Indian Institute of Technology Bombay, India

Team UMIC

Unmesh Mashruwala Innovation Cell

Team no: 27

UAS Challenge 2023

Design and Development Specification

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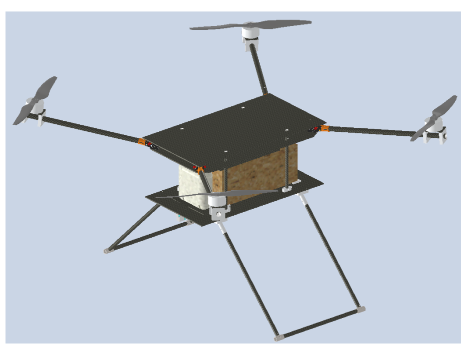

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Contents

1 DESIGN SUMMARY:

The problem statement issued by ImechE pertains to the construction of an autonomous aerial vehicle that is capable of executing humanitarian aid missions. Several constraints were imposed upon the physical dimensions of the apparatus, and the maximum allowable takeoff weight was set at 10kg. Given our team's extensive expertise and prior experience with autonomous quadcopters, we elected to pursue a custom-designed quadcopter - which has been wholly conceptualized and developed by our team, UMIC - for the purpose of completing tasks such as identifying the optimal pathway to traverse a maximum waypoint, maximizing the overall score, navigating through these waypoints, delivering a payload to a specific location, all while conserving energy to the fullest extent possible.

Throughout the design process, we have remained committed to achieving a maximum aircraft-to-mass ratio, as well as ensuring superior power efficiency. As such, our quadcopter has been meticulously engineered to meet all of these constraints, while simultaneously guaranteeing the utmost safety, flight readiness, and manufacturability. The following pages contains details of our design, our control algorithms, the onboard circuitry deployed and how we are attempting to ensure this all round perfection with all the constraints being satisfied.

Our solution to the mission is a custom X-shaped quadcopter. Projected weight of the vehicle excluding the payload is 6.7kg with a frame size of 1.23m. Each brushless DC motor-propeller pair is capable of producing a maximum thrust of 6680gm. The mission is powered by one 6S lithium polymer battery with a capacity of 22000mAh. The payload is packaged in the centre and occupies most of the volume of the core. It is delivered using a servo-driven hatch mechanism. The mission is designed to fly at an maximum speed of 17m/s while cruising.

2 PROJECT MANAGEMENT

ID	Task	Deadline	Remarks	New timeline - Start date	New timeline - End Date
Design and optimization phase					
A1	Vehicle selection and sizing	20-Dec-22	Quadcopter selected over a hybrid aircraft, sizing completed	✓	✓
A2	Auxiliary design and CAD models	10-Jan-23	Landing gears, drop mechanism designed	✓	✓
A3	Design analysis and optimization	18-Jan-23	Design reviewed ; structural analysis done after making the necessary changes	✓	✓
A4	Cost and manufacturability analysis	26-Jan-23	Designed reviewed after manufacturability constraints posed by vendor	✓	✓
Software testing					
B1	Integrated, timed mission in simulation	20-Jan-23	Waypoint navigation algorithm tested with power consumption model to validate endurance run	✓	✓
Hardware testing phase (on prototype)					
C1	Testing navigation algorithms on a prototype	28-Feb-23	Frame, electronics assembled, onsite testing ongoing	✓	✓
C2	Independent testing of parachute prototype	15-Feb-23	Awaiting arrival of parachute	10-Mar-23	26-Mar-23
C3	Testing of wind estimation algorithm on prototype	15-Feb-23	Estimating the wind-speed using ArduPilot parameters	✓	✓
C4	Testing of flight termination system	20-Feb-23	Validating geo-fencing and RC failsafe	✓	✓
Manufacturing and assembly phase					
D1	Getting vendor quotations and engaging vendors	20-Mar23	Vendors will be contacted post Manufacturability analysis	On time	On time

D2	Ordering, assembling electronics array	27-Mar-23	Vendor comparison based on cost and time	On time	On time
D3	Completion of manufacturing and assembly	10-Apr-23	After precise part manufacturing is completed	On time	On time
D4	Flight readiness	15-Apr-23	Scrutiny of the joints and mechanism	On time	On time
D5	Cooling and waterproofing	20-Apr-23	Incorporating minor changes for weather proofing	On time	On time
Hardware testing phase					
E1	Testing parachute deployment	28-April-23	Checking correctness of drop point estimation	On time	On time
E2	Manual flight testing	25-April-23	Ensuring flight stability with and without payload	On time	On time
E3	Testing precise payload delivery system	05-May-23	Testing reliability of servo mechanism	On time	On time
E4	Autonomous flight testing	10-May-23	Mitigating missed waypoints	On time	On time
E5	Integrated and timed mission test	30-May-23	Validating overall mission	On time	On time

ID	Risks and potential issues	Mitigation
D4	Unprecedented tolerances and vibrations	Post manufacturing refining of parts for appropriate fitting
D4	Surface asymmetries	Flight testing to locate irregularities, fine tuning and creating offsets in software
D5	Exposure to moisture	Reiterative designing of waterproofing layers
D5	Overheating of electrical components	Running copper tubes in electronics deck, keeping one end exposed to air
E1	Failure of drop mechanism	Solve by studying problem, fixing mechanism or code, adding failsafe to avoid in-flight instability
E2	Instability of drone in takeoff	Extensive controller tuning
E3	Unstable flight and inability to perform desired banking	Improve drone tuning and alter mission parameters
E4	Strong wind gusts during drop	Measure the wind speed and its direction, and realign the drone to hit the target accurately

