Louvre

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ABBREVIATIONS AND NOMENCLATURES

AIAA- *American Institute of Aeronautics and Astronautics*
DBF- Design/Build/Fly
M1- Mission 1
M2- Mission 2
M3- Mission 3
GM- Ground Mission
FOM- Figure of Merit
AR- Aspect Ratio
LW- Length of Wing
SW- Area of Wing
CW- Chord of Wing
CVT- Vertical Tail Volume Ratio Co-efficient
LVT- Distance between aerodynamic centers
SVT- Area of Vertical Stabilizer
CHT- Horizontal Tail Volume Ratio Co-efficient
LHT- Distance between aerodynamic centers
SHT- Area of Horizontal Stabilizer
Cl- Co-efficient of Lift for Airfoil
Cd- Co-efficient of Drag for Airfoil
Cm- Co-efficient of Moment for Airfoil
LPackage-Length of Package in M3
P/W- Power to Weight Ratio
CL- Co-efficient of Lift for Wing NPackages Drop
CD- Co-efficient of Drag for Wing
CM- Co-efficient of Moment for Wing
CF- Co-efficient of Skin Friction
FF- Component Form Factor
Q- Interference Drag
SWET- Wetted Surface Area
XCG- Location of Center of Gravity
V Cruise- Cruise Velocity
q- Dynamic Pressure
α- Angle of Attack
CD0- Co-efficient of Parasite Drag
CDi- Co-efficient of Induced Drag MACWing- Mean Aerodynamic Chord

n- Load Factor
u- Velocity in X-Axis
v- Velocity in Y-Axis
w- Velocity in Z-Axis
PLA- Poly Lactic Acid
TWR- Thrust to Weight Ratio
COG- Centre of Gravity
SM- Static Margin
b- Span
ε- Span Efficiency Factor
XNP- Neutral point Position
ρ- Density of Air
W- Weight of the Aircraft
UPES- University of Petroleum and Energy Studies
TGM- Time Taken to complete Ground Mission
NCargo boxes -number of Cargo boxes carried for M2
NLaps- Number of Laps in M3
NPackages-Number of Packages Dropped in M3

1.0 EXECUTIVE SUMMARY

The objective of Testbed 2021-2022 aims to design, build and test an airdrop plane capable of transporting cargo boxes and dropping essential supply packages without sustaining any damage. The aircraft is designed for accomplishing the following missions: empty flight, transporting cargo boxes, and dropping of supply packages per lap. The maximum allowable wingspan is 5 ft and it must takeoff within a field length of 100 ft, with or without payload onboard. The cargo boxes must be 3.94 in x 3.94 in x 3.94 in (0.1 m x 0.1 m x 0.1 m) and weigh about 5.29 oz (150 g) while the supply packages must have a square cross-section of 1.57 in x 1.57 in (0.04 m x 0.04 m) with a minimum length to side ratio of 1.5 and a minimum weight of 3.53 oz (100 g) . The aircraft is capable of completing three-flight missions and a ground mission [1].

For mission 1, the unloaded aircraft has to complete 3 laps within a 5-minute flight window. For mission 2, the aircraft is required to carry and deliver the cargo boxes in minimum time. Finally, for mission 3, the aircraft is required to fly as many laps, transport, and drop the supply package after each 360° turn within a flight window of 10 minutes. Additionally, the score from each mission is secured after a successful landing. The operational demonstration of all the missions is tested in the ground mission.

The team progressed with the conceptual design of the plane and prioritized greater lift to counter the payload weight. Various computer-aided tools like Python programming language, AVL, CFD, XFLR5, ECalc, and Motocalc software were used for the design process of Louvre. From the score sensitivity analysis, initial design parameters like chord, aspect ratio, and weight were obtained. Consequently, mission 2 and mission 3 were equally prioritized for achieving a greater overall score.

Louvre is a high-wing aircraft with a rectangular wingspan of 5 ft (1.524 m), consisting of a conventional empennage, and a tractor motor system. The configurations selected were based on simplicity and greater stability thus ensuring a smooth flight. The fuselage is designed specifically to provide maximum payload carrying capacity and offering minimal drag. It is equipped with a dropping and bay door opening mechanism for releasing the supply packages. Carbon fiber is used in the fabrication of spars and fuselage due to its greater strength to weight ratio. The ribs of the wing and empennage are 3-D printed and corrugated plastic sheet is used for the skin.

Three descent control tests were performed with a parachute to ensure the safe landing of supply packages which is briefed in the later sections. Louvre is capable of completing 3 laps for mission 2 while carrying 16 cargo boxes and 11 laps for mission 3 while carrying 16 supply packages flying at a top speed of 85.3 ft/s (26 m/s). It weighs about 15.43 lbs (7 Kg) and the weight is distributed such that CG lies beneath the wing.

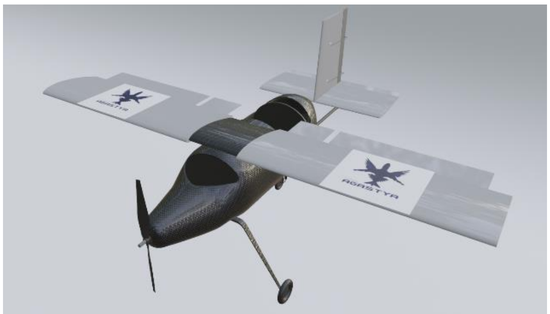


Figure 1: Louvre in Final Configuration

2.0 MANAGEMENT SUMMARY

Team Agastya is the official aero-design unit of UPES, Dehradun that represents the university at the AIAA DBF student design competition. The team consists of 11 students from the aerospace domain of engineering and is diversely constituted by freshmen, juniors, and senior year students.

2.1 TEAM ORGANIZATION

Team management is organized in a hierarchical structure to distinguish the responsibilities and for the smooth functioning of the team. It consists of Student Advisors and members from sub-domains collaborating as shown in Fig 2. Student Advisors share their experience and knowledge from the previous year's competition thus, guiding the team towards acquiring greater accuracy and precision.

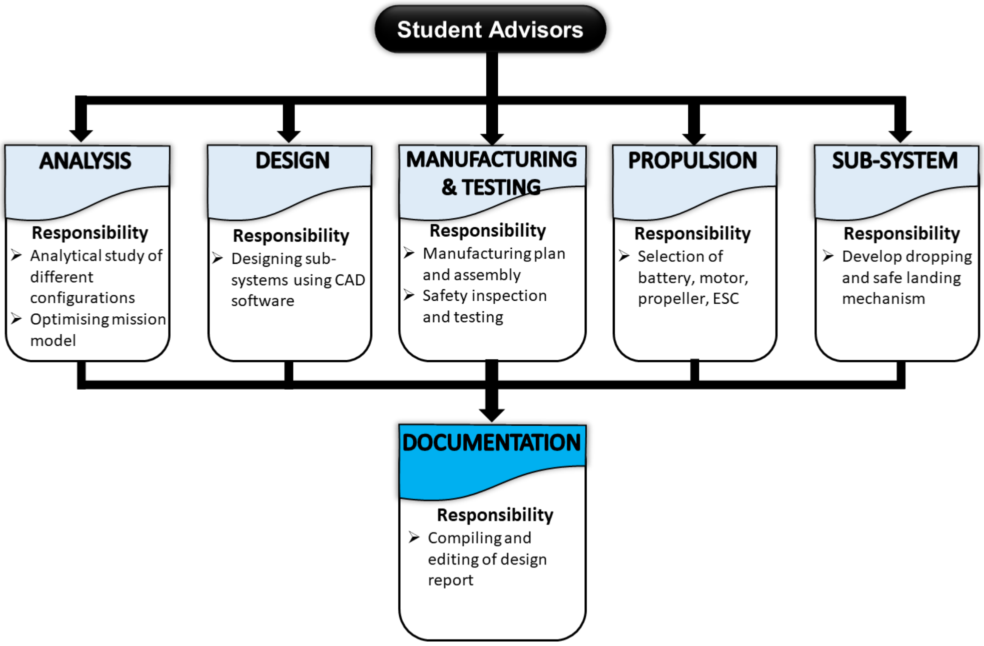


Figure 2: Team Organization Chart

All members coordinate with other domains and comply with the deadlines. Weekly meetings are regularly scheduled to oversee the smooth working pace.

2.2 MILESTONE CHART

A schedule was maintained in the form of a milestone chart to track the progress and ensure smooth functioning within the team. The chart was referred regularly to ensure adherence to the deadlines by the team members.

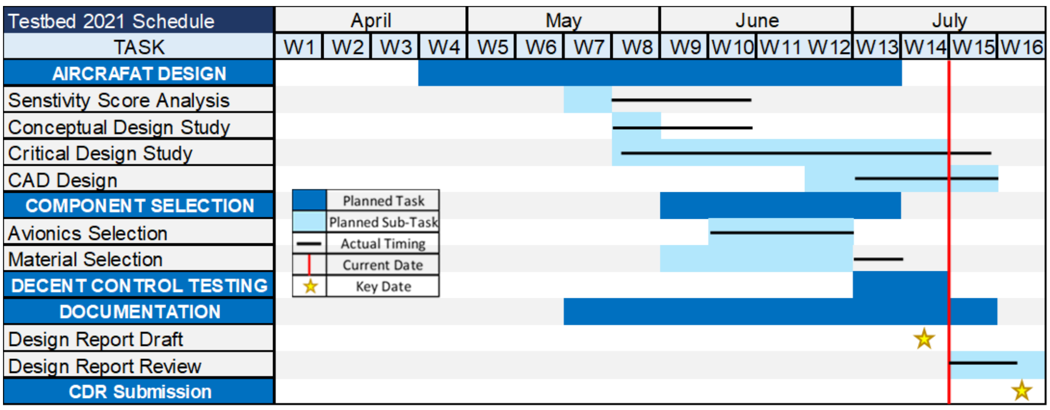


Figure 3: Competition Milestone Chart

3.0 CONCEPTUAL DESIGN

For the conceptual design of the aircraft, the mission requirements and scoring equations were critically analyzed to determine the crucial design parameters. Various configurations were considered and finally selected such that they fulfilled the design requirements and resulted in achieving a greater overall score.

3.1 MISSION REQUIREMENT

The problem statement of Testbed 2021-22 [1] entails the design of an airdrop plane capable of transporting and delivering cargo boxes and essential supply packages. The competition consists of three flight missions and a ground mission. The general rules state that the maximum allowable wingspan is 5 ft (1.524 m) with a predefined weight and dimension of the cargo box of about 5.29 oz (150 g) and 3.94 in x 3.94 in x 3.94 in (0.1 m x 0.1 m x 0.1 m) respectively. The supply package has a minimum weight of 3.53 oz (100 g) and a square cross-section of 1.57 in x 1.57 in (0.04 m x 0.04 m) with a minimum length to side ratio of 1.5.

The takeoff field length is 100 ft (30.48 m) and the score for each mission will be awarded after a successful landing. The aircraft takeoffs within the takeoff field length and flies along the flight course which consists of four straight paths (500 ft each), two 180° turns, and a 360° turn as shown in Fig. 4 The first two missions require the completion of 3 laps in the specified flight window. For mission 3, the plane is expected to fly for 10 minutes and drop the supply package after each 360° turn while completing the number of laps.

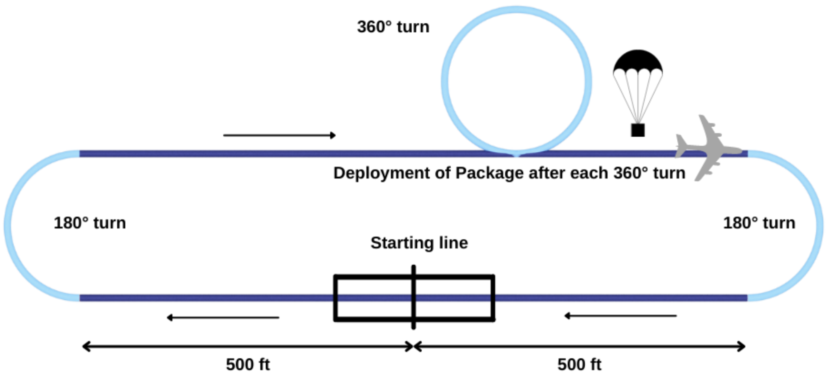


Figure 4: Flight Path Layout

3.1.1 MISSION SCORING

The total score for each team will be calculated from the Written Report Score and Team Mission Score which is represented by:

SCORE = Written Report Score * Total Mission Score

Total Mission Score is computed from the scores of each flight mission and ground mission, that is shown by:

Total Mission Score = M1 + M2 + M3 + GM

M1, M2, M3, and GM represent Mission 1, Mission 2, Mission 3, and Ground Mission.

1. **Ground Mission – Operational Demonstration**

   The ground demonstration of M2 and M3 by loading and unloading the payload for the respective missions along with deployment of the supply package will be performed in minimal time. The pilot demonstrates the flight controls of the aircraft are active and the assembly crew member is responsible for loading and unloading the payload for the ground mission. The score for the ground mission will be granted based on:

$$\mathbf{GM} = \frac{(\mathbf{T_{GM}})_{\mathbf{Minimum}}}{(\mathbf{T_{GM}})_{\mathbf{Agastya}}}$$

   T_{GM} represents the time taken for completing the Ground Mission.

2. **Flight Mission 1 – Staging Flight**

   The aircraft must fly three laps within a timeframe of 5-minutes along with the package dropping mechanism installed onboard. It should be followed by a successful landing to receive a full score as shown:

$$\mathbf{M1} = \mathbf{1.0}$$

3. **Flight Mission 2 – Delivery Flight**

   The aircraft must fly three laps while carrying the cargo boxes and package dropping mechanism in the least possible time. The other requirements are the same as the above mission. Scoring for this mission is shown:

$$\mathbf{M2} = \mathbf{1} + \frac{\left(\frac{\mathbf{N_{Cargo\ boxes}}}{\mathbf{T_{M2}}}\right)_{\mathbf{Agastya}}}{\left(\frac{\mathbf{N_{Cargo\ boxes}}}{\mathbf{T_{M2}}}\right)_{\mathbf{Maximum}}}$$

   $N_{Cargo\ boxes}$ represent the number of cargo boxes carried for Mission 2.

4. **Flight Mission 3 – Package Drop Flight**

   The aircraft is required to take as many laps as possible for a flight window of 10-minutes while dropping a package once every 360° turn per lap. The M3 score will be received after a successful landing. Scoring for this mission is shown:

$$\mathbf{M3} = \mathbf{2} + \frac{(\mathbf{N_{Laps}\ X\ L_{Package}\ X\ N_{Packages}\ X\ N_{Packages\ Drop}})_{\mathbf{Agastya}}}{(\mathbf{N_{Laps}\ X\ L_{Package}\ X\ N_{Packages}\ X\ N_{Packages\ Drop}})_{\mathbf{Maximum}}}$$

   N_{Laps}, $N_{Packages}$, $L_{Package}$, and $N_{Packages\ Drop}$ represent the number of laps, packages, package length, and the number of successful packages dropped in Mission 3.

3.1.2 AIRCRAFT DESIGN CONSTRAINTS

The aircraft must comply with the additional design constraints emphasized by the problem statement [1].

