UNIVERSITA DI PAVIA

DEPARTMENT OF ELECTRICAL, COMPUTER AND BIOMEDICAL ENGINEERING

MASTER'S DEGREE IN INDUSTRIAL AUTOMATION ENGINEERING

Master's Thesis

"ITEG as a flight propeller in eVTOL smart flight"

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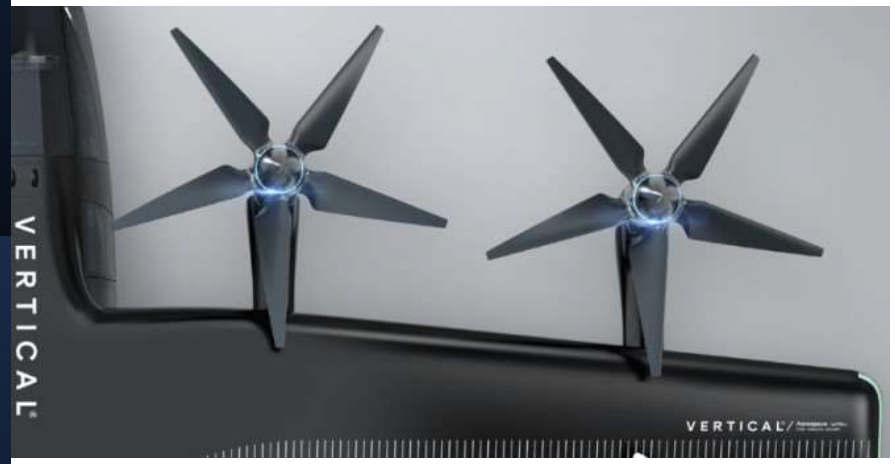
Aim

To design and introduce the ITEG as a propeller in eVTOL smart flight to maximize the thrust, efficiency along with the good stability of the flight.



Standard blade propeller

ITEG propeller

What is an eVTOL smart flight?

- An eVTOL smart flight is an aircraft that uses electrical power to hover, take off and land vertically.
- These are smart flights fly on electrical propulsion powered by batteries.
- eVTOL stands for electric vertical take-off and landing.
- Since electric vehicles are rapidly replacing internal combustion engine vehicles, short-haul helicopter travel may soon be replaced by eVTOL aircraft..
- eVTOLs are quieter, faster, and more environmentally friendly than helicopters. They therefore appeal to time-constrained business travellers. Since eVTOLs can take off and land vertically, unlike helicopters, they can fly in places with constrained runway space.

eVTOL smart flight

- These aircraft use distributed electric propulsion technology and build with multiple motors for various functions as well as to increase efficiency and ensure safety.
- These aircraft use various concepts such as multi-rotors, fixed-wing, and tilt-wing that are backed by sensors, cameras, and even radar.
- It helps to open the possibilities of a new sustainable transportation system in urban areas without depending on the runways.

❖ **Existing companies of eVTOL aircrafts**

Joby aviation, Jaunt Air Mobility, Archer Aviation, Volocopter,

Wisk, Airbus, Ehang, Vertical Aerospace, Urban Aeronautics, etc.

eVTOL aircraft	
Max speed	200kmph
Max range	250km
Max payload	500kg
Max altitude	4000ft
Max take-off weight	1000kg
No. of passengers	1 pilot + 5 passengers

What is an ITEG?

Integrated turbine electric generator)

