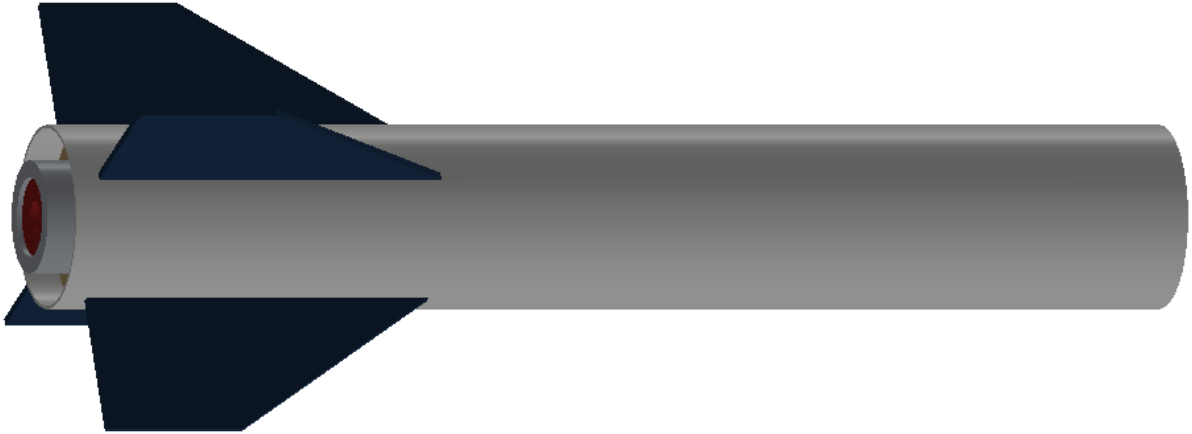


A flutter-checked, flight-simulated fin can for a K-class, 4-fin student rocket

Sized to EirSpace's Bell Burnell (K700 motor, 4 fins, 2 km target) · Anish Achar · 08 October 2026



What this is. A self-directed structures project: I designed the fin can (fins, motor mount, centering rings, recovery attachment) for a rocket like Bell Burnell, then checked it with a flight simulation, a fin flutter analysis and hand-calculated load cases, and modelled it in SOLIDWORKS from the same parameters.

Result. 4 x 4.0 mm G10 fins (200/80 mm chords, 80 mm span, swept leading edge) with through-the-wall tabs, a 54 mm motor mount, three birch-ply rings and the forward ring doubling as the recovery bulkhead.

Key result	Value	Requirement / note
Apogee (K700W, 6 m rail, 85 deg)	2,000 m	2,000 m target - met with no ballast
Max speed	235 m/s (Mach 0.69)	subsonic, max q 32.5 kPa
Static margin	2.19 cal rail exit, 2.86 at burnout	1.5 - 3.0 cal band
Fin flutter margin	1.95 x flight speed	>= 1.5 (NACA TN 4197)
Lowest structural factor of safety	2.31 (aft ring bending, full thrust)	>= 2.0 on every case
Rail exit speed / peak acceleration	37.5 m/s / 12.1 g	comfortably stable off the rail
Fin can mass (excl. airframe tube)	1.10 kg	fins 0.44 kg, matching the CAD to the gram
Lift-off mass	8.25 kg	assumed mass budget (section 1)

1. Scope, sources and assumptions

EirSpace publishes three numbers for Bell Burnell: a **K700 competition motor**, **4 fins (Katana-derived)** and a **2 km target apogee**. Everything else here is an assumption sized like a typical 4-inch, K-class student rocket, so the absolute numbers are only as good as those guesses - the method is the point, and every input lives in one file (analysis/design.py) so the team's real numbers can be dropped straight in.

