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Investigation of The Blade's Sweep Size Effect On the Air Flow Field and The Energy Efficiency of the Ceiling Fan

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Abstract

The ceiling fan is the most economic device to cool the residential areas and as well as commercial areas. The ceiling fan plays vital role in thermal comfort for the people in those areas. Due to recent advancement in technologies ceiling fans are become energy efficient. This paper talks about the comparison of energy efficient and changes in flow field across the user perceiving annulus radius of three different sweep size of ceiling fan. Also suggesting user to select the ceiling fan based on their flow-field requirement. It explains the flexibility of blade design and its effect on flow field. This approach also talks about the power consumption and volumetric airflow for energy efficiency. Specifically, variation from 0.9m, 1.2m and 1.4m sweep size blades considered and compared. The flow field generated by the ceiling fans are captured by Reynolds Averaged Navier-Stokes (RANS) technique. All the tree different sweep size ceiling fans are analysed through CFD. The CFD results shows that the 1.4m sweep size blade fan gives more spread and energy efficient than other type of fans.

Keywords: *Ceiling Fan; Ceiling Fan Blade Sweep Effect; CFD Simulation; Energy Efficiency.*

1. Introduction

The ceiling fans circulate the air inside the room for cooling purpose. So it helps heat will be transferred from lower temperature air region to higher temperature air region. It is famous in tropical countries because of its cooling requirement with lower operating and maintenance cost. The main components of the ceiling fans are blade and motor. The blade plays the important role in aesthetics and aero performance of the ceiling fan. There are multiple ceiling fan categories available in the market . Sheet metal blades , plastic blades are two major categories in terms of blade material. The motors of the ceiling fan also evolved from induction motor to BLDC to increase the energy efficiency of the fan.

There are multiple experimental and numerical studies conducted in the past by M Pushpesh Singh and Dr. Gajendra et al [1], Lagudu Bhargav et al [2], Dr. Nitin K et al [3], Mohammad et al [4], Adeeb1 et al [5], Maithilee Jadhav et al [6], Ehsan Adeeb[7], E. Adeeb [8] to study the flow field for same sweep size and increase the energy efficiency of the ceiling fan for the different international standards. The objective of this research work is to study the flow field under the fan and energy efficiency for the different blade sweep sizes of the ceiling fan. This research work is carried out by using Reynolds Averaged Navier-Stokes (RANS) simulation methodology. In India most of the houses has1.2m sweep fans. However, there are other sweep sizes used in commercial areas for cooling purpose. This study covers the three important blade sweep sizes are 0.9m, 1.2m, 1.4m.

2. Method

2.1.Description of the Geometry

The blade designs used for this research is described in Figure 1, 2 & 3. The 0.9m sweep size blade means it covers circular area with 0.9m diameter while rotating and other two sweep sizes (1.2m,1.4mm) also defined in the same way. We considered only hub and blades for all the three fans and the angle between each blade is 120°. The length of the blades are 1L, 1.37L, 1.63L for 0.9m, 1.2m and 1.4m respectively where L is the unit length of the small blade shown in Fig 02a. All the blade has chord

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length of the root is 0.3L and tip is 0.25L. The thickness of the blades are 1mm each and shank part which is connecting hub and blades are ignored for this research because its effect are ignorable. The shank angle, v-bend angle, lift angle are X°, 3.75X°,2X° respectively. The maximum height, width and length of the air delivery test room is 4m, 6.9m,6.9m and full room details shown in Fig 03. The Ansys Spaceclaim used for designing the Air delivery test room and blade geometries. The MRF interface used between rotor and stator.

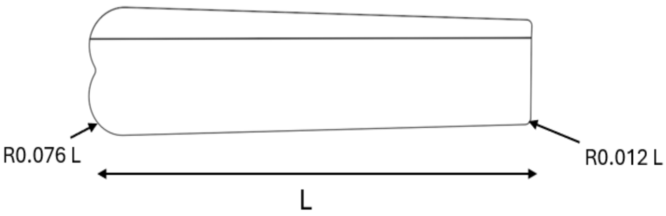

Figure 1 Blade Dimension (0.9m Sweep)

