A
AUTONOMOUS DRONE DEVELOPMENT CHALLENGE 2023

DESIGN REPORT

ADDC2023033–

HAWK TEAM

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DATE (29th May 2023)

STATEMENT OF COMPLIANCE _

SAEISS AUTONOMOUS DRONE DEVELOPMENT CHALLENGE 2023

Certification of Qualification

Team Name	HAWK
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Statement of Compliance

As Faculty Advisor:

I certify that the registered team members are enrolled in collegiate courses.

I certify that this team has designed, constructed and/or modified the autonomous drone with the intention to use it in the **SAEISS Autonomous Drone Development Challenge 2023** competition, without direct assistance from professional engineers, R/C model experts or pilots, or related professionals.

I certify that this year’s Design Report has original content written by members of this year’s team.

I certify that all reused contents have been properly referenced and is in compliance with the University’s plagiarism and reuse policies.

Prasad Pokkunuri

Signature of Faculty Advisor Date **(29 May 2023)**

Soumen Sinha

Signature of Team Captain Date**(29 May 2023)**

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1. APPENDIX

- L - Length
- B- Breadth
- W - Width
- Kp is the proportional gain,
- - Ki is the integral gain,
- - Kd is the derivative gain,
- - S is the Laplace variable.
- - RPM - Revolutions per minute
- - TWR - Thrust Weight Ratio
- - Cg- Centre of Gravity

2. INTRODUCTION

Drone research and RPAS (Remotely Piloted Aircraft Systems) have emerged as dynamic and rapidly growing fields, revolutionizing various industries and opening up a world of possibilities. These unmanned aerial vehicles (UAVs) have captured the imagination of researchers, engineers, and innovators worldwide, propelling them to explore the vast potential of this technology.

RPAS have shrunk and become more popular because of recent advancement in processing , battery and sensor device technologies. Drone research encompasses a broad range of disciplines, including aerospace engineering, robotics, computer science, and more. It involves the study and development of drones with enhanced capabilities, improved flight dynamics, advanced sensors, and intelligent control systems. Researchers delve into areas such as drone autonomy, swarming, machine learning, and computer vision to enhance their performance and unlock new applications.

3. OBJECTIVE

The main purpose of the competitions is to develop a drone for carrying a medical parcel and autonomously deliver packages on designated areas and upon recognising humans where this operation will be executed as a part of search and rescue event. The entire mission should be autonomous starting from take off , payload dropping and then returning to home base. The mission has to be completed within 10 mins and should be completely autonomous.

4. MISSION PARAMETERS

- Take off point will be determined randomly by the organizers.
- 5 minutes will be given for mission preparation time. The timer will open upon receiving a signal from the human at the remote location.
- 10 minutes will be given to complete the mission.
- The payload dropping spot will be decided by the committee.
- During the mission the pilot won't control the aerial vehicle.

5. RESEARCH

The research was conducted prior to commencing the design process, aiming to examine existing design solutions and relevant research documents. The purpose was to establish a robust theoretical foundation that would underpin the design efforts.

This competition being our first drone-related competition, we looked to projects done by our seniors to gain some expertise in drone design. Our major concern is to meet the weight requirements. Hence, for every component we chose, weight vs power trade-offs were looked at. Our aim is to meet the requirements of the competition with minimum weight and high accuracy.

Our first step was to select an appropriate motor. The maximum weight of the drone as stipulated by the rule book is 2 kg. So, our aim was to find a motor that provides a thrust of at least 500 gms at 50% throttle, while giving us a good thrust-to-weight ratio. We also kept in mind the voltage rating for the motor, so we can go with a battery with lesser cells, which will reduce weight further. After selecting the motor, we chose the propellers and ESCs accordingly. We then chose the battery capacity by calculating the required capacity that gives us a minimum flight time of 10 minutes, at 50% throttle.

6. COMPONENTS

1. MOTORS

We have selected the SunnySky V2806 Brushless Motor for several reasons. Firstly, its compatibility with a 4S battery is a crucial factor. Moreover, the motor's performance characteristics are well-suited for a quadcopter configuration. With a thrust output of approximately 600g at 50% throttle, each motor provides ample power. Considering the use of four motors, the combined thrust reaches 2.4kg, effectively meeting the weight requirement. Furthermore, the thrust-to-weight ratio, a crucial indicator of maneuverability, surpasses the nominal value of 1. At 50% throttle, the quadcopter achieves a thrust-to-weight ratio of 1.26 (assuming the weight of our drone to be 1.9 kg), ensuring the necessary performance during flight. These factors establish the SunnySky V2806 Brushless Motor as an ideal choice for our drone project.

