Volume 9, Issue 10, October – 2024 International Journal of Innovative Science and Research Technology
ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT747

Design and Analysis of Fixed Wing Unmanned Aerial Vehicle

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Abstract:- This study focuses on designing and developing a fixed-wing unmanned aerial vehicle (UAV) to meet strict operational requirements while maximizing cargo capacity. The design must adhere to specific constraints, including a maximum wingspan of 80 inches and a structural weight limit of 5 kilograms. Achieving these goals involves a delicate balance between maintaining the UAV's structural integrity and ensuring its maneuverability, effectiveness, and ease of transportation. The challenge lies in maximizing the structural strength within these limits to ensure the UAV's long-term reliability in field operations. The ultimate goal is to create a proficient and efficient UAV, utilizing resources and methods to optimize performance.

Keywords:- *Unmanned Aerial Vehicle; Fixed Wing; Design; Analysis; High Lifting UAV, Sizing.*

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), or drones, are a major development in aviation technology. UAVs are a subset of the larger Unmanned Aircraft System (UAS), consisting of ground-based controllers and communication systems. UAVs are aircraft without pilots, crew, or passengers on board. Because of their greater capabilities over human aircraft, UAVs have attracted the attention of aircraft designers in recent years. Because there are no human lives aboard, its design can have a lower factor of safety, allowing for improved combat performance—including higher G-forces and more aggressive maneuvers—without being constrained by human physiology.[7] UAV design has a special set of difficulties, especially for fixed-wing models. These difficulties entail deciding between decreasing take-off weight, preserving structural robustness, and fulfilling performance criteria. This study focuses on the conceptual design process for fixed-wing UAVs, employing various methodologies and approaches to solve these challenges. This endeavor aims to deliver a thorough design framework that improves UAV performance and usability.

A. Problem Statement

Design and fabricate an aircraft that weighs a maximum of 5kg, can carry the maximum payload and fits within dimensional constraints. The dimensions should not exceed 170 inches in L+B+H, with a payload bay.

B. Scope

A high-lifting fixed-wing UAV has a significant payload capacity and is versatile in various applications. It can be used for aerial surveying, mapping, cargo delivery, agriculture, infrastructure inspection, environmental monitoring, search and rescue operations, military and defense purposes, scientific research, and emergency response. Its capabilities include carrying heavy loads, capturing detailed aerial images, transporting supplies, monitoring crops, assessing infrastructure, and aiding in disaster situations.

C. Methodology [1]

- Define objectives, tasks, and requirements.
- Conduct a feasibility study (technical, regulatory, economic).
- Analyse and document functional and performance requirements.
- Develop high-level conceptual design and perform simulations.
- Refine design with detailed engineering specifications.
- Iterate design based on test results and improvements.

II. DESIGN

A. Environmental Considerations

Calculations were done considering the climatic conditions of India to understand the performance of the aircraft.

- Temperature: 26-35°C
- Kinematic viscosity: 1.569e-5Ns/m^2
- Density: 1.153kg/m^3
- Dynamic viscosity: 1.84e-5Ns/m^2
- Pressure: 1008.7millibar
- Elevation: 1417ft

B. Material Selection and Mass Properties

Material survey was carried out before starting the designing phase to get an idea about all the materials available in the market for procurement. The properties of all the materials used in the aircraft are as follows. [8]

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT747

Table 1: Material Data

Sr.no.	Material	Density (kg/m3)	Elastic Modulus (MPa)	Yield Strength (MPa)	Poisson's Ratio
1.	Balsa	268.3	7960	17.91	0.3742
2.	Aeroply	520.0	14500	7800	0.35
3.	Aluminum 6061	2713.0	67350	259.2	0.33
4.	Spring Steel	7850.0	2.114e+05	377.9	0.29

C. Design Layout and Features [6]

The aircraft is based on these decompositions.