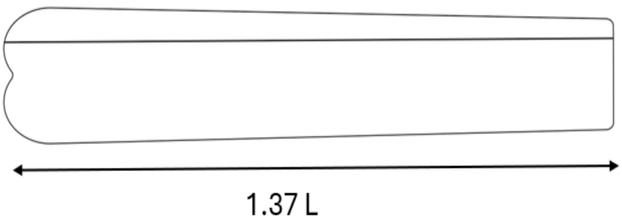

Figure 2 Blade Dimension (1.2m Sweep)

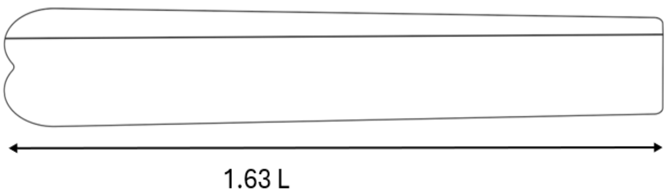

Figure 3 Blade Dimension (1.4m Sweep)

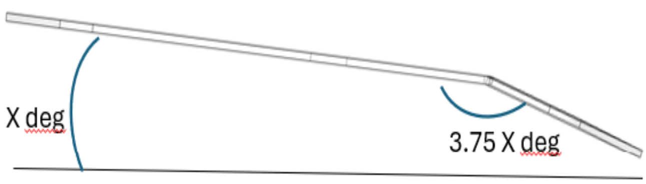

Figure 4 Blade Angle for All the Three Blades

2.2 Computational modelling and setup

The compuatational domain splitted into two different domain as stator and rotor. The stator is a non rotational domain and rotor domain which is very close to fan region is the rotational domain. The ANSYS Fluent is a Finite volume faced solver used in this study. The moving reference frame approach is used to capture the rotational effects of the rotor. The Reynolds-Averaged-Navier-Stokes (RANS) system of equations is solved using coupled-implicit solver. The incompressible and ideal gas properties is used for this CFD analysis. The viscous effects are captured by using one equation Spalart Allmaras [10] model. The choice of this turbulence model is due to its best correlation shown in various research issues for similar CFD domain setup[3,7&11].

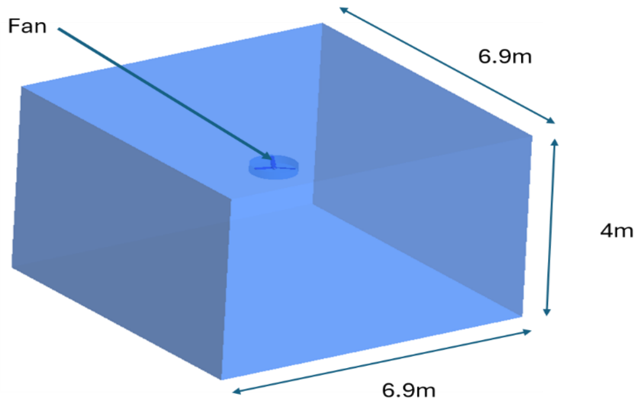

Figure 5 Computational Domain

All the walls and blades are considered as no slip walls. The adiabatic boundary condition also applied to the wall and blade, so that it will not allow the heat through it. The total temperature of the air domain is considered as 288K with the total pressure value of 101325pa. The polyhedral mesh is used for stationary and rotating domain in this study .The mesh elements are shown in Figure 4,5,6,7,8&9. The grid independence case study is done for the computational domain and final grid size is chosen based on it. This study will eliminate the computational error due to variation in mesh size. The total number of three grid sizes used for this grid independence study. The final grid size is chose by calculating the torque convergence with economical mesh count.

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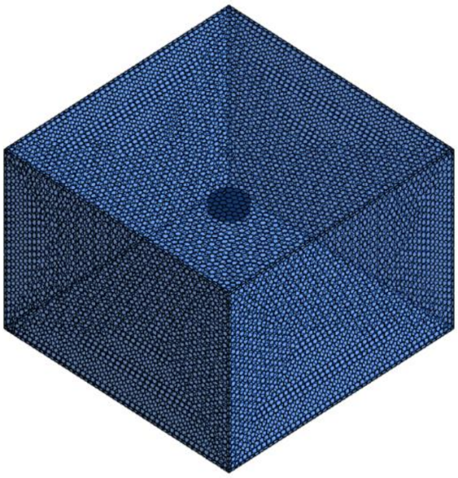