2. ESCs

The choice of an Electronic Speed Controller (ESC) plays a vital role in the performance and safety of a UAV. Regardless of the UAV's design quality, a defective or inadequate ESC can lead to severe consequences. To ensure the optimal functioning of our motors, which require a current ranging from 1A to 12.8A for generating the required thrust, we have selected the ReadytoSky 30A 2-4S ESC. This ESC has a continuous current handling capacity of 30A and can sustain a burst current of 35A. With a weight of 23 grams, it strikes a balance between functionality and minimizing overall weight. By choosing this ESC, we aim to ensure reliable and efficient power management for our drone, reducing the risk of any potential failures or performance issues during flight.

3. PROPELLERS

The chosen motor is compatible with the EOLO CN12*5 Propeller. Having a length of 12 inches and a weight of about 2 grams, it meets our drone’s size constraints of 14.23 inches, in addition to being lightweight. The propellers are 12 inches in diameter, 1/6th of it is 2 inches. This implies that we should at least have a clearance of 2 inches between the propellers, which we are able to satisfy with the chosen propellers.

4. FLIGHT CONTROLLERS

In our setup, the flight controller, serving as the central processing unit of the control systems, is the Pixhawk 2.4.8. This advanced flight controller incorporates a comprehensive range of sensors and features. It is equipped with three triple-axis gyroscopes, accelerometers, and magnetometers, as well as barometers. With 128 KB RAM and a 32-bit STM32F427 CortexM4 core with FPU, the flight controller delivers robust processing power and efficient data handling capabilities. Additionally, it includes a 32-bit failsafe co-processor for enhanced safety measures. It offers a variety of connectivity options and interfaces to support diverse peripherals. This versatility enables seamless integration with various components and accessories, expanding the potential functionalities of the UAV system.

Key specifications of the Pixhawk 2.4.8 flight controller include a 32-bit STM32F427 CortexM4 core with an FPU processor, an L3GD20H 16-bit gyro, and an input voltage range of 3.3V-6.6V. With a weight of 40 grams, it strikes a balance between functionality and minimizing overall weight, contributing to the agility and performance of the UAV.

The Pixhawk 2.4.8 flight controller's comprehensive sensor suite, powerful processing capabilities, extensive connectivity options, backup system, and optimal weight make it an ideal choice for our setup, ensuring precise and reliable control for our UAV in the competition.

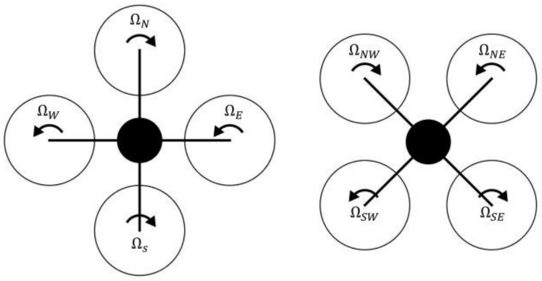
5. BATTERY

We decided to go with a LiPo (Lithium Polymer) battery. These are highly preferred for drone applications due to their exceptional characteristics. One key advantage is their high energy density, allowing them to store a significant amount of energy in a compact and lightweight form. This is crucial for drones as it ensures a favorable power-to-weight ratio, enabling enhanced flight performance and maneuverability. Additionally, LiPo batteries can provide high discharge rates, delivering bursts of power when needed.

Hence we chose a 4S 10000mAh LiPo battery as it strikes a balance between capacity and weight. While it provides a substantial amount of energy, it doesn't add excessive weight to the drone, ensuring optimal flight characteristics and maneuverability. This combination of capacity and weight is crucial for achieving a balance between endurance and agility.

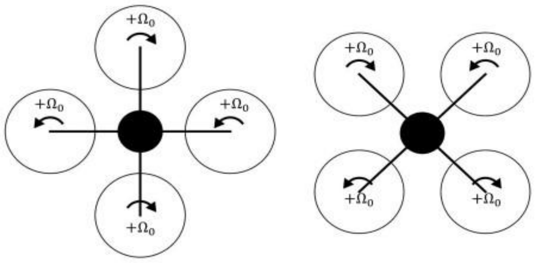
7.OVERALL VEHICLE CONFIGURATION

Configuration of our aerial vehicle is a multi rotor quad copter.



