3D PRINTED BLENDED WING DRONES

Development Engineering Project

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ENDSEM REPORT

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CANDIDATE'S DECLARATION

We hereby certify that the work which is presented in the report, entitled "3D PRINTED BLENDED WING DRONES" in part fulfillment of the requirement for the award of the Degree of Bachelor of Technology and submitted in the Department of Mechanical Engineering of Indian Institute of Technology Ropar is an authentic record of our own work carried out during the period from January, 2023 to May, 2023 under the supervision of Dr. Srikant Sekhar Padhee

The matter presented in the report has not been submitted by us for the award of any other degree of this or any other University/Institute.

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Signature of the Candidates

This to certify that the above statement made by the candidates is correct to the best of my knowledge

Date: May 9, 2023

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Introduction

Blended-wing drones, also known as blended-wing body (BWB) drones, are an emerging type of unmanned aerial vehicle (UAV) with a unique design that differs from traditional drones. Blended wing drones have a blended wing design where the drone's body is integrated with the wings, creating a more aerodynamic and efficient shape. Blended wing body shape combines the benefit of both a flying wing and conventional aircraft. A typical quadcopter design has four rotors, while this has a blended wing design where the drone's body is integrated with the wings. The design of blended-wing drones allows for greater lift and increased range while reducing fuel consumption and noise levels.

Blended-wing drones have several advantages over traditional drones:

1. Increased Payload capacity: As blended-wing drones have a large internal volume, it allows them to increase their payload capacity compared to traditional drones.
2. Greater Range and Endurance: Blended-wing drones can stay in the air longer as they are more fuel efficient than traditional drones.
3. Reduced Radar Signature: Blended wing design helps us reduce the radar cross-section area, making it difficult to detect by radar.
4. Improved Maneuverability: Blended wing design and lack of tail help improve the system's aerodynamics, which helps in maneuverable flight.
5. More space for sensors: As blended-wing drones have a large internal volume, it provides space for different types of sensors and other equipment, which can increase the application of the system.

However, blended-wing drones have certain constraints:

1. Limited Maneuverability in tight spaces: The larger size and blended wing design of BWB drones can make them more difficult to maneuver in tight spaces, such as urban environments.
2. Complexity in design: Designing blended wings requires specific industry experts and manufacturing techniques.
3. Increased Production cost: Blended-wing drones have complicated designs and require special expertise and manufacturing, resulting in higher production costs.
4. Limited Flexibility: Specialized design leads to less modification flexibility than traditional drones.

Blended-wing drones are being developed for various applications, including military operations, cargo delivery, environmental monitoring, and aerial surveying. They are also being considered for urban air mobility, which involves transporting people and goods in urban environments using unmanned aircraft.

3D printing has emerged as a popular drone manufacturing technique, including blended-wing drones. 3D printers are an effective tool for rapid prototyping since they can produce complex geometry in various materials. Using advanced materials and printing techniques, designers can create parts with high strength-to-weight ratios, reducing the drone's overall weight and improving its performance.

Some advantages of 3D printing for drone manufacturing include faster prototyping, reduced costs, and greater design flexibility. However, certain limitations, such as material strength and durability, need to be considered when designing and manufacturing drones.

Some common 3D printing methods for drones include Fused Deposition Modeling (FDM) and Stereolithography (SLA). We should choose materials that are lightweight, durable, and can withstand the stresses of flight.

Fused Deposition Modeling(FDM): Fused Deposition Modeling (FDM) is a popular 3D printing technology used to create three-dimensional objects by depositing layers of molten material on top of each other. A spool of thermoplastic material, like ABS or PLA, is heated and extruded via a nozzle in this additive manufacturing technique. The first step in the process is to slice a digital 3D model of the item to be printed into numerous layers. After reading the sliced file, the printer begins printing the item layer by layer, working its way up. The build plate moves down along the Z-axis to make space for the next layer as the nozzle moves back and forth along the X and Y axes as each layer is printed.