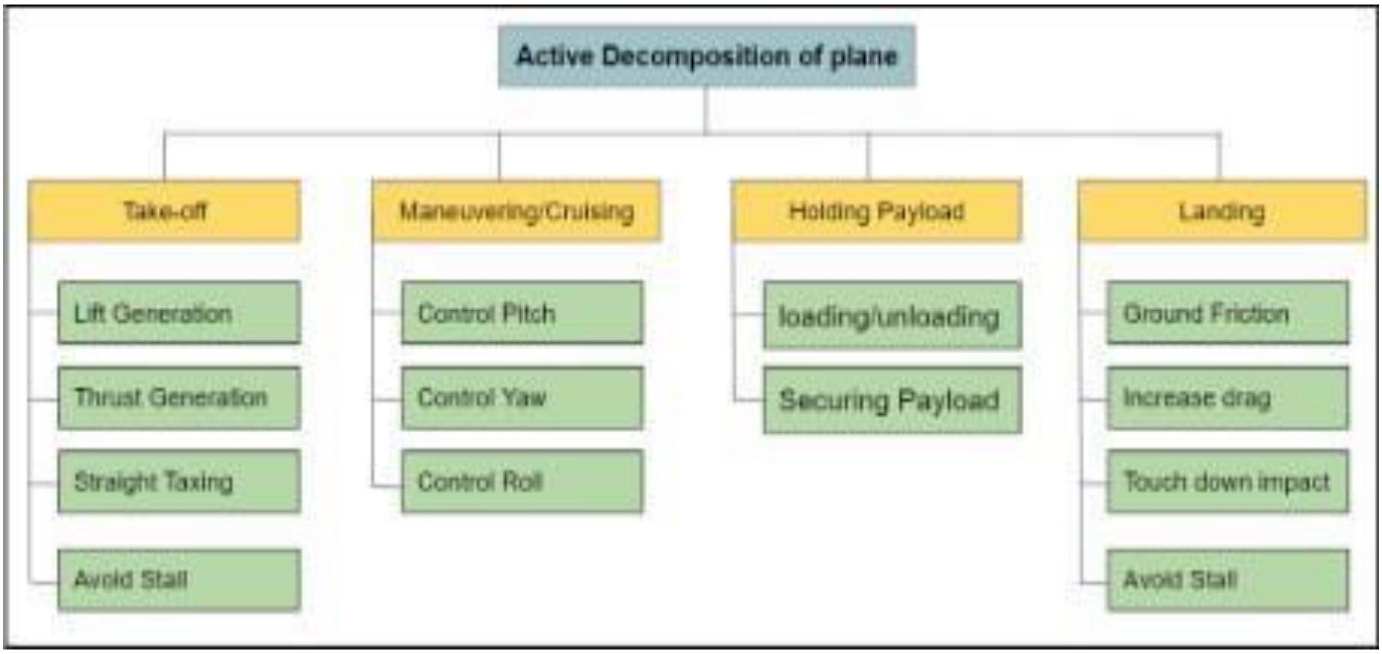

Fig 1: Active Decomposition of Plane

D. Overall Design Layout and Size

The final layout of our aircraft is as follows:

- Wingspan - 80 inches
- Wing Chord - 14 in
- Airfoil Wing - CH10
- Airfoil Tail – N 0015
- Empty Estimated Weight-4.98kg
- Total Estimated Weight 15.8kg
- L+B+H - 55+80+31 in
- Propeller - 22x10E

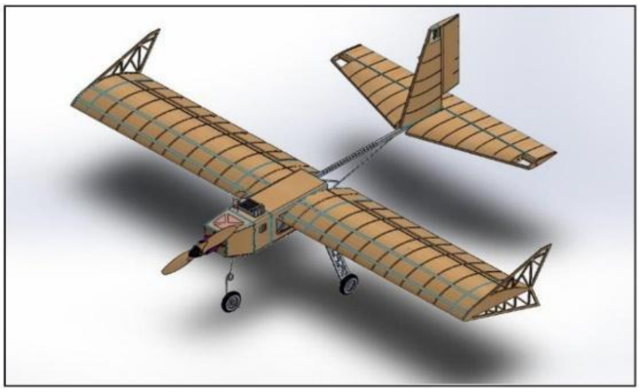

Fig 2: Full Plane Design

III. WING

A split-high wing configuration was considered because of the Keel effect, more ground clearance, better stability, assembly, and manufacturability.

A. Airfoil [3]

The airfoil tools database was considered based on low Reynolds number, gentle stall with moderate pitching moment, maximum L/D, and good manufacturability for the airfoil selection. The below table consists of all the considered airfoils. (*Parameter rating is out of 5)

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Table 2: Airfoil Comparison

Srno	Airfoil	Aerodynamic Performance	Strength	Manufacturability
1.	Selig (S1223)	5	2	2
2.	Eppler (E423)	4	3.5	3.5
3.	CH10	4.5	4	4

From the above-considered airfoils, S1223 was not considered further. So, the narrowed airfoils were CH10 and E423. The following graphs show their comparison.

