FEEG2001 Systems Design and Computing

Technical Design Report

Project Title: CubeSat

Group: 06

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Date:

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Table of Contents

1 Team Management Review

The group divided tasks based on the Low Friction Environment Platform (LFEP) and the Light Tracking (LT). To ensure no one team member bore the weight of a task, most goals were split between a minimum of 2 members each. It was the individual responsibility of the team members to decide how to split these tasks within their respective teams.

Our main team roles were divided as follows:

Evangeline: team leader, LT code and mathematics, mode switching, yaw control.

Rohit: initial design, entire structure, LT code, SD card data storage, reaction wheel code.

Harrison: entire structure, manufacturing, reaction wheel, construction.

Jack: power distribution and connections, manufacturing, construction.

Matthew: programming the receiver, transmitter and mission planner.

The project management approach considered that every team member had commitments outside of this project: allowances must be made, and meeting times adjusted. This meant group members had to be honest and upfront about progress made and ask for help when they needed it.

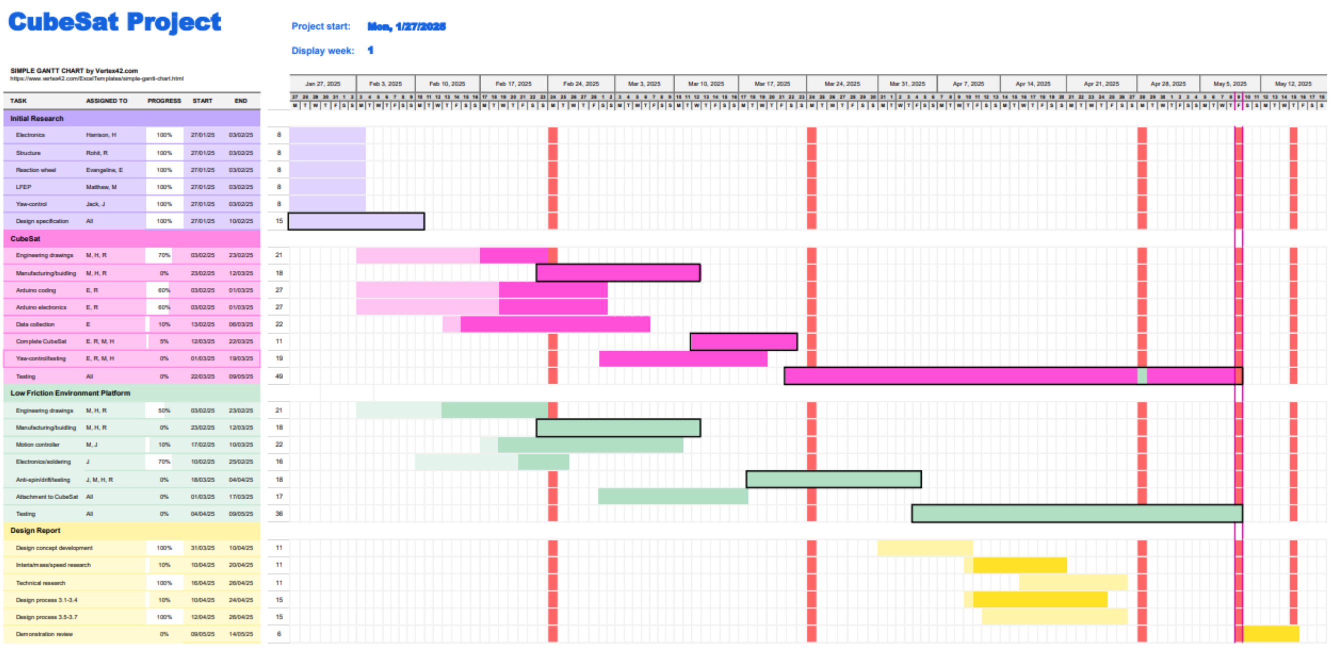


Figure 1 - Gantt Chart with Critical Path

The Gantt chart assisted with this approach: group members were able to access it and update their progress. The black boxes highlight the critical path, which outlined the crucial tasks and therefore the minimum amount of time needed to complete this project. The vertical red lines represented summative assessments, which acted as targets for work to be completed.

2 Design Concept Development

2.1 Design Context and Concept Development

The objective of this project was to design and prototype a CubeSat system capable of yaw-attitude tracking through reaction wheel mechanics, while operating within a low-friction environment that simulates conditions experienced in space. The system explores principles of angular momentum conservation, rotational dynamics, and frictionless motion by integrating a custom-built reaction wheel and LFEP with two hover fans and 4 translation fans. The key to the project was the ability to track a light source, requiring accurate orientation control in the horizontal plane. The entire prototype had to be constructed using only materials and tools available at the Boldrewood Design Studio, remain under 2.3 kg, resist torsional and compressive forces, and maintain a low centre of gravity (CG) for stability. Easy disassembly was essential, eliminating the use of adhesives and favouring mechanical fasteners, friction-fitted parts, and precisely tolerated 3D-printed components.

2.2 Concept Development and Final Design

To start our design early on, we began with hand-drawn sketches and developed structured decision matrices to evaluate each initial concept, as shown in Figure 2. These matrices helped compare options based on criteria such as structural integrity, internal space efficiency, ease of disassembly, and overall weight, reflecting the priorities outlined in the design specification. From these evaluations, we hand-drew designs and proceeded with CAD modelling. This digital modelling phase allowed us to experiment with component placements, analyse the effects on CG and simulate mechanical performance using FEA before physical prototyping. Maintaining a low and central CG remained a consistent design priority.

Number of Platforms

Platforms	Space Between Platforms	Sufficient Space for Components
2	3	1
3	4	4
4	2	5

Method of Supports

Support Type	Simplicity	Structural Stability	Ease of Disassembly	Internal Size	Weig
4 Pillars	5	2	3	5	
Joints	4	5	5	3	
Glue	5	2	2	4	
Laser-Cut Wooden Support	4	4	5	5	

Weight Saving Cutouts

Cutout Shape	Simplicity	Structural Stability	Amount of Weight Saved
Triangles	4	4	5
Circles	5	2	5
Hexagons	4	4	5

Reaction Wheel - Material

Material	Time to Manufacture	Easiness to Manufacture	Izz Value
Metal	1	1	5
Wood	5	5	2

Reaction Wheel - Spokes

Number of Spokes	Izz Value	Weight Saving
Solid Wheel	5	1
2 SPOKES	4	5
4 SPOKES	3	5

Reaction Wheel - Taper

Taper	Izz Value	Weight Distribution
Yes	5	5
No	3	3

LFEP Base

Configuration	CG location	Ease of assembly	Space for components	Structural stability
Bottom base	5	4	4	5
Top base	3	3	5	3

Hover Fan Placement

Fan Placement	CG location	Ease of assembly	Effectiveness	Structural stability
Sideways	5	5	5	4
Pointing Down	3	2	4	5

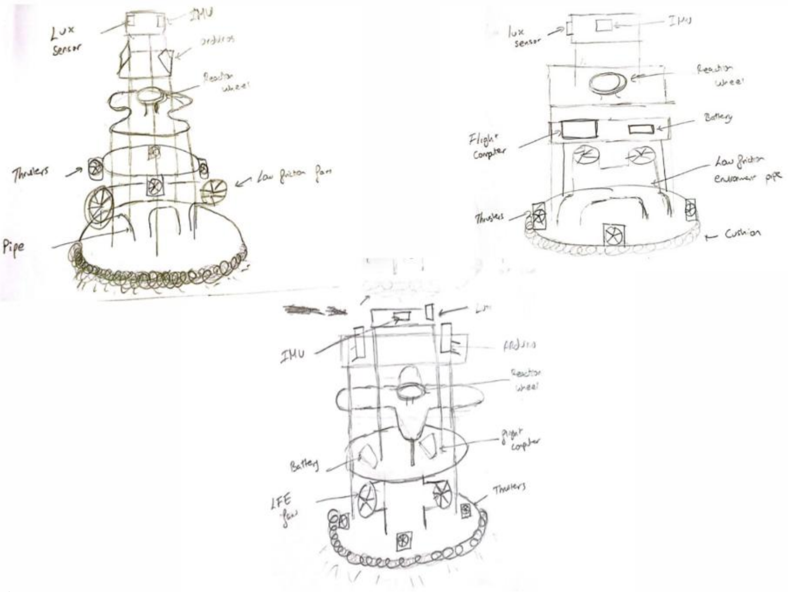


Figure 2: Decision Matrix & Initial Concept Drawings

Our initial physical concept featured a multi-layered CubeSat structure with vertically aligned threaded rebar rods spanning the different levels. This layout aimed to group subsystems logically, placing heavier components like the reaction wheel centrally, with the power distribution board (PDB) and motor driver mounted on the sides. The design quickly proved suboptimal due to the high mass and instability introduced by the steel rods, which significantly raised the CG and compromised performance. Another contributor was the reaction wheel, which was too heavy and pushed the system over the 2.3 kg limit. We removed mass from the wheel while, ensuring the wheel met the angular momentum requirements for effective CubeSat rotation.

The design specification was a critical guiding force throughout development. Constraints like the 2.3 kg weight limit, resistance to twisting and crushing, and the need for straightforward disassembly significantly shaped material and construction decisions. While adhesives were allowed, none were used to join core components. For structural support, we adopted laser-cut wooden components which were glued, which offered weight saving and ease of assembly while meeting rigidity and modularity requirements. As we refined the prototype, weight reduction became a priority, especially after initial builds exceeded the 2.3 kg limit. To address this, we cut triangles into the CubeSat's walls. For the larger LFEP base, hexagonal cutouts were used extensively, offering an ideal balance between structural integrity and mass reduction. These adjustments played a crucial role in meeting our weight requirements.

We designed a custom 3D-printed duct that accommodated the fans snugly and allowed bolts to pass over the sides for firm fastening. This feature improved the stability and safety of the fan mounting and simplified installation and removal, supporting modular assembly. A key research addition during development involved airflow control through plenum dynamics. Initial tests revealed that airflow from the hover fans was uneven, resulting in reduced lift stability. This led us to investigate plenum designs to diffuse and regulate the airflow beneath the CubeSat. We studied various plenum geometries and concluded that it could distribute air more uniformly. These insights were later incorporated into the CAD model, resulting in a more stable LFEP during physical tests.

This iterative process, guided by the design specification, enabled us to progress from a heavy, unstable concept to a functional and robust CubeSat system suitable for a space-like testing environment.

