# C-25 Sigma

## Indus-Luft Dynamics

### Real World Design Challenge FY22

**Delhi Public School R.K Puram, New Delhi, India**

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02 Design Rationale

03 Electronics

04 Concept of Analysis


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# Team Formation

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## Mentors

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Aryan Goel

Ahaan Sinha

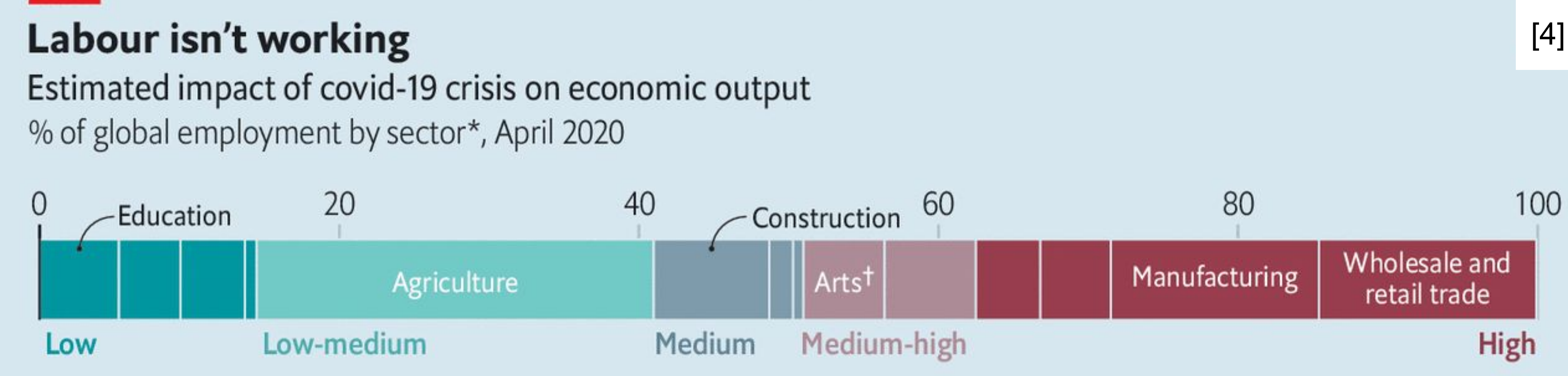
# Background


[1]


[2]

At present, the delivery industry is growing at unprecedented rates. In 2020 alone, 20 billion parcels were shipped in the United States, exhibiting a growth of 37% in volume from the previous fiscal year, thus proving its worth.

[3]




[4]

As the global COVID-19 pandemic progressed, the human resource became a fundamental liability for delivery companies, as automation and other alternatives turned into the need of the hour.

[5]

As the amount of deliveries made increased, the pollution generated increased too. [6] Greenhouse gas emissions are consequently reaching alarmingly critical levels too.


[7] As per the United Nations Development Programme, an estimated **18%** of the GDP of the world economy could be wiped off if temperatures rise by 3.2° Celsius by 2050.

[8] The undeniable threat posed by global warming and climate change cannot be ignored, as the usage of conventional delivery trucks majorly accelerates this ever-growing problem.

# The Problem

- ➔ The need for an affordable UAS capable of delivering packages at a range of 15 kilometers.
- ➔ The system needed to be highly efficient in order to be profitable at the given scale.
- ➔ A comprehensive solution consisting of effective DAA and C3 architecture was deemed to be important.
- ➔ Charting out a good concept of operations and an ideal business model were necessary too.

[9]

# Our Solution

- A state of the art UAV based on a vintage Gyrodyne design.
- Relatively affordable pricing, attracting a diverse and large clientele.
- A through logistics plan that promises maximum efficiency and streamlined operations.
- A highly reliable and redundant avionics system.

# Design Rationale

## Indus-Luft Dynamics

# Engineering Design Process


## Team Strategy to Win

An exhaustive design process aided by empirical research & intrinsic communication

↓

***The formula for a quintessential design***

# Air Vehicle Design Process

## EVALUATION METRICS

**PAYLOAD CAPACITY**
The aircraft must be capable of carrying a 5 Kg package with a MTOW of 25 Kg.

**FULL VTOL CAPABILITY**
RWDC FY22 made it compulsory for the UAV to perform VTOL hence conventional fixed wings were immediately eliminated.

**RANGE**
The distance between the air base and the delivery location is set at 15 Kms.

**ENDURANCE/EFFICIENCY**
While carrying the 5 Kg package over 15 Kms the aircraft must display superior endurance and efficiency.

**VIBRATIONS/NOISE EMISSIONS**
As the scene is set in an urban city, noise levels must be in compliance with FAA regulations.

**HOVER/LOITER**
Before beginning the final approach a 10 min hover/loiter pattern must be followed while also countering a 10 kts crosswind.

*Fixed Wing - NM&F300* [10]

*Tail Sitter - PX4* [11]

# Airframes Considered (Conceptual)

The team considered a large variety of airframes, and thoroughly examined various types to deliberate on the best airframe options.

With an open-minded approach, the following airframes were looked into:

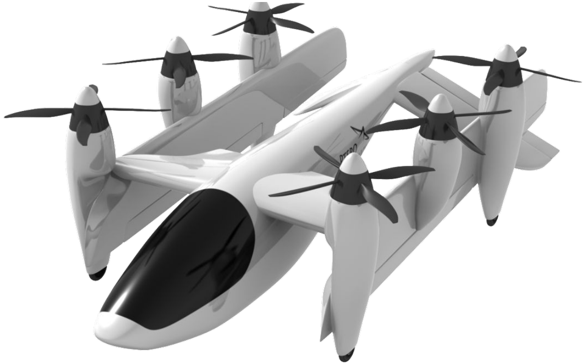
- **Airframes**
  - **Fixed Wing**
    - Conventional Airframe
  - **Hybrid**
    - Gyrodynes
    - Compound Rotorcraft
  - **Rotor-Design**
    - Single Rotor
    - Multirotor
  - **Tilt-Design**
    - Tiltrotor
    - Tilt-Wing

# Airframes Considered (Conceptual)

*Tiltrotor - Joby S4* [12]


*Single Rotor - PRODRONE* [13]


***Multirotor - Amazon Prime Air*** **[14]**



***Tilt Wing - PteroDynamics Transwing*** **[15]**

# Airframes Considered (Preliminary)

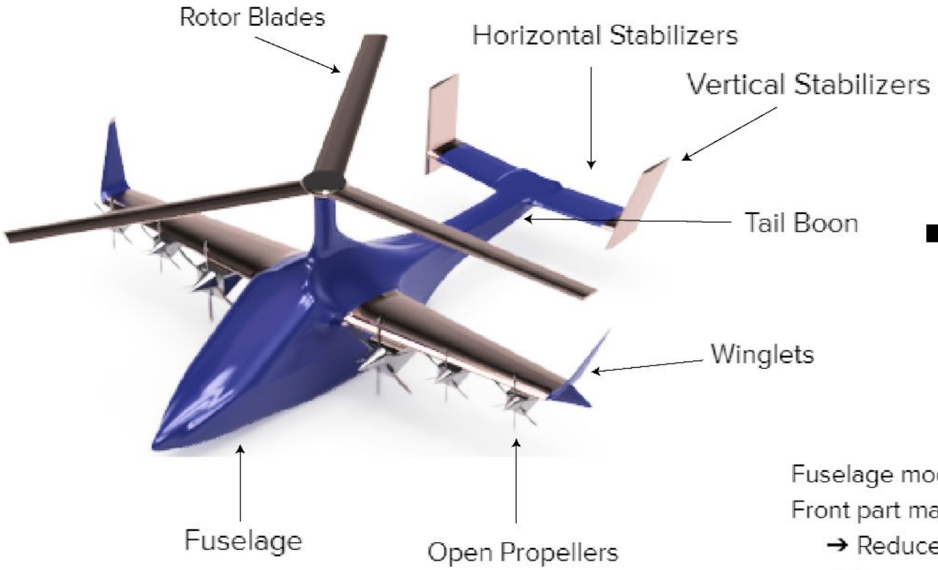

***Fairey Rotodyne*** **[16]**

***Sikorsky S-72 X Wing*** **[17]**

***Airbus Racer Prototype*** **[18]**

# Airframe Transition

## National Challenge Airframe




## International Challenge Airframe


Fuselage modified to upgrade overall aerodynamics. Front part made sleeker to:

- ➔ Reduce drag
- ➔ Improve air flow characteristics.

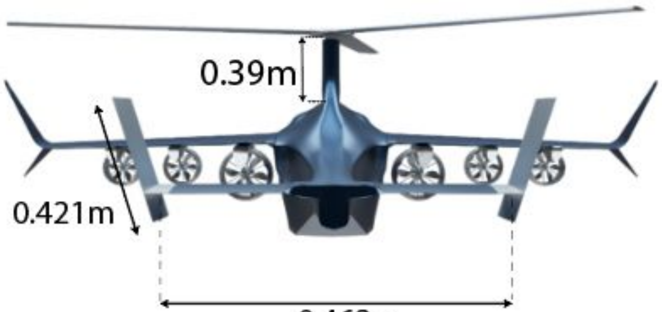
Conventional propellers enhanced into more efficient ducted propellers.

- ➔ Greater thrust production
- ➔ Lower tip losses
- ➔ Lower noise levels
- ➔ Increased safety on ground

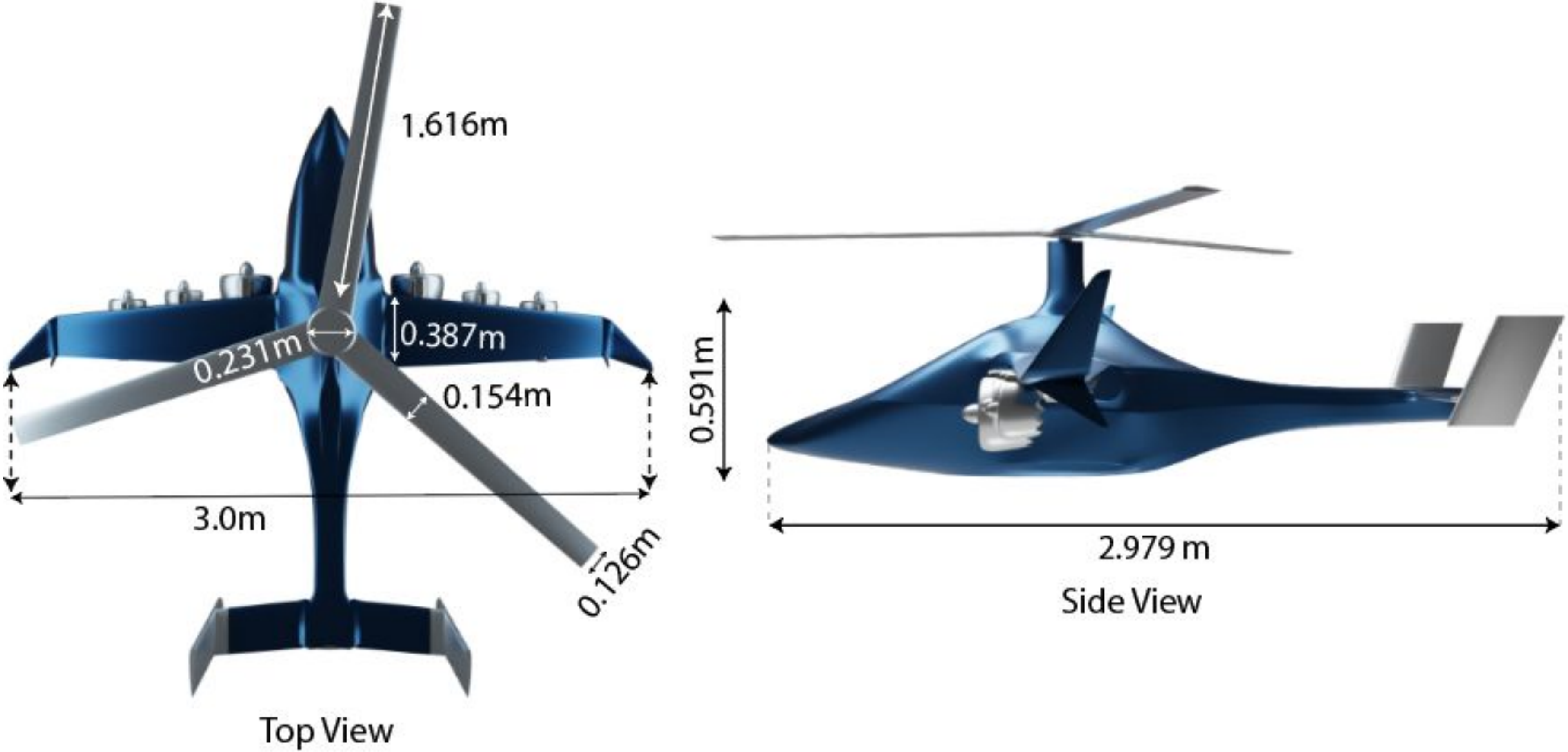
# Final Airframe: C-25 Sigma



Front View




Rear View

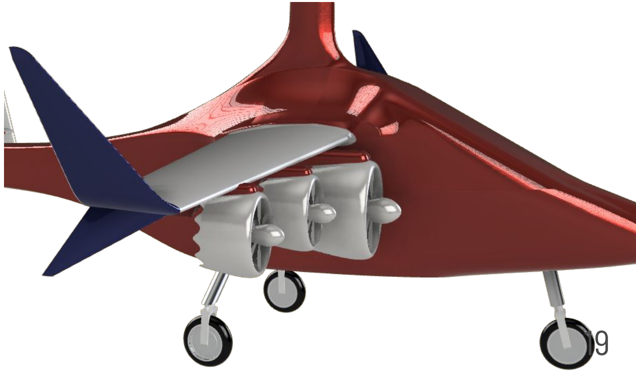

1.616m
0.387m
0.231m
0.154m
3.0m
0.126m
Top View
0.591m
2.979 m
Side View

# Wing Design

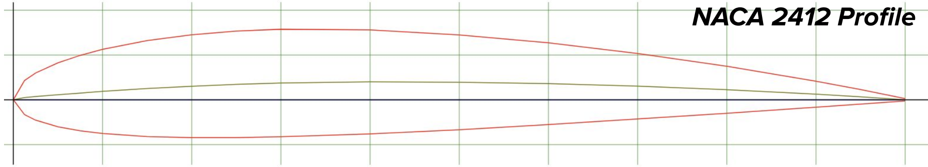
The C-25 Sigma features an **Integrated Propulsive Wing.**

- ➔ Distributed electric propulsion
- ➔ Greater propulsive efficiency at low speeds
- ➔ Elimination of additional control surfaces
- ➔ Increase in range
- ➔ Allows for STOL in case of Main Rotor failure (i.e no VTOL )
- ➔ Lower complexity
- ➔ Split Scimitar Winglets

Due to greater efficiency gains, and an overall better-adapted system for electrical power, an integrated propulsive wing was chosen as opposed to box wings, which were also an attractive option.

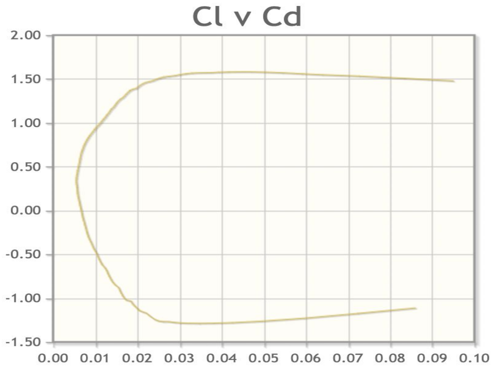


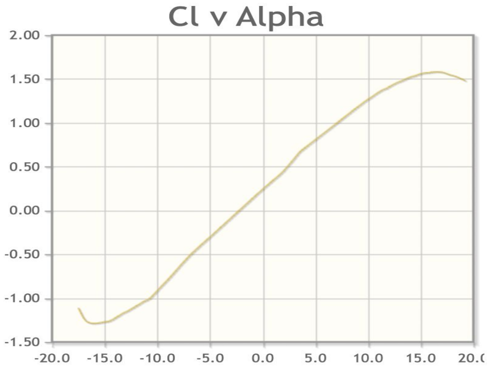
# Wing Airfoil

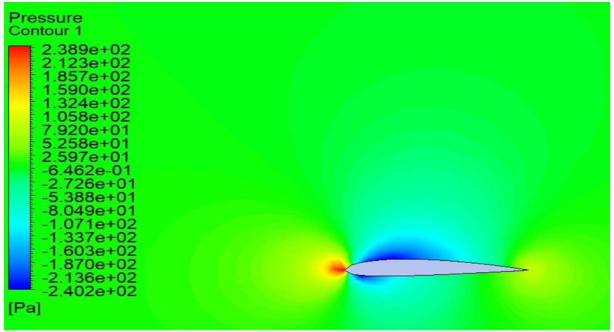



Asymmetrical airfoil, **NACA 2412** was chosen.

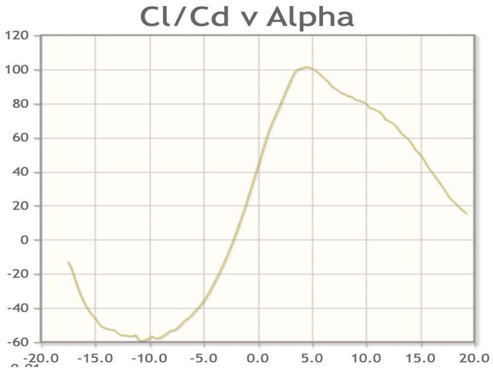
- ➔ High Cl/Cd (Max-101.4 at α=4.5)
- ➔ Low AOA
- ➔ Good stall characteristics
- ➔ At 40 m/s Lift - 222.36 N, Drag - 42N
- ➔ L/D ratio  5.2 : 1

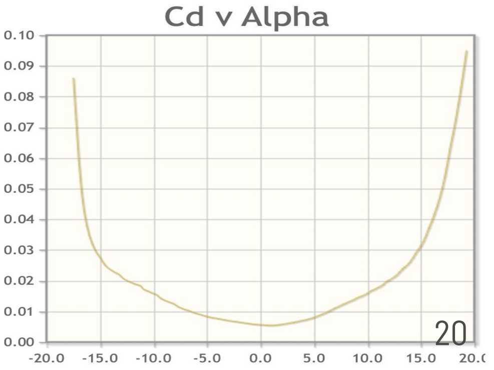



*Pressure Contours CFD - NACA 2312*



# Ducted Propellers

Maximise Efficiency

Minimise Noise

## Efficiency

➔ If radius is constant, thrust :

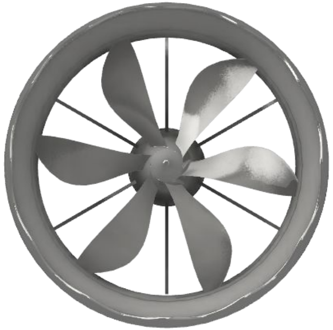
Ducted Propellers Open Propellers

➔ A1 . V1 = A2 . V2 - *Equation of Continuity*

When radius ⇩ pressure ⇩ velocity ⇧

➔ Low Tip Losses : No place for vortex formation

➔ Safer : The ducts screen and conceal the propeller blades, reducing the risks of the blades colliding with any personnel or objects.



## Noise Profile

- ➔ Quieter: Limit Tip Speed
- ➔ Chevrons: Serrated edges at the exhaust nozzle

As hot air from the engine core mixes with cooler air blowing through the engine fan, the shaped edges serve to smooth the mixing, which reduces turbulence that creates noise.

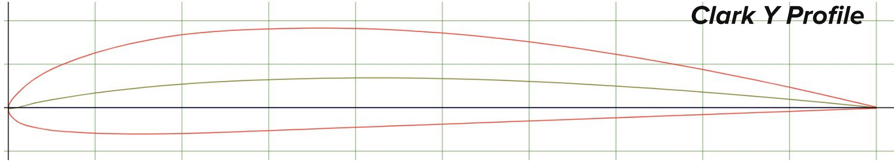
## Final Configuration

- ➔ 6 Propellers - 3 per wing
- ➔ 2 x Large Propellers ; 4 x Small Propellers

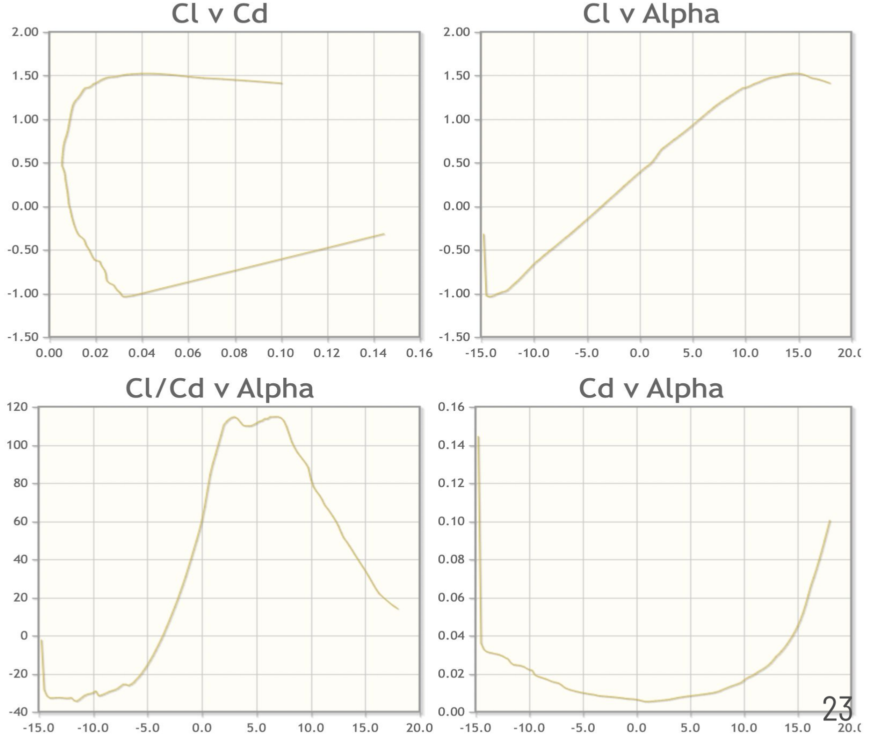
# Propeller Airfoil

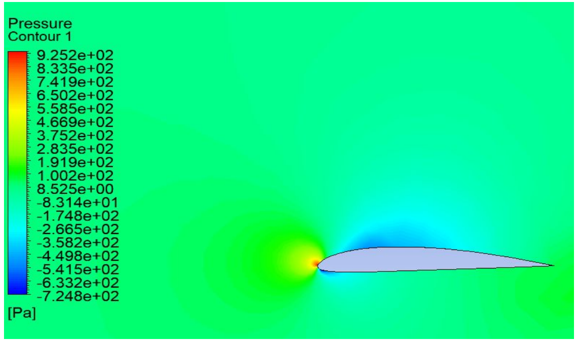
Asymmetrical airfoil, **Clark Y** was chosen.