Item	Value used	Basis
Motor	AeroTech K700W, 2,249 Ns, 3.6 s	only K700 in regular production; ThrustCurve.org certification curve
Airframe	102 mm OD x 1.8 mm filament-wound glass	typical 4-inch tube; 54 mm motor mount
Overall length	1.783 m (4:1 tangent ogive nose)	assumed layout
Mass budget (no motor)	6.21 kg incl. 1.0 kg payload/avionics	itemised in results.json
Launch	6 m rail, 85 deg, sea level	conservative rail length for rail-exit speed
Materials	G10 fins, birch-ply rings, A2-70 M6 U-bolt	typical published properties
Design rules	flutter margin ≥ 1.5 ; FoS ≥ 2.0	my choice; common student-team practice

'Katana-derived' is the only planform hint, so I read it as a swept, blade-like leading edge with the trailing edge square to the body (which also protects the fins on landing). I don't know the real Katana planform.

2. Reference rocket and flight simulation

Reference rocket (sized like Bell Burnell): static margin 2.19 cal at rail exit, 2.86 cal at burnout

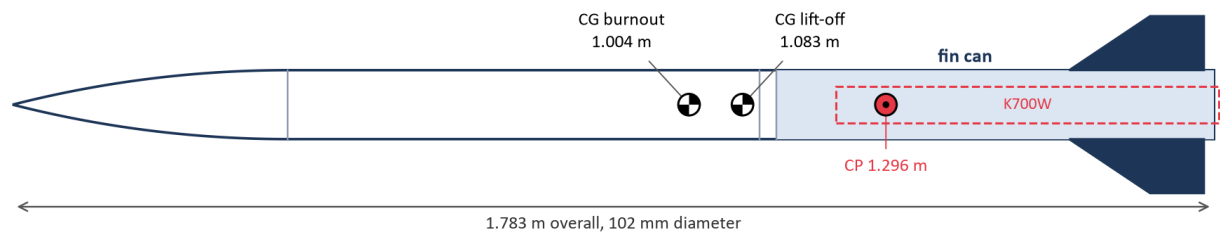


Figure 1 - Reference rocket. Barrowman centre of pressure (red) and the CG at lift-off and burnout.

The flight model is a 2-DOF point-mass simulation (RK4, 2 ms steps): rail-guided, then a zero-angle-of-attack gravity turn, with the ISA atmosphere and the K700W certification thrust curve. Drag is built up component by component in the style of OpenRocket - turbulent or roughness-limited skin friction with a compressibility correction, fin leading-edge drag, base drag (trimmed while the motor burns) and a 10% allowance for rail buttons and joints. The coast drag coefficient comes out at 0.57.

