Vehicle Level Preliminary Design Review

Spaceport America Cup 2024

IREC 30k SRAD Hybrid Engine, Experimental Payloads, and Airframe

10/30/23

Agenda

1. Purpose of PDR
2. Stakeholder Needs Identification
   - IREC Team Members
   - KXR Executive Board
   - Experimental Rocket Sounding Association
3. Concept Definition
   - Mission
   - Spaceport America Cup Competition
4. Element Architectures
5. System Architectures
6. Questions

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Purpose of PDR

- Reiterate and clarify stakeholder needs
- Present Design Solutions for potential redirection
- Receive feedback on progress and where to improve
- Establish a baseline for our architecture
- Ensure architecture is feasible within given requirements/constraints

Stakeholders

Our Team

Students striving to push themselves to prepare for industry through hands on experience.

ESRA

The platform to launch 30k rockets, competition, rules, and requirements.

KXR Executive Board

Provides students the opportunity to achieve their goals through funding.

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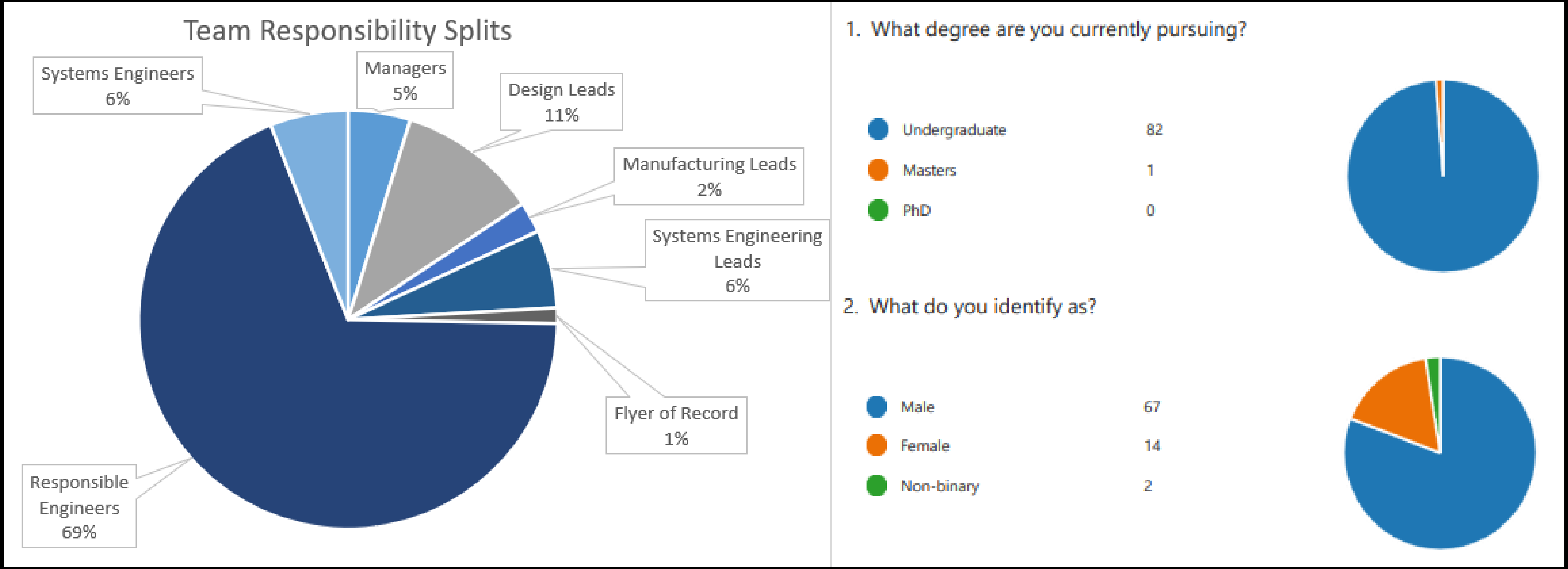
Our Team - Demographics



ESRA – Deliverables

Deliverables	
Item	**Deadline**
1st Interim Report	12/15/2023
2nd Interim Report	2/16/2024
3rd Interim Report	4/19/2024
Flight Readiness Review	5/10/2024
Technical Report	5/10/2024
Poster and Podium Materials	5/10/2024
School Participation Letter	5/10/2024
Final Launch Day	6/22/2024

ESRA – Spaceport Cup Scoring Summary

Deliverable	Category	Sub-Categories	Pts. Available
Early Deliverables (60 Points)	Entry Form	N/A	15
	1st Interim Report	N/A	15
	2nd Interim Report	N/A	15
	3rd Interim Report	N/A	15
Technical Report (200 Points)	Completeness	N/A	20
	Style and Format	Style	20
		Mechanics	10
		Format	10
	Analysis	Depth of Analysis	50
		Assumptions and Sensitivity Analysis	30
		Verification and Validation tests	40
		Use of Charts and Figures	20
Design Implementation (240 Points)	Design Quality & Decisions	Team Design Vision, Goals and Systems Engineering	50
		SRAD components	50
		Team Knowledge	20
	Build Quality	Design Quality and Robustness	30
		Manufacturing and Construction Methods	30
		Consistent Design	30
		Compliance with DTEG	30
Flight Performance (500 Points)	Apogee Performance	See Equation	350
	Recovery Performance	N/A	150
Total			1000

2.7.1.7 BONUSES FOR CUBESAT BASED PAYLOADS

Teams whose payload(s) qualify for the form factor exemption described in Section 2.3.5.2 of this document, yet still adopt the CubeSat standard form factor, will be awarded 50 bonus points in addition to their total earned score. This promotes ESRA and SDL's encouragement that teams adopt the CubeSat standard for their payload(s) whenever possible – either as the payload structure itself, or as an adapter which the payload is mated to prior to the combined assembly's integration with the launch vehicle (such an adapter could be included in the official payload mass).

2.7.1.8 BONUSES FOR EFFICIENT LAUNCH PREPARATIONS

Teams whose preparedness, efficient operations, and hassle-free design permit their being launched in a timely manner will be awarded bonus points in addition to their total earned score according to the following tiered system. Launch readiness is declared when competition officials managing Launch Control receive the team's completed Flight Card. No bonus points will be awarded for launch attempts ending in catastrophic failures (CATO).

- 50 bonus points will be awarded to teams declared launch ready by the end of the designated field preparation day and flown by the end of the first launch day. They remain eligible to receive these points until the end of the first launch day, or until their first launch attempt ends in a scrub – at which point the team is no longer eligible for the 50 point bonus, but may still achieve bonus points awarded for teams declared launch ready on the first launch day.
- 25 bonus points will be awarded to teams declared launch ready and flown during the second launch day. They remain eligible to receive these points until the end of the second launch day. or until their first launch attempt ending in a scrub – at which point the team may attempt to regain eligibility by attempting a return to launch readiness by the end of the day. Otherwise, the team is no longer eligible for bonus points.
- 0 bonus points will be awarded to teams declared launch ready and flown during the third launch day.

$$Points = 350 - \left(\frac{350}{0.3 \times Apogee_{Target}}\right) \times \left|Apogee_{Target} - Apogee_{Actual}\right|$$

where $Apogee_{Target}$ may equal either 10,000 ft AGL or 30,000 ft AGL

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ESRA – SDL Payload Challenge Scoring

Awards:

- 1st Place Payload Award: $1000
- 2nd Place Payload Award: $750
- 3rd Place Payload Award: $500
- SDL Technology Relevance Award
- Honorable mentions as warranted (judges discretion)

Judging Criteria (1000 points possible):

- Scientific or Technical Objective(s) (400 points)
  - How relevant and well-designed is your scientific or technical objective?
- Payload Construction and Overall Professionalism (250 points)
  - Includes make/buy decisions, craftsmanship, material usage, poster, handouts, reports, etc.
- Readiness / Turnkey Operation (50 points)
  - Will the payload interfere with launch operations? Will the payload operate after hours of launch preparation, rail time, heat, waiting for other launches, etc?
- Execution of Objective(s) (300 points)
  - Judges should be informed of results by Saturday at noon or a zero in this category will be assessed.
  - How well did it accomplish the objective(s)?
  - Note that rocket failure results in 150 points (half credit – don't know if payload would have worked or not)

SDL Technology Relevance Award

- This is a separate award and has no impact on the overall SDL payload challenge.
- This provides an opportunity for students to focus on and integrate technologies relevant to SDL's mission into their payload.
- 2024 technology areas: Robotics, Artificial Intelligence, and Infrared

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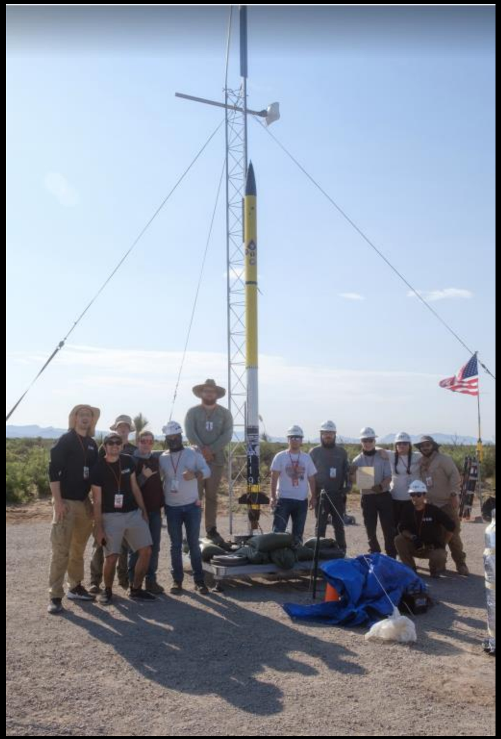
IREC Team: The Mission

1. Launch a rocket carrying an Experimental Payload to 30,000 feet AGL.
2. Score points through successful flight, recovery, and payload deploy.
3. Meet industry professionals and student teams from across the world at Spaceport in Las Cruces, NM.



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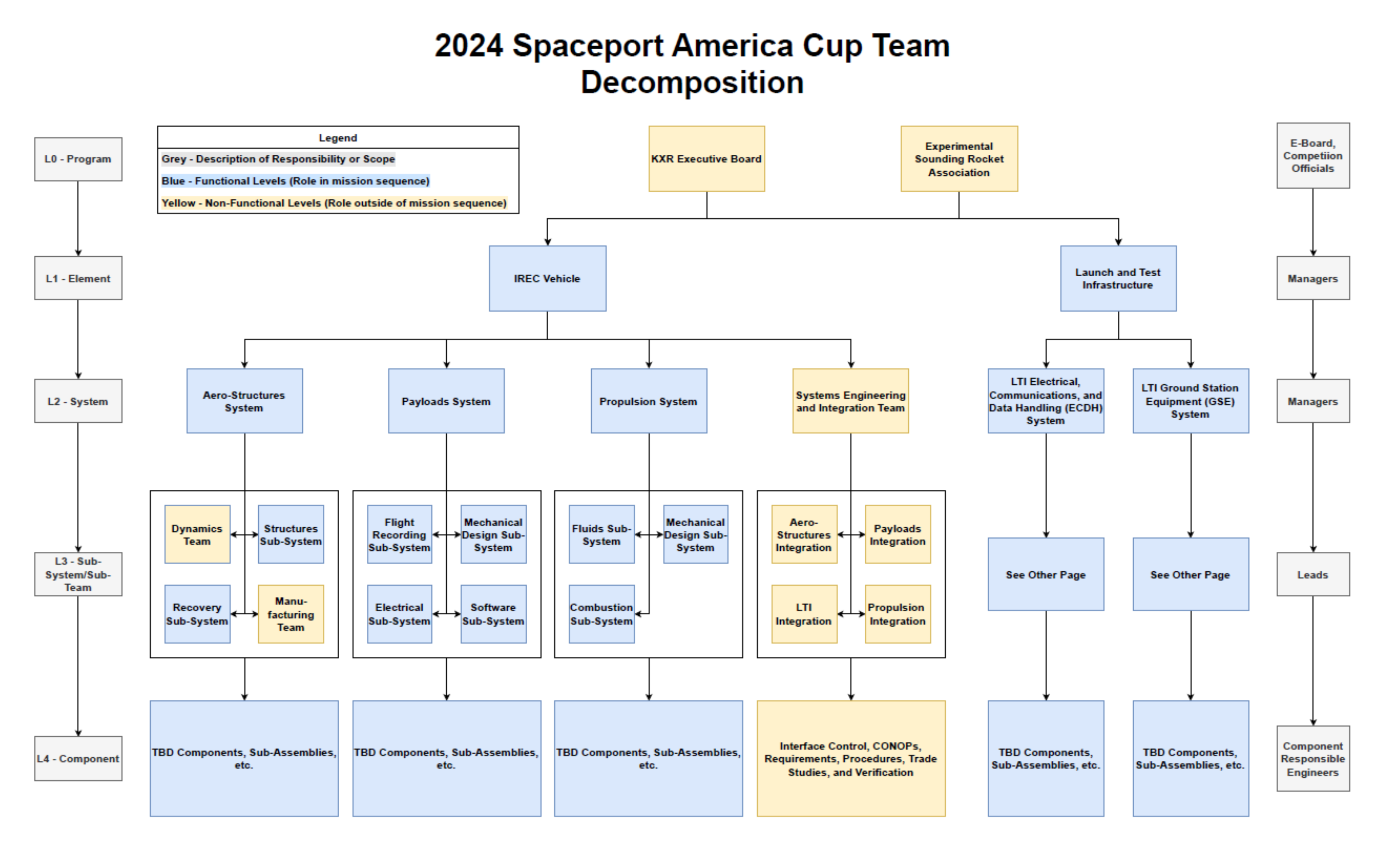
IREC Vehicle Team Decomposition



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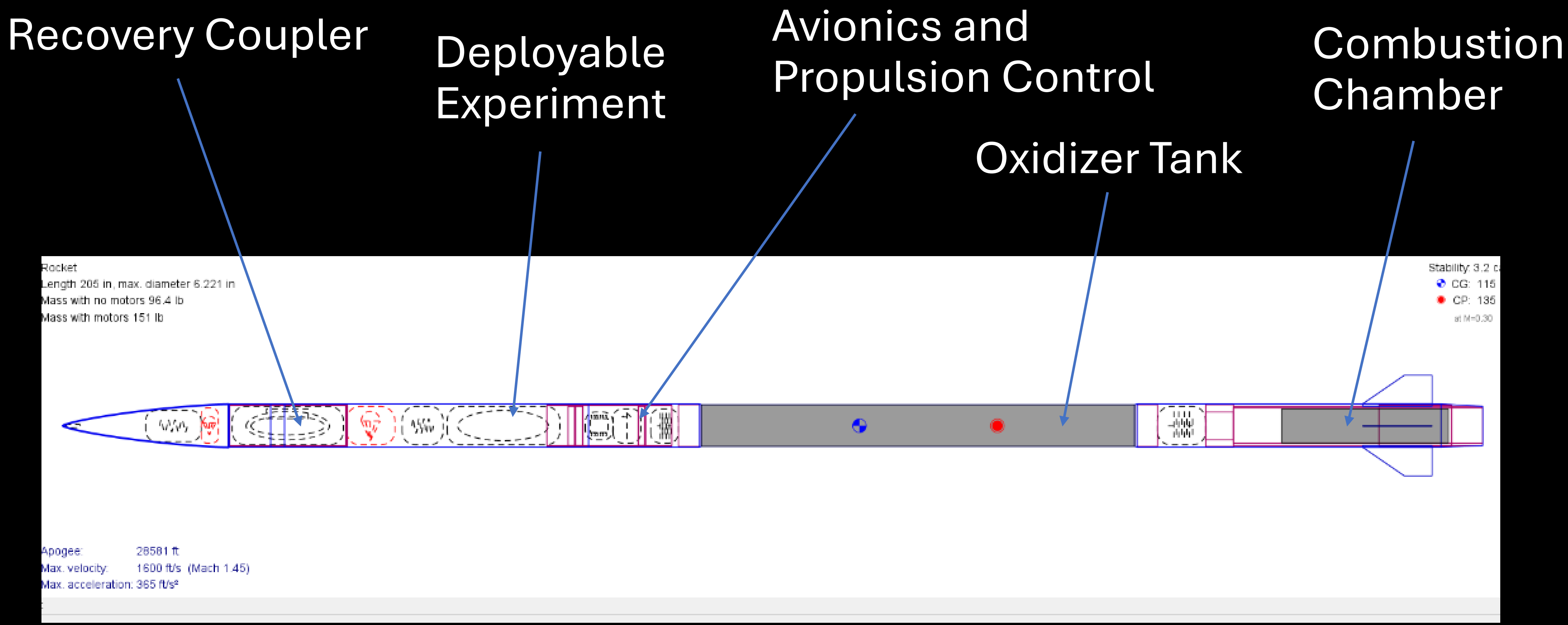
IREC Vehicle Architecture



IREC Vehicle Requirements and TPMs

Requirement	Verification Method
The Vehicle **shall** launch to [30,000] feet.	Demonstration
The Vehicle **shall** have a weight of [150] lbs.	Inspection
The Vehicle **shall** be successfully recovered.	Demonstration
The Vehicle **shall** contain separate avionics, payload, aerostructures, and propulsion systems.	Inspection
The Vehicle **shall** interface between external ground support equipment (GSE).	Inspection
The Vehicle **shall** withstand [120 degree farenheight] for [3 hours] at a time.	Demonstration
The Vehicle **shall** be reusable.	Demonstration
The Vehicle **shall** be prepared at the launch field within [2 hours].	Demonstration
The Vehicle **shall** be launched using hybrid propulsion.	Demonstration
The Vehicle **shall** be transported using vehicles.	Demonstration
The Vehicle **shall** be verified through test launch by [April 11th, 2024].	Demonstration
The Vehicle **shall** be designed by the [End of November 2023].	Inspection
The Vehicle **shall** exceed a velocity off the rail of [120] ft/s.	Test
The Vehicle **shall** launch off a [30-foot] rail.	Demonstration
The Vehicle **shall** be designed, manufactured, and verified within a budget of [$15,800].	Demonstration
The Vehicle **shall** have a maximum height of 18 feet.	Inspection

Measure	TPM Value	Units	Verification
Length	[17]	ft	Inspection
Weight	[150]	lbs	Inspection
Maximum Speed	[1,500]	ft/s	Test
Apogee AGL	[28,000-30,000]	ft	Test
Engine Class	O-Class	N/A	Test
Thrust-to-Weight	[12.24:1]	N/A	Test
Outer Diameter	[6.22]	in	Inspection

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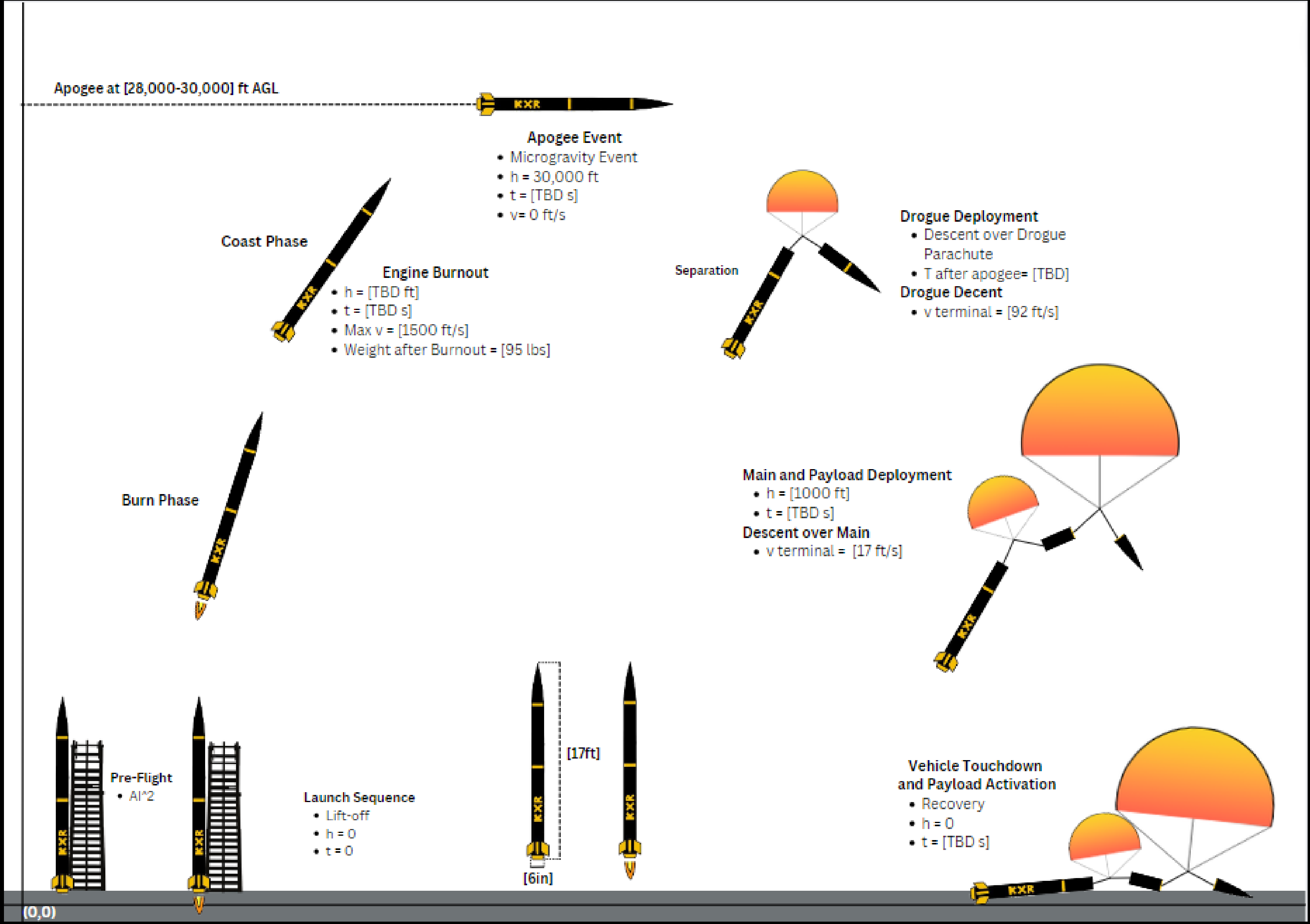
IREC Vehicle CONOPs



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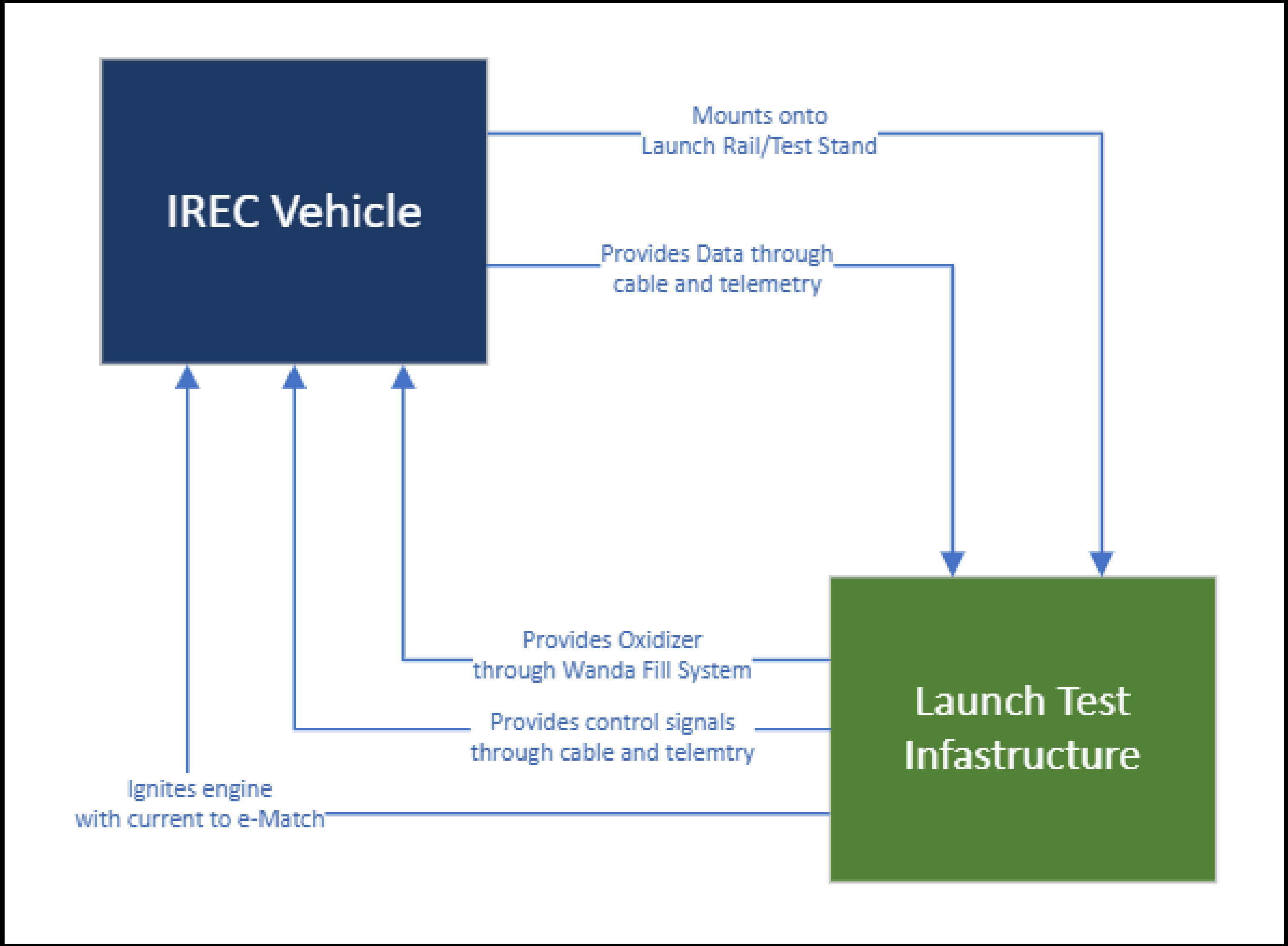
IREC Vehicle Interface Diagram



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IREC Vehicle Cost

The Vehicle has a budget of $15,800 that can break down into each System:

Propulsion: $8,300

Aerostructures: $5,500

Payloads: $2,000

5-20% from each system will be used as a buffer for overhead or emergency costs.

IREC Vehicle Schedule – 9 Month Process

PI 1: August – Mid-December (5.5 months)

- System Requirements Reviews (Systems and Vehicle)
- Preliminary Design Reviews (Systems and Vehicle) **(October 30th – November 9th)**
- Design Solution Development Phase
- Critical Design Reviews (Systems and Vehicle) **(November 27th)**
- ERFs for long lead time items are created and approved.

PI 2: Mid-December – End-of-February (2.5 months including Winter Break)

- Finish all procurement.
- Finish initial and component-level simulation models for verification.
- Begin and Finish Manufacturing of all vehicle components necessary to proceed *to testing*.
- Book plane tickets and housing.

IREC Vehicle Schedule – Continued

PI 3: March – Mid-June (3.5 months)

- All assembly, testing, fill, launch, safety, recovery, etc. procedures shall be officially completed and released, pending changes after collecting testing data.
- Testing campaign, verification across entire vehicle
- Flight Readiness Review
- Technical Report submission, Poster creation, and paper deliverables are finalized.
- Itinerary is established and finalized for travel.

PI 4: Mid-June – End-of-July

- Attend competition and complete competition mission sequence.
- Post-competition debrief.
- Prepare documentation for future project cycle.

IREC Vehicle Risks

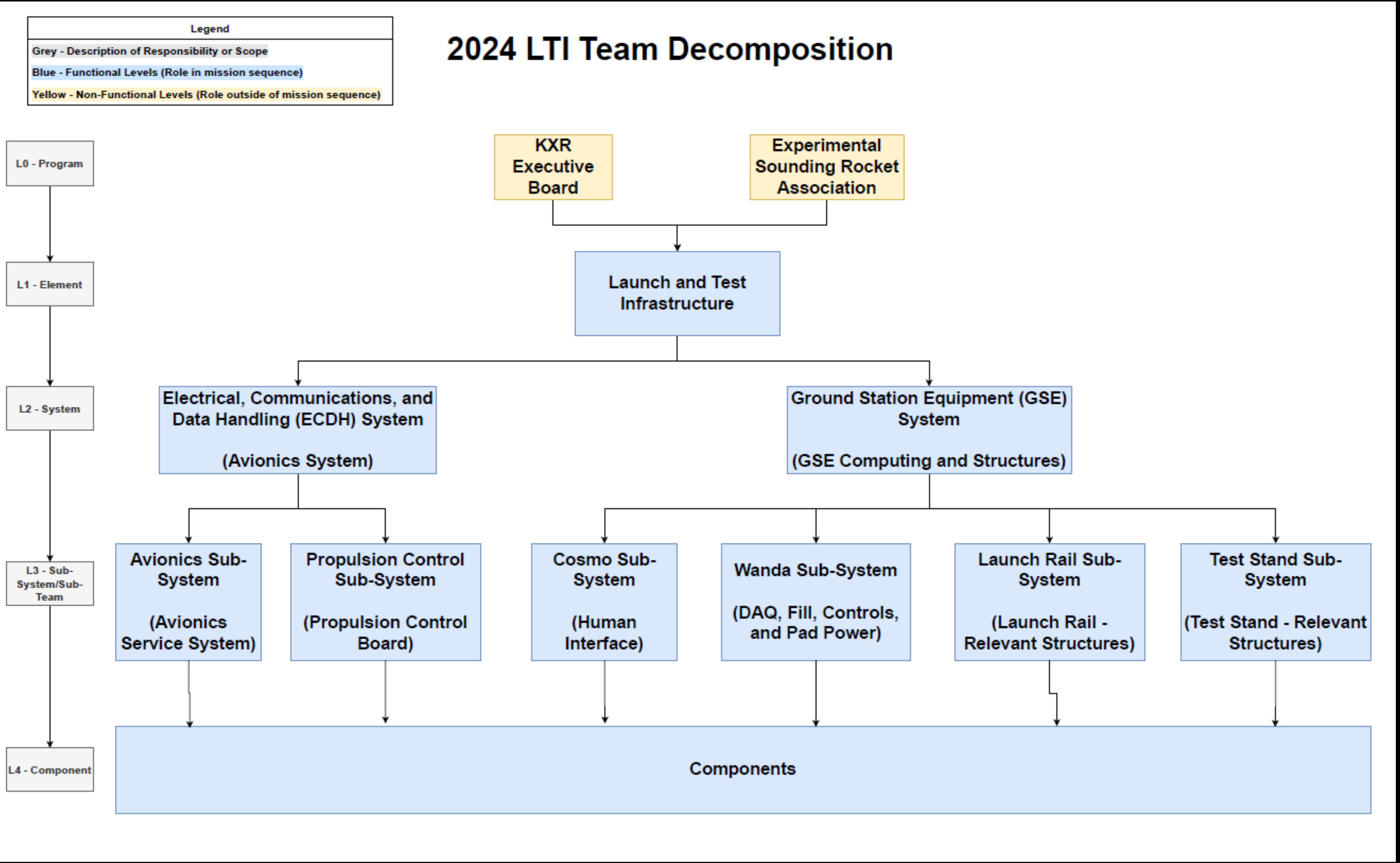
Possible Failure Modes:

- The vehicle does not reach desired altitude
- The vehicles stability fin system breaks
- The GSE does not ignite the propulsion system
- The vehicle loses connection to the ground station during fill
- The vehicle does not separate at main deployment
- The vehicle does not separate at drogue deployment

IREC Vehicle Verification Plans

- Dry Fit Demonstration
  - Verify through demonstration that all interfacing components within the vehicle fit together and can be assembled with ease.
- Full Vehicle Verification Testing
  - Propulsion System Verification Testing
  - Payloads System Verification Testing
  - Aerostructures Verification Testing
- Test Launch
  - Verify and validate by demonstration that the vehicle and fulfills all functional requirements and mission sequence

IREC's Interpretation of LTI Team Decomp



- Restructured within IREC strictly for requirements and interface writing
- **Please refer to LTI's own Team Breakdown if you are on their team!!**

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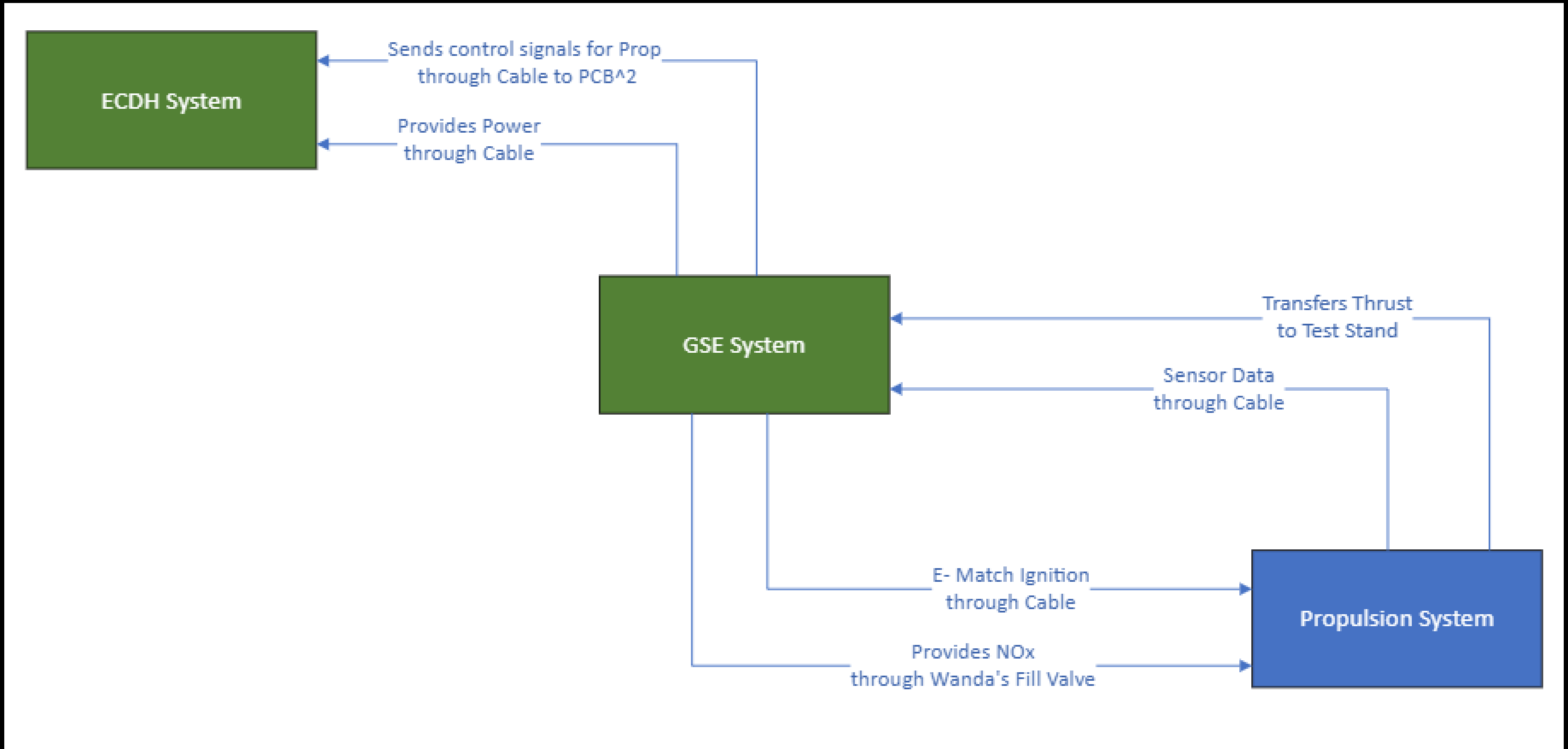
GSE – Test Configuration



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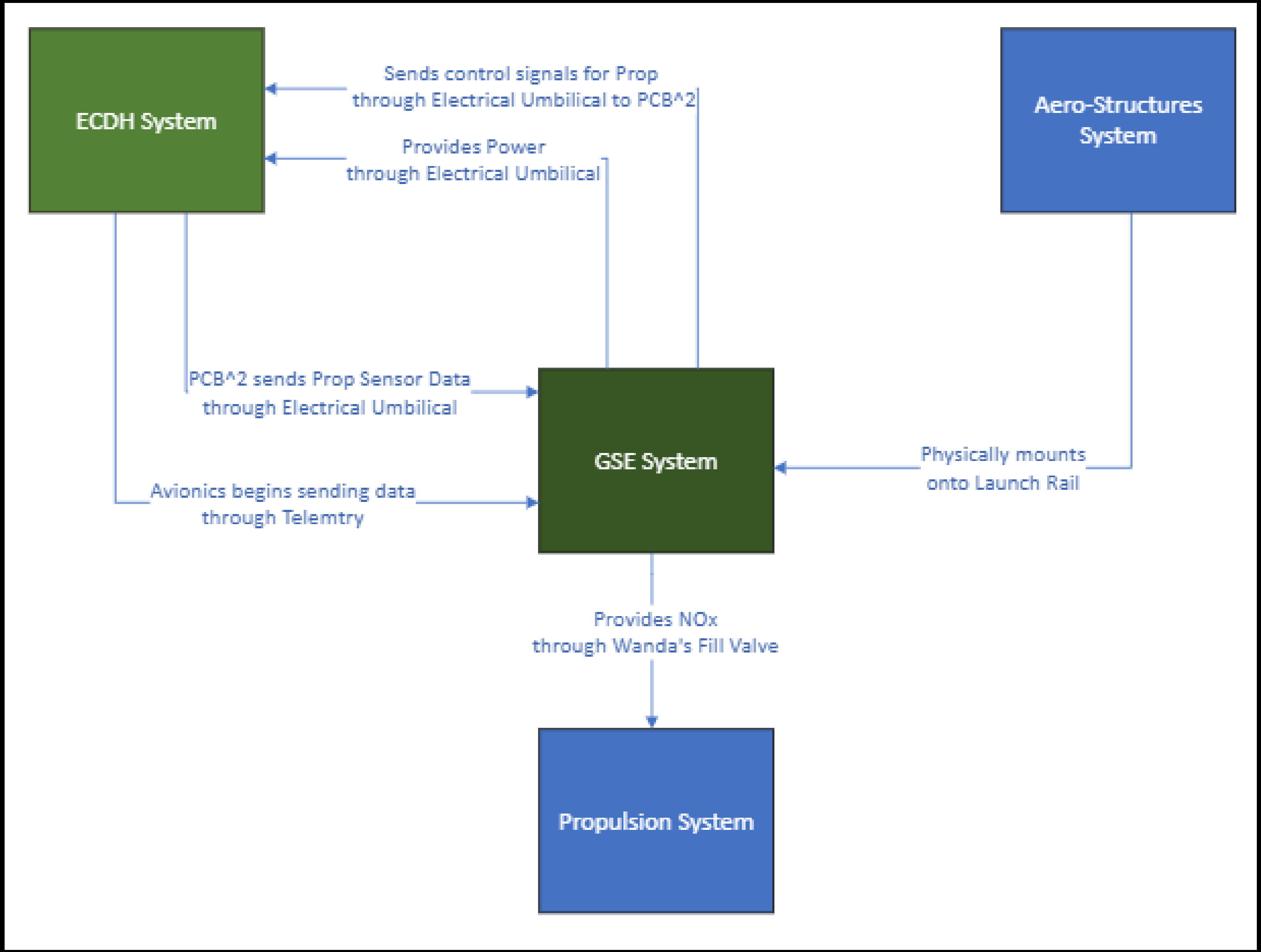
GSE – Launch Configuration



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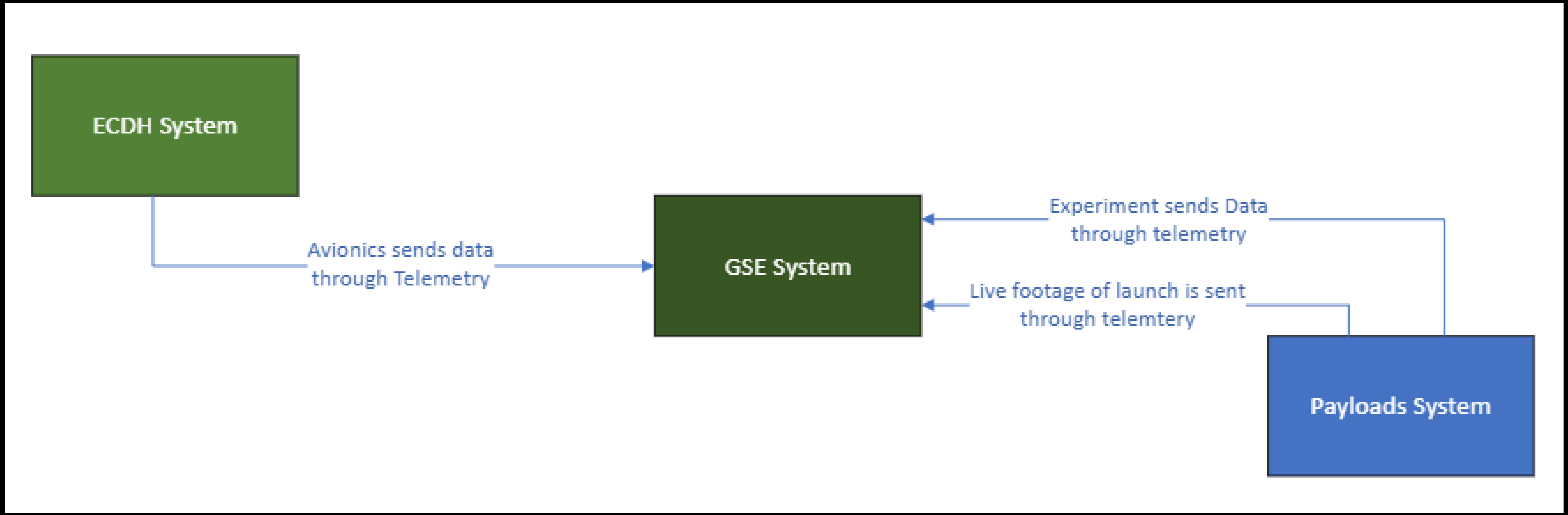
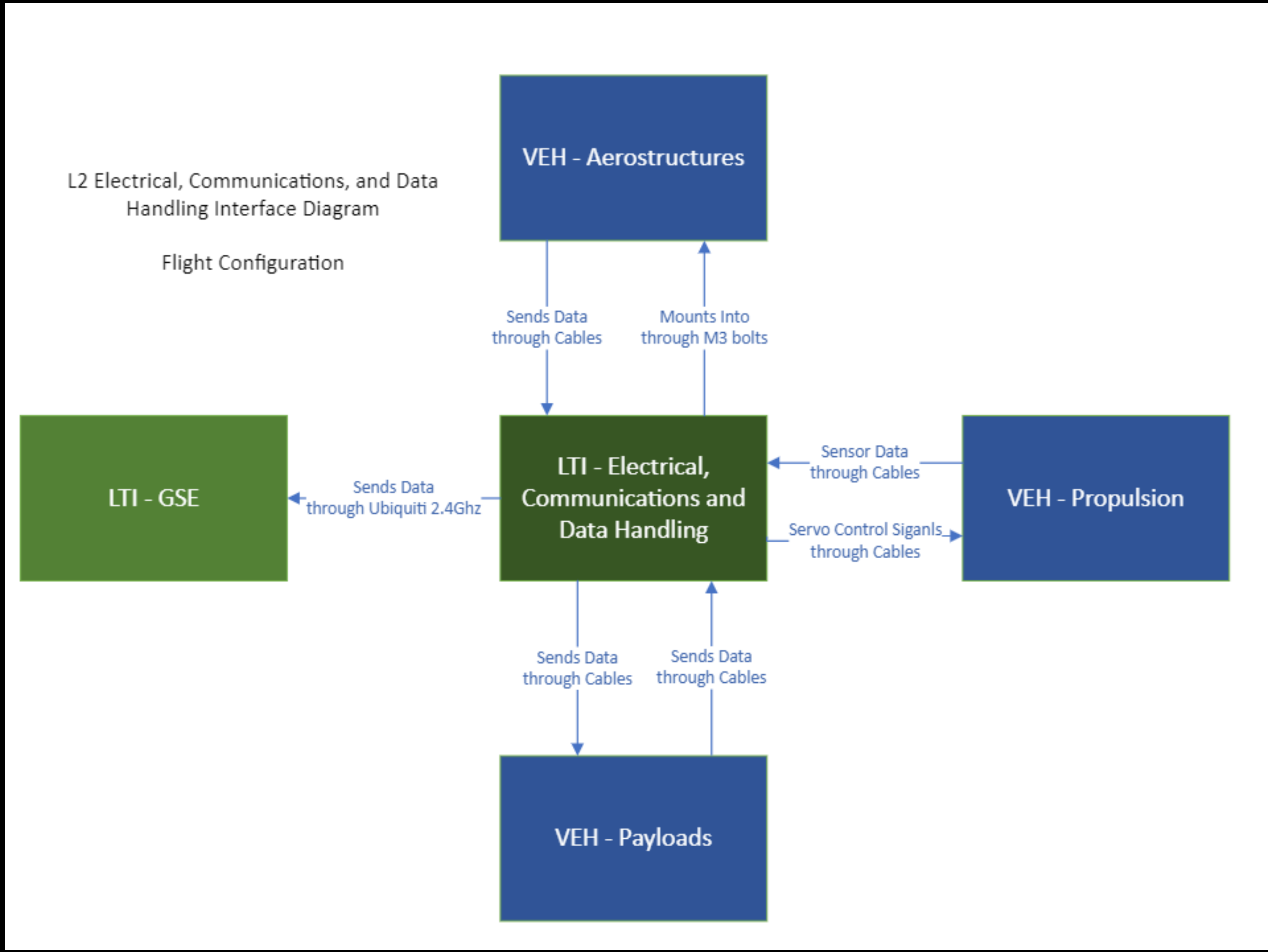
GSE – Flight Configuration



ECDH (Avionics and PCB^2)– Flight Config



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Questions?

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Aero-Structures System Preliminary Design Review

Spaceport America Cup 2024

Project Helios

11/14/23

Agenda

1. General Aero-Structures Overview
2. Dynamics
3. Structures
4. Recovery
5. Manufacturing

Disclaimer: The question section is at the end of every sub-system section. Please hold questions until the designated question slide.

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Aero-Structures Architecture

Target Apogee: 30,000ft

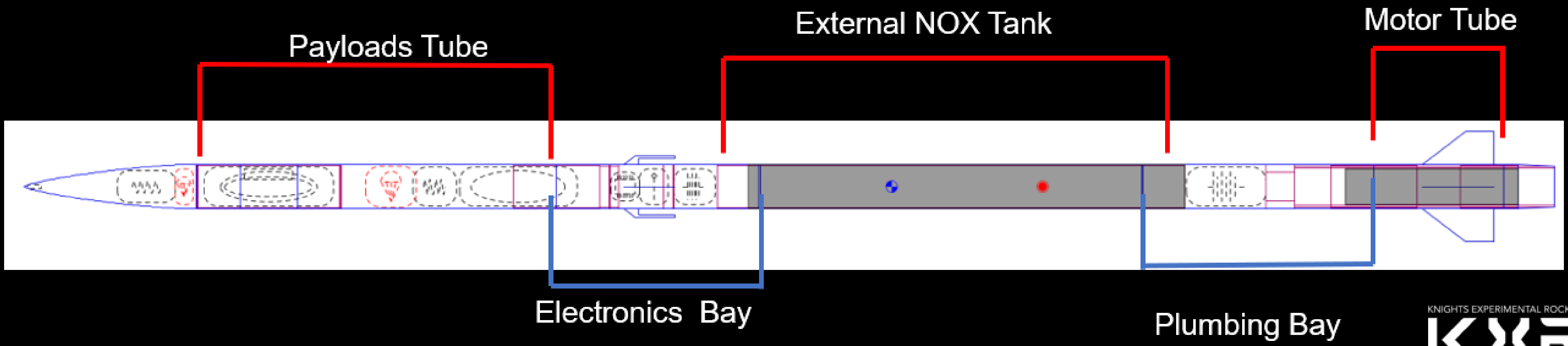
Max Speed :1700ft/s

Length :17 ft

OD: 6.22 inches

Max Dynamic Pressure: 15.5 PSI

Dry Mass: 98 lbs



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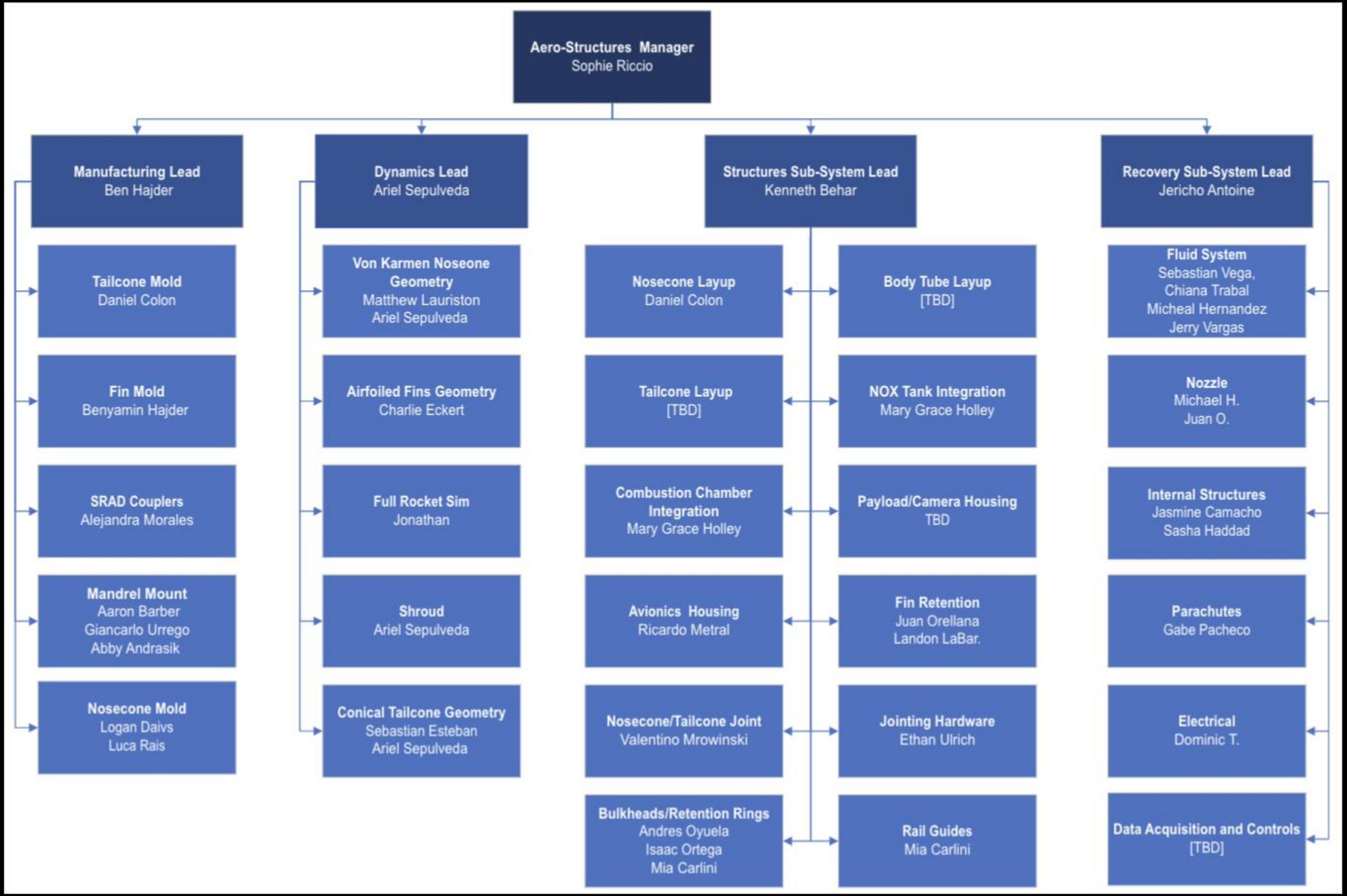
Aero-Structures Requirements

Requirement	Verification Method
The Aero-Structures System **shall** withstand a load of [12] G's.	Analysis
The Aero-Structures System **shall** have a Weight of [30] lbs.	Inspection
The Aero-Structures System **shall** deploy the Payload Experiment System during Main Deployment Event.	Inspection
The Aero-Structures System **shall** house the Avionics System.	Inspection
The Aero-Structures System **shall** house the Propulsion System	Inspection
The Aero-Structures System **shall** consist of Recovery and Structures Sub-Systems.	Inspection
The Aero-Structures System **shall** utilize non-functional Manufacturing and Dynamics Teams.	Inspection
The Aero-Structures System **shall** house all internal components.	Inspection
The Aero-Structures system **shall** have a minimum stability of [1.5] Calibers from launch and until apogee approach.	Analysis
The Aero-Structures System **shall** fully be designed by the [first week of December 2023].	Inspection
The Aero-Structures System **shall** fully be procured by the [last week of January 2024].	Inspection
The Aero-Structures System **shall** fully be manufactured by the [last week of February 2024].	Inspection
The Aero-Structures System **shall** fully be tested by the [last week of March 2024].	Inspection
The Aero-Structures System **shall** be designed to withstand their respective loads within a minimum Safety Factor of [2].	Analysis
The Aero-Structures System **shall** be completely resuable.	Test
The Aero-Structures System **shall** successfully launch off the launch rail at an azimuth of [6] degrees.	Test
The Aero-Structures System **shall** be designed, manufactured, verified, and launched within a budget [$5,500].	Inspection
The Aero-Structures System **shall** have a total length of [17.083] ft.	Inspection
The Aero-Structures System **shall** be adequately vented throughout flight.	Inspection

Aero-Structures Organization Chart



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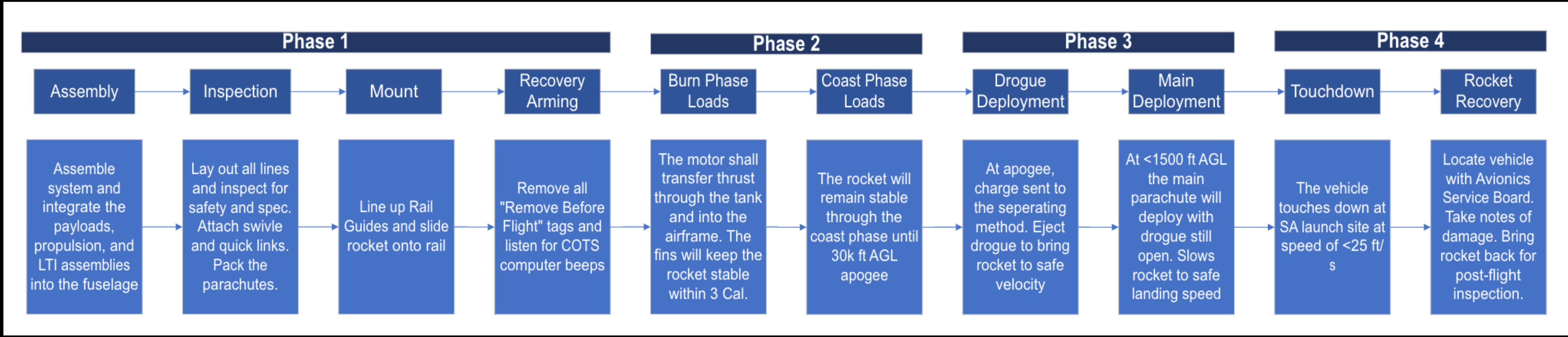
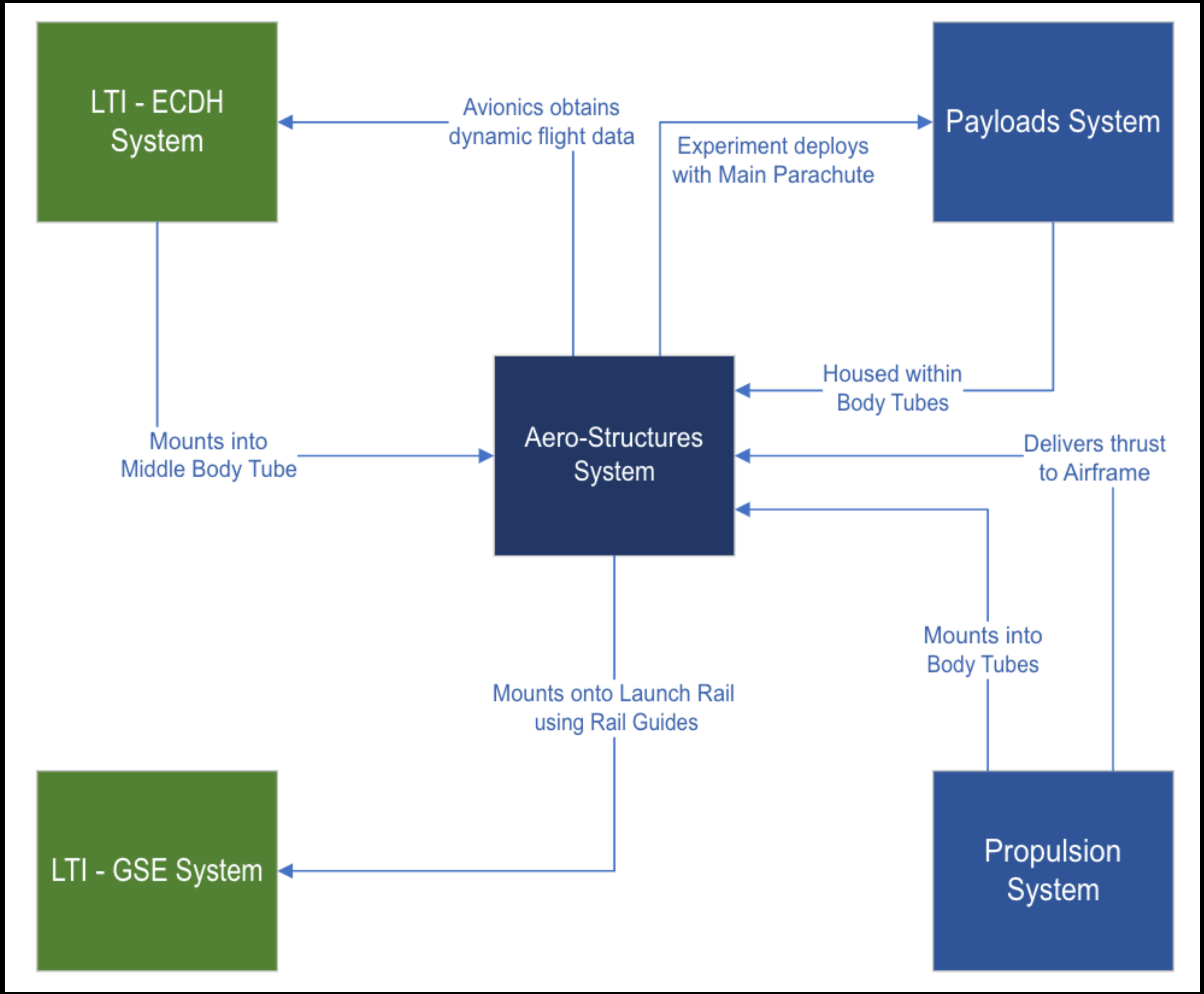
Aero-Structures CONOPS



Aero-Structures Interface Diagram



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Aero-Structures Verification Plans

Planned Tests	Details
Carbon Fiber Composite Testing	Compressive, Tensile, Bending, and Bolt Tear Out
FEA	Bulkheads, Tubes, Nose Cone, Tail Cone, Fins, and Fin Brackets
Full Rocket Fluent Sim	Iteration of simulation with improvents to full rocket CAD assembly
Mold Testing	Nose Cone, Tail Cone, Fin, etc...
Manufacturing Test Article	6-8 inch section of body tube
Parachute CD Testing	Done through UCF or neighbor universities.
Inspection of all Componets	Damage, sizing, weight, etc...
Airframe Dry Fit	Full Dry Dress Assembly.
Recovery Ground Test	Rocket with ballast weight tested.
Launch	Full vehicle assembly, loading of propellants, and fire sequence.

