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Design and Analysis of Humanitarian Aid Delivery RC Aircraft

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Abstract:- A radio-controlled aircraft is an unmanned aerial vehicle operated through a trans-receiver module – one located at the controller's end, other inside the aircraft. The following section discusses an RC aircraft mirroring a miniature cargo aircraft, the notable features being the glow-plug engine and data acquisition system (DAS) using an altimeter and first-person view (FPV) camera. The RC aircraft is equipped to perform tasks simulating payload airdrops and carrying stationary cargo. A RC aircraft poses similar engineering problems as involved in designing large scale aircraft, albeit at lower speeds. The airworthiness of a RC aircraft is established during the conceptualization, design and modelling, construction, assembly, and testing phases. Softwares such as NX Cad 12.0, ANSYS-Fluid, and XFLR5 were used while developing an airworthy aircraft. Reinforcements of Carbon-fibre during assembly were integrated to make the structure light and sturdy.

Keywords:- *Lift, Drag, Aspect Ratio, Angle of Attack, Stall.*

I. INTRODUCTION

This report is a collective account of the theoretical, analytical, and developmental data compiled during the development of a RC Aircraft. A detailed analysis of every aspect is performed using various techniques and softwares to ensure a fail-safe model. As avionics are vital in flight, a number of iterations were performed to decide the final combination of avionics in the aircraft. The aircraft was designed to carry zircon sandbags as releasable payload. We had to devise a project plan by evaluating the pros and cons of the dropping mechanism and finally arrive at a suitable mechanical solution, all while considering the budget constraints, and various other environmental and technical factors in the process.

➢ *Design Objectives:*

- To develop a cargo model aircraft.
- To successfully take-off, airdrop humanitarian aid at prespecified ground target, and land the aircraft.
- To carry maximum static and dynamic payload.
- To record instantaneous dropping altitude using DAS.

Wing area, airfoil shape, wing design and airspeed are the factors that influence lift and drag. Lift and drag are directly proportional to each other. Stalling is due to the effects of flow separation and that is characterized by loss of lift, as well as increase in drag. There are aspects of aircraft behavior and handling at and near the stall which depend on the design of the wing. Stability of an aircraft is one of the most vital parameters of an airworthy aircraft. Static stability is the ability of an aircraft to remain upright when at rest, or under acceleration or deceleration. Whereas dynamic stability is the characteristic of an aircraft body when disturbed from an original state of steady motion that causes it, in an upright position, to damp the oscillations set up by restoring moments and gradually return to its original state.

It is of paramount importance to recognize factors affecting the aircraft performance, so as to tackle the adverse environmental issues. The most decisive factors of them being – temperature, pressure, density, and viscosity. In any given situation the physical properties of the fluid (air) may vary considerably within the region under consideration, quite apart from variations with altitude. The fluid characteristics tend to differ at local and free stream regions. These different values determine the Mach number, which is defined as the ratio of fluid velocity to the speed of sound in the fluid. Besides, the aerodynamic forces experienced by the aircraft vary with the conditions of flow. Another important concept of Reynolds' number determines the boundary layer conditions past an aircraft. Equations such as Bernoulli's continuity equation, Prandtl's lifting line theory assume some idealistic flow conditions which may be practically unattainable. Even the avionics components have to compensate for the atmospheric attenuation. Noise, physical surrounding, and travel distance are the factors causing attenuation. Atmospheric attenuation limits the highest usable frequency to about 10GHz for communicating with the ground source. Following assumptions were made during research to be considered while designing the aircraft –

- Fluid density - 1.225 kg/m^3, Temperature - 285-295 K, Atmospheric pressure - 1.013 atm
- Flight altitude range - 0-200ft
- Mach number - 0.04
- Reynolds' number - 250,000-650,000
- Atmospheric attenuation factor - 0.02 dB/km for 2.4GHz

