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Research on Aerodynamic Axial Flow Fan Efficiency Improvement

Mr. S. Samraj, Mr. K. Sedhuramalingam, Dr. V. Shantha, Dr. B. Rajeshkumar, Dr. Indra Vijay Singh

Associate Professor [3,5] Assistant Professor [1,2,4]

ssamraj@actechnology.in, sedhuramalingam.k@actechnology.in, shantha.v@actechnology.in, rajeshkumar.b@actechnology.in, indiravijay@actechnology.in

Department of MCT, Arjun College of Technology, Thamaraikulam, Coimbatore-Pollachi Highway, Coimbatore, Tamilnadu-642 120

Abstract: Fans used to move air in commercial and industrial buildings account for a significant portion of the total energy consumption. Since much of the city's planned structures have yet to be built, and since both the cost of electricity and its availability are on the rise, there is an immediate need for fan designs that minimise energy consumption. This research compared two fan designs in terms of the overall effort needed to achieve certain output levels using a retrofit experimental approach. Due to their equal output characteristics, an aerodynamic axial flow fan and a belt-driven centrifugal fan are compared to find out which one is better. The aerodynamically optimised design of the axial flow fan used in this research drastically reduces the total power input, connected load, and rated motor KW. An additional advantage of this fan type is the smaller air handling unit. The current centrifugal fan design's performance characteristics are evaluated and documented. These stringent requirements prompted the development of a state-of-the-art axial flow fan with an aerodynamic design. After the retrofitting procedure, the performance of the improved fan design is assessed by a second comprehensive performance analysis. Considering the mechanical efficiency of the fan, the system's efficiency is calculated both before and after the refit. By using computational fluid dynamics (CFD), we were able to simulate the two systems' operation and investigate the impact of various design parameters on efficiency. These parameters included the twist of the rotor blades, the geometry of the hub, and the guiding vanes. The Ansys flow solver allows us to perform the simulation and determine the power requirements of the fan in order to achieve the desired airflow. Using a return on investment (ROI) technique, we may determine whether it is feasible to replace the current fan with a new, more efficient one. Thanks to this cutting-edge, environmentally conscious method, HVAC energy consumption may be reduced by up to 30%. Computational fluid dynamics study of the system may help optimise the design further for better performance and efficiency.

Aerofoil guiding, retrofitting, aerodynamic axial flow, and computational fluid dynamics performance parameters are some of the topics discussed.

Introduction

The circulation of air is fundamental to all living things. Fan is the mechanical device that was created to meet this need. In commercial and industrial air movement systems, fans account for over 40% of the total power consumption. Better energy-efficient fan designs might cut fan power consumption by as much as half. According to comprehensive research, the typical efficiency of industrial fans range from 33% to 55%. Fan inefficiency is mostly caused by the design of the fan's impeller or rotor. The overall mechanical efficiency of the fan has the potential to reach 92% with this optimisation. There is a pressing need for energy-efficient fans since a large portion of the city's new buildings are still under construction, and because power prices are rising and supplies are becoming more scarce. The rated motor kW, connected load, and total power input of the axial flow fan used in this research may be significantly decreased with the aid of its optimised aerodynamic design. The smaller air handling unit is an extra perk of this fan type. The amount of force needed to pump the specified air volume is dictated by the drag that is produced by the blade design. Reduced drag from an aerofoil's design means less thrust is required to pump large air volumes, which means less power consumption from the engine.

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set up to turn the fan's impeller. In order to improve the fan's efficiency, we looked at a number of aerodynamic design characteristics. Industry standards are used to realistically quantify the enhanced performance. We will submit the revised design to industry experts for execution so that we may transition to renewable energy sources to power these machines, which will have a good effect on the environment.

TypesOfFans

Considerations like as efficiency, space constraints, material type, flow rate, pressure, and volume dictate the choice of fan and blower. Different kinds of fan designs have different efficiency. Centrifugal flow and axial flow are the two main types of fan motion. When air enters and exits a centrifugal flow device, the direction of the airflow may be either forward curved, backward curved, inclined, or radial. Axial flow (also known as propeller, tube, or vane axial) occurs when air flows into and out of a fan in a straight line.

