جامعة الأمير محمد بن فهد
PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering Department of Mechanical Engineering

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Senior Design Project Report

Design and Manufacturing of a Micro Axial Jet Engine.

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

Team Members

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Abstract

Jet engines are used in air, sea and land transportation, as well as in power generation. Recently micro jet engines find application in power generation and vehicle propulsion. The purpose of this project is to design and build a small-scale jet engine from off-the-shelf components. The compressor and turbine are of axial flow, machined by CNC or 3D printed. The fuel is in liquid form (gasoline/diesel) supplied through a bubbler to the engine.

The students will have to:

- Calculate the blades angle, shaft loadings and bearings life
- Design the engine components.
- Manufacture the engine.
- Test the engine at different speeds and with different fuels.

Acknowledgement

The achievement and ultimate result of this project required a great deal of direction and help from numerous individuals and we are incredibly advantaged to have this up and down the fruition of our project. All that we have done is just because of such supervision and help and we would not forget to thank our guide Dr. Panos Sphicas. We regard and express gratitude toward Dr. Panos Sphicas, for giving us a chance to do the project work in time and giving all of us backing and direction, which made us complete the project appropriately. We are incredibly grateful to him for giving such a pleasant help and direction, in spite of the fact that he had occupied timetable dealing with the corporate issues. We owe our profound appreciation to our task manager Dr. Mohammed AlMahdi, who took unmistakable fascination on our project work and guided all of us along, till the fruition of our project work by giving all the important data to building up a decent framework. We thank our project guide, Dr. Fdjavanroodi, the chairman of the engineering department, for his direction and recommendations during this task work. We are grateful too and lucky enough to get steady consolation, backing and direction from all teaching staffs of our building division which helped us in effectively finishing our project work. Likewise, we might want to stretch out our earnest regards to all staff in research facility for their convenient help.

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Chapter 1

Chapter 1: Introduction

1.1 Project Definition

Axial flow jet engines are a sort of axial compressors in the turbomachinery field and can has a very big impact especially in the aviation industry dominantly. Moreover, axial jet engines are capable enough to produce a great deal of thrust and power for the required use which can be widely seen in the aviation industry as well as aerospace technology from the olden times. So, with such a consideration in mind, we as a group has opted to design and manufacture a micro scale of an axial jet engine which after optimization and experimentation will be set up to achieve our define objectives. Moreover, the reason behind such a project also comes from our interest in turbomachinery applications and also because axial flow jet engines are fairly simpler than centrifugal or turbojet and ramjet engines and a small scale miniature jet engine could be run successfully while maintaining proper health and safety check on us and the people around us.

1.2 Project Objectives

- Create enough power to drive a bigger object that can give us work.
- Give a real life example of what a turbine looks like for students to see and learn.
- To explore the details and concepts behind the physics of how it work.
- To challenge ourselves and the limits to what we can achieve.
- To sell it in the market.
- To show that big projects can become a reality from scrape.

1.3 Project Specifications

A jet engine is a type of reaction engine discharging a fast-moving jet that generates thrust by jet propulsion. This broad definition includes airbreathing jet engines (turbojets, turbofans, ramjets, and pulse jets). In general, jet engines are combustion engines. The term "jet engine" is commonly used only for airbreathing jet engines. These typically feature a rotating air compressor powered by a turbine, with the leftover power providing thrust through the propelling nozzle – this process is known as the Brayton thermodynamic cycle. Jet aircraft use such engines for long-distance travel. Early jet aircraft used turbojet engines that were relatively inefficient for subsonic flight. Most modern subsonic jet aircraft use more complex high-bypass turbofan engines. They give higher speed and greater fuel efficiency than piston and propeller aeroengines over long distances. A few air-breathing engines made for high speed applications (ramjets and scramjets) use the ram effect of the vehicle's speed instead of a mechanical compressor. Since it is axial jet engine, we'll probably use;

- A long pipe with the desired diameter

- A spark plug to ignite the fire

- A blade which we'll probably create from a metal sheet

- A shaft, we'll probably find one that is already made with the desired size we want

1.4 Project Applications

The primary purpose of this study is to formulate a methodology for designing axial turbines for use in small jet engines. This is achieved through five secondary objectives.

- To produce high thrust.
- Increase the efficiency in the jet engine.
- Less Vibration.

Chapter 2

Chapter 2: Literature Review

2.1 Project Background

A micro turbine (MGT) engine has become popular technology in Remote Control (RC) jets. They are also used in small electrical power generation plants, hybrid electric vehicle applications and as auxiliary power units (AUPs) for modern aircrafts. As at present, a substantial number of re-search and papers have been published in this area to assess and improve the performance of MGTs. This paper intends to present an outlook of MGTs system performance analysis and improvement evaluation-based methods available in open literature. The performance of an engine at the design and off-design points can be obtained from turbine performance modelling. Off-design evaluation is required to model the operating range of turbines due to the engine ˘A´Zs nonlinear thermodynamic behavior. Off-design behavior is also used to examine the impact of a change in engine component characteristics on engine output. Cumpsty (2003) agrees that a turbine â ˘A´Zs performance at off-design conditions should be satisfactory and safe irrespective of its non-linear behavior-Sayed (2008) emphasizes that although turbines are designed to operate effectively at specific design points, the engine should also work acceptably at off-design conditions. According to Asgari (2014), off-design modelling is the most suitable means of optimizing, maintaining and predicting the performance of a turbine. The off-design performance of a turbines involves performance predictions, condition monitoring and degradation analysis. The engine diagnosis and degradation analysis are normally executed based on the performance predictions (Suraweera, 2011). The off-design performance of turbines can be evaluated using the following methods: component matching, stage stacking (Thirunavukarasu, 2013). These modelling methods are mathematically formulated with linear and non-linear equations into computer programs for performance simulations. [1]

2.2 Previous Work

A group of students conducted their own project for their final year design project in which they also designed a micro-axial jet engine and conclusively this is what they had to offer as an advice or a hint to follow “In order to provide assistance to any future project groups interested in manufacturing their own miniature turbine, we have provided a list of recommendations that will expedite the design and manufacturing process and possibly facilitate the integration of instrumentation, thrust considerations, and efficiency into their design.

• We recommend avoiding super alloys, like Inconel 718, when constructing a turbine unless the group has access to proper CNC tooling and equipment and experience machining with other similar alloys.

• We recommend that when selecting or manufacturing a compressor, ensure a CAD model is available. A CAD model enables the use of computer software to quickly design a compressor inlet shroud that meets tolerances necessary for engine efficiency.

• We recommend further research into flange design in order to create a flange that can integrate gasket material and ensure a proper, reliable seal.” [2]

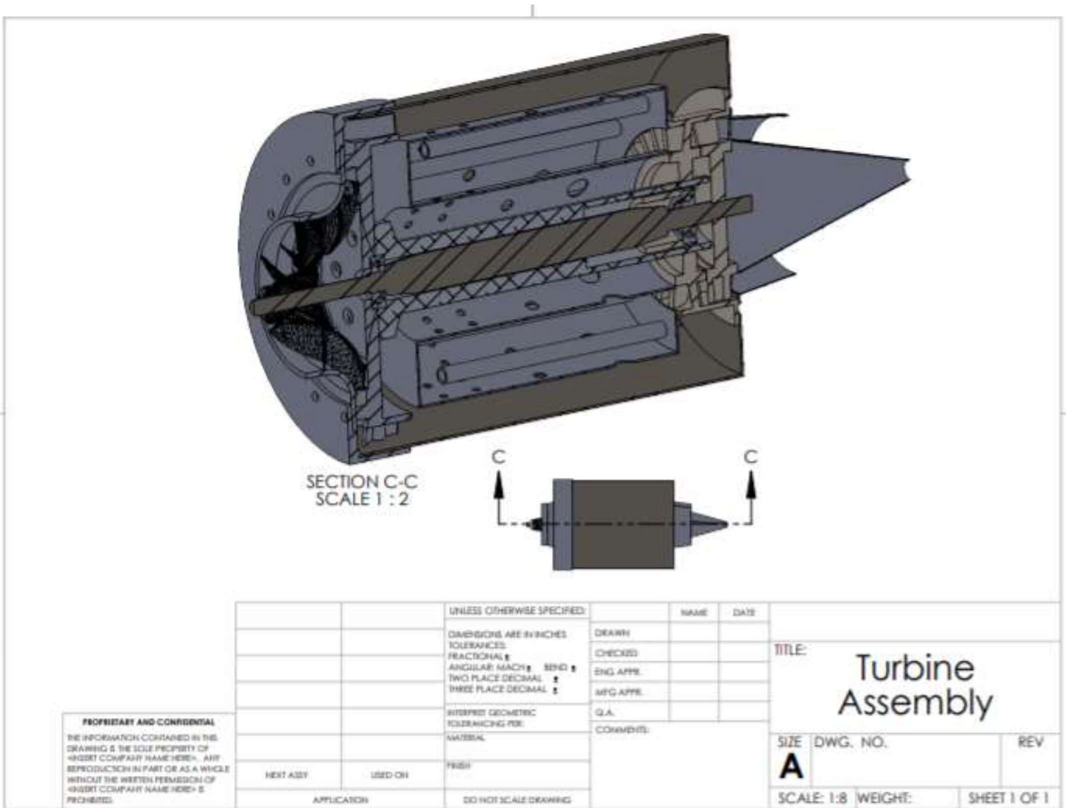

Figure 1: Turbine Assembly for Miniature Axial Jet Engine.

