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Design, Modelling & Development of VTOL with weight optimisation and avionics selection

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ABSTRACT

VTOL has made significant growth in recent years. Be it surveillance and rescue purposes in Military operations, Transportation, Environmental Monitoring, Agriculture and so on. In the last 8-10 years different concepts related to vertical take-off and landing aircrafts have been tested. This research focuses on the comprehensive design, modelling, and development of a Vertical Take-off and Landing (VTOL) aircraft, emphasizing the pivotal aspects of weight optimization and avionics selection. The study aims to enhance the overall performance, efficiency, and functionality of VTOL systems through a multidisciplinary approach. The design process prioritizes weight reduction strategies without compromising structural integrity and safety. The research methodology involves a systematic modelling process, employing state-of-the-art simulation tools to assess the aerodynamic, structural, and propulsion aspects of the VTOL aircraft. The study incorporates real-world constraints and operational scenarios to ensure the practical applicability of the proposed design. By amalgamating theoretical frameworks with empirical data, the research aims to establish a robust foundation for the development of high-performance VTOL aircraft capable of meeting various customization capabilities. The outcomes of this research are anticipated to contribute significantly to the field of aviation by providing a holistic understanding of the interplay between weight optimization and avionics selection in VTOL systems. The findings hold implications for both academic research and industry applications, offering insights that can influence the future design paradigms of VTOL aircraft, ultimately paving the way for more efficient, versatile, and technologically advanced aerial platforms

Keyword: - Vertical Take-off and Landing, Tilt Rotor, Pixhawk Flight Controller, 3-D Printing, Air-Foil Goe-137, Delta Planform

1. INTRODUCTION

VTOL stands for "Vertical Take-off and Landing”, It represents a groundbreaking idea in aviation: the ability of aircraft to fly vertically, doing away with the requirement for traditional runways. The fundamental characteristic that distinguishes vertical take-off and landing (VTOL) aircraft is their ability to lift off and land vertically, which overcomes the constraints of conventional aircraft that need a large runway to perform take-off and landing operations. This incredible ability changes the dynamics of flight and provides unmatched manoeuvrability and operational flexibility by allowing aircraft to hover, take off straight from the ground, and descend smoothly in confined spaces.

The military, commercial, emergency services, and urban mobility sectors are all changing their paradigms as a result of the operational significance of vertical take-off and landing aircraft. VTOL capabilities provide military applications with strategic advantages by facilitating quick deployment and manoeuvrability in a variety of difficult terrains. The Lockheed Martin F-35 Lightning II is a prime example of how VTOL technology is combined with cutting-edge combat systems, demonstrating the flexibility and agility required for contemporary warfare. Beyond the military, urban air mobility is about to undergo a revolution thanks to the commercial potential of vertical takeoff. Ideas like electric vertical take-off and landing (eVTOL) vehicles picture a time when congested cities will welcome the speed and convenience of on-demand air travel. These developments have the potential to completely alter urban environments by providing a smooth and environmentally responsible way to commute through busy.

When considering the future, VTOL technology has a lot of potential and promise. The goals of ongoing research and development are to increase scalability, sustainability, and efficiency. New developments in autonomous systems, electric propulsion, and battery technology usher in a new era of vertical takeoff and landing (VTOL) aircraft that are more accessible, have less of an impact on the environment, and use less energy. Furthermore, the incorporation of vertical take-off and landing (VTOL) capabilities into developing aerial mobility services and urban infrastructure portends a future in which skyways are crowded with a variety of aerial vehicles that will change the face of transportation and influence cities of the future.

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1.1 Problem Statement and Identification

This project presents an analysis of the design and development process of a more intelligent, aerodynamically faster, and efficient unmanned aerial vehicle (UAV) known as VTOL. It was accomplished by conducting in-depth market research, examining the available options to determine customer preferences, analysing customer challenges, and benchmarking our design to adhere to industry standards. Both the VTOL's speed and efficiency drop as a result of its heavy frame. In order to solve the aforementioned issue, the frame's design must be altered utilizing aerodynamics, and weight must be decreased using topology, weight optimization, and lattice structure with the aid of CAD software. Quick Deployment: They can be swiftly sent out to perform a range of activities, such as military operations, surveillance, and search and rescue. Decreased Infrastructure: The lack of a large runway infrastructure needed for VTOL aircraft can result in cost savings and increased operating flexibility. Access to Remote Areas: The ability to fly vertically overhead (VTOL) allows access to places that would be challenging for traditional aircraft or vehicles to reach. VTOL aircraft do, however, have certain drawbacks, including greater complexity and generally higher fuel consumption when compared to fixed-wing aircraft.

1.2 Objective of Work

- The primary purpose of using this VTOL is to be user-friendly, more efficient, and relatively economical than other VTOL. The VTOL (UAV) works on a battery-powered by the motor and offer several advantages such as Flexibility: VTOL aircraft can operate in confined spaces, making them suitable for missions in urban environments or remote locations without proper runways.
- Rapid Deployment: They can be quickly deployed to carry out various tasks, including search and rescue, surveillance, and military operations.
- Reduced Infrastructure: VTOL aircraft do not require extensive runway infrastructure, which can save costs and increase operational versatility.
- Access to Remote Areas: VTOL capabilities enable access to areas that are otherwise difficult to reach by conventional aircraft or vehicles. However, VTOL aircraft also have some limitations, such as increased complexity and typically higher fuel consumption compared to fixed-wing aircraft.
- Additionally, some companies are working on electric vertical takeoff and landing (eVTOL) aircraft for urban air mobility purposes, which could revolutionize urban transportation in the future.
- To provide a convenient and effortless commute
- Eco-friendly and energy-efficient VTOL and faster.
- To improve the design of the VTOL (UAV).
- To reduce the weight of the VTOL and to improve the efficiency and range.
- Reducing the required effort of the motor by using a newly modified aerodynamic design and weight calculation.