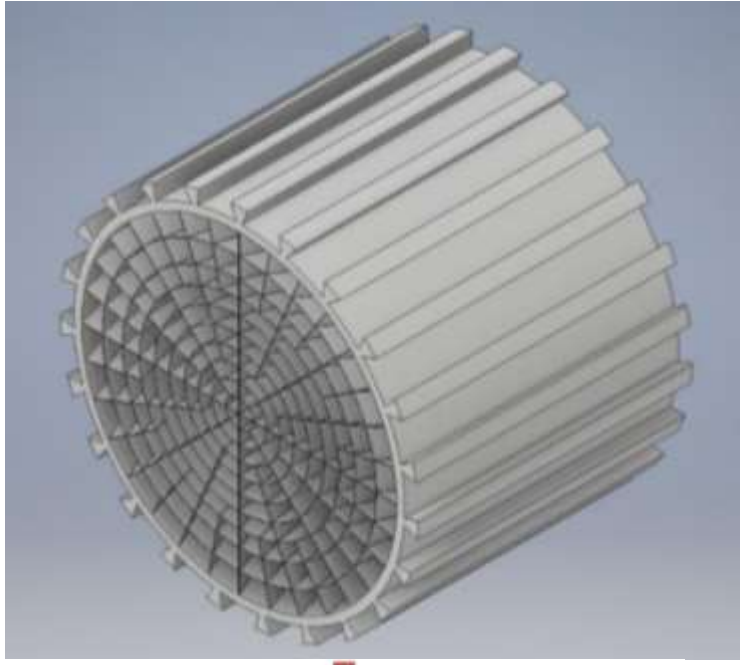
- It is a type of an in-runner electric motor.
- This is a dual function device where it acts as turbine and also as pump.
- The hubless design plays very important role in delivering max amount of

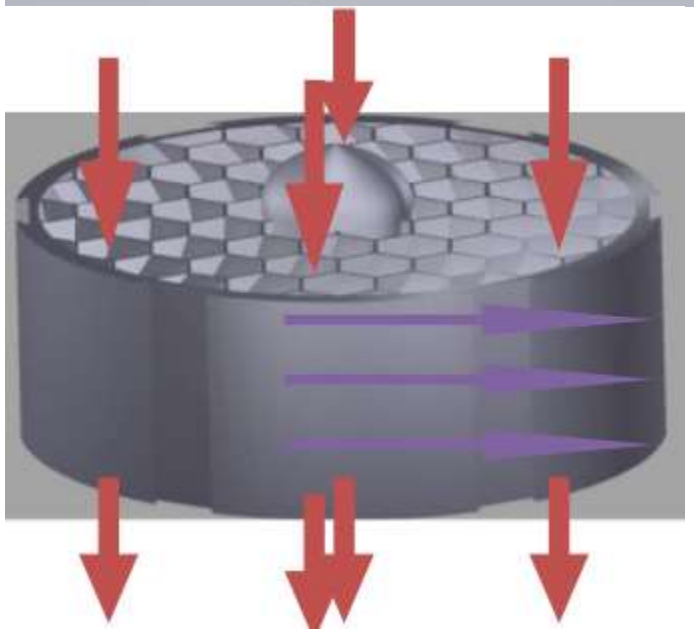
  fluid through it.
- The rotor floats inside the stator cylinder. The circular permanent magnets

  provides magnetic bearing in the stator pushes rotor from both ends to settle

  in the centre.
- The rotor has different shape of ducts in which air or any fluid can pass through

  it, the walls of the ducts are very thin so that it cannot resistor obstruct air or fluid.
- It works like a typical electric motor when we talk about energy requirements. 3 phase current pass through the coils of electromagnets it interacts with PM of rotor.





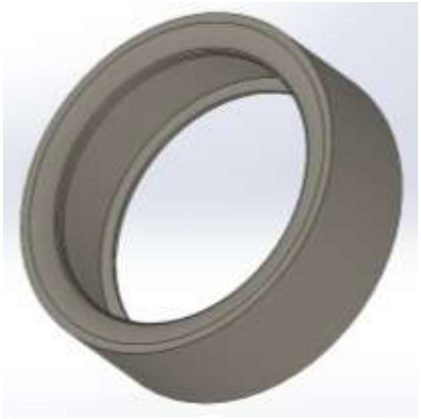
Design of ITEG propeller

Our main focus is designing.

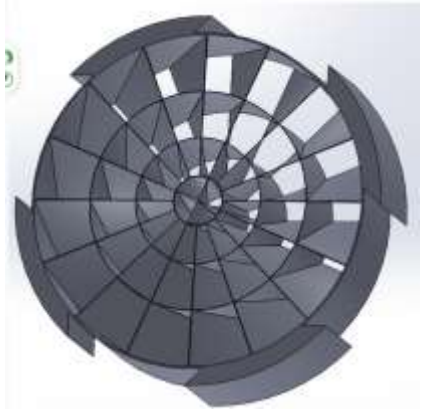
- The design is a hubless rim-driven thruster.
- The centre axis of the rotor has a Archimedean screw shaped duct.
- The material of the propeller will be a light weight aluminium or carbon fibre,
- The purpose of the propeller design is the energy generated will be turned into thrust.
- The propeller is approx. 1m in diameter and 35cm in height.
- The tensile structure of the rotor, it involves lower losses due to bending in the blades and their greater turbulence generated.