2.3 Comparative Work

A student, also carrying out his final year project related to design and development of a micro axial jet engine went through several stages of achieving his goals which are described by him as “Micro turbines are becoming widely used for combined power generation and heat applications. Their size varies from small scale units like models crafts to heavy supply like power supply to hundreds of households. Micro turbines have many advantages over piston generators such as low emissions fewer moving parts, accepts commercial fuels. Turbine cycle and operation of micro turbine was studied and reported. Brief description on CAD software and

CATIA studied and reported. Different parts (Inlet. Storage, Nozzle, Rotor, coupling, outlet, clip, housing) of turbine are designed with the help of CATIA (Computer Aided Three-Dimensional Interactive Analysis) software. Then they were assembled to a single unit and coupled to a generator to produce power. The turbine is of Axial input and axial output type. Finally, rapid prototyping machine features and parts were discussed and presented" [3].

In another research paper, this project deals with researching, designing and building jet-engines. A simple turbojet engine was designed and construction was begun. The design was made by studying the work done by industry and researchers over the course of the history of jet engines. The methods were then discussed and chosen in a way that would simplify the design work as well as the construction of the engine. The goal was to create a self-sustaining combustion within the engine. The design settled upon consists of a radial compressor, an annular combustion chamber and an axial turbine. Since the compressor would have been the most difficult part to machine the decision was made early on to use the compressor from a turbocharger out of an automotive engine. Upon further study it was discovered that the characteristics of this compressor was not compatible with the rest of the design, as the compressor was made for an RPM range outside of what we could achieve and the compression ratio was too low. Most of the rest of the engine had already been built, and there was not enough time to design and build another compressor so work was aborted on the engine [4].

Following such a literature review and having an insight towards what have been done in the past and what could be achieved by our team, it looks pretty promising that we as a group will be able to achieve such a milestone by having a constant reference to the previously done projects so as to not deviated from our path and troubleshoot problems which could be a concern.

Chapter 3

3.1 Design Constraints and Methodology

A micro axial jet engine is a very small scale jet engine which comprises of the same type of components as used in an actual jet engine used for propulsion systems and in industries. The design of components of the axial flow jet engine has to be done carefully that it fulfills the performance criteria.

The design of the jet engine is based on two important parameters. First is thermodynamic efficiency to be optimized. Second is aerodynamic efficiency. A requirement of fuel consumption has to optimize also. The components of this engine which include compressor, turbine, shaft, combustor, etc are designed in such a way that above mentioned parameters are to be estimated and are a crucial part of design specifications.

The thermodynamic analysis is used for the determination of mass flow of gas through the inlet, compressor, combustor, turbine, exhaust and what pressure ratio is needed in the compressor to achieve required efficiency. What is temperature distribution along with the components of the engine. All these parameters are estimated so this data is needed for further proceeding towards the determination of aerodynamic efficiency. The number of blades required for different stages is to be estimated, how much rotational speed is required to do the required amount of compression, what should be the geometrical size of compressor and turbine blades. Weight and material requirements are to be considered. The actual mechanical design has to ensure the low weight of system components, the durability of components during the period of operation and design of life for operational time is to be ensured.

High-speed rotation of shaft and passing of gas through compressor and turbine blades can cause vibrations to be induced. Usually, detailed vibration analysis is needed to ensure safe operation because it may affect the operational life of the shaft. Any kind of unbalance in the components has to be removed. Similarly, failure from fatigue has to be avoided because of continuous dynamic loading upon the components of the engine. The selection of materials has to be done accordingly.

High-temperature requirements in the combustor have to be considered because thermodynamic efficiency depends on it and materials selection is such that they can withstand the heat from the combustion process. Bearing design is to ensure safety because the failure of these will cause all components to fail. As every component is mounted on the shaft and shaft is held with bearings so proper selection of the type of bearing is to be ensured. Proper lubrication of bearings is also necessary.

Item	Size	Geometry	Environment	Weight	Cost
Shaft	The size of the shaft for the purpose of the project is of circular shaft of diameter 1.5 cm. And the length is about 20 cm.	The geometry of the shaft is circular cross-section and is in the shape of a cylinder.	The shaft must be balanced statically and dynamically to avoid any effects on the surrounding components.	The material used for the manufacturing of shaft is steel as it is easily available in the market and is not much heavy.	The estimated cost of material required to make a shaft is 200 SR.
Compressor blades	The size of the blades in terms of diameter is a little less than the outer casing to leave some clearance. It covers a diameter of almost 11 cm.	The geometrical shape of blades is that of an airfoil. Its aerodynamic design is done using cad modeling.	The blades should be mounted properly on the shaft and there must not be any chance for these two components to get separated. There should be clearance between blades and outer casing.	The compressor is the main component of the engine and its weight contributes much to the total weight of the engine.	The cost of material for the nickel blades is high. Because nickel is expensive metal. The price for this is 3000 SR.

Turbine blades	The size of the blades in terms of diameter is a little less than the outer casing to leave some clearance. It covers a diameter of almost 11 cm.	The geometrical shape of blades is that of an airfoil. Its aerodynamic design is done using cad modeling.	The blades should be mounted properly on the shaft and there must not be any chance for these two components to get separated. There should be clearance between blades and outer casing.	The turbine is the main component of the engine along with the compressor so its weight contributes much to the total weight of the engine.	The cost of material for the nickel blades is high. Because nickel is expensive metal. The price for this is 3000 SR.
Combustor	The size of the combustion chamber is the same as outer casing but in the center, it is a hub shape to give an annular shape.	The geometry is annular in which combustion takes place.	The material for the chamber must be heat resistant to withstand the high temperature due to combustion.	The weight of the chamber is very less because it is hollow for combustion to take place.	The cost of the chamber is not very much as it is made of ceramic material. The price is 500 SR.

Casing	The size of the outer casing is about 40 cm long and 13 cm in diameter.	The geometry of casing is a hollow cylinder in which all components are mounted.	The casing must not transfer the heat from the inside of the engine to outside otherwise thermal efficiency may decrease.	The weight of casing is not much and is of light material but it covers all the components into it.	The cost of material for the casing which is aluminum is not very high. The price is 1500 SR.
Bearings	The size of the bearing must be according to the size of the shaft so it may fit properly on the shaft.	The geometry is circular just like the shaft. It has an inner diameter and an outer diameter.	The bearing must be made of high strength material to withstand the forces transmitted to it by the shaft. It must also be resistant to dust and needs lubrication from time to time.	Bearings are of less weight but it must handle the weight of the compressor and turbine.	The cost of bearing is very less because small size bearings are required for the project. Four bearings are needed. The price of one bearing is 15 SR.

Environmental

The device must be such that it must not affect the surrounding environment. The operation of the device must not bring any damage to the surrounding people.

Economical

The design of components is to maintain and operate on maximum efficiency while keeping the cost of manufacturing and operation to the minimum. As the components used in actual jet engines are very expensive and they have a finite life and need to be replaced so the design must include cost optimization.

Manufacturability

During the optimization of design for cost reduction, low weight, high integrity of components, it is to be considered that the parts or components are easily manufacturable. The mechanism of joining the components is to be ensured that the design is manufacturable in reality.

Safety

The safe operation of a device is one of the most important requirements. This puts more and more constraints on design procedure and it may be that design has to be reviewed many times to ensure safe operation.

Sustainability

The design of the device has to be done in such a way that components work over a long time to ensure sustainability. Components must not fail before the period for which design is done. The components selection and material selection matters while considering the sustainable operation.

Geometrical Constraints

The design of the device must ensure proper geometrical requirements so that the reduction of weight, lowering of cost, safe operation of the device can become possible. Dimensions of components must be selected carefully and checked if the component fails or not. And if it fails then change the dimensions and check again. An iterative procedure is required while designing geometrical parameters.

Engineering Standards

Every component of a device has to designed while checking and making sure that it agrees with the design standards. Various engineering standards are available internationally which have to be used for the designing of each and every component or part.

3.2 Engineering Standards

There are many separate parts and components making up the complete product. Each and every mechanical component is to be designed while considering available design codes and standards. These engineering standards provide ease during the design phase that which components or dimensions are to be taken and where to make assumptions. These make it possible that design is not totally unique and available parts in the market can be used. So parts can be interchangeable if any component is required again or the earlier component failed. And this also ensures compatibility of components.

The design of components which include compressor, shaft, bearings, nuts, bolts, turbine, outer casing, and combustor can be done by various standards available such as ASME, ISO, ASTM standards.

3.4 Product Subsystems and Selection of Components

Air inlet

The intake of air into the engine is the first step before going to the compressor. As this jet engine is being designed for low-speed flow, the intake duct is just the part of the outer casing of all components. The diameter of the intake is the same as the outer casing.

Axial Compressor

The flow of air is parallel to the rotational axis of the shaft on which the compressor rotates. The primary purpose of this compressor is to increase the pressure of the gas as it passes through the compressor. It consists of rotating blades and stationary blades. The shaft drives the compressor. The diameter of the compressor drum increases as going towards the end of the compressor. This is to ensure that less volume is given for air to flow and it gets more compressed. The blades of the compressor are actually airfoils. The rotating airfoils accelerate the flow of air and stationary blades of stator convert the kinetic energy of flow into static pressure. In this compressor, three rotors and one stator comprise the compressor portion. Nickel blades are used for the compressor.

Combustor

Fuel is added to the compressed air and burnt with spark ignitor to cause an increase in the temperature of gases. The choice of the fuel injector, spark ignitor and the rounded hub upon the shaft are to be considered. The amount of fuel for the required amount of burning has to be set accordingly. Ceramic material is selected for the combustion chamber as ceramics can withstand higher temperatures. The cost is a bit high but it is suitable for such an application.