1. **Aircraft Configuration**
   - The maximum allowable wingspan is 5 ft (1.524 m)
2. **Take-off**
   - The aircraft must take-off within 100 ft (30.48 m) of the start/finish line for all three flight missions.
3. **Propulsion**
   - Propulsion power total stored energy cannot exceed 200 watt-hours.
   - The battery may be NiCad/ NiMH or LiPo among which only one type can be used.
   - If selecting LiPo batteries, they must be unaltered and commercially procured. A fuse must be in line with the positive battery terminal with a maximum continuous current rating not exceeding the maximum continuous discharge current rating of the LiPo battery pack. Battery packs must have a minimum of 0.25 in (0.00635 m) air gap between them.
   - An external safety plug or fuse should be mounted on the exterior of the aircraft.
4. **Payload**
   - The payload must be stored internally.
   - Cargo Box
     - The cargo box must be 3.94 in x 3.94 in x 3.94 in (0.1 m x 0.1 m x 0.1 m) and weigh about 5.29 oz (150 g).
   - Essential Supply Package
     - The supply package should have a square cross-section of 1.57 in x 1.57 in (0.04 m x 0.04 m) with a minimum length to side ratio of 1.5 and weigh at least 3.53 oz (100 g).
   - Package dropping Mechanism
     - The mechanism for package dropping must be present for all the missions.
     - Only one package should be dropped in each lap
   - Safely Landing Mechanism
     - The package must land on the ground without sustaining any damage.

3.2 DESIGN REQUIREMENTS

The design requirements were estimated by scrutinizing the scoring equations and design constraints mentioned in the prior sections. This helped in maximizing the overall score by realizing the critical parameters involved in the selection of different aircraft configurations. The translation of mission requirement into design requirement is shown in the following table:

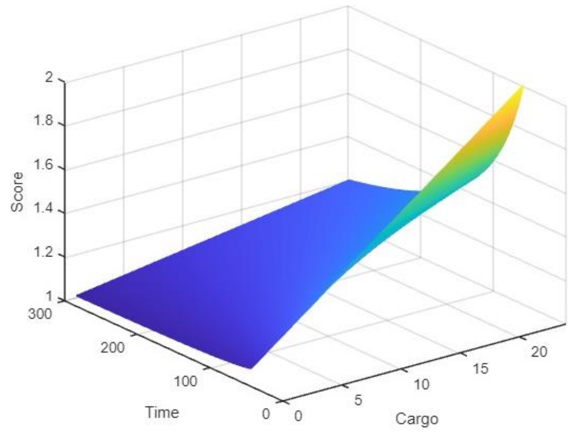
MISSION	OBJECTIVE	DESIGN PARAMETER
GM	Quick loading and unloading of payload	Time
M1	Stable and steady flight	Time
M2	High speed with maximum cargo boxes	Number of cargo boxes, Time
M3	Greater number of laps, packages and successful drop without affecting overall stability	Number of laps, packages, package length and successful drop

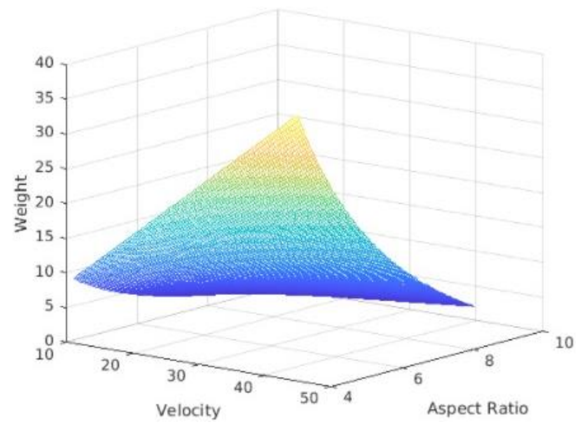
Table 1: Design Requirements

3.3 SENSITIVITY ANALYSIS

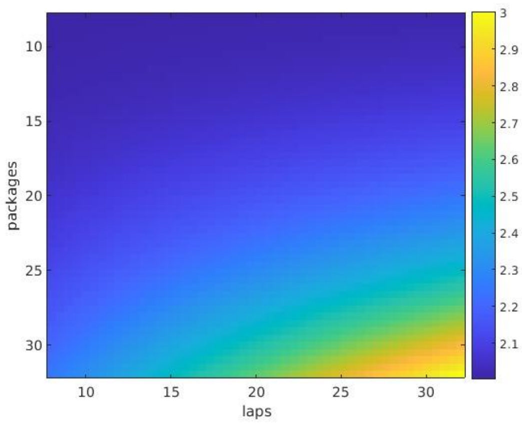
The design parameters were quantified based on a mathematical model to maximize the total score. The team initialized the sensitivity process by considering an attainable speed and empty weight estimation as baseline parameters for determining other design constraints. Therefore, a mesh was plotted between gross takeoff weight, speed, and aspect ratio to determine the above-mentioned design attributes. The analysis [5] concluded by selecting an aspect ratio of 6.93 and a gross take-off weight of 15.43 lbs (7 Kg).

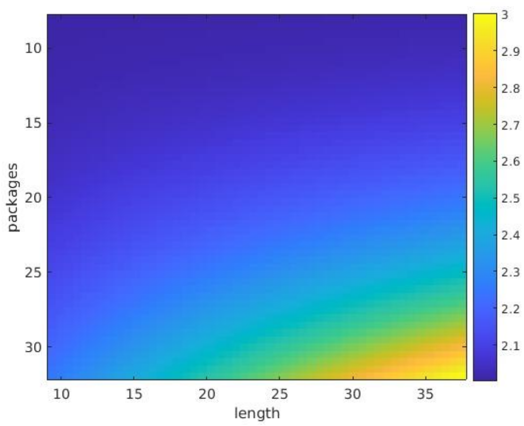
The objective of the ground mission was to take the least possible time for demonstration, loading, and unloading of payload. Similarly, the team will receive a full score for mission 1 after flying three laps within 5 minutes followed by a successful landing. The scoring equation for mission 2 depends on two factors that are, the number of cargo boxes and time. Therefore, the least structural weight was considered a crucial factor for flying more cargo boxes in minimal time. A mesh was plotted to determine the possible number of cargo boxes that can be carried for achieving a higher score in mission 2.





The scoring equation of mission 3 has a linear relation with the number of laps, packages, successful package drop, and package length. It was observed that the number of packages and successful package drop, drastically decreased with an increase in the package length. This further decreased the mission 3 score hence, affecting the overall score. Consequently, increasing the number of laps, packages and successful package drops was prioritized along with an optimal package length for achieving a higher score. A colormap was plotted between the above-mentioned parameters to determine the potential values for the desired score of mission 3.





After a thorough analysis of the scoring equations and design constraints, the team decided that Louvre is capable of carrying 16 cargo boxes stacked in 2 x 2 configuration and 16 supply packages stacked in 6 x 3 configuration for mission 2 and 3 respectively. The number of laps, package length, and weight obtained were estimated to be 11, 3.69 in (0.093 m), and 5.53 oz (156.7 g) respectively. The predicted score for each mission is shown in the table with a total score of 5.019.

MISSION	GM	M1	M2	M3
Maximum Score	1	1	2	3
Predicted Score	0.59	1	1.408	2.021

Table 2: Score table

3.4 Conceptual Weighing And Selection

For the design selection process, the team analyzed different configurations of aircraft subsystems based on a FOM table in which various parameters were scored from 1 to 5. A score of 5 indicated the best performance while a score of 1 indicated the least performance for the specified FOM. The score factors are shown against the FOM in the following table:

Figure Of Merit	Score Factor
Weight & Drag	5
Stability & Control	5
Simplicity & Strength	4
Repairability	4
Space Availability	3
Interference	3
Ground Clearance	3

Table 3: Score FOM table

The configuration with the highest total score was selected as the final configuration. The total score was calculated using :

Total Score = FOM Value X Score Factor

Weight & Drag: Least weight and minimal drag were considered as the key parameters for an efficient and quick flight due to less power consumption. Less structural weight maximized payload carrying capacity which can secure a good score for the team.

Stability & Control: Stability and control were prioritized so that the plane can withstand unfavorable weather conditions like a gust. A stable flight helps in completing the missions faster and without any difficulty.

Simplicity & Strength: Simplicity and strength were considered other important aspects since a simple approach was less prone to failure and high structural strength was necessary to counter the stresses developed.

Repairability: The ease of reparability was believed to be an essential factor to ensure quick prototyping of the aircraft.

Space Availability: Space availability was given average importance by the team. Additional payloads can be stowed with greater space availability.

Interference: The components should least interfere since this may lead to potential damage to the other subsystems and occupy additional space.

Ground Clearance: There must be a clearance between propeller and ground with the landing gear for a reliable takeoff and landing without imposing any risk to the plane.

3.4.1 AIRCRAFT CONFIGURATION

The aircraft configurations selected were conventional, twin-boom, and twin-fuselage designs. The twin-fuselage design was considered due to its greater payload handling capacity. However, it led to a significant increase in weight and complexity. Initially, the team decided to go for a conventional design but later the plane analysis ruled out the idea because of additional weight. Thus, the twin-boom configuration was opted for because of its less weight and simplistic approach when compared to other configurations.

Figure Of Merit	Value	Conventional	Twin Boom	Twin Fuselage
				
Weight & Drag	5	3.5	4	2
Space Availability	3	3.5	3	4
Simplicity	4	3	3	2.5
Total		40	**41**	32

Table 4: FOM for different configurations

3.4.2 FUSELAGE CROSS-SECTION

The three cross-sectional designs considered by the team for the fuselage included a square, elliptical, and circular design. A square cross-section maximizes the space available for the payload. However, it has stress points at corners affecting its structural strength and develops additional drag. The circular and elliptical cross-section created minimal drag and ensured high structural strength. The space available for the payload is less in circular cross-sections in contrast to elliptical. Therefore, an elliptical cross-section was selected as the optimal design for the fuselage.

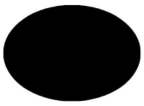
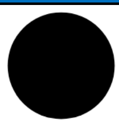
Figure Of Merit	Value	Square	Ellipse	Circle
				
Drag	5	2	3.5	3.5
Strength	4	3	4	4
Space Availability	3	3.5	3	2.5
Total		32.5	**42.5**	41

Table 5: FOM for various shapes

3.4.3 WING PLANFORM

The team considered delta, rectangular and elliptical wing planforms primarily due to their strength and weight. The rectangular wing planform was finally selected due to its simplistic design, ease of manufacturing, and attachment. It is also an optimal configuration for high-lift and low-speed flights.

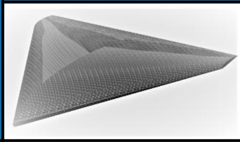
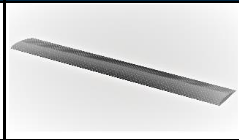
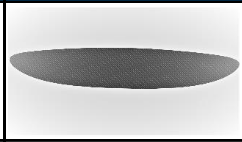
Figure Of Merit	Value	Delta	Rectangular	Elliptical
				
Weight	5	3	3.5	3
Simplicity & Strength	4	3	4	3
Repairability	4	3	3.5	2.5
Total		39	**47.5**	37

Table 6: FOM for different wings

3.4.4 Wing Placement

The team proceeded with the placement of wing and considered high-wing, mid-wing, and low-wing configurations. Mid-wing configuration involved the least space availability and higher interference with other components of aircraft. Low-wing design resolved the space availability concern however caused difficulty with payload dropping. Thus, a high-wing configuration was selected due to its simplicity, space availability, and less interference with the other subsystems.

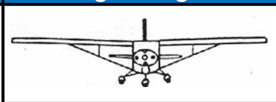
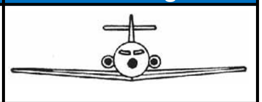
Figure Of Merit	Value	Mid Winger	High Winger	Low Winger
				
Space Availability	3	3	4	4
Interference	3	2.5	3.5	3
Simplicity	4	3	4	3.5
Total		28.5	**38.5**	35

Table 7: Wing placement FOM

3.4.5 Empennage Design

The three main empennage designs selected were T-tail, a conventional tail, and H-tail design based on previous experience of the team. The conventional tail was opted as the optimal design due to its high stability, least weight, and simplicity. Moreover, H-Tail and V-Tail incorporated additional weight because of the vertical stabilizer.

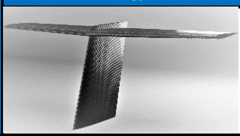
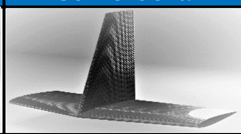
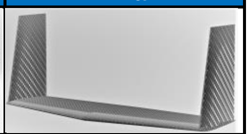
Figure Of Merit	Value	T-Tail	Conventional	H-Tail
				
Weight	5	3.5	4	3
Stability & Control	5	3	4	3.5
Simplicity & Strength	4	3	3.5	3
Total		44.5	**54**	44.5

Table 8: FOM for various tail configuration

3.4.6 Propulsion Placement

The team considered three major placements for the propulsion package that is, tractor, twin, and pusher motor configuration. The pusher configuration involved complexity and greater interference while the twin motor configuration included additional weight and complicated the mounting. Furthermore, it was not considered feasible for the team economically. Therefore, tractor motor configuration was selected such that it provides sufficient thrust along with the least weight, less interference, and simplicity.

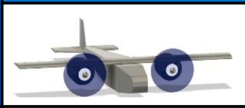
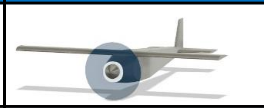
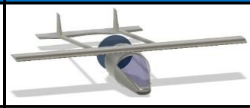
Figure Of Merit	Value	Twin-motor	Tractor	Pusher
				
Weight	5	2.5	4	3.5
Interference	3	3.5	3.5	2.5
Simplicity	4	2.5	3.5	2.5
Total		33	**44.5**	35

Table 9: FOM for different propulsion position

3.4.4 Landing Gear

The three major landing gear configurations selected by the team were tricycle, tail dragger, and a modified tail dragger. Modified tail dragger was designed exclusively taking into consideration the ground clearance and provided a high angle of attack during the take-off. This design however included extra drag. Therefore, tricycle and tail dragger configurations were further analyzed based on greater ground clearance, control, and least drag. Tail dragger configuration was finally selected due to greater support and ease of control compared to the tricycle configuration.

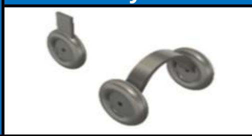
Figure Of Merit	Value	Tricycle	Tail Dragger	Modified Tail Dragger
				
Stability & Control	5	3	4	3.5
Drag	5	3.5	3.5	3
Ground Clearance	3	3	3	3.5
Total		41.5	**46.5**	43

Table 10: FOM for different landing gears

3.4.8 Dropping Mechanism

The team designed two dropping mechanisms for mission 3 which are the conveyor belt mechanism and lever dropping mechanism. The conveyor belt mechanism was a complex mechanism that occupied more space. Therefore, the team decided to go for the lever dropping mechanism due to its simple approach and quick release mechanism.

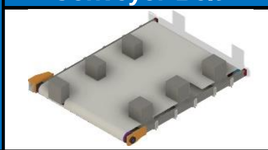
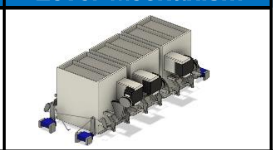
Figure Of Merit	Value	Conveyor Belt	Lever Mechanism
			
Space Occupied	3	2	3.5
Simplicity	4	3	4
Total		18	**26.5**

Table 111: Dropping mechanism FOM

3.4.9 Descent Control Mechanism

For a secure landing of the supply package, the team considered two configurations of the parachute that is, cruciform and dome-shaped. The dome-shaped parachute offered greater drag in comparison to cruciform and allowed the safe landing of the supply package. Thus, the dome-shaped parachute was selected as the optimal configuration.