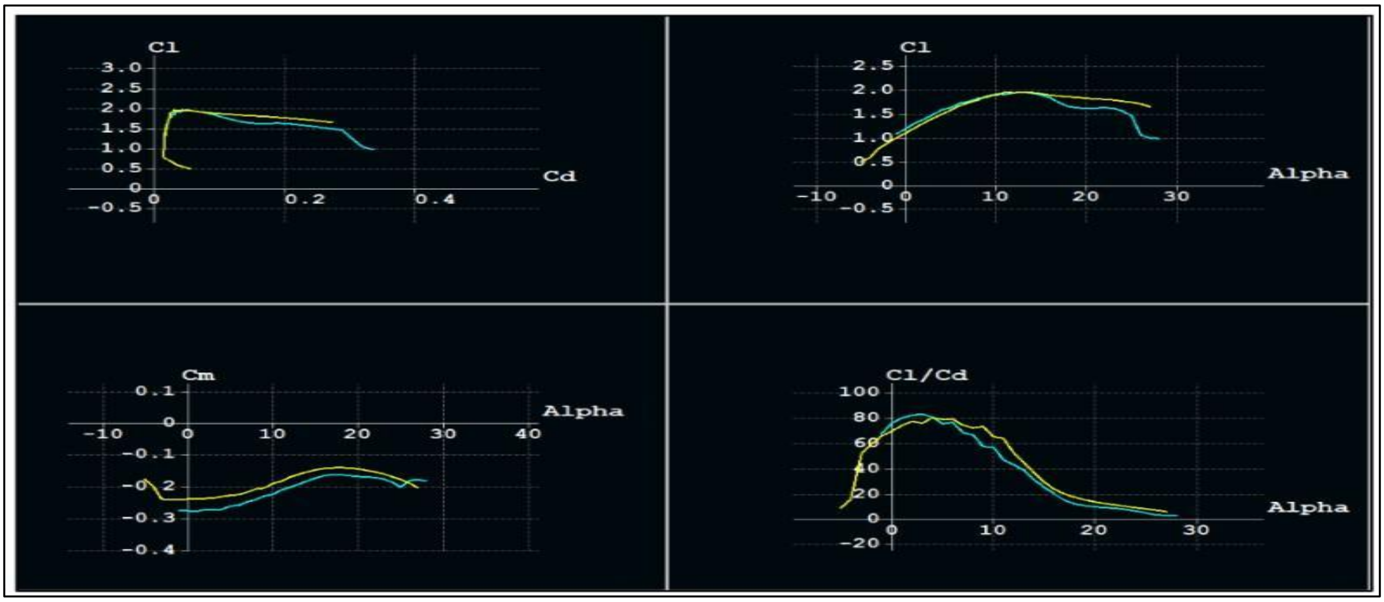

Fig 3: Airfoil Comparison

B. Planform [10]

We decided on the planform sizing based on the required amount of lift, which was 150N, to maintain equilibrium and a stable flight for the payload. The types of planforms considered were rectangular planforms and Tapered planforms. Accordingly, 80 inches of wingspan and 14 inches of wing chord satisfied the lifting conditions and dimensional restraints, giving an aspect ratio of 5.7. Based on the XFLR5 results, we concluded that the efficiency of the rectangular planform for our dimensions is 96.7%; a rectangular planform was considered.

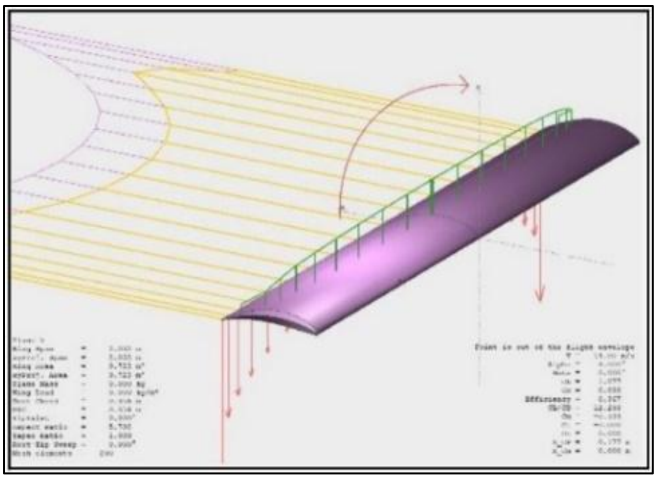

Fig 4: Lift Distribution on Wing

C. Analysis

- **CFD-** We iterated various conditions such as takeoff with flaps, cruising, and landing. CFD for different AOA was performed for takeoff to check the wing's Lift, Drag, and pressure characteristics. The values for the wing for the velocity of 10m/s at 3° AOA are 38.08N for lift, 4.47N for drag, and pressure of 68.6Pa and for 10.75° AOA, lift of 73.05N, 7.109N drag with 148Pa pressure.

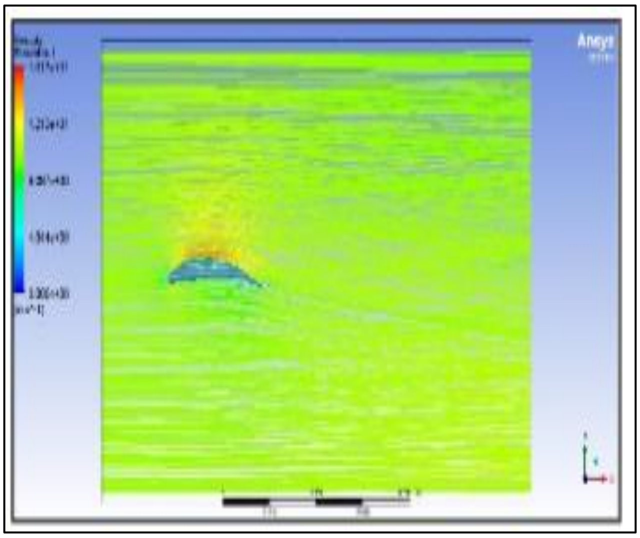

Fig 5(a): Wing at 3 Degree

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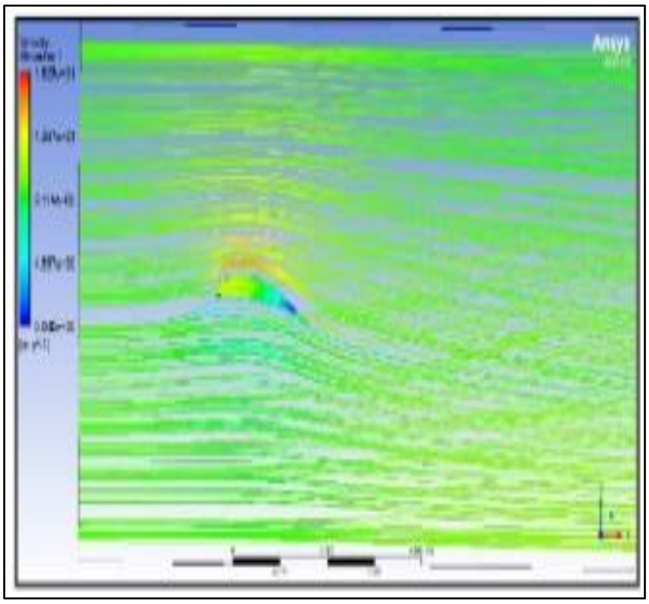

Fig 5(b): Wing at 10.75 Degree

- **FEA-** Lift can be achieved only with good structural integrity that can withstand wind gusts and impact forces. Each wing was subjected to upward pressure and analyzed for 250Pa (from CFD at 17m/s). The maximum total deformation was 40.623 mm for 250Pa, which was minimized with the help of struts.