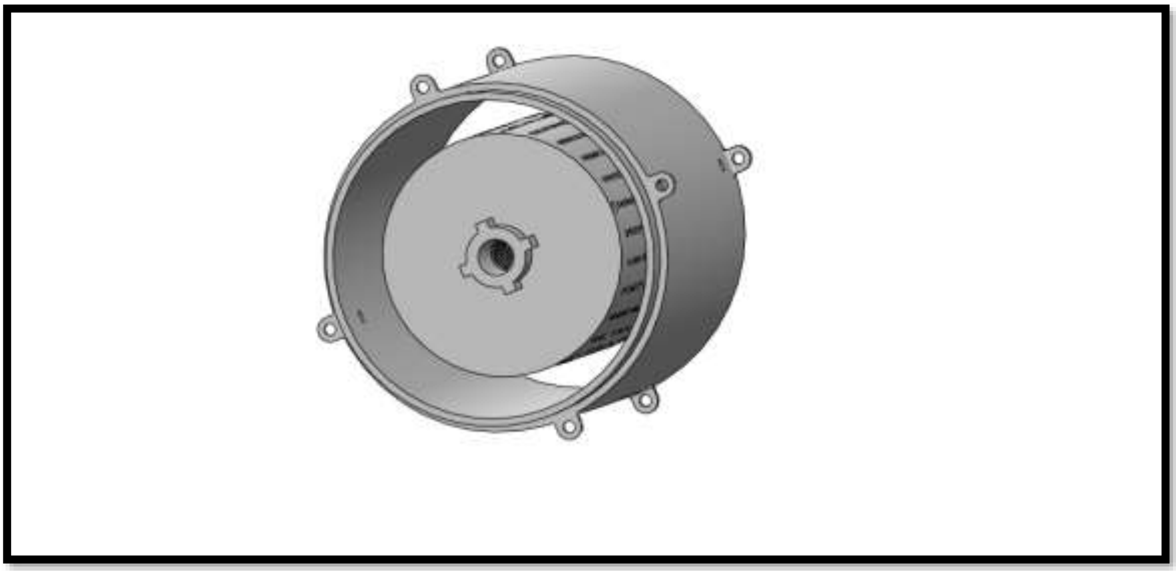

Figure 2 Combustion Chamber

Turbine

The turbine contains blades that extract energy from the flow of gases coming from the combustion. These blades are also airfoils and are designed to get maximum aerodynamic efficiency. There are also multiple stages of turbine blades containing rotating blades and stationary blades. The stator blades guide the flow of gases. In this turbine, there are two rotating turbine blades and two stationary blades. The diameter of the drum on which turbine blades are attached decreases in the direction of the exhaust so pressure increases and more kinetic energy is extracted. Blades of nickel are used. It can withstand the temperatures for this engine as it is a small scale project.

Blades are shown as:

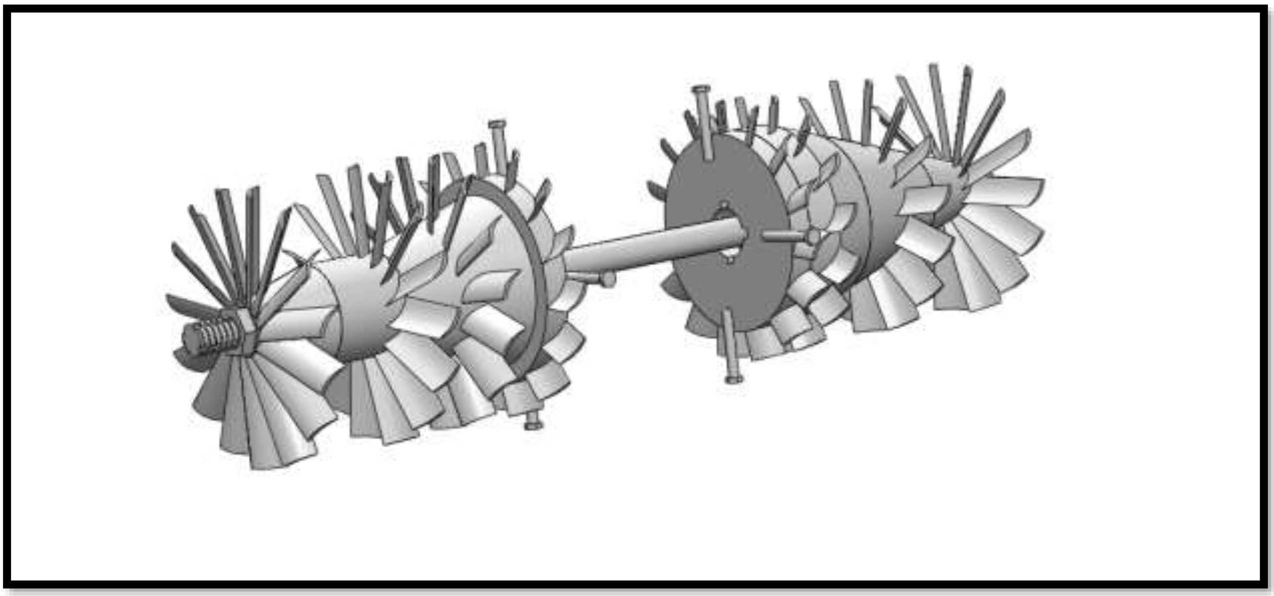

Figure 3 Turbine Blades and Shaft

Outer casing

The casing which encloses all of the components of the jet engine is the outer casing and is a kind of duct which directs the flow of air while passing through all of the components. The diameter of the casing is constant in this design. In actual engines, this shape of casing is also optimized to have an increased amount of flow needed for cooling purposes. The aluminum casing is used as it is lighter compared with steel or iron. It is also easily available in the market.

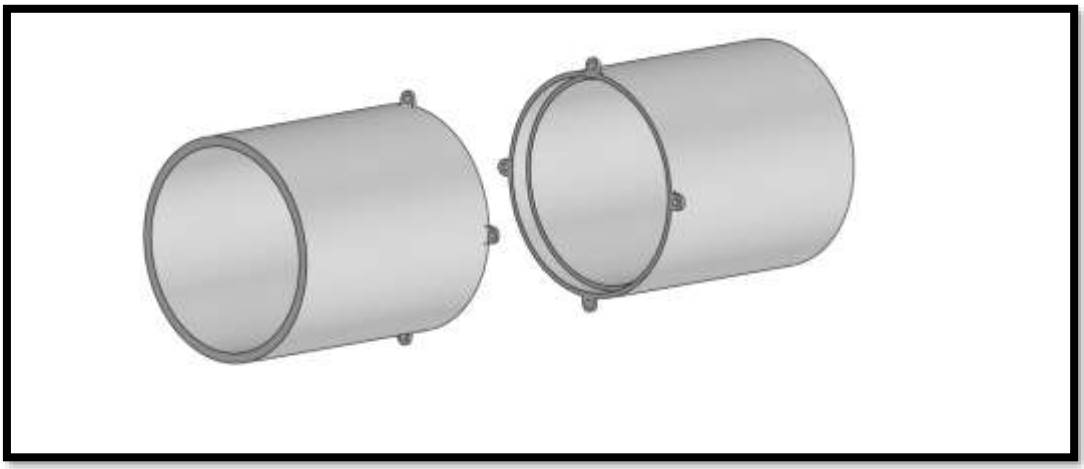

Figure 4 Outer Housing

Shaft

The main component which holds all the components while in the rotation is the shaft. The shaft is mounted in bearings. Compressor blades and turbine blades are fixed with the shaft and rotate along with the shaft. The material of the shaft must withstand bending and torsion. It must be balanced statically and dynamically so vibrations are not induced into the system and the chances of failure become very low. Steel is used for the material of the shaft as it has good strength. Easily available in the market and is suitable for small scale projects.

Bearings

Bearings are a crucial part as the shaft is going to rotate inside the bearings. These have to of high strength so it can handle the dynamic loading due to rotation. Proper lubrication from time to time is necessary for the proper functioning of the engine and to avoid friction losses. These must be resistant to dust. Small size bearings are used for this project and are easily available in the market.

3.5 Implementation

After the purchasing and manufacturing of all components, the next task is to assemble all the components to give it the shape of a complete jet engine.

First of all, the casing of the engine is mounted with the ground. The shaft is mounted in the bearings in a proper way. It is important to ensure the correct locations of bearing along the shaft.

The blades of compressor blades and turbine blades are mounted on the shaft with the bolts. While mounting the shaft, it is to be ensured that the shaft is completely balanced to avoid any kind of unbalance and vibrations. The static and dynamic balancing of all the components (compressor stages and turbine stages) is to be ensured.

Stator blades have to be fixed completely and oriented in the right direction for proper functioning. All the components are to be bolted in correct places to hold every component in its specific location.

The alignment of the compressor, combustor, and turbine is very important to extract the maximum amount of energy from the gases. The correct alignment ensures gases to be incident with blades at the proper angle.

The casing is divided into three parts and joined together with bolts and nuts. It is to be ensured that the clearance between blades and outer casing while blades are in rotation, is fixed and they do not come into contact. Otherwise, it may cause the failure of components.