Advantages:

1. Ease of use and accessibility
2. Create complex shapes and geometries

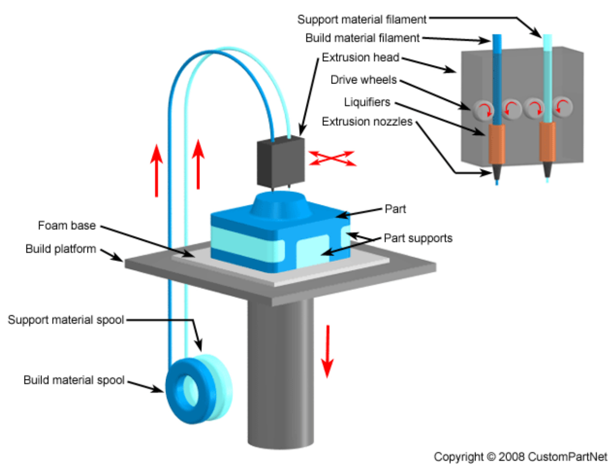

Fig 1: Fused Deposition Modeling

Objective/Aim

The field of drone technology has seen significant advancements in recent years, with 3D printing playing a key role in developing these unmanned aerial vehicles. 3D printing allows for the creation of complex and customised parts, making it an ideal technology for designing and producing drones.

Using blended wings in drone design has also gained popularity as it offers numerous benefits, such as increased aerodynamic performance, better energy efficiency, improved stability, and reduced drag. These wings, which are seamlessly integrated into the drone's body, allow for smoother airflow and reduced drag, resulting in increased flight time and range.

By combining 3D printing and blended wing design, we can create highly efficient and customisable drones that can be tailored to specific needs and applications. These drones can be used for various purposes, such as surveillance, agriculture, mapping, etc. 3D printing will allow for the production of lightweight and strong materials that can withstand the high stresses and strains that drones encounter during flight. This makes creating durable and efficient drones possible, essential for long-term use and cost-effectiveness. It also has the potential to make drones more affordable.

Overall, the combination of 3D printing and blended wing design will offer numerous benefits in the development of drones, including increased efficiency, customisation, and durability.

Problem Description

Drones or UAV technology for Unmanned Aerial Vehicles are being deployed to more and more applications and industries. These drones can operate under remote control by a human operator or autonomously by onboard computers. The opportunities offered by drones are endless; they are now used in several sectors, such as agriculture, military, aerospace, cinema, and security.

Designing and producing drones with optimal aerodynamics and minimum operational weight is a major challenge. Achieving the right balance between weight and power is crucial for drone performance. Unfortunately, many drones are caught in a problematic cycle where they rely on batteries for power and require greater power reserves when carrying payloads. This results in a need for bigger batteries to generate more power, which adds more weight. To counteract this weight, more power is required, leading to the need for even bigger batteries, and so on. This creates an unforgiving cycle that can spiral in the wrong direction, ultimately impacting drone performance.

The military's reliance on UAVs for carrying out missions highlights the potential significance of on-demand manufacturing and repair services. In situations where delivery is difficult or time is of the essence, locally, having the ability to quickly produce a drone or necessary spare parts, such as propellers, could be the most dependable procurement method. Additive manufacturing technology can facilitate the rapid production of needed items. Moreover, manufacturing and repair can be made even easier and faster if a military unit is located at a base with a 3D printer.

Payloads can be a major factor in adding weight to drones, which can harm the overall balance and stability of the aircraft. Such weight imbalance can adversely affect various aspects of flight performance, including range, speed, and manoeuvrability. Additionally, operating a drone with an added payload requires additional power, which ultimately reduces flight time and the overall operating efficiency of the aircraft. However, the blended wings design presents a potential solution to the problem of carrying payloads. This design provides a larger internal volume that can accommodate more payloads without compromising the balance and stability of the drone. This means that the blended wings design can potentially allow drones to carry more weight without negatively affecting flight performance, range, and operating efficiency.

Aerodynamic drag results from air resistance that drones experience when they move through the air. It can lead to decreased flight performance and increased energy consumption, especially when drones fly at higher speeds or in windy conditions. However, the Blended Wing Body (BWB) design can address this problem by reducing drag and improving the overall aerodynamic efficiency of the drone. Doing so can significantly increase the drone's flight time and range, proving advantageous in various applications such as aerial mapping and surveying, where drones must cover vast areas.