- ➔ Positive Cl/Cd from 0°- 15°(114.8 at α=6.75)
- ➔ Average peak Cl/Cd
- ➔ High coefficient of lift
- ➔ At 40 m/s Lift - 195.50 N, Drag - 26.42 N
- ➔ L/D ratio 7.4 : 1



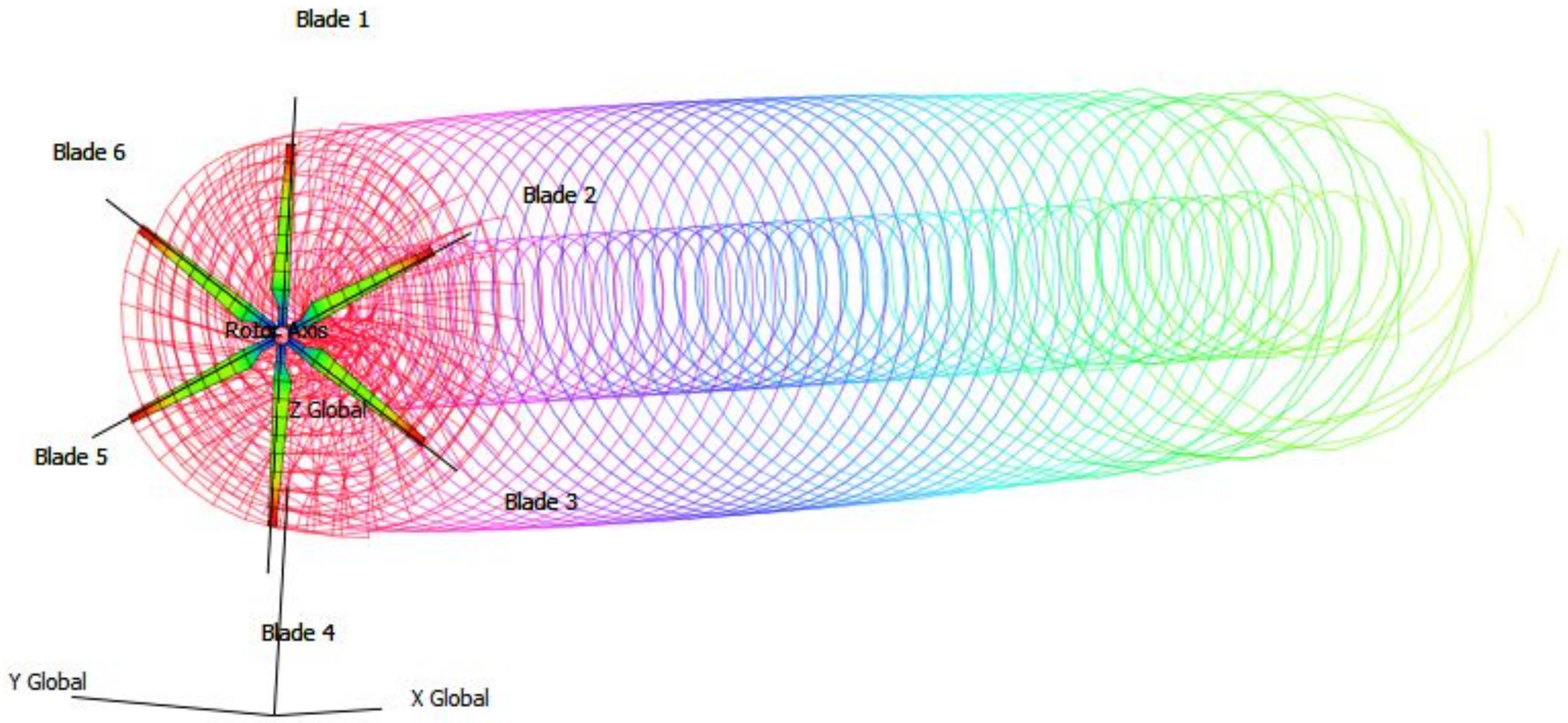
*Clark Y Profile*




***Pressure Contours CFD - Clark Y***

# Spinning Blade CFD Analysis - Clark Y



# Rotor Head

## 3 Blade Rotor System

- ➔ Stable COG
- ➔ Mechanically balanced
- ➔ Natural vibration of the rotor goes down sharply
- ➔ 3 blades divide the lift into smaller per-blade loads

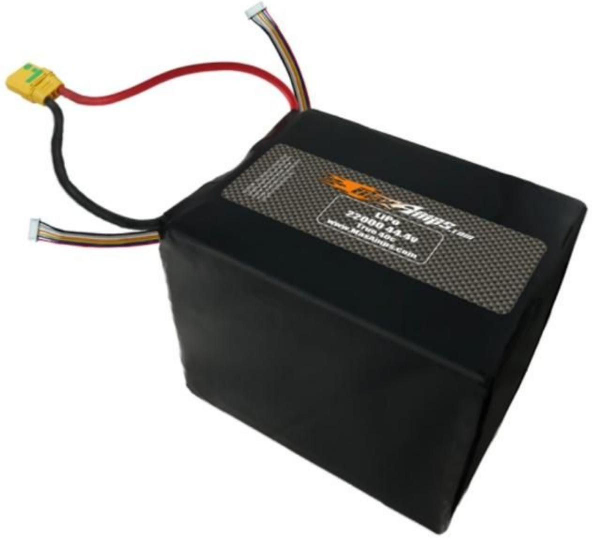
## Rigid Rotor System

- ➔ Reduction in Rotor Hub drag
- ➔ Comparatively Lighter
- ➔ Easier/Cheaper maintenance
- ➔ Simplicity factor

# Power Plant and Batteries

➔ The size-based limitations combined with the UAVs weight requirements resulted in the team choosing a electronic power plant, with the main power source being **Lithium Polymer batteries** due to the low overall weight offered.

➔ After thorough market research and upon analyzing the power requirement of the UAV (detailed in the Flight Profile Analysis), a battery pack of three **MaxAmps 12S 22Ah 44.4V Lithium Polymer batteries** were considered as an ideal choice for our UAV.



[19]

# Rotor Blade Airfoil

## INBOARD SECTION

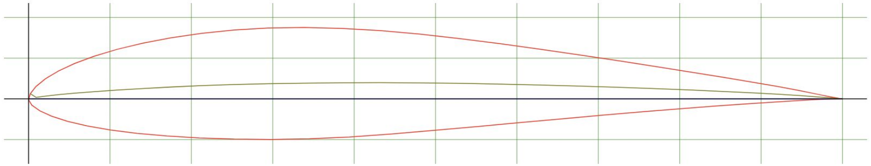
Asymmetrical airfoil, **Eppler 209** was chosen.

- ➔ High Cl/Cd (Maximum-121.6 at α=6°)
- ➔ Low camber
- ➔ High coefficient of lift
- ➔ At 40 m/s Lift - 195.50 N, Drag - 26.42 N
- ➔ L/D ratio 7.4 : 1

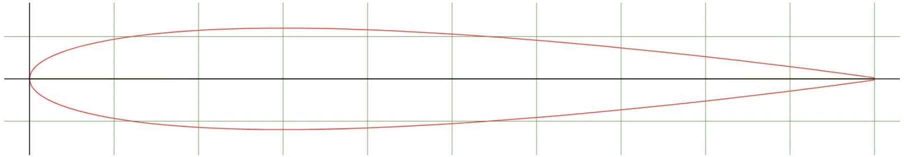
## OUTBOARD SECTION

Symmetrical airfoil, **NACA 0012** was chosen.

- ➔ Satisfactory Cl/Cd (Maximum-75.6 at α=7.5°)
- ➔ Desirable stall characteristics
- ➔ More stable as AOA changes which in our case is exactly what the retrieving blade is experiencing.

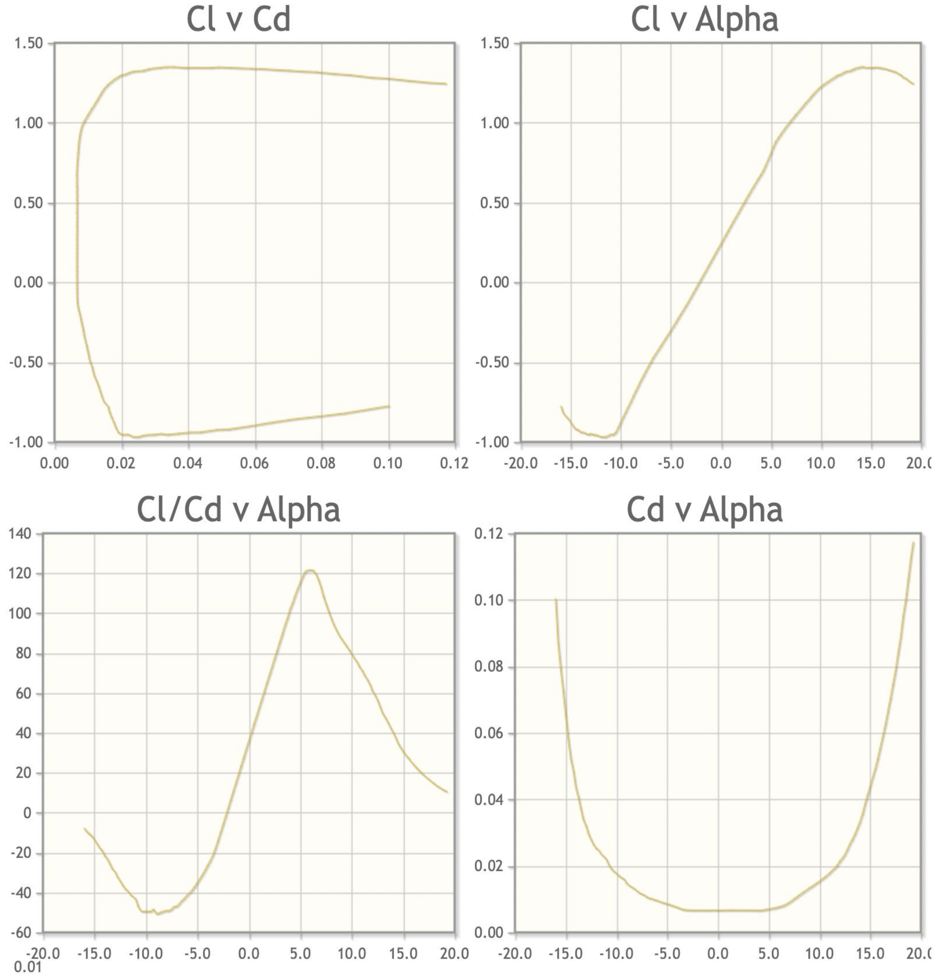


***Eppler 209 Profile***

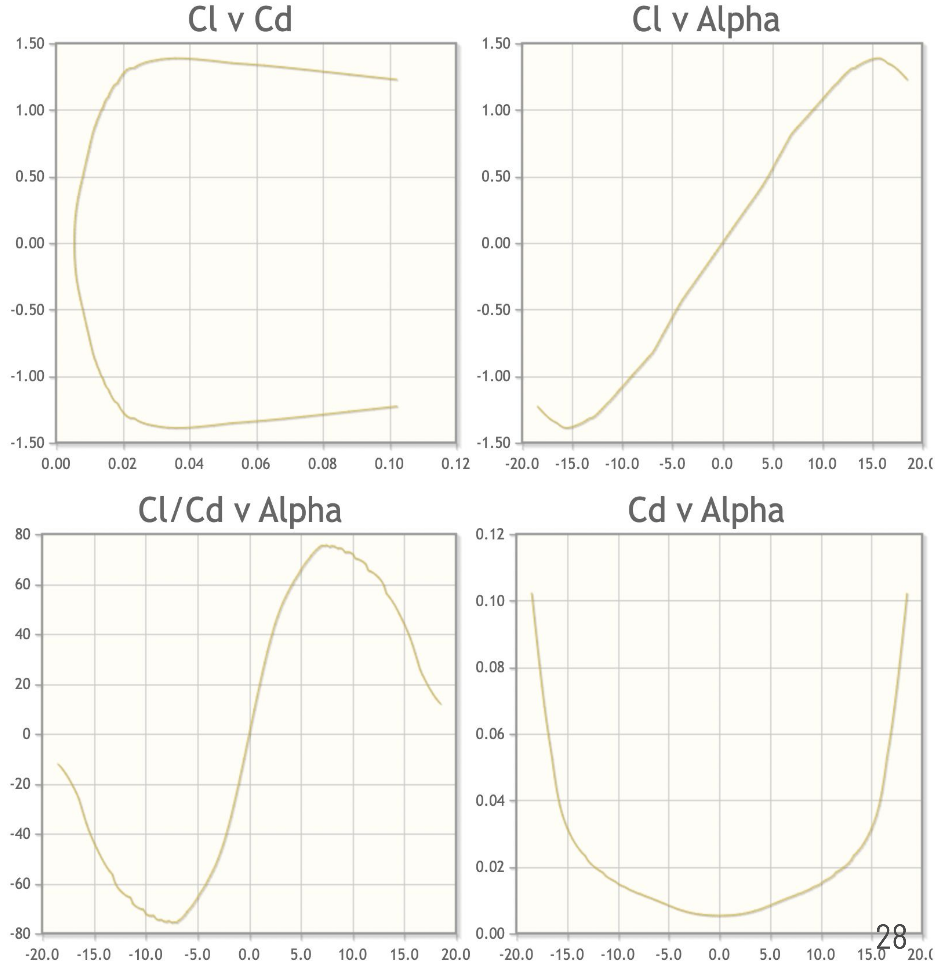


***NACA 0012 Profile***

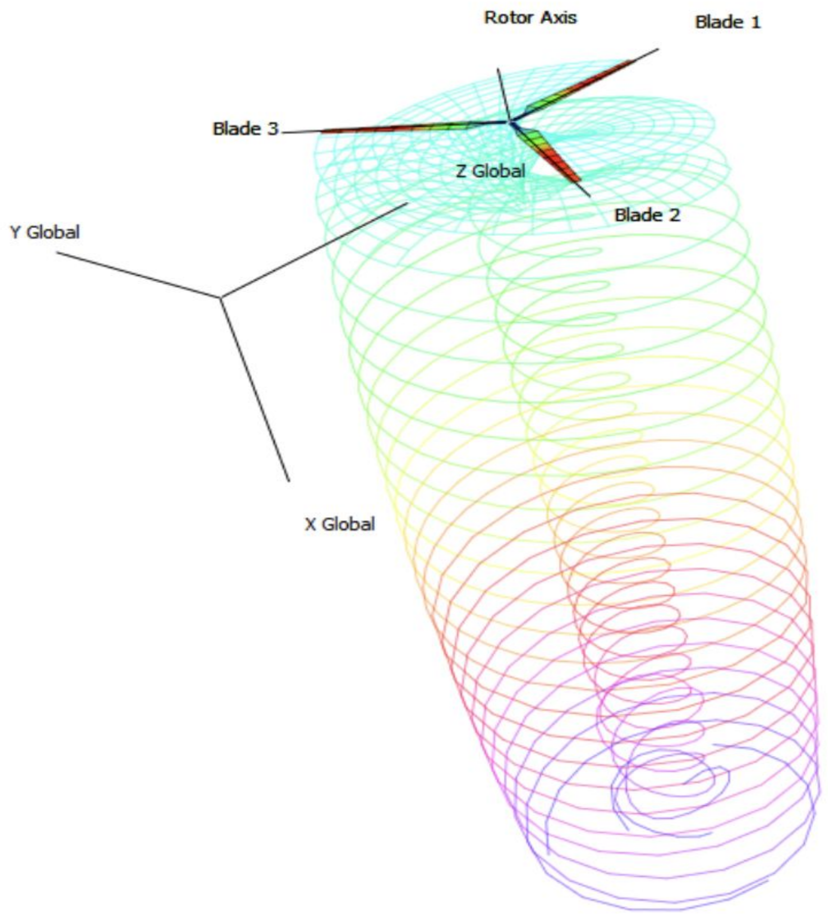
## *Eppler 209*




## *NACA 0012*



# Spinning Rotor Blade CFD



# Motors: Propeller and Main Rotor

➔ **Propeller** Power Requirement:

0.771kW - Small Propeller

0.945kW - Large Propeller

➔ Motors:

4 x KDE600XF-1100-G3 Brushless DC Motor

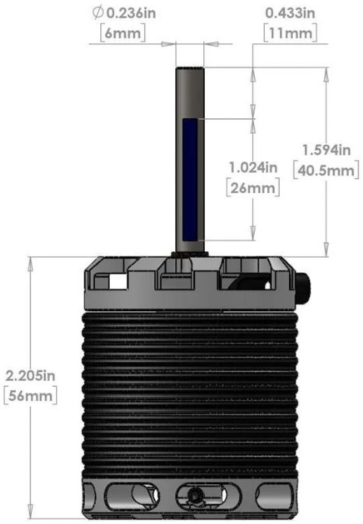
2 x  KDE600XF-530-63 Brushless DC Motor

➔ **Main Rotor** Power Requirement -

➔ Motor:

1 x KDE700XF-295-G3 (8MM) Brushless DC Motor

[20]




[21]

★ Optimised Stator Construction

★ High-Volume Centrifugal Fan

# Composition

| Materials | Tensile Strength (MPa) | Density (g/cc) | Strength-Weight Ratio (MPa/g/cc) | Elongation (%) | Surface Area ($m^2$) | Thickness (m) | Total Mass (Kg) |
|---|---|---|---|---|---|---|---|
| Aluminium 6061 | 315 | 2.7 | 115 | 17 | 3.022 | 0.001 | 8.159 |
| CFRP | 5407 | 1.79 | 3026 | 1.75 | 4.211 | 0.001 | 7.158 |

## Why Aluminium 6061?

- ➔ Economical
- ➔ Excellent weight-to-strength ratio
- ➔ Great fracture toughness
- ➔ Corrosion resistance
- ➔ Most proven material in the Aviation Industry

## Why Carbon Fibre?

- ➔ Excellent Strength-Weight Ratio
- ➔ Extremely Light
- ➔ Low density
- ➔ Great temperature tolerance
- ➔ Corrosion resistance

# Material Distribution: C-25 Sigma

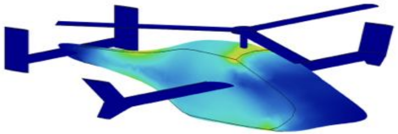
- Silver - Aluminium 6061
- Dark Grey - Carbon Fiber

# Static Stress Test Results

⊟ **Stress**

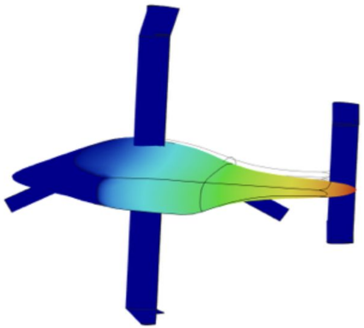
⊟ **Von Mises**

[MPa] 0 – 9.623E-04



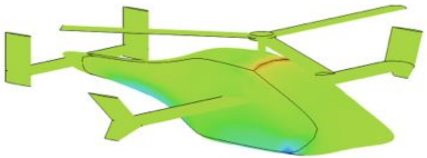
⊟ **Total**

[mm] 0 – 1.678E-05



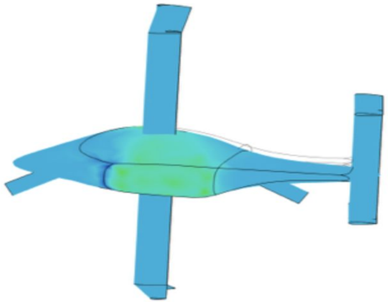
⊟ **3rd Principal**

[MPa] -7.044E-04 – 4.324E-04



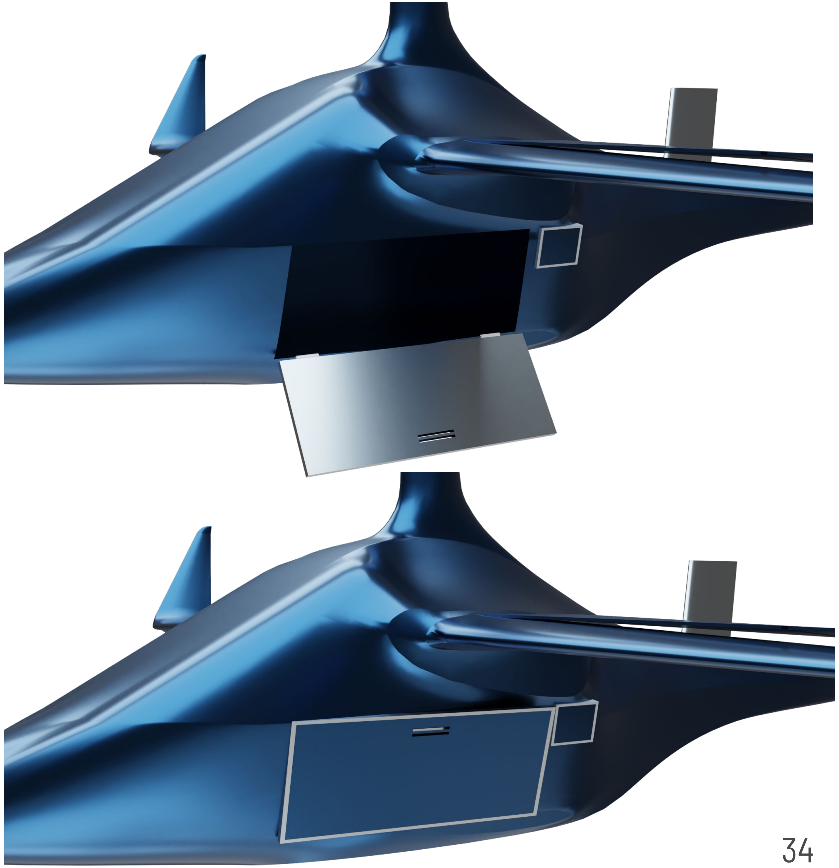
⊟ **1st Principal**

[MPa] -1.558E-04 – 8.421E-04



# Package Loading-Unloading Mechanism

- ➔ Mechanism is simple and practical
- ➔ Inbuilt hatch under the left wing
- ➔ Location is easily accessible for handlers
- ➔ Location doesn't interfere with any components
- ➔ Hatch has a handle which opens outwards