1.3 Scope of Work

- Being more efficient, cost-effective, and user-friendly than other VTOL is the main reason to utilize it. The motor-powered battery-powered VTOL (UAV) has various benefits, including Adaptability Because VTOL aircraft may fly in small areas, they are appropriate for missions in urban settings or isolated areas lacking adequate runways.
- To further improve urban air mobility, some businesses are developing electric vertical takeoff and landing (e-VTOL) aircraft, which has the potential to completely transform urban transportation in the future.
- To make commuting easy and convenient
- VTOL is more rapid and environmentally and energy-efficient.
- To enhance the VTOL's (UAV) design.
- To lighten the VTOL and increase its effectiveness and range.
- Reducing the required effort of motor by using a newly modified aerodynamic design and weight calculation.

2. LITERATURE OF REVIEW

Win Ko Ko Oo et al, [1] designed, developed and implemented Tri copter mode and aircraft mode for VTOL aircraft system. Firstly, the aircraft design is considered for VTOL mode and then, the mathematical model of the VTOL aircraft is applied to test stability and develop the VTOL mode and the next part is the transition of VTOL mode to aircraft mode.

B. HERISSE et al, [2] describes that VTOL is associated with certain tasks. The first task it concerns is to stabilize the vehicle relative to the moving platform, that is maintaining a constant offset from a moving reference. The second task is concerned by the regulation of automatic vertical landing onto a moving platform. Precise analysis of system stability is provided and simulations are presented.

Akshat Misra et al, [3] demonstrates that by design, Propulsion Analysis, Computational Tools and Simulation, Tilt-Rotor and Control System Development, Flight Control and Navigation, Prototype Development and Testing. These methodologies combine theoretical analysis, computational modelling, experimental validation, and practical testing to advance the understanding and development of VTOL aircraft with enhanced capabilities and efficiency for diverse applications.

Shailesh Sharma et al, [4] portrays a study of VTOL UAV is a hybrid of a helicopter and fixed-wing aircraft because it has the functionality of both types of aircraft. These aircraft possess high hovering efficiencies like a helicopter and a better cruising speed like a fixed-wing aircraft with an enhanced payload capacity. Many interesting applications of these aircraft is attracting researchers to work in this field. In this paper, a CFD approach has been adopted for the analysis of TURAC tilt-rotor type VTOL UAV with the help of XFLRs.

Mohammadreza Mousaei et al, [5] describes the study on design and modelling of a custom tiltrotor VTOL UAV, which is a combination of a fixed wing aircraft and a quadrotor with tilting rotors, where the four propellers can be rotated individually. Afterward, they analyzed the feasible wrench space that the vehicle can generate and design the dynamic control allocation so that the system can adapt to actuator failures, benefiting from the configuration redundancy. The proposed approach was lightweight and was implemented as an extension to an already-existing flight control stack. Extensive experiments validated that the system was able to maintain the controlled flight under different actuator failures.

Giuseppe Notarstefano et al, [6] illustrates the study which focuses on an aircraft structured as a blended wing body with a tilting rotor, enabling vertical take-off and forward flight transition. Also, captures the main features of innovative tilt-rotor aircraft, highlighting challenging control and maneuvering capabilities with complex nine degrees of freedom model to explore the aircraft's dynamics and maneuvering abilities. The optimal control-based strategies to generate non-stationary, aggressive trajectories, particularly for transitions from near hover to forward flight. Numerical computations illustrate these trajectory generation techniques.

Yu, S et al, [7] describes that VTOL combines the benefits of multicopters and fixed-wing aircraft, enabling vertical take-off and landing with high-speed flight. While multicopters can't exceed the speed of sound and fixed-wing aircraft need runways, VTOL provides versatility for various industries. Also, it supports high-resolution photography, smartphone integration, and control of forest, water, and traffic situations.

3. METHODOLOGY

Developing a tilt-rotor VTOL aircraft using 3D printing and PLA material, it starts with an initial study defining the project's objectives, followed by the literature review to understand similar projects and best practices in VTOL design and 3D printing. Next, selecting an best airfoil shape based on performance requirements and optimize it for efficiency. Design the VTOL using CAD software, performing structural, aerodynamic, and thermal analyses to ensure the integrity and performance of the design. Choose avionics components that meet the requirements and integrate them into the aircraft. Develop detailed models and simulate flight dynamics and control systems, making design adjustments which is needed. Preparing the models for 3D printing, adjusting printer settings for optimal results, and print the components using PLA. Post-process the printed parts and assemble the VTOL, integrating avionics and other systems. Conduct ground and flight tests, collecting and analyzing data to evaluate performance and efficiency. Iterate on the design and continue testing as necessary to optimize the VTOL.

4. AIR-FOIL ANALYSIS

For Air-foil selection, 96 different air-foils were analysed on the XFLR5 software. In order to obtain the optimum results from the XFLR5 software, considering all the performance parameters the team followed the method of Weighted Sum Model. Weights were assigned according to the most desired and undesired characteristics of an air-foil and 3 air-foils out of 96 were shortlisted. Out of all the analysed air-foils E-471il presented most Optimum results and thus was finalized.