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II. PRELIMINARY DESIGN

A. Wing

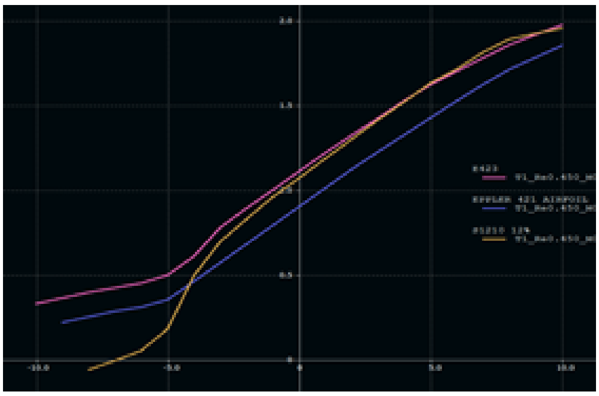
Wings are used to generate lift. To estimate the wing parameters, a value for wing loading needs to be chosen. This is one of the most important parameters that not only decides the wing parameters but also plays an important role in the performance of the airplane. An initial estimate of 0.025 lbs/in^2 is considered for wing loading. From aerodynamic considerations, it is desirable to have a large aspect ratio, probably in the range of 6-8. However, structural considerations dictate a moderate value for it. The values after arduous analysis is given below.

- Wing loading = 0.022 $lbs./in^2$, Aspect Ratio = 7.68
- Lift = $C_L * {}^1/_2 * \rho * v^2 * S = 46.65$, where $C_L = 1.112$
- Drag = $C_D * {}^1/_2 * \rho * v^2 * S = 0.55$ lbs., where $C_D = 0.013$

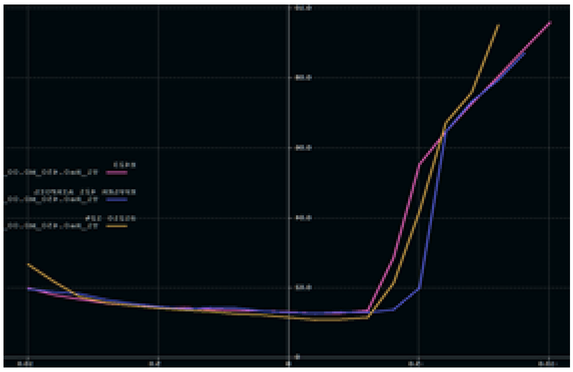
The tapered wing was a good option because it provided us with the benefits of an elliptical wing while still being rectangular in shape. The tapered wing also has added advantages from the standpoint of weight and stiffness. The tapered wing was also a better choice from weight efficiency point of view since the amount of material, as we go away from the root, decreases. Dihedral angle increases the stability of the aircraft as compared to a straight wing and minimizes drag which will be fulfilled by selecting suitable airfoil. With the wing span calculated, other requirements satisfied and carefully placing the control surfaces, below is the wing planform preliminary design parameters.

- *Airfoil Selection:*

Airfoil selection affects the overall aerodynamic efficiency during all phases of flight. The airfoils are compared on the basis of C_L, C_D, C_P, C_G, thickness, range of angle of attack, etc. The comparison gives us an idea about the performance of the airfoils under different parameters and circumstances. The airfoils E423, E421, S1210 were considered for comparison purposes.



Graph 1:- C_L v/ s α Comparison



Graph 2:- C_D v/s α Comparison

B. Fuselage

Fuselage should be compact in size but also have sufficient volume to accommodate the cargo and avionic components viz. battery, sensors, transreceiver, servos, and DAS, plus it has to have a dropping mechanism. A fuselage has to have a compact aerodynamic design and also, be light weight. Therefore, the fuselage would be considered to be kept short with a tail boom.

C. Landing Gear

An ideal landing gear has to have a main landing gear carrying about 80% of the total weight. The landing gear has to be designed considering the total take-off weight force and landing impact force on each wheel. The landing gear has to take all the load, and should dampen the impacts. The under-carriage provides strength against bending and should be strong enough to survive heavy impact loads. Tricycle, tail dragger, etc. are some options considered for an effective design.