2.3 Mass, Inertia and Velocity Progression

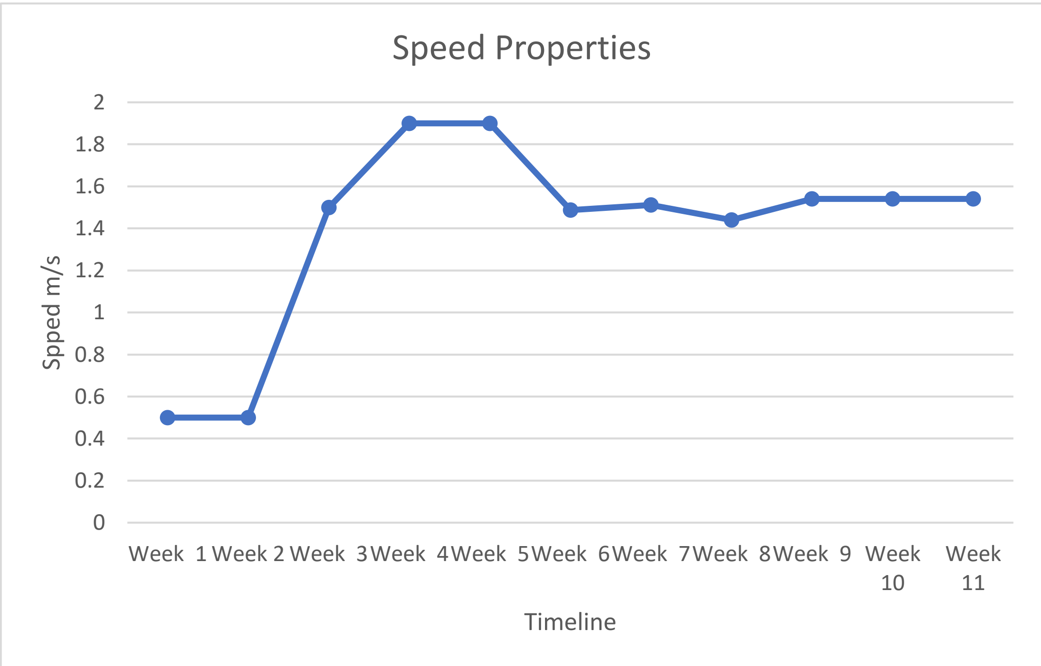


Figure 3. Speed Properties

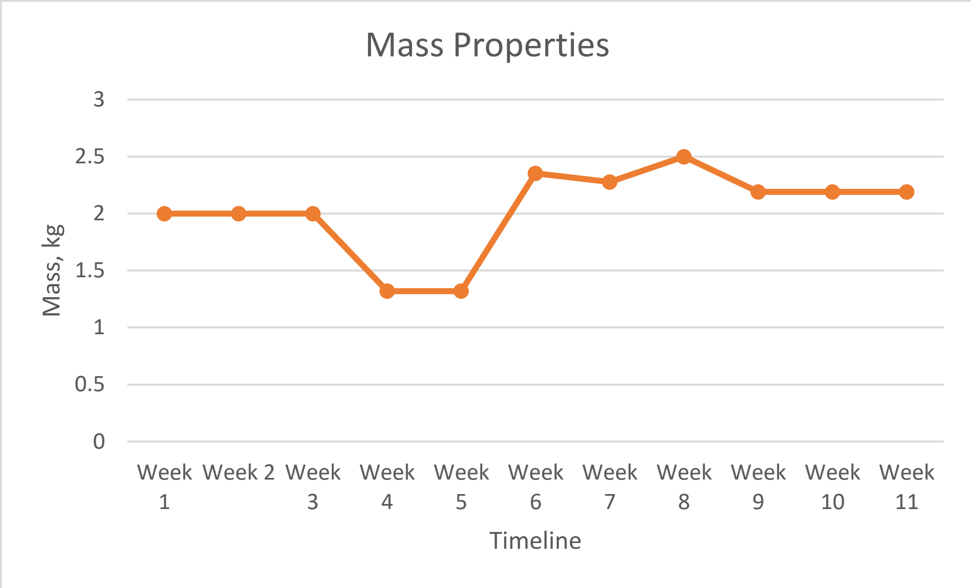


Figure 4. Mass Properties

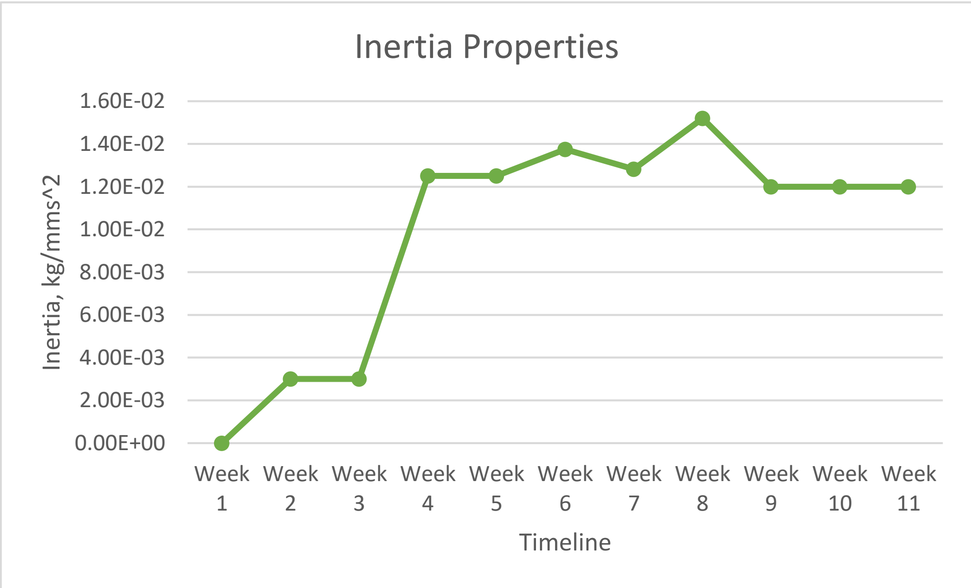


Figure 5. Inertia Properties

Figures 3, 4, and 5 track the progress of three essential parameters: mass, inertia and speed. These values all fall within the brief and advisory guidelines, allowing the CubeSat to operate as expected. By observing the graphs, it is clear where major structural design choices were made, ultimately in weeks 4, 6, and 9. In week 4, a very basic structure was assembled, which had a much lower mass than projected. In week 6, all the components were placed on the structure, and in week 9, a new low mass structure was completed to lower the mass below the threshold. Along the timeline, it is clear that there is a direct correlation between mass and inertia & speed.

3 Detailed Design Process Overview:

3.1 Final Design Overview with Performance Specification

The final design consists of a five-layer structure optimised for stability, modularity, and functionality as shown in Figure 6. The lower two layers house the hover and translation fans, which form the core of the LFEP. The centre of gravity was kept low by placing most of the system's weight in these layers, increasing stability and meeting key design requirements. The middle platform features extensive cutouts and a honeycomb structure to reduce mass while maintaining strength. A 3D-printed duct was precisely modelled to securely hold the hover fans and ensure safe operation. The CubeSat utilises laser-cut slits that allow for easy and secure assembly without added fasteners. Two Arduinos, in a master-slave configuration, enable effective control, communication, and real-time data logging. The electronics, including the PDB, motor driver, flight controller and battery, are mounted on the middle layer, improving weight distribution.

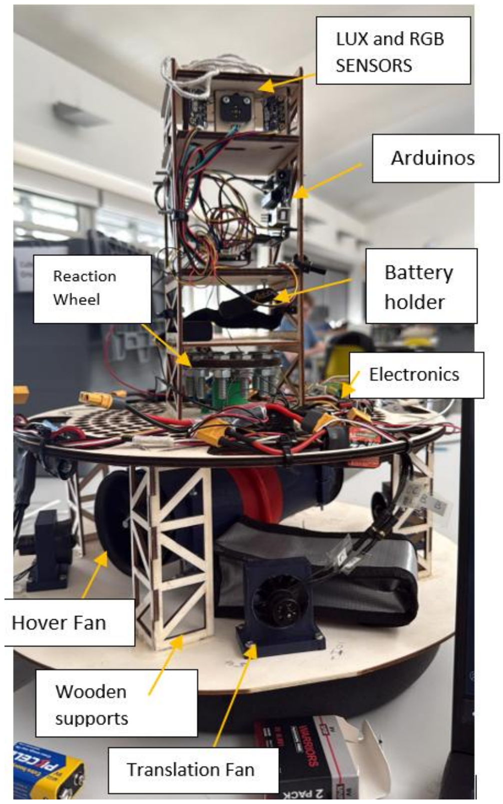


Figure 6. Schematic of Final Design

System Performance Specification

The CubeSat system is designed to perform precise light tracking using attitude control and movement using the LFEP. Its core goal is to simulate a space environment where both translational and rotational motion can be accurately tested and controlled. Each subsystem ensures the CubeSat remains responsive, accurate, and adaptable during operation. The table below outlines the primary performance specifications.

Table 1. Performance Specification

Feature	Performance Specification	Desired Outcome
Light-Tracking Accuracy	±2.5 degrees	CubeSat consistently aligns with a moving light source within tight angular bounds
Translational Motion (LFEP)	Fast and responsive movement across surface	CubeSat can move quickly and smoothly to new positions on the platform
Rotational Control (Reaction Wheel)	Stable and reliable angular motion	CubeSat can rotate to change direction accurately
Spin Correction (Reaction Wheel)	Counteracts residual spin from LFEP movements	CubeSat maintains controlled orientation after translation
Manual Control Input (Controller)	Real-time motion commands	LFEP responds immediately to user input
Data Recording (SD Card)	Reliable storage of sensor and control data	All operational data is saved for later analysis
Mode Switching (Controller)	Functional switching between movement and sensing modes	CubeSat can alternate between LFEP control and light-tracking seamlessly

System and Subsystem Requirements

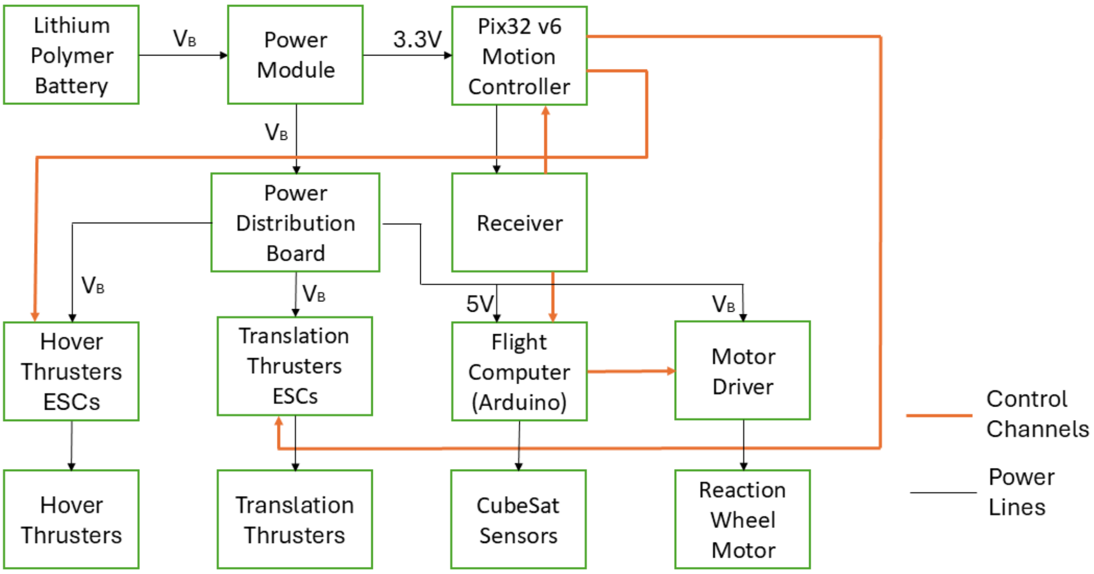


Figure 7. Electronic Connections

As shown in Figure 7, the system is powered by a lithium polymer (LiPo) battery, which feeds into a PDB to supply consistent voltage to all components. The Pix32 flight controller manages high-level system behaviour, including mode switching and actuation commands for the hover/translational thrusters and reaction wheel. A dedicated Arduino flight computer handles sensor data acquisition and communicates directly with the Pix32, forming a two-way control and feedback loop between sensing and motion.

3.2 Technical Research

The design of the LT portion of the CubeSat included determining the optimum placement of the light sensors. Testing involved a bright light placed at 3 different angles around the CubeSat at one set distance between 0.2-2 metres. The orientation of the light sensors had to allow for the widest range of light input to make light tracking as easy as possible. A Python programme helped analysed the behaviour of the sensors in two parts.