# Landing Gear

## Retractable Nose-Wheeled Tricycle

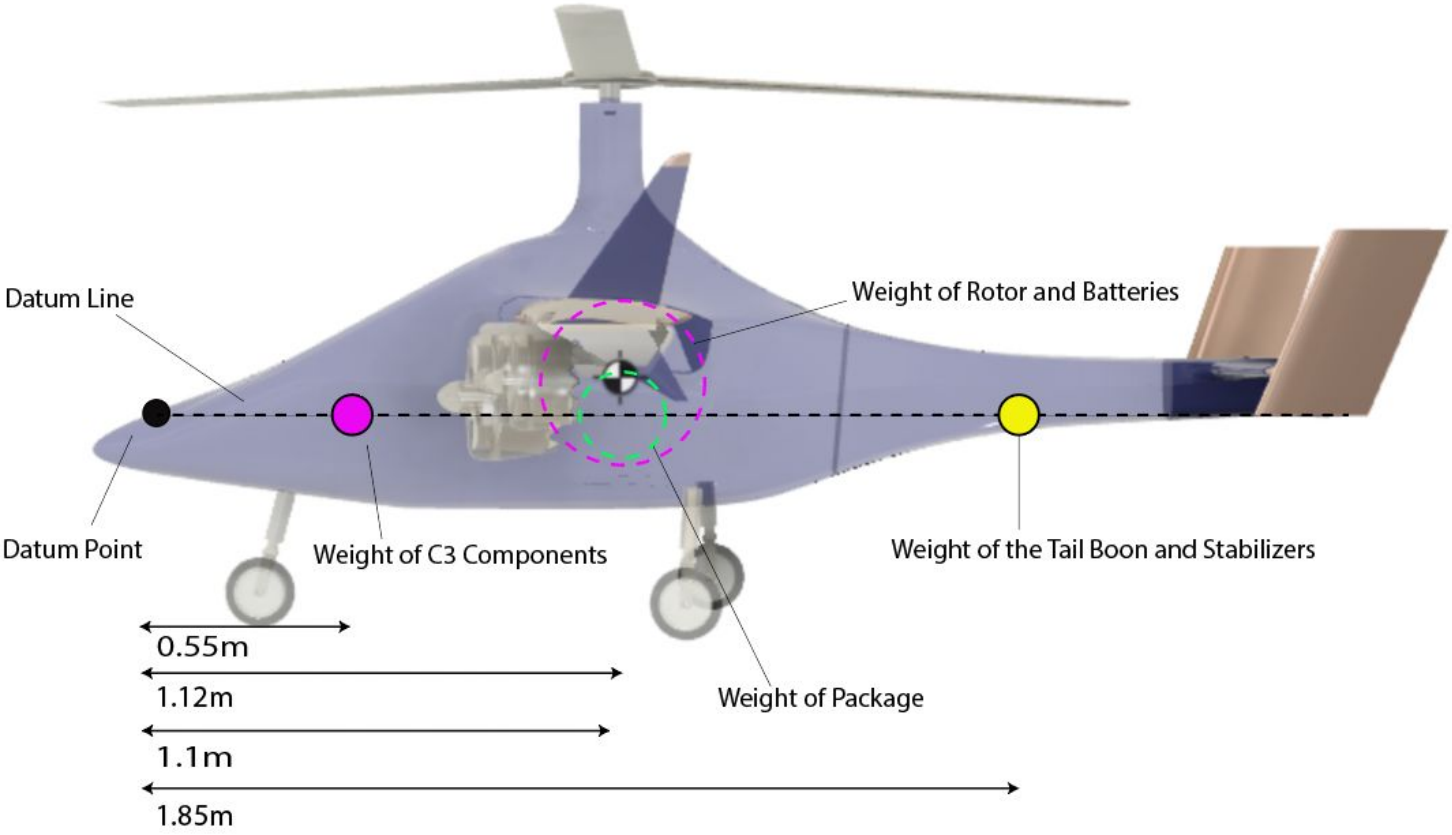
➔ Greater flexibility on ground
- Taxiing
- CTOL

➔ Significant reduction in drag
- Increased climb performance
- Higher cruise speeds

➔ Wheel Wells

➔ The landing gear placement is based on crashworthiness considerations. If the wheels are lowered in a vertical crash situation, they will not penetrate the cargo hold or any instrumentation.

# Centre of Gravity Analysis



| Component | Weight (W) (Kg) | Distance from Datum Point (R) (m) | Moment (W x R) |
|---|---|---|---|
| Fuselage and Package | 9.03 | 1.12 | 10.08 |
| Rotor and Batteries | 8.69 | 1.10 | 8.9 |
| Electrical Components | 1.46 | 0.55 | 0.48 |
| Tail Section | 5.82<br>**NET = 25Kg** | 1.85 | 8.51<br>**NET = 26.27** |

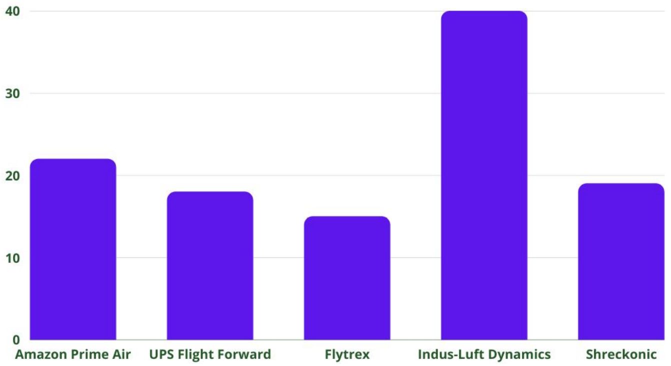
COG = Net Moment ÷ Net Weight of the UAV

= 26.27 ÷ 25 = 1.1m

On calculation, the COG came out to be at 1.1m from the datum point. This result reaffirms the COG point obtained graphically from Fusion 360.

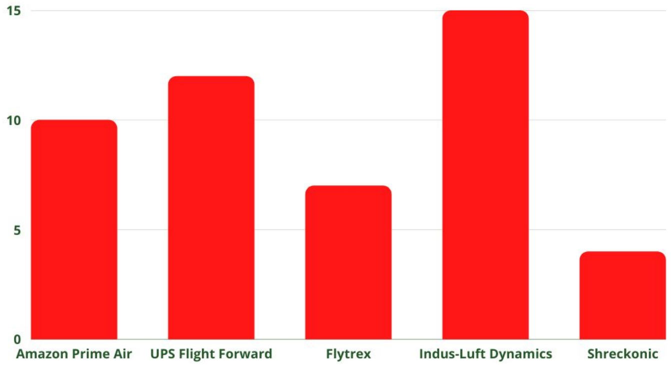
## CRUISE SPEED COMPARISON
**with other Air Delivery Services (in m/s)**

APRIL 2022



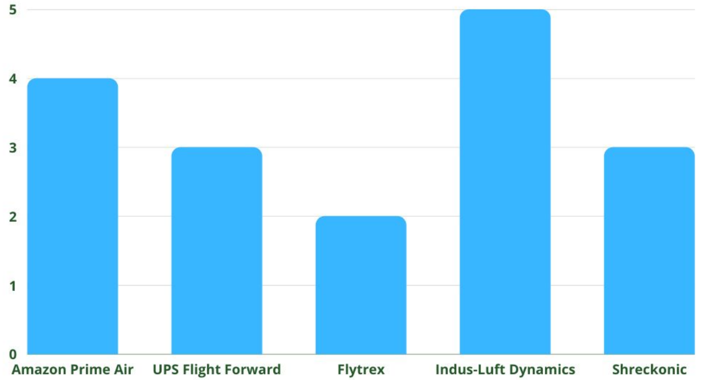

## RANGE COMPARISON
**with other Air Delivery Services (in Kms)**

APRIL 2022



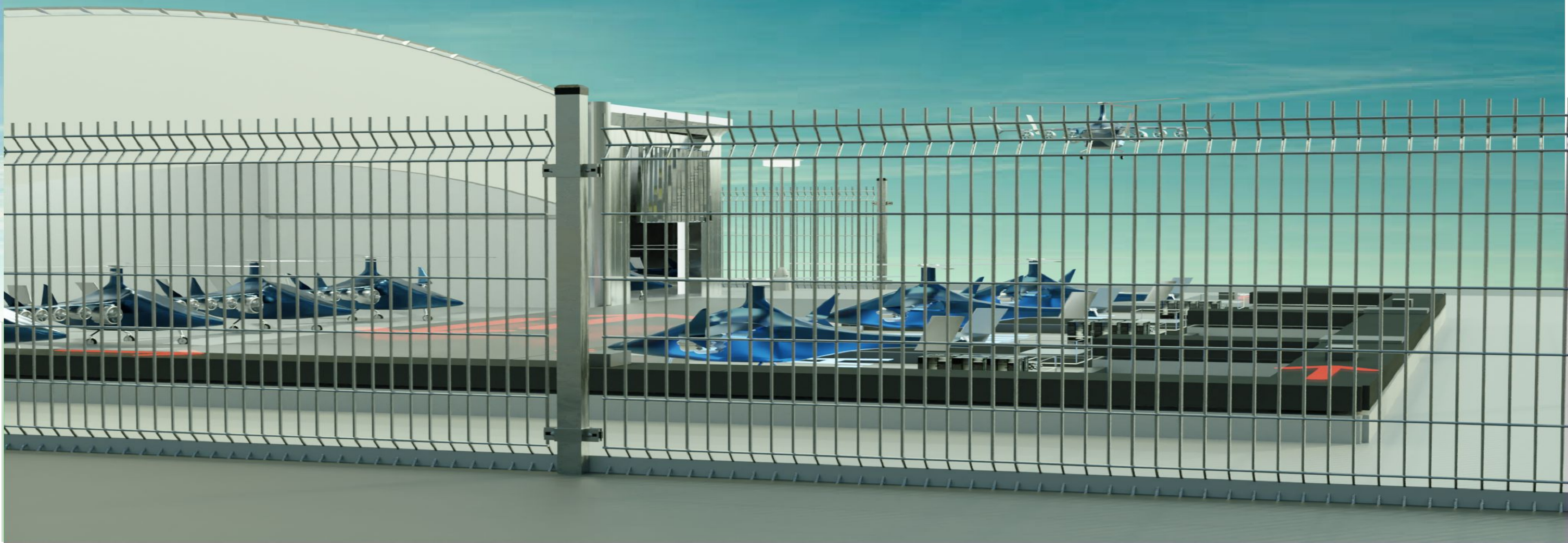

## PAYLOAD CAPACITY COMPARISON
**with other Air Delivery Services (in Kgs)**

APRIL 2022



# Electronics

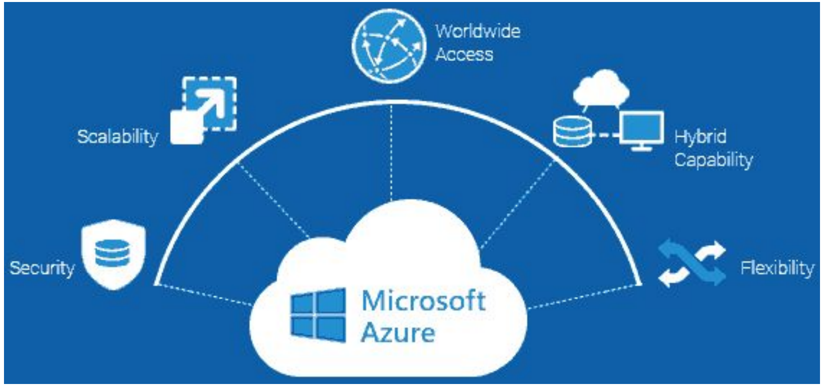
## Indus-Luft Dynamics



# Cloud Server

- ➔ **Microsoft Azure's** 'Hot' plan is chosen.
- ➔ Downloads and stores all softwares and flight planning data for Indus-Luft Dynamics
- ➔ Provides unlimited storage space
- ➔ No paperwork or any external storage site is required
- ➔ Security patches and software updates are covered by the Cloud Server Provider


[22]




[23]

# Command, Control, and Communication (C3)

**Criteria for C3**

1. Degree of Automation
2. Safe GPS System
3. Lightweight and Power Efficient

# Navigation Systems

- **Active Systems**
  - Enhanced GPS (GNSS)
    - Satellite Communication
- **Supporting Systems**
  - INS
    - Utilizes data from inertial sensors
  - Sensor Fusion
    - Utilizes DANFIS model to produce orientation data
  - RTK
    - Enhances INS and GNSS systems
- **VANET**
  - Spontaneous wireless network of automobiles
    - Enables V-V and V-I communication using RSUs

# Active System for Navigation BVLOS

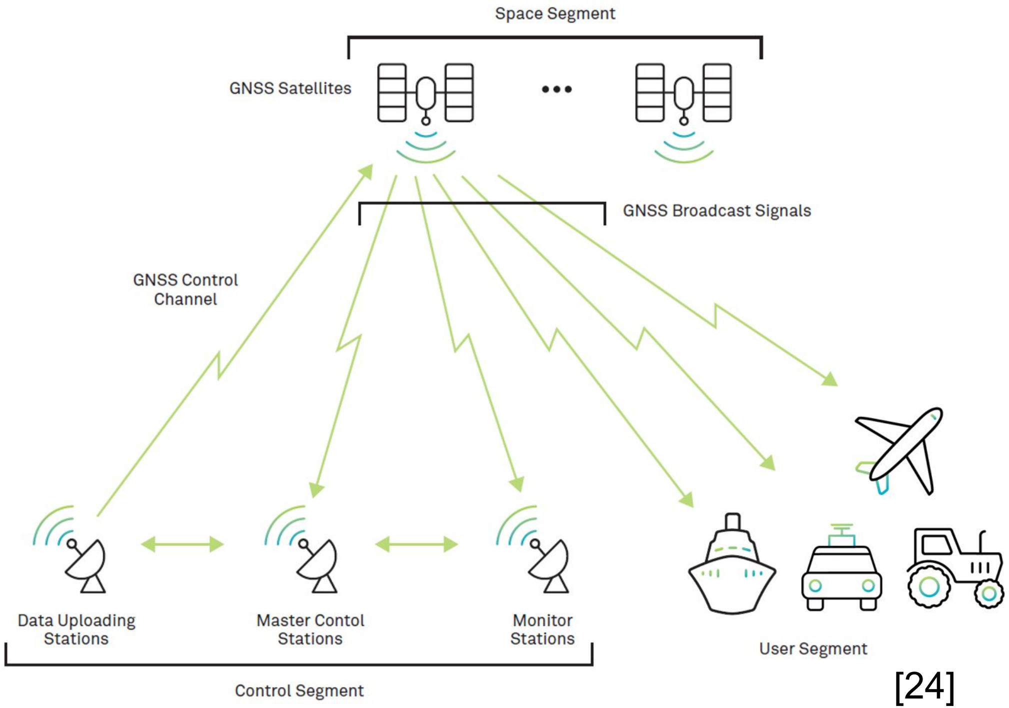
## Enhanced GPS (GNSS)

### Advantages

- ➔ GNSS constellations improve and increase range of GNSS signals
- ➔ Low Cost
- ➔ Ease of Implementation
- ➔ Reliable

### Disadvantages

- ➔ High rise buildings often block signals
- ➔ Unpleasant weather affects GNSS accuracy




[24]

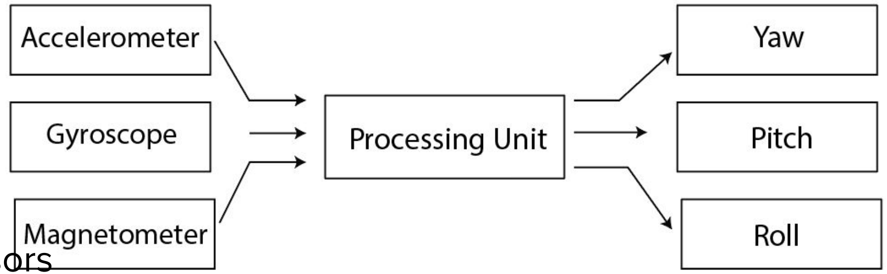
# Supporting Systems for Navigation BVLOS

Supporting GPS systems have been introduced to ensure functionality in case of GNSS mishap.

## INS - Inertial Navigation System

### Advantages

- ➔ Dead reckoning system which utilizes data from onboard inertial sensors
- ➔ Provides three-dimensional position, velocity, and orientation estimations by fusing data from IMU sensors
- ➔ No external references are required



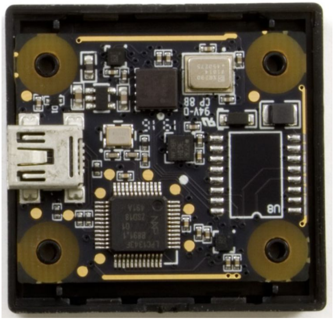

### Disadvantages

- ➔ Comparatively expensive

## PhidgetSpatial Precision IMU 1044_1B

[25]


[26]



## Sensor Fusion

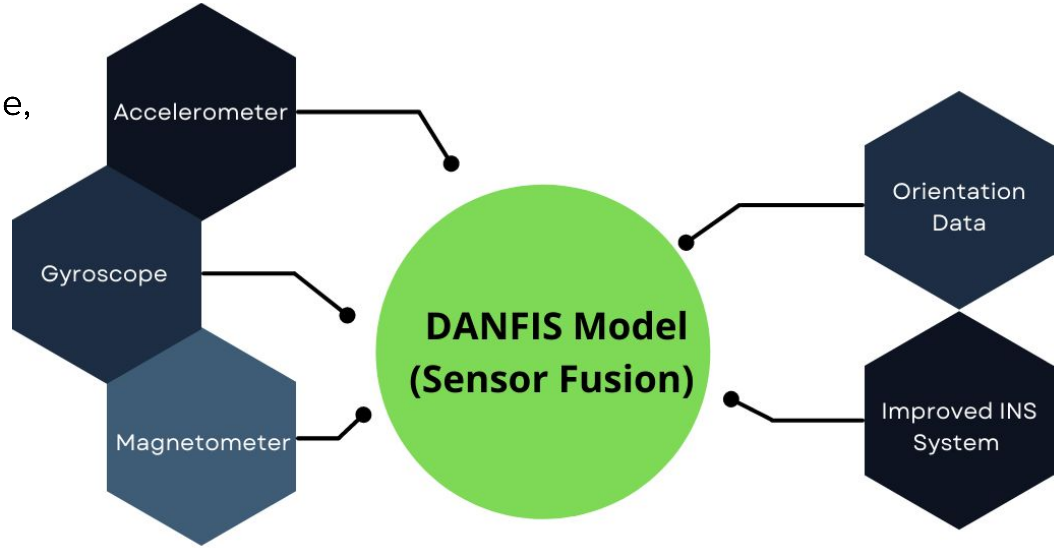
→ Involves taking multiple sensor measurements and combining them using a DANFIS Model (Dynamic Adaptive Neuro Fuzzy System).

### Advantages

→ Output from the accelerometer, gyroscope, and magnetometer is fused in order to deliver meaningful data for the flight controller

→ Independent of communication with the GCS

→ Provides highly accurate flight data




### Disadvantages

→ Requires higher computational power

## Real Time Kinematics (RTK)

➔ The UAV calculates its position using both the GNSS receivers onboard and GNSS signals from the GCS.

**Advantages**

➔ The UAV is able to navigate itself to a centimeter level accuracy

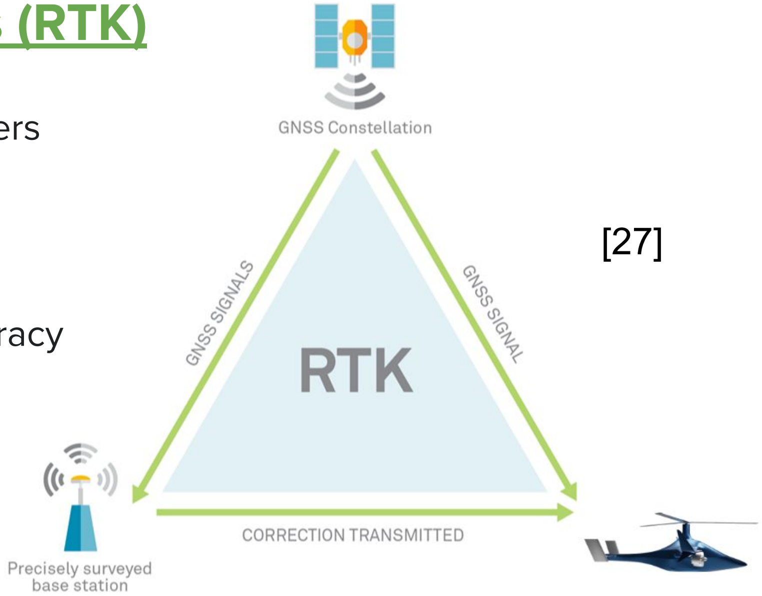
➔ Provides GPS position in real time

➔ Better waypoint navigation, required for urban areas

**Disadvantages**

➔ Needs higher computational power

➔ Datalink dropouts and high latency




[27]

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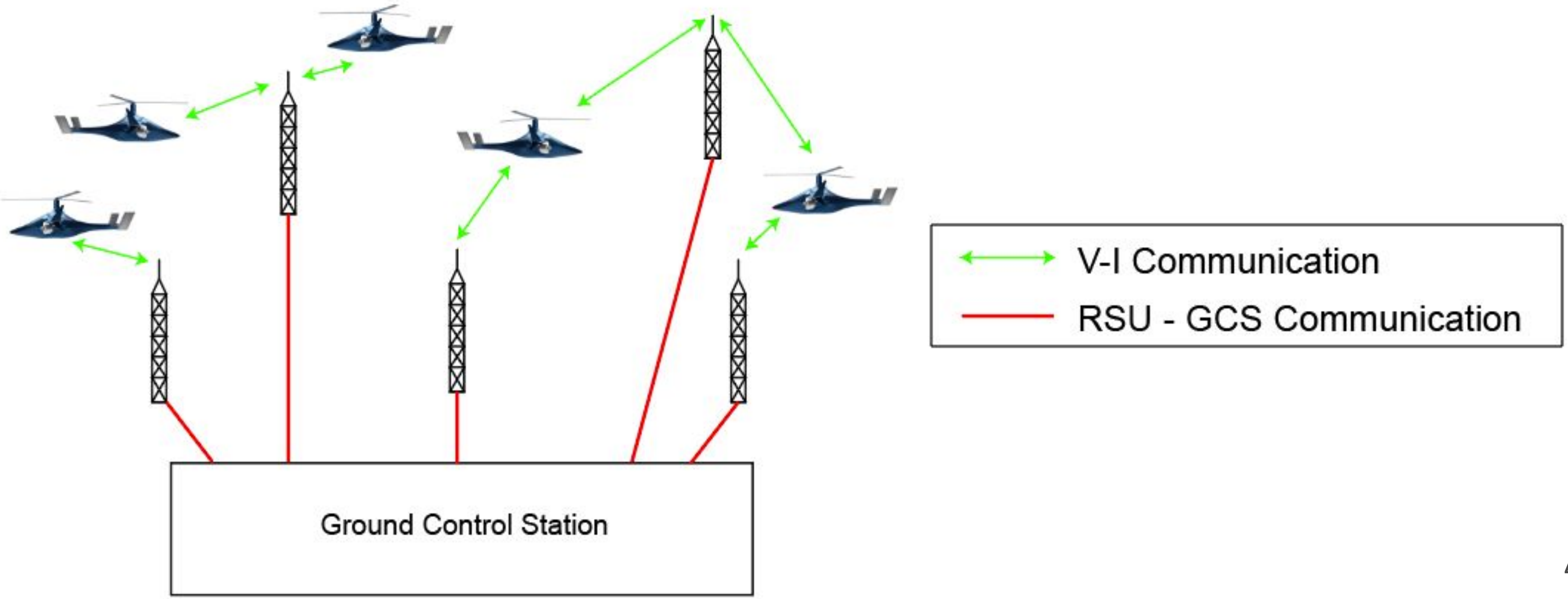
**CubePilot Here+ GNSS Module with integrated RTK**

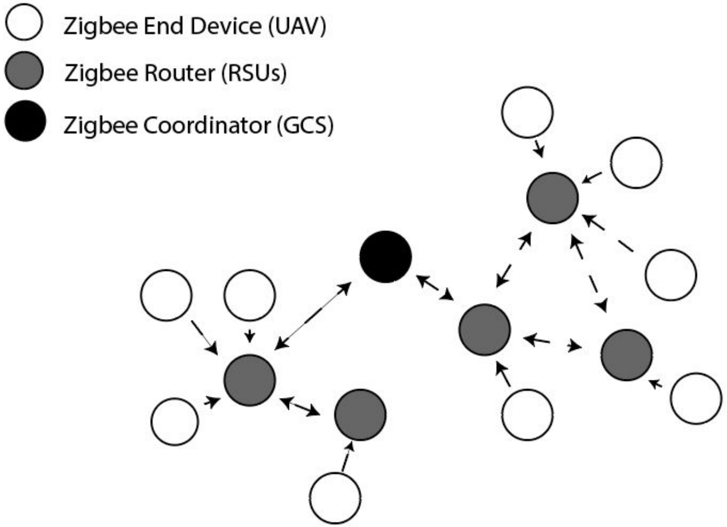

[28]

# VANET

- ➔ VANET (Vehicular Ad-Hoc Network) is a spontaneous wireless network for transport vehicles that is used to enable V-V (vehicle-to-vehicle) and V-I (Vehicle-to-Infrastructure) communication.
- ➔ An arbitrary vehicle can broadcast signals to other surrounding vehicles through V-V, including vehicle speed and path.



