COGNIZANCE 2023
IIT-R

EVENT- FLIGHTFURY
Team Name: SKYBIRDS

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Contents:

Competition requirements

1. The plane should be able to carry at least 50 grams of weight along with the weight of its body and electronic components including battery, propeller motor, servo motors etc.
2. The fuselage body should be able to hold ball of 43mm diameter.
3. Wingspan should be less than 150cm.
4. Weight should be as low as possible and necessarily less than 2500 grams.
5. Single propeller airplane with motor kV less than or equal to 1000kV
6. The plane should have sufficient speed and stability. It should be sufficiently manoeuvrable to perform air shows.
7. It should have a cargo container and a box opening mechanism which can be used to drop cargo objects accurately at it’s desired location.

Design requirements:

Keeping in mind the requirements of the competition, the following things were decided to get optimum results:

1. The plane should be able to maintain high lift while maintaining high speed (necessary for air shows) and should be easily manoeuvrable. However, the requirements contradict each other. This could be done by reducing weight, making wings smaller which allowed for higher speeds, while maintaining the lift necessary to keep the plane held in air.
2. Since the drop mechanism will be manually operated, the aircraft should be able to maintain lift at low speeds, but it calls for higher wing area and higher chord length. So, the two requirements contradict each other and therefore must be optimised.

To maintain these requirements, the following design points were decided:

1. **Wing cube Loading: 8.7** (max necessary for high speeds during air show. this will obviously change during the payload round, when the weight will be more and to maintain accuracy, the speed should be less.)
2. We decided that the plane would have a **maximum speed of 20-21 m/s.**
3. Consequently, to perform stunts during the air show, the minimum limit for **thrust to weight ratio is taken as 0.8**, so that it can perform manoeuvres.

General Introduction:

Airplanes have been a fascinating piece of invention by us human beings. From being used as an airliner for daily passengers/tourists travelling from one place to another, to being used as cargo vehicles for delivery of important commodities like food, medicines etc during natural calamities, to serving the purpose of protecting the country’s airspace from hostile nations. With the advent and rise of Unmanned Aerial Vehicles, it has become necessary for us to innovate upon the same through remote control technology. In this event, we will try to design an RC plane, which will not only be capable of delivering cargo goods to the desirable location for dropping, but will also be able to perform stunts and tough manoeuvres, which normal airliners/gliders won't be able to perform.

Equipment Selection:

1. Brushless DC Motor, 1000 KV
2. 3s 11.1V Battery with capacity of 2200mAH . So, the unloaded rpm is 1000*11.1=11100 rpm (approx.)
    a. 11.1V
    b. Capacity:2200mAH
    c. Rated
3. Propeller:
    a. 2 blades
    b. 10-inch diameter
    c. Pitch of 4.5 inches
    d. Static rpm of 11200rpm. So, we consider 9600rpm in loaded condition (untested)

With these properties, we get a static thrust of 806 grams. Calculated from this website (https://rcplanes.online/calc_thrust.htm)

4. Servo Motors- (4.8 -6V, 9 grams)one each for rudder, elevator, alerions, and door opening mechanism. So total 4- 5 depending on whether we can implement single servo motor to operate both alerions on both the wings.
5. Electronic speed controller: 30A
6. Transmitter of 6 channel. One for controlling pitch of propeller, one for the fuselage, wings etc. The entire body will be made of foamboard, with some parts being supported using 3mm plywood, for toughness.

Total approximate weight of RC plane:

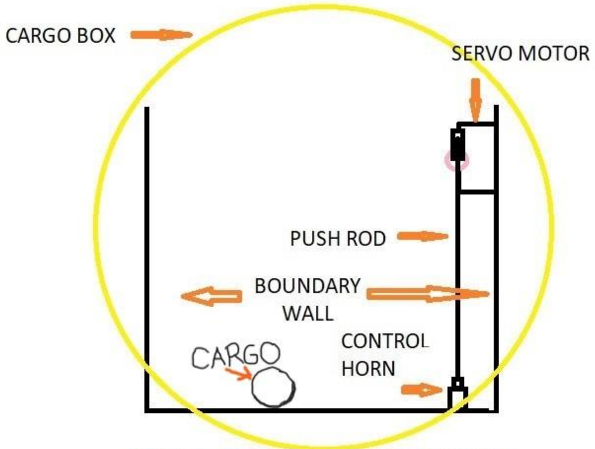
Sl. No	Name of components	Quantity	Weight (approx. In grams)
1	Battery	1	175
2	Main Motor	1	64
3	propeller	1	14
4	Servo motor	5	9*5=45
5	30 A esc	1	29
6	Control rods	4	15
7	Control horn	4	5
8	Body	-	200
9	Landing Gear wheels, axle etc	3	38
10	Drop mechanism	1	40
11	Misc.	-	200

Total : 850 grams

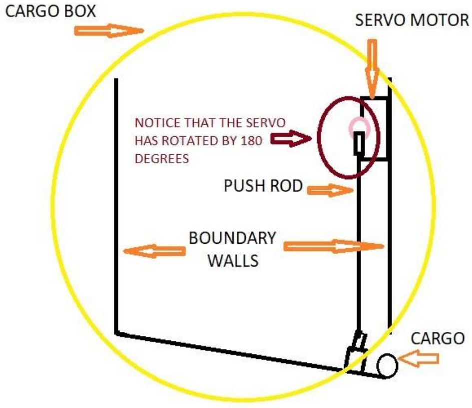
Design of RC plane:

1. **Landing Gear Selection:** We will use the tricycle gear. One wheel towards the front, this was chosen such that it maintains the balance and does not disturb the moment and does not topple the aircraft on trying to take-off or land.

2. Payload and drop mechanism:



STATE-1: WHEN CARGO DOOR IS CLOSED



STATE-2: WHEN CARGO DOOR IS OPENED

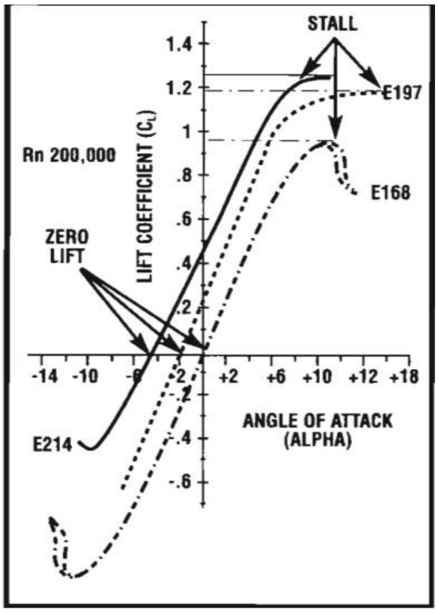
This section is just a proposal on how we tend to do things. This can change if things don't work as we intend.
For the door mechanism to drop cargo, we basically create a cargo box which is a chamber separated from the rest of fuselage by walls.
At the base we make a rectangular hole and place a relatively small sized foamboard which is attached to the static component of the plane through a hinge on one side and a control rod on the other side which is operated by a servo motor attached vertically to the wall. When the signal is given, it rotates by 180 degrees so that the cargo door opens in a clockwise direction with respect to the hinge, and thus dropping the cargo. When the second signal is given, it closing the door.

3. **Wing Design:**

There are three broad types of air foil (as in Figure 7):

1. heavily cambered, (E214)
2. moderately cambered (Ag-03 or E197)

1. no camber, or symmetrical (E168)



Each type has its own characteristics.

