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EXPERIMENTAL STUDY OF THE SLITTED BLADE FAN PERFORMANCE

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EXPERIMENTAL STUDY OF THE SLITTED BLADE FAN PERFORMANCE

A THESIS
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BY

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بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

وَٱلضُّحَىٰ (1) وَٱلَّيۡلِ إِذَا سَجَىٰ (2) مَا وَدَّعَكَ رَبُّكَ وَمَا
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فَهَدَىٰ (7) وَوَجَدَكَ عَآئِلٗا فَأَغۡنَىٰ (8) فَأَمَّا ٱلۡيَتِيمَ فَلَا تَقۡهَرۡ (9) وَأَمَّا
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DISCLAIMER

I confirm that the work submitted in this thesis is my work and has not been submitted to another organization or any other degree.

Hassanain Kadem Jaffer

Signature:

Date: 2025/ /

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2025/ /

SUPERVISORS CERTIFICATION

We certify that the thesis entitled **" Experimental Study Of The Slitted Blade Fan Performance"** submitted by Hassanain Kadem Jaffer, has been prepared under our supervision at the Department of Mechanical Engineering Techniques of Power, College of Technical Engineering-Najaf, AL-Furat Al-Awsat Technical University, as partial fulfillment of the requirements for the degree of Master of Techniques in Thermal Engineering.

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Abstract

The relative movement between the fluids and the moving bodies through represents the develop many engineering concepts like boundary layer and its application, drag, lift forces, their application in automobiles, airplanes, rockets, and heat transfer where the liquid is used to remove or add heat to the system. Fans represent the optimal device that puts this phenomenon in the way of practical applications, where moving blades in air forces the surrounding air to move forward or backward and deliver air volumetric flow. An axial fan is the most common type of fan and it can be seen in different shapes and sizes depending on application. The axial fan is simple in construction and its performance is related to many parameters such as air volumetric flow, weight, geometry of blades, angle of attack, and rotation speed. In this study, seven models of axial fans have been manufactured and tested for average speed (volumetric flow rate), noise, and power consumed. The models have been modified based on a patent of a new blade design (divided blade rotor), they have been noted as M1-M7. First an M0 model has been constructed and tested against the original model in patent, after that other models have been constructed and divided into two groups based on the direction of rotation where the group M1-M4 rotates counterclockwise while the group M5-M7 shows a clockwise rotation. The M1 blade model made of a 1mm galvanized steel sheet with 220mm length and 100mm width, and the hub is made of 2mm galvanized steel and 150mm diameter. The M2-M4 is made from 3mm aluminum sheet with the same length and width while the hub in model M2-M3 is made from 5mm aluminum sheet and 3mm sheet for M4. The hub in M3 is 100mm and the width of the blade in M4 is 138mm. The models M5-M7 are the same as M2-M4, only the direction of rotation is different. The experiments have been conducted by altering the speed of rotation and the power consumed has been taken as an indicator of work.

The comparison results show that at the maximum motor velocity 890 rpm the model M4 gives the best performance where the volumetric flow rate increases by 13.3% and noise level reduces by 2%. Therefore, The M4 has been compared to the fan that used in the outdoor unit of an air conditioning spilt unit type installed in Imam Ali Holy Shrine and has some efficiency issues. The results show that the new tested M4 model decreases the outlet compressor line temperature (refrigerant temperature) by $12C^0$, preventing the compressor from going in to overload protection mode on summer hot days.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure No.	Title of the Figure	Page No.

NOMENCLATURE

symbol	Definition	Unite
P	**Pressure**	**N/m2 (pa)**
t	**Time**	**Sec**
L	**length**	**m**
$\dot{m}$	**mass flow rate**	**kg/s**
V	**Axial velocity**	**m/s**
Q	**volumetric flow rate**	**m3/s**
ρ	**air density**	**kg/m^3**
k	**Constant of thermal conductivity**	**W/ m. K**
A	**flow area**	**m^2**
ΔP	**pressure difference**	**N/m2 (pa)**
ΔV	**Velocity difference**	**m/s**
η	**Fan Efficiency**	**%**

Abbreviations

SYMBOL	DESCRIPTION
RPM	Revolutions Per Minute
CFM	Cubic feet per minute
dB	Decibels
CFD	Computational fluid dynamics
LES	Large Eddy Simulation
CNC	Computer Numerical Control
FDM	Finite Difference Method

CHAPTER ONE

INTRODUCTION

Introduction

Fans are essential mechanical devices that play a crucial role in various industries and every day application. The motivation and different need led the development of fans, from personal hand-held to a precise fan in electronic devices or large wind turbine[1]. The history of fans dates back thousands of years. The earliest known fans were hand-held devices made from materials such as feathers, leaves, or cloth, used primarily to create a breeze and provide comfort in hot climates. Ancient civilizations, including the Egyptians and Chinese, utilized fans not only for personal cooling but also as symbols of status and power.

In ancient Egypt, fans were often made from palm fronds and used in religious ceremonies and royal settings[2]. The Chinese developed more sophisticated designs, including the folding fan, which became a prominent cultural artifact during the Tang Dynasty (618-907 AD)[3].

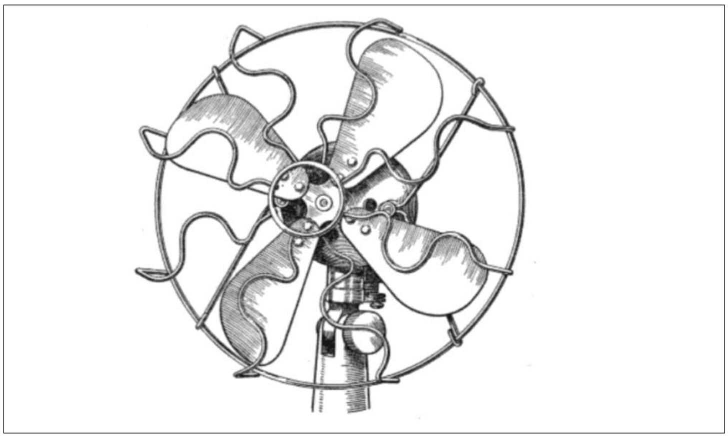
The industrial revolution marked a significant turning point in fan technology. The introduction of electric motors in the late 19th century led to the creation of electric fans, which revolutionized indoor climate control. These fans became widely accessible to the public, transforming not only personal comfort but also the design of residential and commercial buildings[4].

1.1 Fan types

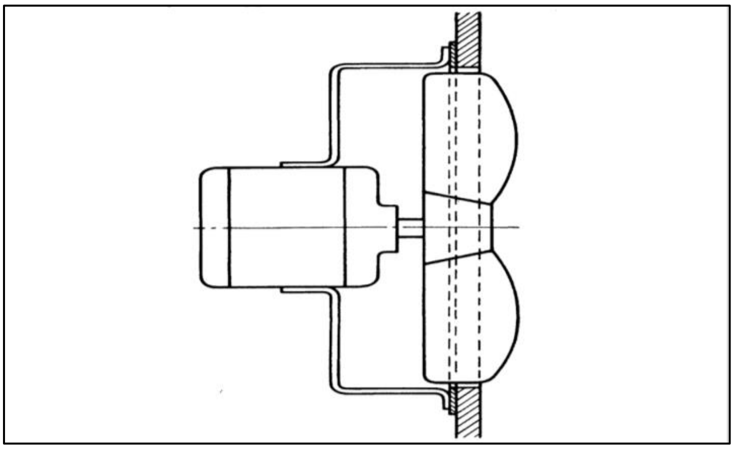
Fans in general are classified into two groups depending on their way of delivering fluid and the operation.

1.1.1 Axial flow fans

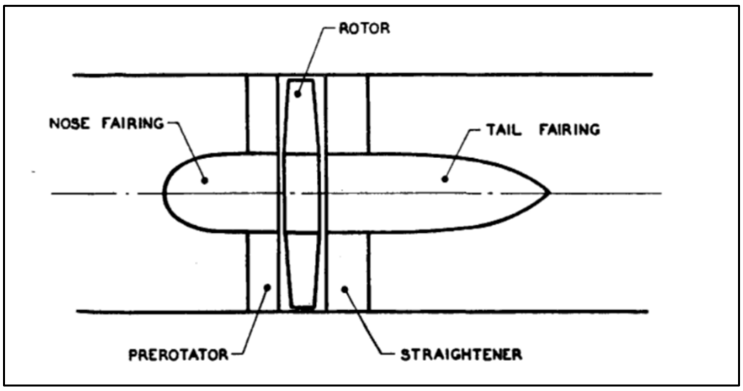
In axial flow fans, the working fluid (usually air) flows parallel to the axis of the rotation. The axial fans are simple in design and construction. The blades of the fan are usually designed in the shape of an airplane (streamlined body), directing air along the fan's axis. Depending on the application, the fan could be a free fan, diaphragm mounted fan, or ducted fan as shown in figure 1-1[5]



Free axial fan



Diaphragm-mounted axial fan



Ducted axial fan

Figure 1.1 Classification fan Depending on the application

1.1.2 Centrifugal fans

A centrifugal fan is a fan that uses an impeller to increase inlet air speed in a radial direction. Its inlet airflow enters from the fan's center and changes 90 degrees due to centrifugal force. Controlled by dampers, vanes, and steering blades, this fan is commonly used in cooling, heating, and air conditioners. It consists of rotating and fixed parts like casing, impeller wheel, drive shaft, bearing, and coupling as shown in Figure 1.2

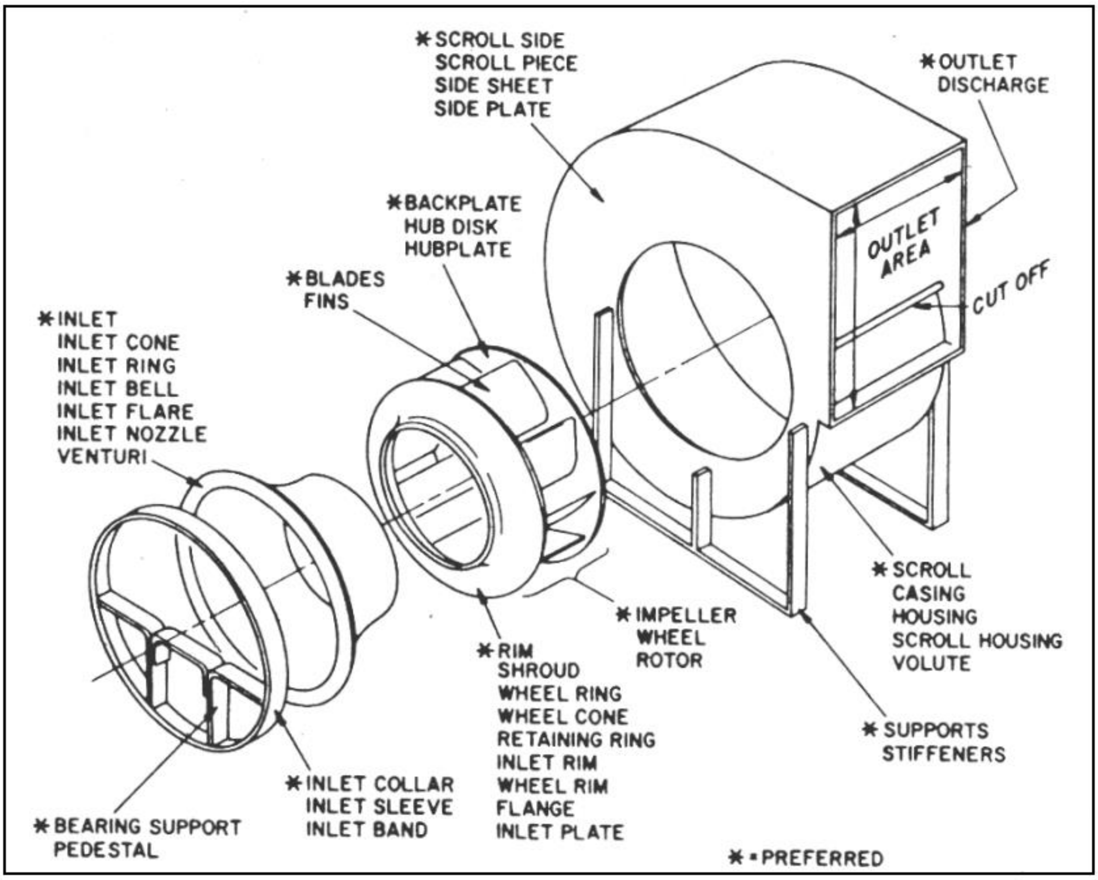


Figure 1.2 Components of centrifugal fan[1]

Centrifugal flow fans are divided into four types:

1- Forward-curved: Forward-curved fans have blades that are bent in the direction of the impeller's rotation, providing low noise levels and suitable for ventilation as shown in Figure 1.3.

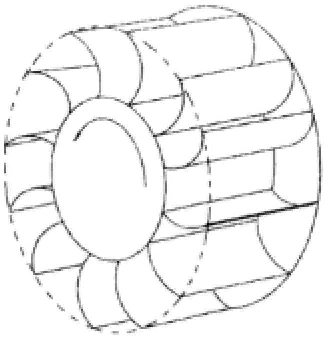


Figure 1.3 Forward-curved[1]

2- Radial blade: Radial blade fans have blades that expand without curvature, making them suitable for low-volume flow rates, and high static pressures as shown in Figure 1.4.

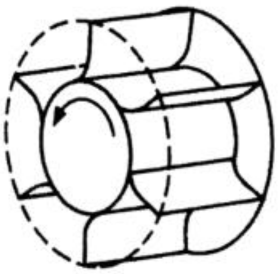


Figure 1.4 Radial blade[1]

3- Backward-curved: Backward-curved fans have blades curved in the opposite direction of the impeller's rotation, making them more efficient and capable of operating with varying static pressure as shown in Figure 1.5.

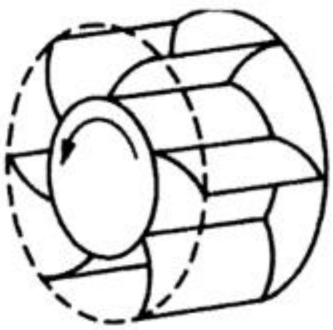


Figure 1.5 Backward-curved[1]

4- Airfoil blade: Airfoil blade fans are the most efficient, providing high airflow volume, making them suitable for industrial, mining, and biochemical applications as shown in Figure 1.6.

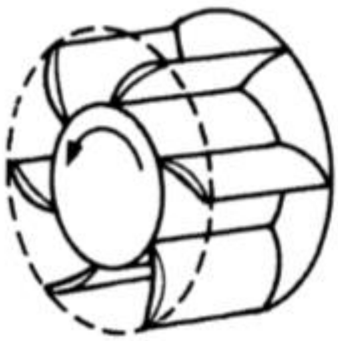


Figure 1.6 Airfoil blade[1]

1.2 Main parameters

Since the application and category of the fan differs, the parameters that motivate the designer differs too. However, the importance of each parameter depends on the application and economic and environmental limitations [6]. The most important parameters are:

1.2.1 Flow Rate (Airflow)

The flow rate of the air needed in any application per time unit usually represents the key parameter to select the type of fan, and it is measured by in ventilation applications cubic feet per minute (CFM) or cubic meters per hour(m3/hr). A bigger fan needs to be used or the category needs to be changed to ensure enough airflow

1.2.2 Pressure

Fans need pressure to overcome the resistance of the air to move. Therefore, the crucial design parameter in fan design and manufacturing is to meet the minimum pressure needed to operate the system, taking in consideration system resistance such as ductwork, filters, or other obstructions. The required pressure increases as the resistance in the system increases.