The table below provides the results from the analysis of air-foils ;

Air-foil	L/D max	Cl max	Cd (L/D max)	Cd (Cl max)
Goe-137	57.27	1.301	0.018	0.070
k3311	46.3	1.102	0.024	0.024
E471-il	47.8	1.313	0.018	0.069

Table 4.1 - Results from Analysis of various air foils

Air foil selection:

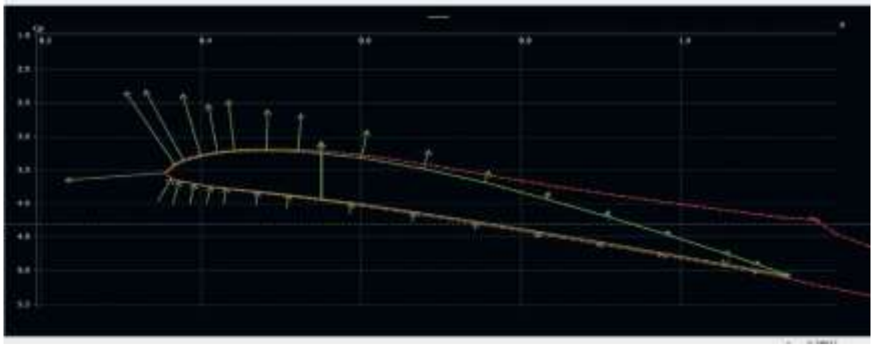

Fig.4.1 – Air-foil GOE-137

Graphs of result :