Figure 8 shows the inverse square law relationship between the light sensor reading and the light source distance. The greater the distance to the light source, the smaller the reading received on the sensors. It also shows that the RGB sensor is far stronger than the two lux sensors.

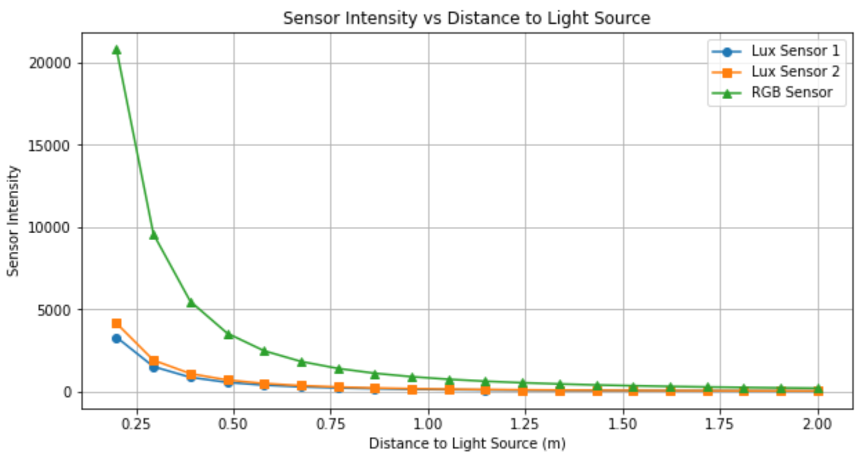


Figure 8. Relationship of Light Sensor Readings and Light Source Distance

This graph shows the relationship between the sensor readings and the angle of the light source, with a constant distance. The two lux sensors here are at 41° and the RGB sensor is sitting flat at 0°. Again, the RGB sensor shows the greatest light sensitivity.

Using data from these two graphs, we iterated through several angles of sensor placements, eventually landing at ±41.9° placement for the two lux sensors, and the RGB sensor sitting at 0°.

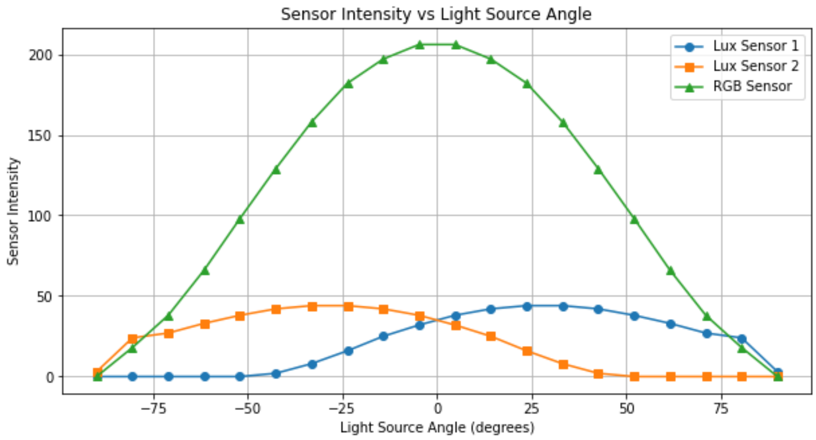


Figure 9. Relationship of Light Sensor Readings with Varying Light Source Angle

$$I_{ZZ,CubeSat} * \omega_{CubeSat} = -I_{ZZ,Reaction\,Wheel} * \omega_{Reaction\,Wheel} \tag{1}$$

$$RPM_{Reaction\,Wheel} = 60 * \frac{2\pi}{\omega_{Reaction\,Wheel}} \tag{2}$$

Following the laws of conservation and a chosen CubeSat angular velocity, $\omega_{CubeSat}$, of 45°/s, the RPM of the reaction wheel can be calculated and kept below the maximum motor RPM of 320[1].The reaction wheel mass had to be high enough and optimally distributed to spin the CubeSat, but not too great to damage the motor, as the stall torque is only 1.7kgcm. By lowering the reaction wheel mass, the motor, with a maximum efficiency at a torque of 0.29kgcm [1], can perform more efficiently. This allowed the motor to run for longer periods without burning out. By finding something denser than plywood i.e. nuts and bolts, 0.5kg/100 items [2], 1.55kg/100 items [3], respectively, it is easy to increase the weight of the wheel to a threshold that will spin the CubeSat.

3.3 Structural Design

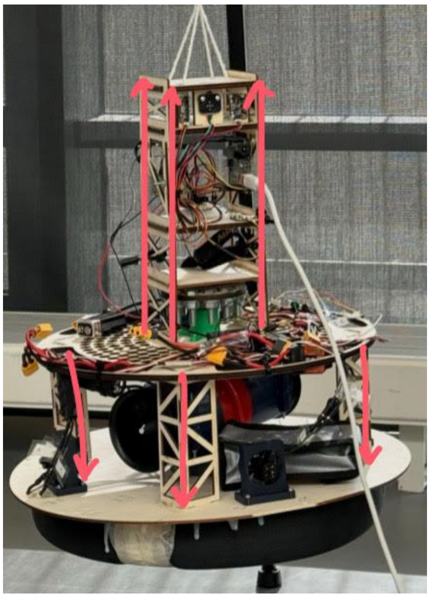


Figure 10: CubeSat Forces

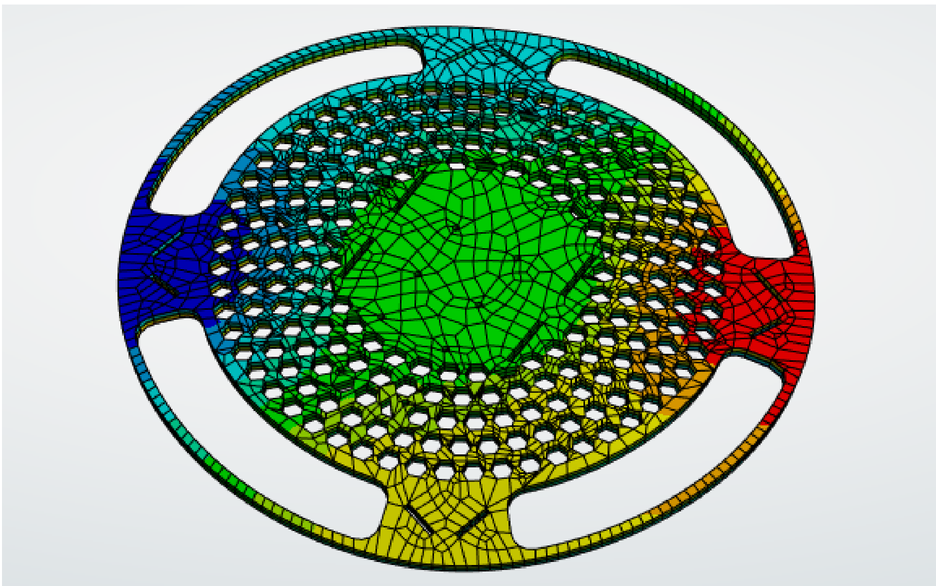


Figure 11: FEA of LFEP

An interlocking frame was created to decrease stresses on the structure; this reduced the need for glueing and bolting parts together, allowing for easy disassembly. A small amount of glue was placed in some of the joints before the final test for added rigidity. To connect the CubeSat structure to the top of the LFEP, as shown in Figure 10, the CubeSat frame protruded through the LFEP base, with wooden slats along the downward face of the LFEP base. These supports massively improved the stability from the upward force when the whole structure was suspended. The LFEP platform will have the vertical forces from the central CubeSat and the outer supports holding the LFEP in place. To ensure the structural stability of the frame, a simple Finite Element Analysis (FEA) was conducted on the main structural part between the LFEP and CubeSat pieces which is shown in Figure 11. All electrical components were organised so they could all be accessed if failure occurred during testing.

In the worst case, the maximum vertical deflection is only 0.005mm. This value is not totally accurate; when the CubeSat is suspended for prolonged periods of time, the wood and glue in the joints will start to slip, which will increase the deflection and stresses until failure. However, it does show there is not an extreme amount of deflection in the wood, and it should be able to withstand the tests.

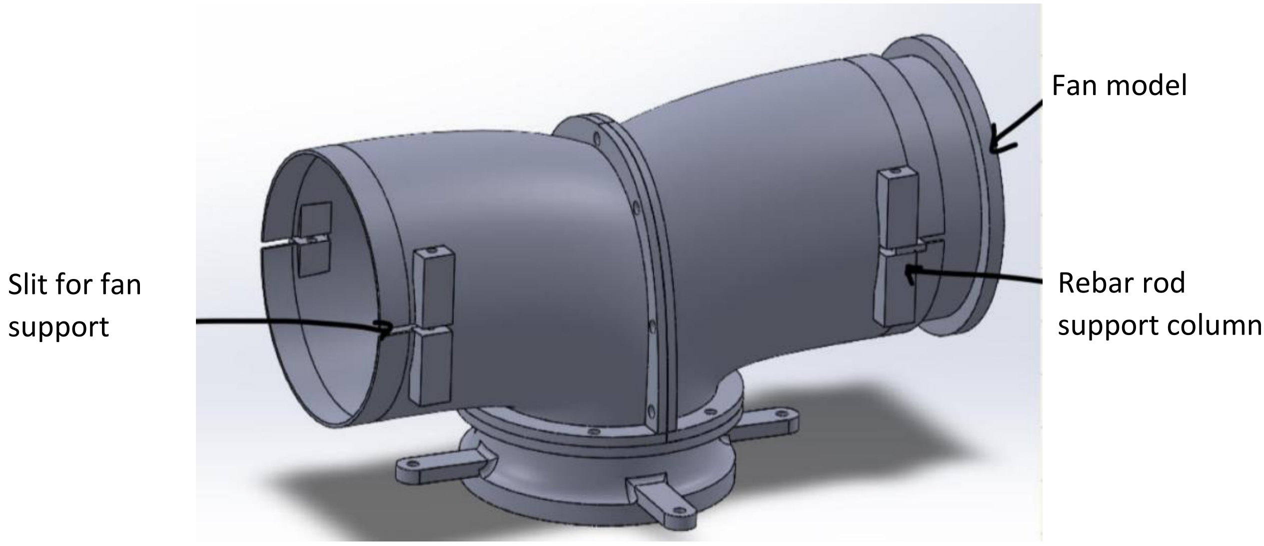


Figure 12. Fan Duct

Initially, the hover fans were going to be held in the fan duct with a friction hold. After considering the safety standards, the model was changed so the fan would slide into the duct with an M4 rebar support passing through the support tab on the fans; the duct is shown in Figure 12. The use of the rebar support significantly increased the safety of the fan and removed risk of the fan dislodging.