Components of the propeller

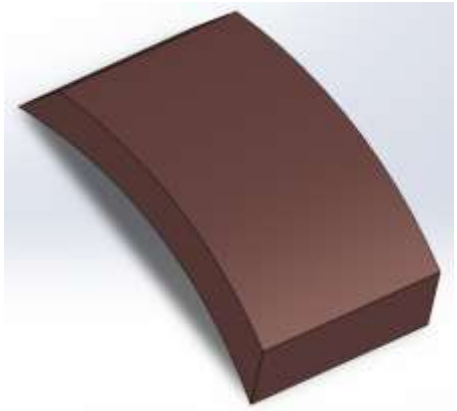
Stator -



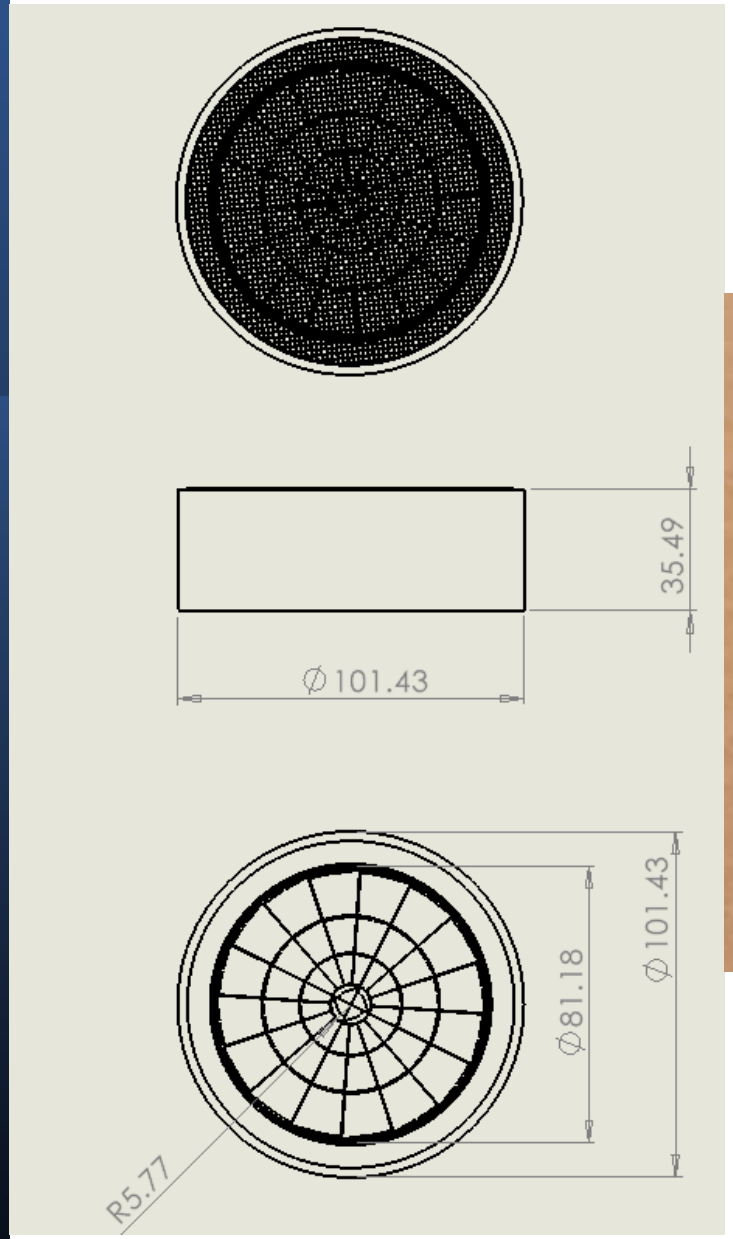
Rotor -

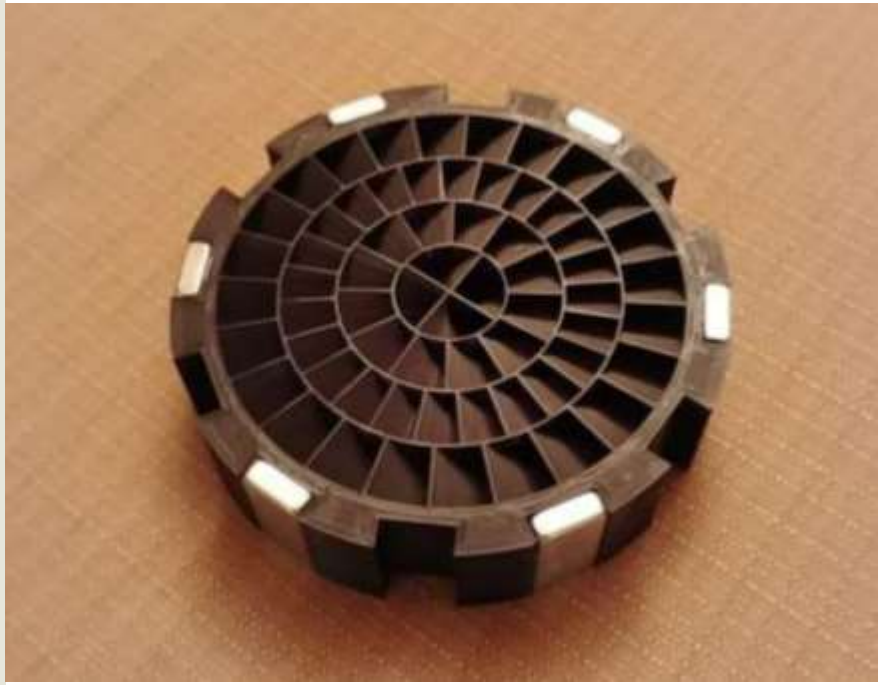


Permanent magnet-



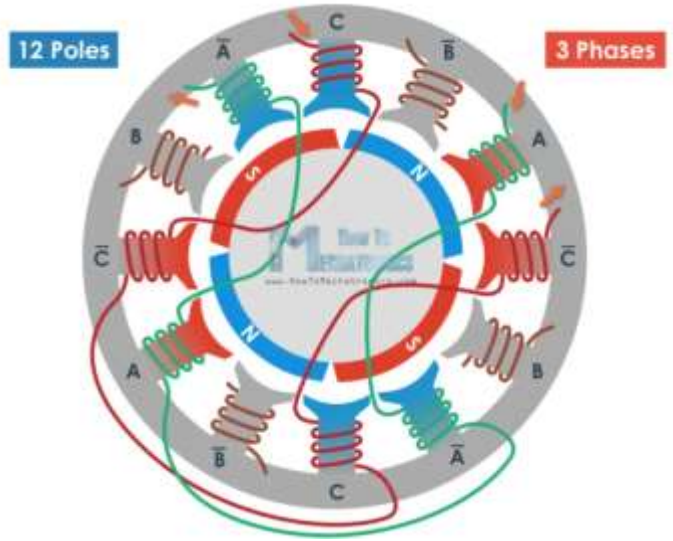
Design of ITEG propeller





Working

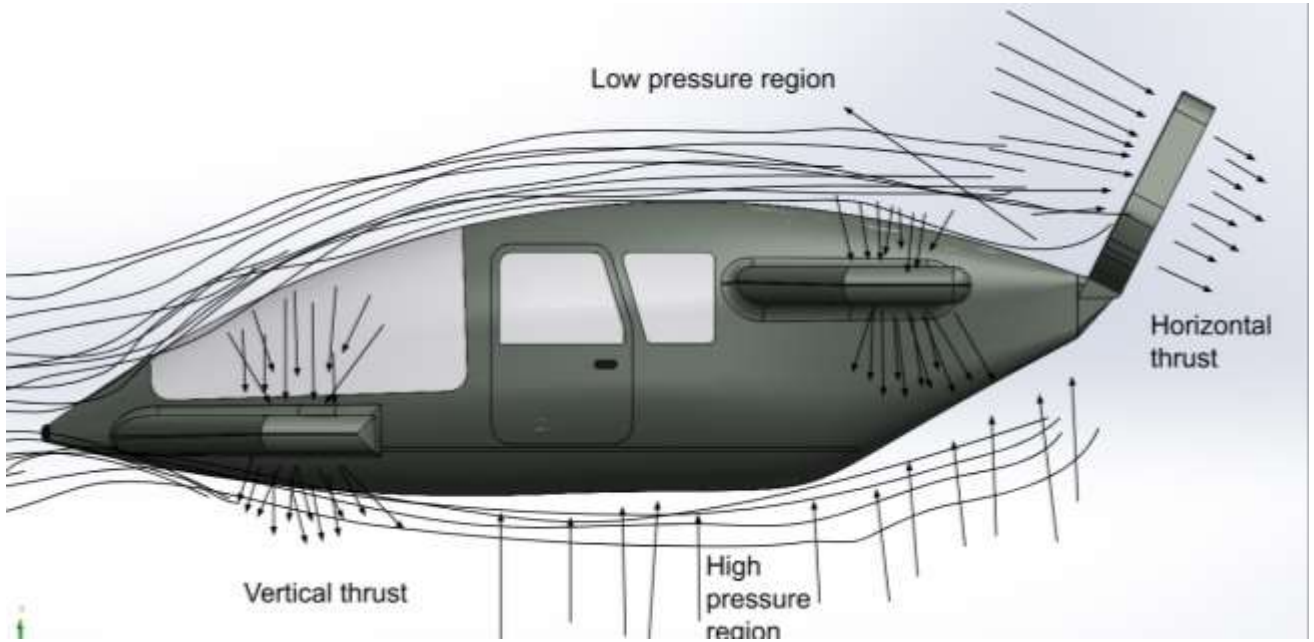
- ITEG propeller works like a typical brushless inrunner electric motor.
- Stator consists of 12 pole 3 phase electromagnets and rotor has 4 PM.