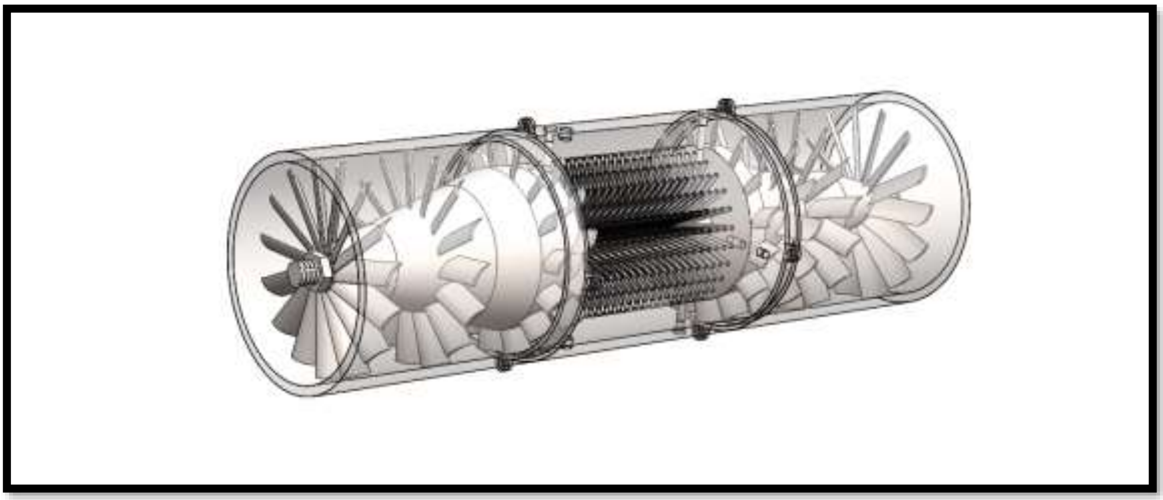

Figure 5 Complete Assembly of the Jet Engine

3.6 Calculations

Thrust Force

D_1= 0.12m D_2= 0.13m

r_1= 0.06m r_2= 0.065m $r_m = \frac{r_1 + r_2}{2} = 0.0625$ $H = r_2 - r_1 = 0.005$

Equation	Solution
$Area = 2\,\pi r_m H$	$2\,\pi\,(0.0652)(0.005) = 1.9633 * 10^{-3}$m
$A_c = \pi r_m^2$	$\pi\,(0.0625)^2 = 0.012272\; m^2$
$U = \frac{2\,\pi}{60} r_m N$	$\frac{2\,\pi}{60}\,(0.0625)(2400) = 15.7\; m/s$
$C_1 = C_3$	= 100 m/s
$\dot{V} = v\; Area$	$(100)\;(1.9635 * 10^{-3}) = \frac{0.2m^3}{s}$

Equation	Solution
$\dot{m} = \rho \dot{V}$	$0.064\; Kg/s$
$c_{y2} = \frac{C_P\, \boldsymbol{\Delta T}}{U}$	$c_{y2} = \frac{(1145)(45)}{(15.7)} = 3287\; m/s$
$\alpha_2 = c_{y2} / c_x tan$	$\alpha_2 = 88.3°$
$C_2 = \frac{C}{\cos \alpha_2}$	$\frac{100}{\cos(88.3)} = 3370.8\; m/s$
$\dot{W} = \dot{m} U c_{y2}$	$(0.065)(15.7)(3287.6) = 3303.38\; W$ $= 3.3\; KW$
F = m (c2 – c3)	(0.064)(3370.8-100)=209.3 N

Combustion reaction calculation:

Standard enthalpy of combustion (ΔH_C°) is the enthalpy change when 1 mole of a substance burns (combines vigorously with oxygen) under standard state conditions; it is sometimes called "heat of combustion." For example, the enthalpy of combustion of ethanol, −1366.8 kJ/mol, is the amount of heat produced when one mole of ethanol undergoes complete combustion at 25 °C and 1 atmosphere pressure, yielding products also at 25 °C and 1 atm.

$$C_2H_5OH(l) + 3O_2(g) \longrightarrow 2CO_2 + 3H_2O(l) \qquad \Delta H_{298}^\circ = -1366.8 \text{ kJ}$$

Phase behavior	
Density (liquid) 0°C	600 kg/m³
Density (saturated vapor) 1 atm, -0.5°C	2.6 kg/m³
Triple point	134.6 K (–138.5 °C), 0.7 Pa
Critical point	425.1 K (152.0 °C), 3796.0 kPa
Std enthalpy change of fusion, $\Delta_{fus}H^\ominus$	4.66 kJ/mol
Std entropy change of fusion, $\Delta_{fus}S^\ominus$	34.56 J/(mol·K)
Std enthalpy change of vaporization, $\Delta_{vap}H^\ominus$	22.44 kJ/mol
Std entropy change of vaporization, $\Delta_{vap}S^\ominus$	82.30 J/(mol·K)

Chapter 4: System Testing & Analysis:

4.1: Experimental Setup, Sensors, & Data Acquisition System:

- In this project, the gaseous fuel that was used was Butane Gas.

The experimental procedure was as follows:
-We start by making sure the hose and the pressure in the gas tank as desired
-We then plug in the drill head inside the front nose of the turbine to rotate the shaft
- when the shaft rotation speed reaches a certain RPM we will ignite the fire

Infrared Thermometer:

Infrared thermometer was used to detect the temperature of the engine at any instant during the operation. In case, the engine got heated up, the temperature of the engine was brought down by means of a water spray at the outside body of the engine.

Figure 6: Infrared Thermometer

- The specifications of this infrared thermometer are given below:
- Range is from -30 degree Celsius to 500 degrees.
- The Distance-spot ratio is 10:1
- A single laser for accurate, precise and repeatable values of temperature.

Tachometer:

The tachometer apparatus was used to determine the rpms of the engine. The experiment was done by connecting the tachometer to the end of the shaft for the evaluation of the angular velocity of the shaft and hence the engine. The tachometer had the following specifications:

- Non-contact measurement range was from 50 to 9999 rpms
- The measuring distance range was from 50mm to 260mm
- There was a 30 sec Auto Power off System
- Data Holding Capability was present.
- Package Weight was about 280 grams.
- m/min and m/sec and in/min scales were present.

Figure 7: Tachometer

Testing Parameters	Objective
Tachometer	To measure the rpms
Infrared Thermometer	To measure the engine temperature
Fuels	For testing of engine at different fuels

Results, Analysis & Discussion:

The data gathered through the calculations above can be summed up in tabular form as follows:

Entity	**Thrust Force**	**Bearing Life**	**Mass of Shaft**	**Maximum Motor Power**	**Torque**	**Blade Angle**
Units	N	Hours	Kg	kW	Nm	Degrees
Symbols	F_{Thrust}	L_{10}	m	P	τ	Φ
Value	1.351	316.07	4.43	0.75	1189506.05	45.03

Chapter 5: Project Management

5.1 Project Plan

A number of tasks were to be done in the project. Every task was divided among the members. The tables below provide a general overview of the tasks, the members of the project team, & the total duration of completion of every project task.

#	Tasks		Week	Weeks to complete	Students
1	Chapter 1: Introduction		2	1	Abdulla, Hussain
2	Chapter 2 : Literature Review	Project Background	3	2	Jehad,Ali, Haitham
		Previous Work			
		Comparative Study			
3	Chapter 3: System Design	Design Constraints & Design Methodology	5	3	Abdulla, Ali, Jehad , Haitham
		Engineering Design Standards			
		Theory & Theoretical Calculations			
		Project Subsystems & Selection of Components			
		Manufacturing & Assembly			
4	Chapter 4: System Testing & Analysis	Experimental Setup, Sensors & Data	10	4	Abdulla, Ali, Jehad , Haitham
		Results, Analysis & Discussion			
5	Chapter 5 : Project Management	Project Plan			
		Contribution of Team Members	10	4	Abdulla, Ali, Jehad , Haitham
		Project Execution Monitoring			
		Challenges & Decision			
		Making			

		Project Bill of Material & Budget			
6	Chapter 6: Project Analysis	Life Long Learning	10	4	Abdulla, Ali, Jehad , Haitham
		Impact of Engineering Solutions			
		Contemporary Issues Addressed			
7	Chapter 7: Conclusions & Recommendations	Conclusions			Abdulla Haitham
		Future Recommendations			
8	Design of Prototype	Casing Design	6	2	Haitham
		Blade Design	6	2	Abdulla
		Shaft Design	6	2	Haitham
9	Parts Purchase	Material for Blades	6	4	Ali, Jehad, Hussain
		Material for Casing			
		Sensors & Measuring Devices			
		Sealants & Fasteners			
10	Manufacturing	Casing Manufacturing	8	5	Haitham, Abdulla
		Blades+ Shaft Manufacturing			
		Assembling			
11	Testing	At different Speeds	13	2	Jehad, Ali, Hussain
		At different fuels			
		Re-testing			

5.2: Contribution of Team Members:

The project tasks were assigned among different group members. This division of tasks was according to the working ability & the time duration for task completion. The table below gives a detailed view about the percentage contribution of every group mate.

5.3 Project Exhibition Monitoring

The project duration involved a lot of activities that targeted to improve the project performance. Essential meetings and events are among these activities. The table given below provides the list of essential meetings & different events of the project.

Time & Date	Important Activities & Events
Once a week	Assessment Class
Weekly	Meeting between group mates
Biweekly	Meet up with Advisor/Co-Advisor
Weekly	Finishing First Prototype
Daily	MidTerm Presentations
Once a week	First Test of the System
Once a week	Finishing Final Prototype
Twice a week	Test the system
Once	Final Submission of the report
Daily	Final Presentation

5.4 Challenges & Decision Making:

In between the project tasks, we went through some really difficult situations that influenced the performance of the project. The main problems & challenges that we went through are listed here as follows:

1. Problems in the Equipment
2. Testing & Safety Issues
3. Design Problems

Equipment Problems:

The equipment we used had some errors by default. Like the temperature sensor was not giving the exact reading of the engine temperature. Also, tachometer apparatus was not working right initially as its ending nobe came out by itself and dis-assembled often. There were also some challenges faced with the manufacturing apparatus. We went to the relevant technicians and got these issues resolved so that we could continue to work on the project efficiently.

