Design and Integration of a Payload Deployment Mechanism for Firefighting UAVs

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ABSTRACT

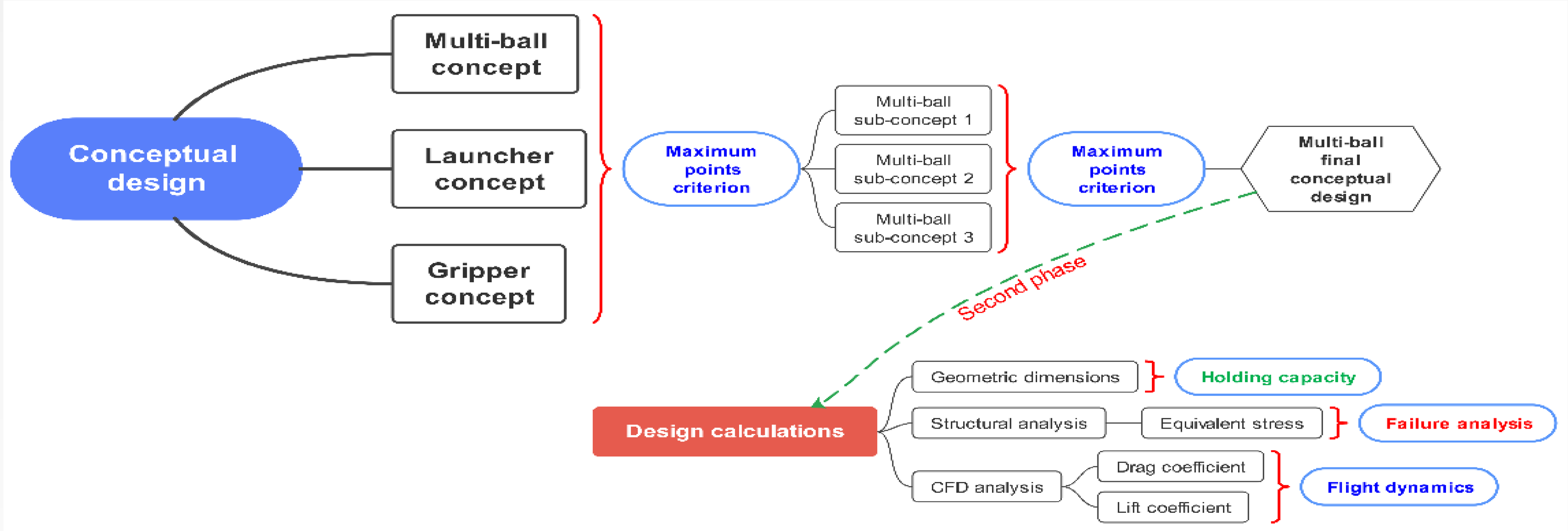
- Precision payload deployment mechanism for a firefighting UAV (mechanical subsystem only)
- Structured design process with multiple concept evaluations
- Arduino-controlled rotating plate for accurate in-flight release.
- FEA (structural) and CFD (aerodynamic) analyses for validation
- Key factors: strength, airflow effects, material selection, payload limits
- All work adheres to relevant engineering standards

OBJECTIVES

- The system saves time in hard-to-reach areas where UAVs are more effective.
- It performs fire suppression faster than humans in close-contact situations.
- It supports Saudi Arabia's Vision 2030 by advancing local industrial technology and innovation.

Methodology

Methodology follows a structured engineering approach that ensures systematic problem-solving, iterative design development, and validation of the firefighting drone mechanism



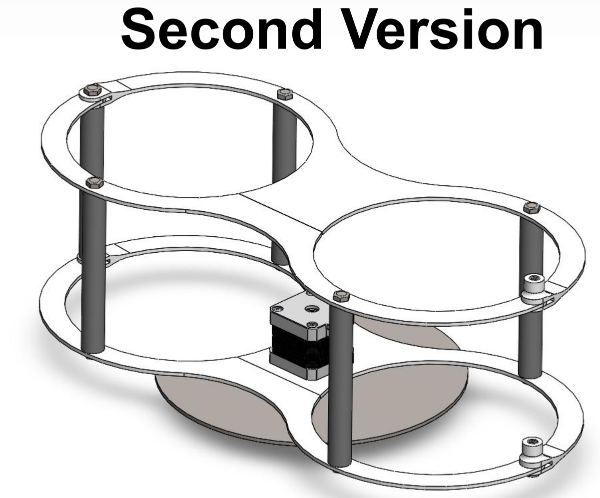
3D Modeling

Design started from basic gripper/basket concepts, then enhanced for manufacturability, stability, and functionality.