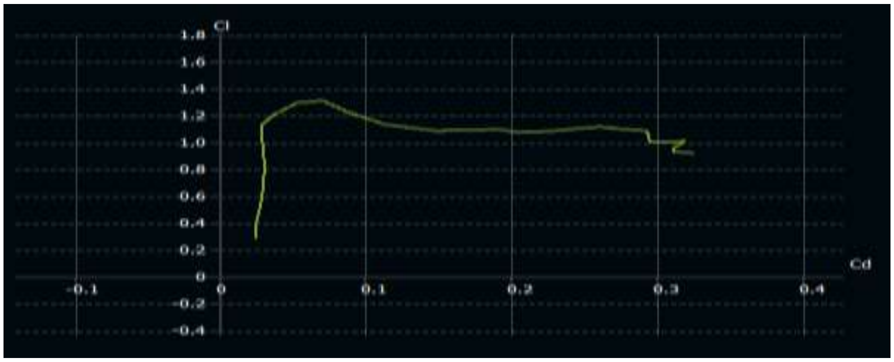

Fig.4.2 Cl v/s Cd graph

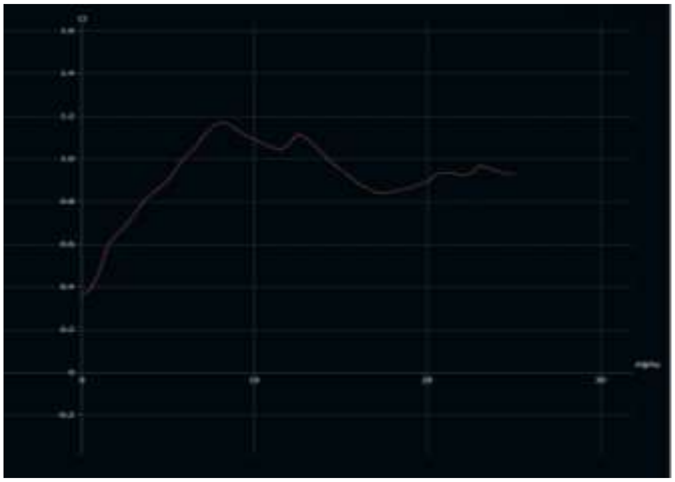

Fig.4.3- Cl v/s Alpha graph

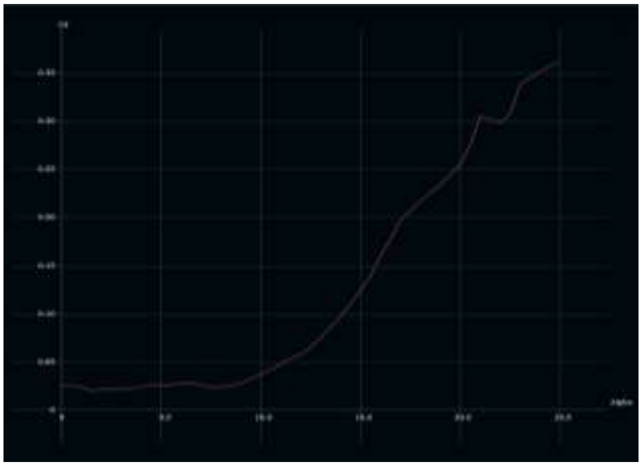

Fig.4.4- Cd v/s Alpha graph

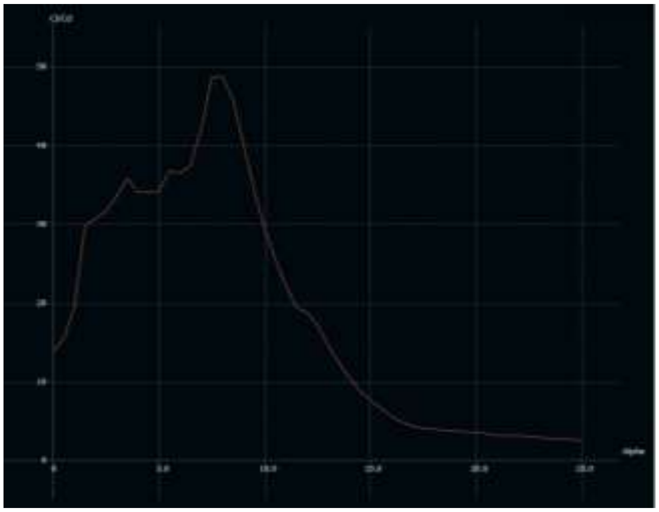

Fig.4.5- Cl/Cd v/s Alpha

5. PLANFORM

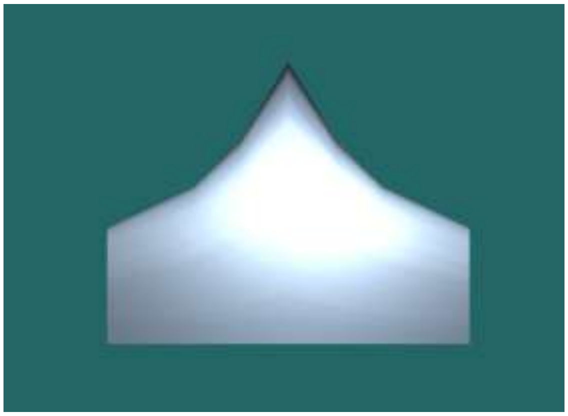

Fig.5.1 Planform

There are multiple types of planforms like rectangular which is easy to design and manufacture but not much aerodynamically efficient. Elliptical form is aerodynamically best but very difficult to manufacture. Tapered and recto-trapezoidal forms are aerodynamically efficient compared to rectangular and easy in manufacture compared to elliptical. The Delta wing is triangular shaped, used in jet fighters

5.1 PLANFORM SELECTION

In this project, the planform selected for VTOL is semi-delta or Concorde. This incorporates the advantages of both Delta as well as tapered recto-trapezoidal.

5.2 Benefits of delta form:

- A delta wing combines low relative wing thickness with a sufficiently thick wing spar for a lightweight structure because of the large root chord. For supersonic aircraft, delta wings are particularly appealing because their low relative thickness reduces wave drag, a drag component that only appears in supersonic flow.
- Even at low relative thickness, the delta wing has a high internal fuel volume thanks to its large root chord.
- Additionally, the large root chord gives it a large surface area, which aids in lowering the aircraft's minimum speed.
- Flow separation can be used to increase lift because a delta wing can create vortex lift with enough leading-edge sweep.

5.3 Benefits of recto-trapezoidal form:

There are a few types of aircraft that use the thin, upswept, short-span, low aspect ratio trapezoidal configuration, which has several advantages for high-speed flight. The leading edge sweeps aft and the trailing edge sweeps forward in this wing configuration. It was successfully employed in the early days of supersonic aircraft and can provide low air resistance at high speeds while maintaining high strength and stiffness.

5.4 Benefits of Concorde form:

Something distinguishes this narrow delta from other wing forms. It can fly successfully at a wide range of angles of attack to the airflow, up to angles well above those that would cause other wings to stall, as long as it produces enough lift. Because of this, Concorde can operate over a large speed range by simply altering its angle of attack, much like a bird. The wing can postpone stalling due to its inherent capacity to enhance lift at elevated angles of attack.

6. DESIGN AND CALCULATION

The most important factor in wing design is the selection of its span. As the design is a compact prototype the idea is to keep the dimensions within 1 meter, so the wing span selected was 750mm for the wing and as discussed earlier the planform is semi-delta or Concorde.

6.1 Wing Design and Calculation

Wing Span, b = 750mm = 0.75mm

As the weight of aircraft is kept at 2 kg with 2 kg of payload capacity & 5kg for safety.
A total lift of 4.5 kg is required.
∴ Lift, L = 45N
Using Lift formula,

$$L = \frac{1}{2}\rho v^2 ACl$$

Here,

ρ : - Density of air = 1.22 kg/m^3

v : - Velocity = 15 m/s

A: - Area

Cl: - Coefficient of Lift = 1.4

$$\therefore 45 = \frac{1}{2} \times 1.22 \times (15)^2 \times A \times 1.3$$

$$\therefore A = 0.25\, m^2$$

$$\therefore \text{Aspect ratio (A.R)} = \frac{(\text{Span})^2}{\text{Area}} = \frac{(0.75)^2}{0.25} = 2.25 \approx 2.3$$

Angle of Swept 'ϕ'

A.R = $\frac{4}{tan^{\beta}(\phi)}$

$\phi = \tan^{-1}\left(\frac{4}{A.R}\right) = \tan^{-1}\left(\frac{4}{2.3}\right)$

ϕ = 60°

6.2. FUSELAGE DESIGN AND CALCULATIONS

Overall Length = Fuselage Length
= (75 % – 80 %) × Wing Span
= 78 % × 750
= 585 mm
Height = 25 % of length = 146 mm
Width = 30 – 35% of length
= 34 % of 585
= 200 mm.

6.3. ELEVATOR DESIGN AND CALCULATIONS

Wing Area = 252750 mm^2

H stab = 631875 mm^2

Elevator surface area = 15796.875 mm^2

Propeller diameter = 11 inches (tentative)

Elevator: -

$\frac{Wing\ Span}{2}$ = 0.5 × midgap = one elevator surface area.

$\frac{750mm}{2}$ **= 0.5** × 5.5 inches

375 – 140 mm = 235 mm = Length

Area = 15796.875 mm^2

Area of one elevator = $\frac{15796.875}{2}$ = 7898.737 mm^2

Area = l × b = 7898.4375 = 235mm × b

b = 33.61 mm ≈ 4 cm.