Design Problems:

There were two basic parts to be manufactured. The engine casing and the rotor blade. The engine casing was manufactured several times as the fitting was presenting several issues. These issues were then resolved by studying several research papers about the casing design of the jet and then altering the design according to the changes and then carrying on with the fabrication process. The problems with the rotor blade were that the number of blades to be present on the jet motor was not being determined correctly which affected the casing as well. Several time, the engine casing and the rotor were damaged. Finally, there also problems choosing the right materials for the casing and the rotor blade. Thorough research was done to correct these problems and choose the best material for the casing and blades and selecting the optimum number of blades of the rotor of the jet.

5.5 Project Bills of Materials and Budget

The table below the budget of the project and the expenses that were made on every part purchased for the project.

Table 1: Bill of Materials

Materials	Costs (SR)
Tachometer	250
Temperature Sensor	135
Material for the Fabrication	9000
Manufacturing of the Engine Casing and blades	3000
Workshop fees	1600
Miscellaneous	1130
Total	15115

Chapter 6: Project Analysis

6.1: Life Long Learning

Our working on this project has made us gain some really important knowledge regarding the essential & basic skills which are helpful in the technical as well as a professional career. These skills also helped us to attain the completion of the project in time. The basic skills that this project has developed in us are time management, resource management, effective & professional communication, management of a project, etc. in addition to the technical skills. This part throws light on the skills and the proficiencies that we have developed by working on this project.

6.1.1: Software Skills

The project enabled us to learn the basic interface and detailed workings of the software like SolidWorks & Microsoft Office, etc. SolidWorks was used in our project for the designing task of the engine and its parts and the simulations run on the parts and the prepared model of the micro-axial jet engine. This project enabled us to get expertise in designing in SolidWorks. The 2nd software used for the project was Microsoft Office. Microsoft Excel was used for the calculations, gathering the data in tabular forms and plotting the essential graphs of the project. Furthermore, Microsoft Word was used for the documentation of the project activities, noting its time to time progress and for the writing of the final project report. Overall, we can say that we explored these software and learned a lot of new things in the project.

6.1.2: Hardware Skills

The testing & fabrication stages of our project enabled us to learn & explore a number of new hardware devices used for the testing of various engine parameters. We learned the basic use, the calibration and the method of use of the tachometer apparatus. Also, we learned about the infrared temperature sensor, its method of use and its different applications while measuring the temperature of the engine during the project. Besides these, some tools during the manufacturing of the engine were also used and it gave us know how about the essential tools for engine fabrication & testing.

6.1.3: Time Management Skills:

The project has taught us one of the most important skills of all times, that is, time management. The success of our project was also dependent on how fast we complete the project activities. We divided the tasks into members and each member delivered its task in the provided deadline. A useful tool to help us in this process was a Gantt Chart.

6.1.4: Project Management

In this project, the work was distributed between the participants of the group. The work was equally distributed and each member had to complete his individual assignment. We met two times a week and we gathered the tasks that were completed by each member. There were two major teams of our project. One time was taking interest in research and report, and the other team was working on prototype and manufacturing.

6.2: Impact of Engineering Solutions

The impacts of our project were very versatile and it had effects on the environment, economy, and society. Some of these important aspects are discussed in detail in this section

6.2.1: Society

The impact of our project on society is very considerable. Different electronic devices have become an essential part of the life of the human being and our project will help in charging these gadgets during the long trips. The prototype can be readily equipped with any automobile and power can be generated from it. It can be used for the sake of camping.

6.2.2: Economy

Our project will have positive impacts on the economy. It will assist drivers in producing power during the driving, and automobiles will not be required in idle times. It was estimated that the cost of the project will be around 8000 SR but at the completion of the project, it was 15115 SR.

6.2.3: Environmentally

Our project is proved very positive for the environment as it saves the environment from the extra pollution. Our project will prohibit the use of automobiles during idle times. In this way, air pollution and noise will be considerably reduced with the implication of our project.

6.3 Contemporary Issues Addressed

The environment is important for everyone, not only for human beings but for the other living organisms also. The bad environment is becoming a major issue around the globe. Air pollution is increasing and it is leaving bad impressions on the health of human beings. Different organs of the human body are being damaged by air pollution. The number of patients of headache, anxiety, and stress are increasing very rapidly. Other diseases related to the lungs, heart, brain, eyes, nose, and throat are increasing at a very fast rate. Another major consequence that is addressed in this project is the consumption of fuel. Saudi Arab is the biggest consumer of fuel in the area and 70% of the total demand of Gulf Cooperation Council (GCC) for diesel and petrol is from the Saudi Arab. The government of Saudi Arab has increased the prices of fuel to cut down the consumption of fuel.

Chapter 7: Conclusions & Recommendations

7.1 Conclusions:

The objective of the project was achieved successfully. All the parts of the jet engine were produced. Also the assembling process of the engine was carried out. The engine after assembly was also tested at different values of speeds & with various fuels. The rpms of the engine were evaluated with the help of tachometer. The temperature was found out using the infrared thermometer. Also the balancing of the shaft assembly was carried out. Furthermore, the mechanism of throttle was also produced. The fuel used was gaseous butane which produced ease in the making of the throttle mechanism. The flow of butane was controlled by the use of an adjustable valve. For the proper sealing of the engine, high temperature gasket sealer made of silicon was used. Also an engine stand was manufactured to provide support to the operating engine and ensure the safety of the operators.

7.2: Future Recommendations:

Despite all the delays in the schedule that were produced due to the problems faced, the project was completed in time The recommendations made after the fabrication, experimentation, and testing are given below for the assistance of any future working done by research groups.

The use of materials for manufacturing the turbine should be a major consideration and experimental performance & tests should be conducted to check the performance differences between turbines made from different materials & castings (made from PrimeCast101 or Solidscape 3Z patterns).

Also, CFD experimentation should also be conducted into checking the effect of different speeds, different fuels, and different work coefficients of turbine stages on the performance & flow field of the engine.

Overall, all the processes we have went through during the design & fabrication of the engine has given us a good amount of realization of what stages and difficulties are overcame while an professional engine is made. A lot of advancements have been made in the micro axial jet engines through numerous iterations & experimental investigations. The design and fabrication of every component developed in this project is as difficult and time taking as any project itself. Decades of research & latest developments can be spent for the design optimization of a single blade of the turbine of the engine.

Taking into account all these aspects, it is a clear conclusion that the project was a comprehensive research & development and it gave us a good amount of knowledge related to jet engines and axial turbines. The project was in general, a success.

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Appendix A: Monthly progress report

	SDP – WEEKLY MEETING REPORT
	Department of Electrical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Fall 2019**	**ACADEMIC YEAR:**	**2019**
PROJECT TITLE	Micro Axial Jet Engine		
SUPERVISORS	**Dr. Panos**		

Month 2: March

ID Number	Member Name
201401617	Jehad Abdulhadi M Alhumood
201101337	Haitham Mishqab
201601003	Abdulla Al Darwish*
201303977	Ali Al Habbas
201402263	Hussain alkhardawi

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
	Research for fuel testing	Haitham Abdullah	50%	
	Calculation for thrust force	Jehad Hussain Ali	90%	
	Prepare for the midterm presentation	All team	90%	
	Working with workshop on prototype	All team	50%	

List the tasks planned for the month of March and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
	Researching for safety testing	All team
	Prepare the calculation	All team
	Take the prototype to test in work shop	Haitham
	2. Take the prototype to test in work shop	All team

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Properly and efficently makes team work plans and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in team work projects to meet objectives	Fails to participate and function effectively in team work projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in team work projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in team work projects to meet objectives	Function effectively in team work projects to meet objectives
MEEN5C: Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	Communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	Abdulla K. Al Darawish	4	4	4	4
2	Ali S. Al Habbas	4	4	4	4
3	Haitham N. Mishqab	4	4	4	4
4	Hussain Alkhardawi	4	4	4	4
5	Jehad Alhamood	4	4	4	4

Comments on individual members

Name	Comments

	SDP – WEEKLY MEETING REPORT
	Department of Electrical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Fall 2019**	**ACADEMIC YEAR:**	**2019**
PROJECT TITLE	Micro Axial Jet Engine		
SUPERVISORS	**Dr. Panos**		

Month 2: March

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201101337	Haitham Mishqab
201601003	Abdulla Al Darwish*
201303977	Ali Al Habbas
201402263	Hussain alkhardawi

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
	Design the solid works	Haitham Abdullah	90%	
	Testing our equipment	Jehad Hussain Ali	90%	
	Prepare for the final presentation	All team	90%	
	Working on milestone -6	All team	50%	

List the tasks planned for the month of March and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
	Researching for safety testing	All team
	Prepare the calculation	All team
	Take the prototype to test in work shop	Haitham
	2. Take the prototype to test in work shop	All team

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Properly and efficently makes team work plans and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in team work projects to meet objectives	Fails to participate and function effectively in team work projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in team work projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in team work projects to meet objectives	Function effectively in team work projects to meet objectives
MEEN5C: Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	Communicates properly and effectively with team members