1.2.3 Fan Speed (RPM - Revolutions per Minute)

The basic definition of the fan is that it is a rotating device. So, the rotational speed of the fan blades is important, increasing the rotation speed will increase the airflow but at the same time it will increase the power consumption and noise level.

1.2.4 Power Consumption

Normally electric power is used to operate the fans. Especially in air conditioning systems, although there are some applications that use mechanical drives such as belts or chains to rotate fans, in most cases electrical power is the main source of power. A more powerful motor typically allows for higher airflow or pressure, but it also increases the operational cost. Efficiency and power usage are important for balancing performance and energy consumption.

1.2.5 Fan Efficiency

Depending on the delivered airflow to the power consumed, the fan efficiency can be calculated. The efficiency represents a comparison of the useful power output to the mechanical power input. Thus, higher efficiency fans require less energy to deliver the same performance, making them more cost-effective and environmentally friendly.

1.2.6 Fan Blade Design and Angle

The fan depends on the effect of the moving blade inside air, so the shape and the size of the blade is important to give the blade good aerodynamic performance, also the angle of the twist affects air movements. Blade design influences airflow capacity, pressure generation, and noise levels. The angle of the blades (blade pitch) is critical in determining the balance between airflow and pressure.

1.2.7 Noise Level

In some application, the noise level, which is usually expressed in decibels (dB), is very important in domestic applications or hospitals, the average acceptable noise level is different base on the application as in figure 1.7. That is why the noise is considered a performance parameter. However, the noise level increases with the increase of the rotation speed. It also increases in some designs where the aerodynamic profile of the fan can increase the noise.

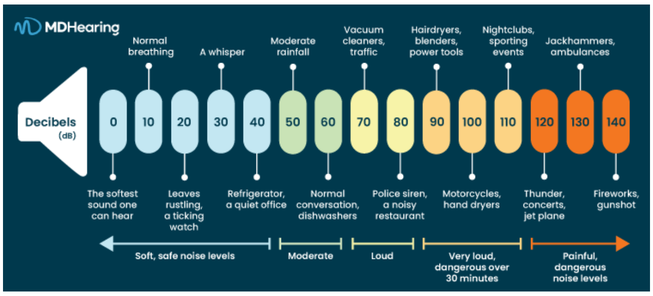


Figure 1.7 Standard noise level

1.2.8 Operating Environment

Certain conditions of the environment may force the designer to consider more options to meet the environmental conditions, such as humidity, dust level and temperature. Therefore, fans may be designed to the maximum performance to resist dust level or high humidity and temperature.

1.3 Fans with heat exchangers

All applications that involve heat transfer between fluid and its surrounding depends on the fluid and surrounding temperature, area of transferring and convection heat transfer coefficient (h). There are two mechanisms of heat transfer that affect the value of (h): natural and forced convection[7].

- In natural convection, the heat transferred through the fluid depends on the bouncy force that is generated due to the density difference between hot and cold zones. The range of convection heat transfer coefficient depends also on the fluid type (density), for example, for air the value of (h) does not exceed 10W/m. K [8].
- In forced convection, the flow of fluid is forced by any device that force the fluid to move rather than bouncy effect. Usually, such movement can be done by fans in gases and pumps in liquids. Fluid flow increases the convection heat transfer coefficient due to the change of the fluid particles that are in contact with hot or cold surfaces which keeps the heat transfer effective and transfers more heat[9]. A heat exchanger is the most known device for transferring heat effectively in most thermal systems such as internal combustion engine cycles, power plant cycles, heat dissipation in electrical devices, and internal and external units in AC systems. The basic work of a heat exchanger is to offer as large an area as possible to transfer heat with the help of suitable airflow. The airflow is delivered through an external fan that could blow or excavate the air through

the heat exchanger compact or shell as shown in figure 1.8. Therefore, the type of the fan that is used in heat exchanger is very important particularly when these heat exchangers are used to prevent other equipment from electrically burned fan or malefaction due to excessive heat such as the case of electrical devices and electronic parts in computers or laptops or the compressors in outdoor units of AC systems. The improvement of fans performance through optimizeing the performance parameters that where mentioned earlier, will be dealt with in next chapter. But, for now one of the patents that aims to improve the air quantity delivered by the fan is the use of slot blade with holes distributed on the blade to improve the aerodynamic characteristics of the blade and increase the flow rate of the fan[10] .

Figure 1.8 Heat exchanger

1.4 Problem statement

Using AC units is common in hot and dry weather regions, as in Iraq, which has a severe hot summer and long warm days during the year. Using the AC unit witnessed a huge increase during the last few years; at the same time the peak of temperature during heat waves passed 55C in shadow and more in direct sun. The performance of the AC units is affected by the increase in the ambient temperature above the design limits. However, most of manufacturing companies provide their system with overload protection control which is designed to shut down the compressor at high temperature and high current in compressor circuit. Also, in some models of vertical external condenser, as in figure 1.9, which have central fan that exhausts the air from circumstance heat exchanger, the motor of the fan electrically burns due to the excessive heat. To overcome this problem, it is worthy to try to redistribute the air flow through the condenser and increase the flow rate with minimum increase in power consumed and noise.

Figure 1.9 Vertical condenser of AC units.

1.5 Aims of Study

After addressing the problem, the study will aims at:

1- Using a patent blade[10] that shows the increase in flow rate delivered by a new manufacturing fan as a base to study the performance when used in AC units.

2- Suggest new models of axial flow fans that could fit with different applications.

3- Redistributing the airflow due to the new manufacturing used in different models to cool the compressor and fan motor and avoid the heat overload circuit breaker.

CHAPTER TWO

LITERATURE REVIEW

Literature review

This chapter provides a literature review of the previous works that used numerical and experimental methods to optimize and enhance the performance of the axial fan. Optimizating the design of the axial fan has been the main aim for numerous articles, also the noise ratio has its part in studies to meet the comfort criteria.

2.1 Geometry of blades

The parameters that affect the axial fan performance which have been a spot of interest for many researchers are: the fan geometry such as blade surface, angle of attack, blade profile, and hub design. Another parameter is the noise of the fan or the acoustic profile of the fan. The power consumed is important in many studies. A summary review will be introduced in this work. In recent years, [12] conducted a numerical study using ANSYS software to optimize the design of an axial fan using CFX to simulate three designs of an axial fan (straight blades, C-type blades and forward swept blades), and they reported that the total pressure efficiency in forward swept is the highest, also the aerodynamic performance of the forward swept and C-type are higher than straight blade fans.

[13] the authors conducted a theoretical and experimental work using inverse design problem (IDP) to optimize the design of the blade based on the air flow required in application. Their results show that the air flow rate can be increased using the algorithm.

[14] used mathematical methods of structural design to optimize the design of the axial fan. The results show that it is possible to decrease the mass of the fan and reduce the power consumed.

[15] conducted a CFD study to optimize the performance of the mining ventilation axial fan. The authors considered four installation angle parameters, number of blades, deflector plate and rational speed. The results led to P-Q performance curve of the fan, which optimizes the aerodynamic performance.

[16] conducted numerical and experimental study to investigate the effect of the flow rate and rotation of the fan with angle of the blade on the performance of heat exchanger. The results show a maximum increase in the total heat transfer around 4.5% at 600r/min, and an increase in the total pressure when rotation speed increases.

[17] experimentally and numerically analyses the performance of the diagonal flow fan. In this study the authors used language learning machine to develop and manufacture a design to increase the flow rate of the fan and their reporting got a 16.3% enhancement in total pressure efficiency.

[18] conducted an experimental study to reduce the total pressure loss and disturbance in the radial flow. The study investigated the near stall and design conditions and found an enhancement in the near stall performance with the new design.

[19] experimentally studied the increase of the flow rate of air by altering the design of the fan in self-service storage cabinet. The results show an improvement of the cabinet performance through reducing the end temperature by 1.316^{0}C and decreasing velocity inhomogeneity coefficient by 2.18%.

[20] conducted an experimental study using a cascade of airfoils based on the blade strip theory. They authors reported an increase in flow rate by 1% when using cascade airfoil's location through span wise location in hub.

[21] conducted a comparative study between two small sized axial fans: ordinary axial fan and the second designed based on Fionacci spiral. The study used the SolidWorks software and studied the variation of the rotation speed and angle of attack, the number of blades and their length. The results show that under the conditions of the study, with the total pressure, the maximum flow gain can reach 41%.

[22] experimentally investigated the effect of the fan planform on the turbulent jet in ducted rotor system with 1 mm tip clearance and 30000 RPM. The blades have 2410 NACA airfoil and test; three planform shapes were used including a rectangular shape with constant chord, and a trapezoidal shape. The results show that the turbulent kinetic energy- which is generated due to the shape the of blade and tip of the blade- is mitigated in trapezoidal and elliptical shape.

Another method to effect on the fan performance through twisting the blade was conducted by [23]. They conducted numerical and experimental study to investigate the effect of bending the blade on the radial distribution of blade angle. The numerical simulation shows a uniform distribution of flow along radial direction and restrains the separation of vortices at the tip of the blade. The experimental results show increase in efficiency by 5.44% and increase in total pressure coefficient by 2.47%.

The angle of twisting could improve the performance. With increasing the angle, the flow rate increases but the danger of separation will increase and a stall could happen and loose the volumetric flow. [24] conducted a numerical study using CFD to analyze the effect of installation angle, pressure variations and the number of blades on the performance of axial flow fan. The results show that the highest performance was obtained at angle of installation 30^0 at boundary condition sets.[25] experimentally investigated the change in the angle of blade on the flow and turbulent intensity of air blast sprayer equipped with a conventional axial fan 90 cm diameter. In this work, the researchers changed the blade pitches and took three values (20^0, 25^0 and 30^0) and two different outlet section (110 and 150mm). They reported that the angle of twist (bitches) had a significant effect on velocity components, but the turbulent intensity remain constant. [26] analyzed the structure of the turbulence and secondary flow at the exit of an axial flow fan with variable pitch blades. The authors used boundary layer similarity and length scale procedure to analyze the flow and asset on the coherent of the flow and linked the blade angle effect on the wake and turbulent intensity behind the blade. Their results show the strength of connection between the angle of blade and the characteristics of the flow.[27] numerically studied the characteristics and uniformity of flow for four blade designs and two angles of attacks 30^0 and 40^0. The study also involves changing the tip design to optimize the results. The results show that the efficiency and uniformity come with system and flow rate, and the optimization is a kind of trade off relationship.

Another technique that has been used in many researches depends on mimetic nature to over come the flow and improve the blade design.[28] conducted a numerical simulation to investigate two types of bionic microstructure, riblet and convex hull to achieve high air flow dynamic characteristics, with optimization processes and techniques. The results show an increase in air volume flow by 5.3%. [29]simulated the flow over impeller that has a blade with altered surface by microtextured. The suggested microtexture is triangular ribs. The study also investigates changing the angle of attack of the micro surface. The results show a decrease in energy loss by 3.7% for a single blade.[30] studied the use of the microstructure on blade surface to enhance the heat transfer and cooling the blade in gas turbine. They used pin-fin structure and self-organized structure, and optimized the topological parameters. The results show an increase by 43% in Nusselt number.

[10] introduced a novel design of blade and registered it as a patent. He introduced the divided blade rotor where the design depends on the aerodynamics principles of flow over surfaces, the blade is divided centrally into two parts, and connected at tip area and fixed to the hub indifferent angle and near the leading-edge number of holes distributed radially. This design was reported to enhance the power generated from a wind turbine by [31].[32]numerically studied the performance of the design and they reported that the design has some promising features with regard to the air velocity and distribution.

2.2 Noise of fan

In many applications where fans are placed in domestic environment or near human or animal where the level of sound is important, the noise level of the fan can be crucial; so many researches focused on improving the blade design to reduce the noise level. The main source of the noise in the axial fan comes from the pressure difference generated before and after the blade or over the surface of the blade in addition to the vibration of the blade itself. Therefore, most of the researches focused on treating the aerodynamic forces and altering the flow.

The main parameters that lead to generate noise in fans were introduced and discussed by[33]. The study pointed out that the vortex shedding at tip of the blade and large-scale turbulence in the flow increase the noise, and the aerodynamic interaction between moving blades and fixed geometry. The following studies try to improve the noise reduction by solve each case and using many techniques. [34] conducted a numerical study to alter the specification of boundary layer on the rotor part without effecting on the flow volume rate. The results show enhancement of aerodynamic efficiency by 5% and a reduction in total sound pressure by 4dB. [35]conducted an experimental study to reduce the noise level of 1.5 stage compact axial fan by leaning the vanes tip and experimenting five different rotation speeds. The results show that the sound band level has been reduced by 5dB in the upstream and 3dB in the down stream, and the optimum lean angle was reported. [36] investigate to numerically the efficiency of using guide flow to control the swirl motion that is generated due to the movement of the fan through air, and causing noise. The study shows that the suggested method was successful in enhancing the aerodynamic characteristics of the flow and reducing the acoustics of the fan at low and high rotation speed.

[37] numerically studied the interaction of two axial fans placed in parallel to cool down the electric devices in electrical car. They compared the results to previous experimental study. In this study two ducted low-pressure fan were simulated, the aerodynamics performance and acoustics from fans were studied. The results show that the aerodynamic interaction of the flow can improve the work of the fans and reduce the sound band level by 6dB. [38] conducted a CFD study using LES (Large Eddy Simulation) to study the effect of adding a perforated body behind the trailing edge of slitted blade. The results were validated experimentally. The results show that the structure of the flow is distributed and the pressure distribution is changed which reduces the fan noise at trailing edge, and the total reduction noise level could reach 6dB. [39] numerically and experimentally studied the parameters that effect on improving aerodynamic and acoustic performance. The studied parameters were the circumstance starting angle, bending degree and radial relative position. The experiment results show that the 10^0 circumstance starting angle with 8% bending degree and 90% radial relative position could improve the noise by 0.54-2.68dB at different operating conditions. [40] conducted a numerical study to predict unsteady flow physics and flow-induced noise generation of a low-pressure axial fan using Lattice-Boltzman/Very Large Eddy Simulation (LBM/VLES). The results show that the fine turbulence that interact with flow at the tip of the blade can strongly affect the broad band sound level.

2.3 Fan in Heat exchanger

Improving the heat transfer from heat exchanger is one of the most common applications of axial fans. Heat exchanger could vary in size from huge heat exchanger in power plant to micro heat exchanger in electronic devices. However, the principle is the same, the air flow induced or moved by fan blades will force heat to transfer in faster rate which help to get ride from excessive heat. [41] conducted a study to investigate the relation of the geometry of the heat exchanger and the axial fan on the turbulence of the flow and the sound level. The results show the importance of the compact flow between the heat exchanger and the axial fan. [42] conducted numerical study to investigate the performance of the heat exchanger performance using three sinusoidal fan blade modules. The results show that the fans with 34-degree tilt have good performance and optimization of this model that involves increasing the area of the blade which increase the performance of the heat exchanger.

2.4 Power consumption

The aerodynamic forces with the mass of the fan are important parameters that increase the power consumed from motor of the fan. [43] numerically studied the effect of the blade shape on aerodynamics performance, fan efficiency, and power consumed. The study tested seven different groove models at blade's tip. The results show that all cases improved the performance and the seventh model which has grooves on the suction side gives the lowest power consumption. [44] studied the power consumed from fan that used to cool a gear box of an engine and the study shows that the power consumed increases with increasing the aerodynamic forces.