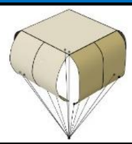
Figure Of Merit	Value	Cruciform	Dome-shaped
			
Drag	5	3.5	4
Simplicity	4	3	4
Total		29.5	**36**

Table 12: Descent Control system FOM

3.4.10 SUPPLY PACKAGE PLACEMENT

The stacking of supply packages was considered so that the weight distribution is uniform and occupies maximum area of the fuselage. The team also took into account the placement of the bay door and a possible shift in CG after dropping the supply packages thus, a horizontal placement was selected for the stacking of packages in a 6 x 3 configuration.

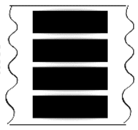
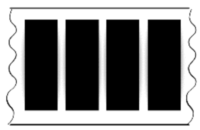
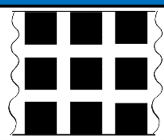
Figure Of Merit	Value	Length	Horizontal	Vertical
				
Space Occupied	3	3.5	4	3
Stability	5	3	3	2.5
Total		25.5	**27**	21.5

Table 13: Packages placement FOM

3.5 FINAL CONCEPTUAL DESIGN

The final configuration of Louvre consists of a high-wing twin-boom plane with a rectangular wing, a conventional tail, and a tractor motor configuration. It is capable of flying 16 cargo boxes stacked in 2 x 2 and 16 supply packages stacked in 6 x 3 for mission 2 and mission 3 respectively. The payload release mechanism installed for dropping the package is a lever dropping and bay door opening mechanism. A tail dragger landing gear configuration is used for supporting the plane and providing sufficient ground clearance.

4.0 PRELIMINARY DESIGN

4.1 DESIGN METHODOLOGY

Using the team's experience from previous years [14], the design methodology has been improved upon each year. Since the scoring factors are proportional to the payload on board, the team decided to keep the payload at the centre of its design methodology. The first step was to estimate the empty weight of the aircraft. Using this data, the sensitivity analysis took place which gave the team the dimensions of the payload as well as the predicted score. The results were utilised in the initial sizing of the aircraft. The team ran wing and tail analysis on XFLR5 using an iterative approach to achieve a stable aircraft. Propulsion systems were shortlisted and analysed. A mission model was created to facilitate the simulation of the various missions and to predict the performance of the aircraft. All the theoretical calculations and data are then verified by testing various prototypes of the aircraft.

Figure 5: Design methodology

4.2 Design Trades

4.2.1 Wing Sizing

The team ran a score sensitivity analysis, which gave the conclusion that to achieve a good score in M2 it is necessary to carry 16 cargo Boxes. Since the dimensions of the cargo, Boxes is large, and they are comparatively heavy the team went with a wingspan of 5 feet, which is the maximum limit of the wingspan according to the DBF rules. Sensitivity analysis between Gross take-off weight, velocity and AR concluded that the appropriate AR of the wing should be 6.93. Since the team is going with a rectangular wing the chord of the wing was calculated to be equal to 8.66 in (0.22 m). [2][3][4]

4.2.2 Fuselage Sizing

The fuselage was designed keeping in mind the size of the payload, sub system mechanism, and the various electronic components of the aircraft. The length of the fuselage was calculated using the formulas in [2]. The width of the fuselage was decided based on the payload dimensions and placement.

4.2.3 Empennage Sizing

Using the sizing formulas in [2] for a conventional tail, the dimensions of the horizontal and vertical stabilisers were calculated. The formulas are as follows:

$$C_{VT} = \frac{L_{VT}.S_{VT}}{b_w.s_w}$$

$$C_{HT} = \frac{L_{HT}.S_{HT}}{c_w.s_w}$$

Using these formulas, the surface area of the tail was calculated and then the dimensions of the tail were found. The tail arm length is about 70% the length of the fuselage and the surface area of the horizontal stabiliser is about 40% of the wing surface area.

4.2.4 Propulsion Sizing

Two key elements formed the foundation to select the propulsion package of the team, minimising the time taken to complete M2 and to maximise the number of laps in M3. The endurance of the propulsion package was decided according to the parameters of M3. The energy and weight were considered while choosing the battery. The team went with a LiPo battery due to its high energy density. The team finalized two 6S 4500mAh battery pack connected in parallel to fulfill the competition guidelines which limited the power rating of the propulsion system to 100Wh per battery pack and 200Wh for the entire propulsion system.

Tools like eCalc were used to find different combinations of motors, propellers, and batteries to find the best compatible system for mission requirements. Analysis was done by keeping power to weight ratio between [] along with the minimum thrust to weight ratio as 0.75 for aerobatic slow RC aircraft. The scorpion motor was selected as it offered high scoring chances for the requirements set. The package selected after analysis is shown in table below.

S.No.	Motor	KV	Cell	Current(A)	Static Thrust	Drive Weight
1	**E-Flite Power 60B**	470	LiPo 4500mAh- 30/45C	2.1 A	6980g	7500
2	**Scorpion SII-4025**	520	LiPo 4500mAh- 30/45C	1.4 A	7856 g	7500
3	**Dualsky ECO 4130C**	470	LiPo 4500mAh- 30/45C	1.5 A	7121 g	7500
4	**Planet-Hobby Joker-6350-8V3**	380	LiPo 4500mAh- 30/45C	1.6 A	9125 g	7500

Table 214: Propulsion packages shortlisted

4.3.2 SUBSYSTEM PRELIMINARY DESIGN

The Subsystem is an important part of M3. As stated before, the team is expected to drop supply packages. To complete this mission, the team decided to have two mechanisms, one of them being the dropping mechanism that will drop the supply packages and the other being the bay door opening mechanism through which the packages will drop through the aircraft.

4.3.1 BAYDOOR MECHANISM

The bay door mechanism is simple yet effective. The team decided to have two doors, each with two independent servo motors. The door opens through the centre, with the dropping mechanism placed above.

4.3.2 DROPPING MECHANISM

The team considered many designs of the dropping mechanism. Keeping the team's design philosophy of rapid prototyping in mind a mechanism was designed. The team uses gravity to drop the supply packages using a lever and sliding plate mechanism. Given the large width and height of the fuselage, the supply packages were placed in 3 sets in a 2x3 configuration. Since the packages were placed one on top of the other, the team had a restraint mechanism in between the payload, such that while one supply package is being dropped, the other does not fall with it, hence keeping the score equation factor i.e., one supply package to be dropped in each mission in mind.

4.4 MISSION MODEL

A mission model was designed by the team to achieve optimal flight performance. This model was developed to estimate the competency of the aircraft and/or any uncertainty that might be encountered during the flight. Thereupon, the model was divided into 4 phases to provide better insights into the flight performance.

1. **Take-off:** Considering the maximum throttle to attain a speed greater than the stall speed, ground take-off is planned. After carrying out flight tests, the take-off speed of the aircraft was brought about to be 75.45 ft/s (23 m/s).
2. **Climb**: With a steady climb rate, the maximum elevation attainable by the aircraft is estimated to be 754 ft (227.06 m) above sea level.
3. **Cruise:** Throughout the flight, there are two straight paths, cruising on which, the aerodynamic forces counterbalance each other. Hence, it is expected to result in a leveled and steady-speed flight of the aircraft.
4. **Turn:** The flight course consists of two 180° and a 360° turn. Taking this into account, a turning radius of 60.36 ft (18.40 m) was modulated from the predicted total flight path. The load

capabilities of the aircraft during flight were determined by this
Baseline parameters to achieve distinct flight criteria like cruise speed and physical characteristics of the payload were decided as a result of efforts and working of distinctive departments of the team, collaboratively. The model development was aided by the use of software like MATLAB and XFLR5 that in turn helped the team to determine these parameters. To run through the theoretical overview of the aircraft's performance, an analysis was done on eCalc and MotoCalc to optimize the propulsion requirements for the missions. This data is used to predict flight time and the expected number of laps flown by aircraft, which are then used to estimate the mission scores.

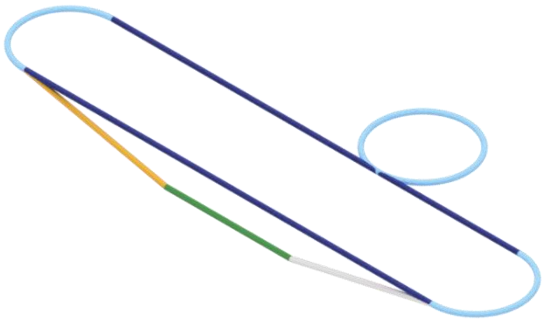


Figure 6: Mission Model

4.4.1 UNCERTAINTIES

There lies a lot of assumptions and predictions of parameters when it comes to the establishment of the design process. Aerodynamic parameters such as lift and drag were analyzed on XFLR5 that does not take into consideration the viscosity and interference between components and hence the values of its coefficients are somewhat uncertain. Throughout the flight duration, the static thrust bench and flight, which are predominantly based on the manufacturer's database, will change as the voltage decays. Here, the change in voltage that occurs due to the presence of batteries has not been taken into account. The predicted level flight condition, constant turning radius, and cruise velocity may also defer in the actual time of flight that may ultimately lead to deflection in the estimation of flight time and the number of laps flown. Some unavoidable uncertainties may arise due to change in some physical quantities like temperature and wind speed, which are both uncontrollable and unpredictable.

4.5 AERODYNAMIC CHARACTERISTICS

4.5.1 AIRFOIL SELECTION

Choosing airfoil forms the backbone of the aerodynamic characteristics of the aircraft. The airfoil affects the lift, drag, and stability of the wing, hence it is a crucial aspect of the analysis process. Various airfoils were considered, their DAT Files were taken from the UIUC airfoil database [6]. The airfoil analysis was performed on XFLR 5 [7], the Mach number and Reynolds number being 0.077 and 366,432 respectively. The most promising airfoils have been summarized in the table below.

Sr. No.	Name of Airfoil	α = 0°			Stall°	α = Stall°			Max
		C_l	C_m	C_d		C_l	C_m	C_d	C_l/C_d
1	**S4110**	0.412	-0.092	0.006	13.000	1.416	-0.033	0.041	98.903
2	**S7055**	0.434	-0.084	0.007	12.000	1.265	-0.017	0.034	97.038
3	**CLARK-W**	0.406	-0.086	0.009	14.500	1.316	-0.001	0.048	92.735
4	**AG 25**	0.310	-0.067	0.006	10.500	1.264	-0.038	0.041	85.090
5	**CLARK-Y 11.7% smoothed**	0.463	-0.095	0.008	16.000	1.373	-0.005	0.061	92.344

Table 15: Selected Airfoils

The eliminated airfoils offered high coefficients of lift but they had the subsequent amount of drag which affected the overall performance of the aircraft. Clark Y was selected because of its properties of efficient performance in respect of its lift to drag ratio and fulfillment of various design requirement of mission specifics. Although, Clark-Y provided better stability and less drag, it also had lesser value for coefficient of lift when compared to some of the eliminated airfoils. Also, being a flat-bottomed airfoil, the Ease of Manufacturing trumps the need of an overly cambered airfoil.

The curves illustrating the variation of parameters like coefficients of lift, drag and moment against different values of angle of attacks, for the above-mentioned airfoils are as follows.

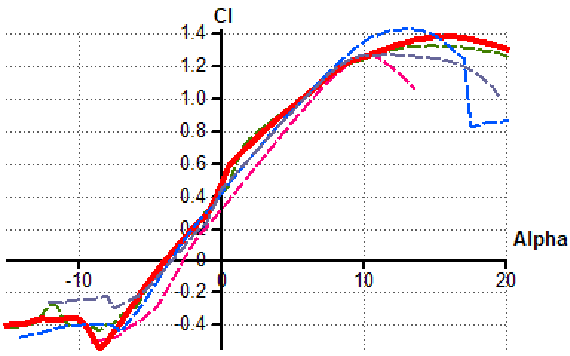


Figure 7:Cl vs alpha for airfoil

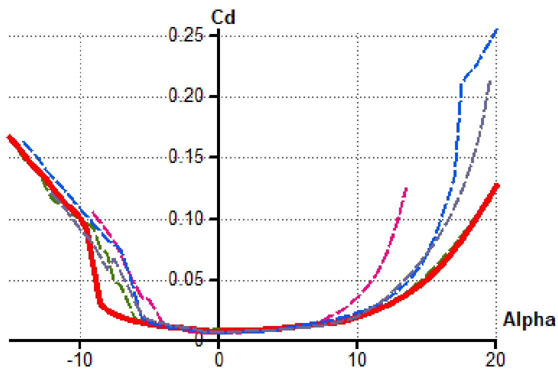


Figure 8: Cd vs alpha for airfoil

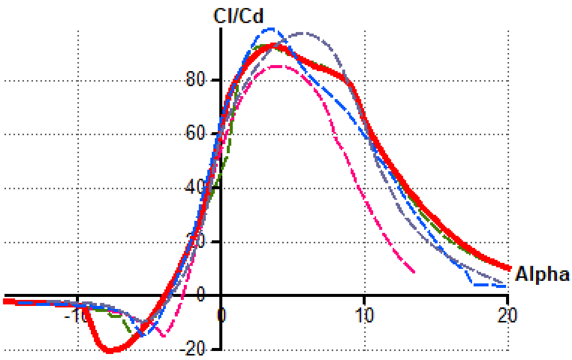


Figure 9: Cl / Cd vs alpha for airfoil

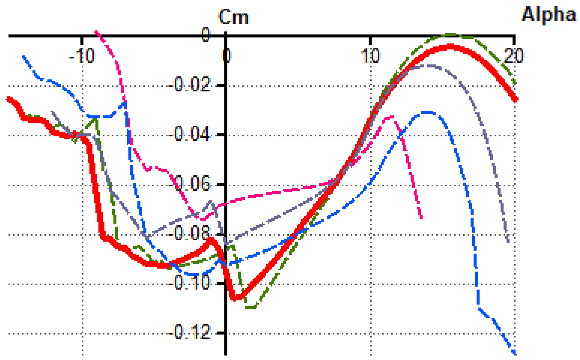


Figure 10: Cm vs alpha for airfoil

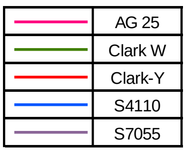


Figure 11: Key for Airfoil Curves

4.5.2 Lift Estimates

The Flight conditions were simulated using XFLR5 [7], to estimate the lift and drag of the aircraft as well as to understand the contribution of each component in the total lift and drag. The graphs were carefully analyzed to understand the performance of the aircraft. The graphs generated by the software have been shown below.

