameter with conventional plastic/metal fan blade of same size showed that the velocities were 4.30 m/s and 4.64 m/s respectively, with airflow of 4.41 cms and 4.77 cms respectively, with efficiencies of 89% and 90% respectively. Fan velocity and airflow had positive correlation with blade area and negative correlation with density of blade. Velocity and airflow of 0.748 and 0.815 respectively resulted when the density was 0.560. While velocity and airflow of -0.710 and -0.750 respectively were realized when the density was -0.372. Regression equation with coefficient of linearity, $R^2$ of 0.999 was obtained, showing effectiveness of wood as engineering material in fans production.

## 1.0 INTRODUCTION

Fans are widely used for circulating air for the purpose of cooling in rooms, buildings, mechanical, electrical and electronic gadgets to create a more comfortable atmosphere. Most postharvest crops processing and storage equipment utilize fans for their effective operations. Agricultural Engineering machines such as threshers, Sheller, separators, winnowers and grains destoners incorporate different types of fans for effective operation. There are various types of fans used for various purposes ranging from larger to smaller sizes. They include: Standing fans for domestic and industrial and office uses, ceiling fans can also be used at the office and in homes to provide cooling system. We also have table fans, wall fans, propellers used at aircraft, fans used at kiln for wood seasoning, computer fan are mounted inside electrical and electronic gadgets such as computers, motors and engines, air conditioners to reduce high temperature during operation (Nobumasa, 1992, Naoki, 2006 and Yoshihiko, 2007).

Wood is the oldest and most widely used engineering materials. It is the only significant building material that is grown, we have a natural inclination that building in wood is good for the environment (Ramage *et al.,* 2017). It is renewable and readily available throughout the world and in Nigeria, wood is available in almost all the geopolitical zones. 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 (USDA, 2010). The tropical region of the world is endowed with different types of wood species relevant for utilization in fans development, but this is scarce. Hence, there is great necessity in the use and application of wood in the design of fans. Hardwoods and softwoods are useful for this purpose (Richardson, 1998).

Fan is a mechanical device that causes a movement of air and is used to induce airflow for a cooling purpose (Bill, 2005). Fans creates flow within a fluid, typically in liquids such as water and in gases such as air. A fan consists of a rotating arrangement of vanes or blades which act on the air fluid. The rotating assembly of blades and hub is known as an impeller, a rotor, or a runner. Most fan blades are protected by the mesh which serves as protection against curious finger and preventing damage to the blades and injury to man (Wedel *et al.*, 2014, Smith, 1989, Bleier, 1998).

According to Hansan (2014), most fans are electrically powered. But there are other sources of power including hydraulic motor and internal combustion engines. 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. Fans are generally made from metallic and plastic materials but there are many more materials that can be used in the design of fan especially the blades. Reports show that the cost of metals and plastics generally are becoming higher than wood as construction materials (Yahya, 2010).

## 1.1 Types of Fan

The three main types of fans used for moving air are axial fan, centrifugal (radial) fans and cross flow (tangential) fans (Ferguson, 1942).

**The Axial Fans are** made up of blades that forces air to move parallel to the shaft about which the blades rotate. Axial fans blow air across the axis of the fan, linearly. This is the most commonly used type of fan and is used in a wide variety of applications (Randon, 2008, AMCA, 2011, Bass, 1996).

**The Centrifugal Fan** has a moving component (impeller) that consist of a central shaft about which a set of blades form a spiral pattern. Centrifugal fans blow air at right angles to the intake of the fan, and spin (centrifugally) outward to the outlet. An impeller rotates, causing air to enter the fan near the shaft and move perpendicular from the shaft to the opening in the scroll shape-casing. A centrifugal fan produces more pressure for a given air volume but are typically noisier than comparable axial fans (Yahya, 2010, AMCA, 2011).

**The Cross Flow Fan** is a squirrel cage rotor (a rotor with a hollow center and axial fan blades along the periphery). Tangential fans take in air along the periphery of the rotor and expel it through the outlet in a similar fashion to the centrifugal fans cross flow fans give off an even air flow along the entire width of the fan and are very quiet in operation. They are comparatively bulky, and the air pressure is low. Cross flow fans are often used in air conditioners and automobile ventilation systems (Randon, 2008).

## 1.2 Research Objectives

The main objectives of this research are design, fabricate, replace wooden components of standing fan and carrying out performance evaluation to ascertain its viability in use.

## 2.0 MATERIALS AND METHOD

### 2.1 Experimental Site

The work was carried out in the Department of Wood Products Engineering, Faculty of Engineering, Cross River University of Technology, Calabar, located on coordinates, 4°57′0″N 8°19′30″E.