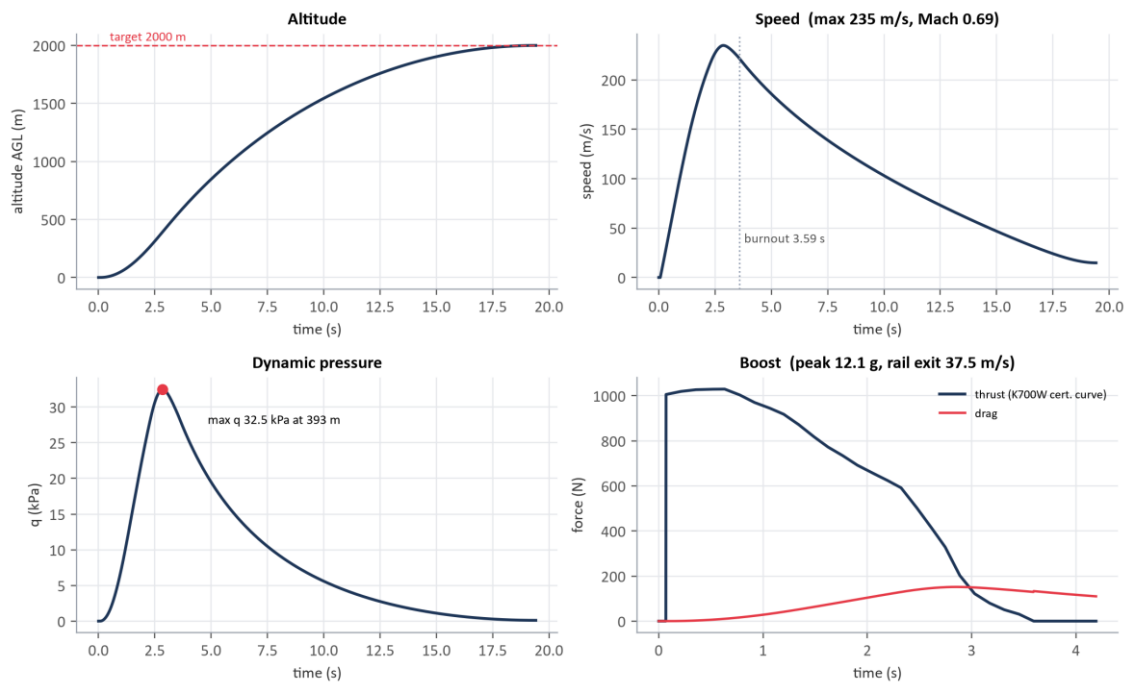


Figure 2 - Flight profile. Max speed 235 m/s at 397 m, burnout at 3.59 s / 564 m, apogee 2,000 m at 19.4 s.

3. Choosing the fins: three design iterations

Each planform was flown with the thinnest standard G10 sheet that keeps the flutter margin, so every option in the comparison is flight-worthy and the trade is purely stability vs apogee vs mass.

Iteration	Planform (root/tip/span)	G10	Static margin (rail / burnout)	Apogee	Fin set
1 first guess	220 / 80 / 105 mm, square TE	4.8 mm	3.01 / 3.64 cal	1,847 m	0.71 kg
2 chamfered TE	same planform	4.8 mm	3.01 / 3.64 cal	1,902 m	0.71 kg
3 planform sweep (24)	200 / 80 / 80 mm, swept LE	4.0 mm	2.18 / 2.86 cal	2,000 m	0.44 kg

- **Iteration 1 was over-stable** (3.0 cal at rail exit) and 150 m short of the target: oversized fins cost drag, mass and - because flutter speed falls with aspect ratio - thickness.
- **Chamfering the trailing edges** removed most of the fins' base drag: +55 m for no mass.
- **Shrinking the span** fixed everything at once: the margin moved into the 1.5-3.0 band, the lower aspect ratio let the fins drop to 4.0 mm, and apogee reached the 2 km target with 266 g less fin.