6.4. C.G BALANCING

Locating C.G of Aircraft
Wires in avionics section = 15gm
Electronic Speed Controller = 3×15 = 45gm
Battery = 170gm
Receiver = 15gm
Autopilot board = 20gm
Video transmitter = 10gm
IR sensor & Camera = 20gm
Transmitter & Modem = 15gm
3D Printed nose = 35gm
Elevators = 12×2 = 24gm
Servo Motors = 10gm
C.G of canard type aircraft = ⅖ of fuselage length
= ⅖ × 585
= 234 mm

Mass of the assumed structure = 1.8 − 0.32 − (0.14×3)
= 1.06 kg
Thrust rod mass = Motor + Servos + Rod
= 110 + 10 + 20
= 140gm

$\therefore \Sigma M$ from datum = (97.5 × (15 + 45 + 170 + 15 + 20) + 150 × (10 + 20 + 15) + 35 × 45 + 10 × 483.5 + 24 × 57.5 + 234 × 1060)
= 300837.5 g-mm
= 0.3008375 kg-m × 9.81

ΣM = 2.9512 N-mm

Now,
(1.8 × 9.81) × d = 2.9512
d = 0.167m
d = 167mm

C.G of completely loaded (without payload) avionics aircraft is located at 167 mm from datum.
With payload C.G

$$\Sigma M_A = 1.8 \times 167 + 2 \times 250$$

$$(1.8+2) \times d^{|} = 800.6$$

$$d^{|} = 210 \text{ mm}$$

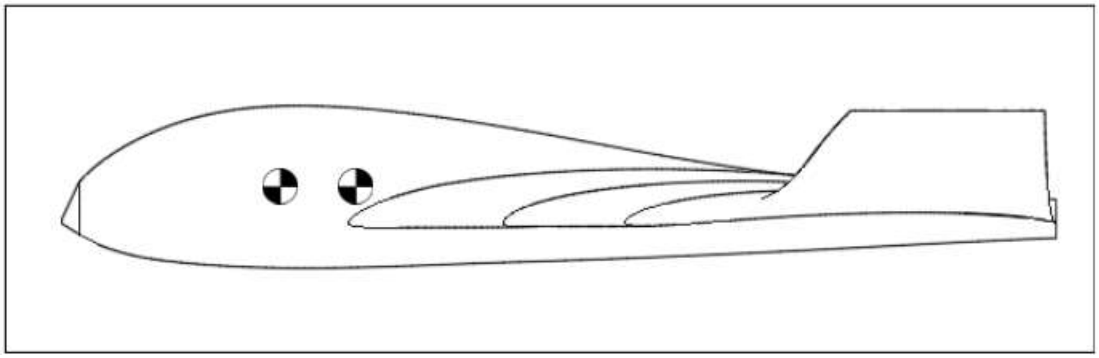

Fig.6.1 C.G. Balancing

Now, positioning the thrust-lift rods.
If the Stability of aircraft has to be maintained the moments by all three rods should be balanced.
∴ Let, d_1 be a distance of two front motors &
d_2 be the distance of one rear motor from C.G.

Front:-
Thrust generated = 1.75kg
Mass of system = 140gm

$\therefore \Sigma M_{CGF} = 2 \times (1.75-0.14) \times d_1$

Taking a value of 110mm from C.G for d_1

$\therefore \Sigma M_{CGF} = 2 \times (1.75-0.14) \times 110$

$\therefore \Sigma M_{CGF} = 354.2$

Rear:-
Thrust generated = 2.5 kg
Mass of the system = 140gm

$\therefore \Sigma M_{CGR} = (2.5-0.14) \times d_2$

$\therefore \Sigma M_{CGR} = 1.86 d_2$

Now,

For Stability,

$$\Sigma M_{CGF} = \Sigma M_{CGR}$$

$$354.2 = 1.86 d_2$$

d_2= 190mm (from C.G)

7. WING ANALYSIS

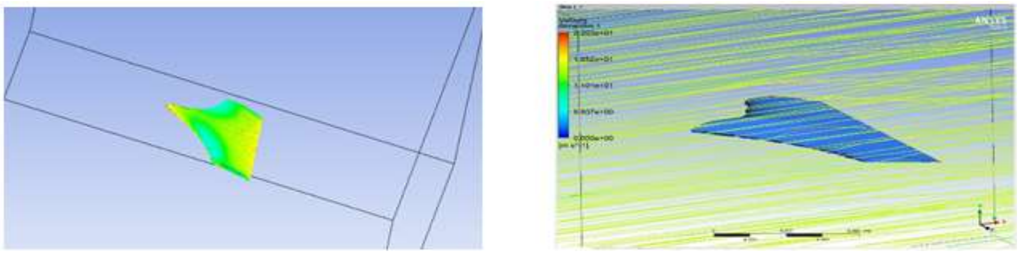

Fig.7.1 Streamlines

Computational Fluid Dynamics (CFD) Analysis:
We aimed to analyse the aerodynamics of our aircraft using computational fluid dynamic analysis, taking into account the various factors involved in an aircraft's flight, such as lift and drag forces

Entity	Value	Entity	Value
Enclosure Dimension	2000*2000*2000 mm^3	Air inlet velocity	15 m/s
Mesh Inflation	20%	Inlet Type	Velocity
Model	Viscous SST K-Omega 2nd Equation	No. of iterations	500
Mesh Type	Fine	Design Modular Boolean	Frozen & Substrate

Table 7.1- CFD Analysis Input Parameters

The table shows the results of CFD analysis. The lift obtained at 10° angle of attack is sufficient to carry the required payload

AOA	Coefficient of Lift	Lift	Coefficient of Drag	Drag
0	0.306	10.68 N	0.132	2.78 N
5	0.563	15.83 N	0.233	4.97 N
10	0.89	25.62 N	0.441	8.56 N