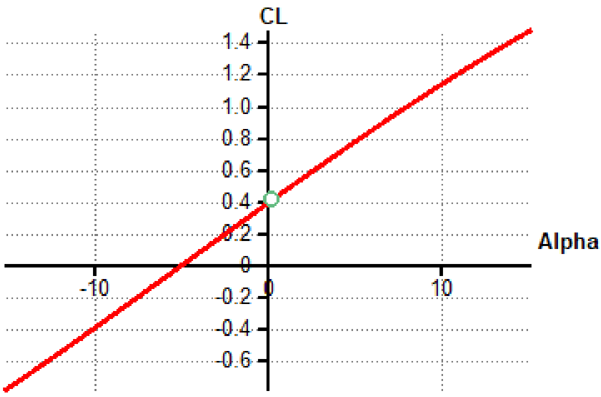


Figure 12: Cl vs alpha for aircraft

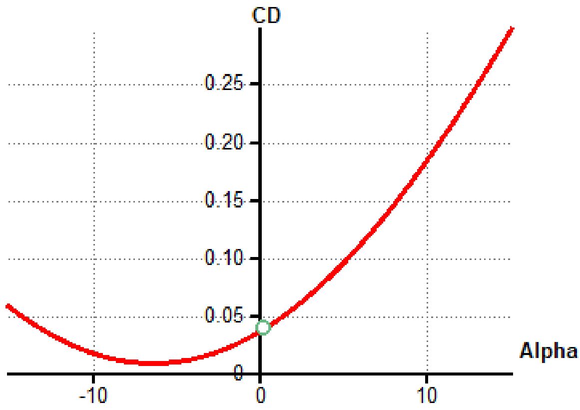


Figure 13: Cd vs alpha for aircraft

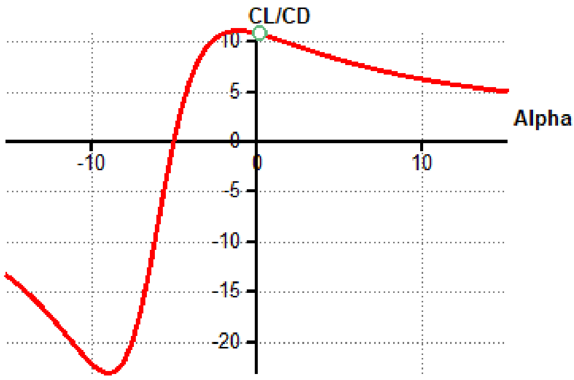


Figure 14: Cl/Cd vs alpha for aircraft

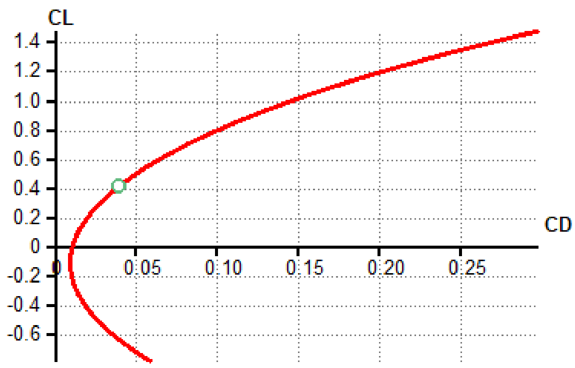


Figure 15: Cl vs Cd for aircraft

As Shown in the Cl v/s alpha curve, the aircraft has a positive lift at alpha=0, for which the coefficient of lift is equal to 0.392 and the lift is equal to (49.37 N), which was found using the equation below [9][10].

$$L = \frac{1}{2} C_l \rho V^2 S$$

The Lift generated by the major component of the aircraft has been shown in the pie chart below. The team reached upon this data by determining the lift generated by the major parts of the aircraft and finding out the contribution in the total lift of the aircraft. As the team had expected the wing of the aircraft is the primary lifting surface, followed by a small but significant contribution of the tail.

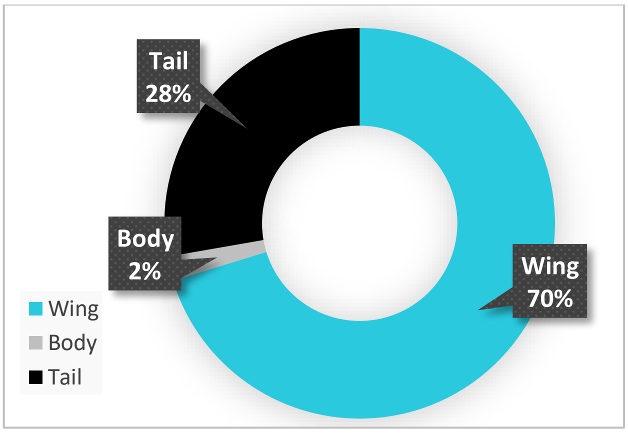


Figure 16: Component lift break down

4.5.3 DRAG ANALYSIS

The overall performance of aircraft depends highly upon its total drag, for which the team performed drag analysis on XFLR5 [7]. Since M3 involves a payload being dropped from a bay door, the component drag increases significantly. The Bay Door was designed keeping in mind the increase in drag that it causes. The Drag by each component of the aircraft was calculated, and the Total Drag was found out from the equation below.

$C_D = C_{DO} + C_{DI}$ [9][10]

The results are as follows:

C_d	0.0535
C_{do}	0.04343
C_{di}	0.0101

Table 16: Drag values

Parasite Drag:

It is the component of drag caused by skin friction and the shape of non-lifting components. The team had to concentrate on reducing parasitic drag by designing an appropriate fuselage. Opting a fuselage with a streamlined body rather than a boxy one, helped the team to reduce the effect of parasitic drag, the value for which was calculated by the following equation:

$C_{DO} = [CF * FF * Q * S_{wet}] / S_w$

Lift Induced Drag:

As the airfoil deflects air downwards, it produces a lifting force in addition to the drag force, this drag is termed as lift induced drag. This drag depends upon the speed of the aircraft as the lift is a function of the aircraft's velocity. Identification of lift induced drag can be done by observing the formation of vortices. To avoid this formation of vortices, winglets can be introduced.

Lift induced drag can be calculated using the following equation:

$C_{Di} = C_L^2 / (\pi * AR)$

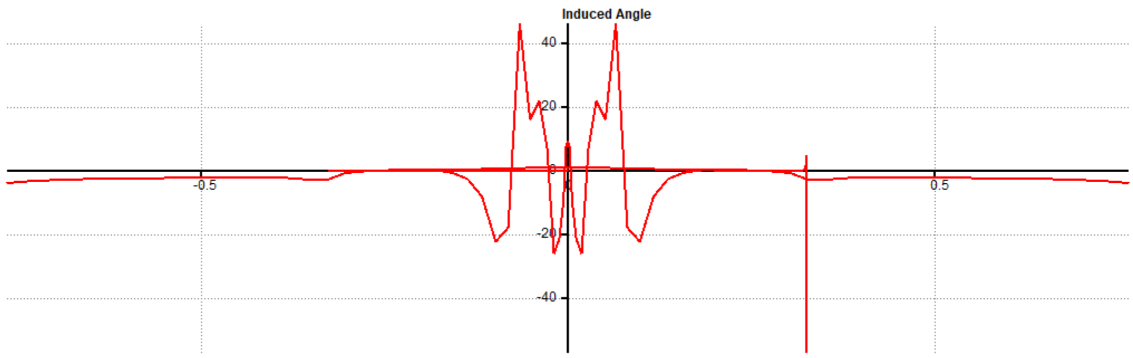


Figure 17: Aircraft trefftz plot

The Pie Chart represents the contribution of drag by each component of the aircraft.

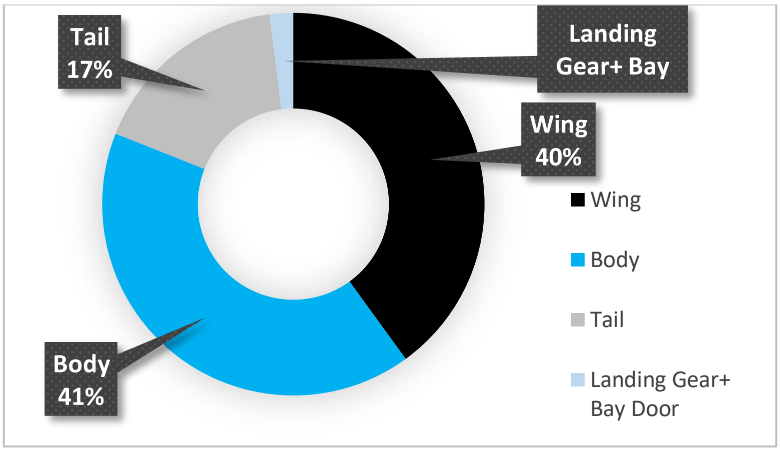


Figure 18: component drag

4.6 Stability And Control

4.6.1 Longitudinal Stability

The Cm vs α curve plays a very important role in determining the stability of the aircraft. A stability analysis was run by the team on XFLR5 [7] to draw the results for the same. The Cm vs α curve for the aircraft that was obtained is shown below.

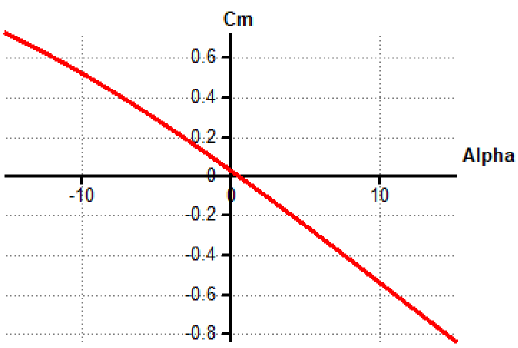


Figure 19: Cm v/s Alpha curve

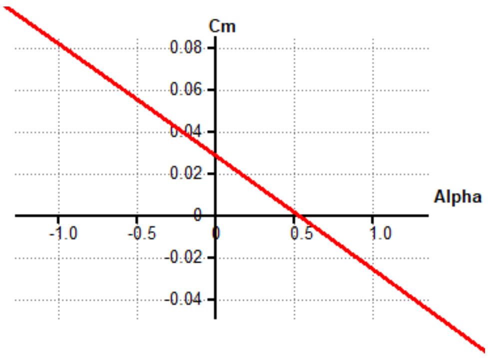
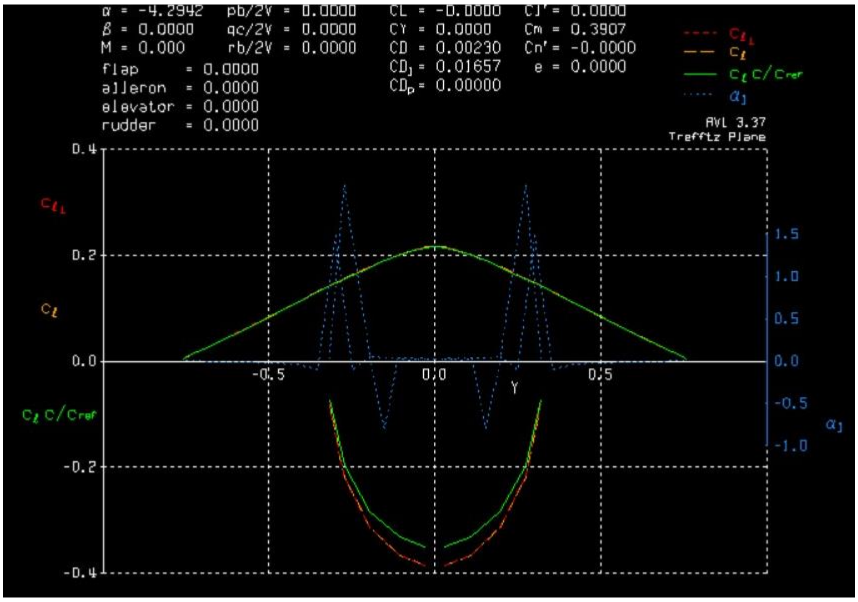


Figure 20: Cm v/s Alpha curve(zoomed in)

Figure 21: Trefftz plot AVL



It can be easily inferred from the above-shown graph that the CM vs α curve has a negative slope. The slongitudinal stability of the aircraft is the direct implication of the theoretical results deduced from the analysis.

$$y = [-0.0567]x + [0.029]$$

The curve is described by Equation []. The slope of the curve is given by -0.0567 The points 0.361 m and 0.464 m are the location of the centre of gravity and the neutral point for the aircraft, respectively. To nearly coincide with the actual and theoretically calculated value of COG of the aircraft, the propulsion system, payload, and avionics were stored accordingly.

$$\mathrm{SM} = \frac{x_{NP} - x_{CG}}{\mathrm{MACwing}}$$

The value of the static margin for the aircraft is calculated using Equation [] and is equal to 0.46. The longitudinal stability of the aircraft is also ensured by the positive value of SM [11][12].

The graph acquired from the AVL [8] analysis describes the lift distribution of wing and tail. Here the green line signifies the normalized lift conditions. For the plane to cruise at a velocity of 85 ft/s the fixed trim condition for angle of attack came out to be -4.2. The neutral point from AVL software came out to be 0.469 which coincided with the result derived from XFLR5 software hence verifying the results.

4.6.2 Dynamic Stability

Using Modal Analysis of XFLR5, the team judged the dynamic stability of the aircraft. The following graphs and tables summarise the results of the said analysis.

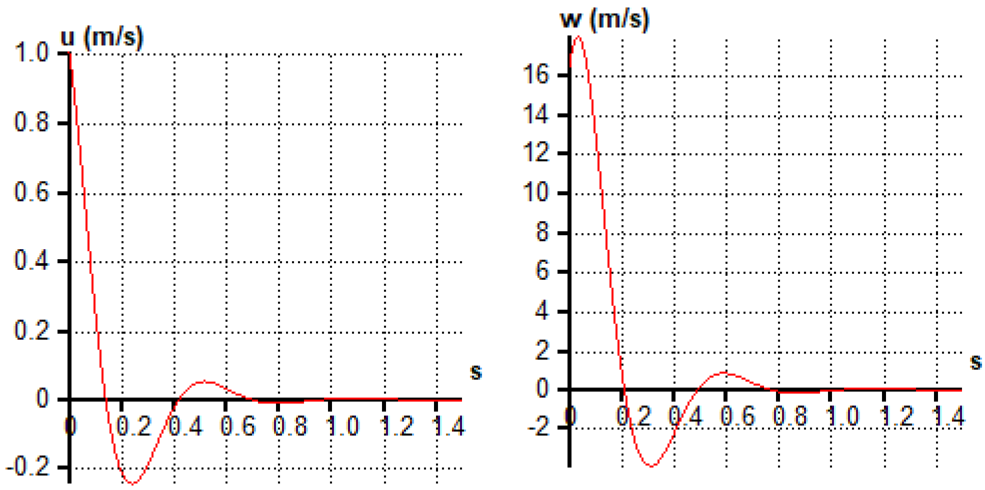


Figure 22: Longitudinal Mode 1 (u vs s) and (w vs s)

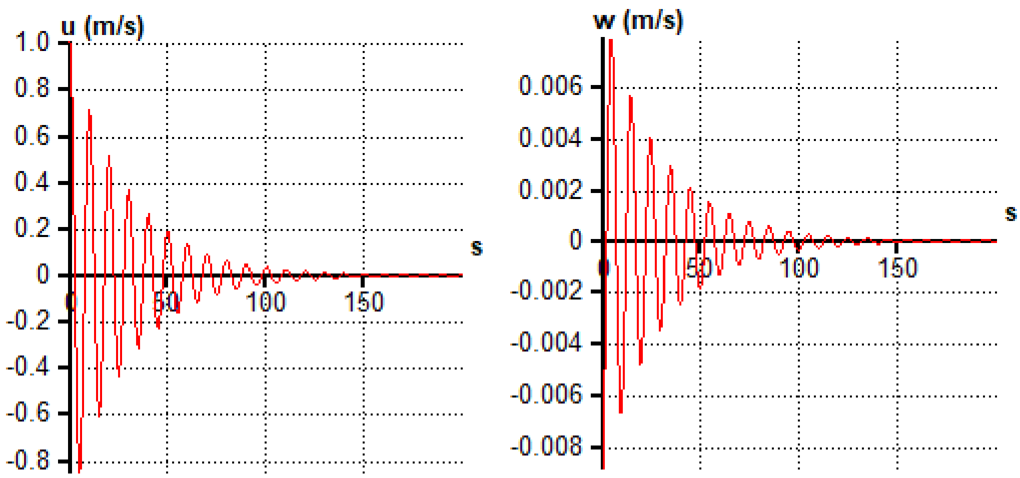


Figure 23: Longitudinal Mode 3 (u vs s) and (w vs s)