2.5 summary

As a summary of all mentioned works it can be seen that the performance of axial fan depends on many parameters, geometrical and aerodynamical, that could play a crucial rule in the final results of the axial fan performance. From the works above, one of the articles which was discussed, a patent of divided blade fan, mentioned that the suggested approach is promising but needs more investigation. In this study, this patent will be taken and employed in a real air conditioning unit, testing many models that are derived from the basic concepts.

CHAPTER THREE

EXPERIMENTAL WORK

EXPERIMENTAL WORK

In this chapter, the experimental setup and rig manufacturing are illustrated. The fan blade has been designed on the patent (Mahmood H Hussain, US Patent 7,396,208) where the blade has been developed to achieve higher efficiency and lower electrical power consumption. Improvements have also been added to the blade to compare it with another fan blade of a cooling company and obtain higher efficiency and lower electrical power consumption. The specifications of both the patent fan blade, the cooling company fan blade and the fan blade modifications have been explained to obtain the best efficiency and lower electrical power consumption.

1- Experimental Rig parts

1.1 The patent fan blade

The patent stated that the slot blades are made of different materials and different dimensions while maintaining the basics of the patent. The model chosen in this work is made of aluminum with a blade thickness of 3 mm and a base thickness of 5 mm, a blade base diameter of 150 mm, blade dimensions of 250 * 100 mm, a number of holes of 14, and the number of blades is two as shown in Figure 3.1.

Figure 3.1 The patent fan model

1.2The cooling company fan blade(G)

This second basic model belongs to the air conditioning unit the blade is made of aluminum with a blade thickness of 1.5 mm and a diameter fan of 550 mm as shown in Figure 3.2

Figure 3.2 The air conditioning external unit fan(G)

1.3 Manufactured fan models Components of practical design for blade:

Improving fan performance in the practical aspect of blade manufacturing depends on the variety of metals used, in addition to varying blade dimensions and metal thickness. Seven blades were manufactured. The manufactured models are categorized into two groups:

1.3.1 Counterclockwise rotating blades:

The fans in this group are manufactured to blow the air in the direction of the motor which is more suitable for external cooling unit used to compare fan blade performance. Based on the material and base diameter They are divided into four models of blades.

1. **Blade M1**

This blade is made of galvanized iron with a blade thickness of 1 mm and a base thickness of 2 mm, a blade base diameter of 150 mm, and a blade dimension of 22 * 10 mm. The Number of holes is 10 as shown in Figure 3.3

Figure 3.3 fan M1 counterclockwise made of galvanized iron

2. **Blade M2**

This blade is made of aluminum with a blade thickness of 3 mm and a base thickness of 5 mm, a blade base diameter of 150 mm, and a blade dimension of 220 * 100 mm. The Number of holes is 10 as shown in Figure (3.4**)**

Figure 3.4 Fan M2 counterclockwise made of Aluminum

3. **Blade M3**

This blade is made of aluminum with a blade thickness of 3 mm and a base thickness of 5 mm, a blade base diameter of 100 mm, and a blade dimension of 220 * 100 mm. The Number of holes is 10 as shown in Figure (3.5)

Figure 3.5 Fan M3counterclockwise made of Aluminum

4. **Blade M4**

This blade is made of aluminum with a blade thickness of 3 mm and a base thickness of 3 mm, a blade base diameter of 100 mm, and a blade dimension of 220 * 138 mm. The Number of holes is 10 as shown in Figure 3.6

Figure 3.6 Fan M4counterclockwise made of aluminum

1.3.2 Clockwise rotating blades

The blade models in this group are manufactured to blow air away from the motor and . Based on the material and base diameter the fans are divided into three models of blades.

1. **Blade M5**

This blade is made of aluminum with a blade thickness of 3 mm and a base thickness of 5 mm, a blade diameter of 150 mm, and a blade dimension of 220 * 100 mm. The Number of holes is 10 as shown in Figure 3.7

Figure 3.7 M5clockwise fan made of aluminum

2. **Blade M6**

This blade is made of aluminum with a blade thickness of 3 mm and a base thickness of 5 mm, a blade diameter of 100 mm, and a blade dimension of 220 * 100 mm. The Number of holes is 10 as shown in Figure 3.8

Figure 3.8 fan M6 clockwise fan made of aluminum

3. **Blade M7**

This blade is made of aluminum with a blade thickness of 3 mm and a base thickness of 3 mm, a blade diameter of 100 mm, and a blade dimension of 220 * 138 mm. The Number of holes is 10 as shown in Figure 3.9

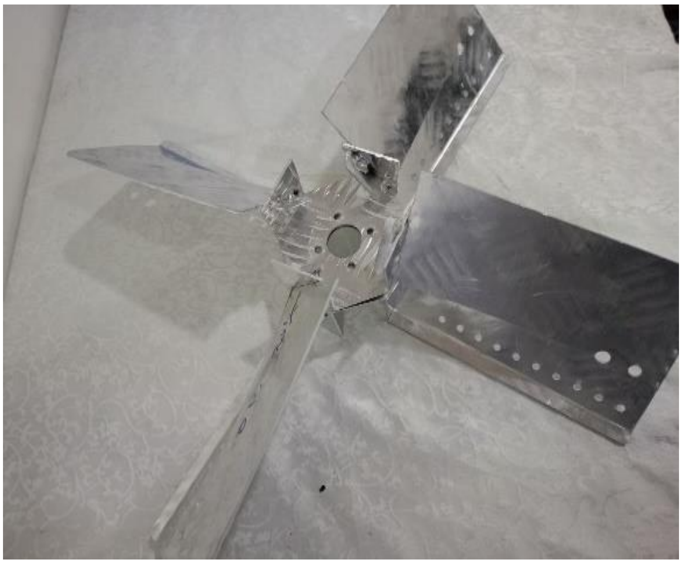


Figure 3.9 fan M7clockwise fan made of aluminum

Table (3.1) The details of the four Counterclockwise models.

Blades							
Model Counterclockwise	Blade base Thickness	Blade Thickness	Blade base diameter	blade dimension	Number of holes	metal	Fan weight
M1	2 mm	1 mm	150 mm	220 * 100 mm	10	Galvanized iron	1720 g
M2	5 mm	3 mm	150 mm	220 * 100 mm	10	aluminum	1780 g
M3	5 mm	3 mm	100 mm	220 * 100 mm	10	aluminum	1045 g
M4	3 mm	3 mm	100 mm	220 * 138 mm	10	aluminum	1215 g

Table (3.2) The details of the three clockwise models.

Blades							
Model clockwise	Blade base Thickness	Blade Thickness	Blade base diameter	blade dimension	Number of holes	metal	Fan weight
M5	5 mm	3 mm	150 mm	220 * 100 mm	10	aluminum	1780 g
M6	5 mm	3 mm	100 mm	220 * 100 mm	10	aluminum	1045 g
M47	3 mm	3 mm	100 mm	220 * 138 mm	10	aluminum	1215 g

3.2. Blade design

The fan blades were designed using AutoCAD AND SOLIDWORKS as shown in Figure 3.10, and the fan blade coupling was also designed as shown in Figure 3.11

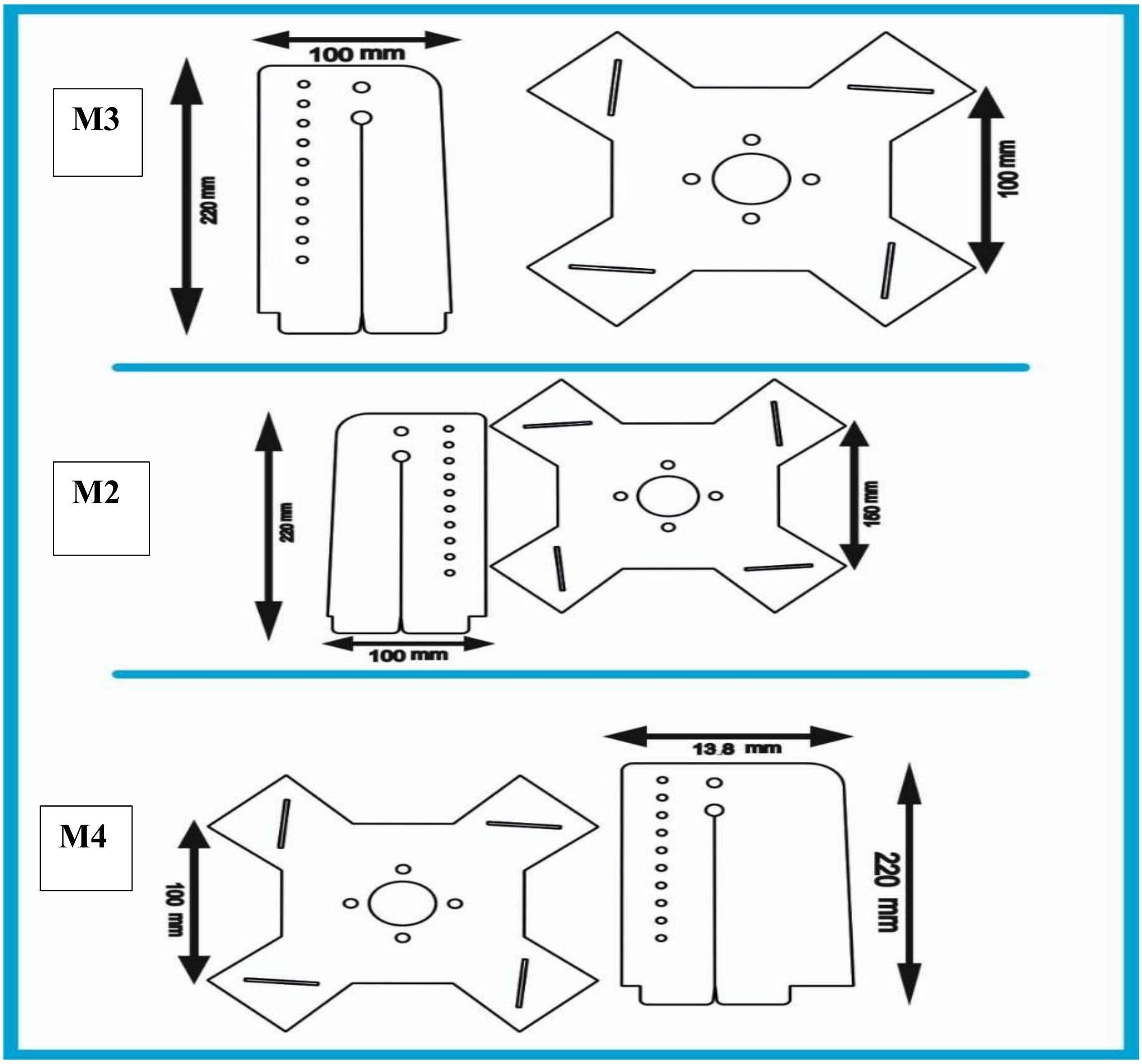
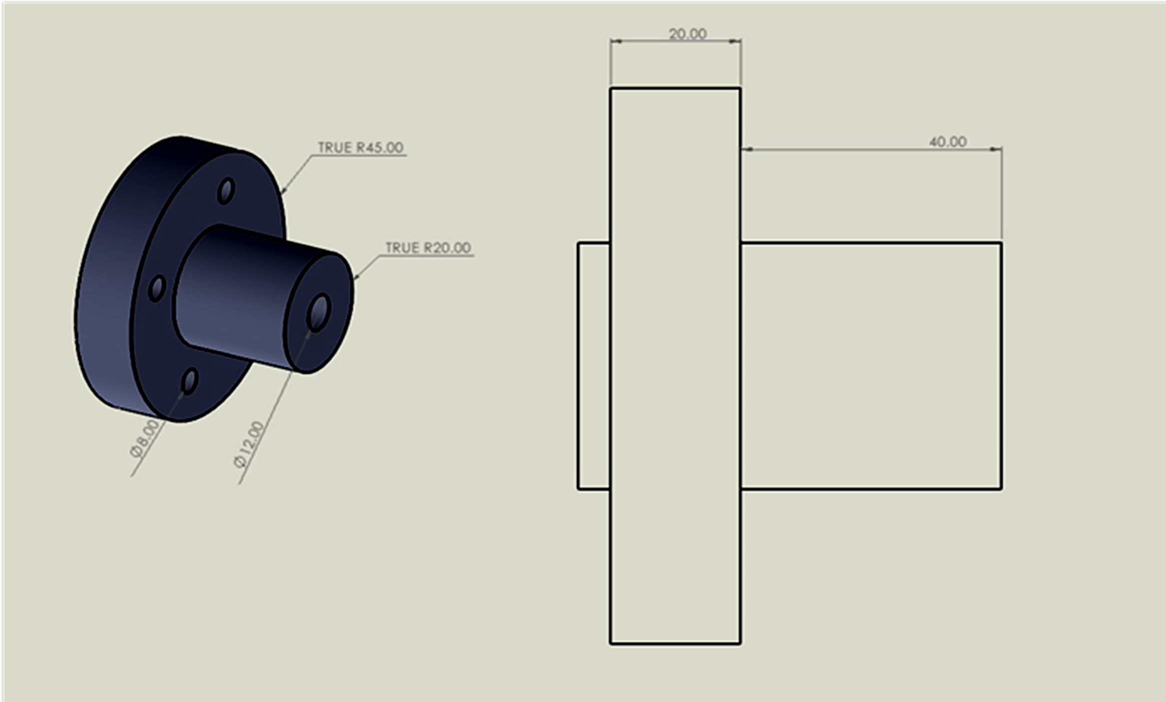


Figure 3.10 fan blade dimensions



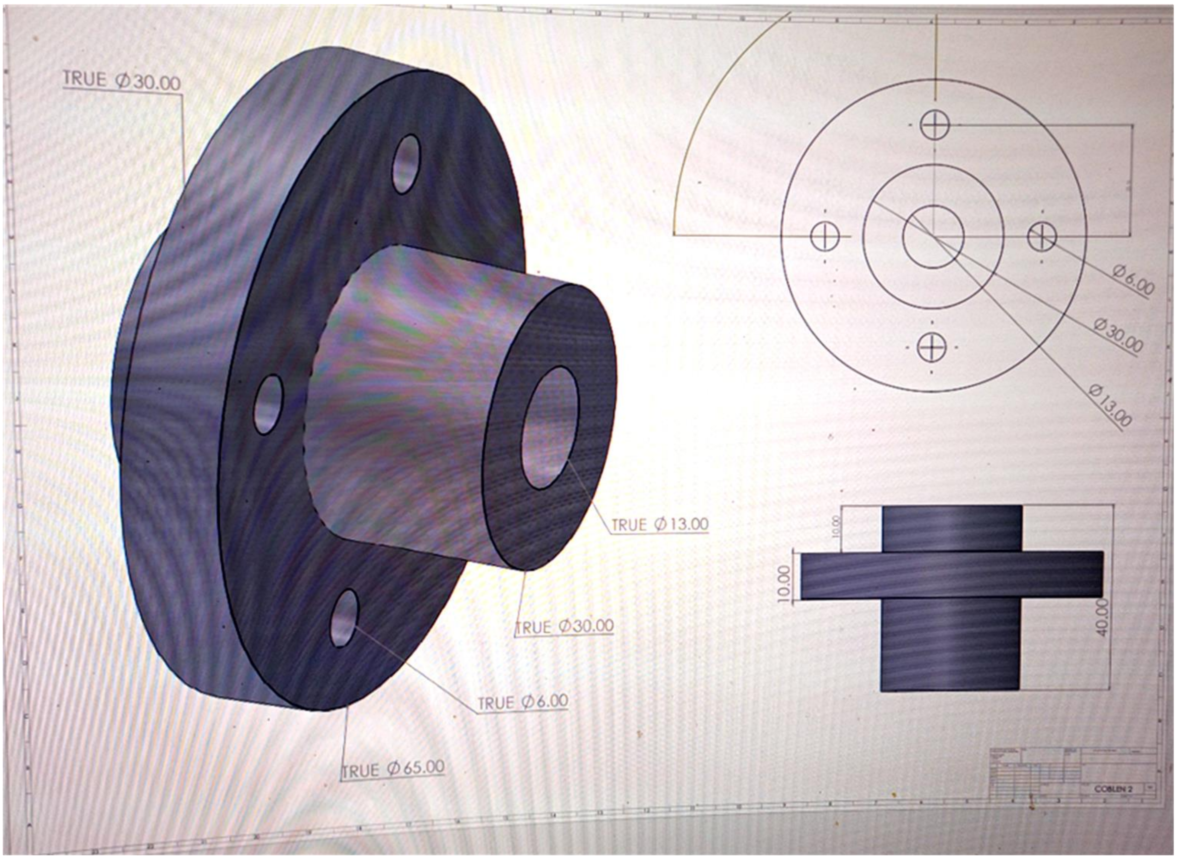


Figure 3.11 Base coupling dimensions

3.3 fan manufacturing

The different models were manufactured in the industrial workshops of the Holy Shrine of Imam Ali, and the following is an explanation of the manufacturing processes:

3.3.1- The process of cutting and bending the fan blades and the blade base

After drawing the fan blades and the blade base using AutoCAD, the thickness of the blade base, the blades, and the type of metal are chosen to be worked on. the**:**

A- Cutting process

Galvanized iron or Aluminum sheet with the chosen thickness has been cut in the warehouse using different power CNC Laser cutting machines. For galvanized iron, a 1330W Laser cutting CNC machine has been used. While for the Aluminum a 6000W Laser cutting CNC machine has been used as shown in Figure 3.12

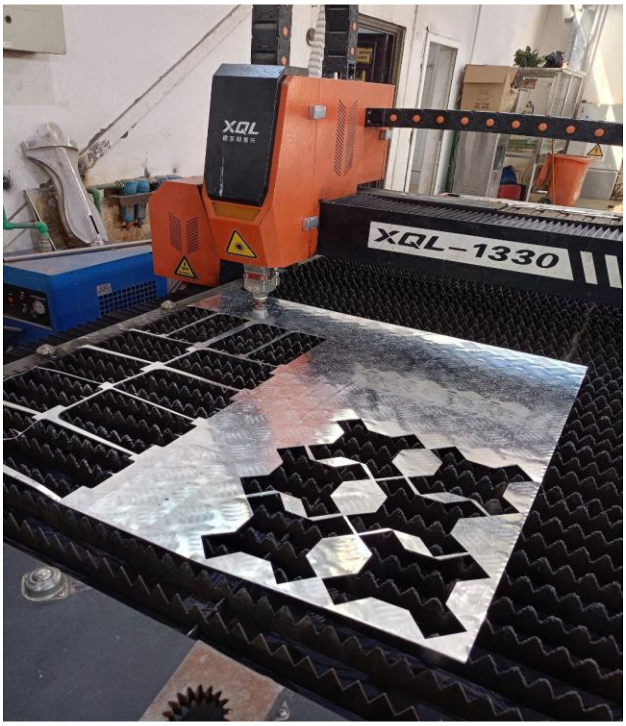


Figure 3.12 Cutting process

B- Bending the blade

After cutting, the blade and base have been bent using a bending machine. The longitude edge of the blade has been bent at 5^0 as in the design of the original patent model as shown in Figure 3.13

Figure 3.13 The bending process

C- The process of installing and welding the fan blades to the blade base

The process of welding the fan blades with the fan base has been done in two steps.

First, the fan bases were installed. Then, we installed the fan blades to the base so that each end of the blades was fixed to a base.

Second, we performed the welding process using a soldering machine as shown in Figure 3.14

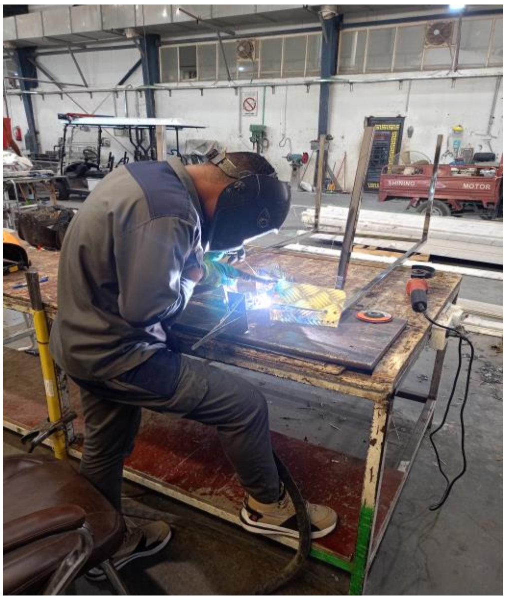


Figure 3.14 welding process

D- Manufacturing the coupler

The coupling has been made as a cause of aluminum metal, which is strong and does not deform when installed in the base and motor, and it works at high speed. It is also easily available in local markets, as we used a lathe machine to make the mold that fits the fan and motor, as shown in Figure 3.15

Figure 3.15 Coupling manufacturing

E- Installing the coupler in the fan to install it on the fan motor

The coupler has been attached to the fan base by screws. Then the fan has been mounted on the motor by the coupler and fixed with a screw to ensure that the fan is secure to the motor as shown in Figure 3.16, The motor specifications are as follows:

1 - Speed 890 r/m

2 - Power 1 /4 HP

3 - VOLTE 220 - 240 V

4- AMPER 1.7 A

Figure 3.16 Blade (fan) installation

3.4 Measuring tools

The main measuring tools used in this work are:

3.4.1 Mini anemometer UT363BT

The range wind speed measurement is 0 to 30 m/s (standard) and the temperature measurement is -10 to 50 in Figure 3.17

Figure 3.17 Mini anemometer UT363BT

3.4.2 A clamp meter

600A Digital Clamp Meter Item number: 56B612A

AC current ACA: 2A/20A/600A DC voltage DCV: 200mV/2V/20V/200V/600V

AC voltage ACV: 2V/20V/200V/600V Resistance Ω: 200/2K/20K/200K/2M/20M

Temperature °C: "-20°C~1000°C NCV: yes, Operation mode: automatic range

Jaw opening: 25mm Packing: color box Warranty period: 3 years

Standard: German quality

Figure 3.18 clamp meter

3.4.3 thermocouple

The range temperature measurement is -20 to +199 Figure 3.19

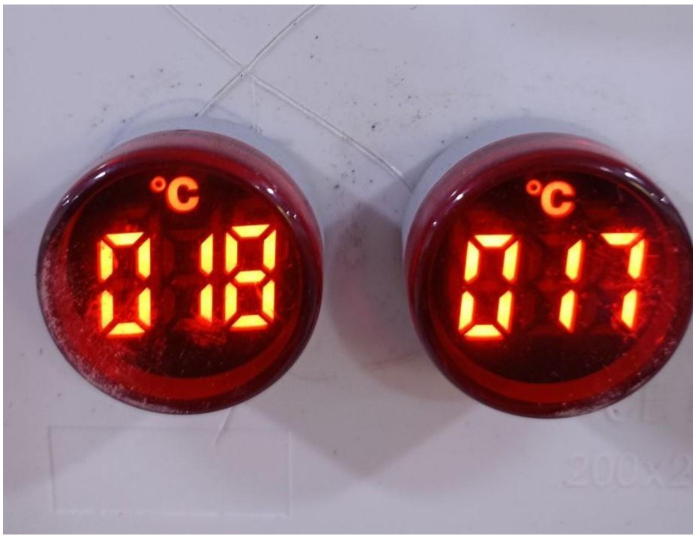


Figure 3.19 thermocouple

3.4.4 fan regulator

Figure 3.20 (fan) regulator

3.4.5 Indicator lamp

Standard IEC/60947-5-1 the range voltage AC30-500V 50HZ and rate current 20A in **Figure 3.21**

Figure 3.21 Indicator lamp

3.4.6 Mini Sound Level Meter

The range Mini Sound Level Meter is 30 to 130 dB in Figure 3.22

Figure 3.22 Mini Sound Level Meter

3.5 Experiments

The seven models were tested correrring flow rate, noise, and power consumed compared to the patented fan and the company's cooling fan. To do so, the experiments on different models were conducted first in the lab. Using a duct described below, the best models were tested on a real air condition spilt unit.

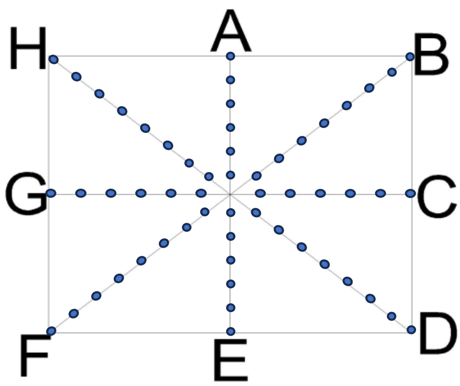
Calibration Process

The calibration of anemometer process involves using the wind tunnel to calibrate the anemometer by changing the speed of the air in wind tunnel and positioning the anemometer at the same level and position of the pitot tube as shown in figure 3.23

Figure 3.23 Anemometer calibration

Flow rate calculations

The outlet area of the duct is divided to 8 main point rows and air velocity at each node is recorded then tabulated and averaged to obtain the total average velocity on entire the are of the duct then the flow rate is calculated by multiplying the average velocity by the cross sectional area of the duct as shown in figure 3.24.



Position	A	E	C	G	B	D	F	H	Average velocity m/s
1	0	1	0	0	0	1.2	1.4	0.4	0.5
2	0.8	1.5	1	0.8	0.4	1.8	1.8	1	1.1375
3	1.5	2.3	2	1.4	1.7	2.6	2.3	1.6	1.925
4	2.5	3	2.4	2.2	2.5	3.2	2.9	2.2	2.6125
5	3.8	3.7	2.9	2.9	3.1	3.7	3.3	3	3.3
6	5.1	4.7	4.1	3.3	3.7	4.3	3.6	3.7	4.0625
7					4.6	4.7	3.9	4.3	4.375
8					6.8	5.7	5	4.8	5.575
Average velocity m/s	2.283	2.7	2.066	1.76	2.85	3.4	3.025	2.625	2.935

Note: Positions are nominated from outside to inside.

Figure 3.24 Average velocity measurement points

3.5.1 duct

A duct with dimensions of 600 mm*600 mm and a duct length of 1500mm was designed. The volumetric wind flow rate test of the fan was conducted by taking wind speed measurements from all points of the duct outlet using an anemometer and calculating the area of the duct outlet as shown in Figure 3.25

Figure 3.25Experiment in duct

3.5.2. Split air conditioner

The amount of heat lost by the split cooling radiator, and the amount of electrical current to the fan motor were tested for all designs with the cooling company’s fan, as shown in Figure 3.26. The implemented designs in the Specifications of the external part of the split unit were the tested and compared to the original fan of the same external part:

1- cooling capacity is 60000 BTU/H

2- dimension 800mm * 700 mm* 700mm

Figure 3.26 Experiment in Split air conditioner

CHAPTER FOUR

RESULTS AND DISCUSSION

Results and discussion

In this chapter, the main results obtained from the experiments are presented and discussed. The patent model and the suggested models are compared to verify the patent concepts based on current, flow rate, and noise level. Modifications in design led to the manufacture of many models, the results of which are presented below.

4.1 Patent Validation

As the first step of the work, a typical fan (Model M0) to the split blade fan was manufactured. The main difference was the weight [10](split blade fan (patent) weight 1945g, M0 weight 1720g). The flow rate delivered by the split blade and basic model was calculated and drawn versus the current to verify the patent concepts as shown in Figure 4.1. Also, the noise level recorded at the max flow rate was 76 dB for the split blade and 75 dB for M0.

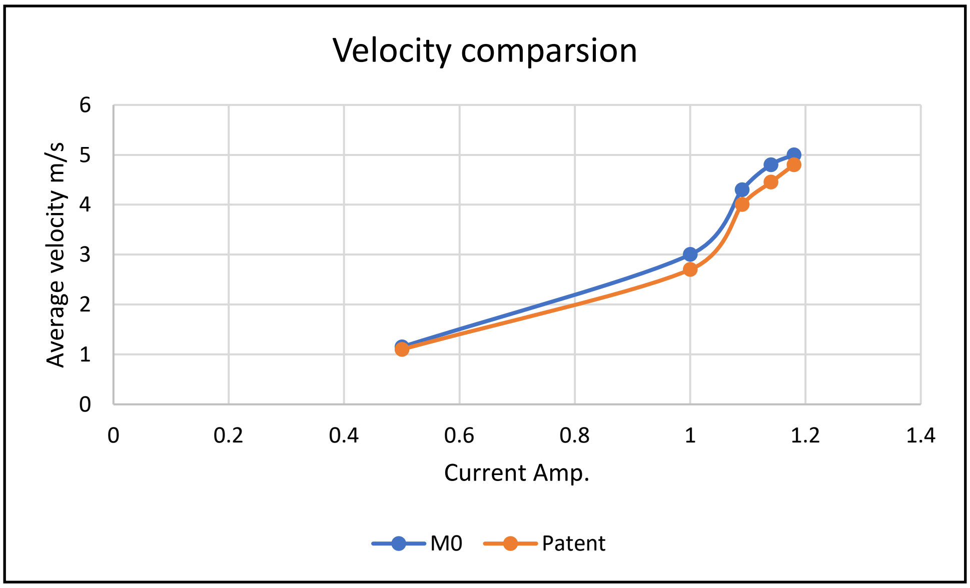


Figure 4.1 Velocity comparison between patent and model M0.

4.2 Average velocity comparison with an industrial fan (G)

Based on the results from model M0, A new model was generated M1 with four blades to compare with a condenser fan in an outside unit of an AC split unit. The industrial fan (G) has four blades (Figure 3.2) and weights 1545g. The average velocities of both fans versus the current are plotted in Figure 4.2. Also, the noise level recorded at the max flow rate was 75 dB for the M1 and 79 dB for the industrial fan. But the main note was that the vibration was much less for model M1. It is worth mentioning that the AC fan motor's max speed is 890 r.p.m.

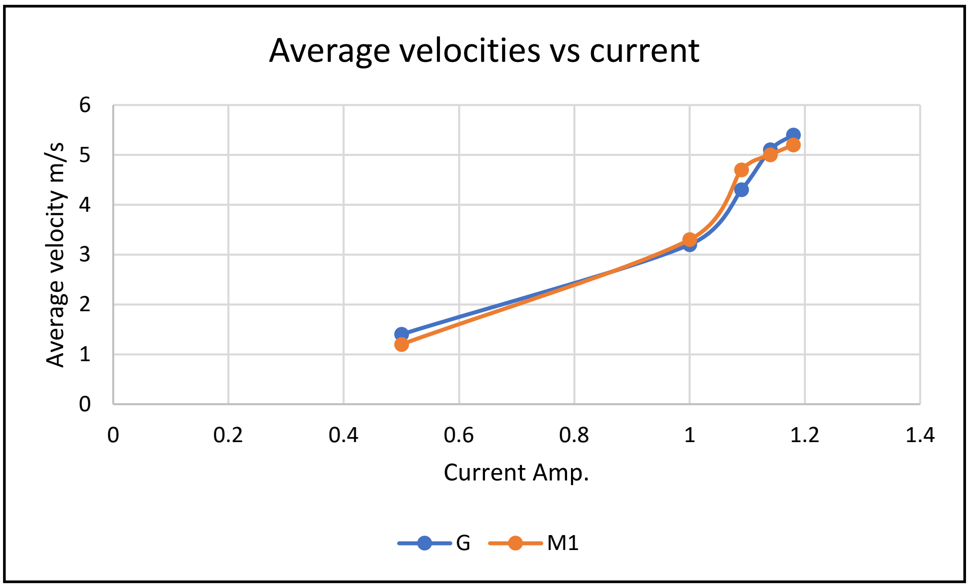


Figure 4.2 Velocity comparison between model M1 and industrial fan.