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Aero-Structures Cost

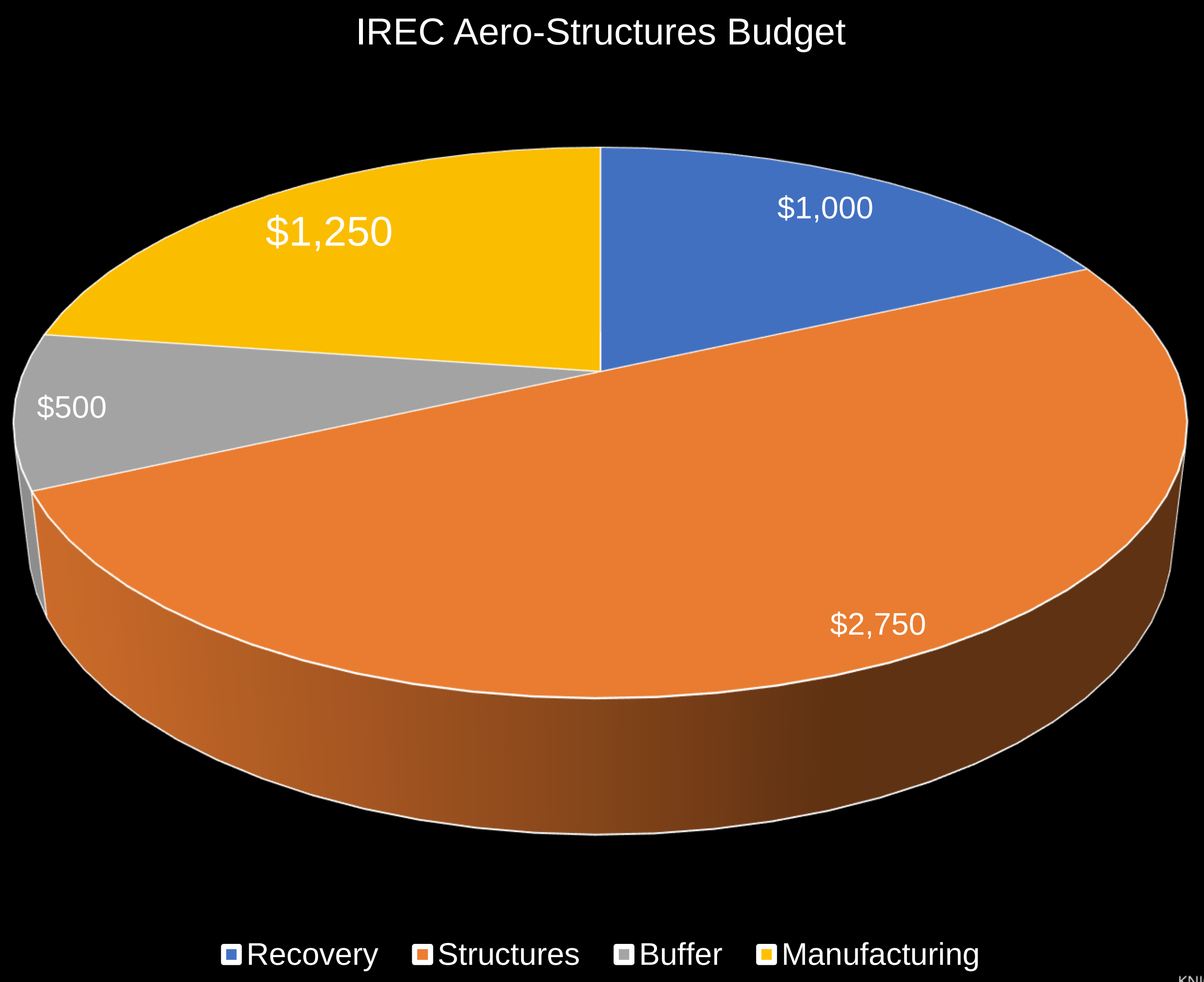
Total Budget: $5500

Structures: $2750

Manufacturing: $1000

Recovery: $1250

$500 Buffer



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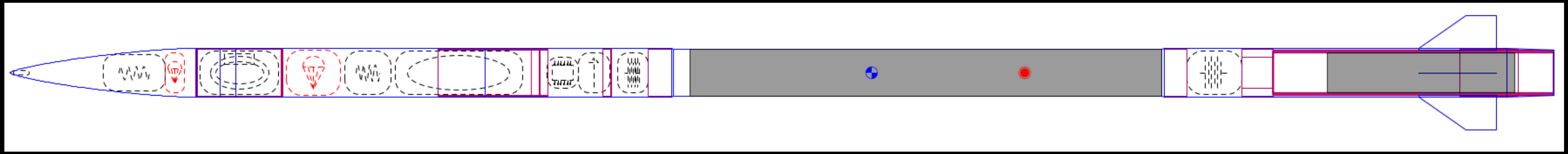
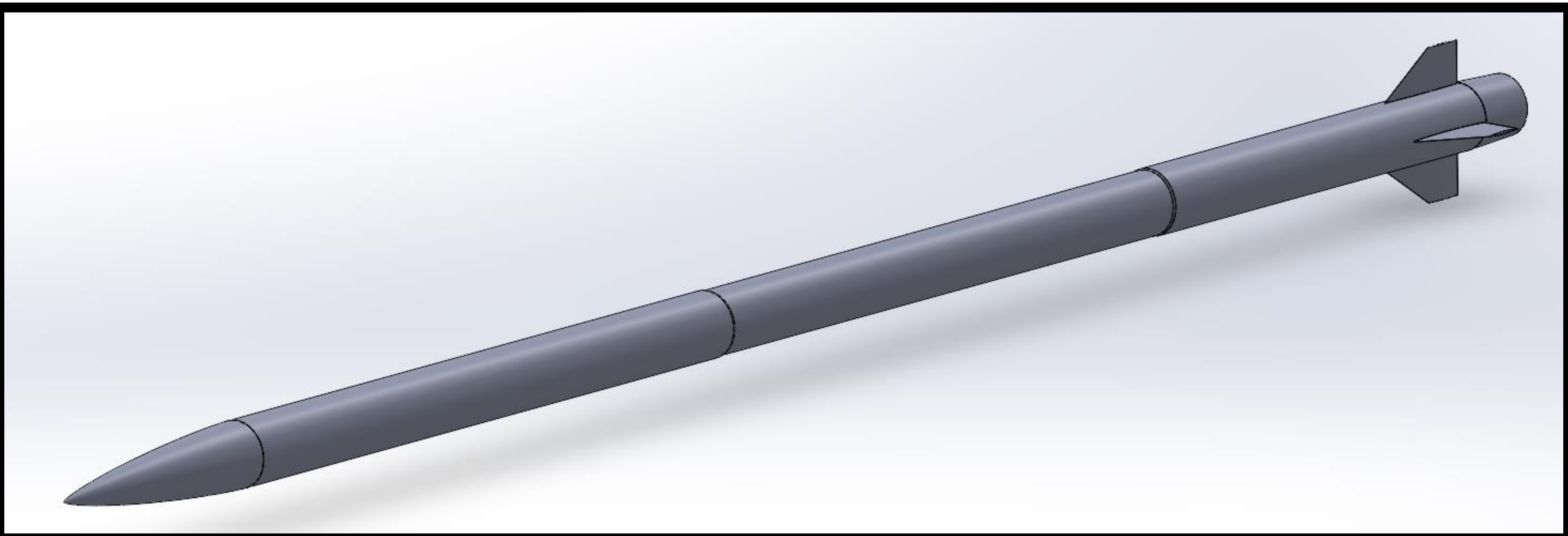
Aero-Structures Risks

Risks	Mitigation Strategies
Delay in materials arriving.	Order materials with long lead times earlier.
Integration Issues between Sub-Systems and Systems	Implement ICD to track all mission critical interfaces between Aero-Structures.
Manufacturing Setbacks	Create test articles and subscale models of full-scale components.
Rocket CATO from structural inadequacies	Perform rigorous hand calcs, simulations, and coupon testing, as well as designing with 2 times safety factor.

Dynamics Team

The Dynamics Team is responsible for designing the geometries of Nosecone, Tailcone, Fins, and Antenna Shrouds. This includes determining the expected Aerodynamic loads that will be experienced by the Airframe.





Dynamics Requirements

Requirement	Verification Method
The Dynamics Team **shall** determine the maximum stresses acting on the rocket from aerodynamic loading to design around.	Analysis
The Dynamics Team **shall** verify drag coefficient for Aero-Structures System components through a variety of testing and CFD methods.	Analysis
The Dynamics Team **shall** verify sufficient stability throughout flight through aerodynamics analysis prior to testing.	Analysis
The Dynamics Team **shall** optimize the entire rocket to reduce Maximum Drag.	Analysis

Requirement	Verification Method
The Nose Cone **shall** have a maximum Drag Coefficient of [] during flight.	Analysis
The Shroud **shall** minimize the drag contribution of the external antenna shrouds	Analysis
The Tail Cone **shall** have a maximum Drag Coefficient of [] during flight.	Analysis
The Tail Cone **shall** minimize drag experienced during flight.	Analysis
The Rail Guides **shall** induce a maximum Drag of [] lbs during flight.	Analysis
The Fins **shall** retain an airfoiled cross-sectional geometry.	Inspection
The Fins **shall** have a maximum Lift Coefficient of [] during flight.	Analysis
The Fins **shall** have a maximum Drag Coefficient of [] during flight.	Analysis
The Fins **shall** provide stability throughout flight.	Demonstration

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Dynamics TPMs

Measure	TPM Value	Units	Verification Method
Maximum Coefficient of Drag	[0.7]	-	Analysis
Maximum Total Drag Force	[337]	lbf	Analysis, Hand Calculation
Maximum Acceleration	[370]	ft/s^2	Analysis
Maximum Moment	[7560]	lb*in	Analysis
Maximum Dynamic Pressure	[15.6]	psi	Analysis
Max Pitch Moment	[7560]	lb*in	Analysis
Max Pitch Rate	[0.081]	rad/s	Analysis
Max Yaw Rate	[-0.016]	rad/s	Analysis
Max Roll Rate	[1.8*10^-7]	rad/s	Analysis

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Dynamics Risks

Risks	Mitigation Methods
Aerodynamic Loads are not calculated correctly, leading to failure during flight.	Ensure Aerodynamic Loads are calculated correctly through repeated verification.
Selected designs are not feasible.	Look for real-world examples from other team reports that have successfully launched for implementing new designs.
Selected designs are not able to integrate with other Sub-Systems.	Ensure constant communication between the other Sub-Systems.

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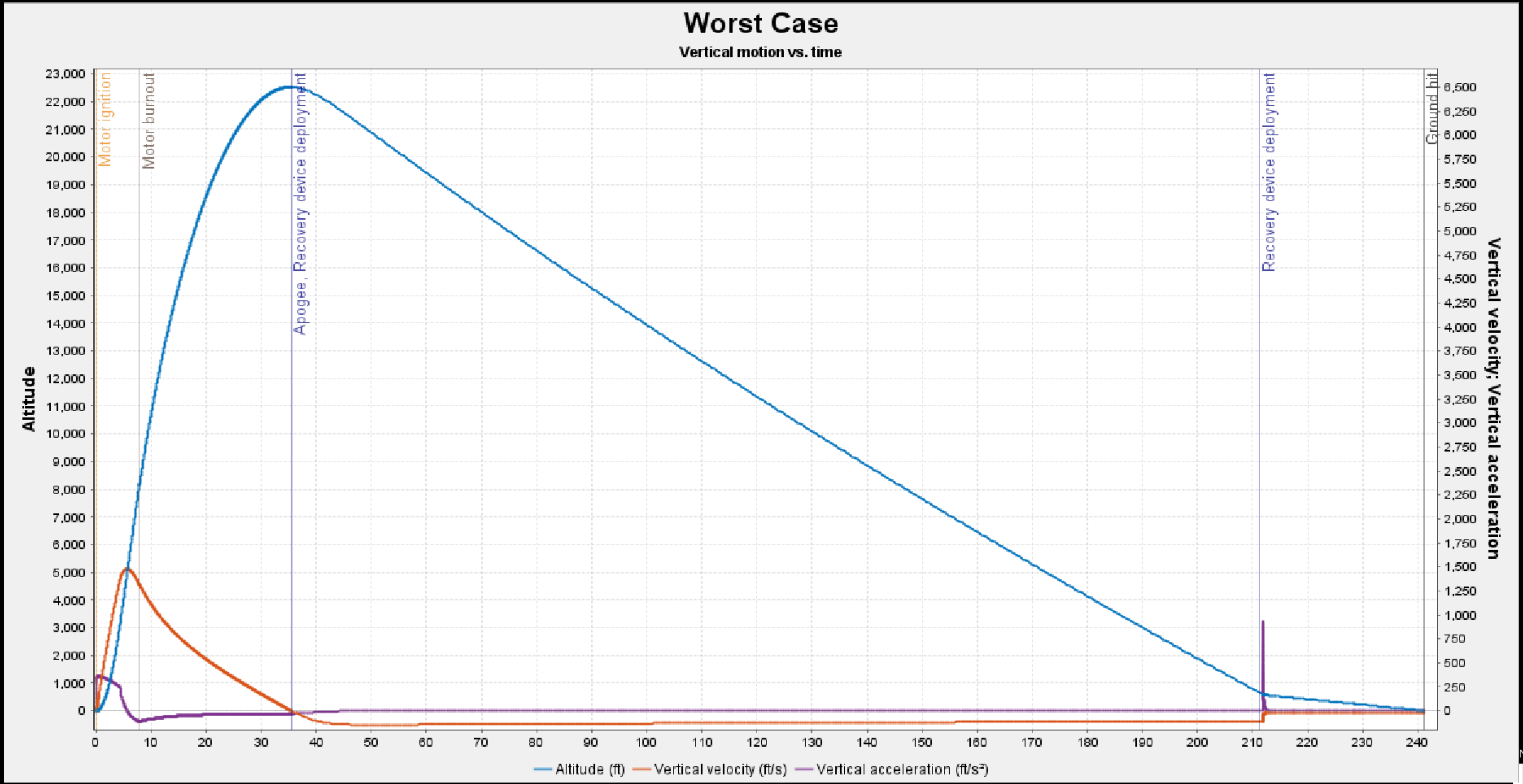
Worst Case - "Rough (19.7 mil)"



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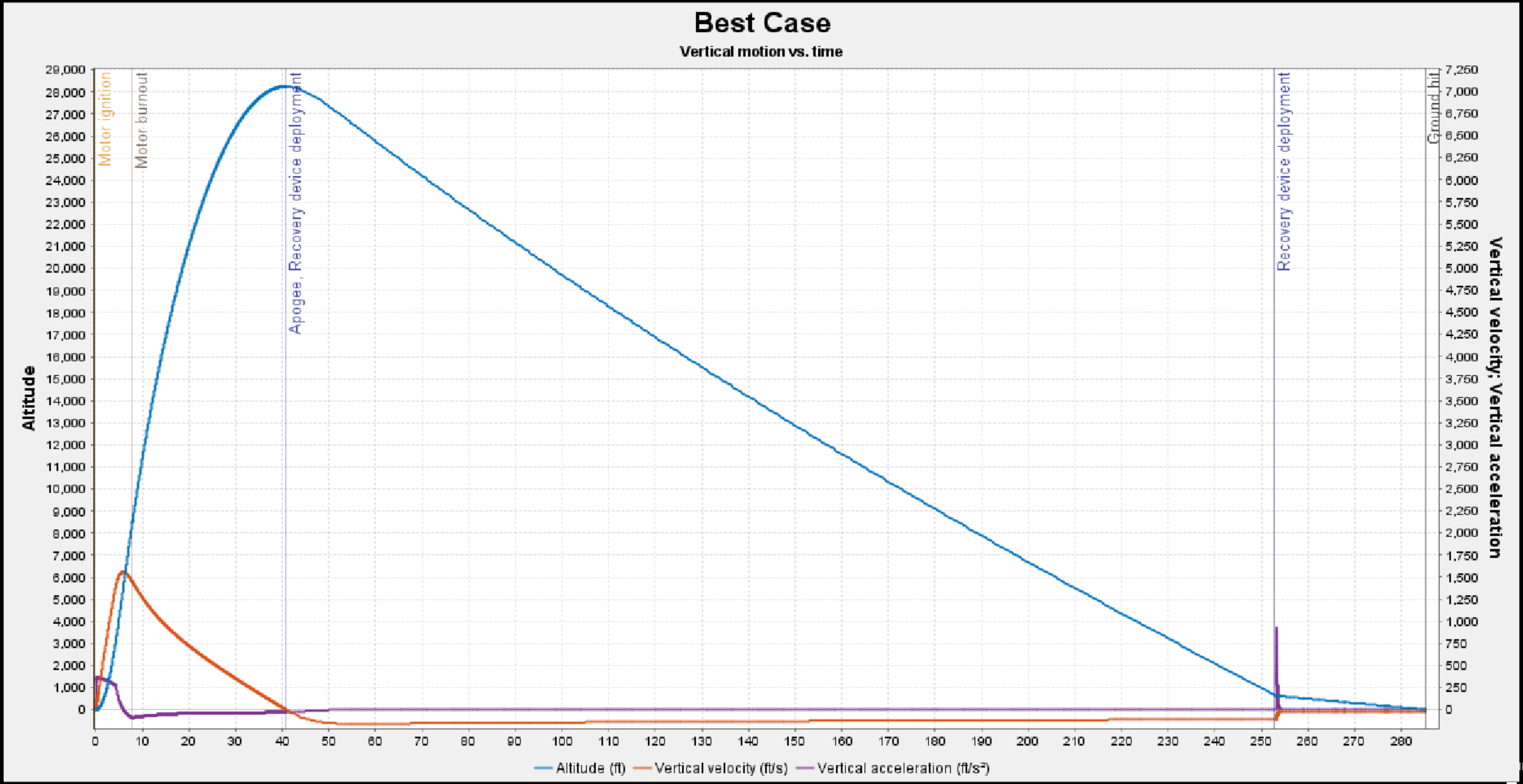
Best Case - "Aircraft Sheet-metal (0.079 mil)"



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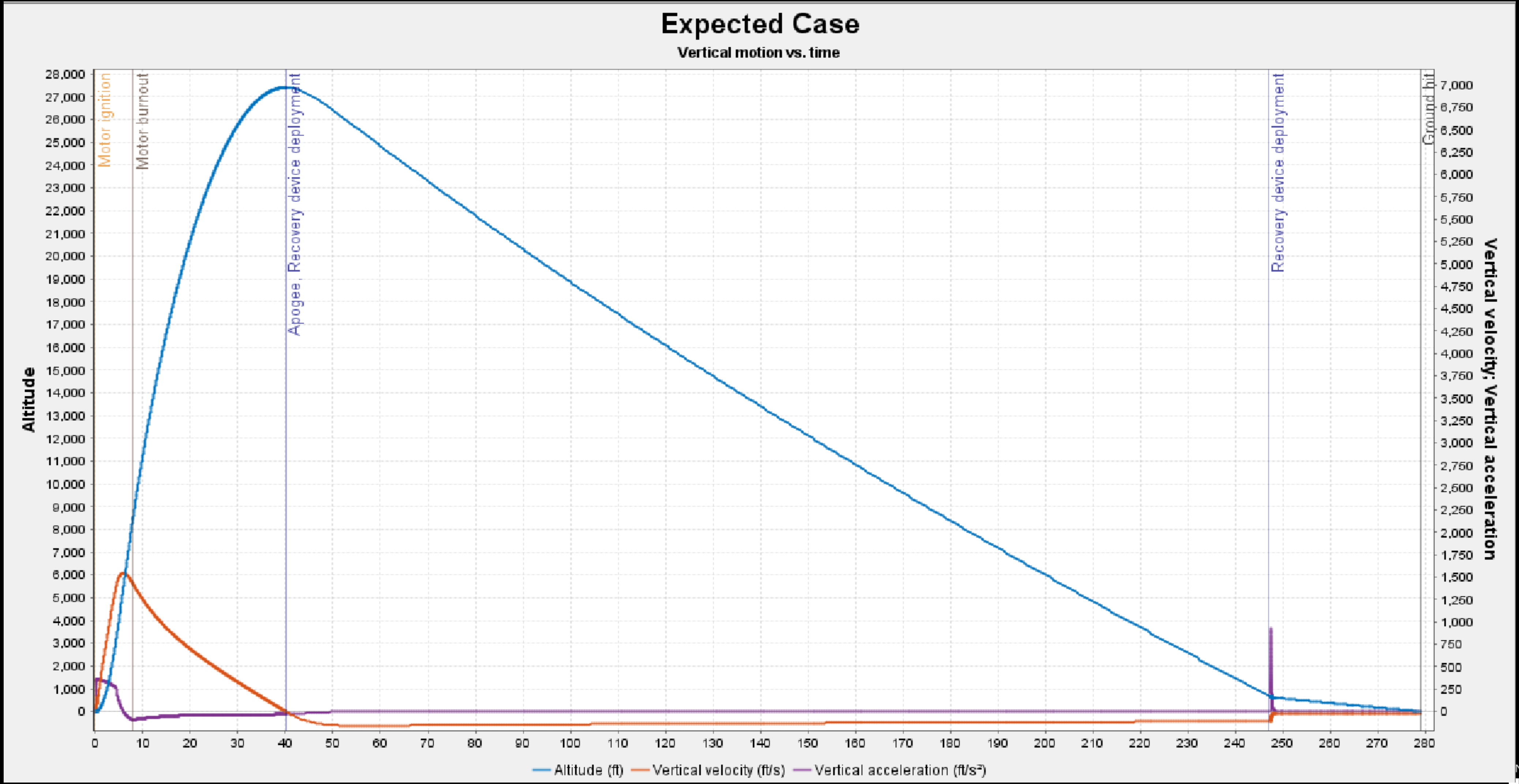
Expected Case - "Smooth Paint (0.787 mil)"



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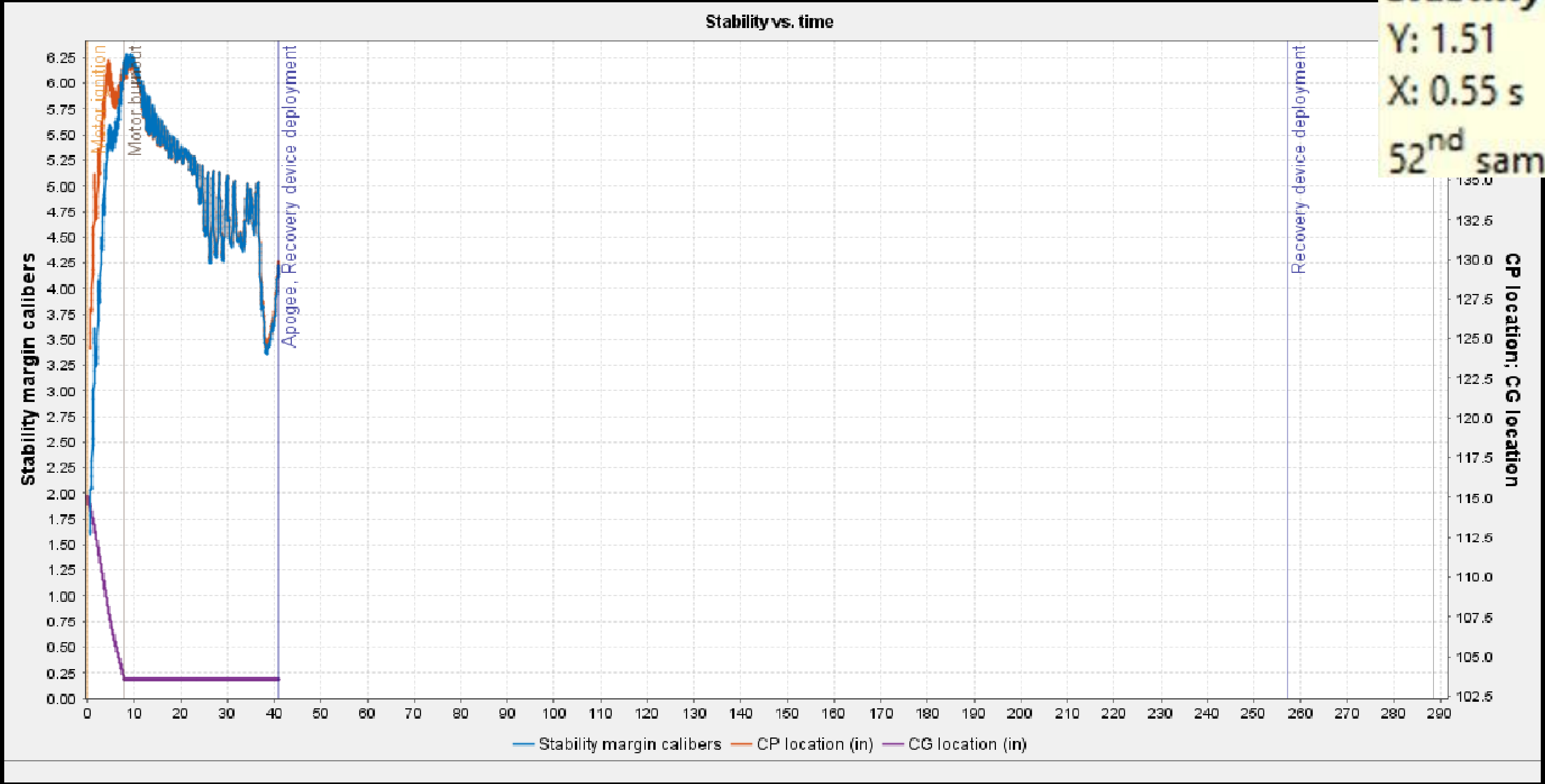
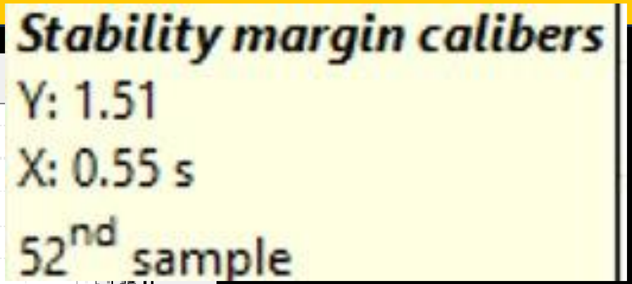
Stability Margin





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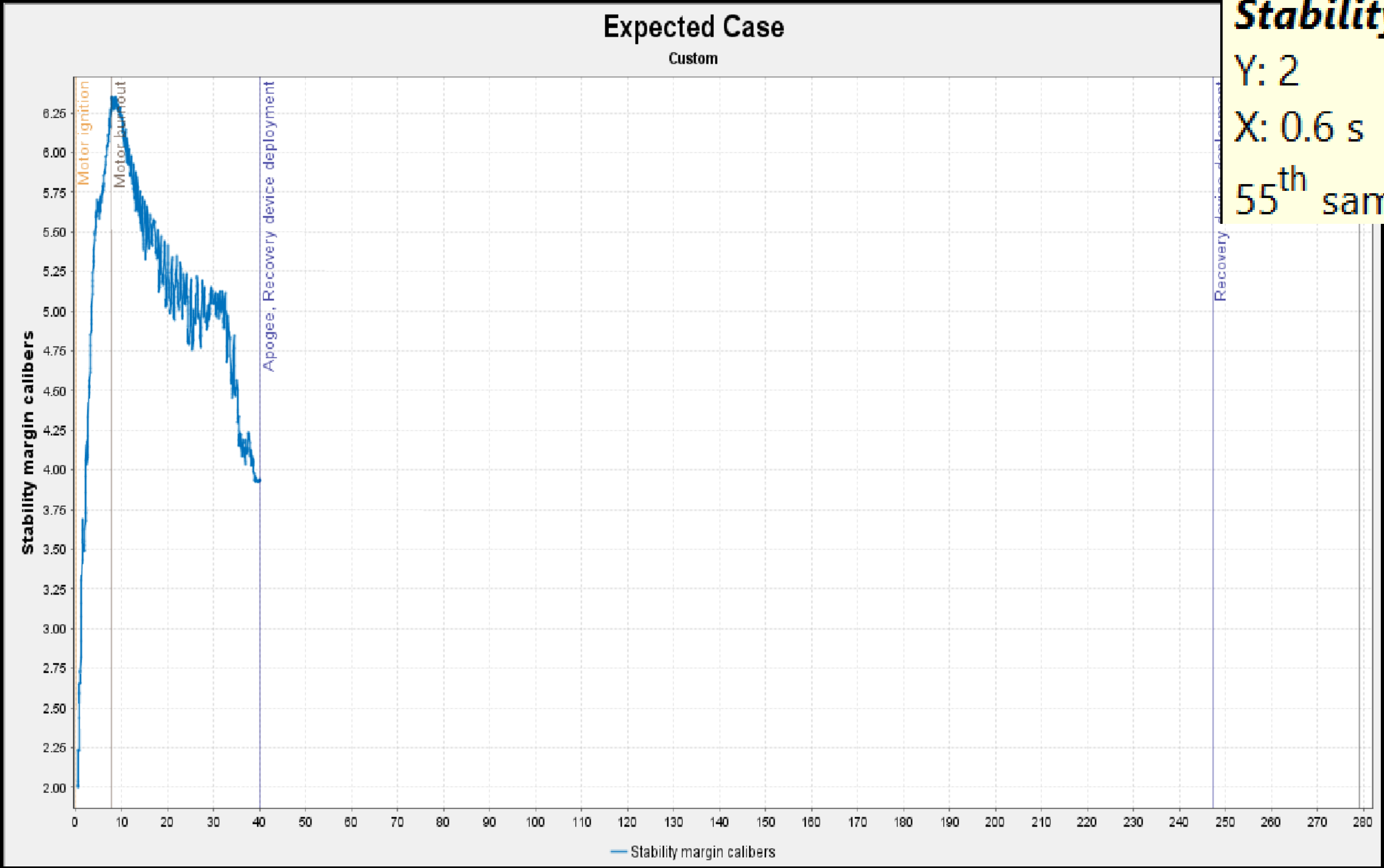
Stability Margin – Expected Case



Stability margin calibers

Y: 2

X: 0.6 s

55th sample

According to OpenRocket Flight Simulation, Stability stays above two for the duration of flight.

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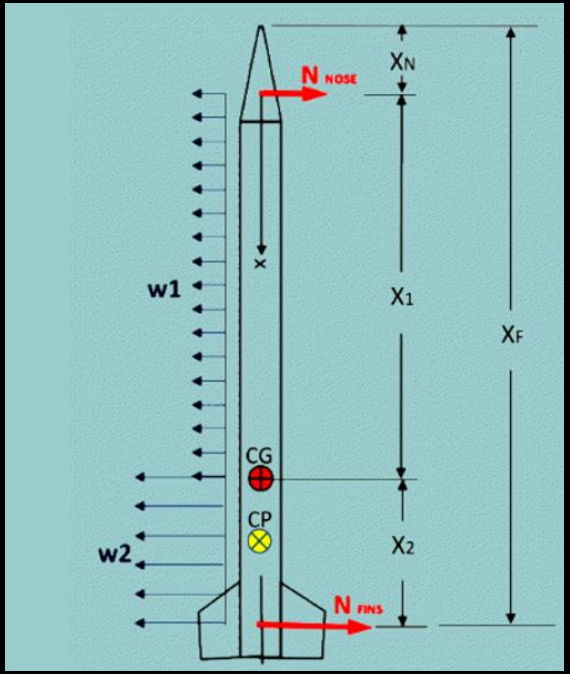
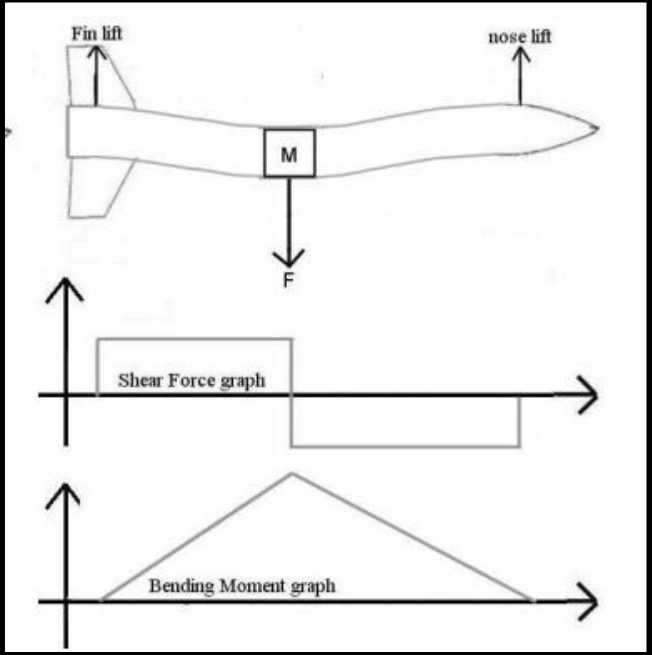
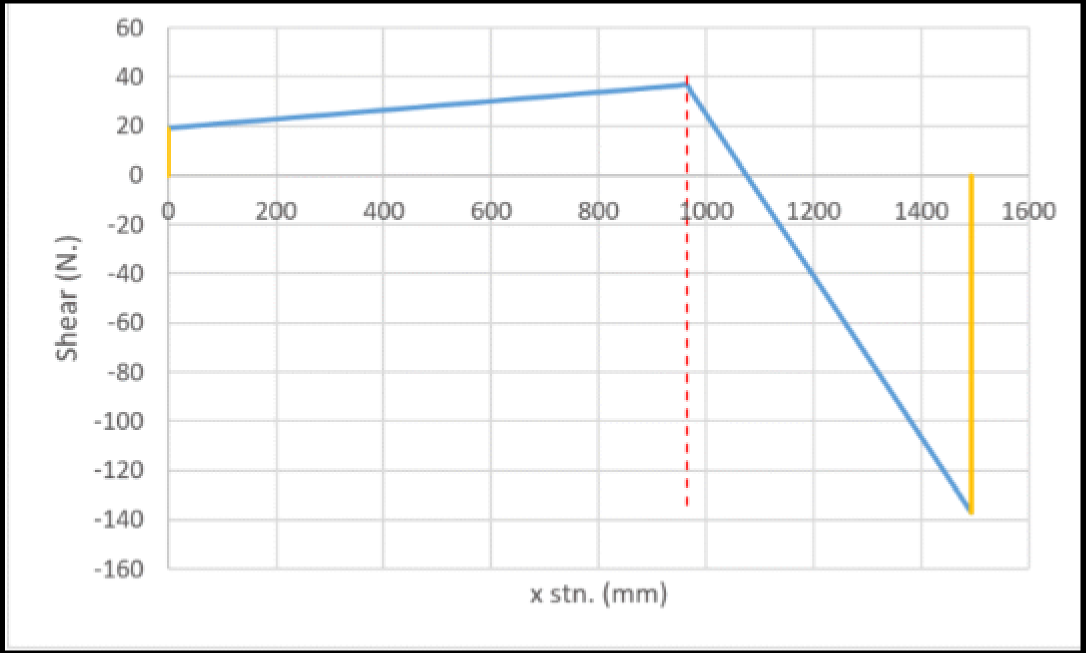
Aero Loads



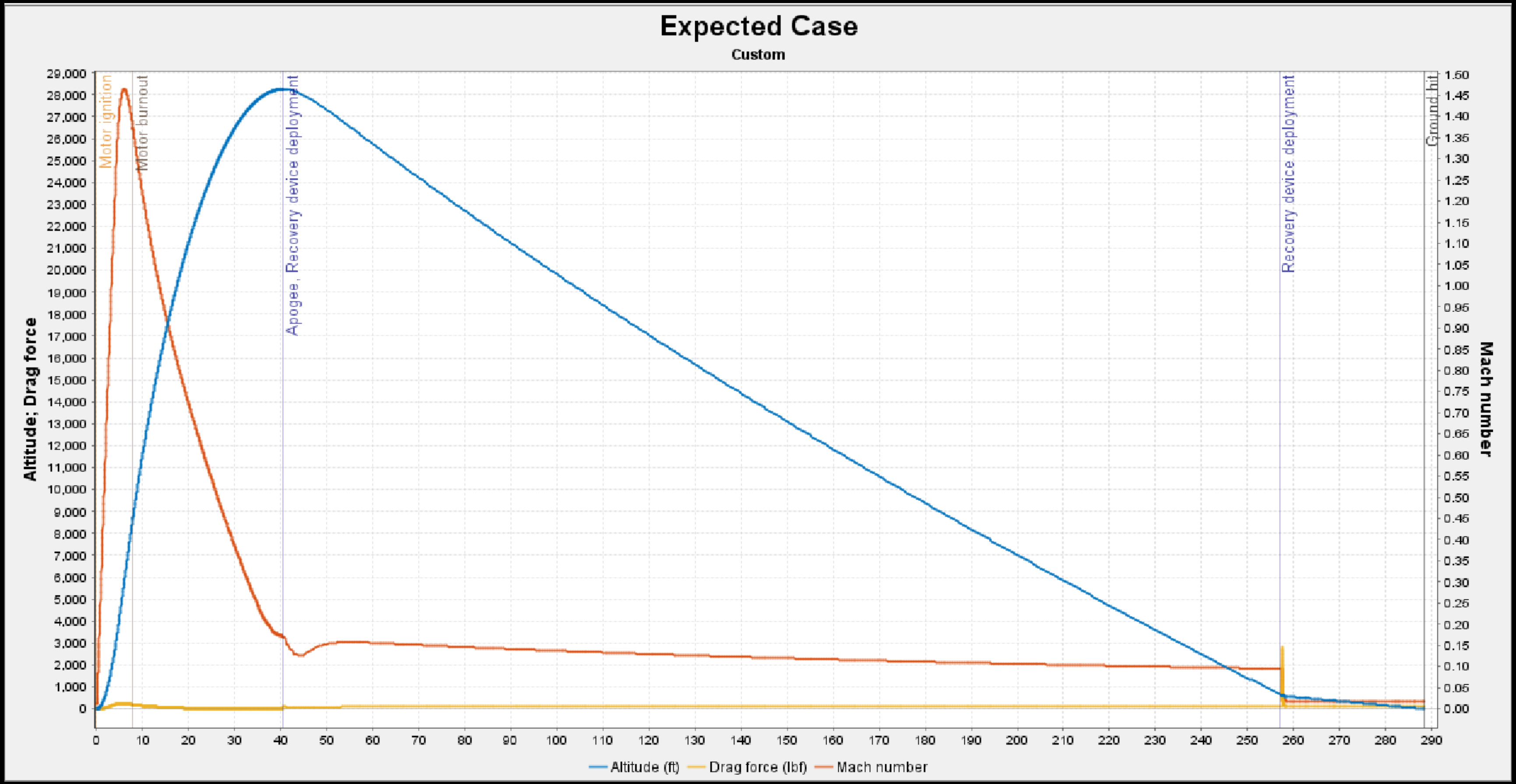




Max Q[Dynamic Pressure] (Psi)	Refrence Area (in^2)	AoA (radians)	Normal Force on Nose Cone(lbf)	Normal Force on Fins(lbf)	Distributed load W1(lb/in)	Distributed load W2(lb/in)	Distance from NC for M1 (in)	Distance from NC from M2 (in)	Section Modulus(in^3)
15.56178729	30.39556944	0.104719755	99.06685421	243.7044614	0.468547479	3.745779337	211.4339712	113.9389167	2.896094428
M1 Max Moment (lbin)	**M2 Max Moment (lbin)**	**Lateral Shear (V1) (lbf)**	**Lateral Shear (V2) (lbf)**	**Max Stress on Body (psi)**	**Drag Force (lb)**	**Compressive Stress (psi)**	**Compressive Stress to Mass Inertia (psi)**	**Total Stress (psi)**	**Safety Factor**
7563.948025	7563.948025	52.21210629	-243.7044614	2611.775346	337.4579929	11.10220993	599.433185	3222.310741	28.40160598

ROCKETRY

Full Rocket Sim



Apogee: 28250 ft
Max. velocity: 1612 ft/s (Mach 1.46)
Max. acceleration: 370 ft/s²

Stability: 3.21 cal
CG: 110 in
CP: 130 in
at M=0.30

KNIGHTS EXPERIMENTAL ROCKETRY
KXR

Nose Cone

- Design Considerations: Ogive, *LD (Von-Karman) and *LV Haack Series, *X^½ and X^¾ Power Series
- Honors Thesis by Chad O' Brien (supervised by principal Research Engineer Dr. David Lineberry)
- Gives insight on slenderness ratio and Haack Series drag comparisons

F. Axial Force from Pressure – Raw Data

Table 4: Axial Force from Dynamic Pressure

	LD-HAACK									LV-HAACK								
	SF_0.5			SF_1.0			SF_2.0			SF_0.5			SF_1.0			SF_2.0		
Mach/File	F3	F4	F5	F3	F4	F5	F3	F4	F5	F3	F4	F5	F3	F4	F5	F3	F4	F5
0.3	0.0025	0.0015	0.0011	0.0085	0.0055	0.0039	0.0340	0.0219	0.0156	0.0029	0.0018	0.0013	0.0102	0.0066	0.0048	0.0417	0.0273	0.0196
0.5	0.0074	0.0045	0.0031	0.0261	0.0166	0.0117	0.1056	0.0677	0.0479	0.0087	0.0054	0.0038	0.0313	0.0203	0.0144	0.1296	0.0845	0.0603
0.7	0.0176	0.0108	0.0074	0.0643	0.0406	0.0285	0.2667	0.1696	0.1192	0.0207	0.0130	0.0091	0.0771	0.0498	0.0353	0.3250	0.2108	0.1495
0.9	0.0470	0.0290	0.0199	0.1894	0.1184	0.0817	0.8197	0.5114	0.3515	0.0543	0.0343	0.0239	0.2191	0.1408	0.0987	0.9485	0.6093	0.4257
0.92	0.0534	0.0330	0.0226	0.2189	0.1366	0.0939	0.9529	0.5926	0.4055	0.0615	0.0389	0.0271	0.2513	0.1612	0.1126	1.0912	0.6991	0.4866
0.94	0.0613	0.0379	0.0259	0.2556	0.1592	0.1089	1.1185	0.6934	0.4719	0.0703	0.0445	0.0308	0.2910	0.1863	0.1296	1.2671	0.8093	0.5607
0.96	0.0710	0.0439	0.0299	0.3011	0.1871	0.1273	1.3230	0.8177	0.5532	0.0810	0.0512	0.0354	0.3399	0.2169	0.1502	1.4832	0.9439	0.6504
0.98	0.0828	0.0511	0.0347	0.3563	0.2209	0.1496	1.5685	0.9672	0.6506	0.0939	0.0593	0.0408	0.3991	0.2539	0.1748	1.7429	1.1052	0.7570
1	0.0965	0.0596	0.0403	0.4203	0.2603	0.1754	1.8484	1.1382	0.7620	0.1089	0.0687	0.0471	0.4677	0.2968	0.2033	2.0403	1.2901	0.8788
1.02	0.1114	0.0690	0.0466	0.4890	0.3030	0.2037	2.1431	1.3198	0.8814	0.1253	0.0790	0.0540	0.5419	0.3436	0.2345	2.3567	1.4879	1.0098
1.04	0.1264	0.0786	0.0531	0.5565	0.3456	0.2324	2.4255	1.4958	0.9994	0.1417	0.0896	0.0613	0.6156	0.3905	0.2663	2.6654	1.6822	1.1404
1.06	0.1403	0.0876	0.0594	0.6175	0.3845	0.2594	2.6735	1.6519	1.1069	0.1572	0.0997	0.0683	0.6836	0.4342	0.2965	2.9441	1.8584	1.2612
1.08	0.1528	0.0958	0.0652	0.6702	0.4182	0.2831	2.8814	1.7825	1.1990	0.1715	0.1090	0.0749	0.7441	0.4728	0.3235	3.1860	2.0101	1.3670
1.1	0.1641	0.1030	0.0704	0.7160	0.4468	0.3035	3.0571	1.8909	1.2760	0.1845	0.1174	0.0808	0.7980	0.5064	0.3471	3.3971	2.1397	1.4576
1.3	0.2526	0.1570	0.1073	1.0578	0.6512	0.4420	4.3526	2.6626	1.7996	0.2903	0.1818	0.1247	1.2174	0.7565	0.5154	5.0206	3.0999	2.1026
1.5	0.3343	0.2072	0.1415	1.3800	0.8486	0.5761	5.6179	3.4388	2.3277	0.3891	0.2425	0.1660	1.6127	0.9976	0.6787	6.5840	4.0539	2.7489
1.7	0.4208	0.2609	0.1784	1.7255	1.0627	0.7230	6.9900	4.2901	2.9115	0.4940	0.3075	0.2105	2.0350	1.2587	0.8571	8.2663	5.0945	3.4604

In Table 4, the listed values are directly collected from the FMSUMparse.sh shell routine showing in Figure 29. These were manipulated into non-dimensional calculations and plotted in the results section of this report. The values listed are in units of Newtons (N), the "F" is the slenderness ratio, and the "SF" is the radial scaling factor.

G. Axial Force from Viscous Effects – Raw Data

Table 5: Viscous Force

	LD-HAACK									LV-HAACK								
	SF_0.5			SF_1.0			SF_2.0			SF_0.5			SF_1.0			SF_2.0		
Mach/File	F3	F4	F5	F3	F4	F5	F3	F4	F5	F3	F4	F5	F3	F4	F5	F3	F4	F5
0.3	0.0115	0.0143	0.0170	0.0400	0.0497	0.0590	0.1398	0.1737	0.2064	0.0124	0.0153	0.0182	0.0430	0.0533	0.0632	0.1503	0.1864	0.2213
0.5	0.0269	0.0335	0.0399	0.0945	0.1178	0.1403	0.3332	0.4156	0.4954	0.0290	0.0360	0.0428	0.1015	0.1263	0.1504	0.3582	0.4462	0.5313
0.7	0.0455	0.0569	0.0680	0.1611	0.2017	0.2410	0.5729	0.7175	0.8575	0.0488	0.0610	0.0728	0.1730	0.2163	0.2583	0.6154	0.7700	0.9196
0.9	0.0645	0.0815	0.0980	0.2324	0.2935	0.3523	0.8361	1.0537	1.2637	0.0694	0.0875	0.1051	0.2496	0.3146	0.3775	0.8979	1.1304	1.3551
0.92	0.0664	0.0839	0.1010	0.2391	0.3024	0.3635	0.8618	1.0875	1.3052	0.0714	0.0901	0.1083	0.2570	0.3244	0.3895	0.9257	1.1668	1.3997
0.94	0.0682	0.0863	0.1039	0.2457	0.3112	0.3745	0.8868	1.1210	1.3465	0.0734	0.0926	0.1114	0.2643	0.3339	0.4014	0.9529	1.2029	1.4441
0.96	0.0700	0.0887	0.1067	0.2522	0.3198	0.3852	0.9108	1.1538	1.3875	0.0754	0.0952	0.1145	0.2713	0.3433	0.4131	0.9793	1.2384	1.4882
0.98	0.0718	0.0910	0.1096	0.2585	0.3283	0.3958	0.9338	1.1859	1.4279	0.0773	0.0977	0.1176	0.2781	0.3525	0.4246	1.0047	1.2731	1.5318
1	0.0735	0.0933	0.1125	0.2645	0.3365	0.4062	0.9560	1.2171	1.4677	0.0791	0.1002	0.1207	0.2847	0.3614	0.4359	1.0290	1.3070	1.5747
1.02	0.0752	0.0956	0.1153	0.2705	0.3447	0.4165	0.9777	1.2476	1.5069	0.0809	0.1026	0.1237	0.2911	0.3702	0.4470	1.0527	1.3402	1.6170
1.04	0.0768	0.0979	0.1182	0.2764	0.3528	0.4268	0.9993	1.2779	1.5457	0.0827	0.1050	0.1267	0.2974	0.3789	0.4580	1.0761	1.3730	1.6590
1.06	0.0785	0.1001	0.1210	0.2824	0.3611	0.4371	1.0214	1.3083	1.5844	0.0845	0.1074	0.1297	0.3037	0.3876	0.4690	1.0997	1.4059	1.7008
1.08	0.0802	0.1024	0.1238	0.2885	0.3694	0.4475	1.0443	1.3392	1.6232	0.0862	0.1098	0.1328	0.3102	0.3965	0.4801	1.1239	1.4390	1.7426
1.1	0.0820	0.1047	0.1267	0.2948	0.3779	0.4580	1.0678	1.3706	1.6621	0.0881	0.1123	0.1358	0.3168	0.4055	0.4913	1.1487	1.4724	1.7847
1.3	0.1003	0.1290	0.1566	0.3624	0.4670	0.5675	1.3186	1.6998	2.0660	0.1072	0.1379	0.1675	0.3873	0.5000	0.6078	1.4113	1.8211	2.2147
1.5	0.1194	0.1541	0.1872	0.4336	0.5593	0.6804	1.5813	2.0404	2.4818	0.1272	0.1657	0.2001	0.4615	0.5986	0.7273	1.6852	2.1809	2.6571
1.7	0.1394	0.1796	0.2185	0.5065	0.6556	0.7985	1.8504	2.3872	2.9033	0.1476	0.1911	0.2329	0.5393	0.6960	0.8505	1.9651	2.5463	3.1031

In Table 5, the listed values are directly collected from the FMSUMparse.sh shell routine showing in Figure 29. These were manipulated into non-dimensional calculations and plotted in the results section of this report. The values listed are in units of Newton (N), the "F" is the slenderness ratio, and the "SF" is the radial scaling factor.