Table 7.2- CFD Analysis Results

Results of Analysis

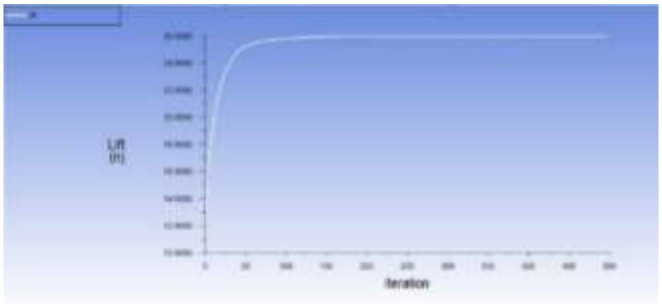

Fig.7.2 C.G. Lift

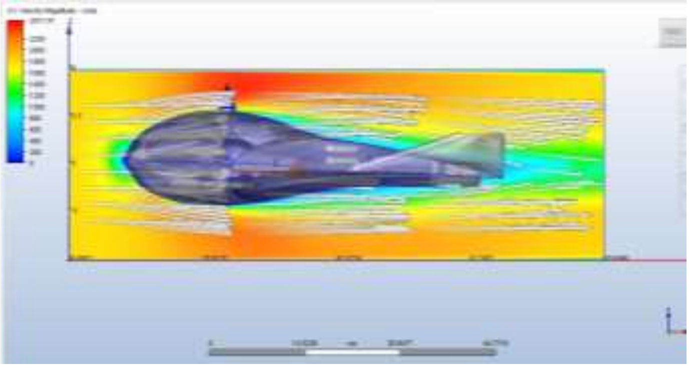

Fig.7.3 C.G .Full Body contour lines

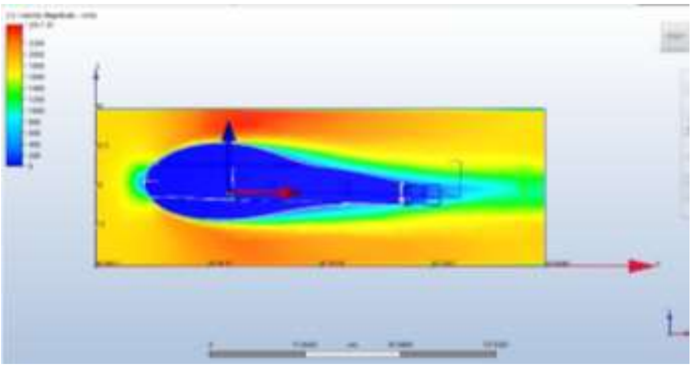

Fig.7.4 Velocity Distribution

7.1. LIFT ANALYSIS

Calculating and validating the lift was a critical part of the overall design process, given the mission's objectives. The team iterated the aircraft design in XFLR against various criteria such as planform area, taper ratio, aspect ratio, and freestream velocity to achieve the optimum results for all parameters such as lift coefficient, drag coefficient, L/D ratio, and wing loading for a fixed 10-degree angle of attack. A lift coefficient of C/= 1.2 was calculated from XFLR, and this value was validated with the Open VSP software.