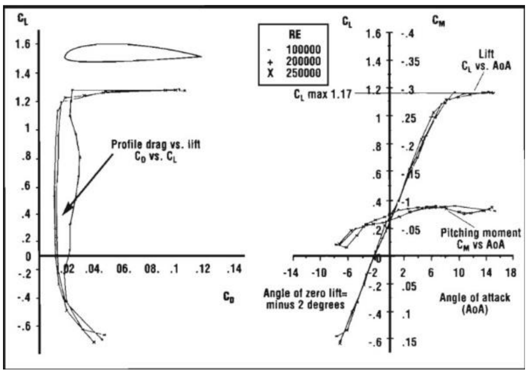
Greater camber increases CL max, i.e., moves the lift curve to the left so that the angle of zero lift becomes increasingly negative, and the positive AoA of the stall is reduced. Note that symmetrical air foils lift equally well upright or inverted. But building symmetrical air foils is tough, on the other hand a rectangular cross sectional air-foil has many negative features, so we optimize the situation by creating a moderately cambered air foil since it has a flat base which makes it easier to build. Consequently, the air foil performs well, and hence an optimized air foil is achieved.

Now the performance of the wing is decided by several factors:

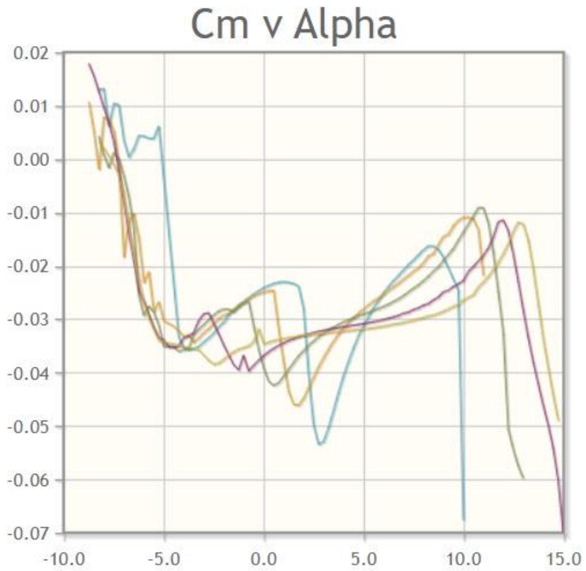
a) Wing area
b) Pitching moment
c) Mission profile
d) Stall Behaviour
e) Mean Line Camber

<u>Wing area</u>: The wing area decides the aspect ratio of the wing, which is nothing but the ratio of the wing span squared to the wing area. The wing produces lift by pushing air down. The more air it pushes down, the more lift we get. This can be done in two ways. It can push a very wide swath of air down gently, which requires a large span, but low forward speed. Or, it can push a narrow swath down a lot more energetically, which requires a smaller span and more speed.
If we push a wide swath down gently, the wingtip vortexes are weak because the overall downwash is weak, so induced drag (which is tip vortex drag) is low. If we push a narrow swath down hard, the tip vortexes are stronger, so induced drag is higher.

<u>Pitching Moment</u>: The air foil's pitching moment is important both structurally and aerodynamically.



In flight-particularly in manoeuvres-the pitching moment tries to twist the wing in a leading-edge-down direction. This adds to the torsional stress placed on the wing structure by the ailerons. High-pitching-moment air foils require wings that are stiff in torsion, and that favours thicker sections and full wing skins, particularly for high-Aspect Ratio wings.



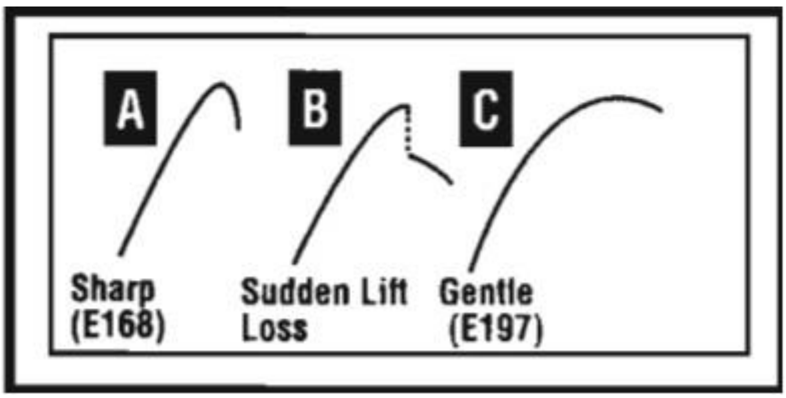
Pitching moment coefficient vs AoA for Ag-03 (from xflr5)

Aerodynamically, the nose-down pitching moment requires a horizontal tail download for equilibrium. This adds to the lift the wing must produce and increases total drag- called "trim drag." The pitching moment is little affected by variations in the Reynold's number.