3 REQUIREMENT REVIEW

ID	Requirement	Response
3.1.1 Airframe configuration and Mass	All up mass <= 10kg.	The requirement has been satisfied and the detailed weight budget has been provided in the design description.
3.1.2 Propulsion Systems	Electric motors only	Our quadrotor only uses electrical motors for propulsion, the specifications for which have been documented in the design description
3.1.3 Electrical Power Systems	Externally removable link incorporated. Battery needs to be easily accessible without tools.	A slot is provided in the Hub of the multi-rotor to accommodate easy placement and removal of battery
3.1.5 Aid package carriage and Delivery	Delivery system incorporates speed retarding device. Aid Package deployed from a minimum height of 50 ft AGL. The Aid Package is not reinforced or protectively wrapped. Aid Package has team number clearly marked.	The Aid Package will be released along with the parachute satisfying the required constraints on the drop height. The drop mechanism design has been elaborated upon in detail in the design specification
3.1.6 Autonomy	Designed for fully autonomous operation.	The mission will be executed completely through scripts written for waypoint navigation, payload drop and the endurance run. These will not require any manual input or control other than the provision of the waypoint coordinates
3.1.7 Radio equipment	Compliant with EU directives and licensed for use in the UK. Reliable operating range of 1 km. Control of the UA and the FTS is 'Spread Spectrum' compliant on the 2.4 GHz band	RfD900 Telemetry radio and frysky x2 receiver would be used for radio communication between GS and UA and radio transmitter and UA respectively. Both devices are compliant with EU directives and have a reliable operating range spanning over to few kilometers
3.1.8 Flight termination system	Acceptable FTS design which transforms the UA into a low energy state should the data links between the GCS and UA be lost, and lands the UA as soon as possible after initiation	The failsafe parameters corresponding to ground station failsafe have been adjusted via ground station so as so that vehicle would land if datalink is lost for more than 10 sec
3.1.9 Navigation System	The UA shall automatically navigate around the course. Nav System shall be capable of storing the co-ordinates of the Geo-fence flying area. Nav system shall automatically activate the FTS when the Geo-fence is breached.	The scripts have been designed to detect when the drone breaches the geofence, and incorporate a functionality to activate the flight termination system.

3.1.10 Location Finder	UA shall make an audible and visual alert to improve ease of UA location if it lands outside the designated landing area.	The UAV would have attached fluorescent strips making it visible in this event. In addition, a python script will run to extract the geofence param and in the event a geofence breach is detected, we will trigger a relay via GPIO output of PixHawk which would eventually cause the buzzer to beep
3.1.11 Ground Control Station	GCS shall display and record UA situational awareness information.	We will be using the Q Ground Control Station and Mission Planner to monitor vehicle status and position.
3.1.12 Storage and Handling	Storage and handling box shall not exceed external dimensions 1500 mm x 600 mm x 600 mm	The measures taken to allow the UA to be packed into a storage container of the given specifications have been highlighted under the design description. These include foldable arms and a compact hub that leaves space for the remaining removable components.
3.1.13 GPS Tracker	The design of the UA shall ensure that the Tracker can be easily fitted and removed, as well as being under a thin covering to prevent degradation of signal.	The GPS device will be installed on the top of the frame, at a safe distance from other electronic components, and covered with a layer of thin plastic to prevent water damage and minimize interference.
3.1.14 Limits on the use of COTS items	Airframe and control systems shall be designed from scratch. A Bill of Materials and costs is provided as part of the design submission. Teams shall demonstrate that the manufacture of the airframe and integration of the UAS has been predominantly undertaken by the students themselves.	The detailed cost budget for COTS items as well as an estimate of the manufacturing costs have been provided in the last section of this report.

4 DESIGN DESCRIPTION

4.1 Functional Description:

Description and reason for selection of :

4.1.1 Airframe:

- Core frame-
  - We had two designs - one with aluminum pipes welded to form one single part and a carbon fiber sandwich assembly
  - The first design had its benefits in ease of assembly. It required a minimal amount of fasteners. The whole core of the drone being a single part, we only had to attach the arms. But this structure included welding numerous pipes. A small human error in one weld would have led to a large deviation at the end of the truss pattern.
  - The total frame weight, estimated from the CAD models, of both structures was very close.
  - Hence, we chose the second design taking into account the ease of manufacturing and cheaper manufacturing cost.
  - Cutouts were then made on the carbon fiber plates considering the areas with low stresses to reduce the weight further.
  - In the current design the payload, battery, and all the other electronics rest in the middle of this sandwich structure.
  - We have tried to bring the payload as close as possible to the center of gravity of the entire drone. So that, upon releasing the payload, the controller would maintain that same altitude quickly and easily. The change in the centre of gravity will be around 1.6 cm.
- Arms-
  - The arms are connected to the core structure by foldable connectors. This would help us in packing the entire drone as one inside a box and we won't waste time assembling the arms to the body.
  - Our central design is a rectangle, from the corners of which the 4 arms extend outwards. The drone resembles an X-configuration i.e. the 4 motor shafts are placed at the corners of a square. To achieve that, the foldable connectors are attached to the body at a very specific angle.
- Landing Legs-
  - The drone will land on legs spread outward from the core body. Two parallel tubes extend downward, which are connected by a horizontal tube on the ground.
  - The inclined tubes will be filled with a rod made of silicone or sorbothane for damping purposes.
  - The bottom connector has a ridge that allows the fastener to slide through it and push the silicone rod upwards upon landing which helps achieve a soft landing.

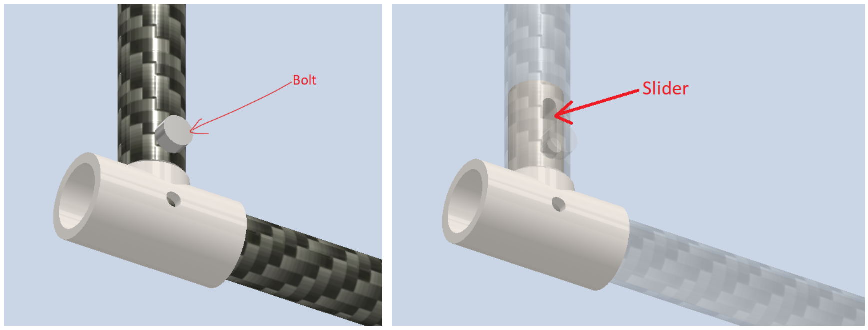


Figure 1: Sliding fastener for soft landing

4.1.2 Propulsion:

- The motor, propeller, and battery combination was chosen based upon the following calculations
- The battery is chosen such that upon completing the mission 30% of it remains unused.
- The propulsion unit provides a maximum thrust of 25kg with a 22-inch propeller having a pitch of 6.6inch
- According to the calculations this set can help the drone achieve a max velocity of 28m/s in straight flight. Considering a loss in the speed at the turns at each way-point, the mission is estimated to be completed within 11min.