Figure 6 Mesh-Fan Inside the Room

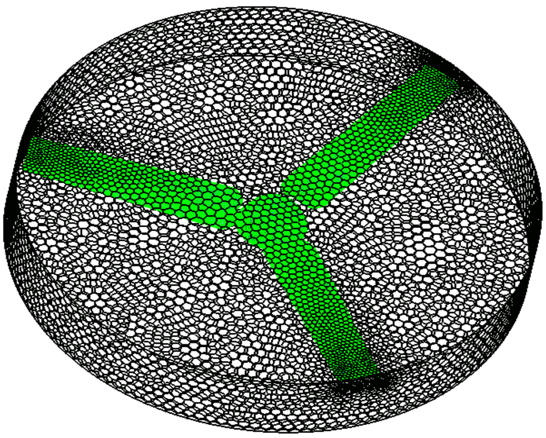

Figure 7 MRF Mesh(rotor)

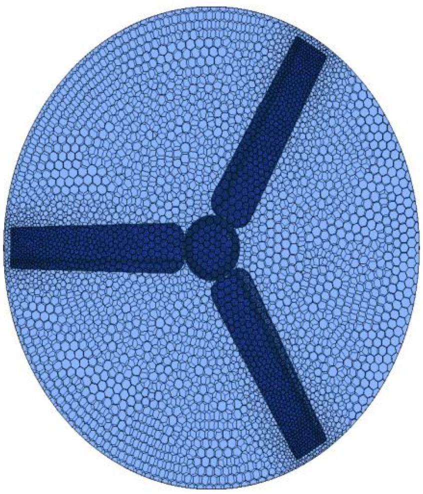

Figure 8 MRF Mesh(rotor)-Top view

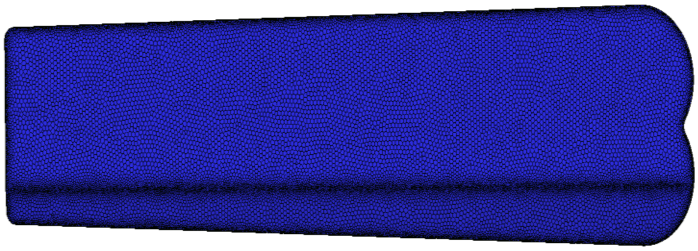

Figure 9 Blade Leaf-Mesh

3. Results and Discussion

3.1.Airflow Pattern Inside the Room

The CFD analysis performed for different blade sweep sizes and the velocity contours inside the room is shown in Figure 10,11&12. The velocity vectors shows that how the air flow field varies inside the room due to different sweep size of the ceiling fan. The ceiling fan spread [9] is defined as the width of the airstream at specified measured distance perpendicular to the airflow direction. The air throw or thrust of the fan is defined by the maximum axial velocity at measured plane. The velocity profiles give the in the energy efficiency, Volumetric flow rate, torque, power are calculated through CFD analysis. The velocity is measured on a surface which is located 1.5m below the fan plane centre. The measured velocity shows the similar trend like the maximum velocity occurs near hub and it is getting decreased over higher annulus radius.

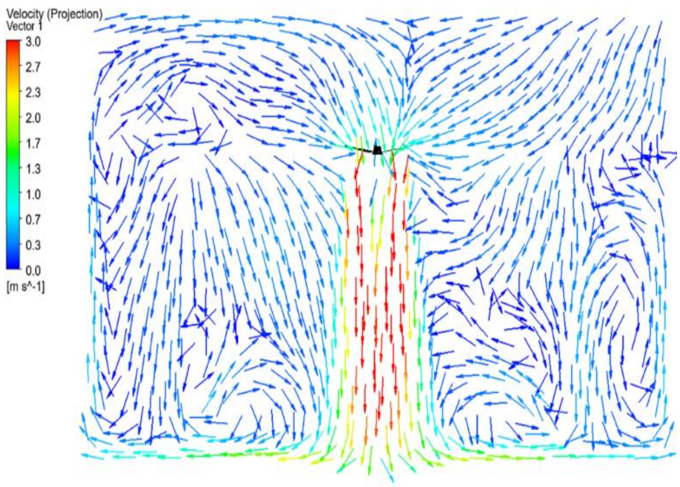

Figure 10 Velocity Vectors (Fan Sweep Size - 0.9m)