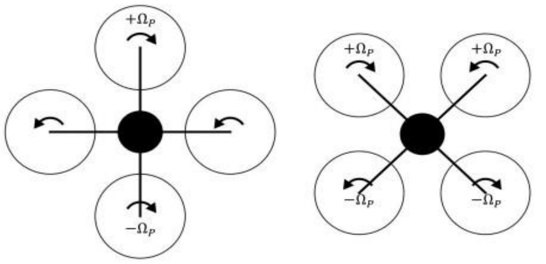
(a) Plus Configuration (b) Cross Configuration

Fig. 1: Quadrotor Flight Configurations



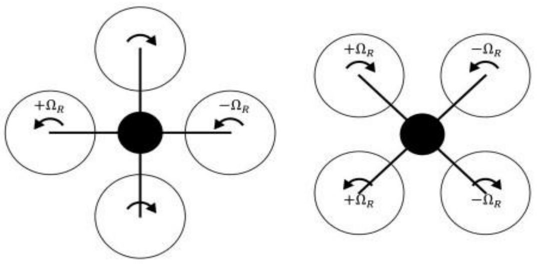
(a) Plus Configuration (b) Cross Configuration

Fig. 2: Collective Control (Ω_0)



(a) Plus Configuration (b) Cross Configuration

Fig. 3: Pitch Control (Ω_P)



(a) Plus Configuration (b) Cross Configuration

Fig. 4: Roll Control (Ω_R)