  For the calculation of Quadrotor's weight analysis[1] and Quadrotor's Speed and Drag analysis [2], the excel sheets can be referred as mentioned in Annexure.

4.1.3 Cargo Delivery:

- A robust and reliable drop mechanism has been designed for delivering the payload.
- The payload falls on opening the two doors, enabled by actuating a single servo motor
- The servo motor rotates a gear, which is further connected to two similar gears to achieve opposite rotation
- Two small arms originate from the two gears, holding the two door plates from opening.
- A signal from the onboard computer opens these gates by rotating the servo. The moment the payload falls the two arms retract to their original position closing the doors along with that.

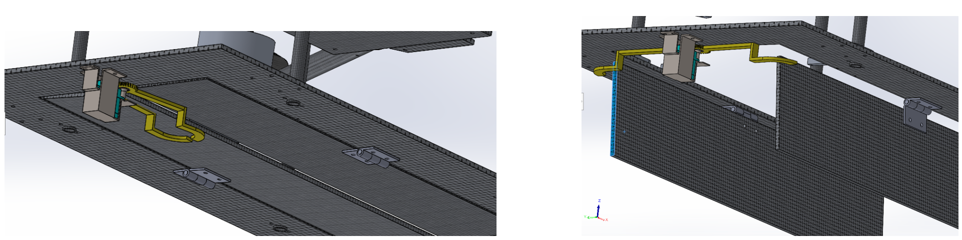


Figure 2: Illustration of the drop mechanism

4.2 Structural Calculations to support sizing:

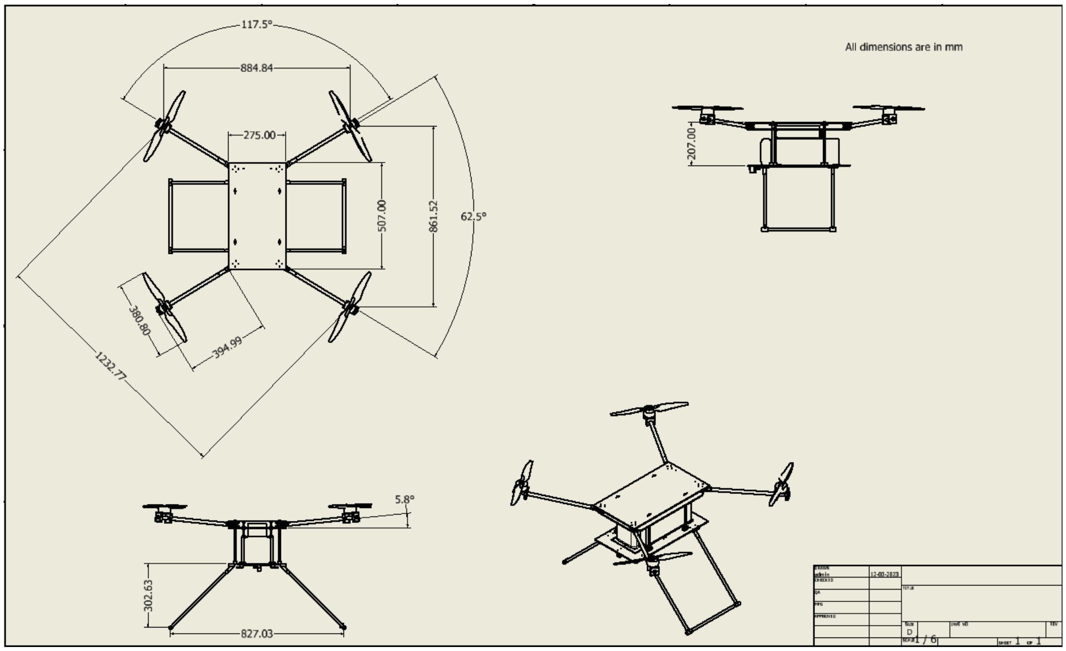


Figure 3: Drawing file for the quadcopter

4.2.1 Core frame

- The dimensions of the core plates majorly depended on the payload dimensions. We used a 3mm thick carbon sheet for the core plates. The deformation analysis showed that the plate was in the safe zone.

The following analysis is done in ANSYS WORKBENCH 2023:

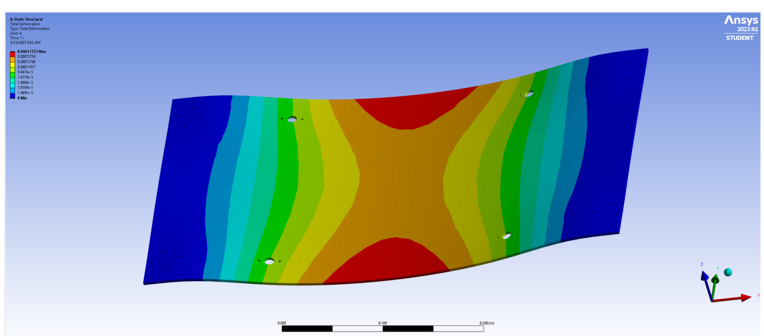


Figure 4: Analysis on deformation of the core plates

4.2.2 Arms

- To keep the wakes of the adjacent rotating propellers from interfering with one another, the minimum distance between the propeller tips is suggested to be one-third of the diameter.