D. Empennage

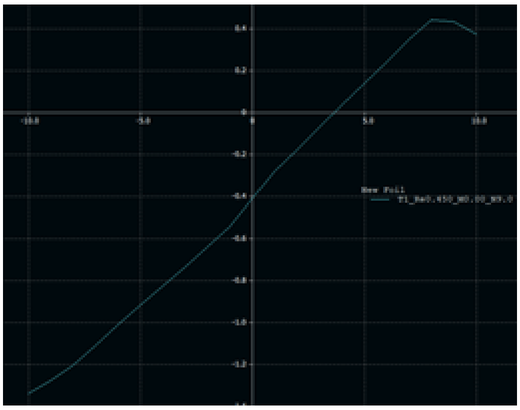
It is also known as the tail or tail assembly of the aircraft. It trims and stabilizes the aircraft longitudinally and directionally. The empennage has a vertical section - stab and rudder, and a horizontal section - stab and elevator. The flight dynamics of yaw and pitch are controlled by these control surfaces. Larger the distance between wing aerodynamic centre and tail aerodynamic centre, lesser is the tail area, and vice-versa.

- Horizontal volume coefficient = 0.7, Vertical volume coefficient = 0.44, Aspect ratio = 3.53

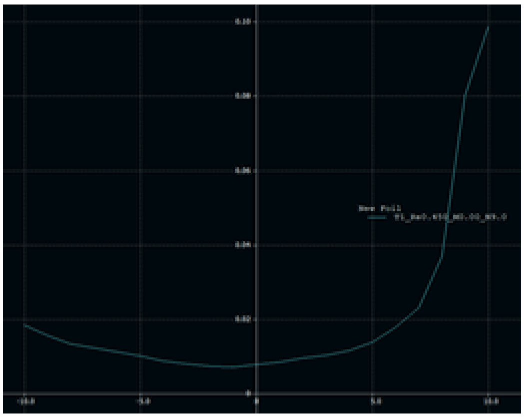
Ideally the horizontal tail should be out of the wing wake region to avoid incident turbulent air. Therefore, the T-tail or V-tail configuration would be an appropriate choice.

- *Airfoil Selection:*

Overall the tail should provide a nose up moment for a stable design. Hence, an inverted flat bottom airfoil for the horizontal section would be used. Clark Y was the only selected/considered airfoil after it gave satisfactory results on the nose pitching moment.



Graph 3:- C_L v/s α Comparison Inverted Clark Y



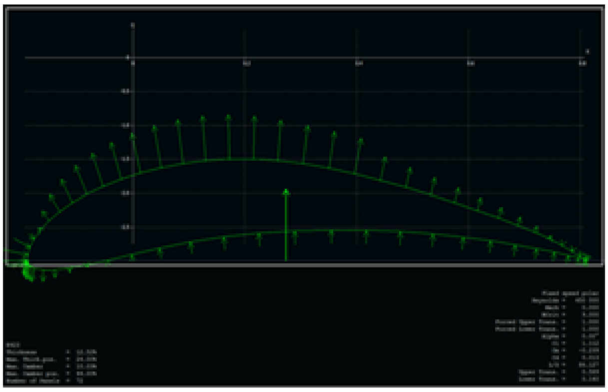
Graph 4:- C_D v/s α Comparison Inverted Clark Y

III. DETAILED DESIGN

A. Wing

The wing configuration is designed with two different aspects in mind - taper, and dihedral. The total wingspan of the aircraft is 127.75 inches. For the final design each half wing has a root chord of 20in, remaining constant for a span of 30in on both sides, and then tapering down to 10in at the tips. The wing has a dihedral of 3° at the root, followed by another dihedral of 2° at the taper root. The control surfaces associated with the wing viz. ailerons and flaps have a width of 2in each, and length of 24in and 18in, respectively. Moreover, the mid winged placement provided us with the least amount of interference drag. The centre of gravity is found to be 5.5 inch from leading edge. As the wing span is large, it is advisable to use 2 dihedrals to stabilize it.