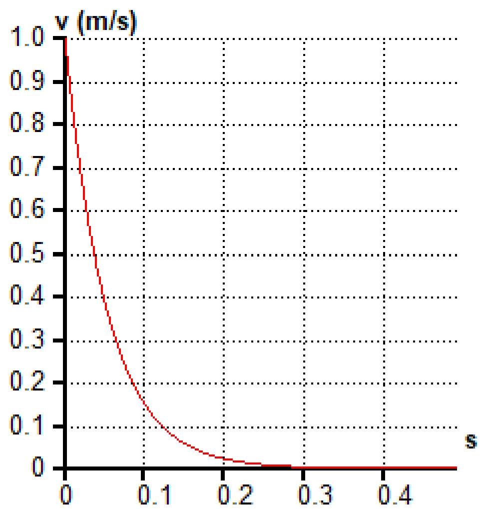


Figure 24: Lateral Mode 1 (v vs s)

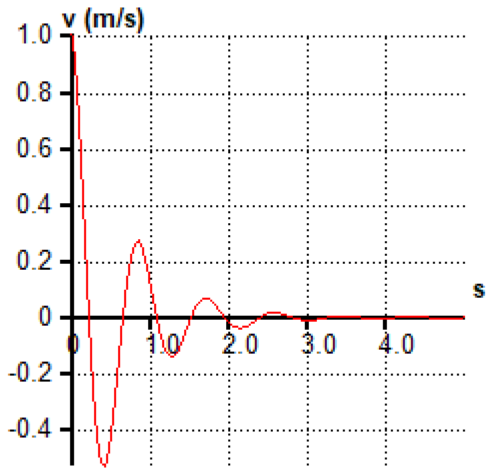


Figure 25: Lateral Mode 3 (v vs s)

Longitudinal Mode				
Mode	**Motion**	**Eigen Values**	**Natural Frequency (Hz)**	**Damping Ratio**
1	**Phugoidal**	-0.0850144	-0.0942037	0
2	**Phugoidal**	-0.876118	-4.2509	21.0456
3	**Short Period**	0.151855	-5.23987	-5.41246
4	**Short Period**	0	0	1
Lateral Mode				
Mode	**Motion**	**Eigen Values**	**Natural Frequency (Hz)**	**Damping Ratio**
1	**Spiral**	-0.506308	0.0355804	-21.957
2	**Roll**	-3.58689	-18.3382	7.88852
3	**Dutch Roll**	2.47378	1.47525	-2.58234
4	**Dutch Roll**	0	1	0

Table 17: Longitudnal and lateral eigenvalues decomposition

Longitudinal				
Eigen Value	-4.841+(-10.47)i	-4.841+(-10.47)i	-0.0336+ (-0.6206)i	-0.0336+ (-0.6206)i
Eigen Vector	1+0i	1+0i	1+0i	1+0i
	15.06+(16.56)i	15.06+(16.56)i	-0.0116+(0.00358)i	-0.0116+(0.00358)i
	7.857+(-7.955)i	7.857+(-7.955)i	0.03941+(0.001059)i	0.03941+ (0.001059)i
	0.3401+(0.9079)i	0.3401+(0.9079)i	-0.00513+(0.06323)i	-0.00513+(0.06323)i
Lateral				
Eigen Value	18.72+0i	-1.406+(-6.959)i	-1.406+(6.959)i	0.1066+0i
Eigen Vector	1+0i	1+0i	1+0i	1+0i
	-14.21+0i	-0.2149+(0.05289)i	-0.2149+(-0.05289)i	0.26+0i
	1.146+0i	0.04003+(0.3031)i	0.04003+(-0.3031)i	1.063+0i
	0.7591+0i	-0.001308+(-0.03115)i	-0.001308+(0.03115)i	2.44+0i

Table 18 3: Perturbation eigenvalues and Eigen vectors

As shown in the Longitudinal mode and Lateral mode graphs above, any perturbation caused by the wind dampens quickly with little to no effect on the aircraft. Hence, it was concluded by the team that the aircraft is dynamically stable.

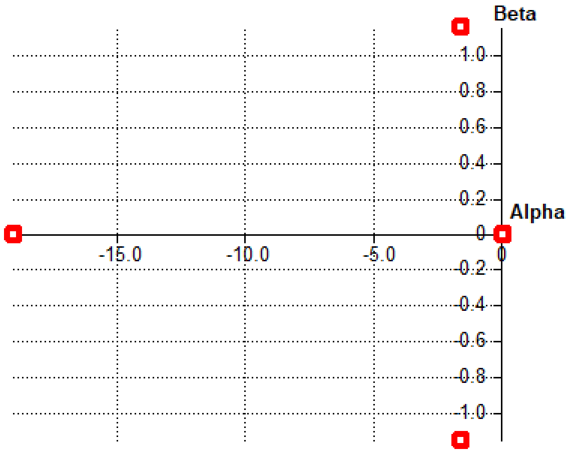


Figure 26: Lateral Eigen values

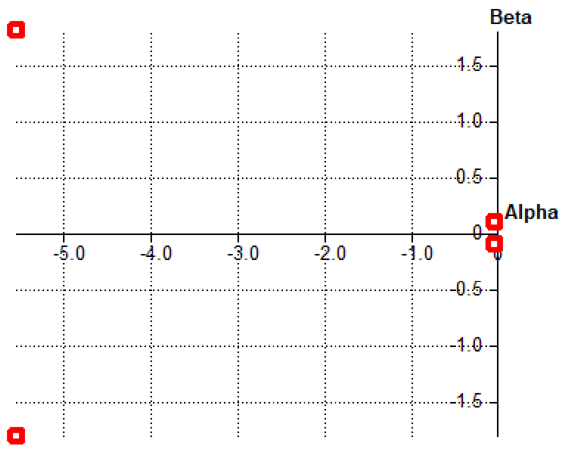


Figure 27: Longitudinal Eigen values

4.7 Predicted Aircraft Performance

The following table summarises all the data of the predicted aircraft performance.

PERFORMANCE PARAMETERS	M1	M2	M3
Climb/Cruise Altitude, ASL (ft)	754	754	754
C_L Max	1.470	1.470	1.470
C_L Cruise	0.392	0.392	0.392
C_D	0.0535	0.0535	0.0535
C_L/C_D cruise	10.594	10.594	10.594
Rate of Climb (ft/s)	7.54	4.921	4.914
Wing Loading (oz/ft^2)	39.20	61.87	62.13
V cruise (ft/s)	85.3	85.3	85.3
V stall (ft/s)	37.89	47.570	47.690
Aircraft weight (lbs)	9.17	14.46	14.57
Carried Payload	None	Cargo Boxes	Supply Packages
Number of Laps	3	3	11
Mission Score	1	1.408	2.021

Table 19: Mission Performance Estimation

5.0 DETAIL DESIGN

5.1 DIMENSIONAL PARAMETERS

Table [ ] summarizes the dimensions of the final aircraft. It gives the dimensions of the wing, horizontal stabilizer, vertical stabilizer, and the aircraft along with details about the propulsion system.

Wing		Parameters	Horizontal Stabilzer	Vertical Stabilizer
Airfoil	Clark-Y	Airfoil	NACA 0009	NACA 0009
Span	60 in (1.524 m)	Span	25.59 in (0.65 m)	12.401 in (0.315 m)
Chord	8.661 in (0.22 m)	Root Chord	7.874 in (0.20 m)	7.874 in (0.20 m)
α	4^o	Tip Chord	7.874 in (0.20 m)	6.299 in (0.16 m)
MAC	8.661 in (0.22 m)	Offset	0	1.574 in (0.040 m)
Area (Projected)	527 in^2 (0.34 m^2)	Planform Area	201.50 in^2 (0.13 m^2)	93 in^2 (0.06 m^2)
Ailerons (Area)	125.55 in^2 (0.081 m^2)	Control Surface (Area)	40.30 in^2 (0.026 m^2)	19.53 in^2 (0.0126 m^2)
Flaps (Area)	33.48 in^2 (0.0216 m^2)			

Table 20 : Wing and Tail parameters

FUSELAGE		PROPULSION SYSTEM		MOTOR	
Total Length	3.937 ft (1.2 m)	Battery	LiPo 4500 mAh 30/45C 6S2P	Model	E-flite-Power 60B 470-kv
Width	0.721 ft (0.22 m)	Cell count	6	No Load Current	2.1 A
Height	0.721 ft (0.22 m)	Rated Voltage	22.2	Effective KV	416
Maximum take-off weight	16.53 lbs (7.5 Kg)	P(out) @max	1486	Weight	380
PROPELLER		Energy Stored	199.8 Wh	CONTROLS	
M1	APC 15"x10" E	Weight	4.585 lbs (2080 g)	Fuse	70 A with each battery
M2	APC 15"x10" E	Gearbox	N/A [1:1]	Receivers	FrSky X8R
M3	APC 15"x7" E	ESC	120 A	Servos	Tower Pro MG90S

Table 214: Aircraft and propulsion system characterstics

5.2 STRUCTURAL CHARACTERISTICS

5.2.1 STRUCTURAL LAYOUT

The structural strength was an important consideration during the aircraft design process. The structure was designed such that it could withstand static and dynamic loads. The aerodynamic load on the wing is borne by the spars and is transferred onto the outer frame of the fuselage. The fuselage is manufactured using carbon fiber and has a hatch on top to easily place the payload in the aircraft. There are bulkheads and longerons which also help in strengthening the structure of the fuselage, The twin carbon fiber boom also acts as the main arrangement to hold the empennage. The motor mount on the front, rubber pads as well as fuselage design help curtail the vibrations caused by the motor. To counter the impact load during landing, the team installed landing gear in a tail dragger configuration. The undercarriage was also strengthened to keep the structural integrity of the aircraft. The Von-Mises stress diagram was used to calculate the stress of the wing and landing gear and has been shown below.

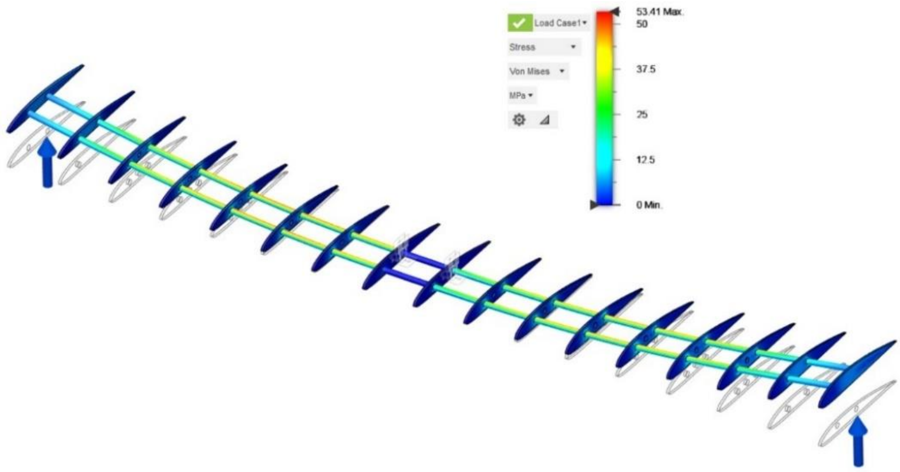


Figure 28: Von mises stress calculation for wing

Figure 295: Von mises stress calculation for landing gear

5.2.2 FLIGHT ENVELOPE

The flight envelope provides a safe window for the plane to operate such that the aerodynamic and structural limits are not crossed. The V-n Diagram [15] depicting the load limits is shown below along with the table showing the maximum limit load factor for each mission.

Mission	Maximum Limit Load Factor
M1	12g and -5g
M2	7g and -3g
M3	7g and -3g

Table 226: limiting load for each mission

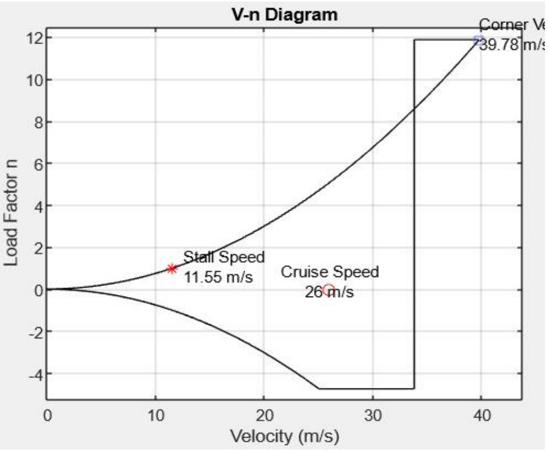


Figure 30:Load Factor Diagram M1

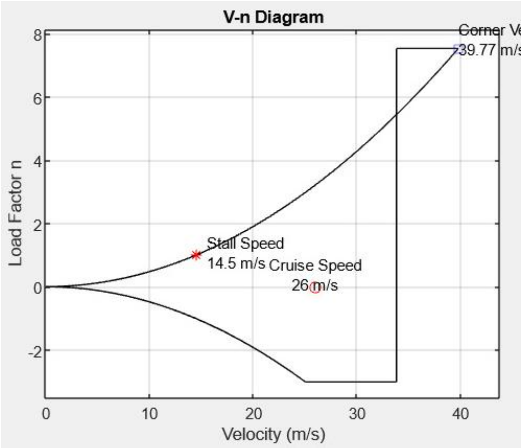


Figure 31:Load Factor Diagram M2

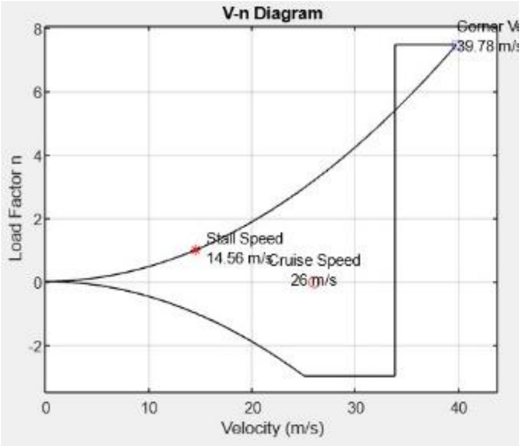


Figure 32: Load Factor Diagram M3

5.3 SUBSYSTEM DESIGN

5.3.1 WING

The wing is designed to withstand all the loads encountered during flight. The team decided to use a rectangular wing instead of an anhedral to get a more stable and agile flight. The internal structure of the wing is equipped with two carbon fiber spars along the wingspan passing through seventeen 3D printed ribs thus making it strong enough to withstand crashes while testing. Coroplast sheet has been used for the skin of the wing to maintain low weight. This year the team decided to use detachable wings for easy prototyping and portability. The wings have a lock mechanism that will slide into the fuselage and remain intact until released deliberately.