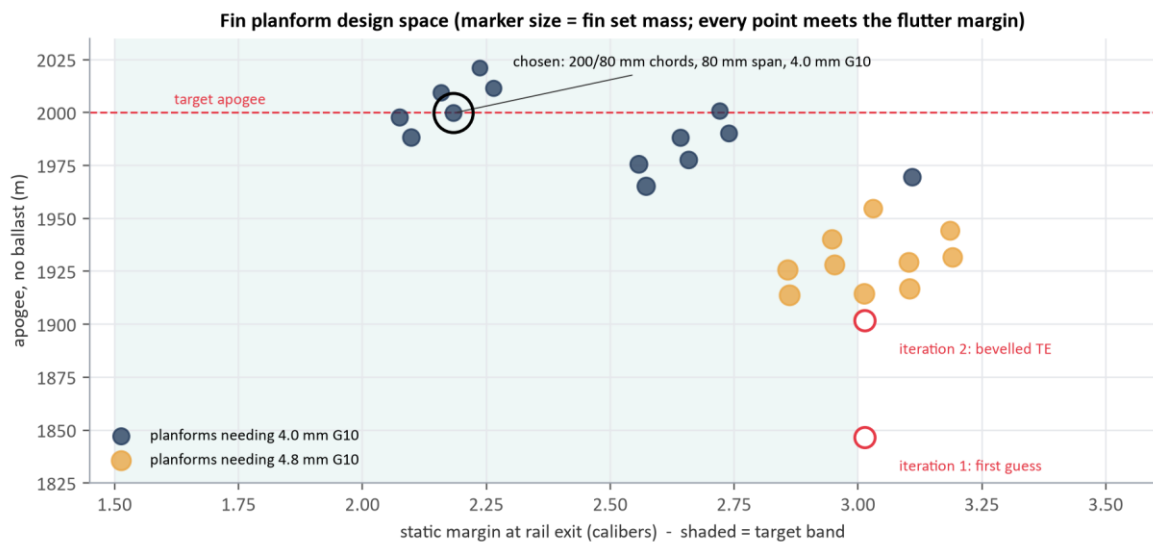


Figure 3 - All 24 planforms of iteration 3 plus the first two iterations. Every point passes the flutter check.

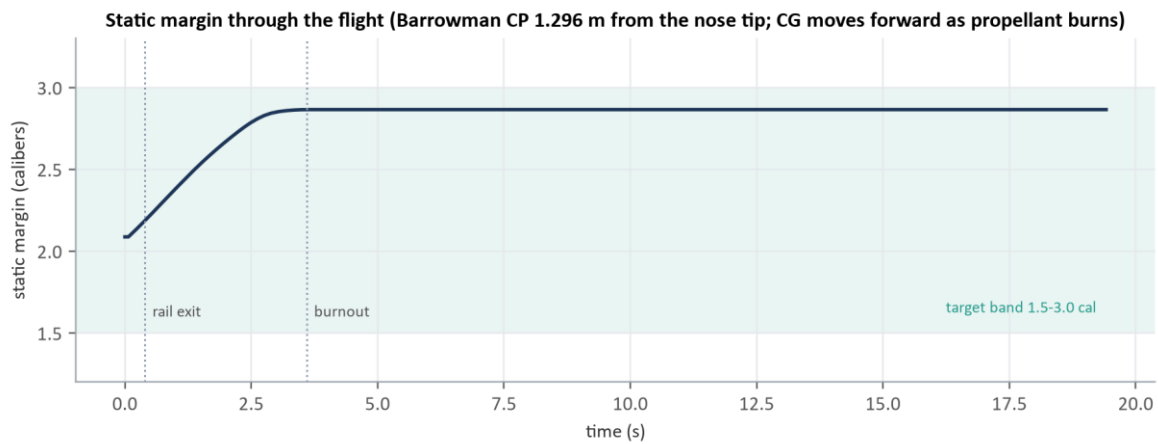


Figure 4 - Static margin through the flight: the CG moves forward as the 1.30 kg of propellant burns.

4. Fin flutter - the sizing case

Fin flutter (a self-exciting bending-torsion oscillation that can shed fins in a few cycles) is what actually sizes these fins: in bending they have a factor of safety of over 100. I used the NACA TN 4197 flutter boundary, the standard tool in amateur rocketry, evaluated at every point of the trajectory with the local pressure and speed of sound - not just at max speed - and required the flutter speed to stay 1.5x above the flight speed throughout. The worst point is just after max speed, at 394 m (235 m/s vs a 458 m/s flutter speed).