- Combining this constraint with the requirement of X-configuration, we get the length of the arms, which is 395 mm.
- The arms are cylindrical with an outer diameter of 1.6cm and a thickness of 2mm. The total deformation observed under the load of the propeller thrust was 2x10^{-3}mm, which is within the safety limit.

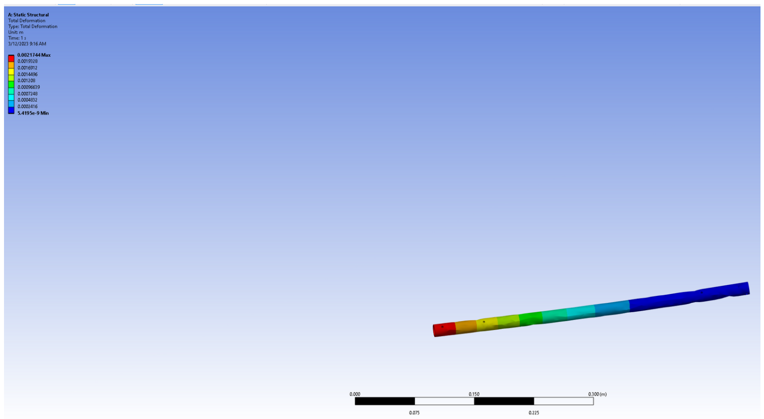


Figure 5: Ansys Arm Simulation

4.2.3 Landing Gears

- The height and the base width of the landing gears were determined by detailed calculations to prevent toppling upon landing.

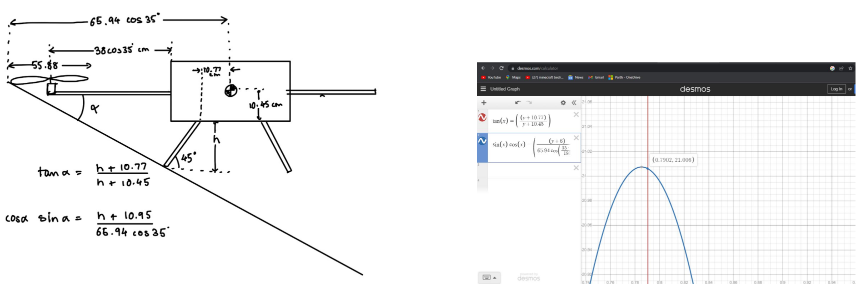


Figure 6: Landing Gear Calculations

4.3 Stability and Control calculations

The stability of the drone in flight is a function of the height difference between the thrust vectors and the center of gravity (CoG) of the drone. A positive difference (CoG above thrust vectors) will lead to a higher likeliness of the drone overturning whereas a negative difference will lead to a "lazy" response of the drone to control inputs.
Our drone is configured such that the CoG of the drone is 17.6cm below the propellers while carrying the payload and 16cm below after the payload is dropped. This is a specific trade-off between the high maneuverability required for navigating the waypoint course and the high stability of flight for a large drone like ours.

4.4 Flight Controls:

The dynamical model of a square quadcopter can be expressed using six degrees of freedom: three linear velocities (u,v,w) and three angular velocities (p,q,r). The state vector is defined as:

$$x = [u, v, w, \phi, \theta, \psi, p, q, r]^{\intercal}$$

where: u, v, w:linear velocities along the body-fixed x, y, and z axes, respectively.
ϕ, θ, ψ: Euler angles that describe the orientation of the quadcopter with respect to a fixed reference frame. ϕ is the roll angle (rotation around the x-axis), θ is the pitch angle (rotation around the y-axis), and ϕ is the yaw angle (rotation around the z-axis)
p, q, r: angular velocities around the body-fixed x, y, and z axes, respectively. The equations of motion for the quadcopter can be written as follows:

4.4.1 Linear equations of motion:

$$m\dot{u} = -gsin(\theta) + T(cos(\phi) * sin(\theta)cos(\psi) + sin(\phi)sin(\psi))$$
$$m\dot{v} = gsin(\phi)cos(\theta) + T(cos(\phi) * sin(\theta)sin(\psi) - sin(\phi)cos(\psi))$$
$$m\dot{w} = gcos(\phi)cos(\theta) + Tcos(\phi) * cos(\theta) - D$$

where:
m: mass of the quadcopter
g: acceleration due to gravity
T: total thrust produced by the four rotors
D: drag force due to air resistance

4.4.2 Angular equations of motion:

$$I_{xx}\dot{p} = L + (I_{yy} - I_{zz})qr$$
$$I_{yy}\dot{q} = M + (I_{zz} - I_{xx})pr$$
$$I_{zz}\dot{r} = N + (I_{xx} - I_{yy})pq$$

where:
I_{xx}, I_{yy}, I_{zz}: moments of inertia of the quadcopter around the body-fixed x, y, and z axes, respectively.
L, M, N : torques produced along the axes.
The torques produced along the axes can be expressed as:

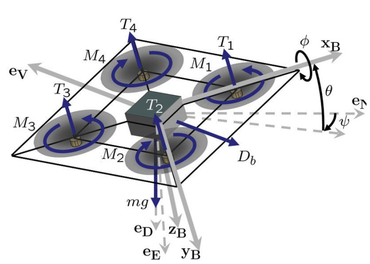


Figure 7: Quadcopter Dynamics

$$L = k * (T_2 - T_4);\ M = k * (T_3 - T_1);\ N = b * (T_1 - T_2 + T_3 - T_4)$$

where:
k: proportionality constant between the thrust given each rotor and its angular velocity.
b: proportionality constant between the torque of each rotor and its angular velocity.
T_1, T_2, T_3, T_4: thrust produced by each rotor.
This dynamical model is a simplified representation of a quadcopter and does not account for various real-world effects such as aerodynamic drag, non-uniform thrust production, and sensor noise. However, it can be used as a starting point for developing more sophisticated models and control strategies for quadcopters.