3.4 Computing and Control

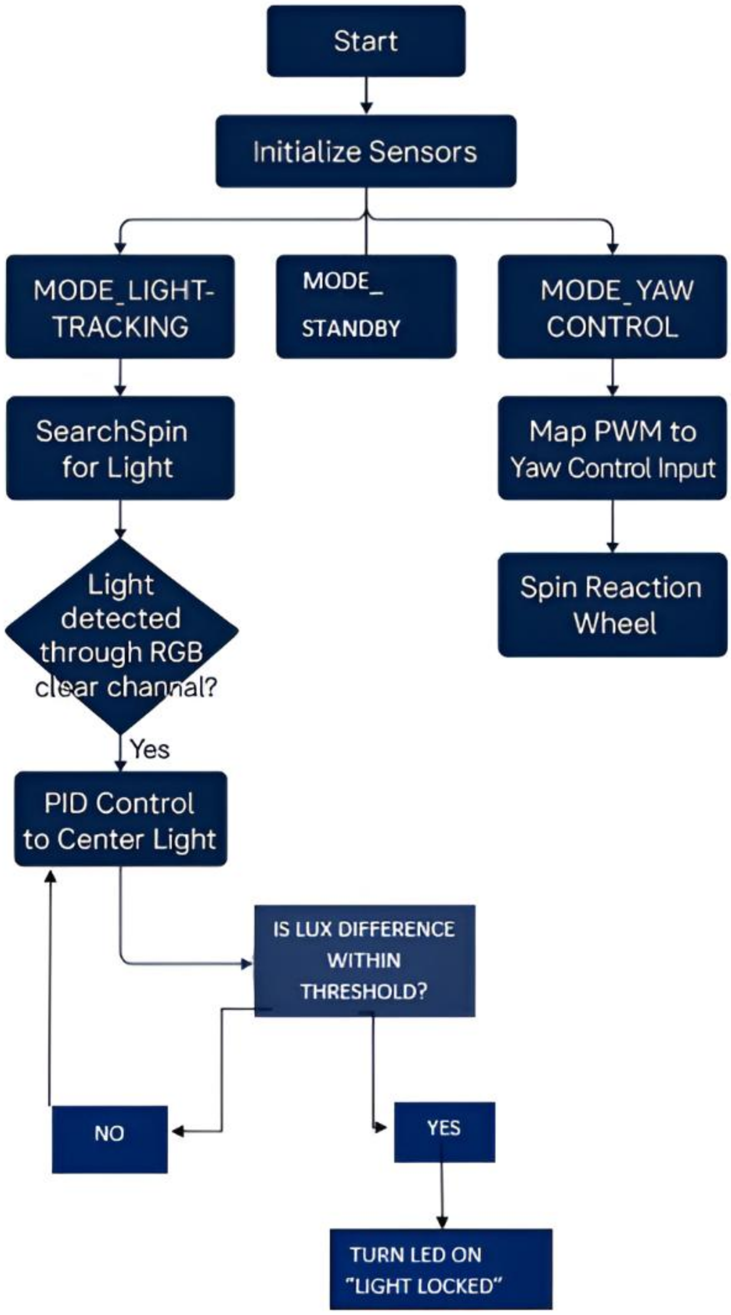


Figure 13. Control Logic Flowchart

The computing and control system of the CubeSat was developed to autonomously track a light source or allow manual control via an RC transmitter. The microcontroller integrates multiple sensors: two Adafruit VEML7700 lux sensors for directional light sensing, one Adafruit TCS34725 RGB sensor for light detection, and an ICM-20948 IMU. Sensor communication is handled via an I2C bus through a TCA9546A multiplexer, enabling channel selection for individual sensor access.

As shown in Figure 13 and 14, the system operates in three primary modes: Light Tracking, Standby, and Yaw Control (YC). Mode switching is achieved using a PWM signal read from an RC receiver. Pulse widths below 1100 µs activate LT, values between 1100–1600 µs place the system in Standby, and pulse widths above 1900 µs enable YC mode. Transitions reset relevant flags and stop motor activity to ensure a clean state between modes.

In LT Mode, the RGB sensor monitors ambient light through its clear channel. If a significant increase is detected, suggesting a flashlight, the system begins active tracking, as shown by Figure 15. The two angled VEML7700 sensors measure relative light intensity, and their readings are used to calculate a normalised error. A PID control system, shown in Figure 16, then uses this error to command the reaction wheel to rotate the CubeSat, centring the light, minimising this error. Once the error falls below a defined threshold, the motor halts, and an LED indicates “light lock.”

```cpp
void loop() {
  unsigned long pulseWidth = pulseIn(pwmModePin, HIGH, 100000);
  Mode newMode = currentMode;
  if (pulseWidth > 800 && pulseWidth < 1100) newMode = MODE_LIGHT_TRACKING;
  else if (pulseWidth >= 1100 && pulseWidth < 1600) newMode = MODE_STANDBY;
  else if (pulseWidth >= 1900) newMode = MODE_YAW_CONTROL;

  if (newMode != currentMode) {
    currentMode = newMode;
    lightDetected = false;
    light_integral = 0;
    stopMotor();
    digitalWrite(LED_PIN, LOW);
  }

  switch (currentMode) {
    case MODE_LIGHT_TRACKING: lightTrackingLoop(); break;
    case MODE_YAW_CONTROL: yawControlLoop(); break;
    case MODE_STANDBY: stopMotor(); break;
    default: break;
  }
}
```

Figure 14: Mode Switching Logic

```cpp
// ----------------- Light Tracking -----------------
void lightTrackingLoop() {
  enableChannel(3);
  uint16_t r, g, b, c;
  tcs.getRawData(&r, &g, &b, &c);
  Serial.print("Clear channel: "); Serial.println(c);

  // Detect if flashlight is present
  if (!lightDetected && c > ambientC + AMBIENT_MARGIN) {
    lightDetected = true;
    Serial.println("Flashlight detected! Switching to tracking mode.");
    delay(100);  // Small delay before transitioning to active tracking
  }

  // If no light detected yet, stay in search spin
  if (!lightDetected) {
    Serial.println("Searching for light...");
    searchSpin();
    return;
  }
```

Figure 15: Light Tracking Ambient Light Detection Effort

```cpp
// PID calculation
light_error = normalizedError;
light_integral += light_error;
light_derivative = light_error - light_previousError;
light_output = (light_Kp * light_error) + (light_Ki * light_integral) + (light_Kd * light_derivative);
light_previousError = light_error;

// Debug output
Serial.print("Lux1: "); Serial.print(lux1);
Serial.print(" | Lux2: "); Serial.print(lux2);
Serial.print(" | Error: "); Serial.print(light_error, 4);
Serial.print(" | PID Output: "); Serial.println(light_output, 4);

// Actuate motor to correct
if (abs(light_error) < LOCK_TOLERANCE) {
  Serial.println("Light centered (within tolerance). Minor corrections.");
  digitalWrite(LED_PIN, HIGH);
  stopMotor();  //
} else {
  digitalWrite(LED_PIN, LOW);
  int pwmVal = constrain(abs(light_output) * 255, 80, 255);
  Serial.print("Tracking light | Direction: ");
  Serial.print(light_output > 0 ? "Left" : "Right");
  Serial.print(" | Speed: "); Serial.println(pwmVal);
  moveMotor(pwmVal, light_output > 0 ? -1 : 1);
```

Figure 16: PID Control

```cpp
// Check for dead zone
if (pwmValue > (deadZoneCenter - deadZoneRange) && pwmValue < (deadZoneCenter + deadZoneRange)) {
  analogWrite(PWM, 0);  // Stop motor
  digitalWrite(IN1, LOW);
  digitalWrite(IN2, LOW);
  Serial.println("Motor stopped");
} else {
  // Map PWM value to motor speed
  int motorSpeed;
  if (pwmValue <= deadZoneCenter - deadZoneRange) {
    motorSpeed = map(pwmValue, pwmMin, deadZoneCenter - deadZoneRange, motorMax, 0);
    digitalWrite(IN1, LOW);
    digitalWrite(IN2, HIGH);  // Reverse direction
  } else {
    motorSpeed = map(pwmValue, deadZoneCenter + deadZoneRange, pwmMax, 0, motorMin);
    digitalWrite(IN1, HIGH);
    digitalWrite(IN2, LOW);   // Forward direction
  }
  motorSpeed = constrain(abs(motorSpeed), 0, 255);

  // Set motor speed
  analogWrite(PWM, motorSpeed);
  Serial.print("Motor speed: ");
  Serial.println(motorSpeed);
}

delay(20);  // Small delay for stability
```

Figure 17: PWM Mapping to Reaction Wheel Using Transmitter

In YC Mode, manual input from the left stick is read as a PWM signal as shown in Figure 17. A dead zone is implemented to prevent minor stick movements from affecting the motor. Outside this zone, the signal is mapped to motor speed and direction, giving the user direct control over CubeSat orientation.

This architecture enabled us to have significant control authority over the motion of the CubeSat during testing and manual override functionality in a compact embedded system.

The data storage requirement of the design brief was attemtped through creating a master-slave Arduino system. The master Arduino, connected to the multiplexer and therefore all the sensors, received data during the running of the CubeSat, and sent it over to the slave Arduino with an attached microSD breakout board via I2C protocol.

To ensure control of the LFEP, a binding process needed to be completed between the receiver, shown in Figure 18, and the controller, which allowed each fan to be connected to different channels and controlled by different switches and levers on the transmitter. The translational fans are connected to the right stick, and the hover fans are activated by rotating the S1 switch. For safety reasons, a kill switch was also added to cut all fans in case of an issue with the LFEP, which can be activated by flipping switch SE.

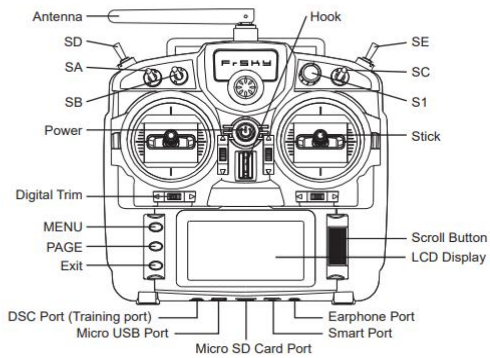


Figure 18: Labelled Diagram of the Layout of the Transmitter

3.5 Manufacture and Materials

The main structures of the LFEP and the CubeSat are made from laser-cut plywood sheets of 3mm and 6mm thickness. This wood is cheap, easy to source, lightweight, and durable. Initially, the vertical supports connecting each platform were made from steel rods, however, they were replaced by plywood as the structure's mass far surpassed the weight requirement. A laser-cut plywood skeleton was produced with steel nuts and bolts to make the reaction wheel, saving manufacturing time. Plywood is very sustainably produced as it uses wood efficiently; the process takes the maximum yield from each wooden log without much waste[4]. However, the production process creates 2.69 kg CO_2e/m^3 of greenhouse gas emissions[5], mainly from the production of the resins used between the wood layers.

Table 2. Energy and CO_2 Footprint of Plywood

Phase	**Energy (MJ)**	**Energy (%)**	**CO2 footprint (kg)**	**CO2 footprint (%)**
Material	49.2	98.1	2.69	97.6
Disposal	0.95	1.9	0.0665	2.4
Total (for first life)	**50.2**	**100**	**2.75**	**100**
End of life potential	-0.19		-0.0133	

The hover fan ducts, translational fan holders, reaction wheel motor base and plenum were all 3D-printed out of polylactic acid (PLA). This was easy to access as it was supplied with the 3D printers by the university. As seen in table 3, the CO_2e footprint is $0.342kg/m^3$ [5].

Table 3. Energy and CO_2 Footprint of PLA.

Phase	**Energy (MJ)**	**Energy (%)**	**CO2 footprint (kg)**	**CO2 footprint (%)**
Material	6.75	99.6	0.342	99.4
Disposal	0.03	0.4	0.0021	0.6
Total (for first life)	**6.78**	**100**	**0.344**	**100**

The foam ring on the base of the LFEP is made of expanded polystyrene. This type of polystyrene is 98% air[6] and uses minimal plastic for the volume of the tubing. The light mass made it perfect for the air seal of the LFEP.

The plywood is recyclable but is not as environmentally friendly as other natural wood as it is not biodegradable[7]. All working university supplied components can be repurposed for other projects. Additionally, some of the PLA structures can be reused with desired components in the future. PLA can also be recycled using chemical or mechanical processes. Standard polystyrene is not recyclable, but the expanded form can be recycled by compressing and using it in new rigid plastic products.