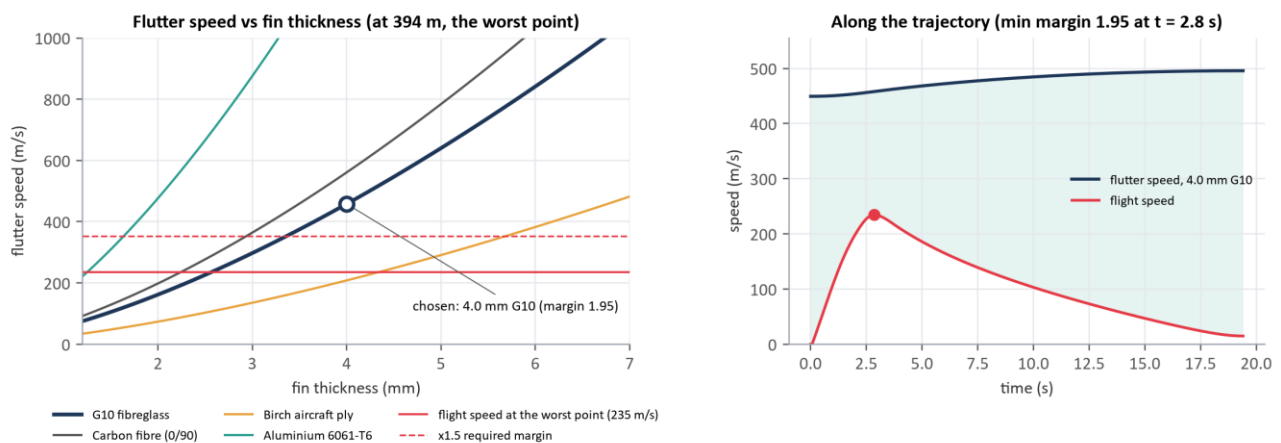


Figure 5 - Left: flutter speed vs thickness at the worst point for four materials. Right: margin along the trajectory for the chosen fin.

Fin material	Thinnest passing sheet	Fin set mass	Flutter margin	Apogee
G10 fibreglass	4.0 mm	0.44 kg	1.95	2,000 m
Carbon fibre (0/90)	3.2 mm	0.30 kg	1.68	2,035 m
Birch aircraft ply	6.4 mm	0.26 kg	1.77	2,000 m
Aluminium 6061-T6	2.4 mm	0.39 kg	2.64	2,030 m

Decision: G10. Carbon and aluminium are lighter for the same margin and aluminium has by far the most flutter margin, but G10 is cheap, easy to cut and bevel, bonds well into a glass airframe and is what student teams already work with. Birch ply is lightest but would need 6.4 mm and is the least durable on landing. If the team wanted the last 35 m of apogee, 3.2 mm carbon is the upgrade path.

5. Structural load cases

Each case is a hand calculation with stated assumptions, chosen to be conservative. Recovery loads use the standard opening-shock estimate $F = C_x \times 0.5 \rho v^2 C_d A$ with $C_x = 1.8$: the main ($C_d A$ 3.1 m², about a 2.2 m canopy for 6 m/s landing) opening at the 25 m/s drogue rate gives **2,068 N (30 g)**. A drogue failure, with the main opening at 45 m/s, gives 6,700 N (98 g) - I checked the recovery hardware against that too, requiring only that it survives.

Load case	Applied	Allowable	FoS	Need
Fin flutter (NACA TN 4197)	234.83 m/s	458 m/s	1.95	1.5
Fin root bending, 10 m/s gust	2.23 MPa	340 MPa	152	2.0
Aft ring bending, full thrust	25.98 MPa	60 MPa	2.31	2.0
Aft ring bond shear (MMT side)	1.49 MPa	10 MPa	6.69	2.0
Airframe axial buckling	2.85 MPa	150 MPa	53	2.0
Forward ring bending	1.77 MPa	60 MPa	34	2.0
U-bolt washer pull-through	1.52 MPa	8 MPa	5.25	2.0
U-bolt legs (M6 A2-70)	51.44 MPa	450 MPa	8.75	2.0
Forward ring bond shear	0.45 MPa	10 MPa	22	2.0
Forward ring bending (no-drogue failure)	5.74 MPa	60 MPa	10	1.0
U-bolt washer pull-through (no-drogue failure)	4.94 MPa	8 MPa	1.62	1.0
U-bolt legs (M6 A2-70) (no-drogue failure)	166.67 MPa	450 MPa	2.70	1.0
Forward ring bond shear (no-drogue failure)	1.45 MPa	10 MPa	6.91	1.0

