Phase Report 2 - Analysis, GD&T, & Prototyping

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v0.2

1.) Objectives

- **CAD Iteration:** Document changes made to the original X-frame design based on FEA and printability constraints.
- **FEA Static Stress Testing:** Perform and record results of gravity, hover-thrust, and drop simulations.
- **Prototype Fabrication:** 3D print the X-frame in polycarbonate, evaluate its fit and functionality with the parts, and integrate necessary modifications.
- **GD&T Documentation:** Create dimensioned and toleranced drawing to communicate manufacturing requirements for the final frame.

2.) CAD Modifications

- Summary of Changes
  - Transitioned CAD environment from NX Student Edition to Autodesk Fusion 360 Student Access to enable FEA functionality.
  - Scaled overall frame dimensions from 248x248x4 mm to 228x228x3 mm to meet the printer bed constraints.
  - Adjusted motor mounter dimensions from 16x16 mm (measured center to center) to 13x13 mm.
- Modification Rationale

Feature	Issue	Modification	Expected Benefit

Software	NX Student Edition lacks access to FEA tools.	Rebuilt model in Fusion360 Student Access (original NX model was incompatible).	Enabled analysis workflows.
Print bed constraint	X-frame too large for Bambu X1C.	Scaled X-frame to 228x228 mm.	Compatible with printers.

3.) FEA Static Stress Results

- Study Setup
  - **Material Properties**
    - Polycarbonate
    - Young's Modulus, E = 2275.00 MPa
    - Possion's Ratio, $v = 0.38$
    - Density, $\rho = 1.2\ g/cm^3$
  - **Mesh Settings**
    - Global element size 3 mm (linear)
    - Local refinement: 1 mm elements in high-stress regions
  - **Component Masses:**

Component	**Mass (kg)**	**Weight Location**
Flight Controller	0.0090	Center plate
4-in-1 ESC	0.0125	Center plate
Motors	0.0160	Motor mount (x4)
Propellers	0.0050	Motor mount (x4)
LiPo Battery	0.1190	Center Plate
X-frame	0.0481	COG

  - **Load Cases:**
    - Gravity: Self-weight ($9.81\ m/s^2$)

- Hover-Thrust: Four upward point loads of 0.55 N each applied at motor-boss locations, electronics' weights applied at their theoretical mounts

- Results Summary

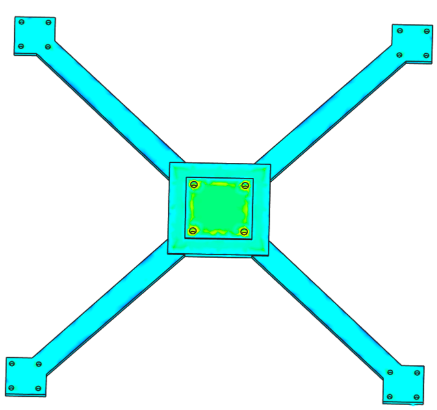
Load Case	Max von Mises Stress (MPa)	Max Displacement (mm)	FoS (vs. 50 MPa)
Gravity	0.003 MPa	1.85×10^{-5}	1.67×10^{4}
Hover-Thrust	1.612×10^{-5}	1.31×10^{-8}	3.10×10^{6}

Note: Factor of Safety is defined as...

$$FoS = \frac{Allowable\ Stress\ (50\ MPa)}{Max\ von\ Mises\ Stress}$$

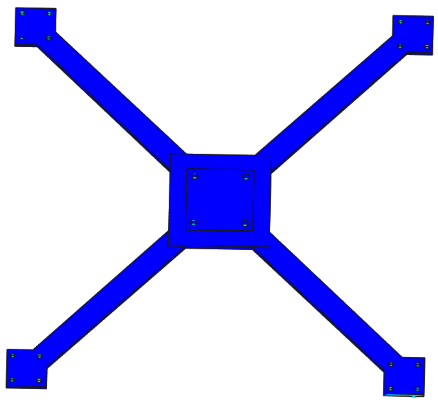
- Contour Figures
  - Gravity
    - von Mises