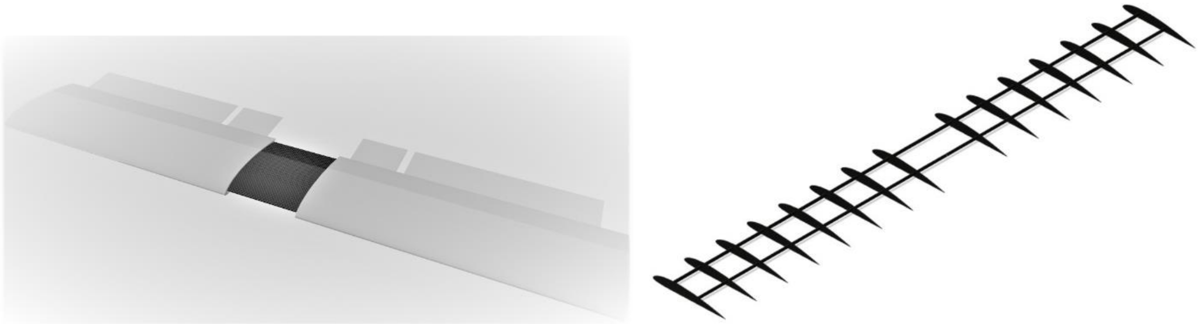


Figure 33: Wing CAD and Internal Structure

5.3.2 EMPENNAGE

The team decided to opt for conventional tail configuration as it assured more stability than other components. The tail is manufactured using chloroplast sheets and ribs are 3D printed using PLA. For maintaining the structural integrity of the tail the team is using carbon fiber spars. The airfoil required for the tail is thin and symmetric therefore, the team decided to go for NACA 0009 airfoil as it met the plane's performance expectations. Aspect ratio of the tail is kept significantly lower than that of the wing because if the wing stalls the tail will be able to manage the stability of the plane.

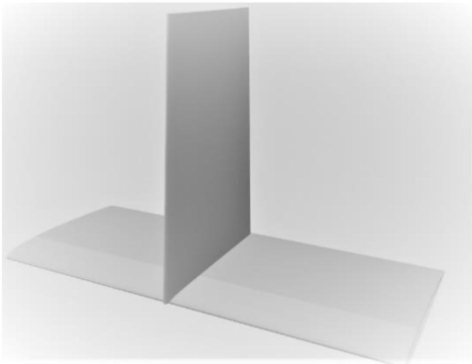


Figure 34: Empennage CAD

5.3.3 LANDING GEAR

The landing gear is designed in such a way that it can withstand a weight of approximately 22.05 lbs (10kg). The team decided to use tail dragger landing gear as it proved to dissipate the impact loads evenly while landing at a sink rate of 0.59 ft/s (1.92 m/s). The landing gear is placed in a way that prevents the nose-over condition and does not hinder the bay door opening.

Figure 35: Landing Gear CAD

5.3.4 FUSELAGE

Numerous iterations and sizing trades were done on Ansys for deciding the ideal fuselage design that meets the mission and design requirements. Finally, an elliptical-shaped fuselage was selected because of its comparatively low coefficient of drag value and was aerodynamically more efficient.

It has two hatches on the top, one placed at the starting of the fuselage for inserting propulsion system and the other placed at the ending for loading the packages or cargo boxes. A bay door opening mechanism is placed at the bottom of the fuselage for the deployment of supply packages.

To keep the fuselage structurally strong and lightweight the team decided to fabricate the fuselage with carbon fiber using a 3D printed mold. To avoid deformation due to loads, the fuselage was reinforced with 3D printed PLA bulkheads. To further decrease the weight of the plane the team decided to replace the rear end of the fuselage with a double carbon fiber rod which is directly connected to the empennage of the plane.

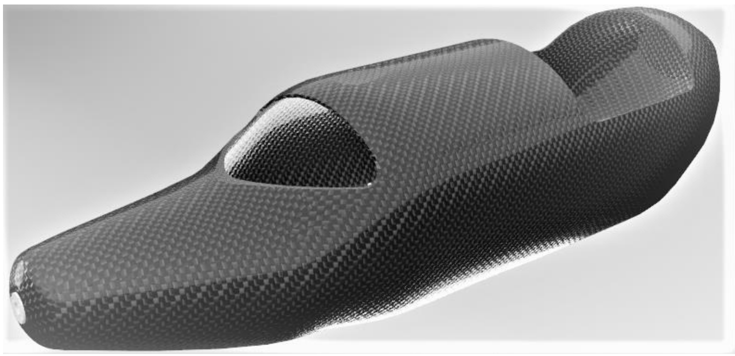


Figure 36: Fuselage CAD

5.3.5 PROPULSION PACKAGE

The following propulsion components were selected by the team considering the pitch speed, thrust to weight ratio, and the estimated temperature. Requirements by the missions as well as TOFL limited the kV greater or equal to 380 kV. For verification of motor efficiency within the required time the team used Motocalc software to plot graphs between speed, time, and thrust. The propulsion package components are shown in the table below.

<table>
<tr><th>Mission</th><th>Motor</th><th>Battery</th><th>ESC</th><th>Drive Weight</th><th>Propeller</th><th>Thrust @ 75%</th><th>P/W @ 100%</th></tr>
<tr><td>M1</td><td rowspan="3">E-flite-Power 60B 470-kv</td><td rowspan="3">LiPo 4500 mAh 30/45C 6S2P</td><td rowspan="3">120 A</td><td rowspan="3">2080g</td><td rowspan="2">APC 15”x10” E</td><td rowspan="2">9.92lbs/4.50 Kg</td><td rowspan="2">106 W/lb</td></tr>
<tr><td>M2</td></tr>
<tr><td>M3</td><td>APC 15”x7” E</td><td>8.15lbs/3.70 Kg</td><td>80 W/lb</td></tr>
</table>

Table 23 : Propulsion package Configuration

The team decided to select a pack of two 6S 4500 mAh ZOP LiPo batteries as it satisfied the required capacity to complete all the missions in the given flight window without exceeding the limit of 200 watt-hours specified in the rules. The following graphs were obtained for mission 2 and mission 3 in which the red line indicates propeller rpm and the blue line indicates the efficiency.

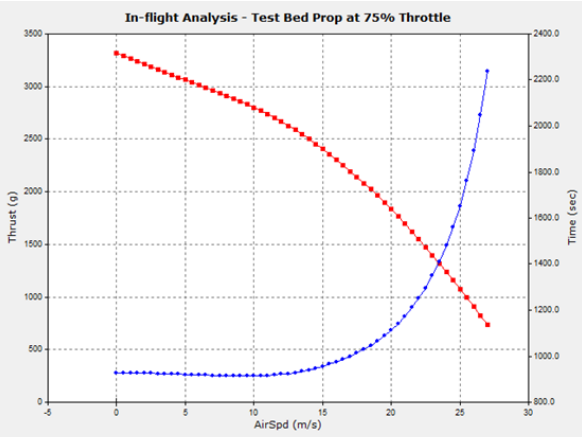


Figure 378: M2 Thrust vs Airspeed vs Time

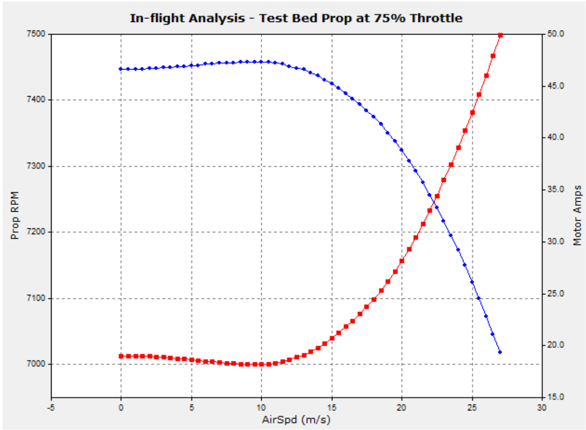


Figure 387: M2 Prop RPM vs Airspeed vs Motor

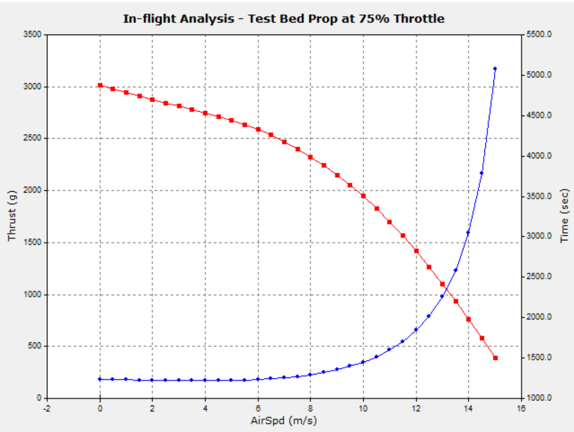


Figure 39: M3 Thrust vs Airspeed vs Time

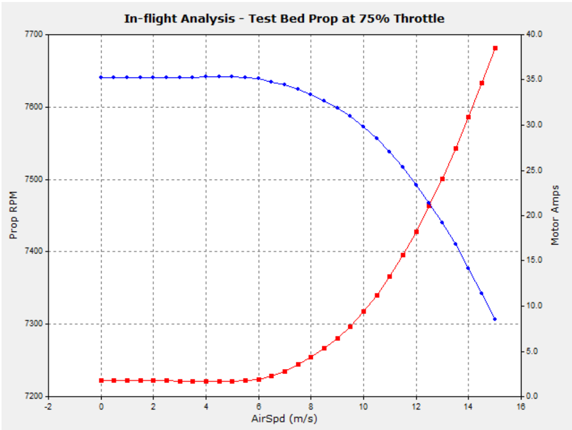


Figure 40: M3 Prop RPM vs Airspeed vs Motor

5.3.6 Essential Supply Packages

The package is a cuboid with dimensions of 1.57in x 1.57in x 3.69in (4cm x 4cm x 9.375cm) and weighs 5.5 oz (156 g). The packages are 3D printed using PLA as it offered quick designing and production. For ensuring the safety of the supply packages the team decided to use a parachute as the descent control system. The team iteratively compared the dimensions of parachute prototypes by testing and selected a dome-shaped parachute as it provided the maximum coefficient of drag which helped in the safe descent of supply packages.

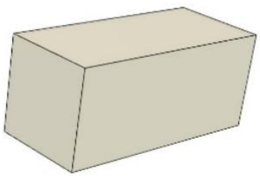


Figure 41: Supply Package CAD

5.3.7 Cargo Boxes

Cargo boxes are fabricated from PLA using the 3D printing technique. The team decided to stack the cargo boxes in a 2 x 2 matrix to achieve the maximum score while maintaining the CG of the plane. The plane is capable of carrying 16 cargo boxes each weighing 5.29 oz (150g) each.

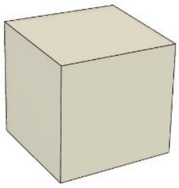


Figure 42: Cargo Box CAD

5.3.8 Package Dropping Mechanism

Mission 3 requires the aircraft to drop an essential supply package per lap in the given flight time window. For this, the team concentrated on a simple yet reliable mechanism, while ensuring rapid prototyping as well. A lever and sliding plate mechanism was found to be most suitable for the given mission. The supply packages would be dropped with the help of gravity, hence stacking of supply packages was deemed necessary. To increase the number of supply packages, stacking was done in the form of three matrices in a 2 x 3 configuration that is, a total of 6 x 3 stacking of supply packages. The lever and sliding plate mechanism are placed on both sides of the stacked matrices to keep the packages balanced.

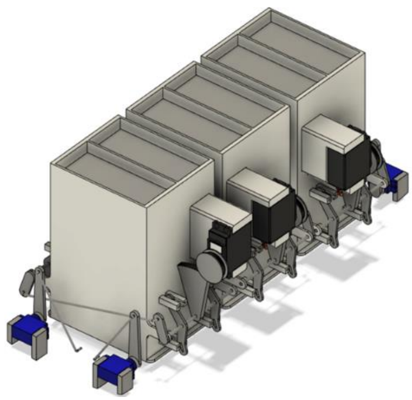


Figure 43: Dropping Mechanism CAD

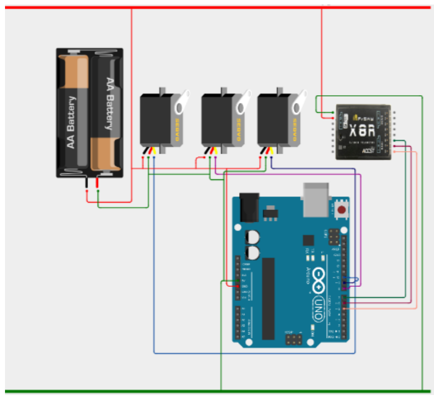


Figure 44: Mechanism Circuit Diagram

Since the lever has two sliding plates, one on top and the other on the base of the package. These plates are controlled via servo motors and spur gears in such a manner that when the base plate moves to release the package, the top plate automatically restricts the packages stacked above. The servo motors will be controlled by an Arduino board. The dropping of the supply package changes the position of CG of the aircraft thus, to minimize the effect of change in CG, the supply packages from the central columns will be dropped initially and then the other columns.

5.4 Weight And Balance

The weight of the aircraft was distributed such that the CG lies within the static margin. The CG of the components of the aircraft has been shown in table [ ]. In M2 configuration the cargo boxes are placed in the mid-section while the mechanism is shifted behind. In M3 the mechanism is placed in the center of the aircraft along with the supply packages above the bay door.

Aircraft Component	Weight		X		Y		Z	
General	**(lbs)**	**(g)**	**(in)**	**(cm)**	**(in)**	**(cm)**	**(in)**	**(cm)**
Fuselage	1.76	800	22.09	56.11	0.00	0	4.72	12
Wing	1.50	680	15.59	39.6	0.06	0.14	4.72	12
Motor	0.84	380	1.18	3	0.00	0	0.00	0
Tail	1.10	499	44.13	112.1	4.72	12	8.86	22.5
Front Landing Gear	0.39	175	13.90	35.3	9.59	24.35	7.80	19.8
Rear Landing Gear			28.93	73.48	4.33	11	4.72	12
M1								
Battery	2.86	1300	19.69	50	-0.20	-0.5	-4.33	-11
Propeller	0.20	89.86	0.79	2	0.00	0	0.00	0
Bay Door Mechanism	0.11	48	13.73	34.88	3.94	10.01	2.17	5.5
Dropping Mechanism	0.80	364	19.53	49.61	3.56	9.03	4.21	10.69
M2								
Battery	2.86	1300	19.69	50	-0.20	-0.5	-4.33	-11
Propeller	0.20	89.86	0.79	2	0.00	0	0.00	0
Containers	5.29	2400	21.02	53.4	3.94	10	3.94	10
Bay Door Mechanism	0.11	48	13.73	34.88	3.94	10.01	2.17	5.5
Dropping Mechanism	0.80	364	23.31	59.2	3.56	9.03	4.21	10.69
M3								
Battery	2.86	1300	19.69	50	-0.20	-0.5	-4.33	-11
Propeller	0.10	45	0.79	2	0.00	0	0.00	0
Dropping Mechanism	0.80	364	19.53	49.61	3.94	10.01	2.17	5.5
Bay Door Mechanism	0.11	48	13.73	34.88	3.56	9.03	4.21	10.69
Supply Packages	5.50	2496	20.63	52.4	3.74	9.5	3.74	9.5

Table 24: Aircraft weight and balance

5.5 Flight Performance

The flight performance of the aircraft was judged using the mission model developed by the team. A lap of the flight path is 2879.2 ft long. The plane will complete 11 laps in 10 minutes for M3 dropping 11 supply packages at a speed of 85.3 ft/s (26 m/s). The performance at various throttle levels was also validated with the theoretical data.