### 2.2 Materials Required

i.   Gmalina arborea was used to construct the fan's root plate cover

ii.  Plywood for the construction of the blade.

iii. Zebrawood for the construction of the stand and base.

iv.  Sander sealant vanish and spar vanish for wood finishing

v.   Sand paper 320 and 250 grit. For improving the smoothness of the wood.

vi.  Record book for taking record of all measurement and readings.

### 2.3 Design Considerations

According to Hudson (2007) and complimented by Yu-Tai Lee *et al.* (2011), one of the most important requirements of a fan wheel is that it must impart to the air stream a uniform velocity and pressure over its entire area (Grainger, 2005).

a.   The individual blade will be narrow at the tip. Where the blade velocity is light and will widen toward the hub where more blade area is required due to lower blade velocity.

b.   The angle of the blades to the plane of rotation will be minimum at the tip and increase as the hub is approached.

c.   Blade Discharge velocities

d.   Hub size should be optimally large enough to pick up where the blades are no longer able to carry load.

e.   Pitch and Blade Angle

f.   Number of Blades and the area of the total blade surface

g.   Blade size in terms of width and length is important as this affects the efficiency.

h.   Blade Speed - Proper wheel design must be closely correlated with blade speed since the total pressure furnished by any wheel is proportional to the square of the RPM.

### 2.4 Design of Component Parts of Fan

The components of the fan including the blades, stand and base were designed based on the works of Hudson (2007), Yu-Tai Lee *et al.* (2011) and Kolmetz and Widiawati (2015). The

overall system energy efficiency for an existing system can be expressed in terms of the specific fan power (SFP). SFP is defined as the installed motor power of all the fans in the air distribution system divided by the design airflow rate. SFP is expressed in terms of KW per 1000 CFM or in KW per ($m^3$/S) (McKenzie, 1997, Elizabeth, 2010, Lewis, 1996). The components parts which were designed are shown in Tables 1 and 2 below.

**Table 1: Design Specifications of the wooden standing fan.**

| S/N | Fan Components | Dimension | Function |
|---|---|---|---|
| 1 | Mesh | 500 mm diameters | Used to protect blade from curious fingers and external forces |
| 2 | Blades | Diameter: 240 mm, 242.5 mm, 247.5 mm, 282.5 mm | A pair of three blades mounted on the blade hub and fix to a rotating shaft for air production. |
| 3 | Motor | 230-volt 50hz single face | Provides rotational force to the shaft which holes the blades. |
| 4 | The stand | Length 604 mm from base to adjustable point, Diameter 105 mm, 496 mm from adjustable point to the top. | Support the fan in perpendicular position. |
| 5 | The base | Diameter 300 mm, | Provides a balance to the fan stand. |
| 6 | Root plate | Area 70 mm X 70 mm | Holds the stand to the base. |

**Source:** Field data, 2017

**Table 2: Designed fan blades and their properties.**

| Blade diameter (mm) | Thickness (mm) | Weight (g) | Area (mm)$^2$ | Volume mm$^3$ | Density g/mm$^3$ |
|---|---|---|---|---|---|
| 240 | 3 | 22.221 | 45238.9 | 135734.4 | 0.000164 |
| 242.5 | 3 | 22.743 | 46186.3 | 138576.9 | 0.0001641 |
| 247.5 | 3 | 22.771 | 48110.6 | 144350.4 | 0.01577 |
| 282.5 | 2 | 21.571 | 62679.7 | 125375.6 | 0.01721 |

**Source:** Field data, 2017

**2.5 Tools and Machines Used in the Construction**

a.   Flexible curve for measuring blade circumference.

b.   Pencil and meter rule used for measuring fan components

c.   Hand drilling machine for drilling the bold holes on the root plate metals

d.   Lathe machine used to create round surface on the wood.

e.   Drilling machine with 3 inches bit size. For drilling the stand of the fan.

f.   Narrow band saw used to cut the shape of blades.

g.   Welding machine for welding the root plate metals.

h.   Praying gun machine for vanishing.

i.   Digital Anemometer for measuring velocity and airflow.

j.   Hand saw for cutting various components of the fan.

k.   Grinding stone machine for cutting the metal sheet.