[MPA] 0.00 E-05 1.845E-05



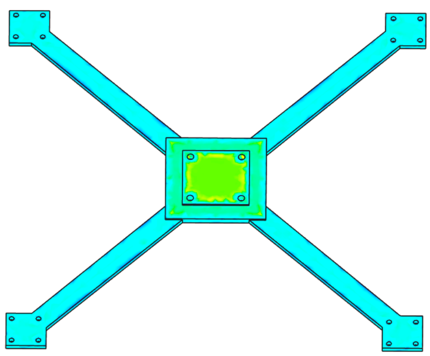
    - Displacement

[mm] 0.00 E-08 1.936E-08



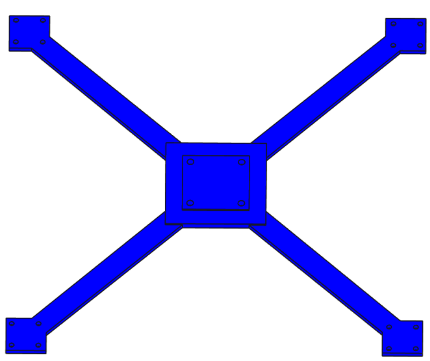
- Hover Load
  - von Mises

[MPa] 0.00 E-05 1.612 E-05



  - Displacement

[mm] 0.00 E-08 1.312 E-08



- Discussion

- Gravity case
    - The frame under self-weight alone produces a maximum von Mises stress of only 0.003 MPa and a displacement of 1.85×10^{-5} mm.
    - This yields an FoS of approximately 16,700, indicating that gravity is negligible for structural sizing.
- Hover-thrust case
    - Applying 0.55 N thrust loads and adding the additional weight of the electronics shows a peak von Mises stress of only 1.61×10^{-5} MPa and a maximum displacement of about 1.31×10^{-8} mm. These values are so small the frame remains virtually undeformed under the theoretical loads.
- Implications & Next Steps
    - Such high safety margins suggest opportunities and flexibility for future structural modifications.
    - Since neither the gravity nor hover-thrust load cases approach the material's strength limit, future analyses should instead target more demanding scenarios (i.e. impact or drop tests) to identify the frame's true performance margins.

4.) 3D Printing & Prototype Evaluation

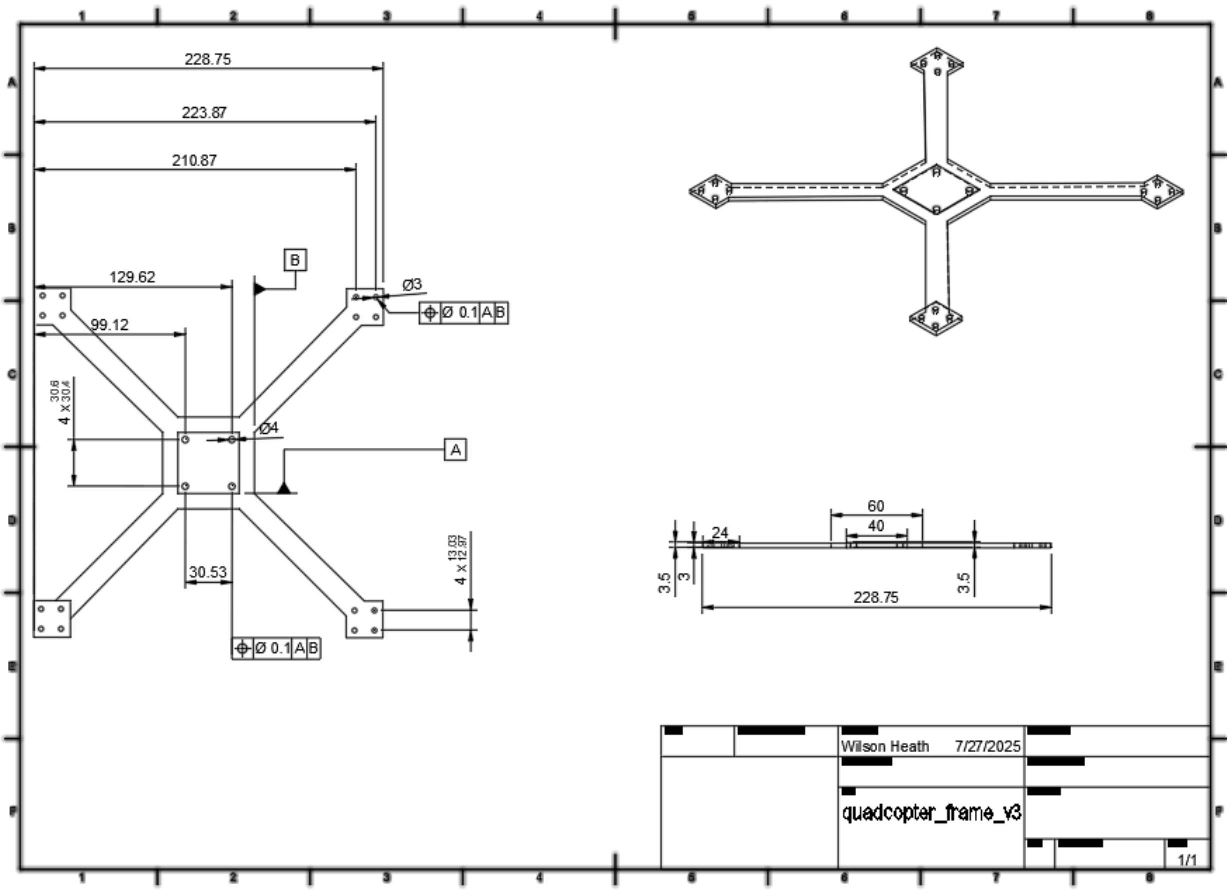
- Prototype Assembly and Observations
    - Components were placed in their intended locations on the printed X-frame.
    - The primary issue identified was with the motor mount holes, which were incorrectly spaced.
    - Considered the routing and clearance of wiring paths and electrical connections between parts.