Nose Cone

- Pressure drag decreases with an increase in slenderness ratio, however it results in a significant increase in viscous drag
- Take this into account when considering best optimization for nosecone

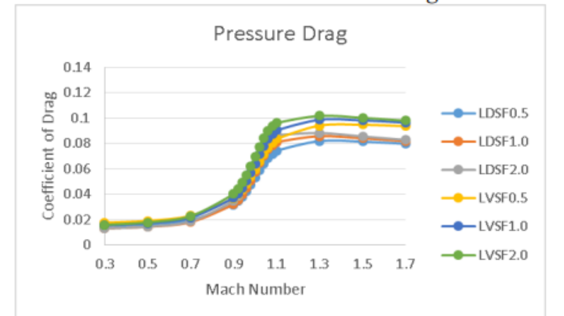


Figure 18: Pressure Drag (f=3)

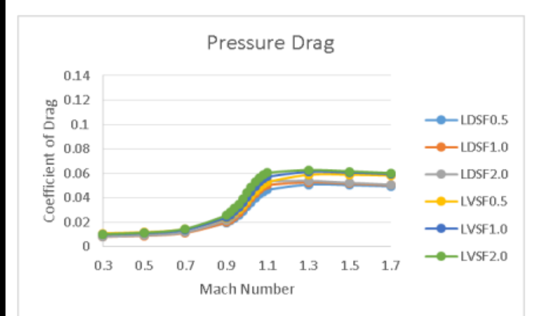


Figure 19: Pressure Drag (f=4)

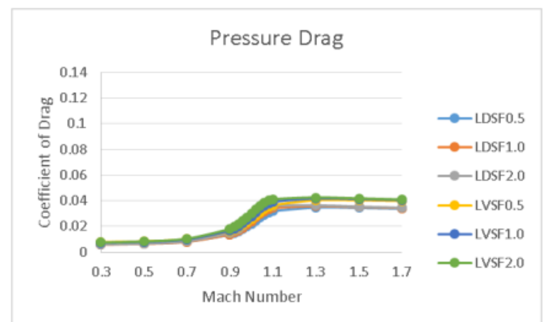


Figure 20: Pressure Drag (f=5)

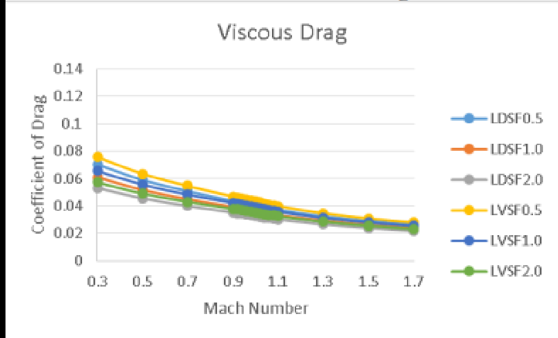


Figure 21: Viscous Drag (f=3)

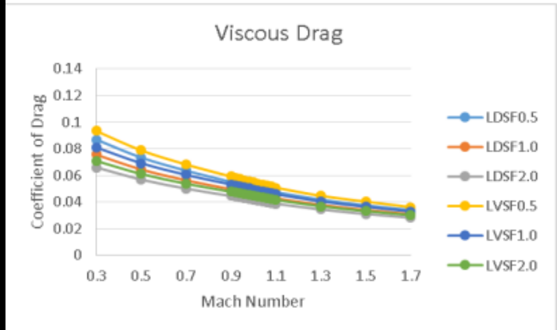


Figure 22: Viscous Drag (f=4)

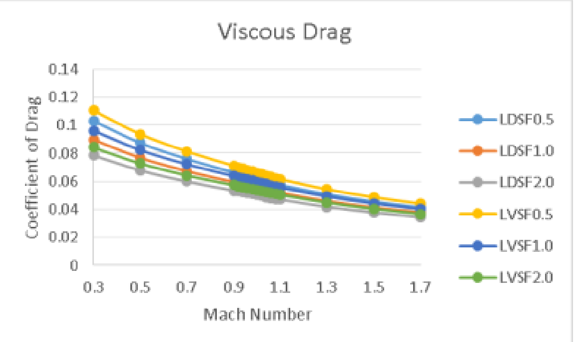
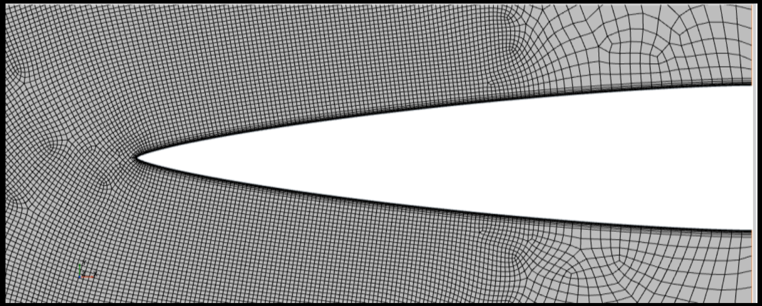
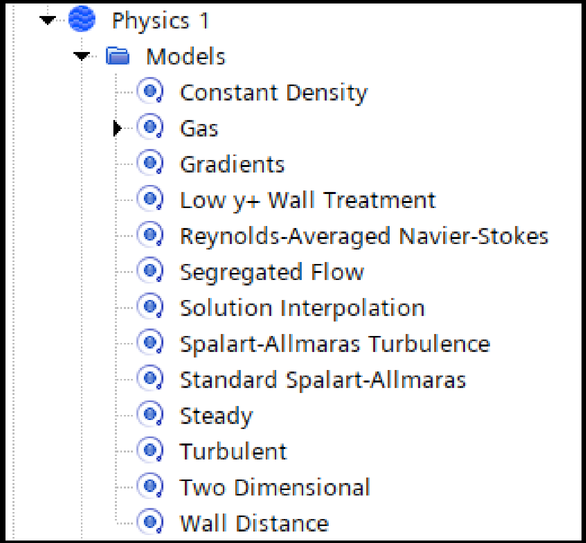


Figure 23: Viscous Drag (f=5)

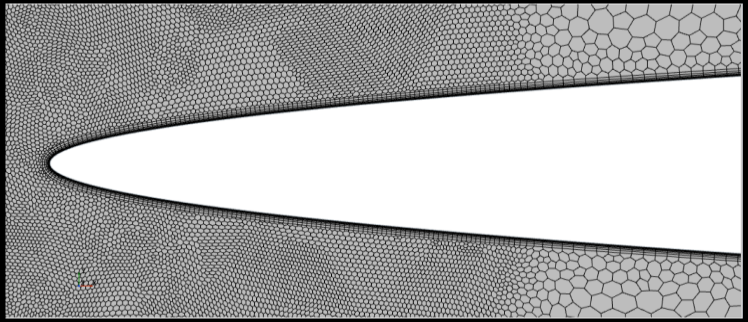
Nose Cone

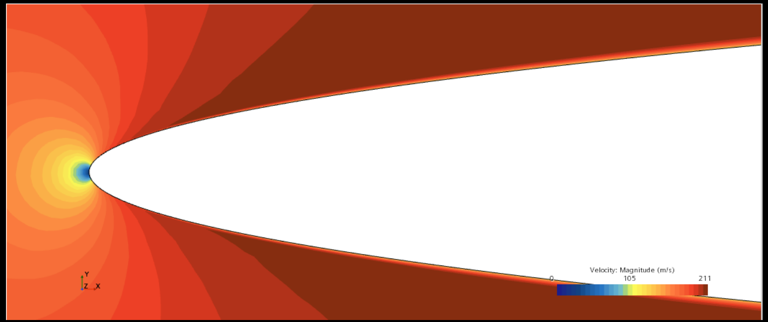
Von-Karman





X^½ Power Series



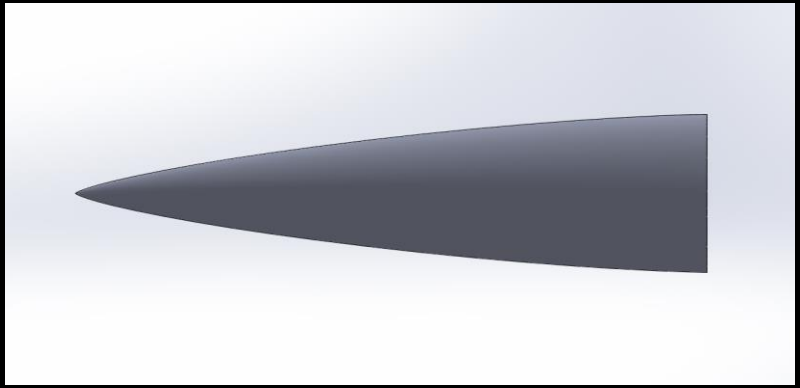


- Simulation done at Mach .6
- Von-Karman minimizes flow separation at the tip
- Velocity increases at a faster rate along the surface of the X^½ Power Series nosecone

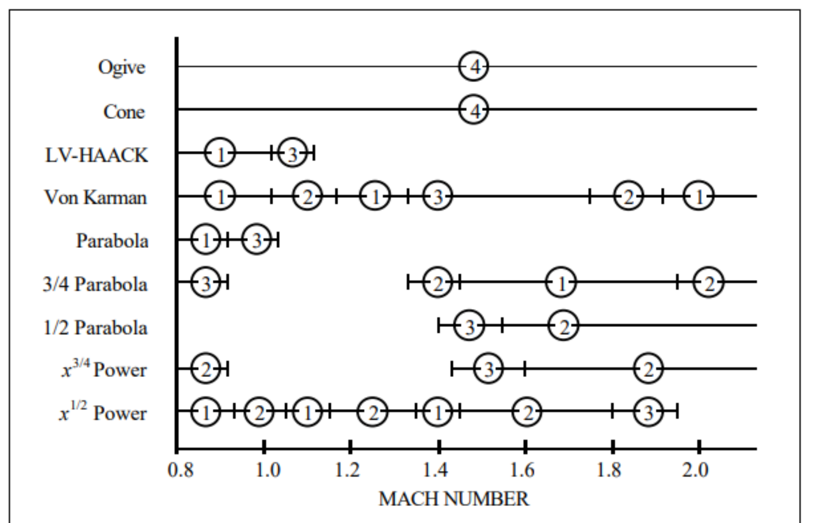
KNIGHTS EXPERIMENTAL ROCKETRY

Nose Cone

Von-Karman

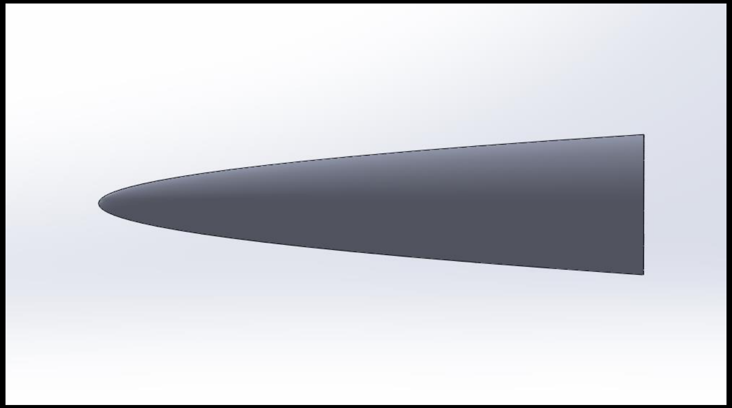


Chinn, S.S.; Missile Configuration Design



Comparison of drag characteristics of various nose shapes in the transonic-to-low Mach regions. Rankings are: superior (1), good (2), fair (3), inferior (4).

X^½ Power series

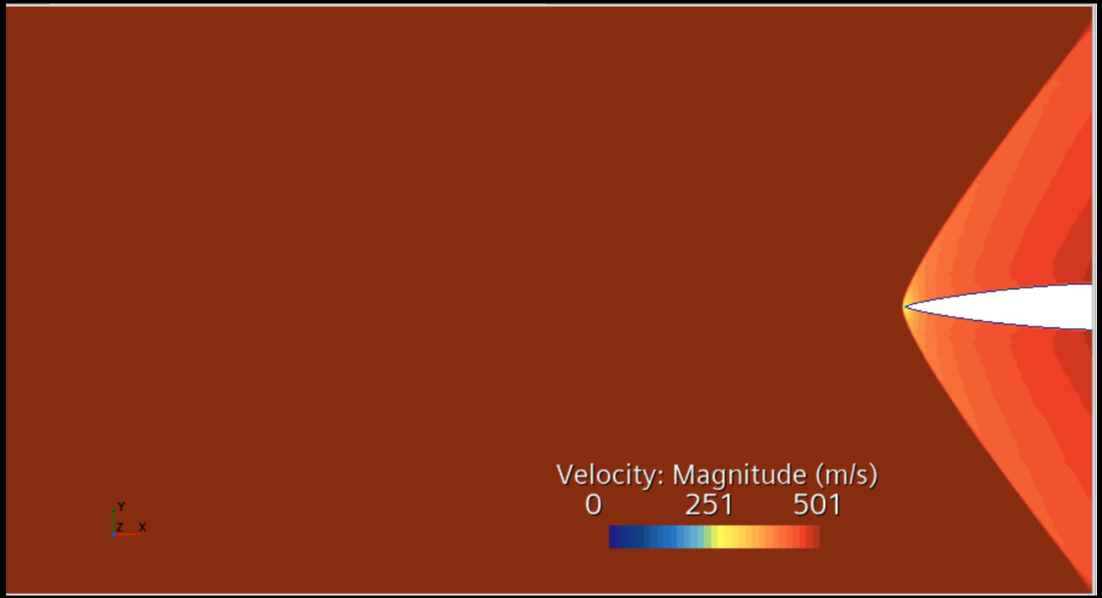


- Current design considerations are 24in L / 6.221in D (approximate slenderness ratio of 4)
- Supersonic- 10 s Transonic- 15 s Subsonic- remainder (Open Rocket)
- Von-Karman performs better in the Transonic region, while the X^½ Power Series performs better in the Supersonic region
- Max drag coefficients at Mach 1.53 (Open Rocket) - Von-Karman(.09) , X^½ Power Series(.08)

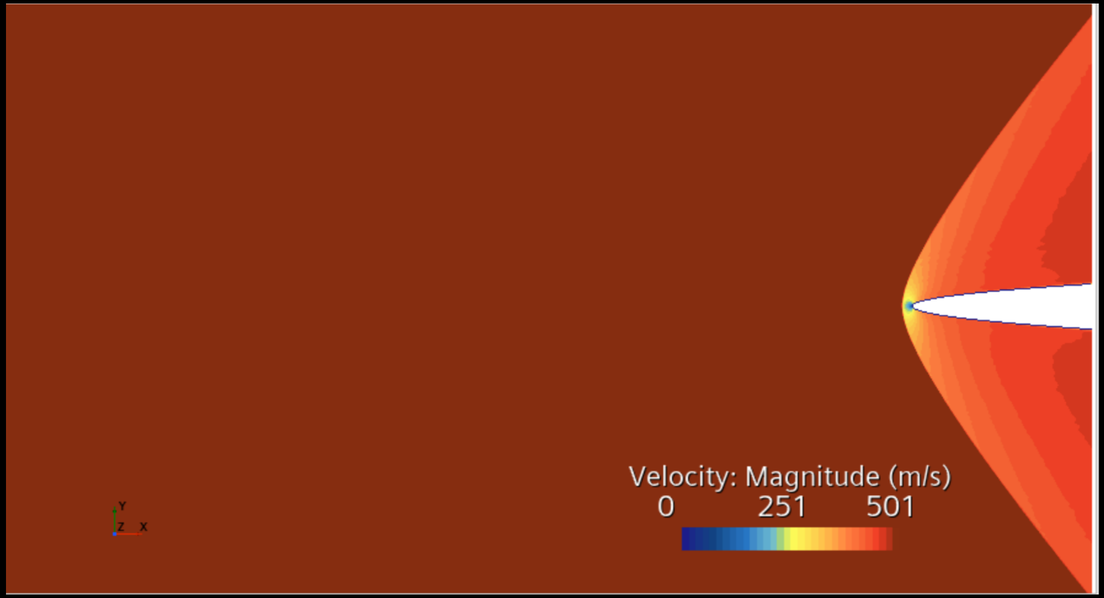
KNIGHTS EXPERIMENTAL ROCKETRY

Nose Cone

Von-Karman



X^½ Power Series

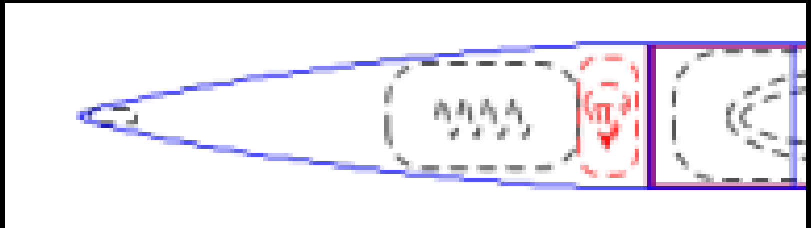


- Oblique shock wave for von-karman occurs at a smaller angle so the shock wave is weaker than the shock produced by x^½ Power Series

KNIGHTS EXPERIMENTAL ROCKETRY

Nose Cone

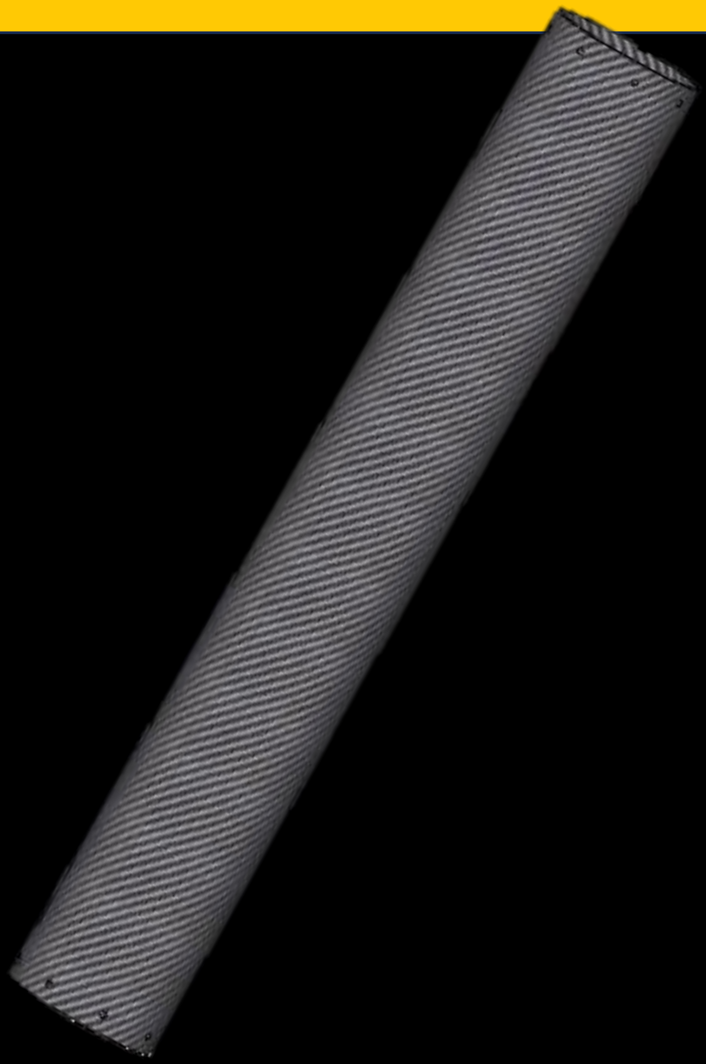
- Currently we are going with the Von-Karman considering the most time spent is in the Transonic region, and it performs fairly well or superior in the other regions
- Component Analysis in Open Rocket has the drag coefficient for X^½ Power Series and Von-Karman NC at .03 all throughout the subsonic region
- Conduct sims in the Transonic and Supersonic regions to get a better idea of how they perform(Open Rocket analysis not highly reliable in supersonic region)
- Conduct 2d/3d sims to research the most effective slenderness ratio
- Utilize Open Rocket to see affects on apogee
- Take into account volume needed for the drogue shock cord and parachute to fit inside, as well as manufacturing issues that could result from lengthening the nosecone



KNIGHTS EXPERIMENTAL ROCKETRY

Body Tubes

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Total	**0.127 (24%)**	**0.144 (28%)**	**0.249 (48%)**	**0.520 (100%)**
Nose Cone	0.066 (13%)	0.000 (0%)	0.020 (4%)	**0.086 (17%)**
nosecone straight	0.000 (0%)	0.000 (0%)	0.004 (1%)	**0.004 (1%)**
switchband	0.000 (0%)	0.000 (0%)	0.002 (0%)	**0.002 (0%)**
upper Tube	0.000 (0%)	0.000 (0%)	0.040 (8%)	**0.040 (8%)**
mid Tube	0.000 (0%)	0.000 (0%)	0.030 (6%)	**0.030 (6%)**
Transition forward nox	0.009 (2%)	0.000 (0%)	0.000 (0%)	**0.010 (2%)**
nox tank	0.000 (0%)	0.000 (0%)	0.076 (15%)	**0.076 (15%)**
Transition aft nox	0.029 (6%)	0.000 (0%)	0.000 (0%)	**0.030 (6%)**
lowest Tube	0.000 (0%)	0.000 (0%)	0.055 (11%)	**0.055 (11%)**
Trapezoidal Fin Set	0.005 (1%)	0.000 (0%)	0.004 (1%)	**0.009 (2%)**
Tailcone	0.000 (0%)	0.144 (28%)	0.007 (1%)	**0.151 (29%)**



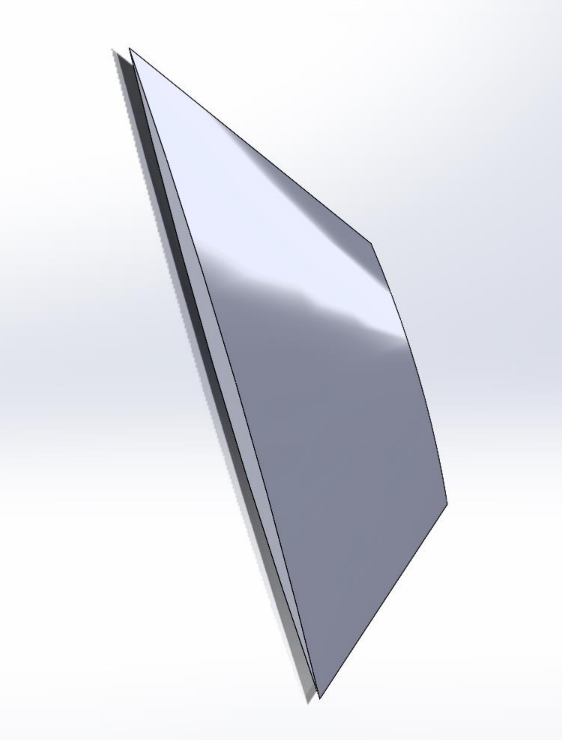
The Overall Coefficient of Drag for the carbon fiber body tubes is 0.257 (summation of coefficients of components).

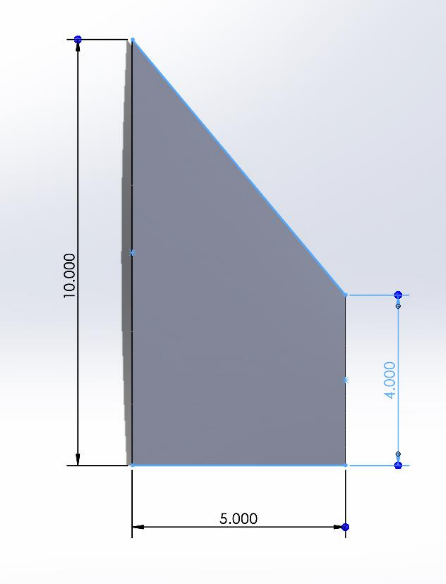
Fins

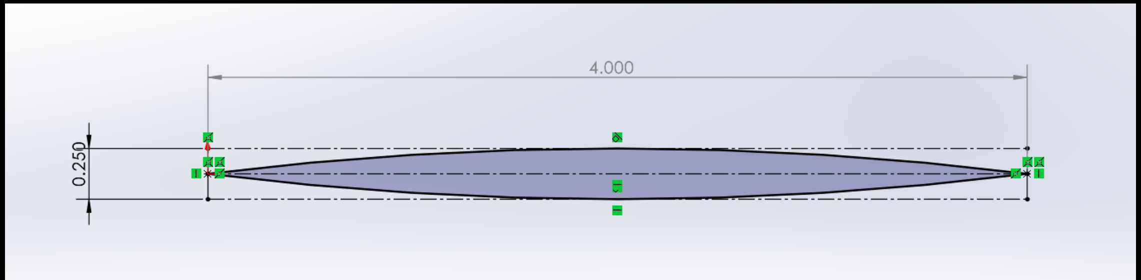
Current planform is a clipped delta with an airfoiled cross section.

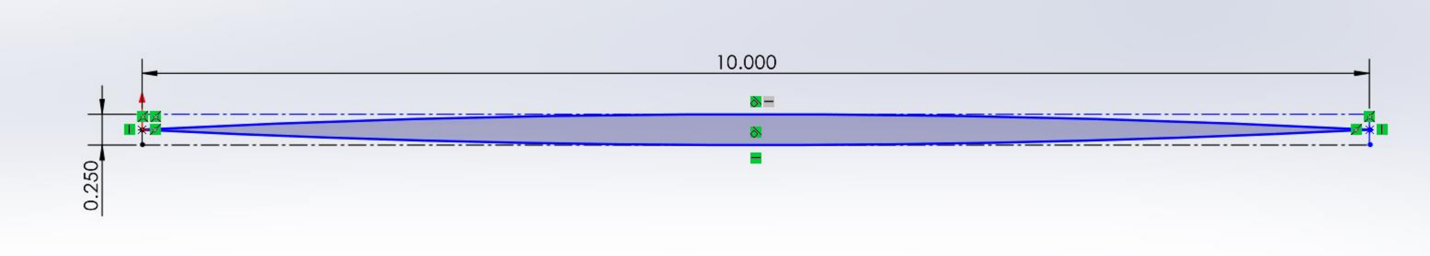
This has been chosen to help reduce drag caused by supersonic shocks.

Preliminary simulations show a drag coefficient of around .0075, which is lower than the OpenRocket prediction of .009.





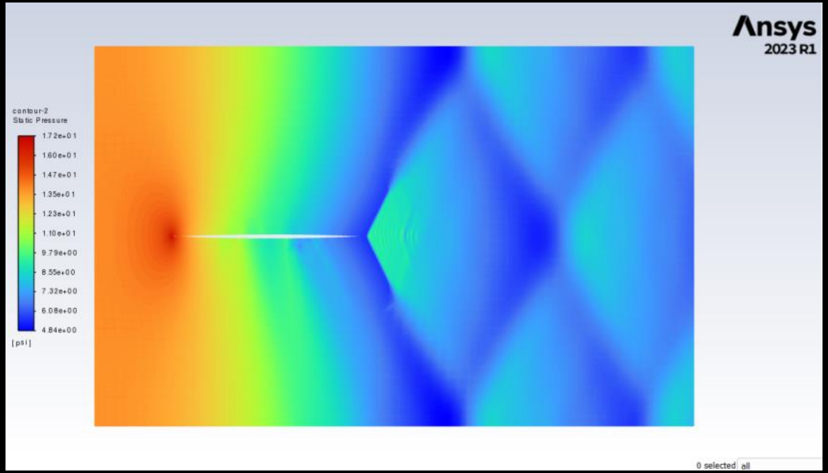




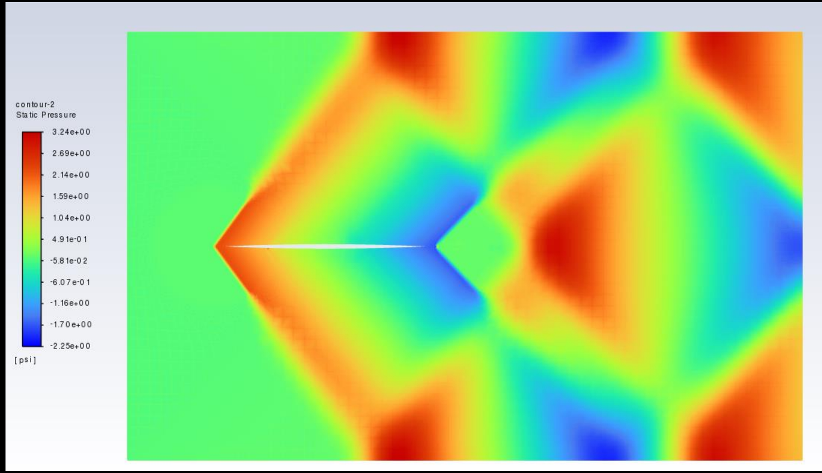
KNIGHTS EXPERIMENTAL ROCKETRY
KXR

Fins

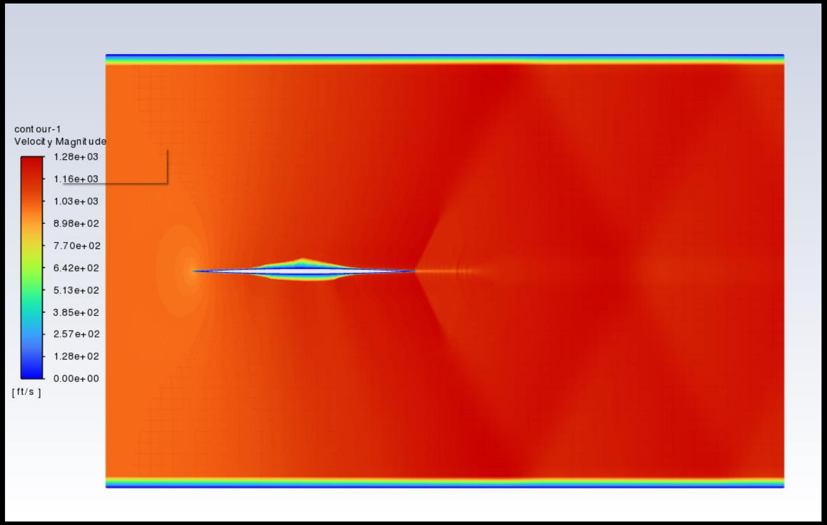
Static Pressure at 1000 ft/s



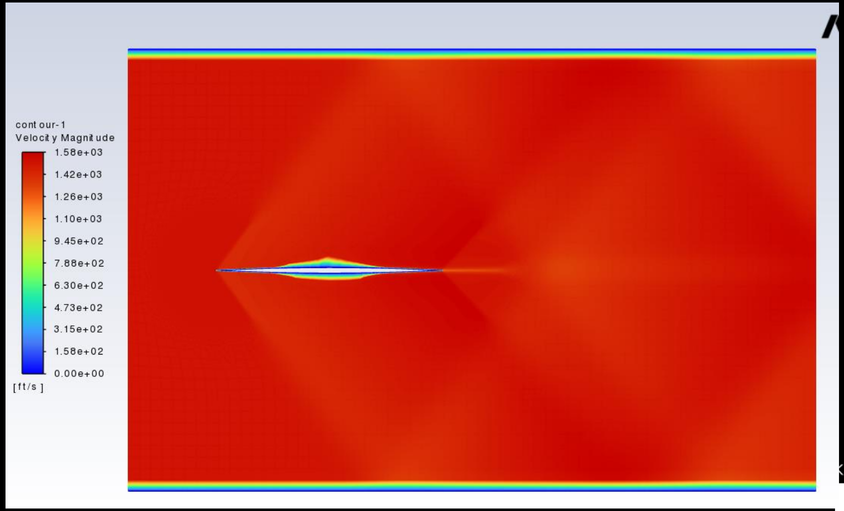
Static Pressure at 1500 ft/s



Velocity at 1000 ft/s



Velocity at 1500 ft/s

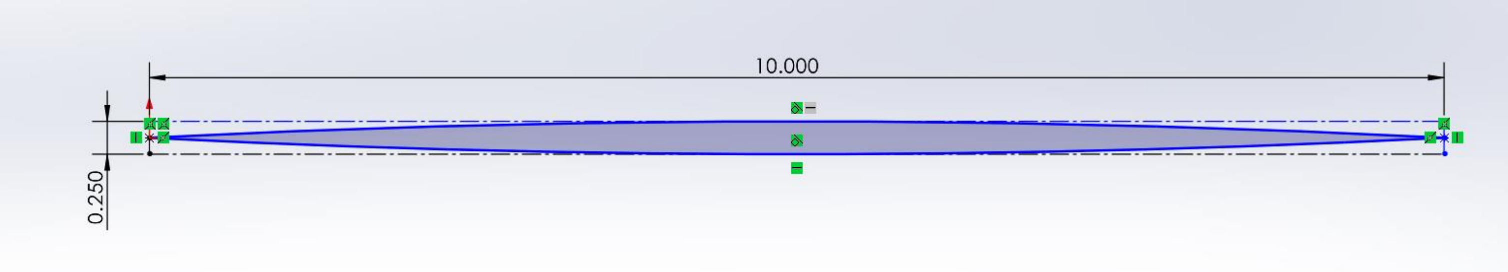


KNIGHTS EXPERIMENTAL ROCKETRY
KXR

Fins

Fin flutter is a major risk of failure for fins, which could lead to their complete failure.

By choosing airfoiled fins, calculating fin flutter velocity became more difficult, as the thickness is not constant. To find a thickness, the area of the base of the fin was found. The area was then divided by the root chord. In essence, this method finds the flutter velocity of a rectangular fin with similar dimensions.



Thickness = 1.667 / 10 = .1667 in

Ansys simulations could provide a more accurate method of calculation flutter velocity.

Fin Flutter Velocity Calculations

$a := 1125.33\ \frac{ft}{s}$ Speed of Sound

$AR := .5714$ Aspect Ratio

$P := 11.77\ psi$ Air Pressure

$\lambda := .4$ Taper Ratio

$t := 0.1667\ in$ Thickness

$G := 7498450\ psi$ Shear Modulus

$c := 10\ in$ Root Chord

$$V_f := a \cdot \sqrt{\frac{G}{\left(\frac{1.337 \cdot (AR)^3 \cdot P \cdot (\lambda + 1)}{2 \cdot (AR + 2) \cdot \left(\frac{t}{c}\right)^3}\right)}}$$

$$V_f = \left(7.419 \cdot 10^3\right) \frac{ft}{s}$$

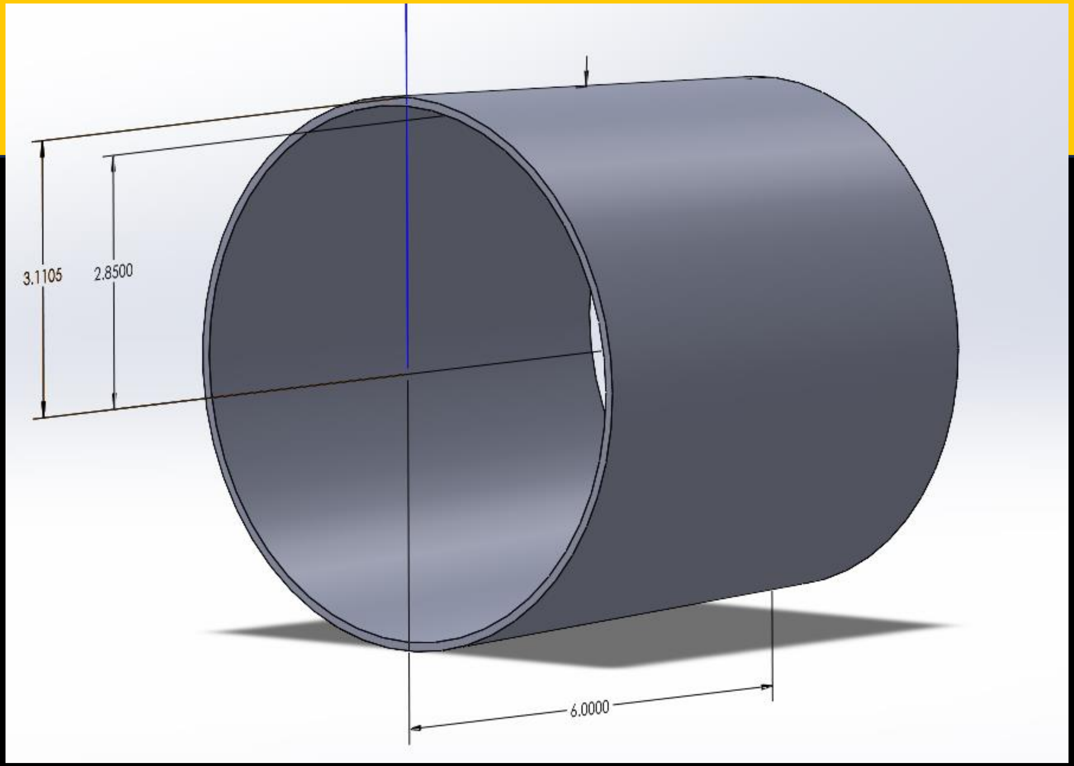
Tail Cone

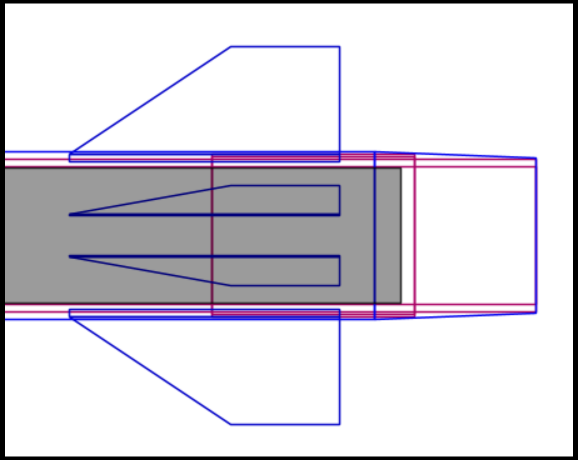
Current design is a Conical Straight Tail Cone.

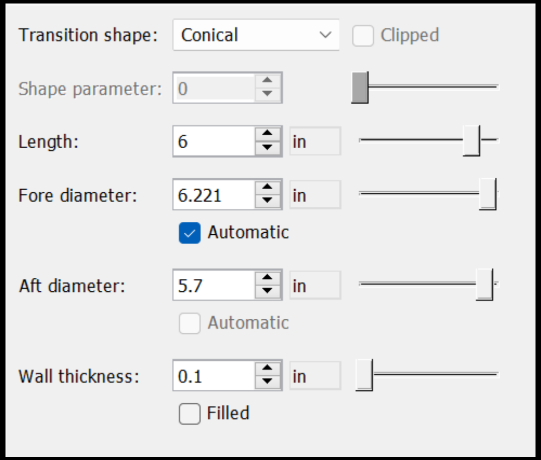
Purpose is to reduce the wake region behind vehicle during flight, reducing drag when compared to exclusion of a Tail Cone.

Conical Tail Cone chosen due to ease of manufacture and combustion chamber size constraints, which make the performance differences between different designs minimal.

Coefficient of Drag is currently 0.155 for this component, according to OpenRocket Component Analysis.







*units are inches

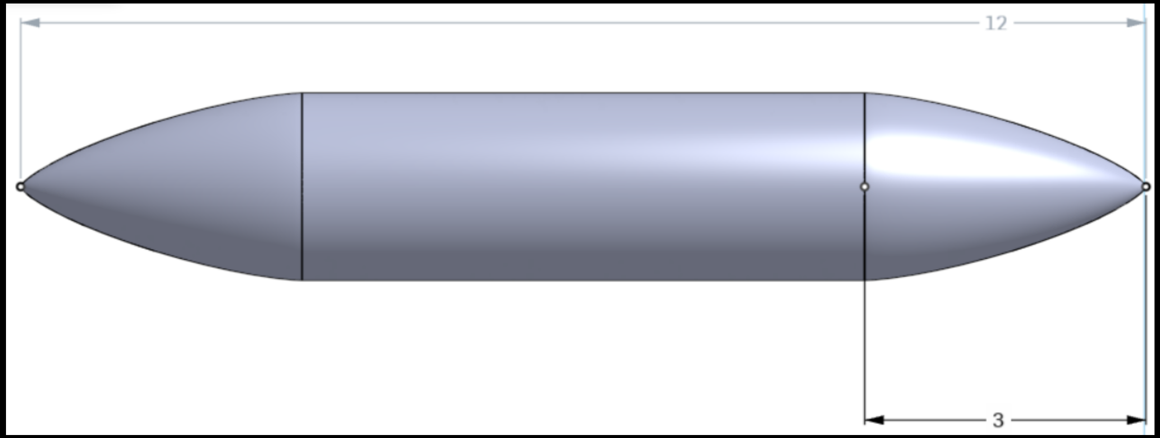
KNIGHTS EXPERIMENTAL ROCKETRY

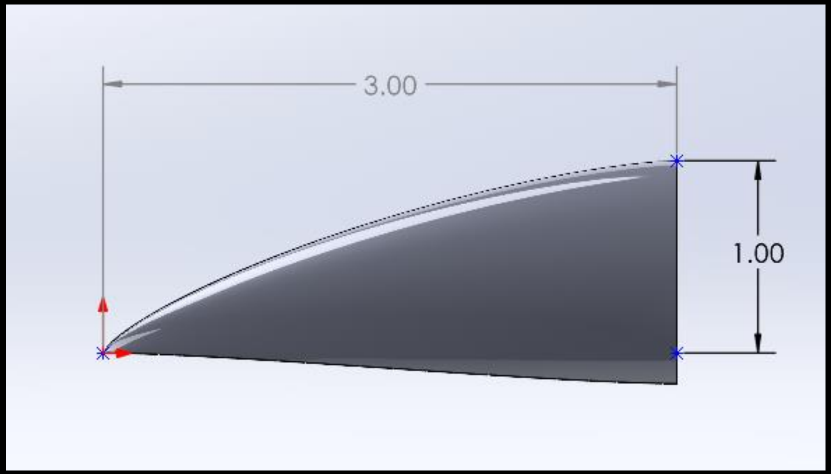
Shroud

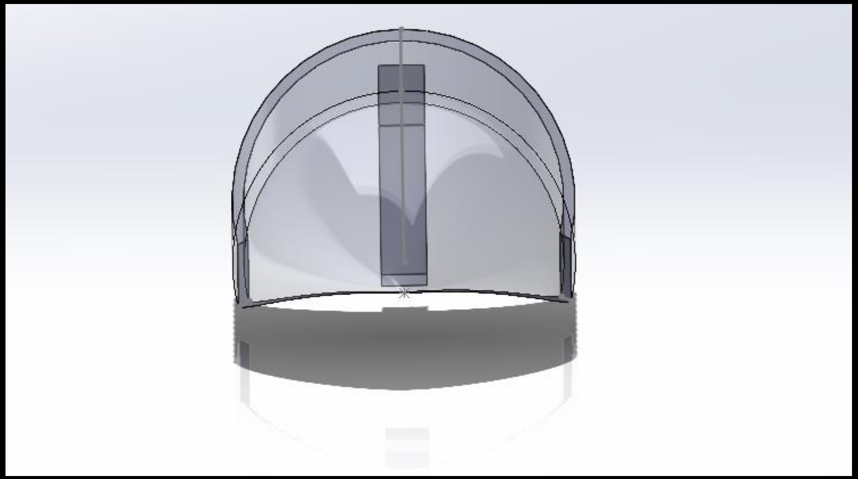
Purpose: protects external antennas from ground impact

The current design uses a Von Karman geometry for its nose and tail sections, with a 6-inch cylindrical section for the antenna

Plastic or fiberglass will be used, allowing for an RF transparent enclosure







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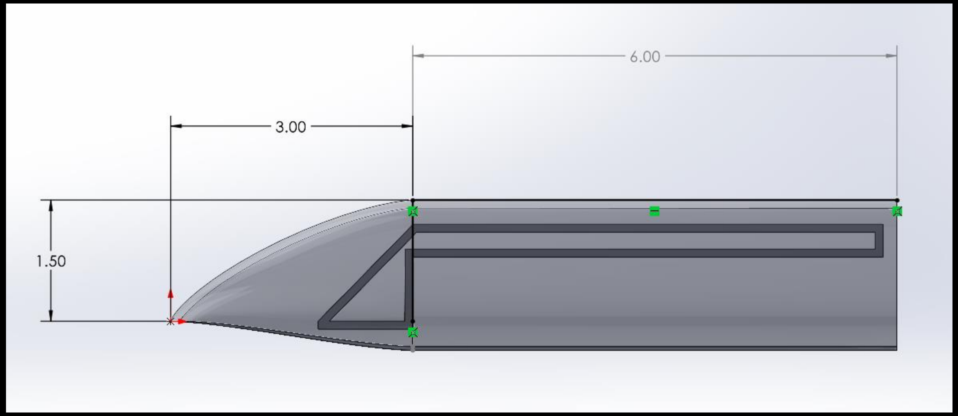
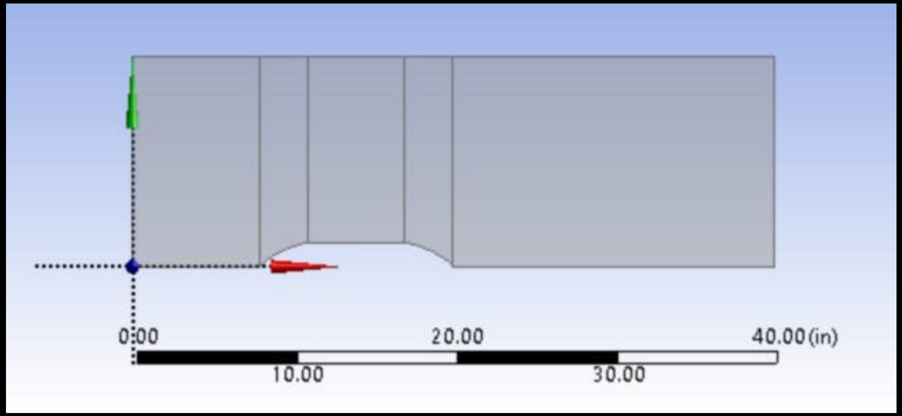
KXR

Shroud

What's next:

- A hook for attachment to the body of the rocket will be included in later iterations
- The design will be further optimized for varying sizes of the antennas
- Different cone designs will be tested and compared
- Testing will be done on the current design





KNIGHTS EXPERIMENTAL ROCKETRY
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Structures Requirements

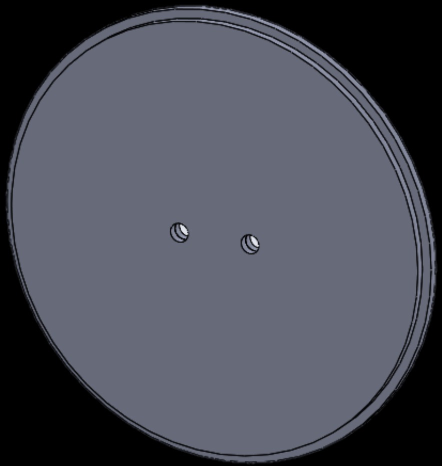
Requirement	Verification Method
Launch vehicles shall be adequately vented to prevent internal pressures developing during flight and causing either damage to the airframe or any other unplanned configuration changes.	Inspection
Joints shall be designed such that the coupling tube extends no less than 1 body tube diameter (1 caliber) into the airframe section from which the coupler will separate during flight.	Inspection
Joints shall be designed such that the coupler tube extends into the nosecone/tailcone/transition to the lesser of 1 body tube diameter (1 caliber) or the maximum depth possible by the design of the nosecone/tailcone/transition.	Inspection
Joints shall be designed such that the coupling tube extends into the mating component to the lesser of 1 body tube diameter (1 caliber) or the maximum depth possible by the design of the mating component.	Inspection
Joints shall be affixed by mechanical fasteners and/or permanent adhesive.	Inspection
Regardless of implementation (e.g., RADAX or other join types) airframe joints shall prevent bending, see https://www.osti.gov/biblio/5007820.	Analysis

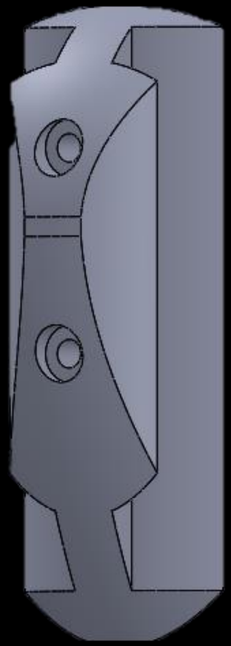
KNIGHTS EXPERIMENTAL ROCKETRY

KXR

Structures Sub-System

The Structures Team is responsible for the robust and nominal design of an airframe that can withstand all applied stresses, pressures of supersonic flight, and integrate all components of the rocket from other systems.





KNIGHTS EXPERIMENTAL ROCKETRY

Structures Requirements

All load bearing eye bolts shall be of the closed-eye, forged type.	Inspection
The load bearing eye bolts, U-bolts, links, and any bolt and eye-nut assembly used in place of an eyebolt **SHALL** be steel.	Inspection
Load bearing U-bolts shall have mounting plates to ensure proper force distribution	inspection
The rail guide shall integrate with the LTI Launch Rail	Inspection
Rail buttons shall be attached using at least one metallic fastener through the reinforced airframe.	Inspection
Rail buttons shall implement "hard points" for sliding mechanical attachment of the rocket to the SA Cup supplied 1515 launch rail, serving to guide the rocket during the initial phase of boost until the rocket achieves sufficient velocity for the fins to provide aerodynamic stabilization	Inspection
The aft most launch rail button shall support the launch vehicle's fully loaded launch weight while the rocket is in a vertical orientation.	Inspection

KNIGHTS EXPERIMENTAL ROCKETRY

Structures Requirements

The IREC Team **WILL** either lift the vehicle by the rail guides and/or demonstrate that the bottom guide can hold the vehicle’s weight when vertical before permitting them to proceed with launch preparations.	Testing
The body tubes shall withstand bolt tear out with a safety factor of 2.	Analysis
The fins shall not be sheared off the rocket during flight	Analysis
The fins shall be securely attached to the fuselage.	Inspection
All bolts torqued down to proper spec.	Inspection

Structures TPMs

Measure	TPM Value	Units	Verification Method
Max load on airframe	[]	lbf	Ansys Fluent
Max size of internal volume (upper/middle tube)	1710	In^3	SolidWorks, Open Rocket
Max size of internal volume (nosecone)	340	In^3	SolidWorks, Open Rocket
Max allowable snatch force	1406	lbf	Handcalcs
Max shear force per bolt	608	lbf	calculator

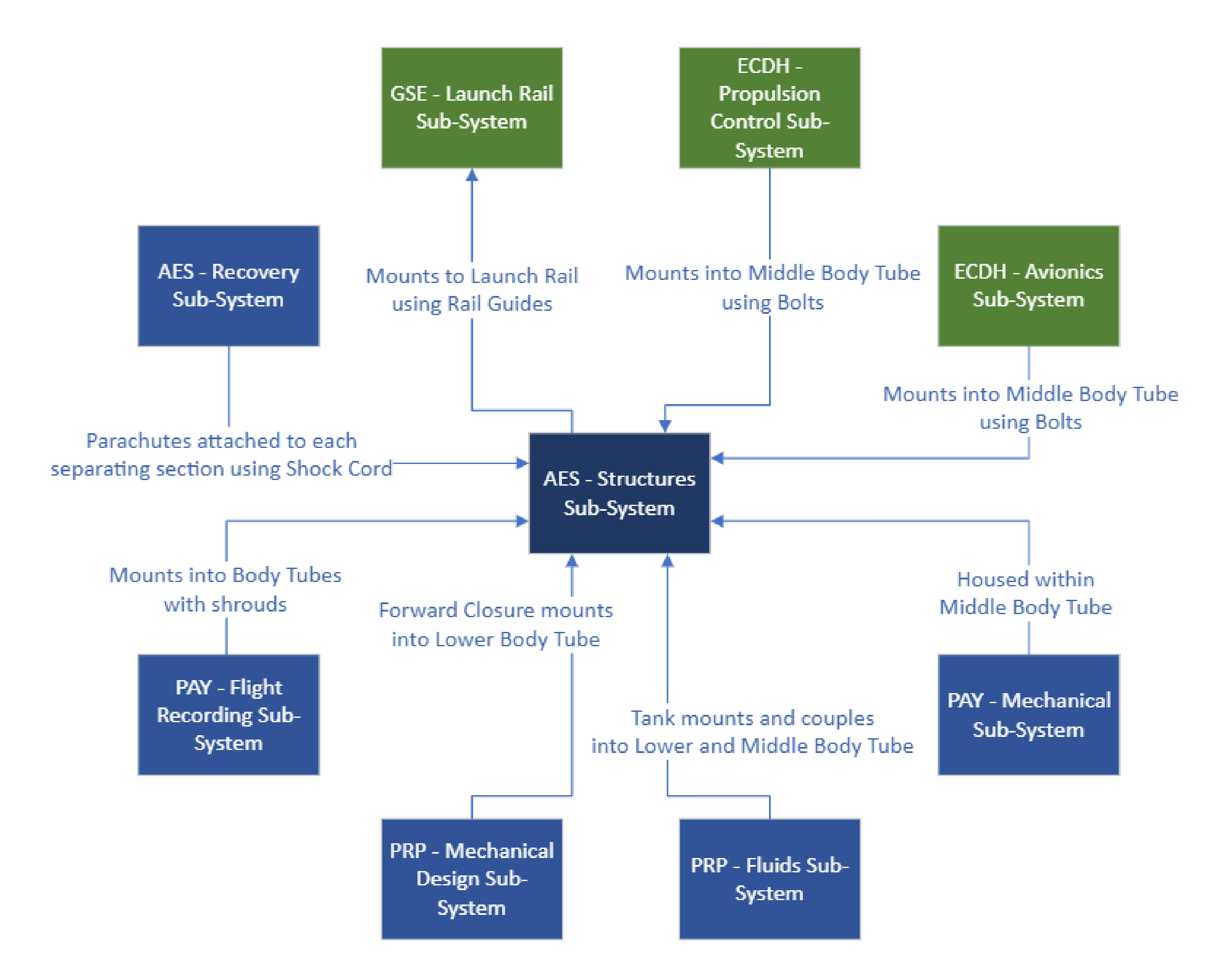
KNIGHTS EXPERIMENTAL ROCKETRY

Structures TPMs

Total body stress	3222	psi	Calculator
Max bending moment	7564	Lb-in	Calculator
Max strain	[]	in/in	Ansys Mechanical/ Composite Prepost
Max size of internal volume (combustion chamber)	210	In^3	SolidWorks, Open Rocket
Component fit tolerancing	[]	In	Component testing
Max allowable bearing stress	29000	psi	Calculator
Max body shear force	245	lbf	Calculator

KNIGHTS EXPERIMENTAL ROCKETRY

Structures Interface Diagram



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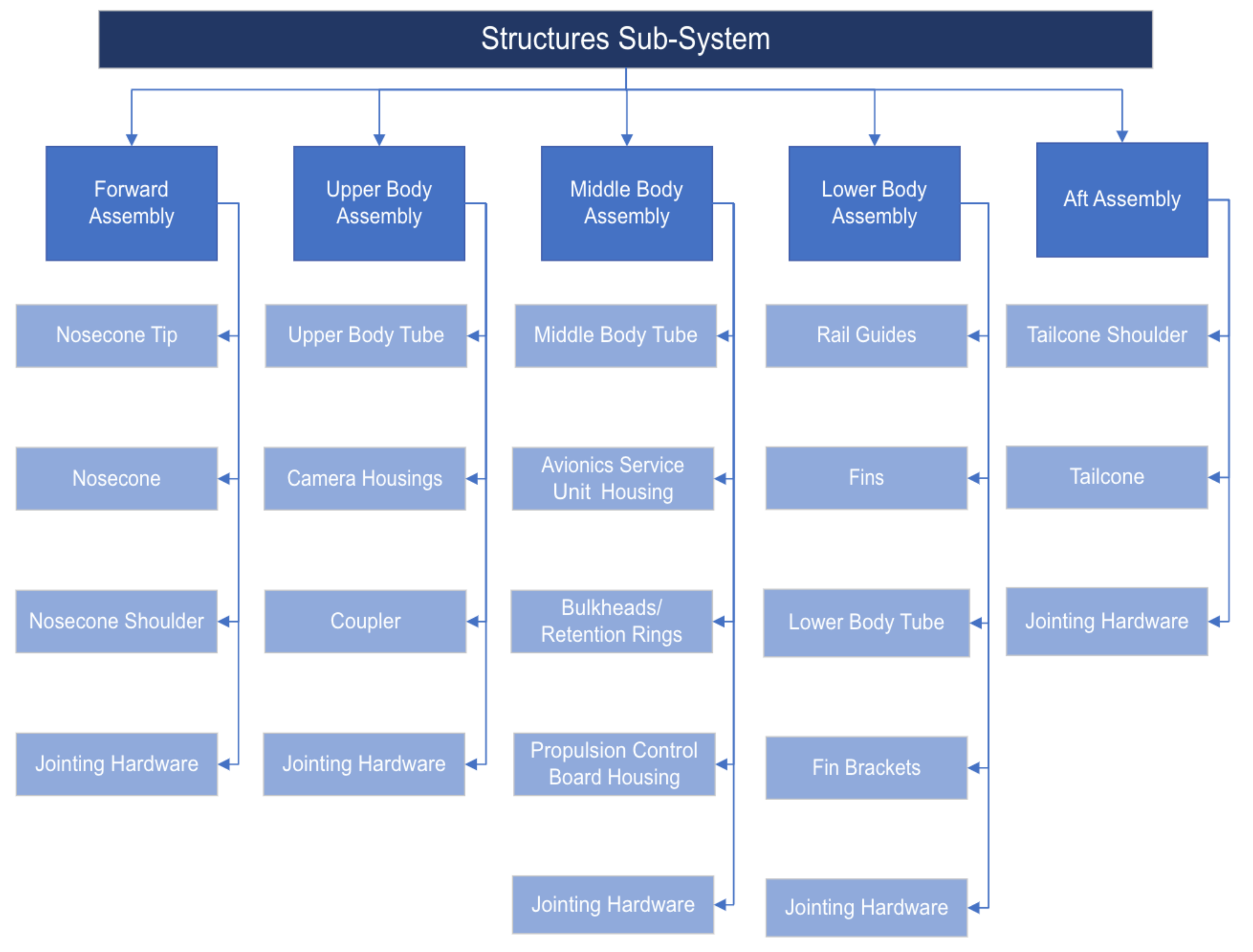
Structures Component Breakdown



