



UC San Diego

Rocket Propulsion Lab - Project Daedalus Mechanical Design, OpenRocket Simulation, Structural Analysis, and Subsystem Integration

Final Technical Report

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October 2024 - June 2025

B.S. Mechanical Engineering, Robotics and Controls Specialization

Design target: simulated apogee of approximately 4,086 ft using an AeroTech G80T motor

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1 Abstract

Project Daedalus was a UC San Diego Rocket Propulsion Laboratory student rocket built around a simulated 4,000-ft apogee objective. I served as Structures Lead, concentrating on nose-cone geometry, the shoulder/body interface, recovery attachment, structural CAD, manufacturability, and mechanical integration. The team manufactured and ground-tested the vehicle. The vehicle was never flown. Incremental sanding and spring-scale checks of the printed nose shoulder gave an approximate 19 N extraction resistance by my recollection. OpenRocket predicted 4,086 ft apogee and a 1.23-caliber stability margin.

The design linked vehicle requirements to the nose and shoulder fit, fin-can integration, recovery load path and avionics packaging. A matched SolidWorks comparison used an assumed 275 N bearing load and isotropic ABS to isolate the effect of eyelet geometry. The wider rounded profile reduced modeled peak stress by 23.5% and maximum displacement by 20.3%. Recovery dynamics, printed material behavior and the eyelet-to-nose connection still require physical validation.

2 Introduction and Scope

A student rocket concentrates several coupled mechanical requirements into a small envelope. The nose establishes the aerodynamic profile, contributes to mass distribution, joins the body through a retention interface, and carries a recovery load path. Fins, motor hardware, parachute volume, wiring and electronics constrain the structural geometry around them. My responsibility was to make the structural interfaces fit, assemble and work with those neighboring systems.

The design target, nominal dimensions and motor selection set the initial envelope. Shoulder fit required iterative printing, test fitting and sanding; the approximate spring-scale pull force is a recalled value without a retained test log. Design-review feedback also prompted a fin-orientation correction. The calculations and eyelet models below quantify these interfaces under stated assumptions without treating modeled results as hardware measurements.

3 System Requirements and Vehicle-Level Targets

Quantity	Reference value	Engineering meaning
Vehicle envelope	25 in long; 1.5 in maximum diameter	Packaging, drag and printer constraints
Motor	AeroTech G80T; 133 N-s total impulse	Propulsion input to flight model
Mass with motor	1.038 lb / 0.471 kg	Modeled mass, not measured flight mass
Predicted apogee	4,086 ft / 1,245 m	OpenRocket simulation
Predicted stability	1.23 calibers	Modeled CG/CP separation
Recovery	24 in parachute; nose separation	Drives fit and eyelet load path

The requirement was not altitude alone. A design that reached the simulated height but could not retain and separate the nose, support the recovery hardware, or package adjacent subsystems would not meet the system objective. For that reason, I treated the nose/body and recovery interfaces as vehicle-level decisions rather than isolated features.

4 Vehicle Architecture

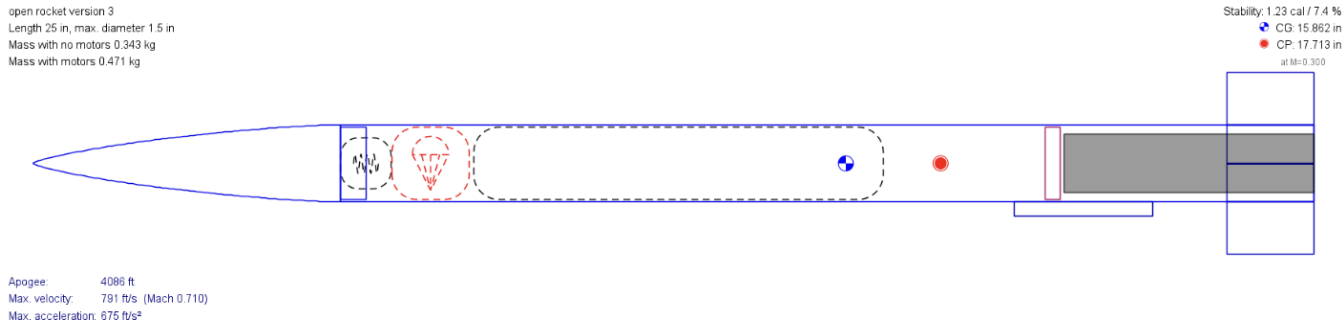


Figure 1. Historical OpenRocket vehicle model. The plot reports modeled CG and CP and a simulated 1.23-caliber stability margin.

Subsystem	Architecture and structural interface
Body	Approximately 19 in tube within the 25 in vehicle envelope; approximately 1.4 in bore.
Fin assembly	Four fins, about 1.7 in root chord and 1.02 in height, integrated with the lower body/fin can.
Recovery	24 in ripstop nylon parachute; nose separation; eyelet transmits line load into the nose.
Avionics	Arduino Pro Mini, BMP280, MPU6050, logger and LiPo constrained internal space; teammates owned electronics.
Motor	G80T motor and retention hardware determine lower-body packaging and axial load path.

My structural integration work addressed the physical consequences of these interfaces: sleeve and tube fit, internal access, mounting space, print envelope, recovery clearance and mass placement. The avionics package and propulsion design were team systems, not my sole design ownership.

5 Mechanical and Structural Design

Mechanical decisions moved between vehicle and component models. A thicker wall or higher infill could increase local stiffness while shifting forward mass and stability. A tighter shoulder could improve retention while making nose deployment less certain. Design-review feedback prompted a fin-orientation correction while maintaining fin-can and body interfaces. The wider eyelet comparison examines a similar tradeoff: a larger load-carrying ligament against added local material and packaging space.