# Zigbee Protocol For VANET




- ➔ VANET operates on Zigbee protocols for communication

**Zigbee offers:**

- ➔ Long battery life
- ➔ Lower costs
- ➔ Sufficient data transmission
- ➔ 1600m outdoor range (clear line of site)
- ➔ Low latency

It requires one ZC device (GCS), ZRs built along the flight path for exchange of packets, ZEDs (UAVs).

The ZEDs communicate with ZRs updating them from time to time.

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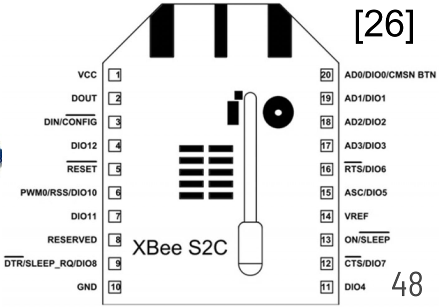
## Zigbee S2C Component


[29]

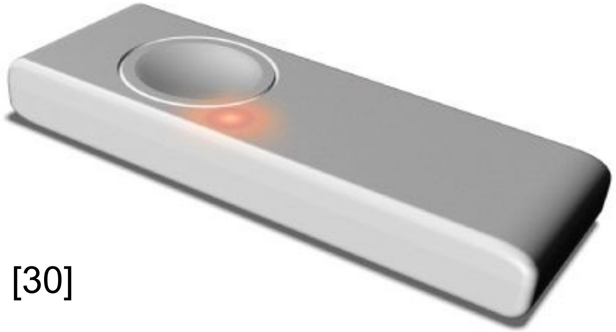



[26]

# Internet for Video Telemetry

## LTE & Wi-Fi

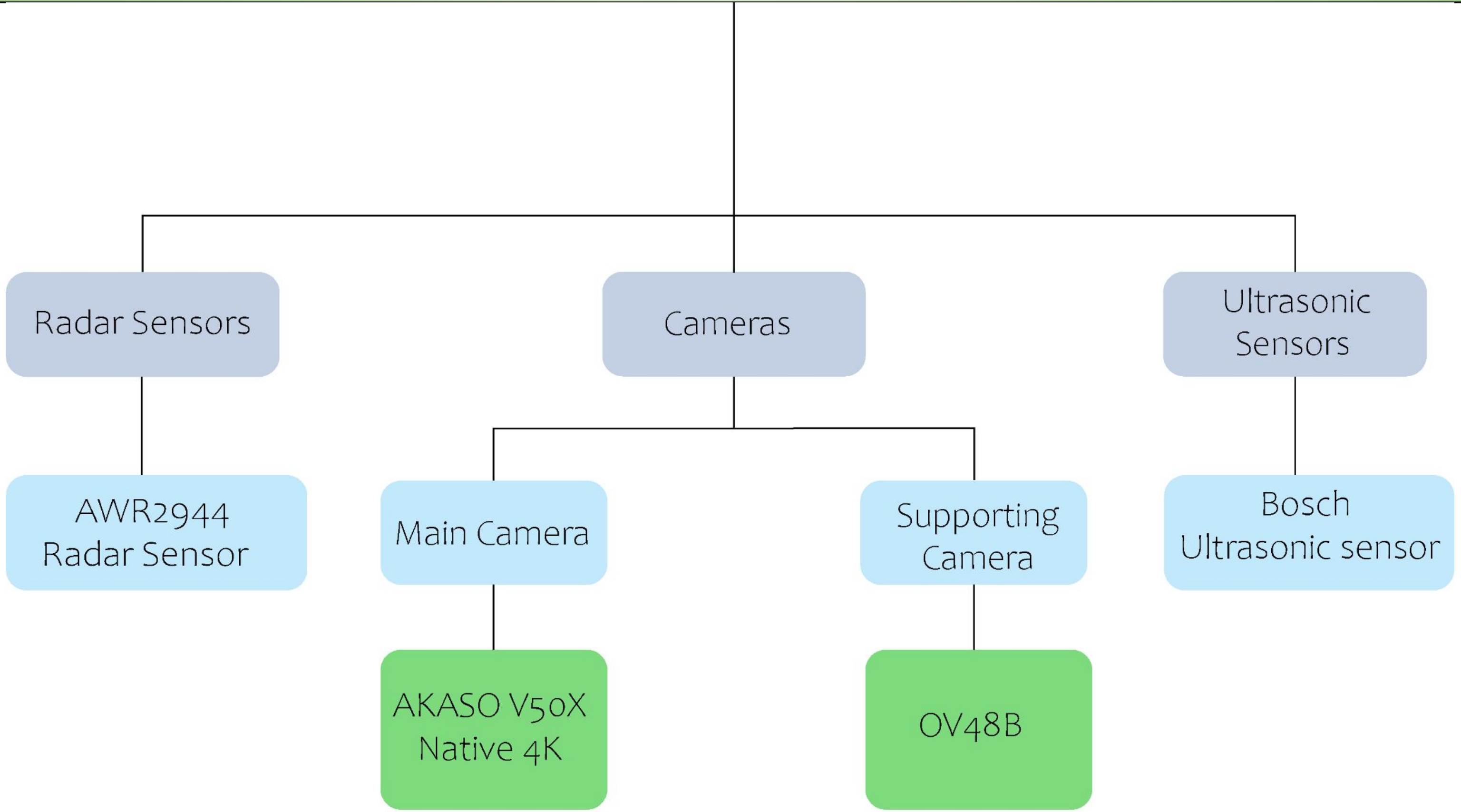
- ➔ LTE and WiFi are both used for data transmission of video telemetry
- ➔ Data rates up to 50mbps
- ➔ Minimal packet loss
- ➔ HUAWEI 4G Dongle E3372 (with 4G Sim) & Simple Pack Wi-Fi Tracker have been used
- ➔ T-Mobile Magenta Max plan has been chosen for our UAVs.



[30]

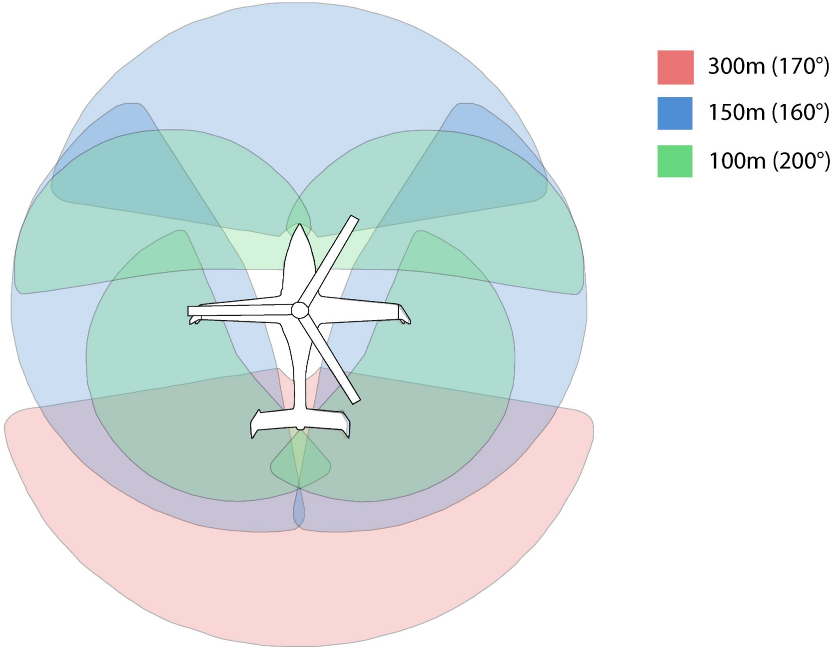

[31]

# Detect & Avoid (DAA)



# Sensory Components for DAA System

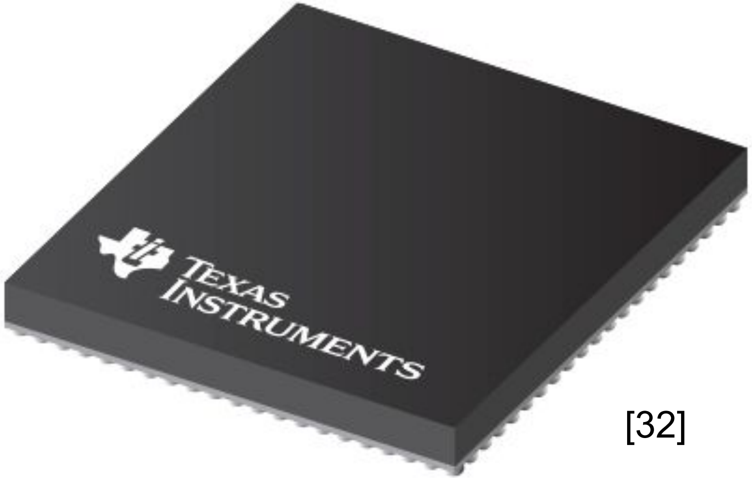
- ➔ Radar sensors, Cameras, and Ultrasonic sensors have been used together to shape our DAA system.
- ➔ Readings from RADAR sensors, along with cameras make the estimations of the distance and relative velocity of the obstacle.
- ➔ A neural network has been set up  with the aim of gradually improving cameras' accuracy.



# Radar Sensor

## Texas Instruments AWR2944 Single-Chip 76 and 81-GHz FMCW

- ➔ This particular RADAR sensor was chosen because of its light weight and low battery consumption (2.09W) .
- ➔ It is a part of the latest generation of automotive RADAR sensors and has a long range.




[32]

# Main Camera

## AKASO V50X Native 4K

- ➔ Positioned at the front.
- ➔ Capable of delivering high quality 20MP resolution videos at 30fps (4k) / 90 fps (hd).
- ➔ Light weight
- ➔ Low battery consumption

[33]



[34]

# Ultrasonic Sensor

## Bosch 0263009637

- ➔ It is a state of the art ultrasonic sensor in terms of robustness, reaction time, and object detection.
- ➔ Not affected by dirt, ice, environmental conditions


[35]

# Supporting Camera

## OV48B (used in Xiaomi Redmi Note 10)

- ➔ Offers 48 MP resolution at 15 frames per second
- ➔ Upto 4k resolution at 30 frames per second.
- ➔ 'Night mode' functionality improves the camera's performance.

[36]

# Transponder System

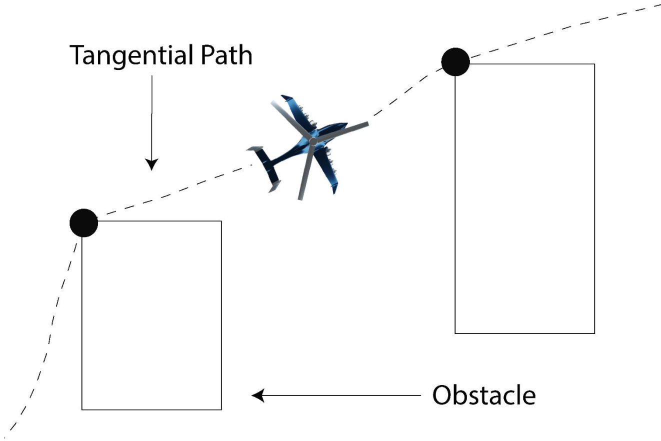
## Ping20S Mode S Transponder

- ➔ A transponder system is used to increase airspace awareness between UAVs, greatly reducing the risk of collision.
- ➔ It transmits information about the UAVs location, speed, and direction. This information is used by the DAA system to make an informed decision.

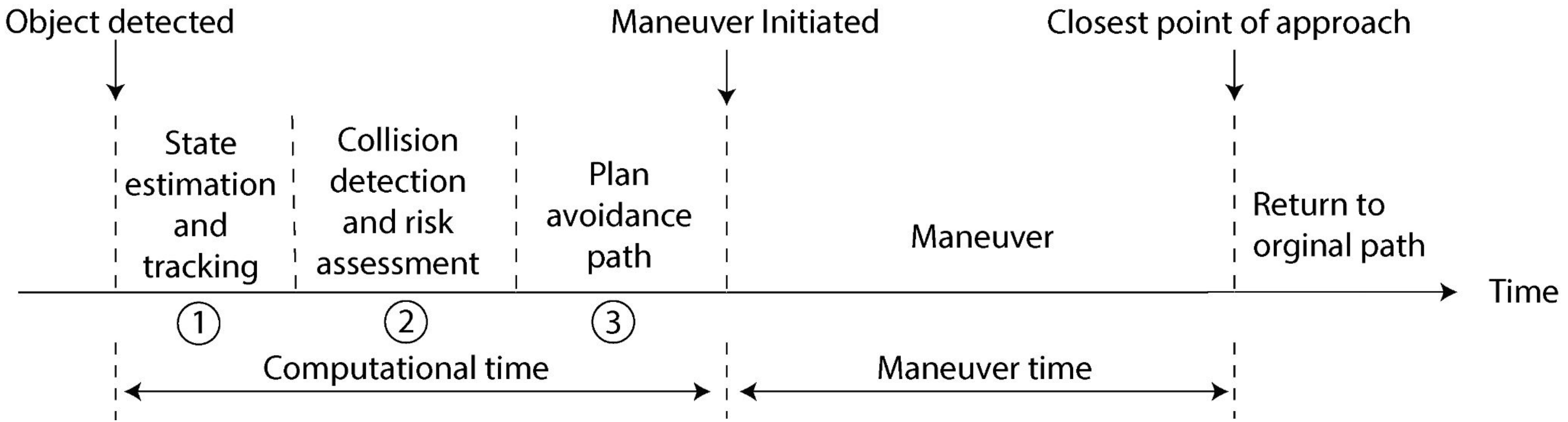

[37]

# DAA Algorithm : Integrated Tangent Bug

- ➔ Minimizes the heuristic distance so that the vehicle has to move minimum to reach the desired location.
- ➔ Works effectively in dynamic as well as static environments
- ➔ Tangential Movement: If the UAV encounters an obstacle, the algorithm finds the edges of the obstacle. Then, the vehicle moves past the edge (which gives the shortest path to the goal) tangentially.
- ➔ The algorithm also checks if there is any point to move to which is closer to the goal than any point on the obstacle, if yes then the vehicle moves towards it, if not, then this is terminated and the aircraft continues to avoid the obstacle.



# Collision Avoidance Algorithm



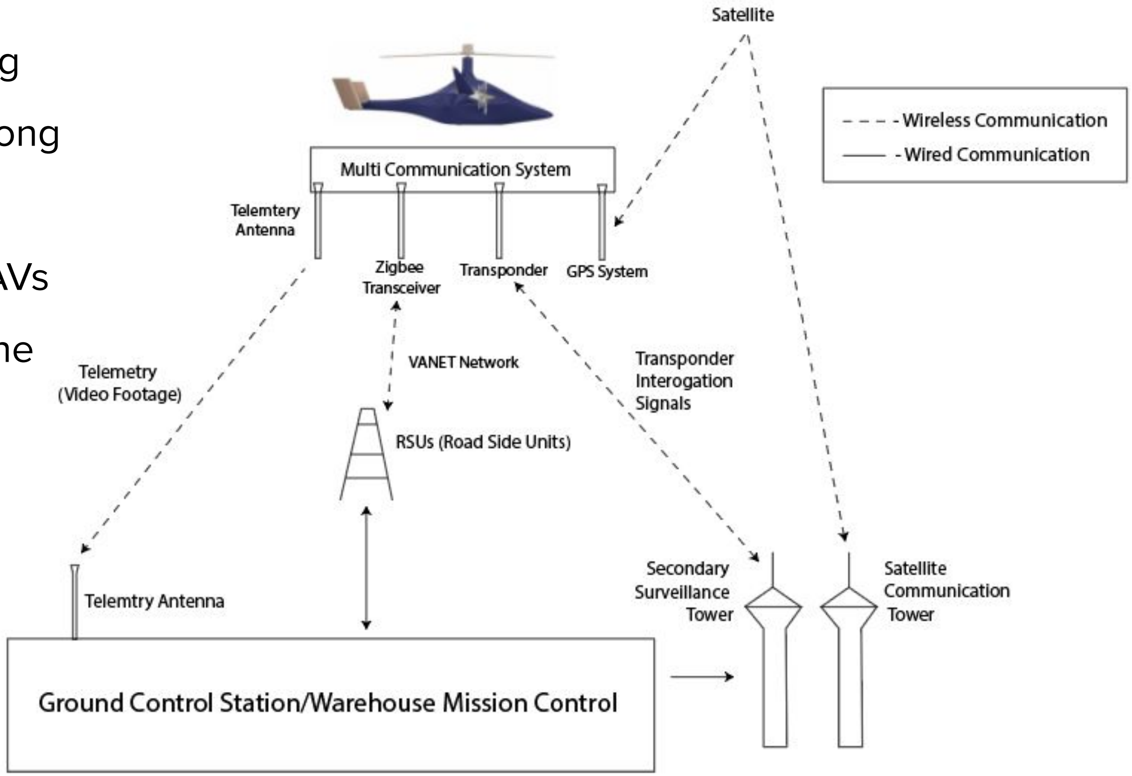

- ➔ The decision of diverting from the UAVs original flight path is made at a safe distance from the obstacle, for this, 2 sets of system factors are accounted for.
- ➔ Set 1: Strength of the signal, frequency, transmitter and receiver parameters.
- ➔ Set 2: Physical capabilities, transmission by other UAVs

# Collision Avoidance Algorithm

- ➔ Transmission characteristics and external factors are taken into account to determine $D_{min}$ (minimum distance) and $D_{max}$ (maximum distance) to prevent collision.
- ➔ The algorithm is trained to prevent different collision scenarios such as ‘head on’ collision for a safer flight.
- ➔ The data from the algorithm, $D_{min}$ and $D_{max}$ values are finally used to prevent collisions.

# Ground Control Station (GCS)

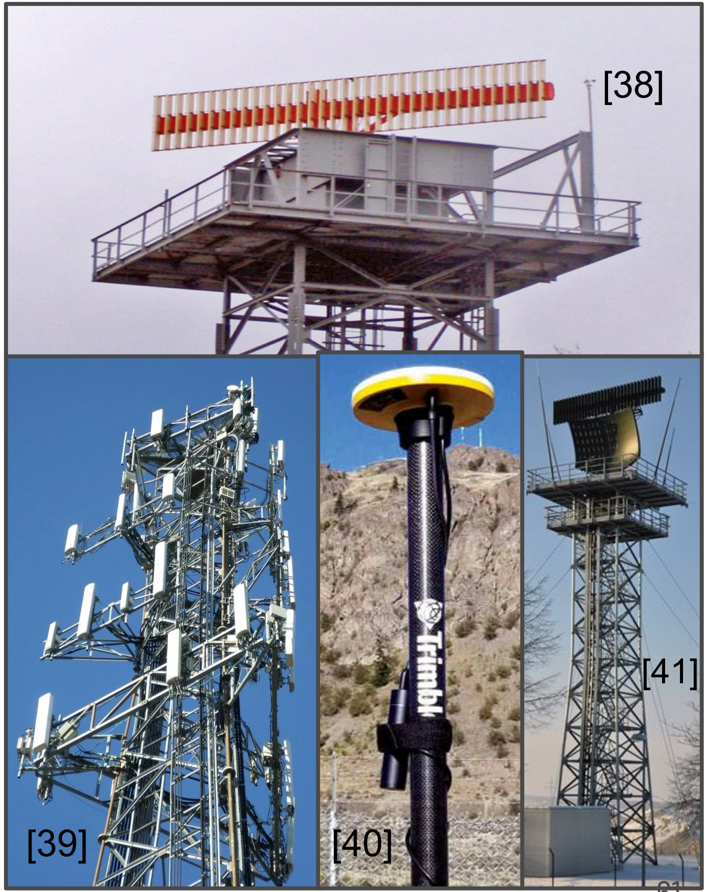
- ➔ Proprietary VANET network consisting of Road Side Units (RSUs) are built along side the flight path.
- ➔ These RSUs provide data to other UAVs through the Zigbee protocol and to the GCS through a wired connection.
- ➔ The GCS analyses this data and provides a flight path for the UAVs.