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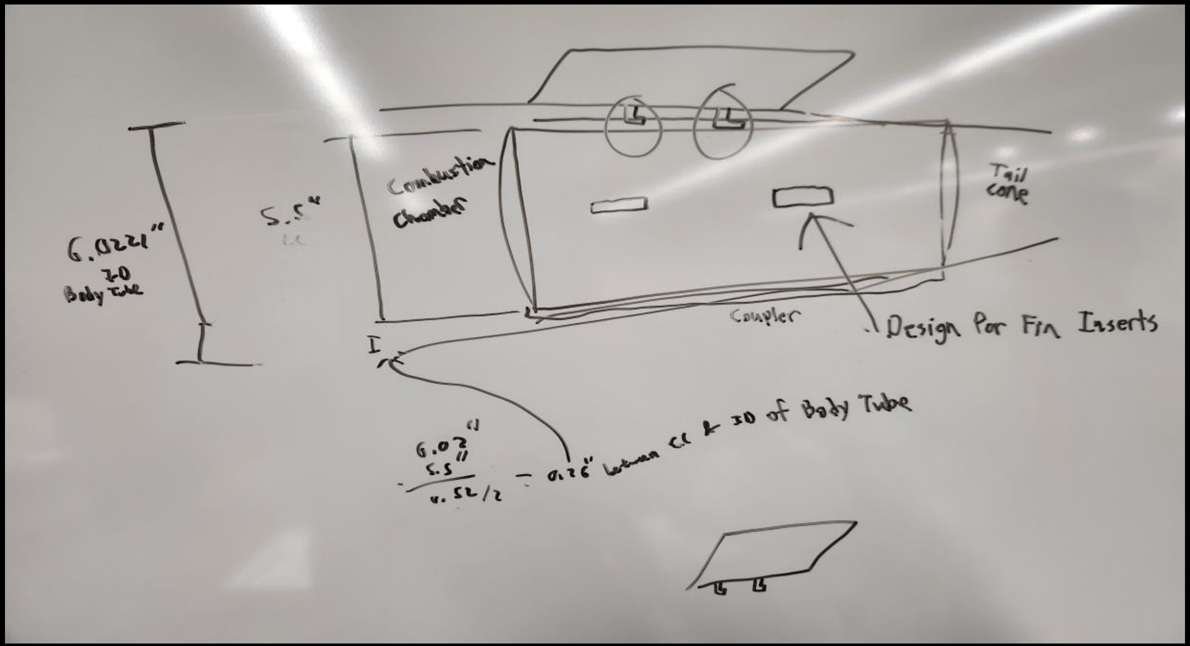
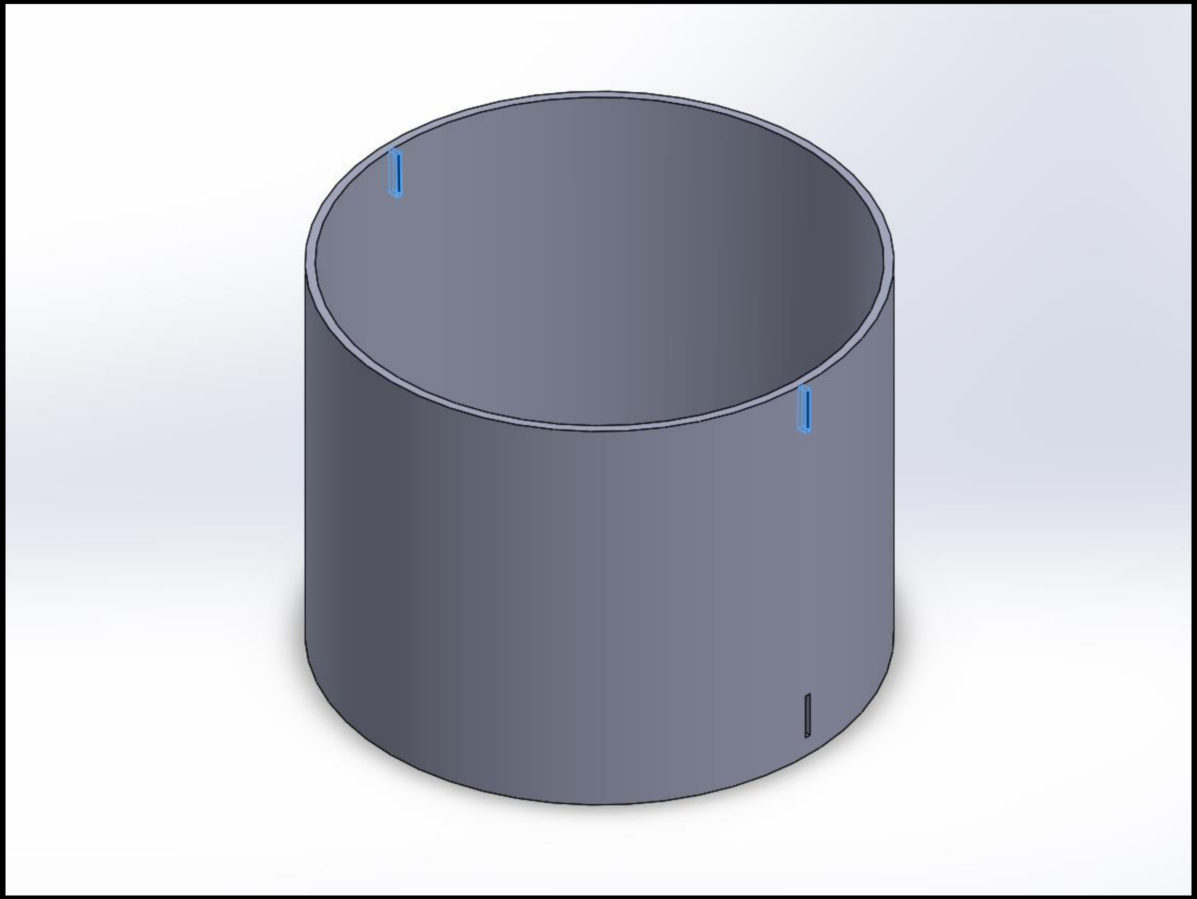
KXR

Tail Cone Shoulder Design

- Creating the Coupler to Fit Between the Body Tube ID (Inner Diameter) and Combustion Chamber, Holes will be Created Allowing Mounting Positions for Fin Inserts (Hole Shape TBD)
- Tail cone shoulder is sandwiched between combustion chamber and fins
- Coupler would have slits to align fin attachment points

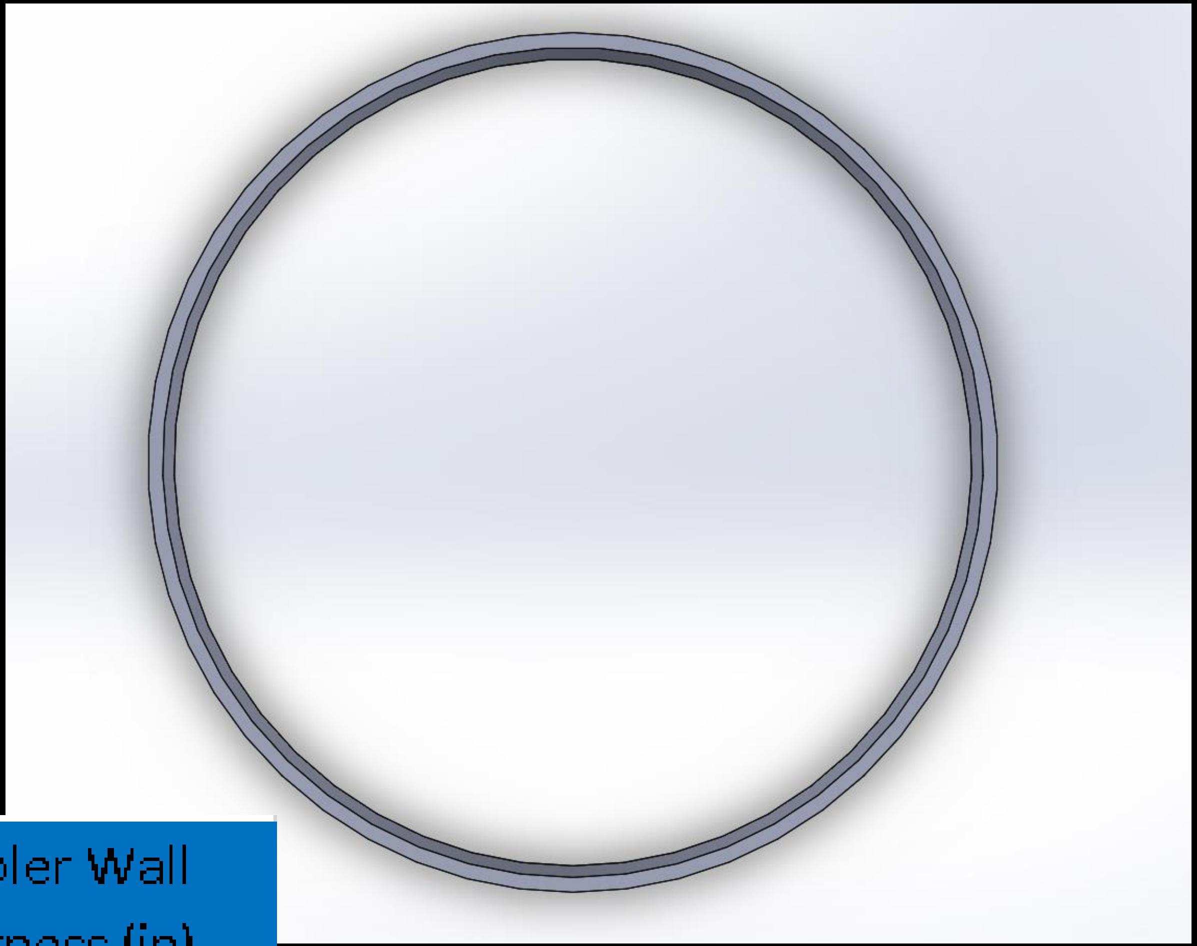




Coupler's Design

- Outer Diameter: 6.021"
- Coupler Thickness Approx 0.111"
- DTEG Coupler Requirement: 1 Cal
- Rocket Diameter is Approx 6 Inches, Requiring Recovery Coupler Minimum Length to be 6 inches plus switch band length
- Internal couplers length
- Composite Envision Cost :

  2x2' $115.90/ lyd

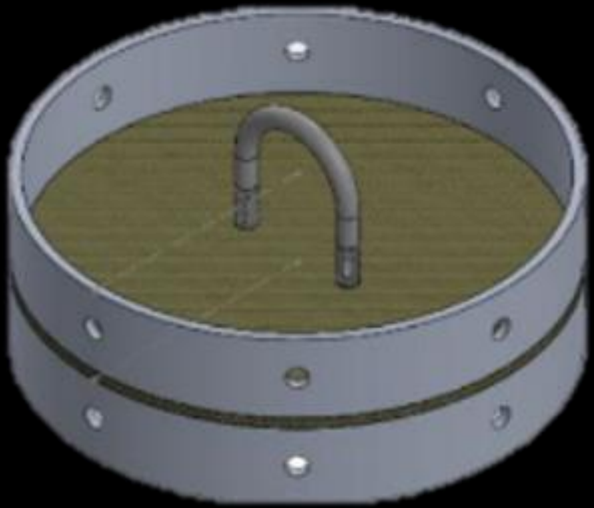


Coupler Wall Thickness (in)
0.111093263

KNIGHTS EXPERIMENTAL ROCKETRY

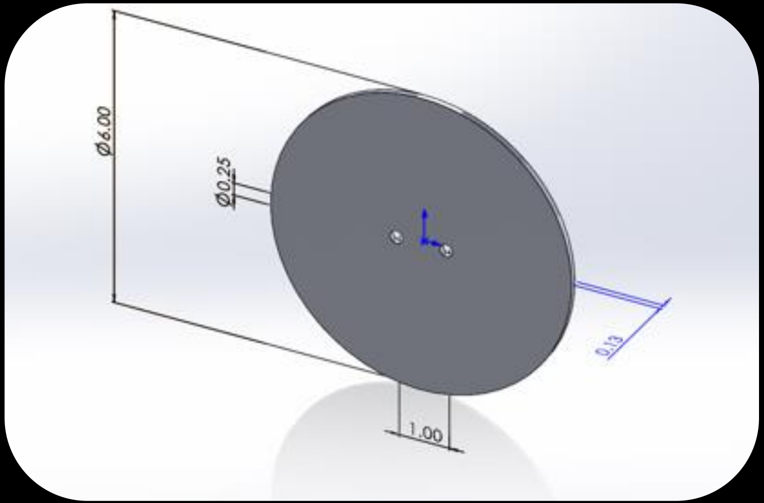
Bulkheads & Retaining Rings

Component	Materials
Retaining Rings	Aluminum Rings
Bulkhead	Pre-Preg Carbon Fiber



Schedule

- ANSYS simulations
- Optimize current design for load cases



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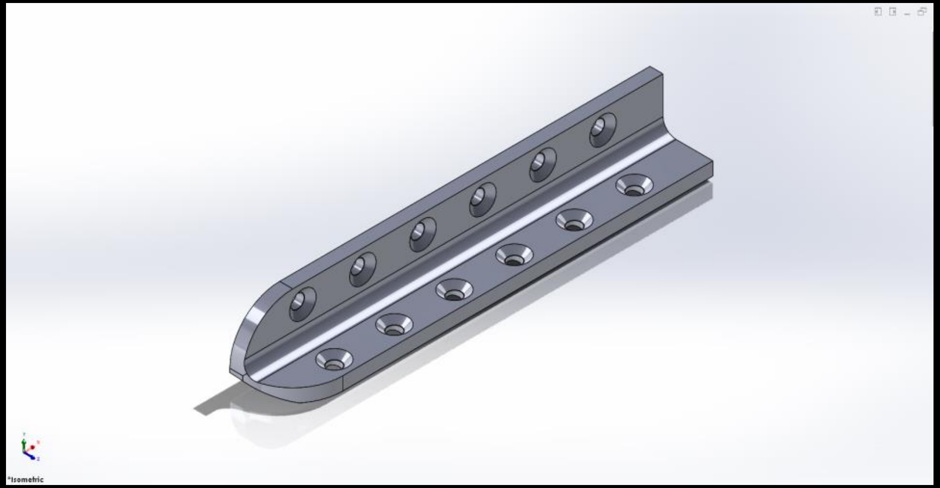
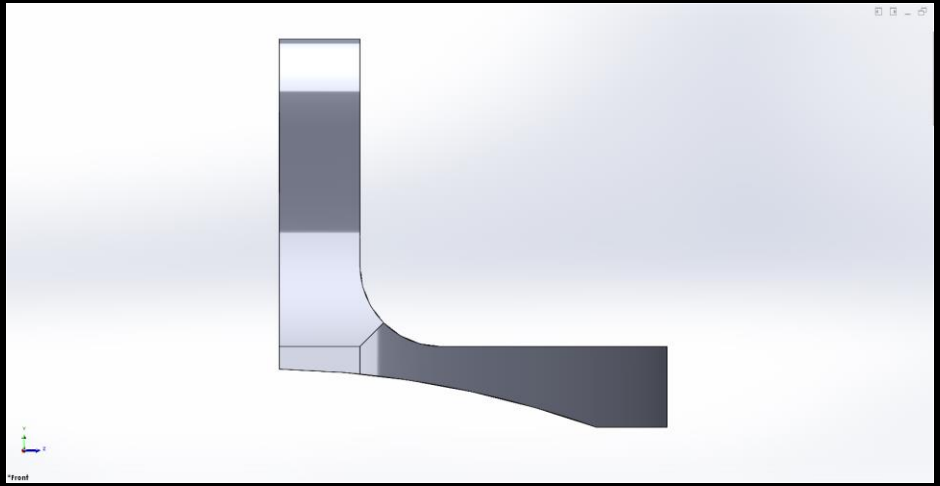
Fin Reinforcement

- Fin brackets attach to the fins and body tube.
- 6061 Aluminum fin brackets
- 12 ¼'' screw holes to attach to the airframe and fins, 6 in each side
- 10 in. long Fin tabs, 8 in. x 1.2 in. Brackets with ¼ in thickness.
- Countersink holes and fillets for dynamic efficiency and stability



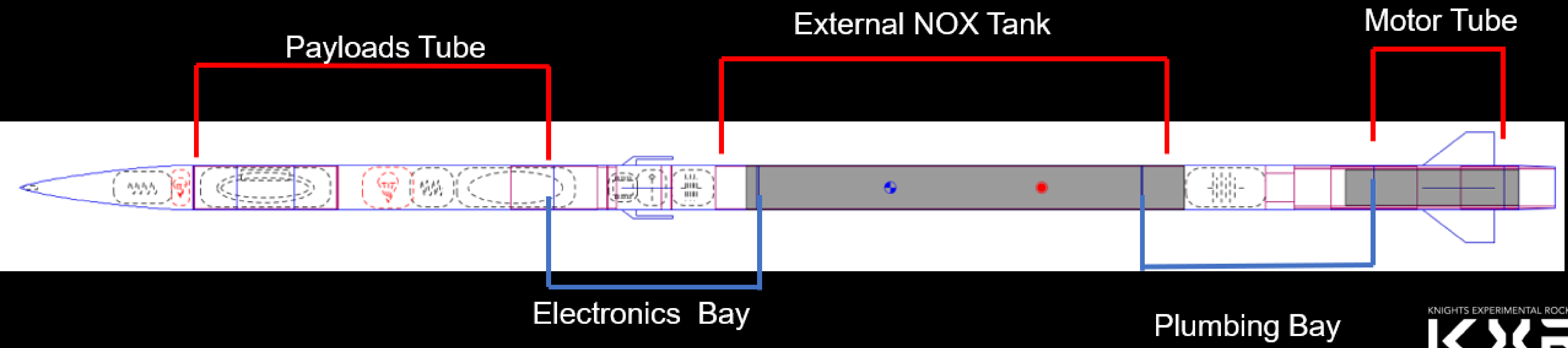
Schedule

- ANSYS Simulation to verify and optimize structural design and efficiency to ensure bracket capable to withstand forces apply to the fin.



Body Tubes

Name of Body Tube	Unit	Payload Tube	Electronics Bay	Plumbing Bay	Motor Tube
Length	in	36	24	32	18
Weight	lb	2.2	1.5	2	1
Thickness	in	0.1	0.1	0.1	0.1



Composite Layup

Material

- 3k Bi-Axial 2x2 Twill Pre-Impregnated Carbon Fiber

Possible Layups

- “Roll” Wrap
- 0/90

Description	Value	Units
Ammount of Fabric to Purchase	≈40	Yards
Layers of Carbon Fiber	6 to 8	Plys
Tube Thickness	0.1	Inches

Future Considerations

- UTM Testing
- Run ANSYS Sims for Layup

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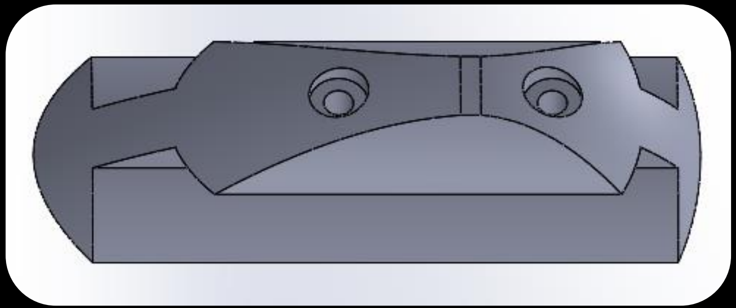
Rail Guides

- SRAD Aluminum Rail Guides
- Optimized for better air flow



Material:

- Scrap Aluminum from machine shop
- Machined through UCF machine Shop

Next Steps:

- Iterative design to optimize air flow over guide
- More Subscale Models to test on KXR 1515
- Create Internal Component

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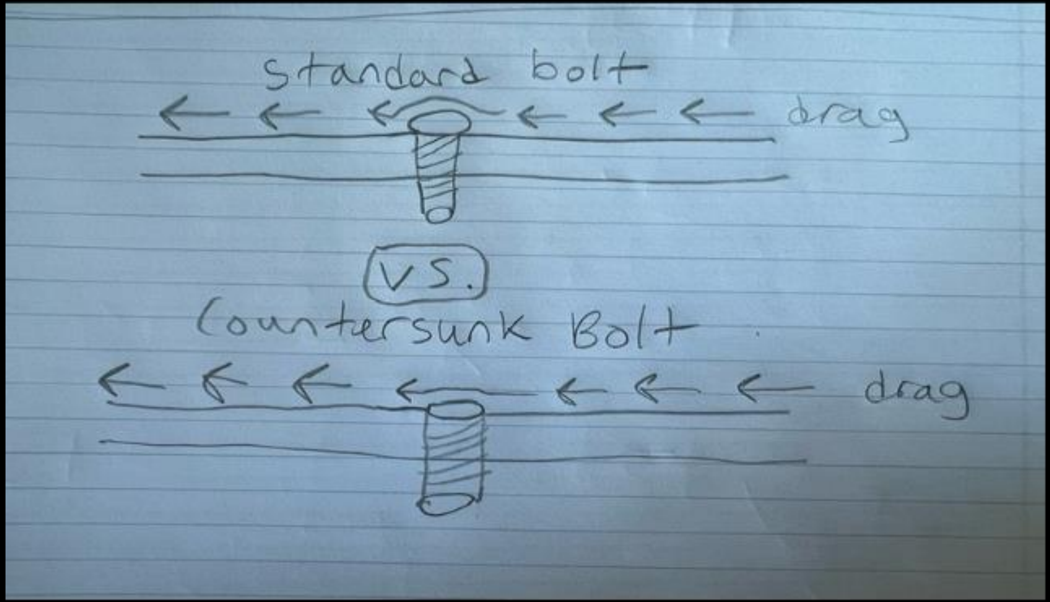
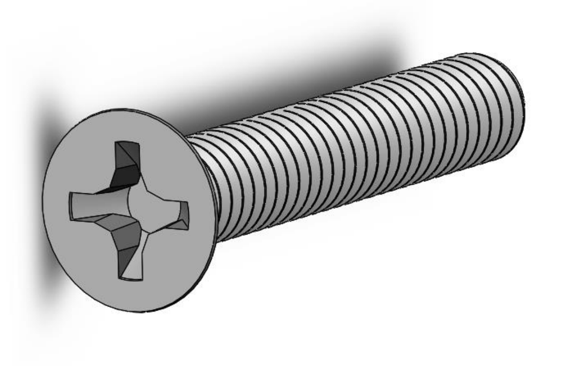
KXR

Airframe Jointing Hardware

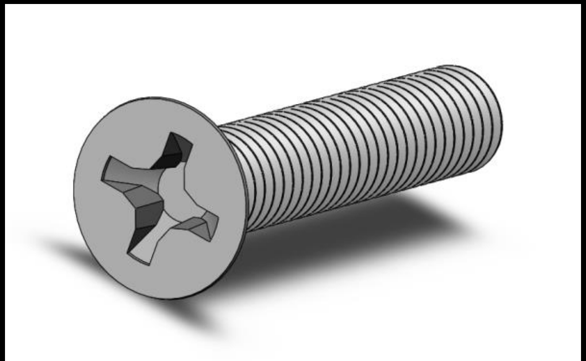


Final bolt length subject to change*

We are choosing ¼-20s, ballpark cost = $40-50 including drill bit

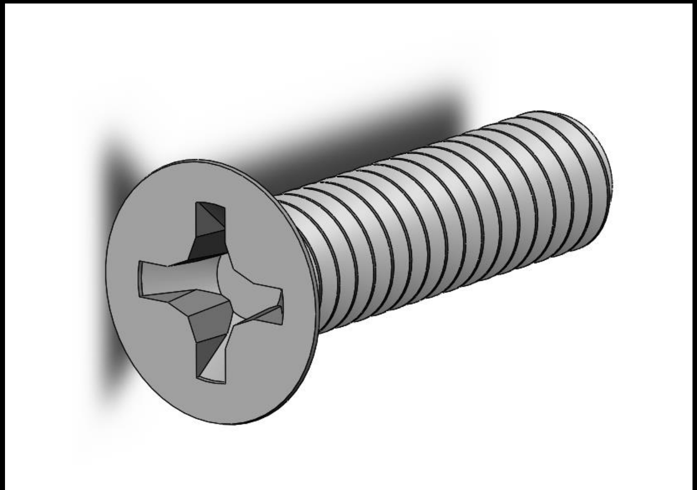


#8-32

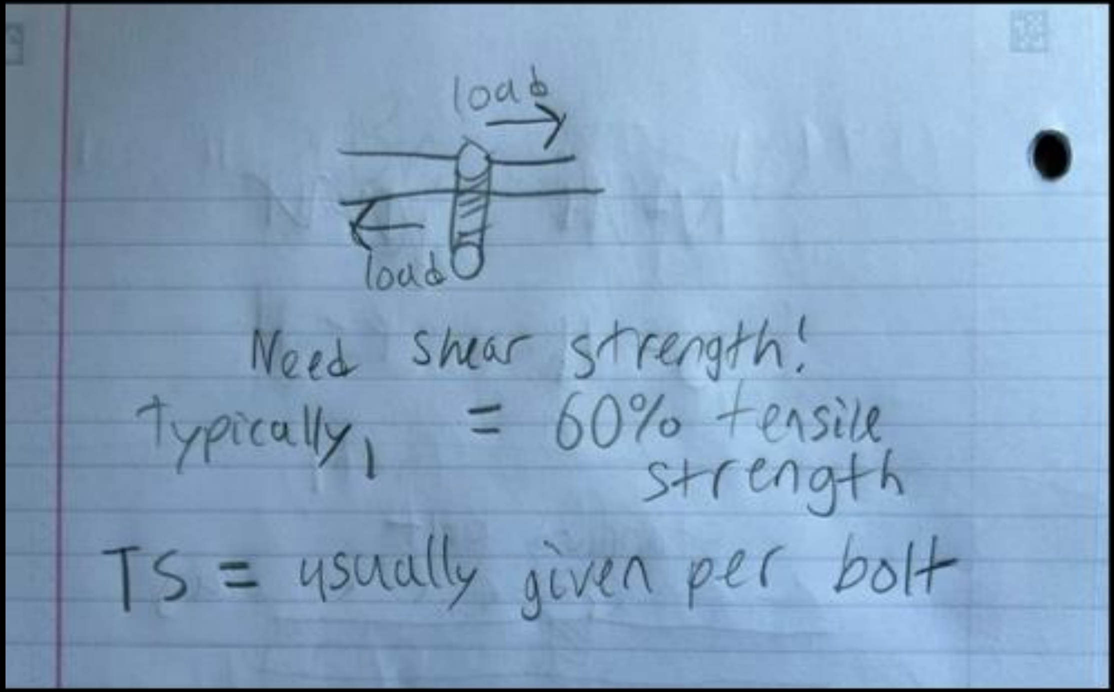


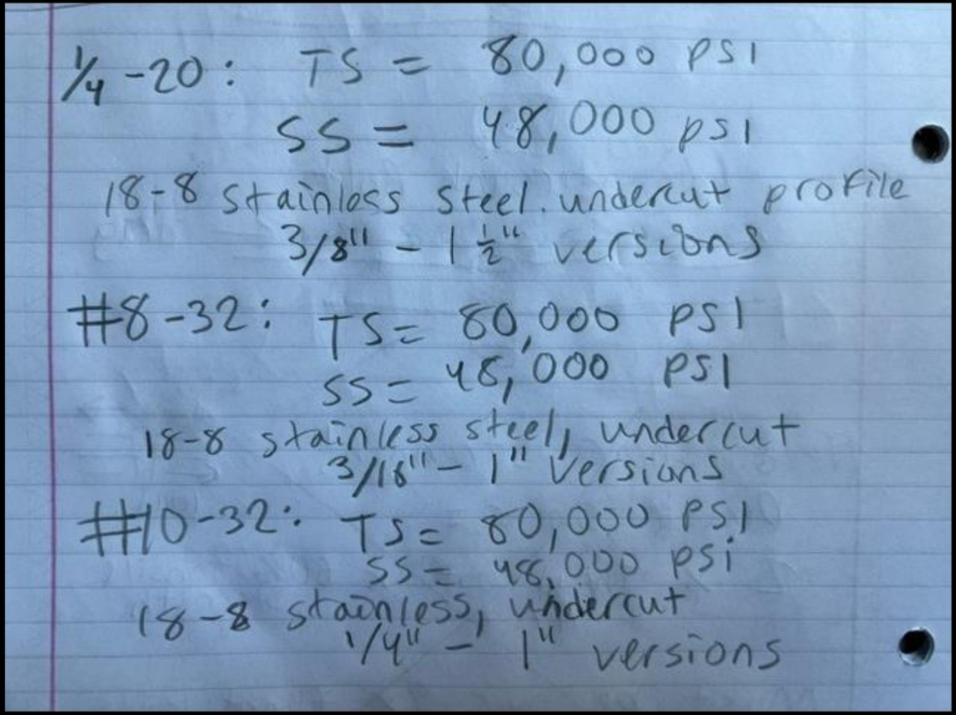
#10-32

¼-20



Jointing Hardware cont.





Essentially, the bolts will be fine. What we really need to worry about is bolt tear out from stress on the airframe.

Jointing Hardware cont.

Bolt Tearout:

Occurs when the force of the bolt pushing against its hole causes the material to fail.

Calculated by:

$$\sigma_{bearing} = \frac{F_{bolt}}{d_{bolt,major} \times t}$$

$$\frac{\text{Force acting on each bolt}}{\text{major bolt diameter} \times \text{material thickness}}$$

number of bolts	bolt major diameter (in)
8	0.25

Ideal numbers from ¼'-20s

Max Shear Force per Bolt (lbf)	Bearing Stress (psi)
607.9366682	24317.46673

SAE			
	Dmajor	Ultimate Strength (lbf)	
Screw size/tpi	(inch)	Shear [1]	Tensile [2]
#2-56	0.086	354	540
#4-40	0.112	577	880
#5-40	0.125	753	1150
#6-32	0.138	865	1320
#8-32	0.164	1330	2030
#8-36	0.164	1402	2140
#10-24	0.190	1664	2540
#10-32	0.190	1900	2900
1/4-20	0.250	3020	4610
1/4-28	0.250	3456	5275

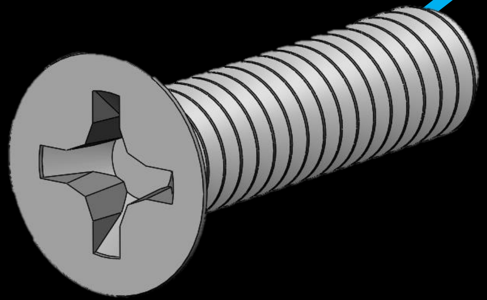
Example calculations for multiple bolt types
Max force pending final verification*

What's next: further testing and calculations to verify the number of bolts relative to max force on the airframe

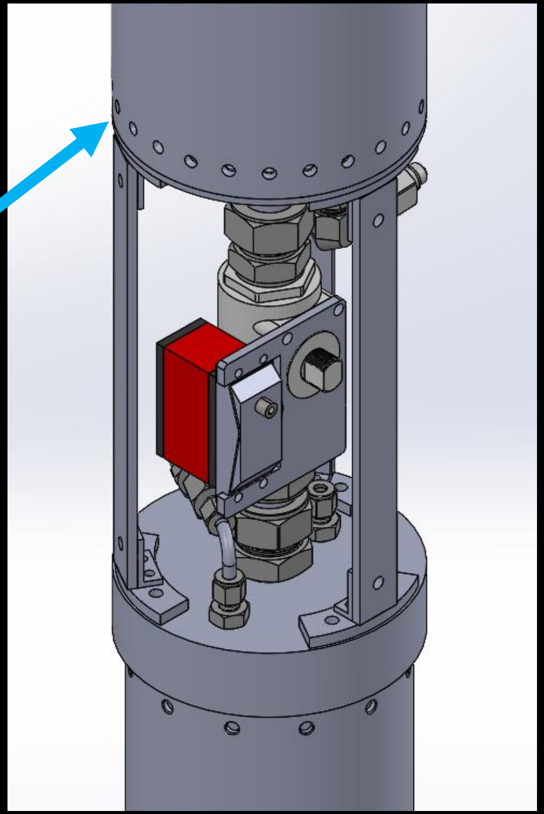
KNIGHTS EXPERIMENTAL ROCKETRY

NOX Tank Interface

- Tube attaches to NOX Tank Bulkhead
  - Threaded ¼-20 holes
  - Slides over tank 1 Caliber or 6 inches
- Approx 60 ¼-20 bolts in a staggered pattern
  - 30 Forward
  - 30 AFT



¼-20



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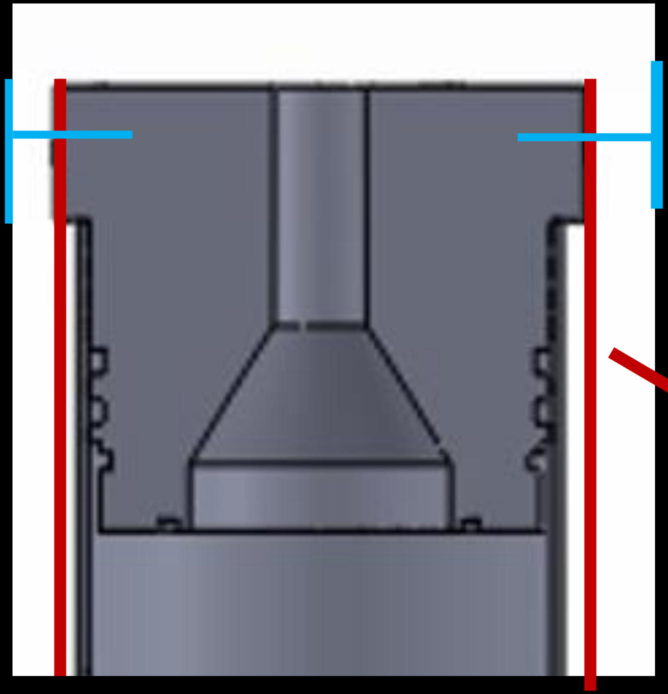
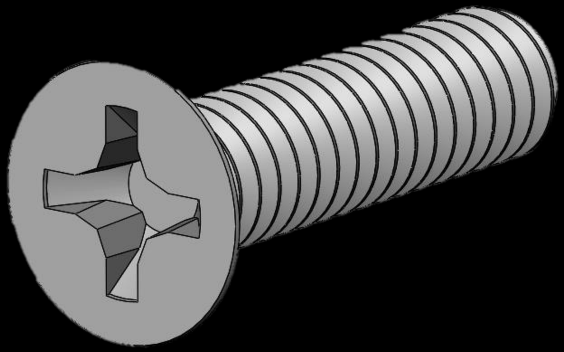
Combustion Chamber Interface

- Stretches from center of lower body tube to end of tail cone
- Retained within airframe with thrust plate
- Centering Ring on Combustion chamber at 1 CAL down





¼-20

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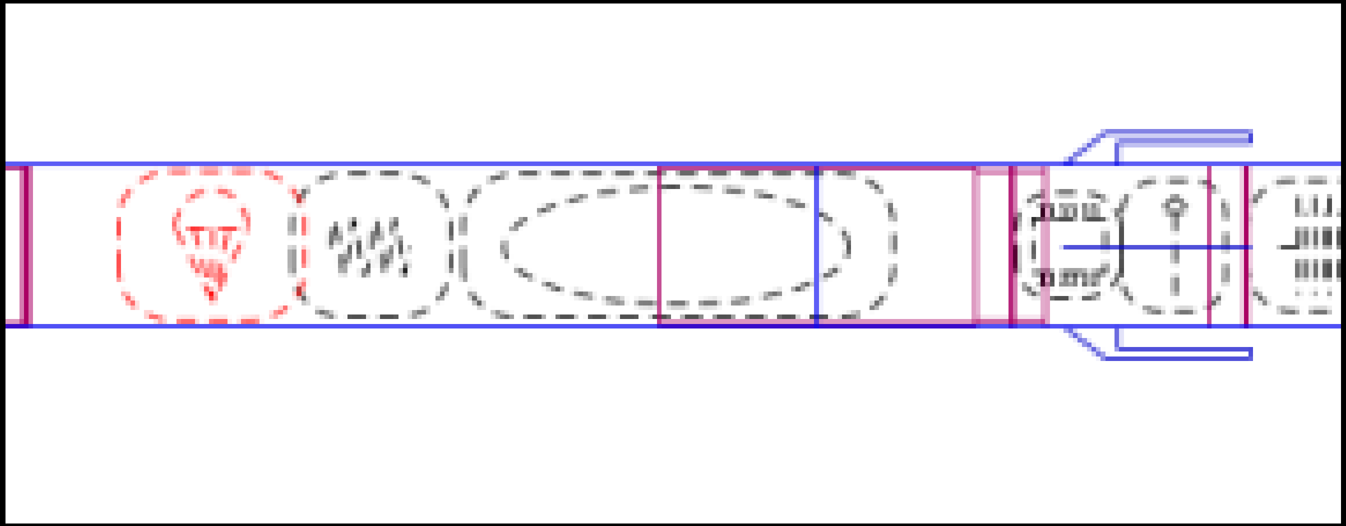
Payload Integration

- Payload will attach to main shock cord in upper body tube
- Payload will be situated above payload bulkhead and inside joint coupler of upper and mid tube



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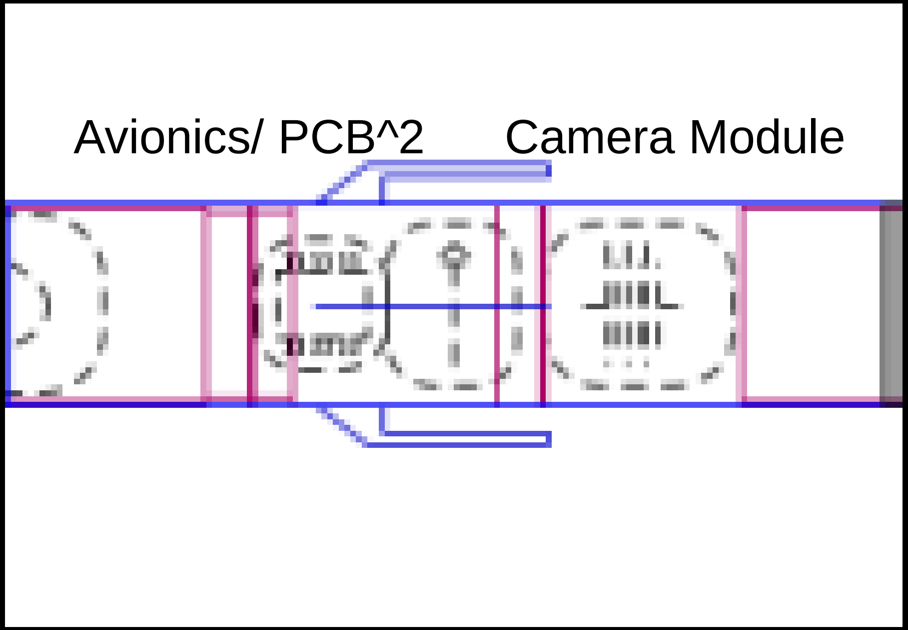
Avionics & Payloads Camera Module Integration

- Avionics Service Module and Camera Module to be located between recovery bulkhead and telemetry bulkhead
- Four equally spaced holes to account for cameras
- QD Camera faces outward away from rail between two camera module holes



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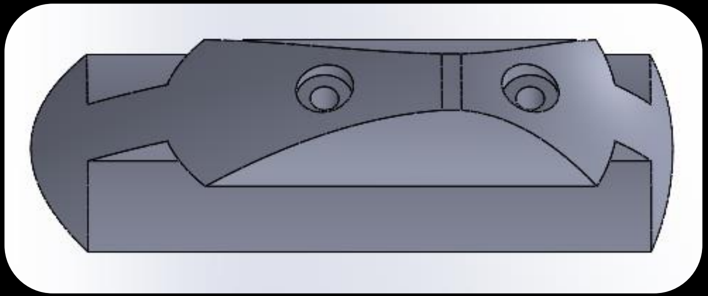
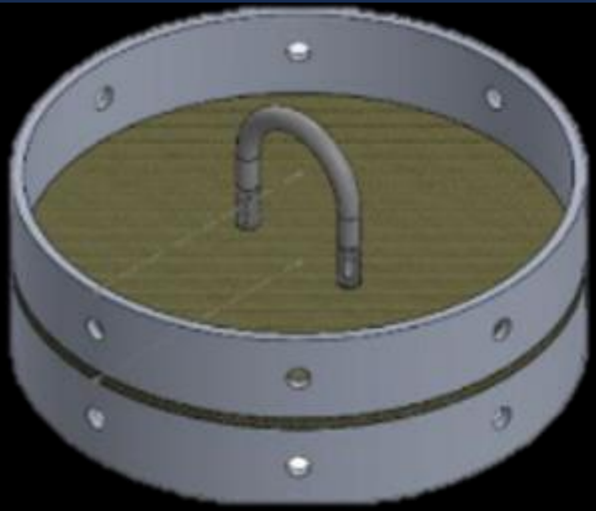
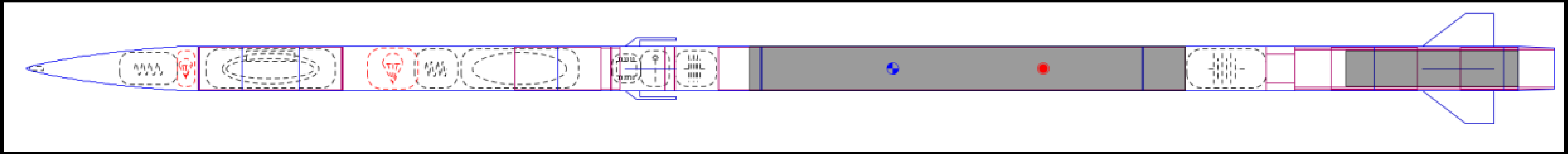
Questions?







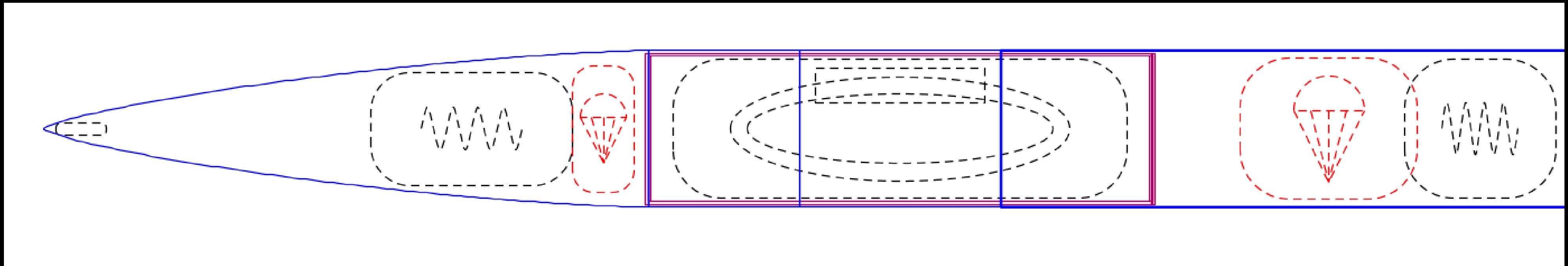
KNIGHTS EXPERIMENTAL ROCKETRY

Risks & Mitigations

Risk	Mitigation
External components shear off	Ensure proper attachment
Bulkhead tear out	Retaining rings are simulated to 2x safety factor
Bolt tear out	Bolts are rated to bearing stress below steel allowable stress
No signal from Avionics	Antennas are mounted properly to gather data
Incorrect simulation give faulty values	Ensure hand calc methods and simulations are verified
Components don't fit together	Track components through ICDs, communicate with REs with design, and track said changes within change log

Recovery Sub-System

The Recovery Subsystem is responsible for designing parachutes that can withstand high opening forces, a robust coupler that can handle all recovery flight loads and all necessary electronics that can operate under supersonic flight conditions to ensure a controlled descent and a safe recovery



KNIGHTS EXPERIMENTAL ROCKETRY
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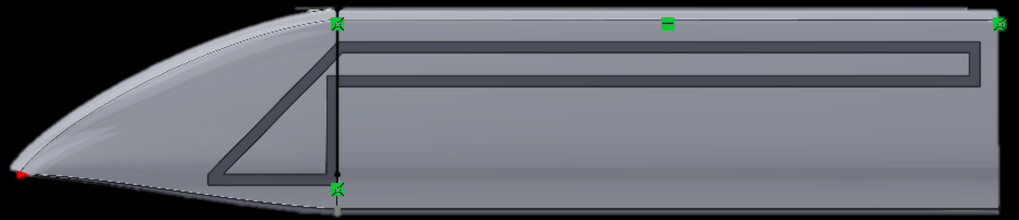
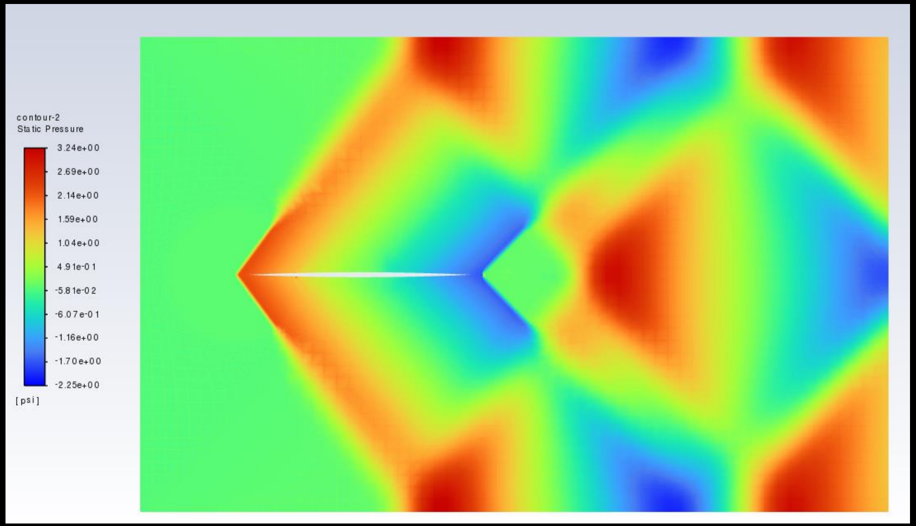
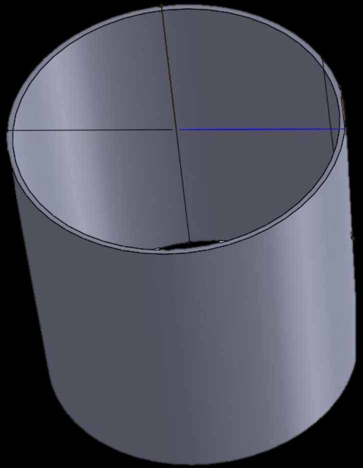
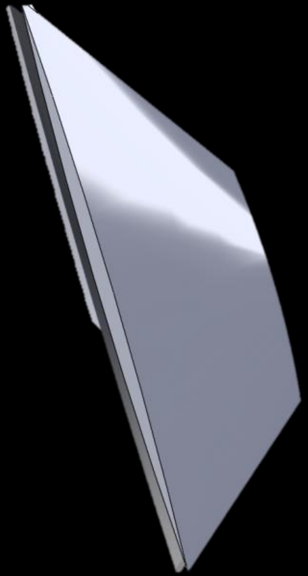
Questions?









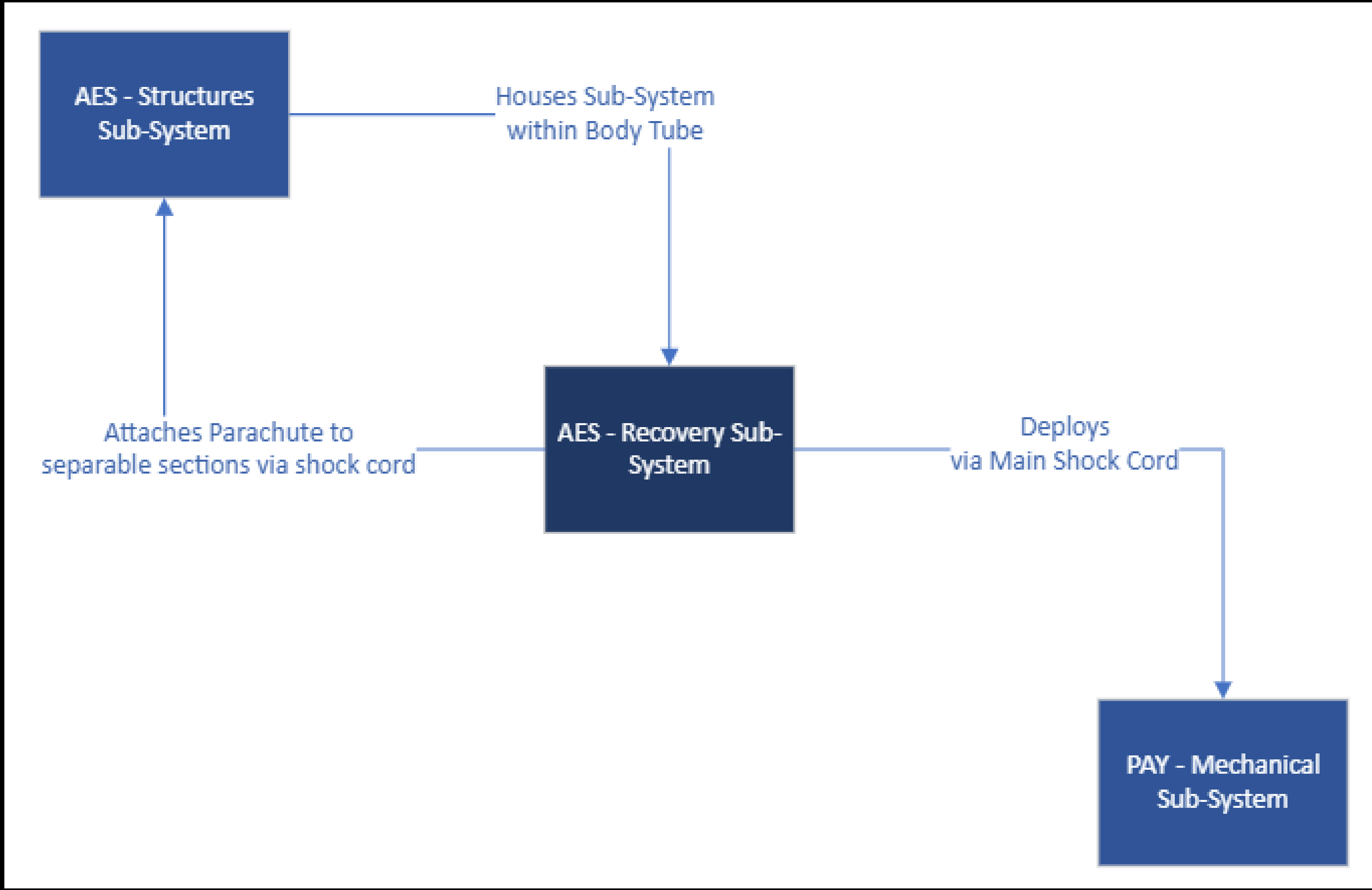
KNIGHTS EXPERIMENTAL ROCKETRY

Recovery Requirements

Requirement	Verification Method
The Recovery Sub-System **shall** safely recover the rocket.	Demonstration
The Recovery Sub-System **shall** be reusable.	Demonstration
The Recovery Sub-System **shall** be recovered in resuable condition.	Demonstration
The Recovery Sub-System **shall** implement adequate protection.	Demonstration
The Recovery Sub-System **shall** fully ground and flight tested.	Demonstration
The Recovery Sub-System **shall** activate the Primary Main Deployment Charges at [1000 ft] AGL.	Test
The Recovery Sub-System **shall** activate Redundant Main Deployment Charges [2] seconds after Primary Main Charges are activated.	Test
The Recovery Sub-System **shall** activate Primary Drogue Charges at apogee.	Test
The Recovery Sub-System **shall** activate Redundant Drogue Deployment charges [2] seconds after Primary Drogue Charges are activated.	Test
The Recovery Sub-System **shall** successfully separate Body Tubes within [1] second of activation.	Test

KNIGHTS EXPERIMENTAL ROCKETRY

Recovery Interface Diagram



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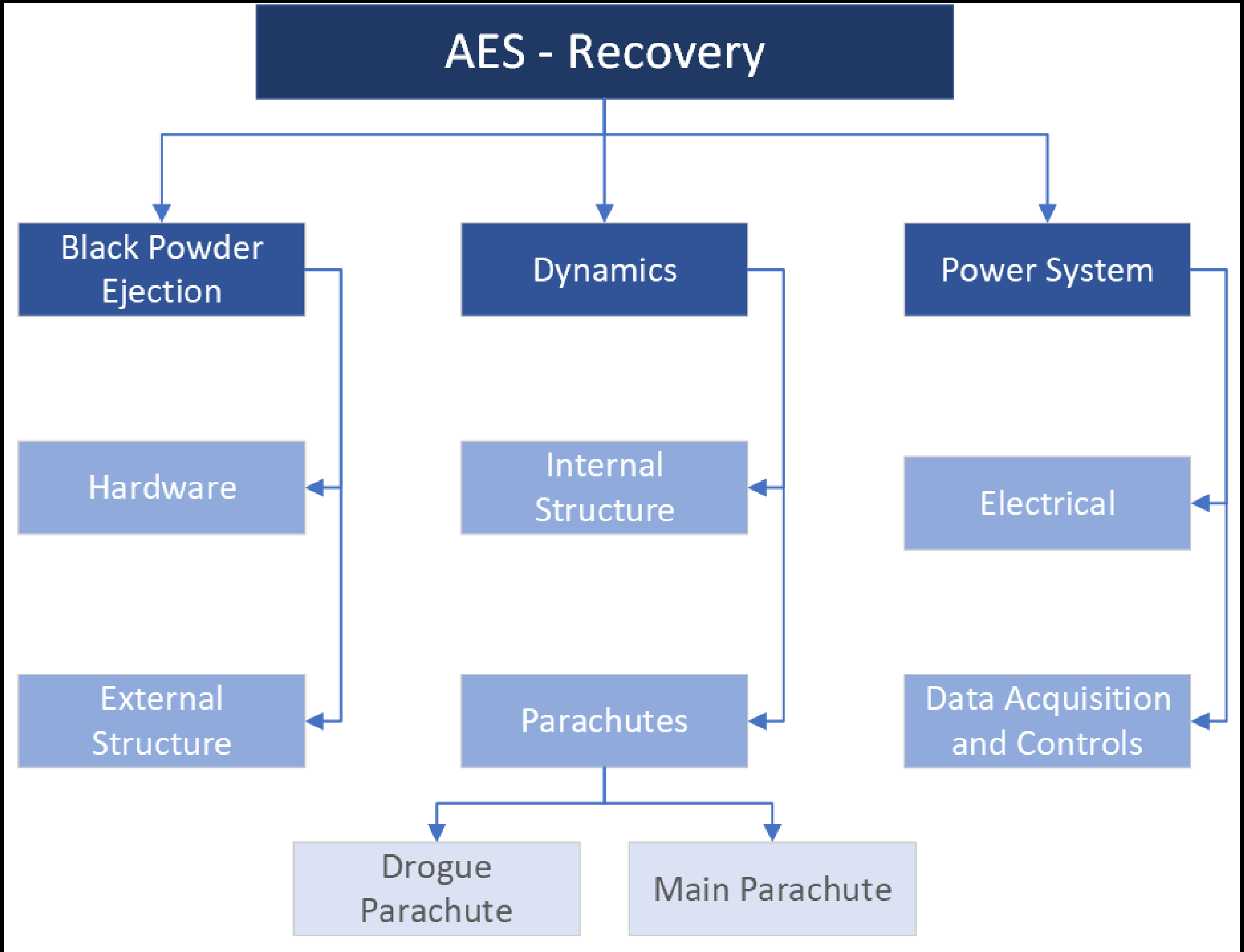
Recovery Component Breakdown



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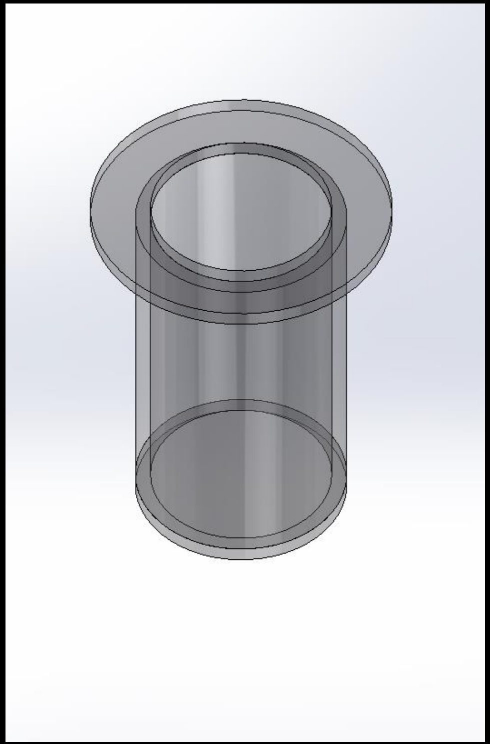
Black Powder Ejection

- Two Methods of Ejection:
  - Drogue – Charge Cannon
  - Main – Charge Well

Methodology of the Charge Cannon

- The Black Powder is ignited and then burns in the barrel. Due to the confined space in the barrel, it burns better without losing to much of its energy to generate the pressure required to shear the pins at high altitudes.

- Charge wells will be designed to fit 1.5x the amount of Black powder required to ensure there's space in the event more is needed.