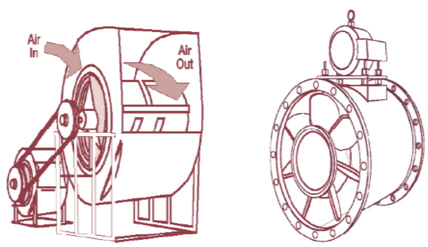

Figure1.1.TypesOfFans

a) CentrifugalFan:Types

The major types of centrifugal fan are: radial, forward curved and backward curvedRadial fans are industrial workhorses because of their high static pressures (upto 1400mm WC) and ability to handle heavily contaminated airstreams. Because of their simpledesign, radial fans are well suited for high temperatures and medium blade tip speeds.Forward-curved fans are used in clean environments and operate at lower temperatures.They are well suited for low tip speed and high-airflow work - they are best suited formoving large volumes of air against relatively low pressures. Backward-inclined fans aremore efficient than forward-curved fans. Backward-inclined fans reach their peakpower consumption and then power demand drops off well within the reusableairflow range. Backward-inclined fans are known as "non-overloading" becausechangesinstaticpressure donotoverloadthemotor.

b) AxialFlowFan:Types

The major types of axial flow fans are: tube a Tube axial fan has a wheel inside acylindrical housing, with close clearance between blade and housing to improveair flowefficiency. The wheel turns faster than propeller fans, enabling operationunder high65%. Vane axial fans are similar to tube axial, but with addition of guide vanes thatimproveefficiencybydirectingandstraighteningtheflow.Asaresult,theyhaveahigherstatic pressure with less dependence on the used generally for

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andmoderatetemperatures.Theyexperiencealargechangeinairflowwithsmallchangesin static pressure. They handle large volumes of air at low pressure or free delivery.Propeller fans are often used indoors as exhaust fans. Outdoor applications include air-cooledcondensersandcoolingtowers.Efficiencyislowapproximately50%orless.