8. CAD DESIGN

In our cad design we present our aerial vehicle in all the 3 views -

1) Left View
2) Top View
3) Front View

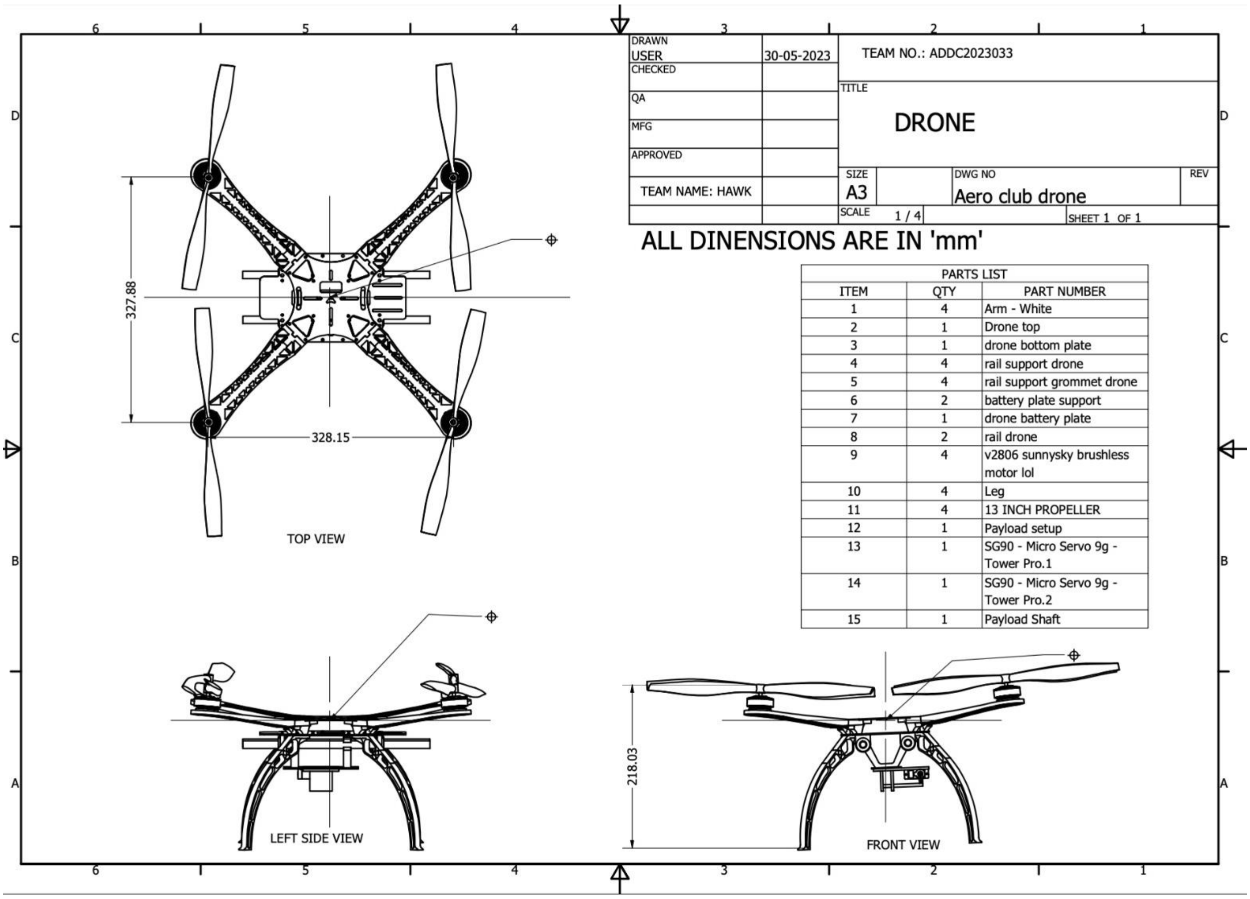


Fig CAD drawing

10. Aircraft Stability and Control

We check the aircraft stability and control of our quadcopter by fine tuning the parameters of PID controller. A PID (Proportional-Integral-Derivative) controller is commonly used in quadcopter drones to stabilize their flight and control their movement. It adjusts the motor speeds based on the difference between desired and actual values, enabling the drone to maintain stability and responsiveness. We will be discussing the transfer function and tuning process for a PID controller in our quadcopter drone.

1) Transfer Function:

The transfer function of a PID controller can be represented as:

$$\boldsymbol{C(s) = Kp + Ki/s + (Kd\,x\,s)}$$

where:

- Kp is the proportional gain,

- Ki is the integral gain,

- Kd is the derivative gain,

- s is the Laplace variable.

2) Tuning Process

Tuning a PID controller involves adjusting the gains (Kp, Ki, and Kd) to achieve the desired response. Here's how we tuned out PID controller to get the optimal parameters.

1. We started with all gains set to zero (Kp = Ki = Kd = 0).

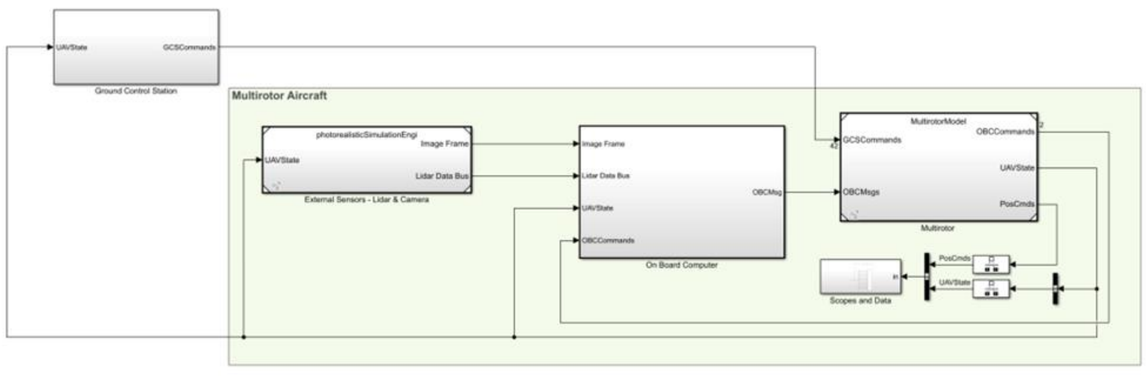
2. Then we increase the proportional gain (Kp) until the system responds quickly but becomes unstable. The drone started oscillating or exhibiting overshoot.

