AS5213 - Design of UAV

GROUP 14

COMMERCIAL DELIVERY VTOL

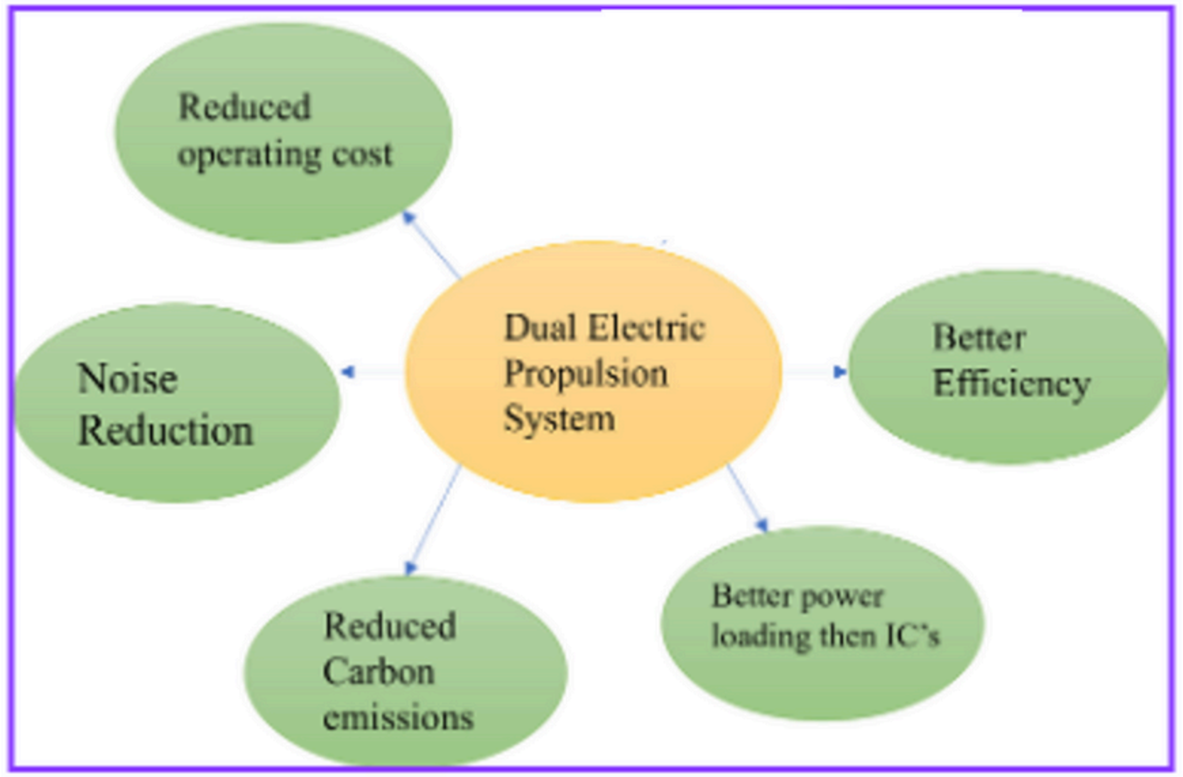
A FIXED WING-VTOL REPORT

MOTIVATION

DUAL PROPULSION ELECTRIC FIXED WING VTOL

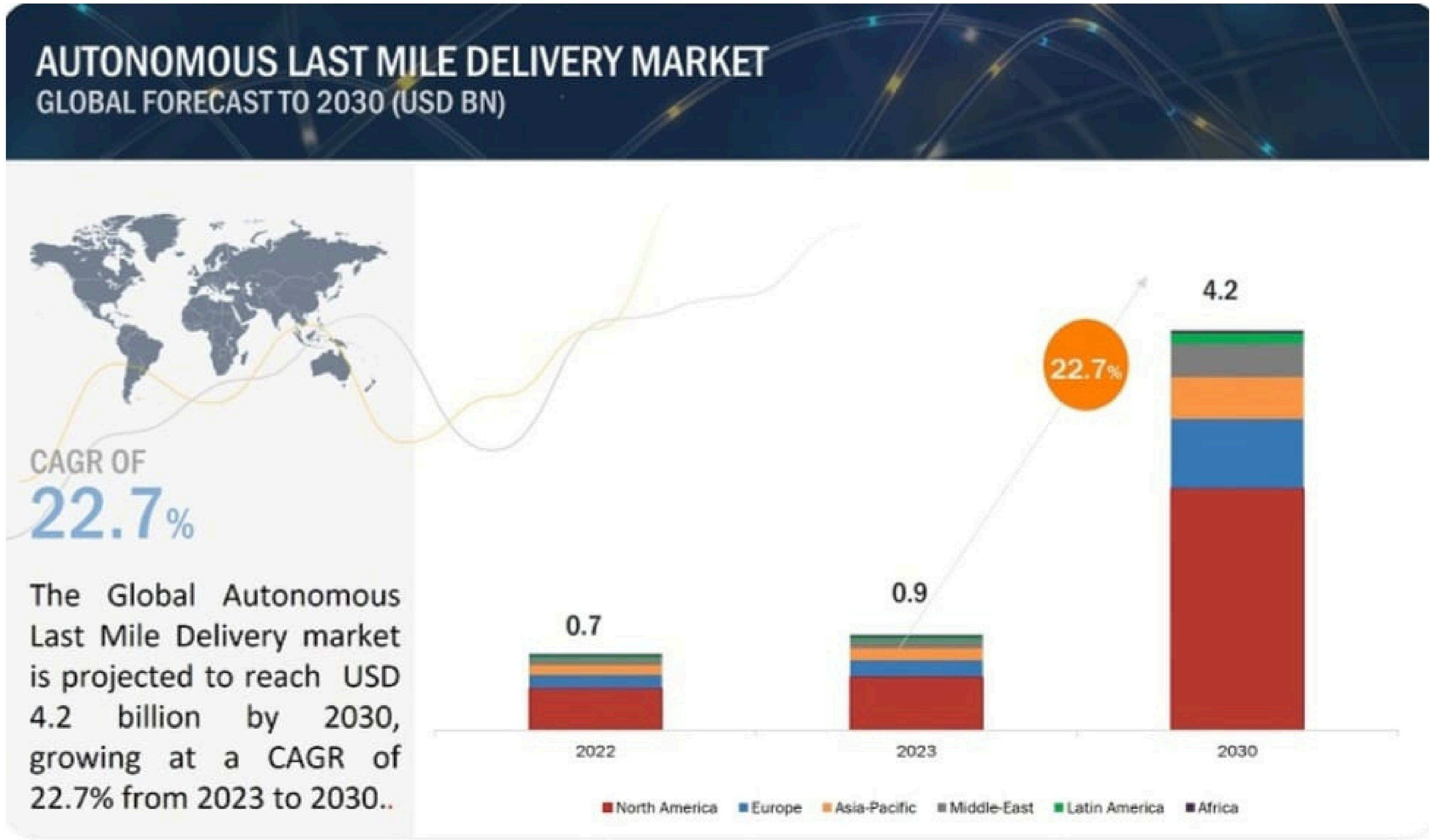
Why commercial delivery?

- Extend delivery accessability across the country
- Reduce traffic congestion
- Scheduled delivery



Why Quad Plane configuration?

1. Vertical Takeoff & Landing
- No runway required
- Payload delivery for confined regions
- Vertical Hovering
2. Fixed Wing
- Extended range and Endurance
- Payload Capacity
- High Speed Cruise

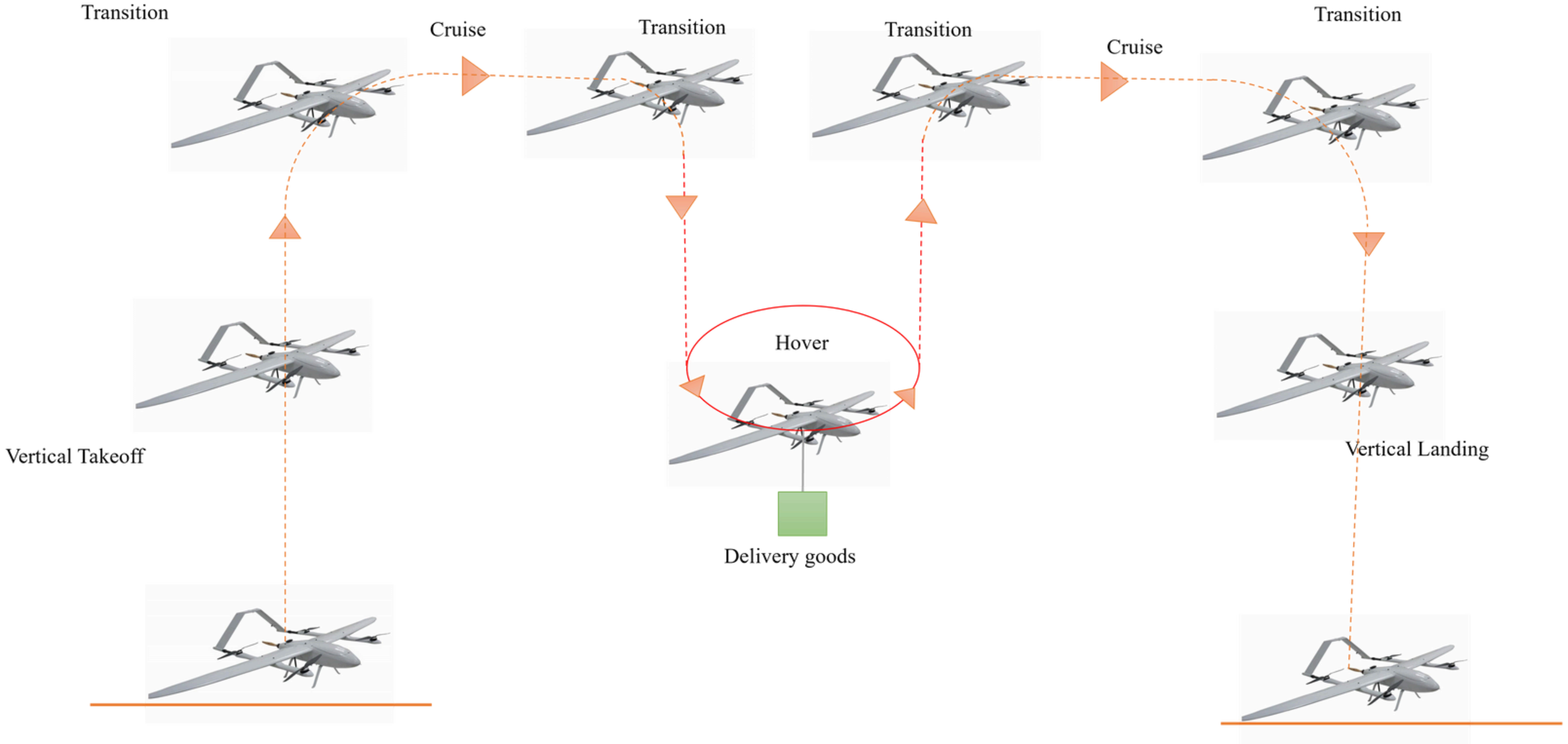


References
[1] "Design and performance analyses of a fixed wing battery VTOL UAV," Engineering Science and Technology, an International Journal.(2020)
\https://www.marketsandmarkets.com/requestsampleNew.asp?id=41240862

MISSION PROFILE

Design of a dual Propulsion Electric Fixed wing VTOL for delivery of commercial goods in urban and rural regions.

- Quad plane like configuration
- Vertical Take off
- Hover



Mission Requirements

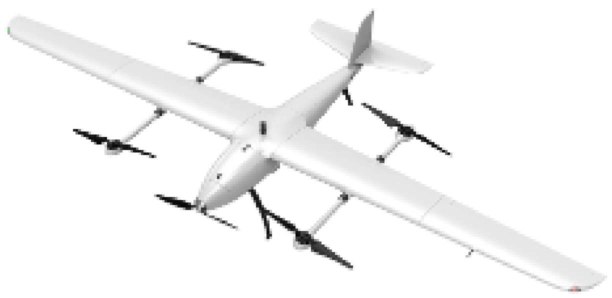
- Payload Capacity
- Confined space maneuver
- Maintain Level Flight

Segment	Time	Distance
Takeoff	70 sec	100 m (up)
Transition	30 sec	-
Cruise (Forward)	21 min	25 km
Transition	30 sec	-
Hover	70 sec	-
Transition	30 sec	-
Cruise (Return)	21 min	25 km
Transition	30 sec	-
Landing	40 sec	100 m (down)

Design Parameter	Value
Payload	3kg - 5kg
Range	150 km - 250 km
Maximum Endurance	1.5 hrs - 2.5hrs
Cruise Velocity	75kph - 90kph

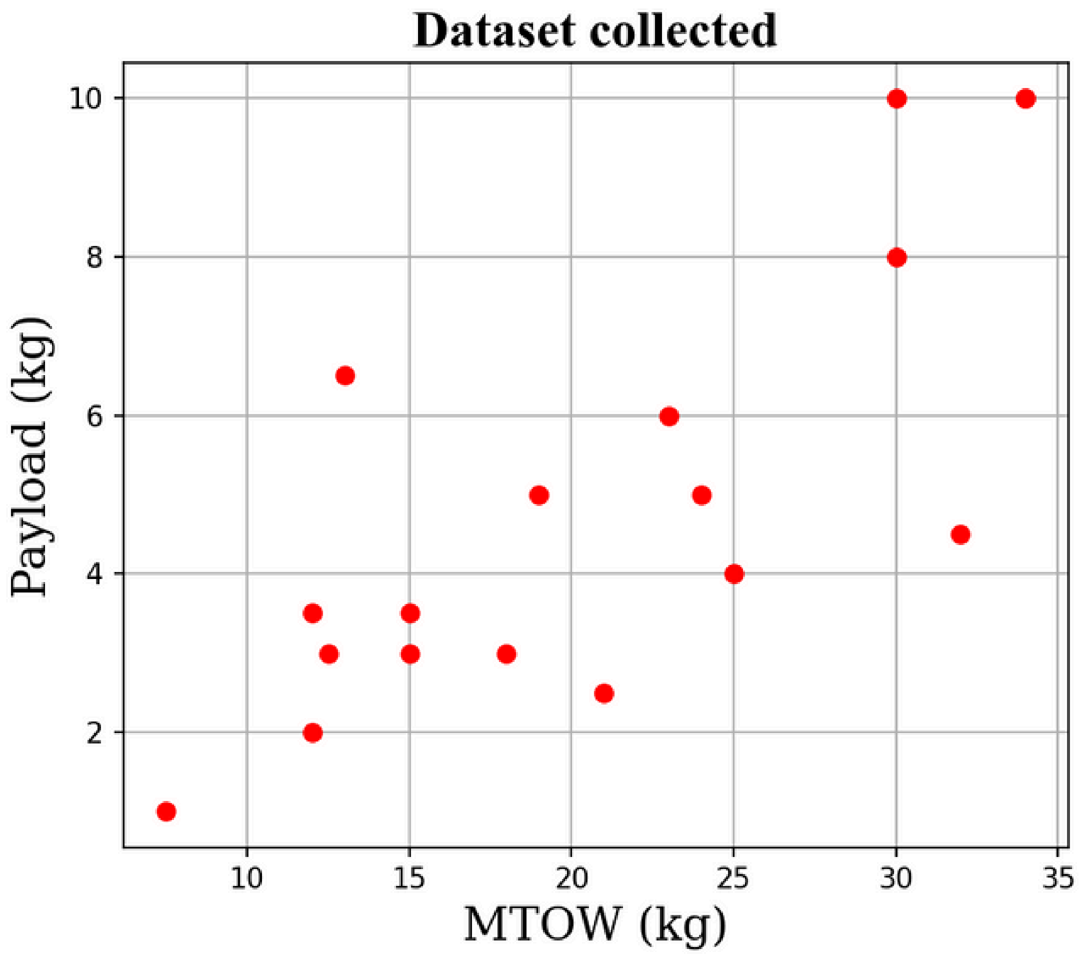
Some typical payload weights

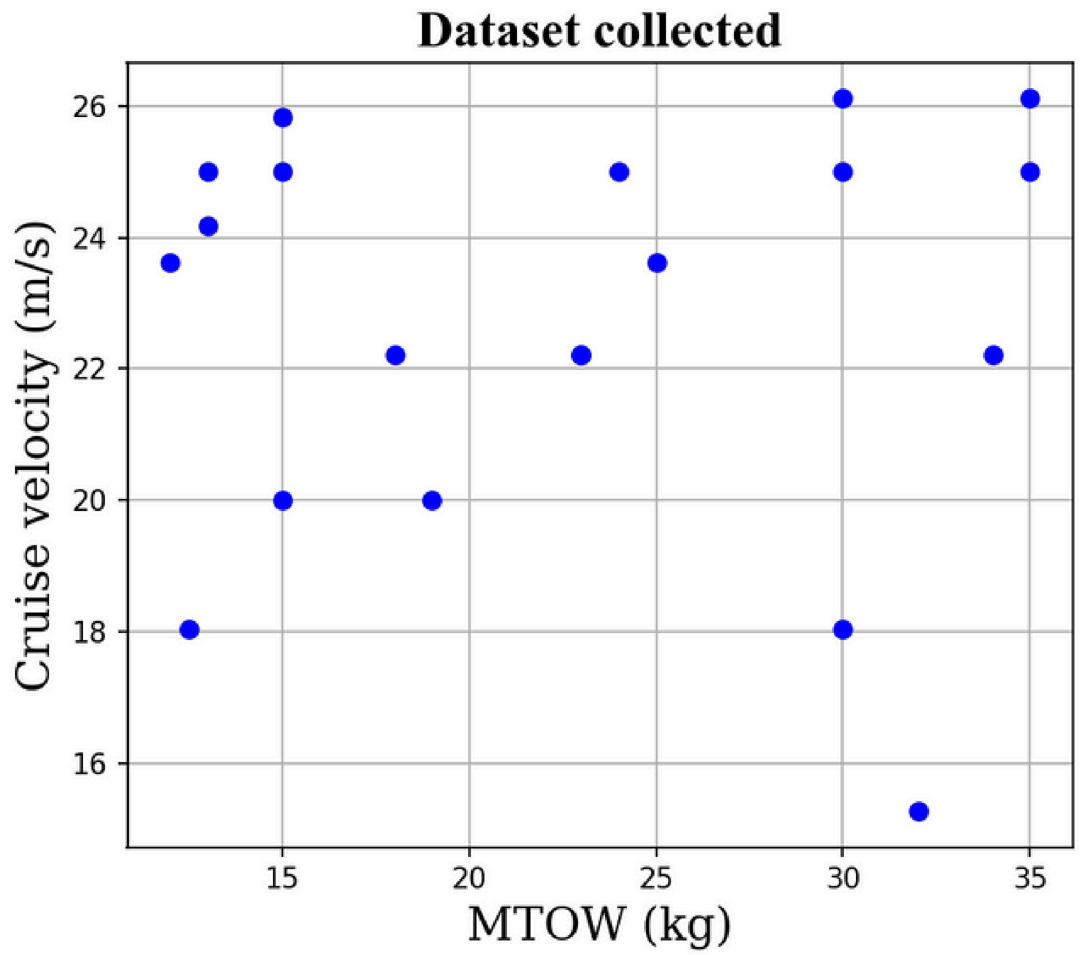
Typical payloads	Weight(kg)
Food/Groceries	1 - 2 kg
Electronics	2 kg
Clothing	0 - 1 kg
Stationaries	0 - 1 kg

