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MASTER'S DEGREE IN INDUSTRIAL AUTOMATION ENGINEERING

MASTER THESIS

"ITEG as a Flight PropellerineVTOL smartflight"

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I would also thank my friends and family who supported and motivated me throughout this journey.

Abstract

The aviation industry is growing rapidly in a smart and efficient way. Helicopters are used to travel short distances these days and with less space for vertical take-off and landing. The eVTOL smart flight or a smart vehicle is a mixture of drone and helicopter concepts where it has smart advanced features with a compact design. The flight can carry up to 4 people approximately 350-400kgs of weight. It runs on electrical energy, so it has zero emissions. Mainly used to travel a short distance in a quick time.

The propellers are the key for any eVTOLs. Generally, blade-type and ducted blade-type propellers were used in the flights. Here in this thesis development, we focused on propellers and their design to be more efficient than the remaining ones. And focused on the aerodynamics of the flight and flight safety.

The idea of the new propeller has been derived from the ITEG concept. It is an electrically driven motor where the air flows through it by covering the entire area of the rotor. So, replacing the normal propeller with an ITEG propeller to get more efficiency and contribute to the stability of the flight. Designing the propeller is more important to reach the aerodynamic requirements to fly smoothly. Improving the eVTOL smart flight by implementing various smart technology in all aspects is the work we achieved till now.

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"We all want to spend less time travelling and more time living".

-Joby

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4.2 Sensors

Acronyms

UAM- Urban Air Mobility
IT – Information Technology
R&D-Research and Development
DEP- Distributed Electric Propulsion
eVTOL- electric Vertical Take-Off and Landing
PAV- Personal Air Vehicle
RGB -Reduction Gear Box
AAM- Advanced Air Mobility
NASA-National Aeronautics and Space Administration
ICEV- Internal Combustion Engine Vehicle
HEV- Hybrid Electric Vehicle
EV- Electric Vehicle
IMU- Inertial measurement unit
D&P-Distributed&Pervasive
GUPC -General Utilities Performance Contract

Chapter 1

Introduction

1.1Industry overview

History has demonstrated that human society has become increasingly reliant on the technology that has been created with each passing century. The world may be on the verge of a new era of airpower, the era of electrified/hybrid aircraft propulsion, according to a strategic scan of the aerospace environment at the start of the twenty-first century. Unquestionably, advancements in propulsion technology have distinguished the various eras of human flight, from the Wright Brothers' 1903 piston engine flight to the 1960s jet engine and today's space age. A new vision for the future of technology was developed as a result of the technological advancements brought about at the start of the twenty-first century by the revolution in data exchange, computational power, sensors, wireless communication, internet, and autonomy.

Urban Air Mobility (UAM) has lately had a resurgence, thanks to developments in drone technology and the need for alternate transportation options in urban areas. Although while on-demand helicopter services have a long history, urban air has only recently been a hot topic of conversation. urban regions' expanding inhabitants and traffic.

Some of the incentives for IT businesses to make incremental investments in R&D for urban air transport vehicles and their ecosystem include traffic congestion on the ground and the absence of alternate transportation options. There have been numerous pilot programs in various locations throughout the world, and the concept's implementation, particularly in passenger transit, is still up for debate.

There is currently a lot of interest in the concept of Urban Air Mobility (UAM). As a potential remedy for capacity

UAM is a promising future market since it offers compelling mobility alternatives to ground transportation in metropolitan locations where there are bottlenecks. To make the idea a reality, potential players from many businesses start a range of adaptable actions.

Designing and creating a suitable airplane is one of these operations that is crucial.

A wide variety of innovative, appealing vehicle design alternatives are now available thanks to distributed electric propulsion (DEP), which is almost scale-free. On the one hand, DEP makes vertical take-off and landing (VTOL) aircraft's effort and complexity more manageable. On the other hand, new dependability and safety criteria are anticipated as a result. Moreover, significant reductions in operating expenses and airplane noise emissions are anticipated.

The technical options must meet UAM's various and modern criteria. Tight emission, noise, and safety requirements may change how the traditional airplane design factors are prioritized.

As a result, for instance, the aviation sector must cope with mass production circumstances comparable to those faced by automakers. Although substantial UAM research and whitepapers have been published, detailed boundary conditions for a target-oriented vehicle design have not yet been established. Even conventional needs for aircraft, like as range, cruise speed, or seat capacity, are still uncertain. There are many fundamentally different aircraft ideas known as electric vertical take-off and landing vehicle (eVTOL), air taxi, or personal aviation, however there are no specific performance criteria.

The past several years saw the introduction of Personal air vehicles (PAV). The range of aircraft designs were depicted in clusters using a two-step classification system based on lift production during cruise and the mechanism to turn on VTOL. The objective is to create clusters of aircraft with comparable performance information and attributes.

For further development and specification of possible UAM scenarios, it is crucial to understand fundamental characteristics like performance potential, design constraints, or technology sensitivities of the vehicle morphologies for the further development and specification of potential UAM scenarios. These factors also serve as the foundation for a system wide UAM evaluation of the vehicle's performance. Understanding how specific aircraft attributes, such as hover efficiency, cruise efficiency, cruise speed, range, maintenance effort and vehicle complexity, physical dimensions, or charging times, affect a potential urban aerial transport system is crucial.

Figure 1Complete industry overview picture of the UAM

1.2 eVTOL smart flight

The World eVTOL (Electric Vertical Take-off and Landing) Aircraft Directory was established in 2016 at a time when there were only six eVTOL designs that were known. More than 450 companies are currently working on prototypes in a fierce startup competition, including Kitty Hawk (US), Lilium (Germany), Joby Aviation (US), E-Hang (China), and Volocopter (Germany), as well as major corporations like Airbus (with a special A3 by Airbus branch located in Silicon Valley), Boeing (US), Bell (US), Embraer (Brazil) and Uber (US).

With the development of aircraft technology for UAM, eVTOL aircraft with previously science fiction-only shapes have been prototyped and will be flown in the upcoming years. Due to the large operating envelopes of these configurations' corresponding aircraft, new flight control schemes, such as adaptive control or fault-tolerant control, are required. The freedom to create novel configurations results directly from the accessibility of dependable electric motors. Fast, closed-loop electronic feedback controllers and sensors are used to manage these motors. The motors are extremely responsive and can be quickly instructed to change speed by those electronic control systems. Indeed, through distributed electric propulsion, electric motors provide thrust for alternative modes of aircraftmanoeuvrability.

Today the electric battery for the storage and availability of electrical energy is more widespread and operative, but it will soon be superseded by the use of hydrogen, which ITEG looks at more carefully, also from a D&P - Distributed&Pervasive perspective (in terms of energy volumes and reduce procurement times in designated stations). The use of hydrogen as fuel is expensive in present days. The pure green hydrogen is expensive to prepare but safer to environment.Hydrogen is a clean fuel that, when consumed in a fuel cell, produces only water.

ITEG lends itself well to optimised solutions proposed in the GUPC (General Utilities Performance Contract) which introduces it into urban realities (both in condominiums and other Real Estate structures), to convey products (preferably strategic, such as sanitary ware) and people, arranging dedicated platforms, on flat roofs or specific inter-floors.Since ITEG is a safe propeller which can be used in any domestic landing site.

The envisioned UAM concept poses several technological difficulties with regard to flight control systems, including the use of novel command and control modules on new systems with varying degrees of automation and autonomy in novel displays and inceptors. For this reason, these new controllers must be properly created and programmed for eVTOL aircraft to fly steadily and precisely.

Common characteristics:

– 1 to 6 person payload

– Shorter hover duration than typical rotorcraft

– Often considerably shorter ranges than conventional aircraft

Other characteristic according to the propellers and its type-

Multirotor, (multi) tiltwing, (multi) tiltrotor, fan-in-wing, separate lift + cruise, compound helicopter, tiltduct, blown flap/tiltduct, advanced rotorcraft, etc.

Some of the present eVTOL designs are attached below.

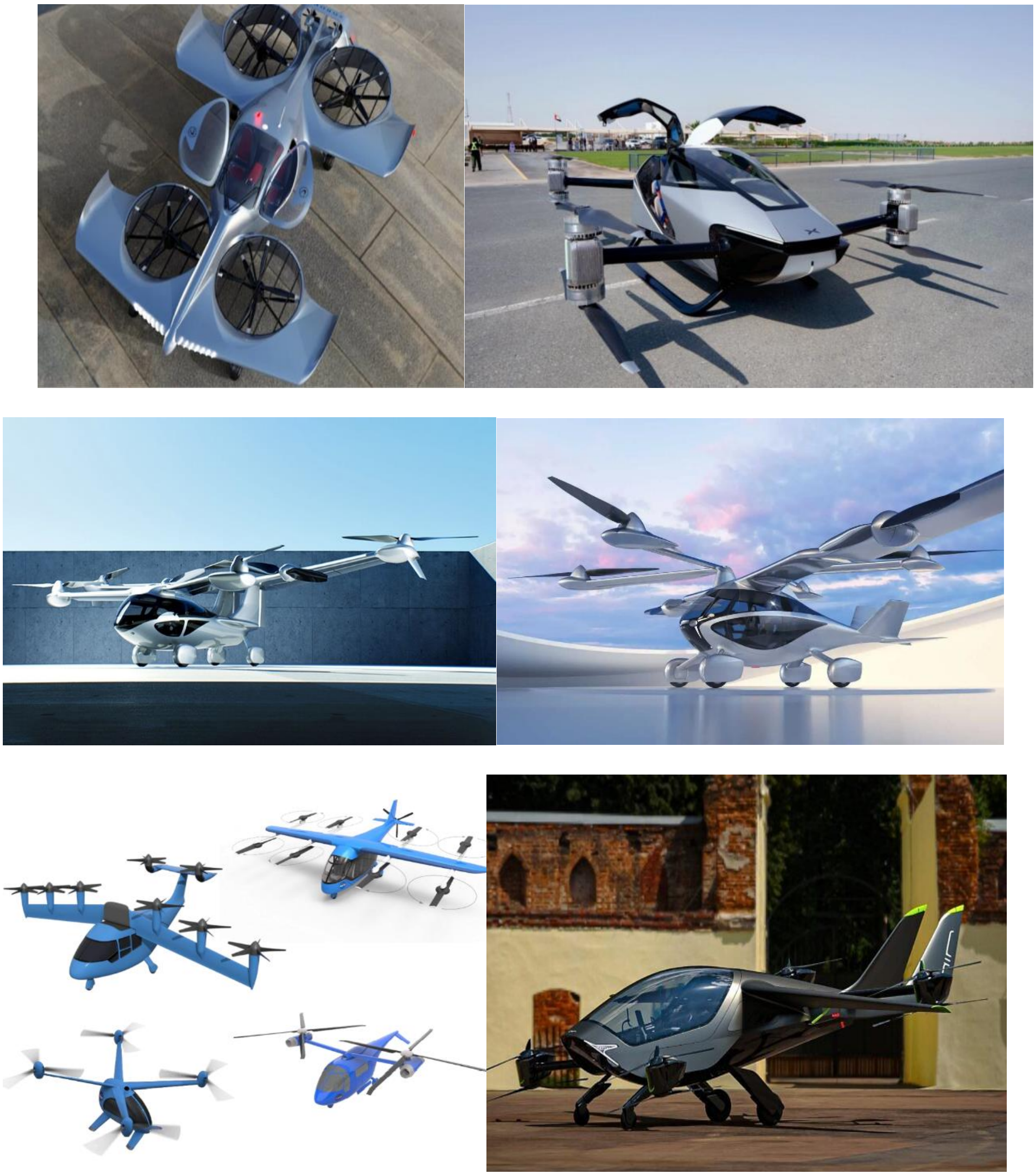


Figure 2 Different types of eVTOL aircrafts.

1.3 Propeller and types

A propeller is an aerodynamic device that uses rotational energy to generate thrust that is roughly perpendicular to the plane of rotation. Propellers serve to generate lift, allowing drones to gain altitude and hover in place. They also provide the propulsion that lets drones move around simply by leaning towards one side. Depending on the application, an electric motor or a gas turbine engine may be used to generate the rotational energy. As is the case with many light aircraft, a propeller can be directly connected to the crankshaft of a piston engine, or it can be driven by a reduction gear box (RGB) that is connected to a piston or jet engine. In this instance, the RGB reduces the high engine rotation speed to one that is more suitable for propeller operation.Propellers are available with fixed pitch or variable pitch configurations, and they have two or more blades that are evenly spaced around the hub. The constant speed, contra-rotating, and counter-rotating types of propellers are among the more complex designs.

How it works- Propellers are connected to motors on an individual basis in multicopter drones. An Electronic Speed Controller (ESC) is then used to manage the speed at which each of these motors rotates. Drones can move in a variety of ways with the help of the ESC by altering the speed at which individual motors rotate.

Propeller rotation forces the air downward by cutting through it. This propeller motion, when the drone is perfectly horizontal, produces lift by pushing against the wind. The size and shape of the propeller affects both the lifting force produced and the energy required to cut through the air. The state of the atmosphere, especially the air density, is also very important.

Types of propellers

Six main propeller types are: -

1.Fixed Pitch

2.Ground Adjustable Propeller

3. Controllable Pitch Propellers

4.Constant Speed Propellers

5.Feathering Propellers

6. Reverse Pitch Propellers

These are the propellers involved in above 6 types-

-Based on material- 1. Metal propeller
2. Carbon fibre propeller
3. Plastic propeller

-Based on length- 1. Long propeller
2. Short propeller

-Based on Blades 1. Two blade propellers
2. Three Blade propellers
3. Four blade propellers

-Based on design andapplication1. Blade type Propellers
2. Ducted Propellers

Given that some options might offer a combination of both, you might not need to go all-in on features that maximize power or efficiency. Your Aircraft intended use should be your top priority when selecting a propeller.

Figure 3 standared blade type propellers

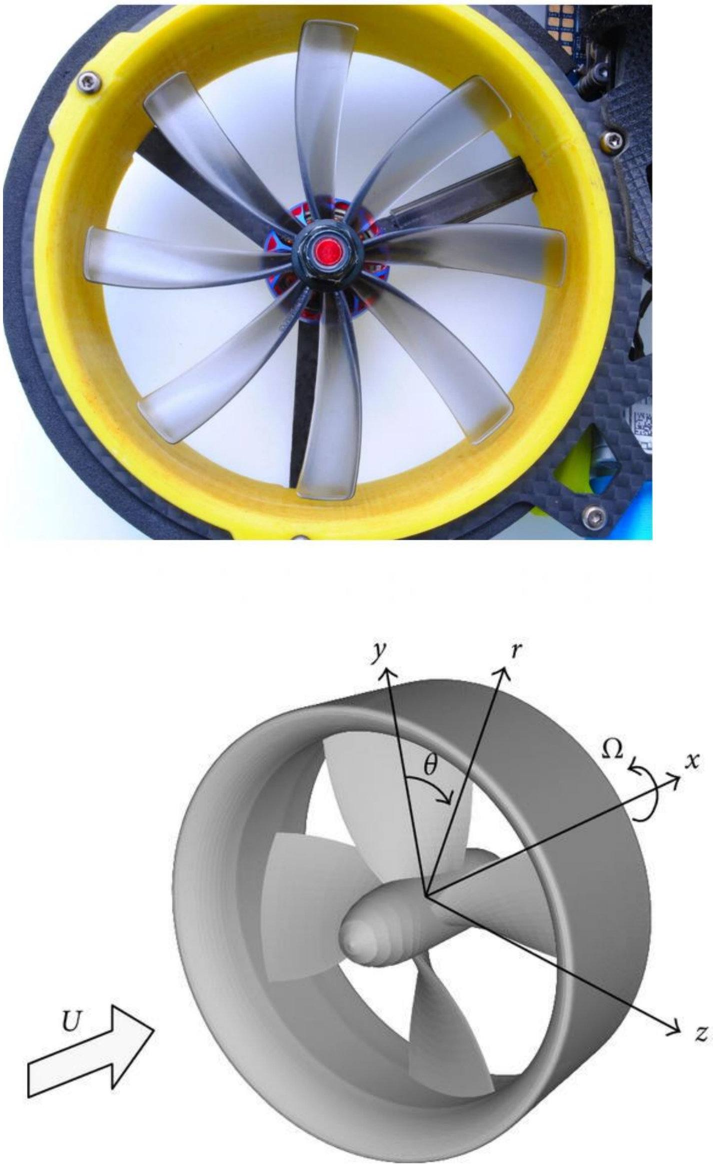


Figure 4 Ducted propellers

This ducted fan propelleris the type of propeller we are focusing on in this thesis.

1.4Thesis outline

-The work aims to design and conclude that the efficiency and stability of the eVTOL flight is better with ITEG ducted propeller.