**2.6 Fabrication of the Designed Wood Components of Fan**

i.   Meter rule was used to measure the length of the base of the fan and the stand of the fan from the wood and the points were marked with a pencil.

ii.   Hand saw was used to cut out the wood into various components of the fan

iii.   Lathe machine was the most important machine I used to turn the wood into the desired circular shape.

iv.   I used grinding stone to cut the metal I used as the base root metal.

v.   Hand drilling machine of 10mm bit was used to drill the bolds holes of the root metal.

vi.   Sand paper (320 grits and 250 grits) was used to sand the wood give it a smooth finish.

vii.   Cutting of the blade was done by means of the narrow band saw into different blade sizes.

viii. Final finishing was done by first praying the fan with a sander finish. Allow it for some 30 minutes to dry. Then I used 320grt sand paper to the surface clean it with a moist cloth and allowed to dry. I now used a neutral spar vanish with thinner to spray again twice to obtain the final brilliant and smooth finish.

ix.   Coupling of the components was done by screw driver and 8mm diameter spanner to fasted the various components.

**2.7 Basic Description of the Fan**

The developed fan is made up of the following basic parts: **Base** - this supports the entire mechanism. **Adjustable Stand** – which carries other parts. **Motor Housing** - this consist of the squirrel cage induction motor to which blade assembly is attached. It is operated by a single phase electric supply, 230 V (50 Hz, 55W). This is operated by 3-speed control switch, usually where you will find the on-off (regulator) with speeds-low, medium and high. There is also **Blade/Impeller Assembly -** which cuts the air and pushes it forward. While the **Blade Guard -** prevents curious fingers from suffering injury. **Oscillator** makes it possible for the fan to rotate left and right.

Figures 1 and 2 show the isometric drawings of the designed fan. While Figures 3 to 6 show the pictorial views of the fan using different types of blade designs. Whereas Figure 7 and 8 show positioning and taking readings using the Digital Anemometer during testing of fan.

**2.8 Coupling and Testing of Fan**

The various fabricated components of the fan including the blades, stand, base and other essential parts were coupled. The fan was connected to a power source and tested for velocity, airflow and efficiency. The various blade sizes were tested. In testing fan performance, a portable MASTECH Digital Anemometer, model MS6252A was used in taking readings.



**Figure 1: Front view of fan.**



**Figure 2: Exploded view of the wooden fan.**

**Figure 3: Fan with Blade Diameter, 282.5 mm.**



**Figure 4: Fan with Blade Diameter, 282.5 mm.**



**Figure 5: Fan Blade Diameter, 242.5 mm.**



**Figure 6: Fan Blade Diameter, 240 mm.**
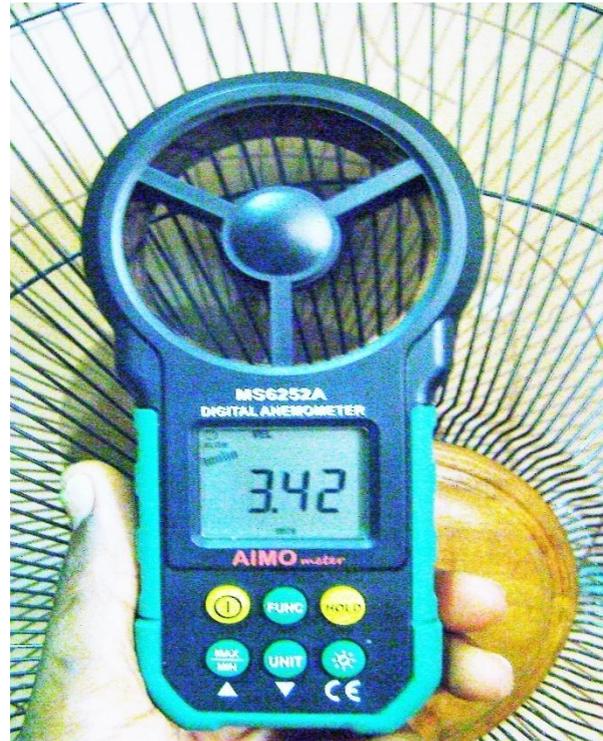
**Figure 7: Positioning the Anemometer.**



**Figure 8: Taking reading with Anemometer.**

## 3.0 RESULTS AND DISCUSSION

### 3.1 Wooden fan Performance Analysis

Data obtained from testing the fan with digital Anemometer are displayed on Table 3 below. Shown below are blade sizes of various diameters 240mm, 242.5mm, 247.5mm, and 282.5mm. Their performance was based on the following units: Velocity in m/s, km/h, mil/h, ft/s, ft/m and knots while air flow is in cubic meter per second (CMS), cubic meter per minuts (CMM) and cubic feet per minute (CFM).