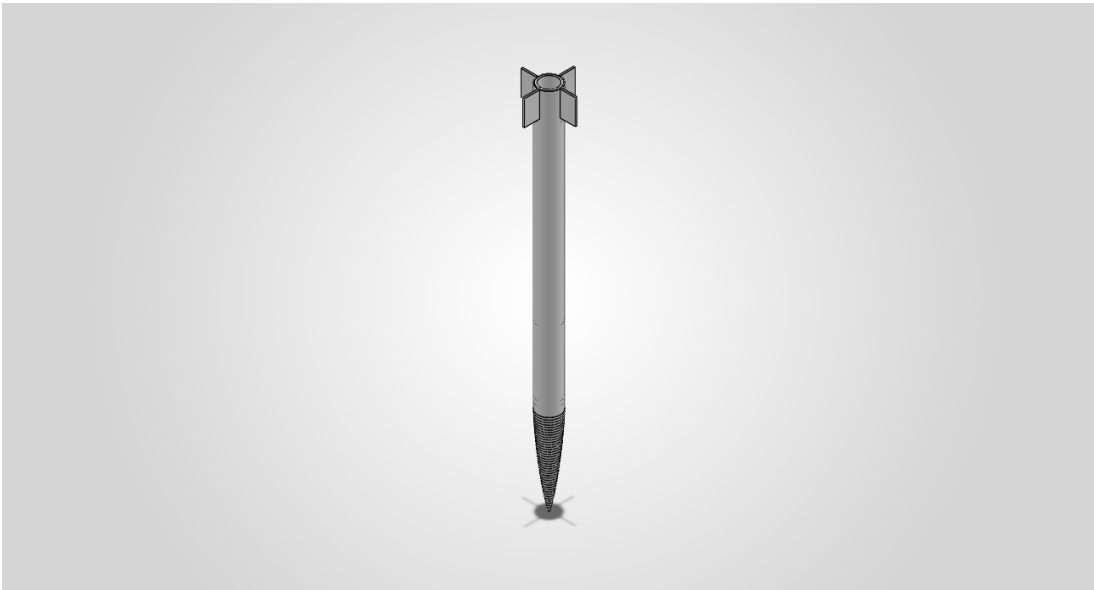


Figure 2. SolidWorks vehicle assembly used to review geometry, packaging and structural interfaces.

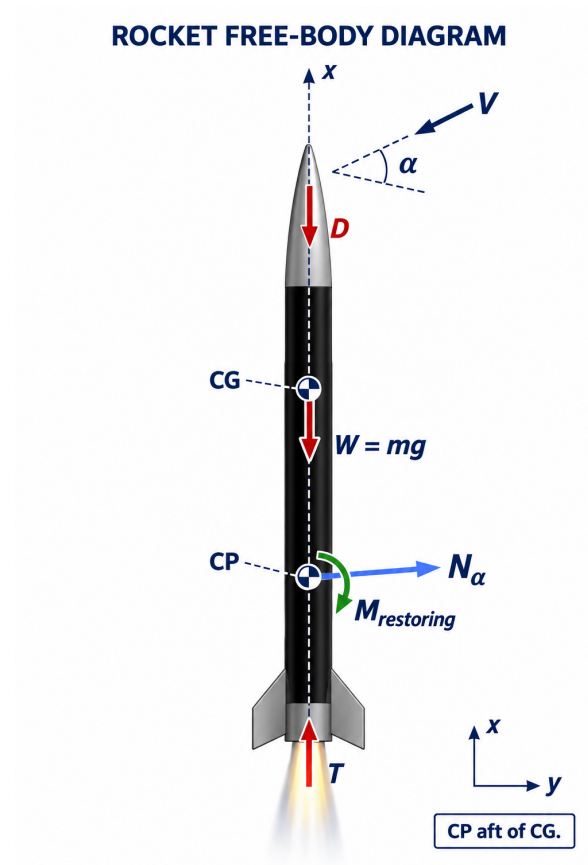


Figure 3. Vehicle force diagram showing thrust, weight, drag and a restoring moment with CP aft of CG; arrows indicate modeled directions, not measured loads.

5.1 Structural load paths

The body and motor region carry thrust and inertial loads during ascent; the fin can carries aerodynamic fin loads into the tube. During recovery, parachute force travels through the shock cord and eyelet into the nose-cone structure, while the shoulder must release from the body. The comparative eyelet study isolates one link in that chain. It cannot establish the strength of the entire recovery system without the lug-to-nose connection and printed material being tested.

5.2 Fin-orientation design-review correction

I recall feedback after an early project presentation that led our team to revisit and correct fin orientation or alignment during the subsequent design iteration. As Structures Lead, I participated in maintaining mechanical compatibility with the fin can, tube and adjacent hardware. I cannot verify whether the change concerned cant, mounting orientation or alignment, and I do not interpret it as reversed leading and trailing edges. A defensible review checks each fin's angle to the longitudinal axis, four-fin symmetry, body clearance, attachment access, unintended rolling moment, drag and the center-of-pressure/stability consequence. The available record has no verified before/after CAD pair or quantified aerodynamic result.

6 Nose-Cone Design

Parameter	Reference value	Constraint
Profile	Von Karman / Haack $C = 0$	Aerodynamic leading shape
Length and diameter	6.0 in; 1.5 in	Fineness ratio 4.0
Shoulder	1.400 in OD; 1.300 in ID; 0.5 in height	Retention, wall and print geometry
Manufacturing	In-house PLA printing; high infill	Stiffness, mass and print consistency