3. Then we increased the derivative gain (Kd) to dampen the oscillations and reduce overshoot.

4. We adjusted the integral gain (Ki) to eliminate steady-state errors, if it was present.

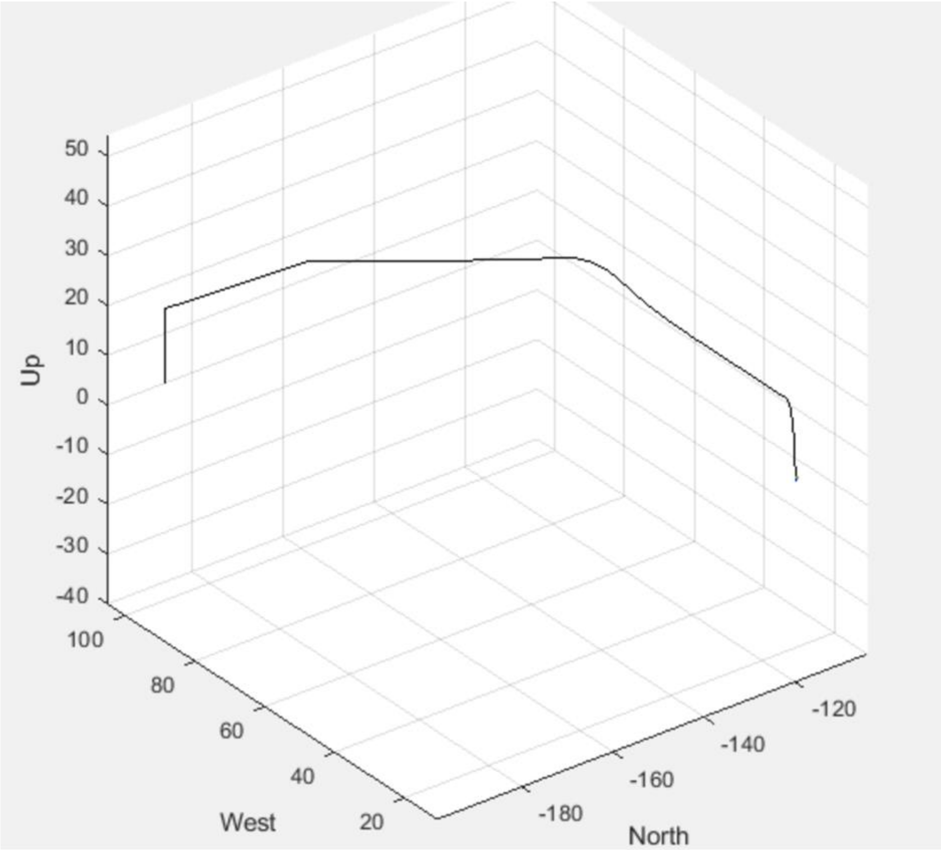
5. Then we repeat the steps 2-4, fine-tuning each gain until the desired response was achieved.

It's important to note that the tuning process can be iterative, and it may require multiple attempts to achieve optimal performance. Additionally, the specific tuning parameters for a quadcopter drone can vary depending on the drone's dynamics, weight distribution, and control system.



UAV package delivery

We set up the model for a four-waypoint mission using a high-fidelity multi-rotor plant model. Using Matlab we modeled out mission, which shows the multi rotor takeoff, fly, and land in a 3-D plot.


Up
West
North
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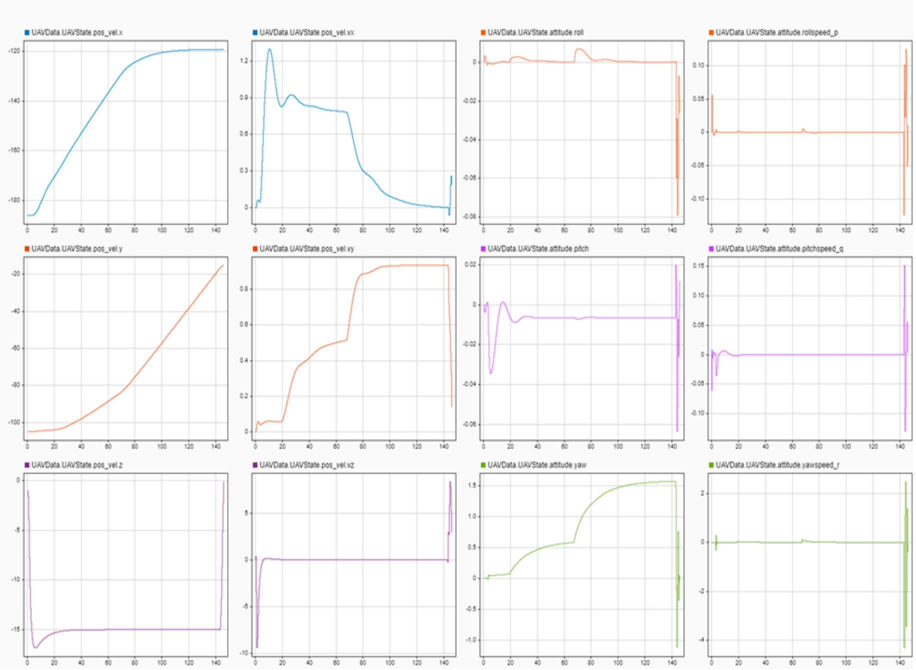
-140
-160
-180