**Table 3: Fan blades, velocity and airflow data of fan during operation.**

| Blade diameter (mm) | Velocity | | | | Average Velocity | Air Flow | | | | Average Air Flow |
|---|---|---|---|---|---|---|---|---|---|---|
| | Units | 1 | 2 | 3 | | Units | 1 | 2 | 3 | |
| 240 mm | m/s | 3.42 | 3.59 | 3.94 | 3.65 | CMS | 3.42 | 3.59 | 3.94 | 3.65 |
| | Km/h | 12.31 | 12.92 | 14.81 | 13.14 | CMM | 205.2 | 215.4 | 236.4 | 219 |
| | Mil/h | 7.84 | 8.02 | 8.81 | 8.16 | CFM | 7247 | 7607 | 8348 | 7734 |
| | Ft/s | 11.21 | 11.77 | 12.92 | 11.97 | | | | | |
| | Ft/m | 672.6 | 706.2 | 775.2 | 718 | | | | | |
| | Knots | 6.66 | 6.99 | 7.67 | 7.11 | | | | | |
| 242.5 mm | m/s | 3.06 | 3.42 | 3.59 | 3.42 | CMS | 3.24 | 3.42 | 3.59 | 3.42 |
| | Km/h | 11.02 | 12.31 | 12.92 | 12.08 | CMM | 194.4 | 205.0 | 215.4 | 614.8 |
| | Mil/h | 6.84 | 7.64 | 8.02 | 7.5 | CFM | 6865 | 7247 | 7607 | 7240 |
| | Ft/s | 10.03 | 11.21 | 11.77 | 11.0 | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ft/m | 601.8 | 672.6 | 706.2 | 660.2 | | | | |
| | Knots | 5.96 | 6.66 | 6.99 | 6.54 | | | | |
| 247.5 mm | m/s | 3.59 | 3.94 | 4.30 | 3.94 | CMS | 3.59 | 3.94 | 4.30 | 3.94 |
| | Km/h | 12.92 | 14.18 | 15.48 | 14.19 | CMM | 215.4 | 236.4 | 258.0 | 236.6 |
| | Mil/h | 8.02 | 8.81 | 9.61 | 8.81 | CFM | 7607 | 8341 | 9111 | 8353 |
| | Ft/s | 11.77 | 12.92 | 14.10 | 12.93 | | | | | |
| | Ft/m | 706.2 | 775.2 | 284.6 | 775.8 | | | | | |
| | Knots | 6.99 | 7.67 | 8.38 | 23.04 | | | | | |
| 282.5mm | m/s | 4.12 | 4.30 | 4.47 | 4.30 | CMS | 4.12 | 4.47 | 4.65 | 4.41 |
| | Km/h | 14.83 | 15.48 | 16.09 | 15.47 | CMM | 247.2 | 268.2 | 279.0 | 264.8 |
| | Mil/h | 9.21 | 9.61 | 9.99 | 9.60 | CFM | 8730 | 9471 | 9853 | 9351 |
| | Ft/s | 13.51 | 14.10 | 14.66 | 14.09 | | | | | |
| | Ft/m | 810.6 | 846.0 | 879.6 | 845.4 | | | | | |
| | Knots | 8.02 | 8.38 | 8.71 | 8.37 | | | | | |

**Source:** Field data, 2017

Table 4 shows the different sizes of blades with different parameters. It can be seen from the data on Table 4 that velocity and air flow is greatly influenced by the blade surface area. The same operating power yielded different velocities and airflows for different blade sizes.

**Table 4: Constructed wooden fan blades parameters and their efficiencies.**

| Blade diameter (mm) | Thickness (mm) | Weight (g) | Area (mm)$^2$ | Volume mm$^3$ | Density g/mm$^3$ (1x10$^{-3)}$ | Air Velocity (m/s) | Air Flow (cms) | Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| 240 | 3 | 22.221 | 45238.9 | 135734.4 | 0.164 | 3.65 | 3.68 | 86 |
| 242.5 | 3 | 22.743 | 46186.3 | 138576.9 | 0.1641 | 3.42 | 3.59 | 90 |
| 247.5 | 3 | 22.771 | 48110.6 | 144350.4 | 15.77 | 3.39 | 3.94 | 83 |
| 282.5 | 3 | 21.571 | 62679.7 | 125375.6 | 17.21 | 4.30 | 4.41 | 89 |

As shown in Table 4 above the blade with the diameter of 240 mm produced velocity of 3.42 m/s at the minimum speed, when the fan speed was increased to the medium speed, the velocity increased to 3.59 m/s and 5.94 m/s at the maximum speed, giving an average of 3.65 cms. The same was observed in the resultant airflow being 3.42 cms at the lowest speed, 3.59 cms at the medium speed and 3.94 cms at the maximum speed, yielding an average of 3.65 cms.