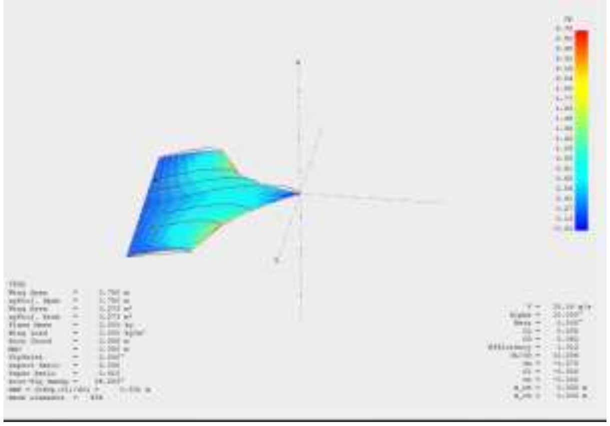

Fig. 7.5 Centre of Pressure

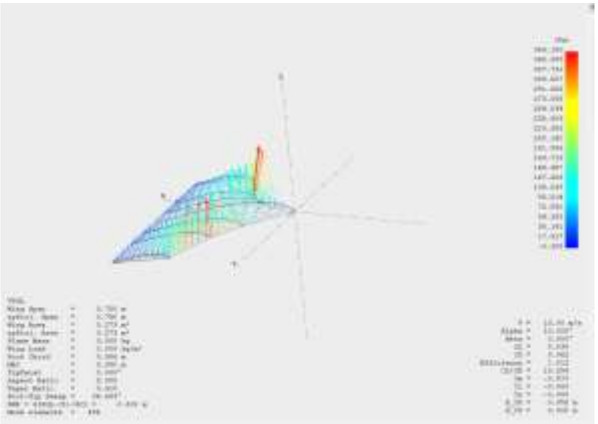

Fig. 7.6 Lift Lines

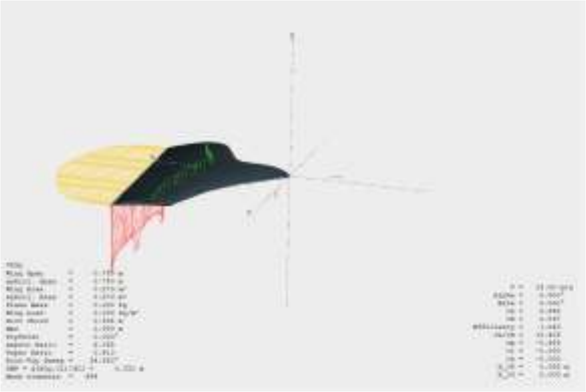

Fig. 7.7 Forces on Wings

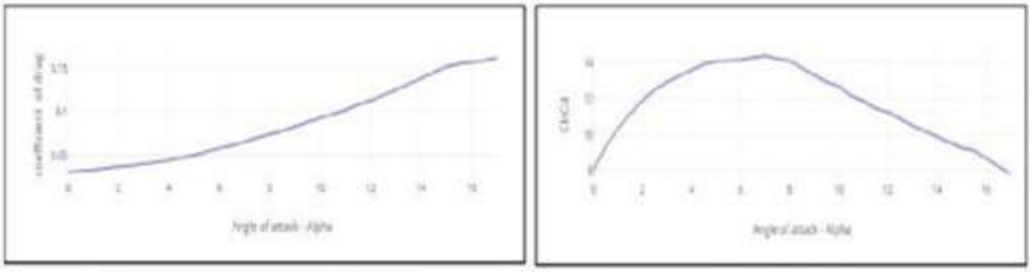

*Figure 14.1: C_d VS Angle of attack

*Figure 14.2: C_l/C_d VS Angle of attack

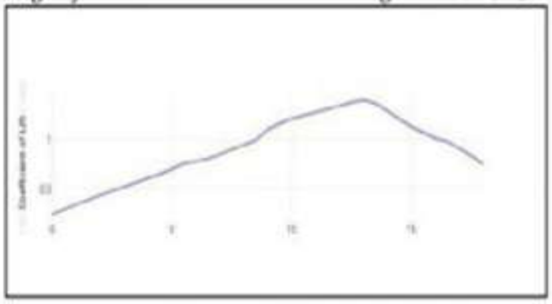

*Figure 14.3:C_l VS Angle of attack

Fig.7.8- Graphs of various factors against angle of attack

7.2. DRAG ANALYSIS:

The Drag analysis includes the estimation of drag considering the parasitic as well as the induced drag that is acting during the flight path.

Induced Drag:
The team did simulation on the selected wing on Ansys workbench for pressure distributions and lift generations. At angle of attack (alpha) 10 we attained maximum lift with Cl and Cd.

Parasitic Drag:
As we know, a body moving through a fluid will experience parasite drag, which is a combined form of friction, and interference drag. The parasitic drag tool on OpenVSP offered us much more sophisticated options and capabilities, even though VSPAERO incorporated estimated the parasitic drag in the calculation of the zero lift drag coefficient. By selecting "Parasitic Drag" from the Analysis drop-down on the top menu bar, we selected the Parasite Drag Tool GUI

Fig.7.9- Estimation of Parasitic Drag

8. MODELLING

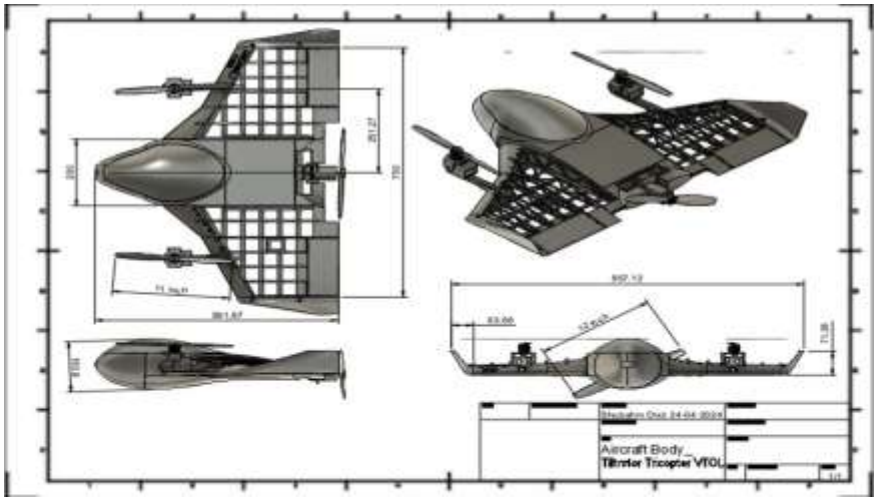

Fig.8.1- Model views

9. FABRICATION

This model is fabricated by the method of 3D printing. The model was divided into sections and each section was first pre-processed to get the sliced model. The material used was PLA for the plane structure. Once each part was printed post-processing was done to get a smooth surface. Then each part was assembled according to the design. As the whole body was made in pieces and the assembled to keep the body structurally integrated using hollow carbon fire rods of 10mm. Carbon fiber was used as it has great strength with low weight density The 3D printing process used here was Fused Deposition Modeling (FDM). Fused Deposition Modeling (FDM) works by melting thermoplastic filament and depositing it layer by layer to build up a 3D object. The printer nozzle moves according to instructions from slicing software, creating the desired shape. Each layer fuses with the previous one as it cools, gradually forming the final object. Support structures may be added for complex features and removed after printing. FDM is cost-effective, versatile, and relatively easy to use, making it popular for prototyping, small-scale production, and hobbyist projects. The model was divided into sections and each section was first pre-processed to get the sliced model. The material used was PLA for the plane structure. Once each part was printed post-processing was done to get a smooth surface.

10. COMPONENTS

The major parts that are effectively employed in the design system are described below:

Sr. No.	Component	Rating/ Specification	Q	Function
1	Power distribution Board (PDB-XT60)	5-12 Volt	1	Power Distribution
2	ESE	50 A	3	Providing required current to motor
3	Flysky Transmitter and Receiver FS-CT6B	6 Channels RF Range- 2.4 to 2.5 GHz	1	For operating and controlling the various functions of VTOL and transmit different operating signals according to the functional requirement
4	Pixhawk 2.4.8 (Flight controller)	5v to 18v	1	To integrate high performance sensors to provide accurate data for flight control and environmental
5	DYS- BLDC MOTOR	1100 Kv	1	To provide 1600g thrust for rear propeller
6	DYS- BLDC MOTOR	900 Kv	2	To provide 1200g thrust for front propeller
7	Turnigy Metal Servomotor (7kg)	3.7V – 11.1V		To operate the front and rear tilting motors of VTOL
8	Micro Servo NG90	3.7V – 11.1V		To operate the elevators
9	Propellers (Clockwise and Counterclockwise)	11 X 4.5		For the front tilt rotors, selected on basis of motor rating and thrust required
10	Propellers (Counterclockwise)	12 X 6		For the rear tilt rotor, selected on basis of motor rating and thrust required

Table 10.1: COMPONENTS AND DESCRIPTIONS

11. CONCLUSIONS

This project aims to design a Vertical Take-off and Landing (VTOL) technology that has uncovered transformative avenues that can revolutionize aviation through strategic advancements in avionics, weight reduction, boundary conditions, and tailored customization. Our research delved deep into the intricate world of VTOL systems, elucidating crucial insights poised to redefine the very essence of these aerial marvels.