5.6 Mission Performance

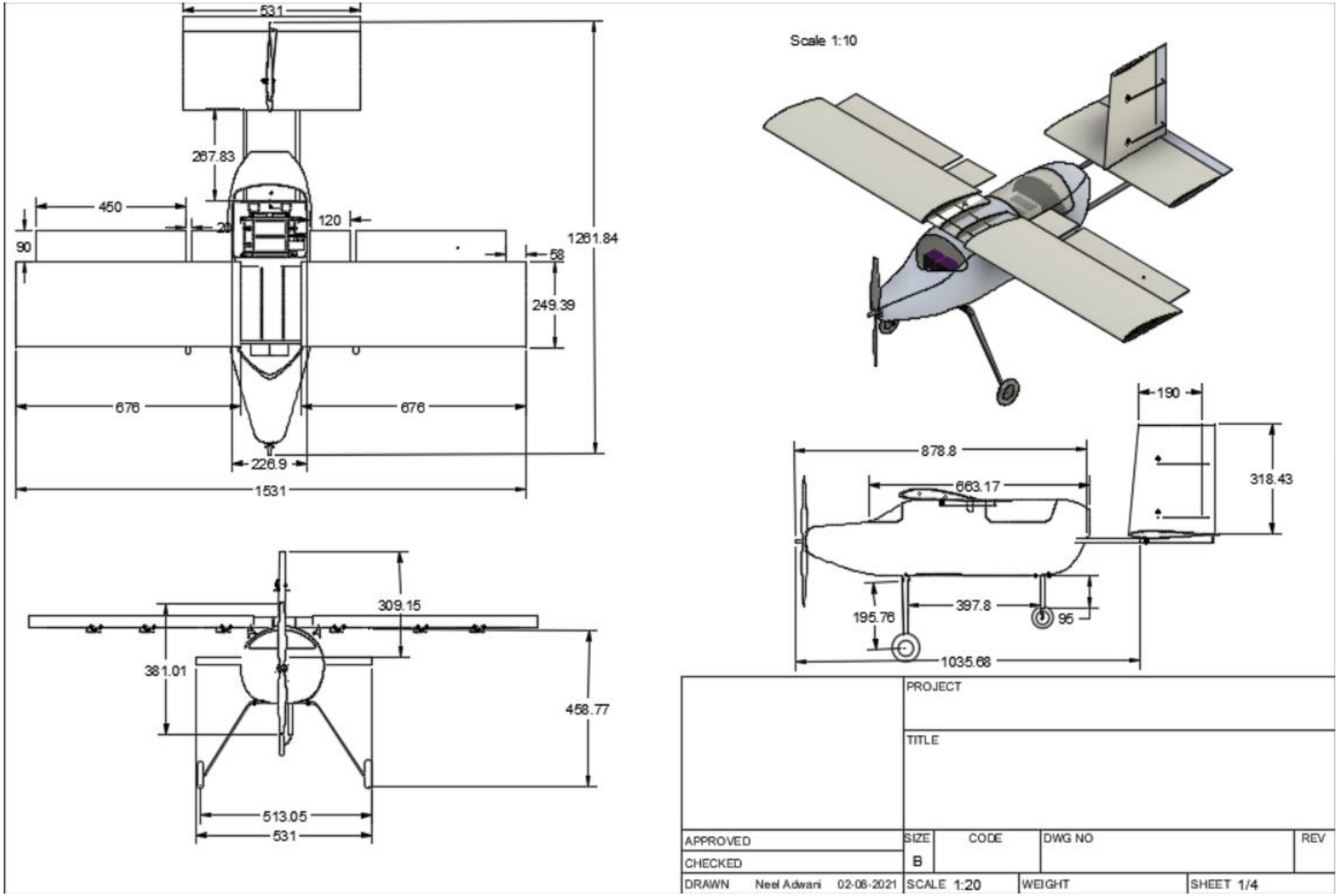
Through the data collected from flight performance, the mission performance was evaluated, the data for which was collected during the flight tests. Scoring analysis was done to evaluate the scores for the different missions and the scores were calculated using the scoring equations in the DBF Rules. The final score of the team for each mission is as follows.

Ground Mission	M1	M2	M3
0.59	1	1.408	2.021

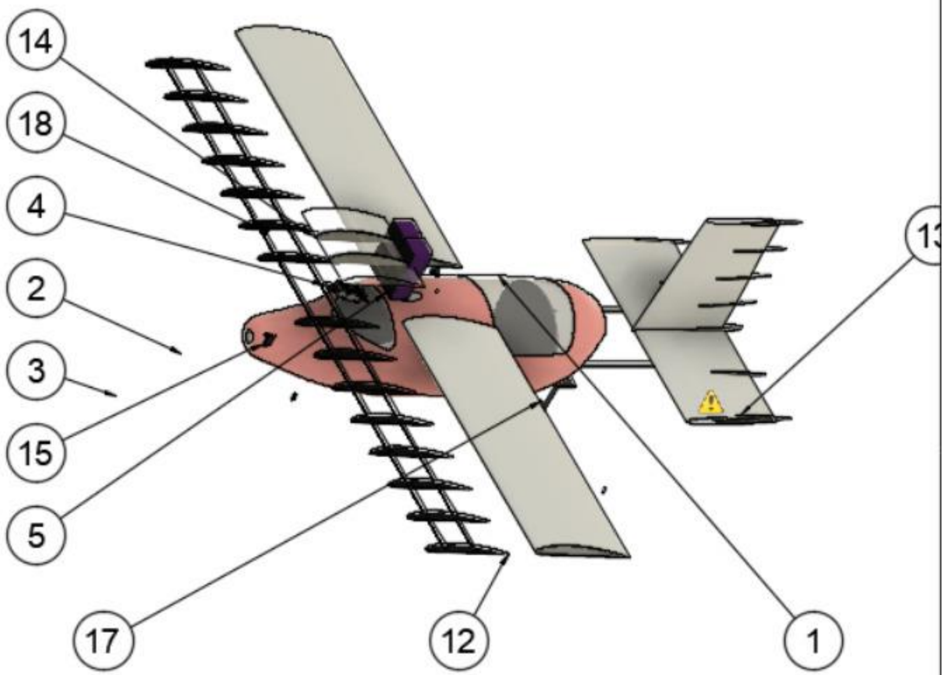
Table 25: Flight tested mission performance

5.7 Drawing Package

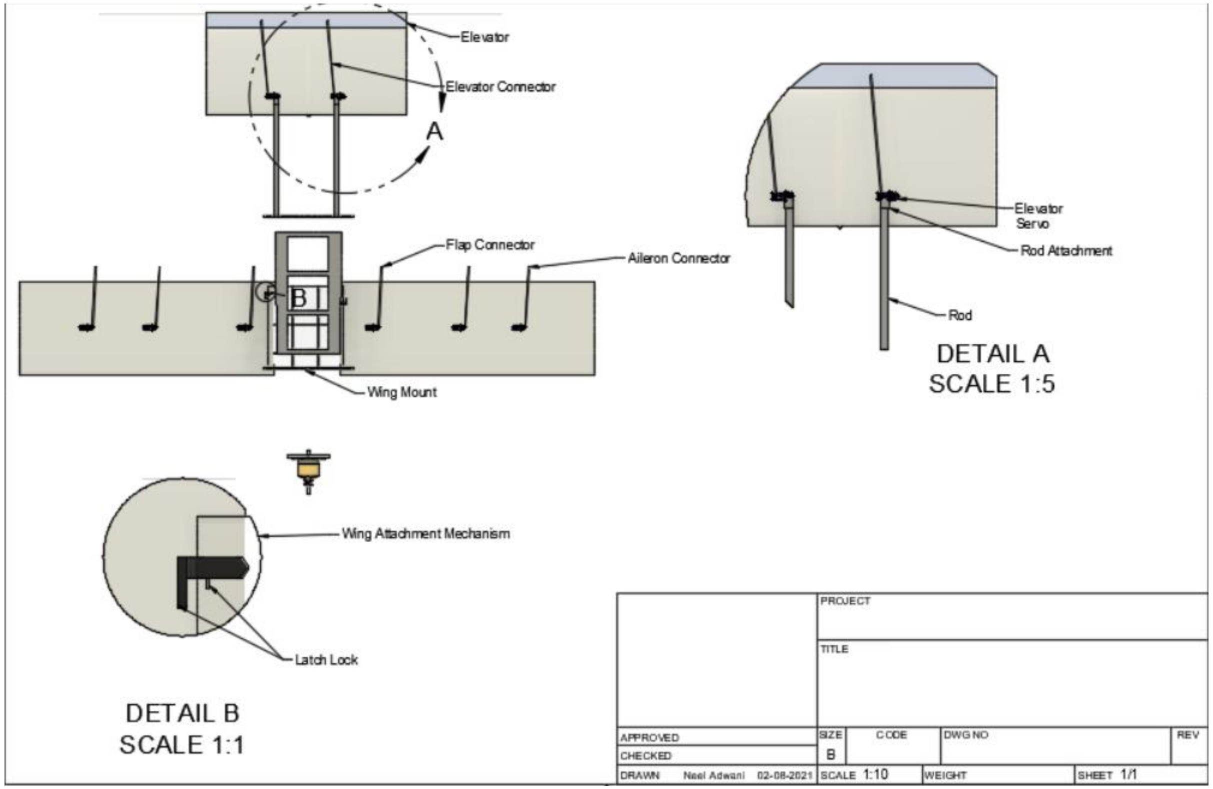
The following drawing package includes a detailed 3-view drawing of the aircraft, an expanded view of the aircraft assembly, the sub-systems of the aircraft, and payload configuration. The drawing package was made using Fusion 360 [13]


531
267.83
450
20
120
90
1261.84
58
249.39
676
676
226.9
1531
309.15
381.01
458.77
513.05
531
Scale 1:10
190
878.8
663.17
318.43
195.76
397.8
95
1035.68
PROJECT
TITLE
APPROVED
CHECKED
DRAWN Neel Adwani 02-08-2021
SIZE B
CODE
DWG NO
REV
SCALE 1:20
WEIGHT
SHEET 1/4

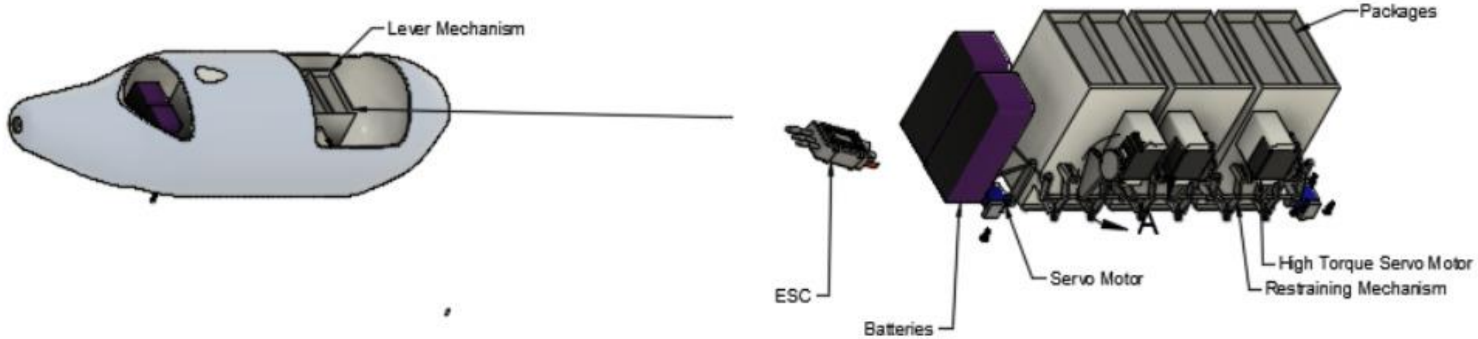
PARTS LIST		
ITEM	PART NUMBER	DESCRIPTION
1	FUSELAGE	CARBON FIBER FUSELAGE WITH 2 HATCHES AND A BAY DOOR
2	MOTOR	E FLITE POWER 60B 470 KV
3	PROPELLER	15 INCH PROPELLER
4	ESC	120 AMP LV ELECTRONIC SPEED CONTROLLER
5	BATTERY	4500 MAH 6S 2P LITHIUM POLYMER BATTERY
12	WING	3D PRINTED PLA RIBS 0.11 INCHES IN WIDTH, WITH A CARBON FIBRE SPAR HAVING A DIAMETER OF 0.39 INCHES
13	TAIL	CONVENTIONAL TAIL WITH 10 RIBS, COVERED WITH COROPLAST SHEET ATTACHED TO THE FUSELAGE THROUGH TWO CARBON RODS
14	WING MOUNT	3D PRINTED WEDGE KEPT AT AN ANGLE OF 4DEG, WITH DETACHABLE WINGS
15	LATCH LOCK	3D PRINTED WITH ABS, 2 ON EACH SIDE, LOCKS THE MOUNT TO THE FUSELAGE
17	TAIL DRAGGER REAR	FLAT CARBON FIBER STRUCTURE WITH RUBBER WHEELS
18	HEXAGONAL M8 X 20	SCREW FOR ATTACHMENT

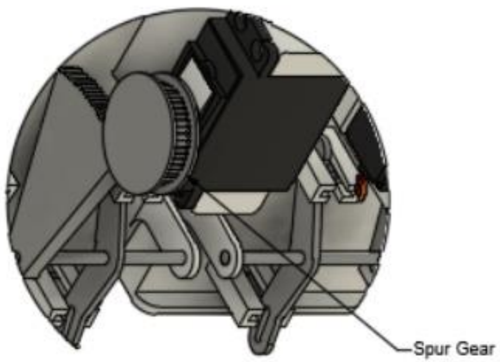


	PROJECT				
	TITLE				
APPROVED	SIZE	CODE	DWG NO		REV
CHECKED	B				
DRAWN Neel Adwani 02-08-2021	SCALE 1:11		WEIGHT	SHEET 1/1	



Elevator
Elevator Connector
A
Flap Connector
Aileron Connector
B
Wing Mount
Elevator Servo
Rod Attachment
Rod
DETAIL A
SCALE 1:5
Wing Attachment Mechanism
Latch Lock
DETAIL B
SCALE 1:1
PROJECT
TITLE
APPROVED
CHECKED
DRAWN Neel Adwani 02-08-2021
SIZE B
CODE
DWG NO
REV
SCALE 1:10
WEIGHT
SHEET 1/1





DETAIL A
SCALE 1:1

	PROJECT				
	TITLE				
APPROVED	SIZE	CODE	DWG NO		REV
CHECKED	B				
DRAWN Neel Adwani 02-08-2021	SCALE 1:10		WEIGHT	SHEET 1/1	

6.0 MANUFACTURING PLAN

To keep things simple and manageable a proper milestone chart with planned deadlines was devised by the team. Different manufacturing processes were investigated for each component of the plane and are discussed in the subsections below.

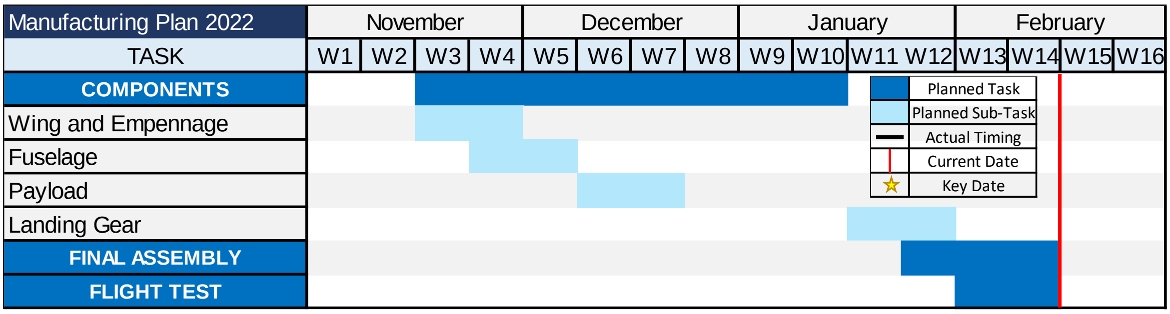


Table 26: Manufacturing plan

6.1 MANUFACTURING PROCESSES INVESTIGATED

The team kept into consideration the following factors during the manufacturing process:

Strength: The toughness and stability of the aircraft are pivotal, and the requirements are achieved by iterative techniques.