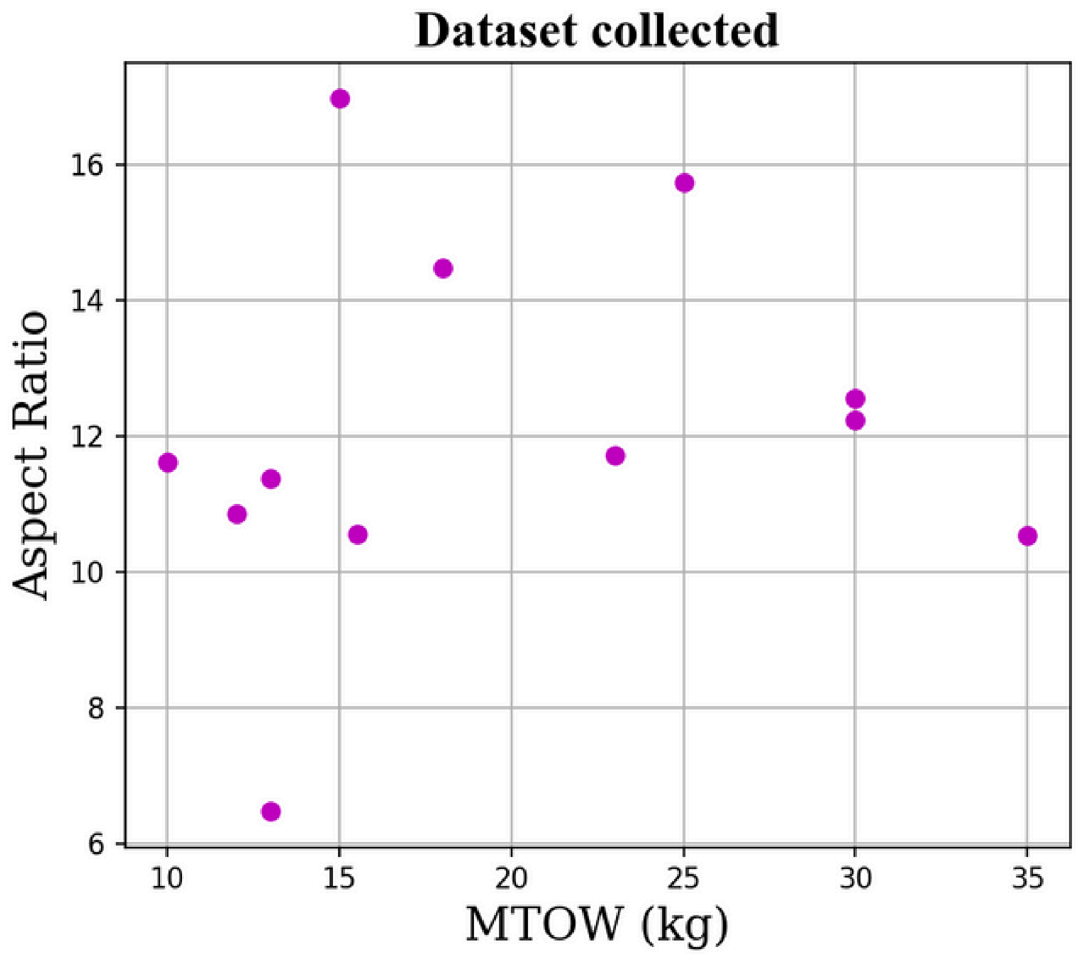


DATASET COLLECTION

The dataset collected from different set of VTOL are plotted with different parameters on Y-axis and MTOW on the X-axis shown below.





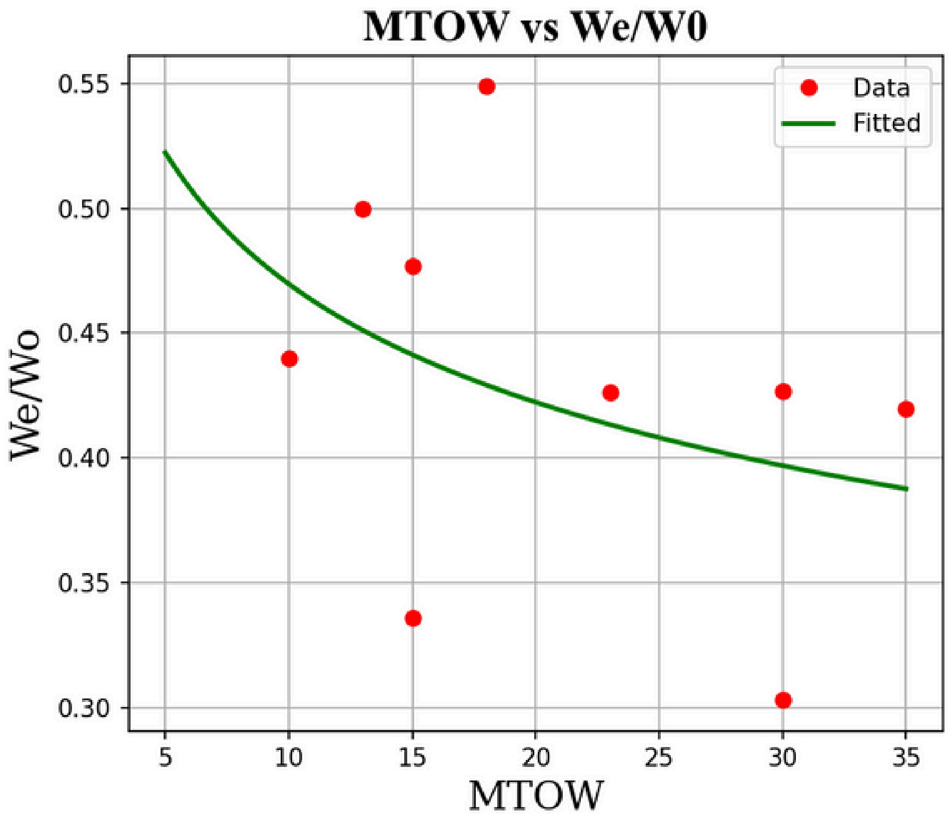


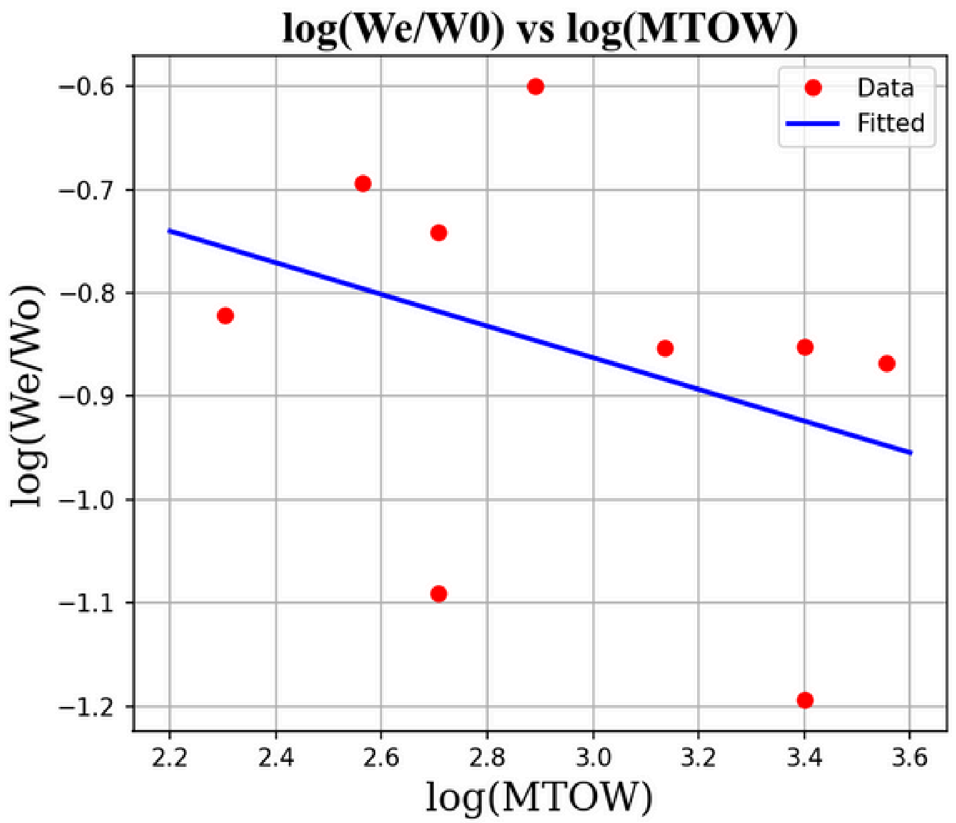
PRELIMINARY WEIGHT ESTIMATE

Empty weight estimate

From the datasets gathered, empty weight fraction is found and fitted as a power function of total weight.
The values found are A = 0.668 and n = -0.15 .

Manufacture/Name	MTOW	Empty weight
FlyDragon/ FDG33 VTOL	18 kg	9.88 kg
FlyDragon/ FDG36 VTOL	30 kg	9.1 kg
FlyDragon/ FDG410 VTOL	30 kg	12.8 kg
FlyDragon/ FDVF15 VTOL	15 kg	5 kg
Yangda / FW-250	13 kg	6.5 kg
Yangda / FW-320	23 kg	9.8 kg
Foxtech AYK 350	35 kg	14.7 kg
Foxtech AYK 250	15 kg	7.2 kg
Foxteck cetus 240	10 kg	4.5 kg





The empty weight fraction found as a function of Total weight[1] is $\frac{W_e}{W_0} = 0.66(W_0)^{-0.15}$

We will use this function in Iterative battery weight estimation which will follow in the next few slides.

References
[1] "Aircraft Design A Conceptual Approach" by Daniel P Raymer.

PRELIMINARY WEIGHT ESTIMATE

Battery weight estimate

In battery weight estimation we will estimate the battery/energy required by assessing each segment in the 'mission profile'.

The Energy/power is calculated for each segments by using the formulas used in the research papers[1],[2].

The formulas which were used from research paper is given below.

Takeoff power

$$P_{TO} = \frac{T_{TO} V_{TO}}{2}\left[\sqrt{1 + \frac{2T_{TO}}{\rho_\infty V_{TO}{}^2 A_{prop}}}\right]$$

$$T_{TO} = K_T W_{TO}$$

Hover power

$$FM = \frac{P_{ideal}}{P_{actual}} = \frac{\frac{T^{3/2}}{\sqrt{2\rho A}}}{P_{elec}}$$

Landing power

$$V_H = \sqrt{\frac{T_{hover}}{2\rho_{SL} A_{prop}}}$$

$$V_i = (K - 1.125x - 1.372x^2 - 1.718x^3 - 0.655x^4)V_H$$

$$P_{landing} = KW_{TO}(V_i - V_{Des})$$

Mission segment values we will use in battery estimation

Parameters	Velocity	Time	Distance
Takeoff	1.5 m/s	70 s	100m (up)
Transition	0 - 20 m/s	30 s	300 m (forward)
Cruise	20 m/s	1250 s	25 km (forward)
Transition	0 - 20 m/s	30 s	300 m (forward)
Descent for hover	2.5 m/s	32s	80 m (down)
Hover	-	70s	-
Ascent for cruise	1.5 m/s	54s	80 m (up)
Transition	0 - 20 m/s	30 s	300 m (forward)
Cruise	20 m/s	1250 s	25 km (forward)
Transition	0 - 20 m/s	30 s	300 m (forward)
Landing	2.5 m/s	40 s	100 m (down)

General parameters to be used in battery estimation

Paramters	Value
Span area	1 m^2
Aspect ratio	10
No of rotors(Quadplane)	4
No of forward propellors	1
Density	1.2 kg/m^3
C_D	0.07
Diameter of propellor	20 in
Thrust to weight ratio(Takeoff)	1.5
Efficiency of propellor in cruise	0.85
Figure of merit (Hover)	0.7
No of runs	3.5

Estimated battery requirement

The battery weight found from each segment is tabulated as below

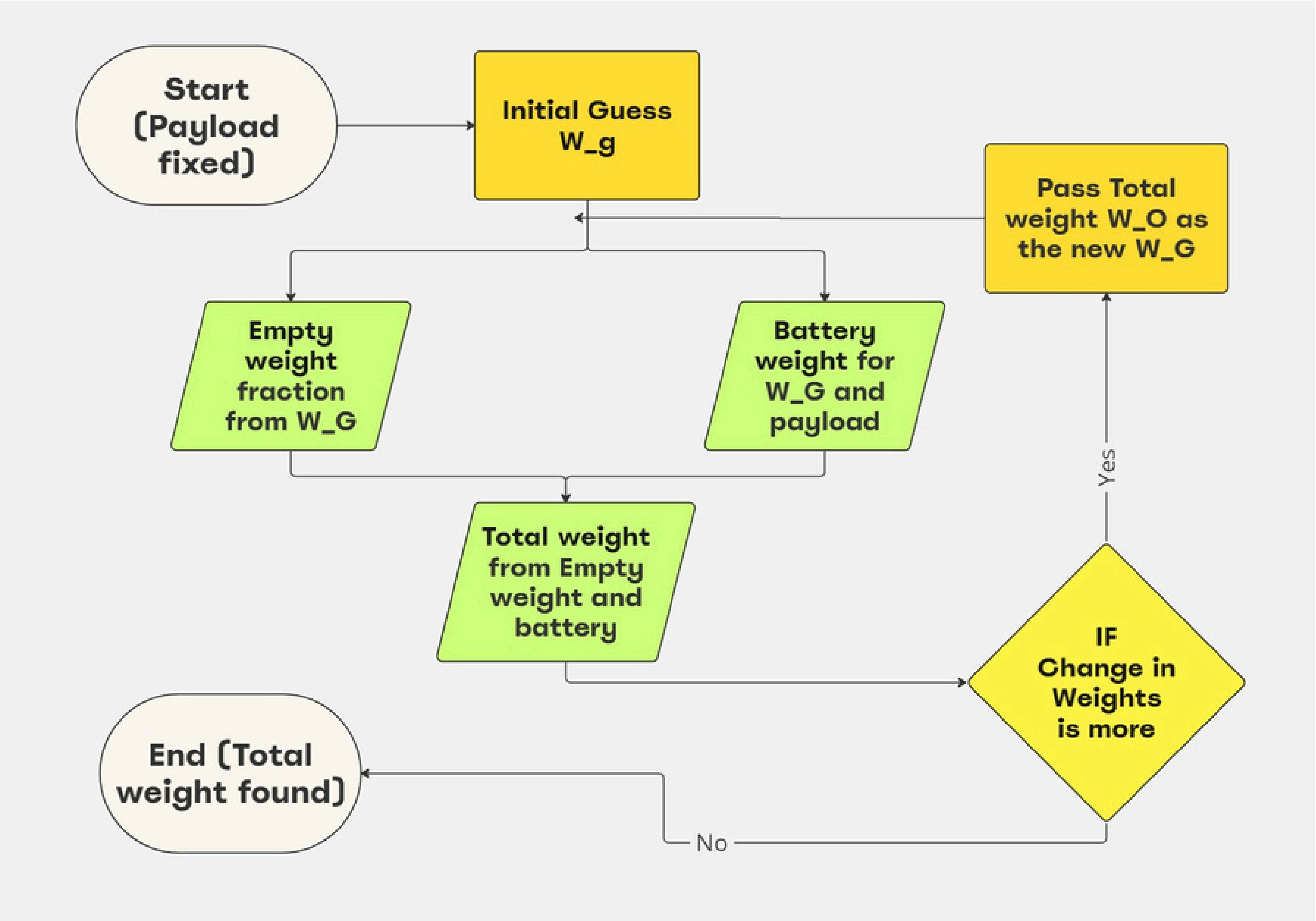
Mission Segment	Power Required(W)	Time(sec)	Energy (Wh)
Take off	4459.77	70	86.71
Transition	2047.09	30	17.05
Cruise (Forward)	395.29	1250	137.254
Transition	2047.09	30	17.05
Descent to Deliver	1297.32	32	7.2
Hover	3995.37	70	77.68
Ascent	4459.77	53	43.35
Transition	2047.09	30	17.05
Cruise (Backward)	395.29	1250	137.254
Transition	2047.09	30	17.05
Landing	1297.32	40	14.41