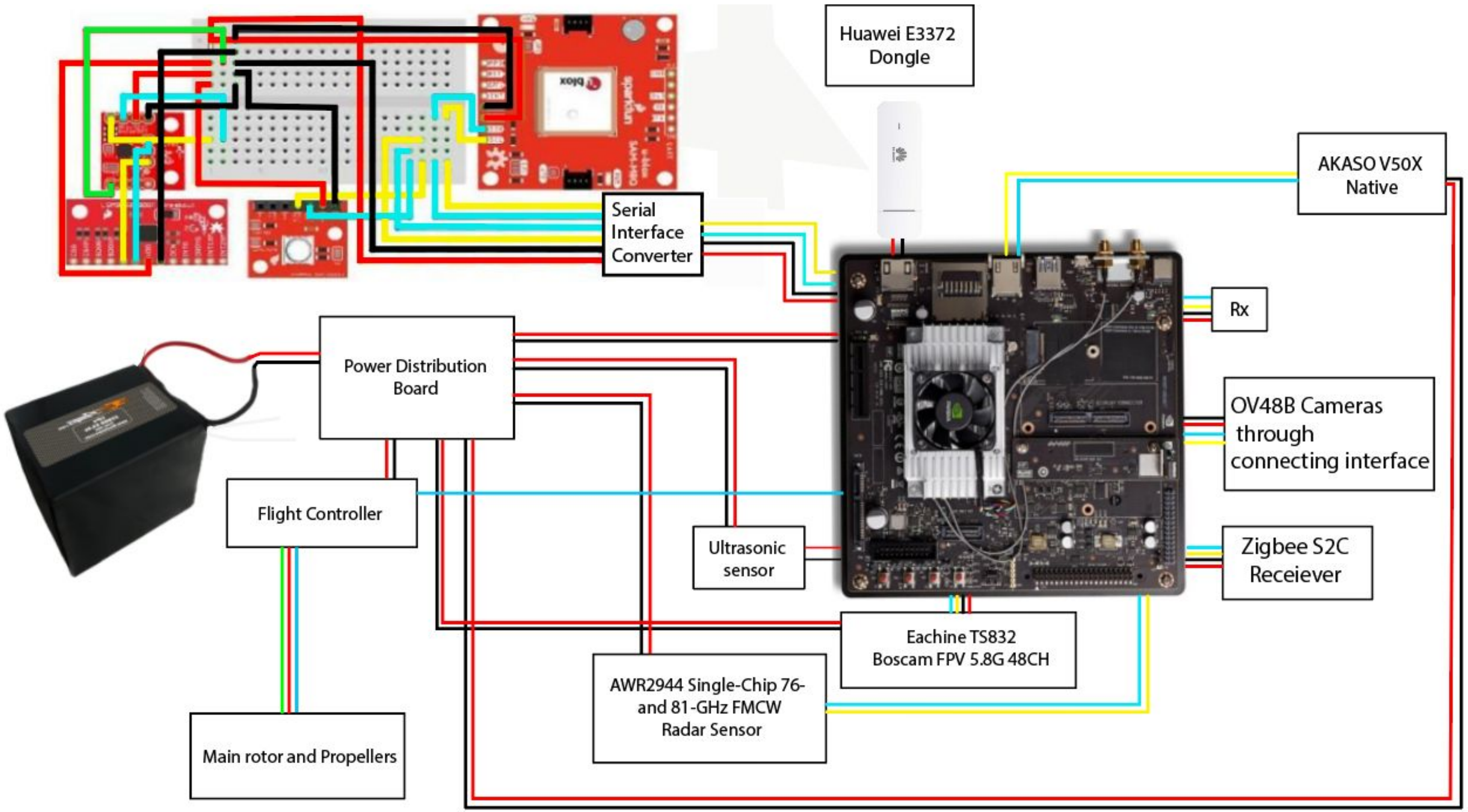
# GCS Communication

Communication Towers

- Satellite Tower
  - For GNSS Communication
- Primary Surveillance Tower
  - For Detecting distance of UAVs through radio waves
- Secondary Surveillance Tower
  - For sending interrogation signals to transponders



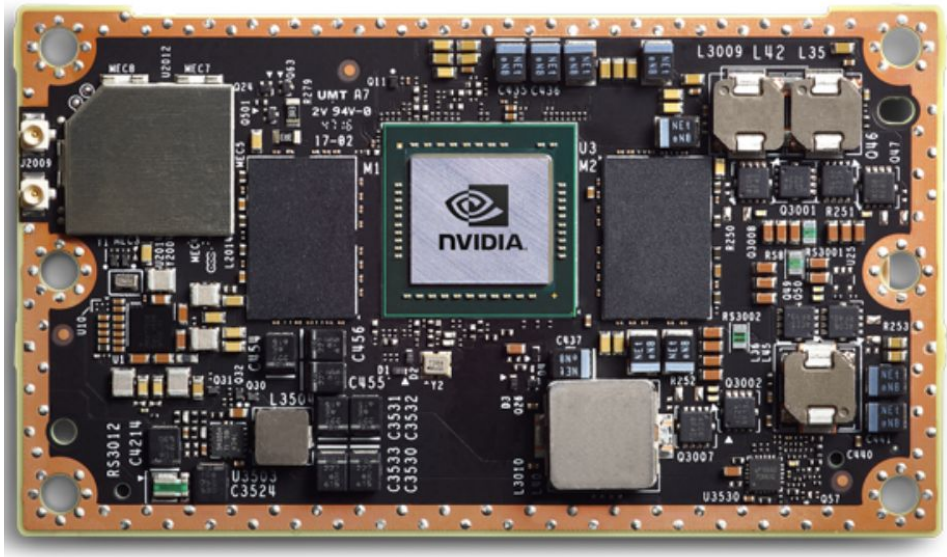
# Final Circuitry



# Additional Components

## Nvidia Jetson TX2

- ➔ It is the fastest AI computing device
- ➔ Most power-efficient
- ➔ Low power consumption of 7.5 W
- ➔ 8GB of memory
- ➔ 59.7GB/s of memory bandwidth




[42]

## Radio Systems

This is used as the main form of communication for controlling the aircraft and for transmission of video footage.

These components allow the safety pilots to control the UAV with the Logitech joysticks with ease.

The following transmitters and receivers are used

➔ **Turnigy T6A-V2 AFHDS**

➔ **Eachine TS832 Boscam**

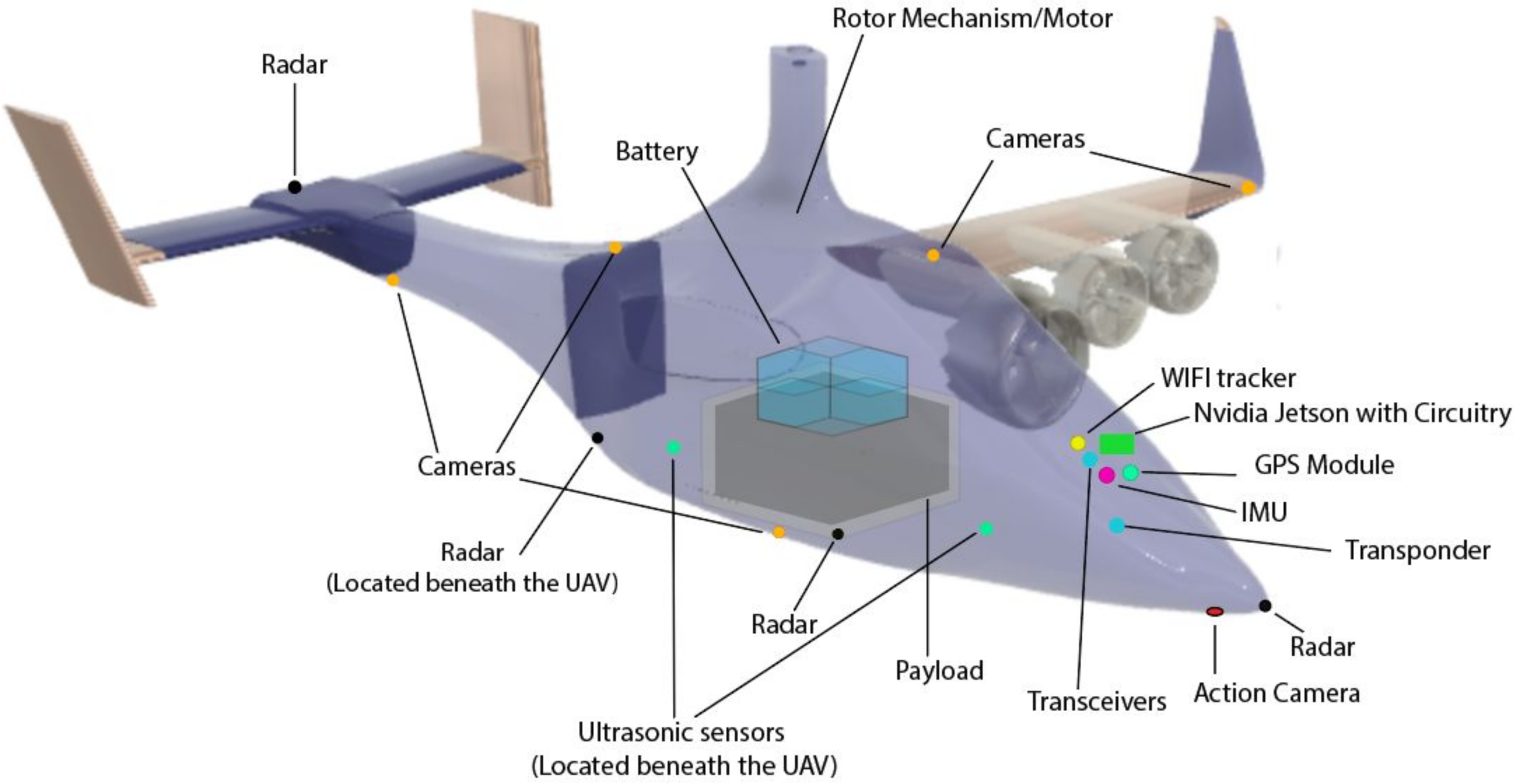
➔ **5.8GHz 48CH FPV AV Receiver (RC832)**


[44]


[43]


[45]

# Component Placement



# Ground Support Equipment

## Dell Inspiron 15 Touchscreen Laptop


[46]

- ➔ Intel Core i7
- ➔ 16GB RAM
- ➔ 6-Cell Battery

## Galaxy Tab S7 FE


[47]

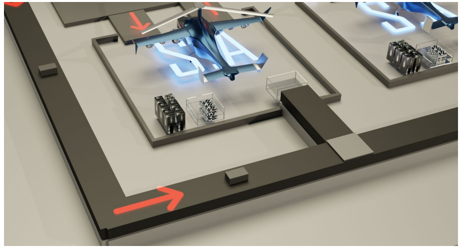
- ➔ Snapdragon 750G
- ➔ 128GB Storage
- ➔ 10500 mAh battery

## Logitech Extreme 3D Pro Gaming Joystick


[48]

- ➔ Simple setup
- ➔ Precision Twist Control
- ➔ Programmable Buttons

## Conveyor Belts


[49]

- ➔ 150m$^2$
- ➔ \$13/m$^2$
- ➔ \$1300

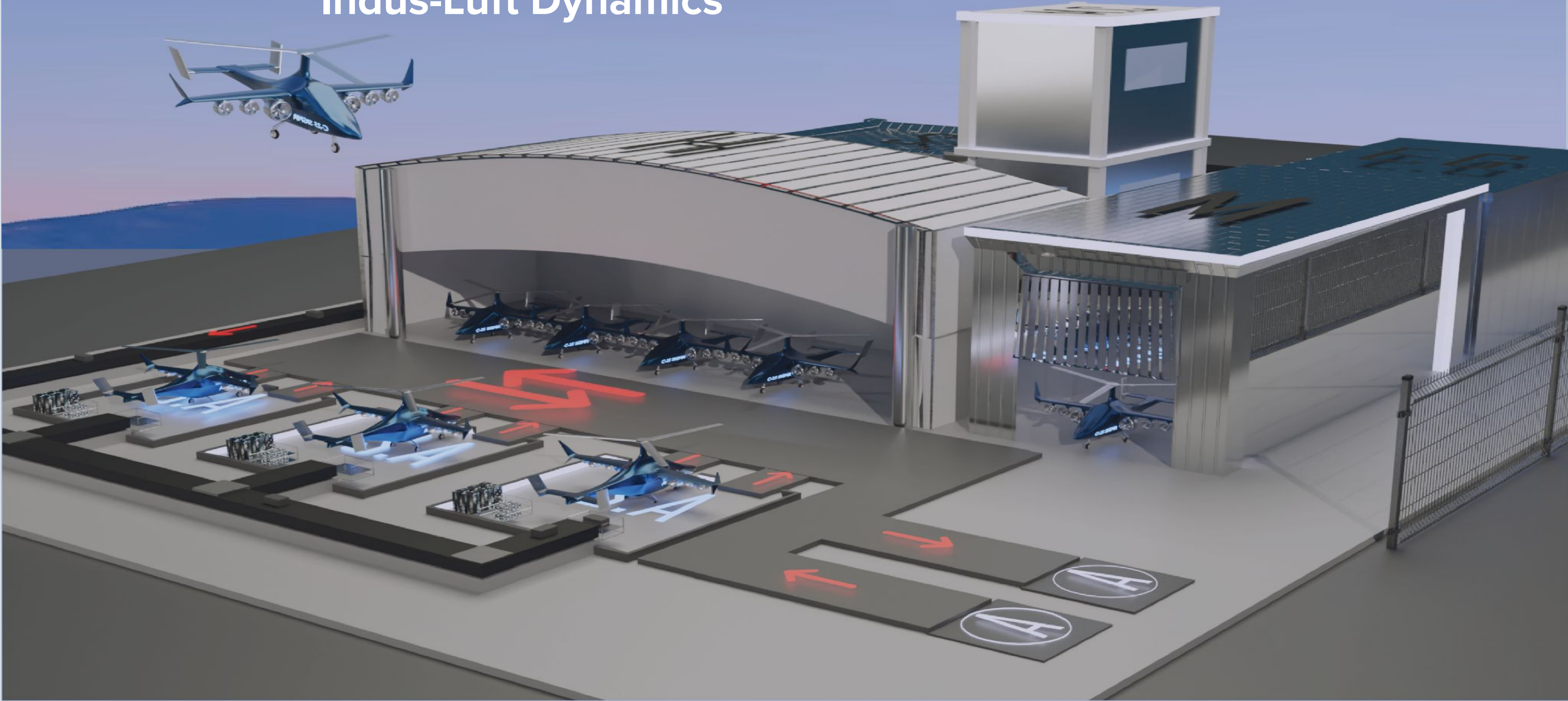
# Ground Support Personnel

| Roles | Number of Employees | Duration Per Day |
|---|---|---|
| Air Traffic Manager | 3 | 11 Hours |
| Supervisor | 1 | 12 Hours |
| Operational Pilot | 5 | 11 Hours |
| Electrician/Technician | 1 | 1.5 Hours |
| Emergency Responders | 2 | 11 Hours |
| Safety Pilot | 2 | 11 Hours |
| Payload Operator | 2 | 11 Hours |
| Range Safety/Aircraft Launch & Recovery/Maintenance Recovery | 2 | 11 Hours |
| Launch and Recovery Assistants/Package Handlers | 3 | 11 Hours |
| Janitor | 1 | 6 Hours |

- ➔ A total staff of **22** employees will help with operations.
- ➔ Workers will work in shifts to ease the workload on individual employees.
- ➔ A comprehensive distribution of tasks among employees and a proper semi-automated warehouse system were key cornerstones in our ground support setup.

# Concept of Operations

## Indus-Luft Dynamics



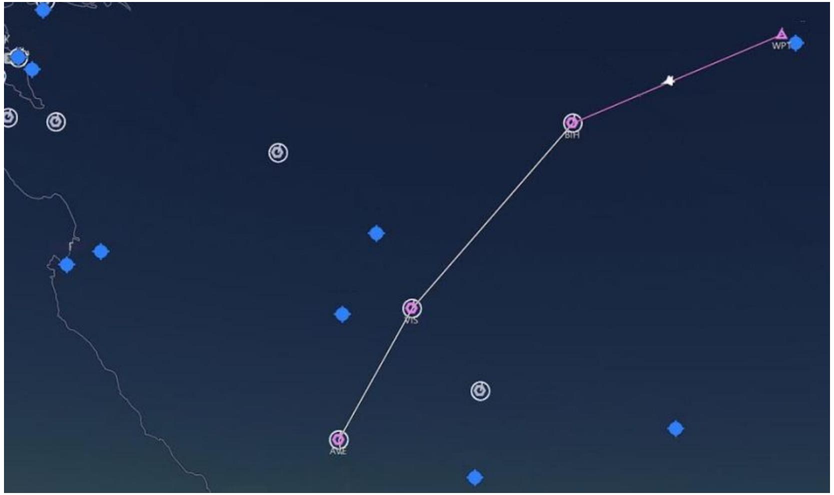
# Pre-Mission

- ➔ **12 hour window** for warehouse operations (0700 hours to 1900 hours local time)
  - ◆ **11 hour window** for flight operations (0730 hours to 1830 hours local time)
- ➔ A comprehensive **Warehouse Management System** powered by **Oracle NetSuite** is used for managing warehouse operations
- ➔ **Proprietary Company Website/Mobile Application** for confirming deliveries/tracking delivery progress, aided by the usage of printed **Barcode stickers** on the packages.
- ➔ Flight plans are individually prepared for UAVs.
- ➔ Checks completed and packages loaded in the UAV by Launch and Recovery Assistants/Package Handlers before UAVs depart.

1. Delivery is confirmed via app/website before operations.
2. Warehouse opens, flight plans made.
3. All Pre-Flight Checks are conducted.
4. UAV takes off after confirmation from CUTC and WMC.

# Flight Plan Generation

- ➔ **Lido Flight 4D** is used to generate detailed flight plans for every UAV, including crucial information like altitude, airspeed, etc.
- ➔ Flight plans are made in accordance to weather information, and also based on any specifications provided by the local airspace authorities.
- ➔ Known obstacles will be accounted for in the UAVs flight plan, and measures to avoid these obstacles will be pre-programmed.



# Aircraft Statistics

- ➔ The total time for one ideal UAV flight (including the turnaround time) was calculated to be approximately **50 minutes**.
- ➔ The total fleet size, i.e. the total number of aircraft used, would be **24 UAVs**.
- ➔ The number of flights made by one UAV per operational day was calculated to be **13**.
- ➔ There will be **19 aircraft in the air at one time** (under the 20 limit as required by the challenge.)

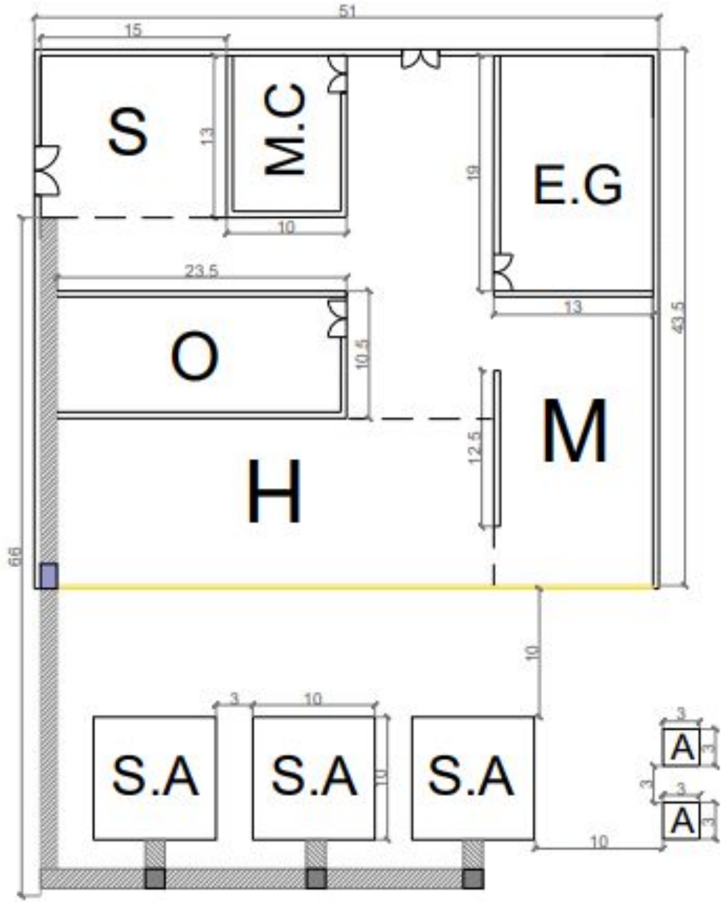
# Procedural Checklist

A checklist highlighting the various tasks and the approximate times taken to complete them will be used, like the one given below:

**Pre - Mission Checklist**
*Ground Personnel*

| Task | Time | Personnel |
|---|---|---|
| Bringing out the UAV from the hanger | ~5 min | Aircraft Launch & Recovery |
| Replacing/putting in batteries | ~5 min | Package Handlers |
| Scanning packages | ~2 min | Package Handlers |
| Programming flight paths | ~3 min | Payload Operator |
| Package Loading | ~5 min | Package Handlers |
| Rolling out UAV from the Staging Areas | ~5 min | Aircraft Launch & Recovery |
| Awaiting takeoff clearance from CUTC | ~ 3 min | Air Traffic Managers |
| Final Takeoff (Power up + Lift off) | ~ 2 min | Operational Pilots |