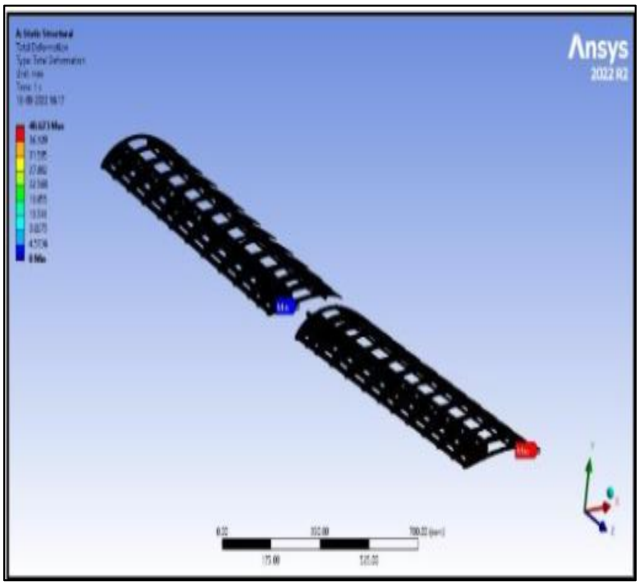

Fig 6: FEA on Wing

D. Flaperons

We performed iterations of the wing planforms to achieve the required lift at cruising velocity for a steady manoeuvre flight. We got a value of 148 N for lift at a maximum velocity of 20m/s in CFD analysis. After adding the flaperons at 30 deg in CFD, the lift increased to 160N.

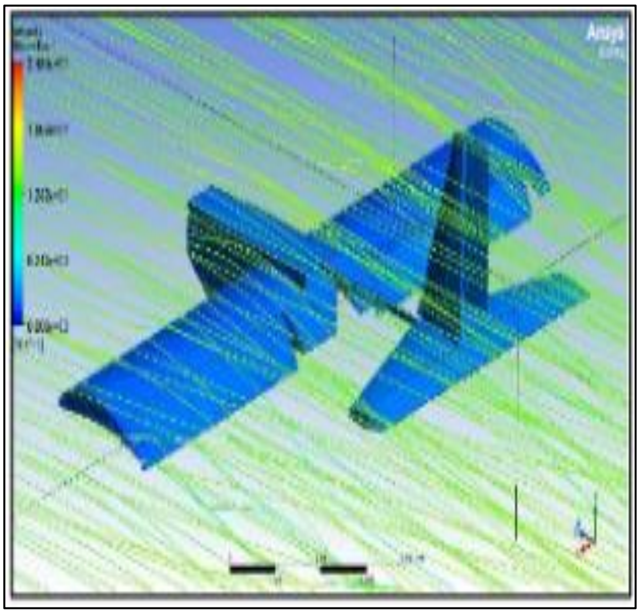

Fig 7: Full Plane CFD with 30-Degree Flaps Deployed

E. Downwash

The wing was mounted 1.5 inches below the horizontal stabilizer to reduce the effects of downwash. The angle of incidence also provides a formal meeting of boundary layer conditions.

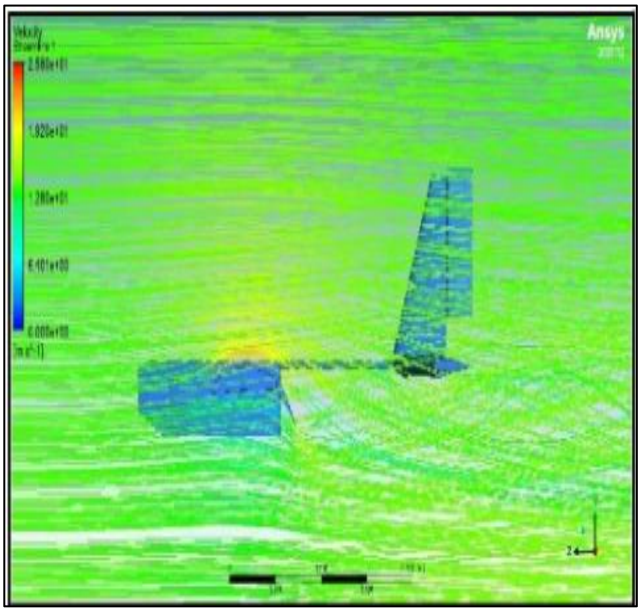

Fig 8: CFD for Downwash

F. Wingtips

CFD analysis was performed on the whole plane. It was noted that the vortices generated were significant due to the sharp edges of the rectangular planform. So, wingtips were added which deflected the vortices away from Stabilizers up to 30%.