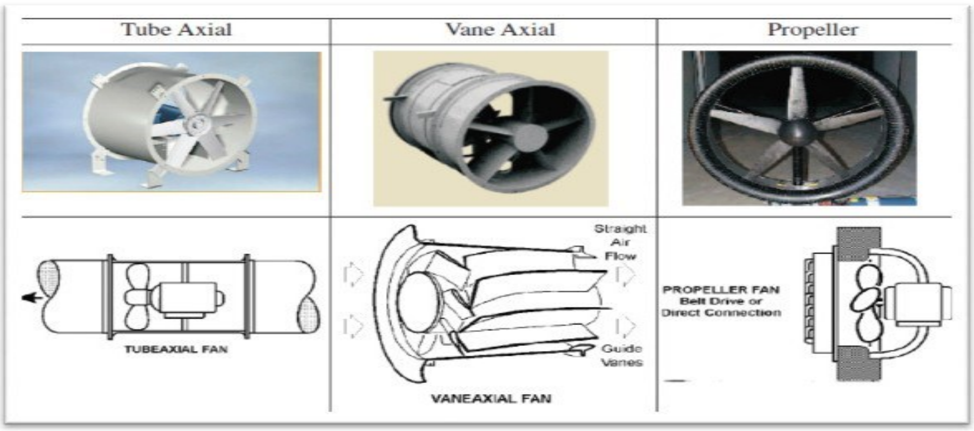

Figure1.2.TypesOf AxialFlowFans

1.2 Typesofbladedesigns

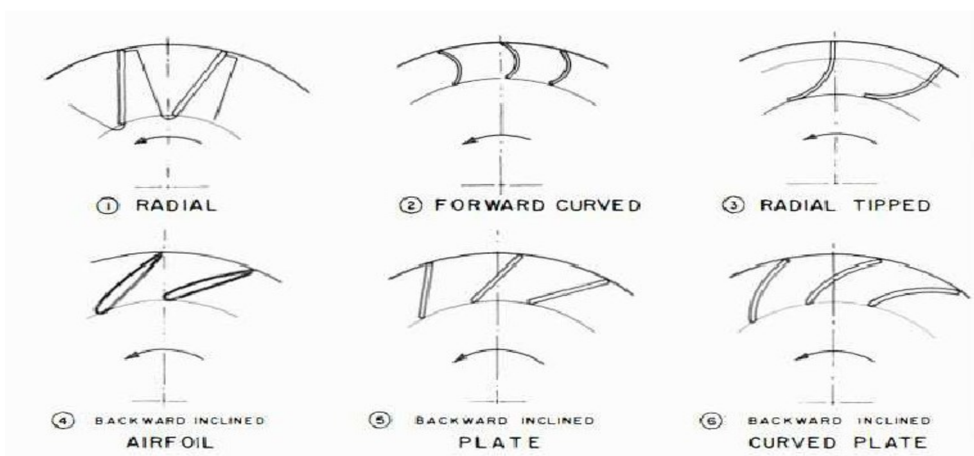

Figure1.3.TypesOfBladeDesigns

Radial blades: Forming a rotor which is essentially a large paddle wheel, this designresults in a relatively inefficient fan with power consumption higher than that usingthe much more common backward inclined blade. Its inherent mechanical strengthandresistancetowearmeanitisgenerallyusedwhenhighquantitiesofabrasivedustarepresentinthegasstream,orwhenveryhighgastemperaturesareexpected.

Forward curved : A forward curved centrifugal fan is characterized by its cylindricalshape and lots of small blades on the circumference of the impeller. In the exampleshownbelow,thefanrotatesinaclockwisedirection.

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Backwardcurved

Anefficientandstrongshape,thisdesignisacost-effectivealternativetothe backward curved design but with flat plate blades instead of curved. This resultsinaslightlylowerefficiency,compensatedbytheeasierfittingofliner

Table1.TypesOfFans,CharacteristicsAndApplications

CentrifugalFans			AxialFlowFans		
Type	**Characteristics**	**TypicalApplications**	**Type**	**Characteristics**	**TypicalApplications**
Radial	High Pressure,Medium Flow.Efficiencyclosetotube axialfans. Powerincreases continuously	VariousIndustrial applications,suitable fordust laden, moist air /gases	Propeller	LowPressure,High flow,Lowefficiency,Peakefficiencyclosetopoint of free airdelivery (zero staticpressure)	Aircirculation Ventilation,exhaust.
ForwardCurvedBlades	MediumPressure, highflow ,dipinpressure curve,efficiencyhigherthanradialfans,power risescontinuously	LowpressureHVAC, packaged unitssuitableforclean and dustladenair/gases	Tube-axial	MediumPressure, highflow higherefficiencythanpropellertype,dip in pressure-flowcurve beforepeak pressure point.	HVAC, dryingovens,exhaust systems
Backwardcurvedblades	Highpressure,highflow,highefficiency, powerreducesasflow increasebeyondpointofhighestefficiency	HVAC, variousindustrialapplications,forced draftfans,etc.	Vane-axial	High pressure,mediumflow,dip in pressure–flowcurve,useofguide vanesimprovesefficiency exhausts.	Highpressureapplicationsincluding HVAC systems
Airfoiltype	Same as backward type,highestefficiency	Same as backwardcurvedbutforclean airapplications			

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MethodologyofDesignStudy

The centrifugal fan, however, is more difficult, particularly when high efficiency isrequired. The blades are given an aerofoil shape to decrease the resistance created for theflow of air. Guide vanes are also made in aerofoil shape and the profile is given such thatthe leading edge of the aerofoil first comes into contact of the airflow to take the most ofthe benefit from the aerofoil design, Apart from the aerofoil design the rotor blades aretwisted along the length which is unique design optimization done in this fan design, thebenefitof whichisdiscussedindetailfurther.

2.1 Designcriteriaofafan:-

The key factors of design criteria of a fan are , specifications of the fan, selection for theapplication,impellerstressing,criticalspeedoftherotor,fieldInstallationandFansound.