- Design Corrections
  - Resized the motor mounts from 16 mm of spacing in between holes (measured center to center) to 13 mm of spacing.
- Reprint & Verification
  - The second prototype allowed for motors to successfully mount to the X-frame.

5.) GD&T Drawings

- Datum Reference Frame
  - **Datum A:** Front edge of mounting plate (X direction)
  - **Datum B:** Left edge of mounting plate (Y direction)
- Feature Control Frames

Feature	Callout
Motor-mount holes	⌖⌀3.0 | A | B
FC/ESC-mount holes	⌖⌀4.0 | A | B



6.) Bill of Materials Updates

Item	Qty	Total Cost (USD)	Notes
Quadcopter X-frame v2	1	3.54	Incorrect motor-mount hole dimensions
Quadcopter X-frame v3	1	3.81	Slightly thicker wing arms.
Phase 1 BOM	1	206.48	N/A
Total		213.83	Currently under budget

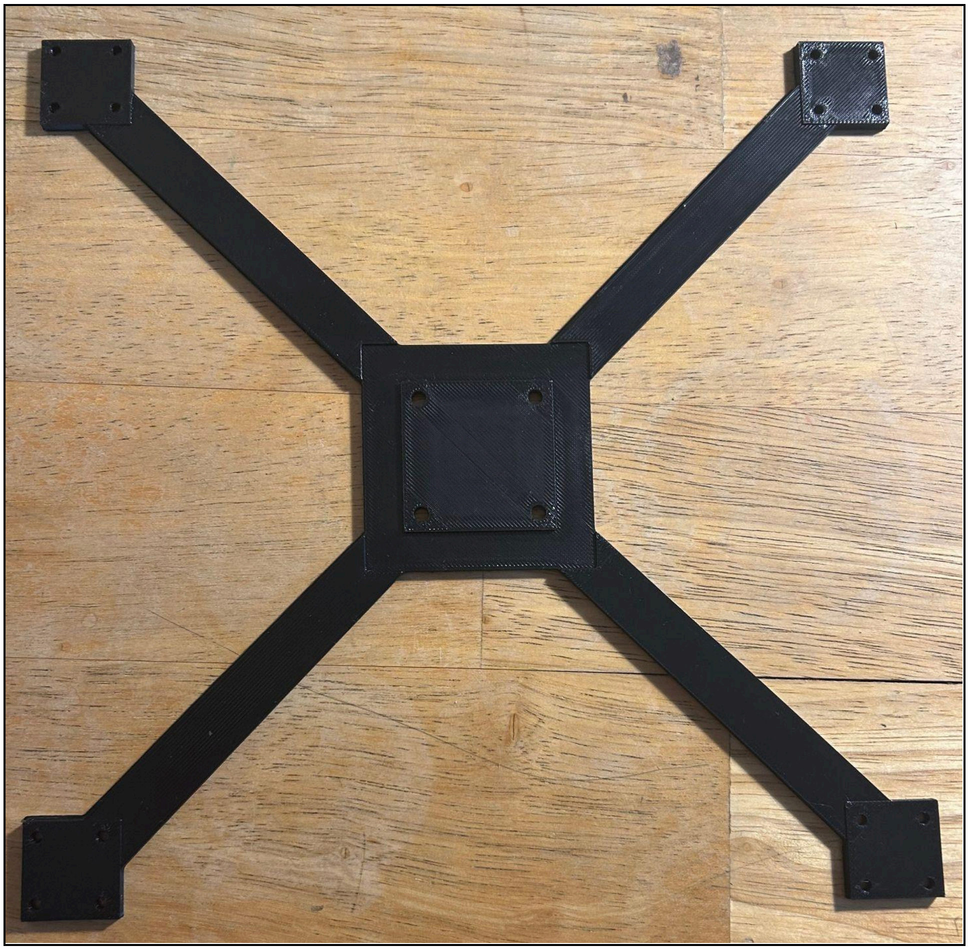
7.) Challenges

- Could not access NX simulation features in Student Edition— Pivoted to Autodesk Fusion360 to simulate and perform FEA.

- Could not successfully perform FEA in Fusion360 with the original X-frame model designed in NX; had to redo the model in Fusion.
- Motor mounting dimensions were listed as 16x16 mm center to center but were actually 16x16 mm edge to edge, 13x13mm center to center; had to redesign and reprint the X-frame with proper motor-mount dimensions.

8.) Photos

Quadcopter components.



Quadcopter X-frame v2.

9.) Next Steps

- **Simulink Simulations:** Model stable hover and sensor feedback.
- **Firmware Setup:** Flash and configure flight controller and receiver.
- **Physical Assembly:** Install ESC, FC, motors, and receiver on to X-frame and plan wiring pathing.