The airfoil E423 is selected after comparing it against E421 and S1220.



Graph 5:- Eppler423

➢ *Wing Parameters*

Wing loading = 0.0256 lbs/in2
Aspect ratio = 7.86
Taper ratio = 0.5
MAC = 18.1 in.
Centre of pressure = 10.31 in.
Wing CG = 5.5 in.
Aerodynamic centre = 4.52 in.

B. Empennage

The conventional tail configuration provides stable option for the tail. Inverted Clark Y airfoil was selected for the horizontal stabilizer. Inverted airfoil provides nose up movement for the aircraft. The tail area (horizontal and vertical) is dependent upon the wing area and tail arm moment. Larger the distance between wing aerodynamic centre and tail aerodynamic centre, lesser is the tail area, and vice-versa. Elevator and rudder, each of width 2 inch are attached to the horizontal and vertical stabilizers respectively.

Graph 6:- Inverted Clark Y

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C. Fuselage

The fuselage is designed with a removable lid on top to allow access to the avionic components contained inside. Plus it has to carry static as well as dynamic payload, which requires a door on the bottom of the fuselage. Therefore all-in-all, it has to have sufficient volume to accommodate as well as access the components and payload easily. The fuselage dimensions measure as follows - width 7.75in, length 30.5in, and height 8.5in.

The fuselage holds the engine, fuel tank, landing gear, tail boom, and wing together. There are two payload compartments in the fuselage, a static payload which will be stationary and another dynamic payload which will be airdropped. Dynamic payload consists of zircon sand which is packed in a Kevlar bag. The static payload compartment is above dynamic payload compartment. There are two compartments for dynamic payloads which will be dropping the sand bags, variably or simultaneously. When the dynamic payload is dropped onto the target there is no disturbance to the C_g of the aircraft, due to this the design is stable. The static payload weighing 15.5 lbs. and dynamic payload has 11 lbs.. There is a tail boom above static load and the size of tail boom is 2 inches * 1.5 inches. The fuel tank is situated in the fuselage's head while the engine is mounted on the head.

➢ *Fuselage Parameters*

Skin Friction = 0.006677
Young's Modulus –
Balsa wood = 4.2 GPa
Aeroply = 7.8 GPa

D. Engine

The fuel used for the engine is a glow fuel with 70% of methanol, 10% of synthetic oil, 10% of castor oil and 10% of nitromethane. The engine can be stopped by closing needle valve through servo placed above fuel tank which can be operated by radio control. We decided to use a separate power source for avionics to avoid power supply failure. The sizes of the propellers considered are 10*7, 11*6, and 11*7. As per the competition regulations for advanced class, after thorough calculations and analysis we has selected a suitable engine with the following specifications:

➢ *Engine Parameters*

No. of strokes = 2 stroke
Maximum RPM = 33000 RPM at 80% throttle
Weight = 1.8 lbs. (with muffler)
Capacity = 0.46 in3
Fuel = Glow fuel
Thrust = 46.3 lbs. at 65 ft/s

E. Landing Gear

The landing gear consist of nose gear and main gear. The total weight of the aircraft is supposed to be distributed so that 80% is bared by main gear and 20% is supported by the nose gear. This phenomenon is efficiently satisfied by the tri- cycle configuration. The material properties also play a key role in the efficient functioning of the landing gear. The materials that are used for the main gear and nose gear is Aluminium 6061 and stainless steel respectively.

F. Avionics

The advanced aircraft has an integrated Data Acquisition System (DAS), which consists of a microcontroller board, first-person view (FPV), barometric sensor, and transceiver. The microcontroller board is programmed to control servos to airdrop the dynamic payload while collecting the altitude readings. The airdrop is actuated by means of 2 servos to control the dropping mechanism. The mechanism opens cabin door-flaps which releases the payload.