-The flight design is such that it fulfils the flight aerodynamic requirements to fly faster and smoother.

-The safety of the passengers is the main priority in any vehicle design. For the safety concern necessary precautions were taken such as parachutes, airbags, autopilot, seatbelts etc…

-The propeller design and implementationare the key element in this thesis.

-ITEG emulates well D&P in the eVTOL smartflight which gives greaterfor high manoeuvrability for roll, pitch, yawmotion.

- The tail of the aircraft has also been developed for D&P propulsion for horizontal thrust.

- The basics of electric motor and the control system.

- ITEG propeller is an electrically driven motor which has a floating rotor which allowing the air to flow through it by making it rotate linearly.

- There are 4 vertical lifting propellers and 3 Tail propellers which contributes mostly to get horizontal thrust and also contributes tovertical thrust.

- Estimating the values of the Power, Flow, Speed, Efficiency and Volume of the ducted rotor of the ITEG propeller.

- Urban Air Mobility vehicles complete study and discussion.

-Applications of eVTOLs in different sectors and its capabilities to improve the travel industry.

Chapter 2

Literature review

2.1Advanced Air Mobility (AAM)

Bringing Aviation into Daily Life

This literature is about the overall outline and detail about the AAM industry Here we can see there are three primary catagoery,

1Urban Air Mobility

2 Small Unmanned Aircraft Systems

3 Regional Air Mobility

1.Urban Air Mobility is the system which comes under urban areas up to 70-80 km around the metropolitan cities. There will be largely installed vertiport for aircraft landing and take-off. eVTOL, potentially eSTOL or eCTOL aircraft and in these aircrafts there will be maximum of 5-6 passengers can travel.

2.Small Unmanned Aircraft Systems this system is Local aerial work or small package delivery missions (e.g., food, small packages). From none to specialized takeoff/landing infrastructure is needed. VTOL-capable aircraft are most common.

3. Regional Air Mobility this system is quite bigger and it is like a small cargo plane type and around 15-20 people can travel and also operates upto 500kms. It takes small airport facility to operate the aircrafts.

--Typically, electrification & automation enable AAM. It has a potential uses in passenger transport, cargoCargo/package delivery Emergency services/public good (e.g., air ambulance, EMT transport, etc.), Aerial work (e.g., infrastructure inspection, photography, tourism, etc.

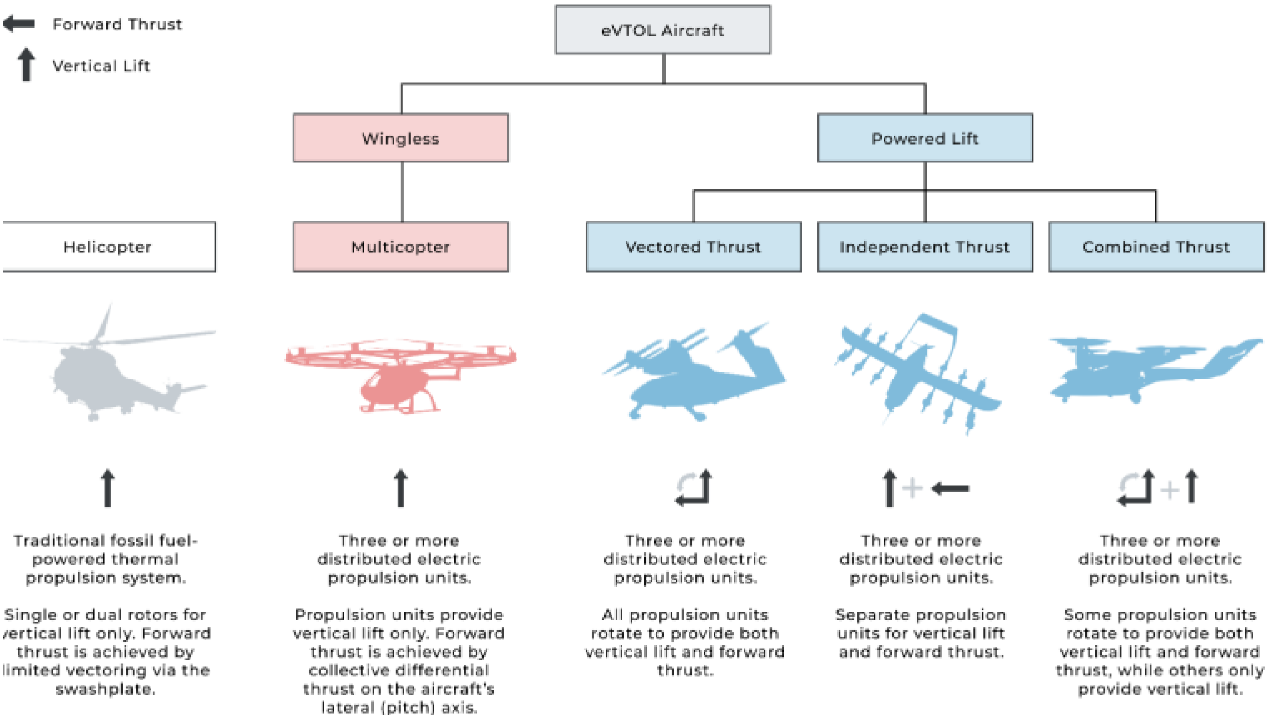
Since it has a connictivity to the airports this literature is also focusing on vertipads at airports so tyravelling to airports will be smoother and fast. So installing vertipads at airports for eVTOls will be operated as airport mobility taxi.

This idea has many potential locations such asany potential locations Greenfield sites, Rooftops, Parking garages, Barges, New overpasses / cloverleafs, Etcthe location should be considered to be Multi-modal connectivity, Noise, Utilities (electric grid), Proximity of other vertiports/pads, Equity, Etc

2.2 Trends in eVTOL Aircraft Development

There will be more than 500 electric vertical take-off and landing (eVTOL) aircraft concepts unveiled by the second quarter of 2022. Because this industry is still young, less than 30% of the concepts have taken off. A technical research database has been created to classify the concepts according to their propulsion architecture and to compare them for performance and safety metrics based on published data and independent analyses in order to keep track of these advancements and the changing urban air mobility landscape. This study looked at 120 eVTOL aircraft concepts that were revealed between 2014 and 2020. The findings are presented in this paper. It examines the development of these aircraft through technological advancement and reviews the current global eVTOL landscape.According to data on the development of eVTOL aircraft around the world, 68% of concepts are being developed by new eVTOL companies. More than 70% of the concepts under development come from the United States, Europe, and China. After a sharp increase in the quantity of concepts revealed between 2016 and 2018, it appears that the volume of new eVTOL aircraft announcements has peaked. This study aims to educate readers about eVTOL development trends and dominant ideas that might be taken into account in trade studies.

The burden on the lives of the residents continues to grow as a result of rapid population growth in urban areas. Air pollution and traffic congestion are the two areas where these effects are most obvious. There is growing agreement among business executives, academics, and governments about the need for clean and sustainable transportation options for the cities of the future as the effects of climate change become more obvious. Urban air mobility has been suggested as a solution to this problem (UAM). The National Aeronautics and Space Administration (NASA) describes UAM as a concept that enables uninhabited and person-carrying aircraft systems to operate safely and effectively in urban areas [10]. UAM solutions are intended to be provided by a sizeable portion of eVTOL aircraft.



Traditional fossil fuel-powered thermal propulsion system.

Single or dual rotors for ertical lift only. Forward thrust is achieved by limited vectoring via the swashplate.

Three or more distributed electric propulsion units.

Propulsion units provide vertical lift only. Forward thrust is achieved by collective differential thrust on the aircraft's lateral (pitch) axis.

Three or more distributed electric propulsion units.

All propulsion units rotate to provide both vertical lift and forward thrust.

Three or more distributed electric propulsion units.

Separate propulsion units for vertical lift and forward thrust.

Three or more distributed electric propulsion units.

Some propulsion units rotate to provide both vertical lift and forward thrust, while others only provide vertical lift.

Figure 5 Propulsion architectures of eVTOL aircraft

For the purpose of tracking advancements in eVTOL aircraft design and UAM, a technical research database has been created [38]. The appendix section includes a list of the aircraft parameters. Additionally, the database contained evaluations and classifications of 120 eVTOL aircraft concepts. The websites of the concept developers, press releases, and articles from the Vertical Flight Society's Electric VTOL News website were used to gather information on the evolution of the ideas [1]. In order to shed light on the global development of eVTOL aircraft, a variety of data and metrics are presented in this section.

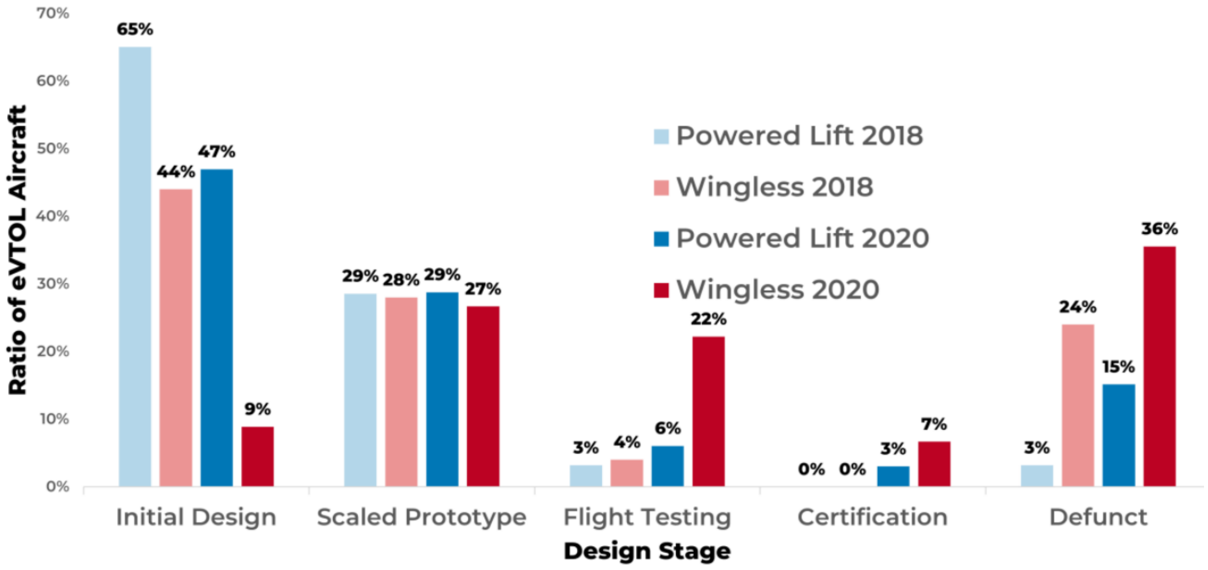


Figure 6Overview of design maturities of eVTOL aircraft concepts between 2018 and 2020

However, additional research on the subject is still being done. The research database is continuously updated as new vehicles are unveiled, prototypes fly for the first time, and more manufacturer data is made available, along with the findings of scholarly studies. This study aims to educate readers about eVTOL development trends and dominant ideas that might be taken into account in trade studies. Although it is still unclear which concepts will endure, those that do will probably require the use of cutting-edge systems and solutions to address the difficulties associated with actually operating eVTOL aircraft within the confines of the pre-established urban air mobility concept of operations.

2.3 ITEG Theory

This is the main aspect of content we should focus on in this literature review. This theory helps us to understand and apply this technology into several useful applications. This is a electric pump and generater concept where mostly used in fluids. The same technology has been developed by rolls royce but they designed it for the marine industry where they developed as ship thrusters. The potential of ITEG, the transfer of energy, with high yields, takes place on circumferences, thus increasing application volumes and consequent greater overall powers. Usually in all propellers the maximum workdone or thrust produced by the circumference. The center part is also a achimedian screw gives less yields.

This machine has been designed by my proffesors Prof. Stefano Farne and Dr. Vito Lavanga. This is an Integrated turbine electric generator(ITEG). ITEG enables the integration of a fluid dynamic machine and an electric motor into a single device, making it flexible and allowing a wide range of uses as both a pump, giving prominence to a fluid, and as a turbine, generating electricity.

ITEG can be more practical than traditional machines, both for producing hydroelectric energy and for pumping purposes, because of how simple it is to install and how little maintenance it requires because it is gearless. The present paper presents the literature review that was looked at in terms of scholarly articles and patents, illustrates the mathematical model that allows ITEG sizing, and simulates the operation of the machine by highlighting various design elements.

The engine which Rolls Royce has develpoed was Rim Driven thrusters is similar to ITEG concepts where they have used mechganical bearings for the rotor stator allingnmet or support the ITEG has overcome these innovations by these two aspects by resorting to magnetic bearings and tensile structure in the rotor, which thanks to suitable materials can face multiple criticalities, by weight specific and resistance to the elements, perhaps corrosive in given contexts.

Here for this thesis we need to concertrate more on electric pump section and its working procedure. When used as a pump, the stator windings are fed with the proper electromotive force, generating an electromagnetic field that interacts with the rotor's permanent magnets to turn it. A very significant portion of the ITEG is covered by the rotor's useful surface, which makes use of the majority of the fluid's surface area when the rotor is being used as a pump to move fluid in a specific direction or to generate electricity. This feature makes ITEG incredibly efficient and functional.

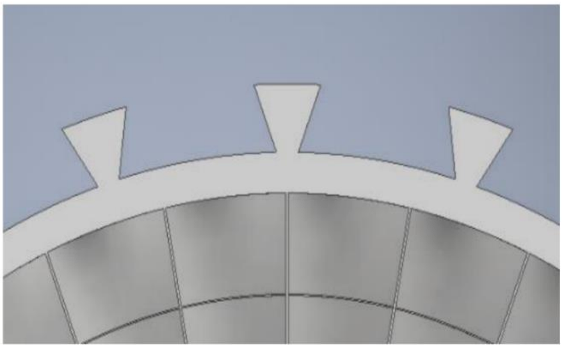


Figure 7 Dovetails to accommodate permanent magnets

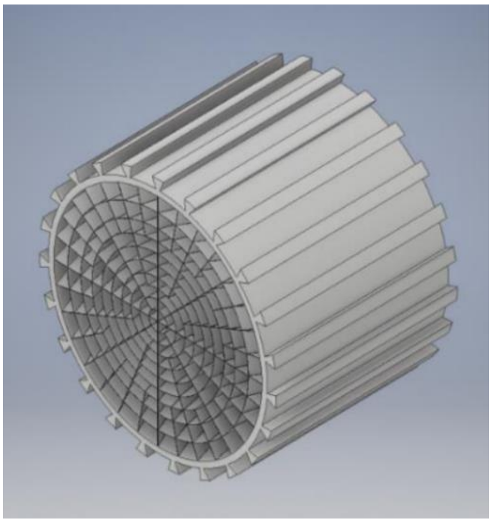


Figure 8Standard view of rotor

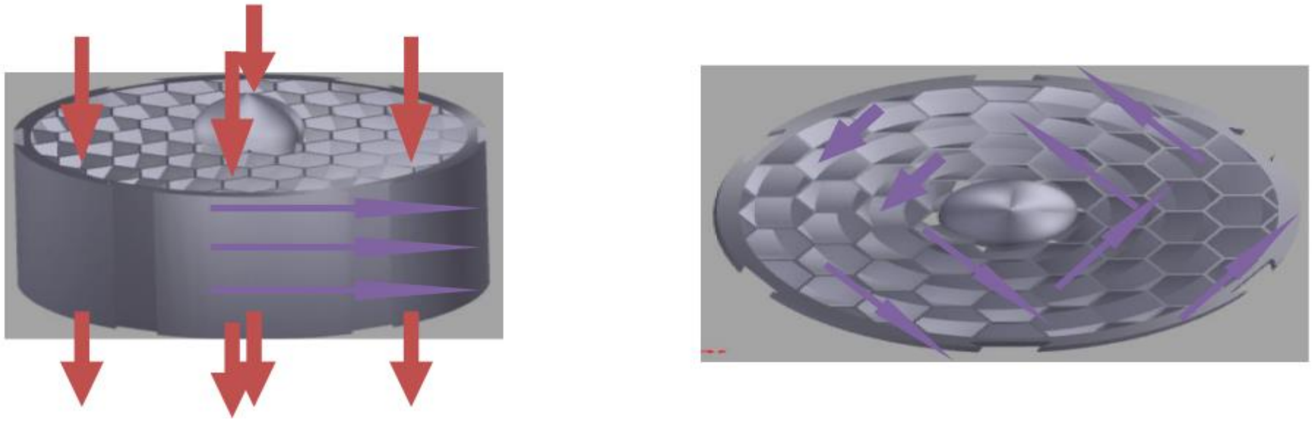


Figure 9 ITEG flowed by the fluid (vertical vectors) and Forces represented on the plane

It can be used as both a pump and a turbine, making the innovative fluid machine dual-purpose. A crucial part of ITEG is played by the cylindrical element known as the rotor. It represents the moving part of the machine whose job it is to catch the fluid that splashes against its own useful surface. The fluid receives energy from the rotor when it is configured as a "pump" or is transformed into mechanical (rotational) energy when it is configured as a "turbine" by the rotor. While significantly fewer in number than in systems where the generator is not integrated with the turbine, the bearings used to maintain the axis of the turbines and generators in all of the examples discussed in the literature review are still essential. especially if they come into contact with substances that cause them to prematurely deteriorate. There are already a variety of pipe-integrated turbine systems available for a wide range of applications, but they all have significant differences from ITEG. It actually has the helpful peculiarity of being entirely devoid of mechanical bearings. Magnetic bearings ensure the rotor is in the proper position and are friction-free for efficiency. A rotor that can "self-float" in a fluid under certain circumstances is also conceivable. As a result, the ITEG efficiency is constant and always equal to very high values, which confirms that the machine will continue to operate at a high efficiency even in the presence of flow variations that may occur over the course of the year along a river or watercourse. Finally, ITEG is distinguished by a high structural resistance (given by the implicit tension-structure and therefore less bending/deformation with respect to bending/twisting in the blades), perfect symmetricality (given by the reversible axial action), reduced turbulence (thanks to the high resolution of the helical grooves), and lack of axial mechanical supports (bearings or thrust bearings), which make it unique.