Mission Profile: The selection of an airfoil depends on the role we want the plane to be assigned to, i.e. the airfoil's mission profile. For a glider, high lift, low drag and pitching moment at low Reynold's number should be the choice. For an aerobatic model, a symmetrical section with low $C_M$and the capacity to operate both upright or inverted is desirable, along with a sharp stall for spins and snap rolls and as high a C_L max as can be found. For a sport model, an airfoil with semi symmetrical section is ideal. It has high C_L max, low drag and a moderate pitching moment. The stall is gentle.

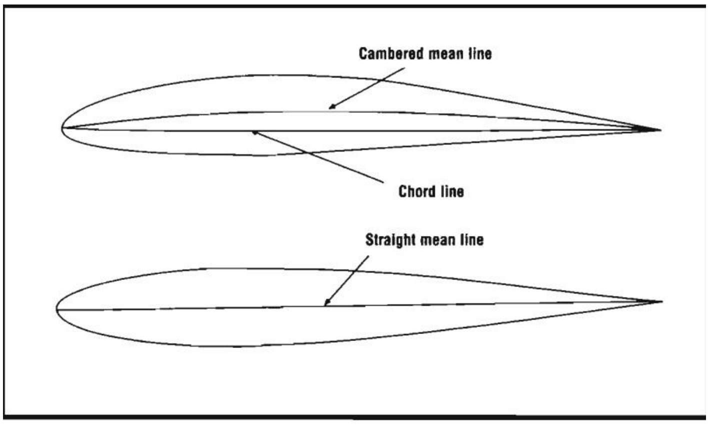
Stall Behaviour: In general, there are three broad types of stalls

a) sharp ;
b) sudden lift drops and
c) gentle.



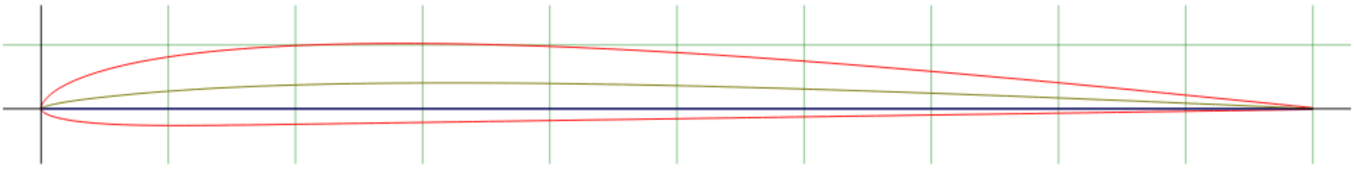
For sport models, a gentle stall is desirable. Sharp stalls and those with a sudden lift drop are appropriate for makeovers in which the ability to stall a wing easily is required, such as spins.

Mean Line Camber: A symmetrical air foil has the lowest C_L max and stall angle.



An air foil with increased camber produces a higher maximum C_L, but it starts to lift at higher negative angles of attack with a broader range of lift before stalling. Increased camber, however, produces increased pitching moments.

We decided upon the Ag-03 air foil since it has a flat bottom and therefore easier to build.



The Ag-03 air foil

Since we decided that our aircraft would have a maximum speed of 20m/s

$$Ma = \frac{v}{a} = \frac{20}{330} = 0.0606$$

$$Re = \frac{\rho \text{V(characteristic length)}}{\mu}$$

For air foil, characteristic length is chord length.