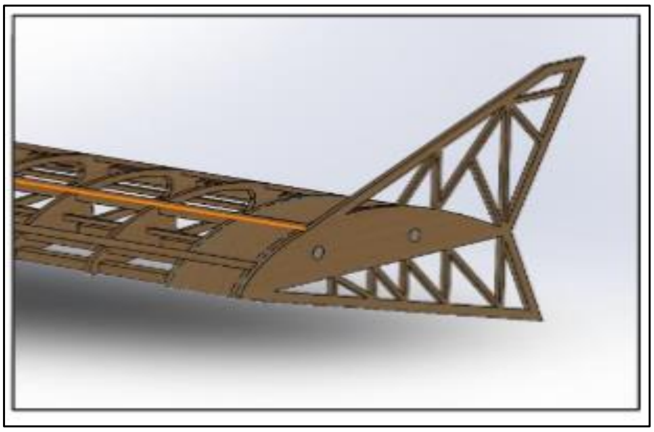

Fig 9(a): Wingtip Design

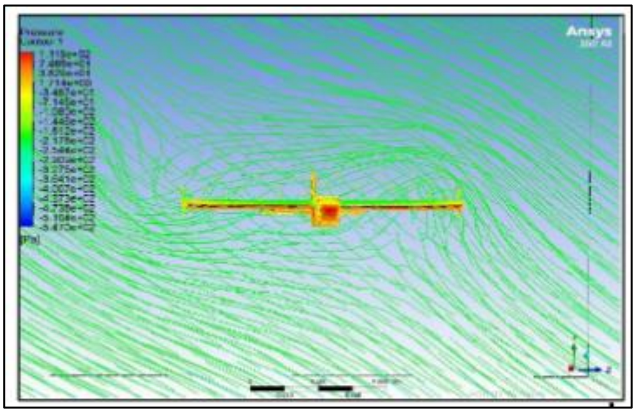

Fig 9(b): Full Plane CFD with Wingtips

IV. EMPENNAGE [5]

For empennage, we had shortlisted two configurations, twin tail, and conventional tail, based on our whole structure. But we selected a conventional tail.

A. Airfoils

For the tail, symmetric airfoil-NACA 0012 and NACA 0015 were considered, out of which NACA 0015 was chosen for the rudder and elevator's adequate stability and manoeuvrability. The thickness of NACA 0015 is 15% of the chord, i.e., 2.2 inches, which helped accommodate servos and gave good structural integrity that can hold the maximum torque of 9 kg.

B. Tail Sizing

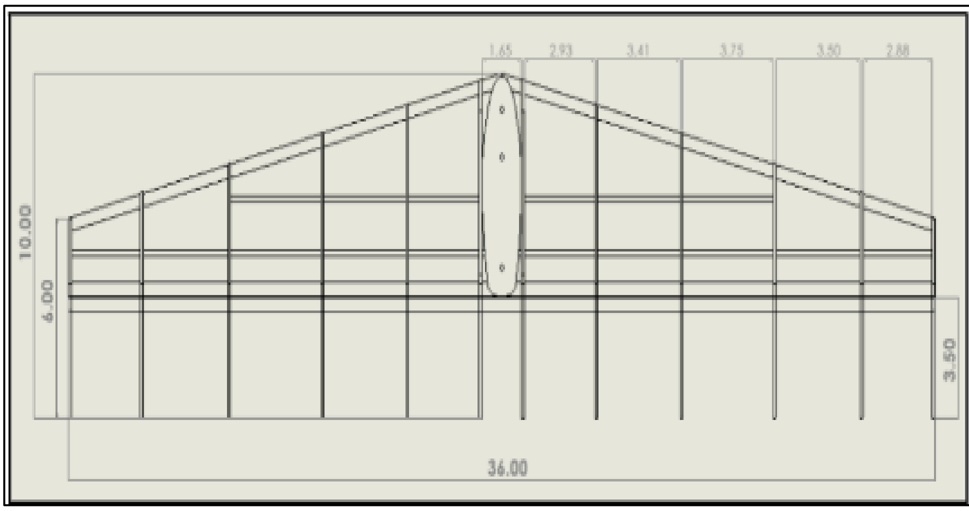

Fig 10(a): 2D of HT

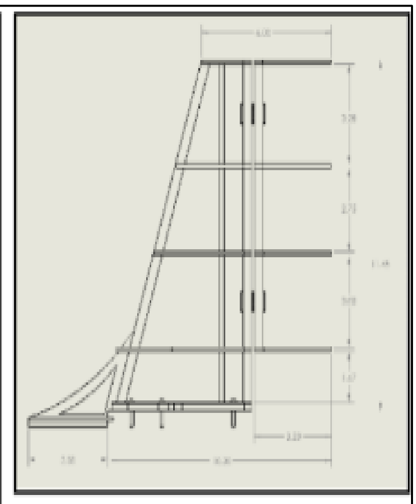

Fig 10(b): 2D of VT

C. Analysis

- **CFD-** We performed CFD on the Vertical Stabilizer and Horizontal stabilizer at various deflection angles that the servo motor can achieve. We obtained a force of 15N when deflected maximum at 30°, which is sufficient for yawing and pitching moments. A pressure of 167.0441Pa was obtained.