We will be using the Pixhawk flight controller to execute our waypoint navigation algorithm. Pixhawk is a popular open-source flight controller designed for autonomous unmanned aerial vehicles (UAVs), which was made to run the open-source PX4 software stack. Pixhawk flight controller offers advanced features such as GPS navigation, altitude hold, waypoint navigation, and automatic takeoff and landing. The controller is connected to sensors such as GPS, accelerometers, gyros, and barometers, which provide information about the drone's orientation, altitude, and speed. Depending on the control inputs we provide to it, such as acceleration or position setpoints, the controller calculates the required power outputs of the drone's motors. The PX4 firmware uses a PID controller, the gains for which can be tuned depending on our drone's weight, size, and aerodynamics.

4.5 Navigation and Mission Control:

Currently, our team is working on modeling our proposed design in X-Plane and simulating the whole mission autonomously. We are using **Ardupilot SITL** [3] coupled with **Q-Ground Control** [4] to communicate with the quadcopter. We have used "Waypoint Navigation" as our current autonomous flight plan. By using **MAVlink** [5] extendable communication protocol, we plan to execute our desired flight plan which will be in the form of a python script.

The Waypoint Navigation strategy works in three steps -

1. Reaching the Payload Release Point while navigating around the waypoints
    - The quadcopter will navigate around the given set of waypoints. We use the **GLOBAL_RELATIVE** frame for this purpose as we can give the set of waypoints in the global frame as provided to us in text format
    - After navigating around each waypoint, the quadcopter reaches the Payload Drop Point which will be estimated by taking the wind and drop conditions into account such that the Payload reaches the Payload Release Point within an accuracy of 10 meters as required in the Problem Statement.
    - A list of waypoint messages is pushed to the mission plan, with a certain set of parameters defined for each message that includes the location of the waypoint and the action we want to perform at it.
    - Each action is denoted by a different number that can be passed through the message as a **command**. A few examples of actions that the UA can perform at a particular waypoint include take-off, land, navigating to the waypoint, or loitering.
    - The MAVROS [6] **waypoint message** allows us to pass the **co-ordinates** of the required waypoint in a frame of reference decided by us. We can also define an **acceptance radius**, which represents the minimum distance that the UAV needs to be from the waypoint before it is considered to have reached it.

- Other additional parameters allow us to decide the altitude, speed and heading that the UAV should use to approach the waypoint.
- These parameters can also be edited directly from the **QGC** (Q Ground Control) software.

2. Custom Control for Static/Dynamic Drop

   - After completing the previous task, the quadcopter will drop the payload depending upon its state (dynamically or statically) by taking environmental conditions into account. The mechanical design of the drone ensures smooth drop conditions without causing much disturbance.
   - For this drop, a custom controller is used which has been written in python. The controller tracks and completes the mission starting from reaching the drop location, dropping the payload, and then going to the next task.

3. Endurance Run using Dynamic Decision Making

   - The last task is executed by designing a smart decision-making strategy which takes into account factors such as -
     - Battery Life Remaining
     - Time of Mission Remaining
   - By optimization of the above two parameters, the drone decides the number of waypoints it can go around to maximize the score in this round.
   - At every waypoint past a certain time threshold, our algorithm iteratively calculates the amount of time it would take for our UA to visit- another waypoint and then return to the launch position. If this time is less than the amount of time left for the mission to end, the UA must return to the launch position immediately.
   - If, however, the amount of time left allows for another waypoint to be visited, the UA continues its mission and repeats this decision-making process at the next point.
   - Since the algorithm may require the endurance task to be cut short due to time or battery constraints, we can simply end the waypoint mission by changing flight modes from **”AUTO”** to **”GUIDED”** .

The flight control system has robust built-in safety and failsafe mechanisms in place. We have programmed a **Geo-Fence Failsafe** in regulation with the competition rules which will ensure that the drone executes Loiter mode in case it escapes the GeoFence and then it will land in the same place. Finally, failsafe mechanisms in case of RC communication and Data-link loss are currently being worked on and will be integrated into the control system architecture.
The whole stack for navigation and mission control including waypoint navigation, dynamic decision making protocols, and FTS algorithms have been tested in simulation to confirm accuracy and proficiency. This flight stack will soon be tested on a smaller prototype quadcopter. After the flight controls are successfully tested on the prototype, the algorithms will be run on the final manufactured quadcopter to test mission.
For simulation video, click here.