➢ *Components*

FPV - 5.8GHz, 40Ch, 600mW
Microcontroller - (Arduino UNO) 16MHz clock frequency, 32kb flash memory, 2kb SRAM, 1kb EPROM, 6 analog input
Transceiver - 900MHz
Sensor (Barometric) - 3.3 to 6.5VDC, -40^0F to 185^0F
Flap servos - 5V, 11 lbs. torque, metal gear, analog

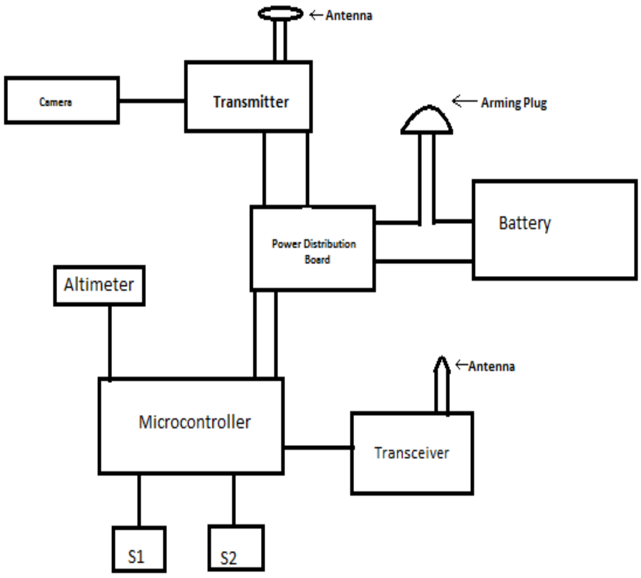

Fig 1:- DAS Circuit Diagram

IV. ANALYSIS

A. Analysis Techniques

➢ *Analysis Tools*

We used XFLR5 and ANSYS for the analysis of the aircraft. XFLR5 compares the airfoils and generates characteristic graphs, thus giving an idea about the lift and drag v/s AoA, coefficients of lift, drag, pressure, etc. It also gives a rough idea about the flow model and aircraft static and dynamic stability to some extent. ANSYS was heavily relied on during the design optimization process. CFD analysis is performed using ANSYS Fluent. It simulates fluid flow models in a virtual environment to generate specific results. Fluent results showed fluid flow and static and dynamic pressure graphs. Structural analysis is performed on the landing gear and fuselage using ANSYS Static Structure. It uses a finite element analysis tool to solve mechanical design problems, and predict model behavior during diverse flight conditions.

➢ *Developed Models*

The developed mathematical model is based on Navier-Stokes equation.

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} - \nu \nabla^2 \mathbf{u} = -\nabla w + \mathbf{g}.$$