2.4 Selection of Electric Motor Drives for ElectricVehicles

This study discusses six different types of electric motor drives for EV drivetrain systems. The demands of EVs on electric motor drives are also discussed. In order to identify the most suitable electric motor drives for electric vehicle applications, a comparative analysis of the efficiency, weight, cost, cooling, maximum speed, fault-tolerance, safety, and reliability of switched reluctance motor, induction motor, permanent magnet blushless dc motor, and brushed dc motor drives is conducted. According to the study, switched reluctance motor drives are the best option for electric vehicle applications.

The term "internal combustion engine vehicle" (ICE) is also used to refer to conventional vehicles because they are powered by ICEs (ICEVs). If a vehicle uses one or more electric motors to power its wheels, the car is referred to as an electric vehicle (EV). Additionally, if a car's wheels are propelled by both an electric motor and an internal combustion engine (ICE), the car is known as a hybrid electric car (HEV). In this paper, only electric vehicles are discussed.

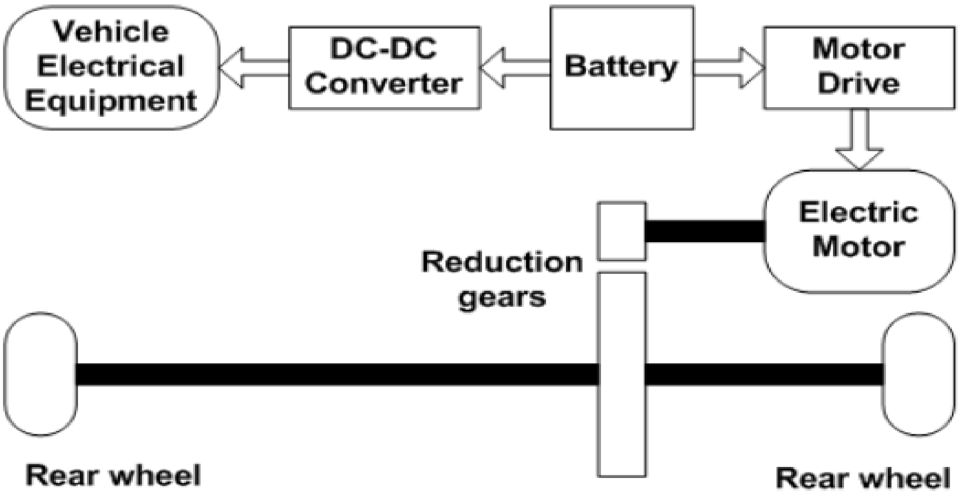


Figure 10 Typical system schematic of Evs

We are aware that there are several different kinds of electric motors used in industrial settings. They power a variety of industrial equipment. All electric motors may be used to move EVs when they are being driven. However, when electric motors are applied to EVs, certain performance indices of EVs, such as efficiency, weight, cost, and dynamic characteristics of EVs, must be taken into consideration. The subject of this study is this one

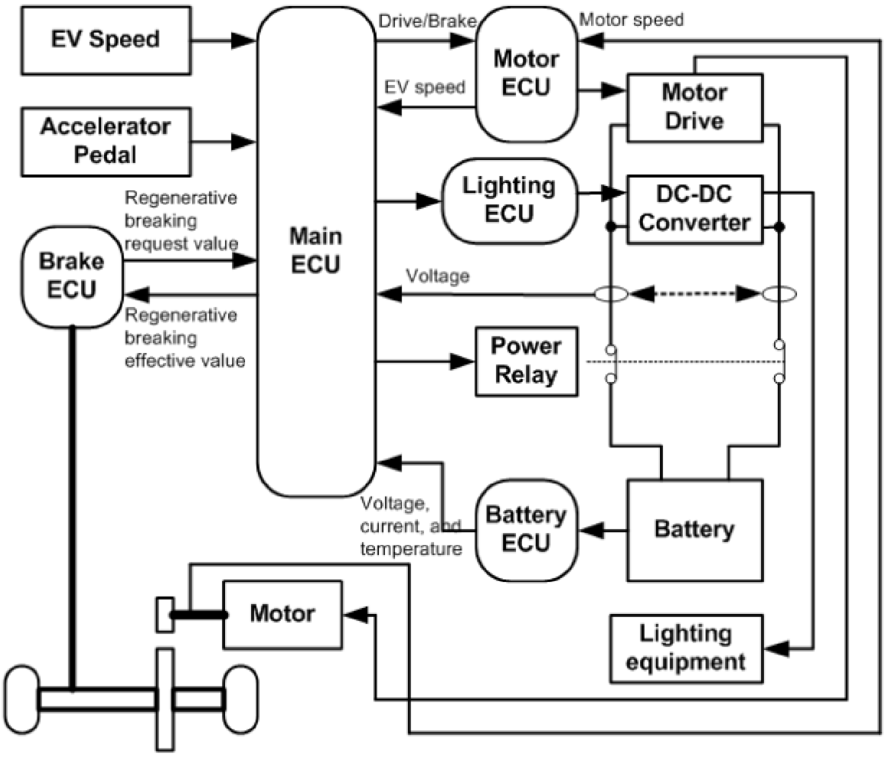


Figure 11 Typical control schematic of EVs

This study has discussed six different types of electric motor drives for EV drivetrain systems. For electric motor drives in EVs that have a wide speed range and a high maximum speed, drivetrain designs with a single-level reduction gear work well. In addition, this paper presents the primary demands made by EVs of electric motor drives as well as the expected output properties of those drives.

SRM, IM, PM BLDC, and brushed DC motor drives have undergone comparative analysis in terms of effectiveness, weight, cost, cooling, maximum speed, fault-tolerance, safety, and reliability.To be more precise, PM BLDC motor drives outperform SRM drives, IM drives, and brushed DC motor drives in terms of efficiency; SRM drives are lighter than PM BLDC motor, IM, and brushed DC motor drives; Brushed DC motor drives cost the least of these four types of motor drives; and SRM drives are superior to other three types of motor drives when the aforementioned three factors are taken into account. Additionally, SRM drives are superior in terms of cooling, top speed, fault tolerance, safety, and reliability.

SRM drives are thus perfectly suited for modern EV applications.

Chapter 3

eVTOL smart flight and Propeller Design

3.1eVTOL smart flight-

The idea that we chose, as well as to develop the idea that will be required in the future. We concentrated on the transportation industry because it is so important to everyone. We need to look ahead and provide whatever assistance we can to this industry in order to improve it because eVTOLs have already been developed and are being used in some countries. We came up with the idea of a new, very efficient set of propellers because I took an automation course. eVTOLs with those propellers installed. This chapter includes an eVTOL smart flight design that is also good from an aerodynamic standpoint.

This aircraft has room for up to 4 passengers and their luggage. This concept-designed eVTOL smart flight is about 7 meters long, or slightly longer than a sedan car, and 3.7 meters tall when the landing gear is installed. For the safety of the passengers, this aircraft has a safety parachute, airbags, and seat belts. It has all the necessary sensors that a cutting-edge air mobility vehicle has, so it never lags behind in terms of sensors. A front face with a sharp muzzle and a curved body can move through the air quickly and with little resistance. Because glass covers the majority of the surface, the view is excellent from inside and offers a panoramic view.

The chassis and support structure are made of metal, while the thick carbon fiber used for the outer body is made of. The goal is to lighten the aircraft as much as possible to reduce the power needed by the motor to lift it. Engine efficiency increases as engine power requirements decrease.

The ground operation centre can automatically control the cruise on this eVTOL, but there is also the option to fly manually under certain circumstances.

Solidworks is the tool, design software use to design the eVTOL.

eVTOL smart flight design-

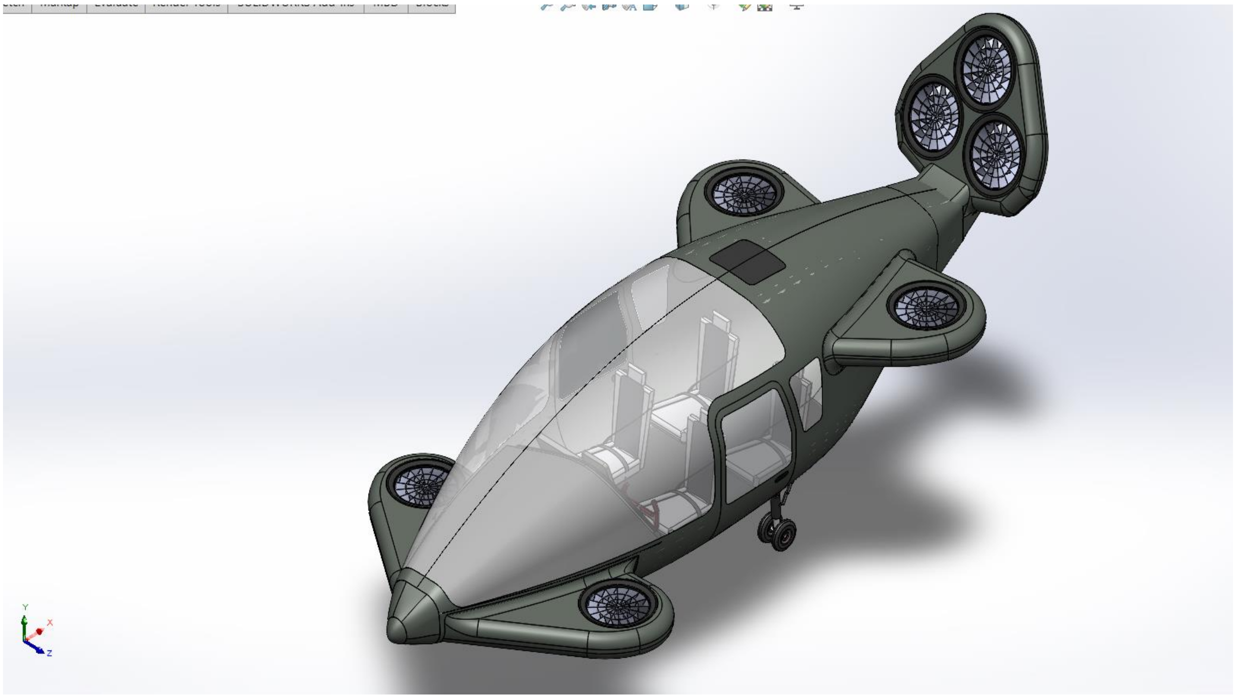
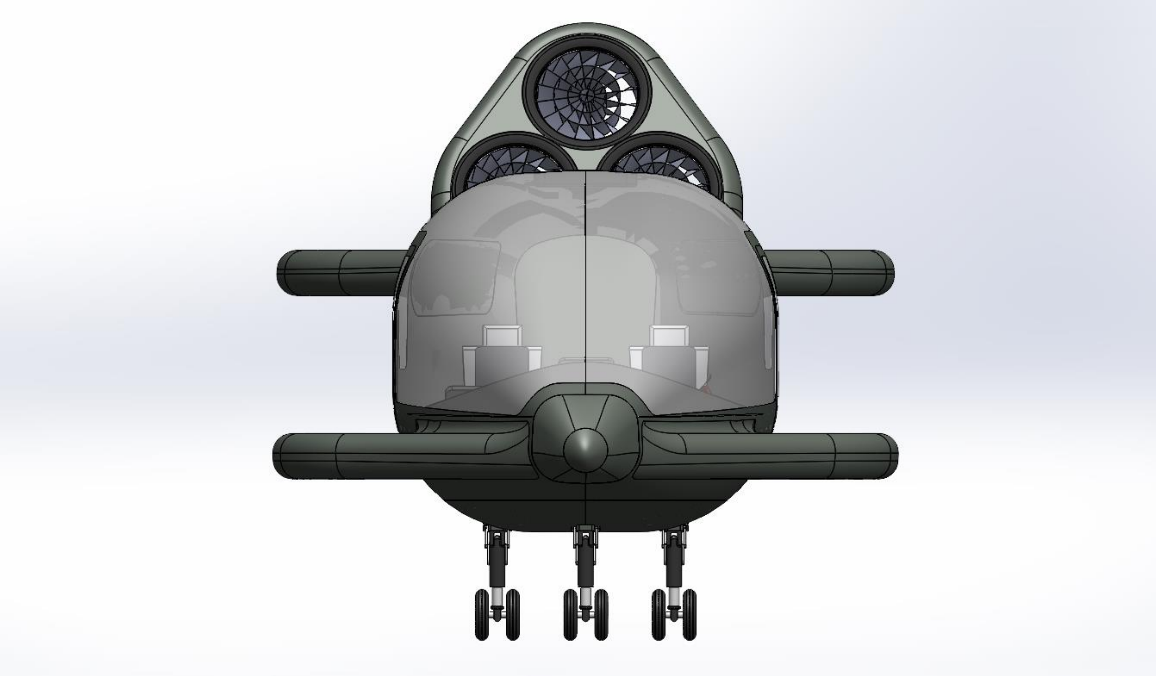
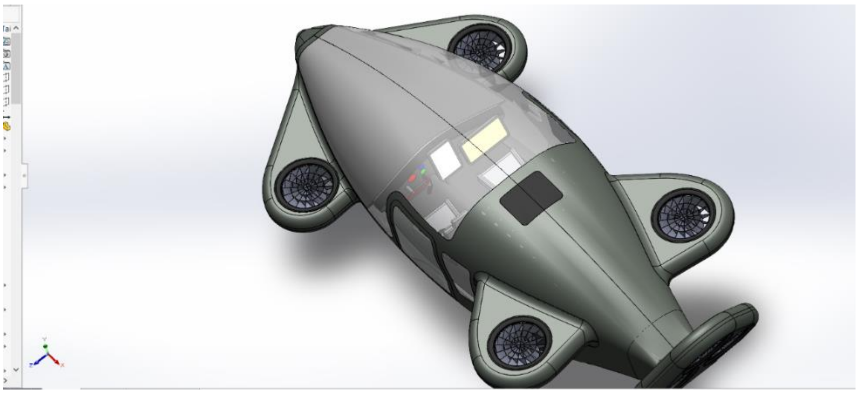


Figure 12Perspective view of the eVTOL smart flight

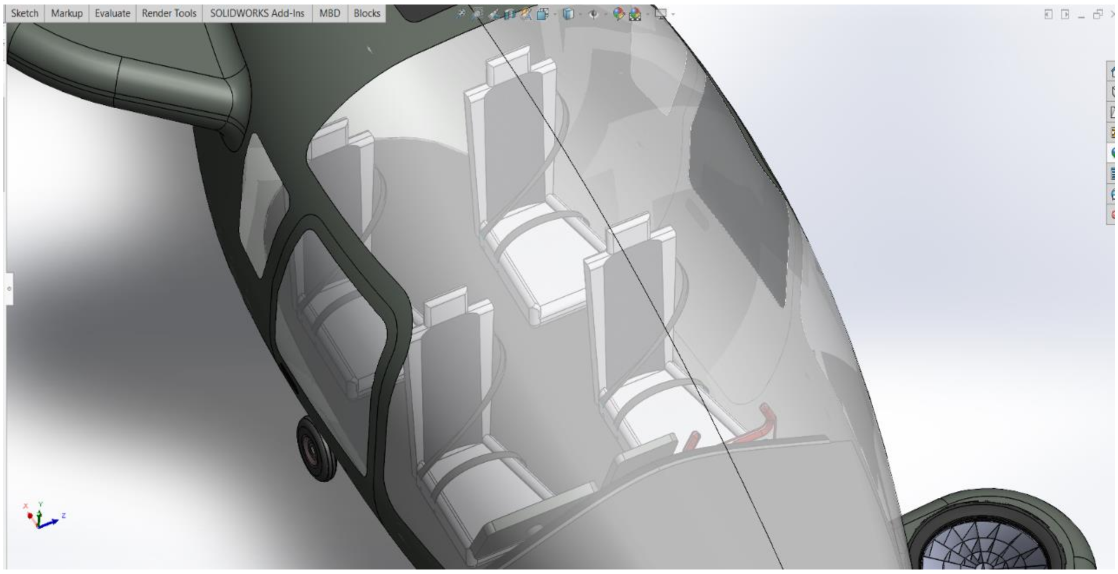


Front view

Side view



Top view



Inside view

3D Rendered picture of the flight.