- ESC is connected to the ITEG motor to controller the motor speed.
- The voltage ranges from 100V-550V and continues current of 200A.

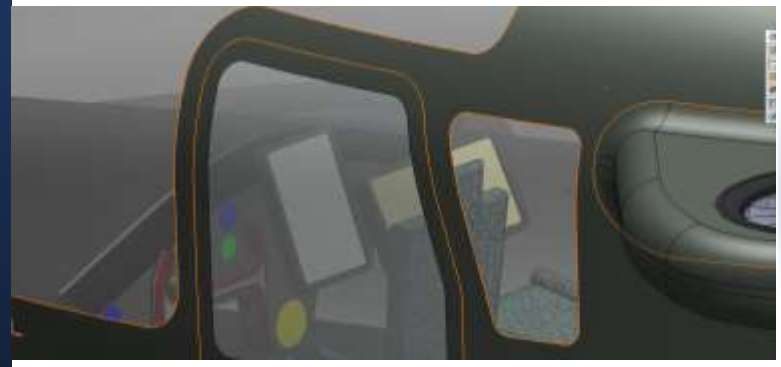


eVTOL smart flight

- This flight consists of 4 vertical thrusters in the side and 3 horizontal thrusters in the tails of the flight.
- The flight can carry 1 pilot + 3 passengers along with luggage.
- The major part of the body is made of carbon fibre and some part will be fibreglass reinforcement, aluminium and steel.
- The body is designed to help aerodynamic requirements, this designed like an aerofoil.
- The sharp front muzzle and curved body helps to move quickly through air with minimal resistance.
- 7 meters in length and 3.7 meters in height. Estimated weight and range will be around 400kg and 200km.
- Flight is well equipped with sensors, actuators and radio transmitters.
- For the passengers safety flight has flight parachute, seatbelts, airbags and mesh protection for propellers.