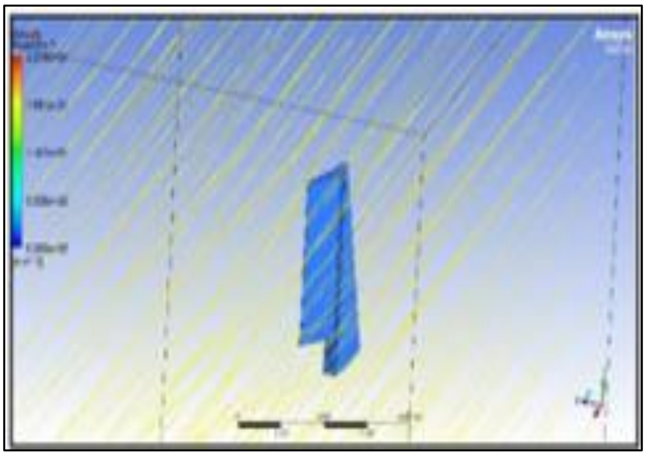

Fig 11: CFD on VT

* **FEA-** The pressure applied on the bottom of the Horizontal Stabilizer was 126.78Pa which we obtained from CFD. The total deformation was observed to be 2.8246 mm. The safety factor was evaluated as 4.9612 from the software. For the vertical Stabilizer, a pressure of 167 Pa was given as input, and the deformations observed were 39.764mm.

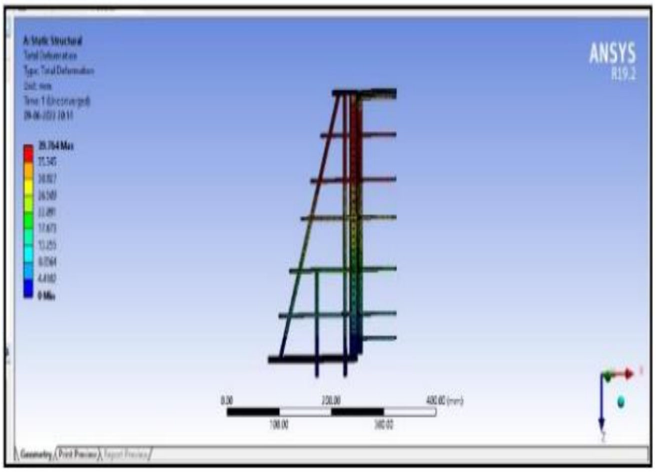

Fig 12(a) FEA on VT

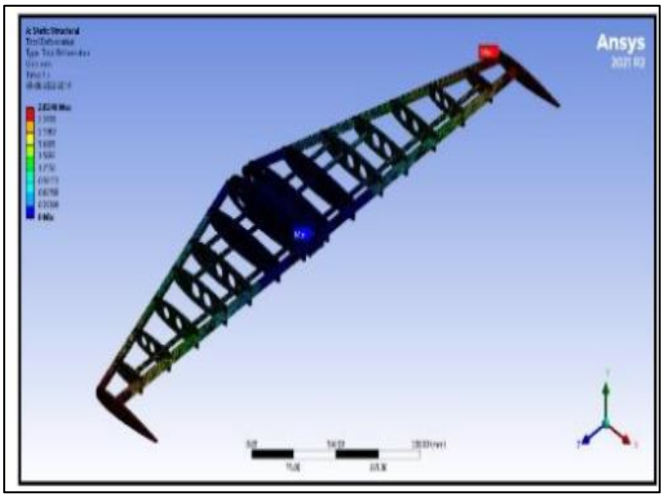

Fig 12(b): FEA on HT

V. FUSELAGE [6]

A conventional tail boom fuselage was thought of, considering the aft structure weight and empennage assembly. The fuselage of the aircraft consists of two parts; the airframe and the nose section, which is designed according to the placement of the avionic components and payload bay assembly.

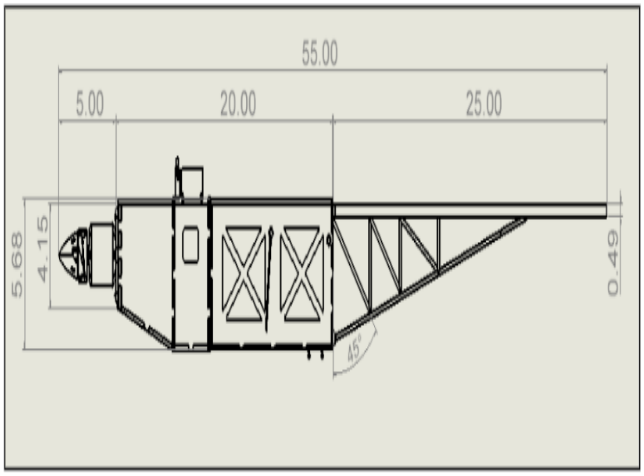

Fig 13: 2D of Fuselage

The Nose structure of the fuselage comprises a balsa and aeroply sandwich sheet reinforced with stringers for structural integrity and loading on the nose.