References
[1] "Design and performance analyses of a fixed wing battery VTOL UAV," Engineering Science and Technology, an International Journal.(2020) https://doi.org/10.1016/j.jestch.2020.02.002
[2] "On the figure of merit and streamwise flow of a propulsive rotor with synthetic jets," Aerospace Science and Technology.(2021) https://doi.org/10.1016/j.jestch.2020.02.002

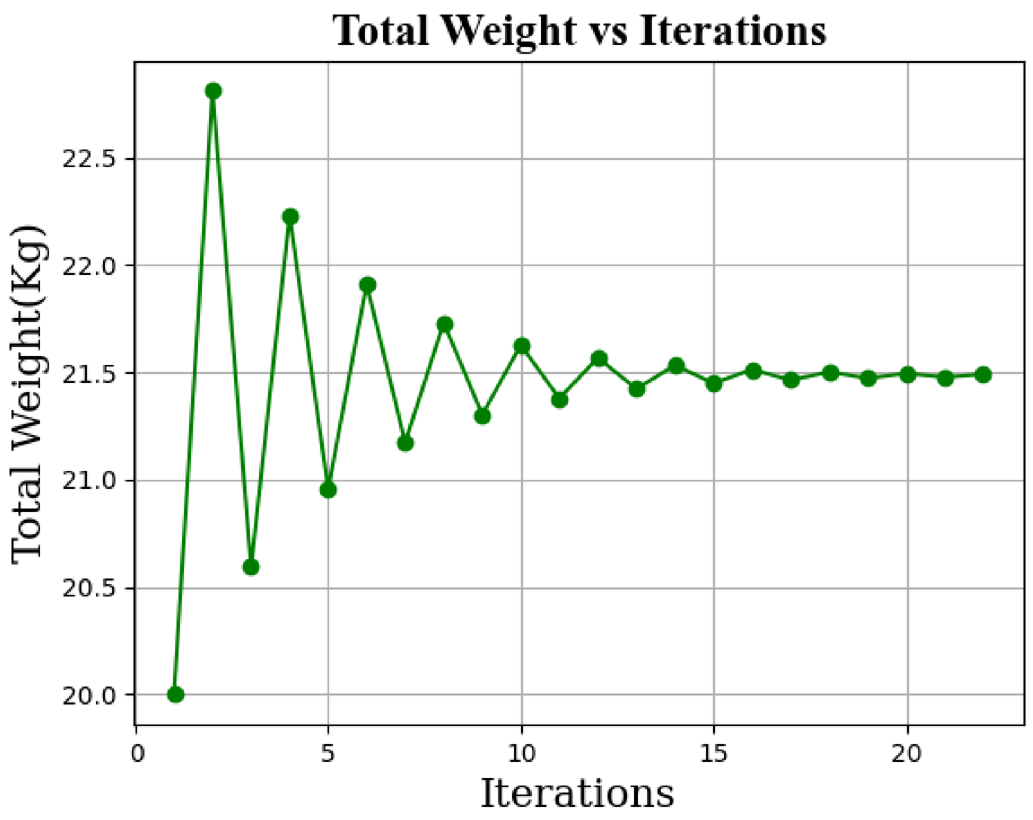
PRELIMINARY WEIGHT ESTIMATE

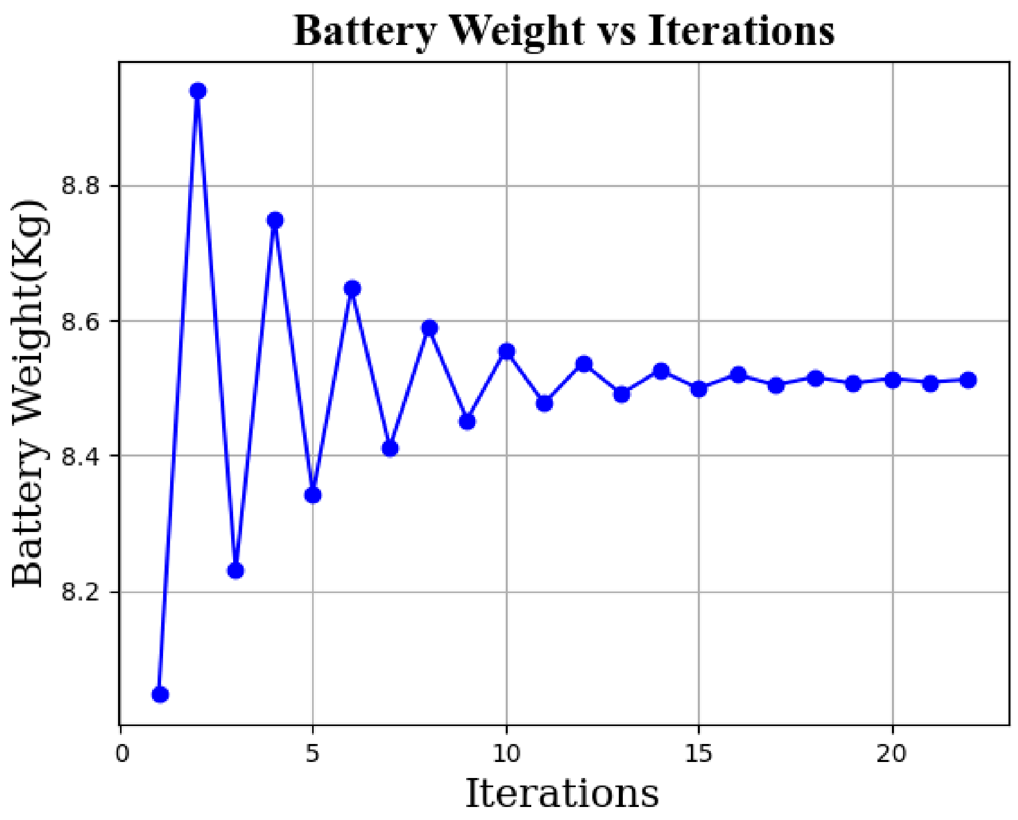
Method behind code

The method behind coding is explained in the following flowchart below,



Results





From the convergence graphs above we get the values of weight to be...(with 10% safety factor)

The MTOW obtained from convergence	23.54 kg
The battery weight correspondingly	9.29 kg
The empty weight of the VTOL	9.845 kg
The payload weight of the VTOL	4.40 kg

POWER LOADING AND POWER PLANT ESTIMATION

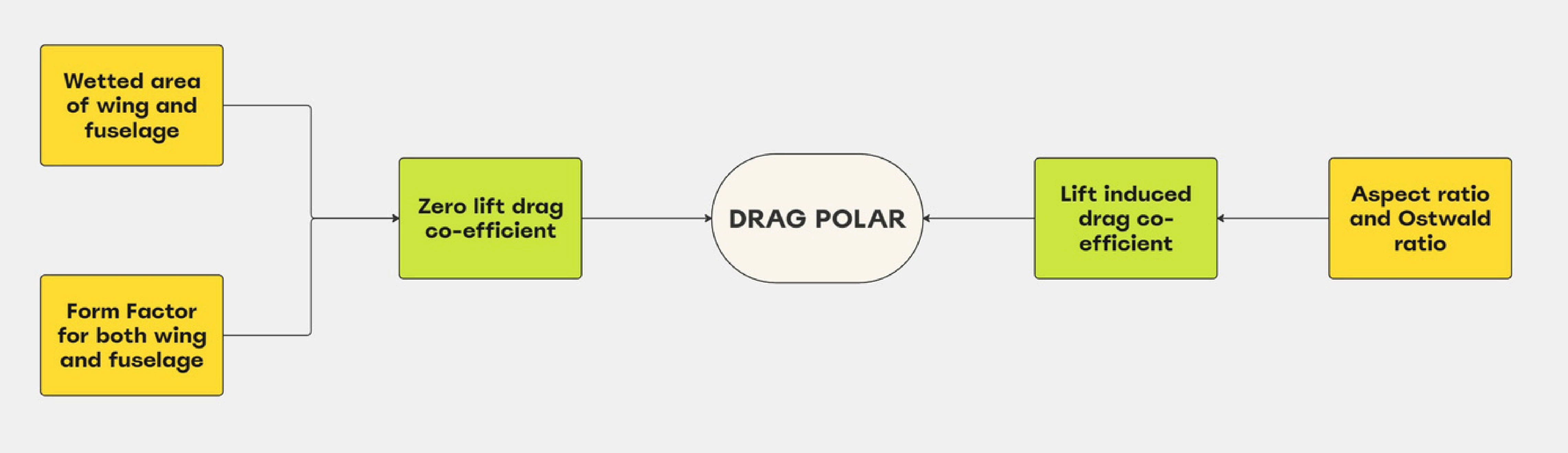
Previous data analysis

From the previous data we have calculated the parameters needed for power loading estimation

Name	MTOW(kg)	Cruise speed(m/s)	Wingspan(cm)	Wing area(cm^2)	Root chord length(cm)	Tip chord length(cm)	AR
foxtrot saber 210	13	20	215	7,141.73	41.9106	20.19	1.86046512
TEKEVER	25	23.61111111	350	7,782.64	24.412	16.1287	1.59281305
FlyDragon/ FLY350 VTOL	15	20	350	7217.0237	28.793	14.6306	1.14285714
Cetus-240 VTOL	10	20	240	4,953.95	26.4205	16.4068	1.66666667
FlyDragon/ Baby shark 220 VTOL	12	22.22222222	250	5758.3318	28.6893	16.6912	1.97530864
Yangda / FW-250	13	22.22222222	250	5494.4724	26.545	17.6213	1.97530864
FlyDragon FDG410 VTOL	30	19.4444	412.8	13,923.45	45.8779	22.3109	0.91590284
Foxtech Great Shark 330	23	22.22222222	320	8741.926	36.5249	18.7278	1.54320988
Foxtech AYK-250 Pro VTOL	15.5	25	250	5,919.04	28.9804	18.8792	2.5
Foxtech Whale 360 VTOL	30	26.11111111	350	9,755.68	34.8119	20.5237	1.94797178
Foxtech AYK-350 VTOL	35	26.11111111	350	11,618.31	39.2124	26.4231	1.94797178
Flydragon /FDG33 VTOL	18	22.22222222	340	7988.71	29.1969	18.4687	1.45243282

Drag polar

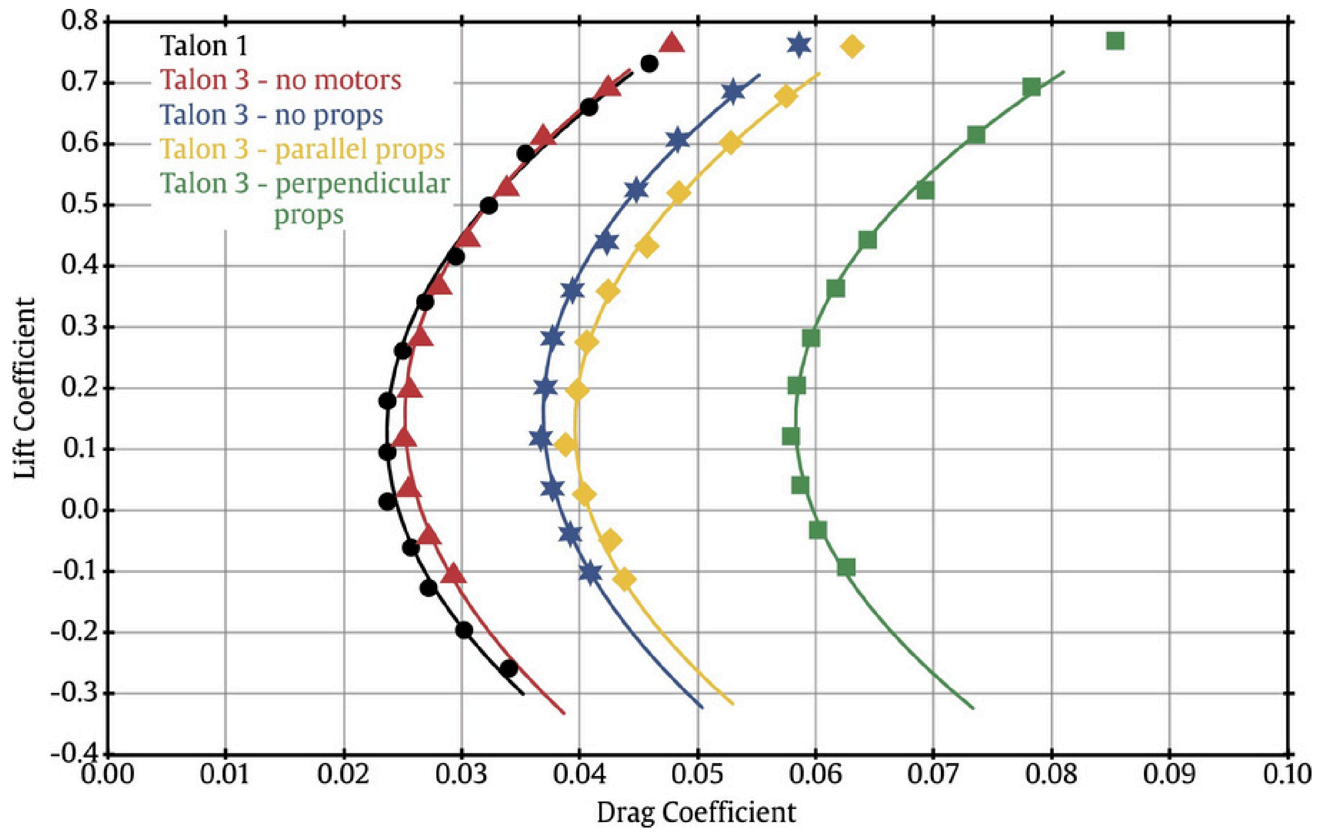
The procedure we followed to estimate the drag polar for each VTOL dataset is attached to the right.



POWER LOADING AND POWER PLANT ESTIMATION

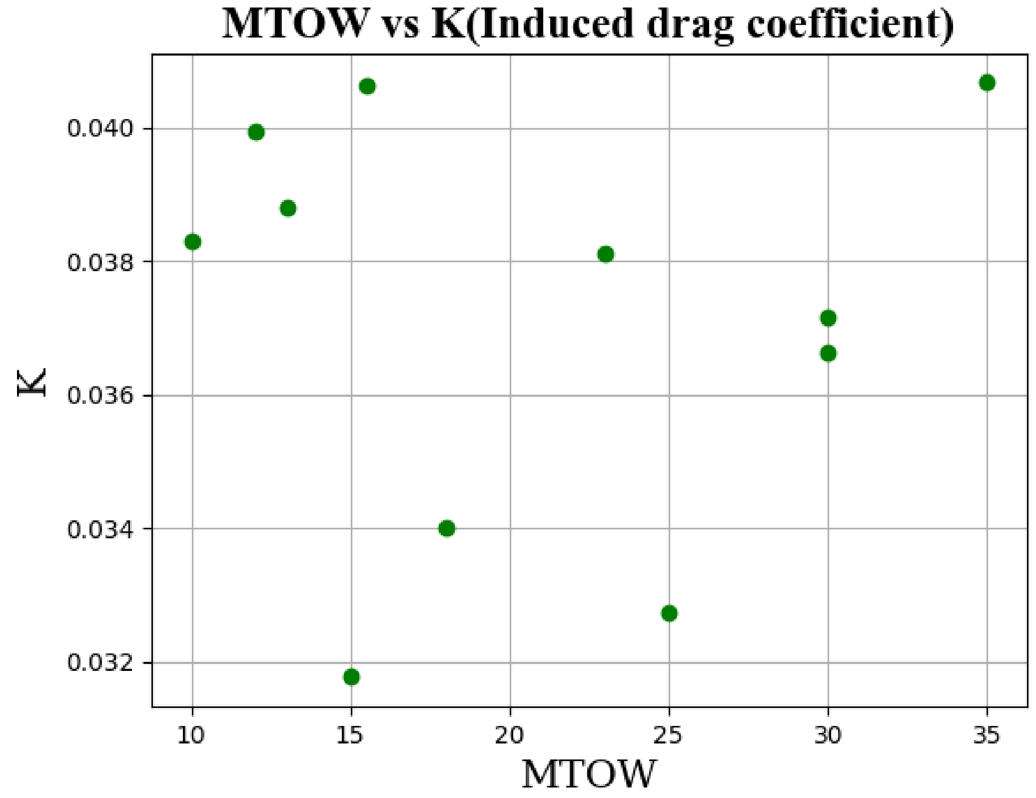
Vertical propellor drag

From the research paper[1], the change in Cd0 is taken to be 0.02.