Table2.SpecificationsofFan

Volumetricflow,m^3/s	11.20
StaticPressure,Pa	640
Density,Kg/m^3	1.20
Speed,rpm	1450
Fandiameter,m	0.9

2.2 FactorsAidingInIncreasedEfficiencyOfFan

The contact of the air with the first physical element of the fan itself starts the relationbetween the performance of the fan directly resulting the design criteria. The inlet conehasaveryvasteffectonthe soundlevelsofthefan.Ifasmoothtransitionwiththehelpofinlet cone is not provided then the air cuts across the diameter of the fan and high soundlevels are experienced. Hence having an inlet cone helps in reducing fan sound levels.Similarly the hub blades and guide vanes along with the tip clearance between the bladesandtherotorcasinghave influenceonthefanperformance.

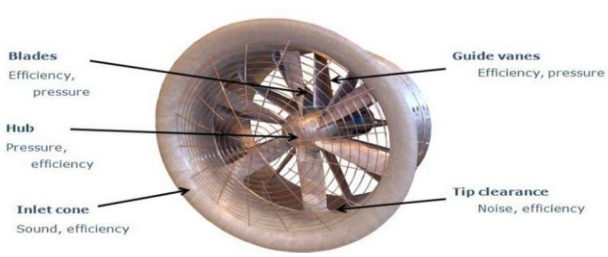

Figure2.1AerodynamicsofhighefficientAxialflowfan

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ThetermAxialflowfanindicatesthattheairflowsthroughthefaninanapproximatelyaxialdirection.Ontheinletside,astheflowapproachesthefanblades,thedirectionoftheflowisaxial,inotherwords,paralleltotheaxisofrotation,providedthereareenoinletvanesorotherrestrictionsaheadofthefanwheel.Thefanbladethendeflectstheairflow.Apropellerisamechanismdesignedtoproduceatractiveforceorpush,whensubmergedinafluidmedium.Thepropellersareaerodynamicelementsthatarecomposedofahuborcentralcoreandanumberofblades.Theoperatingprincipleofaxial-flowfansissimplydeflectionofairflow.Pasttheblade,therefore,thepatternofthedeflectedairflowisofhelicalshape,likeaspiralstaircase.Thisistrueforallthreetypesofaxial-flowfans:propellerfans,tubeaxialfans,andvaneaxialfans.

2.3 TheAerofoildesignoftheblade

Anaerofoilisastreamlineshape.Itsmainapplicationisasthecrosssectionofanairplanewing. Another application is as the cross section of a fan blade. There are symmetric andasymmetric aerofoils. The aerofoils used in fan blade are asymmetric. Fig.2.2 shows anasymmetric aerofoil that has been developed by the National Advisory Committee foraeronautics (NACA), it normally produces positive pressure on the lower surface of theaerofoilandnegativepressureorsuctionontheuppersurface.Thesuction pressureonthetop surface are about twice as large as the positive pressures on the lower surface, but allthese positive and negative pressures push and pull in approximately the same directionandreinforceeachother.The combinationofthesepositiveandnegativepressuresresultsinaforceF.ThisforceFcanberesolvedintotwocomponents:aliftforceL,perpendicular to the relative air velocity; and a drag force D, parallel to the relative airvelocity. Fig.2.3 shows the forces acting on an aerofoil. The lift force L is the usefulcomponent(R:WASETNACA)

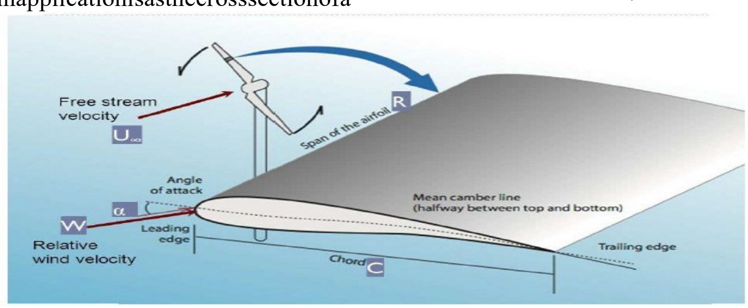

Figure2.2.ShapeofAsymmetricAerofoil

Inthefigure2.2theleadingedgeisthepointatthefrontoftheaerofoilthathasmaximumcurvature(minimumradius).Thetrailingedgeisdefinedsimilarlyasthepointofmaximumcurvatureattherearoftheaerofoil.Thechordlineisthestraightlineconnecting leading and trailing edges. The chord length, or simply chord, is the length ofthechordline.Thatisthereferencedimensionoftheaerofoilsection.Camberlinearethepoints halfway between chord and upper blade surface. Angle of attack is the anglebetweendirectionof airflowandthechord.