Figure 13 Rendered 3D image of the eVTOL aircraft

3.1.1 Tail Design

Tail is an important part when it comes to aircraft. This concept is derived by Hoverboard/Arca aboard concept. It helps in stability and generates forward thrust to move in horizontal direction. Here in this eVTOL smart flight we have a tail which contains 3 propellers of same size and all propellers generates same amount of thrust. This tail will helps aircraft to move in horizontal forward thrust and also contributes to forward thrust since it is placed in some angle at the back of the aircraft.Propellers are held in triangular shape in the tail frame.

Figure 14Tail of eVTOL

3.1.2 Landing gear

Landing gear is the necessary part of any flights weather it is small drones or the big Boeing 747 flight landing gear is must. Here we designed the eVTOL smart flight to land both on the ground and in water for water jets. The landing gear is with wheel is used in ground take-off and landing aircraft andlanding gear with a slide structure is for water landing and used in water application eVTOLs.

Figure 15Landing gear wheel for ground landing

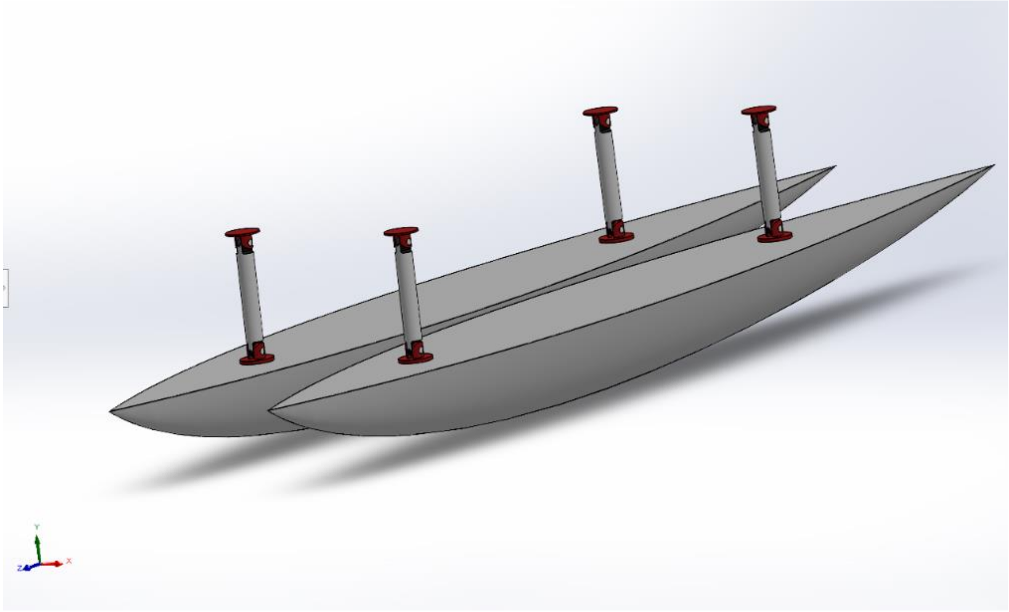


Figure 16Landing gear slide for water landing

The landing gear is considered depending on the type and retraction system.

$WLG = 0.054 \times lst\ 0.501 \times (W \times nz)\ 0.684$

where lst is the strut length in feet, W is the MTOW in pounds and nz is the landing gear load factor. This equation applies to light airplanes with performances up to 300 knots.
Landing gear frontal area is only taken into account in circumstances when the landing gear is fixed and is believed to be constant.Landing gear drag coefficient $CDLG$ is assumed 0.04 for skids and 0.85 for wheeled landing gear.

3.2 ITEG Propeller

As we discussed earlier in the literature review ITEG is a type of electric motor which runs both as motor and generator but here we are only concentrating only on motor perspective. Here I have designed the ITEG propeller which has rotor and stator. Rotor is rotating part and stator is a fixed part. Stator is connected to the body of the aircraft and stator has electromagnets and two permanent magnet bearing to hold the rotor inside the stator set. Rotor has permanent magnets which interacts with the EMF generated by the stator electromagnet and rotate accordingly. There will be 2mm airgap flux between the stator and rotor.

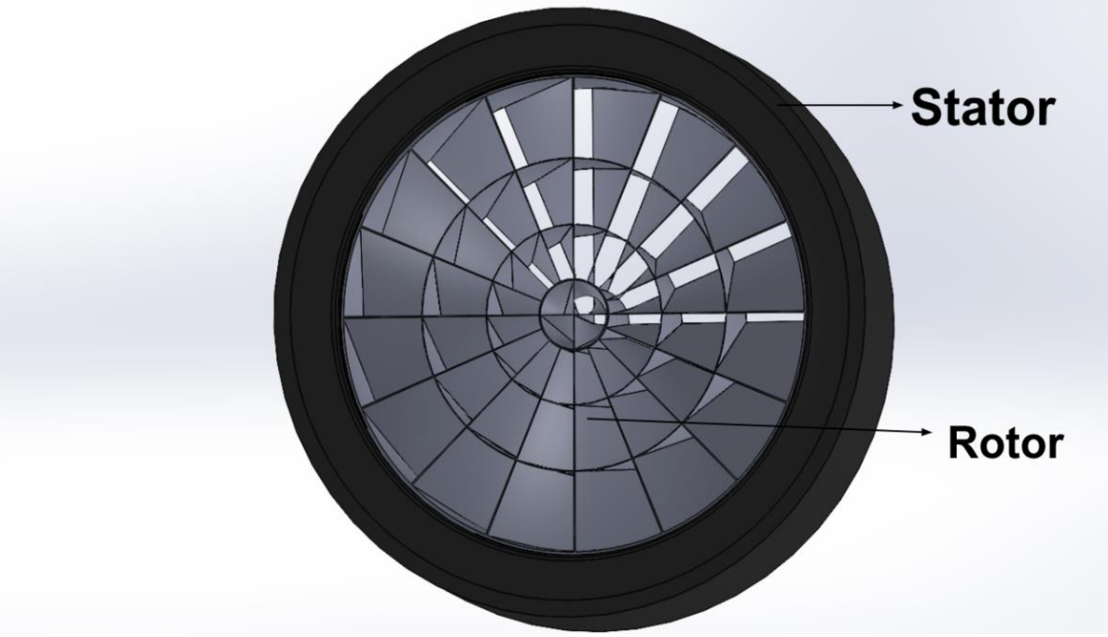


Figure 17ITEG propeller

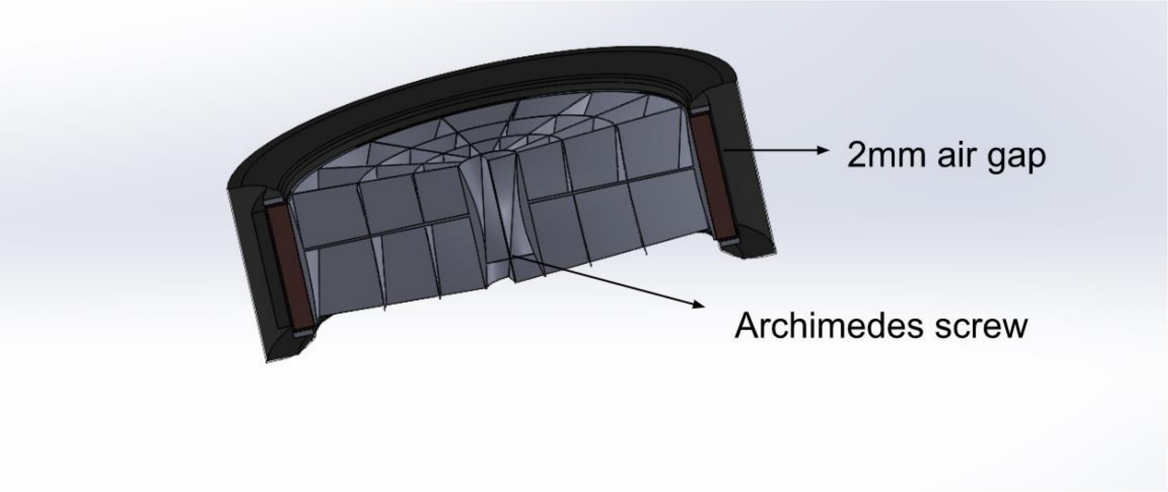


Figure 18 ITEG propeller cross section

3D Rendered picture of the propeller.

Figure 19 Rendered image of the ITEG propeller

3.2.1 Stator

Stator is stationary part and here in this application it has a main role where it will be fixed to the aircraft body and it will be having 12 electromagnets inside it and along with two circular bearing permanent magnets placed at the inside ring of the stator case to hold the rotor in its position and not letting the rotor to escape out of the stator cylinder.

Dimensions

Outer radius =50.5cm

Inner top radius = 40.5cm

Inner cylinder radius =44.2cm

Height = 35.5cm

Thickness of the surface of stator is 0.2cm

Figure 20 Stator

3.2.2 Rotor

This study's central component, the rotor, is where all the ideas are derived from and applied. We used the rotor, which rotates, as a propeller blade or fan in this instance. Through it, air will pass. To produce more thrust than a standard blade-type propeller, we have developed a ducted type of rectangular shape ducts with a surface thickness of 1mm. To make the centre of the rotor more effective than empty space or other objects, we built an Archimedes screw-shaped structure there.This rotor will float inside the stator frame or cylinder, held in place by a stator magnetic bearing. Additionally, the outer surface of the rotor has a cavity for permanent magnets. On the rotor's circular surface, four permanent magnets will be positioned with equal spacing between them. This permanent magnet interacts with rotating electromotive force, or EMF, and the rotor rotates as a result of the electromagnets being pushed by the stator. When operating under moderate conditions, carbon fibre is used as the material; however, for heavy thrust, it is preferable to use metals so that the thin wall can withstand the high air pressure.

Dimensions

Radiustotal = 44cmUseful radius= 39.5cm

Height = 25cmDucted square length= 4cm

Wall thickness= 1mm

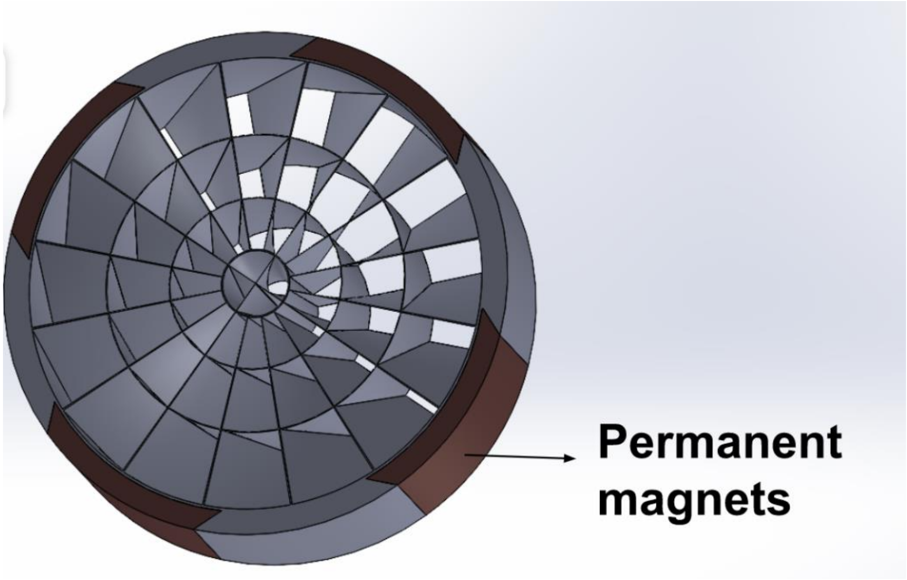


Figure 21 Rotor

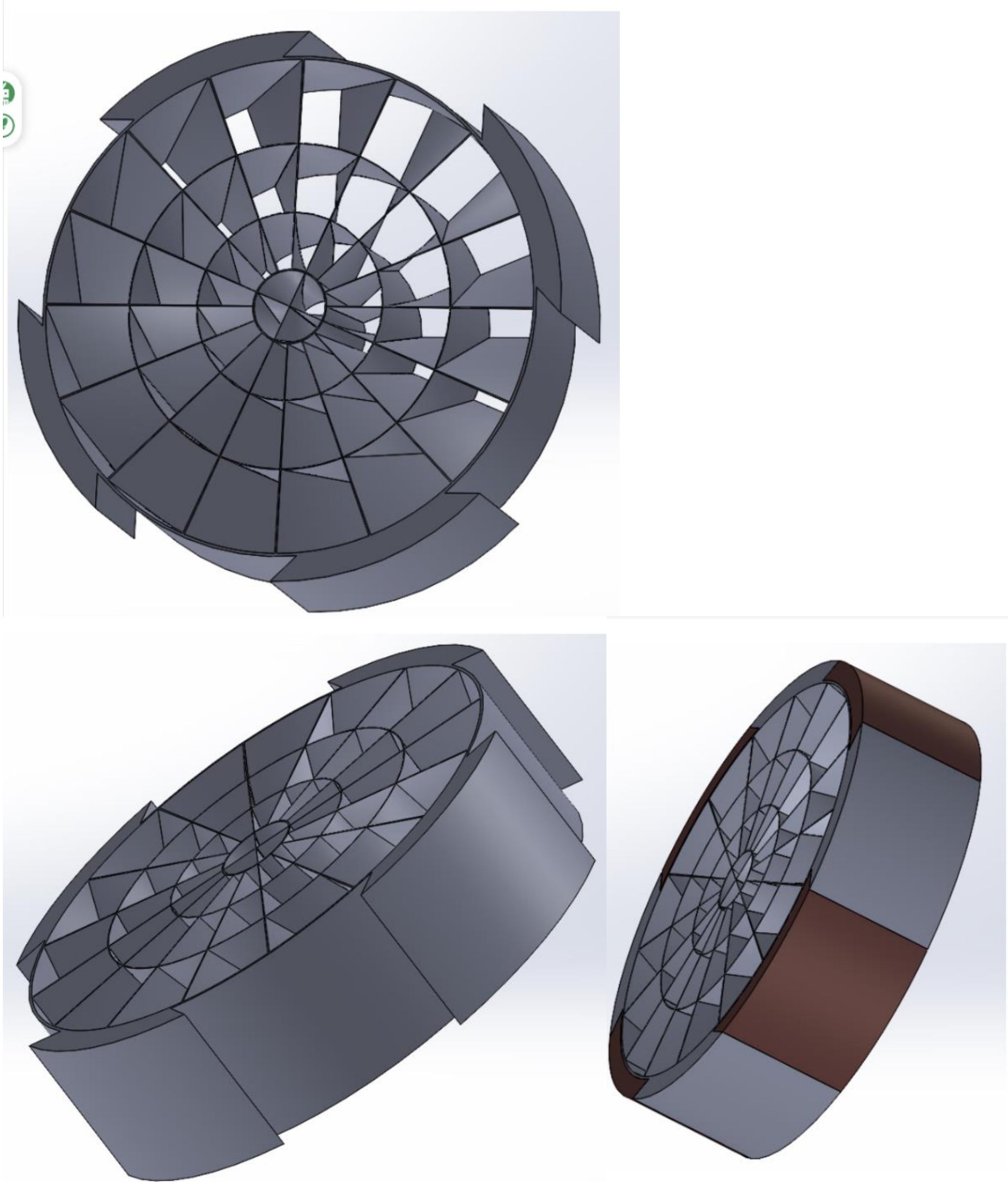


Figure 22Different view of the rotor

3.3 Aerodynamics of flight design

Here we are discussing about the air flow around the eVTOL aircraft and propeller.The aircraft is designed such that the design requirements should satisfy the aerodynamic principles of the flight. Our air is the reduce the air friction to the surface of the aircraft it should flow smooth with very minimal friction. The tail has propellers which generate horizontal thrust as mentioned the airflow it will then contribute to the vertical thrust too. The side or the main propeller thrust direction is also shown below.