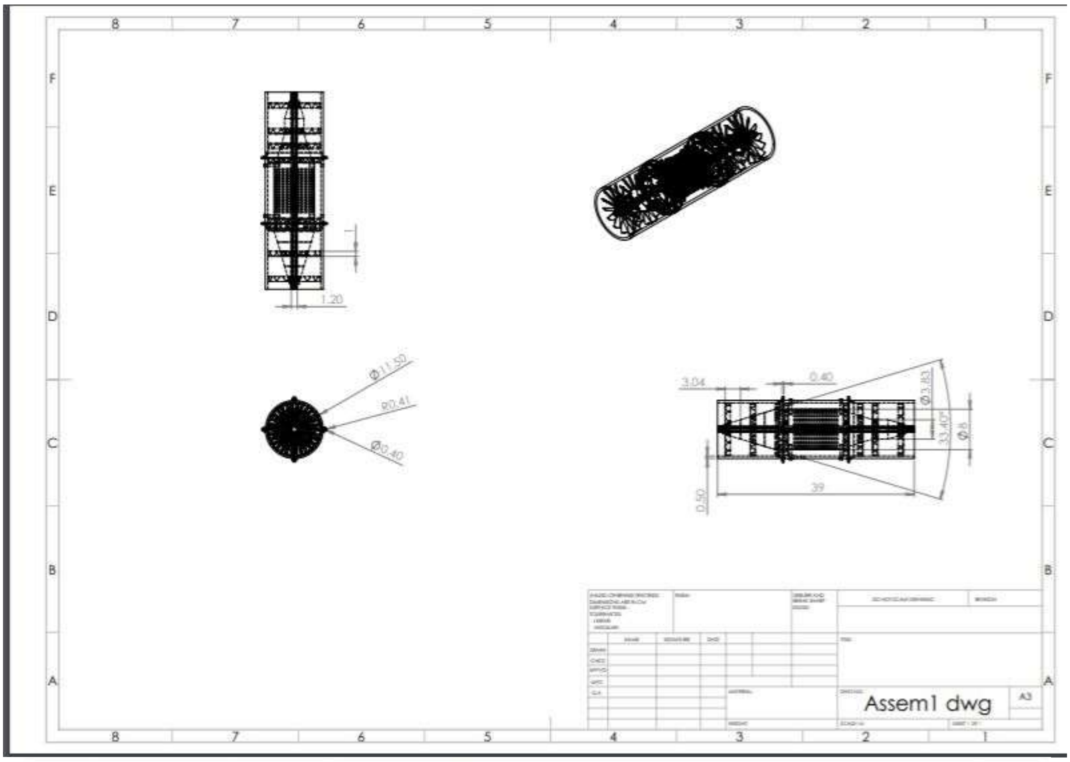
Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

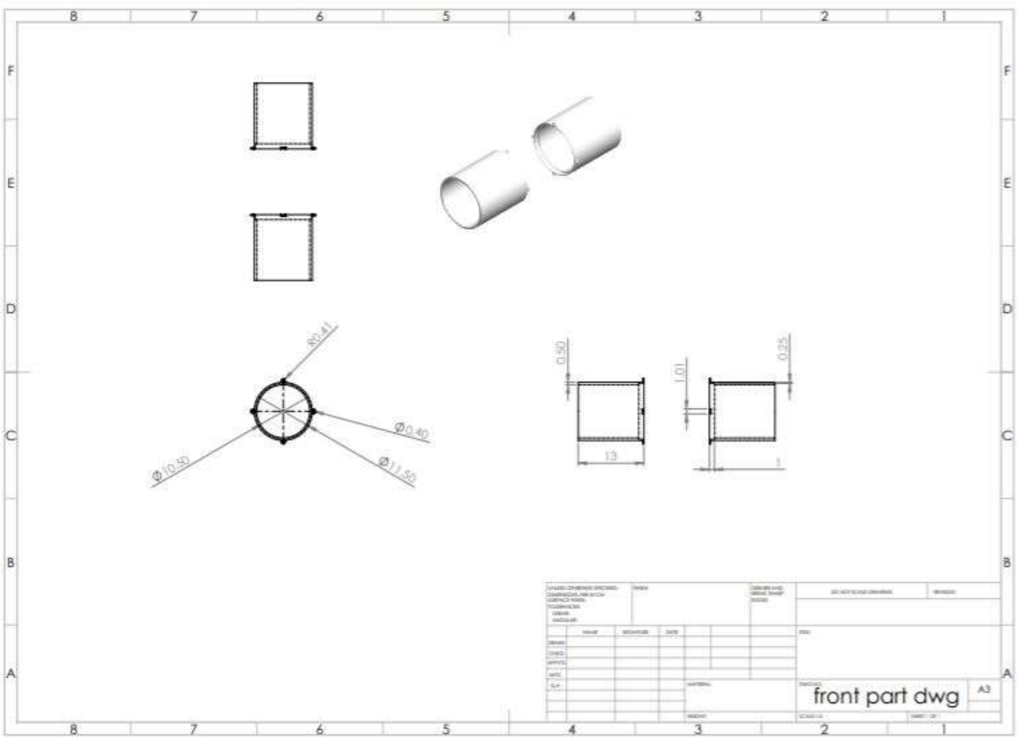
#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	Abdulla K. Al Darawish	4	4	4	4
2	Ali S. Al Habbas	4	4	4	4
3	Haitham N. Mishqab	4	4	4	4
4	Hussain Alkhardawi	4	4	4	4
5	Jehad Alhamood	4	4	4	4