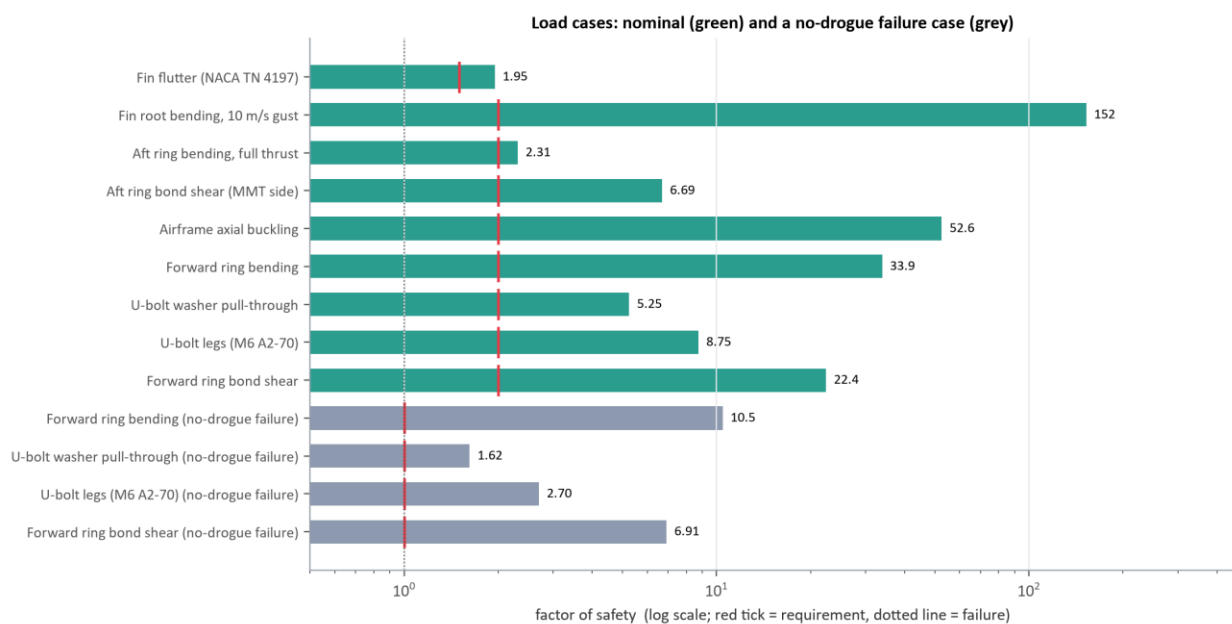


Figure 6 - Factor of safety for every case (log scale). Nominal cases need 2.0, the failure case 1.0.

What the numbers say:

- **The aft centering ring is the critical part** (FoS 2.31) if it alone carries the 1,617 N design thrust. I solved the axisymmetric plate-bending equation for the ring (checked against Timoshenko's closed-form solution) rather than using a lookup coefficient. In reality the thrust also shares into the other rings and the fin tabs, so this is a bound - but it says don't go thinner than 6 mm ply there.
- **The U-bolt washers are the weak point in a drogue failure** (FoS 1.62 against pulling through the 12 mm ply). A larger backing plate under the nuts would be a cheap fix.
- **Fin bending and airframe buckling are not close to critical**, which is itself useful: thickness should be set by flutter and handling, not strength.