4.3 Average velocity for different counterclockwise models

The rotation of the fan can be counterclockwise or clockwise depending on the application. In the specific case under study, the industrial fan was rotating counterclockwise. So, the result of the comparison shows that with an increase in the rotation speed, the industrial fan delivers slightly higher flow rates. But the split blade fan's stability is more than the industrial fan's. Therefore, three parameters were taken into account to optimize the performance of the split blade fan. The parameters are the base diameter and thickness of the fan and the width of the blade. The results are three models M2, M3, and, M4. The average velocities for these models with M1 are plotted in Figure 4.3.

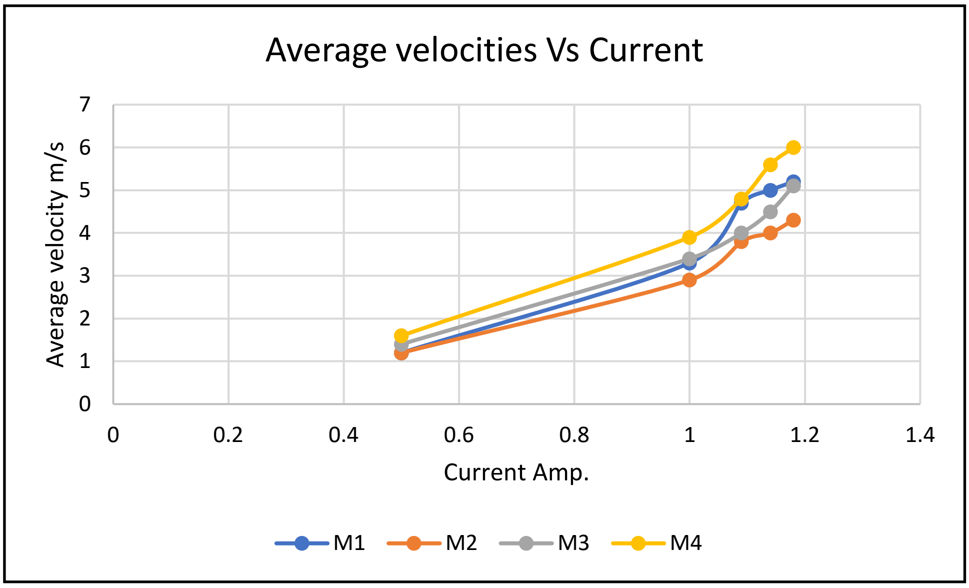


Figure 4.3 Average velocities for different counterclockwise model's vs current

The M4 shows the best performance compared to other models. Figure 4.4 shows a comparison between the M4 and the industrial fan.

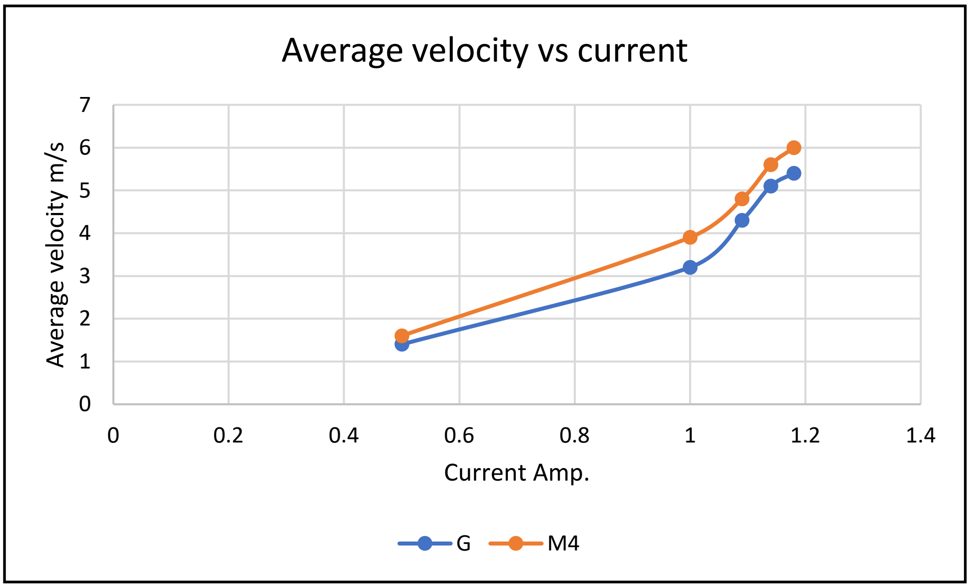


Figure 4.4 Velocity comparison between model M4 and industrial fan.

4.4 Average velocity for different clockwise models

To cover the effect of rotation direction on the performance of the new models, prototype models M2, M3, and M4 were created and designated M5, M6, and M7. The rotation direction of these models is clockwise and they were tested on the same fan motor of the separate outdoor cooling unit. Figure 4.5 shows the average speeds versus current for models M5, M6, and M7.

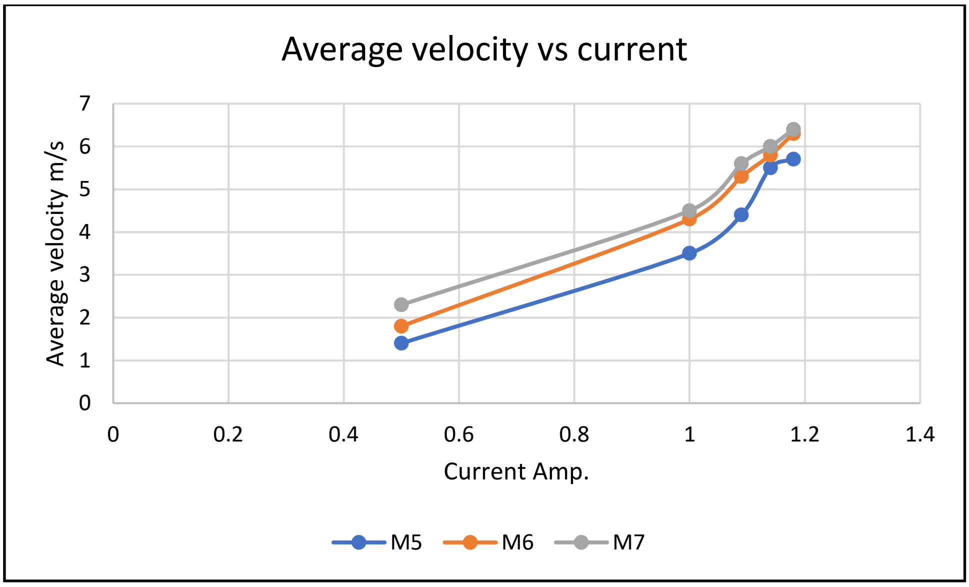


Figure 4.5 Average velocities for different clockwise model's vs current

4.5 Effect of rotation direction on Average velocity

The rotation direction shows an effect on the results of the average speed to put this effect on the contents. Figure 4.6 shows a comparison of the counterclockwise and clockwise average velocities at different values of current.

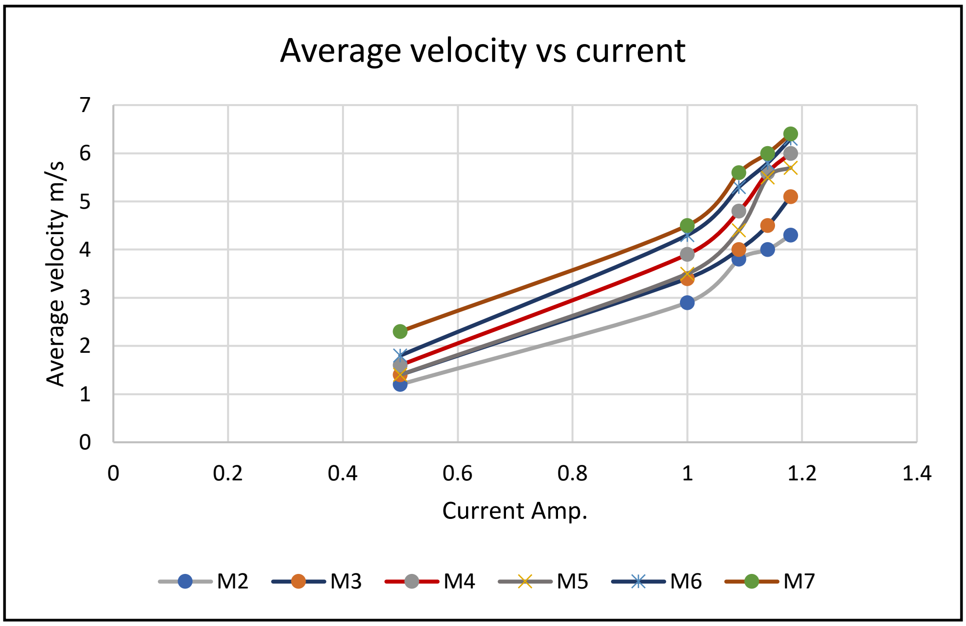


Figure 4.6 Effect of rotation direction on average velocities (M2, M3 and, M4 are counterclockwise M5, M6 and, M7 are clockwise)

4.6 Effect of fan type on compressor temperature

[After collecting the data from duct experiments for the counterclockwise models, the models M3 and M4 were chosen to be tested on real AC units] The outlet temperature of refrigerant from the compressor is shown in Figure 4.7

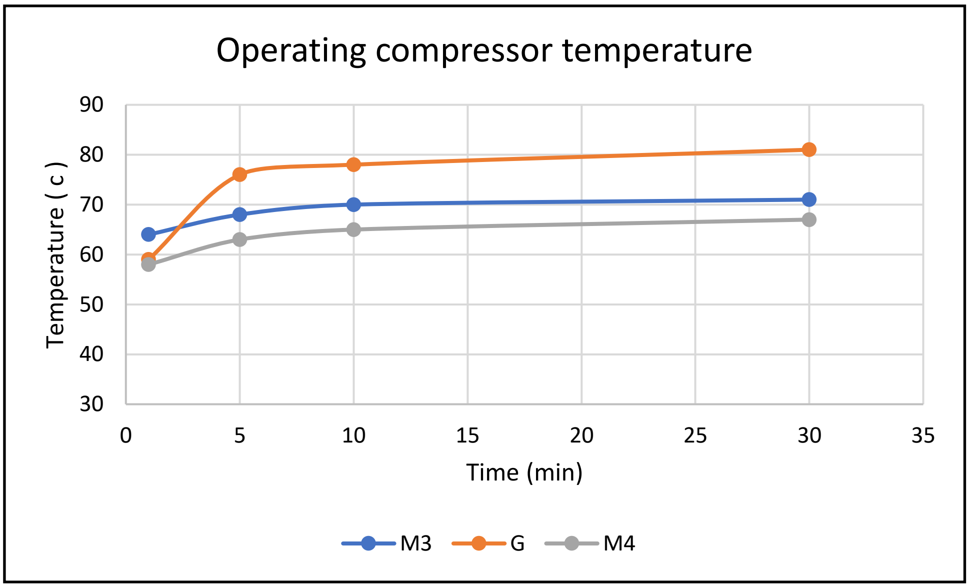


Figure 4.7 Refrigerant temperature at the compressor outlet

4.7 Effect of fan type on condenser temperature

The difference between the inlet and outlet temperature of the condenser with time for M3, G, and, M4 is shown in Figure 4.8

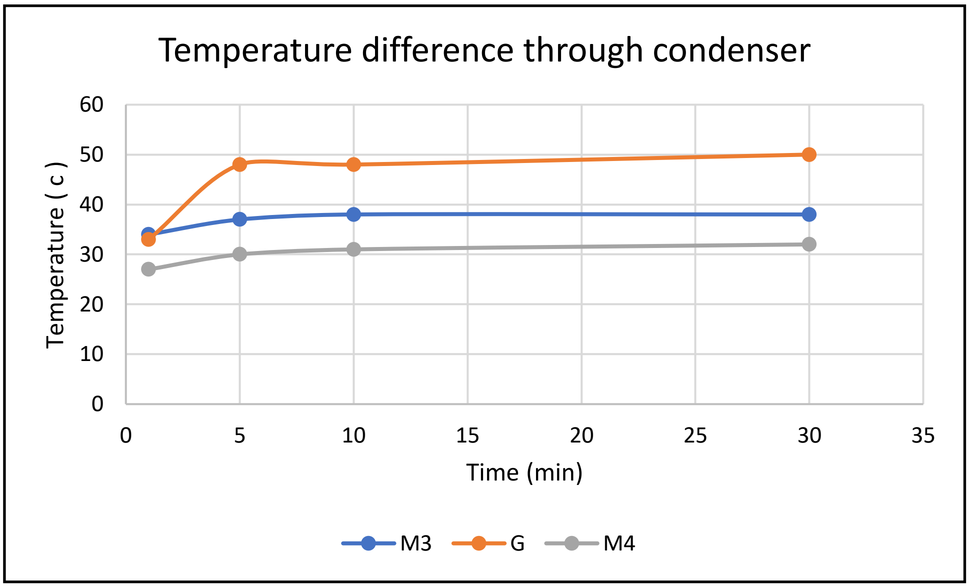


Figure 4.8 Temperature difference through the condenser for different models.

4.8 Power consumed

The current needed to operate each model is plotted verse time as shown in Figure 4.9.

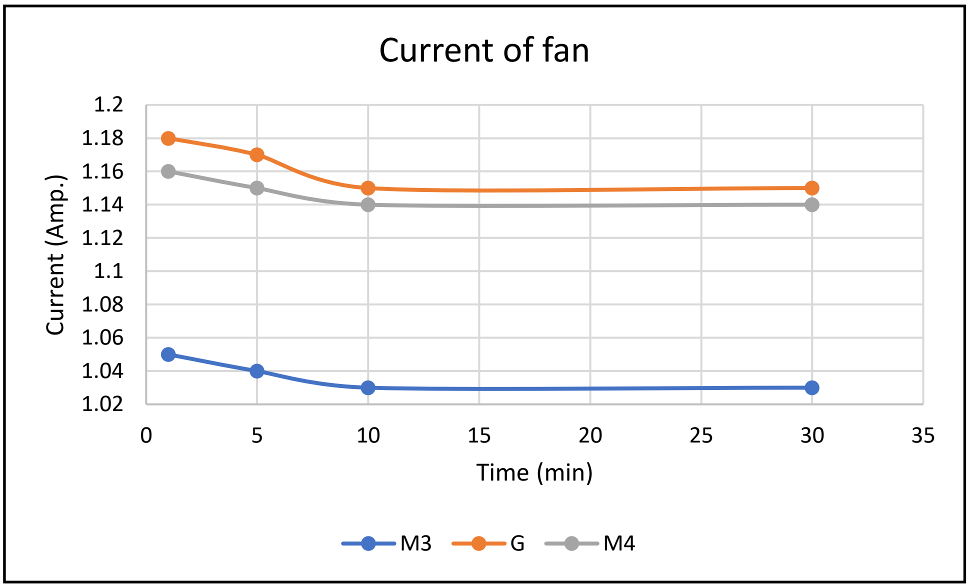


Figure 4.9 Fan current for different models.