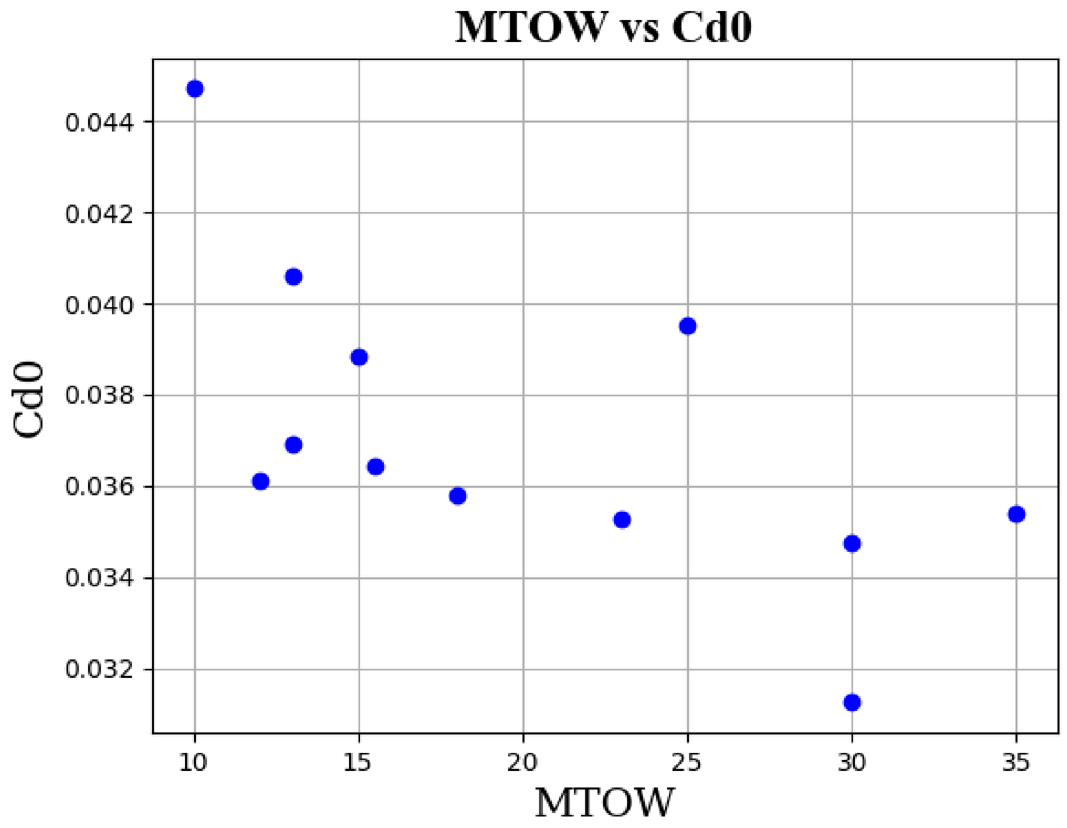
This vertical propellor drag is added in zero lift drag coefficient. In the research paper we have considered propellor placed parallel to flow.

The Drag polars of our datasets



The value of K is seen to vary between 0.04 and 0.032 and we took an average of the VTOL's near our MTOW.

The Cd0 for smaller VTOLS were seen to be large due to the large aspect ratio of the wings .A similar process ok K was followed for CD0 as well.



References
[1] O.Westcott, S. Krishna, R.Entwistle, and M.Ferraro, "Aerodynamic performance of aircraft wings with stationary vertical lift propellers," Aerospace Science and Technology, vol. 141, p. 108552, 2023.

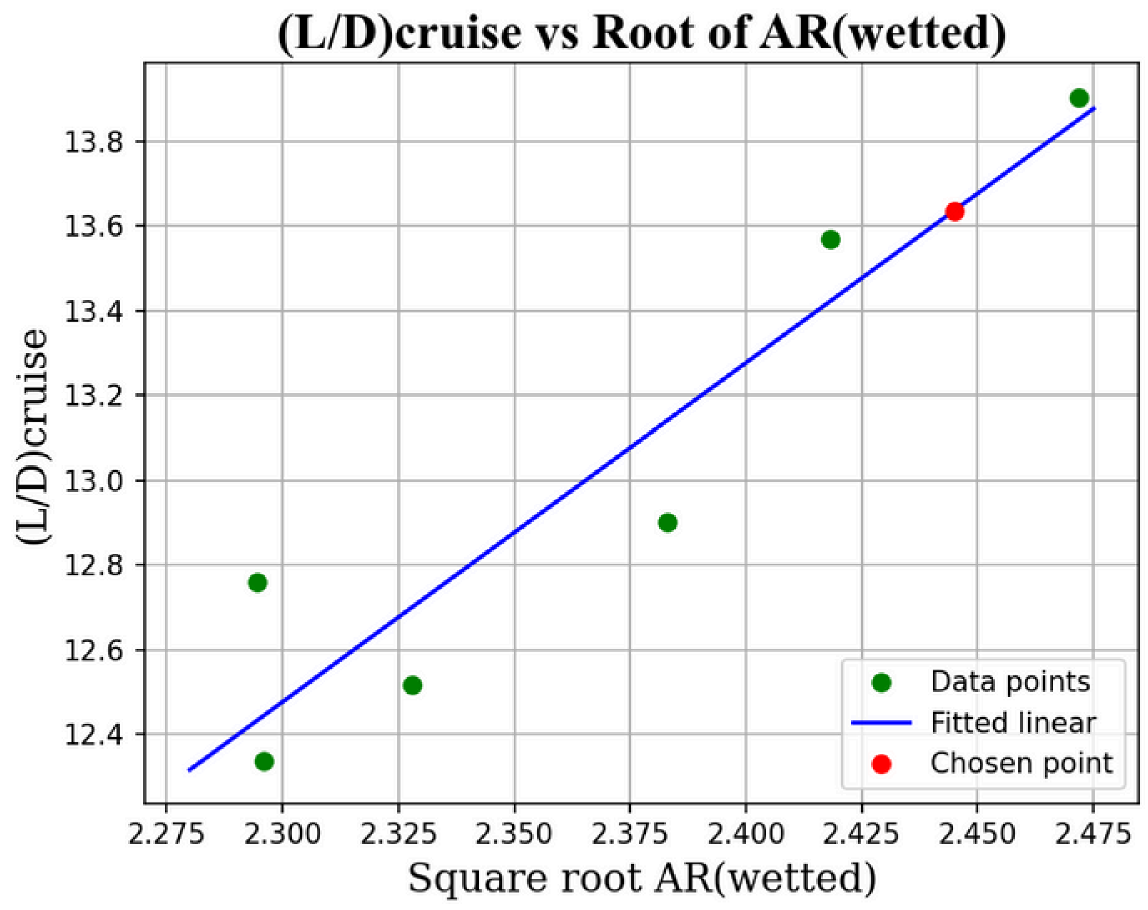
POWER LOADING AND POWER PLANT ESTIMATION

The **L/D vs square root of aspect ratio** plot was obtained using previous dataset. From the estimated L/D the corresponding aspect ratio wet for our design was observed at **2.445.** (Which was taken from the average of of other VTOLS near out MTOW)

The $\sqrt{(AR)_w}$:	2.445
The L/D ratio :	13.636
The lift in cruise :	23.54g

Name	CL	CD_total	L/D	sqrt{(AR)_w}
TEKEVER	0.942102104	0.068554633	13.74235499	2.803264639
FlyDragon/ Baby shark 220 VTOL	0.689965451	0.055120569	12.51738614	2.327829626
Yangda / FW-250	0.783357743	0.06072201	12.90072154	2.383068554
FlyDragon FDG410 VTOL	0.931753588	0.067012297	13.90421802	2.471870896
Foxtech Great Shark 330	0.871090936	0.064192665	13.56994503	2.418276417
Foxtech AYK-250 Pro VTOL	0.685043521	0.05552302	12.33800909	2.296010641
Foxtech AYK-350 VTOL	0.72242395	0.056618416	12.75952239	2.294331087
Flydragon /FDG33 VTOL	0.745999667	0.054739856	13.62808968	2.687819587

From this L/D we could estimate the thrust loading for cruise, we have already assumed a a thrust loading for takeoff. Thus from the thrust loadings we get the power loadings and found that cruise has less power requirement than takeoff,



Power Estimation

By the obtained values we refine the power requirement, The values of power with updated Cd are as follows,

1. **Cruise Power Loading (W/P) = 0.584**
2. **Take off Power Loading (W/P) = 0.453**

Thus for horizontal part we take the power loading of cruise and for vertical part takeoff segment sets the standard for powerplant selection.

POWER LOADING AND POWER PLANT ESTIMATION

Power Plant Selection

Parameters used for selecting the motor

1. For vertical motors:
- Thrust = 71.96N (Note: 4 motors are present)
- Power = 974.66W
2. For cruise motor
- Thrust = 16.89N
- Power = 396.988W

For cruise segment **(Horizontal motion)** we use the motor named TMOTOR MN601-S KV170)[2] with G*20*6 CF propellor. The images are attached below.

Type	Propeller	Throttle	Voltage (V)	Thrust (g)	Torque (N*m)	Current (A)	RPM	Power (W)	Efficiency (g/W)
		40%	23.87	1465	0.28	6.50	3044	155	9.44
		42%	23.86	1552	0.30	7.00	3116	167	9.29
		44%	23.84	1629	0.33	7.50	3215	179	9.11
		46%	23.81	1757	0.36	8.20	3322	195	9.00
		48%	23.79	1883	0.39	8.90	3413	212	8.89
		50%	23.76	2046	0.42	10.00	3564	238	8.61
		52%	23.72	2196	0.46	11.00	3716	261	8.42
		54%	23.69	2354	0.50	11.90	3820	282	8.35
		56%	23.65	2467	0.52	12.70	3904	300	8.21
MN605S	T-MOTOR	58%	23.62	2606	0.56	13.60	4006	321	8.11

For takeoff segment **(Vertical motion)** we use the motor named MN605S - KV170[1] with G*22*6.6 CF propellor. The images are attached below.

Type	Propeller	Throttle	Voltage (V)	Thrust (g)	Torque (N*m)	Current (A)	RPM	Power (W)	Efficiency (g/W)
		40%	47.92	2067	0.52	4.30	3265	206	10.03
		42%	47.91	2208	0.56	4.70	3313	225	9.81
		44%	47.89	2384	0.60	5.20	3509	249	9.57
		46%	47.88	2553	0.65	5.70	3627	273	9.35
		48%	47.86	2704	0.69	6.30	3745	302	8.97
		50%	47.84	2892	0.73	6.90	3860	330	8.76
		52%	47.81	3067	0.77	7.50	3973	359	8.55
		54%	47.79	3273	0.81	8.20	4085	392	8.35
		56%	47.76	3471	0.85	9.00	4208	430	8.08
MN605S KV170	T-MOTOR P22*6.6	58%	47.74	3584	0.88	9.60	4287	458	7.82
		60%	47.71	3736	0.94	10.20	4386	487	7.68
		62%	47.69	3896	0.99	10.90	4473	520	7.49
		64%	47.66	4104	1.03	11.70	4577	558	7.36
		66%	47.63	4283	1.08	12.60	4697	600	7.14
		68%	47.60	4500	1.12	13.50	4808	643	7.00
		70%	47.57	4721	1.18	14.30	4903	680	6.94
		75%	47.48	5477	1.30	17.40	5196	826	6.63
		80%	47.39	6064	1.44	20.20	5450	957	6.33
		90%	47.18	7201	1.72	26.20	5923	1236	5.83
		100%	46.97	8626	2.06	34.60	6469	1625	5.31

References
[1] “T-motor MN605S - KV170 motor and propellor.” https://store.tmotor.com/goods.php?id= 783.
[2] “ “T-motor MN601-S - KV170 and propellor.” https://uav-en.tmotor.com/html/2018/u_0330/ 6.html.

BATTERY ESTIMATION FROM POWER ESTIMATION

Battery Estimation

With assumed time period for each segment and estimated Power, The total Energy was estimated as **2037Whr**

Voltage required = 44.4V

Battery Capacity Required = 43890 mAh

Battery Available = 45000 mAh

Note:

The number of runs calculated is 3.5 . That is the VTOL is capable to do one full run - 3 times. The 0.5 factor is a kind of safety factor to account for some undesired energy loss.

The battery chosen is 12S 45000mAh 44.4V LiPo Battery.

Sigfox GPS module to be used having a range of 50kms

References

[1] "MPower 45000 mAh 12S 44.4V battery", https://maxamps.com/products/lipo-22000-12s-44-4v-battery-pack

Wing Loading Estimation

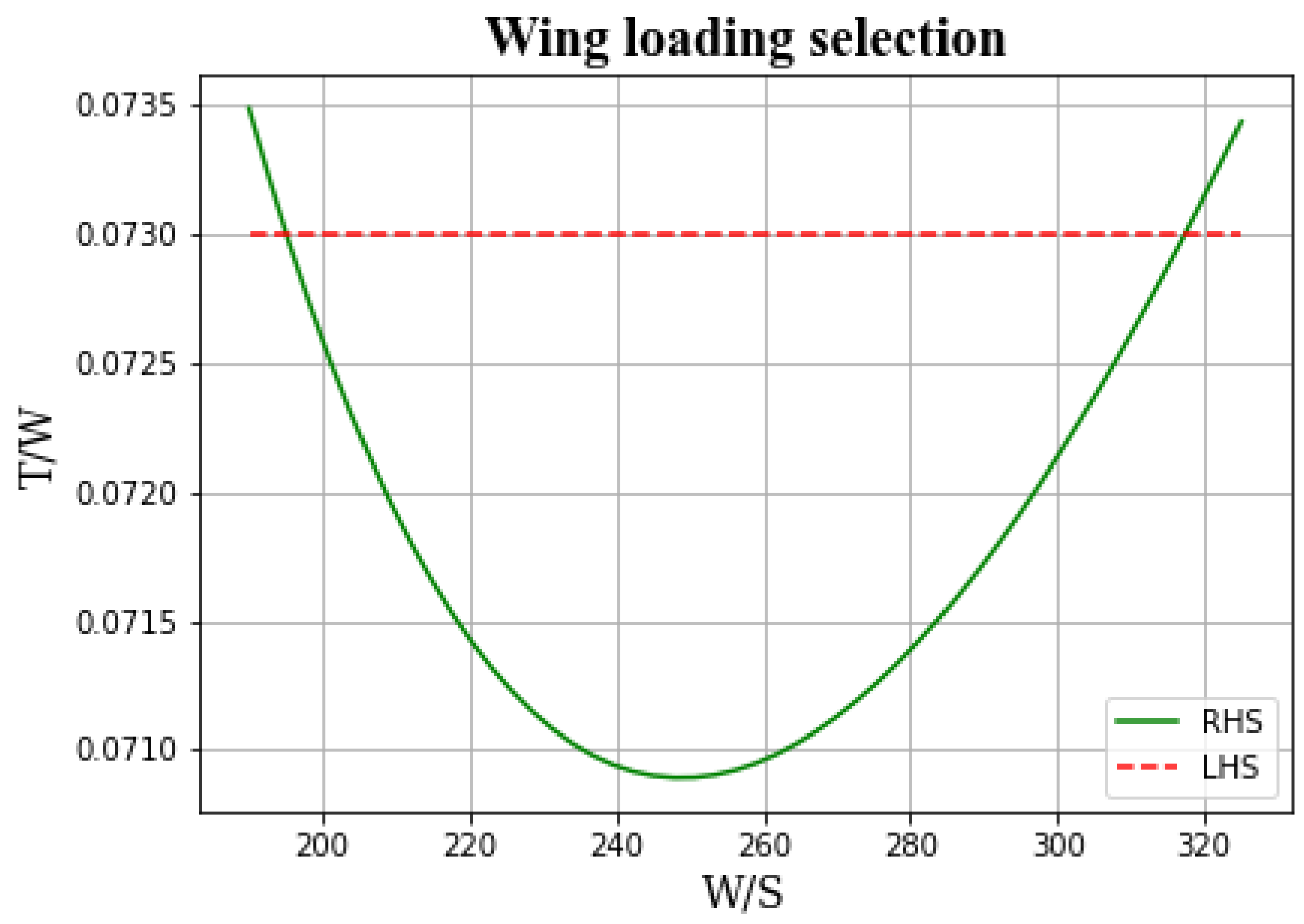
In wing loading estimation, we will estimate the wing loading to be used for calculations of this fixed wing VTOL. It is the weight of the aircraft for unit wing reference area

We estimate the range of wing loading at the following constraints:

Cruise condition

In Cruise condition, We equate thrust with drag. We substitite the drag polar equation in drag coefficient. This generates a quadratic equation in terms of W/S as shown in the green line of the given graph. At a particular T/W value estimated at the cruise condition i.e, Red dotted line, We get a range for W/S.

Range at Cruise Condition: **194.13 < W/S < 319.96**



Graph of T/W vs W/S at cruise condition

Stall speed constraint

In Stall speed constraint, We consider the UAV is at its stall speed. At that condition, we assume maximum coefficient of lift fixed, which results in the upper limit of wing loading.

Range at Stall Condition: **W/S < 216**

Wing Loading Estimation

Maximum forward speed constraint

In maximum forward speed constraint, We consider the UAV is at its maximum forward speed. Upon substituting power loading value in its calculation, we get a quadratic equation in terms of wing loading. By solving that equation, we will get the range for W/S.

Range at Cruise Condition: **$0.45 < W/S < 917$**

Turn condition

In Turn condition, We calculate load factor and substitite it in radius of turn equation. We get one solution for W/S. As radius of turn is directly proportional to wing loading and minimum radius is fixed, the wing loading obtained is the lower bound.