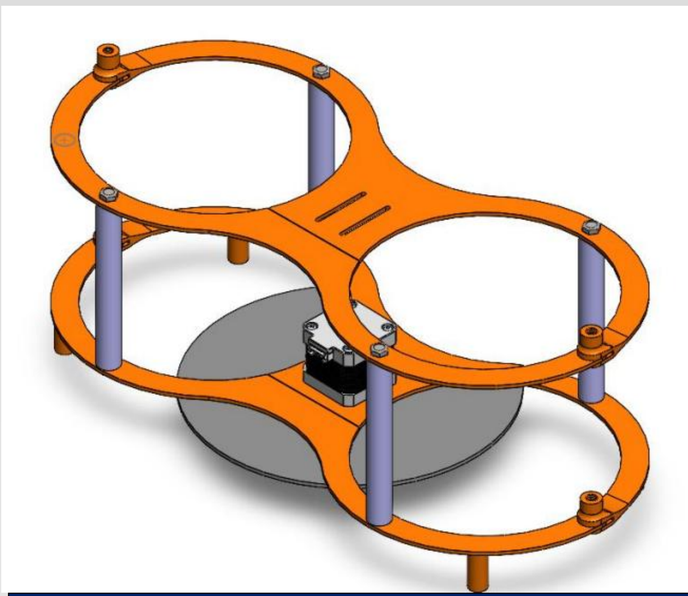
Key upgrades included motor integration, symmetric structure, secure mounting, and controlled release system.

First Version

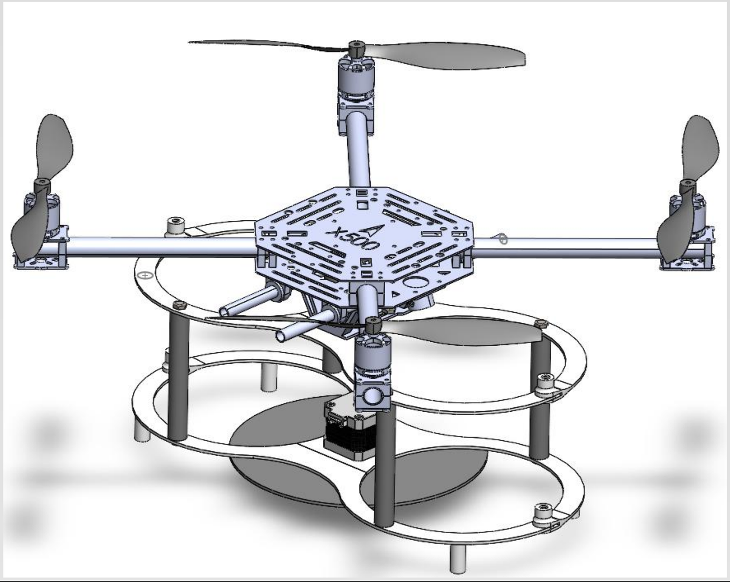
Second Version



Third Version



Final Version



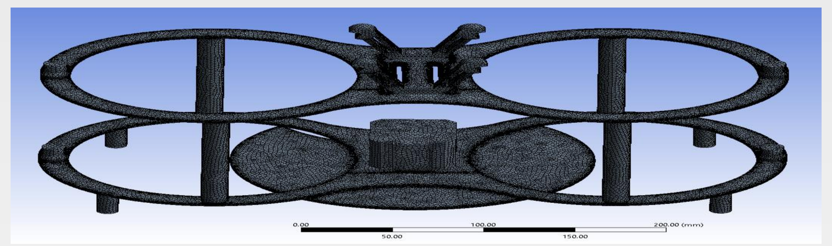
FINITE ELEMENT MODELING

Boundary Conditions

- Fixed Supports: Landing legs were assumed fully fixed to simulate ground contact.
- Structural Load: A 3.815 kg drone weight was applied as a downward force.
- Gravity: 9.81 m/s² gravity was applied in the -Y direction to simulate self-weight.