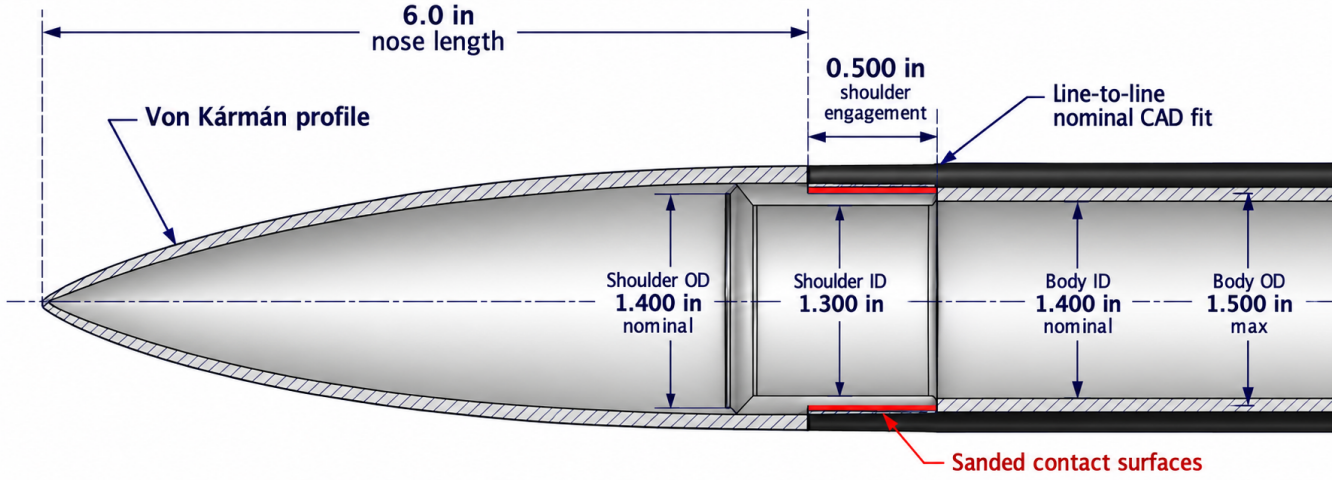


Figure 4. Dimensioned nose/body cutaway. The exterior transition is flush; the listed 1.400 in shoulder and bore diameters specify a nominal line-to-line fit.

$$r(x) = \frac{R}{\sqrt{\pi}} \sqrt{\theta - \frac{1}{2} \sin(2\theta)}, \quad \theta = \cos^{-1} \left(1 - \frac{2x}{L} \right)$$

Equation 1. Von Karman reference profile, with $L = 6.0$ in and $R = 0.75$ in.

The profile choice was bounded by printer volume, wall geometry, mass and the need to house the shoulder/recovery interface. A high infill setting increases local rigidity but does not by itself validate layer strength. Moving mass toward the nose also shifts the CG, so the OpenRocket model was needed to judge its vehicle-level effect.

7 Manufacturing and Tolerance Considerations

7.1 Shoulder fit

$$t_r = \frac{D_{OD} - D_{ID}}{2} = \frac{1.400 - 1.300}{2} = 0.050 \text{ in} = 1.27 \text{ mm}$$

Equation 2. Reference shoulder radial wall from the two listed diameters.

$$C_D = D_{body, ID} - D_{shoulder, OD} = 1.400 - 1.400 = 0.000 \text{ in}$$

Equation 3. The reference diameters give zero nominal diametral clearance; actual fit is unknown.

The original CAD specified a 1.400 in shoulder OD, a 1.400 in nominal tube bore and 0.500 in insertion depth. The listed shoulder diameters imply a 0.050 in radial wall; an archived 0.100 in wall statement conflicts with those diameters. Printing in PLA did not establish fit from CAD alone. I recall test-fitting the shoulder, sanding it incrementally and checking axial extraction with a spring scale until handling retention and motor-driven separation seemed compatible. My current best recollection is approximately 19 N (4.27 lbf), but the original readings, repeated trials, bore inspection and post-sanding diameter are unavailable.

A 0.001 in (0.0254 mm) interference relative to a measured bore remains an illustrative future finishing proposal, not the manufactured dimension. In particular, sanding a nominal 1.400 in CAD shoulder cannot establish a final 1.401 in OD without knowing printer oversize and as-built measurements. Print accuracy, ovality, roughness, layer texture and finishing all change the contact pressure. The remembered force measurement is stronger evidence of extraction resistance than nominal dimensions, although its uncertainty cannot now be quantified.

$$F_{pull} \approx \mu p \pi DL$$

Equation 4. Pull force depends on friction, contact pressure, diameter and engagement length; nominal diameter alone cannot predict it.

7.2 Conditional retention and ejection checks

A separate coast-deceleration screen at the historical predicted peak speed of 241 m/s, with assumed sea-level density, drag coefficient 1.0, 0.300 kg coast mass and 0.050 kg nose mass, gives 35.6 kPa dynamic pressure and an approximate 6.76 N relative-separation load when local nose drag is neglected. The recalled 19 N pull force is about 2.81 times that particular screen. This ratio is not a complete ascent safety factor: the nose drag, motor thrust history, pressure differential and as-built fit were not included. Unrelated scenario maxima should not be added without a consistent flight state.

$$\frac{F_{pull, recalled}}{F_{sep, screen}} = \frac{19}{6.76} = 2.81 \quad (\text{coast screen})$$

Equation 5. Conditional coast-deceleration comparison, not a vehicle safety factor.

The G80T's delayed ejection charge was intended to initiate recovery. Motor burnout and coast would precede charge ignition, recovery-cavity pressurization, nose separation and parachute deployment. A protected gas route around or through the avionics package is necessary if the bay blocks the body bore; the installed route and pressure history have not been verified.

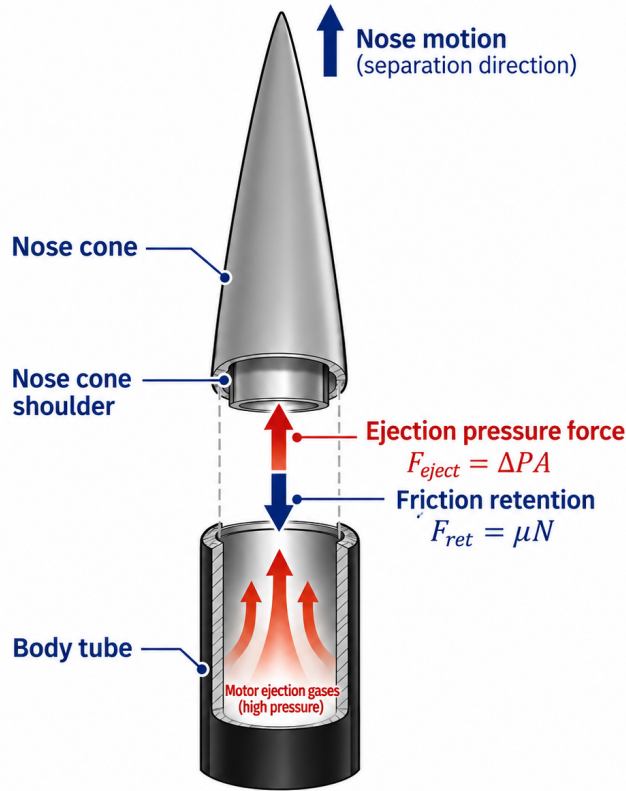


Figure 5. Idealized nose-separation force diagram. Pressure acts on the exposed nose base against shoulder friction; the required gas route past the avionics bay is not shown.