# Warehouse Layout Sketch

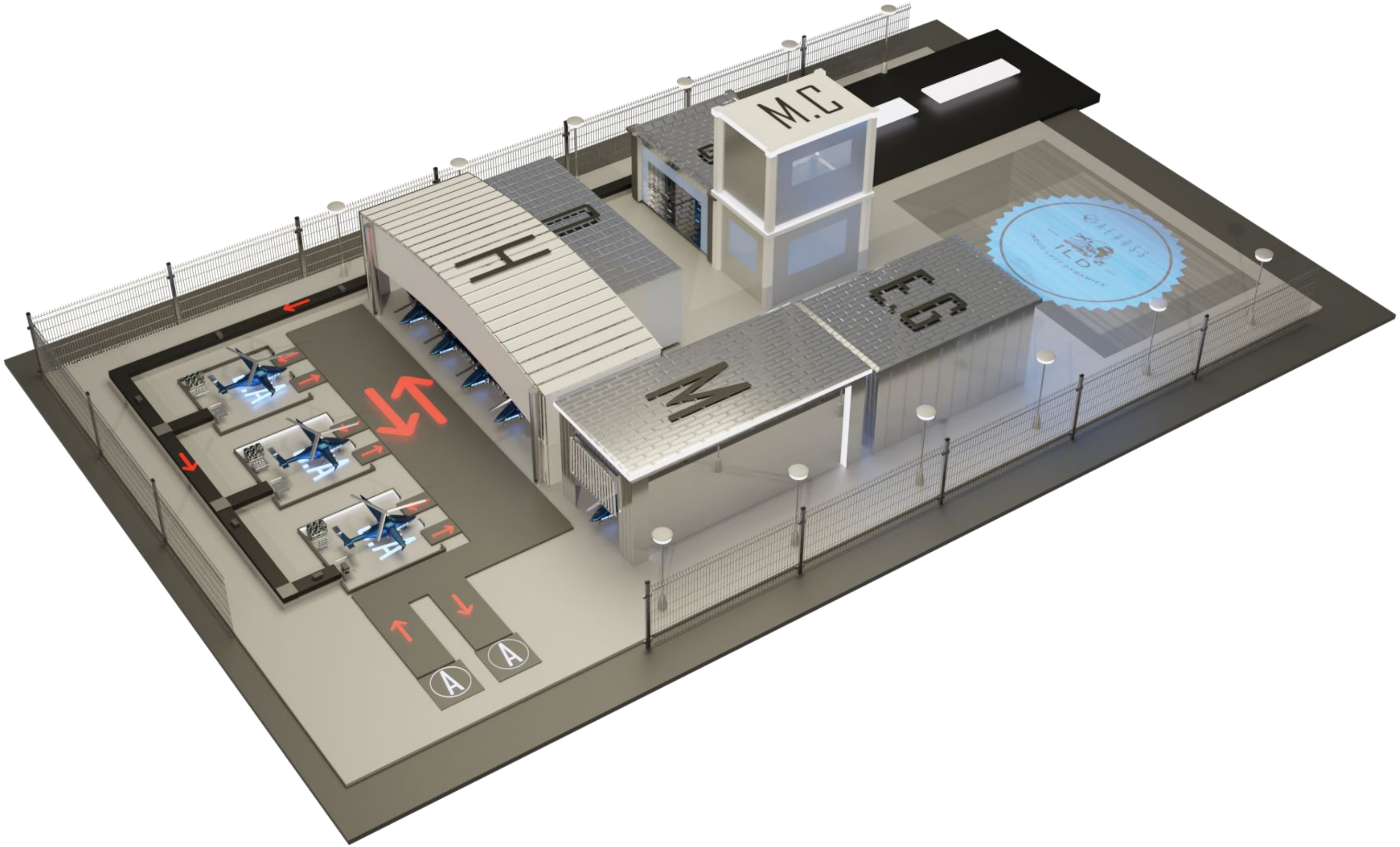



LEGEND

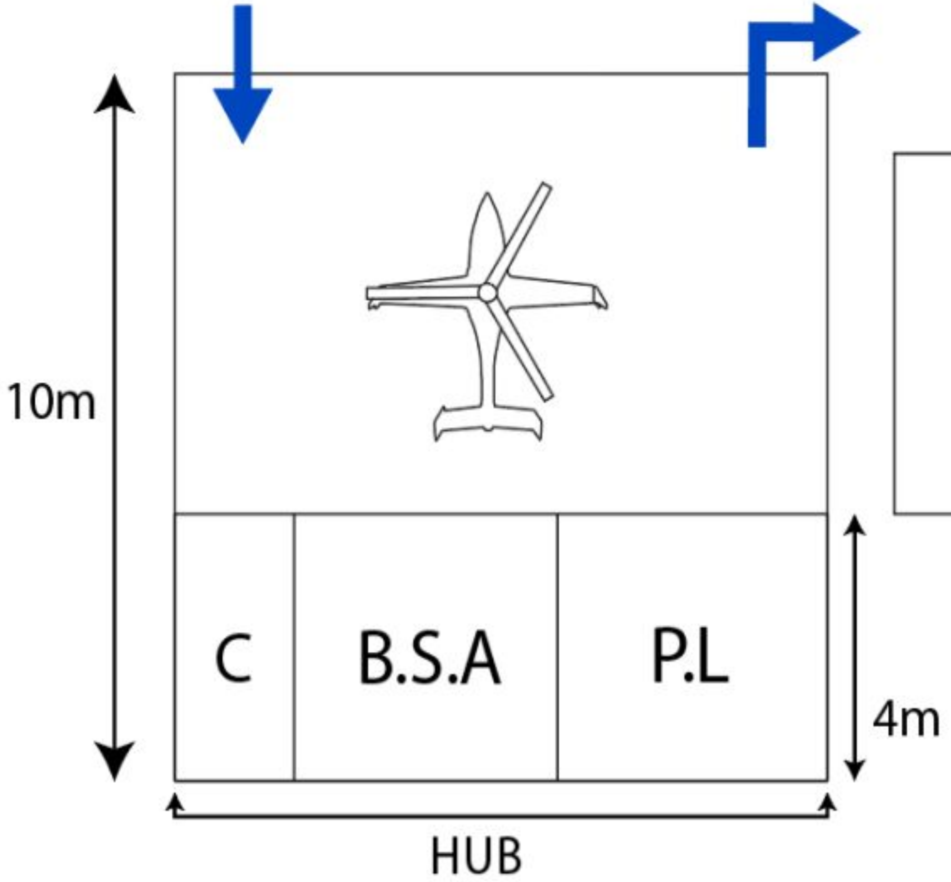
M.C - Mission Control
M - Maintenance
H - Hangar
E.G - Electrical Grid
O - Office
S.A - Staging Area
- Conveyer Belt
- Sliding Hangar Doors
A - Takeoff / Landing Area
- Omni Directional Belt
S - Storage
– – - Demarcation of Area
- Bar Code Scanner

(All dimensions are given in meters)

# 3D Warehouse Layout



# Staging Area Layout




Legend

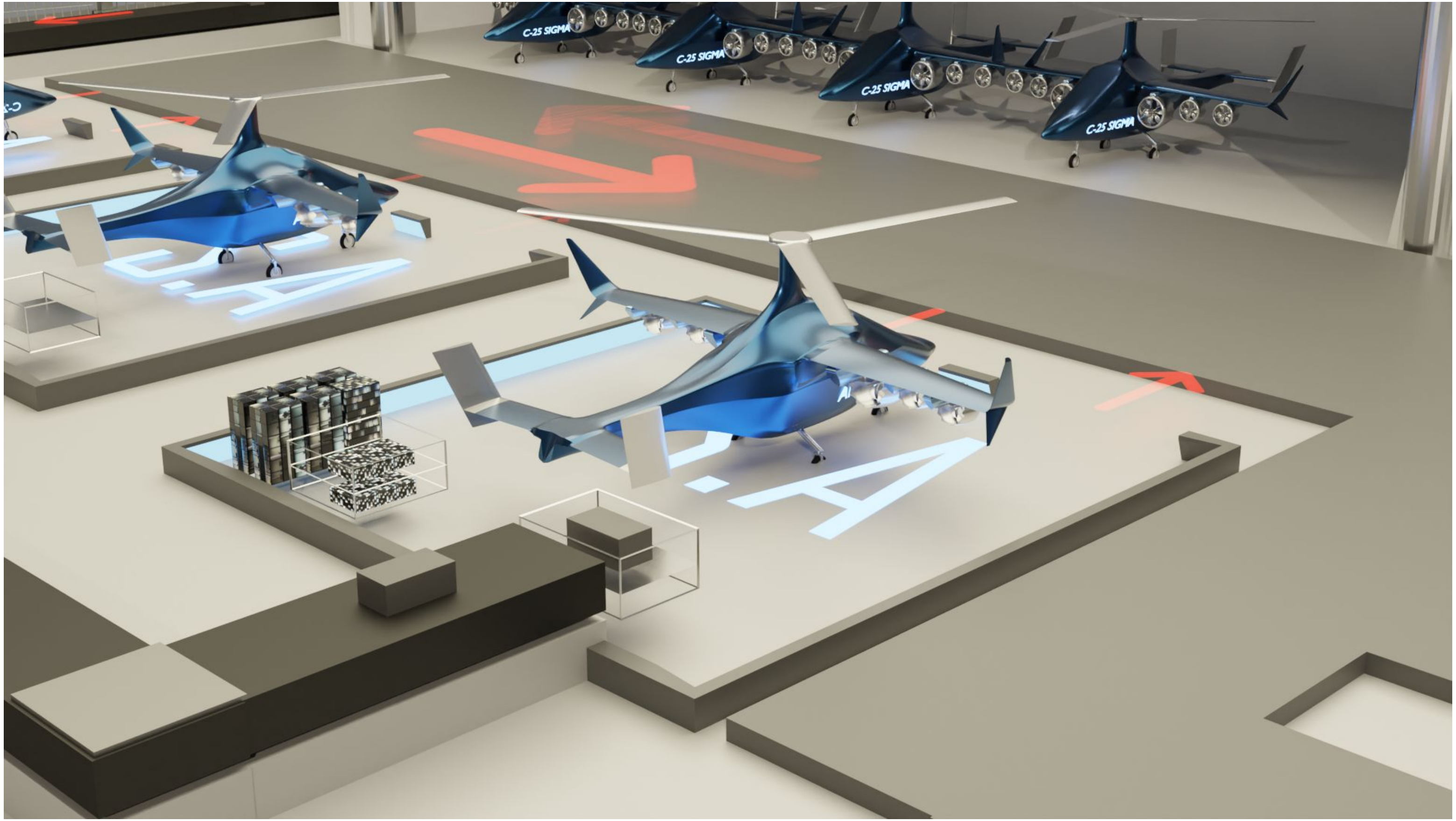
B.S.A - Battery Swap Area

C - Charging Pod

P.L - Package Loading

→ - Entrance & Exit Ramps

# 3D Staging Area Layout

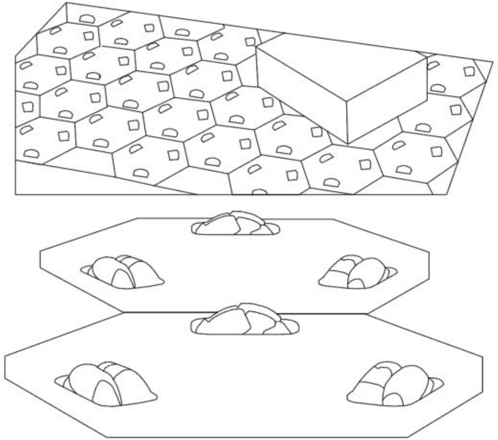


# Salient Warehouse Features

Some of our innovative warehouse features that expedite our operations are:

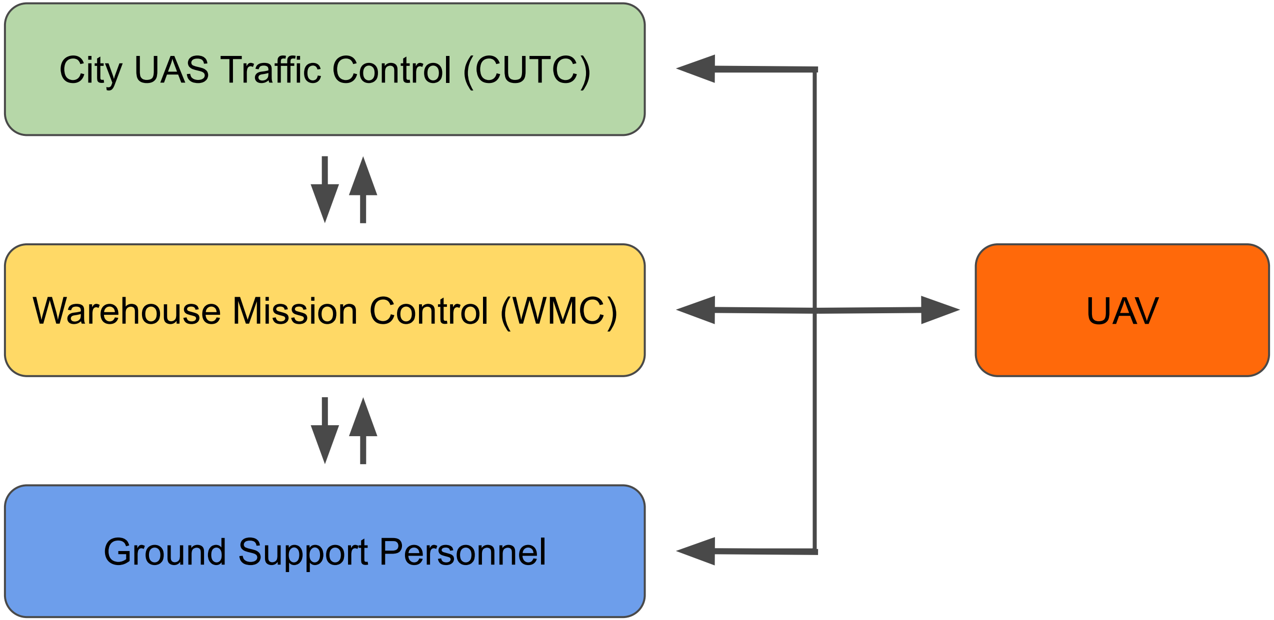

Our state-of-the-art custom **Storage Bots** promise a highly optimal flow of packages within the warehouse.

The implementation of pre-programmed **Omni-directional belts** helps streamline the package sorting process.



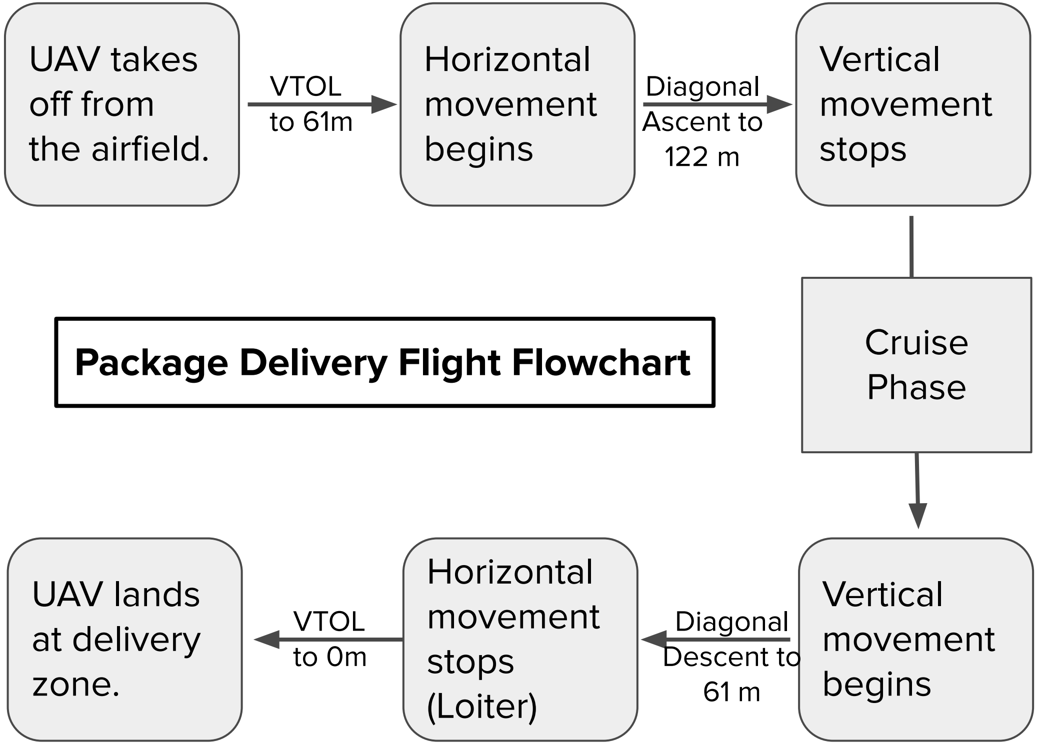
# Clearance Hierarchy

➔ Our UAS will have an intricate hierarchy of clearances, as depicted by the given flowchart.



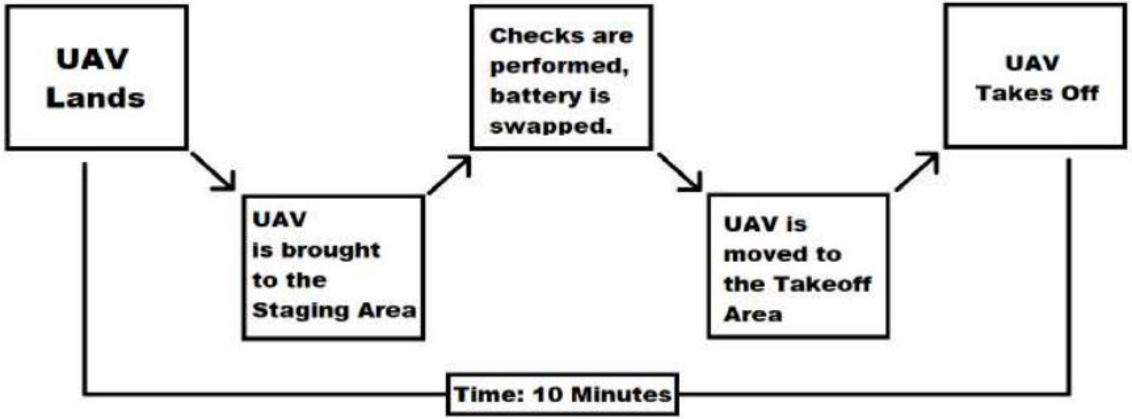
# Package Delivery Flight

- ➔ The delivery areas are located at a **15 km** radius from the UAS airfield.
- ➔ The aircraft flies to the delivery location and returns to the UAS airfield in a cycle time of about **50 minutes**, including all necessary loiter times.
- ➔ Constant communication is maintained between the CUTC, WMC, and the UAV. Cameras and sensors provide a real-time feed to the pilots.
- ➔ The UAV lands at the delivery area, has the package removed by the customer, and then takes off to return to the UAS airfield.



# Post-Mission

➔ After each flight, UAVs will be "turned around" for another delivery within a span of **10 minutes** as shown in the flowchart.




➔ A thorough set of checks will be conducted on the UAV, replacing batteries, examining the fuselage, and an analysis all **electronic systems/hydraulics**.

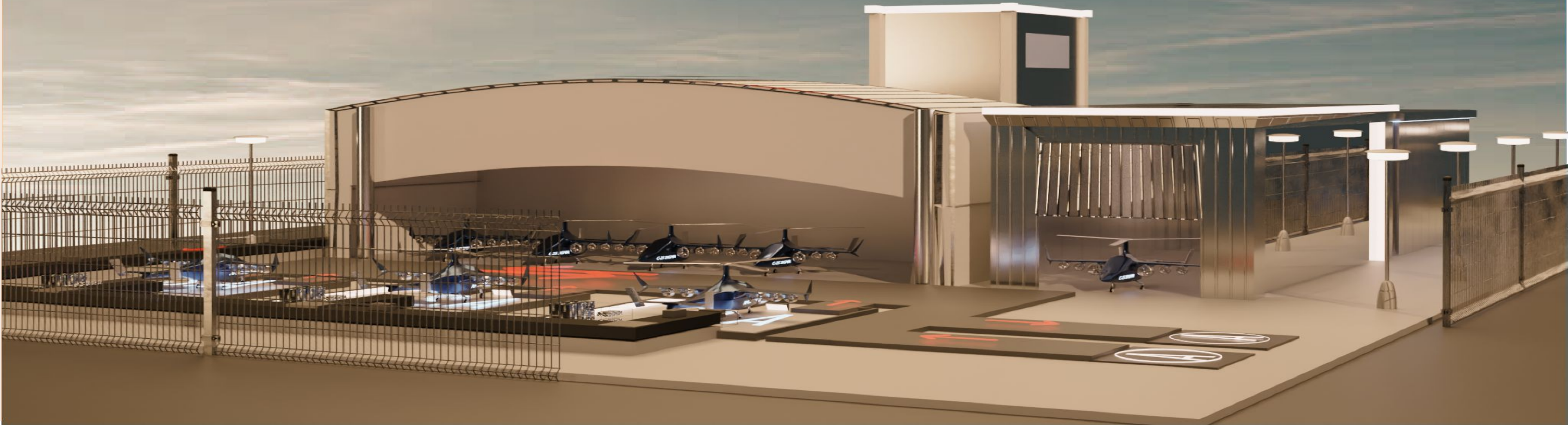
➔ At different time intervals, frequent inspections will be performed on the UAV to ensure the operability of all aircraft.

- For example, UAVs will undergo inspections at the **end of each operational day**.

  A comprehensive form of checks will be done on the entire fleet **at the beginning of each month**.