Fuel efficiency is a major concern for drones, requiring fuel or battery power to fly. Achieving fuel efficiency is challenging due to the weight of the drone and its propulsion system design. A heavier drone requires more energy to stay airborne, reducing fuel efficiency. Propellers with poor design generate more drag, increasing the energy required to maintain lift. Inefficient propulsion systems require more fuel or battery power to fly, decreasing fuel efficiency. Environmental factors such as wind, temperature, and humidity also affect fuel efficiency by increasing the energy required to maintain flight.

Drones can produce a lot of noise, especially larger ones with powerful engines and propellers. This can cause disturbances in residential areas, wildlife habitats, and public spaces and raise concerns about privacy and security. Quieter drones can be more effective in stealth operations such as surveillance and reconnaissance. The blended wings body (BWB) design can be a potential solution to reduce drone noise levels. The unique shape of the BWB design smooths the airflow over the drone's body, reducing turbulence and noise. Moreover, the BWB design can improve lift and stability, allowing the drone to operate at lower speeds and reduce noise.

Overview

We aim to create a 3D-Printed drone. To ensure that the frame parts meet the necessary requirements, we have used several methods during the design process. Our design work is being carried out using 3DEXPERIENCE Solidworks software. The drone's frame comprises two main parts: the centre square plate and the arms. We have used Polylactic acid (PLA) material to manufacture the parts. To achieve the optimal weight and prevent the potential overheating of the drones' batteries or other parts, we have incorporated spaces into the design of the centre plates to allow for adequate cooling. Additionally, the arms of the drone have been developed with a webbed pattern to minimise weight while maintaining the structural stability of the device. After the printing process is complete, we will attach elements such as batteries, propellers, motors and other necessary components. Once all the attachments and connections are in place, we will test-fly the drone to ensure it meets the required performance standards. As we continue to refine our design, we plan to modify the arms with a blended wings body(BWB). BWB is an aircraft design that integrates the wing and body into a single integrated part, resulting in improved aerodynamic efficiency and optimisation. By incorporating this design element into the drone, we believe we can improve its performance and achieve better flight performance.

Existing Studies

3D printing is also known as additive manufacturing, in which objects are created layer by layer. This technology has its inception in the 1980s, and since then, it has evolved a lot. In recent years, there has been a significant increase in the use of 3D printing for manufacturing, especially in the aerospace, automotive and medical industries. Since this technology can produce highly accurate, complex and customised parts quickly and cheaply, it is increasingly used in manufacturing drones. Also, 3D-printed drones are a promising development area for the drone industry, potentially transforming how drones are manufactured. There are several existing studies on the 3D printing of drones. These are

- “A 3D Printed UAV for Environmental Monitoring”(2016) - This study presents the design, development and flight testing of a 3D printed drone for environmental monitoring. The researchers used an FDM printer to create the drone’s frame and other components, and they found that the drone could collect data on temperature, humidity and other environmental parameters.
- “Design and Additive Manufacturing of a UAV wing” (2017) - This study focuses on a UAV wing's design and 3D printing using an FDM printer. In it, the researchers used a combination of computer-aided design (CAD) software and finite element analysis (FEA) to optimise the wing’s design and then printed it using ABS plastic. They found that the 3D-printed wing was structurally sound and performed well in flight tests.
- “3D Printing of Lightweight UAV Propellers” (2018) - This study explores using 3D printing to create lightweight UAV propellers. In it, an FDM printer is used to create the propellers using carbon fibre-reinforced nylon material, and it is found that the 3D printed propellers performed well as compared to traditionally manufactured ones.
- "Design and fabrication of a quadcopter using 3D printing technology" (2018) - This study describes the design and construction of a quadcopter using 3D printing technology. The researchers used a Fused Deposition Modeling (FDM) printer to create the drone's frame and other components. They found that the 3D printed parts performed as well as traditionally manufactured parts.
- “Design and Manufacture of a 3D Printed Quadcopter with Open-Source components” (2019) - This study describes the design and production of a 3D printed quadcopter using open-source hardware and software components. FDM printer is used to create the drone’s frame and other components, and it was found that the drone could perform various tasks, including obstacle avoidance and automated flight.
- “Development and Testing of 3D printed Quadcopter Frames” (2019) - The study focuses on testing the performance of 3D printed quadcopter frames under different flight conditions. A variety of materials and printing methods are used to create the frames, and it is found that some designs are more successful than others.