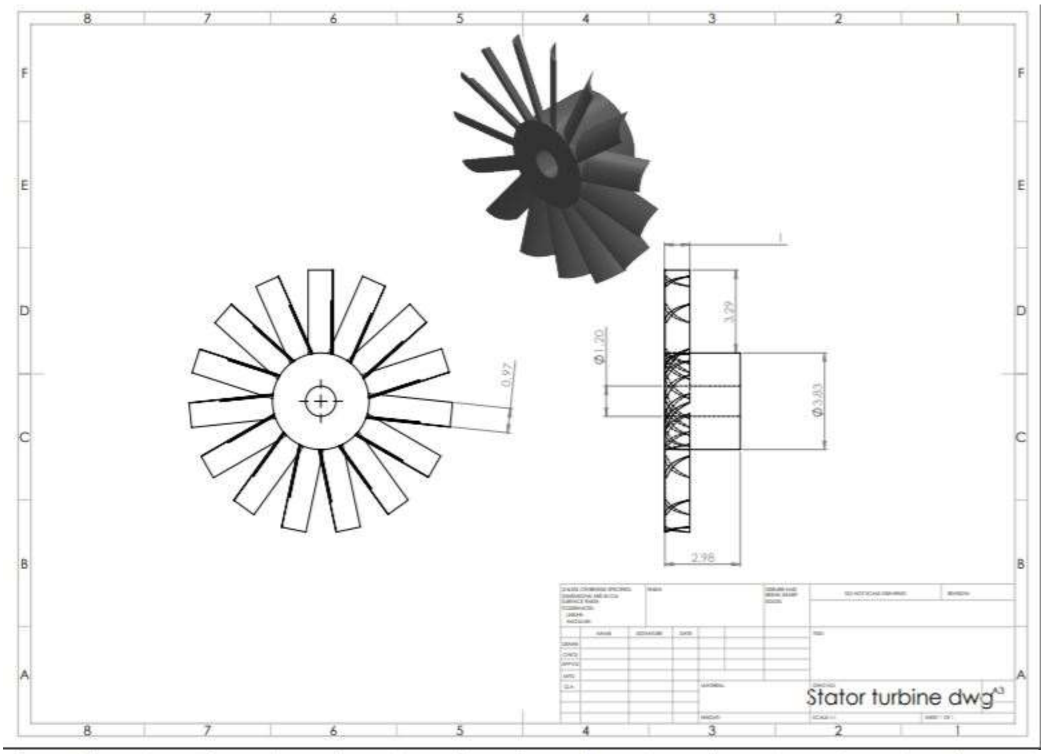
Comments on individual members

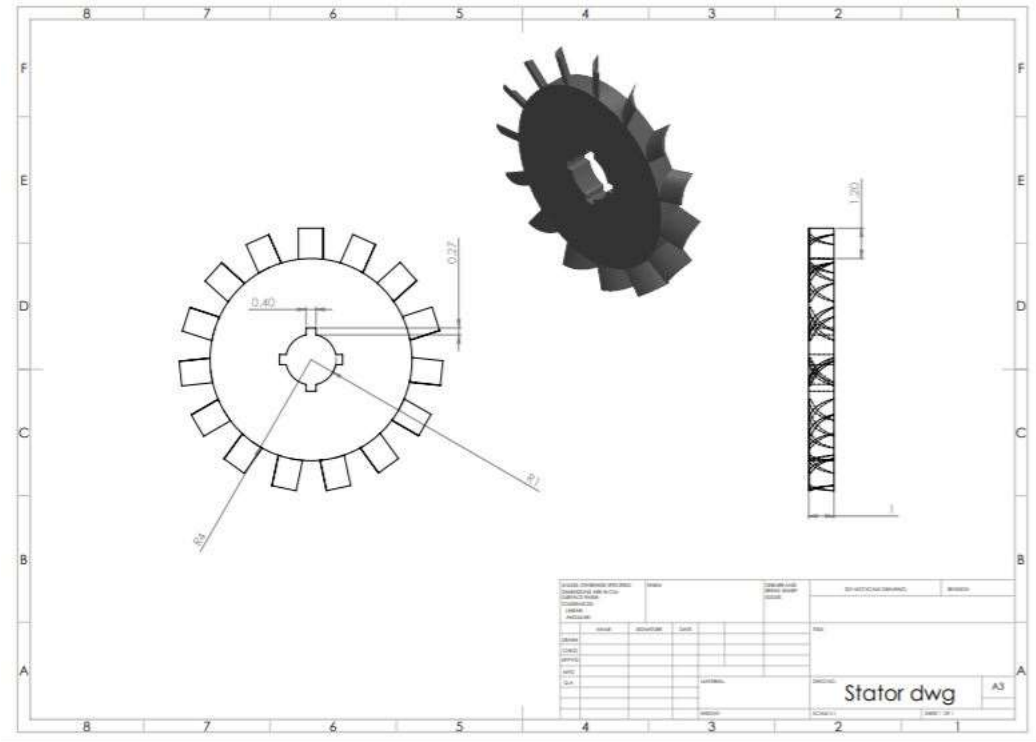
Name	Comments

Appendix B: Solidworks






Stator turbine dwg
A3
0.97
Ø1.20
3.29
Ø3.83
2.98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A3
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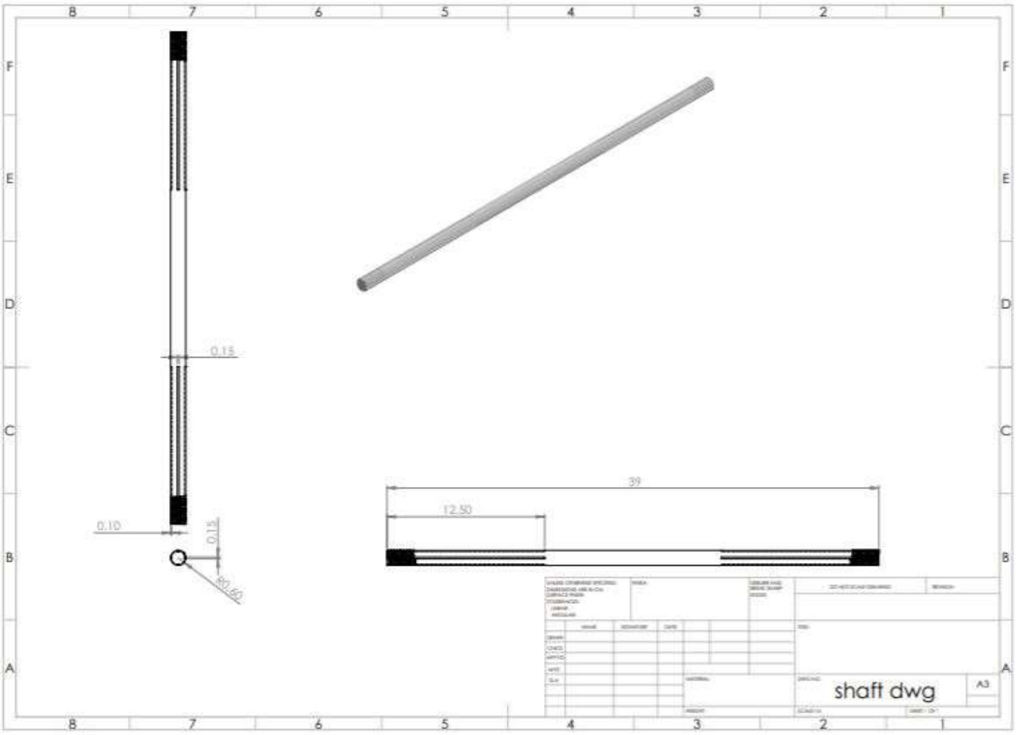
0.27
1.20
R1
R4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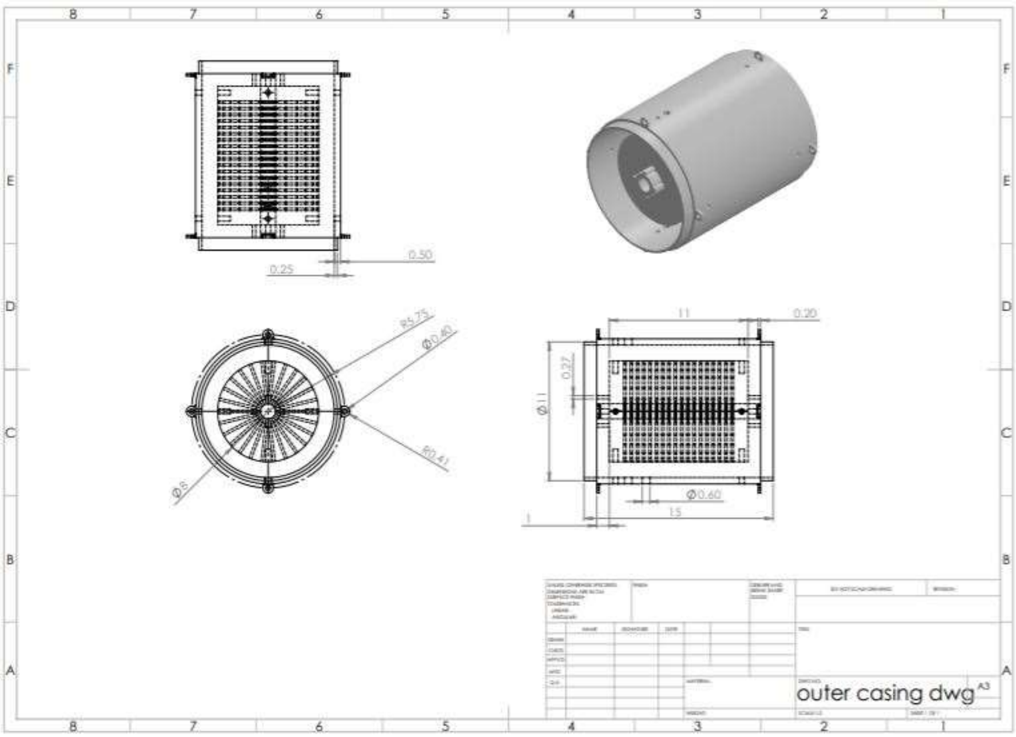
12.50
shaft dwg
A3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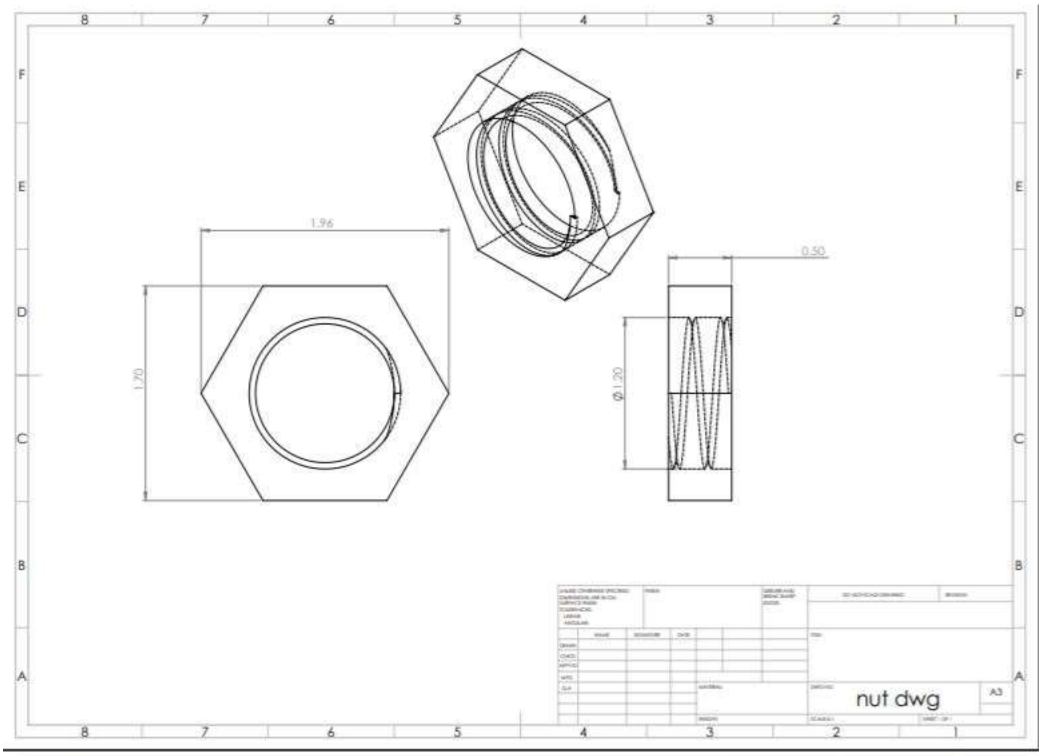
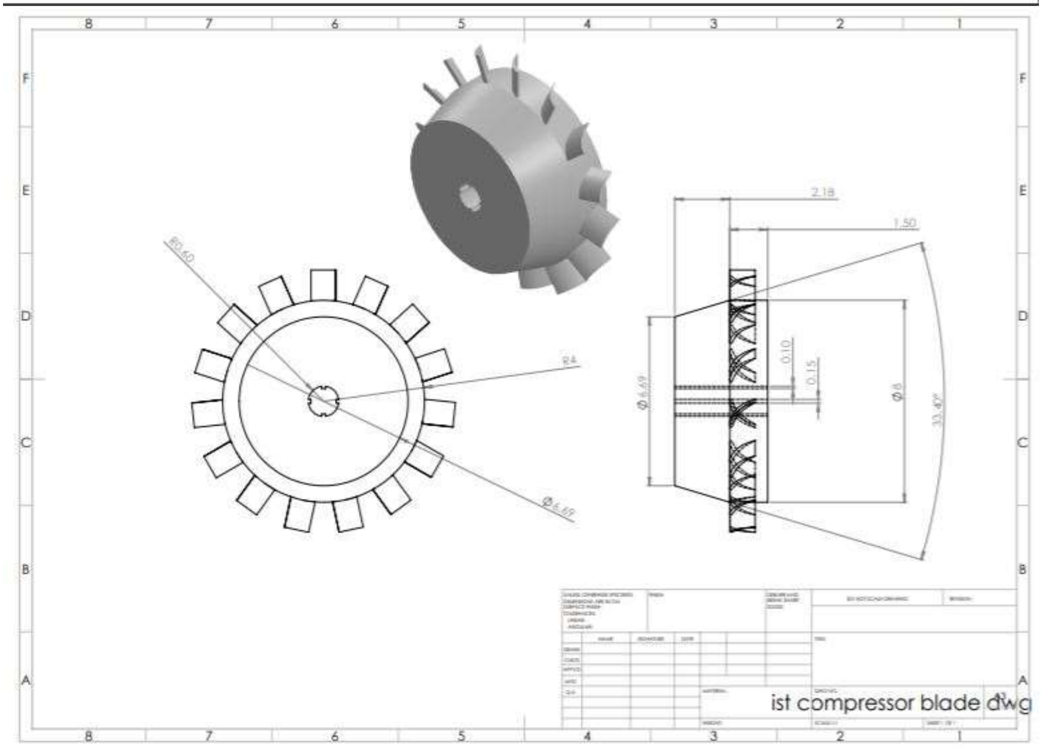
0.25
R5.75
Ø0.40
R0.41
Ø8
11
0.20
0.27
Ø11
Ø0.60
15
1
outer casing dwg
A3