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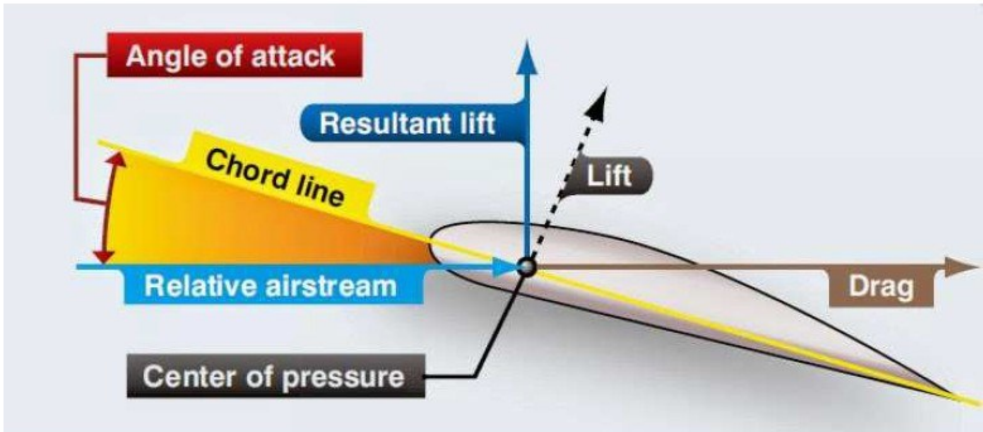

Figure2.3.ForcesActingOnAerofoil

The lift that an aerofoil generates depends on the density of the air, the velocity of theairflow, the viscosity and compressibility of the air, the surface area of the aerofoil, theshapeoftheaerofoil,andtheangleoftheaerofoil'sangleofattack.However,dependenceon the aerofoil's shape, the angle of attack, air viscosity and compressibility are verycomplex. Thus, they are characterized by a single variable in the lift equation, called thelift coefficient. Due to the complexities of the lift coefficient, it is generally found viaexperimentationinawindtunnelwheretheremaining variablescanbecontrolled.Therefore,theliftequationisgivenby

$\rho v^2 sCL$

where$L$istheliftingforce,ρisthedensityofair,$v$istherelativevelocityoftheairflow, s is the area of the aerofoil as viewed from an overhead perspective, and CL is the liftcoefficient.

As with lift, the drag of an aerofoil depends on the density of the air, the velocity of theairflow, the viscosity and compressibility of the air, the surface area of the aerofoil, theshape of the aerofoil, and the angle of attack. The complexities associated with drag andthe aerofoil's shape, angle of attack, the air's viscosity, and air's compressibility aresimplified in the drag equation by use of the drag coefficient. The drag coefficient isgenerallyfoundthroughtestinginawindtunnel,wherethedragcanbemeasured,andthedragcoefficientiscalculatedbyrearrangingthedragequation.

$$D=({}^{1}/_{2})\rho v^2 ACD$$

Inthedragequation,**D**isthedragforce,ρisthedensityoftheair,$v$isthevelocityofthe air,Aisareferencearea,andCDisthedragcoefficient.

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2.4 Twistedaerofoilblade

The blade experiences a relative wind velocity that is a vector sum of the actual windspeed (V) and the speed caused by the rotation of the rotor (Ω r where Ω is the rotationalspeed and r is the distance from the rotation axis). In order to produce lift, an aerofoilshape must be oriented so that its rounded leading edge is facing approximately into theairflow direction. But, the airflow direction for a wind turbine is actually a vector sum ofthewinditselfandtherelativewindcausedbytherotationofthebladethroughtheair.