Here we have considered a simplified tapered wing having a

$$Taper\ ratio\ \lambda = \frac{Tip\ Chord}{Root\ chord} = \frac{13}{18} = 0.72$$

$$Wing\ cube\ loading = \frac{Weight\ of\ the\ plane}{(Area)^{\frac{3}{2}}}$$

Type of Aircraft	WCL (oz/ft^3)
Gliders	under 4
Trainers	5-7
Sport Aerobatic	8-10
Racers	11-13
Scale	over 15

For our plane to perform aerobatics and stunts properly during airshows, we take the wing cube loading to be 8.7. For this value, we referred to the Wing cube loading versus intended role table given above.

Now for the tapered wing, we calculate **the mean aerodynamic chord length** whose value is **17.8cm**. Hence, we can say that:

$$Area = (Span\ of\ the\ wing) \times (Mean\ aerodynamic\ chord\ length)$$

$$= 120 \times 17.8\ cm^2 = 2136\ cm^2$$

$$Weight\ of\ the\ plane = (Area)^{\frac{3}{2}} \times (Wing\ cube\ loading) = (2.299ft^2)^{\frac{3}{2}} \times 8.7 = 30.32\ oz = 859.56g$$

Which is close to that we calculated in our table.

Now from the table provided by the company manufacturing the motor for the RC plane, it is said that for a 1000kv motor being operated with a 10X4.5 propeller, we get a thrust close to 800 grams. Now we set our target **Thrust to weight ratio to be 0.8**. Therefore:

$$\frac{Thrust}{Weight} = 0.8$$

Hence, we get our thrust as 687.65 grams while the original thrust at full throttle is much higher. Hence, we can safely say that the plane having a **Thrust to weight ratio of 0.9 can very well perform stunts during the air show.**

But while checking through many discussions, and realizing the reliability issues with the thrust to weight ratio, we also calculated the battery power to weight ratio. Now

$$Battery\ power = Current \times Voltage$$

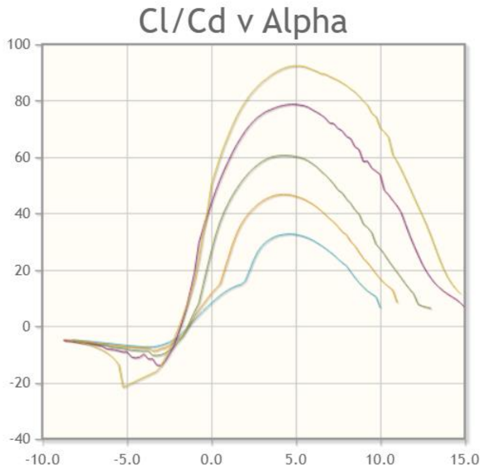
$$= (25 \times 2.2) \times 11.1 = 610.5\ W$$

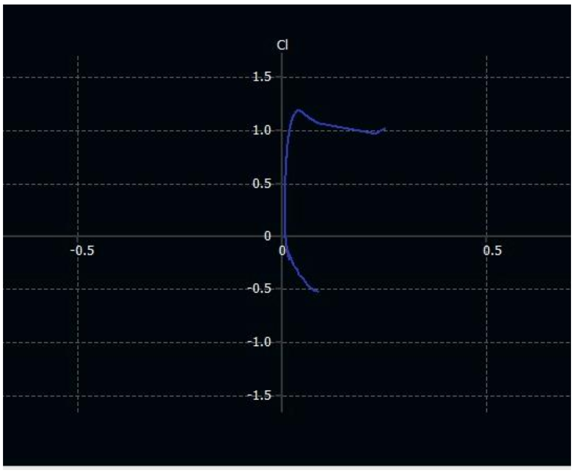
The rating of discharge current as 25C where C is the rated capacity, which in our case is 2.2Ah, so the total discharge current (dropping the unit hour) is 25×2.2=55A. For us the voltage is 11.1V. So, the battery power is found out to be 610.5W. Now weight of our plane is 0.85956kg. Therefore, Power to weight ratio is obtained as:

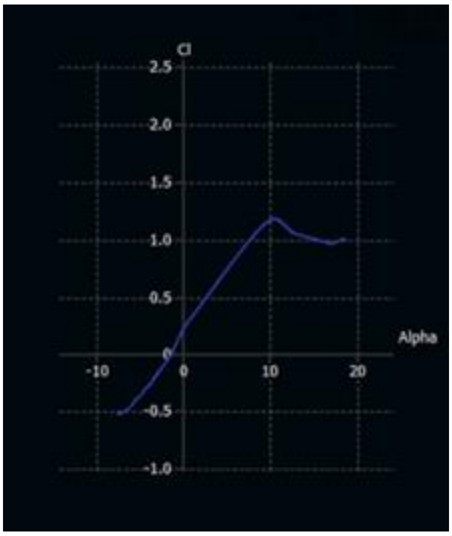
$$\frac{Power}{Weight} = \frac{610.5W}{0.85956kg} = 710.25\left(\frac{W}{kg}\right)$$

which is in the category of high-speed flight. All of these calculations have been done keeping in mind that full throttle is applied. Hence even though the angle of attack could lead to a stall theoretically, the plane would still be able to lift itself, simply due to its thrust.

We performed the analysis for this air foil in XFLR5 software in the velocity range of -20 to +20m/s and Reynold's number in range of 2×10^4 to 2×10^5 to predict the angle of attack for which stall occurs. Here are the results.







Another important conclusion is that the **angle of attack for which the air foil performs the best at most speeds is around 5 degrees.**

We conclude from these graphs that the **air foil would stall at angle of attack a little above 10 degrees.**

As the air foil speed is decreasing, the α for which stall is happening is decreasing, **so we conclude that higher speeds can support higher angle of attack but not more 10 degrees**.

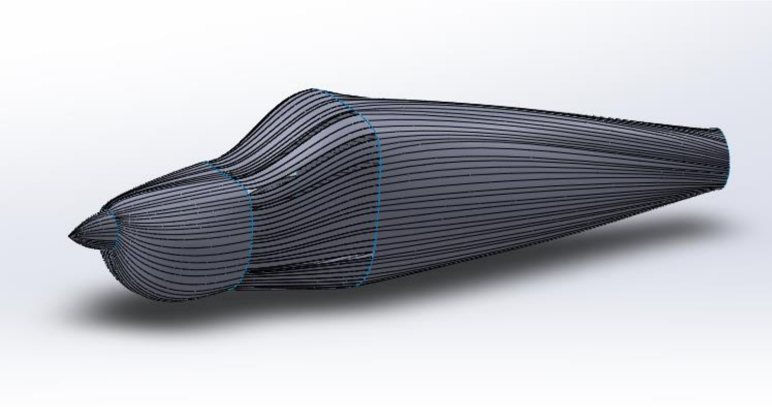
There will be no flaps in our RC plane since it complicates calculations.

Calculations for alerions:

From the basic rules of aerodynamics, we know that the length of alerions is around 15% of the chord length. So,

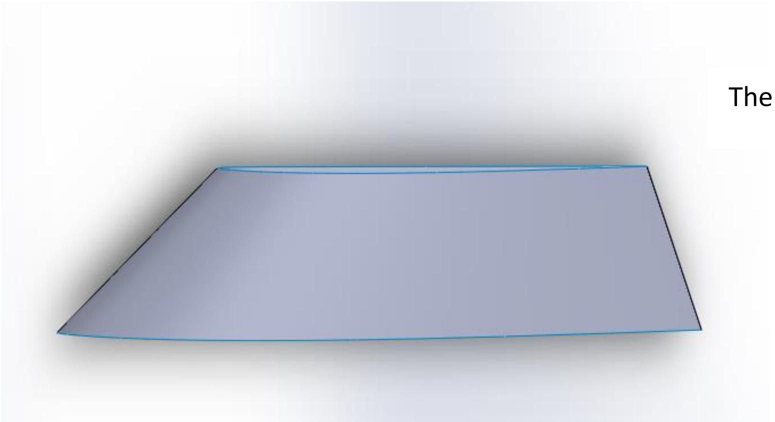
$$length\ of\ alerion = 15\%\ of\ 17.8 = 2.67cm$$

4) **Fuselage:** The nose section of the fuselage is made into a smooth curve instead of a rectangular section in order to improve aerodynamic features and reduce drag. **The length of the fuselage is chosen to be around 80 cm (as per rule it is 75% of wingspan)** so that we can have enough space to place the cargo, the batteries and other parts of the circuit. It has three compartments: the nose section, the cargo box section and the tail section, all of which are separated from each other by walls made of foam-board so that the cargo object cannot interfere with the circuits.