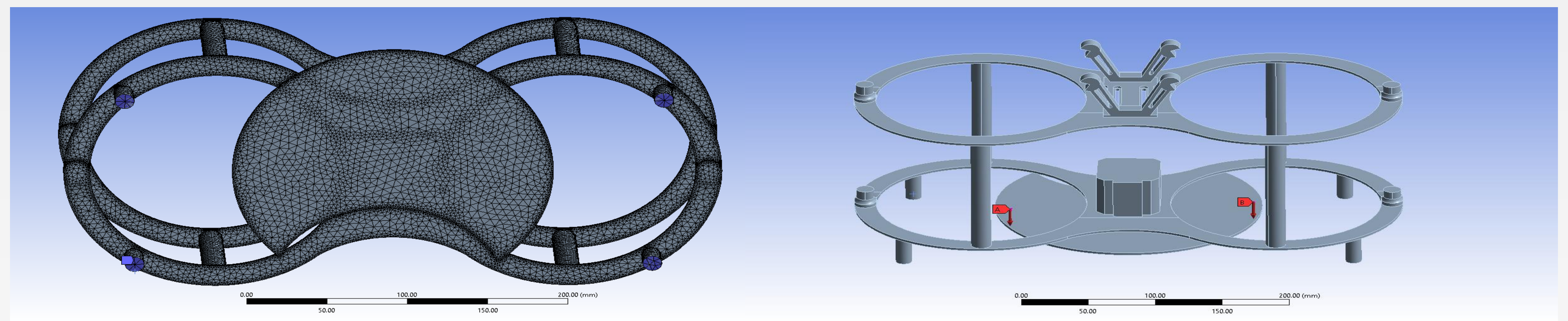
Discretization

The mesh used 2.5 mm elements with ~1.46M nodes and ~936k elements. Curvature and proximity options improved accuracy in complex areas..



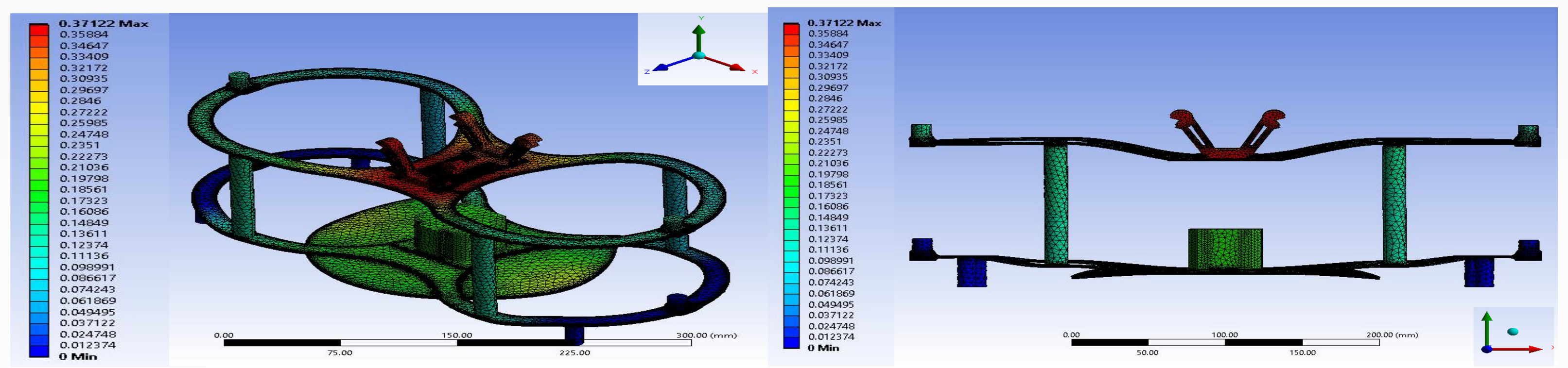
1. Fix Support

2. Loads Applied



Results

FEA was performed on the Payload Deployment using Aluminum 6061-T6 to assess stress, deformation, strain, and safety. Results reflect the structure's response under realistic loading conditions