Flight design



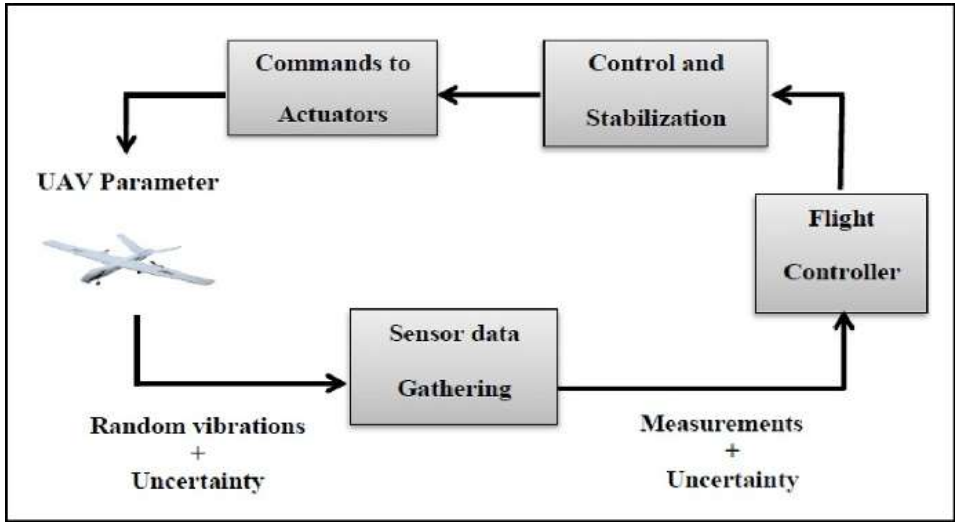


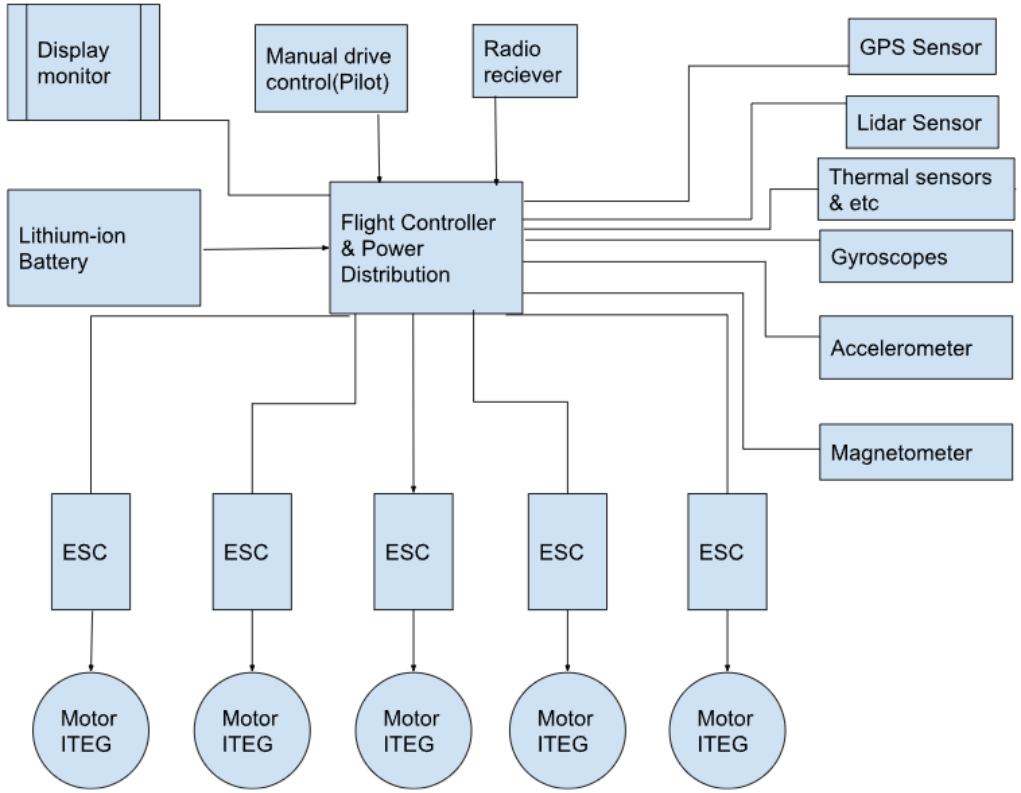
Flight and propeller concepts

- **DEP**- Distributed electric propulsion, it comprises multiple small fans or propellers run by electric motor. Collective propellers in an aircraft instead of one.
- Safety and stability.

- **Rim driven thruster**- The rotor is driven by the rim of the engine. It is similar to ITEG but here rollers are used as bearings. Which resists some amount of rotation.