$$A = \frac{\pi D^2}{4} = \frac{\pi (0.03556)^2}{4} = 9.931 \times 10^{-4} \text{ m}^2$$

Equation 6. Nominal 1.400 in bore as an assumed full effective pressure diameter.

$$\Delta P_{min} = \frac{F_{pull}}{A} = \frac{19}{9.931 \times 10^{-4}} = 19.1 \text{ kPa} = 2.77 \text{ psi}$$

Equation 7. Ideal differential-pressure threshold from the recalled pull force, without dynamic or leakage margin.

This 2.77 psi value is an ideal minimum for friction alone if the full bore is pressure effective. It is not a measured charge pressure or proof of reliable deployment. Charge performance, seal leakage, heating, nose inertia, shear or line loads and friction variation would need ground validation. Earlier ideal-gas force estimates are hypothetical and are not credited as measured ejection capability.

7.3 Conditional pressure retention during ascent

I do not recall intentional body pressure-equalization holes. If internal air were perfectly trapped at 101.3 kPa while outside pressure fell to an assumed 87.2 kPa at the predicted 4,086-ft altitude, the 14.1 kPa difference acting over the nominal bore would push outward. This is a bounding thought experiment, not evidence that the compartment was airtight; joint leakage, temperature, effective area and transient flow remain unknown.

$$F_{\Delta P} = (101.3 - 87.2) \times 10^3 (9.931 \times 10^{-4}) \approx 14.0 \text{ N}$$

Equation 8. Conditional pressure-only separating force at the predicted apogee altitude.

$$SF_{\Delta P} = \frac{19}{14.0} \approx 1.36 \quad (\text{pressure only})$$

Equation 9. Conditional pressure-only retention ratio, not the rocket's overall safety factor.

The coast and trapped-pressure screens use different flight states. Set retention from a validated load envelope and motor-ejection capability, then repeat as-built pull and separation tests.

8 Avionics Packaging and Mechanical Interfaces

The avionics package set mechanical boundaries for internal diameter, access, mounting and wiring. I coordinated available structural space with teammates responsible for the Arduino Pro Mini, pressure and inertial sensors, SD logging and the LiPo battery. Their electrical design and package were not my individual deliverables. The avionics measured and logged flight variables; they were not intended to trigger parachute deployment. The motor's delayed ejection charge provided the recovery actuation, and the internal layout had to preserve a gas path toward the recovery compartment while shielding electronics. The detailed installed gas-passage geometry is unverified.

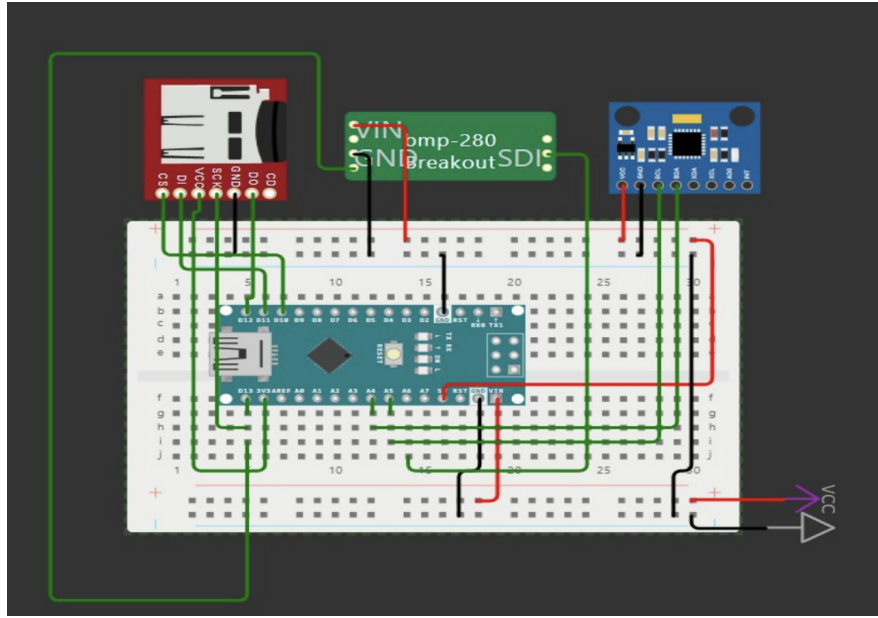


Figure 6. Avionics architecture showing packaging and wiring constraints within the body tube.

9 OpenRocket Modeling and Predicted Flight Performance

OpenRocket supplied the historical performance estimate and a way to review how structural mass placement affects CG, CP, stability and drag. Its stored results are 4,086 ft apogee, 1.23 calibers stability, about 14.1 s to apogee, 791 ft/s peak velocity and 675 ft/s² peak acceleration. The original .ork file was unavailable for this report, so I do not claim an independently reproduced flight result.