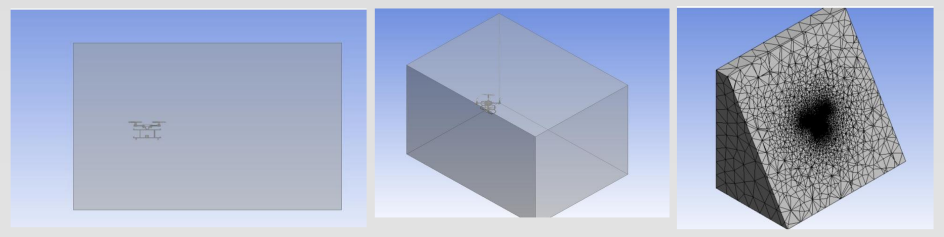


Property	Value	Notes
Maximum Equivalent Stress	79.32 (MPa)	Well below Aluminum 6061-T6 yield strength (260 MPa)
Maximum Total Deformation	0.371 (mm)	Acceptable, no functional interference
Maximum Elastic Strain	0.00113 (mm/mm)	Within the elastic limit
Minimum Safety Factor	3.27	

COMPUTATIONAL FLUID DYNAMICS

Geometry and Domain Setup

We subtract the drone from a large enclosure to isolate its airflow, prevent wall effects, and maintain true free-stream conditions.



Boundary Conditions

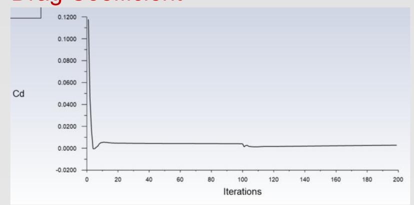
Boundary Type	Boundary Conditions	Value
Inlet	Velocity Inlet	20 m/s
Outlet	Pressure Outlet	0 Pa (atmospheric condition)

Geometry and Domain Setup

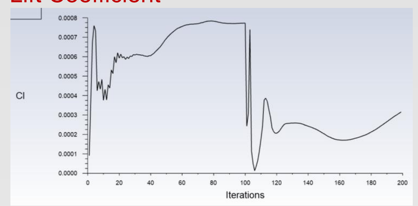
The simulation converged after 200 iterations, letting us quantify the drone and payload's aerodynamic performance.

Quantity	Value
Drag Force (**FD**)	4.92 N
Drag coefficient (**CD**)	0.000281
Lift Force (**FL**)	0.562 N
Lift Coefficient (**CL**)	0.00032