3.6 Testing

CubeSat testing 'split' the structure into two parts for individual testing. The LFEP was tested in an enclosed environment to match where the demonstration would take place. To develop the LFEP control, the transmitter was used to operate the CubeSat's fans at different times. The light testing was completed by suspending the CubeSat from a tripod, like in the final test.

CubeSat Testing:

Testing light tracking allowed us to refine our PID control, accuracy, and threshold for ambient light, through monitoring serial monitor outputs via the Arduino IDE. We noticed issues with the micro-SD breakout kit as it was not suited for Arduinos. There were issues between the power it drew and what it required. We were able to make it work during testing as power requirements were lower; however, during the final test, this was not possible.

LFEP Testing:

In testing, the translation fans were operated to check that they were all working and spinning in the desired direction. If this were not the case, the cables connecting them and the ESCs would be rearranged until the correct configuration was found. During this process, one of the translational fans would not spin despite connecting the cables in every possible combination. This meant that during the final demonstration, the LFEP would be controlled by only 3 fans. Any further rotational motion would have to be adjusted manually by the reaction wheel.

The testing of the LFEP also meant that our pilot had a chance to practice before the presentation day to decrease the time taken on the Low Friction Motion Test.

3.7 Summary of Final Design Physical Properties

Iterative design and constant testing of the CubeSat has led to our design meeting the given design constraints: the centre of gravity is within 20cm and the platform width is 39cm, which is within the 20cm radius constraint set by the brief. The LFEP had an average top speed of 0.44m/s and tracked light to an average accuracy of 135.18˚.

By placing more of the components closer to or over the centre of gravity, the Z-axis inertia could be reduced, increasing control. Another method of reducing the inertia value would be to compact the cable management in a smaller space closer to the centre of gravity. This will have a sizeable impact due to the weight of the ESCs from the fans. By decreasing the inertia value, the CubeSat could be operated at a higher speed in the LFEP test, as it is currently limited by the ability to control, rather than theoretical top speed.

Table 4. Summary of Final Design Physical Properties

Physical property	Value
Total mass, m [kg]	2.19
Z-axis inertia, I_{ZZ} [kg m^2]	0.0120
Predicted translation speed, V [m/s]	1.54

4 Prototype Demonstration Review and Future Developments

Overall, the demonstration was partially successful due to partial light tracking and moderately paced movement in the LFEP demonstration.

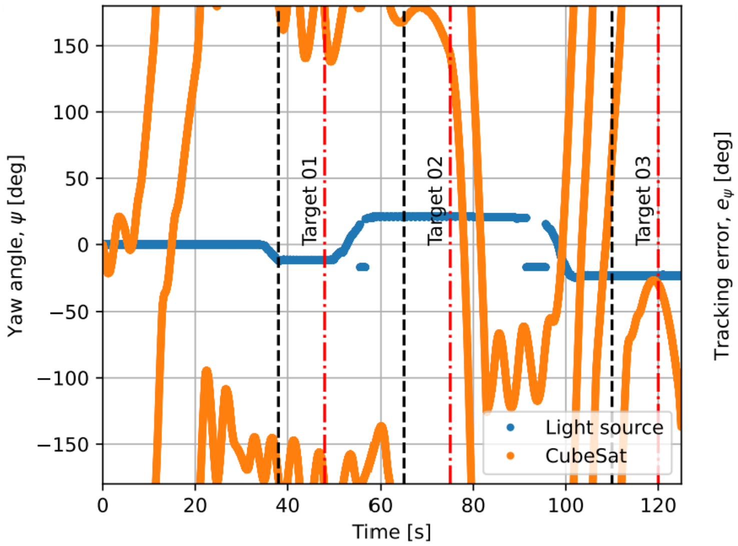


Figure 19 - The Yaw angle (degrees) against time (s) compared to the location of target

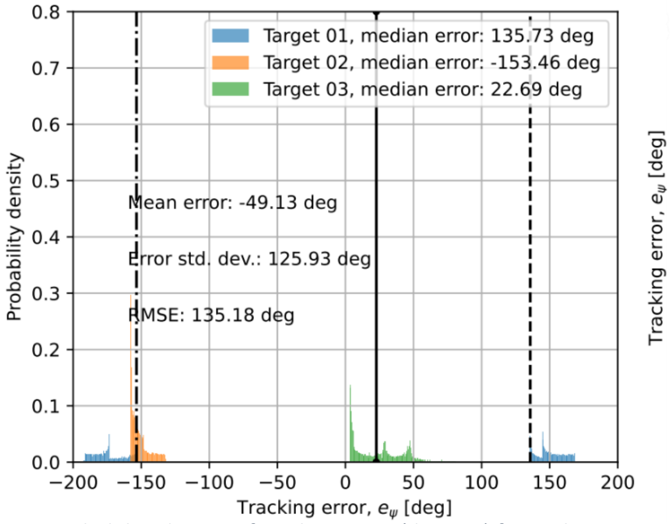


Figure 20 - Probability density of tracking error (degrees) for each target

During LT testing, the CubeSat spent a long time locating the source due to over-rotation. However, the green LED lit up when passing the source, indicating the sensors correctly identified it. With further refined reaction wheel code, the LT would locate the light source correctly. Another issue faced was that external light sources were mistaken for the source. To combat this, the baseline light intensity in the code would have to be adjusted.

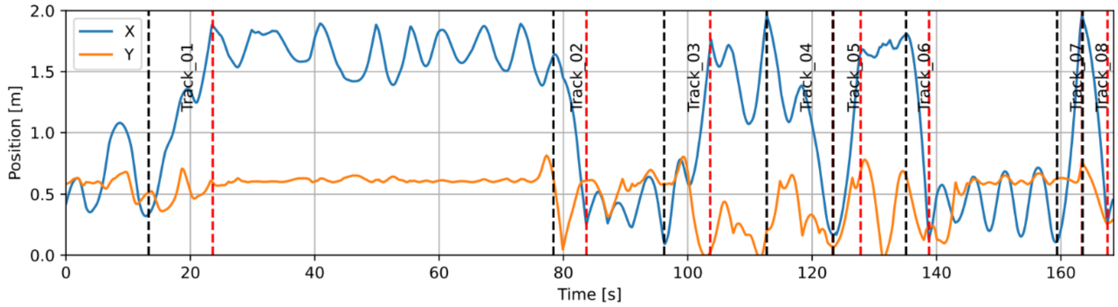


Figure 21 - X and Y position (m) against time (s)

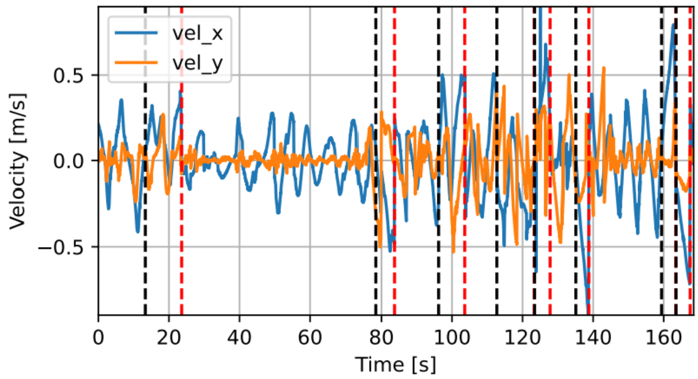


Figure 22 – X and Y Velocity (m/s) against Time (s)

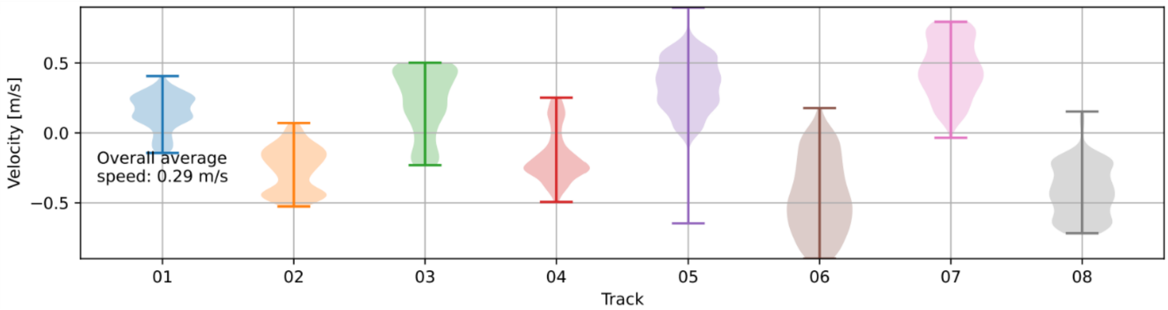


Figure 23 - Average velocity (m/s) for each track

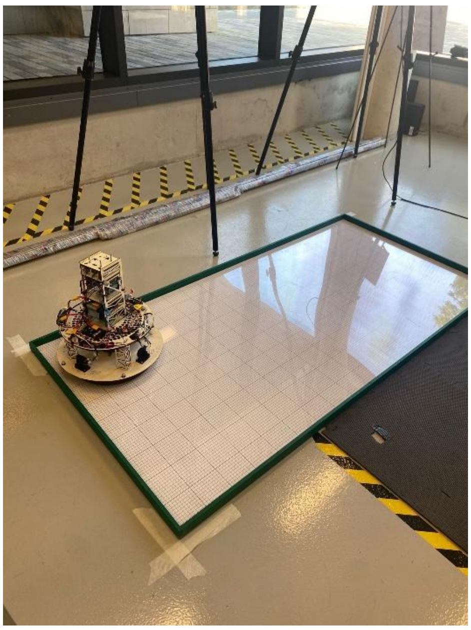


Figure 24 - CubeSat before the LFEP Demonstration

Mode switching worked during LFEP demonstration, allowing for the CubeSat to be controlled via the transmitter. Our CubeSat successfully completed eight laps. However, the velocity was lower than expected; two of the thrusters weren't operational, so it got stuck in a corner during track 2 for 60 seconds. Once out of the corner, the demonstration worked well; the transmitter controlled the reaction wheel to reduce rotation, and the working fans were operated properly to complete the laps. On the final lap, the reaction wheel broke - likely due to damaged gears - so rotational motion could not be controlled. To maintain control, the hover and translational thrusters were operated at low power.

To develop our design further structurally, we could use better interlocking pieces or nuts to fit parts together, instead of glue, for more accessibility when the structure is completed and create more reusable parts as in the design specification (3.5.1).