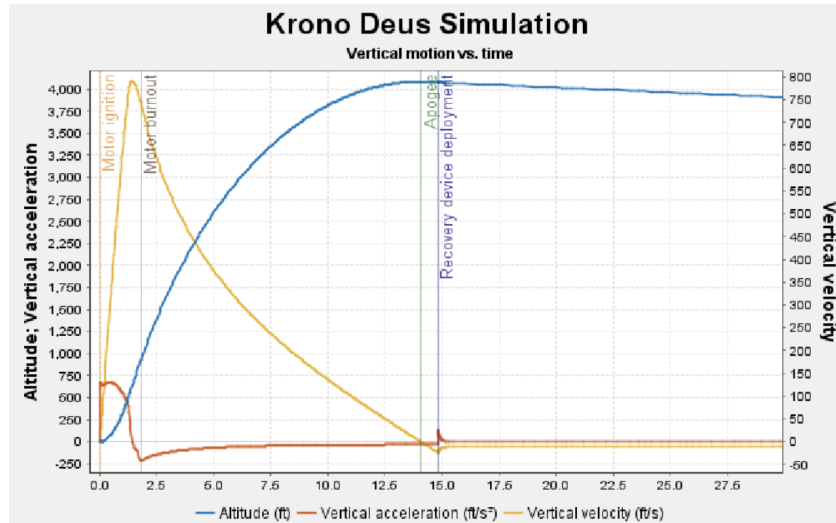


Figure 7. OpenRocket simulated altitude, velocity and acceleration; values are model predictions.

$$SM = \frac{x_{CP} - x_{CG}}{D} = 1.23 \text{ calibers} \quad (\text{historical model})$$

Equation 10. Static margin definition; source positions were not independently remeasured.

A nominal thrust-to-weight check using the cited 78 N average thrust and 0.471 kg modeled mass gives $78 / (0.471 \times 9.81) = 16.9$. This is a gross ratio from published model inputs, not a measured liftoff acceleration. Drag, motor thrust history and mass loss are needed for a flight acceleration profile.

10 Qualitative Flow and Pressure Review

An archived flow image offered qualitative feedback on external geometry. The available record does not identify the turbulence model, boundary conditions, mesh quality, convergence or experimental correlation, so the image cannot support a validated drag coefficient or pressure load. It remains useful as an early visualization of where the team examined flow behavior.

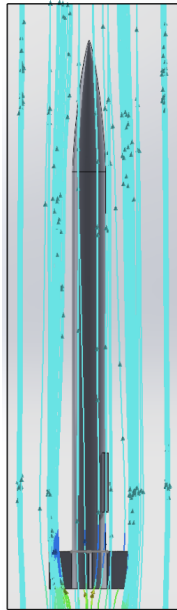


Figure 8. Flow/pressure visualization. The color trends are qualitative because the simulation setup is incomplete.

That archived qualitative work cannot quantify the fin correction recalled after the early design presentation. To evaluate such a change, the original and corrected fin geometry, installation angles, mass properties and matched aerodynamic conditions would be needed. Neither a before/after drag coefficient nor a verified post-correction stability result is available; I do not assign a numerical benefit to the correction.

11 Recovery Attachment: Load Path and Design Iteration

11.1 Free-body diagram and load selection

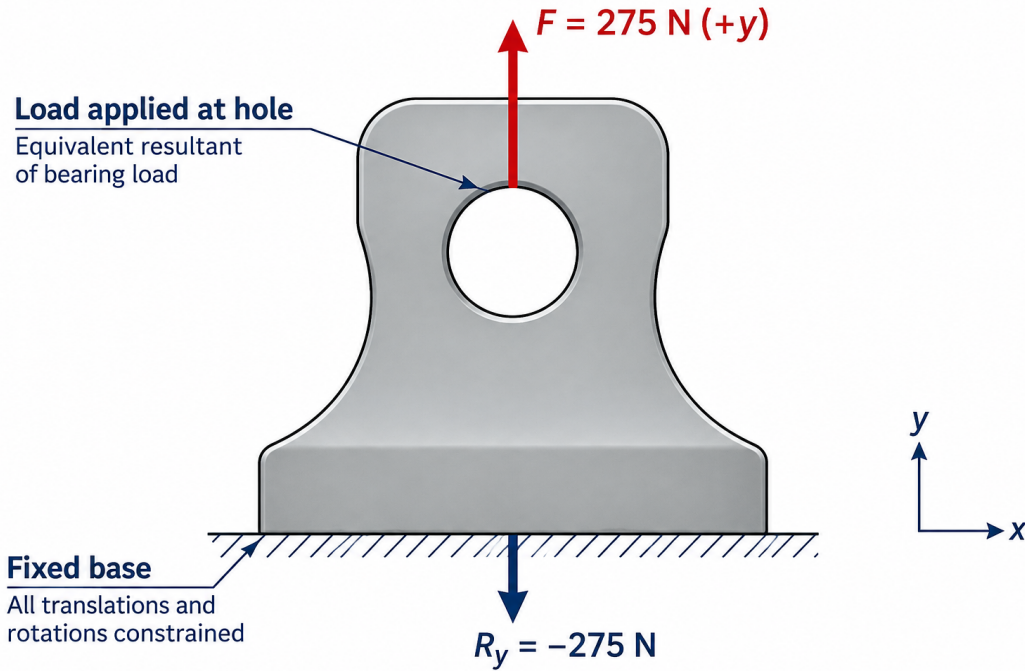


Figure 9. Eyelet free-body diagram for the assumed 275 N bearing-load screen: upward hole load and equal downward fixed-root reaction.

I selected a conditional 275 N static comparison case from an illustrative parachute-opening calculation. The assumed 24 in (0.6096 m) chute gives 0.29186 m² projected area. If deployment is delayed 1.5 s after apogee and the vehicle starts from rest, the simplified speed estimate is 14.715 m/s. At 1.225 kg/m³ air density and assumed drag coefficient 1.75, steady drag is 67.74 N. An opening multiplier of 2 raises this to 135.48 N, and a separate structural screening multiplier of 2 gives 270.96 N, rounded to 275 N.

$$F_{screen} = K_s K_o \left(\frac{1}{2} \rho (gt)^2 C_D \frac{\pi D^2}{4} \right) = 270.96 \text{ N} \rightarrow 275 \text{ N}$$

Equation 11. Conditional design screen; neither multiplier is calibrated by a deployment measurement.