Range at Cruise Condition: **$205.13 < W/S$**

Final range

Collecting all the ranges of wing loading we have in the following table,

Condition (Segments)	**Range of Wingloading(N/m^2)**
Stall condition	$216 > W/S$
Max.velocity condition	$0.45 < W/S < 917$
Cruise condition	$194.13 < W/S < 319.96$
Turn condition	$W/S > 205.13$
Total condition	$205.15 < W/S < 216$

WING DESIGN

Airfoil selection

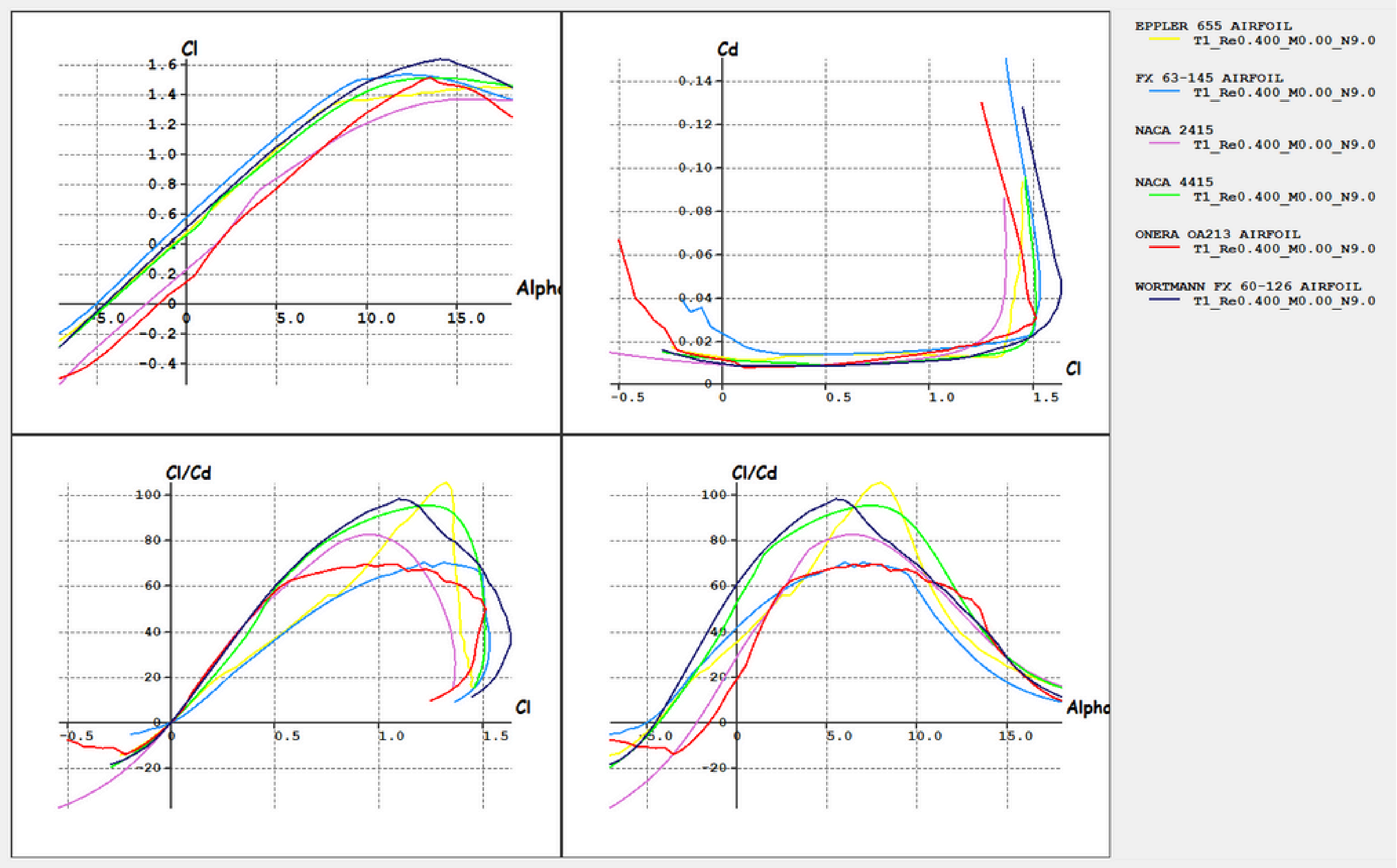
The parameters which are required to choose to airfoil is given in the table below. With these parameters the airfoil which were under consideration is also given in the tables attached.

Parameters	Values
Weight	23.5kg
W/S	210 kg/m^2
V_cruise	20 m/s
Cl_cruise	0.85
Cl_max	1.55
(L/D)_max	13.86

The data of the airfoils which were under consideration

Name of the Airfoil	Cl_max	(CL/CD)_max	Stall angle (degrees)	CL/CD @ operational CL
NACA 2415	1.36	82.36	14.5	79.8
NACA 4415	1.52	95.2	13.1	85.05
ONERA OA213	1.51	70.2	13.5	68.1
EPPLER 655	1.35	104.5	11	60
Wortmann FX 63-145	1.5	70	12	57.8
Wortmann FX 60-126	1.63	97.25	14	87.45

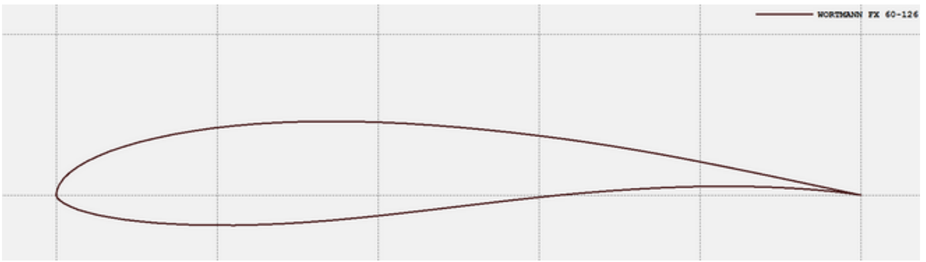
The values in the table were taken from the simulation that were done using the XFLR5 software.



Selected airfoil

Based on the parameters on the table to look the maximum Cl attainable for the airfoil and the location of maximum value of (CL/CD) is at the location where our cruise CL lies.

From the parameters and simulation the airfoil chosen is the **Wortmann FX 60-126** which is a low speed high lift airfoil.



WING DESIGN

Location of wing

The location of the wing was chosen to be high wing configuration due to the following pros/cons.

- Easy to manufacture as the wing can be manufactured as an entire single part.
- Increases the dihedral effect (Clβ). It makes the aircraft laterally more stable.
- There is more space inside the fuselage for payload, powerplant, sensors and other equipment.

Cons

- The wing drag produces a nose-up pitching moment, so it is longitudinally destabilizing.
- A high wing is structurally about 20% heavier than a low wing.

Chosen wing parameters

From the Formulas from Raymer[1] and the previous historical data collected we found the span length, chord length etc. The wing incidence angle is chosen such that at cruise level flight, Cl cruise is attained. Twist of negative 2 degrees is added at the tip considering the fact that control surfaces are present near to the tip and so stall at tip has to be avoided. The final parameters are tabulated.

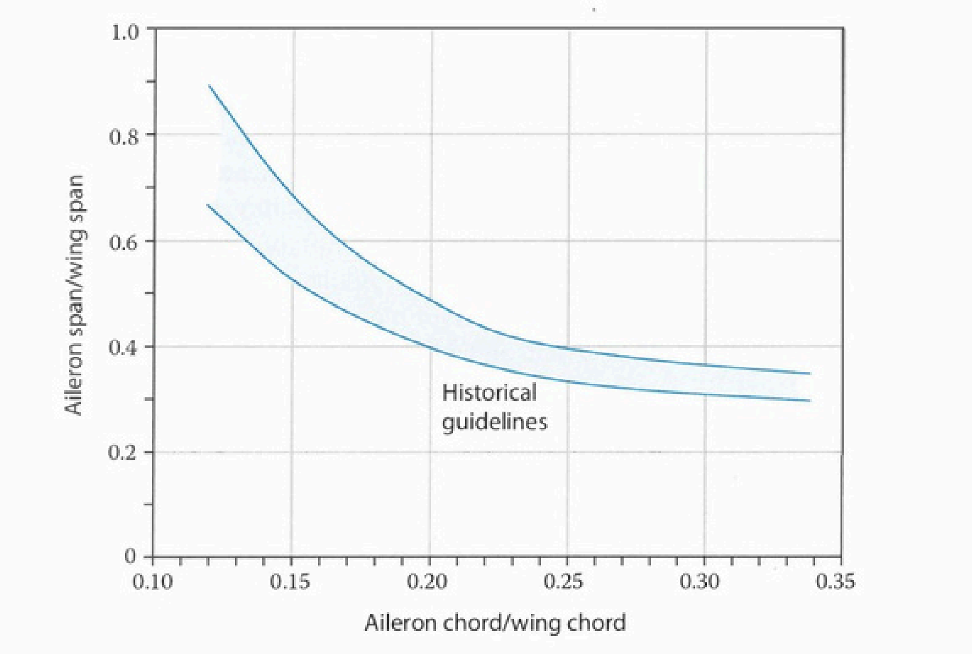
Parameters used	Values used
Span area	1.08 m^2
Wing span	3.6 m
Aspect ratio	12
Taper ratio	0.58
Root chord	0.38 m
Tip chord	0.22 m
Sweep	0 degree
Dihedral angle	0 degree
Twist	- 2 degrees (tip)
Aileron area to span area	0.08
Wing incidence angle	5.6 degrees

Control surface

In reference Raymer[1], there is an section on aileron sizing guidelines from which our aileron sizing was chosen. The image for which is attached.

All these ratios are per semi-wing and one aileron.

Name	Value
c_aileron / c_wing	0.2
b_aileron / b_wing	0.4
S_aileron / S_wing	0.08

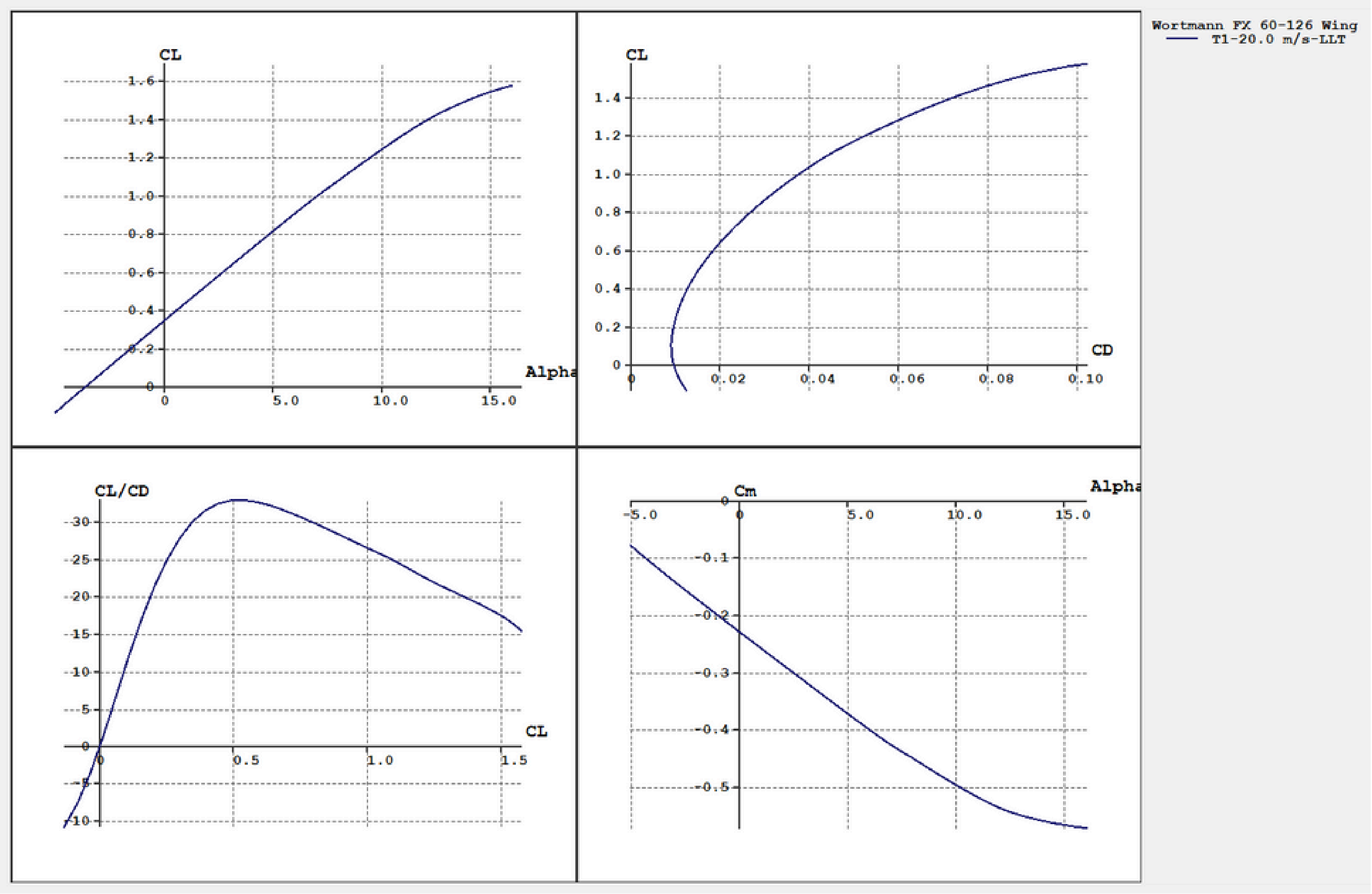


References
[1] "Aircraft Design A Conceptual Approach" by Daniel P Raymer.

WING DESIGN

Analysis

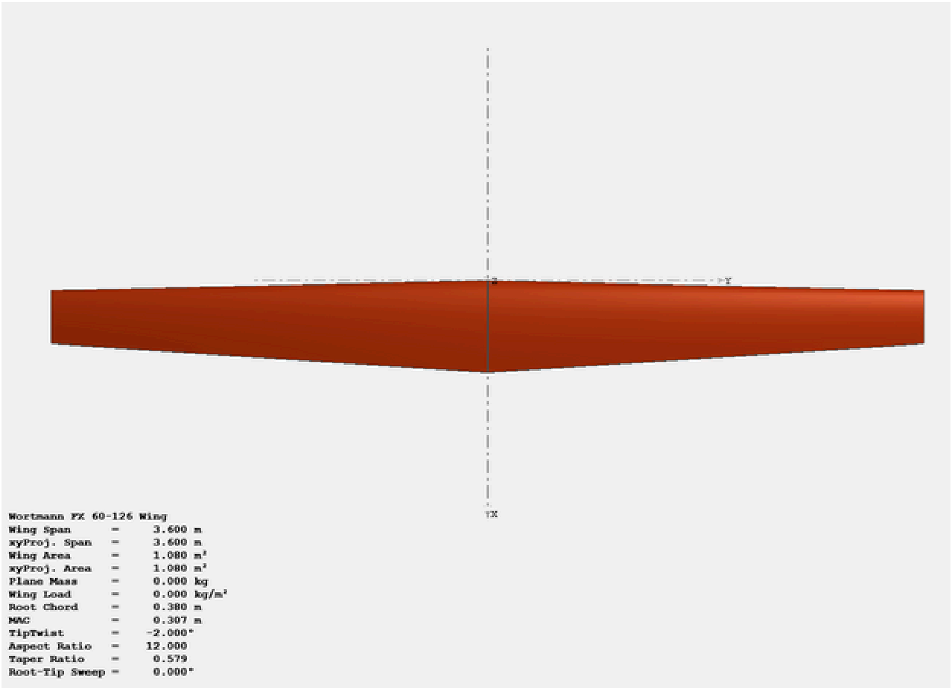
For the chosen airfoil with the given dimension now the wing is built and analyzed in XFLR5 with our cruise conditions, the results for which are attached. With these results we are satisfied to go with this wing.



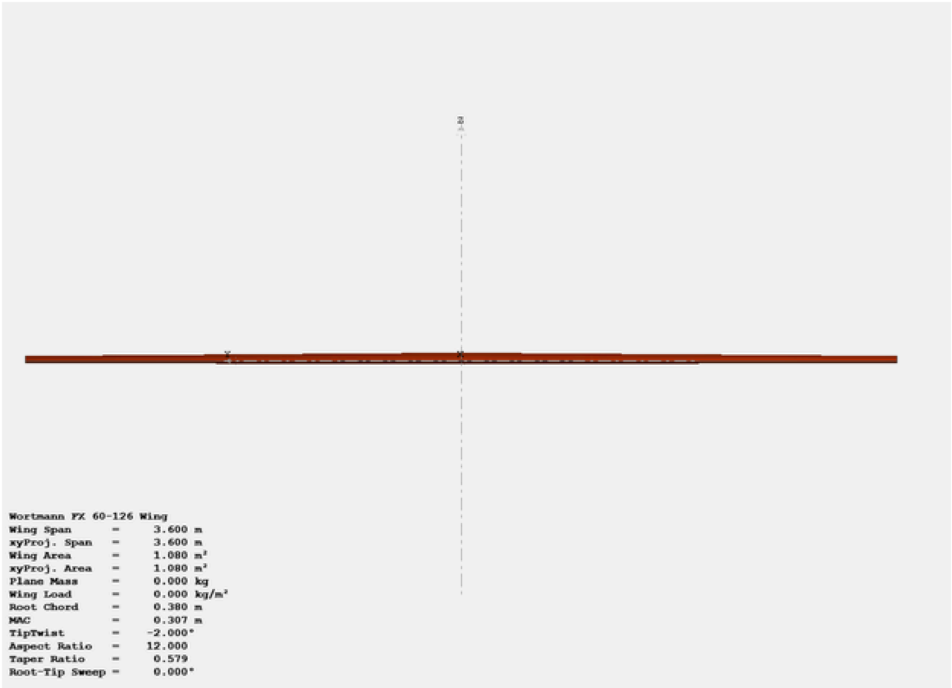
Three view diagram (Wing)

With the airfoil and dimension of the wing being fixed the wing's three view diagram is attached below.