Cost: The team kept in mind the limited resources and therefore worked within the budget. However, the team contributed to higher performance components for the betterment of the aircraft.

Ease of manufacturing: The team opted for simple and quick methods to produce an acceptable quality of products. These methods of less time consumption were chosen to meet crucial deadlines.

Weight: The structural weight of the aircraft was kept to a minimum to increase payload capacity. Weight factors into the flight performance since the plane must overcome its weight through the force of lift.

Ease of Repair: Since the aircraft damages during test flight, reparability must be quick and efficient.

Experience: The teams experience plays a crucial role as it avoided unnecessary mistakes and speed up the selection process.

Factors	Importance
Cost	2
Ease of Manufacturing	3
Experience	2
Ease of Repair	3
Strength	5
Weight	5

Table 27: Manufacturiing Concept Weighing

Based on figures of merit analysis the team concluded and chose different materials for different parts of the plane.

FOM	Value	3D Printing	Carbon Fiber	Coroplast
		Investigated Methods		
Cost	2	2	1	4
Ease of Manufacturing	3	5	2	3
Experience	2	3	2	5
Ease of Repair	3	2	3	4
Strength	5	2	5	3
Weight	5	4	4	2
TOTAL		61	66	64

Table 28: Manufacturing material selection FOM

6.2 Processes Selected

6.2.1 3D Printing

6.2.1 3D PRINTINGThis process is used to generate complex and strenuous components which are time consuming. It helped minimizing the weight of the aircraft and was budget saving. Several components such as ribs, bulkhead, tail mount etc. were 3-D printed. Traditional methods are simply too complex to produce these components.

6.2.2 Carbon Fiber

Carbon fiber has a high strength to weight ratio therefore, it is light weight as well as durable. The team decided to utilize carbon fiber for the manufacturing of fuselage, landing gear, spars and tail booms. Since it is strong, lightweight and has high bending stress, it benefitted in increasing the amount of payload without compromising structural integrity.

6.2.3 Corrugated Plastic Sheets

The team has experience in building prototypes with coroplast composites therefore, it increased efficiency of the team and mistakes were avoided. Corrugated plastic sheets were utilized in the structure of empennage and wing.

6.3 Aircraft Manufacturing

6.3.1 Fuselage

The fuselage was manufactured using carbon fiber. 3D printed molds were prepared in order to achieve the desired shape of the fuselage. A thin layer of wax is applied on the mold in order to create a non-stick surface on the mold once the wax layer is hardened a single layer of carbon weave cloth is applied on the mold then a mixture of epoxy-resin is applied with the help of roller. Bulkheads are placed at the front and rear end of the fuselage for maintaining the structural integrity. The fuselage has a hatch in front for placing the propulsion setup and one hatch in rear end for placing the supply packages for mission 3 besides this the fuselage also has bay door in the bottom center for efficient deployment of supply packages.

The rear end of the fuselage consists of two carbon fiber booms in order attain low weight. These booms are held with the help of holders placed inside the fuselage. The rods are placed in such a way that it does not create hinderance for the cargo boxes and the mechanism.

6.3.2 WING

This year the team decided to make use of detachable wings for the ease of portability and manufacturing. The wing is divided into 3 sections which are left wing, right wing and hatch.

The hatch of dimensions 8.6'' x 7.87'' is placed on the top of the fuselage which is also manufactured using carbon fiber. In order to attain better lift performance an angle of 4° was given to the wing this was achieved by 3d printing a wedge of desired angle and placing it under the hatch. The hatch consists of two ribs of thickness 0.11 inch and 4 holes of diameter 0.39 inch for the spars to pass through. For the locking mechanism the team settled upon the idea of manufacturing a triangular latch which is shown in the figure below.

Figure 45: Lock Mechanism CAD

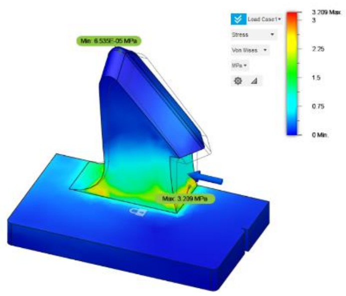


Figure 469: von mises on lock mechanism

4 sections of locking mechanism will be placed on hatch that is two on left side and two on right side. The triangular latch will be 3D printed using ABS plastic which is able to withstand high impact loads.

The wings consist of two carbon fiber spars with outer diameter of 0.39 inch and inner diameter of 0.31 inch passing through seventeen 3D printed ribs of chord length 8.6'' and thickness of 0.11 inch. The ribs are made up of Clark Y airfoil and are equally spaced through a span of 5 feet. Both the part of wings contains triangular latch for locking into the hatch securely. The wing is manufactured using coroplast sheet due to its lightweight property which reduces the structural weight of the plane. The control surfaces were also manufactured using coroplast sheets which were controlled by servo motors and 3d printed control horns. The servo motors are glued to wing in such a way that it does not create interference with the ribs.

6.3.3 BULKHEAD AND REINFORCED RIBS

The team used 3D printed bulkheads for reinforcing the fuselage. The ribs for the empennage and wing were also manufactured using 3D printing technique.

6.3.4 EMPENNAGE

For this year test bed stability was of prime concern thus the team decided to use conventional tail due to its comparatively high stability. The empennage consists of carbon fiber spar of outer diameter 0.31 inches and inner diameter of 0.23 inch. The horizontal stabilizer consists of two holders for holding the booms coming through the fuselage. The empennage is made up of coroplast sheets as it seemed to be ideal in both manufacturing and structure sections.

6.3.5 Landing Gear

The team used carbon fiber for manufacturing the landing gear so that the landing gear can sustain high impact loads while maintaining low weight. The front part of landing gear is placed slightly ahead of the wing and the rear part of landing gear is placed near the tail to avoid tip over condition. The landing gear has a thickness of about 0.25 inch. In order to minimize the wear and tear of the landing gear during crash landing the team attached the landing gear to the fuselage using aluminum plates and nylon screws.

6.3.6 Motor Mount

Motor mount was incorporated in the fuselage by drilling the holes in front section of the fuselage to attach the motor. In order to reduce the vibrations caused by the motor the team decided to install rubber pads.

6.3.7 Bay Door Mechanism

Bay door is situated at the bottom center of the fuselage for the deployment of the supply packages. The team decided to use cupboard door like mechanism for opening the bay doors. Four servo motors with push rods are used, each attached to the corner of the bay door. The two servo motors on the right side will open the right-side bay door and vice versa for left side. Keeping in mind the availability of channels the four servo motors will be operated simultaneously with only one channel thus enhancing simplicity and reducing the risk of misinput.

The packages are made up of 3d printed PLA for easy and quick prototyping. Each package has a parachute as speed retarding mechanism for minimizing the ground impact. The parachute was manufactured from nylon fabric as it delivered more drag and is durable.

7.0 Testing Plan

Testing is necessary to ensure the proper functionality of the aircraft and its components. It helped minimize risks and compare the theoretical calculations and predictions with the results obtained in real-world conditions. The data obtained from the testing played an important role in improving the performance of the competition aircraft.

7.1 Test Schedule

Several flight tests were conducted to validate the design of Louvre and allowed the team to anticipate mission scores. Post-flight comments of the pilot granted the team to predict aircraft stability, pilot workload, and flight performance at different settings. A testing schedule was generated mirroring the aircraft design milestones to examine the validity of the propulsion, structure, and subsystem designs and is represented below:

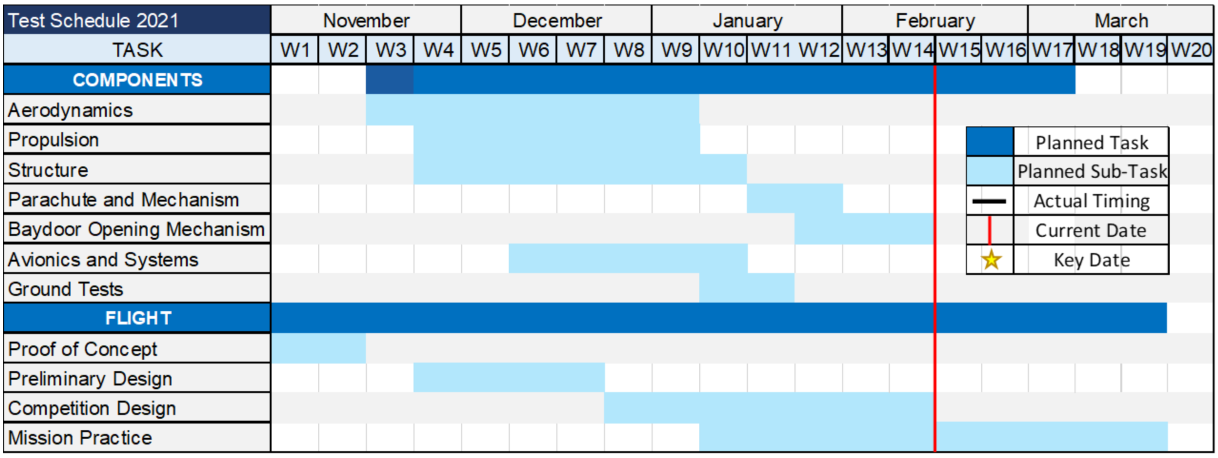


Figure 47: Gantt chart for test schedule

7.2 DETAILED TEST OBJECTIVES

The tests conducted by the team along with their objectives are mentioned below:

7.2.1 WINGTIP LOADING TEST

This test is conducted to ensure that the wing can carry the weight of the aircraft during a flight mission without deforming. To test the wing strength the team applied load at the center of the wing planform till it started to deform significantly. The main objective is to ensure that the wing spar can bear this amount of load during the actual conditions of the competition.

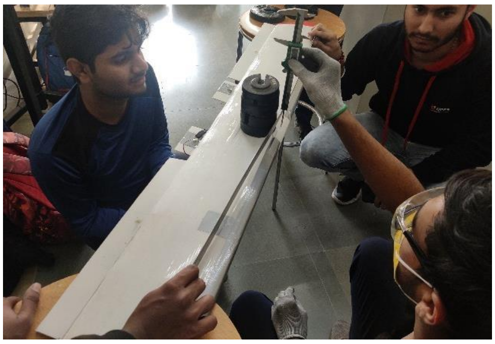


Figure 48: Wing Tip Loading Test

7.2.2 SUBSYSTEM TESTING

1. **Bay Door Mechanism**

   The bay door mechanism was tested to ensure that the supply package does not get stuck when it is being dropped out of the aircraft during the M3. This test also ensured that the parachute attached to a supply package does not get ruptured when it falls out of the bay door.

2. **Dropping Mechanism**

   The mechanism designed to drop the supply package for M3 was rigorously tested and improved. The main objective to conduct the test was to ensure that the package is dropped successfully without any significant constraints that can hamper its movement.

3. **Landing Gear Test**

   For a safe landing in all the missions, it was crucial to check that the landing gear can handle the load of the aircraft and have a safe and stable touch-down. The landing gear was subjected to a weight equal to the aircraft weight in the M2 configuration. Its strength was checked to ensure that it can sustain harsh landings if encountered.

4. **Parachute Drop Test**

Since the supply packages should not encounter significant damage when they land on the ground, the team installed parachutes on it such that it lands safely. To test a parachute, a simulator was manufactured using available materials according to the design from the preliminary analysis. It was dropped in a vertical orientation from a height of about 120 ft and the following results were obtained:

Figure 49: Parachute Drop Test

Test No.	Objective	Results	Time Taken	Improvements/ Comments
1	Parachute String Length	String got tangled	Failed	String size reduced
2	Package dropped horizontally	Package landed successfully	7s	Vertical orientation drop to be tested
3	Package dropped vertically	Safe landing	9s	Vertical landing better

Table 29: Parachute testing

7.2.3 Wind Tunnel Testing

The wind tunnel facility at the university was used to conduct a wind tunnel test on a scaled-down prototype of the final aircraft. The aim to conduct the test was to validate the lift and drag characteristics of the aircraft and to understand the effect on the flight of the aircraft when the bay door opens for dropping supply packages in M3.

7.2.4 Avionics Testing

1. **Static Thrust Bench Test**

This test is used to validate the propulsion system of the aircraft. The finalized motor was tested with different propellers to determine the maximum static thrust of the motor. This was then verified with the theoretical maximum thrust. The results helped the team to finalize the propulsion package.

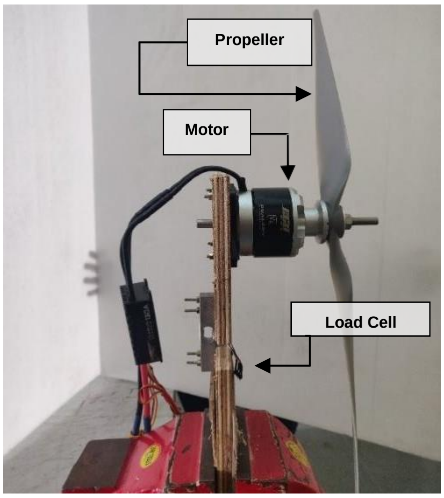


Figure 50: Static Thrust Bench Test

2. **Fuse Test**

According to the DBF rules, a fuse was attached to the LiPo battery. This was done to prevent the overflow of current through the subsystem, which in turn could damage it.

7.3 FLIGHT TEST

Various prototypes were developed keeping in mind each prototype objective. The tests were essential to verify the results of the analysis and propulsion obtained through the respective software. It also helped the team to test out the mechanisms in real flight conditions. The prototype and objectives have been summarized in the table below.

AIRCRAFT	OBJECTIVE
Prototype 0	Sizing and Stability Validation
Prototype 1	Structural and Propulsion Package Validation
Prototype 2	Stability and Mechanism Testing
Prototype 3	Dropping Mechanism Testing
Prototype 4	Mission 2 and 3 Testing

Table 30: Test prototype objective

Date	Aircraft	Motor	Propeller	Payload	Objective	Results	Improvements/ Comments
05 Jan'22	Prototype 2	E flite power 60b 470 kv	15 x 10	M2	Structural and Propulsion package validation	Structural and Propulsion package validated	N/A
08 Jan'22	Prototype 2		15 x 7	M3	Flight control without dropping payload	Plane was controllable but scope for improvement	Payload position changed
11 Jan'22	Prototype 3		15 x 7	M3	Flight control with open baydoor	Plane was controllable with acceptable movement	More testing to be done on the Baydoor Mechanism
14 Jan'22	Prototype 3		15 x 7	M3	Flight control with open baydoor	Plane was quite difficult to control	More study to be done on payload placement

Table 31: Sample flight checklist

All the flight tests conducted helped the team to improve the design of all the elements involved and helped to facilitate the manufacturing of an aircraft capable of completing all missions successfully.

7.4 PRE-FLIGHT CHECKLIST

PRE-FLIGHT CHECKLIST							
General System Checks							
Structural Integrity		CG Location				Date	Time
		X		Y			
Control Surfaces							
Ailerons		Flaps		Rudder		Elevator	
Deflection	Stable	Deflection	Stable	Deflection	Stable	Deflection	Stable
Propulsion and Avionics							
Primary Battery		Secondary Battery		Motor Check		Signal Check	
Battery Normal		Propeller Secure		Connections Secure		Motor Mount Secure	
Payload							
Battery Pack		Connection Secure		Receiver Pack		Payload Secure	
Sub-systems							
Mechanism Secure		Servos Check		Bay Door Check		Fuse	
Approvals							
Testing Head		Team Lead			Pilot		

Table 32: Pre flight checklist

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