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Recovery TPMs

Measure	TPM Value	Units	Verification Method
Maximum Compressive Force	[TBD]	lbs.	Analysis
Average Snatch Force (Main)	[928.4]	lbs.	Analysis/Calculator
Upper Bound Snatch Force (Main)	[1406]	lbs	Analysis/Calculator
Lower Bound Snatch Force (Main)	[492.3]	lbs	Analysis/Calculator
Volume of Recovery Chamber	[290.13]	in^3	Inspection
Drogue Descent Rate (At deployment)	[92]	ft/s	Test
Main Descent Rate	[21]	ft/s	Test
Drogue Black Powder Mass	[20]	grams	Test
Main Black Powder Mass	[35]	grams	Test
Drogue Shear Pins	[10]	6-32	Inspection
Main Shear Pins	[8]	10-32	Inspection

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Black Powder Testing Plan

- Charge Cannons Testing Plan
  - High Performance Filament will be used
  - Use test results to fulfill our TPMs while keeping space to a minimal

- Charge wells test will occur during our scheduled ground test
  - The data acquired will be used to update the Black Powder amount needed

- Vacuum test will be used to test if altimeters are triggering at their respective altitudes
  - This will be conducted by removing the air inside the rocket. A barometer will be inside the rocket to verify results

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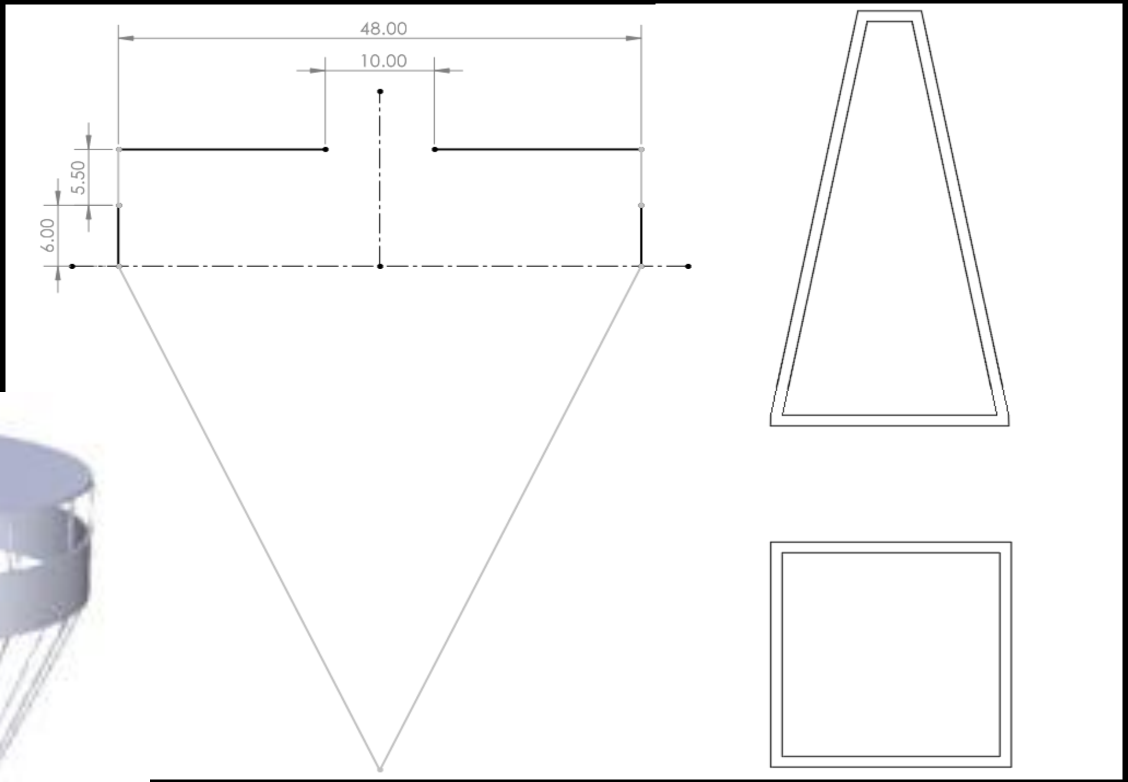
Drogue Parachute

- Slows the rocket to 115ft/s
- Generates a snatch force of 135lb at deployment

- 48" Outer Diameter
- 10" Vent Hole
- 55" Shroud Line
- Drag Coefficient – 0.6

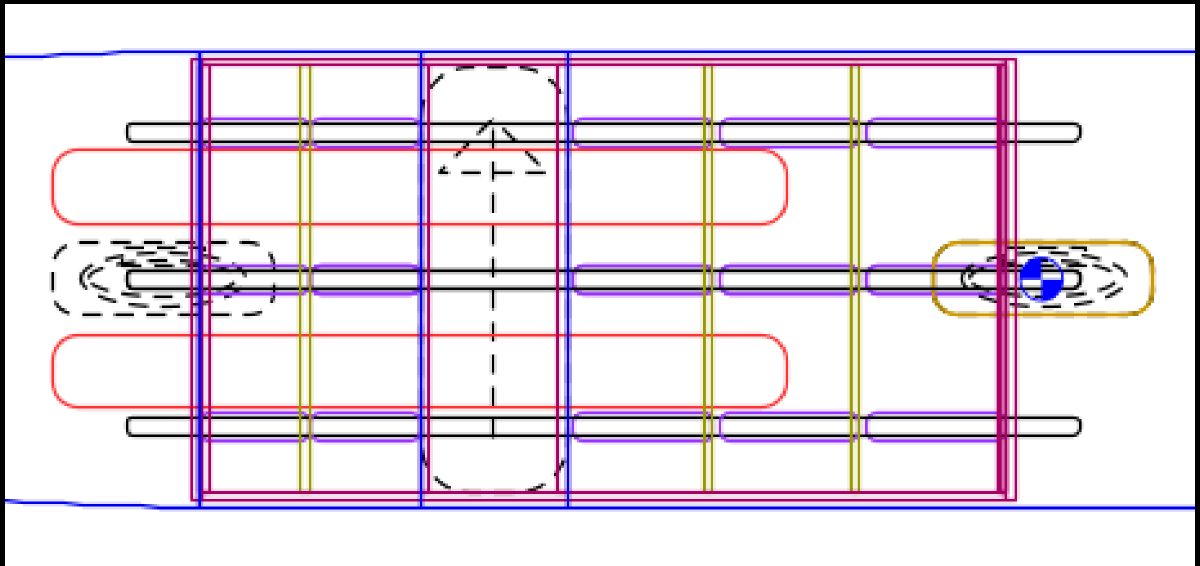


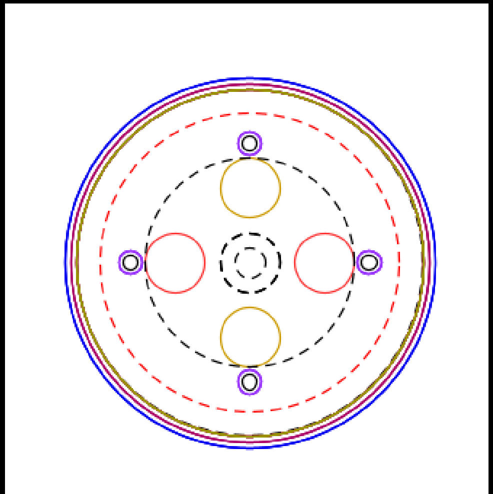
Recovery Coupler Diagram

- Charge Cannons are pictured in red and are the longest cylinders to the left

- All internal components are kept in place 1via PVC pipes. They are pictured in purple

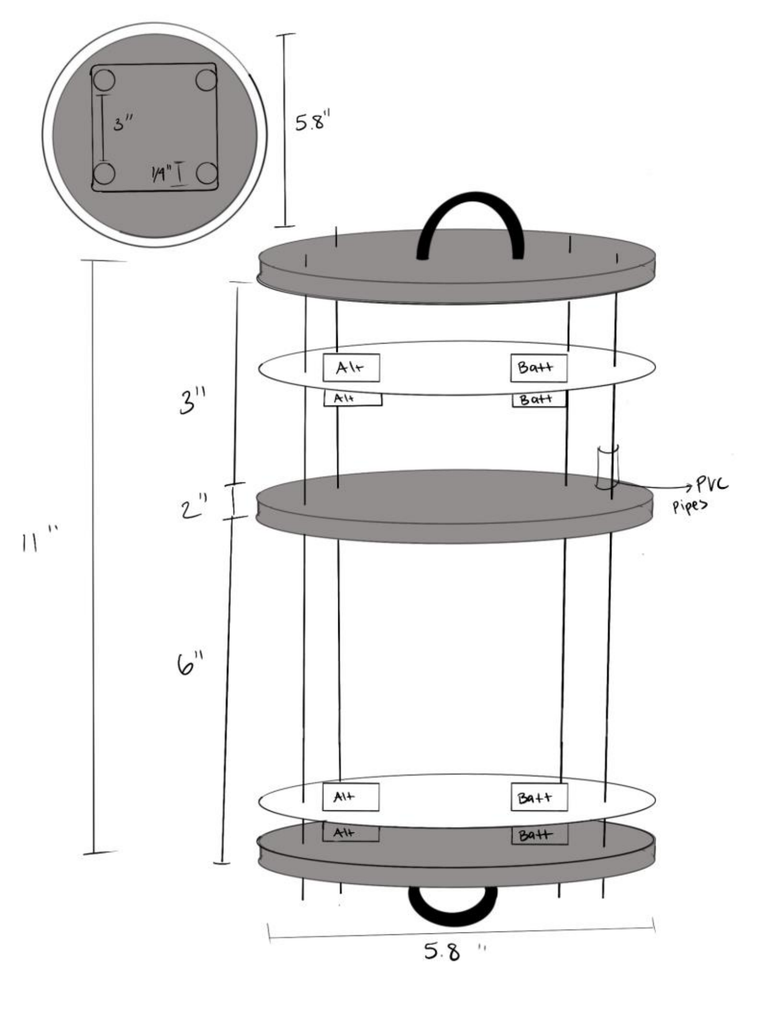
- Main Charge wells are pictured to the right in orange. To make room, they extend outwards





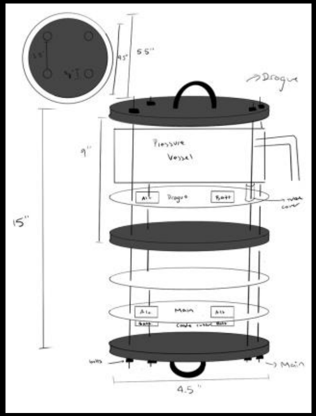
Internal Structures

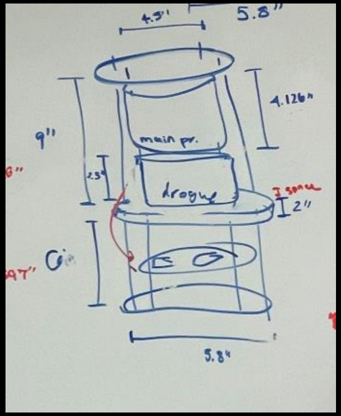
Multiple designs were considered, but ultimately, we chose this one for space reasons, after deciding to go with black powder. -->



Previous Designs:

When we were doing co2 ejections these were the designs considered:





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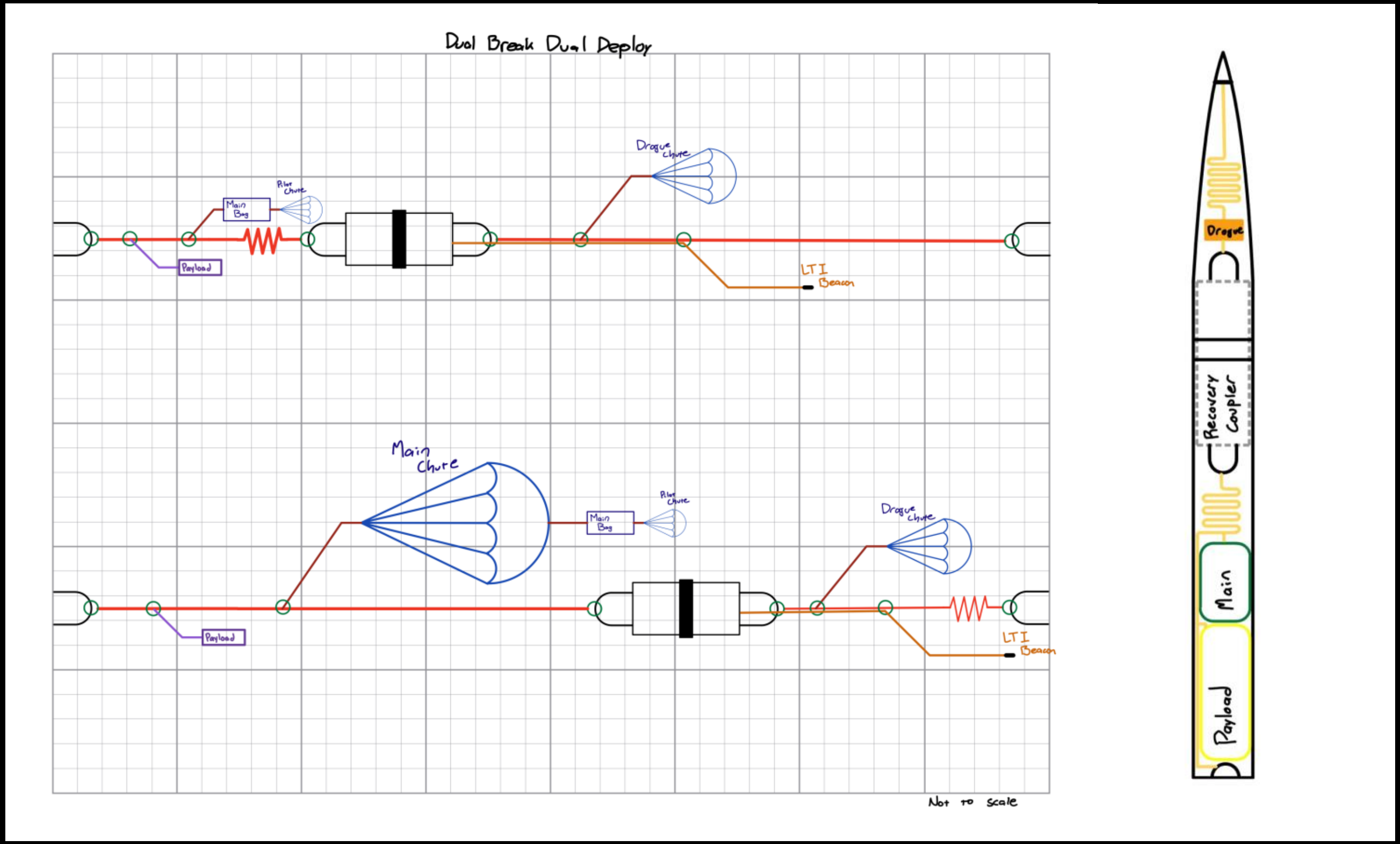
Parachutes Overview

- Drogue parachute deploys from nosecone at 30,000 ft
- Main parachute deploys from body tube at 1,500 ft with payload

- SRAD 48" Disk-Gap-Band Drogue Parachute
- SRAD 132" Toroidal Main Parachute
  - Custom deployment bag and pilot chute
- Kevlar Shock Cords



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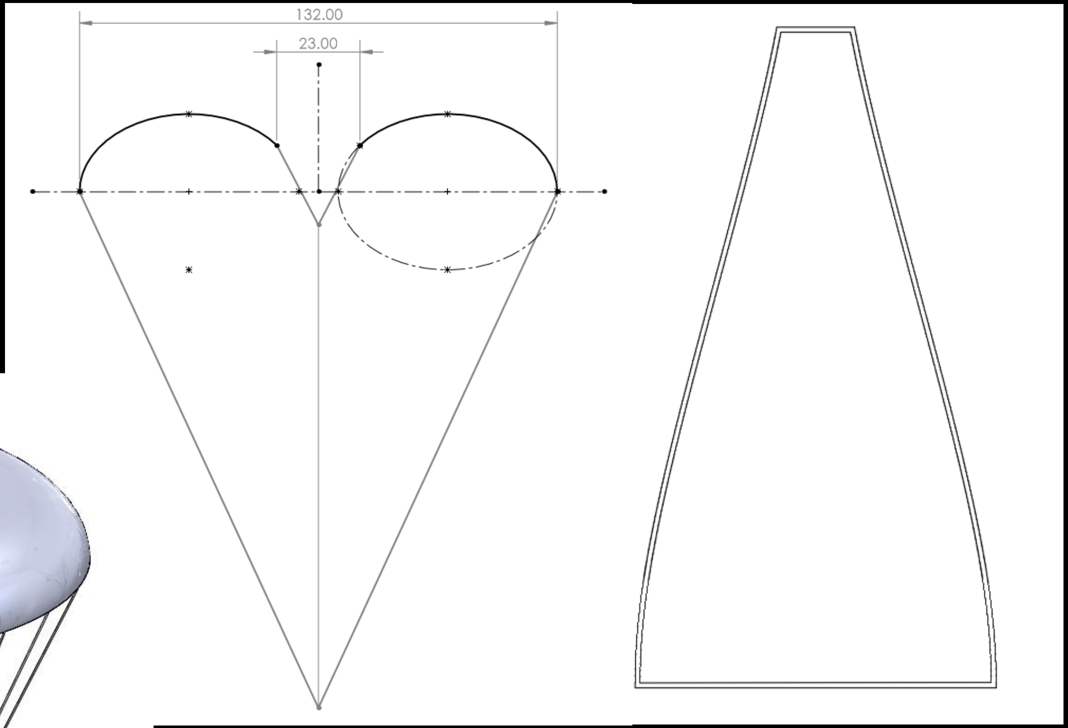
Main Parachute

- Slows the rocket to its touchdown velocity of 21ft/s
- Generates a snatch force of 1,400lb at deployment

- 132" Outer Diameter
- 27" Vent Hole
- 156" Shroud Line
- Drag Coefficient – 2.2



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Parachute Testing Plan

- Manufacture drogue parachute and subscale main parachute
- Test parachutes to validate drag coefficient values (Cd)
    - Either drop test and measure descent rate, or wind tunnel test and measure drag force
- Use test results to update main parachute geometry

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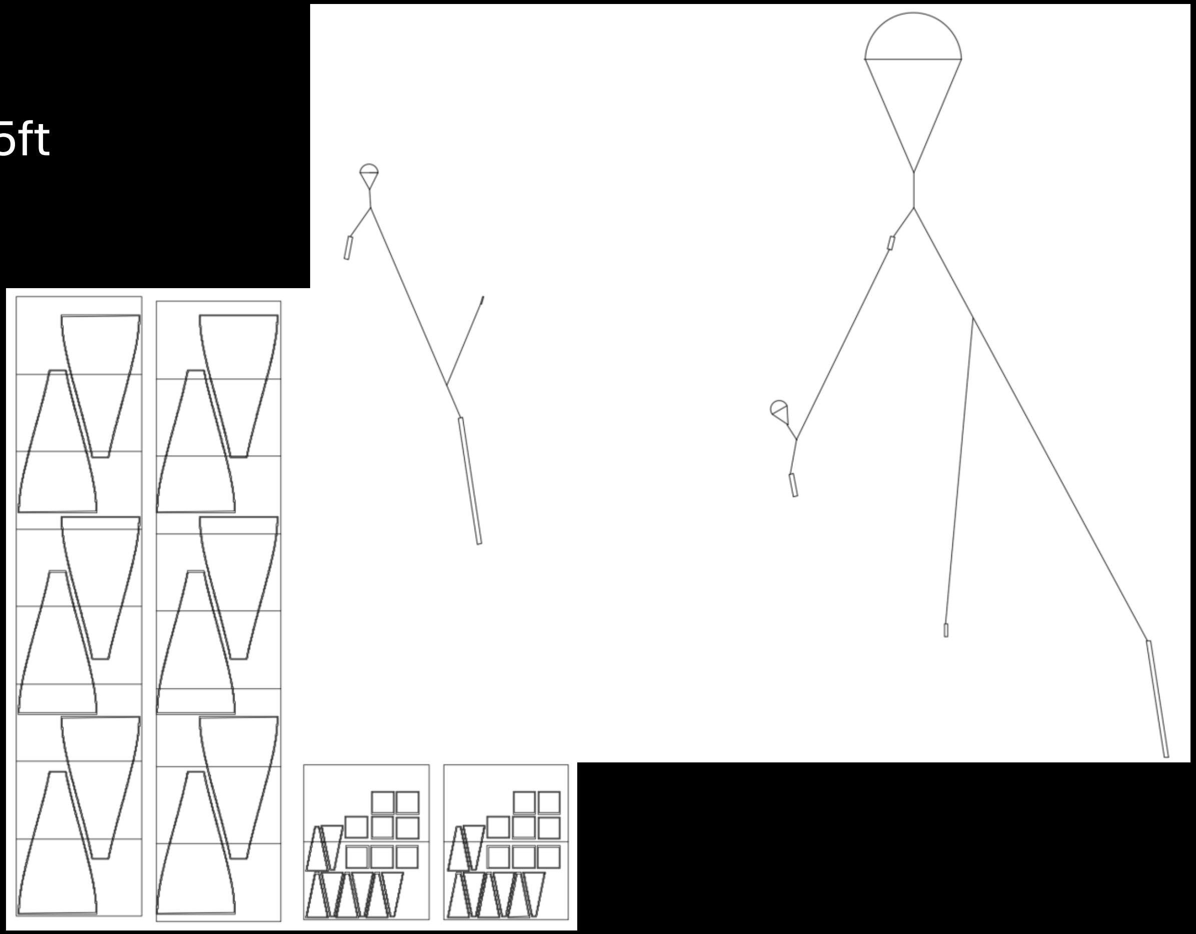
Parachute Materials

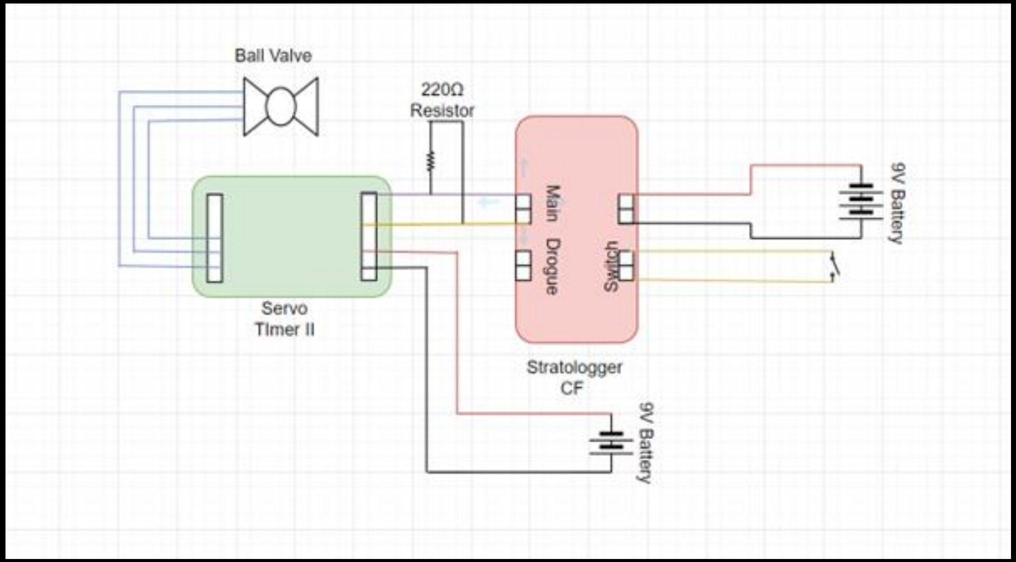
- Shock Cord
  - Drogue Chute Line – 3/8" tubular Kevlar, 45ft
  - Main Chute Line – ½" tubular Kevlar, 85ft
- Canopy
  - Drogue, Main, and Pilot Canopy – 1.1oz Ripstop Nylon, 24yd
- Shroud Line
  - Drogue Line – 275lb Nylon Paracord, 200ft
  - Main Line – 750lb Spectra, 180ft



Electrical and Controls

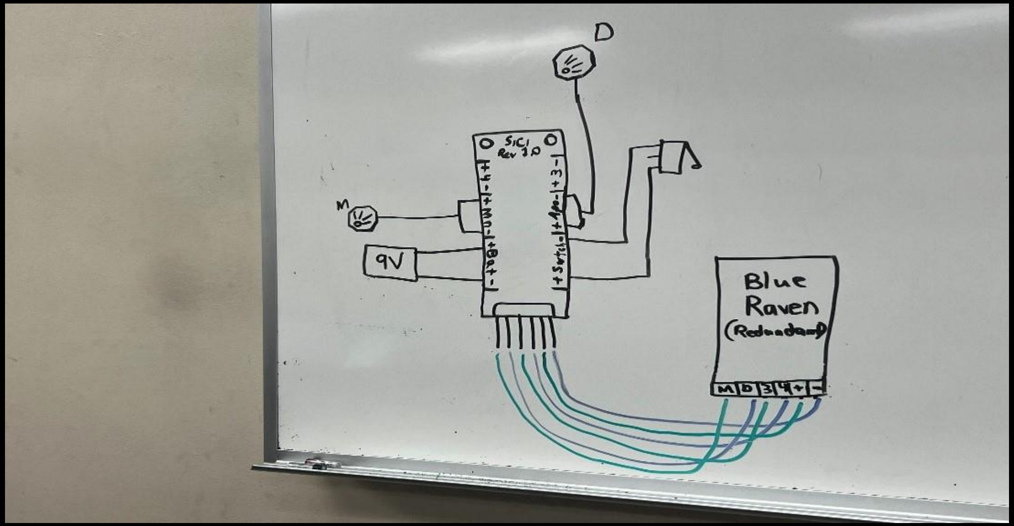
- Primary Altimeter: Stratologger CF
- Redundant Altimeter is the Blue Raven by Featherweight

- For the primary altimeter, the servo board is no longer needed as the e-matches will be wired directly to the altimeter.



- Redundant altimeter does require an interface board due to its complex wiring interface

- Both altimeters utilizes a 9V battery for power and a limit switch to arm and disarm



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Battery Life Calculations

- Blue Raven Altimeter:
  - Power draw will be tested via a drain test
- Stratologger CF Altimeter:
  - 565 mAh / 1.5 mA = 376.6 hours
- Featherweight GPS:
  - Average consumption 400 mAh / 60 ma = 6.66 hours

$$Battery\ Life = \frac{Battery\ Capacity\ in\ Milli\ amps\ per\ hour}{Load\ Current\ in\ Milli\ Amps\ per\ hour}$$

Data Acquisition

- Run-cam 2 is used to collect high-definition videos of our parachute deployment so that we can compare our test opening characteristic and our actual
  - It also enables us to get some cool shots of our deployment for promo videos

- Featherweight GPS will be our primary tracker on locating the rocket. We will have 2 SRAD GPSs (Beacon and ASM)

- Blue Raven will be acquiring the following data
  - Horizontal velocity at apogee
  - Tilt losses during motor burn
  - Max drag acceleration during coast
  - Roll rate and angle

Recovery Hardware

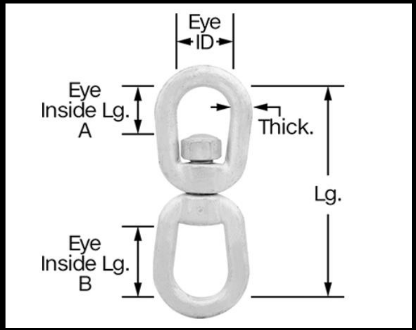
- Main Chute Eyebolt is rated for 3000lbs
- Drogue Eyebolt is rated for 1300lbs

- Drogue shear pins: 6-32 pins (10)
- Main shear pins: 10-32 pins (8)

- Drogue Swivel link rated for 600lbs
- Main Swivel link rated for 1900lbs

- Quick links are rated for 900 lbs

- All hardware are to spec with a margin of safety



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Risks & Mitigations

Risk	Mitigation
Black Powder falling out of the charge well	Ensure that the lid is completely sealed with a cap and tape
Arming sequence	Utilize a Stethoscope to listen to the beeps
Altimeter doesn't ignite the black powder	A redundant altimeter will be installed in the coupler to fire off the redundant charges
Charges go off after going sonic	All altimeters must have a mach lockout
Parachutes getting burned	All parachutes will be surrounded by Nomex fire resistant material to ensure the hot gases doesn’t burn it
Components don't fit together	Track components through ICDs, communicate with REs with design, and track said changes within change log

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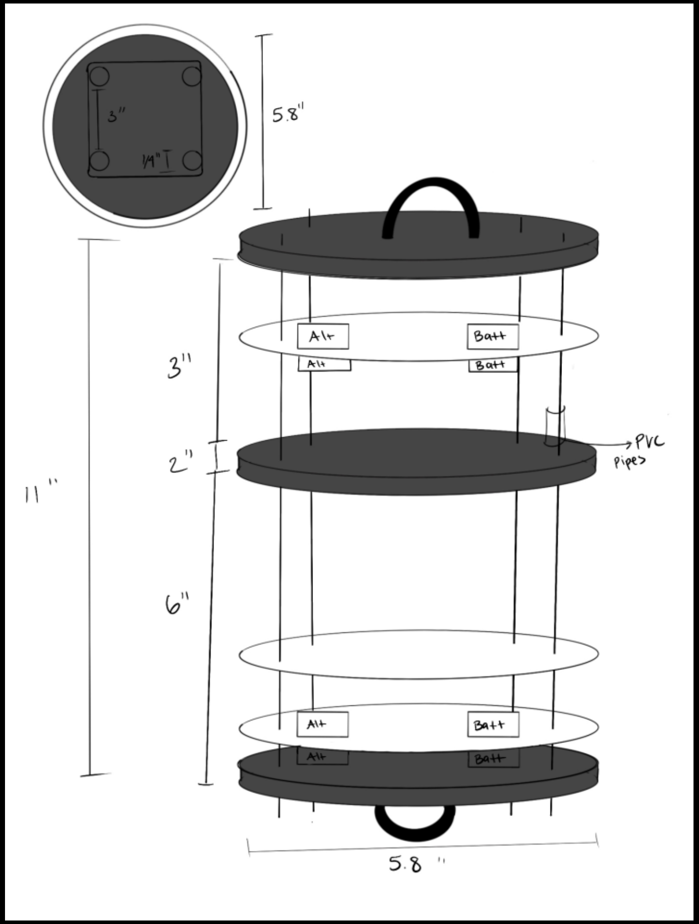
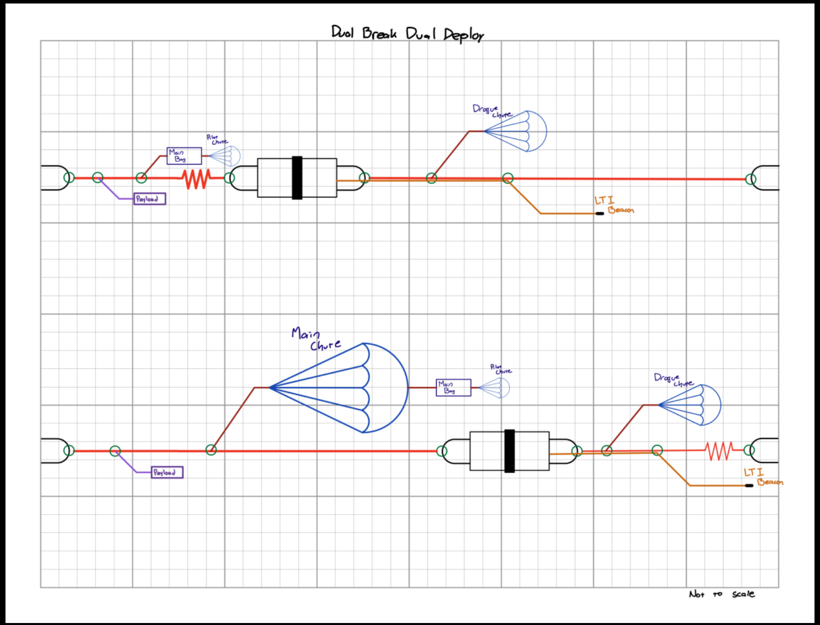
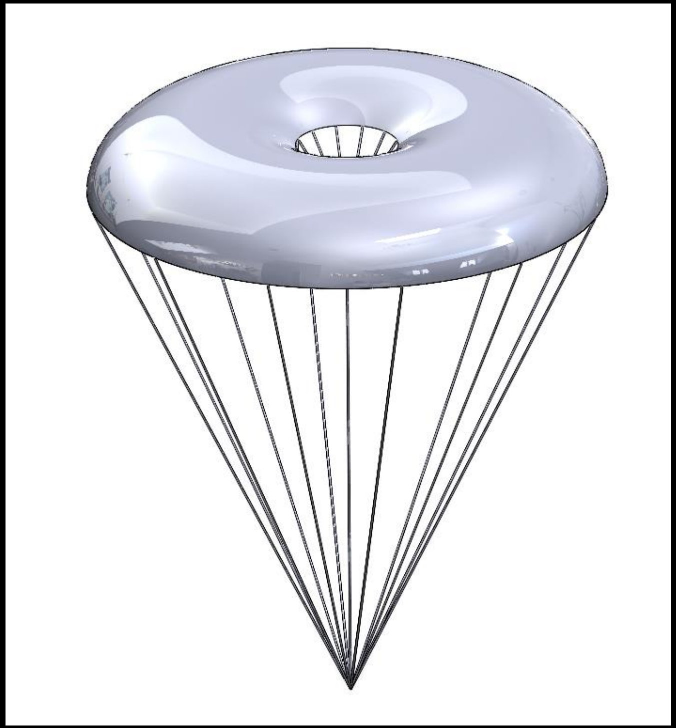
Questions?







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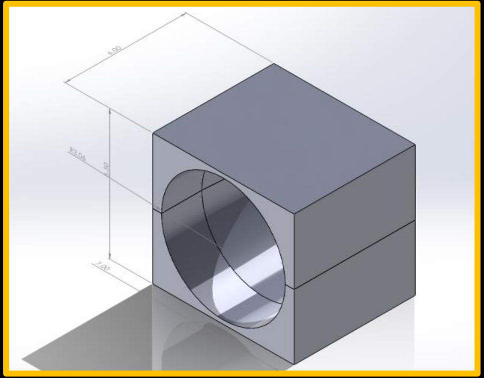
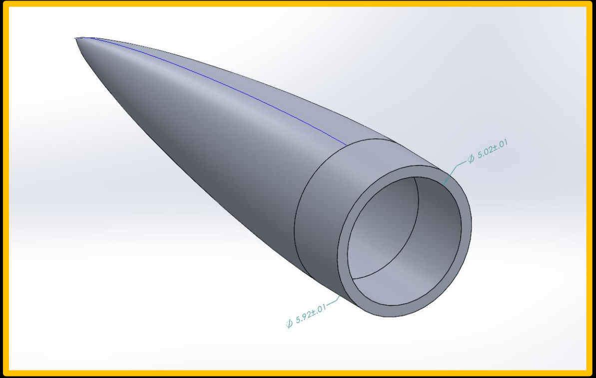
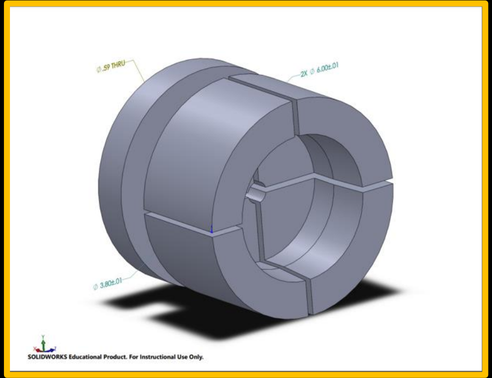
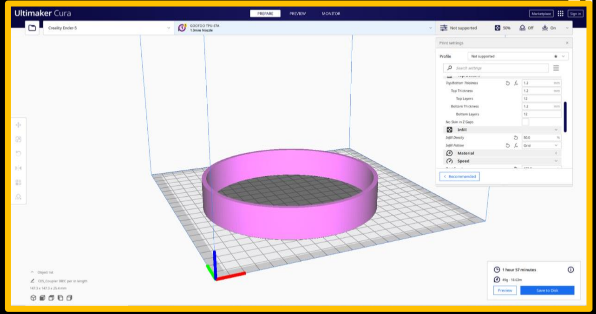
Manufacturing Team

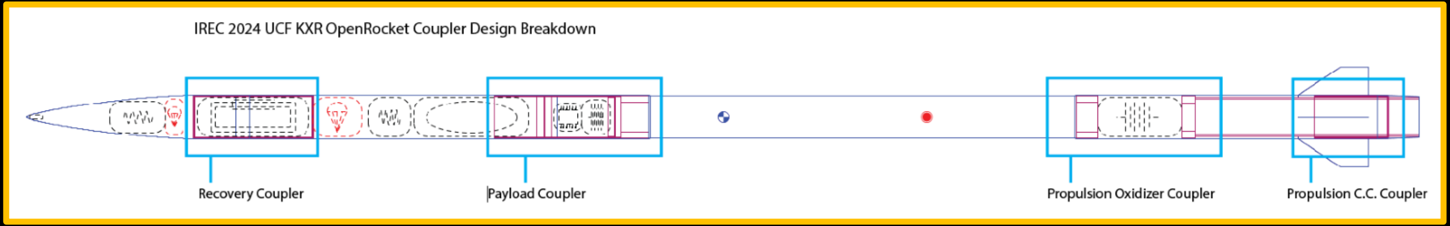






The manufacturing team is responsible for all steps of the engineering process as it relates component fabrication, mold design, material selection, and physical airframe architecture. We take into consideration the machinability, compatibility, cost, and scheduling when making manufacturing decisions. Our components have been separated amongst designated REs (Responsible Engineers) who are responsible for overseeing and managing the part throughout the manufacturing process.





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Manufacturing Requirements

Requirement	Verification Method
The Manufacturing Team **shall** produce external structure components with minimal surface roughness.	Demonstration
The Manufacturing Team **shall** produce tubular components that are sufficiently round within [0.005] inches.	Inspection
The Manufacturing Team **shall** create manufacturing procedures and verify said procedures prior to manufacturing flight articles.	Inspection

Requirement	Verification Method
All Molds **shall** be able to withstand a vacuum pressure of [1] ATM.	Demonstration
All Molds **shall** be able to withstand the [300 Degrees Fahrenheight] temperature of the autoclave.	Demonstration
All Molds **should** be non-reactive with acetone.	Demonstration
All Molds **shall** be chemically resistant to bonding with chosen matrix material.	Demonstration
All Molds **shall** be easily reproducible for means of reusability.	Demonstration
All Molds **shall** resist bonding with composite fabric.	Demonstration
The Mandrel Mount **shall** safely secure the mandrel during the layup process.	Demonstration
The Mandrel Mount **shall** provide a means to achieve a secure vacuum seal.	Demonstration
The Mandrel Mount **shall** be able to withstand the temperatures of the autoclave.	Demonstration
The SRAD Couplers **shall** have a length of at least [12] inches.	Inspection
The SRAD Couplers **shall** have a diameter of [TBD] inches.	Inspection
The SRAD Couplers **shall** be stiff when joined with Body Tubes.	Demonstration
The SRAD Couplers **shall** have a diametrical tolerance of [-0.003] inches.	Inspection

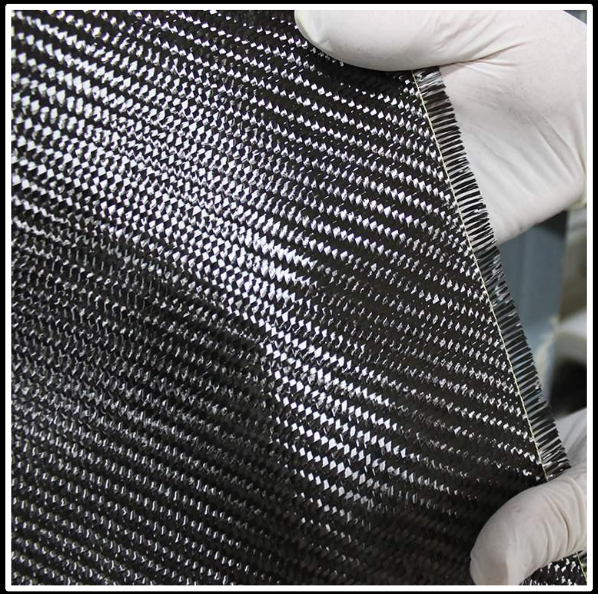
Manufacturing Risk Assessment

Risks	Mitigation Strategy
Delay in arrival of manufacturing materials	Order materials with longer processing/shipping timeline ahead of schedule
Errors during the manufacturing process leading to a scrap of the entire part	Implement preliminary testing period with sub-scale models to ensure familiarity and proficiency with rocket layup technique/principles
Collapsing occurring during the 3D fabrication process	Perform excessive calibration of the 3D printer used as well as using practice prints to ensure the final product is optimized
Imperfections during the manufacturing process being extrapolated towards the final product	Combine all procedures and cautious practices when dealing with expensive components
Human errors in post-processing of components	Implement procedure to ensure that excessive care is utilized when dealing with layup product to prevent scrap

Airframe Material

Material Decision: We are going to be utilizing a *3k 2x2 twill biaxial carbon fiber* for our rocket's airframe. Initially, we considered using a hybrid composite carbon fiber/fiberglass, but ultimately decided that the increased costs and weight-to-thickness ratio were significant constraints that convinced us otherwise.

Using a pre-impregnated carbon fiber reinforcement will offer increased material strength properties while keeping the price within our budgetary constraints.



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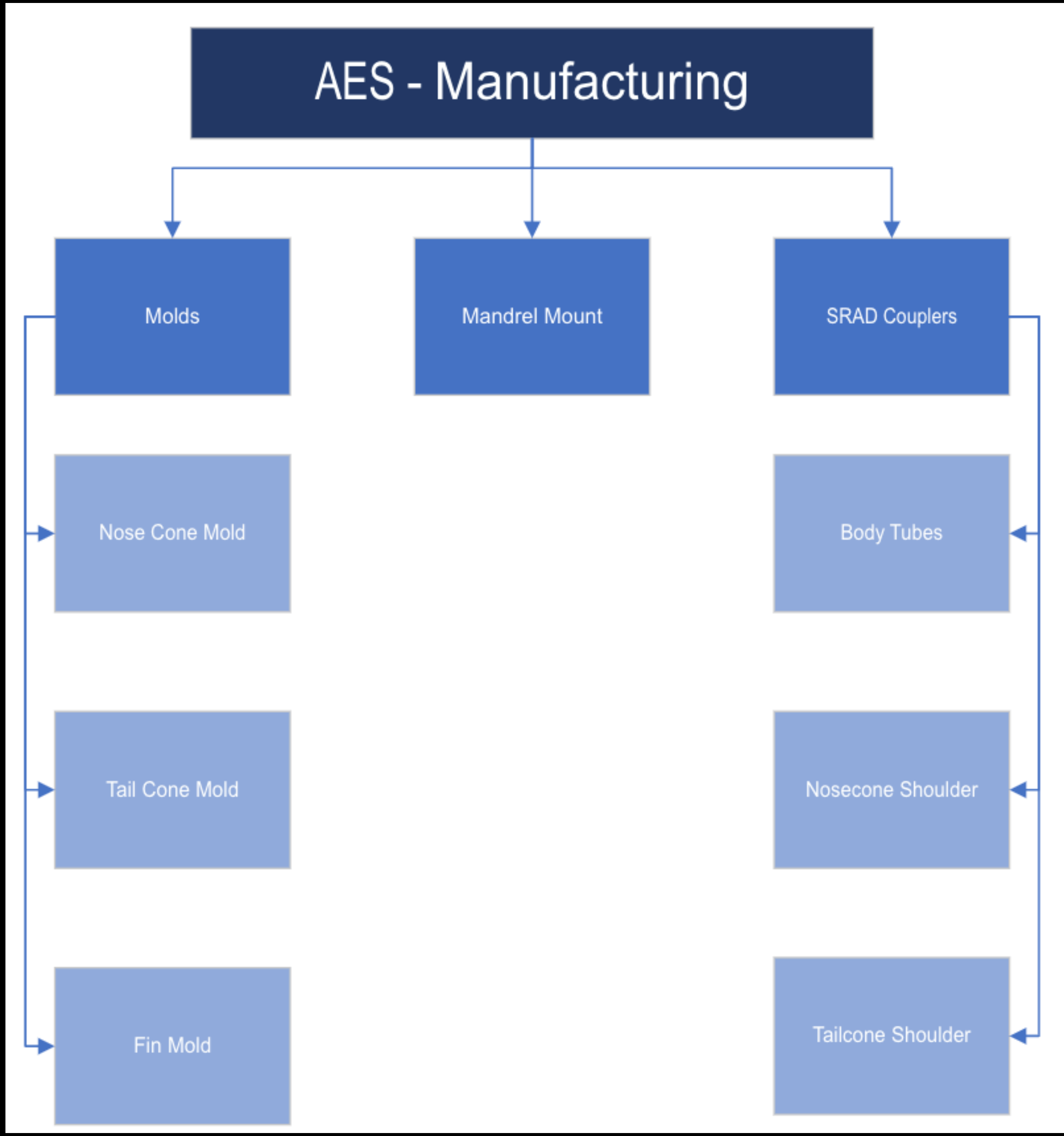
Manufacturing Component Breakdown



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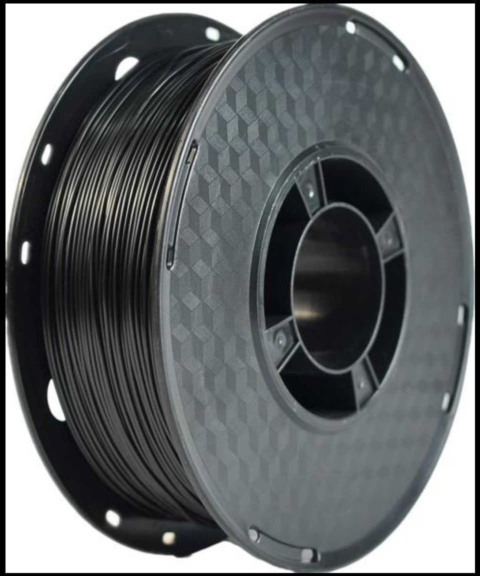
Mold Material

	TPU	ABS
Temperature Resistance	*250-300° F*	*200-250° F*
Price	*$20/Kg*	*$30/Kg*



Material Decision: TPU due to its advantageous thermal capacity, ease of printing, and price difference.

Female Mold	Male Mold
No experience/familiarity with process	*More experience within KXR*
Better surface finish before PP	*Vacuum bag compatibility*
High separation difficulty post-cure	*Easier separation post-cure*

Mold Decision: Male mold due to the team's experience and practicality. The surface finish benefit from a female mold does not warrant the extra difficulty in post processing.

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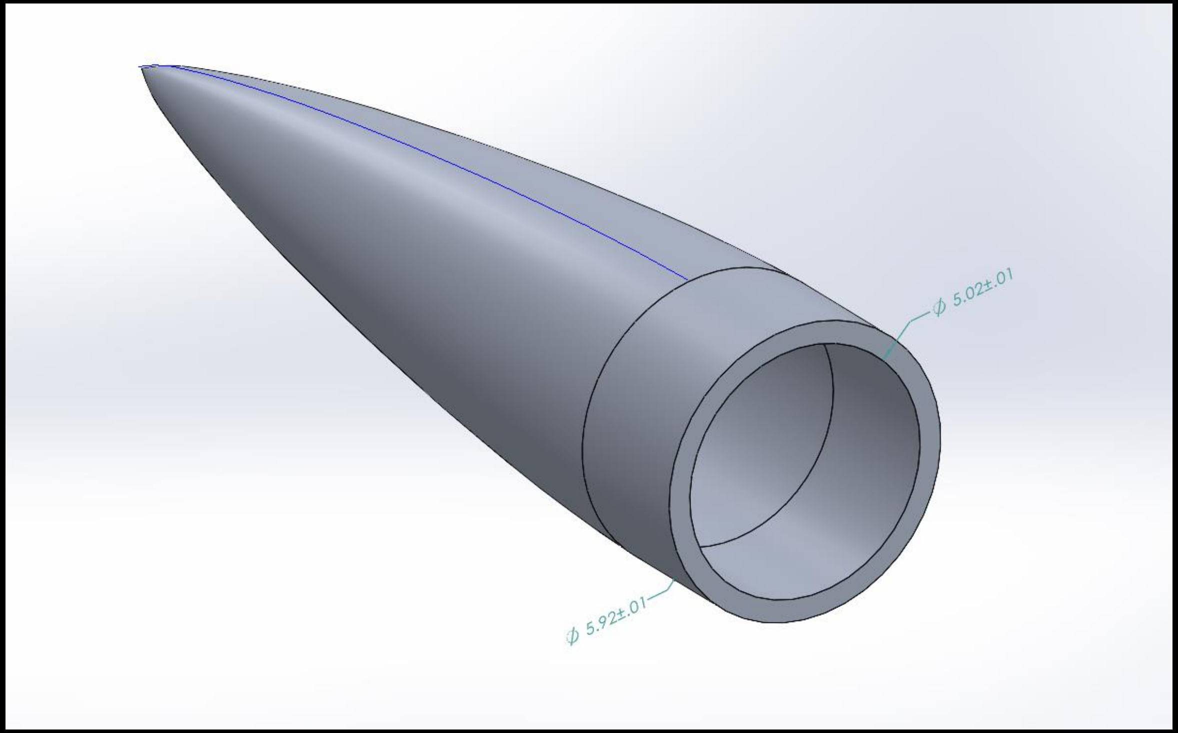
Nose Cone Fabrication

Material: TPU (Thermoplastic polyurethane)
- Heat Resistance – 250-300F
- Pressure Resistance – 14.7 psi

Sub-scale Model
- Can be made simply by adjusting dimensions in CAD
- Will give new engineers experience for lay-up

Reasoning for male-mold selection
- Increased ease of removability of Nosecone after use.
- Cheaper to 3D-Print than a female mold due to a smaller amount of TPU filament being used.



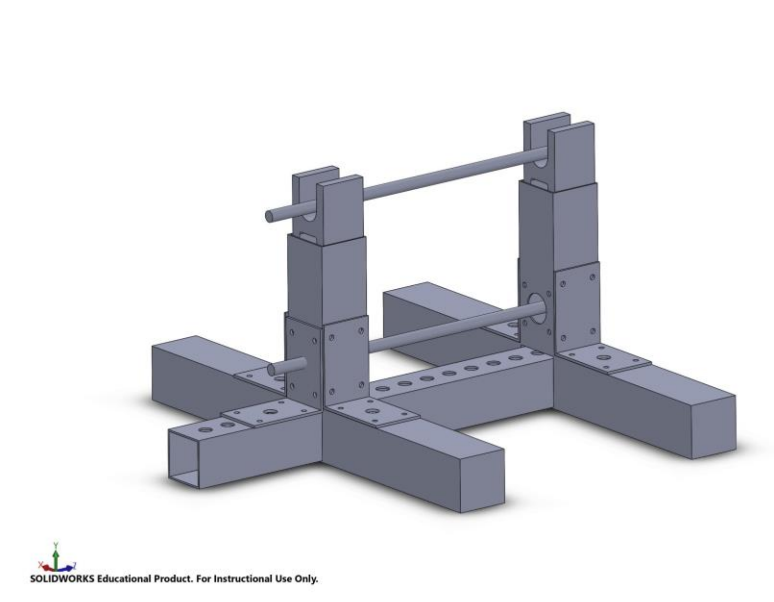
Mandrel Mounting Method

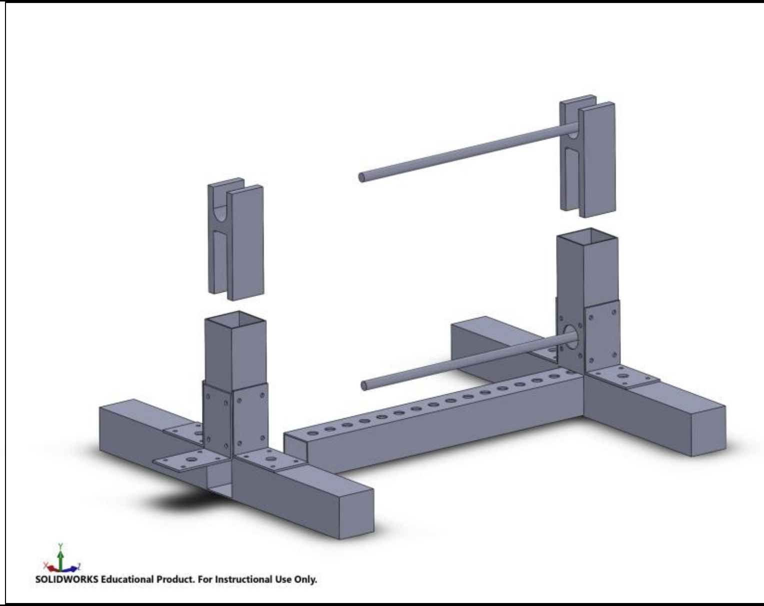
Goals for the Mandrel Mounting Stand:

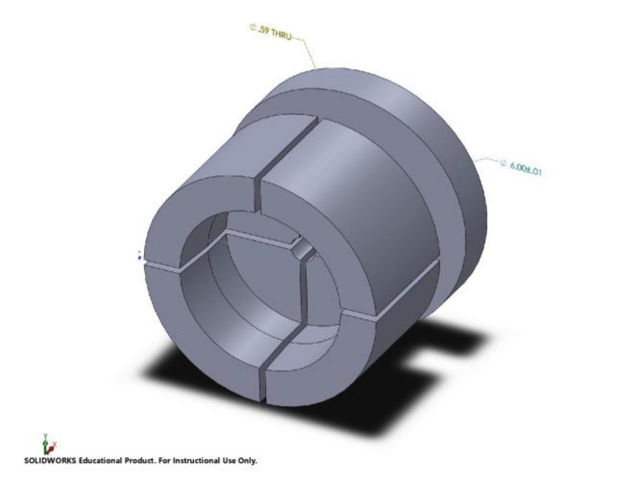
- Mandrel Size: 44in

- Responsible for both holding the mandrel up, and creating a smooth body tube product via the rolling pin style system

- This design is a modular system which will allow the team to disassemble the stand to fit within the space of an autoclave.







Expanding Mandrel Plug:

- This is a concept of an expanding mandrel plug; this is the female interface which would accept a wedge into the opening. Secured by a threaded fastener, when tightened, the wedge would cause the plug to expand.
- Material: Steel
- Reason of Refusal: High Cost (est. $800/ft per 6" steel rod)

-Material: Steel/

Aluminum

-Temp Resistance: 932-1275 F

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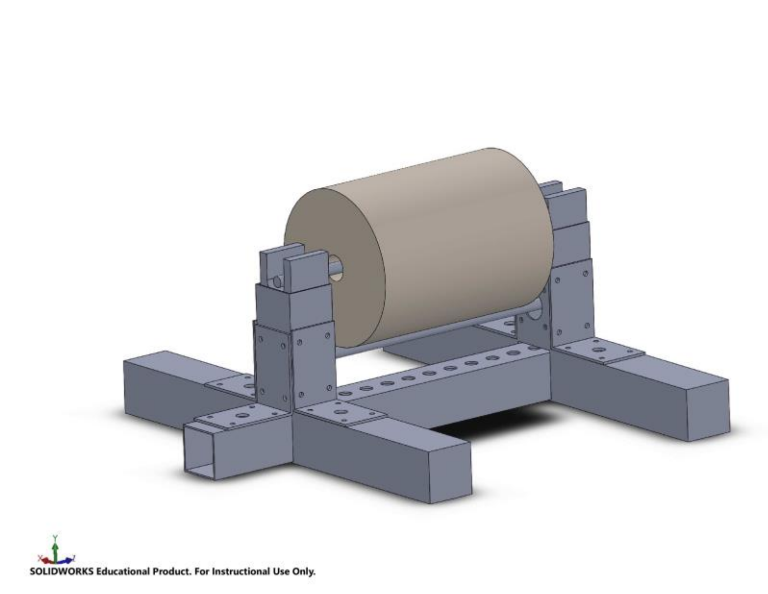
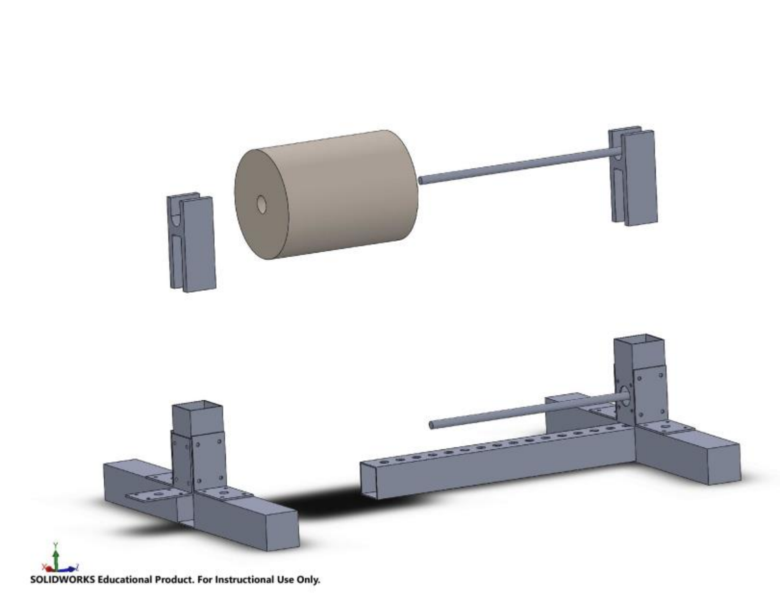
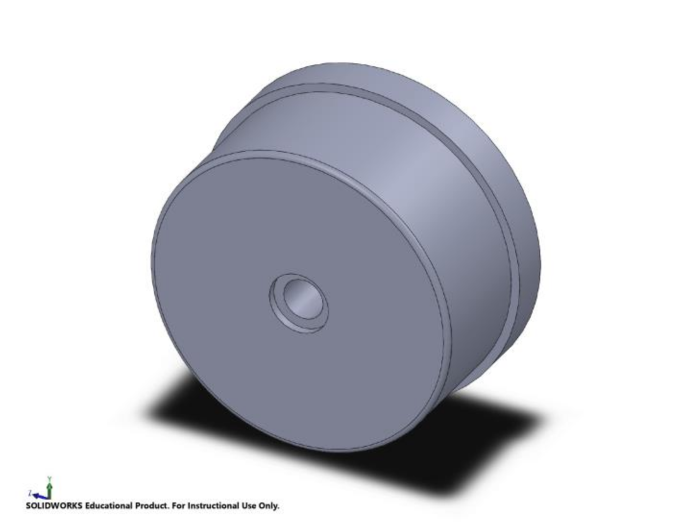
Mandrel Mounting Method





Cost:
- 2" Square tubing ≈ $8.00/ft
- ½" Steel rod ≈ $3.00/ft
- 90° Brackets ≈ $2.00/bracket
- Ultem Filament ≈ To be Determined



Summarized Body Tube Layup Procedure
- The Mandrel will be set down into place, then be secured via nuts and washers on either side of the assembly.
- Carbon Fiber Prepreg will then be rolled onto the mandrel.
- Entire assembly will be put into autoclave to be hardened.