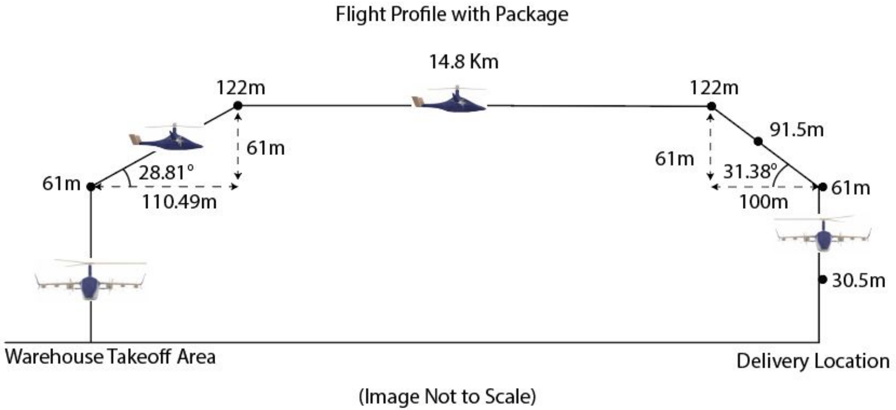
# Flight Profile Analysis

## Indus-Luft Dynamics

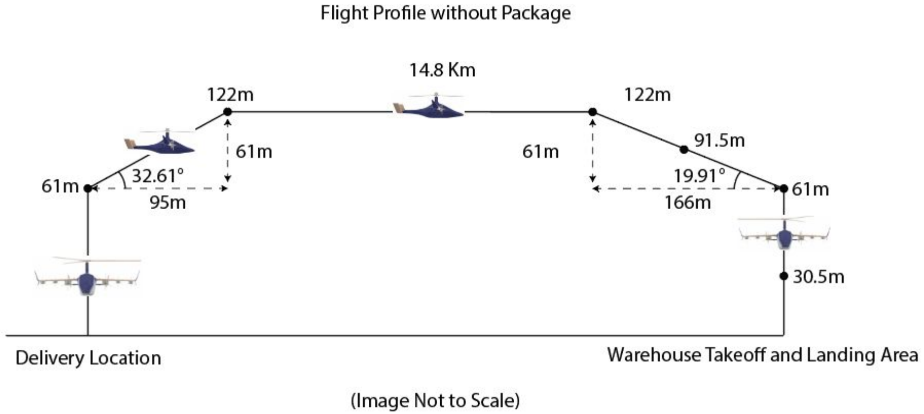


# The Two Phases

a) From Warehouse to Delivery Location (with package)




b) Return Flight to Warehouse (without package)



# Warehouse to Delivery Zone

Vertical Ascent - Initial ascent to 61 meters

Diagonal Ascent - The UAV gains horizontal velocity

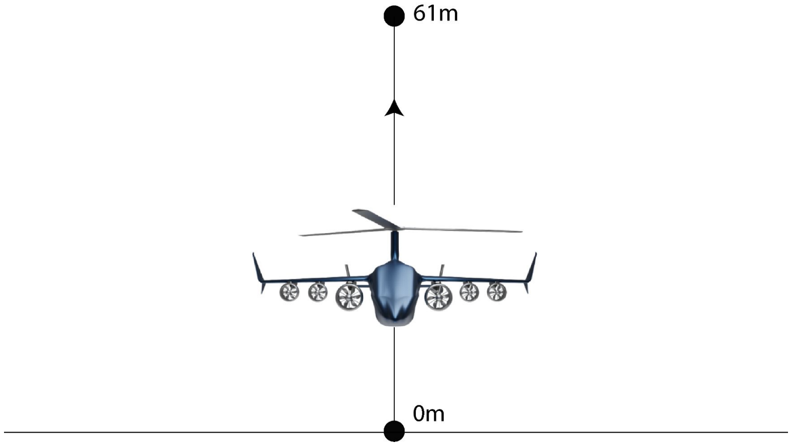
Cruise - Steady, sustained flight to the delivery location

Diagonal Descent - Descent with a gradual horizontal slowdown

Loiter - 10 minutes of loiter at 61 meters altitude

Vertical Descent - Gradual descent to the ground

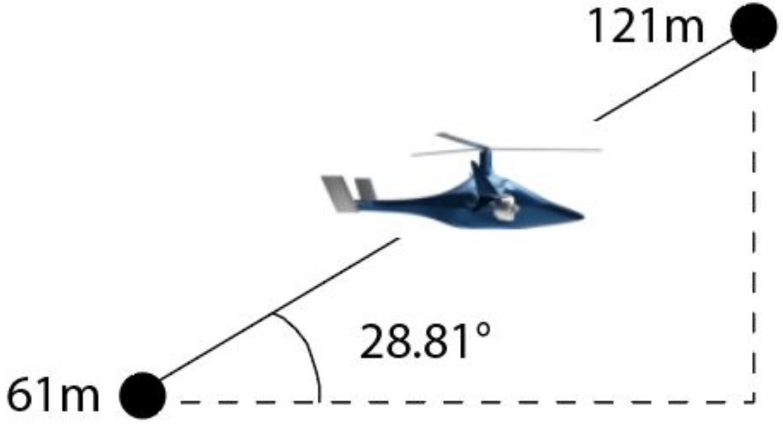
# Ascent With Package




Rotor Thrust - 345N

Acceleration - 4$m/s^2$

Power - 2.82kW




**Vertical**

Thrust - 145N

Acceleration - (-4)$m/s^2$

Power - 0.76kW

**Horizontal**

Thrust - 296N

Acceleration - 7.24$m/s^2$

Power (Big Propeller) - 0.945kW

Power (Small Propeller) - 0.771kW

# Cruise

### Vertical

Thrust - 245N

Acceleration - $0 m/s^2$

Power - 1.68kW

### Horizontal

Thrust - 115N

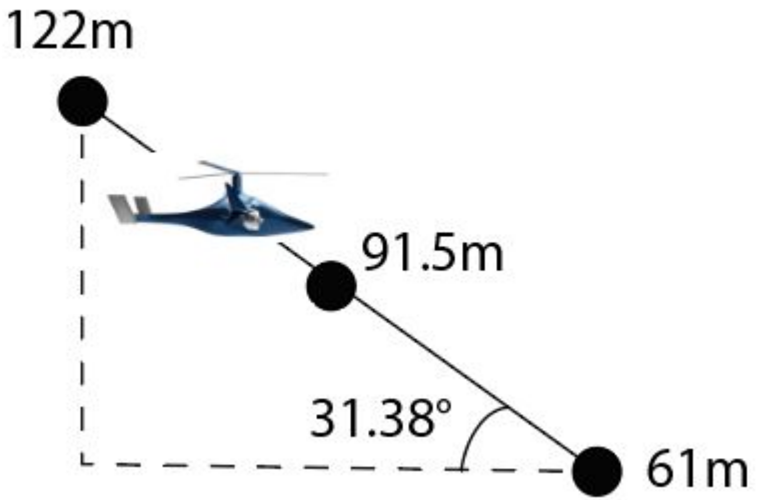
Acceleration - $0 m/s^2$

Velocity - 40m/s

Power (Big Propeller) - 0.228kW

Power (Small Propeller) - 0.186kW

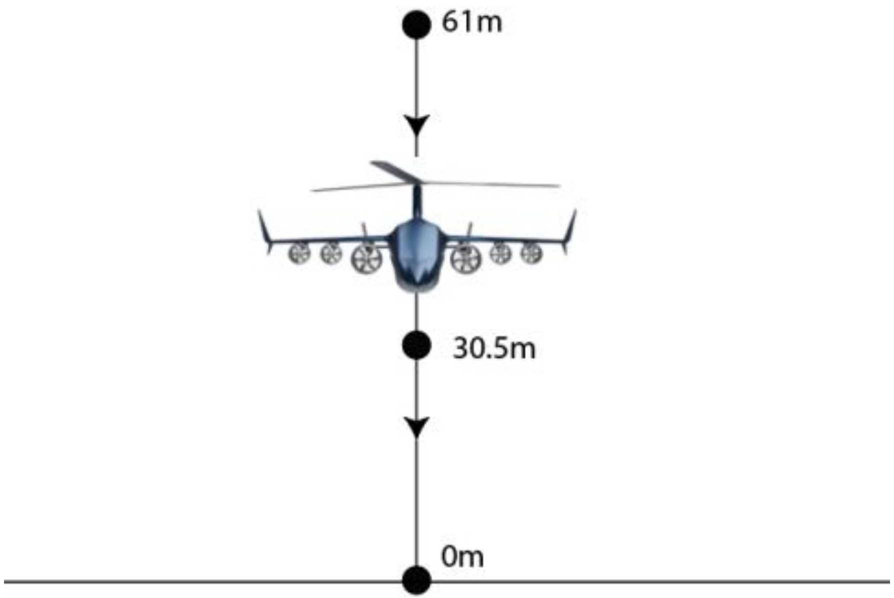
# Descent With Package




Rotor Thrust - 145N and 294.75N

Acceleration - (-4)m/$s^2$ and 1.99m/$s^2$

Power - 0.76kW and 2.22kW




Rotor Thrust - 145N and 294.75N

Acceleration - (-4)m/$s^2$ and 1.99m/$s^2$

Power - 0.76kW and 2.22kW

# Return Flight to Warehouse

**Vertical Ascent - Initial ascent to 61 meters altitude**

**Diagonal Ascent - The UAV gains horizontal velocity**

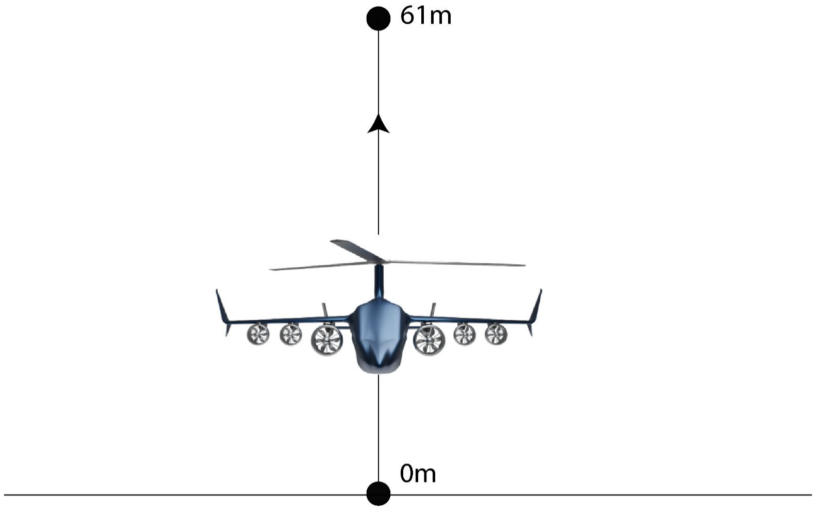
**Cruise - Steady, sustained flight back to the warehouse**

**Diagonal Descent - Descent with a gradual horizontal slowdown**

**Loiter (additional crosswind) - 10 minutes of loiter at 61 meters altitude with a special maneuver to deal with crosswind**

**Vertical Descent - Gradual descent to the ground**

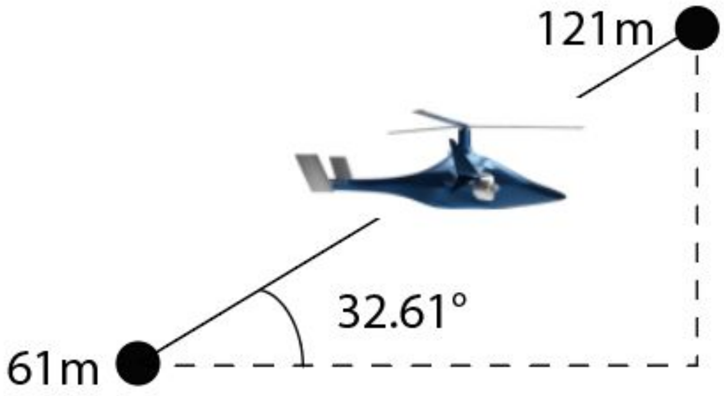
# Ascent Without Package




Rotor Thrust - 304.13N

Acceleration - 5.4m/s$^2$

Power - 2.02kW




**Vertical**

Thrust - 88.13N

Acceleration - (-5.4)m/s$^2$

Power - 0.55kW

**Horizontal**

Thrust - 283.4N

Acceleration - 8.42m/s$^2$

Power (Big Propeller) - 0.778kW

Power (Small Propeller) - 0.634kW

# Cruise

**Vertical**

Thrust - 196.13N

Acceleration - 0m/s$^2$

Power - 1.2kW

**Horizontal**

Thrust - 115N

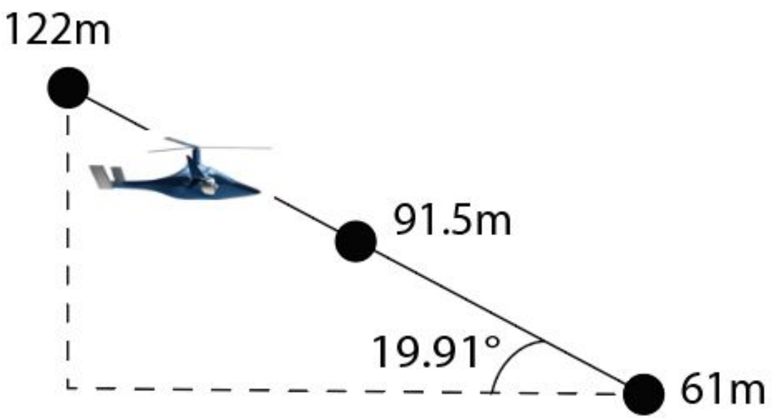
Acceleration - 0m/s$^2$

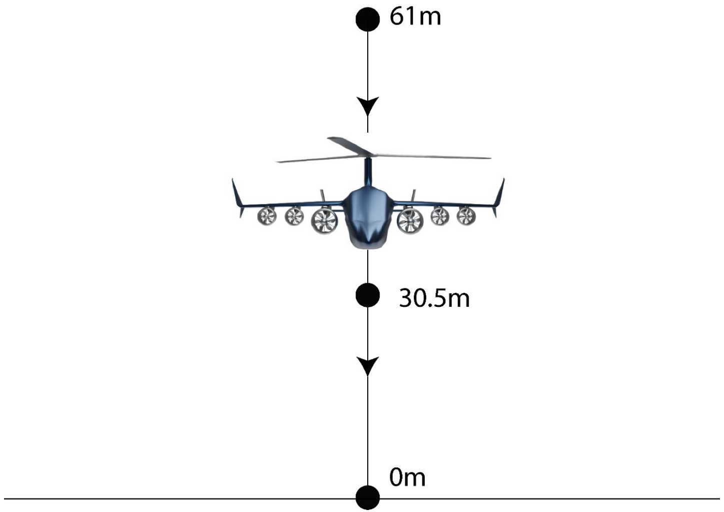
Velocity - 40m/s

Power (Big Propeller) - 0.228kW

Power (Small Propeller) - 0.186kW

# Descent Without Package




Rotor Thrust - 116.13N and 235.75N

Acceleration - (-4)m/s$^2$ and 4.82m/s$^2$

Power - 1kW and 1.59kW

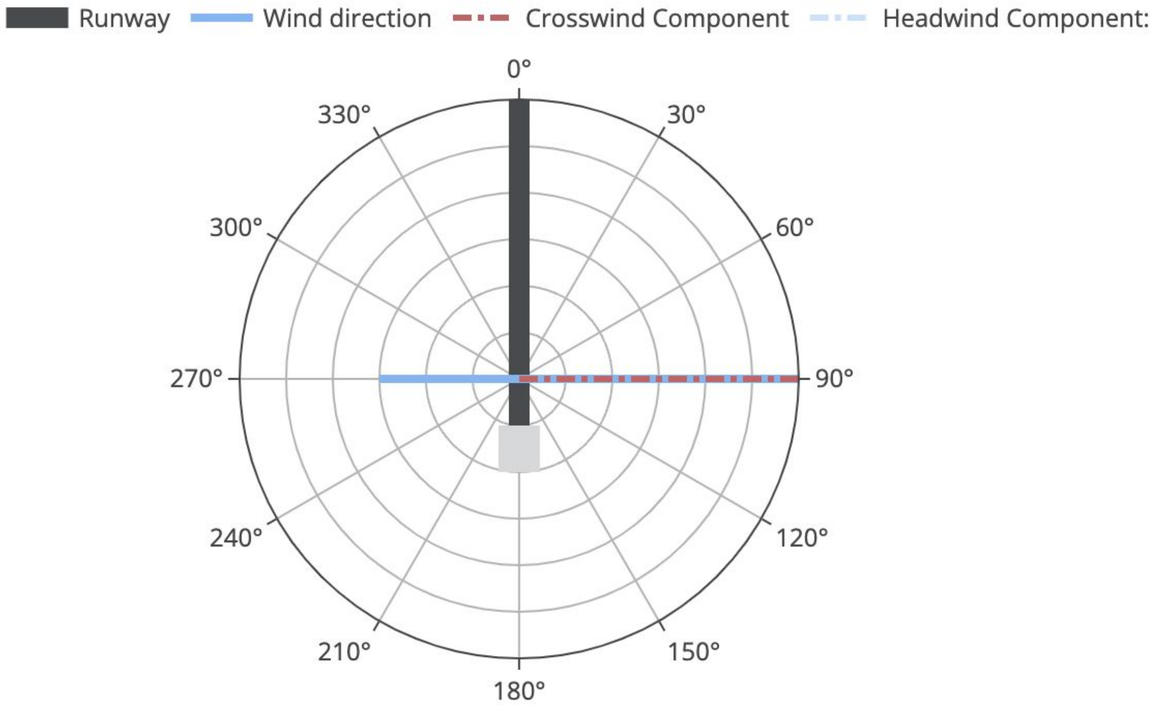
Rotor Thrust - 116.13N and 235.75N

Acceleration - (-4)m/s$^2$ and 4.82m/s$^2$

Power - 1kW and 1.59kW

# Dealing With The Crosswind

- ➔ The UAV is faced with a 10kt (5.14m/s) crosswind during its 10 minute loiter phase on return flight.
- ➔ A 15N thrust is required to counter the effects of the crosswind.
- ➔ A special maneuver using the yaw movement of the UAV will be conducted to counter the crosswind.



# Challenges Fixed

1. Limited ascent/descent distance
2. Loitering and additional time and power consumption
3. Crosswind
4. Maximising efficiency within speed and altitudinal limits
5. Physical Limits of the UAV

# Power Requirement and Batteries

- After the power calculations, the team found that the UAV had a power requirement of 2.733 kWh including all onboard sensor components.
- With the calculations, it was computed that the UAV would require a battery that could provide at least 61.55 Amp Hours.
- The team deemed a battery pack of three MaxAmps 12S 22Ah 44.4V batteries to be the most viable option. The three batteries together provided 66 Ah, which translated to 2.93 kWh.
- These batteries would allow the UAV to successfully complete its flight profile with a sufficient margin to spare as a redundancy.

# Safety Requirements

**Indus-Luft Dynamics**

# Lost Link Protocol

- ➔ A highly interconnected system allows for several redundancies in the case of a Lost Link. A scenario-based approach was used for determining an ideal protocol for such a situation.
- ➔ Upon first "realizing" that the link has been lost, the UAV will automatically attempt to re-establish communication by a pre-programmed procedure.
- ➔ The lost UAVs situation will be quickly evaluated, and the CUTC will be immediately notified by the air traffic manager in charge.
- ➔ Simultaneously, the UAV will compute the coordinates of the **Last Known Position (LKP)** at which the UAV had an established link. This position will be used as the basis of calculations for future decisions regarding the flight path.
- ➔ An emergency signal will also be broadcasted to other UAVs in the vicinity via the **Vehicular Ad-Hoc Network (VANET)** if possible.

# One Engine Out Condition

- ➔ With a design having six propellers and a fixed-wing design, it was deemed that there are **sufficient redundancies in our aircraft systems** to prevent a single engine failure from compromising the airworthiness of the aircraft.
- ➔ Acknowledging that an engine failure may occur at any flight phase, in most cases, the UAV will be able to return to the UAS airfield safely.
- ➔ If more than one engine fails and maintaining flight becomes impractical, the UAV will begin gliding and gradually descend.
- ➔ In case a failure of the main rotor occurs during the VTOL phase, all the propellers would immediately engage to commence an emergency forward flight, to prevent the UAV from entering a free-fall.
- ➔ In all scenarios, the UAV will notify the air traffic managers (Mission Control) at the Warehouse, who shall initiate emergency protocols if required.

# One Engine Out Condition

In all engine failure conditions, the Safety Pilots will take over control from the Operational Pilots. The Safety Pilot in charge will refer to a checklist similar to the one provided below for deciding an appropriate course of action:

## One Engine Out Checklist

*Safety Pilots*

**1) ENGINE OUT**

1.1) Identify engine(s) lost.
Also confirm availability of main rotor.

1.2) Confirm current flight phase of UAV.
Command immediate initiation of forward flight if in VTOL w/o main rotor.

1.3) Analyze airworthiness.
a) Altitude
b) Airspeed
c) Vertical speed
d) System functionalities
e) Extent of damage
f) Determine closest destination.
g) Decide between continuing flight or an emergency ditching.

**2) CONTINUING FLIGHT**

2.1) Find distance to closest landing destination.
2.2) Adjust propeller balance compensating for excessive yaw/roll.
2.3) Program a change in flight path if necessary.
2.4) Monitor the concerned UAV.

**3) EMERGENCY DITCHING**

3.1) Assess vertical speed.
3.2) Choose and approve location of emergency landing area.
3.3) Notify CUTC and issue an advisory for the landing vicinity.

*Inform authorities in case of any engine failure situation.*

# Emergency Landings

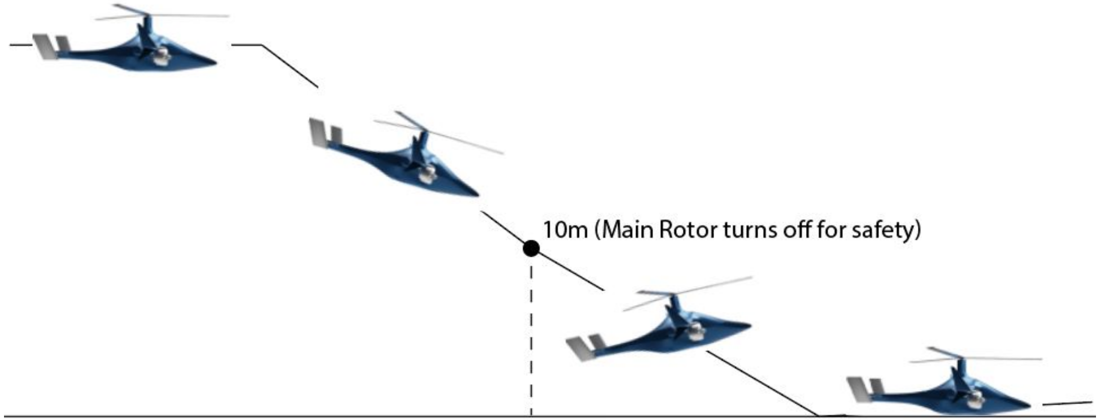
➔ Emergency Landings serve as a last resort, and will only be performed when resuming flight becomes impractical.

➔ As our UAV is a fixed-wing design, gliding will be utilised decisively to aid in an emergency landing.

➔ Ensuring there is no damage done to either people on the ground nor property was deemed to be paramount, and thus **a safe/ideal landing area will be scouted** by using the UAV's camera and sensor data.

## Ditching

- An initial gradual glide will be aided by additional lift generated by the main rotor.
- As the UAV approaches the ground, it will **pitch its nose up before impact** to reduce damage.
- Safety Components will activate before touchdown to alert bystanders.



# Safety Components

The team selected a few crucial components to help in alerting citizens in the vicinity as to the presence of the descending UAV and can serve multiple purposes.

The components chosen include:

1) **YoungRC JHE20B Buzzer:**

   This is a loud and capable buzzer which will emit an unmistakable 100 decibel auditory signal, alerting people in a 125 meter radius of the aircraft.