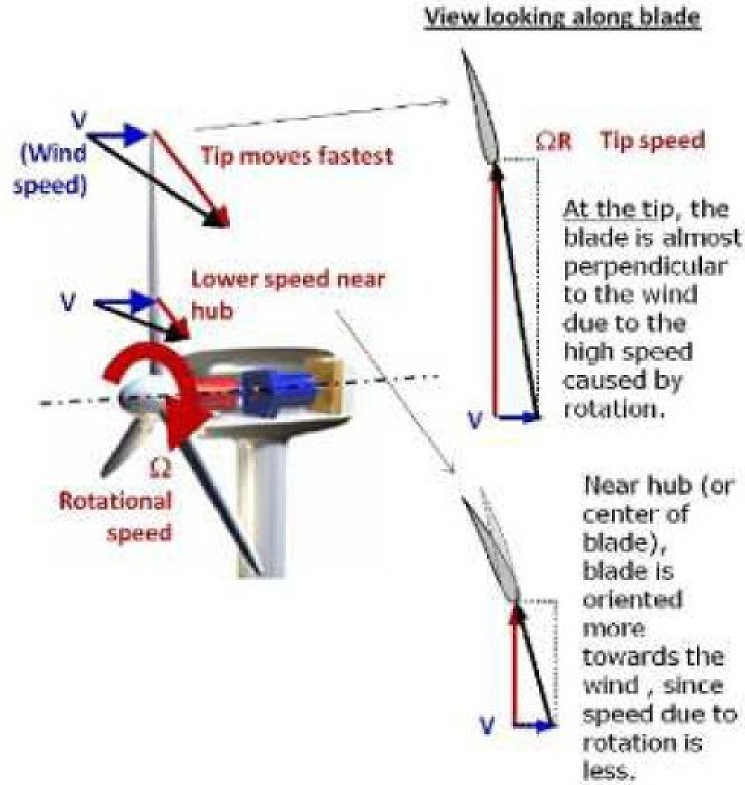

Figure2.4.Mechanicsofatwistedbladesetup

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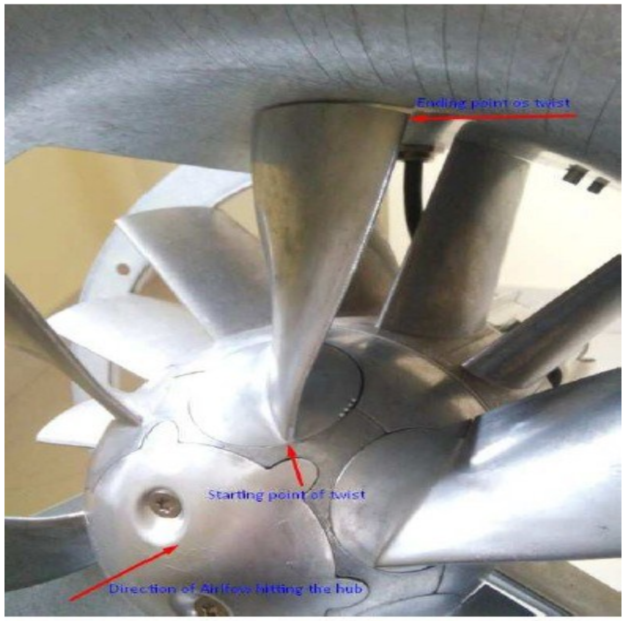

Figure2.5.Mechanicsofatwistedbladesetup

Figure 2.4 shows the example of a wind mill blade.TSR= ΩR/V, where Ω is the angularvelocityoftherotor,Ris thedistancebetweentheaxisofrotationandthetipoftheblade,and V is the wind speed.Since the speed of a rotating blade varies from the center to thetip, the angle with which the airflow encounters the aerofoil varies along the blade (seeFigure2.5).Toaccountforthis,therotorbladesmustbetwisted

It is important to note that the leading edge of the blade aerofoil mounted on the impelleris facing approximately into the airflow direction across the length of the blade. It is thisdesign criteria which drastically help in reducing the resistance to the movement ofimpeller.