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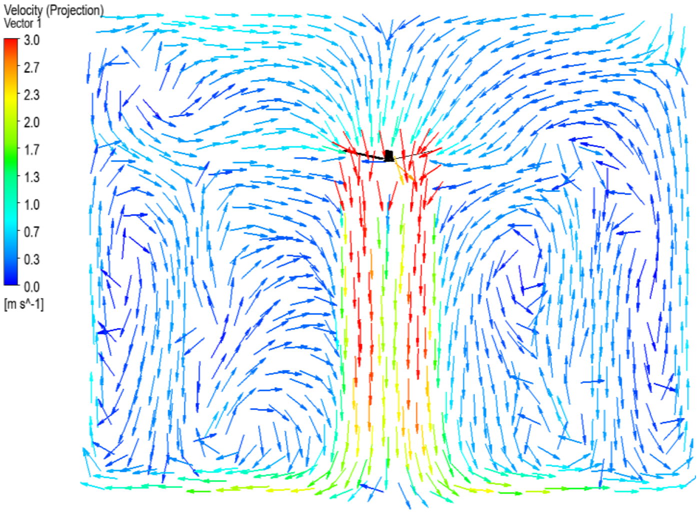

Figure 11 **Velocity Vectors (Fan Sweep Size - 1.2m)**

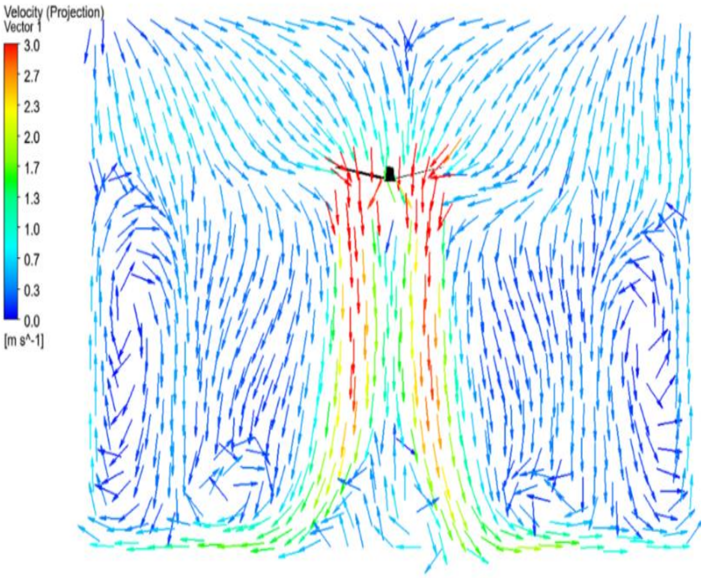

Figure 12 **Velocity Vectors (Fan Sweep Size - 1.4m)**

However, the thrust and spread behaviour for different sweep size blade fan varies based on its sweep size. The lower sweep size(0.9m) blade gives maximum axial velocity near lower annulus region. Higher spread is achieved by large sweep(1.4m) blade by covering large area in measurement surface. The velocity values across the measurement annulus radius at 1.5m below the fans are shown in Figure 13.

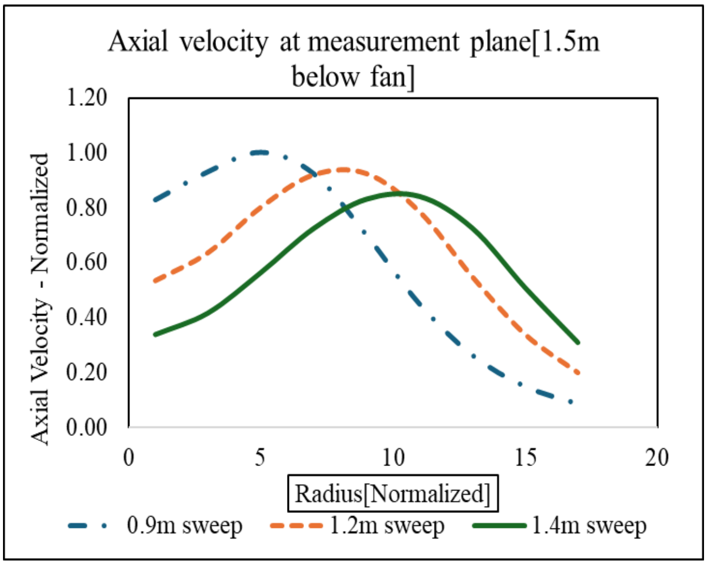

Figure 13 **Axial Velocity at Different Annulus Measurement Radius**

3.2 Volume flow rate & energy efficiency

Volumetric flow rate is the amount of unit volume air reached measurement surface at a specific unit time. The range of volumetric flowrate is given in Figure 14 for the varius sweep size blades. The 1.4m sweep size is giving maximum volumetric flow rate compare than other two sweep size blades. The volumetric flow rate is increasing steadily as shown in Figure 14 for the increasing sweep size of the blades. Volume flow rate is defined as amount of mass going through unit surface area per unit time.