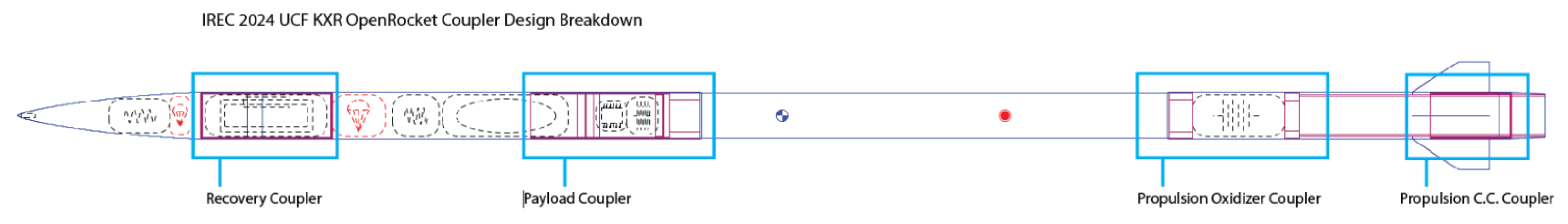
Updated Mandrel Plug
- Press fit design.
- Accepts bearings for smooth operation of rolling procedure.
- 3D Printable Design.

KNIGHTS EXPERIMENTAL ROCKETRY

Coupler Fabrication

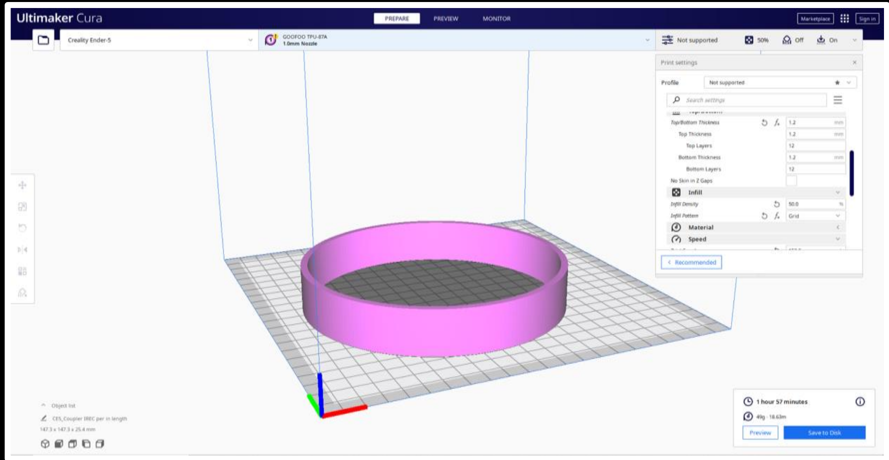
Design Consideration

Material of choice: *Carbon Fiber (same as airframe)*
Fabrication Method: *Pre-impregnation with 24'' Steel Mandrel*
3 – 4 couplers for rocket body



Measure	TPM Value	Units	Verification Method
Axial Compressive load	-	Lbs	Numeric calc. / Ansys
Bending moment load	-	Lbs	Numeric calc. / Ansys
Load Safety Factor	-	F.S./Lbs	Numeric calc.
Bending Moment Load Safety Factor	-	F.S./Lbs	Numeric Calc.
Parachute shock load	-	Lbs / in/in	Numeric Calc. / OSCALC software
Bolt holes shear value	-	Lbs	Numeric Calc.
Bolt requirements F.S. base	-	Lbs	Numeric Calc.

Requirement	Verification Method
The couplers **shall** be 1.5 cal into each side of the airframe	Design specification
The couplers **shall** be structurally stable	Ansys/Numeric Calculations
The couplers **shall** include specific subsystem requirements (i.e. access holes)	Design specifications
The couplers **shall** include specific length tolerancing is accounted for from the propulsion-payloads –recovery section	Design Specifications



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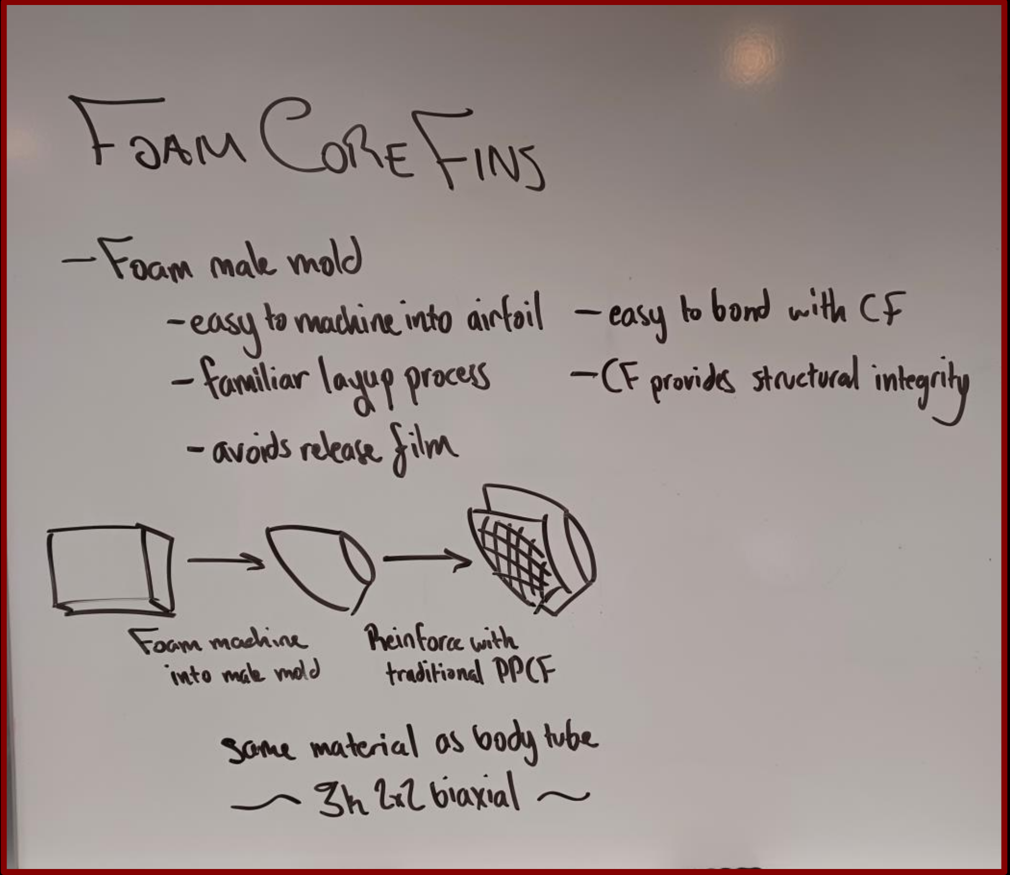
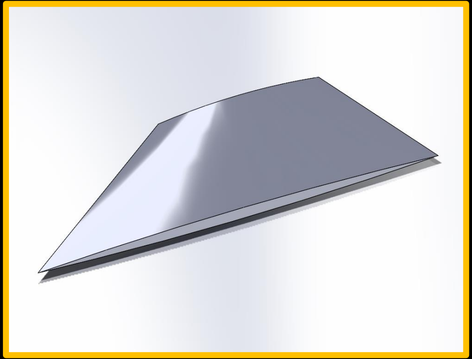
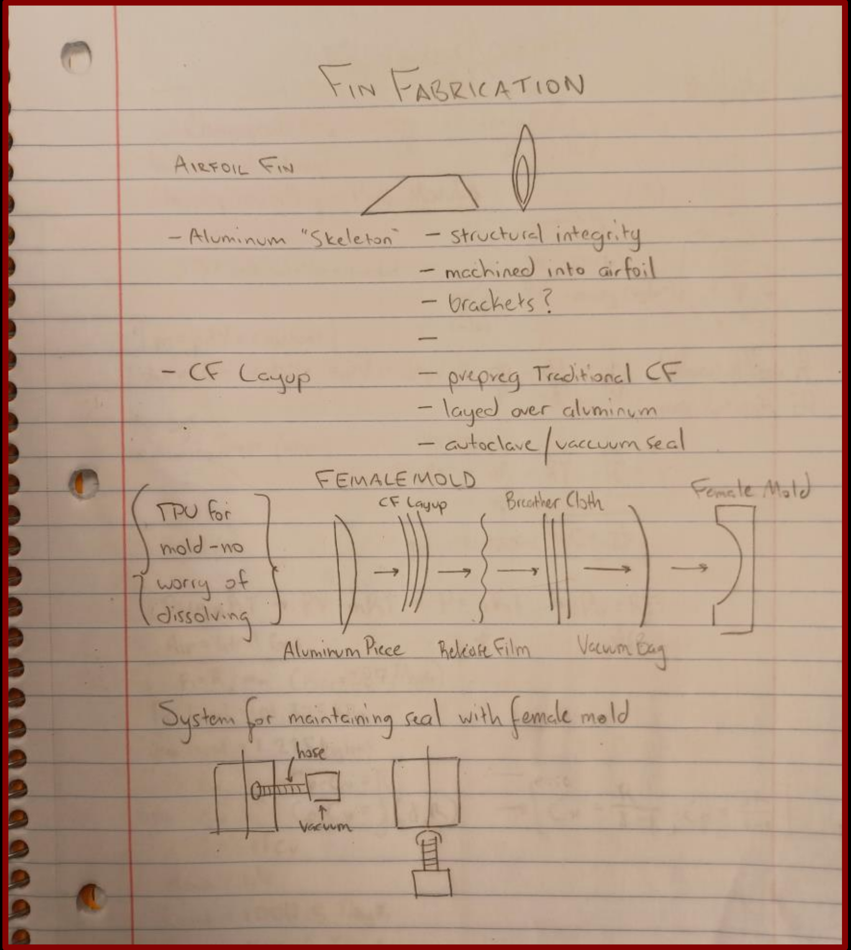
Fin Fabrication



Using a foam core fin structure to combine the machinability properties of foam to generate a male mold and the structural integrity provided by the 3k carbon fiber reinforcement.





The layup process will be optimized as the foam core is not intended to be separated, meaning the separation agent present in most mold layups will be abandoned to create a bond with the carbon fiber shell. Instead, a 3M High Bond Adhesive will be used to encourage binding.

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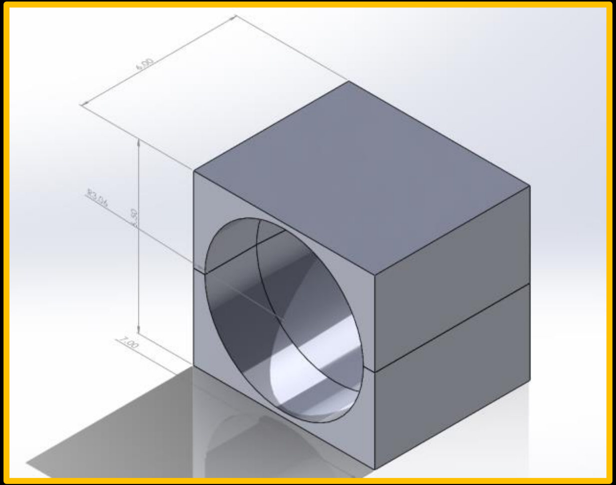
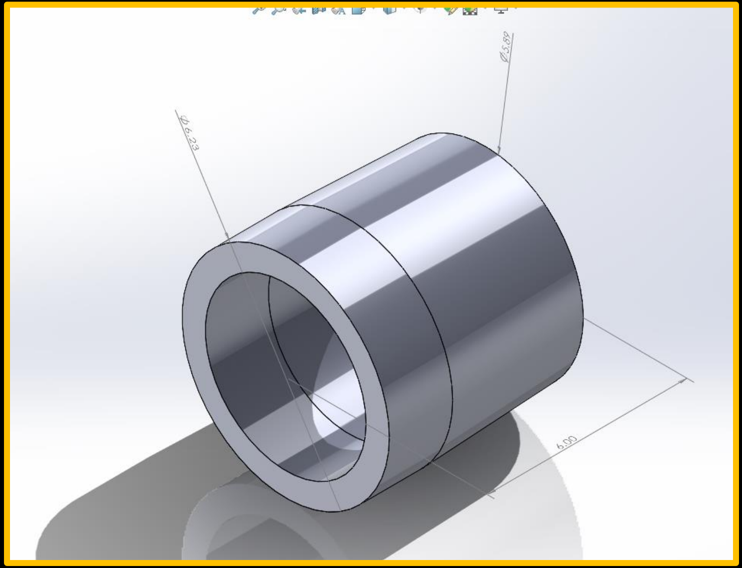
Tail Cone Fabrication



Mold Requirements:

- Withstand curing temperature of 250° Fahrenheit and a pressure of 14.7 Psi (1 atm) inside of the autoclave
- Easily reusable with minimal processing
- Doesn't bond to the composite



Design Considerations:

- Material choice for the mold
- Type of mold (Female/Male)
- Sizing and Structuring

Schedule

Material Order Date – Order materials

Estimated Lead time – 1-2 weeks

Date – Materials arrive

[2 days] - 3d printer subscale printing

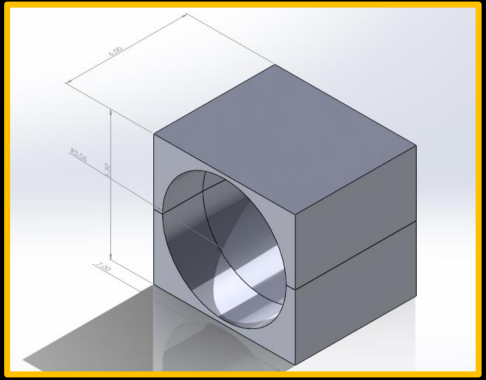
[2-3 days] - full scale prototype printing

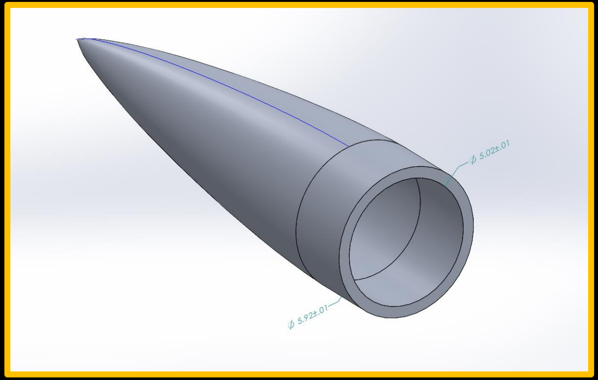
[2-3 days] - autoclave testing/adjusting thickness

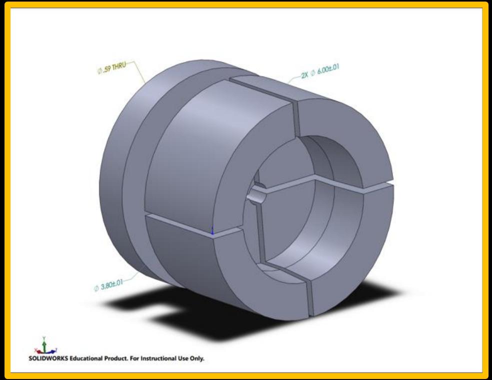
[3 days] - flight layup + curing process

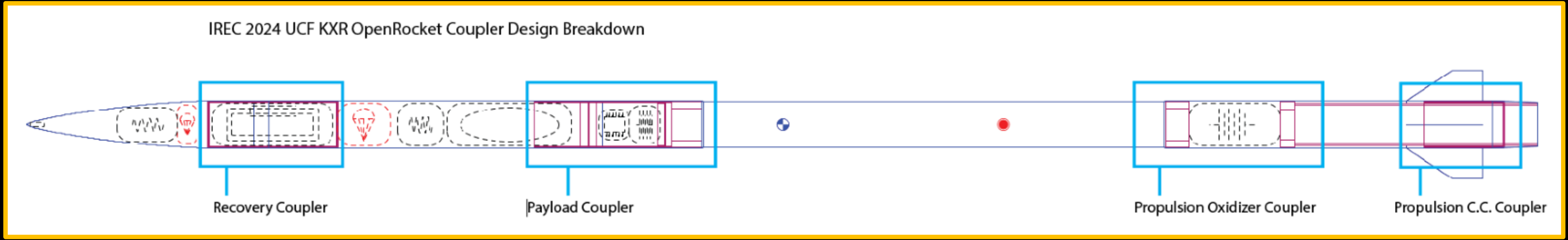
[1 day] - post processing and flight ready product

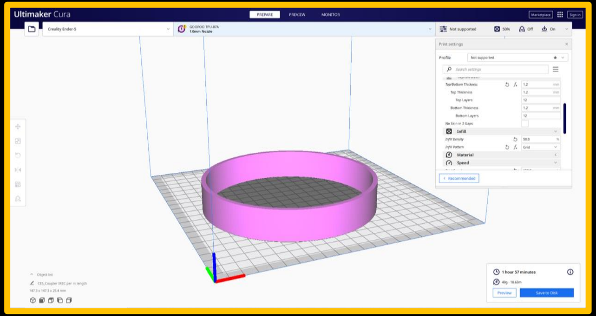
Questions?

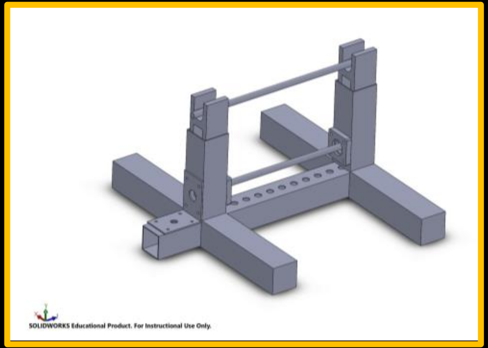












KNIGHTS EXPERIMENTAL ROCKETRY

Propulsion System Preliminary Design Review

Spaceport America Cup 2024

IREC 30k SRAD Hybrid Engine, Experimental Payloads, and Airframe

10/30/23

Propulsion System Architecture

- 40 in Combustion Chamber
  - Fuel: Paraffin Wax-Sorbitol Grain
- 68in Oxidizer tank
  - Oxidizer: Liquid Nitrous Oxide

- Total System Height: ~10 feet
- Total System Weight: ~75 lbs wet
- Target Apogee: 30,000ft AGL
- Target Thrust:
  - 1,500lbf peak
  - 8,992lbf-s impulse (40,000Ns)

KNIGHTS EXPERIMENTAL ROCKETRY
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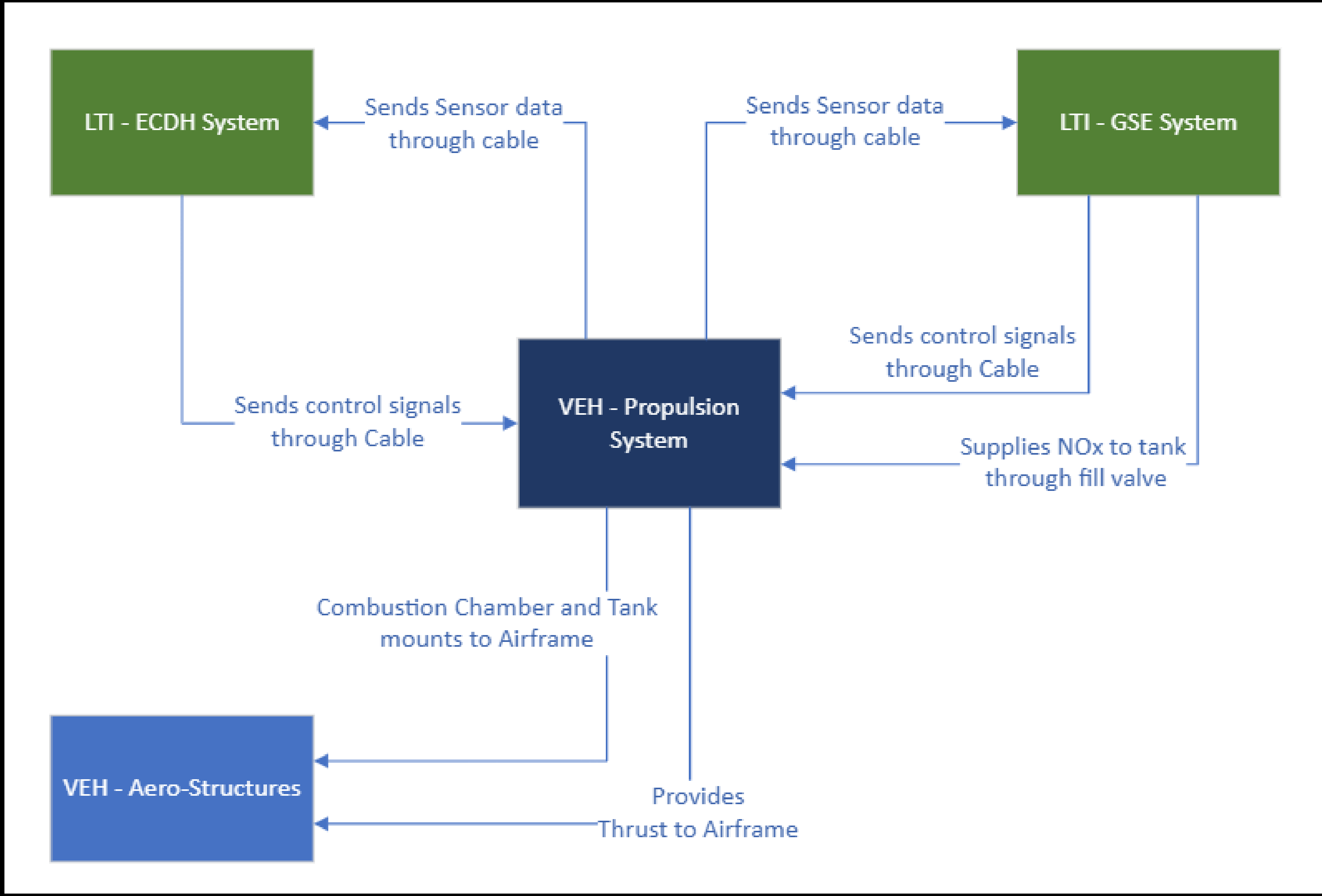
Propulsion System Requirements

Requirement	Verification Method
The Propulsion System **shall** have a wet mass of [80] lbs.	Inspection
The Propulsion System **shall** have an impulse of [36,948] Ns	Test
The Propulsion System **shall** have a dry mass of [55] lbs.	Inspection
The Propulsion System **shall** easily fit into the inner diameter of the airframe.	Demonstration
The Propulsion System **shall** have a peak thrust of [1,837] lbs.	Test
The Propulsion System **shall** implement Liquid Nitrous Oxide as an oxidizer.	Demonstration
The Propulsion System **shall** passively vent under [30] minutes.	Demonstration
The Propulsion System **shall** provide thrust to the Vehicle.	Demonstration
The Propulsion System **shall** withstand aerodynamic forces.	Analysis
The Propulsion System **shall** withstand its own produced forces.	Demonstration
The Propulsion System **shall** recover safely and without damage.	Demonstration
The Propulsion System **shall** be reusable.	Demonstration
The Propulsion System **shall** fill in under [30] minutes.	Demonstration

Propulsion System Interface Diagram



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Propulsion System CONOPS

Phase	Step	Description
Phase 1	Assembly	Assembly of propulsion system inside airframe
Phase 1	Inspection	Inspection of motor, leak test of plumbing with N2O, and GSE functionality test
Phase 2	NOx Fill	Open NOx bottle Open Main fill Valve
Phase 2	NOx Vent	Cycling vent solenoid until nominal fill status
Phase 2	QD	Wait for go-no go by range officer Actuate QD
Phase 3	Countdown	10 Second Countdown
Phase 3	Ignition	e-match ignited by Wanda relays and heats fuel grain
Phase 3	Ball Valve Actuation	Actuation of ball valve in order to allow NOx to flow through the system
Phase 4	Liq - NOx Burn	Liquid NOx arrives at the injector, atomizes, and injects into fuel grain
Phase 4	Gas - NOx Burn	Liquid NOx exhausts, and slowly tapers off
Phase 5	Burnout	PCB^2 sends signal to shut main ball valve

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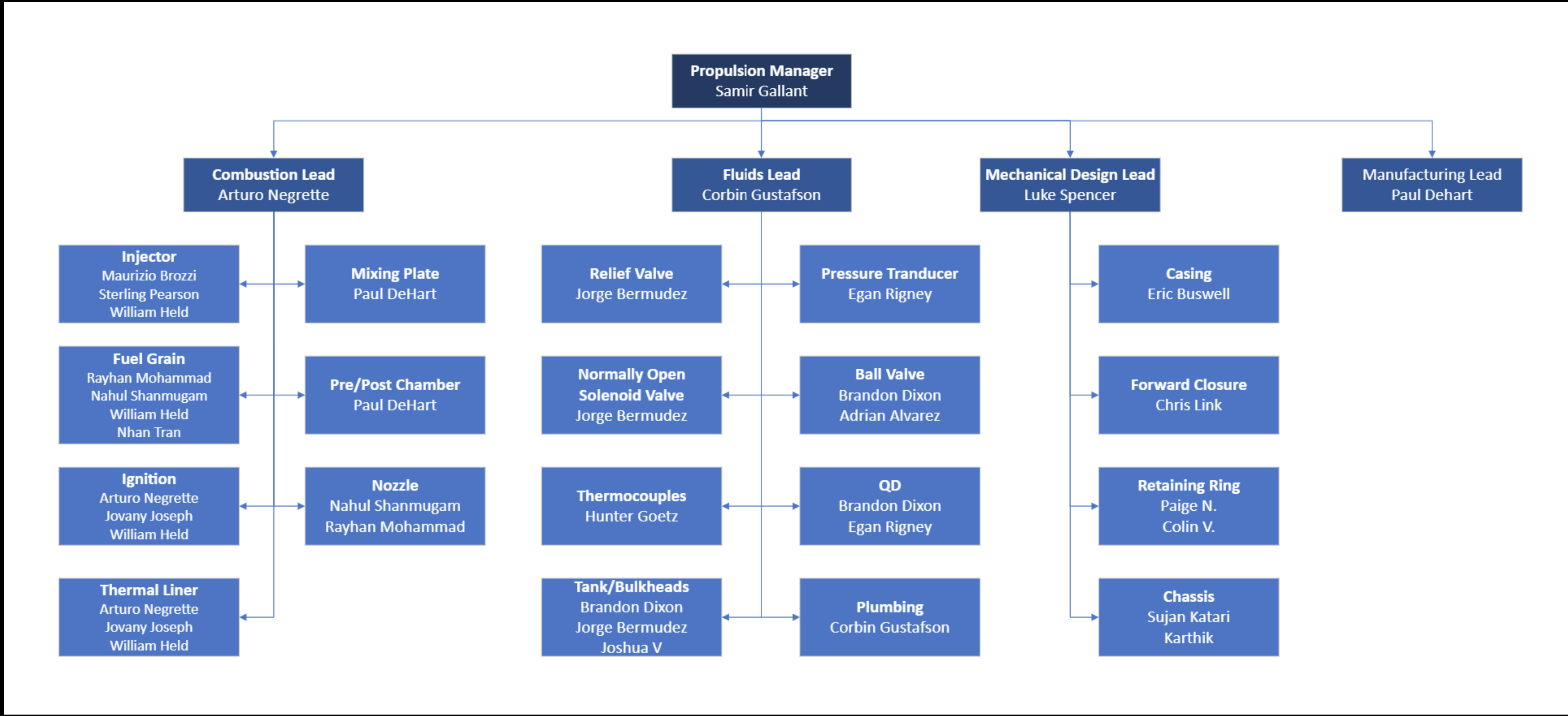
Propulsion Organization Chart



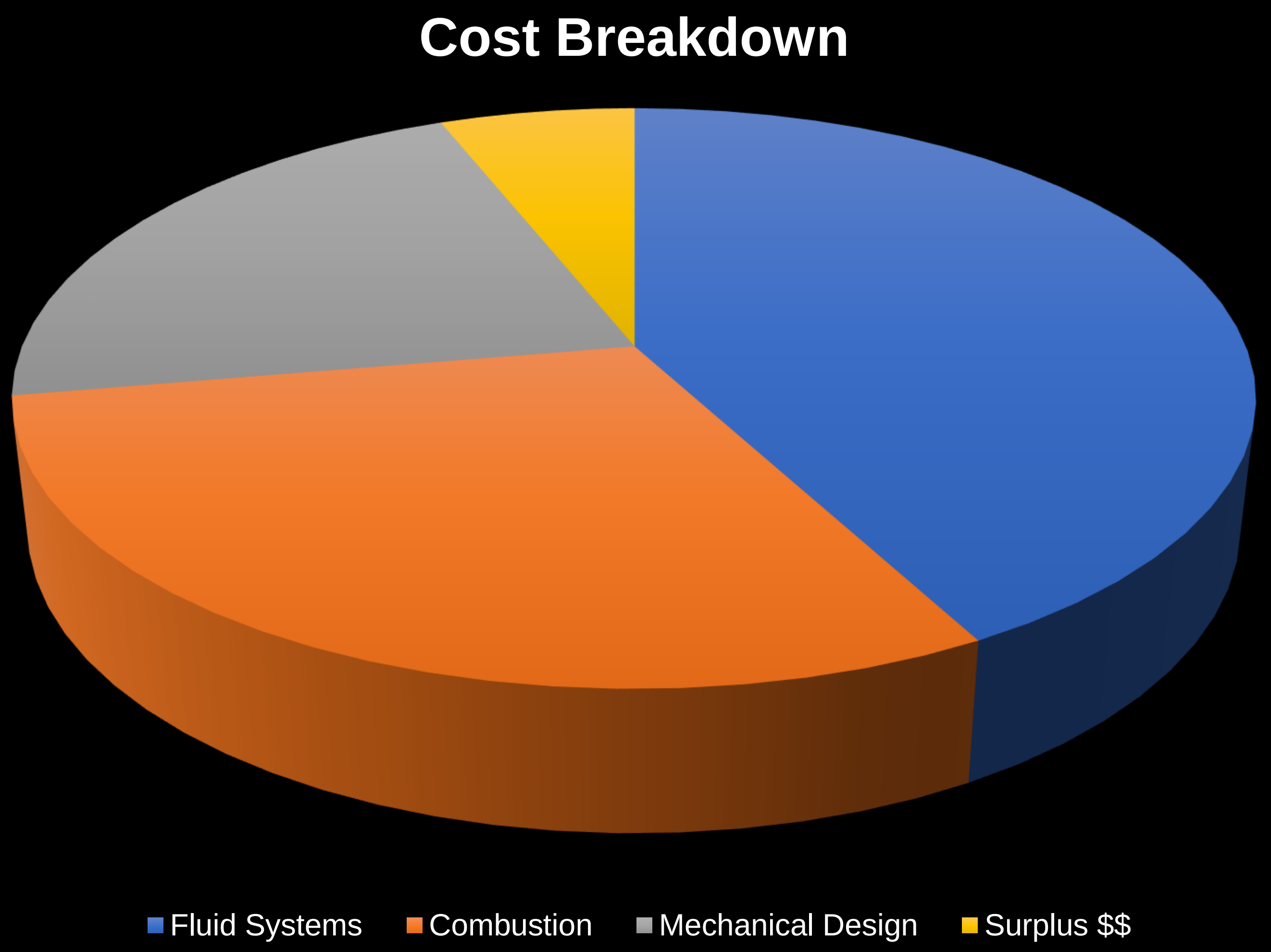
KNIGHTS EXPERIMENTAL ROCKETRY

Propulsion System TPMs

Measure	TPM Value	Units	Verification Method
Total Length	[120]	in	Inspection
Max OD	[6]	in	Inspection
Peak Thrust	[1837]	lbf	Testing
Impulse	[36,948]	Ns	Testing
Total Burn Time	[10-12]	s	Testing
Dry Weight	[25]	lbs	Inspection
Wet Weight	[80]	lbs	Inspection

Propulsion System Cost

- Fluids Cost ~ $3500
- Combustion Cost ~ $2500
- Mechanical Cost ~ $1800
- Buffer ~ $500
- **Total ~ $8300**



KNIGHTS EXPERIMENTAL ROCKETRY

Propulsion System Risks

Risk	Mitigation
NOx Leak	Properly installing all fittings, as well as choosing Yor/Swage/Hy-Lok fittings.
Ignition Failure	Using two E-matches for redundancy, as well as including a mold in the fuel grain that will retain the igniter at the top and in the port of the grain.
Incomplete Ignition	Using a mold in the fuel grain to hold the igniter against it.
NO Solenoid Burnout	Designing a system that automatically closes the Solenoid if it's duty cycle is a starting to get reached, as well as monitoring the time it's open.
Burn through	Oversizing and properly casting the fuel grain. Also thickening exposed parts of the liner.
Incomplete Fill	Adding redundant sensors as well as coordinating with LTI to ensure tha there's enough NOx for each fire/launch attempt.

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Propulsion System Verification Plans

1. FEA on mechanical design and fluids sub-systems components
2. CFD on nozzle and injector
3. Inspection of COTS and machined components
4. Dry fit of propulsion system
5. Valve and electronic component testing
6. Hydrostatic Test
7. Water Flow Injector Test
8. Cold Flow Test
9. Static Fire Test
10. Launch

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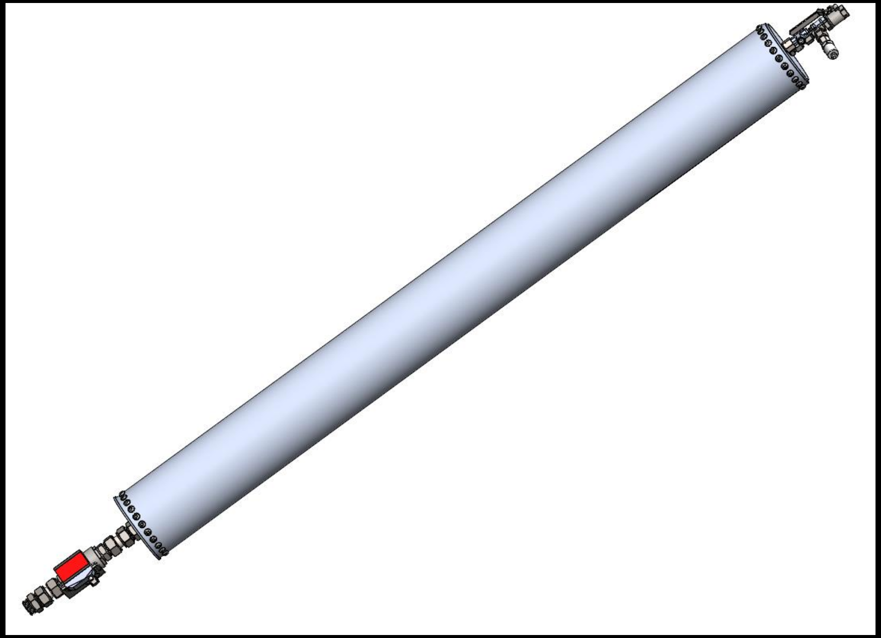
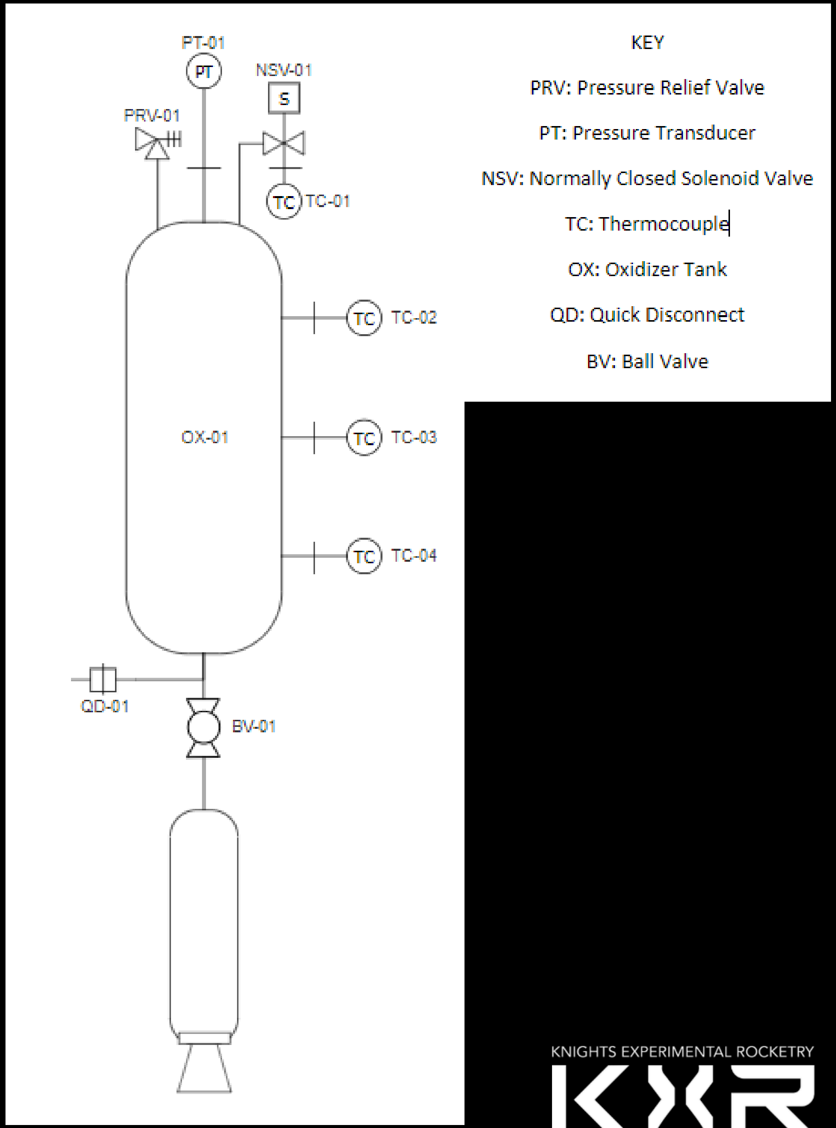
Fluids Sub-System

- Store oxidizer
- Provide mass flow to combustion chamber
- Fill through GSE
- Measure tank temperature and pressure
- Regulate pressure
- Integrate with airframe





KNIGHTS EXPERIMENTAL ROCKETRY

Fluids Sub-System Requirements

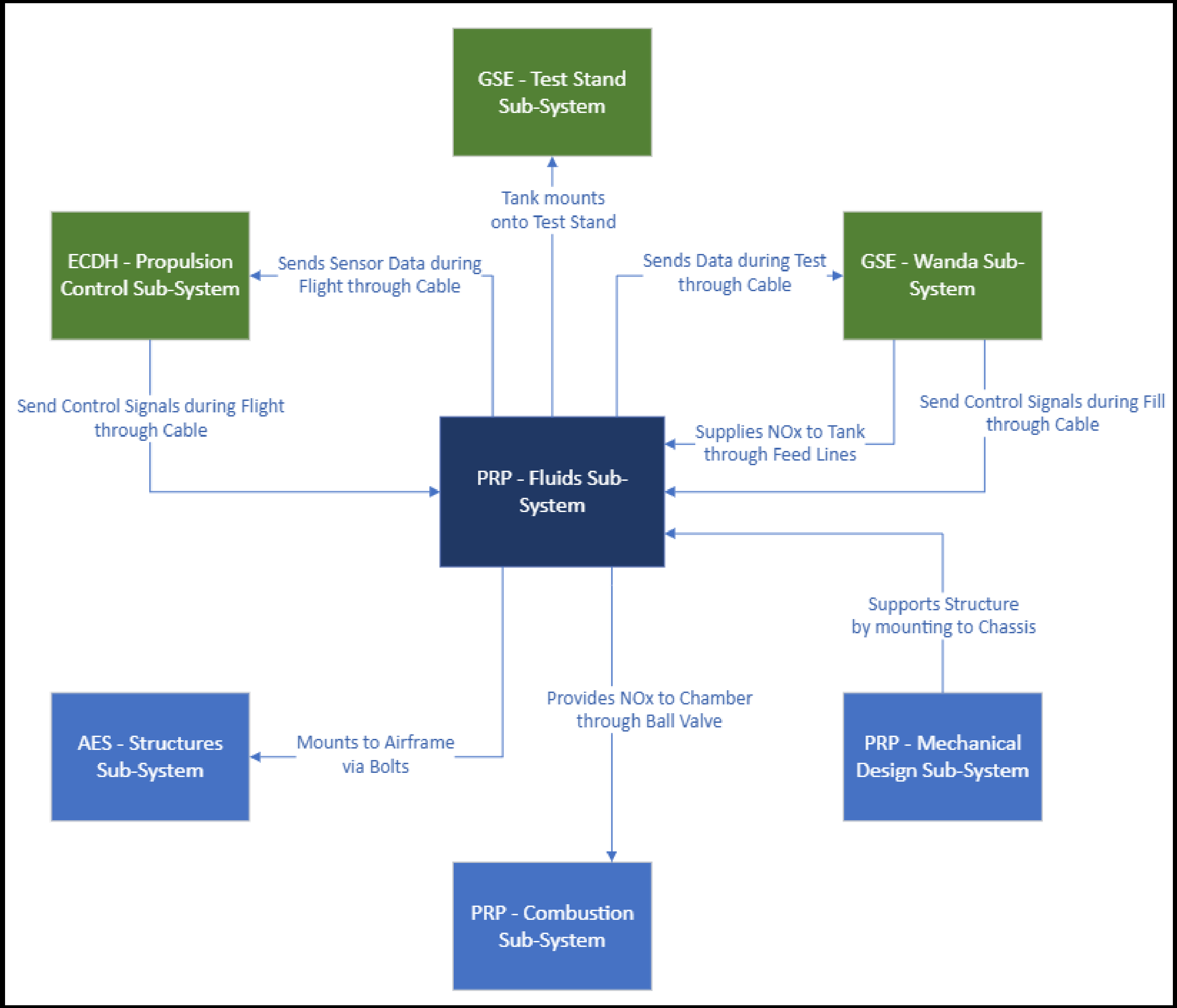
Requirement	Verification Method
The Fluids Sub-System **shall** have a Dry Weight of [TBD] lbs.	Inspection
The Fluids Sub-System **shall** have a Total Length of [TBD] inches.	Inspection
The Fluids Sub-System **shall** withstand a minimum temperature of [223.15] Kelvin.	Analysis
The Fluids Sub-System **shall** withstand a Maximum Expected Operating Pressure of [1500] psi.	Test
The Fluids Sub-System **shall** be reusable.	Demonstration
The Fluids Sub-System **shall** provide liquid Nitrous Oxide to the Combustion Sub-System.	Demonstration
The Fluids Sub-System **shall** provide sensor data to the Propulsion Control Board.	Demonstration
The Fluids Sub-System **shall** provide an initial Oxidizer Mass Flow Rate of [4.8 lb/s] to the Injector.	Test
The Fluids Sub-System **shall** contain all liquid Oxidizer without unintentional flow or leaking.	Test
The Fluids Sub-System **shall** vent when overpressurized.	Demonstration

KNIGHTS EXPERIMENTAL ROCKETRY

Fluids Sub-System TPMs

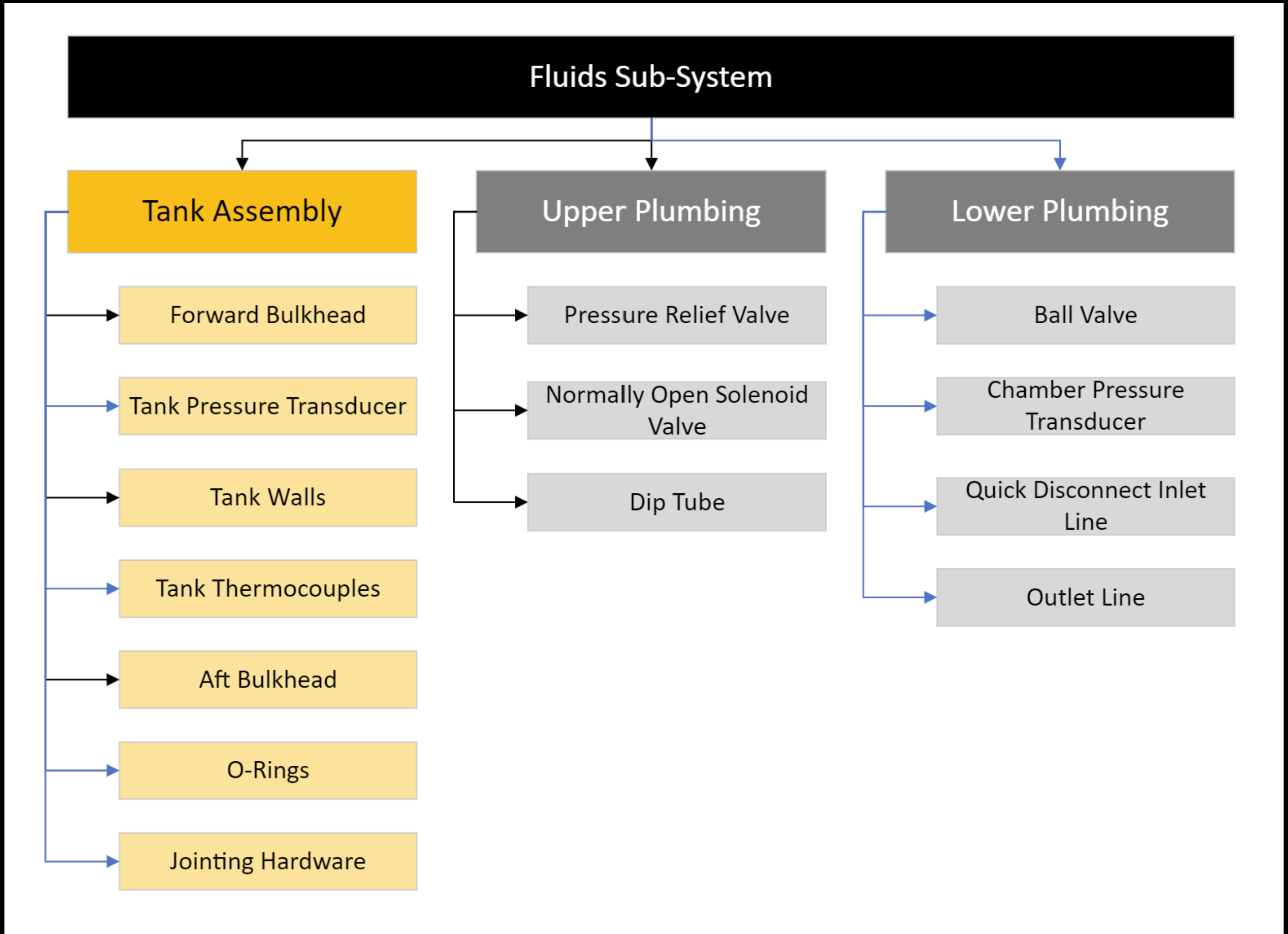
Measure	TPM Value	Units	Verification Method
Total Length	[80]	inches	Inspection
Total Oxidizer Weight	[45]	lbs	Inspection
Maximum Expected Operating Pressure	[1000]	psi	Test
Delivered Mass Flow	[7.97]	lb/s	Test

Fluids Sub-System Interface Diagram



KNIGHTS EXPERIMENTAL ROCKETRY

Fluids Sub-System Component Breakdown



KNIGHTS EXPERIMENTAL ROCKETRY

Oxidizer Tank Casing

Thin Wall Approximation Validity:

$$31 = \frac{D}{t} > 20$$

Barlow's Formula:

$$P = \frac{2\,TS}{D_O}$$

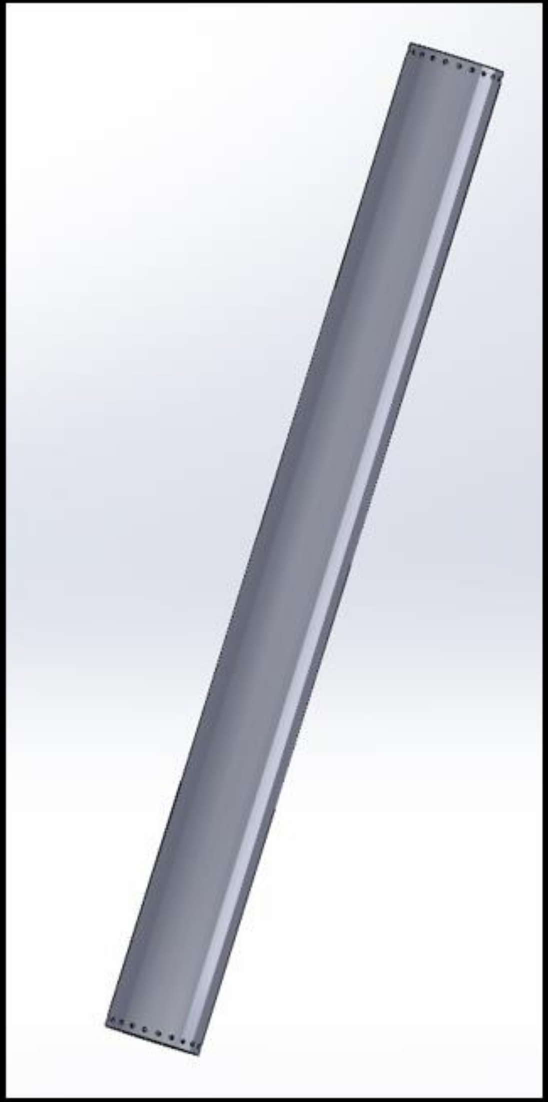
Hoop Stress:

$$Q_H = \frac{PD_I}{2\,T} = 22{,}500 \text{ psi}$$

Axial Stress:

$$Q_A = \frac{PD_I}{4\,T} = 11{,}250 \text{ psi}$$

Measure	TPM Value	Units
Total Length	[68]	in
Outer Diameter	[6]	in
Dry Weight	[23.42]	lbs
Volume	[27]	L
Tank Wall Thickness	3/16	in



Machined from Aluminum Cylinder: $138.23

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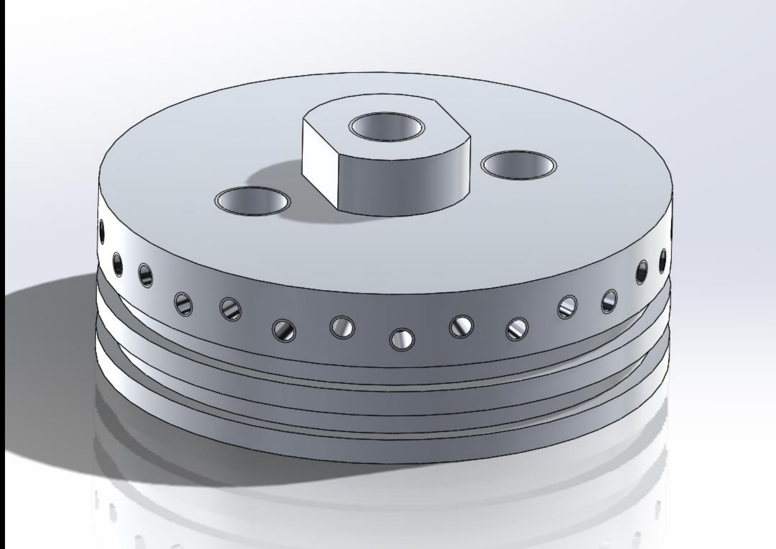
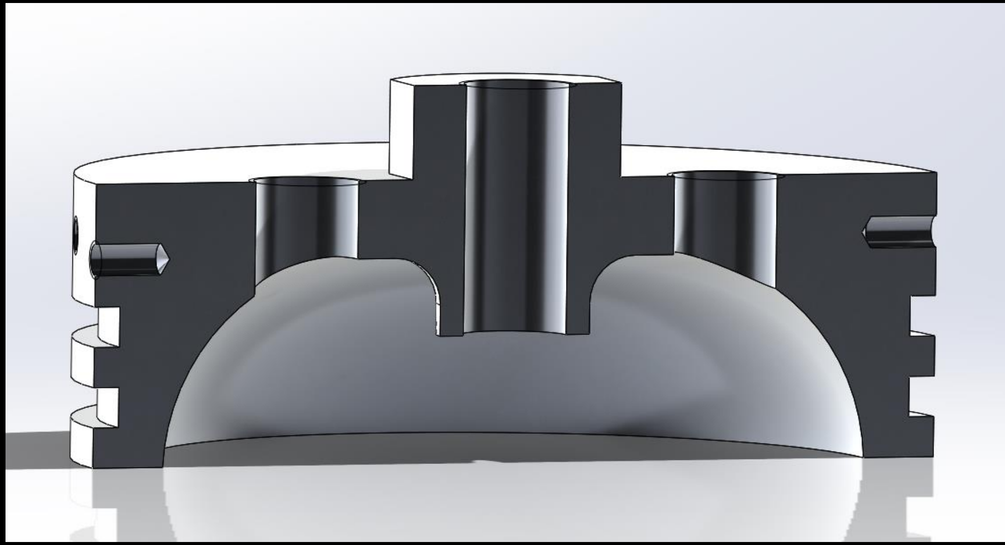
Oxidizer Tank: Forward Bulkhead

- Aluminum 6061 T6
- ¼-20 bolts X30
- 2 radial bolt patterns
- ¾-16 threads X3
- 2-355 O-rings
- Machined in house





Force on Bulkheads

Surface Area of ½ a 5.625" diameter sphere.

$$A = 2\pi r^2 = 2\pi\left(\frac{5.625\text{ in}}{2}\right)^2 = 49.7\text{ in}^2$$

$$F_{\text{on each bulkhead}} = (49.7\text{ in}^2)(1000\text{ psi})(1.5) = 74550\text{ lbs}$$

$$\text{Number of bolts} = \frac{F_{\text{on bulkhead}}}{A_{bolt} \cdot \sigma_{shear\,bolt}}$$

$d_{minor\,bolt} = 0.196"$, $\sigma_{shear} = 90{,}000\text{ psi}$

$$N = \frac{74550\text{ lbs}}{\frac{\pi}{4}(0.196\text{ in})^2(90{,}000\text{ psi})} = 27.45\text{ bolts}$$

$$\boxed{N = 30\text{ bolts}}$$

Two rings of 15 bolts. $t = 3/16"$

$$F_{bolt} = \frac{74550\text{ lbs}}{30\text{ bolts}} = 2485\frac{\text{lbs}}{\text{bolt}}$$

$$\sigma_{tear\text{-}out} = \frac{F_{bolt}}{(E_{min})(2t)} = 30\text{ ksi}$$

shear strength 6061-T6 = 30 ksi

$$E_{min} = \frac{2485\text{ lbs}(1.5)}{\left(\frac{6}{16}\text{ in}\right)(30{,}000\text{ psi})} = 0.3314\text{ in}$$