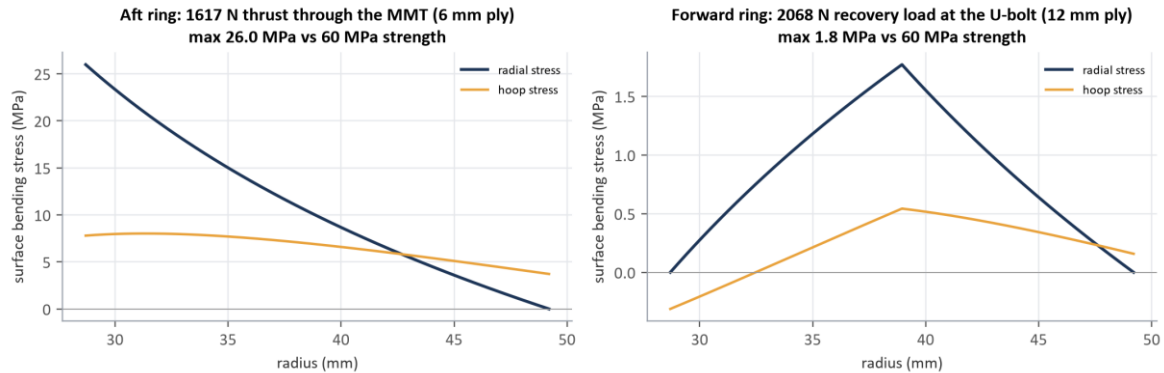


Figure 7 - Surface bending stress across the two loaded rings from the plate solution.

6. CAD model

The SOLIDWORKS model is generated by a C# program from the same design.txt the analysis writes, so the CAD can never drift from the numbers. It has 12 components; the interference check finds **no clashes** (an early version found my motor retainer overlapping the motor case, which led to a more realistic retainer: a sleeve round the motor-mount end that clears the motor's thrust ring, with a cap lip behind it).

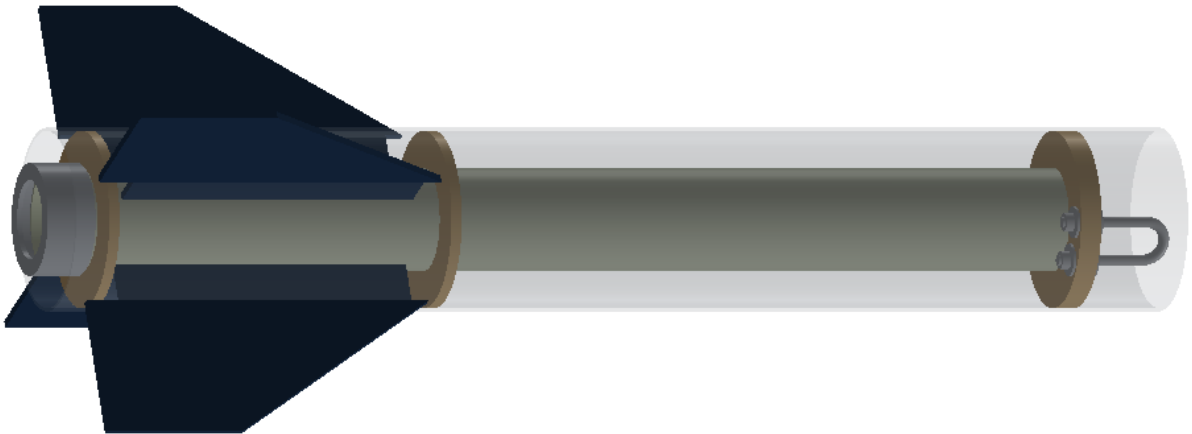


Figure 8 - X-ray view: retainer, aft ring, through-the-wall fin tabs on the motor mount, mid ring, forward ring with the M6 U-bolt.