Flight control system





Results

- **Useful volume of the ITEG propeller-**

$V = S * \mathrm{L}$

$V = \{\pi(R\ 2 - r\ 2\ ) - [\sum \mathrm{k}\ \pi(Rj2 - rj\ 2\ ) + (R - r) * s * n\ k\ j{=}1\ ]\} * \mathrm{L}$

S- total useful surface in the rotor crown

R- max radius of the circular crown

L- length of the rotor ducts

r- min radius of the circular crown

k- no. of circular crowns

n- no. of radial walls

- **Flow**

$Q = n * \mathrm{V}$ V- total useful volume n – number of revolution/unit of time

Results

- **Thrust**

T= ρSV(1+a)[Vs-V]

T=2ρSV 2 a(1+a)

Let Vo= V+Vi

Vi=aV

a=Vi/V

substitute value of "a" in thrust equation

T= 2ρSVi(V+Vi)

Vo= Velocity at the propeller

V= Velocity at section 1 at free stream

Vs= Slip stream velocity

S- area of the propeller

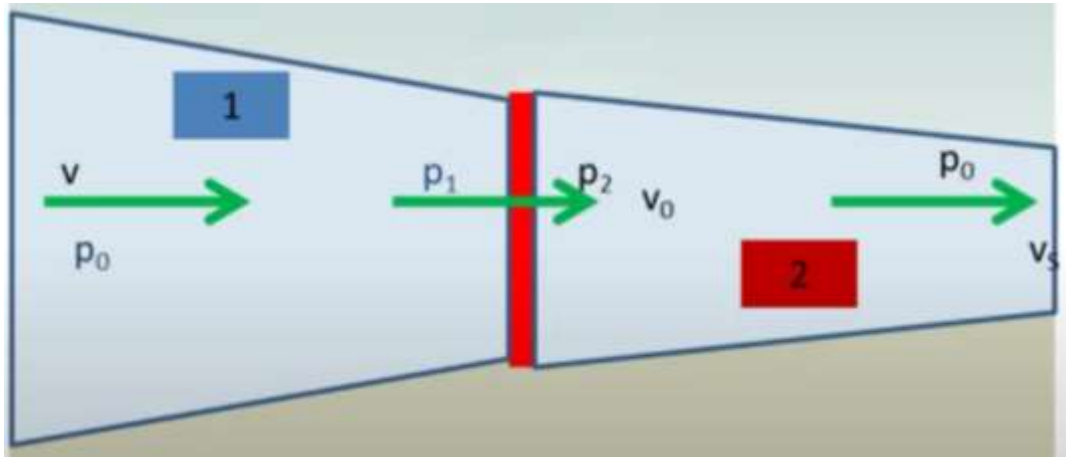
P1= Pressure at the inlet of propeller

Po= Pressure at section 1 and section 2 at V and VS

P2= Pressure at the outlet of the propeller

a = Inflow factor

ρ= density of the air



Results

- **Efficiency**

  η= TV/P

  We can rewrite efficiency equations as

  η = 1/1+a

  η = 1 / 1+(Vi / V)

- The estimated aerodynamic efficiency is $\eta i = 0.95 - 0.99$
- The estimated volumetric loss is $\eta v = 0.99$
- The estimated mechanical loss is $\eta m = 0.99$
- The total efficiency of the machine is $\eta = \eta v * \eta m * \eta i$ it ranges between 0.95 and 0.98.

Advantages

- eVTOL aircraft helps in **vertical take** off and landing which is very helpful for cities and any small landing site.
- It is **emission free** since it uses electric motor as its propeller, **Less noisy.**
- ITEG is more **efficient** so its operating cost will be less.
- 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.
- It is cheaper to operate or **low operating cost** compared to helicopter, cargo jets etc
- Anyone can able to fly in this eVTOL aircrafts, **no pilot license** required to fly this vehicle.
- eVTOL smart flight can fly in **low altitudes**. So it can safe energy and also with low atmosphere pressure it can be operated.
- The ITEG propeller gives **good stability** to the flight.

Applications

❖**ITEG propeller**

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

Applications

❖**eVTOL smart flight**

1. Air taxi service for passenger travel.
2. Emergency and medical evacuation
3. Cargo transport
4. Rescue operations
5. Low Altitude flying vehicle
6. Coast guards, navy and army to monitor the region.

Future scope

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

Conclusion

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.

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

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.

Thank you