For two rows of bolts:

$$E_{min} = \frac{E_{min1} + E_{min2}}{2}$$

$$E_1 = E_{min1} + \left(\frac{d_{minor\,bolt}}{2}\right) = 1.5\, d_{bolt\,major}$$

$$E_{min1} = 0.277\text{ in}$$

$$E_{min2} = 2E_{min} - E_{min1} = 2(.3314\text{ in}) - 0.277\text{ in}$$

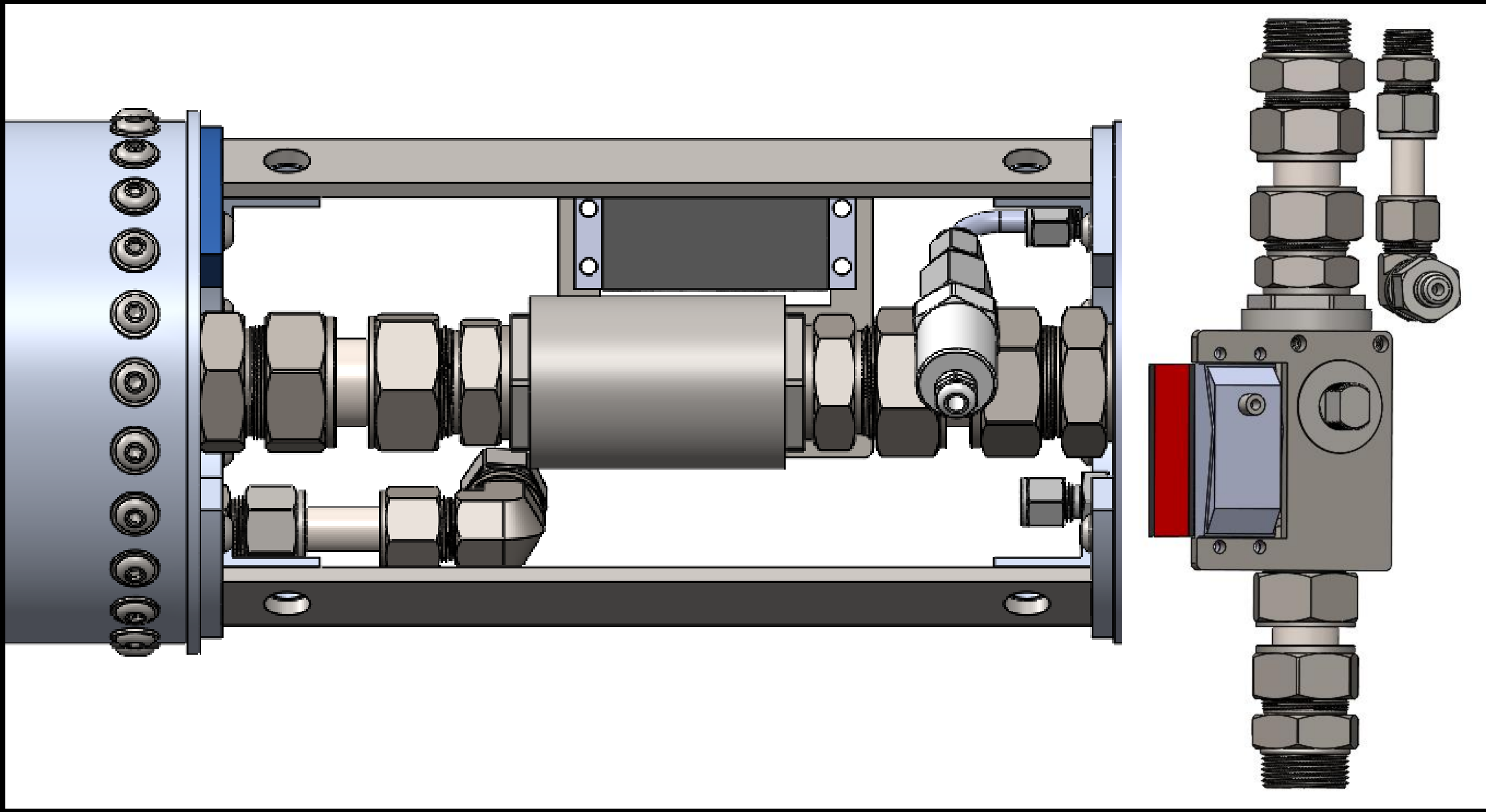
$$E_{min2} = .3858\text{ in}$$

$$E_1 = 0.375\text{ in}$$

$$E_2 = 0.4838\text{ in}$$

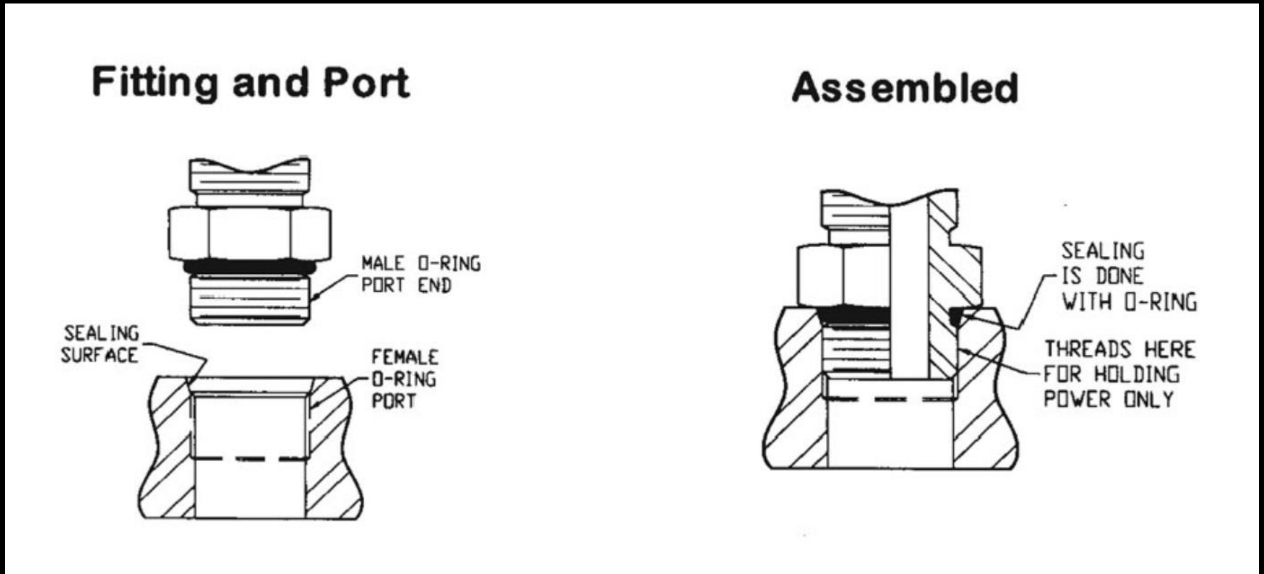
Main Plumbing Overview

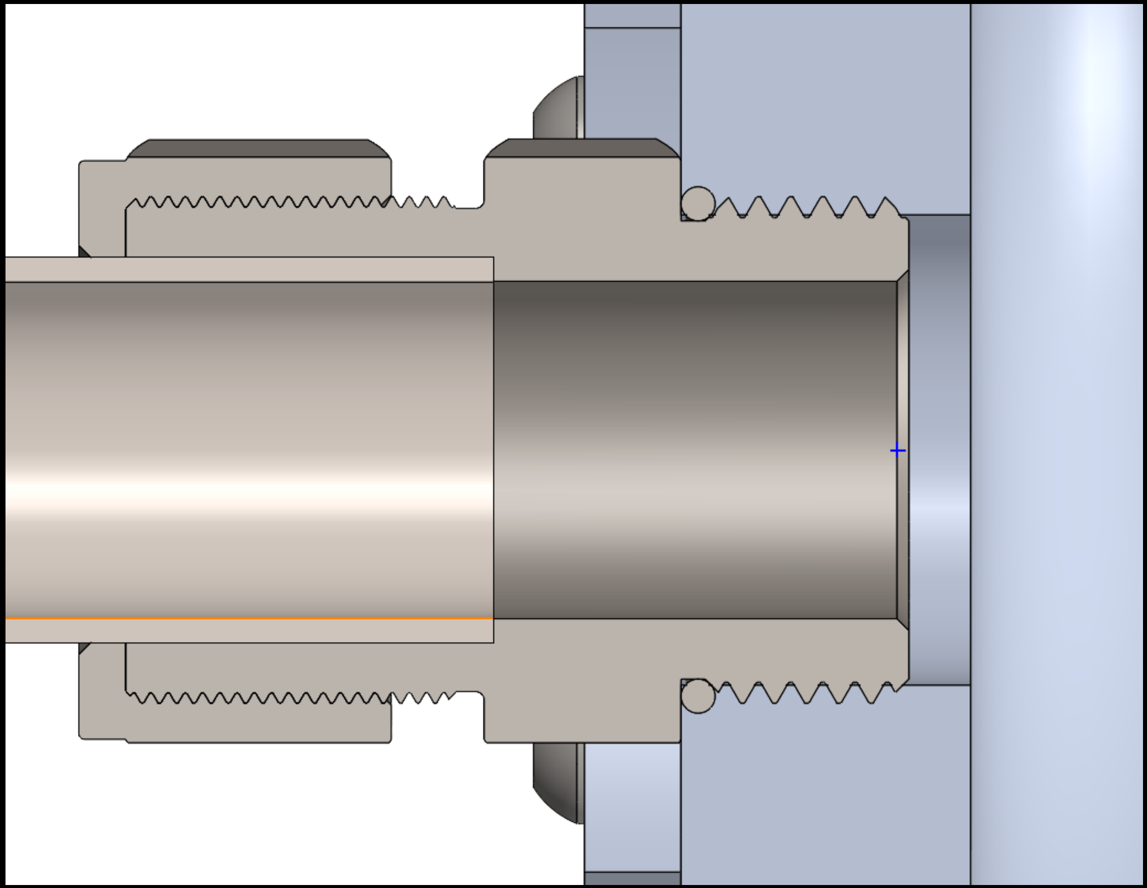
- 1'' OD Stainless Steel Lines
- Servo Ball Valve Control
- Standardized torque specifications
- ~10'' overall length
- Constrained by the tank-chamber chassis



Fitting Selection

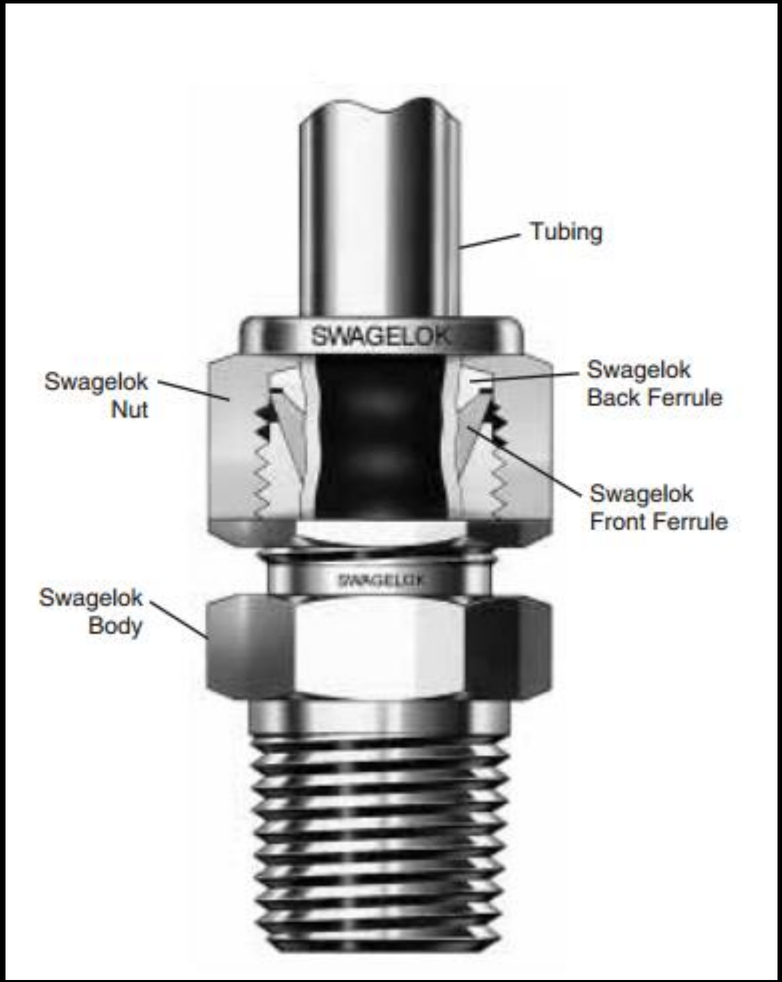
- SAE Straight Thread Fittings
  - Designed following SAE J1926
  - No need for consumable sealing

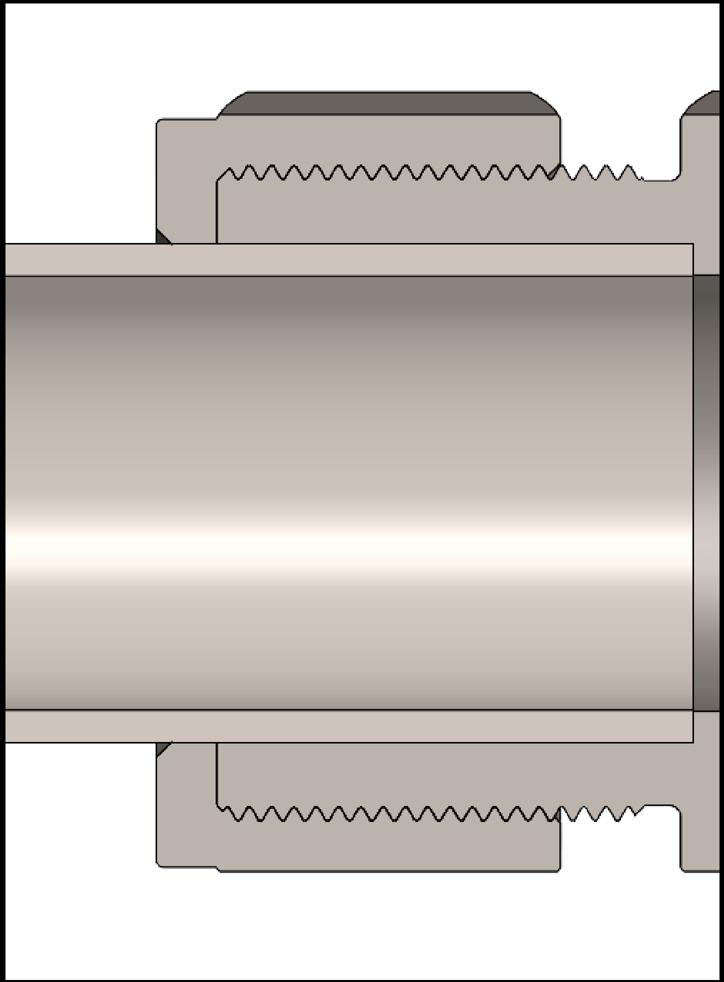




Fitting Selection

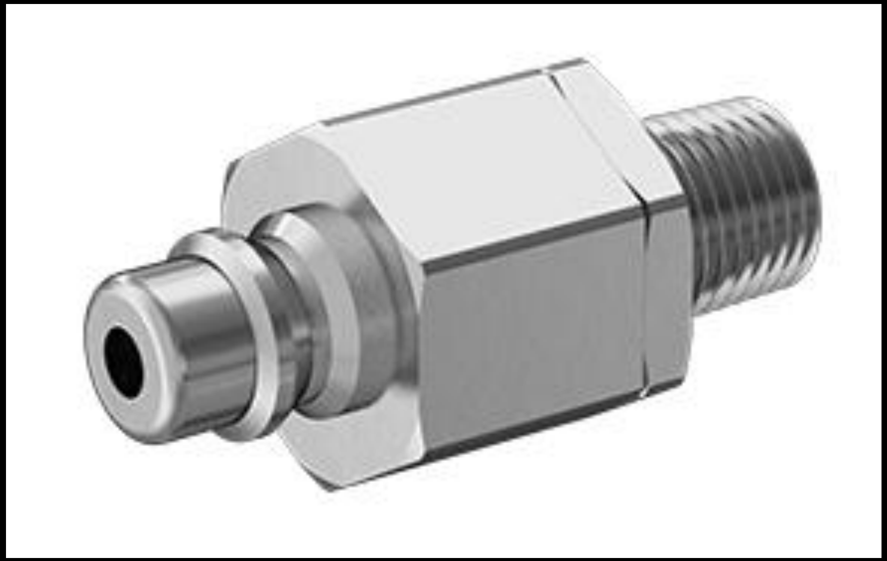
- Swagelok-type Tubing
  - Aerospace standard, widely available at any price range
  - No flaring = no need for special tooling
  - Pre-swaging is recommended for hard tubing but not required

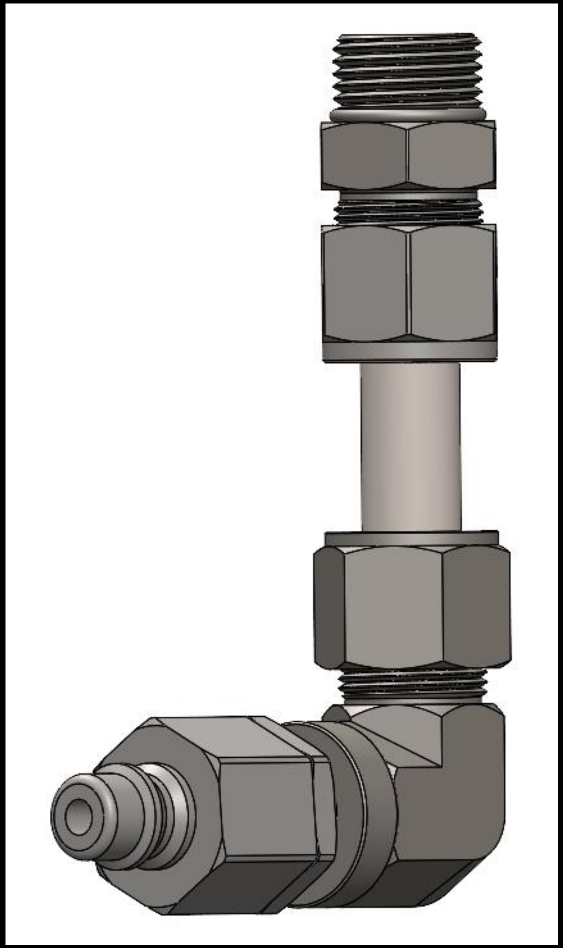


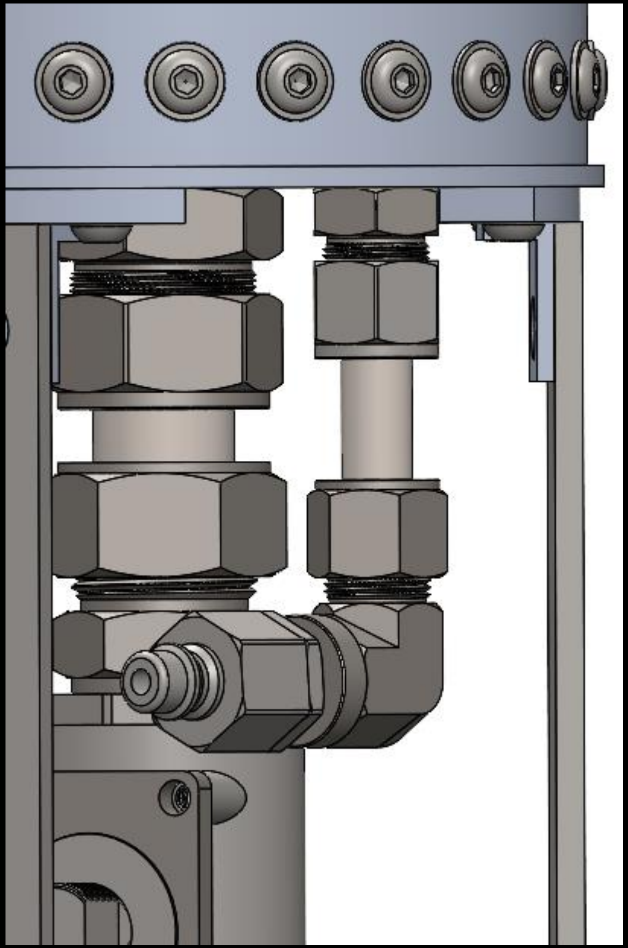


Fill Line Overview

- 1/2'' OD Stainless Steel Lines
- Automatic shut-off post umbilical retract

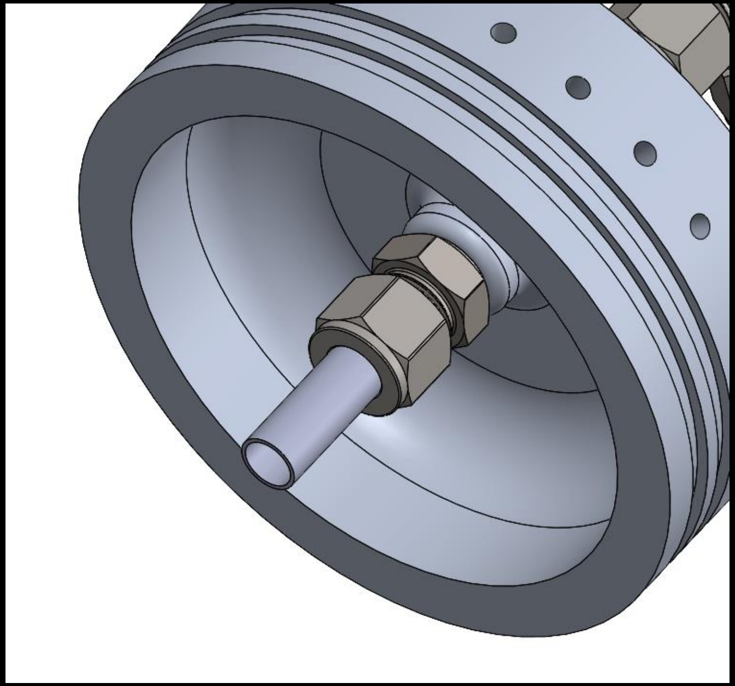




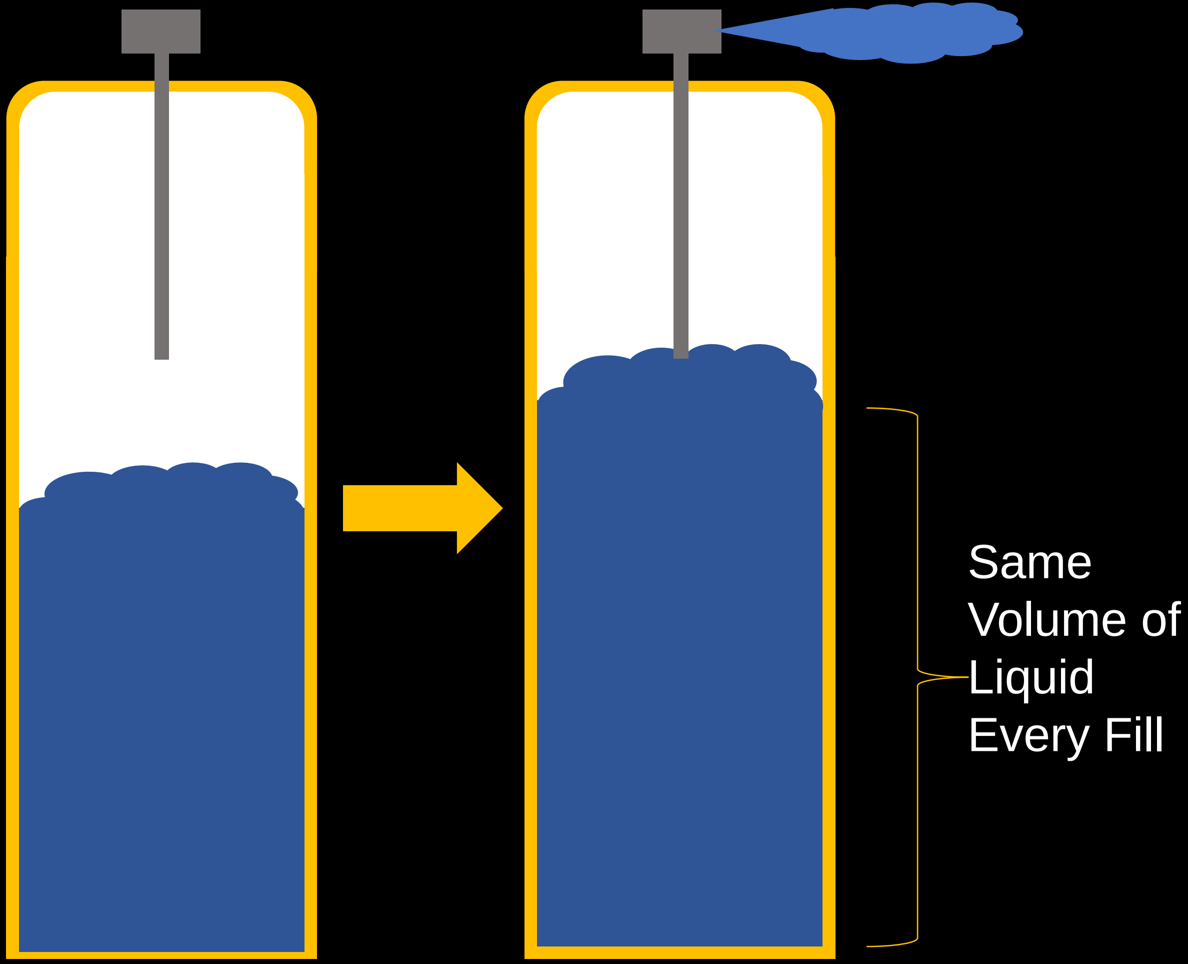


Dip Tube

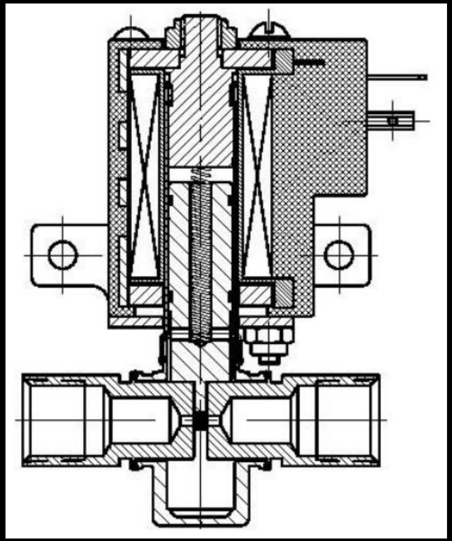
- Adjustable length
- Ullage is guaranteed through vapor lock

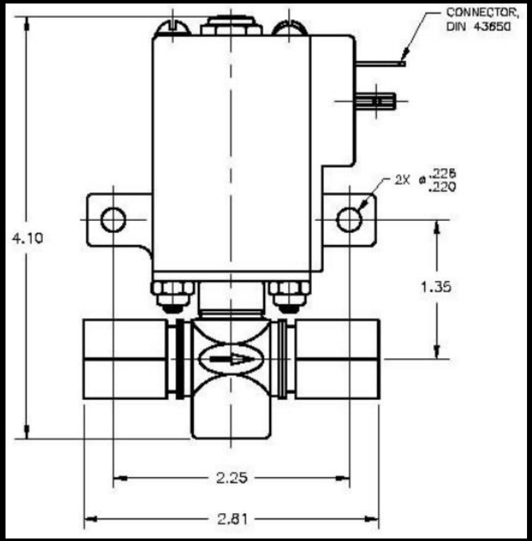


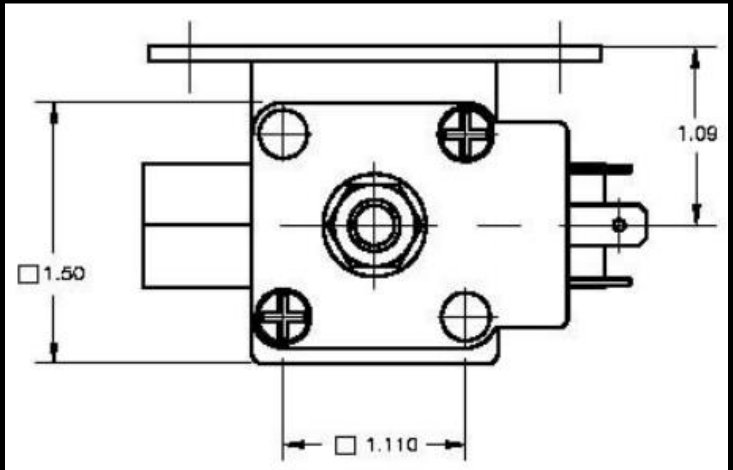
Placeholder Dip Tube As Integrated with Bulkhead



Normally Open Solenoid Valve







Valve Parts in Contact With Fluid	
Body	SS
Seal Disc	Polyimide
Plunger Tube	303 SS
Plunger	430F SS
Plunger Stop	430F SS
Spring	303 SS
Rider Rings	PTFE

Port Size (NPT)	Orifice Size (ins.)	Cv	Max. Pressure (PSI)				Model Number				Wattage	
			AC		DC		Normally Closed		Normally Open			
			Gas	Liquid	Gas	Liquid	AC	DC	AC	DC	115/ 60Hz	24/ DC
2-Way Normally Closed & Normally Open												
3/8	3/32	0.20	1200	800	400	125	SV91D28C1C	SV91D24C1C	SV91D28O1C	SV91D24O1C	14	21

Normally Open Solenoid Valve

Measure	TPM Value	Units	Verification Method
Discharge Coefficient	0.89	Cd	Calculation and Testing
Orifice Size	2.38	mm	Inspection
Dimensions	73.66 x 46.74 x 104.14	mm	Inspection
Temperature Range	-452°F - 200°F	°F	Inspection
Pressure Range	≤ 1200	psi	Inspection
Voltage	21	W @ 24DC	Inspection
Continuous Lifecycle	5	minutes	Demonstration

Coefficient of Discharge:

$$C_d = \frac{\dot{m}}{\rho \dot{V}} = \frac{\dot{m}}{\rho A u} = \frac{\dot{m}}{\rho A \sqrt{\frac{2\Delta P}{\rho}}} = \frac{\dot{m}}{A\sqrt{2\rho \Delta P}}$$

Mass Flow:

$$\dot{m} = \frac{dm}{dt}$$

Schedule:

- 4-7 Weeks Estimated Shipping

Design Considerations:

- Replace COTS NOSV with an SRAD normally open purge valve

Integration:

- NOSV is Attached to Forward Bulkhead of Tank

KNIGHTS EXPERIMENTAL ROCKETRY

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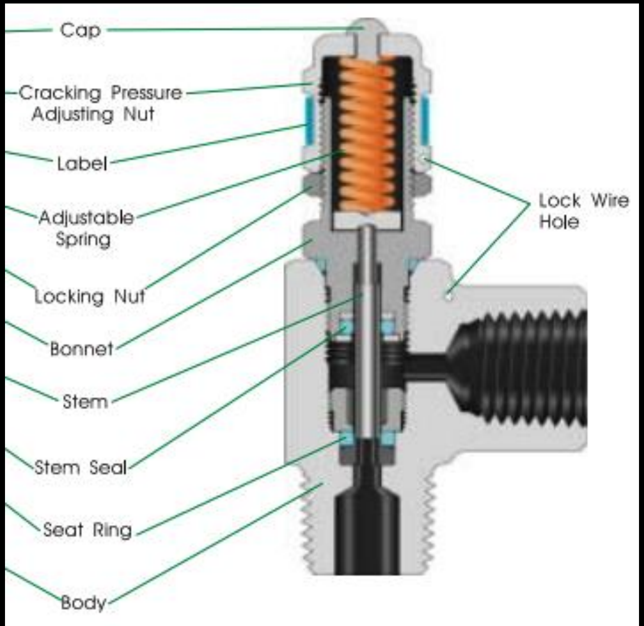
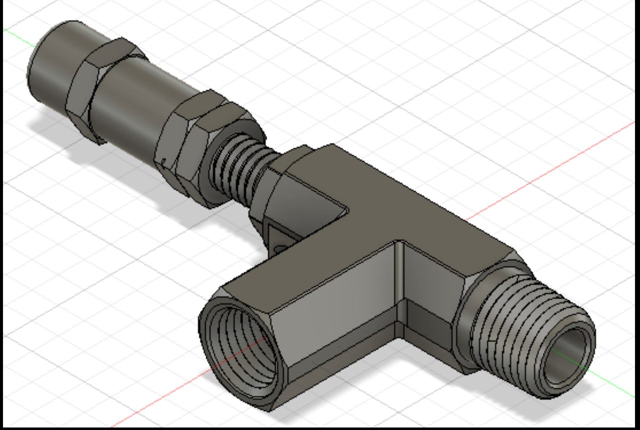
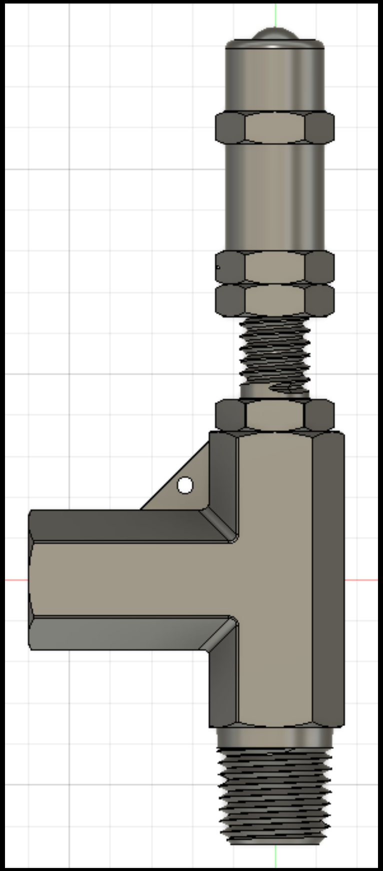
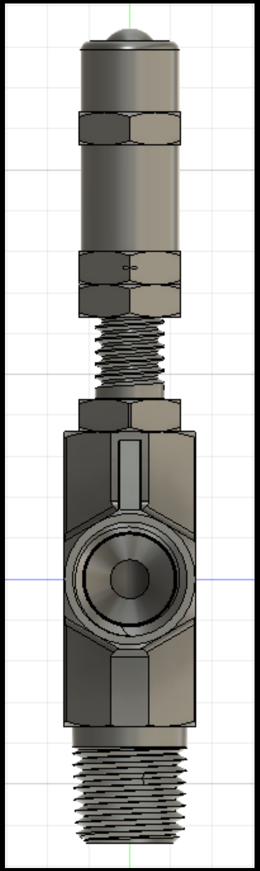
Pressure Relief Valve









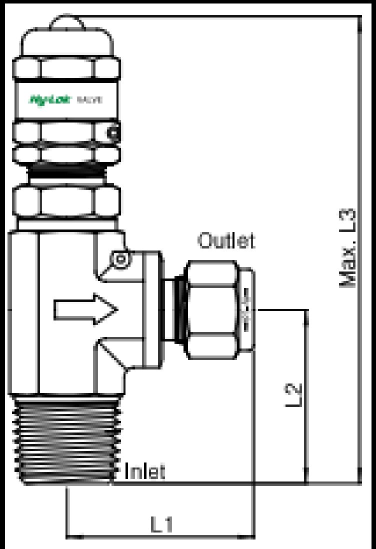


Table of Dimensions

Basic Part No.			Orifice	End Connections: Inlet	End Connections: Outlet	Dimensions: L1	Dimensions: L2	Dimensions: L3
RV1 or RV2	H	-4 T-	4.8	1/4" Hy-Lok	1/4" Hy-Lok	38.7	37.3	104.6
	H	-6M-		6mm Hy-Lok	6mm Hy-Lok			
	H	-8M-		8mm Hy-Lok	8mm Hy-Lok			
	H	-8 T-		1/2" Hy-Lok	1/2" Hy-Lok	46.7	46.7	114.0
	H	-12M-		12mm Hy-Lok	12mm Hy-Lok			
	MH	-8N8T-		1/2" Male NPT	1/2" Hy-Lok		35.7	103.0
	MH	-8N12M-		1/2" Male NPT	12mm Hy-Lok			
	MF	-4N-		1/4" Male NPT	1/4" Female NPT	30.0	32.2	99.5
	MF	-6N-		3/8" Male NPT	3/8" Female NPT	34.5		
	MF	-8N-		1/2" Male NPT	1/2" Female NPT	38.0	35.7	103.0

All dimensions are in millimeters.

KNIGHTS EXPERIMENTAL ROCKETRY

Pressure Relief Valve

Measure	TPM Value	Units	Verification Method
Orifice Size	4.80	mm	Inspection
Dimensions	99.5 x 33.099 x 15.65	mm	Inspection
Weight	124.59	g	Inspection
Pressures	≤ 1500	psi	Test
Temperatures	-10°F ≤ x ≤ 400°F	°F	Test

Discharge Coefficient:

$$C_d = \frac{\dot{m}}{\rho \dot{V}} = \frac{\dot{m}}{\rho A u} = \frac{\dot{m}}{\rho A \sqrt{\frac{2\Delta P}{\rho}}} = \frac{\dot{m}}{A\sqrt{2\rho\Delta P}}$$

Mass Flow:

$$\dot{m} = \frac{dm}{dt}$$

Schedule:

- 3-6 Weeks Estimated Shipping

Design Considerations:

- Search for PRV Smaller in Length
- Alternative with lower minimum working temperature

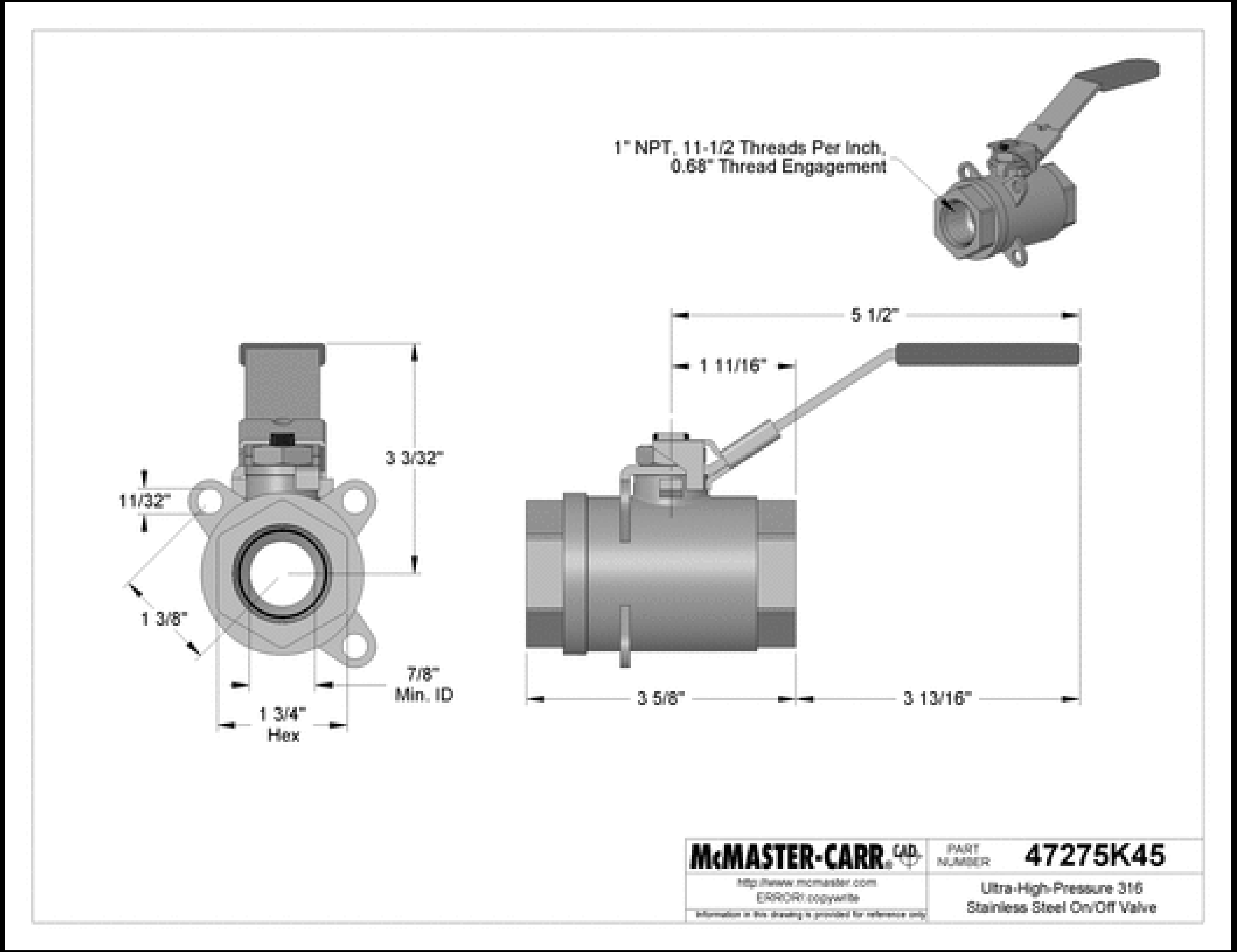
Integration:

- PRV is Attached to Forward Bulkhead of Tank

KNIGHTS EXPERIMENTAL ROCKETRY

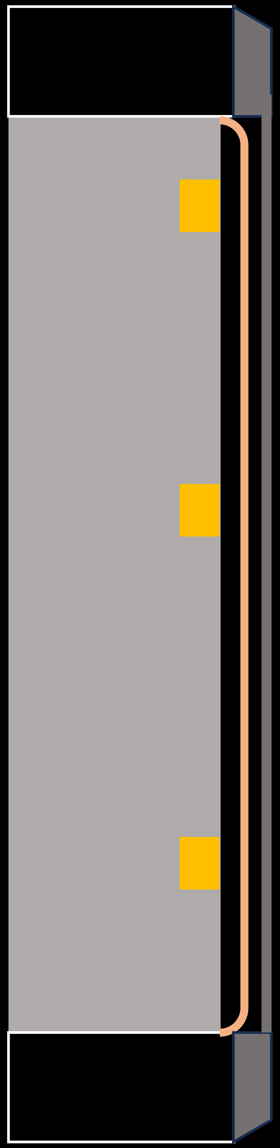
Servo Actuated Ball Valve

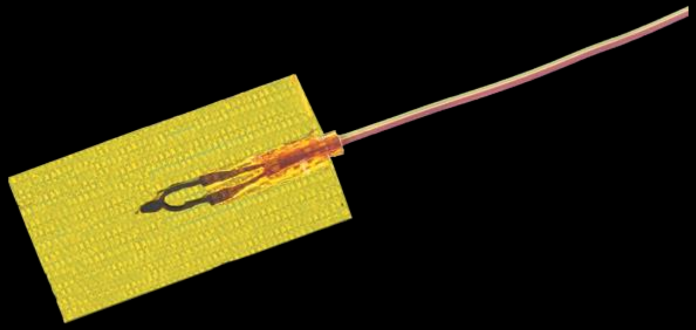
- COTS
- 7/8 inch internal diameter
- 4500 psi at 120° F
- -40° to 230° F
- 44 CV
- $300
- 316 Stainless Steel



Thermocouples + Tank Raceway

- Thermocouples bonded to surface of tank
- Ribbon cable
- 3D printed shroud, depends on integration with aerostructures



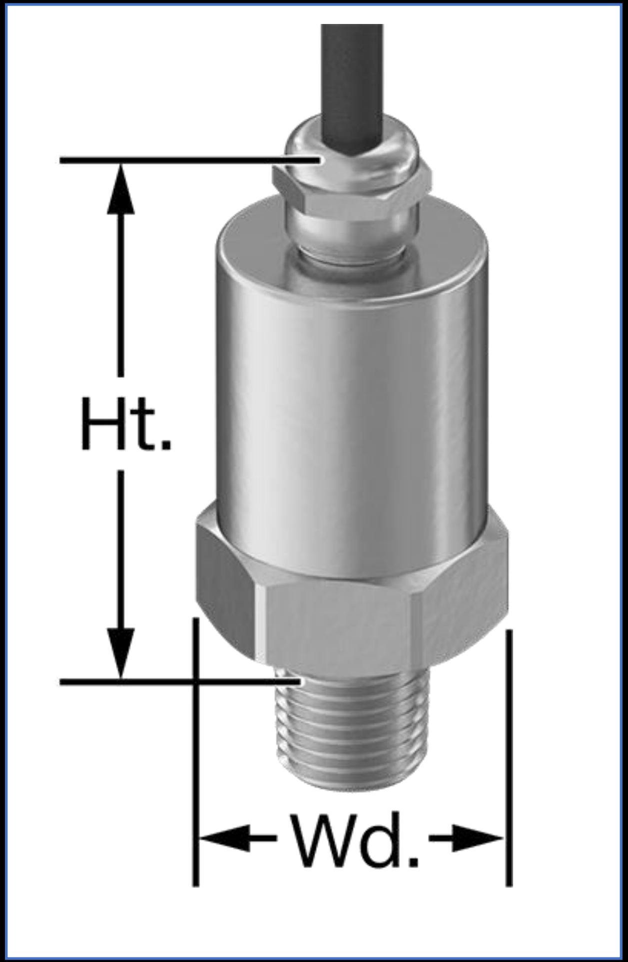


KNIGHTS EXPERIMENTAL ROCKETRY

Top Plumbing Pressure Transducer: Important Details

- Given ratings by Sub-System level requirements:
  - <0C
  - >1500 psi
  - Corrosive oxidizer fluids

- Needs to be properly rated to avoid over pressurization and reliability.
- Only required material is the component itself.
- Made of 204 Stainless Steel, which is known to be corrosion resistant.
- $107.56, ships from McMaster NJ warehouse



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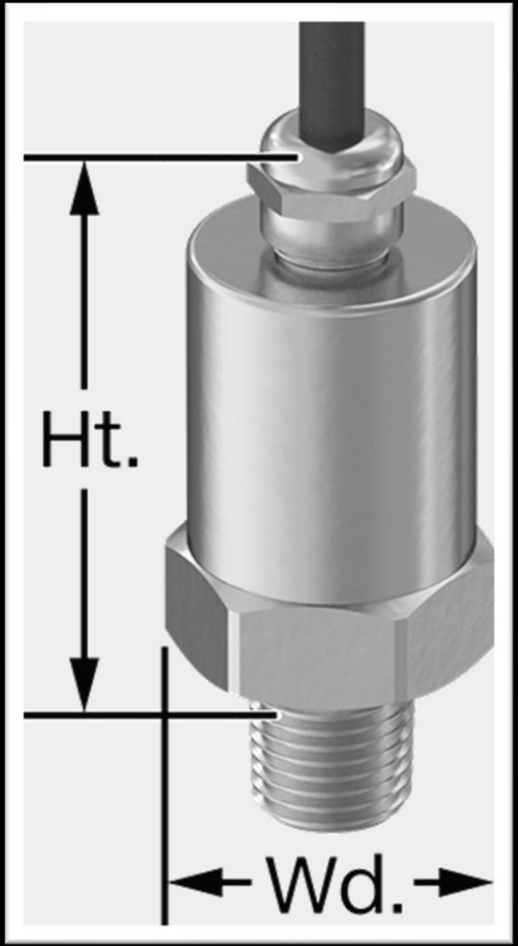
Top Plumbing Pressure Transducer: Item Details

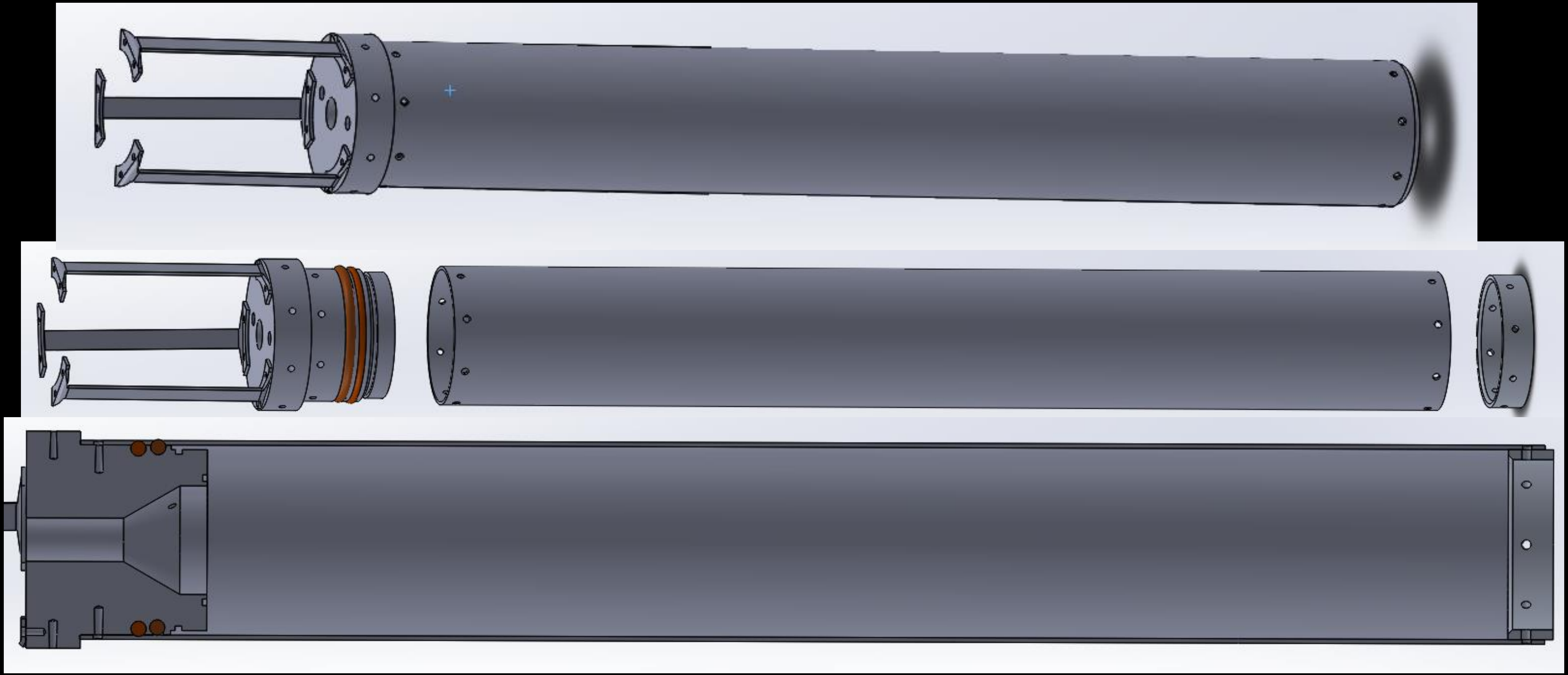
Pressure Range: 0-1500psi
Max Short-Term Pressure: 2250 psi
Output Signal: 4-20mA
Accuracy: +/- 1.5%
Response Time: 0.001 s
Connection: ¼" NPT, Male
Temp Range: -20F – 220F
Wire #: 2
Wire Length: 18"
Material: 304 Stainless Steel
Height: 1 13/16"
Width: 15/16"



Future Plans

- NOS is changing to QD normally open relief
- Ball Valve Servo design
- Finalize NOX Tank – Airframe connection
- Finalize Thermocouple selection

Mechanical Design Sub-System



Mechanical Design Requirements

Requirement	Verification Method
The Mechanical Sub-System **shall** withstand maximum operating temperature of [2600] Kelvin	Test
The Mechanical Sub-System **shall** withstand maximum operating pressure of [1000] PSI.	Test
The Mechanical Sub-System **shall** withstand all flight loads.	Analysis
The Mechanical Sub-System **shall** withstand all engine loads with a safety factor of [2].	Analysis
The Mechanical Sub-System **shall** be reusable.	Demonstration
The Mechanical Sub-System **shall** have a weight of [TBD] lbs.	Inspection
The Mechanical Sub-System **shall** have a length of [TBD] feet.	Inspection

Mechanical Design TPMs

Measure	TPM Value	Units	Verification Method
Weight	18.305	lbs	Inspection
Length	40	in	Inspection
MEOP (with Safety Factor)	[1000]	psi	Testing
MEOT	[2600]	K	Testing
Max Thrust to Withstand	[1837]	lbs.	Testing/Analysis

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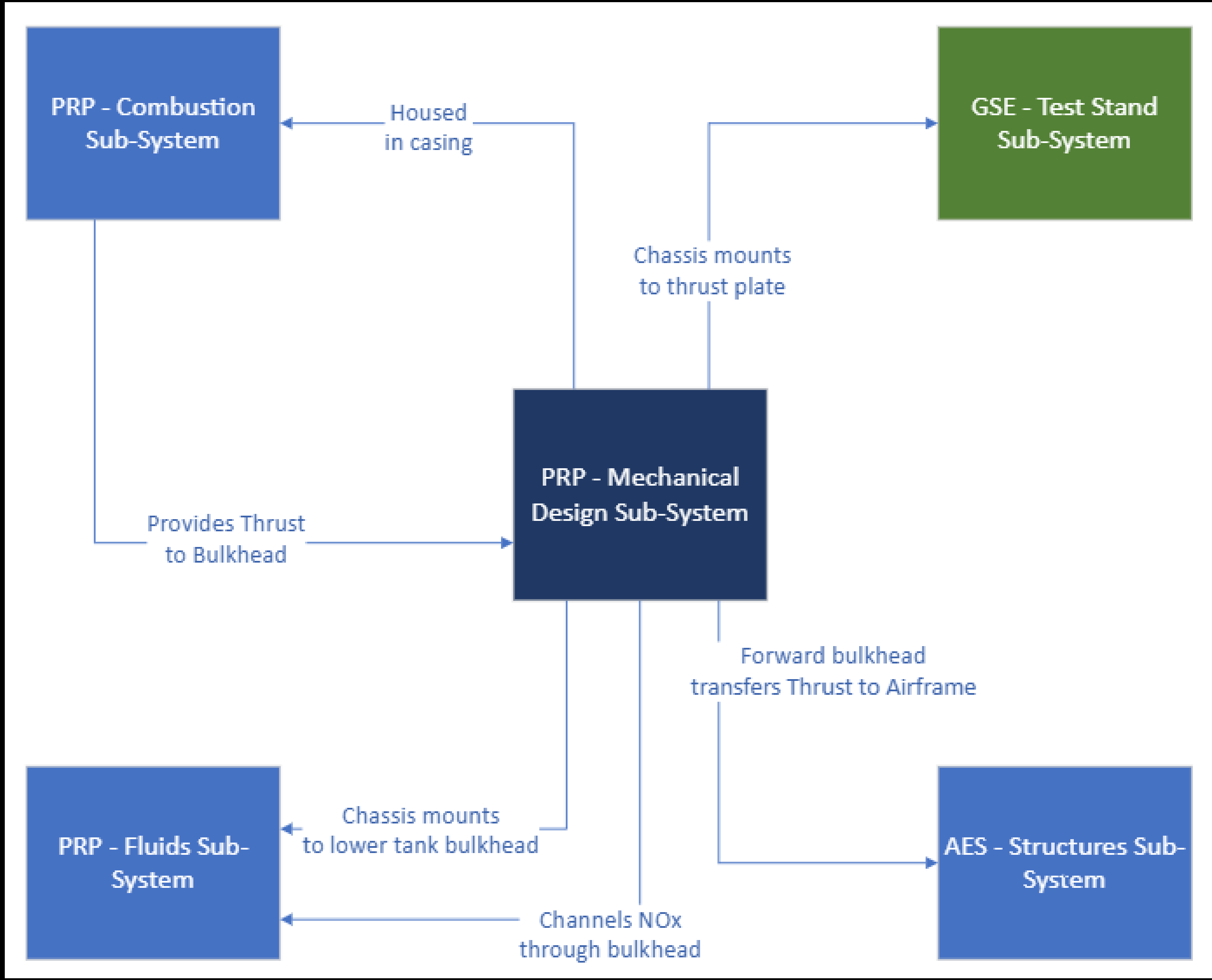
Mechanical Design Interface Diagram



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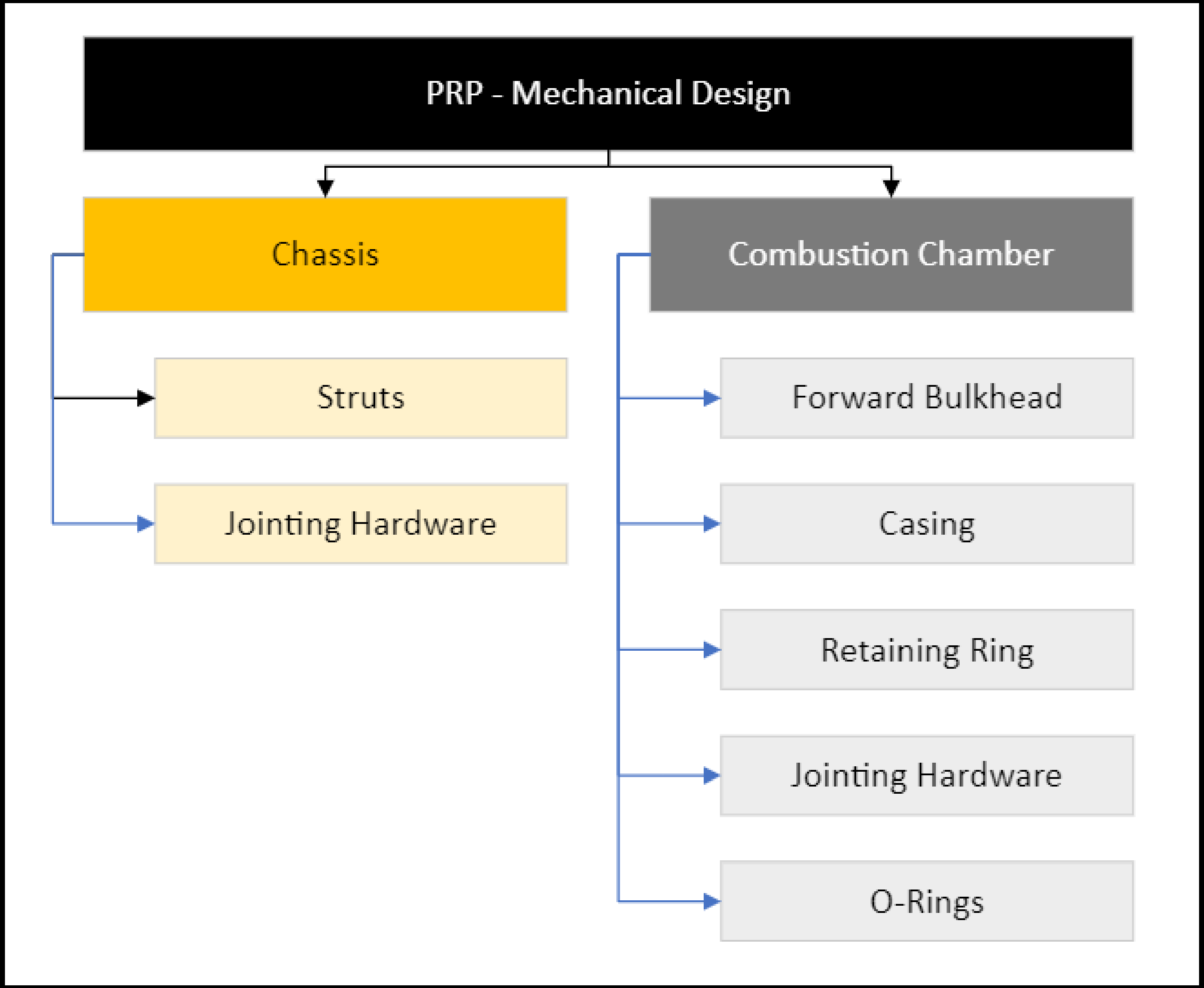
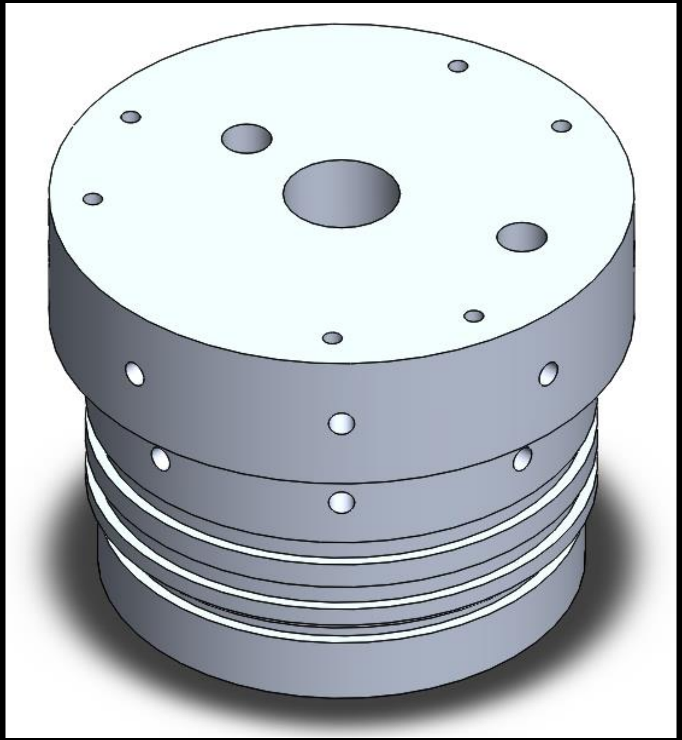
Mechanical Component Breakdown

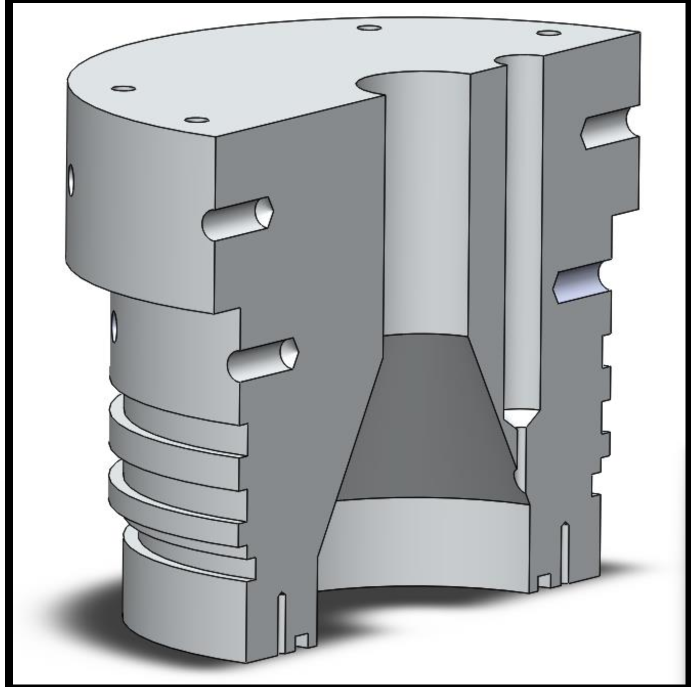


KNIGHTS EXPERIMENTAL ROCKETRY

Chamber Forward Closure/Bulkhead

- The forward closure is integrated with four components
  1. Integrated with Airframe to transfer thrust to the rest of the rocket.
  2. Integrated with the oxidizer tank to allow the flow of oxidizer to the combustion chamber.
  3. Integrated with the chamber casing to maintain pressure inside the combustion chamber.
  4. Integrated with the injector plate to allow even distribution of oxidizer inside the combustion chamber.