UAVData.UAVState.pos_vel.x
UAVData.UAVState.pos_vel.vx
UAVData.UAVState.attitude.roll
UAVData.UAVState.attitude.rollspeed_p
UAVData.UAVState.pos_vel.y
UAVData.UAVState.pos_vel.vy
UAVData.UAVState.attitude.pitch
UAVData.UAVState.attitude.pitchspeed_q
UAVData.UAVState.pos_vel.z
UAVData.UAVState.pos_vel.vz
UAVData.UAVState.attitude.yaw
UAVData.UAVState.attitude.yawspeed_r

We use a closed loop PID Auto tuner block from Matlab Simulink software to tune controllers used in the attitude and position control of a multi rotor.

We can see that the multi rotor takes almost 150 seconds to complete the four waypoint path with the baseline set of gains. In order to improve this performance, retune the PID Controllers.

The Closed-Loop PID Auto tuner blocks inject perturbation signals to the output of each of the eight existing PID Controllers. The auto tuners then use the feedback signals and the output of the PID Controllers in order to perform the auto tuning process. With the exception of the innermost control loops, pitch and roll rate, the two axes being controlled are decoupled from each other. For example, the x velocity and the y velocity

loops are decoupled from each other. This allows you to tune these two loops simultaneously which reduces the overall time to perform auto tuning. For the pitch rate and roll rate loops, tune the control loops sequentially because they are coupled. This results in the following sequence for tuning the PID Controllers:

1. Pitch Rate
2. Roll Rate
3. Pitch and Roll
4. X and Y Velocity
5. X and Y Position

We now allow our copter to follow the same four waypoint mission but this time it hovers for sometime so that it retunes the parameters.

The Closed-Loop PID Auto tuner blocks are configured with different performance criteria for each control loop. This is done to optimize the system's performance while avoiding instabilities in cascaded control.

For the pitch and roll rate loops, which require the highest bandwidth, the settings are as follows:

- Bandwidth: 50 rad/sec
- Phase margin: 60 degrees
- Perturbation amplitude: 0.001

The pitch and roll loops, on the other hand, have a slightly lower bandwidth:

- Bandwidth: 20 rad/sec
- Phase margin: 60 degrees
- Perturbation amplitude: 0.1

Moving on to the x and y velocity loops, their bandwidth is set even lower:

- Bandwidth: 5 rad/sec
- Phase margin: 60 degrees
- Perturbation amplitude: 0.02

Finally, the x and y position loops have the slowest bandwidth:

- Bandwidth: 1 rad/sec

- Phase margin: 60 degrees
- - Perturbation amplitude: 0.1

To ensure stability, the bandwidth for the pitch and roll rate loops must be less than 60 rad/sec. However, the Closed-Loop PID Auto tuner requires that the product of the bandwidth and the sampling time (Ts) should be less than or equal to 0.3. Considering a sampling time (Ts) of 0.005 seconds, the bandwidth needs to be adjusted to a value lower than 60 rad/sec.

It is important to maintain a phase margin of 60 degrees for all loops as it provides a good balance between performance and damping.

The perturbation amplitudes are carefully chosen to be less than 5% of the maximum expected output of the individual controllers. This ensures stability during tuning. If the perturbation values are too high, the system can become unstable, while too low values may lead to inaccurate estimates of the plant and suboptimal gains.

Therefore, the configuration aims to set the bandwidths as high as possible while respecting stability requirements for each control loop and to select appropriate perturbation amplitudes for accurate tuning without causing instability.

As we can see the multi rotor hovers for a period of time in order to perform auto tuning. After the auto tuning process is complete, around 185 seconds into the simulation, the multi rotor follows the same four-waypoint path as in project first step, but the quadcopter is able to complete the path in a much shorter time due to the tuned gains increasing performance.

During the auto tuning process the gains are updated for the eight controllers:

- Pitch rate — Kp = 0.00425, Ki = 0.01479, Kd = 0.0000045, N = 398
- Roll rate — Kp = 0.003477, Ki = 0.01215, Kd = 0.0000031, N = 398

- Pitch angle — Kp = 19.38
- Roll angle — Kp = 18.95
- X velocity — Kp = 0.5153, Ki = 0.2581
- Y velocity — Kp = 0.5201, Ki = 0.2979
- X position — Kp = 0.9365
- Y position — Kp = 0.9291

11.POWER PLANT SELECTION

Drones typically use electric propulsion systems rather than traditional power plants. The electric propulsion system of a drone consists of electric motors, propellers, and the associated power supply, usually a rechargeable battery. The electric motors convert electrical energy from the battery into mechanical energy to spin the propellers, generating thrust and enabling flight.