[50]

2) **Lume Cube Strobe Lights:**

   A powerful assortment of strobe lights, providing visual cues with a one-hertz fast strobe, and given it's rated at 500 lumens, it can be viewed from up to 4 km away.

[51]

*Parachutes were explicitly not chosen as they are impractical in a real-world application at our UAVs scale.*

# FAA Guidelines

Our UAS's compliance with FAA Regulations Part 107 has been summarised in the given table.

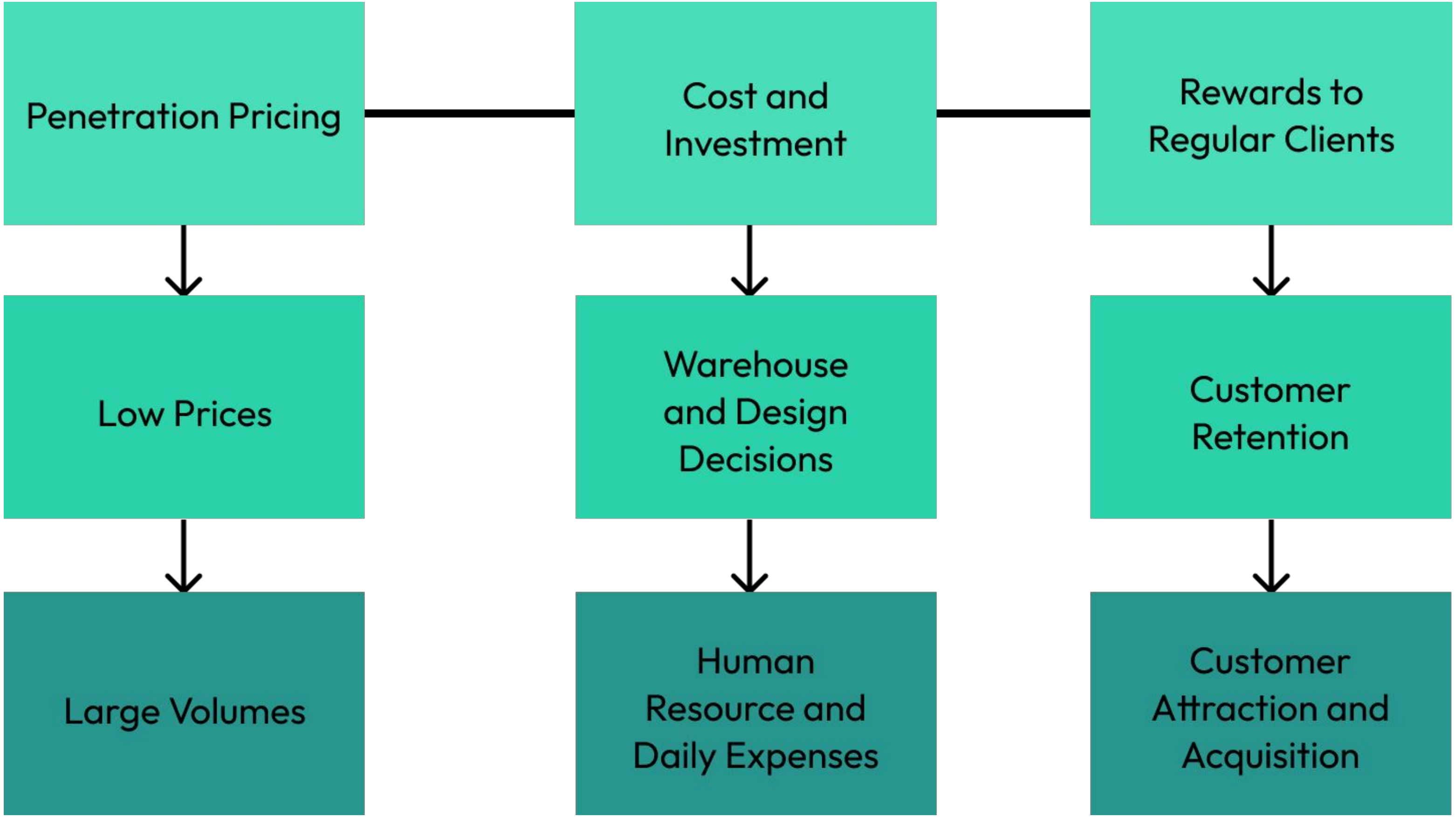
| FAA Regulations Part 107 | Specifications | Met |
|---|---|---|
| § 107 | The unmanned aircraft must weigh less than 55 lbs. (25 kg) | |
| § 107.15 | Requires preflight inspection by the pilot in command | |
| § 107.25 | Operations not in a covered structure/delivery not with moving UAV | |
| § 107.29 | Daylight-only operations, or during civil twilight. | |
| § 107.31 | Aircraft must always be within Visual Line of Sight. | |
| § 107.37(a) | Right of Way must be yielded to other aircraft. | |
| § 107.51 | A maximum altitude of 400 feet above ground level (AGL). | |

The UAS also complies with several requirements posed in Part 135 of FAA's regulations.

# Business Case

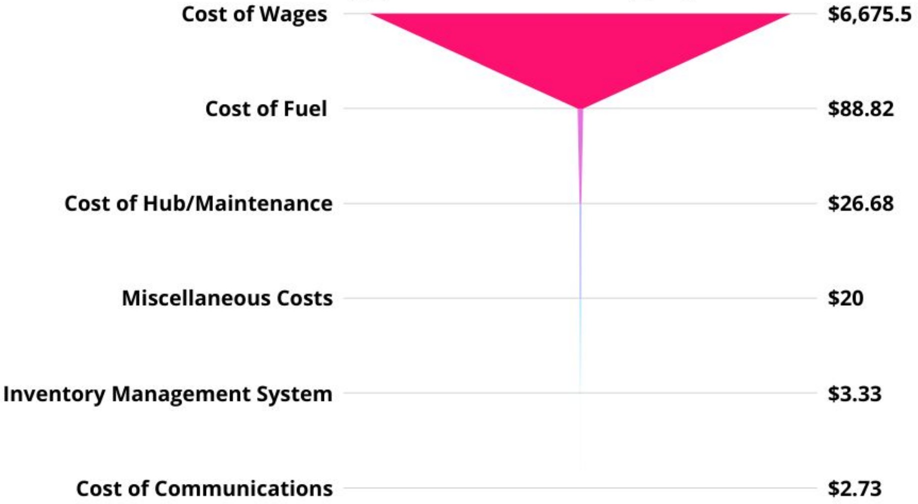
## Indus-Luft Dynamics

# Strategy - Salient Features

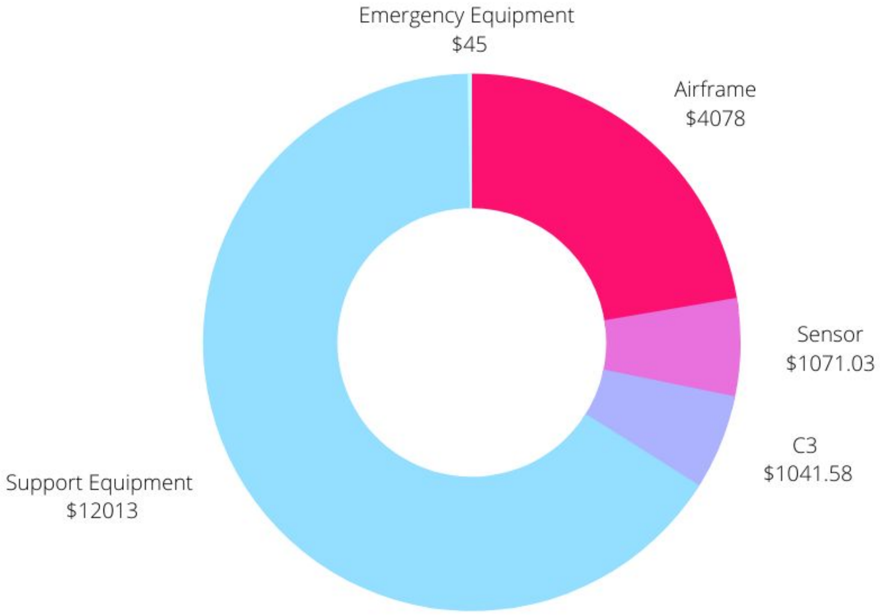


# Cost Summary

## Funnel Graph for Operating Costs (per day)

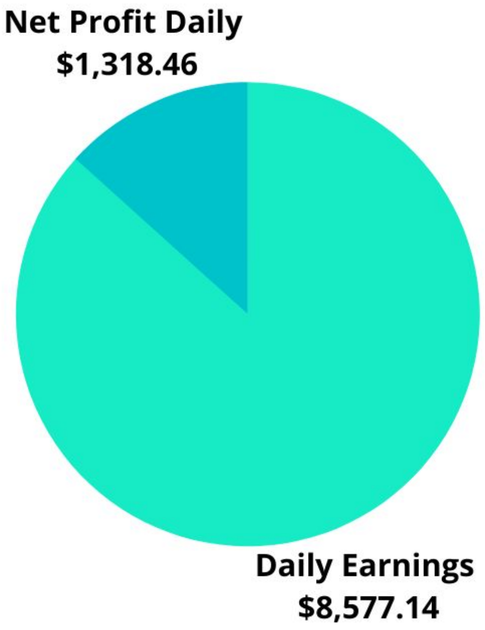



## Donut Chart for Fixed Costs

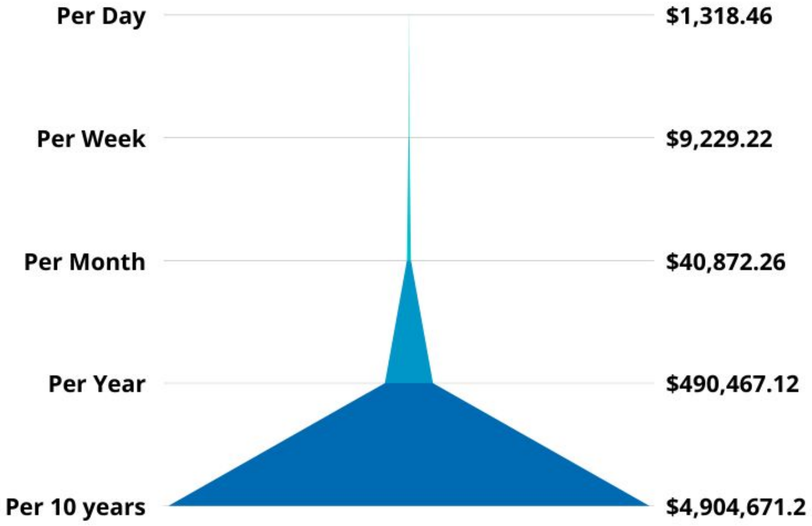


# Penetration Pricing

## Revenue Earned

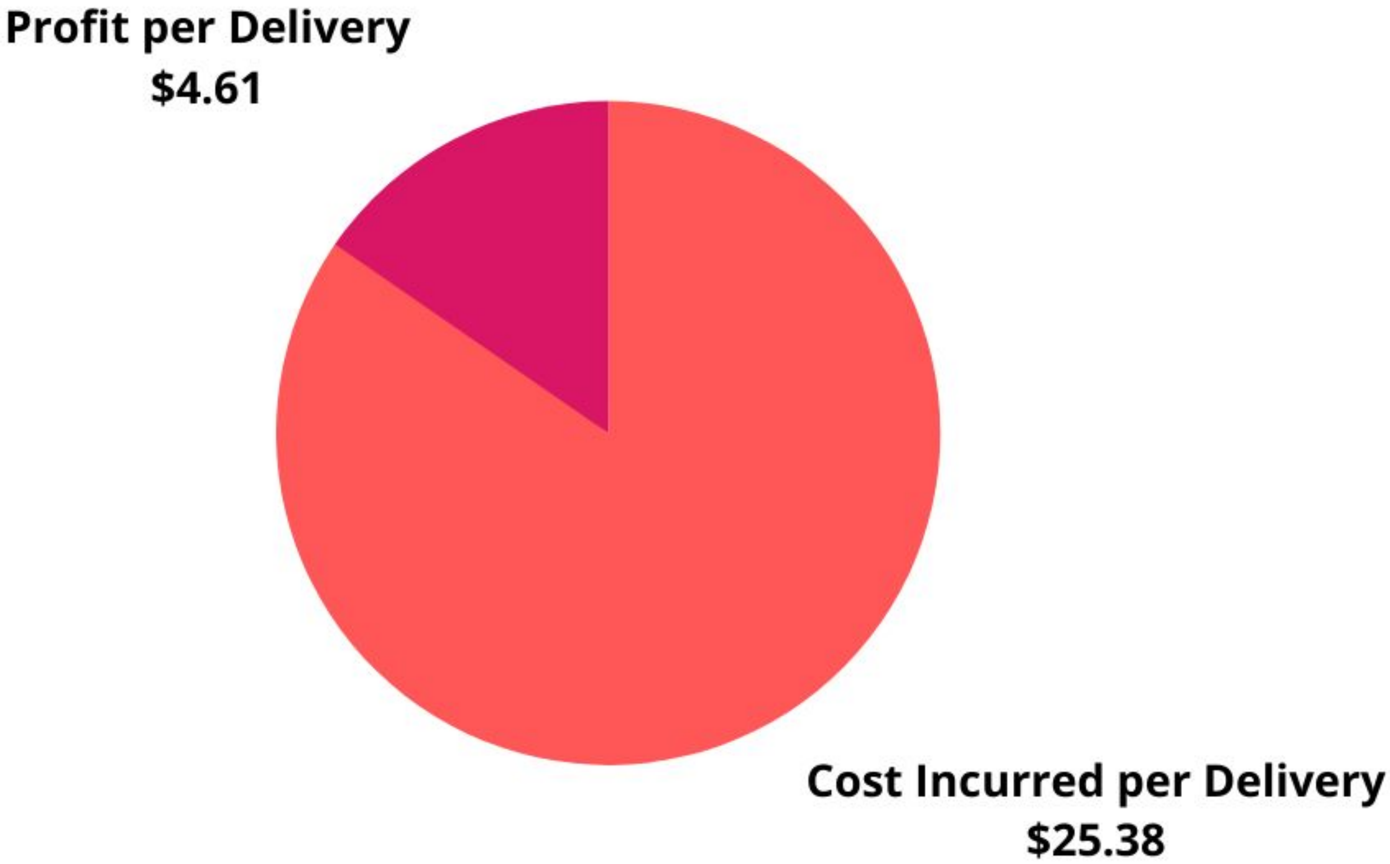



## Total Profit



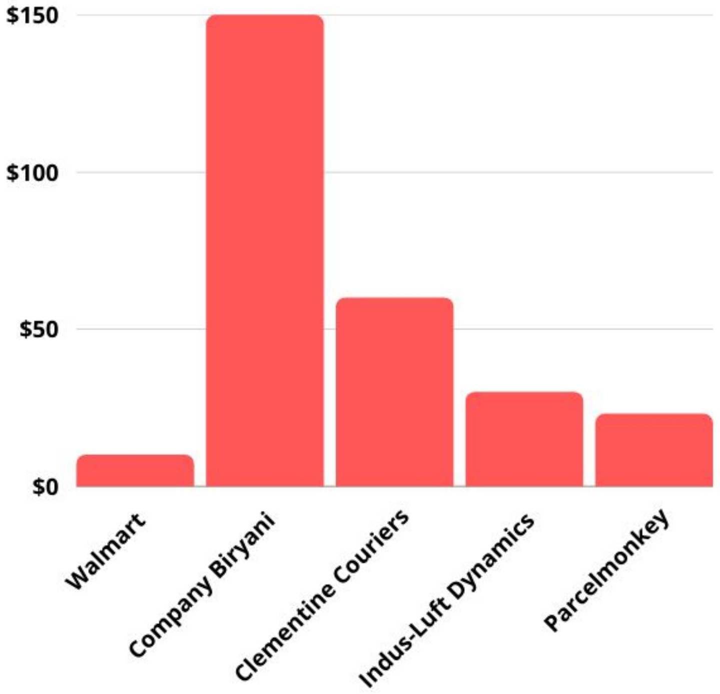

**Break Even achieved within 19.5 Months**

# Delivery Cost Break-up



# Comparison with other Delivery Services

## Cost to Customer



# Important Business Decisions

- Design Decisions
- Conventional Electricity Supply
- No Drone Insurance
- Rewards to Regular Clients
- Minimizing Slack Time and Maximizing Drone Deliveries

# Our Vision: Future Plans

**2022**
**MAY**
Operations Start

**2023**
**NOVEMBER**
Breakeven in Business

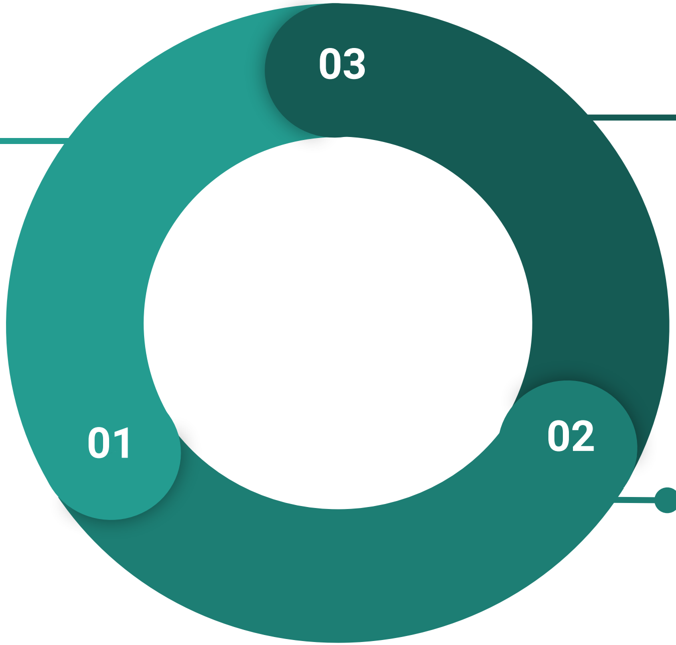
**2024**
**APRIL**
Expand Operations

**2025**
**OCTOBER**
Shift to Solar Energy

**2026**
**MARCH**
Setup Operations in Different Locations

**2027**
**JULY**
Meet 150 UAVs Fleet Target

# Why Indus-Luft Dynamics?




## Thorough Aircraft Features

An intricate Gyrodyne design, our UAV offers unmatchable performance with its cutting-edge avionics.

- ➔ **Low Carbon Footprint**:
  - C25 Sigma: 160 hours = 700 Kgs of $CO_2$
  - 737: 160 hours = 15000 Kgs of $CO_2$
- ➔ **Expandable Model**

  This UAS can be rapidly scaled up and faster, and thus cheaper deliveries will be possible in the future.

## Unique Business Model

- ➔ Competitive Profit Margin -> Expanding Volumes
- ➔ Affordable Prices -> Large & Diverse Clientele
- ➔ Attractive Business Strategies

## Practicality of the System

- ➔ Special attention was paid to real world circumstances
- ➔ The UAV is designed to deal with a whole range of adverse situations.
- ➔ The flaws in the design were rigorously assessed and dealt with using realistic simulations.

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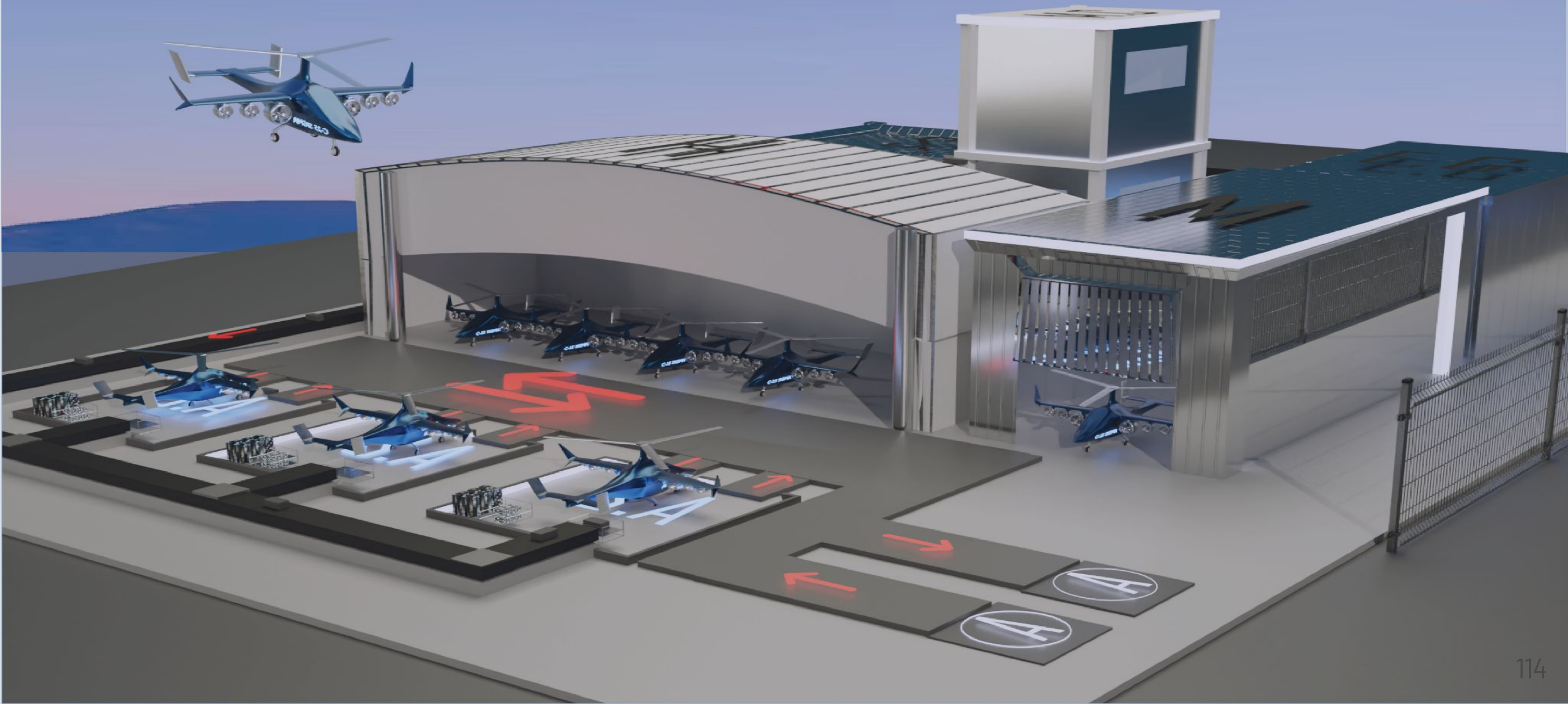
# Thank You.



# Questions?