$$Q = v \times A$$

Where Q - volume flow rate, A – Cross sectional vector area, v- Axial velocity

The ceiling fan sweep effect on the volume flow rate is shown in the Figure 15 based on the results of CFD simulation of different sweep size of ceiling fan blades. The volume flow rate is increased with increase in sweep size of the blades.

$$\text{Fan power} = \text{Torque} \times \text{Angular velocity}$$

The ceiling fan performance is measured by important parameter called energy efficiency which is defined as the ratio between the volumetric flow to

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the fan power of the ceiling fan. The torque is calculated from there surface of the ceiling fan blade. The higher sweep size blade has the maximum value of energy efficiency compare than other two lower sweep size blades. It is observed that higher volumetric flow rate for the same aerodynamic power of the higher sweep size blade leads to higher energy efficiency. Also observed lower sweep size leads to lower in energy efficiency which is shown in Figure 15.

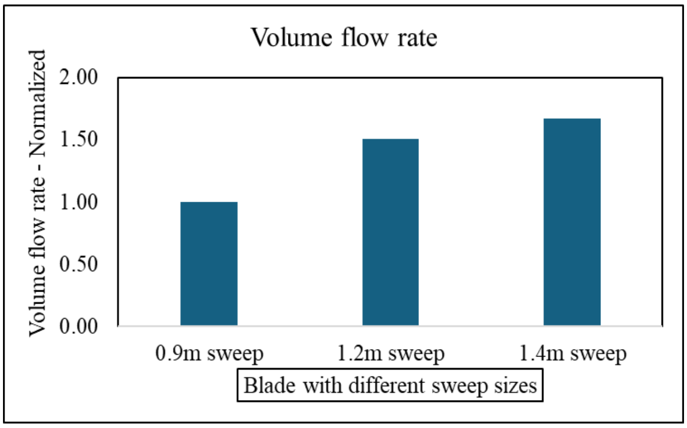

Figure 14 Ceiling Fan Sweep Size Vs. Volume Flow Rate

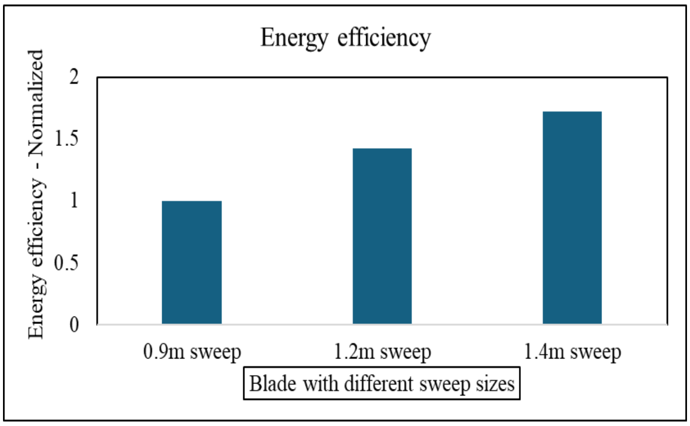

Figure 15 Ceiling Fan Sweep Size Vs. Energy Efficiency

Conclusion

In this work, comparative study is carried out to find the effect of ceiling fan blade's sweep length on the energy efficiency and the flow field of the fan inside the AD testing room. The air velocity data of the ceiling fans are calculated using CFD simulation. The CFD simulations are conducted by using Reynolds Averaged Navier Stokes approach. It is observed that lower sweep size blades gives higher thrust and lower spread whereas higher sweep size blades gives higher spread and lower thrust on the flow field. The highest velocity region location in the measurement plane shifted for different bade sweep size. Also this detailed analysis supports that cieling fan blade sweep length has more effect on energy efficiency.

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