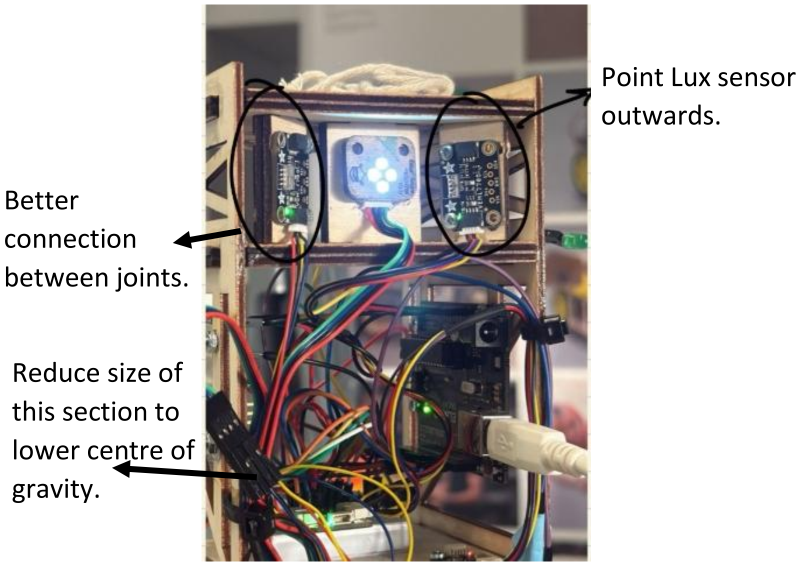


Figure 25. CubeSat Improvements 1

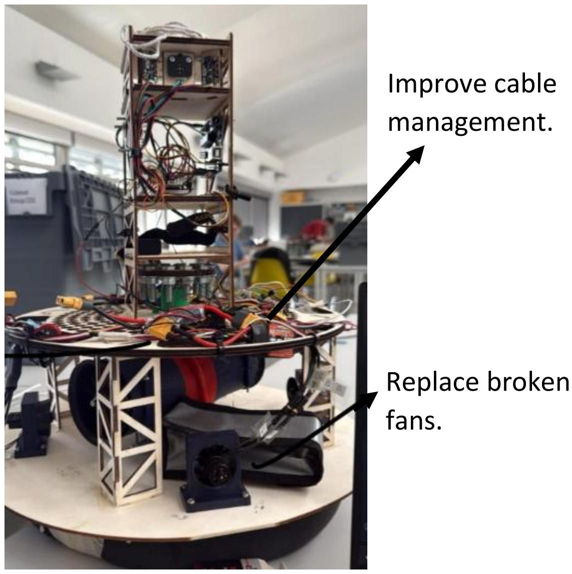


Figure 26. CubeSat Improvements 2

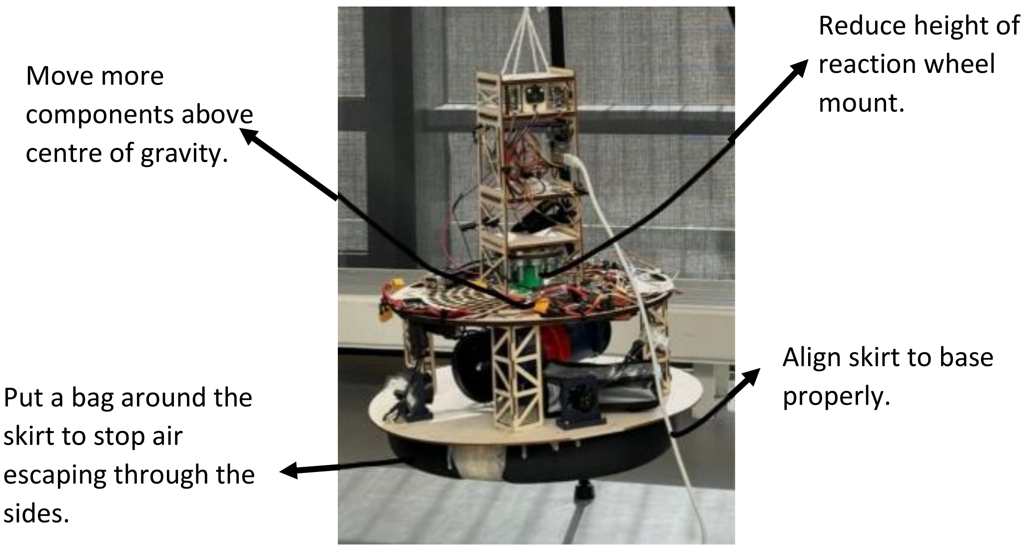


Figure 27. CubeSat Improvements 3

- **References**

[1] "100:1 Micro Metal Gearmotor HP 6V." Pololu.com, 2024, www.pololu.com/product/1101. (Accessed 12 May 2025.)

[2] "Buy M8 Hexagon Nuts (DIN 934) - Stainless Steel (A2) - Accu." Accu, 2015, www.accu.co.uk/hexagon-nuts/7894-HPN-M8-A2. (Accessed 12 May 2025.)

[3] "Buy M8 X 30mm Full Thread Hexagon Bolts (DIN 933) - Stainless Steel (A2) - Accu." Accu, 2015, www.accu.co.uk/full-thread-hexagon-bolts/18902-SEBF-M8-30-A2. (Accessed 12 May 2025.)

[4] Furlong, T. (2024). *Is Plywood Sustainable? A Guide for DIYers*. [online] Cut My Plastic. Available at: https://www.cutmy.co.uk/ideas-advice/plywood-sustainability/. (Accessed 13 May 2025.)

[5] Ansys Granta Edupack R2021. (Accessed 12 May 2025)

[6] British Plastics Federation (2019). *Expanded Polystyrene (EPS)*. [online] Bpf.co.uk. Available at: https://www.bpf.co.uk/plastipedia/polymers/expanded-and-extruded-polystyrene-eps-xps.aspx. (Accessed 13 May 2025.)

[7] Nguyen, Q. (2023). *How Sustainable Is Plywood? Here Are the Facts*. [online] Impactful Ninja. Available at: https://impactful.ninja/how-sustainable-is-plywood/. (Accessed 13 May 2025.)

Appendix A – Full Design Specification

Design Specification

Title: A set of CubeSat systems that can control yaw-attitude, collect and store data, and has a low-friction environment platform (LFEP).

Issue Level			
Issue	**Changes**	**Author**	**Date**
A	Original Document	Evangeline Maloney Harrison Stokes Matthew Grennell Jack Lawler Rohit Kumar Bajaj	12/02/2025

1.0 Scope

This specification relates to a CubeSat and a low-friction environment platform.

2.0 Background

The space industry is growing rapidly growing from 280 billion USD in 2010[1] to 432 billion USD[2] in 2019 with predictions to rise as high as 1.8 trillion USD in 2035[3]. The lowering costs of spaceflight have a large impact on the industry, making it more accessible for smaller companies to launch their payload into space.

Cube satellites, or 'CubeSats', are an extremely cost-effective satellite type due to their compact nature and ease of manufacture, decreasing costs for the customer. CubeSats have become increasingly important over the past decade, with only 25 CubeSat launches in 2012, increasing to 380 in 2023[4]. This trend shows the growing need for small-scale satellites and the increasing importance of having small, cheap satellites for both government and corporate needs.

3.0 DETAILS

3.1 Performance

3.1.1 Product must accurately and stably track a target light source using yaw attitude control from 0.2 to 2m.
3.1.2 Product must locate the light source within 10 seconds of light movement.
3.1.3 Product must locate the light source within 360°.
3.1.4 Product must indicate visually that it has located the light source.
3.1.5 Product must accelerate effectively within the testing platform.
3.1.6 Product must have minimal spin.
3.1.7 Product must have minimum drift.
3.1.8 Product must counteract rotation caused by the uncertainty in the fans.
3.1.9 Product must be able to remain secure and intact in a low-speed collision or quick direction changes.
3.1.10 Product must be controlled remotely using a transmitter and receiver.
3.1.11 Product must have to record data (reference/sensor signal, yaw rotational rate, feedback error signal, feedback command to motor).

3.2 Ergonomics

3.2.1 Suitable controls and manufacturability for UK adults in the 5th – 95^{th} percentile.

3.3 Materials

3.3.1 Materials must be restricted to those provided by the University of Southampton Engineering Design and Manufacturing Centre (EDMC), and by the module.
3.3.2 Materials should be resistant to actions such as crushing or twisting.

3.4 Safety

3.4.1 Product must be safe and easy to transport.
3.4.2 All batteries must be safely enclosed in a Li-Po bag on the CubeSat platform.
3.4.3 During testing, batteries must be kept in the labs.
3.4.4 All coding and wiring must be checked before connecting to the battery.
3.4.5 All wiring and boards must be securely fastened.
3.4.6 Product should not have any sharp edges or potential to cause injuries.

3.5 Environment

3.5.1 Product should be able to be deconstructed at the end of the project into individual pieces ready for reuse or recycling if possible.
3.5.2 Where possible, manufacturing should minimise the amount of wasted material from offcuts.
3.5.3 Product must be usable in the Boldrewood Design Studio (177/3011).
3.5.4 Product should be able to withstand temperatures of -5°C to 30°C in storage.
3.5.5 Product should be able to withstand temperatures of -5°C to 30°C in operation.

3.6 Manufacture

3.6.1 Product will be a one-off production.

3.7 Cost

3.7.1 No additional money should be spent on this product.
3.7.2 The cost should be kept low by using resources provided by the University.

3.8 Aesthetics

3.8.1 Product must have all cables managed neatly in an organised fashion.
3.8.2 When product locates the light source in testing an LED should light up.

3.9 Weight

3.9.1 The product must not exceed 2.3kg.

3.10 Users

3.10.1 The users will be members of the team who are familiar with controlling the product's motion.
3.10.2 There will be a minimum of two users who are trained to control the product.

3.11 Market

3.11.1 The product is a prototype and can be developed for any market.

3.12 Size

3.12.1 The product should not exceed 40cm x 40cm.
3.12.2 The CubeSat should not exceed a vertical envelope of three 100mm cubes.

3.13 Life in Service

3.13.1 The intended life in service for this product is a 3-hour testing period.

3.14 Disposal

3.14.1 The product should be easy to disassemble and dispose of.
3.14.2 The electronic components and fans should be able to be reused.
3.14.3 Materials should be able to be separated where necessary for appropriate disposal.

3.15 Quantity

3.15.1 One unit will be produced.

3.16 Product Life Span

3.16.1 The product will be produced for a 12-week timescale.

Design Specification References

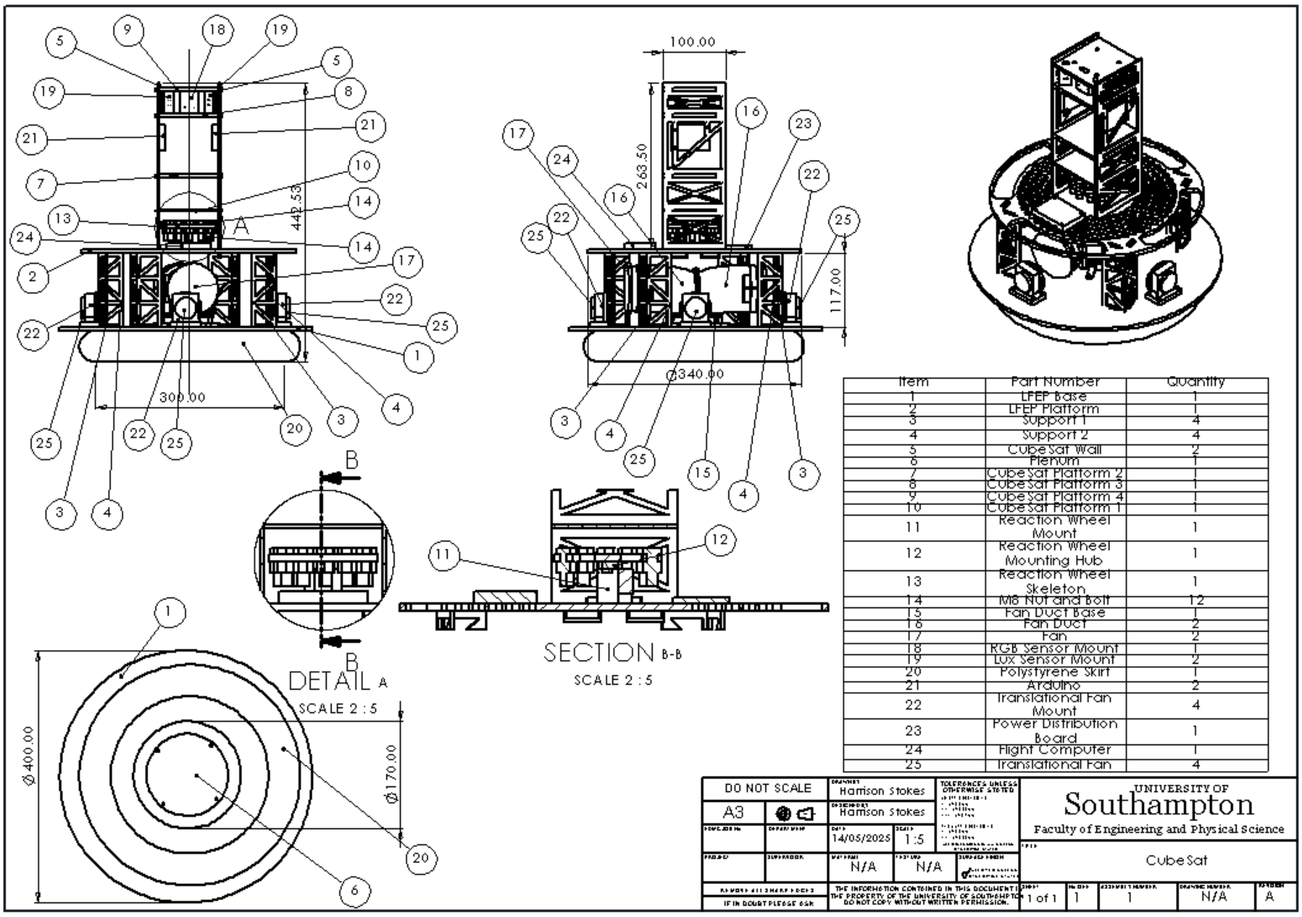
[1] "A Giant Leap for the Space Industry." *McKinsey & Company*, 19 Jan. 2023, www.mckinsey.com/featured-insights/sustainable-inclusive-growth/charts/a-giant-leap-for-the-space-industry. Accessed 12 Feb. 2025.