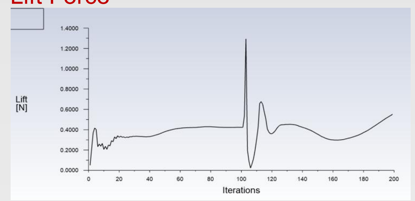
Drag Coefficient



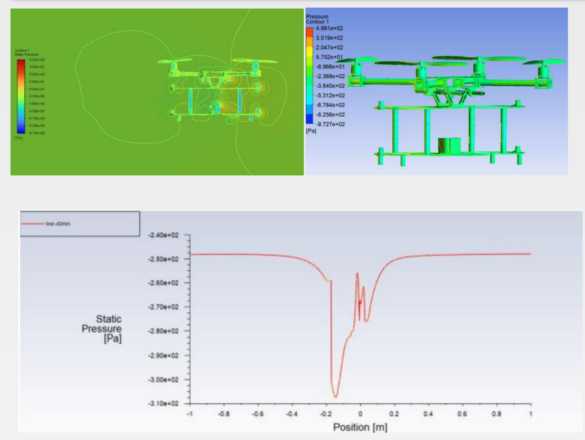
Lift Coefficient



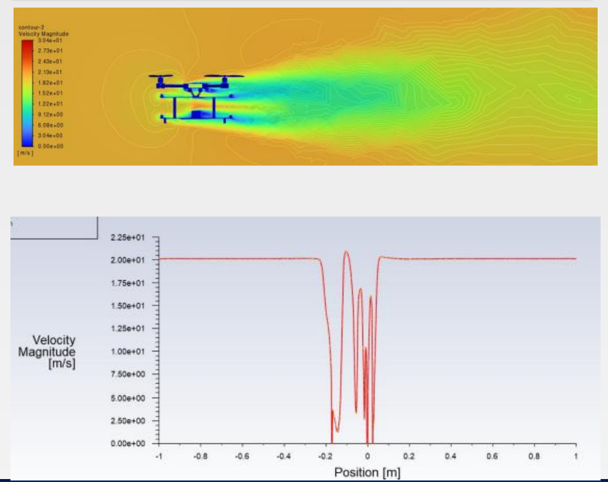
Lift Force



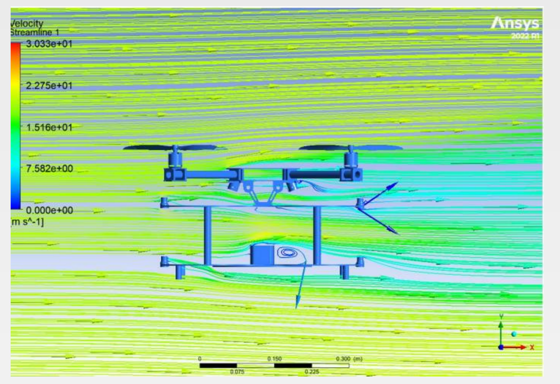
Pressure Distribution



Velocity Magnitude



Streamline Patterns



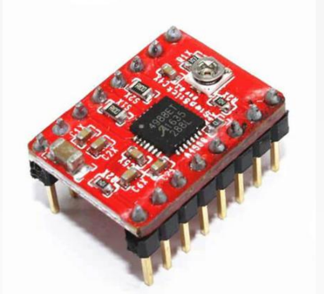
Prototype and control system

Arduino Code

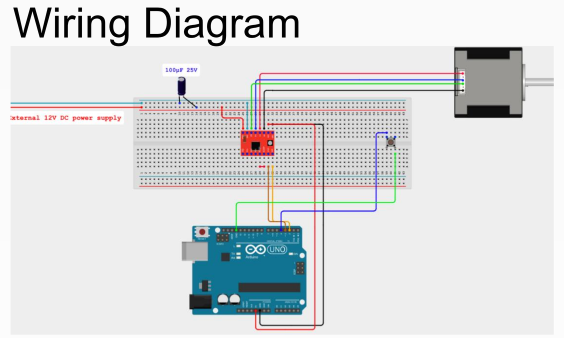
```
const int dirPin = 2;     // Direction pin
const int stepPin = 3;    // Step pin
const int btnPin = 4;     // Push-button pin

void setup() {
  pinMode(dirPin, OUTPUT);
  pinMode(stepPin, OUTPUT);
  pinMode(btnPin, INPUT_PULLUP);  // Enable internal pull-up resistor

  digitalWrite(dirPin, HIGH);     // Set default direction (change to LOW for revers
}

void loop() {
  static bool lastBtnState = HIGH;
  bool currentBtnState = digitalRead(btnPin);

  if (lastBtnState == HIGH && currentBtnState == LOW) {
    // Button was just pressed
    for (int i = 0; i < 50; i++) {  // 90° = 50 steps
      digitalWrite(stepPin, HIGH);
      delayMicroseconds(2000);     // Pulse width – adjust for motor speed
      digitalWrite(stepPin, LOW);
      delayMicroseconds(2000);
    }

    delay(200);  // Simple debounce delay
  }

  lastBtnState = currentBtnState;
}
```

Stepper motor

Motor Driver (A4988)



Wiring Diagram



CONCLUSIONS

- Developed and tested a UAV-mounted firefighting system to address challenges in hazardous or hard-to-reach areas.
- Created a cost-effective mechanism capable of accurately releasing fire extinguisher balls.
- Validated the design through SolidWorks modeling, analytical calculations, and simulations (FEA and CFD).