4.9 Results discussion

4.9.1 average speed

The previous paragraphs present all data collected from experiments on the duct test section and real AC unit. In Figure 4.1 the comparison was made between two blade models; from split blade fan (patent) and basic model M0 the only difference between these two fans was the weight where M0 is less in weight than the Patent fan. The plotted results showed a typical behavior between the two models with a slight increase in the average velocity of M0. The slight increase in average velocity could be assigned to the physical properties of air between the patent registration location (Sweden) and the local environment in Iraq. But another option was the weight since the model M0 was weighting less. Moreover, the noise level was so close and both fans had the same level of noise; and the most important issue was that the vibration of the fan during the operation was unnotice which is not common for the commercial fans used in AC units-usually having noticeable vibration-.

The aim of this work is to verify the ability of using split blade fan model in AC units. New models were made based on the performance of M0. The specifications of new model's have been discussed in chapter three. However, the main difference of these models with basic model M0 is the number of blades as the new models have four blades. In Figure 4.2, a velocity comparison between model M1 and industrial fan (G) is plotted. The figure shows that the average speed of air increased with the increase of the current due to the increase in the rotation speed of the fan, and with increasing the rotation speed, the fan G has more average velocity, but the level of noise increases also and started to vibrate in a noticeable way. The air moved on the large surface of the G fan blade and started to change due to the speed, and it could apply more aero forces on the blade and increase the level of noise and vibration. While in M1 model, the blade has a central slot and many holes that help more in connecting the air to the blade, decreasing the instability of the flow over the fan blade, and at the same time reducing slightly the average velocity of the delivered air which helps in noise and vibration reduction.

The results of this comparison opened more questions about the effect of the fan weight since M1 is weighted more than G1 and made of galvanized steel sheet. Also, due to the design of the patent which depends on twisting with a sharp degree and which is slotted from the middle with number of holes, the base of the design causes high drag resistance from the aerodynamics concepts also changes the material of the fan to aluminum. Therefore, changes in the manufactured models aim to answer these questions. Additional three models were manufactured M2, M3, and, M4, where M2 is made of aluminum with the same diameters of M1, M3 that have has smaller base diameter than M1. Finally, M4 has a wider blade and the same area as the G. The average velocity of these models is shown in figure 4.3. The results show that changing to aluminum with the same dimensions caused a decrease in flow rate. The main reason is that the leading edge of the blade in M2 model has a thickness of 3mm which causes high drag and turbulence in flow and reduces the flow rate of air delivered from the blade. The average speed increases with the increase of the current as the rotation speed increases. In model M3, the average speed is better due to the reduction of the base diameter, the reduction in base diameter led to decrease in drag and increase the flow rate by the blades. Although the thickness of the blades was still big but that was necessary for solidary of the blades. When the surface area of the blade is increased, the increase in average velocity is significant, and the increase is more obvious with an increase in the current at the maximum current or maximum rotation speed of the motor. The increase in average velocity was around 15% compared to M1.

The M4 model surface area is the largest between other models which can be compared to the G model as shown in Figure 4.4. The results show that the model M4 gives higher average velocity, the increase of the surface area helps the fan to deliver more air flow rates but at the same time the aero forces will increase.

4.9.2 Effect of rotation direction

The effect of the rotation has been studied since the rotation of the fan will inverse the direction of the airflow which means that the flow will not pass the body of the motor and increase the turbulence of the flow downwards the condenser. However, the average speed is higher in the same model that rotates counterclockwise as shown in Figure 4.5, but its behavour is still the same, the average speed increases with the increases of the current. When the blade rotates clockwise the air excavated from the tip of the fan and the blockage area will be represented only by the base of the fan, but when the blade rotates counterclockwise the air flows first on the motor body which decreases the flow rate and average speed as a consequence.

In Figure 4.6, a comparison between the different models when they rotate counterclockwise and clockwise direction is represented. The improvement in flow is noticeable for each model, for example the models M3 and M6 which are identical in geometry with the clockwise model M5 delivers more flow rate of 23.5% higher than M2 at the maximum current.

4.9.3 Effect of fan on compressor temperature.

The experiment on a real AC unit involves recording three main parameters, the outlet refrigerant temperature from the compressor which could be considered as an indicator of the compressor temperature, the outlet temperature from the condenser, and the power consumed by AC unit.

In Figure 4.7, the temperature of the refrigerant outlet from the compressor is shown when using fan G, M3, and M4. The results show that the temperature of the refrigerant is decreased significantly when using model M3 and M4. The increase in the flow rate of the air inside the external unit of the AC led to more cooling of the compressor which represent a decrease in the outlet temperature, also the geometry of the blade distributes the air closer to the middle of the unit where the compressor is located and increases the heat dissipation from compressor body.

4.9.4 Effect of fan on condenser temperature.

The condenser unit works to reject the heat from the refrigerant to the ambient with the aid of the fan using the airflow. The big difference between in and out temperature through the condenser means more effectiveness of the compressor. For the comparison between the effects of using different models, figure 4.8 represents the results. For instance, the G fan did the best performance and the M4 was the worst. However, the fact that the M4 decreases the refrigerant that comes from compressors too low shows a weakness in the condenser performance of the M4 model. However, the performance is slightly less than G if compared with the same input temperature due to the change in the flow distribution inside the condenser unit.

4.9.5 power consumed

The power consumed by fan depends on many parameters such as weight, back pressure and forces on fan blades. Figure 4. Shows the current consumed over time for each model of fan. The power increases with the increase of the flow rate because the increase in air flow will put more pressure on the blades from air forces and increase the torque on the fan motor which increase the power consumed.

CHAPTER FIVE

CONCLUSION

Conclusion

The patent that suggests a new design of axial fan has been tested and new models at different parameters have been studied and developed. It has been noted that the new models M1-M7 cover two operation rotation directions; clockwise and counterclockwise which is the best performance model compared to a commercial design of axial fan used in air conditioning spilt unit. The main results come with following conclusions:

1- Based on the suggested design in patent, the modified models M1-M4 show different average speed results, but analyses of the results show that changing material to lighter material and thicker blades results in increasing the volumetric flow rate.
2- Decreasing the hub diameter causes in increasing the flow rate due to the reduction in the resistance area that faced the flow delivered by the fan.
3- The new design generates less noise due to the fact that the slot in blade eliminates the flow wise direction of the blade which reduces the tip vortex generation and noise.
4- Clockwise rotation gives more flow rate since the flow will pass across the motor fan body after air blowing; hence, only the flow changes, not it's the quantity.
5- Using lighter fan reduces the power consumed due to the reduction of the torque required by the motor to operate the fan at the required rate.
6- The new distribution of air from the new models leads to an increase in the cooling effect of the compressor body and refrigerant in the system.

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APPENDICES

Appendix A

US007396208B1

(12) **United States Patent**
Hussain

(10) **Patent No.: US 7,396,208 B1**
(45) **Date of Patent: Jul. 8, 2008**

(54) **DIVIDED BLADE ROTOR**

(76) Inventor: **Mahmood H. Hussain**, Abu Neas Street, Baghdad (IQ)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 394 days.

(21) Appl. No.: **11/351,073**

(22) Filed: **Feb. 9, 2006**

Related U.S. Application Data

(60) Provisional application No. 60/652,938, filed on Feb. 15, 2005.

(51) **Int. Cl.**

F04D 29/38	(2006.01)
F01D 5/14	(2006.01)
B64C 11/16	(2006.01)

(52) **U.S. Cl.** .... **416/91**; 416/227 A; 416/231 R

(58) **Field of Classification Search** .... 416/91, 416/227 A, 227 R, 231 A, 231 B, 231 R, 416/DIG. 3; 415/181
See application file for complete search history.

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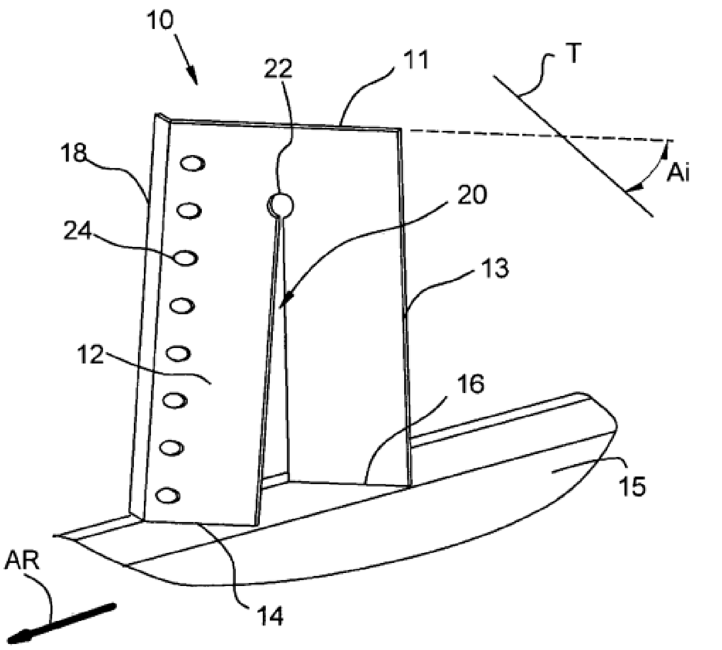
(74) *Attorney, Agent, or Firm*—Sven W. Hanson

(57) **ABSTRACT**

A novel rotor blade is presented with an integral tip portion from which two diverging blade portions extend to separated respective roots. The blade may have conventional airfoil sections, or may be made from flat or curved sheet material. The two rotor blade portions may have dissimilar angles of incidence. Leading edge holes or slots are located behind the leading edge of the blade. The two blade portions may have distinct angles of incidence.