When selecting a drone, the focus is on evaluating the overall system and its components rather than specifically selecting a power plant. The key considerations when choosing a drone include:

1. Flight Performance:

2. Payload Capacity:

3. Size and Portability:

4. Reliability and Support

We researched various motors available out there in the market like T-motor MN2806, MN 2205, SunnySky V82806 ,MN 2205 , U8 Lite, F 40 -pro etc. After carefully analyzing each of the motors on all the criteria mentioned above we found that Sunny sky V82806 650 KV fits our mission requirement and is the most suitable motor for the drone.

12 . THRUST CALCULATION

To determine the thrust generated by the quadcopter, we need to consider the motor specifications and the characteristics of the propellers.

1. Motor Thrust:

The maximum thrust provided by a single SunnySky V2806 motor is 1.1 kg (1100 grams). Since we have four motors in a quadcopter configuration, the total maximum thrust generated by all motors is 4 x 1.1 kg = 4.4 kg (4400 grams).

2. Propeller Selection:

Eolo Foldable Carbon Fiber Reinforced Nylon UAV Propellers with dimensions of 12x5 inches are used in this setup.

3. Static Thrust Calculation:

Static thrust is the thrust generated by the propellers when the quadcopter is at rest. It is influenced by the motor and propeller combination.

To calculate the static thrust, we use the following formula:

Thrust (in grams) = RPM x Propeller Diameter^3 x Pitch Speed / 6000

Where:

- RPM: Revolutions per minute (provided by the motor's KV rating)

- Propeller Diameter: 12 inches (converted to centimeters: 30.48 cm),pitch = 5 inches(12.7 cm).

- Pitch Speed: We assume an average pitch speed of 80% of the propeller's tip speed (to account for efficiency losses).

Pitch Speed (in inches per minute) = RPM x Pitch = 6448*5 = 32,240

RPM =6448

Using the above formula, we can calculate the static thrust for each motor.

4.Dynamic thrust calculation:

Dynamic thrust refers to the thrust generated while the quadcopter is in motion. It is influenced by various factors, including the quadcopter's weight, air density, and efficiency losses.

To estimate dynamic thrust, we typically use a thrust-to-weight ratio (TWR) approach. A TWR of 2:1 is often considered a good starting point for a quadcopter's performance.

Total Dynamic Thrust = Total Quadcopter Weight x TWR

Dynamic Thrust:

- Assuming a quadcopter weight of 2 kg (2000 grams), a TWR of 2:1 would require a total dynamic thrust of 4 kg (4000 grams). Our motors would provide us sufficient thrust to maintain a good TWR.

The SunnySky V2806 High Efficiency Brushless Motors, combined with the Eolo Foldable Carbon Fiber Reinforced Nylon UAV Propellers, provide sufficient thrust to lift the S500 quadcopter frame and carry a payload. The quadcopter's total static thrust is approximately 5200.

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5. **Flight Time Calculation**:

Flight time = (Battery Capacity * Battery Discharge /Average Amp Draw) *60

Battery Capacity = 10000 mah

Battery Discharge = 80 %

Average Amp Drawn = 12.8 (per motor) X 4 = 51.2 amp (100 percent throttle)

Flight time = (10 * 0.8 / 51.2) * 60 = 9.2 minutes

Drone will last in the air for 9.2 minutes at full throttle.

13) AUTONOMOUS PAYLOAD DROPPING

Mission Planner is a full-featured ground station application for the ArduPilot open source autopilot project. We have used this software to automate our drone path and payload dropping mechanism. Below is the home page of the Mission Planner software.

1. Setting coordinates of mission

Setting Coordinates using mission planner

1. Open Mission Planner software into the ‘data’ tab
2. Select the COM port and press connect.
3. Check the battery voltage, flight mode, GPS status, satellite count and the telemetry signal. Also check that it is in ‘auto mode’ (can be found under 'actions’)
4. Move into the flight plan tab, plot waypoint 1 and set it as the takeoff point, additionally specify the altitude.
5. Continue to plot multiple waypoints and specify the altitude for each one of them.
6. The last waypoint must be set to landing or ‘return to launch’
7. Press the ‘write’ button twice to confirm the instructions
8. Go back into the ‘data’ tab, press the ‘actions’ and press ‘arm’
9. To start the mission press ‘do action’

2. Enabling Failsafe

There are three major failsafe functions in order to recover the vehicle if anything goes wrong namely radio, GCS and battery.

a. **Radio Failsafe:**

Config -> Full Parameter Tree -> **FS_THR_ENABLE** Set measure as return to launch.