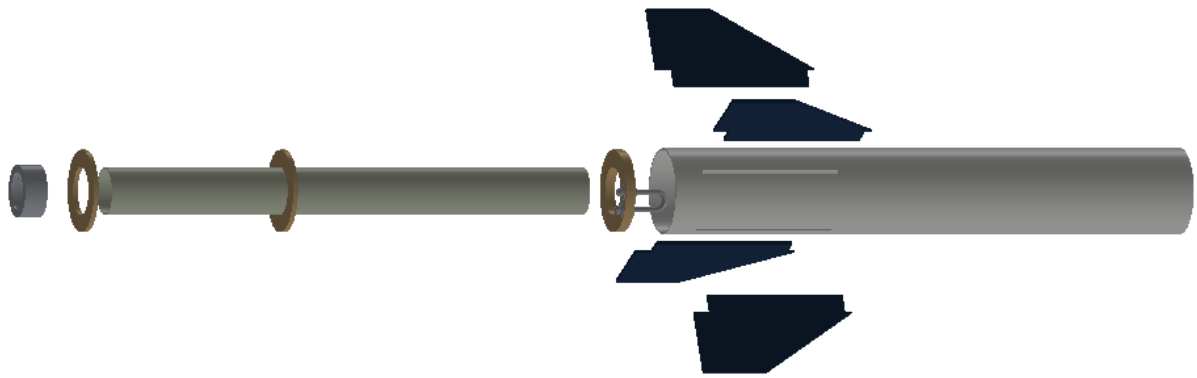


Figure 9 - Exploded: the motor-mount sub-assembly is built first, slid in from the aft end, then the fins go in through the slots.

Component	CAD (volume x density)	Analysis estimate
Motor mount tube	273 g	273 g
Centering rings x2	41 g	41 g
Forward ring / bulkhead	40 g	41 g
Fins x4	444 g	444 g
Motor retainer	44 g	90 g
U-bolt + hardware	46 g	60 g
Epoxy fillets (not modelled)	-	150 g

The fins, tube and rings agree to within a gram (the CAD forward ring has its U-bolt holes cut); the retainer and U-bolt were estimated from catalogue masses, which is why they differ. The files include a STEP export for anyone not on SOLIDWORKS.

7. How I'd build and test it

- **Fins:** cut from 4.0 mm G10, round the leading edges and chamfer the trailing edges (the drag saving in iteration 2 assumes this). Align them with a printed or laser-cut jig at 90 degrees.
- **Assembly order:** bond the rings and retainer to the motor mount, slide it in from the aft end, then fit the fins through the slots onto the tube. Internal fillets go in through the forward end before the forward ring closes it off. External fillets go on last.
- **Proof tests before flight:** pull the U-bolt to 2x the design recovery load (about 4,136 N) with the ring bonded into an offcut of tube. Coupon-test the epoxy fillets. Tap-test the fins to measure their natural frequency - that is the input a better flutter model needs.
- **Quick FEA check (SimulationXpress, included with SOLIDWORKS):** open 'Centering Ring 6 mm', fix the outer cylindrical face, apply 1,617 N axially on the inner face and compare with the 26 MPa hand calculation.

8. Limitations and next steps

- The mass budget and airframe are assumed. With the team's real masses the apogee, stability and flutter numbers would all move, but the pipeline re-runs in under a minute.
- Barrowman ignores body lift and compressibility, and NACA TN 4197 treats the fin as a flat cantilevered plate. Both are standard first-pass tools, which is why I kept a 1.5x flutter margin. A next step is to compare against OpenRocket and a fin-mode FEA using the measured tap-test frequency.
- The load cases are hand calculations. The aft ring and U-bolt are the two parts that deserve a proper FEA or a physical test first.
- Questions for the team: what airframe and ring materials do you use, how is thrust taken out today (thrust ring or centering rings), and what flutter method or margin do you work to?

Files: analysis/ (Python: design.py, physics.py, run_analysis.py, explore.py), cad/ (SOLIDWORKS parts, Fin Can.SLDASM, Fin Can.STEP, C# generator in cad/source). Sources: ThrustCurve.org (K700W), EirSpace website (Bell Burnell), NACA TN 4197 (Martin, 1958), Barrowman (1967), Niskanen/OpenRocket technical documentation, NASA SP-8007, Timoshenko & Woinowsky-Krieger, Theory of Plates and Shells.