12 Claims, 5 Drawing Sheets



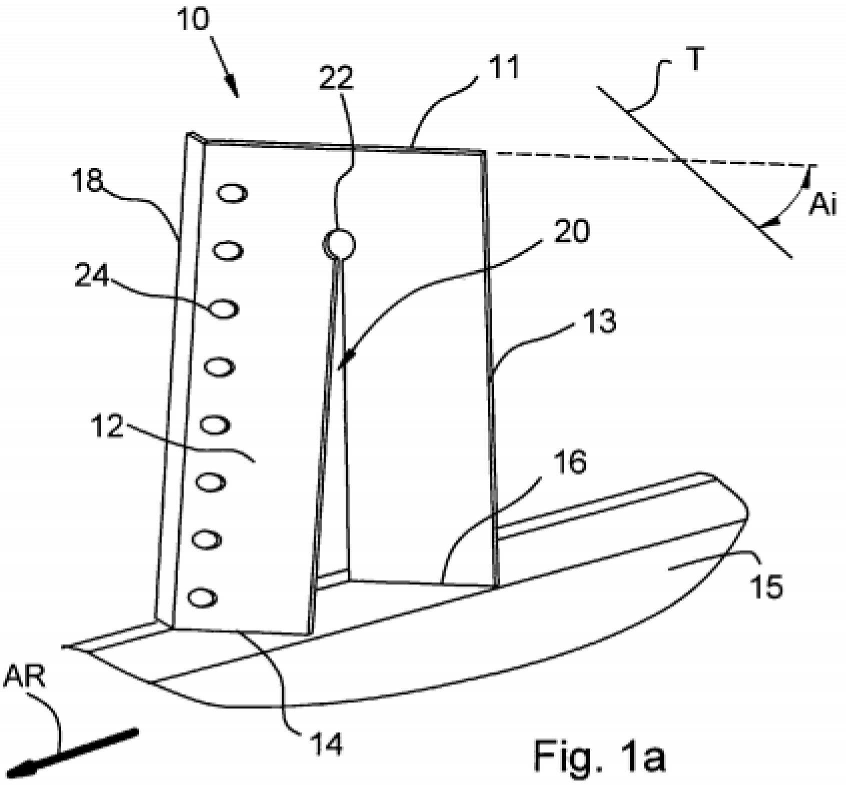


Fig. 1a

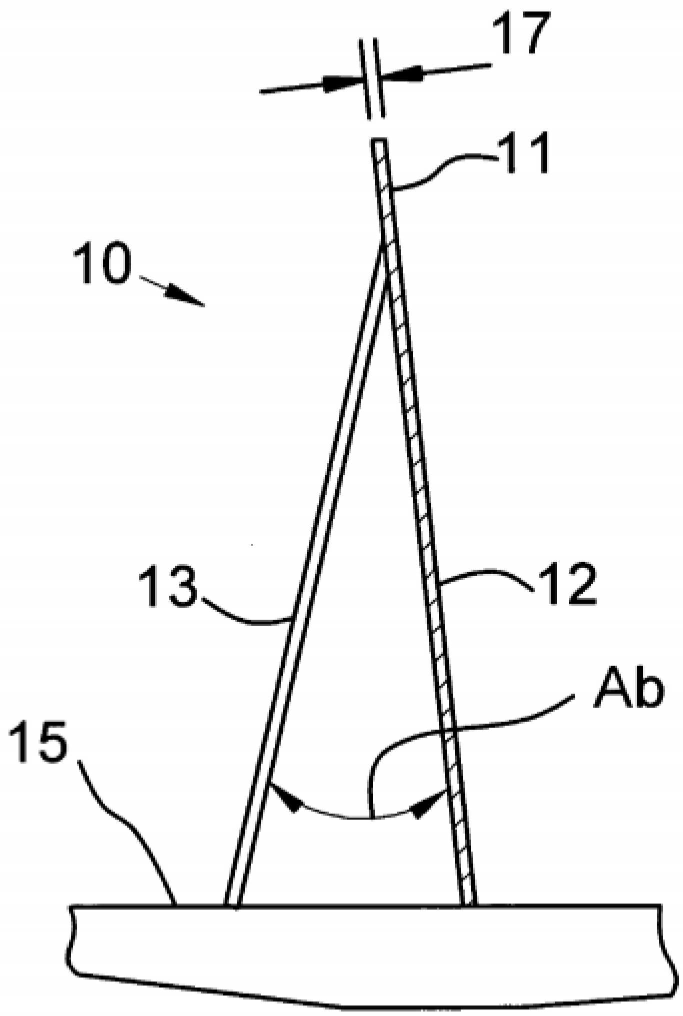


Fig. 1b

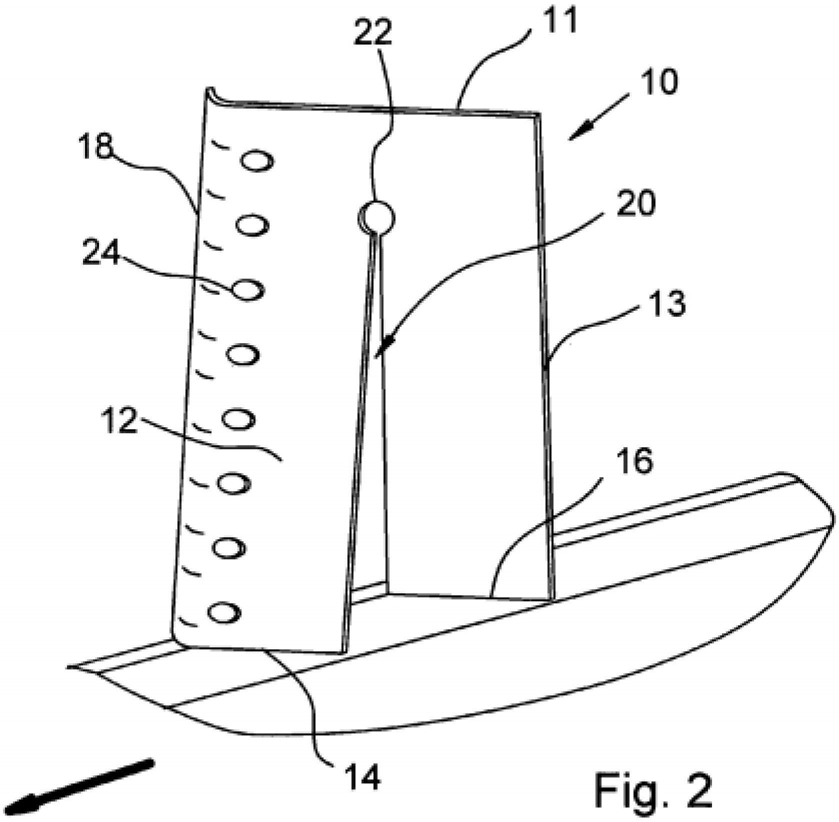


Fig. 2

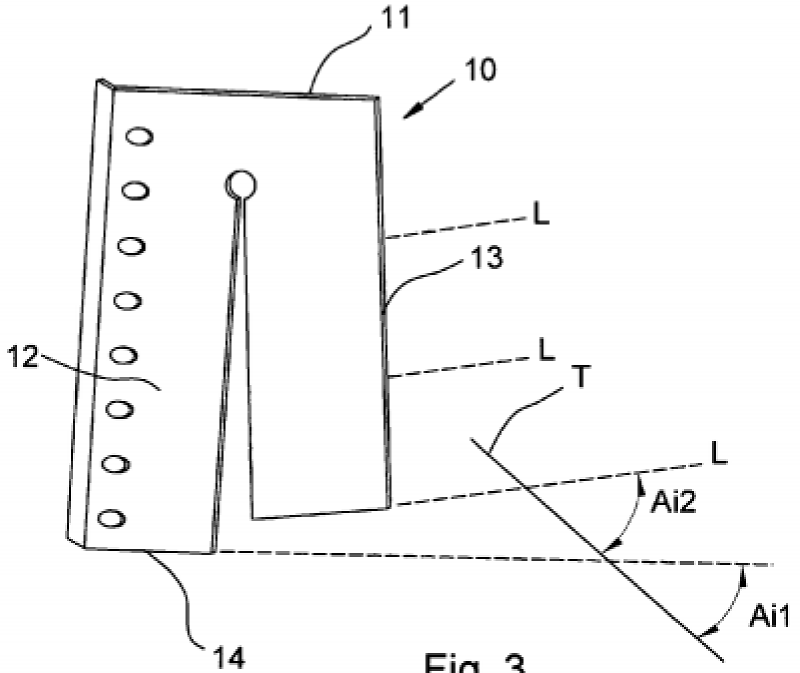


Fig. 3

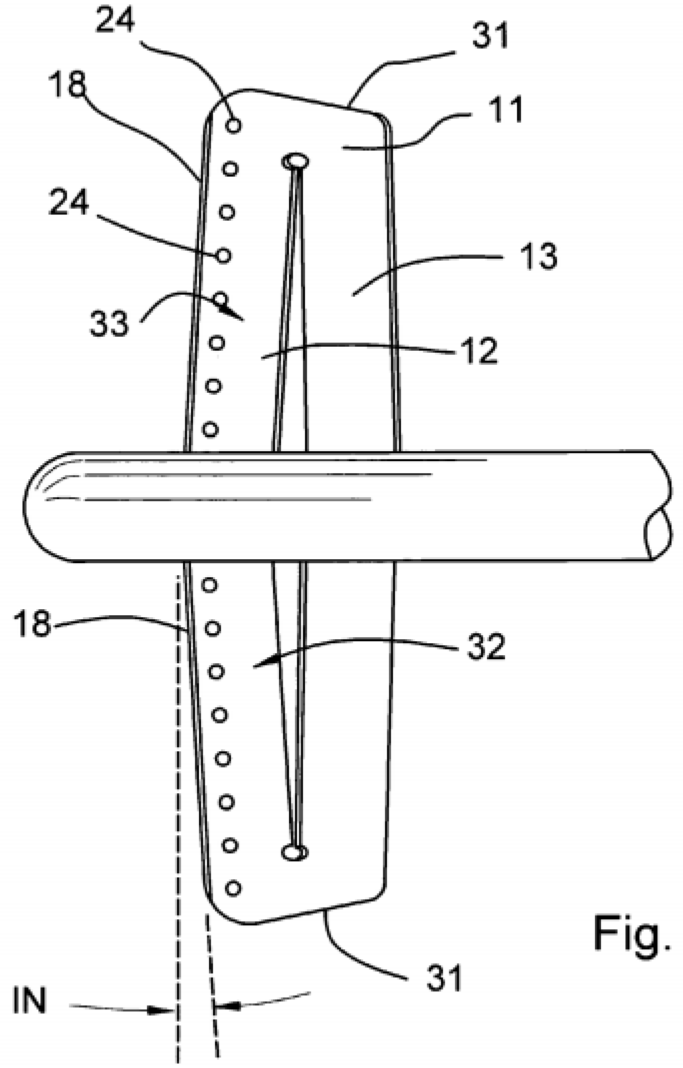


Fig. 4

DIVIDED BLADE ROTOR

RELATED APPLICATIONS

This application incorporates by reference the disclosure of, and claims priority from, the U.S. Provisional Patent application filed Feb. 15, 2005 and having Ser. No. 60/652,938.

BACKGROUND OF THE INVENTION

The present invention relates generally to rotor and propeller blades and similar devices that are used to move a fluid medium, to move in a fluid medium, or to be moved by a fluid medium. More particularly, the invention concerns a divided rotor blade having a single integral tip and two discrete blade portions that can operate at a high angle of incidence, and which has integral leading edge holes or ports to allow medium passage through the rotor body and across the rotor chord to delay or prevent cavitation, turbulence, and stalling.

DISCUSSION OF THE PRIOR ART

Conventional rotor and propeller blades are typically supported by a single root portion and operate effectively only at subsonic tip speeds. They are generally subject to flutter at transonic and supersonic tip speeds resulting in cavitation, accelerated stalling and loss of function, often followed by sudden catastrophic failure. Most conventional rotor and propeller blades are relatively long and are entirely unsupported along their length. Accordingly, they must have relatively large root sections in part to obtain sufficient strength to prevent bending and twisting in ordinary use. In part to reduce weight, conventional rotor and propeller blades have a chord length which is decreased significantly in the tip, where relatively little thrust is produced as a result. Conventional rotor and propeller blades are also relatively noisy, and the wasted acoustic energy represents a significant inefficiency.

A prior divided rotor blade is taught in EPC Patent Number EP0295353 issued to al Majed. The al Majed device is made from a single piece of flat sheet material and has divided rotor blade portions and separated blade roots (see FIG. **1** herein). The blade portion roots are oriented relatively axially displaced on a shaft such that one blade portion leads the other. Angled leading and trailing edges are intended to enhance laminar flow and increase lift. The blade portions are not twisted and have a common angle of incidence. While the al Majed rotor blade operates efficiently, and is superior to conventional blades in several respects, such as stall resistance, quietness, strength, lightness and ease of manufacture, it operates with a higher degree of drag than is desirable, and it is subject to cavitation, turbulence, and accelerated stalling when operated at high speeds and high angles of incidence.

Accordingly, a need has arisen for an improved rotor blade having the advantages of a divided rotor blade, but which operates with a lower degree of drag, and which is less subject to cavitation, turbulence, and accelerated stalling when operated at high speeds and high angles of incidence.

SUMMARY OF THE INVENTION

The present invention is a rotor blade having two distinct blade portions with respective roots which are separated from each other. The blade portions extend convergingly from their roots to join at a common tip. In use, operating medium flows through the gap formed between the blade portion, and through holes in the lead blade portion, providing improved

performance. In preferred embodiments providing significantly reduced cost of manufacture, a divided blade rotor is formed from flat sheet metal. The present invention includes methods of forming a rotor blade from sheet material.

A first object of the present invention is a simplified design, and improved operation, divided rotor blade that can be formed from flat sheet material.

A second object of the invention is a divided rotor blade comprising true airfoil sections in tip and root to decrease drag and increase effective lift or thrust.

A third objective of the invention is a rotor blade which can be operated effectively at supersonic tip speeds.

A fourth object of the invention a rotor blade which is resistant to cavitation, turbulence, and accelerated stalling otherwise initiated by high speed operation at a high angle of incidence.

A fifth object of the invention is a divided rotor blade with root portions having dissimilar angles of incidence.

In various embodiments, a single metallic sheet is split partially through its length to form two blade portions joined at a common tip portion. The blade is permanently bent to displace one blade portion out of the plane of the other to form a generally tapered gap therebetween. One blade portion is angled or twisted to change its angle of action relative to the other blade portion thereby critically effecting cavitation, lift, and stall characteristics of the entire blade. One blade portion, to be mounted as a lead blade, includes a leading edge portion bent to decrease the angle of attack. A series of holes are located behind the leading edge. In various configurations, the trailing blade portion may include a bent trailing edge portion.

Methods of forming the inventive blade include forming and joining processes that result in the same geometry as suggested for forming by bending sheet material. Other benefits and novel aspects of the invention will become apparent from the following description of various particular embodiments and the accompanying figures.

DESCRIPTION OF THE DRAWINGS

FIG. **1***a* is a perspective view of a first preferred embodiment of the present inventive rotor blade mounted on a shaft.

FIG. **1***b* is a horizontal section view, of the same embodiment, through the leading blade portion and looking toward the trailing blade portion.

FIG. **2** is a perspective view of an alternative configuration of a preferred embodiment of the rotor blade having a curved leading edge blade portion.

FIG. **3** is a perspective view of an alternative embodiment of the present invention in which the blade portions have dissimilar angles of incidence.

FIG. **4** is a side view of two rotor blades mounted on a shaft for use in the manner of an airplane propellor.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1***a* is a perspective view of a preferred embodiment of the invention. A rotor blade **10** is formed from flat sheet material for simplicity and economy. Here, the term "flat" is intended to mean having a uniform thickness to the degree typically found in commercial stock sheet steel. The flat sheet is divided or split longitudinally, leaving an undivided tip portion **11**. The divided sheet forms a leading blade portion **12** and a trailing blade portion **13**, extending from the tip portion **11** to respective blade roots **14**, **16**. The leading blade portion **12** and tip portion **11** remain in a common plane, while the trailing blade portion **13** is angled from the tip out of the plane to form an angled gap **20** between the blade portions. This angle of the trailing blade portion, out of the plane of the tip portion **11** and leading blade portion **12**, is preferably 20 (twenty) degrees. The relative orientation of the leading and trailing blade portions **12**, **13** and the included trailing blade angle Ab between them is depicted in FIG. **1***b*. This trailing blade angle Ab may be other than 20 degrees in various applications. The optimum angle for a specific application may be determined experimentally. FIG. **1***b* is a section view through the leading blade portion of the embodiment of FIG. **1***a*, looking toward the trailing blade portion. Because the blade portions are parallel, only their respective edges are seen. The hub **15** to which the rotor blade **10** is mounted is seen at an oblique angle. The uniform rotor blade thickness **17** can be seen in this view. In configurations using airfoils or other non-uniform thickness blade geometries, the location of the trailing blade portion root can be defined by its relative displacement perpendicular to the first blade portion root chord to provide the same effective gap angle. The size of the tip portion **11** is not aerodynamically critical as the tip portion is provided primarily as a structural support of the outer extents of the blade portions **12**, **13**—securing them together. In alternative configurations, the tip portion **11** may have a thicker section allowing reduced area while providing the same effective bending and shear strength and rigidity.

In forming the blade portions, the sheet material is bent at the intersection of the tip portion **11** and the two blade portions to allow the blade portions to remain substantially straight and planar. In operation, the gap **20** functions to accelerate the fluid flow between the leading and trailing blade portions **12**, **13**, progressively as the gap narrows toward the tip portion **11**. At the point of the gap **20**, a stress relief hole **22** is provided. The necessary size of the stress relief hole **22** is dependent upon the final desired size and shape of the rotor blade **10**, and the thickness of the blade material, and may be determined experimentally. As well, the relief hole **22** provides flow conditioning, reducing tip turbulence.

The blade portions **12**, **13** are each secured at their roots to the hub **15** or shaft or other base for operation. When the blade roots **14**, **16** are secured to a shaft or hub the operational angle of incidence of the rotor blade **10** is established. The angle of incidence is meant herein (consistent with normal use of the term) as the angle between the plane of the rotor blade and the surrounding medium through which the blade travels. For purposes here, this can be measured as the angle between the blade portion considered and a plane transverse and perpendicular to the axis of rotation AR, which is presumed to be the central axis of the respective shaft or hub. The transverse plane is represented in the figure by the reference line T. The angle of incidence Ai is the same for both blade portions in the embodiment of FIG. **1**. In prototype divided rotor blades, angles of incidence of up to 45 degrees were used successfully.

The rotor blade **10** is preferably formed from sheet steel that, as well as being readily formed into divided blade portions, allows the rotors to be secured to a steel shaft by standard welding methods. In FIG. **1** the rotor blade **10** is shown, for clarity, secured to a flat longitudinal surface of a polygon cross-section shaft. The shape and manner of attachment are not critical and other modes and devices are applicable.

The trailing blade portion **13** is substantially planar, although some bending in the proximity of the tip portion **11** will exist. The substantially planar trailing blade portion **13**, without angled leading or trailing edge portions, reduces overall drag and turbulence without adversely affecting lift. The leading blade portion **12** has a narrow leading edge portion **18** bent and angled to provide a decreased angle of incidence at the leading edge. The leading edge portion **18** preferably extends forward from the leading blade portion **12** about 20 percent of the width or chord dimension of the leading blade portion **12**, at a relative included angle of 45 degrees. The length and relative angle of the leading edge portion **18** may vary in some applications, and may be determined experimentally.

A series of ports in the form of through-holes **24** are located in the leading blade portion **12**, behind (inward) and adjacent to the leading edge, on a longitudinal line. The function of the ports is a means of allowing high pressure fluid medium (e.g., air, water) to bleed from the bottom of the blade to the top, across the blade chord, thus reducing cavitation and turbulence, and delaying the onset of stalling, particularly when operating at high speeds and high angles of incidence. To reduce friction and pressure loss, the holes **24** should be bored at an angle from the leading edge and face of the rotor blade portion **12**, rearward to the backside. For this reason, the holes **24** in FIG. **1***a* are seen as ellipses. The ports are a departure from the prior art and significantly increase the effectiveness of the rotor blade **10**. Ports in the form of circular holes are effective and most easily and inexpensively formed, and are preferred for most applications. Ports having other geometries are also contemplated to provide the same function.

The holes preferably occupy 10 percent of the total top surface area of the rotor blade **10**, exclusive of the leading edge portion **18**, or any curved edge portion. The holes **24** should have sufficient diameter and area to bleed high pressure fluid in a nonturbulent flow, through the rotor blade, from the underside of the leading edge portion **12** to the upper side thereof. The combined number, size and spacing of the holes **24** (or other port element) will vary according to the size of the rotor blade **10** and the application and may be determined experimentally.

In FIG. **2**, an alternative configuration of the inventive rotor blade **10** includes a curved leading edge portion **25** that replaces the bent leading edge portion **18** discussed with respect to FIG. **1**. In this configuration the curved leading edge portion **25** is smoothly curved into a decreased angle of incidence. This embodiment provides more lift with less drag than the bent leading edge portion **18**.

In alternative configurations of the above embodiments, the blade tip portion **11** and the leading and trailing blade portions **12**, **13** have conventional airfoil sections. Where different rates of airfoil curvature converge at the meeting of the tip portion and blade portions, they are blended and faired in the normal fashion. A divided blade using a conventional airfoil section is more complicated to manufacture, but is particularly effective in high-temperature applications where low drag is of great importance, and the rotor blade is not required to operate at high angles of incidence (e.g., turbojet engine). This embodiment, operating at conventional angles of incidence, may serve adequately without the leading edge ports discussed above.