2.5 RoundedHub

Arounded hubbenefitisshowninthefigure above,usually axial flowfansaregivenflathubsornotasmuchradialshapeasneeded,onesuchhubcanbeshownintheFigure2.6.Before hitting the blades the air comes into contact with the hub, which experiences thefluid and transfers the flow to the blades, if the hub isn’t correctly rounded as in ourdesignitwillhavealossin pressureandefficienciesofthefanasthesurfaceofthebladenear the hub doesn’t have good contact to the laminar fluid hence disrupting the smoothflowofairreducingtheabilityoffantocreatehighpressuresandefficiencies.

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Figure2.6.RoundedHubandinletcone

Conventional Axial Flow Fan	Aerodynamically Deisgned Axial Flow Fan
	

Figure2.7.ComparisonbetweenconventionalandourAerodynamicfandesign

2.6 TheGuidevanesinfandesign

The guide vanes at the outlet of air are provided to provide a near laminar effect to thefluid exiting the impeller, this will help to reduce the turbulence and also increases theefficiencyofthefanasithelptoreducethelossesduetoturbulence.

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Figure2.8. AsymmetricAerofoilguidevanesofactualdesign

Turbulence not only causes increased noise levels but also causes massive pressure losses in the moving air. The design incorporates guiding vanes to make the system more efficient and to transfer the impeller's pressure without any loss. Figure 2.8 shows the asymmetrical form of the guiding vanes, which are aerofoils.
The fixed guiding vanes' aerofoil design greatly enhanced the system's efficiency. These vanes are used to transfer the impeller-generated pressure without any loss of pressure.

2.7 Adjusting the Guide Vanes' Profiles to Face the Leading Edge Into the Airflow

When air is released from the impeller, it meets the leading edge of the guiding vanes because the aerofoil's rounded leading edge is angled perfectly such that it faces towards the direction of the airflow,

as seen in the picture below.

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Figure2.9.Inlineleadingandtrailingedgeofbladeandguidevane

The second optimised part is the small space between the blade tips, which results in less noise and improved efficiency. The rounded tip and inlet cone work together to improve efficiency by distributing airflow more uniformly. As seen in the image below, the airflow is directed to the beginning point of the blade by the rounded hub without any loss, restriction, or diversion. The following are examples of standard axial flow fan designs for your reference.

Figure2.10.Closeupview ofbladetipclearanceinourdesign

This study's aerodynamic fan design stands out due to the narrow space between the housing and the tip of the moving blade. Minimal blade tip clearance reduces noise and improves efficiency. As shown up above, it's so thin that a business card might squeeze through.

3.1Comparisonbetweendesignofconventionalaxialfanandaerodynamicaxialflowfan

Figure3.1.Clusteroffandesignshowingconventionaldesignsandaerodynamicfandesign

How an axial fan simulator works at its most basic level. The three primary parts of these procedures—computational domain, meshing, and solving—will serve as the framework for this discussion.

An entrance, a casing that contains the geometry of the blades, and an outlet make up the geometric domain. The produced mesh is very sensitive to the actual dimensions and geometries of the three domain components. The fan's performance is affected by its most crucial aerodynamic component, the blade. Being the sole moving portion of the fan, the blade cuts through air and propels it forward. As a first step, we used reverse engineering to model the fan using all of the existing aerofoil drawings and the real design concepts.

Figure 3.2 below shows the 3D CAD models compared to the original design.