1.96
1.70
0.50
Ø 1.20
nut dwg
A3


R0.60
R4
Ø 6.69
2.18
1.50
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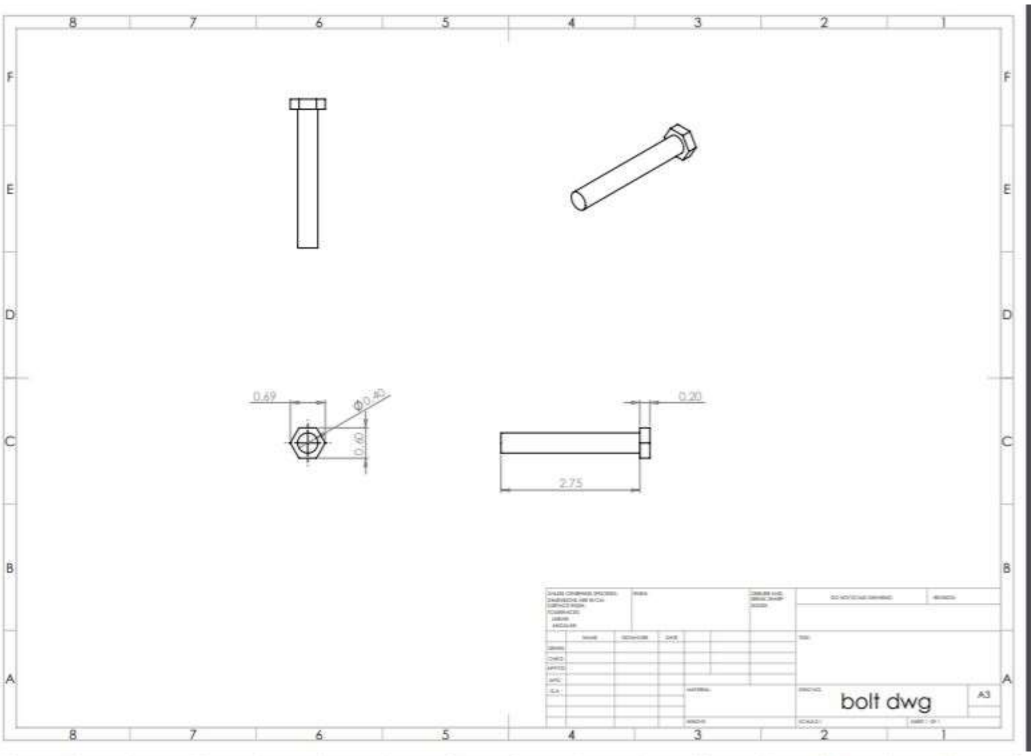
0.15
Ø 4.69
Ø 8
33.40°
ist compressor blade dwg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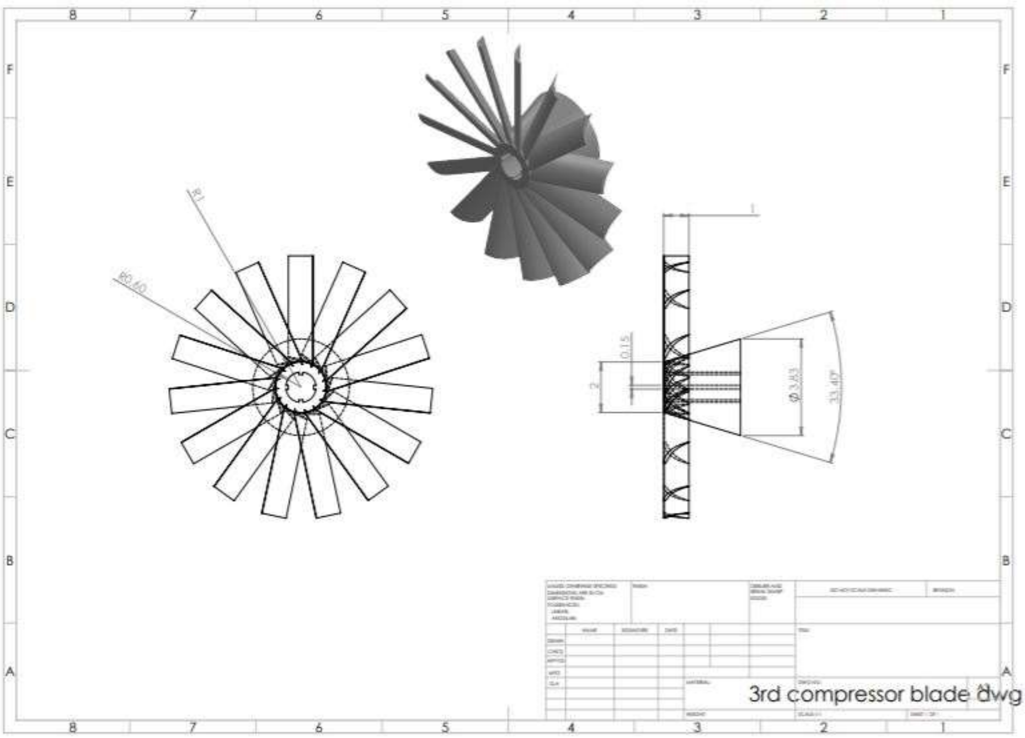
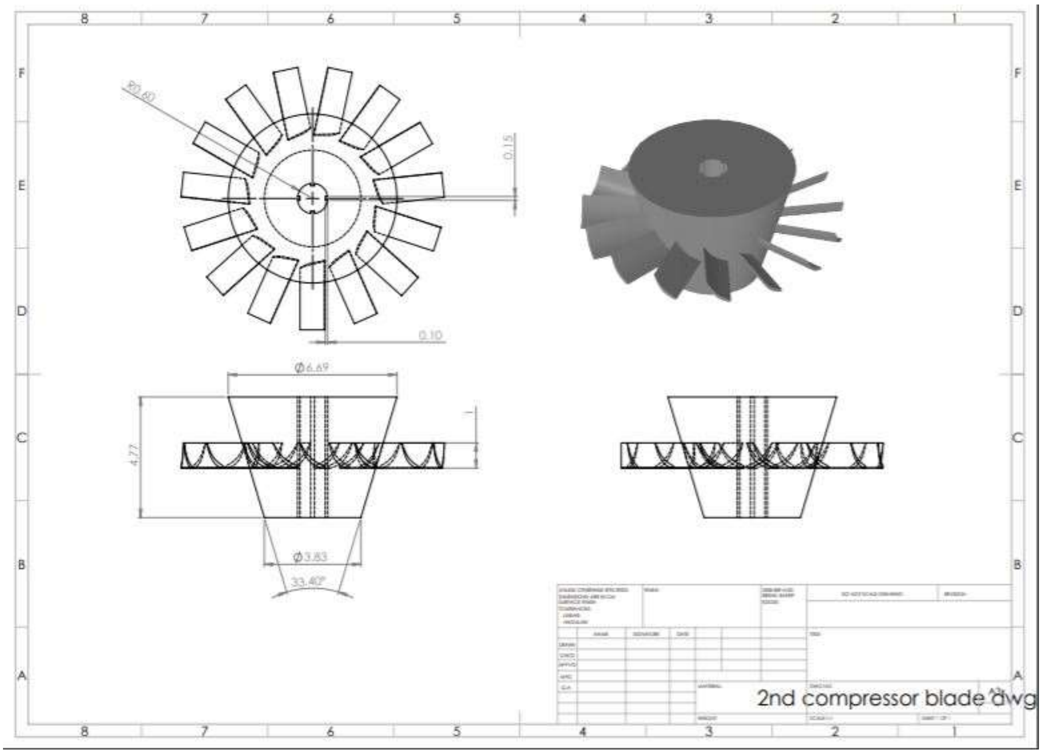
A3


R1
R0.60
1
0.15
2
Ø3.83
33.40°
3rd compressor blade dwg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0.10
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4.77
1
Ø3.83
33.40°
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