The aerodynamics make heavy use of Venturi and Coanda effect on the aircraft body the first on macroscopic and more directly aerodynamic aspects, the second involves specific studies on materials and adhesion/cohesion forces of the components and materials involved.

According to the Bernoulli principle for air foil, this flight outer design also relates that so we can conclude that air flowing below the aircraft will have more pressure than the above. The upper pressure of the aircraft will be low so lift force will be generated.I have mentioned the low and high pre4ssure regions in the picture below.

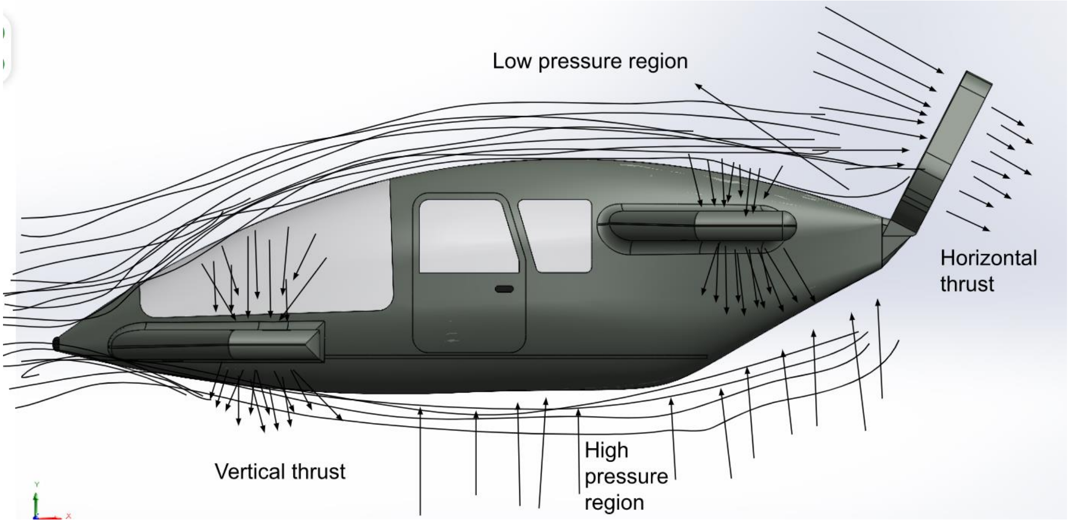


Figure 23Airflow around the aircraft

This is the best example for an aircraft with -Distributed&Pervasivesystem.

Figure 24 Distributive propullsion system.

Chapter 4

Flight control system

Here in this chapter, we will discuss about the type of sensors and the main components which is used in this eVTOL aircraft construction. This chapter is all about the inside mechanism components rather we can say the nerve system or the internal system which supports the engine to run the aircraft. The electronic components which have inbuilt coding system which operates to high level precision and accuracy of the aircraft.

Here we discussed about electronic part of the aircraft. we aren't mainly focusing on this concept our main focus is on outline design and propeller construction and its aerodynamics. In addition to that we just complete the whole aircraft system by this study.

The distributive and propulsive system will be used for good hovering and stability along with obtaining high speeds with multiple propellers. Thehigher levels of dedicated Sw / Hw / Fw will have to be usedbut today we use what already exists, and much could be improved in this regard in the near future. The sensors also should be more specific to the particular part like stator and winding control for feedack information.

In order to create a successful system design, a wide range of engineering disciplines must coordinate their abilities and efforts in the fascinating and technically challenging field of flight control. Flight control system development is continuously pushed forward by aspirational aircraft programmers and the fierce competition between aircraft manufacturers. which offer enhanced performance toward more effective development processes to accomplish these goals.It is common practice to assume that the aircraft can be defined as a rigid body defined by set of body axis coordinates when studying the mechanics of the flight and flight controller. With three translations along with three rotations about the axis, the rigid body dynamics has six degrees of freedom. Every force and moment acting on the vehicle is modelled within this framework. The flight controller, which receives signals from the sensors, will control the entire coordinate system. The sensors are essential for transmitting information about flight tilt angles. This chapter will examine each individual component and how it contributes to a successful aircraft journey.

4.1 Flight components

4.1.1 Flight controller

‘TheBrain of the flight’.The flight controller determines the desired speed for each of the four motors using the information gathered by the sensors. The Electronic Speed Controllers (ESCs), which are connected to the flight controller, receive the desired speed from it and convert it into a signal that the motors can understand.A group of sensors are connected to the flight controller. The flight controller receives data from these sensors about the aircraft, including its height, orientation, and speed. Common sensors include a barometer for height, an inertial measurement unit (IMU) for angular speed and acceleration, and distance sensors for obstacle detection. The drone filters a lot of this information and fuses some of it, much like how humans perceive things. This results in information that is more accurate and efficient. Advanced flight controllers are able to sense more precisely and quickly identify differences.The flight controller determines the desired speed for each of the four motors using the information gathered by the sensors. The Electronic Speed Controllers (ESCs), which are connected to the flight controller, receive the desired speed from it and convert it into a signal that the motors can understand.

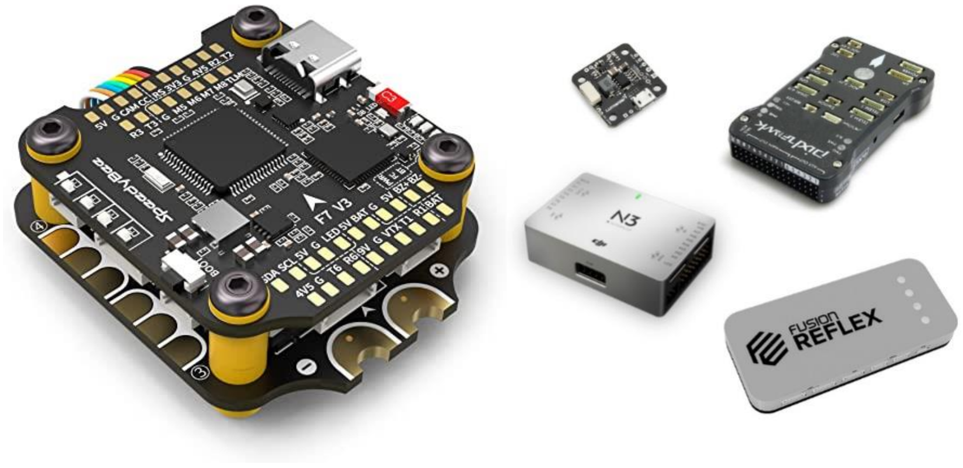


Figure 25 Flight controller

4.1.2Electronic speed controller(ESC)

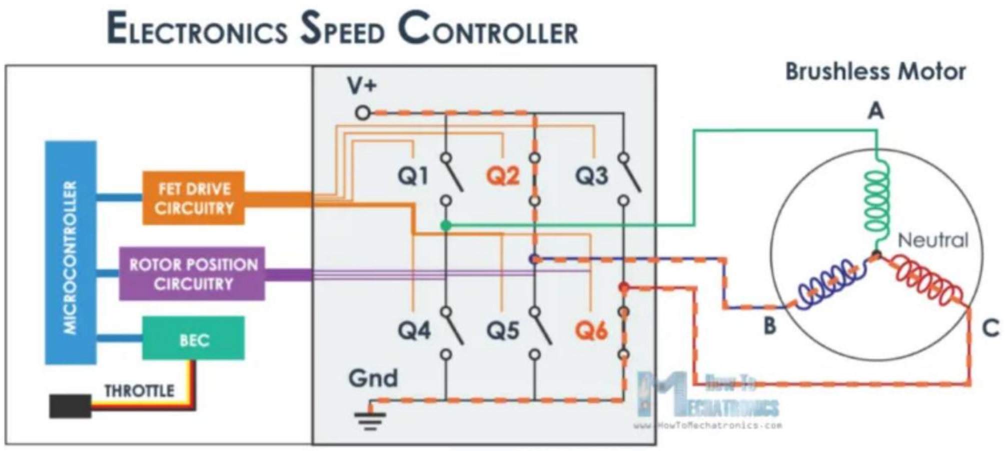


Figure 26 Circuit diagram of ESC with motor

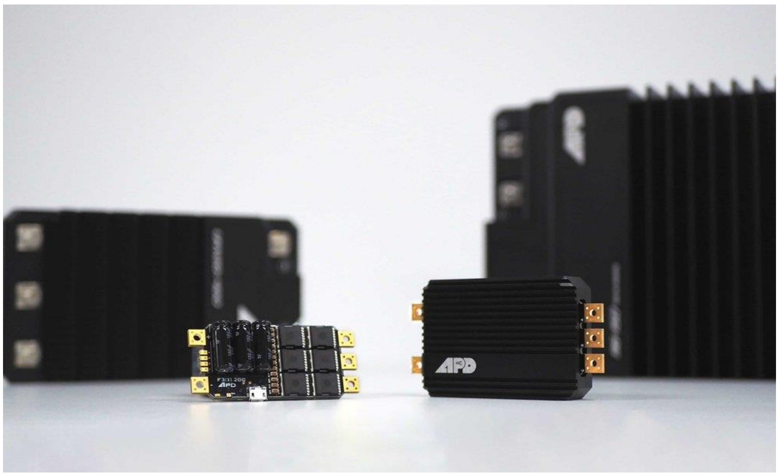


Figure 27Picture of ESC

They may have been referred to as inverters or even motor controllers in the past. A specially constructed tool called an Electronic Speed Controller (ESC) is used to regulate the speed of an electric motor. ESCs drive motors to a specified speed using a specialized set of hardware and firmware. Under a variety of conditions, such as the dynamic load of a propeller, they maintain motor speed.

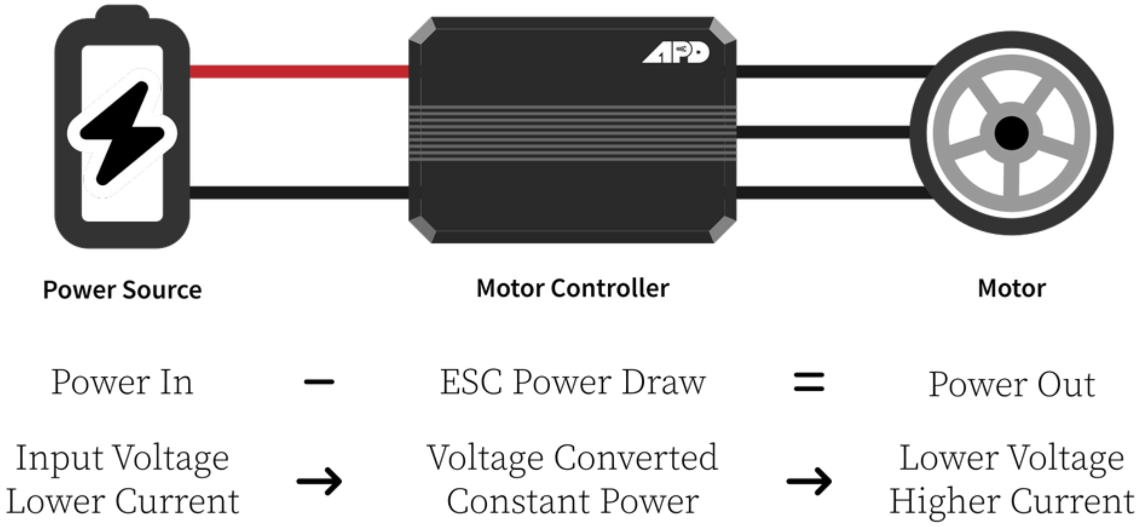


Figure 28Energy flow between battery to ESC to motor

4.1.3 Battery

Flying cars, also referred to as electric vertical take-off and landing (eVTOL) aircraft, have emerged as the most revolutionary technology to alter future urban transportation systems. Batteries face several difficult challenges because of their distinctive operating profiles and needs.Up to 50% of the take-off weight of eVTOL aircraft comes from batteries. Because to their inability to carry huge amounts of energy, eVTOL aircraft have much shorter ranges than conventional aircraft of the same size.

Batteries also have restrictions with regard to power density, which could be a limiting factor for size as well as a limitation on charging power and, consequently, the amount of time needed to charge a battery while it is on the ground. Moreover, high power charging stations are not yet available at airports, and their installation would be expensive. And last, getting an aircraft airborne without being charged may be necessary for operation from off-airport landing places. These reasons encourage an onboard internal combustion engine to lessen these issues.

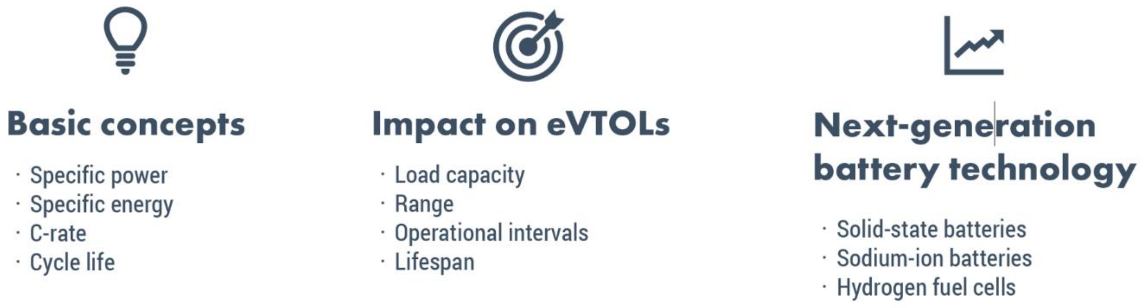
Type	Minimum Specific Power (W/Kg)
Multicopter	400
Slowed Rotor	450
Vectored Thrust	500
Lift + Cruise	700

Table 1Specific power requirements for different power types of eVTOLs

Some guidelines from a few years ago envisaged the threshold of 400 W/Kg as a condition for the toning of many industrial plans, which are also being implemented for the usual air carrier, currently in use and on a mass scale.

On In comparison to electric vehicle (EV) batteries, the main performance metrics needed for eVTOL batteries are analysed in this work. We demonstrate that eVTOL batteries have longer peak-power durations and operate at higher C-rates than EV batteries. Additionally, to maintain continuous eVTOL operation during rush hours, it is essential to fast charge enough energy during passenger-swapping gaps. Additionally, the high vehicle utilization rate significantly reduces battery cycle life.Notably, we stress the value of fast charging, which is necessary for reducing the size of aircraft and batteries to lower costs while maximizing vehicle use rates to maximize revenues. We emphasize that any fast-changing technology must simultaneously meet the following three requirements: charge time of 5–10 minutes or less, charged energy adequate for the subsequent trip, and a long cycle life. We experimentally show two energy-dense Li-ion battery designs that can recharge enough energy for 80 km eVTOL trips in five to ten minutes and withstand more than 2,000 fast-charge cycles. We anticipate that the innovative development of eVTOL batteries will be sparked by these initial designs.Yet, outside of the aviation industry, numerous other industrial sectors are interested in battery technology.

This section will introduce current battery technology, as well as its direction for the future.



Basic concepts

- Specific power
- Specific energy
- C-rate
- Cycle life

Impact on eVTOLs

- Load capacity
- Range
- Operational intervals
- Lifespan

Next-generation battery technology

- Solid-state batteries
- Sodium-ion batteries
- Hydrogen fuel cells

With superior battery, eVTOLs will have considerably broader fields of application in the future, and switching to the new battery technology will only require exchanging battery packs. An ICE could be employed in the interim to boost the amount of energy carried by the ship.

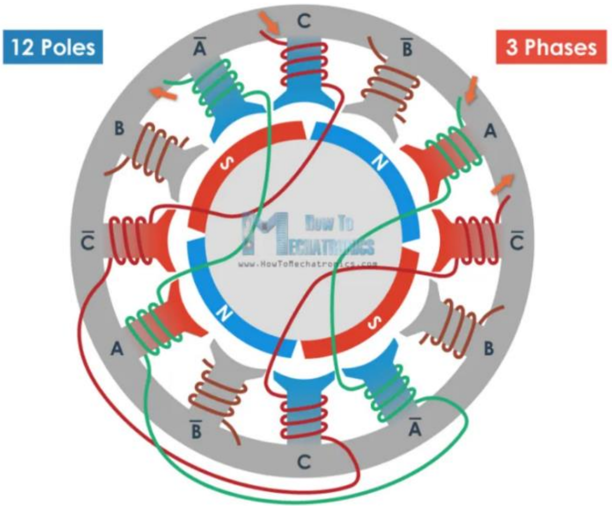
Figure 29 Battery cells of eVTOLs

4.1.4 Electric motor

Electric motors are essentially inverse generators: they rotate a mechanical object by passing a current through wire coils. The core principle underlying \motors is electromagnetic induction. According to Ampere's law, the current creates a magnetic field that interacts with other magnetic fields to create a force that can move objects mechanically.In eVTOL concept the propeller will be driven by electric motor. The large carrier like aeroplane and helicopter were using IC engines using fuels. The electric motor is the key concept where emission free and noise reduction while operating. Generally, the most common example which we can we relate to us is electric cars. We focused on brushless AC motor or Induction motor where motor is operated by AC supply. The ITEG concept motor is the one which used as propeller for eVTOLs.