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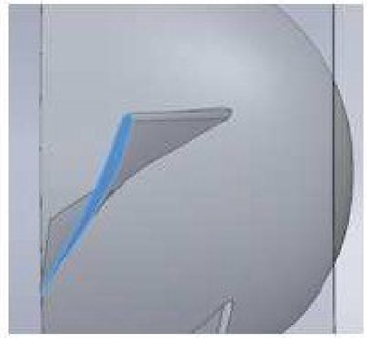
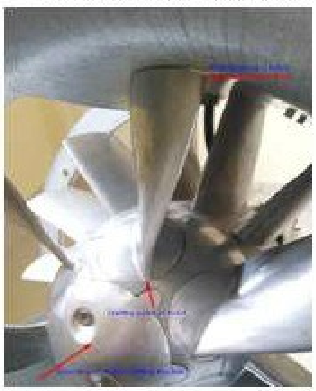
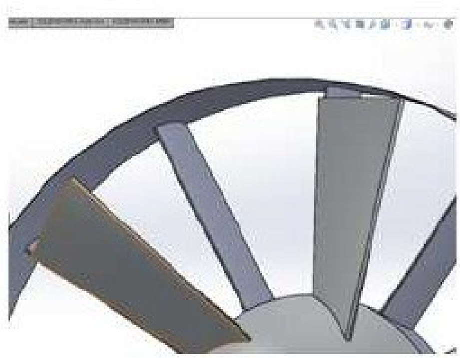
Original Fan Model	3D CAD Model for Analysis
 Aerofoil shape of the blade	
 Twist of the blade along the axis of rotation	
 A closer look at the twist	

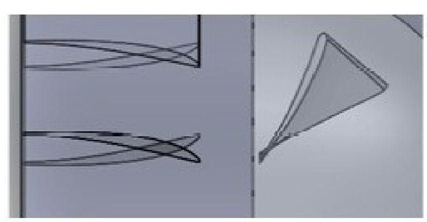
Original Fan Model	3D CAD Model for Analysis
	

Figure3.2.TableofpicturescomparingoriginalmodelandCADmodel

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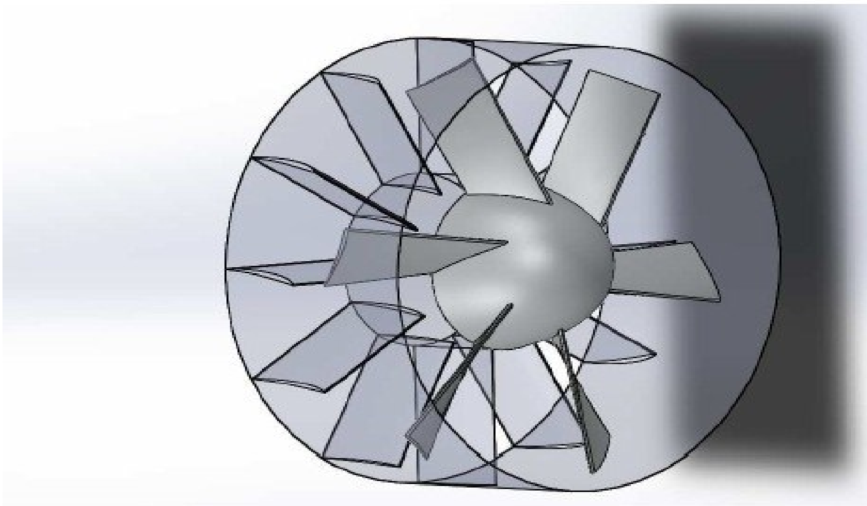

Figure3.3.AnIsometricviewoftheFan3DCADmodelforAnalysis

CONCLUSIONS:

An efficient fan design with an aerofoil-shaped impeller and guide vanes was investigated through experimental modelling, reverse engineering, and validation using the ANSYS CFX solver. The model was created in Solidworks. In comparison to a traditional centrifugal fan, the aerodynamically built fan significantly reduced power consumption, leading to a 68.75% savings and an increase in fan efficiency from 58.8% to 89.8%. Computer assisted design (CAD) and computer aided engineering (CAE) have helped model and simulate circumstances identical to those in the real experiment, and the findings obtained are within acceptable limits.

Experimental results showed that the new fan design had a number of advantages over the old centrifugal fan design, one of which was a much lower pressure need. Engineers will be able to choose the best fan model for future retrofit projects if this pressure analysis can be done in the simulation programme.

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[2] September 2013, stellen Bosch university, "Experimental and Numerical Analysis of Axial Flow Fans" by Ockert P.H. Augustyn.

(1) "How to improve energy efficiency of fans for air handling units" (Nejc Brelih, 2012), published in the REHVA journal in February.

Report from the Physics Department of the College of Wooster in Wooster, Ohio, 44691, USA, authored by Alex Sullivan and dated May 6, 2010, regarding aerodynamic forces operating on an airfoil.