- "Design and prototyping of a 3D-printed blended-wing-body UAV" by F. Topuz and M. Colak, published in the Journal of Intelligent and Robotic Systems in 2019. This study describes the design and prototyping of a 3D-printed blended wing drone for environmental monitoring applications, including the design and optimisation of its propulsion system, control surfaces, and sensors.
- "3D Printing of Multi-Material UAVs for Rapid Prototyping and Customization" (2020)- The study presents a method for 3D printing multi-material UAVs using an FDM printer. A custom printing nozzle is created that allows the researchers to print multiple materials in a single pass, and this method is used to create a drone with both rigid and flexible components. It is found that the multi-material printing process allows rapid prototyping and customisation of UAV designs.
- "3D Printing of Unmanned Aerial Vehicles (UAVs): A Review" (2020) - This paper provides a comprehensive review of the use of 3D-printed drones specifically designed for search and rescue missions. A Stereolithography (SLA) printer is used to create the drone's frame and other components, and it was found that the drone performed well in flight tests.
- "Design and testing of a 3D printed blended wing-body micro air vehicle" by D. Parker et al., published in the Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering in 2020. This study focuses on designing and testing a 3D-printed micro-blended wing drone, including its aerodynamic performance, stability and control, and payload capacity.
- "Design and testing of a 3D-printed blended wing-body UAV for low-altitude surveillance applications" by S. S. Sreejith and S. N. Omkar, published in the Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering in 2021. This study describes designing and testing a 3D-printed blended wing drone for low-altitude surveillance applications, including its payload capacity, endurance, and stability performance.

These are some of the existing research on 3D-printed drones. As the technology continues to develop, we can expect to see more studies exploring the use of 3D printing in drone production and its potential applications in various industries.

Methodology and current status

- Design:

  For our 3D-printed drone, we have decided on a quadcopter design with 2 square centre plates. The centre plates have been designed with spaces to reduce weight and allow cooling to prevent overheating of batteries or other components. Between the two centre plates, there will be space for the battery, the controller and other electronic components. The arms of the drone have been designed in a webbed pattern to reduce weight while still being structurally stable. The motors and propellers will be mounted at the end of the arms. We have performed a centre of mass analysis to make sure the centre of mass is between the two plates and as close to the centre as possible. Because the battery is heavier than other components, the centre of mass is slightly on one side. A rendering of our design is given below;

Fig 2: A rendered image of CAD design

An image of our 3D-printed parts is attached below;

Fig 3: Printed base plate

Fig 4: Printed arm

Fig 5: All parts kept together after printing (Not attached)

Once the basic design is ready and verified, we plan to move to our main part, the blended wing. This wing will be designed like an aerofoil shape, and then 3D printed. We plan to test multiple shapes and iterations for a good configuration with the best possible efficiency.

- Electronics:
    1. Propellers: We are using 10 inches diameter propellers made of ABS with a 4.5 inches pitch.
    2. Motors: We are using A2212 1000KV brushless motor. The motors will be connected to the controller via an Electronic Speed Controller (ESC). We are using a 30A ESC.
    3. Batteries: We are using a 3-cell 2200mAh battery.
    4. Power distribution board: We are using a power distribution board to divide the power from the battery to the motors and the controller.
    5. Flight controller: We are using a KK 2.1.5 LCD flight control board to control our drone.

       A brief about the controller:

       The KK2.1.5 Multi-Rotor controller manages the flight of multi-rotor drones. The drone remote controller's purpose is to stabilise the aircraft during flight; to do this, it takes signals from onboard gyroscopes (roll, pitch, and yaw). It passes these signals to the Almega324PA processor, which processes signals according to the user's selected firmware (e.g. Quadcopter) and passes the control signals to the installed Electronic Speed Controllers (ESCs). The combination of these signals instructs the ESCs to make fine adjustments to the motors' rotational speeds, stabilising the craft. It also takes input from the receiver we are using and passes the signal via the Almega324PA processor to the motors.