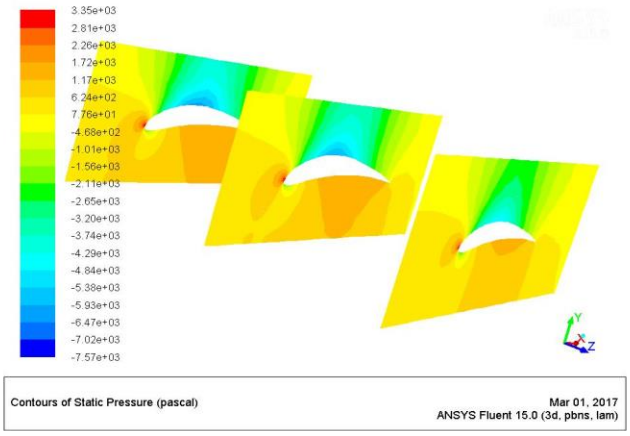

Fig 2:- Static Pressure at Root, Taper Root, Tip Chord

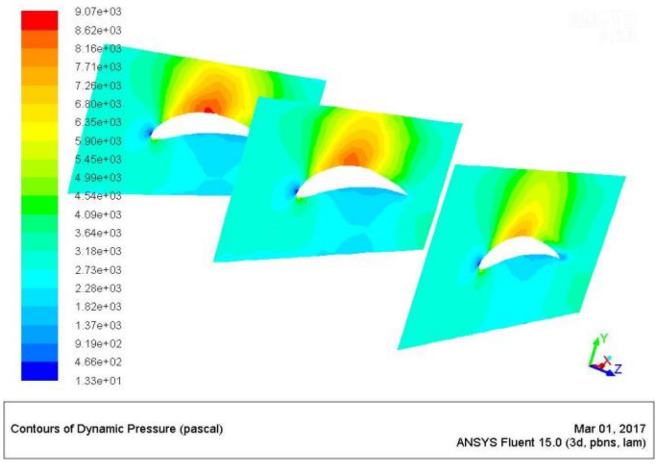

Fig 3:- Dynamic Pressure at Root, Taper Root, Tip Chord

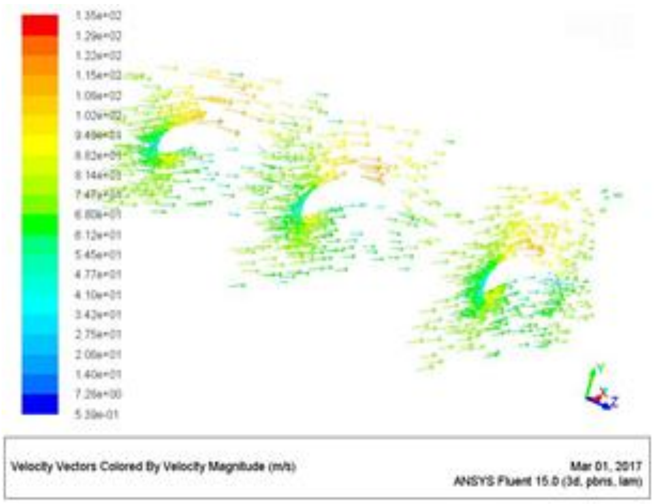

Fig 4:- Velocity Vector at Root, Taper Root, Tip Chord

B. Performance Analysis

➢ *Runway/Launch/Landing Performance*

- Take-off Distance = 61.5 ft.
- Landing Distance = 39.37 ft.
- Take-off acceleration = 14.43 ft/s^2
- Take-off Velocity = 39.37 ft/s

➢ *Flight and Maneuver Performance*

- Static Thrust = 10.5 lbs.
- Lift = 46.649 lbs., Drag = 0.545 lbs.

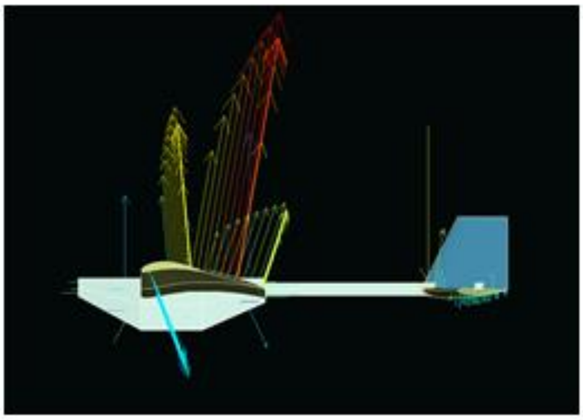

Fig 5

➢ *Lifting Performance and Margin*

The aircraft is designed to lift a total load of 40 lbs. It maintains a safety margin of 0.2 which is crucial in deciding the safety of the aircraft. The aircraft has to operate under different circumstances depending upon the environmental factors. The lift generated varies with air density, moisture, etc. The calculated take-off lift approximately equals 48 lbs.