GCS Failsafe:

Config -> Full Parameter Tree -> **FS_GCS_ENABLE** Set measure as return to launch.

b. Battery Failsafe:

Config -> Full Parameter Tree -> **FS_LOW_VOLT**

Set measure as return to launch.

Config -> Full Parameter Tree -> **FS_LOW_VOLT**

Set measure as land immediately.

c. Advanced Failsafe:

If you want to continue the mission in auto mode even after the radio and GCS failsafe is triggered then,

Config -> Full Parameter Tree -> **FS_OPTIONS**

Continue if in Auto on RC failsafe Continue if in Auto on GCS failsafe.

14. PAYLOAD DROPPING MECHANISM

For the payload dropping mechanism we have come up with a method which involves servo and a small covering to it . Our fragile payload along with the egg would be placed in a small packet which would be locked to the servo. On reaching the destination we will have to release the lock and the payload would drop down to the drop zone.

For the above implementation we have used the following servo - **EMAX** ES3001 (43g) Plastic Analog Servo. The servo implements a parabolic release mechanism of dropping the payload.

Fig. Servo

F

Parabolic Lock Mechanism

The picture below is a CAD model of our lock which would lock the payload before taking off. The axle will pass through the hole in our lock and lock the payload. The lock can hold up to 4-6 kgs of payload but due the constraints set by the competitions we will be lifting around 300 grams of payload. We use EMAX ES3001 (43g) Plastic Analog Servo for implementing the payload dropping mechanism.

The servo's role is to provide controlled movement to disengage the lock, allowing the payload to be dropped at the desired time and location. By controlling the servo's position using an appropriate control system or programming, you can trigger the release of the lock and initiate the payload dropping process.

Overall, the Parabolic Lock Mechanism coupled with the EMAX ES3001 Plastic Analog Servo provides a reliable and controlled solution for securely locking and subsequently dropping the payload during your competition flights. For the fragile payload to stay intact we would be bubble wrapping the entire payload and locking it with our lock.

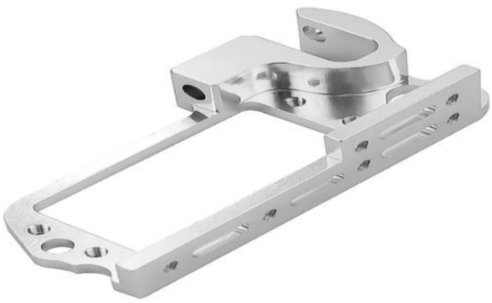

Fig. Pay Load Locking Tool

Configuration Procedure:

Step 1: Connect the servo to one of the available servo ports on the Pixhawk module

Step 2: In Mission Planner, Initial Setup Menu -> Mandatory Hardware -> Servo Output -> configure servo output channel -> set minimum and maximum PWM (Pulse Width Modulation) values.

Step 3: In Mission Planner -> Config menu -> Full Parameter List -> **SERVOx_FUNCTION** (replace 'x' with the servo output channel previously configured) -> Set the value of **SERVOx_FUNCTION** to a custom command code that will trigger servo release.

Step 4: As mentioned previously, define the waypoints for your mission and specify the waypoint where you want the payload to be released.

In the 'Actions' section for the release waypoint select the 'Do Jump' option.

Demonstration,

Pre-launch:

Initially the hands of the servo are placed in a diagonal position and the payload is mounted onto the upper diagonal hand.

On reaching the destination:

The servo is programmed to rotate 45 degrees on reaching the drop point, this will ensure that when the drone takes off again the payload will remain at the drop point.

15 . WEIGHT BUILDUP SHEET

Components	Weight (in grams)
Motors (4pcs)	.047kg x 4
Frame	.480kg
ESCs (4pcs)	.023kg x 4
Servo	.043kg
Parabolic Locking Tool	.055kg
Pixhawk	.038kg
Payload	.250kg
Connecting Wires	.050kg
Propeller	.0175kg x 4
Total Weight	**1.266 kg**