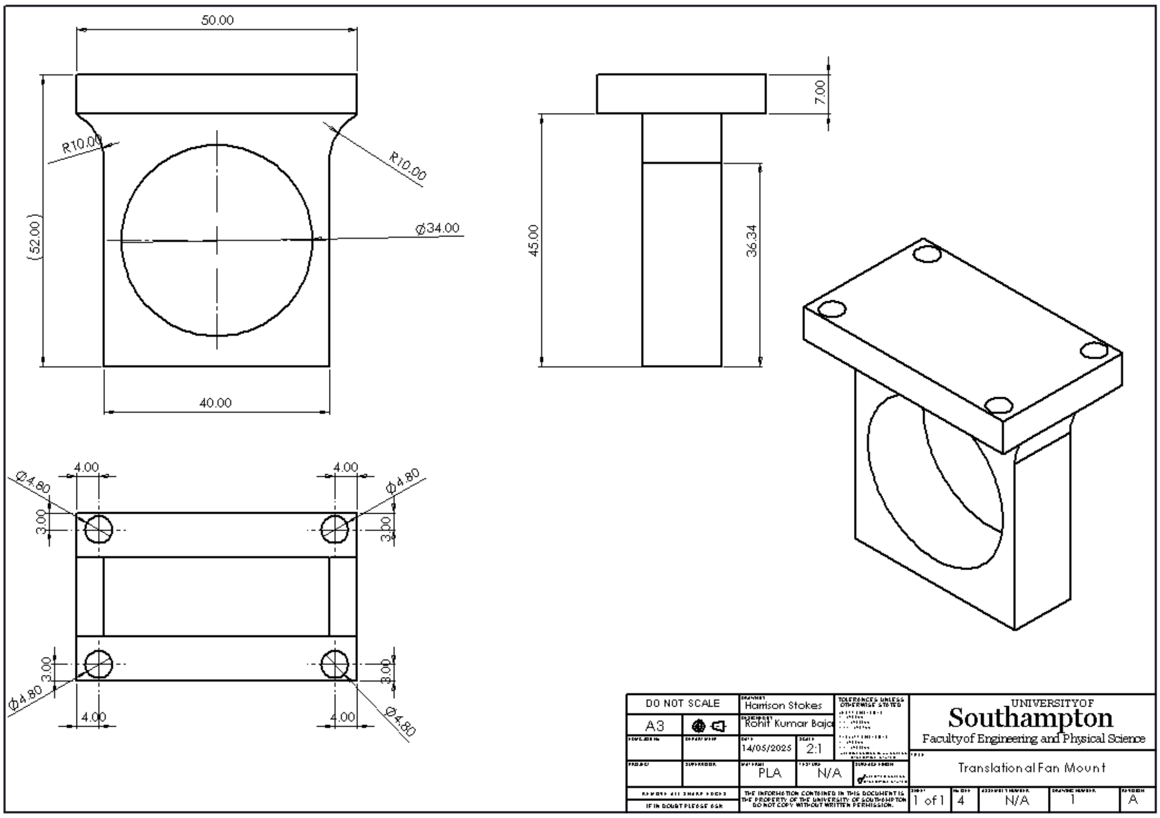
[2] Acket-Goemaere, Alizée, et al. "Space: The $1.8 Trillion Opportunity for Global Economic Growth | McKinsey." *Www.mckinsey.com*, 8 Apr. 2024, www.mckinsey.com/industries/aerospace-and-defense/our-insights/space-the-1-point-8-trillion-dollar-opportunity-for-global-economic-growth.

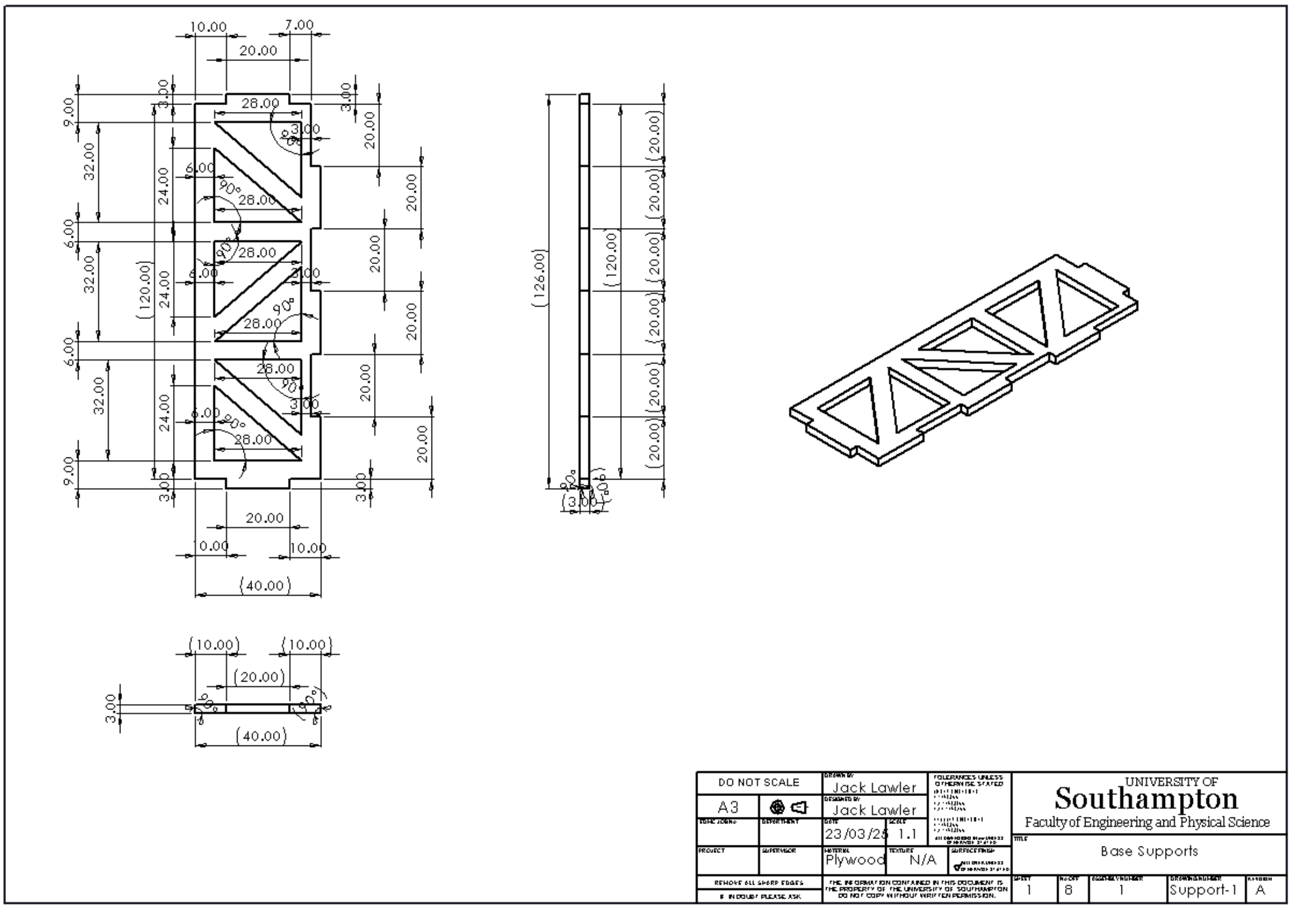
[3] cycles, This text provides general information Statista assumes no liability for the information given being complete or correct Due to varying update, and Statistics Can Display More up-to-Date Data Than Referenced in the Text. "Topic: Space Industry Worldwide." *Statista*, 18 Dec. 2023, www.statista.com/topics/5049/space-exploration/.

[4] Kulu, Erik. "Nanosats Database." *Nanosats Database*, 31 Dec. 2024, www.nanosats.eu.

Appendix B – Full set of Engineering Drawings






DO NOT SCALE
A3
Jack Lawler
Jack Lawler
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Southampton
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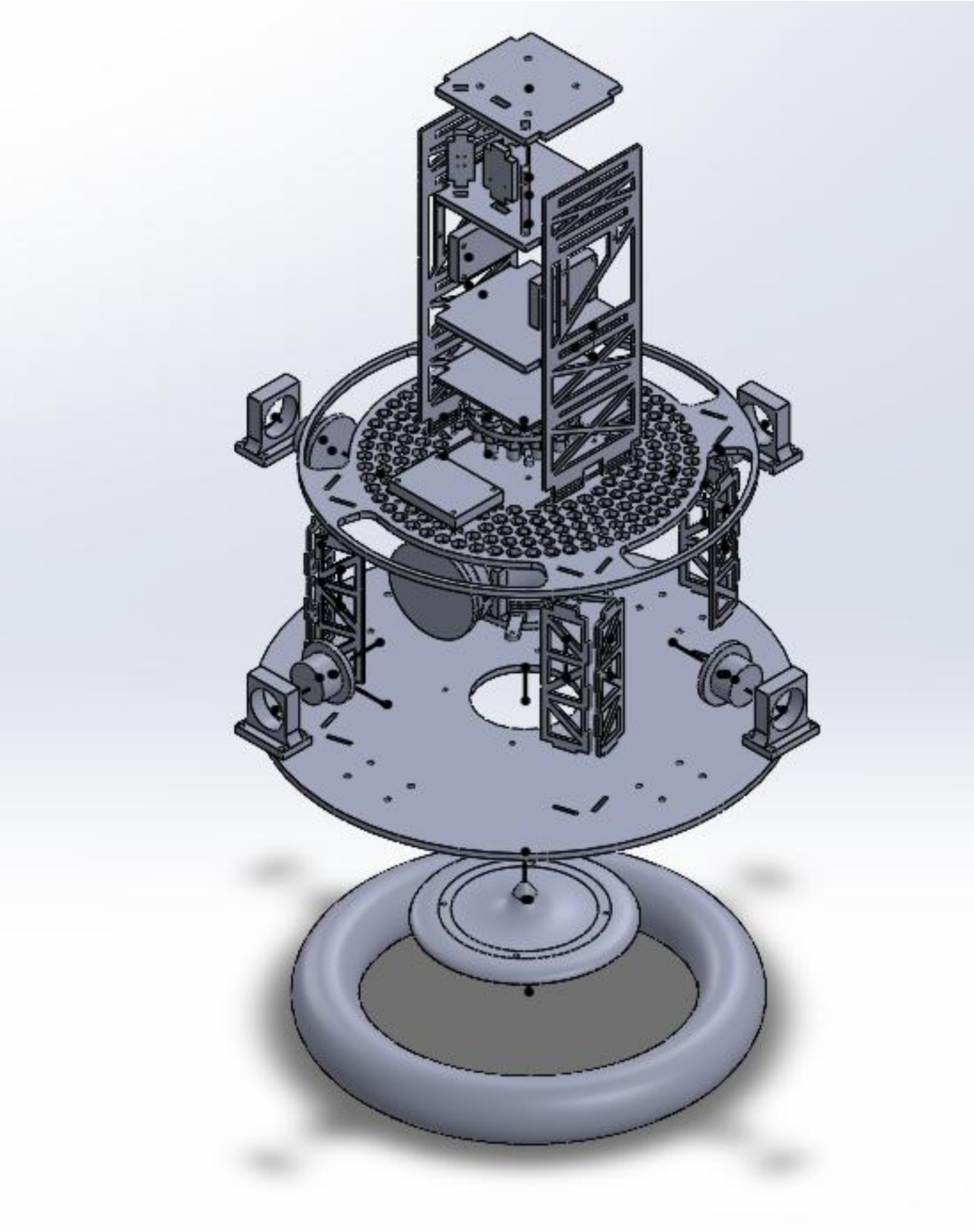