6. Controller and Receiver: We are using FlySky FS i6X 2.4GHz 6 channel RC transmitter coupled with FS-iA10B 2.4GHz Receiver. This is needed to give user input to the controller and hence the drone.
   A circuit block diagram is shown below;

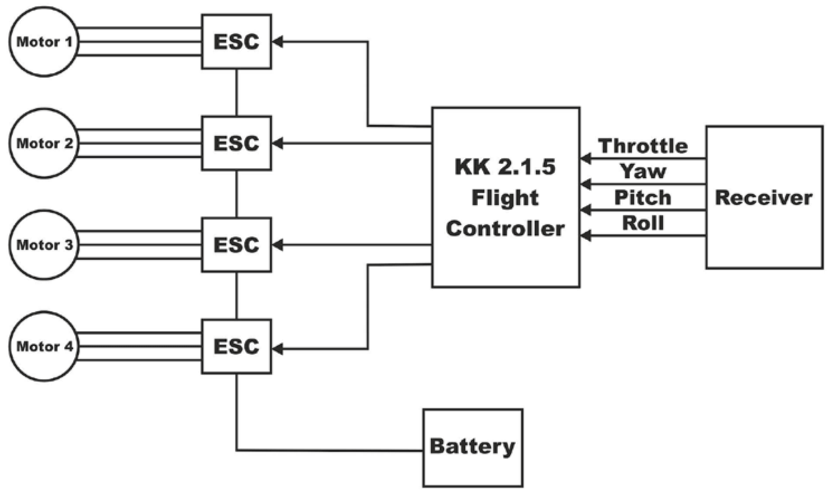

Fig 6: Block diagram of the circuit

- Current Status: In the second half of our project, we assembled all the parts of our drone. We faced multiple challenges during the assembly. Since 3D printed parts are not very strong, we had multiple fractures in our parts while trying to put a nail inside etc. Apart from that, we also had issues related to the sizing of the electronics and the printed parts. We had to make changes in the design of the arms to adjust for these discrepancies. After this, we re printed these newly designed arms which were finally used in the assembly.
  Once the printed components were assembled we moved on to the electronics. The motors were installed on the arms and the propellers were then installed on them. The 4 motors were connected to an Electronic Speed Controller (ESC) each. The ESCs will also be connected to the batteries using a Power Distribution Board (PDB). We did not receive our KK 2.1.5 flight controller due to reasons unknown to us. Without this flying the drone was impossible and hence we could not accomplish that.

Fig 7: The drone with all available parts assembled

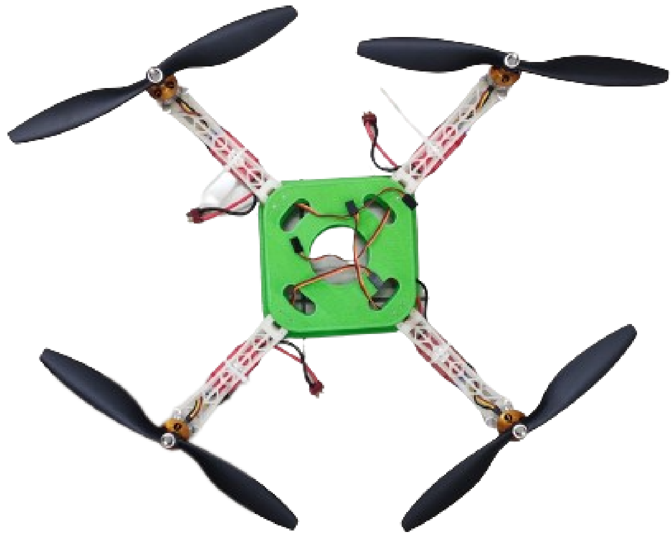

Fig 8: The drone with all available parts assembled

While waiting for the Flight Controller to arrive, we started working on the design for our wing. We designed our wing in a modular way so that it could be easily clipped onto the existing arms whenever required. We printed this design in 2 different printers on 2 different settings to have 2 different wings which we could then study for properties. We tried installing the wings and they fit perfectly. Because of the modular design, it can also be removed as and when required. Since we did not have our Flight Controller, we could not test these wings as well. The design and the actual printed wings are attached below;