* **ANALYSIS-** The airframe must sustain 15kg of force while landing and be able to take the impact of these forces while landing. So, the force was applied at the bottom members of the frame, wing rods, and the end of the tail boom rod. The airframe showed a deformation of 15.88mm at the ends of the wing rods. Accordingly, the analysis was done at 300N (double the lift) as well, and for landing shocks, the deformation obtained was 73.401(maximum at the wing spar). In the above static analysis, the balsa fuselage parameters were checked with 150N of force to see how much the structure could withstand without the aluminium airframe. The maximum deformation obtained was 0.15mm, and the minimum FOS was 3.6.
* **OPTIMIZATION-** We did topology optimization on the Airframe to reduce the overall weight while maintaining structural integrity. 4mm diameter holes were drilled in the square hollow rod to reduce the maximum weight possible.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24OCT747

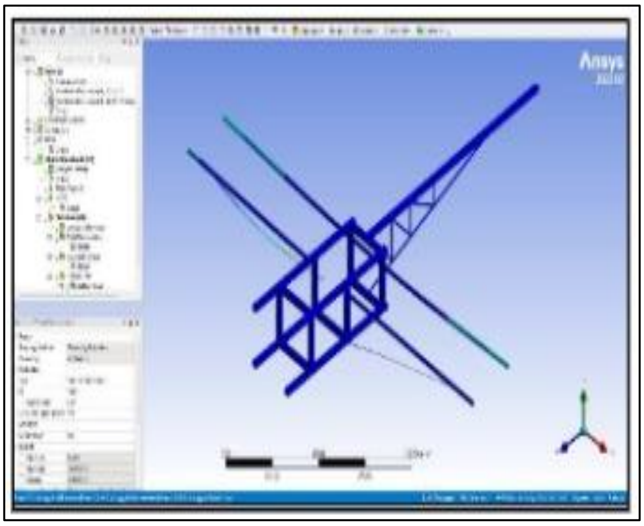

Fig. 14(a) FEA on Airframe

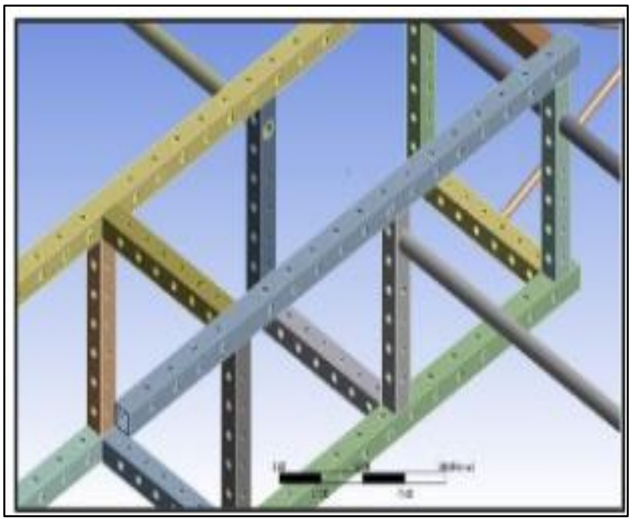

Fig 14(b): Topology Optimization

VI. LANDING GEAR

Conventional and tricycle landing gear was decided. The team chose a front tricycle landing gear system based on controllability and maneuvering performance while being stable for carrying a high payload. The height of the landing gears was determined such that the propeller clearance.

Table 3: Landing Gear Parameters

Sr.no	Gears	Thickness	Position (wrt CG)	Material
1.	NLG	5mm	-261.8mm	Spring steel (IS4454)
2.	MLG	4mm	+106.2mm	Aluminum 6061

A. Main Landing Gear

The aluminium plate structure selected is the finest in absorbing high-impact loads, is easy to manufacture, and is widely used in RC aircraft. After performing topology optimization, we gave hexagonal cutouts with the vertical axis of symmetry parallel to the direction of the applied tensile force. A positive camber of 3° was given to the wheels for better stability while taxiing.

Explicit Dynamic analysis was performed for a velocity of 20m/s with a height of 50cm for Loading 300N calculated for Landing Momentum. The maximum deformation obtained was 43mm. To reduce this, struts were added. The total drag generated by the landing gears was 0.150kg.

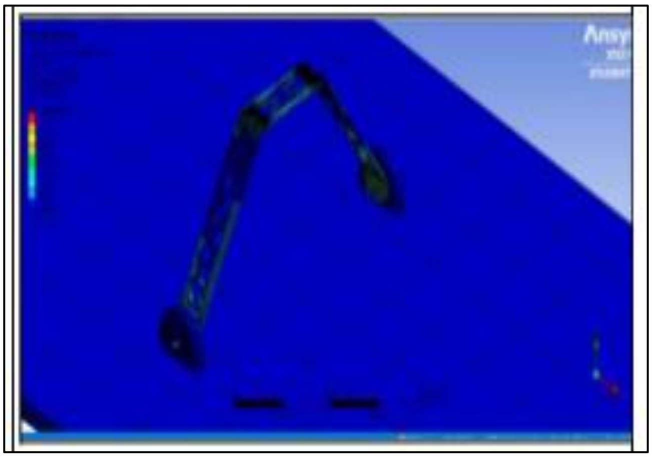

Fig 15: Explicit Analysis of MLG

B. Nose Landing Gear

The NLG was selected as a torsional spring-type system with 2 coils. Spring steel was used as a material for the NLG because of its high modulus of elasticity and tensile strength. The calculated spring constant for the spring is 7682.2N/m, for an internal diameter of 25 mm.