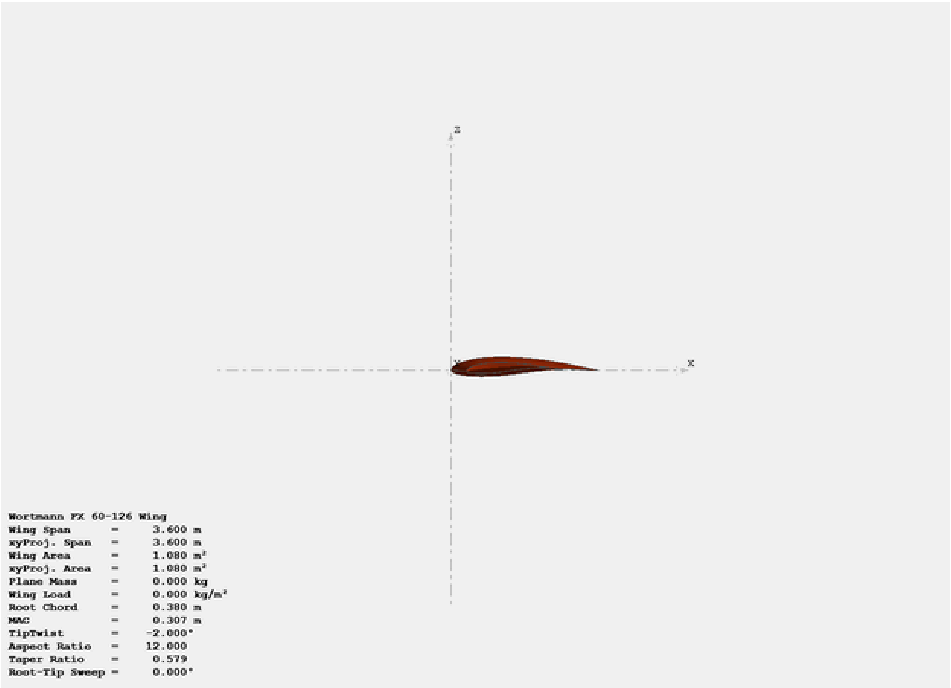
Top view of the wing



Front view of the wing



Side view of the wing



FUSELAGE DESIGN

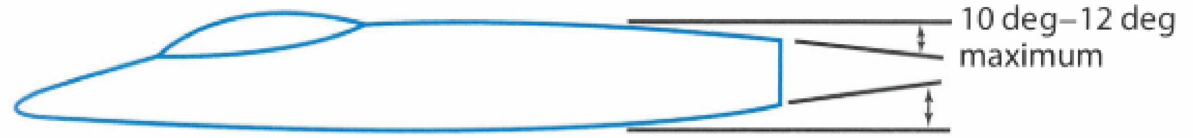
Parameters to be considered

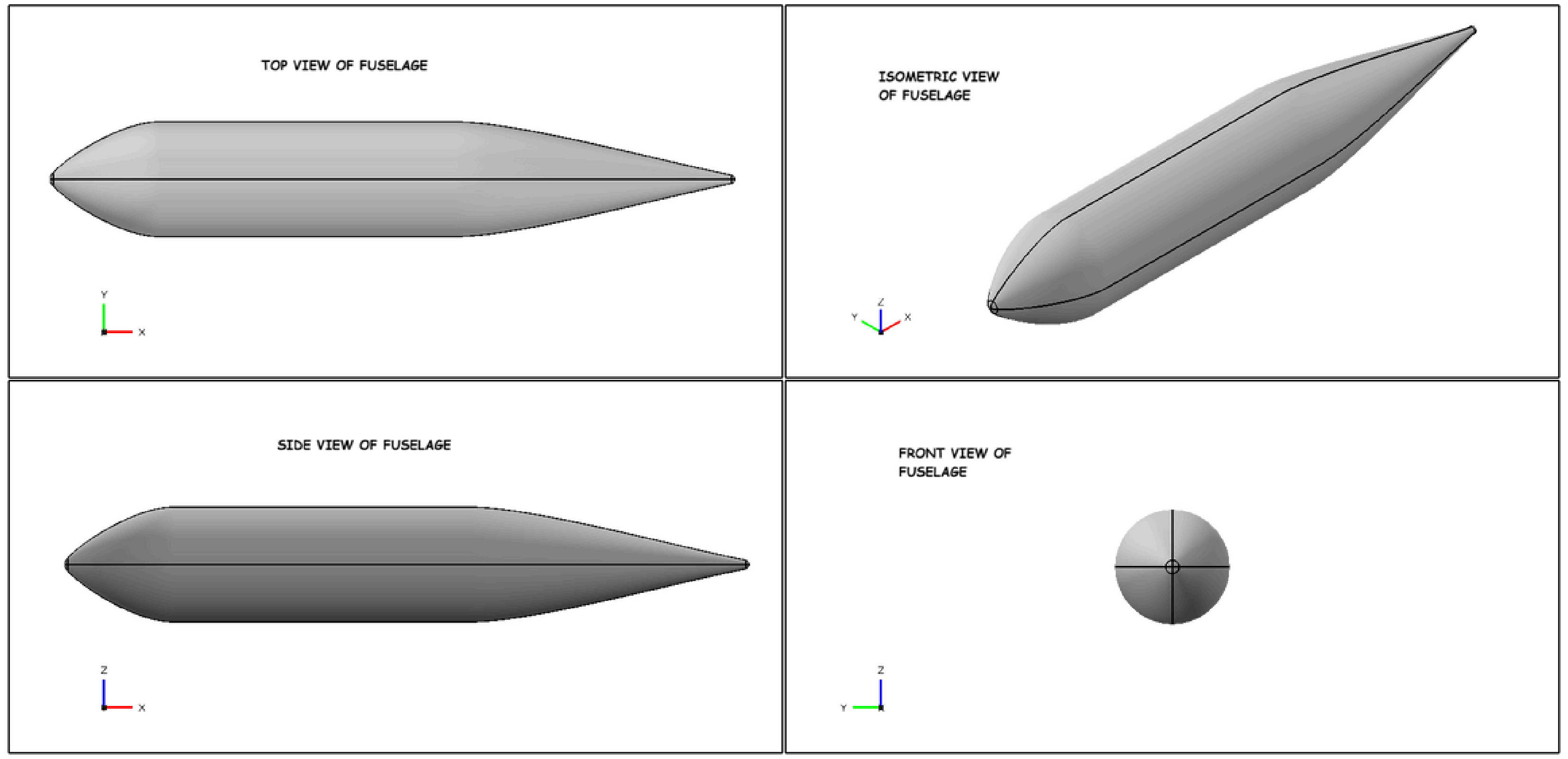
The parameters to be considered for the design of fuselage is tabulated. From the previous historical data the fuselage length near our MTOW was found out to be around 1.6m.

Also a point to note is that the payload dimension is not fixed one and thus we can fix a payload dimension as our choice (Maximum size). By considering the fact that payload is placed behind battery and the upsweep angle is to be maintained less than 12 degrees as given in Raymer[1] to reduce flow separation the value of payload dimension is chosen as given in the table.

Parameters Used	Value
Length of the fuselage	1.6 m
Maximum diameter fuselage	27 cm
Dimension of battery	25.6 * 19.3 * 8.0 cm^2
Dimension of payload	ϕ = 25 mm ; L=52 cm
Rounded edge of nose	ϕ = 3.2 mm (motor shaft)

From Raymer[1]





Thus with these under consideration the fuselage is modelled with the help of OpenVSP software. The three view diagram of which is attached. Here the fuselage is designed with a circular cross-section from around 0.25m - 1 m with a diameter of 27cm. Then the cross-section uniformly reduce towards the tail.

The detailed description will be in the component placement on the fuselage slide.

References
[1] "Aircraft Design A Conceptual Approach" by Daniel P Raymer.

TAIL DESIGN

Configuration

The configuration of the tail is chosen to be **conventional tail** type on considering the following pros/cons,

- It leads to a compact and lightweight construction.
- Though it has reduced efficiency due to the tail lying in the wake region, it provides appropriate stability and control.
- The stability analysis of the conventional tail is easier compared to others which become more complex.

Horizontal tail parameters

Parameters	Value
Tail arm	0.96 m
Tail area	0.172 m^2
HTVR	0.5
Aspect ratio	8
Span	1.05 m
MAC	0.1375 m
Taper ratio	0.55
Sweep,dihedral angle	0

Sizing and design

For the horizontal tail and the vertical tail the dimensions of the tail we estimated using the formulas from M.Sadraey[1]. The estimated values are tabulated.
Note that we are using NACA0012 airfoil for both the tails.

Vertical tail parameters

Parameters	Value
Tail arm	0.96 m
Tail area	0.1215 m^2
VTVR	0.03
Aspect ratio	2.96
Span	0.5 m
MAC	0.2025 m
Taper ratio	0.75
Sweep,dihedral angle	0

References
[1] “Aircraft Design A System Engineers Approach” (2012) by Mohammed H. Sadraey.

TAIL DESIGN

Control surface design

Data was collected from the historical data which had clear photos of the tail and those values are attached below.

From the book M.Sadraey[1], we have a range of values for the elevator and rudder control surface sizing. The control surface dimensions are attached in the table below.

The sizing of the control surface elevator is attached,

Parameters	Values
Elevator area	0.0516 m^2
c_elevator/c_HT	0.35
b_elevator/b_HT	0.9

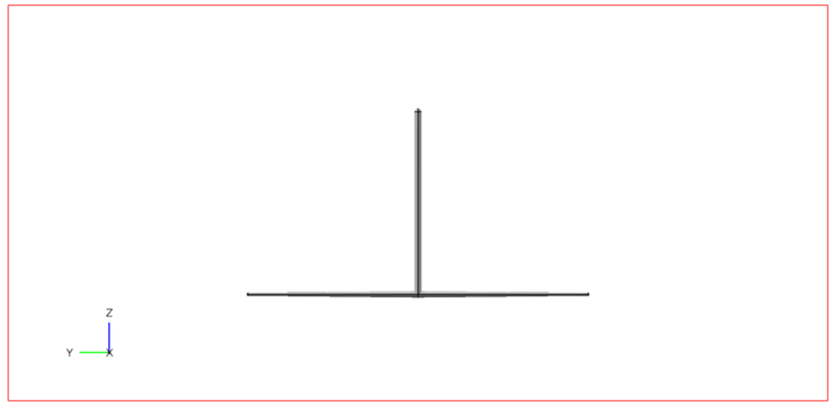
The sizing of the control surface rudder is attached,

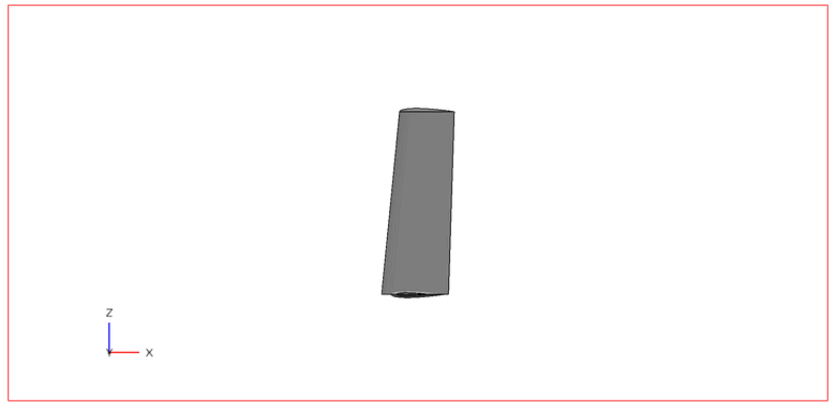
Parameters	Values
Rudder area	0.018 m^2
c_rudder/c_VT	0.3
b_rudder/b_VT	0.6

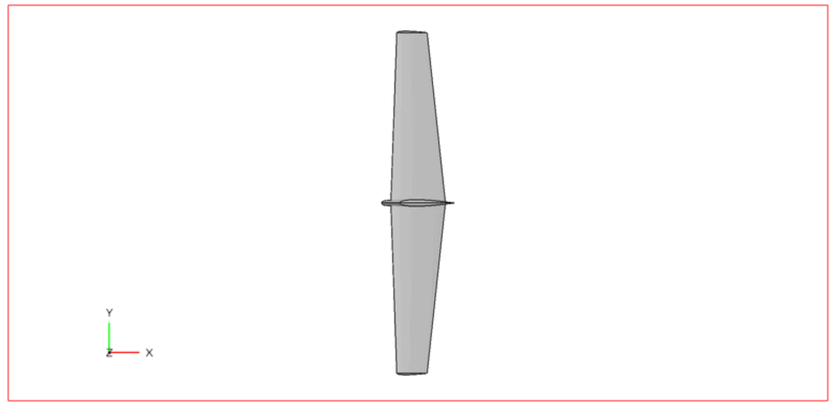
The values in the above table were check against the range given in the reference book[1].

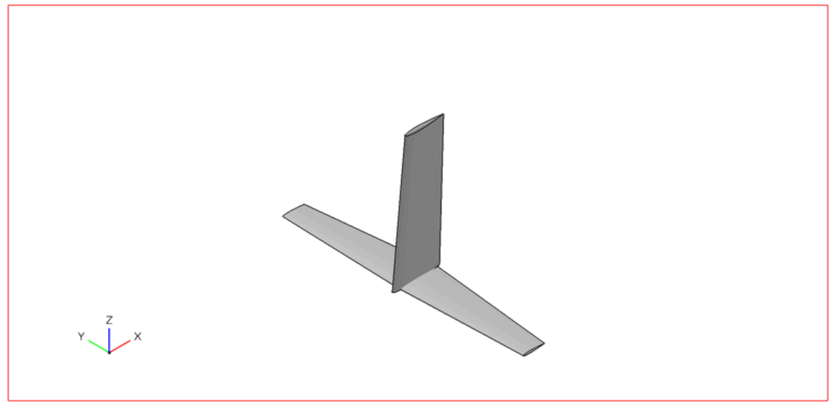
Views of tail

The dimensions of the tail is known and is designed with the help of OpenVSP software ,the three view diagram is attached below.









References
[1] “Aircraft Design A System Engineers Approach” (2012) by Mohammed H. Sadraey.

LANDING GEAR DESIGN

Configuration

Since VTOL we do not need a rigorous design on the landing gear part. We choose the configuration similar to the **tail dragger (two legs in front and 1 at rear)** type without wheels as the landing is vertical.

- Taildragger gear provides more propeller clearance for forward fuselage, has less drag and weight.
- The rear part of the landing gear provides lateral stability.

The impact load on the landing gear is found out to be the sum of the weight component and impact when the VTOL hits the ground. For our case we land with a velocity of 2 m/s. By taking the time of impact to be 0.5s, the impact load is found to be 93.5 N. The total impact load including the weight is around 325N.

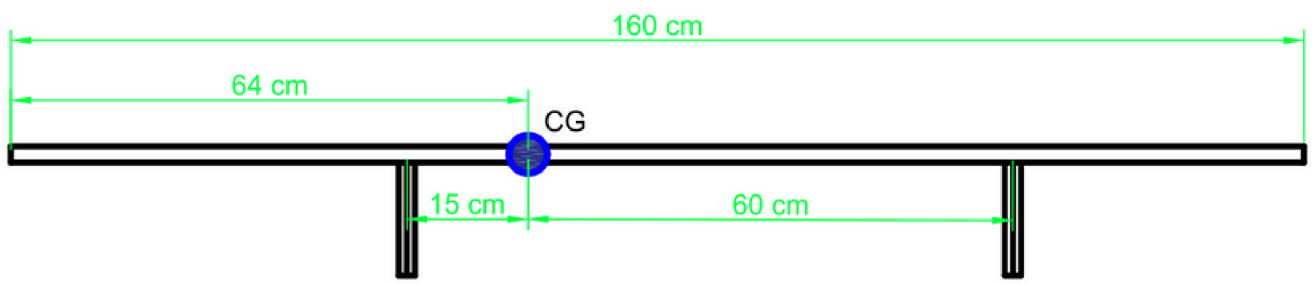
Location of the landing gear

From a tentative placement of components and weights a tentative CG was found , with that we chose the location of the landing gear components such that the front part takes about 80% of the load.