The voltage that a motor can operate at, the rotor speed (or range of speeds), the electrical power drawn by the motor (often given in horsepower rather than Watts), and finally the "torque" or effective turning force of the motor are all typically included in motor specifications (discussed further below). All of these quantities are widely spread out in modern motors.

The ITEG has 12 electromagnets in stator and 4 permanent magnets in rotor. The electromagnets will be connected to ESC where inverters will help to switch the current between every electromagnet rapidly. Thus, the RMF rotatingmagnetic field will generate in electromagnets the rotor permanentmagnets will follow this RMF and rotate in the same direction. This is basic motor rule. Since it is brushless it is very efficient.



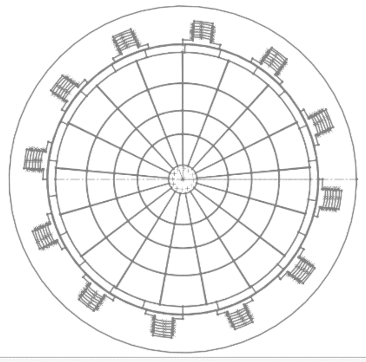


Figure 30 2D sketch of the ITEG propeller

Figure 31 Electric motor circuit

With regard to propeller torque, the electric motor module sizes the motors. The power the propeller absorbs divided by rotating speed yields the propeller torque. In the internal combustion engine concept, generators employ the same module.

Motor	Power(kW)	RPM	Weight (kg)	Torque (Nm)
Emrax 188	30	6000	6.9	48
Emrax 208	40	6000	9	64
Emrax 228	55	5500	12.2	95
Emrax 348	100	4500	20.9	212
Joby JMIS	150	4000	39.5	358
Joby JM1	8.2	6000	1.8	13
Joby JM2	13.2	6000	2.75	21

Table 2 List of electric motors used for weight-torque regression

4.1.5 Radio Communications

Radio waves are used extensively in both navigation and communication in aviation. The first radio frequency transmissions in aviation were used for radio communication.Today, air traffic control towers all over the US monitor every aircraft in the sky. All commercial aircraft and most US aircraft are equipped with a transponder. The transponder serves as an identification tool for aircraft, enabling ATC towers to quickly identify each aircraft. They function by identifying radar frequencies as they communicate with the aircraft. When the radar alerts the transponder, the transponder responds by sending a signal of its own back to the tower, which identifies the aircraft. Transponders can be used to prevent collisions with the ground and with other flying objects.

The unmanned aerial vehicle, or drone, has transformed aerial surveillance thanks to sophisticated radio and GPS systems as well as the ability for pilots and controllers to automatically identify planes, greatly enhancing air security.

The aircraft is equipped with receiver antenna and transmitting antenna to receives signals from ground stations. The antenna is connected to flight controller, and it does all the work processing the signals/commands and perform accordingly.

The sustained D&P presence of ITEG thrusters (with the concentrated actions of moving electromagnetic and permanent magnetic fields) could imply specific considerations/countermeasures in the evolutions of major radio controls in the making.

4.1.6 Manual cruise control

Future transportation will involve urban air mobility, which calls for an entirely new kind of vehicle. Electrical vertical take-off and landing (eVTOL) vehicles are one of the ideas that are currently being researched and developed. In this paper, a nonlinear dynamic inversion-based control law for this vehicle concept is discussed. In this configuration, the effective decoupling of the control axeswhich are tightly coupled for this type of vehicleand the inherent flexibility of dynamic inversion, which eliminates the need for gain scheduling, are two advantages of the method.Due to their wide range of operating conditions, which range from hover to forward flight, and their ability to switch between them, these are advantageous for controlling VTOL vehicles. The inner dynamic inversion control loop functions as the inner core flight control system for the entire envelope and includes a blended control allocation strategy that is optimized for both the rotors and the control surfaces. A group of linear controllers, reference models, and command filtering are added to this configuration to support the various manual control modes during the various flight phases. There is also an auto flight mode available. The overall controller becomes significantly less dependent on precise aircraft model properties when incremental nonlinear dynamic inversion is used, especially when it comes to the aerodynamic properties.

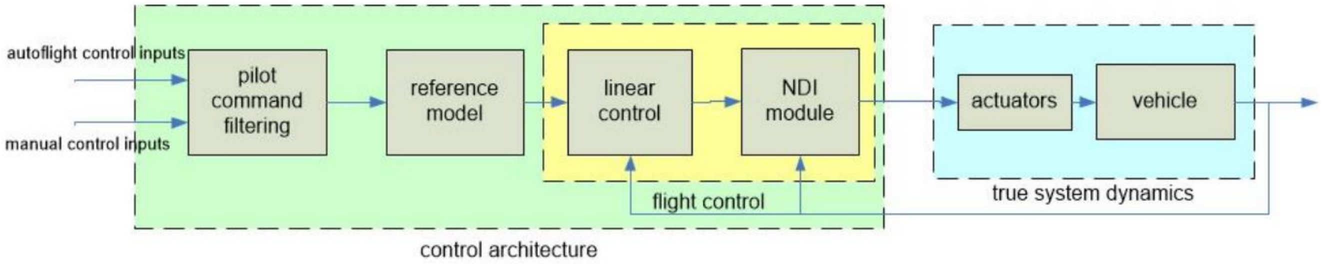


Figure 32 Global overview of the manual and autoflight control setup

4.2 Sensors

As our society pushes for more adoption of modern technology, we discover that in order to create prototypes that work, we must enhance the way we monitor and acquire data. When creating a prototype for an Electric Vertical Take-off and Landing (eVTOL) aircraft, Sensors are essential for gathering vast amounts of data and precise measurements in important contexts. For an all-electric eVTOL large enough to carry passengers a system that could track temperature, vibration, and strain. Both component bench tests and in-flight analyses required this. Moreover, an inertial measurement unit was needed to precisely track pitch, roll, angular rate, location, and velocity readings.

4.2.1 GPS

For navigation, location, and tracking purposes, GPS (Global Positioning System) sensors are frequently employed in airplanes. The precise location, altitude, and speed of the aircraft are determined by these sensors using satellite signals.Overall, GPS sensors have substantially increased both the safety and effectiveness of air travel and are a crucial part of contemporary aircraft navigation systems.

4.2.2 Lidar

Particularly for remote sensing and mapping applications, Lidar (Light Detection and Ranging) sensors are becoming more and more common in aviation applications. Lidar sensors operate by firing laser pulses and timing how long it takes for the pulses to return to the sensor after reflecting off of an item. This information can then be utilized to produce thorough 3D maps of the terrain below.Overall, Lidar sensors are a potent tool for mapping and remote sensing applications based on airplanes, and they are playing a bigger role in a number of sectors, including forestry, agriculture, and urban planning.

4.2.3 Air pressure sensors

Air pressure sensors are a crucial part of the instrumentation system on an airplane. These sensors assess the air pressure inside and outside the aircraft and give the crew and pilots crucial information.

4.2.4 Magnetometers

To detect the magnetic field of the Earth, airplanes employ magnetometer sensors. As they enable pilots to identify their heading and position in relation to the Earth's magnetic field, these sensors are crucial for navigation and orientation. For airplane navigation, magnetometer sensors are crucial, particularly when GPS signals might not be available or trustworthy. To add redundancy and boost accuracy, they are also employed in conjunction with other sensors like GPS and inertial navigation systems.

4.2.5 Accelerometer

In aviation, accelerometer sensors are frequently employed to measure acceleration, both linearly and angularly. These sensors track the speed and three-dimensional orientation changes of the aircraft.Several aircraft systems, including as the autopilot, flight control systems, and avionics, depend on accelerometer sensors. They are utilized to ensure safe and effective flight operations by giving pilots and flight crews vital information regarding the motion and orientation of the aircraft.

4.2.6Gyroscopes

Aircraft gyroscope sensors are used to measure the orientation and angular velocity of the aircraft in three dimensions. For navigation, flight control, and stabilization systems, these sensors are crucial.Several aviation systems, such as the autopilot, flight control systems, and navigation systems, require gyroscope sensors. They are utilized to ensure safe and effective flight operations by giving pilots and flight crews important information regarding the direction and motion of the aircraft.

4.2.7 Thermal sensors

In an aircraft, thermal sensors can be used for a number of things, such as engine monitoring, environmental control systems, and fire detection. Engine temperature sensors,Cabin temperature sensors,Fire detection sensors.For sustaining secure and effective aircraft operations, thermal sensors are crucial. They can help avoid damage or failure by providing crucial information to pilots and flight crews regarding the condition of the aircraft's systems. Thermal sensors need to be regularly calibrated and maintained to provide accurate readings and dependable performance.

4.2.8 Barometer

Aircraft utilize barometers to detect atmospheric pressure, which is crucial for calculating aircraft performance and measuring altitude. The aneroid barometer is the one that is used in aircraft the most frequently.Calculation of true airspeed and Mach number, Detection of weather patterns, Detection of cabin pressure changes. Barometers are a crucial part of an aircraft's instrumentation system since they provide significant data for flight operations and guarantee the efficiency and safety of the aircraft.

Chapter 5

Overview of an existing eVTOL concepts

5.1 Joby S4

The Joby S4 is a continuation of Joby's eVTOL development, with the assertion that the S4's design incorporates the knowledge gained from the S2's design. It is provided to provide a data point between huge eVTOLs (>2200 kg) and small eVTOLs (1300 kg).

Although the study demonstrates that this is not feasible with the existing dimensions and MTOW, the mission that is specified for the S4 is a flight range of 150 miles at 200 mph. Yet, the demonstration flight, which covered 15 miles at 60 mph, paints a more believable picture. The lift split was revised to 40% wing lift and 60% powered lift during cruise after it was discovered that the S4 cannot fly solely on wing lift at 60 mph. This lift split is reflected in the L/D value.

Figure 33 Joby S4

	PTO W (kg)	CTO W (kg)	Hover power (kW)	Cruise power (kW)	Battery weight (kg)	Hover W/kg	Cruise W/kg	kWh /100km	paxkm /kWh	Cruise L/D	Hover FoM
Joby S4	1815	1961	413.0	151.6	374.6	210.6	77.3	136.3	1.4	4.1	0.611

Table 3Data sheet of Joby S4

5.2 Airbus Vahana α

The Vahana is an electric aircraft built by Airbus that is more suited to high-speed cruising than hovering. To reduce development costs, the use of commercial off-the-shelf (COTS) components was given priority. The rear wing chord is used to simulate both wings since the tilting wing module was built to have a single tilting wing for the aircraft, making it impossible to mimic the variation in chord between the front and back wings.

Figure 34Airbus vahanaα

	PTOW (kg)	CTOW (kg)	Hover power (kW)	Cruise power (kW)	Battery weight (kg)	Hover W/kg	Cruise W/kg	kWh /100km	paxkm /kWh	Cruise L/D	Hover FoM
Vahanaα	726	711	153.3	51.6	138.8	215.5	72.5	29.9	0.00	7.4	0.664

Table 4 Data sheey of Airbus vahana

5.3 Lithium Jet

The Lilium Jet is a distributed electrical propulsion idea design with 36 redundant fans dispersed throughout the aircraft. Selecting ducted fans designed for more thrust in order to reduce noise and increase size. Nevertheless, the hovering ducts' tiny width makes them exceedingly inefficient and necessitates the use of very large batteries to provide the necessary electricity. A downward cycle of rising hover power and battery weight is produced by the power-limited battery's poor hovering characteristics. As a result, the design is judged impractical for the intended task since it carries the aircraft weight to infinity.The Lilium was tested with 0, 2, and 5 passenger cases, but it failed to fulfil its stated purpose. In other words, the Lilium is unable to carry a sufficient battery to complete its task even when there are no people on board. To determine whether the Lilium's design holds any promise, methods to boost the device's efficiency were looked at. The first item to test is if the airplane can lift itself while empty to determine whether Lilium's design has any validity. Range and passenger capacity are set to 0 for this. The battery is initially power-limited, and its weight exceeds the stated take-off weight. Because of this, the current structure of the Lilium makes it hard for it to even take flight.

The key finding is that it uses jet engine-type propellers with ducted fan theory, which somewhat resembles our propeller. But, it also has a motor in the middle and a supporting structure that can impede some air while hovering.

Figure 35 Lithium jet

5.4 City Airbus

The City Airbus is Airbus's flying taxi concept prototype, with an emphasis on low noise and failure-tolerant architecture. The City Airbus is employed to advance the technology for remote piloting. The large payload and emphasis on urban operations are consistent with the lack of a fixed wing and ducted lifting rotors.City Although the battery energy capacity of Airbus is given, the battery weight is not. This number, standardized to weight by the battery packing factor and battery specific energy, is used to compare different battery sizes.

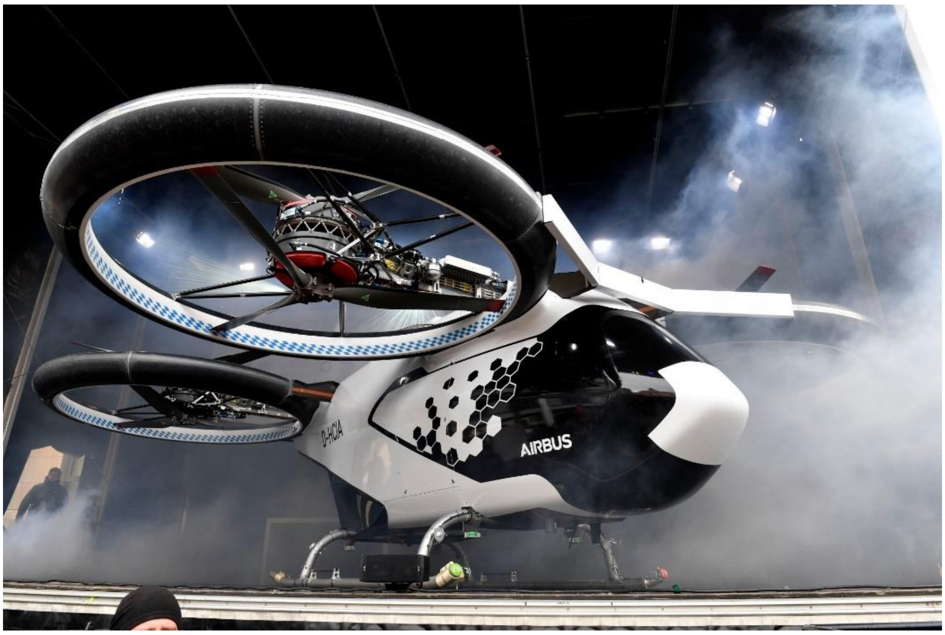


Figure 36 City airbus

	PTOW (kg)	CTOW (kg)	Hover power (kW)	Cruise power (kW)	Battery weight (kg)	Hover W/kg	Cruise W/kg	kWh /100km	paxkm /kWh	Cruise L/D	Hover FoM
City Airbus	2200	2033	462.5	372.9	684.9	227.5	183.4	309.7	0.8	1.8	0.816

Table 5Data sheet of City airbus

5.5 Bell Nexus 6.5

Bell's suggestion to Uber Elevate led to the Nexus. It is one of the few commercial airplanes with an internal combustion engine. For the ICE and its connection with the electrical infrastructure, Bell collaborated with Safran.According to Safran's comments, the amount of electricity produced during voyage was set to 100 kW, and the study was then carried out from that point on.It may be deduced from Safran's statement that "a power pack capable of delivering more than 600 kWe with 100 kWe tested" that the power pack would be able to provide 600 kWe peak power and 100 kWe sustained power when used with an ICE.

A total of 117 kilograms—of which 53 kg are fuel—are added to the airplane by the ICE and its accompanying parts. The fuel is equivalent to 181 kWh when the thermal and electrical efficiency are considered. The Nexus would need to carry an additional 890 kg in batteries if it were to transport a battery with this much energy, taking into account the battery packing factor as well. This demonstrates how significantly the ICE enhances an eVTOL'scapabilities.