Avionics Empowerment: The heart of our research pulses with the potential of avionics—a pivotal realm where safety, precision, and technological finesse converge. By comprehensively understanding and refining avionics systems with Boundary Conditions and Operational Flexibility, we unlock pathways for enhanced navigation, superior control mechanisms, and real-time data analytics. Our findings catalyze optimizing avionic architectures, empowering VTOL aircraft with smarter, more responsive, and safer systems

Weight Reduction Strategies: Weight is a critical factor influencing VTOL efficiency and performance. Our research has unveiled strategies for shedding excess weight without compromising structural integrity or operational safety. Innovations in materials science, streamlined design methodologies, and novel construction techniques emerged as beacons for weight reduction, offering a promising path towards lighter, more agile VTOL platforms

Customization for Diverse Needs: Our research spotlights the potential for customization, acknowledging that different missions demand tailored solutions. Whether it's military operations, urban transport, or emergency services, our findings underscore the importance of customizable VTOL configurations. This adaptability ensures that VTOL aircraft are optimally equipped to cater to specific operational needs.

In conclusion, our research is more than a repository of discoveries—it's a blueprint for transformative evolution within the VTOL landscape. By championing advancements in avionics, weight reduction, boundary conditions, and customizable configurations, our findings unlock doors to a future where VTOL aircraft transcend current limitation

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13. REFERENCES

[1]. Oo, W., Tun, H., Naing, Z., & Moe, W. (2017). Design of vertical take-off and landing (VTOL) aircraft system. *International journal of scientific & technology research*, *6*(4), 179-183.
[2]. Herissé, B., Hamel, T., Mahony, R., & Russotto, F. X. (2011). Landing a VTOL unmanned aerial vehicle on a moving platform using optical flow. *IEEE Transactions on robotics*, *28*(1), 77-89.
[3]. Misra, A., Jayachandran, S., Kenche, S., Katoch, A., Suresh, A., Gundabattini, E., ... & Legesse, A. A. (2022). A review on vertical take-off and landing (VTOL) tilt-rotor and tilt wing unmanned aerial vehicles (UAVs). *Journal of Engineering*, *2022*.
[4]. Sharma, S., Sharma, R., Kumar, V., & Chandel, S. (2021, April). Analysis of a tiltrotor vertical take-off and landing unmanned aerial vehicle: Cfd approach. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1116, No. 1, p. 012096). IOP Publishing.
[5]. Mousaei, M., Geng, J., Keipour, A., Bai, D., & Scherer, S. (2022, October). Design, Modeling and Control for a Tilt-rotor VTOL UAV in the Presence of Actuator Failure. In *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 4310-4317). IEEE.
[6]. Notarstefano, G., & Hauser, J. (2010). Modeling and dynamic exploration of a tilt-rotor VTOL aircraft. *IFAC Proceedings Volumes*, *43*(14), 119-124.
[7]. Yu, S., Heo, J., Jeong, S., & Kwon, Y. (2016). Technical analysis of VTOL UAV. *Journal of Computer and Communications*, *4*(15), 92-97.
[8]. Intwala, A., & Parikh, Y. (2015). A review on vertical take off and landing (vtol) vehicles. *International Journal of Innovative Research in Advanced Engineering (IJIRAE)*, *2*(2), 187-191.
[9]. Ciopcia, M., & Szczepański, C. (2017). Concept of tiltrotor UAV control system. *Journal of KONES*, *24*(1), 83-89.
[10]. N. C. A. Vishwath, J. B. Batchu, & Anand Swaroop G.B (2019).Stability of a tilt rotor unmanned aerial vehicle. Journal of Emerging Technologies and Innovative Research, vol. 6, no. 5, pp. 443–447.
[11]. Gasco, P. S. (2012). Development of a dual axis tilt rotorcraft uav: Modelling, simulation and control. *Master's thesis, Cranfield University*.
[12]. Carlson, S. J., & Papachristos, C. (2021, June). The minihawk-vtol: Design, modeling, and experiments of a rapidly-prototyped tiltrotor uav. In *2021 International Conference on Unmanned Aircraft Systems (ICUAS)* (pp. 777-786). IEEE.
[13]. PATRA, A. K., PATEL, K., BUNDELA, G. S., & Vinay, P. (2017). Design and development of transition autopilot for VTOL UAV. *International journal of innovations in engineering research and technology*, *4*(6), 1-16.
[14]. Panigrahi, S., Krishna, Y. S. S., & Thondiyath, A. (2021). Design, analysis, and testing of a hybrid VTOL tilt-rotor UAV for increased endurance. *Sensors*, *21*(18), 5987.
[15]. Axten, R. M., & Johnson, E. N. (2021). VTOL Freewing Testbed Vehicle in Hover and Forward Flight. In *AIAA Scitech 2021 Forum* (p. 1931).
[16]. Sahin, H., & Oktay, T. (2017). Powerplant system design for unmanned tricopter. *The Eurasia Proceedings of Science Technology Engineering and Mathematics*, (1), 9-21.
[17]. Paul J. Coco, PE. (2012). Tricopter Design. http://assets.flitetest.com/article_files/TRICOPTER-FALL2012_1364524711.pdf