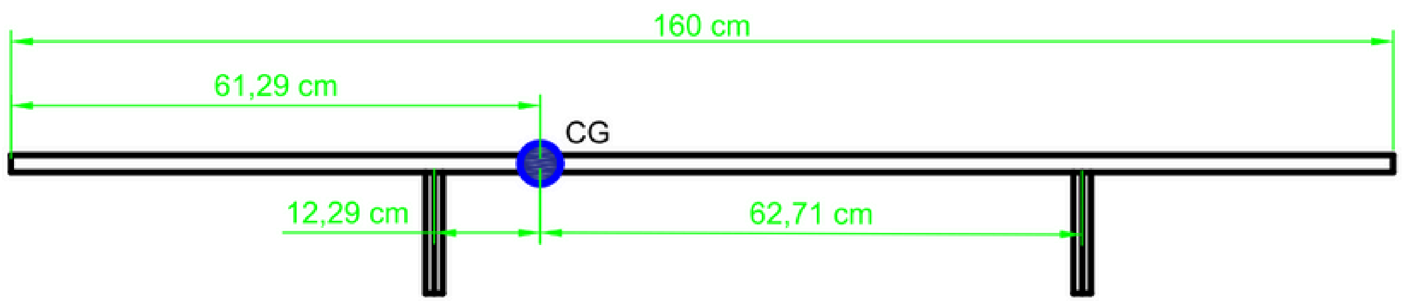
Tentative placement of components

Components placed	Mass (kg)	Location of the CG of object
Battery	8 kg	23 cm - 48 cm (COM : 35.5 cm)
Payload	4 kg	48 cm - 103 cm (COM : 75.5 cm)
Wing	2kg	54 cm - 80 cm (COM : 64 cm)
Tail	1kg	COM : 160 cm
Fuselage	2 kg	COM : 75 cm
Powerplant	4kg	COM : 80 cm

Placement of the landing gear(with payload)



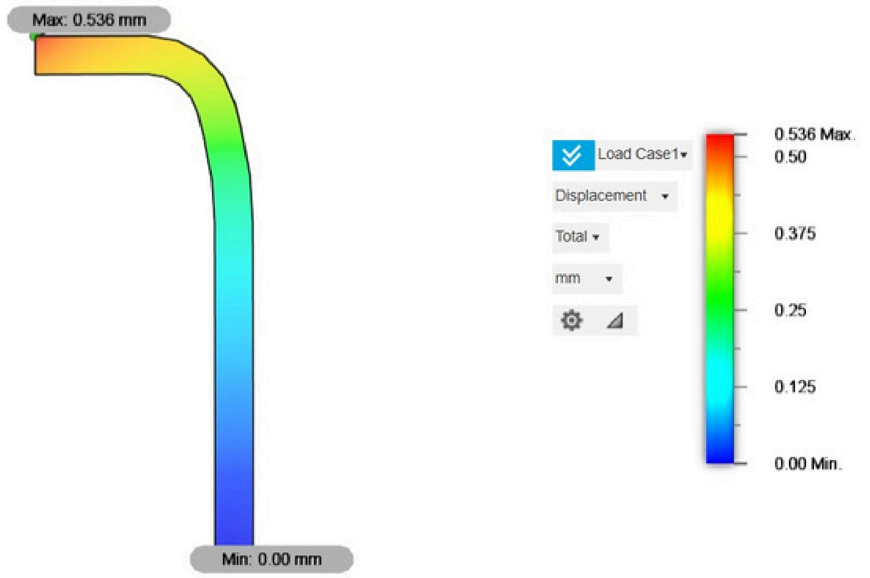
Placement of the landing gear(without payload)



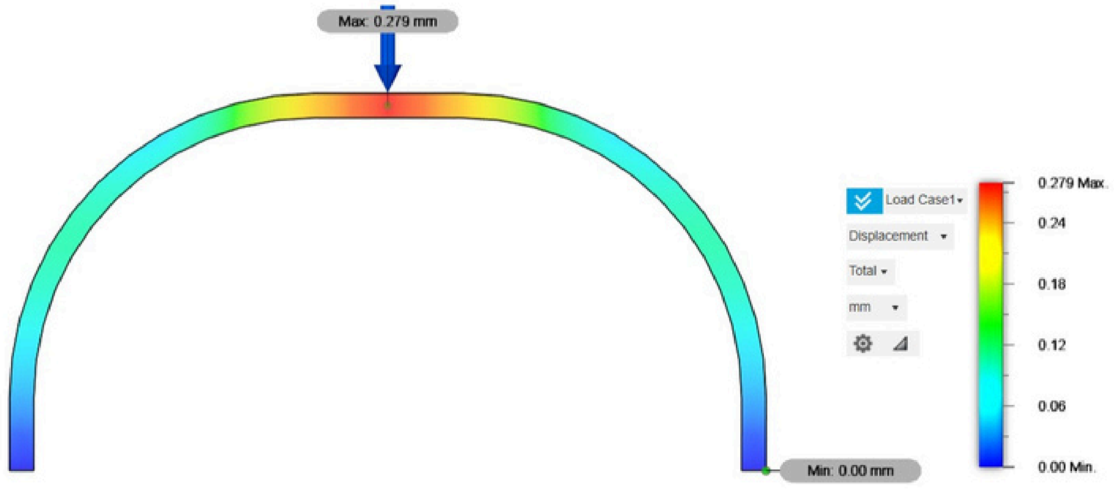
LANDING GEAR DESIGN

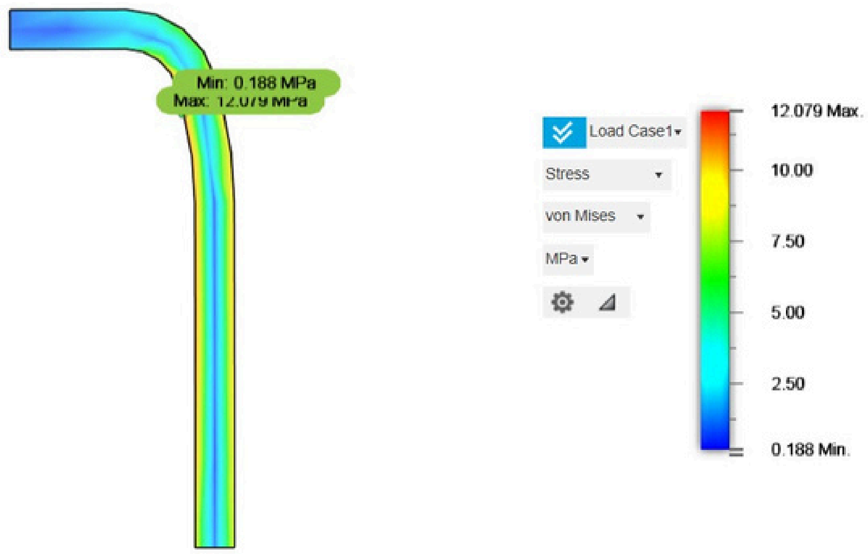
Design and analysis

The structure of the landing gear components are attached and has be simulated with the Fusion360 Finite element solver for the impact load taken by the landing gear components. The results are attached below. The material used is **Aluminum T6-6061.**

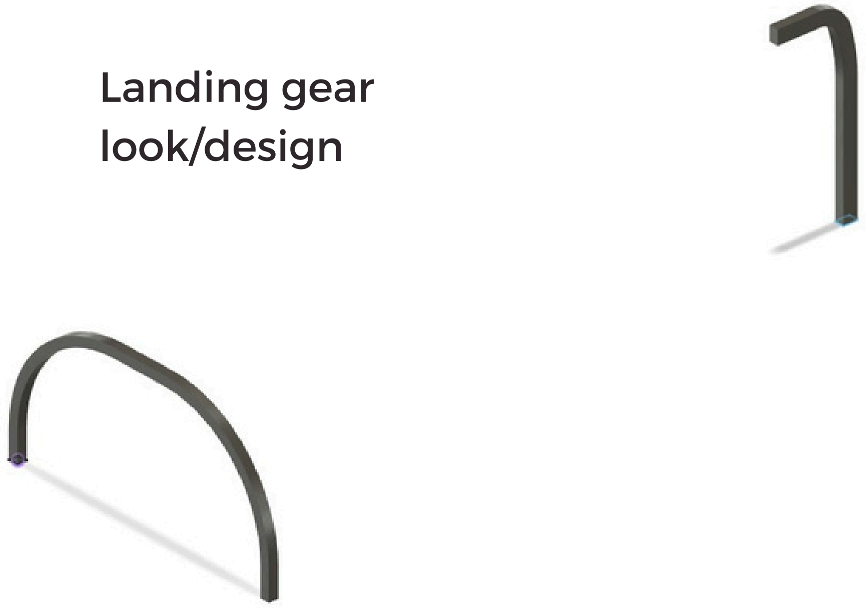


Dimension	Value
Front landing gear	
Cross section	1cm * 1cm
Height	15 cm
Width	30 cm
Rear landing gear	
Cross section	1.5cm * 1cm
Height	25 cm
Length	8 cm





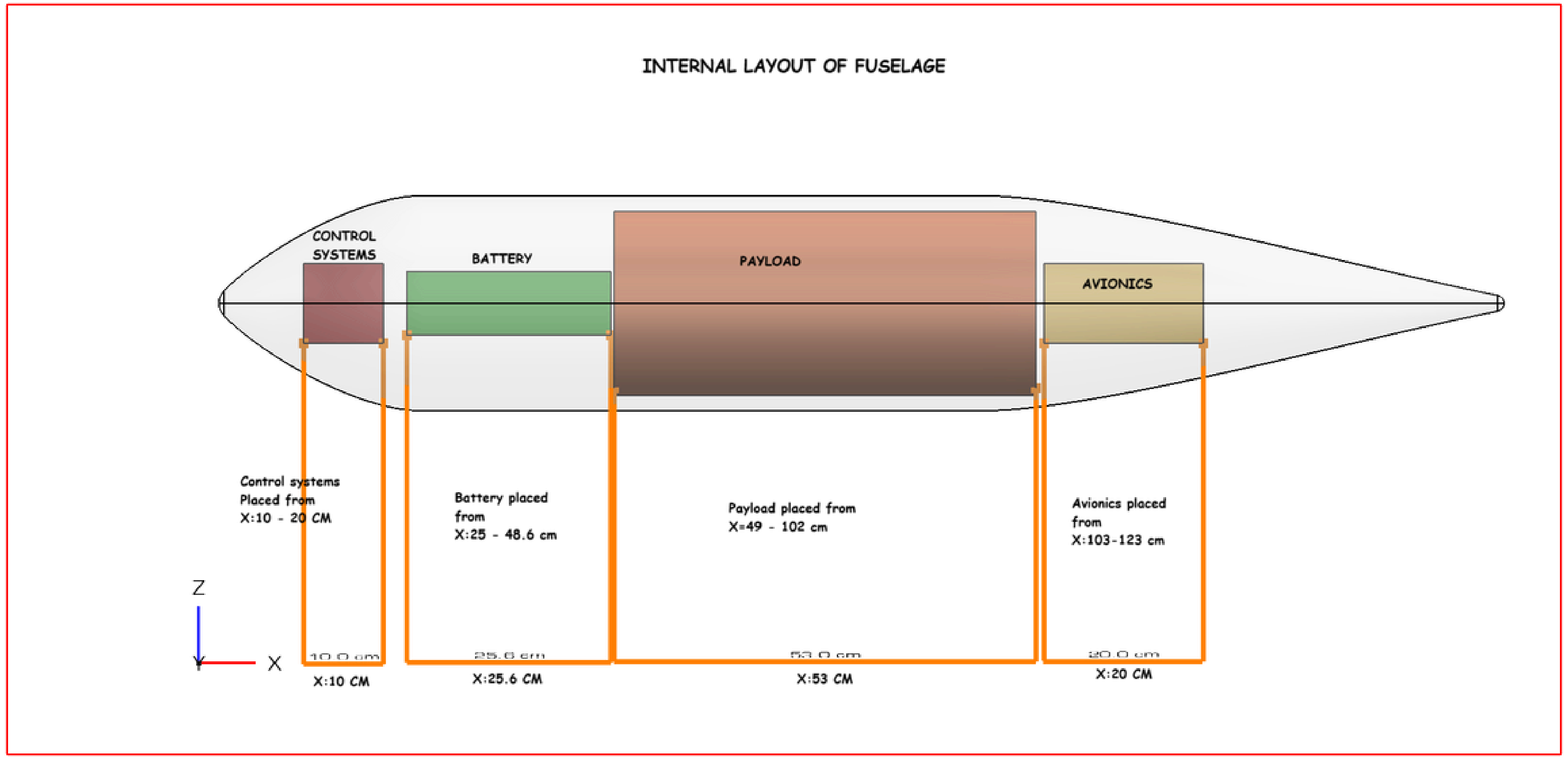
Landing gear look/design



CENTER OF GRAVITY ESTIMATION

Internal layout

The internal layout of the components are depcited in the table and figure below,



Note that in the calculation of CG we dint consider the vertical propellor because vertical propellor will be placed such that the CG is unaltered. From the given value the CG is found to be at **58cm** from the nose.

The vertical propellors are placed as a square of side **a=84 cm**, which was taken from the research paper which says optimal placement is a square of side(1.5D)[2]

Component names	Dimensions (x*y*z) (cm)	Placed location (cm)
Control system	10 * 10 * 10	10 cm - 20 cm
Battery	25.6 * 19.3 * 8	25 cm - 48.6 cm
Payload	Cylinder L:53cm Dia:25cm	49 cm - 102 cm
Avionics	20 * 10 * 10	103 cm - 123 cm

Weight of the components

The weight of each individual components are estimated with the help of both Fusion360 and formulas theoretically from Raymer[1].

Component	Weight (kg)	Location of COM (x) [cm]	Location of COM (z) [cm]
Battery	8	35.8	-4.6126
Payload	4	74.8	0
Control System	1	15	0
Avionics	1	113	0
Wing	2.225	64	14
Vertical tail	0.4087	150.36	22.587
Horizontal tail	0.2635	146.5	0
Landing gear	0.24	81.8125	-14.5
Fuselage	1.624	72	0
Horizontal powerplant	0.2	72	0
Vertical powerplant	3.5	58	0

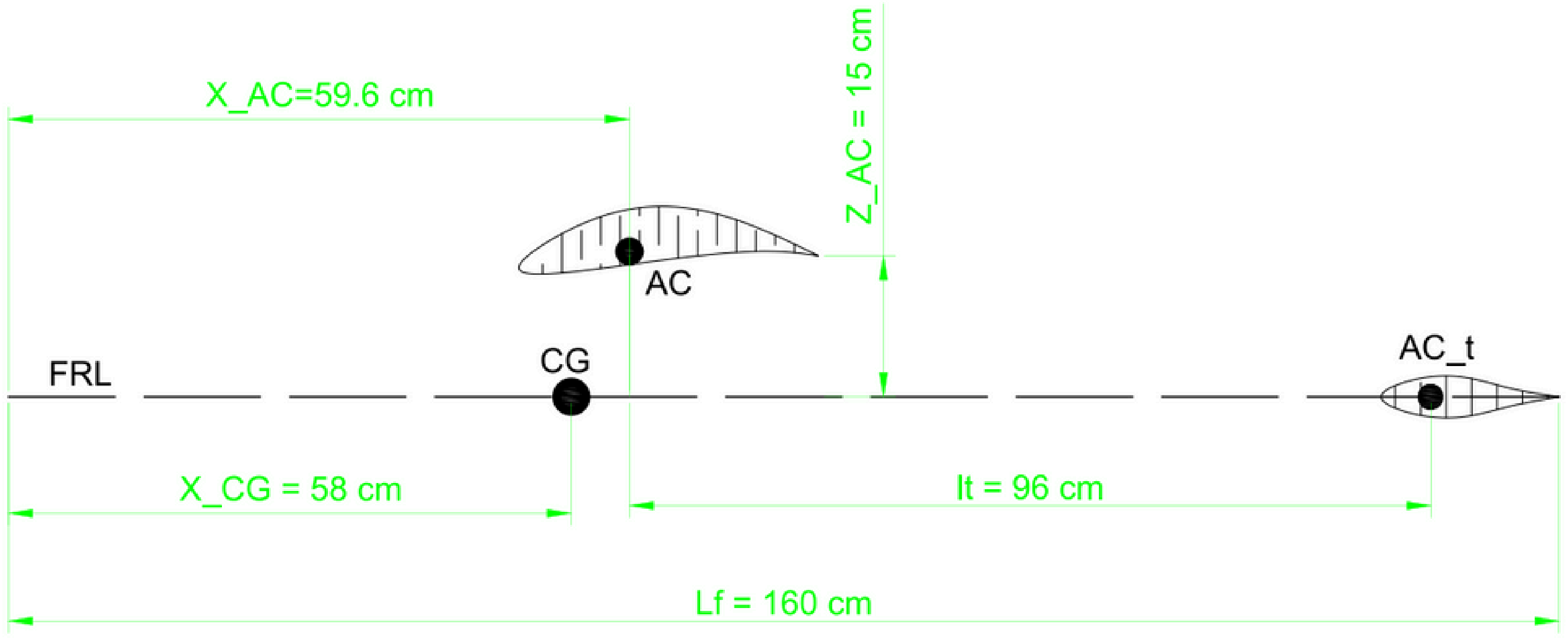
References
[1] “Aircraft Design A System Engineers Approach” (2012) by Mohammed H. Sadraey.
[2] O.Westcott, S. Krishna, R. Entwistle, and M. Ferraro, “Aerodynamic performance of aircraft wings with stationary vertical lift propellers,” Aerospace Science and Technology, 2023.

STABILITY ANALYSIS

Longitudinal analysis

The parameters that are used in the analysis are tabulated.

Aerodynamic Parameters	Values
C_{L0}^{wb}	0.3465
$C_{L\alpha}^{wb}$	0.09258 /degrees
Wing incidence	5.5 degrees
MAC of wing ($\bar{c}$)	0.3 m
C_{mAC}^{wb}	-0.12539
$C_{D_{AC}}^{wb}$	0.03
$Z_{AC}^{w}/\bar{c}$	0.5
X_{AC}^{wb}	0.596 m
X_{CG}	0.58 m
$h_{AC}^{wb} - h_{CG}$	0.0533
HTVR (V_H)	0.5
$C_{L_\alpha}^{t}$	0.10 /degree



Results from longitudinal	Value
Cm_{AC}^{wb}	-0.125
Trim C_L^{t}	-0.3
ϵ	2.58 degrees
i_t (tail incidence)	-0.1 degrees
Neutral point(X_{NP})	74 cm
Static margin	0.48
Cm_α	-0.03926
Cm_0	0

The formulas used for calculating the results tabulated are taken from Raymer[1], N.KSinha[2].

References
[1] "Aircraft Design A System Engineers Approach" (2012) by Mohammed H. Sadraey.
[2] "Elementary Flight Dynamics with an introduction ot Bifurcation and Continuum Mechanics" by N.K.Sinha and Ananthkrishnanan

STABILITY ANALYSIS

Lateral stability analysis

The parameters that are used in the analysis are tabulated.

Since there is no dihedral, sweep, etc their contribution to the derivatives are zero.