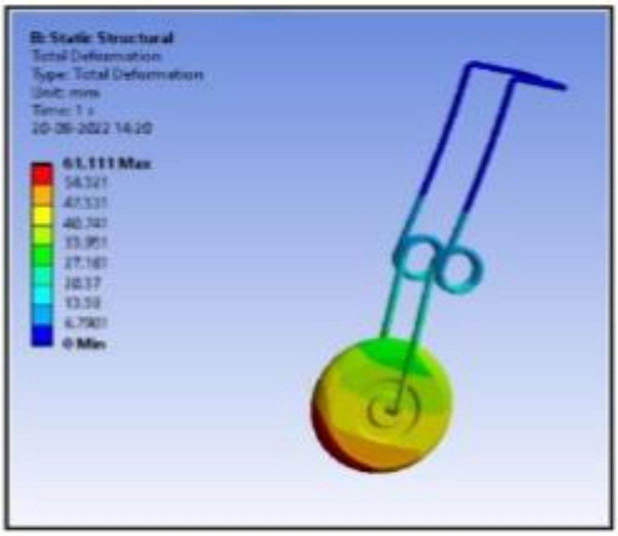

Fig 16: FEA on NLG

VII. CONCLUSION

In conclusion, we have successfully designed an aircraft and analyzed that meets the specific requirements and objectives. The aircraft weighs a maximum of 5kg, ensuring that both its structural integrity and performance are not compromised. Through careful aerodynamic design, we have optimized lift and minimized drag, resulting in efficient flight performance.

Additionally, structural analysis has been conducted to ensure that the aircraft can withstand operational loads, ensuring its durability and reliability. We have considered lightweight and durable materials in the fabrication process, striking a balance between weight reduction and strength. This has contributed to the overall performance of the aircraft.

In summary, our aircraft design has achieved its objectives, resulting in a well-designed, lightweight, and efficient aircraft that meets the specified requirements. This project showcases the successful integration of various engineering principles and techniques to create a reliable aircraft.

VIII. FUTURE SCOPE

The future scope of fixed-wing UAVs (Unmanned Aerial Vehicles) is quite promising and encompasses several areas. Here are some key areas where fixed-wing UAVs are expected to make significant advancements:

- Surveillance and Monitoring: Fixed-wing UAVs are already widely used for surveillance and monitoring applications such as border patrol, wildlife conservation, and infrastructure inspection. In the future, we can expect improved capabilities in terms of longer flight endurance, higher-resolution sensors, and advanced onboard analytics. This will enhance their ability to gather real-time data, perform detailed analysis, and assist in decision-making processes.
- Delivery and Logistics: Fixed-wing UAVs have the potential to revolutionize the delivery and logistics industry. With advancements in flight control systems, autonomous navigation, and payload capacity, they can efficiently transport goods over long distances. Companies like Amazon and Google are already exploring the use of fixed-wing UAVs for package delivery, and further developments in this field are expected.
- Agriculture: Fixed-wing UAVs are increasingly being employed in agriculture for tasks like crop monitoring, yield estimation, and spraying. In the future, these UAVs can become even more sophisticated, incorporating advanced imaging technologies, multispectral sensors, and machine learning algorithms to provide detailed information about crop health, water management, and pest detection. This can optimize agricultural practices, improve productivity, and reduce environmental impact.
- Disaster Management: Fixed-wing UAVs offer significant advantages in disaster management scenarios. They can provide rapid aerial assessments of affected areas, search for survivors, and aid in disaster response planning. Future developments may include enhanced sensors for detecting gas leaks, thermal imaging for identifying heat signatures, and improved communication systems to facilitate coordination among rescue teams.
- Military and Defense: Fixed-wing UAVs have been extensively utilized for military and defense purposes, including reconnaissance, surveillance, and target acquisition. Future advancements may focus on stealth capabilities, extended flight durations, and improved payload capacity, enabling these UAVs to carry out more complex missions with increased autonomy.

REFERENCES

[1]. Sadraey, M. H. (2013). Aircraft design: a system engineering approach. Wiley.
[2]. Anderson Jr., J. (1999), Aircraft Performance and Design. McGraw-Hill.
[3]. Abbot, I.H., & Von Doenhoffn, A.E. (1959), Theory of Wing Sections. Including a Summary of Airfoil Data. E.U.A. Elsevier, Inc.
[4]. Etkin, B., & Reid, L. D. (1996). Dynamics of flight: stability and control. Wiley.
[5]. Nicolai, Leland M. (2009). Estimating r/c model aerodynamics and performance.
[6]. Simons, M. (1994). Model aircraft aerodynamics. Argus Books.
[7]. (1980). MIL-F-8785C Military specification flying qualities of piloted airplanes.
[8]. Wood handbook: wood as an engineering material. (1974). Madison: The Laboratory. ort.pdf
[9]. Old Dominion University. (2015). 2015 SAE Aero Design East Technology Report.
[10]. Raymer, D.P. (2004). Aircraft design: A conceptual approach. Retrieved from http://soaneemrana.org/onewebmedia/AIRCRAFT%20DESIGN%20%3B%20A%20 Conceptual%20Approach%20BY%20DANIEL%20P%20RAYMER.pdf
[11]. Miranda L.E. (2013), Fundamentos Da Engenharia Aeronáutica.PD