Figure 37 Bell nexus 6.5

	PTO W (kg)	CTO W (kg)	Hover power (kW)	Cruise power (kW)	Battery weight (kg)	Hover W/kg	Cruise W/kg	kWh /100km	paxkm /kWh	Cruise L/D	Hover FoM
Bell Nexus 6.5	2720	2728	663.8	223.7	785.5	243.4	85.7	84.1	4.6	9.2	0.691

Table 6Data sheet of Bell nexus 6.5

Chapter 6

Workflow

6.1 ITEG Propeller working.

ITEG is the concept which developed byStefanoFarne and Vito Lavanga. It is Integrated turbine electric generator which initially developed to use in fluid transfer like a pump and generator. It is very efficient and its bearing friction is nill since the rotor floats inside the stator cylinder. The main aim of any development is to get max efficiency and work done with less power input. The current work demonstrates the different design features of this ground-breaking device, provides a survey of the literature based on academic articles and patents, and provides an illustration of the mathematical model that enables ITEG sizing and operation simulation. we have already understood this concept in detail in the literature review.

This paper is focused on propeller develpoment. The more efficient propeller design is the aim of this thesis along with eVTOL design and addtinals features. The ITEG concept is introduced to the propeller of eVTOL. Before this innovation was made to work on fluids and now we applied on air. The desiogn is similar to that with the fluid ones.

The propeller has many type of designaccording to its apllication. Ducted propeller relates quite a bit to this thesis. The thrust generated by the ducted is more when compared to blade type propeller. The airfoil type design will contribute more when it comes to lift force. The ITEG is more efficient when it comes to total work. So while combining all these we derived to build the propeller which can gives more work done (generate thrust) with less power.

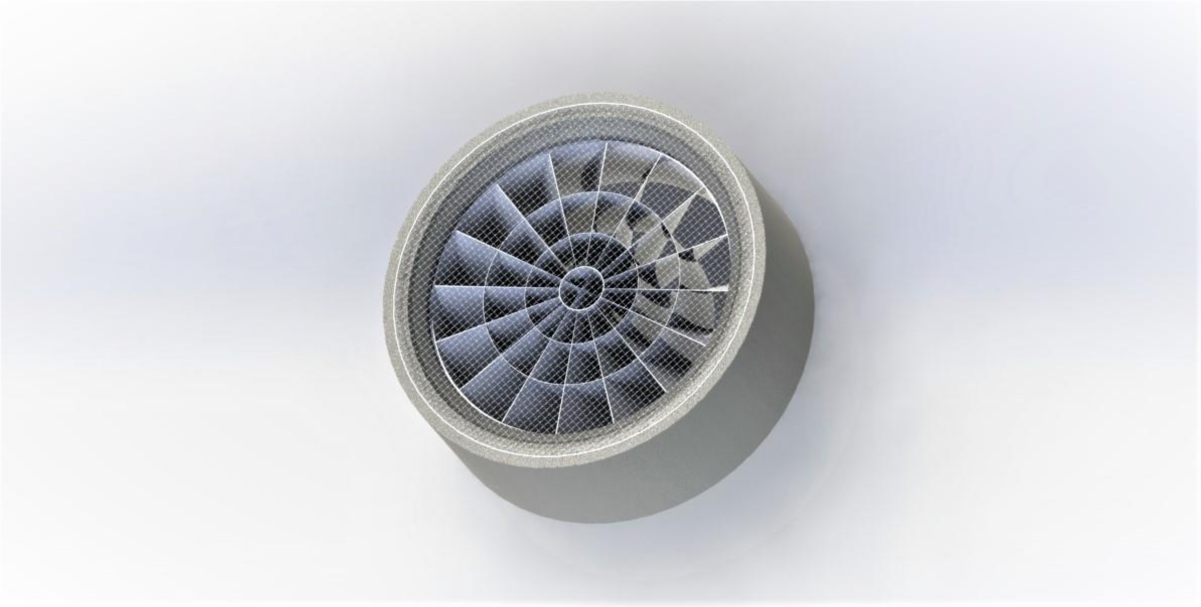


Figure 38 Rendered image of proepller

The ITEG propeller is the one that was previously discussed. The stator is the exterior component, while the rotor is the inner cylinder; there is a 2 mm air gap between the two. In the stator's magnetic bearing, the rotor floats. The rotor's permanent magnet is repelled from acting as a bearing by the circular crown magnet in the stator, which is installed in both ends of the stator cylinder. In order to interact with the stator electromagnets, the rotor features four permanent magnets in the outermost portion of the cylinder. Air is ducted through the holes in the middle second cylinder as it rotates. The construction of the walls will have an angle that serves as airfoils to provide thrust. The walls between the ducts are just about 1mm to 1.5mm thick. In the preceding chapter, the propeller's design dimensions were covered. The achimedien screw structure in the inner cylinder has a small but discernible impact on the total amount of thrust.

Three circles of magnets in each of the 12 electromagnets on the stator are connected to it by three phases of voltage. Two circular permanent magnets were positioned on either side of the ring-shaped stator to serve as a magnetic bearing for the rotor. The stator, which is attached to the eVTOL body, is a stationary component.

The propeller, which controls speed, is coupled to the ESC. The stator's copper windings, which include ferromagnets, conduct three phases of alternating current, creating a magnetic field surrounding it. The next winding will produce a magnetic field after the inverter switches the supply to it, causing a quick rate of change that will result in the production of RMF inside the stator. The rotor's permanent magnets follow the RMF. As a result, the rotor revolves at the ESC's set speed. The rotor turns more quickly the faster the switching. In order to keep the rotor inside the stator cylinder, two crown magnets were inserted in the stator.

The power of the propeller is supplied from the outer radius of the propeller known stator.

The center of the typical propeller houses the motor, which will block airflow. Hence, the flow is unhindered here through the flow's center. Although it won't add much to the total thrust, there will be some air going through the center region due to an archimedien screw-shaped duct that draws air. Despite this, it doesn't have an obstruction like a motor or housing that may reduce flow.

The efficiency it greater than the convectinal propeller. Since the ducts have very low thickness respect to useful working section. The section of the ducts can be of any size it may be circular, square etc of any shapes. Once the rotor tends to rotates the air inside the ducts rotates and flows outside the rotor. The pitch and radius of development of the winding propeller will be functional depending on the nature of the air (density, viscosity, molecular structures, etc.) and on fluid dynamic structures in which it is assumed to operate. The rotor ducts have sections aimed at maximizing the energy exchange with the air and the rotor. In order to better endure centrifugal forces and instability, the third outermost cylinder has a number of polar pairs produced by permanent magnets in the form of circular crown sections shaped like an omega or a dovetail and inserted in the support material. Depending on how ITEG is used and the fluid it works with, the fastening can be finished with adhesives, glue, resins, or other adhesives to stop the magnet from axially slipping out of its housing. The stator cylinder, which is firmly fastened to the operating environment and made up of magnetic sheets and electrical windings capable of producing or inducing an electromagnetic field that is combined with the rotor's electromagnetic field in accordance with the known laws of electromagnetic induction, houses the rotor cylinder. By applying the proper electromotive force to the stator windings, an electromagnetic field is created that interacts with the rotor's permanent magnets to turn it. As it utilizes the majority of the surface touched by the air that will drive the rotor, some energy will be recovered, making the useable surface of the rotor a highly significant component of the ITEG.

In general, they are solutions that use little D&P, with propulsion concentrated in some points, well supported by arms (or wings) critically anchored to the carrier, and in some cases also with active mechanics to condition for high manoeuvrability for roll, pitch, yaw, their attitudes; ITEG aims to shorten if not eliminate these levers/arms, bringing the propulsion in adherence with the vector, organising equal surfaces of action/thrust.

As a propller of eVTOL the ITEG plays very important role. In this thesis we have implimented the ITEG to the eVTOL aircraft. 4 side propellers which produces verticle thrust and 3 at the tail of the aircraft which produces the horizontal thrust along with some contrubution to the verticle thrust. The basic aerodynamics has been explained in this paper about thrust generation by aircraft, pitch motion, yaw motion, torque of the propeller, lift and drag theory of the aircraft.

6.2 Energy flow analysis in eVTOL smartflight

The electrical system of the eVTOL flight has been studied in this chapter.

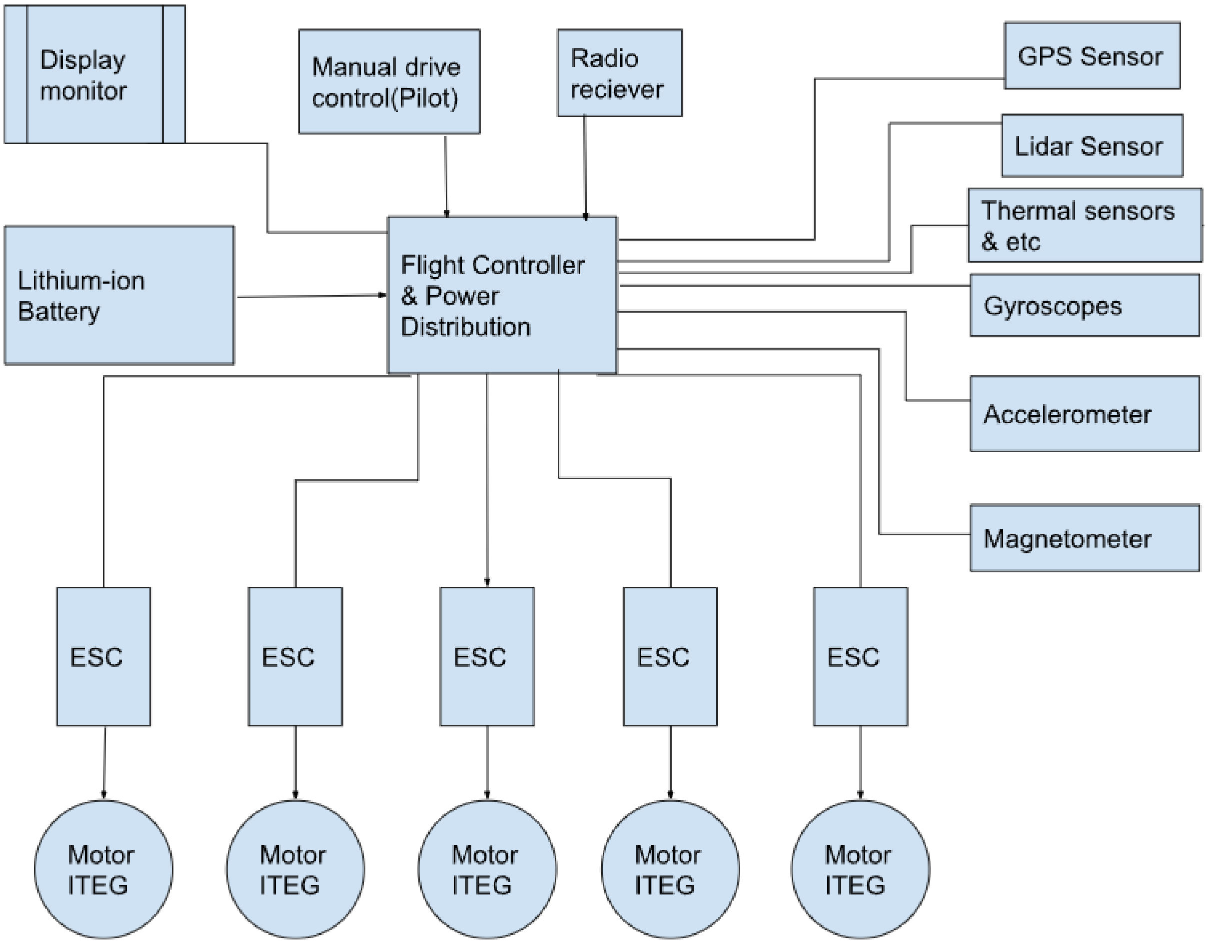


Figure 39 Electric system of the eVTOL smart flight

The above figure shows the electrical circuit diagram of the entire eVTOL aircaft. Well this paper is not focusing depth about electrical part but we covered this part for overall knowledge about aircraft. The basic elelctrical connection is shown above.

Lithium ion batteries are used as a power source for eVTOL aircraft because energy is the primary factor in any task that needs to be accomplished. The battery's kW/Kg ranges from 400 to 550. The flight controller is connected to the battery, and it oversees all work and actions in the flight system. The flight's control system is its brain, or flight controller. The necessary tasks have been digitally programmed into it. All sensors will be linked to this flight controller, some of which will provide feedback on the propeller rpm, flight tilt angles, etc., which the flight controller will monitor and control.The flight controller, which connects to the power distribution, transfers energy to all of the flight's components. There are separate 5 ESC in this eVTOL, of which 4 connect and control the 4 side propellers that provide vertical thrust. The ESC is connected next to the flight controller. The fifth one is connected to the tail propeller set, which simultaneously controlled all three propellers.

The ITEG motor propellers are also controlled by the ESC. ESC has control logic that can be used to switch three-phase electric current among different poles using an inverter.

ESC operate in accordance with the flight controller's signal. The ESC will switch the inverter, and the motor will operate in accordance with the controlled signals. The motor has sensors that track its rotational speed (rpm) and transmit that data to the flight controller. The information is then sent to the display monitor by the flight controller. The pilot will be able to see all the flight information on a display monitor inside the aircraft. as an illustration. air pressure, weather, tilt angles, and engine speed are a few examples. The pilot can fly and land the aircraft manually using the flight control gears in the event of an emergency (signal loss from the ground station and some technical errors in the flight).. The radio antenna receives signals from the ground station and is connected to the flight controller, who has access to all of the flight data, and who then relays that data back to the ground station. The autopilot mode will be used to automatically steer or control the flight.

The pilot will be able to manually operate the landing gear and parachute in addition to the intelligent flight controller, which will automatically carry out this mechanism.

Chapter 7

Results and Theoretical calculations

The most important component is to figure out how to increase thrust while using less electricity from the eVTOL propeller. We are aware that the propeller is an ITEG, meaning that mechanical losses are practically nonexistent because the rotor floats inside the stator cyclinder. The rotor's hubless construction will also help it produce more thrust. When a new technology enters the market, efficiency is quite important. Better products result from more efficiency. Right here in this paper we focus only on propeller calculations.

The outcome depends on the material used to make the propeller. For instance, carbon fiber is lightweight, requiring less power because it requires less initial torque to pull the rotor than some other heavy materials. The flexibility of the rotor material in relation to the aerodynamics plays a crucial role in the calculation of the desired results.

7.1Useful Volume

Calculating the volume of air inside the rotor is the first stage. The area occupied by the walls that divide the chambers must be removed from the useable section when looking at the rotor from the front and considering the air intake section. The volume's initial equation –

$V = S{*}L$

'S' is the total useful surface in the rotor. The surface which air interaction takes place. The surface is futhur divide into two circular part or circularcrowns. This surface area is calculated by larger radius minus smaller radius of the circle. The circular crown area can be calculated as follows.

$Ac = \pi(Rj\ 2 - rj\ 2\ )$

The rotor has several circular crown so we have to repeat the operation for all the sections to obtain the total useful surface.

$S = \pi(R\ 2 - r\ 2\ ) - [\sum \pi(Rj\ 2 - rj\ 2\ ) + (R - r) * s * nkj{=}1\ ]$

with k equal to the number of circular crowns and n equal to the number of radial walls.

As for L calculation, considering a generic circular crown j, the length Lj of the duct is given by the formula: $Lj = \surd(2\ rj{+}Rj{-}1\ 2\ \pi)\ 2 + (m*p)\ 2$

where m is a coefficient equal to 1 if the length of the rotor is equal to p. By iterating the procedure on all the circular crowns, the relative lengths are calculated. The average value of the lengths of the Lj is equal, with good approximation, to the L value sought. A more precise calculation may be made, but it is beyond the scope of this paper. Therefore, the useful volume of the rotor is:

$V = \{\pi(R^2 – r^2\ ) - [\sum^k \pi(Rj^2 - rj^2) + (R - r) * s * nkj{=}1\ ]\} * L$

7.2 Flow

Consider the rotor have ducts in it. The circular crown j has ducts adjacent to each other. And these all having same radius or distance fro the centre rotation axis. The ducts have helical shape throughout the rotor length. The volume of the duct for a complete pitch is V imagine the air passes through it. At first it filled inside the duct and then after the complet rotation it comes out of the rotor ducts. If the length of the duct is equals to one pitch or rotation. If the length of the duct or rotor is half of the one pitch or rotation the half amount of volume of the air will comes out of the rotor ducts.

V = total useful volume, n = number of revolutions/units of time

the flow rate Q is:

$Q = n * V$

7.3 Efficiency

The main aspect/ aim of every technology or new innovation is about machines efficiency. So here the efficiency of the propeller (ITEG) will be estimated. We have three type of losses in the machine system they are volumetric, mechanical, aerodynamic. These are the losses that occur in propeller while operarting.

The aerodynamic losses are due to the dissipation of energy following impacts, deviations or section variations that are encountered by the air during its flow through the rotor ducts.