On the other hand, blade size of diameter, 242.5 mm produced lesser velocity of 3.06 m/s at the minimum speed, 3.42 m/s at medium speed and 3.59 m/s at maximum speed, giving an average velocity of 3.36m/s and airflow of 3.24 cms at the minimum speed, 3.42 cms at medium speed and 3.59 cms at maximum speed giving an average airflow of 3.42 cms. This was due to the clearance angle of the smaller blade. It indicates that clearance angle is also an

important factor to consider when selecting blades that will produce a better velocity and airflow.

It can also be observed that there was increase in velocity and airflow when the blade diameter was increased to 247.5 mm. Velocity of 3.59 m/s at minimum speed, 3.94 m/s at medium speed, 4.30 m/s at maximum speed with an average velocity of 3.94 m/s were recorded. The resultant airflow was 3.59 cms, 3.94 cms, 4.30 cms with an average airflow of 3.94 cms at the respective fan velocities.

Finally, increasing the blade to diameter of 282.5 mm, the fan produced velocities of 4.12 m/s, 4.30 m/s and 4.47 m/s and average velocity of 4.30 m/s. The resultant air flow was 4.12 cms, 4.47 cms and 4.65 cms with average air flow of 4.41cms. These results prove that velocity and air flow are closely interrelated and determined greatly by the blade's surface area and speed of the blade.

Thus, comparing the wooden fan blade of 282.5 mm diameter with conventional plastic fan blade of same size showed that the velocity as recorded by the anemometer were 4.30 m/s and 4.64 m/s respectively. While the airflow in cubic meter per second (cms) for wooden blade and plastic blade of same size were 4.41 cms and 4.77 cms respectively, with efficiencies of 89% and 90% respectively. These results revealed that the wooden blade of same diameter works efficiently well compared to the plastic conventional blade of same size.

**3.2 Relationship Between the Blade Sizes, Velocity and Airflow**
The relationship between the blade area, weight, volume, density, velocity and resultant airflow can be determined using the method of correlation and regression. Table 5 shows results of correlation of blade properties and parameters during operation of fan. Results showed that fan velocity and airflow had positive correlation with blade area and negative correlation with density of blade. Thus a velocity and airflow of 0.748 and 0.815 respectively resulted when the density was 0.560. While velocity and airflow of -0.710 and -0.750 respectively were realized when the blade density was -0.372.

**Table 5: Results of Correlation of Blade Properties and Parameters during Operation of Fan.**

|  | **Blade_Area** | **Weight** | **Volume** | **Density** | **Velocity** | **Airflow** |
|---|---|---|---|---|---|---|
| Blade_Area | 1 | -.891 | -.917 | .560 | .748 | .815 |
| Weight |  | 1 | .956$^*$ | -.372 | -.710 | -.750 |
| Volume |  |  | 1 | -.227 | -.547 | -.615 |
| Density |  |  |  | 1 | .904 | .892 |
| Velocity |  |  |  |  | 1 | .994$^{**}$ |
| Airflow |  |  |  |  |  | 1 |

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).


Regression equation was obtained for Air flow $A_f$ as the dependent variable while blade area, $A_b$ and blade velocity, V were the independent variables.

Airflow $= -0.49 + 0.003 \, A_b + 0.925 \, V$

$A_f \qquad = -0.49 + 0.003 \, A_b + 0.925 \, V$

$R^2 \qquad = 0.999$

Where,

$A_f \qquad$ = Airflow from fan

$A_b \qquad$ = Blade Area

V $\qquad$ = Fan Velocity


## 4.0 CONCLUSION

The research provided insight into the effective utilization of wood as an alternative material in the production of fan compared to the conventional materials such as metals and plastics. Wood species of different types exist in tropical rain forest region of Africa that have basic engineering properties useful for the construction of different machines components. Wood is naturally available and reclaimable through afforestation and proper conservation. Hence there is a growing need for efficient utilization of this raw material in the design of engineering products such as the electric fans. Gmalina arborea, Zebrawood and Plywood were utilized in the design, fabrication, replacement of component parts and testing of fan. Results obtained revealed that the wooden blades of same diameter works efficiently well compared to the conventional plastic/metal blades of same size and has high economic value with reduced cost of production, hence recommended for production and application in homes, offices, agricultural and industrial sectors. Well treated plywood is safe for use as a

fan blade. The test conducted on the fan showed that it has the potential to resist bending stress and pressure as a result of centrifugal force induced on the blade as it rotates.

It is hereby recommended to make maximum utilization of these locally available engineering materials in the design of engineering products for advancement in economy of the nation and the world at large. Studies in the utilization of different species of hard and soft woods in constructing engineering products such as fans and other machines should be encouraged.

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