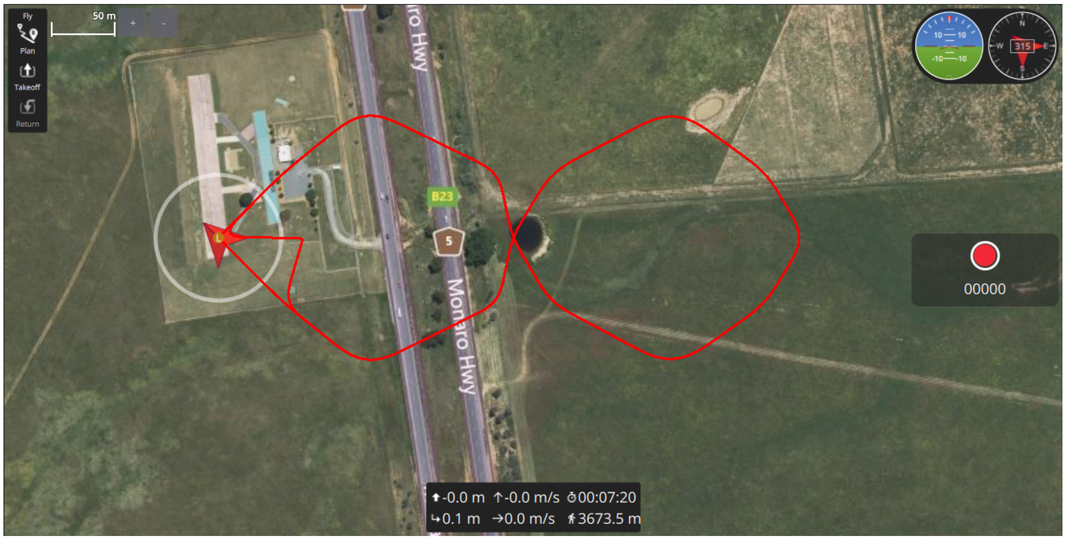
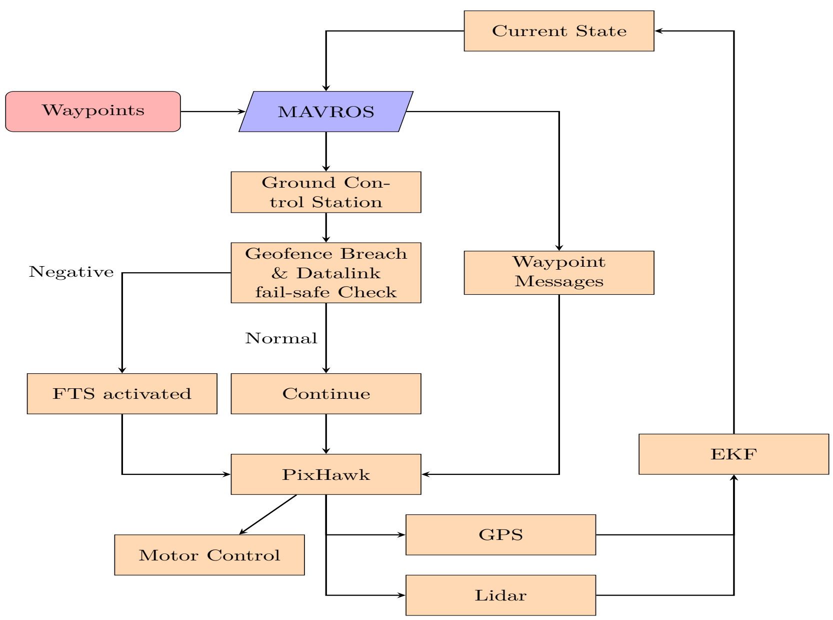


Figure 8: Mission Simulation

4.5.1 System Architecture and Data-Flow



4.6 Payload Drop:

The Payload drop is an integral part of the mission. To ensure a smooth and accurate drop, we came up with a basic model which predicts the final landing position given the initial drop coordinates, the initial velocities, wind conditions, and other dynamic parameters like viscosity. For this, the system is modeled using the Navier Stokes equations, the initial and final parameters are stored and numerical methods are used to generate a trajectory that predicts landing points with imperceptible errors.

As a first step, we will perform the task of payload drop from a stationary mount from a given height in given wind conditions and use linear approximations to predict the landing coordinates. Upon this, we will analyze the error on account of this linear approximation. If it is acceptable, we shall continue with the linear approximation for the mission. If not, we will move on to more sophisticated modeling as proposed

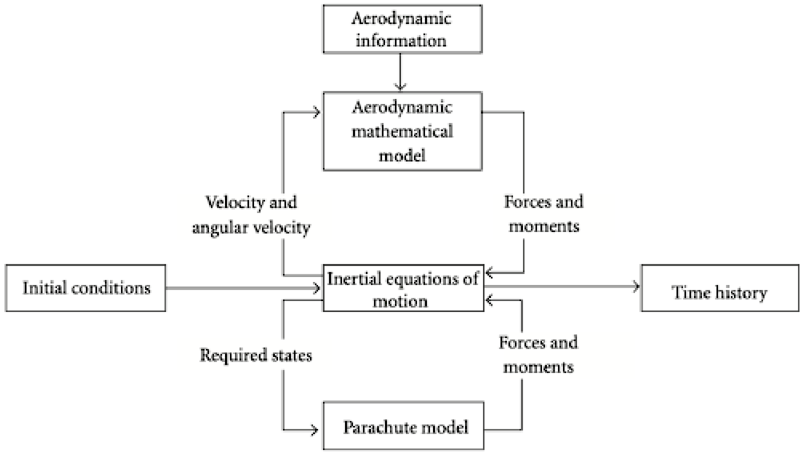


Figure 9: Payload Drop Architecture

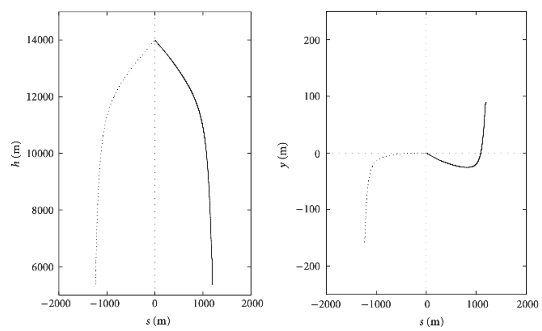


Figure 10: The simulation of the trajectory profile for the parachute-payload system

Now, linear estimation is good but not as accurate as we would desire. So we will simulate this by using Python and use appropriate wind conditions and drag coefficients for plotting :

The program[7] predicts the final landing positions given initial coordinates and wind speeds along with drag coefficients. We can rework this into an optimisation problem and do the following: We input final position targets and hence get the initial conditions

4.6.1 Flight Termination System-

The PixHawk supports upto 14 channels for PWM output. Thus the servo is actuated directly from the AUX output of the pixhawk which is externally provided a constant 5V supply
Automatic Operations-
A Flight Termination System (FTS) is incorporated as part of the design to land the UAV in any event that triggers it.