Parameters	Values
η_v	0.9
l_{vt}	0.96m
k_{fl} (correction)	0.75
D_f	0.27m
W_f	0.27m
$C_{L\alpha}$	0.1/deg
τ_e	0.55

Parameters	Values
Cn_β	0.0176
Cl_β	-0.025

Control derivatives

With the dimensions and size of the control surfaces and other parameters from the stability analysis we have attached the results from the calculations.

The calculations of these derivatives we done with the help of XFLR5 software for finding the Cm derivative and then using the formulas form Raymer[1] and N.K.Sinha[2].

Parameters	Values
$Cm_{\delta e}$	-0.022
δe_{max}	20.8 degrees
$CL_{\delta e}$	-0.007
$Cn_{\delta r}$	-0.01

References
[1] “Aircraft Design A System Engineers Approach” (2012) by Mohammed H. Sadraey.
[2] “Elementary Flight Dynamics with an introduction ot Bifurcation and Continuum Mechanics” by N.K.Sinha and Ananthkrishnanan

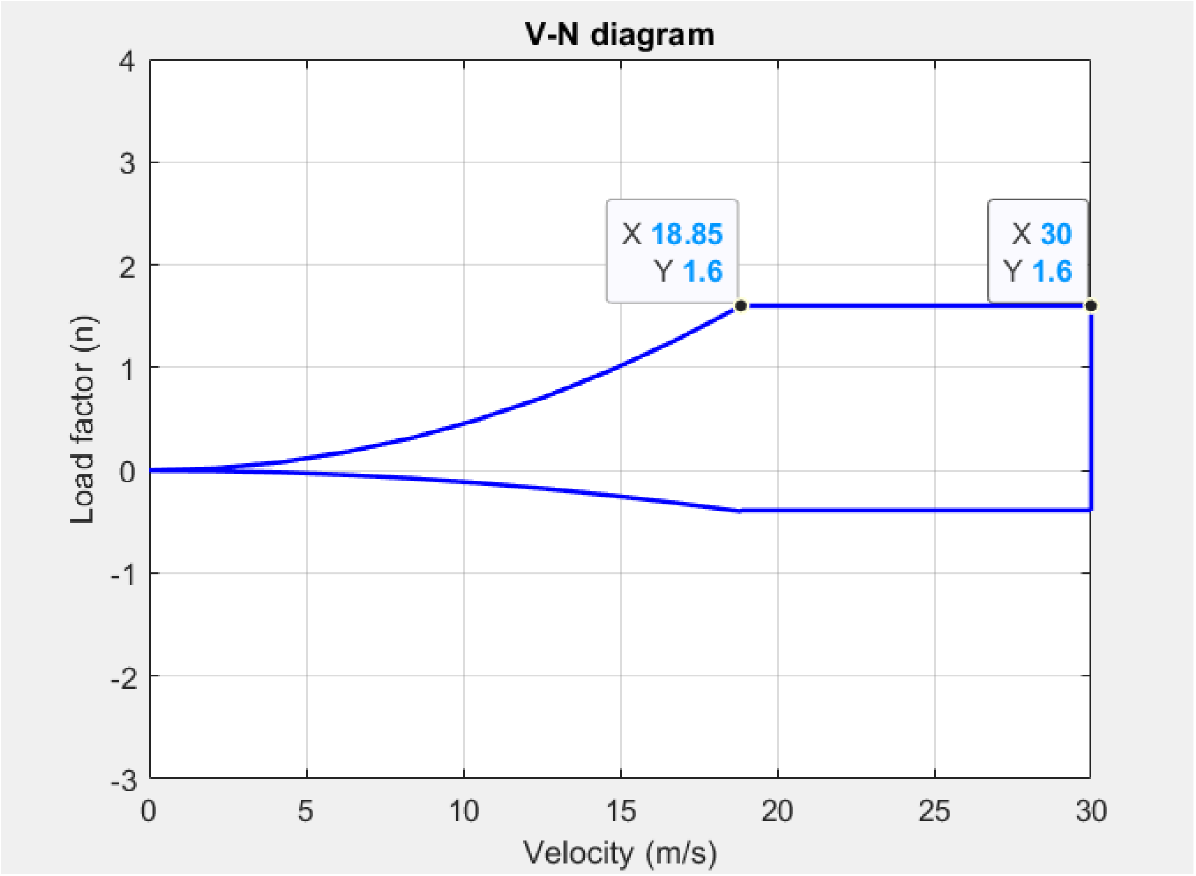
PERFORMANCE ANALYSIS

Performance calculations

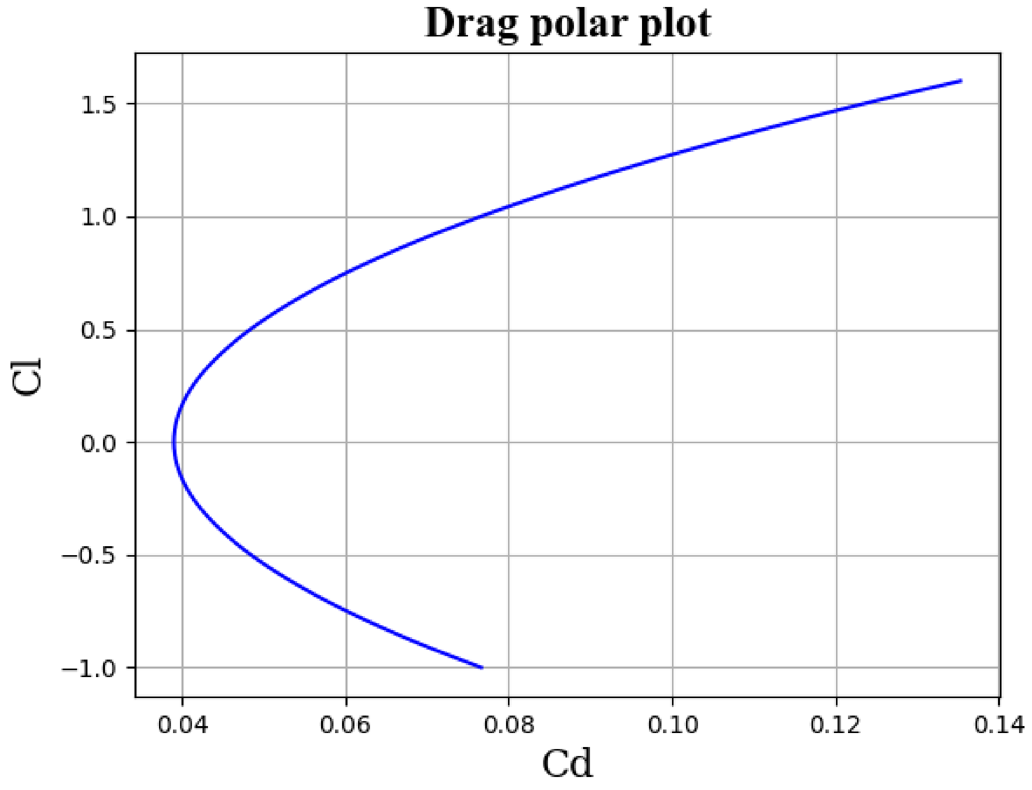
The results from the performance analysis are attached. The results were obtained from the formulas given in Raymer[1].

Parameters	Results
C_{D0}	0.039
K	0.0376
n_{max}	1.6
Cornor velocity	18.85 m/s
Dive velocity	30 m/s
Range	170 kms
Endurance	2.65 hrs

V-n Diagram



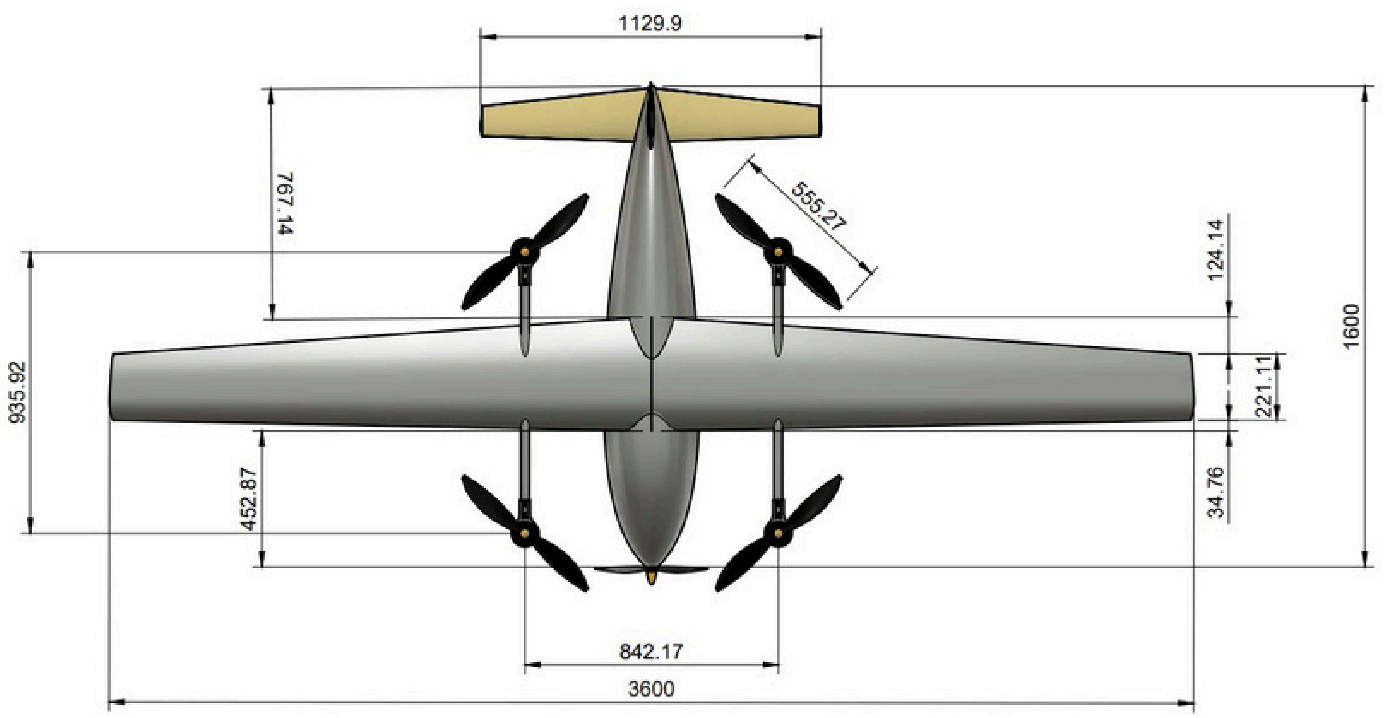
Drag polar



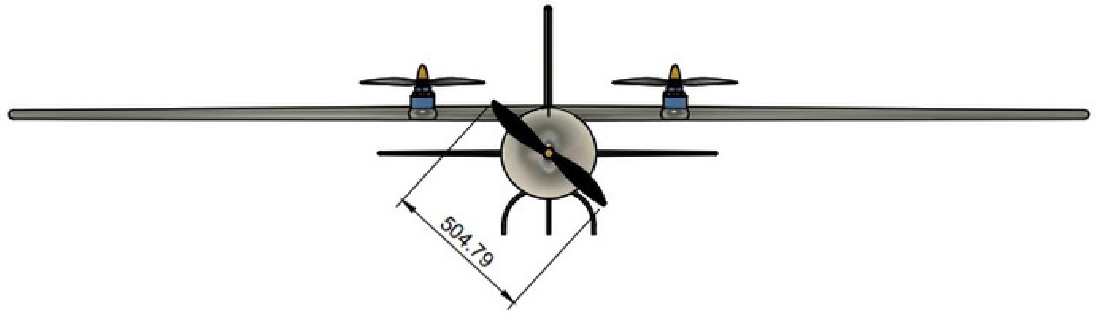
References
[1] "Aircraft Design A System Engineers Approach" (2012) by Mohammed H. Sadraey.

THREE VIEW DIAGRAM

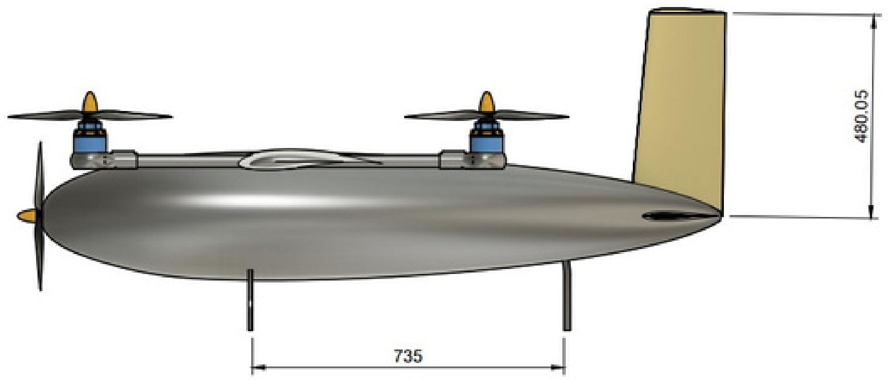
Top view



Front view



Side view



CONTRIBUTION OF TEAM MEMBERS

Joel J (AE21B105)

- Collected the whole dataset for first chapter. Fixing the mission profile of the segments.
- Wrote the python code for the convergence of preliminary weight estimate and empty weight fraction. Helped in battery weight estimation formulation.
- Calculated the required parameters for drag estimation. Estimation of Cd0 and K for all datasets. Finding the formulation for all chapters.
- Finding the battery required for our VTOL according to requirements.
- Finding the constraints of mission segments for wing loading estimation. Also done the turn condition.
- Collected many airfoils sections and ran the analysis on XFLR5 and chose the optimal airfoil from it.
- Wing design: Found and estimated all the necessary parameters for the wing design. Designed the wing in XFLR5 completely and added the analysis in the report.
- Calculated the parameters required for fuselage and designed the fuselage using CAD. Done the parameter estimation in both the tails, tail sizing.
- Calculated the tentative CG, internal placement of components on the fuselage, placement of the landing gear
- Chose the required parameters for estimating weight of the components, optimal placement and calculated the CG.
- Done the whole part of longitudinal stability, by choosing the optimal placement of wing.
- Estimating the parameters for performance analysis, wrote the code for finding range and endurance.
- Made the whole presentation after the midsem.
- Done the major Latex part for all the reports.

Ira Rai (AE21B024)

- Determined the mission profile of the design and it's requirements.
- Helped battery weight estimation , power required for each segment, through a matlab code.
- Helped in battery selection according to mission requirements, by calculating the time period and energy for each segment
- Did thrust and second power estimation from obtained L/D ratio, determined power loading for cruise and take off.
- Calculated wing loading constraints for stall speed and maximum speed.
- Literature survey in ruling out the idea of using flaps. Did the wing analysis for the 2 wing designs, the designs were overruled in performance.
- Did the tail Layout portion, decided some of parameters for both vertical and horizontal tail.
- Researched types of landing gears and Calculated the impact load due to landing gear.
- Calculated the position for vertical propellers to have maximum thrust.
- Found all the parameters and equations required for lateral stability and lateral derivatives and control derivatives.
- Wrote latex reports for all the above specified sections.

A.S.A.Raviteja (AE21B005)

- Collected Battery weight of the historic data.
- Researched formulas for calculating power required for various flight segments.
- Collected top and side view pictures of previous UAV's and calculated wetted area of those datasets
- Estimated wingspan, wing area, fuselage area and various other parameters of previous datasets using MATLAB.
- Calculated W/S range for cruise condition.
- Measured various parameters for both horizontal & vertical tails by using image processing.
- Calculated the weights of the wing, horizontal tail, vertical tail, and fuselage.
- Calculated Zero lift drag (Parasite drag) for the UAV by calculating parasitic drag for each component in it. Estimated the Drag polar and Coefficient of drag at cruise condition.
- Wrote Latex reports for Weight calculation, Zero Lift drag and few other sections.

Harish S (AE21B021)

- Collected data on UAVs with a mission profile similar to ours.
- Latex formatting for the whole report.
- Searched and selected motor and propellor combinations according to our power and thrust requirements.
- Estimated drag polar for UAV in the dataset from wetted area data.
- Helped formulate the wing loading range.
- Collected weights of various components used. Researched various choices like dihedral, twist, sweep and helped in choosing the optimal one.
- Designed the cad model of the landing gear. Performed simulations for various thickness, and chose the optimum thickness.
- Did the 3 view diagram. Calculated Range and Endurance parameters for our UAV.

Jishnu S (AE21B028)

- Assembled images for various VTOLs from different POVs. Collected data for various flight parameters for the cruise.
- Estimated the dimensions of VTOL for the dataset using MATLAB and ImageJ.
- Found out about the constraints on wing loading (Maximum speed, stall speed).
- Found out the ideal ranges area for the ailerons. Measured various parameters for both horizontal & vertical tails by using image processing.
- Did parts of the main report relating to the above mentioned sections.

Gaurav (AE21B018)

- Collected the UAV battery weight data from different sources which are used in estimating.
- Investigated online sources to gather top and side views of various UAV models.
- Calculated the approximate values of areas of wing and fuselage from the images of UAVs.
- Calculated the approximate values of lengths of the chord at root and tip which are used in various calculations.
- Measured various parameters for both horizontal & vertical tails by using image processing.
- Helped in calculating the weights of the wing, horizontal tail, vertical tail, and fuselage.

AS5213 - Design of UAV

GROUP 14

THANK YOU

Group - 14

- Joel J - (AE21B105)
- Ira Rai - (AE21B024)
- Harish S - (AE21B021)
- A S A Raviteja - (AE21B005)
- Gaurav - (AE21B018)
- Jishnu S - (AE21B028)