Appendix C - GenAI Declaration Form

You must read this section and complete the declaration form if you have used GenAI as part of this project.

Please delete the GenAI guidance (red text) and just include your individual declaration forms under Appendix C.

Generative AI (GenAI) is defined* here as Artificial Intelligence (AI) technology that automatically generates content in response to user prompts. The generated content includes texts, software code, images, videos, and music.

Student: For Tiers 2/3, complete “2. Declaration” and submit with your assignment.

Definition:

Tier 1: No use
Students are prohibited from using any GenAI tools for their assessed work. This includes entering any part of an assignment or assessed work to GenAI, whether by pasting/typing text, uploading files, or describing content directly or through plugins. Basic tools that assist spelling and grammar, translation and calculation without generating new content or ideas, can be used unless specified otherwise by the assessment setter. GenAI may be used to explain lecture slides and notes to enhance understanding of relevant topic areas.
Tier 2: Assistive use
Students may use GenAI to help achieve intended learning outcomes, which are still achievable without GenAI use. The assessment setter must specify allowed use cases using the **Specification Table.** Students must complete **"2. Declaration"**.
Tier 3: Integral use
Students must use GenAI tools to achieve the intended learning outcomes. The assessment setter must specify the allowed use cases using the **Specification Table**. Students must complete section **"2. Declaration"**.

1. Tier Specification

Enter "All" if applied to entire assignment, or specify applicable question numbers/parts:

Module Code	**Assignment name / description**
FEEG2001	Technical Design Report
Applies to	**Assigned tier**
	Tier 1: No use (no further information is required on this form)
All	Tier 2: Assistive Use (fill **Declaration Requirement** and **Specification Table**)
	Tier 3: Integral Use (fill **Declaration Requirement** and **Specification Table**)

Declaration Requirement (Tier 2/3 only): For Tier 2 and 3 students must complete the standard declaration at the end of this form unless it is explicitly stated as unnecessary below. Additional and other requirements should be specified here (modify the default 'Applies to' entries as required):

Applies to	**Additional GenAI declaration requirements**
Not needed	Full chat logs must be submitted (additional)
Not needed	Annotated version of assignment must be submitted (additional)
All	Standard declaration is required
Not needed	Other (please specify below)

Specification Table (Tier 2/3 only): Enter "All" or specify applicable question numbers/parts:

ID	**Applies to**	**GenAI use case**	**Definition**	**Example prompts**
Assistive: A1-6 are assistive GenAI use cases where "outputs produced by GenAI are not a part of the final submission material".				

A1	All	Debugging code	Inputting code and error messages into GenAI to identify syntax or logical errors.	"Here are 20 lines of Python code and an error message. Identify why this error is occurring."
A2	All	Critiquing spelling punctuation and grammar	Using GenAI to identify and suggest corrections for spelling, punctuation, and grammar mistakes without changing the overall meaning.	"Check my technical report on fluid dynamics for spelling, punctuation, and grammar mistakes without altering the overall meaning."
A3		Essay planning	Using GenAI to help outline the structure and subsections of an essay based on the topic and research findings.	"Create an outline for an essay on the impact of automation on manufacturing, including suggested sections and subsections."
A4	All	Source recommendations	Using GenAI to find and suggest relevant academic or credible sources related to the assessment topic.	"Find peer-reviewed articles on renewable energy solutions for my mechanical engineering research project."
A5	All	Suggesting design solutions	Using GenAI to generate ideas and suggestions for solving specific design challenges.	"Suggest amplifier circuits that require low power consumption while having little noise."
A6	All	Function and library recommendations	Using GenAI to suggest appropriate functions or libraries to use in programming tasks.	"Recommend Python libraries suitable for simulating electrical circuits."
Generative: G1-6 are generative GenAI use cases where "outputs produced by GenAI are a part of the final submission material".				
G1	All	Generating or correcting a segment of Code	Using GenAI to write or correct a segment of code based on a given prompt describing the desired functionality.	"Write Python code to control a servo motor using a Raspberry Pi."
G2	All	Rewriting written material	Using GenAI to help restructure and modify the text in a document, including grammar and stylistic improvements.	"Rewrite my technical report on the design of an electronic circuit to improve clarity and coherence."
G3	All	Generating images / figures	Using GenAI to create diagrams, charts, or figures for use in a report or presentation.	"Generate a schematic diagram of a microcontroller-based temperature control system."
G4		Language translation	Using GenAI to translate text from one language to another and correct grammar mistakes in the translated text.	"Translate this technical documentation from German to English and correct any grammar mistakes."
G5		Writing sections of a report or producing slides in a presentation	Using GenAI to generate parts of a report, such as abstracts, introductions, or conclusions.	"Write an abstract for my research paper on the optimisation of power systems."
G6		Analyse data that is not subject to additional ethics approval	Inputting large datasets into GenAI to identify trends, correlations, and insights.	"Analyse this dataset of sensor readings from an IoT network to identify trends and generate visualisations."

ID	Applies to	Other allowed GenAI use cases (define below and assign an ID)

For more information on completing this form visit: https://sotonac.sharepoint.com/sites/FEPSGenAI

Declaration

All students must complete this section for all Tier 2 and 3 assessments

One declaration is required for each student for this group submission. Simply copy and paste the form below for those students who have chosen to use AI/GenAI.

Answers on this form will NOT IMPACT your marks unless an Academic Responsibility and Conduct breach is found.

General university guidance regarding GenAI can be found via the library

Name		Student ID
Evangeline Maloney		35002107
Module Code		Assignment name / description
FEEG2001		Technical Design Report
Have you used GenAI? (Tick for yes)	☐	Date: 12/05/2025
Which GenAI tools have you used? (Include version / leave blank if not used)		

Standard declaration: Complete this for all Tier 2 and 3 assessments unless specified as not required

For each GenAI use (see definitions and codes over the page), summarise which questions and how each was used (suggest 1 or 2 sentences per use category)

If **Full chat logs** and/or **annotated assignment versions** are required, examples can be found via the link in the footer.

Academic Conduct

I acknowledge I have answered honestly on this declaration form	☒

I understand if I was unsure about whether my actions met academic conduct requirements, it is my responsibility to confirm with the teaching team prior to submission	☒
I am aware of and have critically reviewed the content generated by GenAI used in this submission. I accept responsibility for this content and can be asked about it in the future	☒

Name		Student ID
Matthew Grennell		35139978
Module Code		Assignment name / description
FEEG2001		Technical Design Report
Have you used GenAI? (Tick for yes)	☐	Date: 15/05/2025
Which GenAI tools have you used? (Include version / leave blank if not used)		
N/A		

Standard declaration: Complete this for all Tier 2 and 3 assessments unless specified as not required

For each GenAI use (see definitions and codes over the page), summarise which questions and how each was used (suggest 1 or 2 sentences per use category)
N/A

If **Full chat logs** and/or **annotated assignment versions** are required, examples can be found via the link in the footer.

Academic Conduct

I acknowledge I have answered honestly on this declaration form	☒
I understand if I was unsure about whether my actions met academic conduct requirements, it is my responsibility to confirm with the teaching team prior to submission	☒
I am aware of and have critically reviewed the content generated by GenAI used in this submission. I accept responsibility for this content and can be asked about it in the future	☒

Name		Student ID
Harrison Stokes		34915079
Module Code		Assignment name / description
FEEG2001		Technical Design Report
Have you used GenAI? (Tick for yes)	☐	Date: 15/05/2025
Which GenAI tools have you used? (Include version / leave blank if not used)		
N/A		

Standard declaration: Complete this for all Tier 2 and 3 assessments unless specified as not required

For each GenAI use (see definitions and codes over the page), summarise which questions and how each was used (suggest 1 or 2 sentences per use category)
N/A

If **Full chat logs** and/or **annotated assignment versions** are required, examples can be found via the link in the footer.

Academic Conduct

I acknowledge I have answered honestly on this declaration form	☒
I understand if I was unsure about whether my actions met academic conduct requirements, it is my responsibility to confirm with the teaching team prior to submission	☒
I am aware of and have critically reviewed the content generated by GenAI used in this submission. I accept responsibility for this content and can be asked about it in the future	☒

Name		Student ID
Rohit Kumar Bajaj		34491147
Module Code		Assignment name / description
FEEG2001		Technical Design Report
Have you used GenAI? (Tick for yes)	☐	Date: 15/05/2025
Which GenAI tools have you used? (Include version / leave blank if not used)		
Answer here		

Standard declaration: Complete this for all Tier 2 and 3 assessments unless specified as not required

For each GenAI use (see definitions and codes over the page), summarise which questions and how each was used (suggest 1 or 2 sentences per use category)
Answer here E.g. A1: Debugged my python code that didn't work on line 25 A4: I used ChatGPT to help me find similar sources to the given reports A6: I asked Gemini what functions would be best to process the lab data. It came up with NumPy with the numpy.GenAI function. G5: I generated captions for figures 3 and 7 as well as created an abstract for my report

If **Full chat logs** and/or **annotated assignment versions** are required, examples can be found via the link in the footer.

Academic Conduct

I acknowledge I have answered honestly on this declaration form	☒
I understand if I was unsure about whether my actions met academic conduct requirements, it is my responsibility to confirm with the teaching team prior to submission	☒
I am aware of and have critically reviewed the content generated by GenAI used in this submission. I accept responsibility for this content and can be asked about it in the future	☒

Name		Student ID
Jack Lawler		35233303
Module Code		Assignment name / description
FEEG2001		Technical Design Report
Have you used GenAI? (Tick for yes)	☐	Date: 15/05/2025
Which GenAI tools have you used? (Include version / leave blank if not used)		
N/A		

Standard declaration: Complete this for all Tier 2 and 3 assessments unless specified as not required

For each GenAI use (see definitions and codes over the page), summarise which questions and how each was used (suggest 1 or 2 sentences per use category)
N/A

If **Full chat logs** and/or **annotated assignment versions** are required, examples can be found via the link in the footer.

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