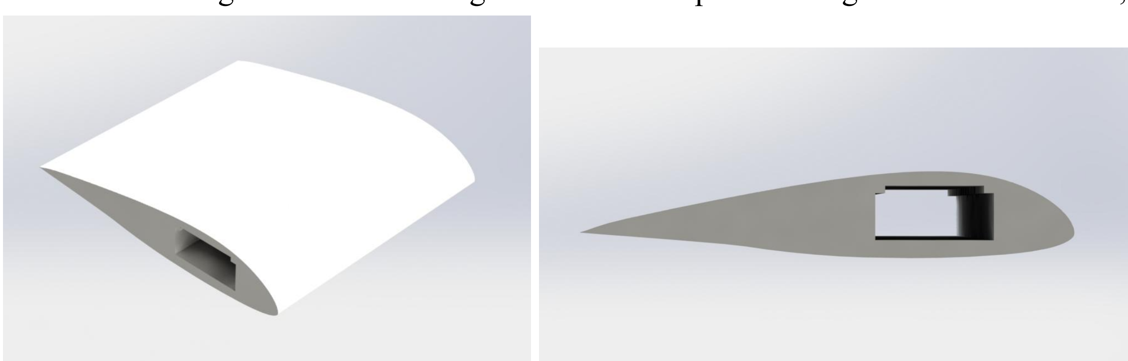

Fig 9 and 10: Isometric and Side views of the designed wing

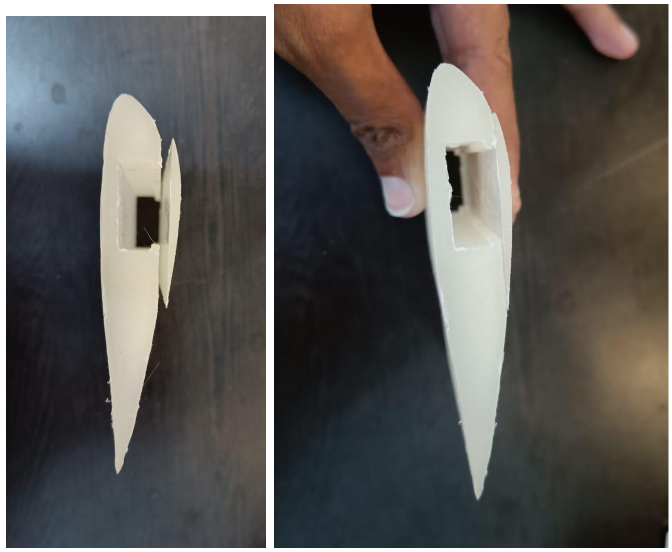

Fig 11 and 12: The printed wing parts from 0.2mm nozzle printer

Fig 13 and 14: The wing clipped onto the arm of the drone.

Fig 15 and 16 : Another printed wing parts from 0.4 mm nozzle printer

Calculations

The drone uses 4 motors of 1000kV,
Other Motor and Propeller Specs are as follows:

- Blade length = 10 inches
- Prop Pitch = 4.5 inches
- Operating Voltage for Motors =11.1 V
- Max Current = 13.5A
- Motor Efficiency = 80% (4-10 A)
- Max.Power = 150W