- **Activating Triggers** - In the event UA breaches geofence, in case of loss of datalink (communication from ground station exceeds 10s) or RC signal timeout (loss of signal) exceeds a threshold of 5 s. In any of the above cases, UAV will enter into the flight termination system.
- **After FTS is triggered** - parameters are adjusted in the ground station to incorporate the landing of the UAV as soon as the flight termination system is initiated, the UAV

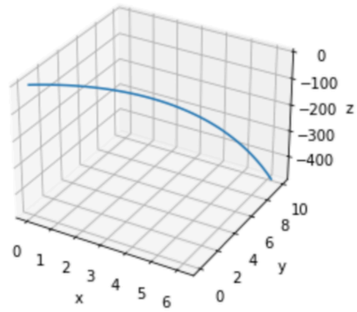


Figure 11: Final Landing Coordinates : x = 6.18, y = 9.90, z = -480.50

will remain in 'land' mode once it enters flight termination system by satisfying any of the above cases even if the failure criteria is no longer valid (eg, regaining communication between the ground station and autopilot in 15 seconds).

- **Working of FTS**- The following parameters were tweaked using GUI provided by Q Ground Station to ensure UA lands whenever FTS is triggered:
  - RC_FS_TIMEOUT : set to 5s so that the UA enters FTS in case the RC communication is lost for more than 5s
  - FS_GCS_TIMEOUT : set to 10s so that the UA enters FTS in case the RC communication is lost for more 10s
  - FS_GCS_ENABLED : set to land the drone as soon as GCS failsafe triggered
  - FENCE_ACTION : set to always land the drone as soon as Geo-Fence is breached (enabled by FENCE_ENABLED parameter of autopilot)

4.7 Sensors:

Name	**Use**	**Specifications**
Holybro pixhawk cube	To be used as a flight controller to control the Quad-rotor as well as its systems.Pixhawk cube/ was selected owing to on-board processing power, low-level control, programmable firmware, failsafe and integrated sensors for state estimation	32bit ARM® STM32H753 Cortex®-M7, ICM 20649 integrated accelerometer/gyro, MS5611 barometer on base board, 14x PWM servo outputs (8 from IO, 6 from FMU,S.Bus servo output,32 bit STM32F103 failsafe co-processor
TF 1-d lidar	To be used for correction in altitude estimation done by the flight controller to improve accuracy	Accuracy – ±6cm, Frame Rate is 10 – 1000Hz, Communication Interface – UART,Supply Voltage – 5V

HEX HERE3 GPS	Used for global pose estimation i.e to tell pixhawk its position	Receiver - u-blox high precision GNSS modules (M8P-2), ICM20948 imu sensor, position accuracy - 3D FIX: 2.5 m / RTK: 0.025 m, protocol -DroneCAN 1Mbit/s
Telemetry (RFD 900x Radio Modem Bundle)	Allows for two-way communication with the ground station, the given telemetry pair was selected considering the greater range and maximum compatibility with Pixhawk	New Processor, ARM 32-bit core, Air data rate: 500kbit/s, frequency Range: 902 - 928 MHz, Long range >40km, Temp. Range: -40 to +85 deg
FrySky X8R Receiver	Is the perfect receiver for the FrSky Taranis, with its built-in XJT Module or any of the D8 systems to take advantage of the new digital Smart Port sensors. Additionally, it supports 8 standard servo outputs	16 channels, operating range - >=1.5km, 4- 10V operating voltage

5 SAFETY

5.1 Firmware Safety Requirements:

- The Pixhawk flight controller provides several safety features for drones.
- These features include a motor arming safety mechanism during take-off and landing.
- The flight controller also has RTL, FailSafe, and GeoFence modes that respond to signal loss or motor failure scenarios.
- RTL mode can be programmed to return the drone to its launch location, while FailSafe mode ensures the drone's safety in emergencies.
- The GeoFence mode transmits the drone's current location to the operator or ground control station.
- A beeping alarm as soon as the drone leaves the geofence to alert everyone around the area
- To enhance drone safety, it is recommended to implement mechanical and electronic safety features such as propeller guards, fuses, emergency cut-off switches, and a return-to-home feature

5.2 Operational Safety Requirements:

- Pre-flight checks on all components, including structural integrity and stability tests, are crucial for safe drone operation.
- Personal protective equipment such as insulating gloves and helmets can also contribute to ensuring the safety of the drone's operators and other personnel around the drone.
- Motor arming safety, RTL, FailSafe, and GeoFence modes can be customized to meet the specific requirements of different drone applications.

5.3 Design Safety Requirements:

- Structural Integrity- performing finite element analysis for the structure under static loads and analyzing vibrational frequencies of arms
- Stability, control, flight, and navigation performance - testing on simulations, followed by prototype testing

5.4 Safety and Risks:

Our drone testing complies with the IIT Drone Flying and DGCA regulations as follows:

- Geo-fencing activation for flying within the IIT Bombay Gymkhana Grounds only
- Altitude cap of 20 meters
- Flying time is restricted to 10 AM - 3 PM
- The Nodal officer and DGCA will be intimated 48 hours before every testing on the IIT Drone Flying Portal
- All the Standard Operating Procedures mentioned in the SOP for Drone Flying Ecosystem for IIT Bombay will be duly followed

The drone complies with UK Drone Regulations:

- We will obtain a UK CAA Operator ID

- Our aircraft will comply with the UK CAA A3 Open Category Rules
- Dropping of payload - under Article 16 authorization
- Insurance - not required; our flying weight is about 10 kg only

FTS will be implemented as part of a python script that will terminate the control algorithm program and automate the landing of the UA. FTS shall be incorporated as described in the UAS rulebook.
GeoFence will be set up at the beginning of our run in the competition using GCS, as mentioned in the concept paper.