The air must enter without impact and exist with minimal speed. The impact of air to the surface of the rotor dissipates some energy at the expense of some possible work produced and then the kinectic energy produced by the air at the inlet of the rotor. While designing the rotor we have to consider the aerodynamic efficiency high as possible. So the estimated aerodynamic efficiency is

$\eta i = 0.95 - 0.99$

Now the volume of the rotor ducts plays very crucial role in this and there by no leaks in the ducts but the air drawn from the rotor can enter the small gap between rotor and stator so there by some amount of enegry will be lost so it can be considered as volumetric loss

$\eta v = 0.99$

The mechanical losses are due to the dissipation of energy necessary to overcome the frictions of the components. The mechanical frictions will be practically zero as the rotor "floats" in a magnetic field and, for this reason, it must not overcome the frictions between the bearings;

$\eta m = 0.99$

The total efficiency of the machine, given by the product of the three partial efficiencies, will therefore be very high and will be in a range between 0.95 and 0.98.

$\eta = \eta v * \eta m * \eta i$

7.4 Thrust

This paper is about obtaining the high efficiency and thrust than the standard propeller. Thrust is the sudden force or the push force which is excerted by the propeller which results in movement of the vechicle. Thrust is measured in kilograms.

The below attached figure shows the propeller thrust analysis. The air stream line flow has been showed below, the section1 is initial air spaceit is called as free stream velocity before the propeller and section 2 is the thrust or blown air from the propeller which is slip stream velocity. The red part in the middle section is the propeller which the air velocity is $V_{o..}$ The initial air pressure is P_o at V at section 1. And similarly same pressure P_o will be there at a distance after the propeller at V_s at section 2. Theie will be change in pressure at the inlet and outlet of the propeller they are represented by P_1,P_2at V_o.

V_o=Velocity at the propeller P$_1$= Pressure at the inlet of propeller

a = Inflow factorP_o=Pressure at section 1 and section 2 at V and V_S

V=Velocity at section 1 at free stream P_2= Pressure at the outlet of the propeller

V_s=Slip stream velocity

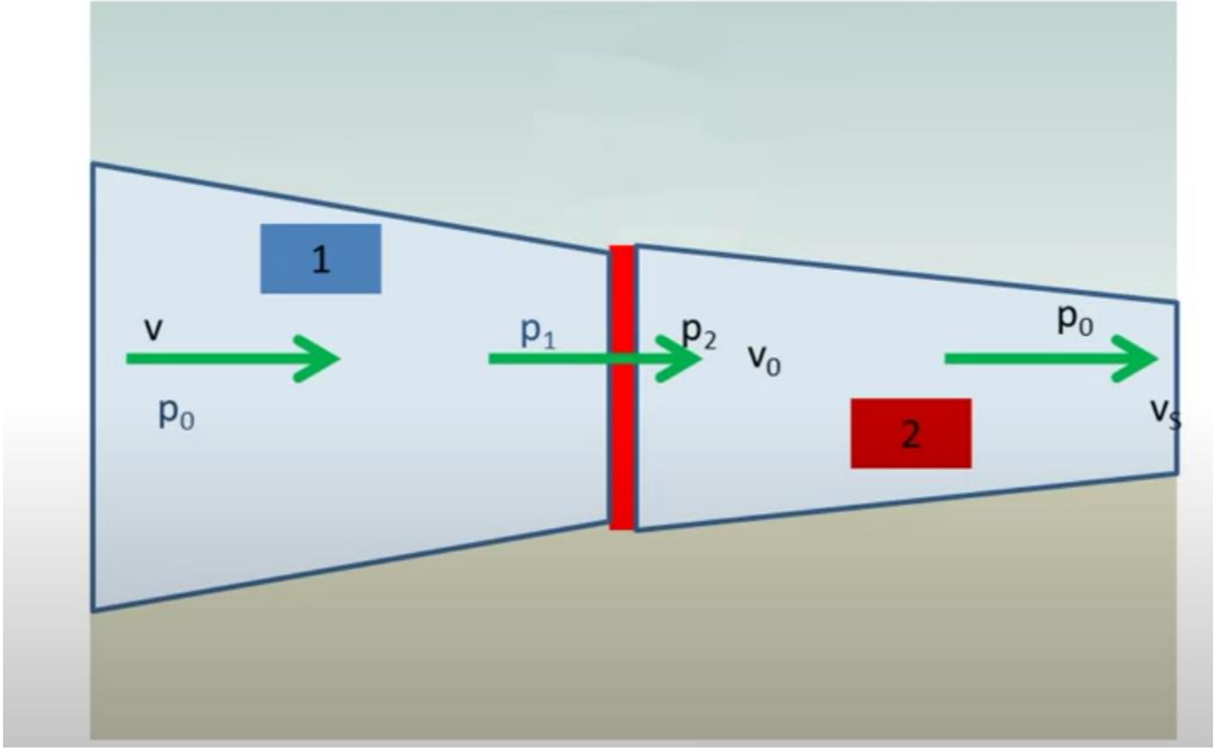


Figure 40The overview of the airflow through thepropeller

The differenc in kinetic energy is the power required by the propeller. The free stream and the slip stream velocity difference is the power required by the engine or propeller.

The power required = The change in kinetic energy

$\Delta KE=P=1/2\ m(V_s^2-V^2)$

$m=\rho sV_O=\rho SV(1+a)$

$V_s=V(1+2a)$

So, $\Delta KE=P=2\rho SV^3a(1+a)^2$

So the thrust of the propeller will be

$T=\rho SV(1+a)[V_s-V]$

$T=2\rho SV^2a(1+a)$

So the efficiency will be

$\eta= TV/P=2\rho SV^2a(1+a)V/2\rho SV^3a(1+a) = 1/(1+a)$

Let $V_o=V+V_i$

$V_i=aV$

$a=V_i/V$

substitute value of “a” in thrust equation

$T=2\rho SV_i(V+V_i)$fina**l thrust equation**.

We can rewrite efficiency equations as

$\eta= 1/1+a$

$\eta = 1/1+(V_i/V)$ final **efficiency equation**.

Chapter 8

Application, Advantages and Saftey

8.1 Application

➢ ITEG propeller

- Marine vehicles, such as ships and yachts, are the first and most significant application for this technology.
- As refrence to this paper eVTOLs can use this engine for safe and eficient flight.
- Aircraft industries can use this engine propeller to maximize the efficiency.
- ITEG can also used in hairdryer, cooling fans, etc
- As the name implies, it will be easier to use in a water pump.
- In hydraulic plant (dams), to produce electricity this ITEG can work as turbine.
- In Arcaboard this can replace normal propeller.

➢ eVTOL smartflight

- Air taxi service for passanger travel.
- Emergency and medical evauation.
- Cargo transport
- Rescue operations

- Farmers to moniter the farming land
- Coasr gaurds, navy and army to moniter the region.
- Low Altitude flying vechicle

8.2 Advantages

- eVTOL aircraft helps in verticle ake of and landing which is very helpful for cities and any small landing site.
- It is emmision free since it uses electric motor as its propeller
- Less noisy compared to the combustion engine propellers.
- ITEG is more efficient so its operating cost will be less.
- Adavtage of autopilot mode, sono pilot required
- Manual cruise control option for emergency
- Since eVTOLs are compact and verticle take off and landing any commercial building can handle this aircraft on the roof top.
- Ducted propeller is very safe, since the rotor is covered with stator frame or hull, there will not be any blade that can cause serious injury if anyone touches it.
- eVTOL aircraft are very useful in travelling one place to another in quick time.
- It is cheaper to operate or low operating cost compared to helicopter, cargo jets etc.
- Anyone can able to fly in this eVTOL aircarfts, no pilot license required to fly this vechicle.
- It can be able to fly and operate in any remote area or isolated arera where fixed wing or big helicopters would ususally not able to take off and land, this aircraft has that flexibility to operate in that condition.

- eVTOL smartflight can fly in low altitudes. So it can safe energy and also with low atmosphere pressure it can be operated.

8.3 Saftey

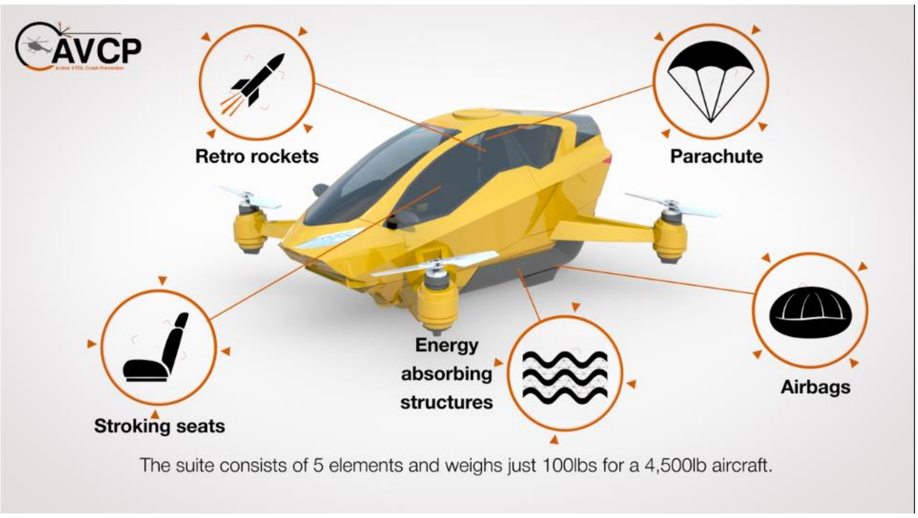


Figure 41 Saftey features of the aircraft

8.3.1 Distributed Electric Propulsion (DEP)

The design's redundancy is one of the numerous advantages of Distributed Electric Propulsion (DEP), which is used in many personal eVTOLs. There are still four or more rotors available to make a secure recovery if one fails.

Yet, a completely unsuccessful eVTOL descent can be even riskier than an aircraft losing power. In particular, this is valid for eVTOLs without fixed wings.

8.3.2 Airbags

By limiting the movement of the occupant's torso, seat cushion airbags are intended to lessen stresses on the occupant's chest and abdomen. It will reduce the amount of impact in crash. Ususally we can see this cars. So it is so important in eVTOLs to have this airbags for passanger safety.

Figure 42 Airbag system

8.3.3 Seat belts

For passenger safety, seat belts are crucial. In the event of an accident, it will prevent passengers from moving forward and colliding with the aircraft interior. then there are connections to the airbags. The airbags work when the seats are in place. The seat belts in cars are just like this.

8.3.4 Airframe Parachute

Quick response of the parachutewhen flight is in danger to ensure the safety of the passengers. Since it is fly in low altitude there wont be much time to crash down to ground when it has some problem or accident to the parachute should be quick enough to shoot up reduce the fall speed.

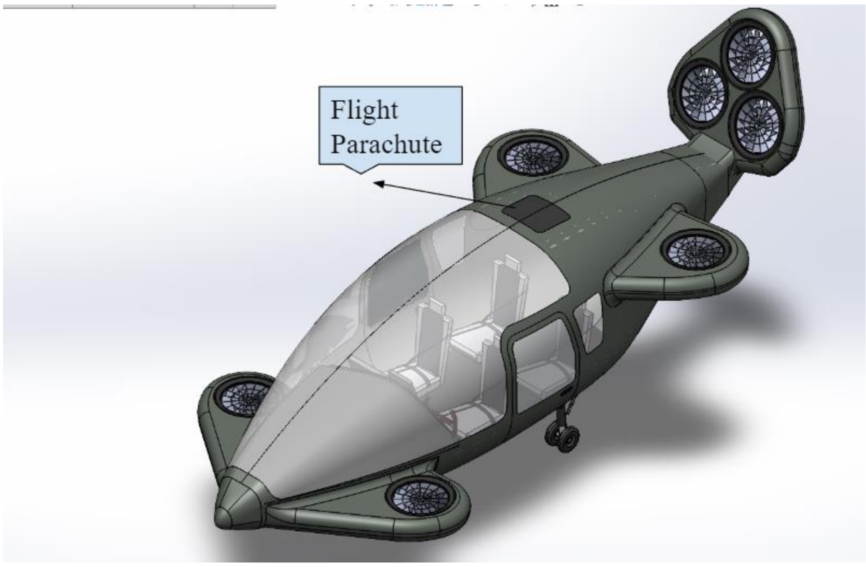
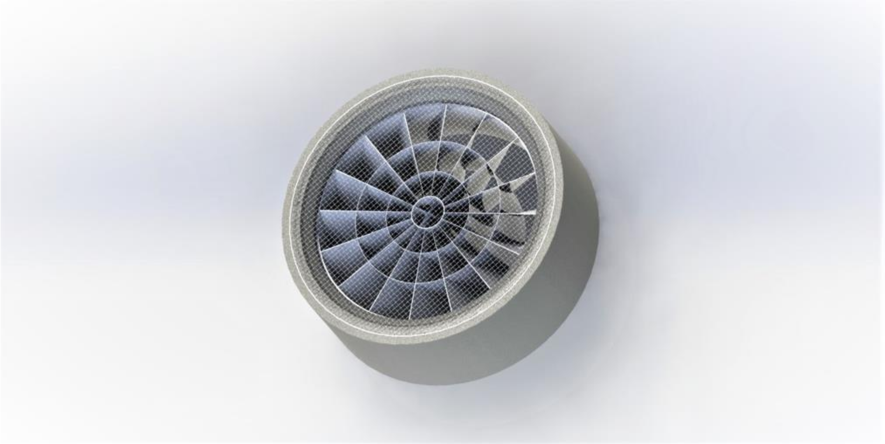


Figure 43 Saftey parachute

8.3.5 High-stiffness airframe

The aviation aluminum structure and carbon fiber material are combined to create the aircraft body material. The body becomes stronger, lighter, and more resilient as a result.

8.3.6 Mesh protection for propellers



When the airplane is still on the ground, the propellers are dangerous to be around when they are turning. In the event that humans come into contact with it accidentally, they risk suffering grave injuries and even dying. Compared to blade-type standard propellers, ducted propellers are significantly safer. And since the ducted rotor has small ducted holes, there will be various incidents that could happen while flying, such as a bird getting sucked into the propeller. If this happens, it could cause a problem for the aircraft. Moreover, the duct can be used to draw in various polymers and other materials. We therefore created netting to shield the propeller from all of these situations in order to prevent them.

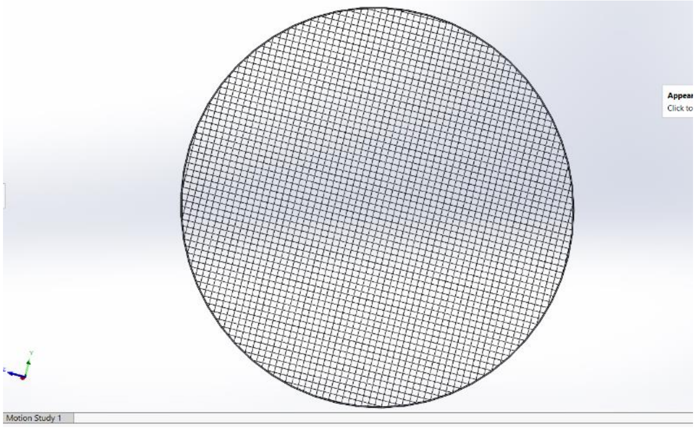


Figure 44 Saftey mesh for propellers

8.3.7 Real Time Command and Dispatching Center

This is the task that the ground station is instructing to monitor the flight data from the monitoring hall. to remotely pilot and dispatch the aircraft to prevent airborne mishaps before they happen. This is equivalent to the airport flight control tower.

Figure 45 Air control center

Chapter 9

Conclusion and Future scope

This thesis is focused on the propellers in eVTOL aircraft and the designing of an eVTOL aircraft. Here the ducted ITEG propeller is the main aspect of this thesis, which we conclude that this will be most efficient and convenient propeller for all the propelling vehicles either in land or water.

Thehub lessdesign of ITEG propeller make a big impact in delivering significant amount of air through it. Since the rotor is floating inside the stator cylinder there shouldn't be any kind of friction while operating. The rotation will be smooth and less noise comparatively. It delivers maximum thrust with less power consumption. As far the ducted fans are the best for thrust in the industry, so this ITEG has outer circular ducted stator and inner rotor ducts which makes it better for the thrust and stability to the aircraft. The rigid structure makes the smooth rotation of the rotor hence it contributes to the stability and less vibration to the standard blade-type propeller.

The eVTOLsmart flight design in this thesis comes under the aerodynamic requirements, it has sharp muzzlewhich makes air to pass through it with less obstruction. The outer body is made with aluminium and inside carbon fibreinteriorwhich is light in weight and strong enough to withstand high atmospheric pressure.

In the coming years these can be represented as flying cars by developing the retractable propeller wings so in land it can beoperated as car, and it can also fly as eVTOLs. The propeller ITEG design can be used in many applications in aerospace and marine industries.

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