Power Input to the motor = 11.1 V * 13.5 A = 150 W
Motor Efficiency = 0.8

Applying Energy Conservation,

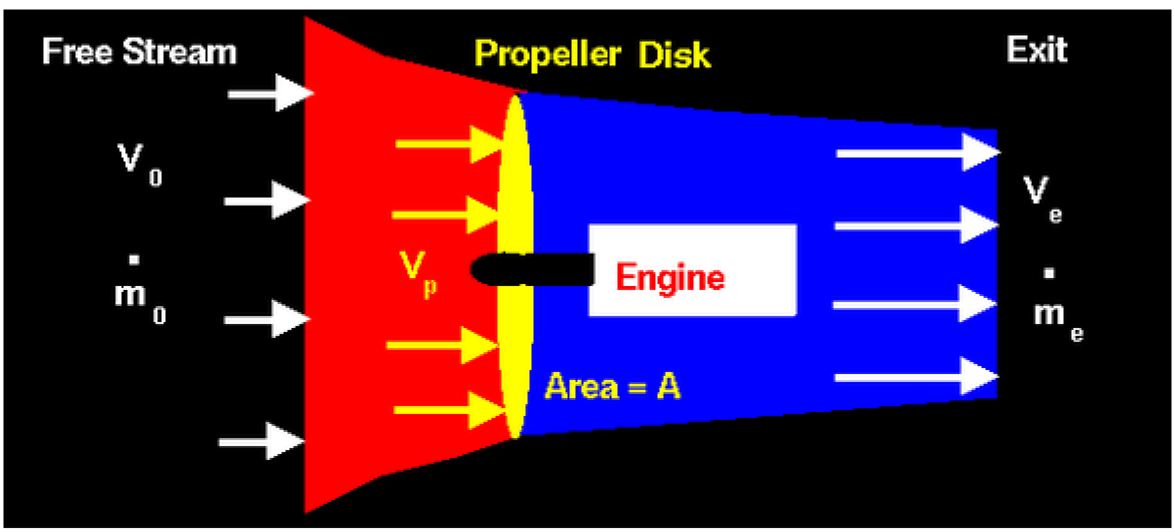

Fig17: Schematic of air movement around the propellers

$$P + V \times (P_1 + \frac{1}{2} \rho v_1^2 + \rho g) = V \times (P_2 + \frac{1}{2} \rho v_2^2 + \rho g)$$

Where,
V= Volume of Air flowing through the Propeller
P_1= Initial Pressure of Air

P_2= Final pressure of Air
ρ= density of air
v_1= initial velocity of air
v_2= final velocity of air accelerated by propeller
g= acceleration due to gravity
P= Input Power from propeller

Assuming,
- ➢ Negligible change in Potential Energy across Propeller,
- ➢ No change in pressure
- ➢ The density of air remains constant,
- ➢ Propeller is Ideal, i.e., the air flow remains rectilinear and uniform

Input Power from propeller,

$$P = \frac{1}{2} \times \rho \times (v_2^2 - v_1^2) \times V$$

In hover, input velocity, v_1=0

Implies,

$$A * v_0 * v_2^{\ 2} = 2 * \frac{P}{\rho}$$

Assuming velocity of air at propeller = (Velocity at entry + velocity at exit)/2

$$v_0 = \frac{(0+v_2)}{2}$$

$$v_2 * v_2^{\ 2} = 4 * \frac{P}{(A*\rho)}$$

$$v_2^{\ 3} = 4 * \frac{P}{(A*\rho)}$$

Now,
Input Power= (Efficiency* Max. Power input to motor)
= (Efficiency of propeller* efficiency of motor * 150)
$= (\eta_p * \eta_m * P_m)$
$= \eta_p * 0.8 * 150$ W

$$\boxed{v_2 = (\frac{4*\eta_p*\eta_m*150}{(A*\rho)})^{1/3}}$$

Thrust force = $(\frac{d}{dt})(m) * (v_2 - v_1)$

$= \rho * V * (v_2 - v_1)$

$= \rho * A * v_2 * \frac{v_2}{2}$

$= \rho * A * \frac{v_2^{\,2}}{2}$

Putting Value of v_2, we get,

Thrust Force,

$$\boxed{T = (\frac{1}{2} \times \rho \times A \times (\frac{4\ \eta_p \eta_m\ P_m}{(A \times \rho)})^{2/3})}$$

Area Spanned by Propeller $= \pi \times \frac{dia^2}{4}$

= 3.1415 * 25 sq. in

= 78.5 sq. in

= 0.05067 sq. m

Density of Air @20C and 1 atm Pressure = 1.204 kg/m^3

$$T = \frac{1.2}{2} \times 0.05067 \times (\frac{4 \times 0.8 \times 150}{0.050607 \times 1.204})^{2/3} \times (Propeller\ Efficiency)^{2/3}$$

$$= 12.124 \times \eta_p^{\,2/3}$$

Assuming Propeller Efficiency of 50%,
T = 7.644 N
Load Carrying Capacity Per motor = 781.24 g

This confirms with seller specification, 800g thrust for 1045 propellers per motor, justifying the propeller efficiency assumption

Number of Motors =4
Total Thrust Force = 30.57N
Total Load carrying Capacity = <u>3.117 Kg</u>
(This includes the weight of the drone as well)

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