Assumed delay	Speed	Opening estimate	Structural screen
1.0 s	9.81 m/s	60.21 N	120.43 N
1.5 s	14.715 m/s	135.48 N	270.96 N
2.0 s	19.62 m/s	240.85 N	481.71 N

The 275 N selection covers the illustrative 1.5 s screen, not the 2.0 s case. It omits canopy inflation history, line stretch, body/nose mass split, deployment impulse, porosity, angle and air-density variation. Rocket mass does not enter this simplified drag expression. A flight load envelope requires measured or validated recovery dynamics.

11.2 Original-style versus wider rounded geometry

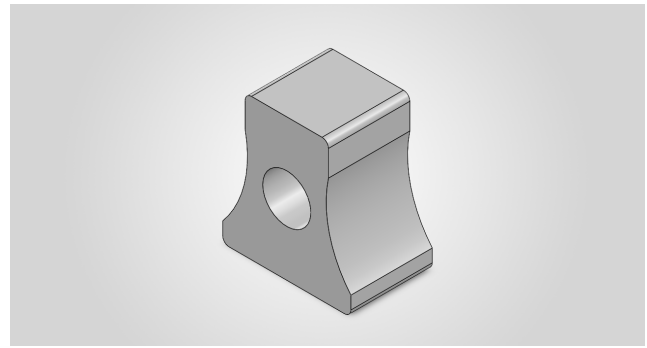
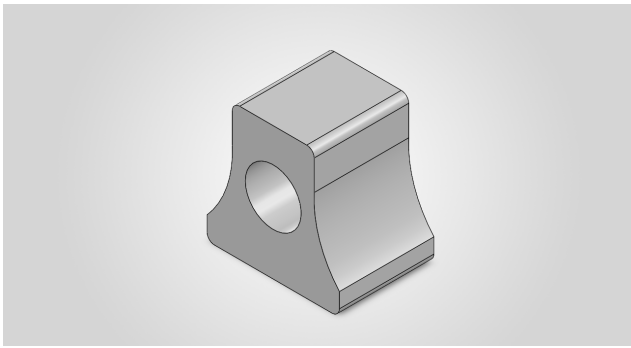


Figure 10. SolidWorks original-style rounded eyelet (left) and wider rounded geometry (right), modeled with the same assumed hole and thickness.

Feature	Original-style model	Wider concept
Envelope	17.78 x 17.78 x 12.7 mm	20 x 22 x 12.7 mm
Hole diameter	7.5 mm assumed	Same assumed 7.5 mm
Thickness	12.7 mm	12.7 mm
Reason for change	Reference curved profile	More net section and top ligament

The wider profile places material around the hole where load must flow toward the constrained root. Keeping hole, thickness, material and loading constant makes the contour comparison more interpretable. It also increases local material and envelope; the actual root/nose attachment may move the highest stress elsewhere.

$$P_{bearing, avg} = \frac{F}{td} = \frac{275}{12.7 \times 7.5} = 2.89 \text{ MPa}$$

Equation 12. Average projected bearing pressure, useful only as a first-order load check.

12 Structural Simulation and Mesh Verification

12.1 Matched SolidWorks setup

Model input	Both eyelet studies
Material	SolidWorks built-in isotropic ABS; no printed-part strength credit
Applied load	275 N distributed +Y bearing load on the assumed 7.5 mm hole
Fixture	Fully fixed root surface representing attachment restraint
Mesh	Matched 0.65 mm target; original 80,448 nodes; wider 110,803 nodes
Solver output	Von Mises stress, resultant displacement and reaction force