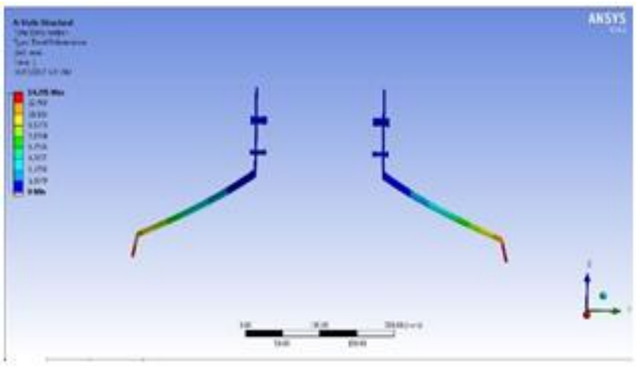

Fig 6

➢ *Dynamic and Static Stability*

Static stability is the ability of an aircraft to remain upright when at rest, or under acceleration or deceleration. Static margin is a concept used to characterize the static stability and controllability of an aircraft. Dynamic stability is a characteristic of an aircraft body when disturbed from an original state of steady motion that causes it or when disturbed from an original state of steady motion in an upright position, to damp the oscillations set up by restoring moments and gradually return to its original state.

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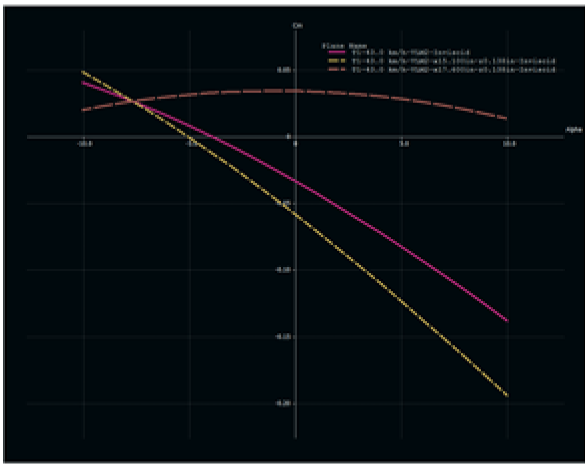
Static Margin = $(X_{Np} - X_{Cg})/MAC * 100$
= 10.13%

The static margin defines the stability of the aircraft. Greater the static margin, more stable is the aircraft. However, it makes the aircraft less responsive to acrobatic maneuvers.



Graph 7:- Relative Position between C_G and C_P

C. Structural Analysis

➢ *Applied Loads and Critical Margins Discussion*

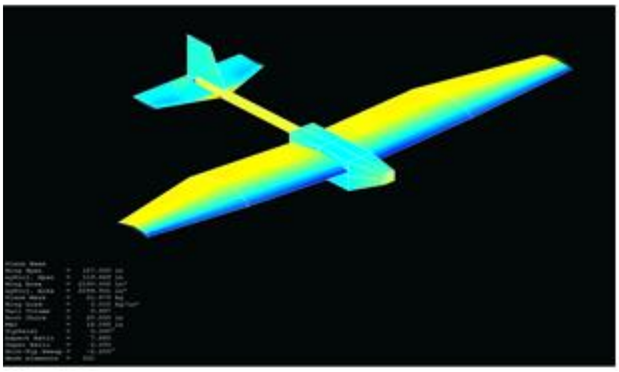


Fig 7:- Load Analysis.

The aircraft had to be flown probably under strenuous conditions, hence it was designed with a low value safety margin.

V. CONCLUSION

The project concluded with successful flight tests of the aircraft, which tested its integrity and capability in standard environmental conditions. Along the course of the project, the team encountered a number of complications which taught us a lot more about aerodynamics, aviation and project management. As every aspect is crucial during designing and fabrication of a radio controlled aircraft, a scrutinized study was performed on every trait to ensure a thorough and full proof model with utmost stability. The project completed within a time period of 9 months with an approximate budget of Rs 150,000. Through component selection and design optimization, it was possible to build the aircraft on a limited budget.

The objective being to deploy humanitarian packages on remote and inaccessible terrains, we have fabricated an aircraft worthy of deploying around 11 lbs. while carrying a static payload of 15.5 lbs. successfully. This is achieved without tampering the stability of the aircraft.

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