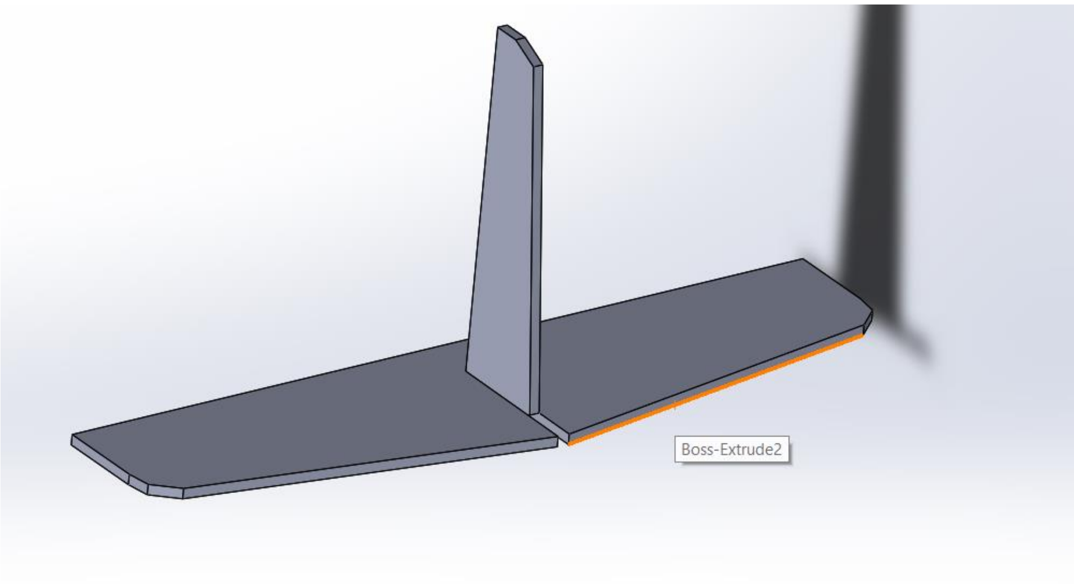
The proposed main fuselage designed in soildworks

5) **Main wing: The main wing has a wing span of 120cm**. It is built to have a tapered section, solely to reduce drag, with **the tip chord length being 13cm** and **the root chord length being 18cm**. The wing is attached to the top of the fuselage to simplify the design and development of the plane. It has two servo motors to operate the ailerons attached to the wings. Introduction of Flaps to the design is avoided to reduce further complications during the process of building the aircraft.



The right wing as designed in soildworks

6) **Tail section :**
   a) **Stab section:** The stab section is 15-20% of the wing area
   $Stab\ area = 18\%\ of\ wing\ area = 18\%\ of\ 2136\ cm^2 = 384.48\ cm^2$
   b) **Elevator :** The area of the elevator is 20-30% of the wing area
   $Elevator\ area = 25\%\ of\ 2136 = 534cm^2$
   c) **Fin area:** The fin is 33% of stab area.
   $Fin\ area = 33\%\ of\ 384.48 = 126.88cm^2$



d) Rudder: The rudder area is 33-50% of the fin.
$Rudder\ area = 40\%\ of\ 127 = 51cm^2$

The design was designed after looking at several designs online.

Conclusion, Motive of this project:

Through this event/project, we intend to learn more about aerospace engineering, by getting a first-hand experience at designing an aircraft and attempting to fly it under given boundaries and conditions. We feel that through this event, we would be able to learn quite a bit about our flaws in the design, and mend the same while applying our knowledge in our professional life.

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