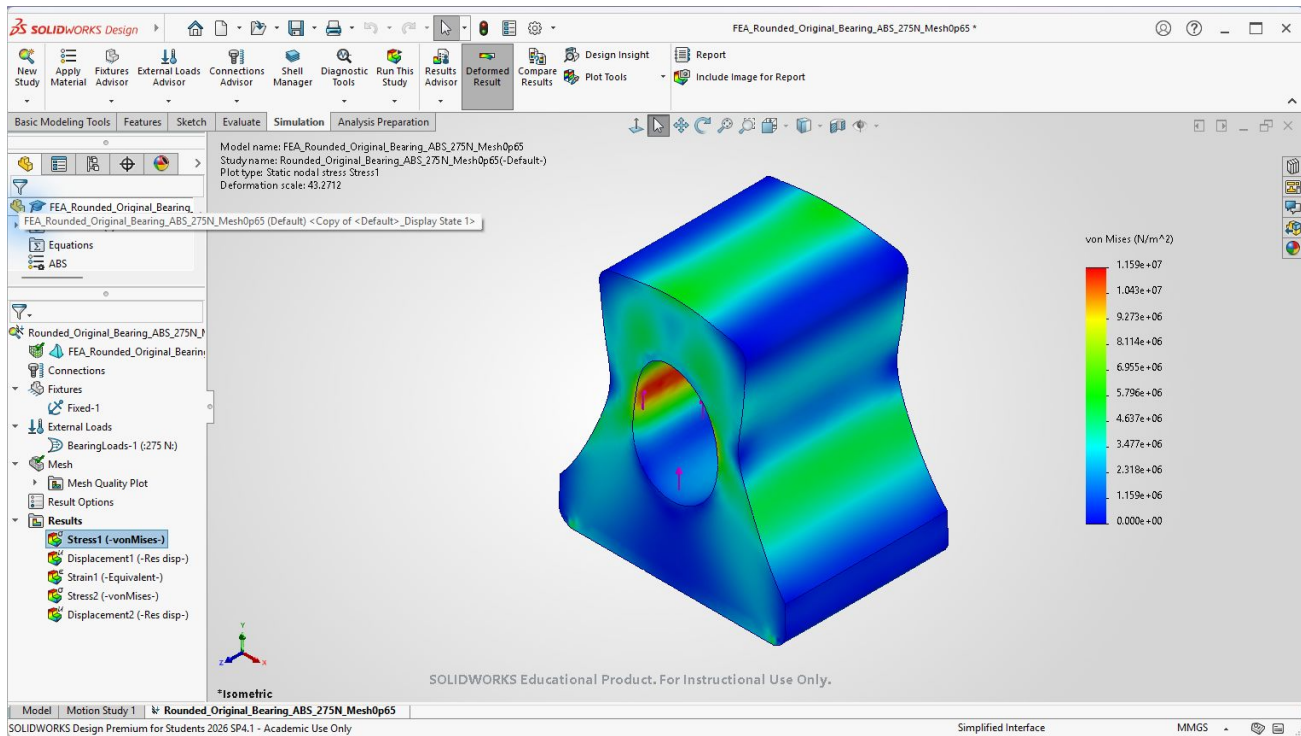


Figure 11a. Original-style eyelet, assumed 275 N, 0.65 mm mesh target: 11.591 MPa peak. SolidWorks plot includes load, fixture, legend and units.

The original-style model places the largest reported stress near the bearing hole and curved transition into the constrained root. The image retains the study tree, applied bearing arrows, root fixture and stress legend so the boundary conditions can be read with the result. A local contour maximum is sensitive to the idealized contact and root restraint; it is not a measured hardware stress.

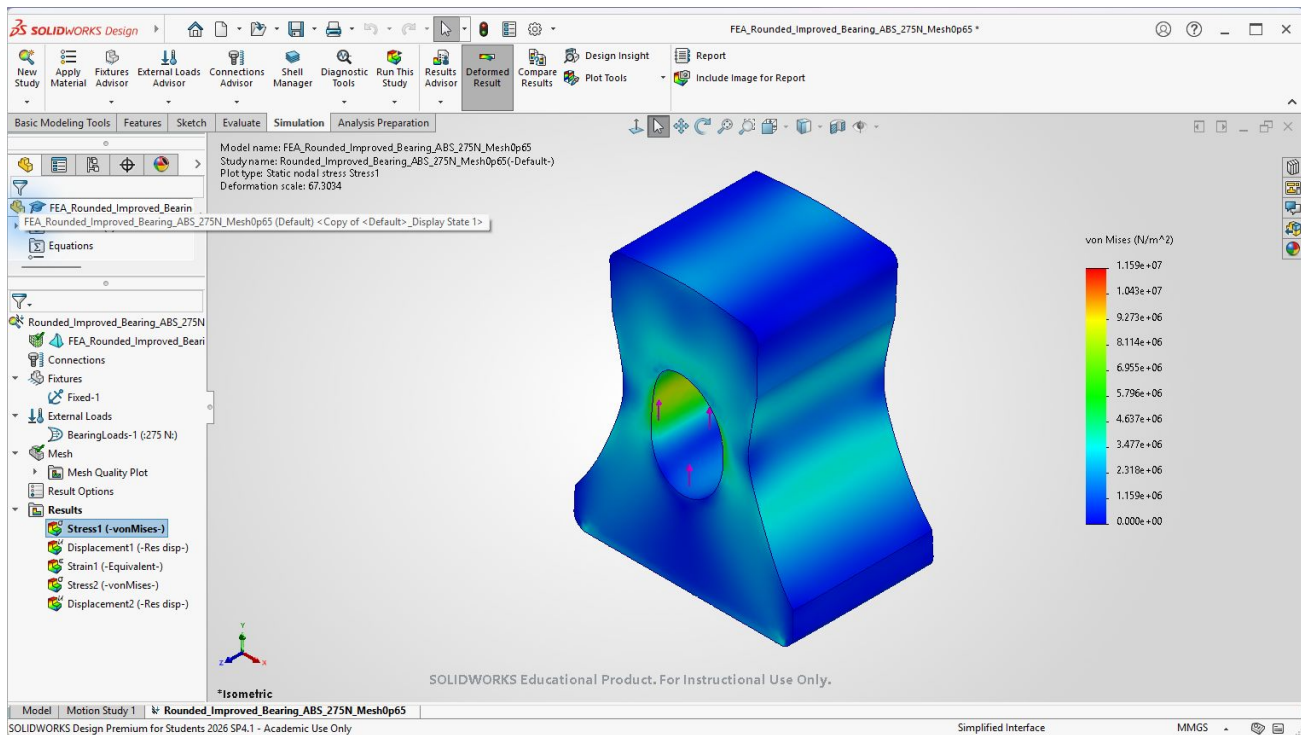


Figure 11b. Wider rounded eyelet, same orientation and common 0-11.591 MPa display scale: 8.869 MPa peak.

Output at 275 N	Original-style	Wider concept	Change
Peak von Mises	11.591 MPa	8.869 MPa	23.5% lower

Output at 275 N	Original-style	Wider concept	Change
Maximum displacement	0.04138 mm	0.03299 mm	20.3% lower
Root reaction Y	-275.0017 N	-274.9988 N	<0.002 N imbalance
Representative stress	2.846 MPa	1.335 MPa	Same extraction method

$$\Delta\sigma_{max} = \frac{11.591 - 8.869}{11.591} \times 100\% = 23.5\%$$

Equation 13. Modeled peak-stress reduction under matching conditional inputs.

$$\Delta u_{max} = \frac{0.04138 - 0.03299}{0.04138} \times 100\% = 20.3\%$$

Equation 14. Modeled maximum-displacement reduction under matching conditional inputs.

The common display scale makes the two stress fields visually comparable; the percentage changes come from saved solver values, not color matching. The lower peak and displacement are meaningful within the matched ABS model, but a material allowable and validated connection model are required before a safety factor or flight-ready claim can be made.