Sr. No.	**Example**	**Severity**	**Probability**	**Mitigation Measure**
1	Injury to the people if near the Aircraft	Catastrophic	Improbable	Wear helmet, insulating gloves and operate from at least 30m away
2	Overheating of UAS	Marginal	Occasional	Cooling systems and heat sinks on components
3	Bird hits	Catastrophic	Improbable	Cannot manage
4	Disintegration of Structure	Marginal	Remote	FEA analysis and tests done prior to flying
5	Failure of Autonomy	Marginal	Remote	Optional Manual Mode Available
6	Battery set to fire	Minor	Improbable	Autopilot monitors their temperature and triggers respective fail-safes
7	Injuries due to propellers	Major	Improbable	Operate at least 50m away from all personnel and objects
8	UAS does not follow waypoints (random path followed)	Marginal	Occasional	Activate the FTS manually
9	Propellers damaged	Marginal	Frequent	Replace propellers
10	Short Circuit caused due to water inside the circuit	Minor	Improbable	Water-proofing is done so that no water enters
11	Drifting of UAS in certain direction	Marginal	Occasional	Control Algorithms take wind into consideration
12	Battery low charge in Mid-Flight	Marginal	Occasional	Lands automatically if Battery voltage drops below certain value
13	UAS goes outside Geofence	Marginal	Remote	Activates the FTS Automatically
14	Injuries while assembling the UAS	Minor	Remote	Keep a first aid box ready in case of minor Injuries

6 MANUFACTURING AND SUPPORT

6.1 Manufacturing processes:

- **CNC Cutting and Milling** for aluminum parts of 6000 series grade, such as connectors for arms and landing gears.
- **Gas Tungsten Arc Welding** of those aluminum parts, that will be undergoing high stress. Since our parts dimensions are in mm to some cm, we need high-precision welding.
- **Filament winding** is used to make carbon fiber tubes of different internal and external diameters based on our requirements.
- **Prepreg Lamination** technique will be used to manufacture carbon-fiber sheets. It is a precise and repeatable process because the quantity of resin is controlled.

Safety: All the manufacturing processes will be outsourced to skilled vendors with years of experience. The reason being is we don't have such equipment to carry out the processes, and we have minimal expertise in this domain.

6.2 Environmental concerns:

- Besides high energy consumption and noise pollution, CNC machining has no major environmental concerns. In fact, precision reduces the amount of material waste generated during the machining process, leading to increased material efficiency and reduced environmental impact.
- The disposal of carbon fiber tubes can be a major issue since it's not easily bio-degraded, so we have decided to reuse them in our future projects.
- We will be using an innovative method to replace thermocols for packaging and shipping, involving dried straws that are also very cheap and readily available.

6.3 Fixtures/Equipments:

- The parts are designed in such a way, that they complement each other and easily fit in the tightly constrained space of the packaging box.
- Straw-based natural packaging system will be incorporated to design molds for fragile items like propellers and electronic items.
- In the folded configuration the drone will rest on the motor mounts inside the box. Cushioned platforms will be designed to prevent damage to these mounts.
- For presentation purpose we will be attaching propeller guards to ensure safety of the judges and fellow competitors.
- As mentioned above, the arms are already attached to the core frame which can be folded while shipping.

7 QUALIFICATION TEST PLAN

ID	Objective	Method	Success criteria	Test results and date
QTP1	Maximum take-off weight of 10 kg	Weighing the UA without the payload and adjusting the amount of sand to be added to the aid package to keep the total weight within a given threshold	Total weight<=10 kg	Awaiting manufacture
QTP2	Preliminary manual quadcopter testing	Initial tuning of firmware parameters, verifying the stability of landing gears in manual take-off and landing, manual roll and pitch maneuvers to observe vibration tolerances of the build	Stable manual take-off and landing, stable response to manual roll-pitch commands	Awaiting manufacture
QTP3	Manual flight tests with payload	Banking maneuvers with payload attached, stationary manual payload drop to observe recoil	Smooth flight with minimum vibrations, post-drop stability	Awaiting manufacture
QTP4	Autonomous flight test 1	Autonomous take-off, landing tests,position-altitude hold mode trigger tests.	Stable position and altitude hold at the given co-ordinates	Awaiting manufacture
QTP4	Autonomous flight test 2	Waypoint navigation tests	All waypoints in the circuit are circumvented at a decided radius with minimal corner-cutting	Currently testing on a prototype, awaiting manufacture for testing on the mission UA
QTP5	Autonomous flight test 3	Testing trajectory tracking for basic circuits with the payload attached, performing static payload drop in position hold mode	Accurate payload drop within a 10 m radius of the payload release point	Awaiting manufacture
QTP6	Autonomous flight test 4	Autonomous mission resemblance, with the endurance, run included by using a set of dummy waypoint inputs	Accurate payload drop within a 10 m radius of drop location, maximum waypoints visited, the mission concluded in <= 15 minutes	Awaiting manufacture

8 COST BREAKDOWN

Mechanical	**Cost(INR)**
Carbon fibre tubes	25000
Lead screw mechanism	8000
Linear bearings	800
Cooling copper tubes	4000
Aluminum Connectors	28000
Total	**∼81,000 INR**

Electronics	**Cost(INR)**
Motors(x4)	24000
Battery 6S	15000
ESCs(x4)	9000
Pixhawk	13499
Onboard Computer	7000
Transmitter & Receiver	15278
Propellers 22”(x4)	8000
PDB	349
Servos(x2)	500
Geared Motors(x2)	768
Connectors XT60, XT90	720
Buck-Boost Converter	329
Telemetry	10729
1-D Lidar	3149
GPS	11349
Total	**93,541 INR**

9 References:

- Giorgio Guglieri, "Parachute-Payload System Flight Dynamics and Trajectory Simulation", International Journal of Aerospace Engineering 2012.
- Quan Quan (2017). Introduction to Multicopter Design and Control. Springer.
- Özgür Dündar, Mesut Bilici, Tarık Ünler, "Design and performance analyses of a fixed-wing battery VTOL UAV", Engineering Science and Technology International Journal, 2020

10 Annexure:

- [1] Quadrotor's weight Analysis
- [2] Quadrotor's Speed and Drag analysis
- [3] Ardupilot Documentation
- [4] Q-Ground Control Documentation
- [5] MAVlink Documentation
- [6] MAVROS Documentation
- [7] Payload Drop Simulations