It is contemplated, in alternative configurations of the invention, that leading edge ports can be combined advantageously with a divided rotor blade portion having a conventional airfoil section. In such an alternative configuration, the form and details of the holes are substantially as discussed above with respect to flat rotor blades.

FIG. **3** is a perspective view of another embodiment of the present invention wherein the two blade portions **12**, **13** have dissimilar angles of incidence. For clarity, the base hub is not shown. The trailing blade portion **13** has an angle of incidence

Ai2 that is greater than the leading blade portion angle of incidence A11. In each blade portion, the respective angle of incidence is constant over the length of the blade portion. This is shown by the multiple coplanar extension lines L extending from the trailing blade portion. The increased angle of incidence of the trailing blade portion **13** may be obtained in a rotor blade formed of sheet metal by a twist or straight bend along an angled line at the junction of the trailing blade portion **13** and the tip portion **11**. A slight area of transitional angles of incidence may result between the tip portion **11** and the trailing blade portion if a twist used as a transition. Preferably, the angle between the leading and trailing blade portions is about five degrees. That is, with respect to the figure: Ai**2** minus Ai**1** equals five degrees (Ai**2**−Ai=5). In this configuration, the trailing blade portion is more fully able to use the fluid flow that is redirected by the leading blade portion to create lift. The result is a small but a significant increase in the net lift produced by the rotor blade **10**. A conventional airfoil section as discussed above may also be employed with the features of this embodiment.

The divided blade of the present invention may be employed to extract energy from a working fluid, as in the case of a windmill, or to create motion in a fluid by the application of energy, as in the case of crude oil moved by an impeller pump, or to generate motion through a fluid, such as air or water, by application of external power as in the case of a ship's screw or airplane propeller.

It is contemplated that the divided blade of the present invention may form a wing which may be advantageously used in a rotating application as a rotor or propeller. It is also contemplated that the present divided blade may be advantageously used in non-rotating applications such as fixed-wing craft, such as and airplanes and hydrofoils, and also as the wing of a rocket or other projectile. It may further be employed as a winglet at the tip of a conventional wing to extract energy from a wing tip vortex. The invention includes novel devices incorporating one or more rotor blades as disclosed.

FIG. **4** depicts, by way of example, a two-bladed propellor designed in accordance with the invention and using the present rotor blades. In this application, two identical rotor blades **10** are mounted, as discussed above, on a shaft **30** in a configuration for use as a thrust generator in the manner of an airplane or boat propeller. The figure shows the device as viewed from a transverse side of the shaft **30**, both the leading and trailing rotor blade portions being at an angle to the direction of view. For this reason, the port holes **24** are seen as circular due to their bore angle through the leading blade portion. To reduce turbulence and increase efficiency, the rotor blade corners are rounded and the tip edges **31** are cut back at an angle from the leading edge **18**. In the figure, the leading edges **18** project either substantially toward or away from the direction of view (five degree angle of incidence) on the respective blades, and, consequently, their profiles are not visible. The leading edge **18** extends forward from the leading blade portion a length of 10 millimeters (mm).

The propellor blades in the configuration of FIG. **4** are each formed of 13 gauge (2 mm) sheet steel, each using a sheet blank of 400 mm. long by 200 mm. wide. Each blank is split and divided for 300 mm. of its length to form leading and trailing blade portions **12**, **13**. Port holes **24** have a diameter of 20 mm and are placed on 35 mm center spacing on a common line parallel to the leading edge. The holes are bored transverse to the blade portion, at an angle of 45 degrees, from behind the border of the leading edge on the bottom surface **32**, rearward to the top surface **33** of the respective blade portion.

Note that the leading blade portion **12** is inclined on the shaft such that, when the blades are rotating on the shaft, the leading edge defines a cone. The inclination angle IN of the leading blade portion **12** is a product of the angle of incidence, the angle between the divided blade portions and the relative lengths of the blade portions. In the example design, the inclination angle IN is about 10 degrees. In many applications, an inclination angle of 10 to 15 degrees is preferred, although an inclination angle of up to 45 degrees may be used. To effect inclination angles of more than a few degrees, it is necessary to cut back, at an angle, the end of each rotor blade portion at its respective root to rake the blade backward, in the plane of the blade. This is most easily accomplished before the blank sheet material is divided.

The above propeller design would have a finished outside diameter of 850 mm and when turned at 2400 RPM, would develop over 200 pounds of static thrust. The required shaft power at 2400 RPM is expected to be 30 horsepower.

It is well known that conventional propeller blades are not well suited for operation at transonic and supersonic speeds. The United States National Aeronautics and Space Administration (NASA), for example, has characterized a "high-speed" propeller as one that can operate with tip speeds as high as Mach 0.9. As this limit includes the vector sum of the rate of propeller tip rotation, and the rate of travel of the propeller upon an aircraft, propeller-driven aircraft cannot achieve supersonic speed in level flight. This limitation is due almost entirely to the structural inadequacies of the conventional propeller, which, being unsupported along its length, is very subject to bending and twisting under the high loads encountered in the transonic and supersonic ranges. This results in violent fluttering and accelerated stalling, typically leading to rapid catastrophic failure of the propeller.

The divided blade of the present invention has increased support along its length by the separated blade portions and respective roots which increase the overall effective bending section to make the blade sufficiently rigid that it may be operated at transonic and supersonic speeds without fluttering.

Moreover, the divided blade of the present invention does not stall at high angles of attack, due in part to its rigidity, and in part due to the use of the leading edge holes. Conventional prior art propeller blades may operate efficiently at an angle of incidence in the range of six to 12 degrees, generally, and only in the range below transonic tip speeds. In contrast, the present divided blade may be operated effectively in many applications at an angle of incidence as high as 45 degrees at tip speeds well into the supersonic range.

Similarly, the exceptional rigidity of the present blade is of advantage in non-rotating applications, such as airplane wings. A straight-winged aircraft experiences extreme wing flutter in the transonic region, and is subject to sudden catastrophic structural failure. For this reason, modern supersonic jet aircraft employ delta wings, which are stronger over a given span, but which have greatly inferior low-speed performance. The lack of lift at low speeds, particularly during landing, is of such significance that supersonic aircraft have been designed at great expense with wings that move between delta and straight configurations, according to the speed of flight. Additionally, the high angle of incidence characteristic of the divided blade of the present invention, coupled with its high stall resistance, produces a higher lift for a given wing area, permitting the use of smaller wings for a given payload. This results in greater aircraft maneuverability and lowers the cost of construction.

While the above examples have discussed steel as a material of construction for the present divided blade, other materials having sufficient strength, toughness and stiffness may also be used. In constructions using other than easily plastically formed steels, other methods of construction are contemplated and the method of construction does not influence the function of the invention as shown and discussed.

The invention includes methods of forming a rotor blade from sheet material consistent with the constructions discussed above.

The preceding discussion is provided for example only. Other variations of the claimed inventive concepts will be obvious to those skilled in the art. Adaptation or incorporation of known alternative devices and materials, present and future is also contemplated. The intended scope of the invention is defined by the following claims.

I claim:

1. A blade for operating in a relatively moving fluid medium comprising:

a blade tip;

first and a second blade portions extending divergingly from the blade tip to respective blade roots, each blade root separated from the other, such that an angled gap is defined between the blade portions;

the first blade portion having a leading edge and a plurality of through-blade bleed ports adjacent the leading edge.

2. A blade according to claim **1** and wherein:

the blade portions and tip have a common uniform thickness.

3. A blade according to claim **2** and wherein:

the blade portions have respective angles of incidence, the first blade portion angle of incidence different from the second blade portion angle of incidence.

4. A blade according to claim **3** and wherein:

the second blade portion angle of incidence is five degrees greater than the first blade portion angle of incidence.

5. A blade according to claim **4** and wherein:

the first blade portion angle of incidence is less than or equal to 45 degrees.

6. A blade according to claim **1** and wherein:

the blade portions extend divergingly from the blade tip at an included angle of 20 degree.

7. A blade according to claim **1** and wherein:

the bleed ports have a total effective area of ten percent of the first blade portion surface area.

8. A device for moving fluid, comprising:

at least two rotor blades oriented symmetrically about a central axis of a rotatable base;

each rotor blade comprising:

a blade tip;

first and a second blade portions;

the blade portions extending divergingly from the blade tip to respective blade roots that are axially separated and secured to the rotatable base such that an angled gap is defined between the blade portions;

each first blade portion also having:

a leading edge portion extending, at decreased angle of incidence, from the first blade portion, and

and a plurality of bleed ports adjacent the leading edge.

9. A device according to claim **8**, and wherein:

each rotor blade first blade portion has an angle of incidence equal 45 degrees.

10. A device according to claim **8**, and wherein:

the first blade portion having a first angle of incidence and the second blade portion having a second angle of incidence different from the first.

11. A device according to claim **10**, and wherein:

the second angle of incidence is five degrees greater than the first angle of incidence.

12. A device according to claim **8**, and wherein:

the base is an aircraft propeller shaft.

* * * * *

Appendix B

Axial fan design

The axial fan is considered the simplest and most common type of fan. The basic equations and concepts that are used in axial fan design are explained below[5]:

B1- Continuity Equation

The continuity equation ensures mass conservation in the fan

$\dot{m} = \rho A V$ ………………………………………………………….. 1

Where $\dot{m}$ is mass flow rate (kg/s), ρ is air density (kg/m^3), A flow area in (m^2) and V axial velocity in (m/s). knowing the mass flow rate helps in selecting the fan diameter and maintaining within limits is critical to avoid turbulence or excessive noise.

B2- Momentum Equation

In the momentum equation, the pressure generated by the fan is related to the change in velocity of the air.

$\Delta P = \rho\ V\ \Delta V$ …………………………………………………………… 2

Where ΔP is the pressure difference across the fan (Pa) and, ΔV is the change in axial force velocity (m/s)

In this equation the pressure rise must cover the pressure losses (duct losses, static pressure, and requirements), also the efficient design must minimize the ΔV because higher velocity change increases energy losses and noise.

B3- Energy Equation (Bernoilli's Equation)

This equation describes the energy conversion between kinetic energy (velocity) and pressure in the airflow. In axial fans, pressure rise is a function of the blade geometry and rotor speed.

$\Delta P = \frac{1}{2}(V_2^2 - V_1^2)$ …………………………………………… 3

In axial fan design, the static pressure rise builds by the fan blade curve, the blade design optimizes ($V_2 - V_1$) to ensure efficient conversion of kinetic energy to pressure.

B4- Euler's Turbomachinery Equation

The Euler equation describes the done by the fan blades on the air.

$$\Delta h = (U_2 V_{\theta 2} - U_1 V_{\theta 1}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. 4$$

Where Δh is the enthalpy difference in (kJ/kg) U is the blade tip speed (rotational speed times radius) in (m/s) and, V_θ is the tangential velocity component (caused by blade rotation and air interaction). The tangential velocity is optimized through the design of the blade angle of attack and chord length to ensure maximum energy transfer. Also, Δh directly relates to pressure rise using:

$$\Delta P = \rho \, \Delta h \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 5$$

B5- Fan Efficiency

The efficiency term represents a comparison the useful power output (pressure rise times volumetric flow rate) to the mechanical power input (torque times angular velocity).

$$\eta = \frac{\Delta P \dot{V}}{\tau \omega} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 6$$

الخلاصة

تمثل الحركة النسبية بين السوائل والأجسام المتحركة داخلها القاعدة الأساسية لتطوير العديد من المفاهيم الهندسية مثل الطبقة المتاخمة وتطبيقاتها، وقوى السحب والرفع وتطبيقاتها في السيارات والطائرات والصواريخ، وكذلك في نقل الحرارة حيث يستخدم السائل لإزالة أو إضافة الحرارة إلى النظام. تمثل المراوح الجهاز الامثل الذي يضع هذه الظاهرة في الواقع على طريق التطبيقات العملية، حيث تعمل الشفرات المتحركة في الهواء على دفع الهواء المحيط إلى التحرك للأمام أو للخلف وتوصيل تدفق حجمي للهواء. المروحة المحورية هي النوع الأكثر شيوعًا من المراوح ويمكن رؤيتها بأشكال وأحجام مختلفة حسب التطبيق. المروحة المحورية بسيطة في البناء ويرتبط أداؤها بالعديد من العوامل مثل تدفق الهواء الحجمي والوزن وهندسة الشفرات وزاوية الهجوم وسرعة الدوران. في هذه الدراسة، تم تصنيع سبعة نماذج من المروحة المحورية واختبارها من حيث متوسط السرعة (معدل التدفق الحجمي) والضوضاء والطاقة المستهلكة. تم تعديل النماذج بناءً على براءة اختراع لتصميم شفرة جديدة (دوار شفرة مقسم)، تمت الإشارة إلى النماذج باسم M1–M7، ولكن تم أولاً إنشاء نموذج M0 واختباره مقابل النموذج الأصلي في براءة الاختراع، بعد ذلك تم إنشاء نماذج أخرى وتقسيمها إلى مجموعتين بناءً على اتجاه الدوران حيث تدور M1–M4 عكس اتجاه عقارب الساعة بينما تدور المجموعة M5–M7 في اتجاه عقارب الساعة. صنع نموذج شفرة M1 من صفائح فولاذية مجلفنة ١ مم وطول ٢٢٠ مم وعرض ١٠٠ مم والمحور مصنوع من فولاذ مجلفن ٢ مم وقطر ١٥٠ مم. يتكون M2–M4 من صفائح ألومنيوم ٣ مم بنفس الطول والعرض بينما يتكون المحور في النموذج M2–M3 من صفائح ألومنيوم ٥ مم وصفائح ٣ مم لـ M4. يبلغ المحور في M3 100 مم وعرض الشفرة في M4 138 مم. النماذج M5–M7 هي نفسها M2–M4 فقط اتجاه الدوران مختلف. أجريت التجارب بتغيير سرعة الدوران وأخذت الطاقة المستهلكة كمؤشر للعمل. أظهرت نتائج المقارنة أن نموذج M4 يعطي أفضل أداء من حيث معدل التدفق الحجمي بزيادة مقدارها ١٣.٣٪

ومستوى الضوضاء انخفظ بمقدار ٢٪. لذلك، تمت مقارنة M4 بالمروحة المستخدمة في الوحدة الخارجية لوحدة تكييف الهواء من النوع المنفصل المثبتة في حرم الإمام علي (ع) ولديها بعض مشاكل الكفاءة. أظهرت النتائج أن نموذج M4 الجديد المختبر يقلل من درجة حرارة خط ضاغط المخرج (درجة حرارة المبرد) بمعدل ١٢ درجة مئوية مما يمنع الضاغط من الدخول في وضع حماية الحمل الزائد في أيام الصيف الحارة.

دراسة تجريبية لأداء مروحة ذات ريش مشقوقة

رسالة مقدمة الى

قسم هندسة تقنيات ميكانيك القوى

كجزء من متطلبات نيل درجة الماجستير في هندسة تقنيات ميكانيك القوى / الحراريات

تقدم بها

حسنين كاظم جعفر

إشراف

الاستاذ المساعد الدكتور

محمد عبد الرضا حسين

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة الفرات الأوسط التقنية

الكلية التقنية الهندسية، النجف

دراسة تجريبية لأداء مروحة ذات ريش مشقوقة

حسنين كاظم جعفر

(ماجستير في هندسة تقنيات ميكانيك القوى)

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