12.2 Mesh refinement and equilibrium

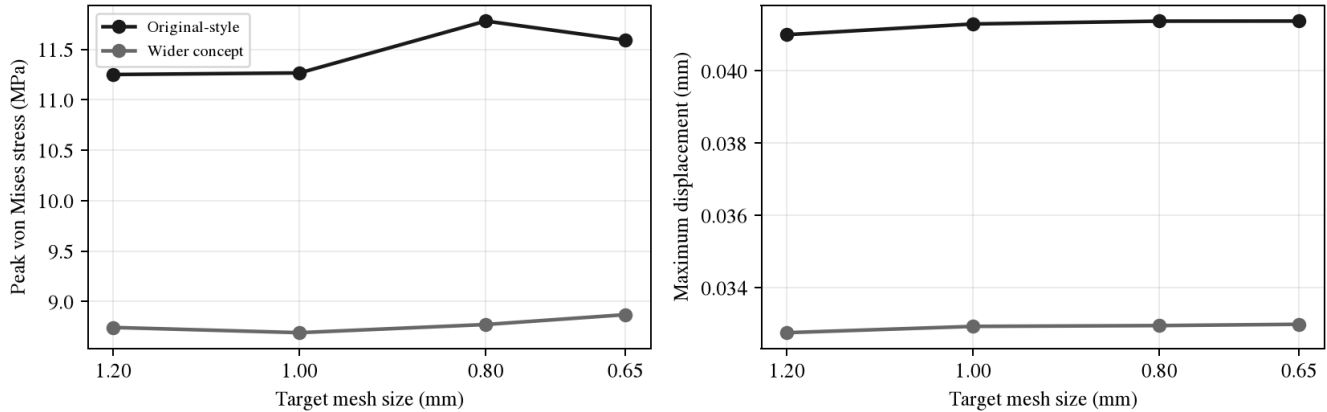


Figure 12. Saved 275 N mesh refinement on both geometries at 1.20, 1.00, 0.80 and 0.65 mm target sizes; peak stress and displacement retain their measured solver values.

Both eyelet geometries were solved at four target mesh sizes under the same assumed 275 N bearing load. From 0.80 to 0.65 mm, peak stress changed by -1.6% for the original-style model and +1.1% for the wider model; maximum displacement changed by less than 0.2% in each. The peak varies locally with mesh, so this is a refinement check for the comparison rather than proof that the idealized root and bearing contact represent the hardware.

At the 0.65 mm target, the original and wider models gave 11.591 and 8.869 MPa peak stress, respectively. Their fixture reactions oppose 275 N within 0.002 N, confirming force equilibrium for the solved model. Pin contact, root attachment and printed material still govern the physical interpretation.

12.3 Material sensitivity

An assumed isotropic PLA run used $E = 3.0$ GPa, Poisson ratio 0.35, $G = 1.111$ GPa and density $1,240 \text{ kg/m}^3$ to test stiffness sensitivity. No tensile or interlayer allowable was entered. A print's raster, build orientation, porosity, temperature and layer bonding can dominate the actual failure path. Therefore this sensitivity cannot be translated into a printed-part factor of safety.

13 Design Process and Engineering Tradeoffs

13.1 From requirement to comparison

Step	Evidence and decision
Define	4,000-ft simulated target, vehicle envelope, stability, recovery and fabrication constraints.
Integrate	Historical nose, body, fin can, motor and avionics interfaces reviewed in vehicle context.
Correct fins	Recalled design-review feedback prompted an orientation/alignment correction; exact geometry unverified.
Fit hardware	Historical PLA print, manual fitting, sanding and spring-scale pull check; about 19 N recalled.
Trace load	Recovery FBD and conditional 275 N structural screen.
Compare	Matched ABS eyelet models show lower stress and displacement for the wider geometry.
Test next	Repeat extraction/ejection tests, inspect as-built geometry and validate pin/nose connection.

13.2 Integration decisions

The nose profile, shoulder engagement, avionics clearance and recovery attachment share a small forward-body envelope. Increasing local eyelet width improves the modeled load path but adds material and can restrict packaging. Shoulder sanding changes extraction force, while a sealed avionics package must still permit a verified gas route into the recovery cavity. Fin alignment and structural mass placement also affect the modeled CG/CP relationship. Each change therefore requires a vehicle-level check.

13.3 What improved and what it costs

- Geometry: a wider eyelet reduces modeled stress but adds mass and occupies more space.
- Fit and stability: shoulder retention, fin alignment and forward mass all affect recovery or flight behavior.
- Model fidelity: idealized root and bearing loads isolate a design effect; pin contact and printed PLA require testing.

14 Validation Status, Limitations, and Next Tests

Item	Status / limit
Manufacture and ground test	Team activity documented; approximately 19 N extraction recalled, but original spring-scale log absent.
Flight performance	OpenRocket apogee and stability values are simulated.
Nose/body fit	Manual PLA fitting/sanding recalled; final bore/shoulder dimensions and ejection pressure unrecorded.
Fin correction	Design-review correction recalled; exact before/after geometry and aerodynamic effect unverified.
Eyelet CAD	The compared hole and root dimensions are model assumptions.
FEA	Saved solver results and UI screenshots verified for matched ABS comparison; root/real pin unvalidated.
Printed material	PLA stiffness sensitivity only; no build-direction or interlayer strength allowables.

Next tests should measure the finished bore and shoulder, repeat extraction and ejection checks, verify the avionics-bay gas route, and load the printed eyelet with its actual pin and nose attachment. Measured mass and CG should then update the flight model. The 275 N study remains a conditional structural comparison.

15 Conclusion

Daedalus demonstrates the need to connect CAD, flight modeling, manufacturing and recovery mechanics at the vehicle level. My Structures Lead work centered on nose-cone geometry and fit, recovery attachment, structural interfaces and compatibility with adjacent subsystems. PLA nose fit involved printing, test fitting, sanding and spring-scale checks, with approximately 19 N extraction by recollection. Design-review feedback also led to a fin-orientation correction. The 4,086 ft apogee remains an OpenRocket prediction.

Under the same assumed 275 N bearing load and isotropic ABS model, the wider rounded eyelet lowered peak stress by 23.5% and displacement by 20.3%. Those results favor prototyping the geometry and testing its attachment, printed material and recovery load path before use.