- Additional uses for the forward closure
  - Housing for combustion chamber sensors.

Chamber Forward Closure/Bulkhead

- Measurements
  - Upper diameter (6 in)
  - Lower diameter (5 in)
  - Length (4.50 in)

- Calculations for the forward closure
  - # bolts for the thrust plate portion (4 bolts minimum given from aerostructures) using 8 for a safety factor of 2.
  - Thrust plate portion 1 in tall with bolts .5 in from the edge (over safety factor of 2 for tear-out)
  - # bolts for mounting casing to bulkhead calculated at 8 for safety factor of 2
  - 3 Buna O rings

- Risk
  - There are four main risk of failure

1. Bolt shear
2. Bolt tear-out
3. Shear where the thrust plate and the casing meet
4. O-ring failure

- Schedule
  - 3 weeks to procure the raw metal.
  - 2 weeks to fabricate the part.

- Cost
  - $150 for 6 in diameter, 4.5 in long Aluminum 6061 cylindrical rod.
  - $100 for the fabrication of the part.

Tensile to shear stress.

$$\sigma_{yield}(0.75) = \tau_{yield}$$

Factor of safety

$$FOS = 2$$

Shear stress equation

$$\tau_{yield} = \frac{F_{thrust}}{A_{in\ shear}}$$

Bolt tear-out

$$distance_{edge\ to\ center\ of\ bolt} = 2(diameter_{bolt})$$

Number of bolts for the thrust plate portion of the forward closure

$$\tau_{yield} = \frac{F_{thrust}}{A_{in\ shear}} = \frac{4F}{\pi d^2} = \frac{4(1500 \times FOS)}{\pi(0.196)^2} = 99430.41\ PSI$$

$$\tau_{yield} = 85{,}000\ PSI(0.75) = 69{,}000\ PSI$$

$$\tau_{yield} = 69{,}000 \times N_{bolts}$$

$$N_{Bolts} = \frac{99430.41}{69000} = 1.44 \approx 2\ Bolts$$

For symmetry purposes 4 Bolts

Thickness of thrust plate portion of forward closure (by bolt tear-out)

$$distance_{edge\ to\ center\ of\ bolt} = 2(diameter_{bolt})$$

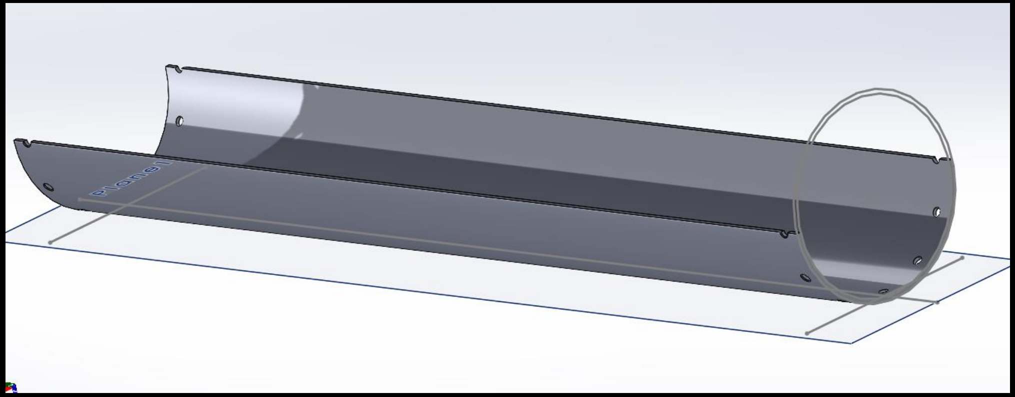
$$distance = 2\left(\frac{1}{4}\right) = 0.5\ in$$

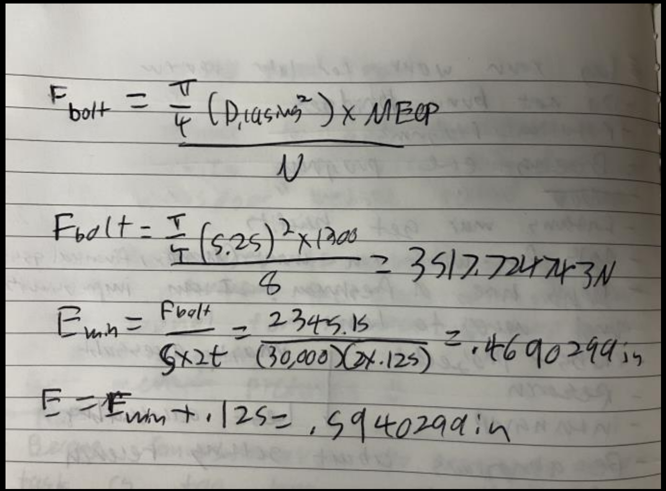
$$thickness = 2(distanse) = 2(0.5) = 1\ in$$

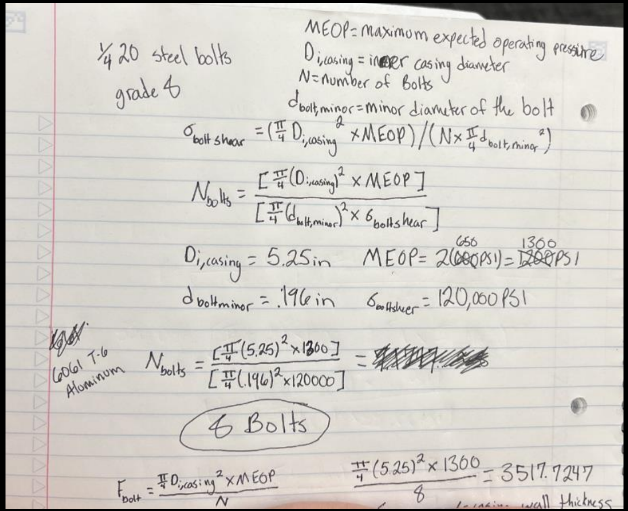
KNIGHTS EXPERIMENTAL ROCKETRY

Chamber Casing

- Assumed safety factor = 2
- Machined in house (UCF Machine shop)
- Outer diameter is 5.5 inches and inner diameter is 5.25 inches
- Calculated force on each bolt is 3517N which using the safety factor of 2 it was found bolts should be .6 inches from the edge of casing to prevent bolt tear-out
- The calculated number of bolts on each side to prevent bolt sheer with a safety factor of 2 is 8







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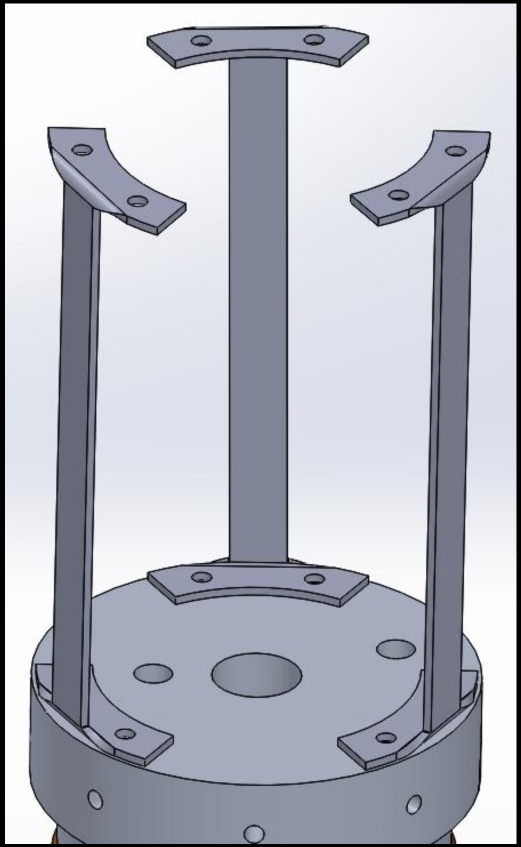
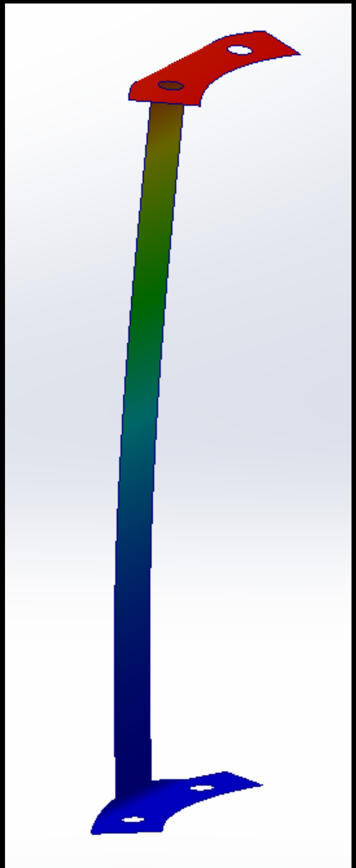
Tank-to-Chamber Chassis





- Purpose: to hold the oxidizer tank in place above the combustion chamber while also protecting the plumbing system from the force of the tank

- Implementation: We will install 3 struts made of cut and bent sheet metal (probably aluminum) that run from the bottom tank bulkhead to the forward closure (bolted directly downward)

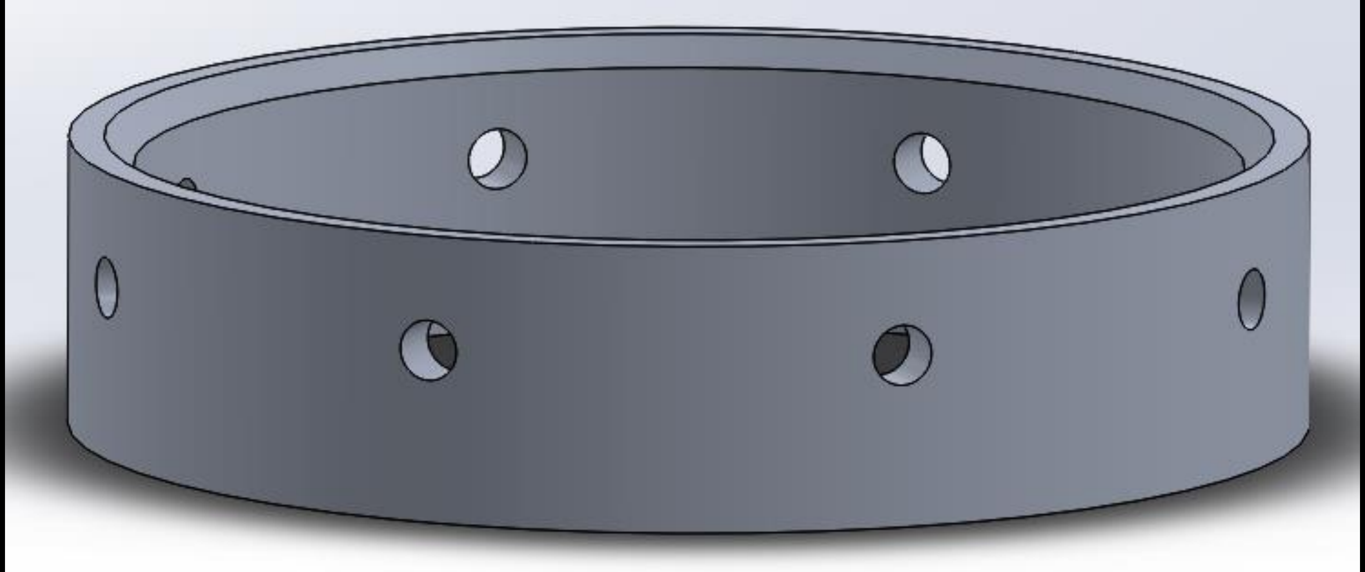
- The sheet metal gauge is still being determined

- The chassis will only need to withstand the weight of the tank during the test fire

KNIGHTS EXPERIMENTAL ROCKETRY

Nozzle Retaining Ring

- Outer Diameter: 5.25in
- Inner Diameter: 4.7in
- Calculated number of Bolts: 8 (safety factor of 2)
- Holes are .6in from edge (safety factor of 2)
- Alloy: Aluminum 6061-T6
- There will be slant on top of the ring to alleviate stress



Tensile to shear stress.

$$\sigma_{yield}(0.75) = \tau_{yield}$$

Factor of safety

$$FOS = 2$$

Shear stress equation

$$\tau_{yield} = \frac{F_{thrust}}{A_{in\ shear}}$$

Bolt tear-out

$$distance_{edge\ to\ center\ of\ bolt} = 2(diameter_{bolt})$$

Number of bolts for the thrust plate portion of the forward closure

$$\tau_{yield} = \frac{F_{thrust}}{A_{in\ shear}} = \frac{4F}{\pi d^2} = \frac{4(1500 \times FOS)}{\pi(0.196)^2} = 99430.41\ PSI$$

$$\tau_{yield} = 85{,}000\ PSI(0.75) = 69{,}000\ PSI$$

$$\tau_{yield} = 69{,}000 \times N_{bolts}$$

$$N_{Bolts} = \frac{99430.41}{69000} = 1.44 \approx 2\ Bolts$$

For symmetry purposes 4 Bolts

Thickness of thrust plate portion of forward closure (by bolt tear-out)

$$distance_{edge\ to\ center\ of\ bolt} = 2(diameter_{bolt})$$

$$distance = 2\left(\frac{1}{4}\right) = 0.5\ in$$

$$thickness = 2(distanse) = 2(0.5) = 1\ in$$

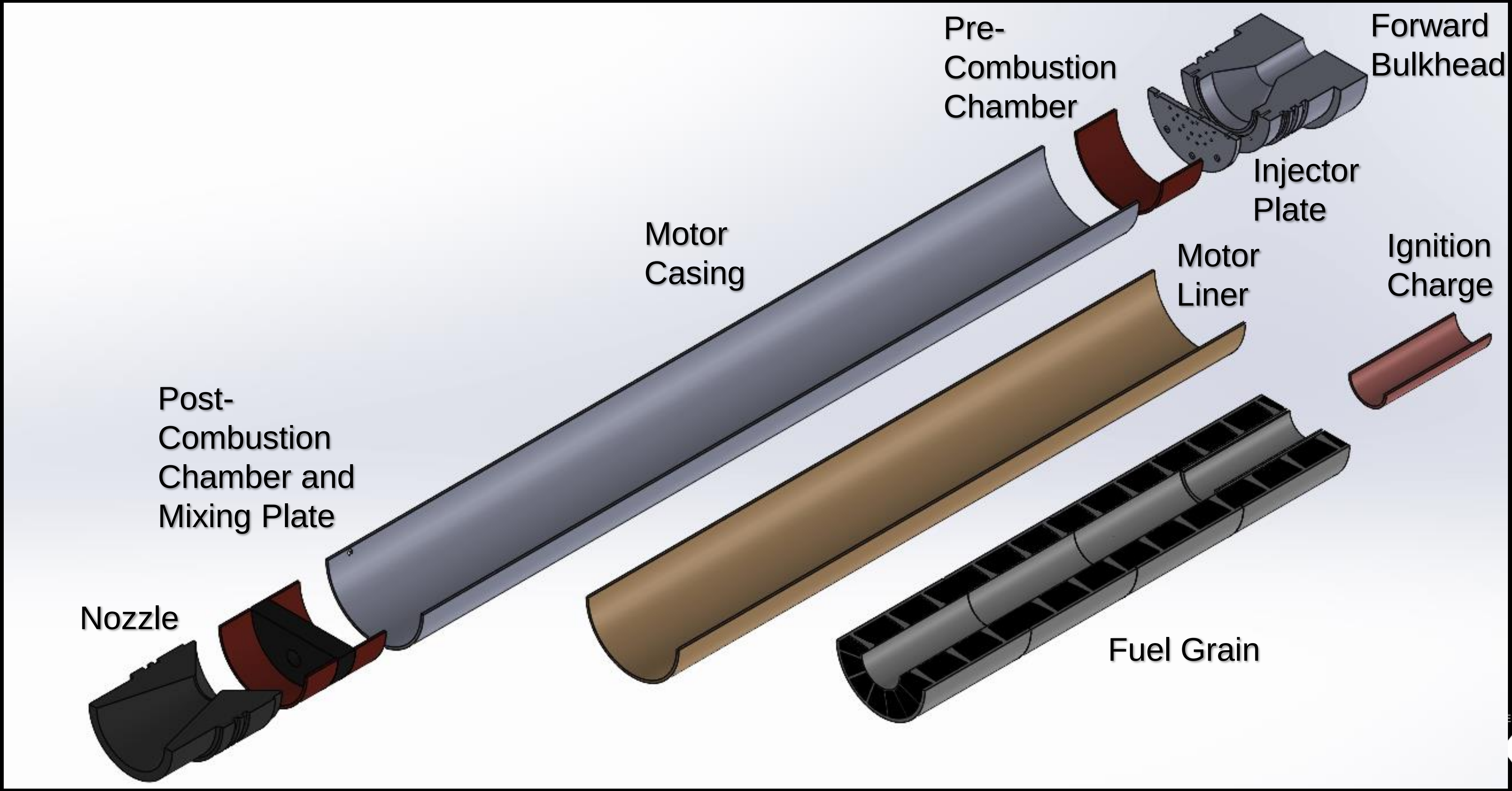
Future Plans

- Finalize chassis calculations
- Finalize O-Ring Calculations

KNIGHTS EXPERIMENTAL ROCKETRY

Questions?

Combustion Sub-System



Combustion TPMs

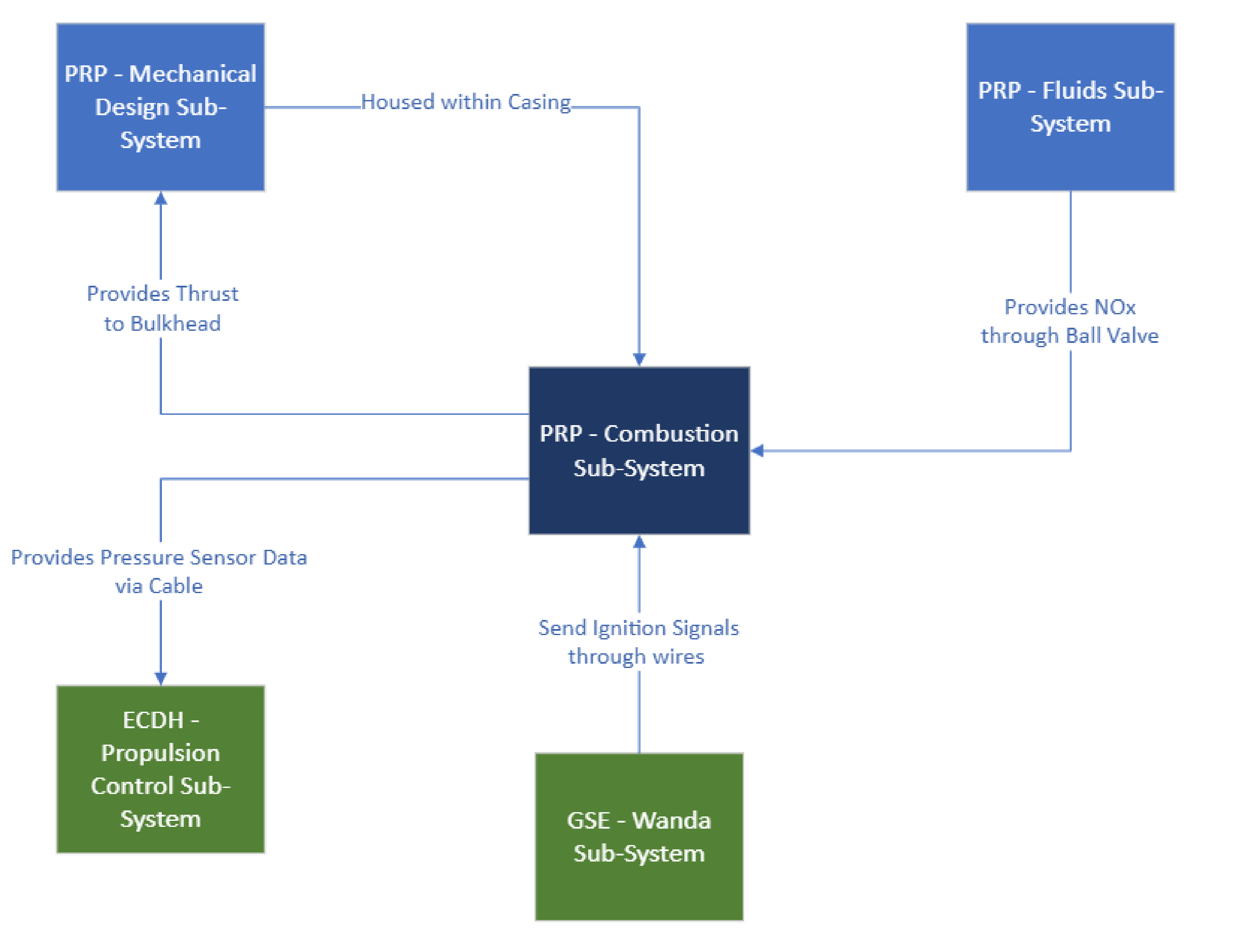
Measure	TPM Value	Units	Verification Method
Thrust (peak)	[1837]	lbs	Testing
Maximum Expected Operating Pressure	[500]	psi	Testing
Burn Time	[10-12]	seconds	Testing
C* Efficiency	[>93%]	N/A	Testing
Impulse	[36,948]	N-s	Testing

Combustion Sub-System Requirements

Requirement	Verification Method
The Combustion Sub-System **shall** shall produce a C* Efficiency of [95%].	Test
The Combustion Sub-System **shall** adequately mix propellants during combustion.	Demonstration
The Combustion Sub-System **shall** produce a maximum chamber pressure of [500] psi.	Test
The Combustion Sub-System **shall** be housed within the Combustion Chamber Casing.	Inspection
The Combustion Sub-System **shall** shall have a Burn Time [10] s.	Test
The Combustion Sub-System **shall** provide a stable burn with minimal pressure instabilities.	Test
The Combustion Sub-System **shall** emit non-toxic exhaust.	Inspection

KNIGHTS EXPERIMENTAL ROCKETRY

Combustion Interface Diagram



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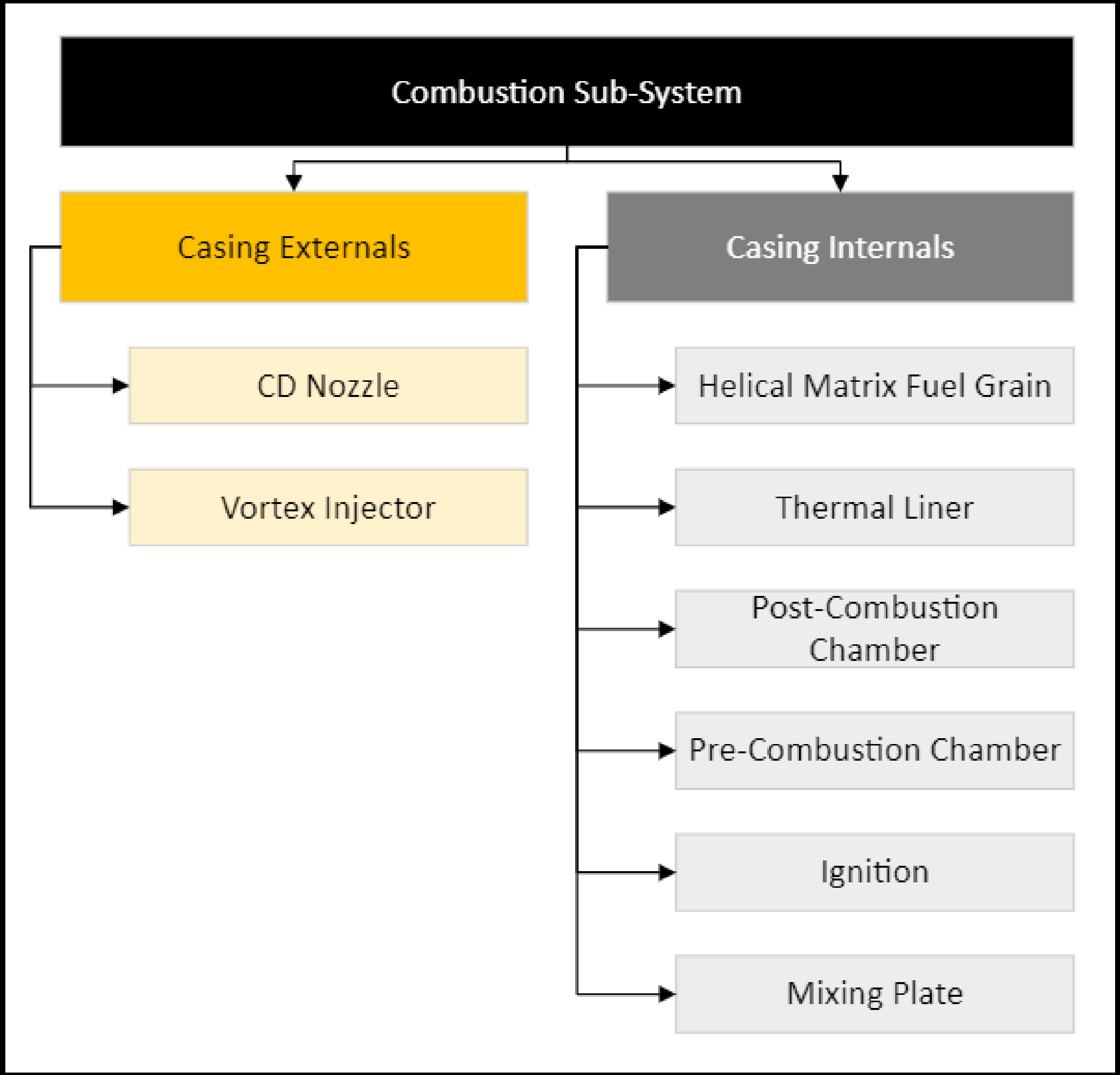
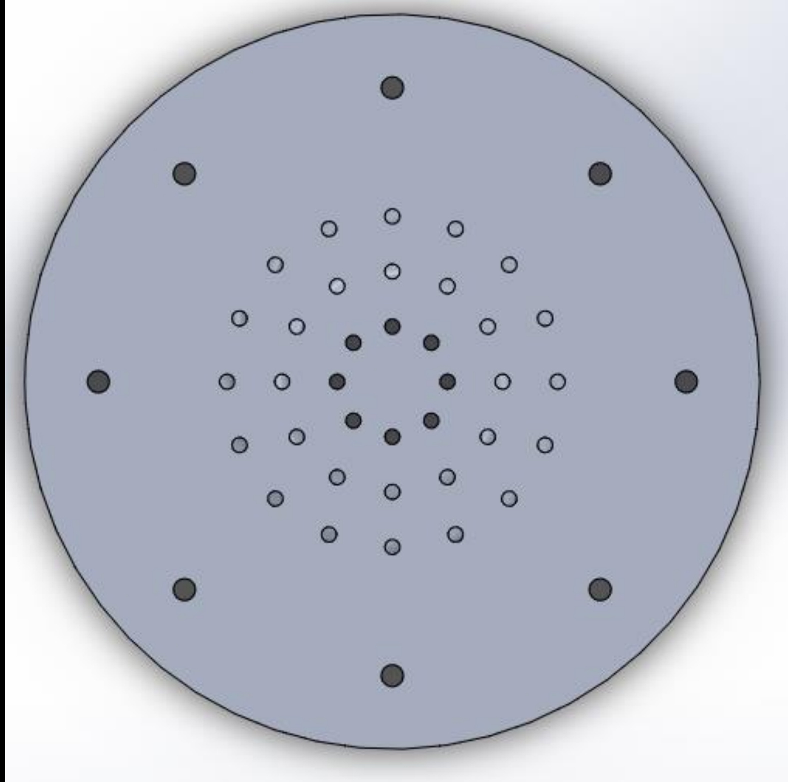
Combustion Component Breakdown

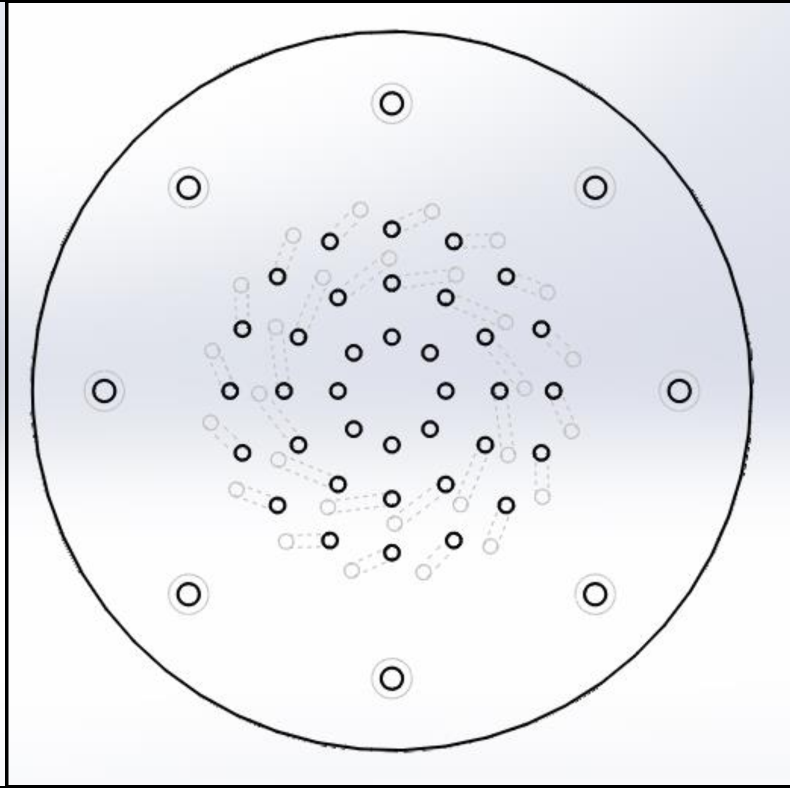


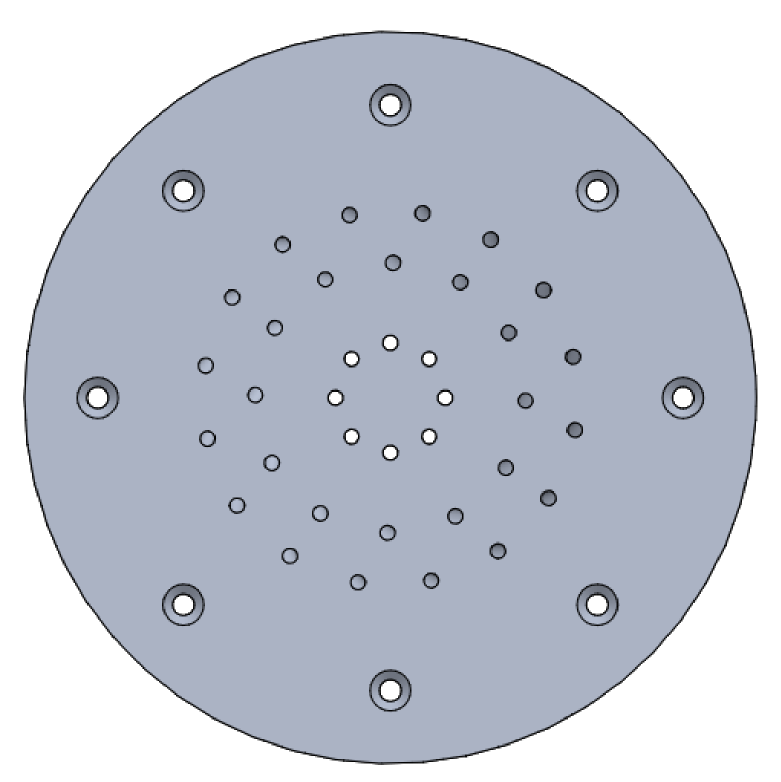
KNIGHTS EXPERIMENTAL ROCKETRY

Injector Plate

Visual Representations

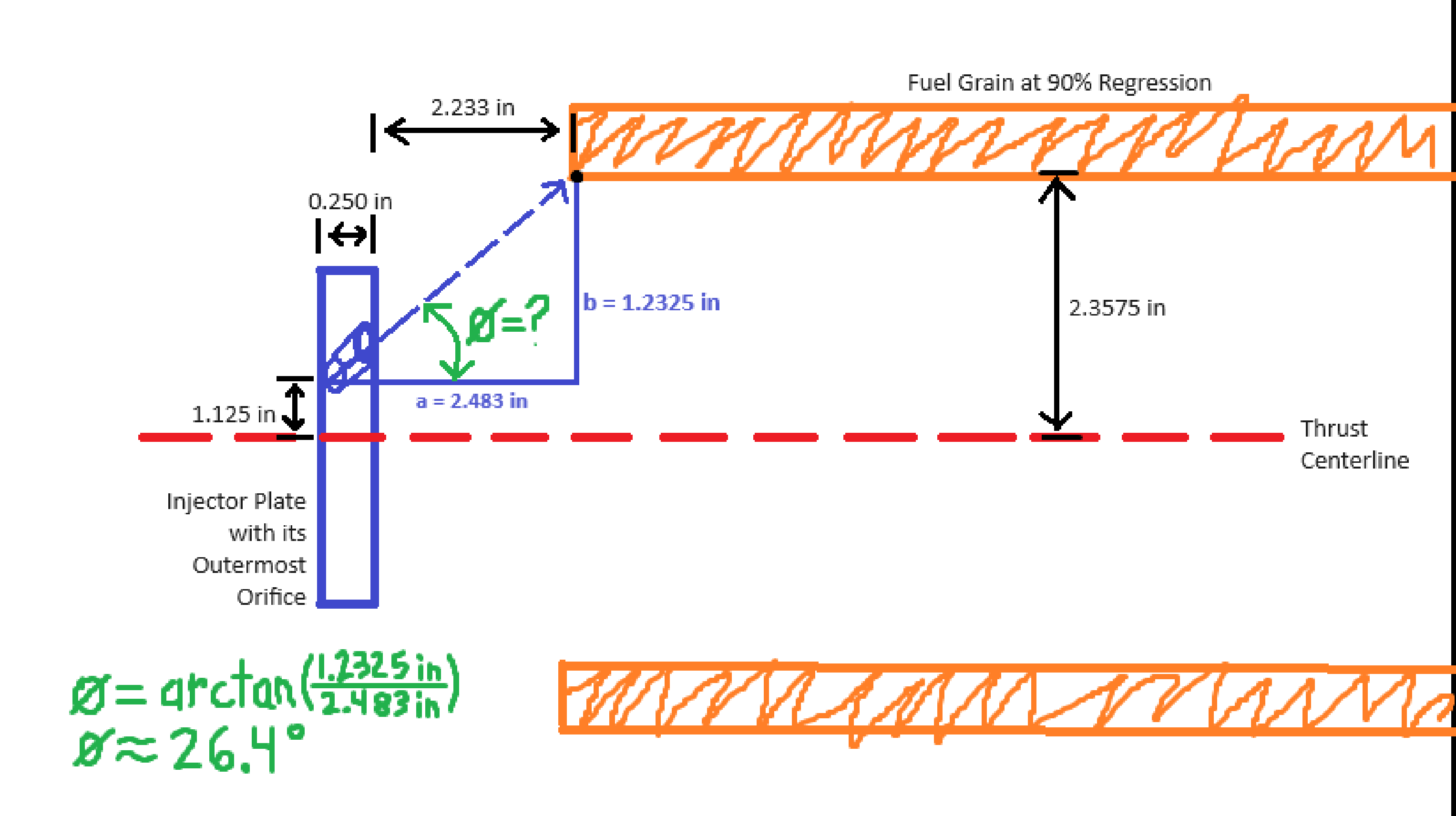






Injector Plate

Design Sheets – Orifice's Angles



Injector Angle Relative to Thrust Centerline	Angle (degrees)
Conical Angle (causes diverging flow)	26.4 for outer, 13.2 for mid, 0 for inner
Vortex Angle (causes vortex flow)	45 for outer, 60 for mid, 0 for inner

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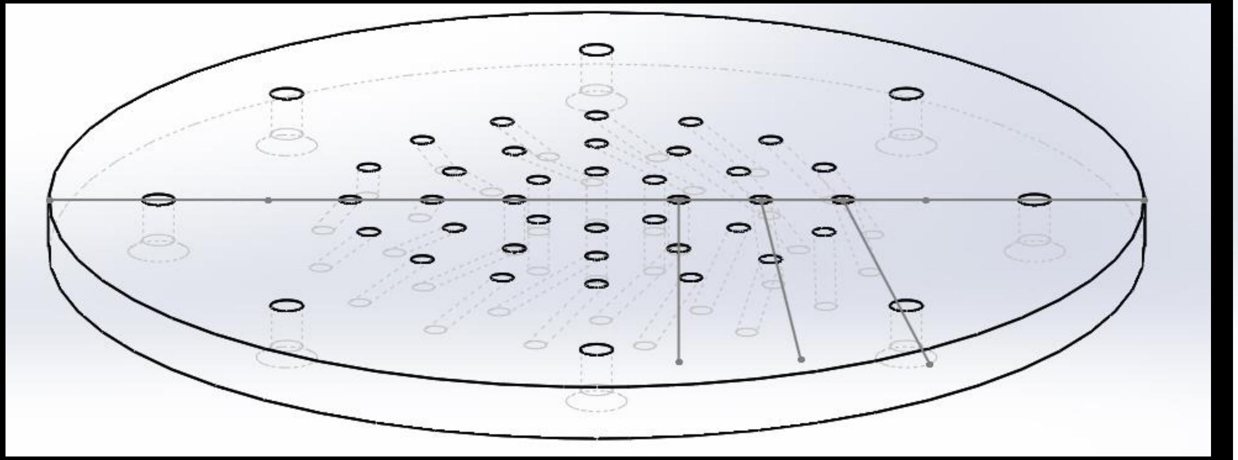
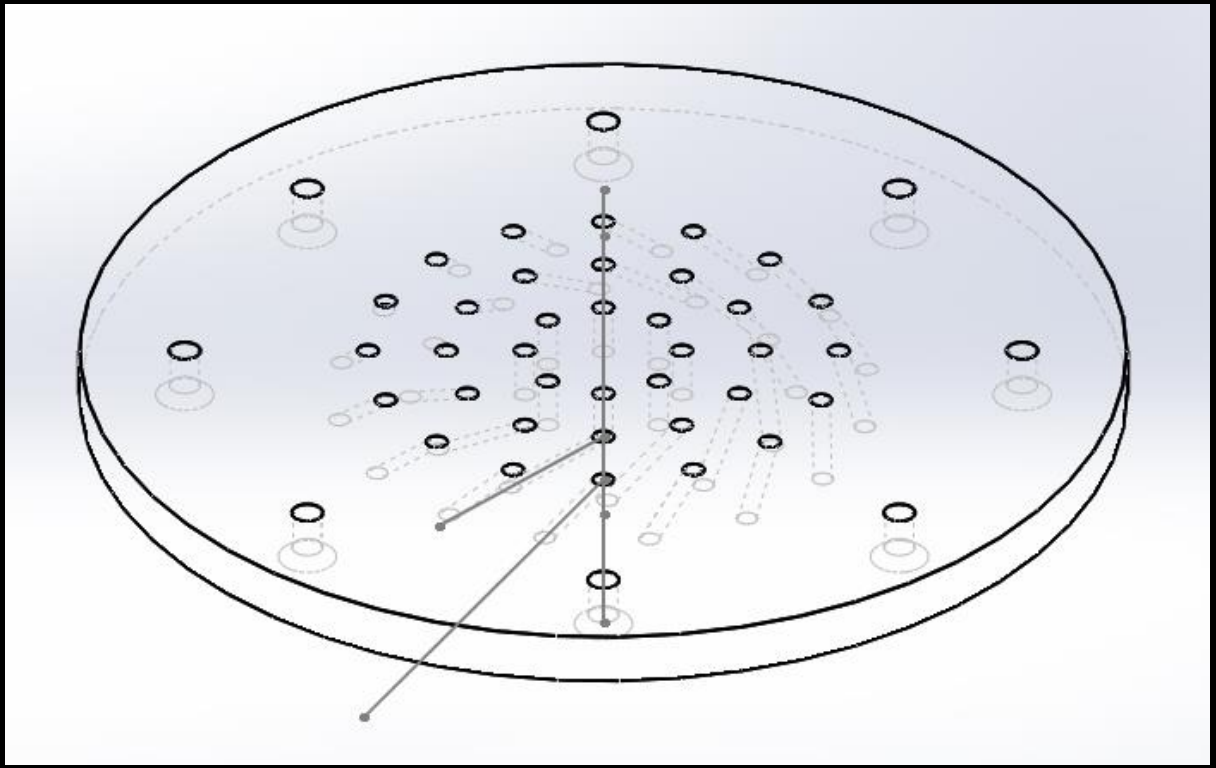
Injector Plate

Visual Representations (cont.)





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Injector Plate

Design Sheets - MathCAD

Chamber Pressure: $P_c := 500\ psi$

Oxidizer Tank Pressure: $P_{tank} := 800\ psi$

$\rho := 589.4\ \frac{kg}{m^3}$

Head-Loss Coefficient: $K := 1.7$

Pressure Drop: $\Delta P := P_c \cdot 20\%$

Hole Count: $N := 36$

O/F Ratio: $OF := 5$

Mass Flow Rate: $m_{dot} := \frac{F_{thrust}}{I_{sp} \cdot g} = 3.402\ \frac{kg}{s}$

Oxidizer Mass Flow Rate: $m_{dot\_ox} := m_{dot} \cdot \left(\frac{OF}{OF+1}\right) = 6.25\ \frac{lb}{s}$

Injector Area: $A_{inj} := m_{dot\_ox} \cdot \sqrt{\frac{2.238\ K}{\rho \cdot \Delta P}} = 0.425\ in^2$

$D_{inj} := \sqrt[(2)]{A_{inj} \cdot \frac{4}{\pi}} = 0.736\ in$

Orifice Diameter: $d_{orif} := \sqrt{\frac{4 \cdot A_{inj}}{\pi \cdot N}} = 0.12263\ in$

Injector Plate

Technical Preliminary Measures

Measure	TPM Value	Units	Verification Method
Component Weight	[0.467]	lbs	Inspection
Mass Flow	[6]	lbs/s	Test
Number of Orifices	[36]	N/A	Inspection
Diameter of Orifice	[0.122]	in.	Inspection

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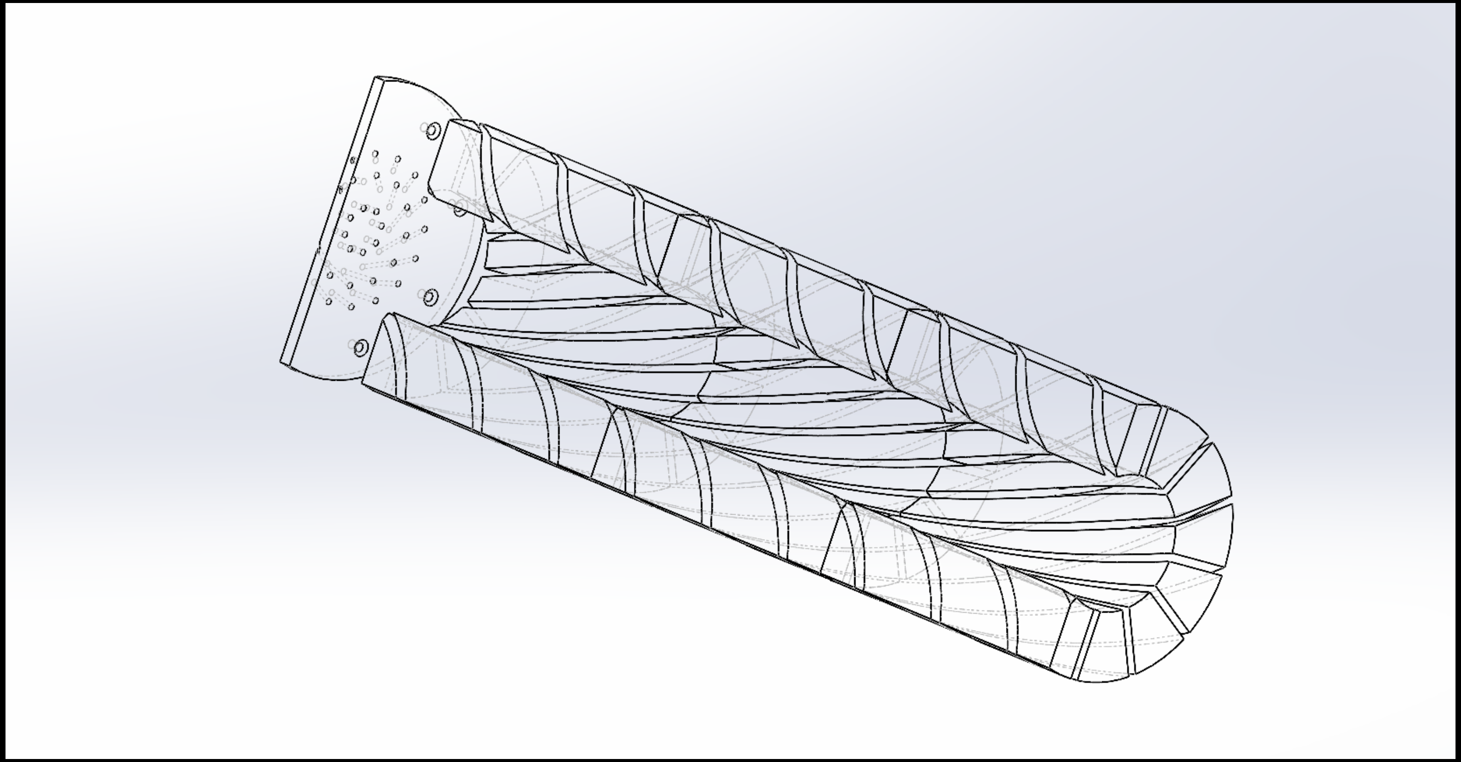
Injector Plate

Failure Modes

- Bad alignment with fuel grain geometry.



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Injector Plate

Implementation Plans

- Student Researched And Developed Component.
- Vortex injector plate with angled orifices of increased steepness as we get closer to the center of the plate.

Estimated Cost

- Injector Plate - $ 120

Schedule

- About a week to manufacture, contingent on stock lead times.

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Injector Plate

Other Options Considered

- Before deciding on the vortex injector plate, we considered a showerhead injector, an impinging injector, and a swirl injector as well.

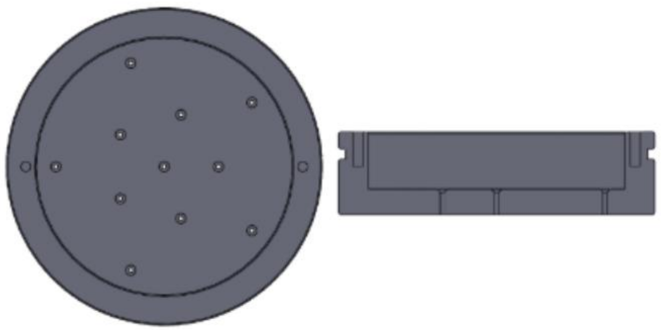
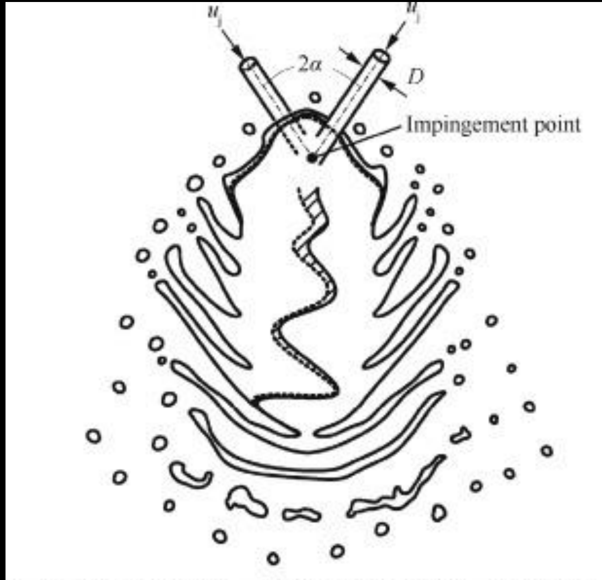


Figure 2.2: CAD of a showerhead injector [30]



u_j—Mean jet velocity; 2α—Impingement angle; D—Jet diameter

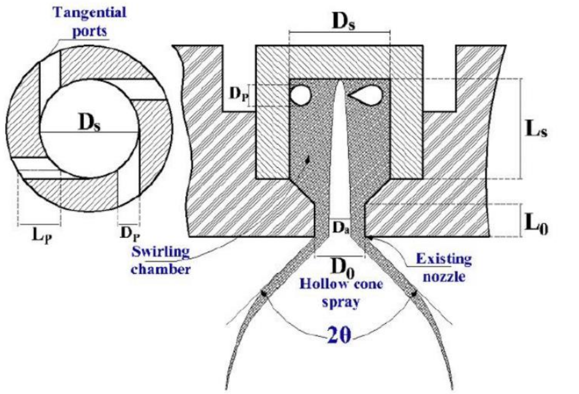


Figure 2.6: Schematic of a swirl injector element [38]

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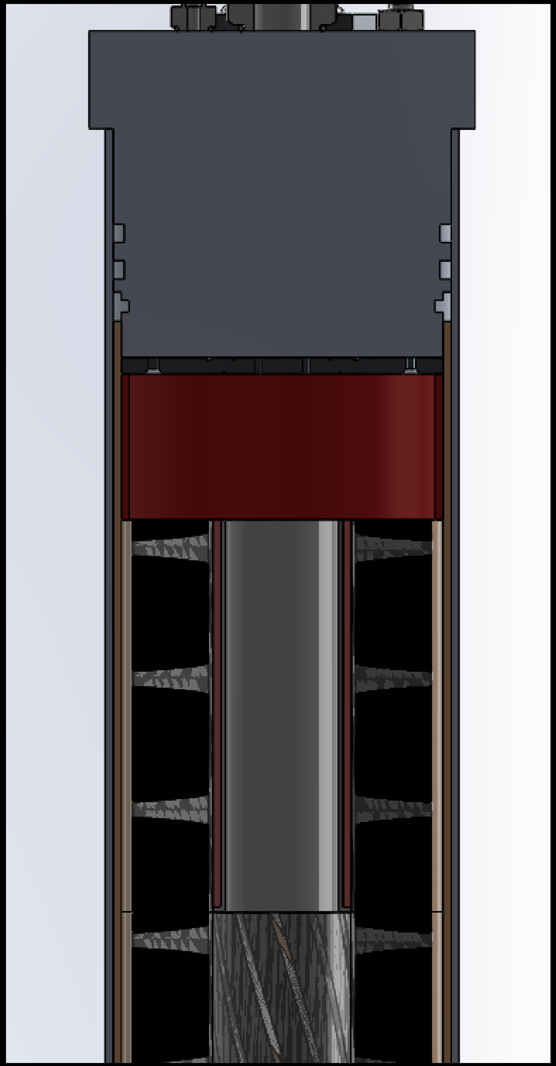
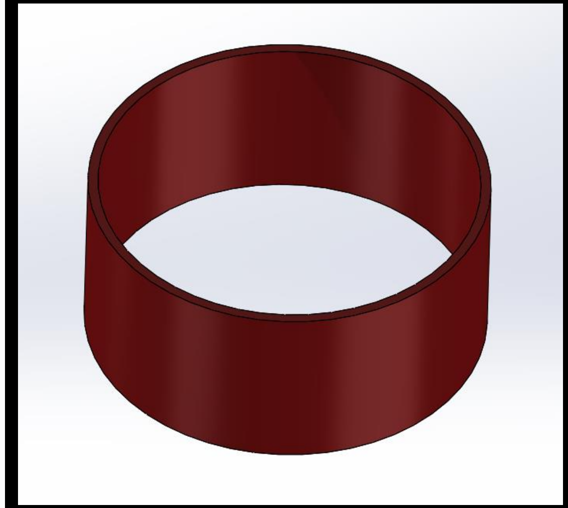
Pre-Combustion Chamber

- Increased NOx residency time
- Pre-heating of NOx
- Ideal length-to-diameter ratio of 0.5
- Actual length 2.233"
- Extra layers of thermal liner

- TPMs
  - Pre-combustion chamber pressure and temperature
  - Pre-combustion chamber dimensions and thickness





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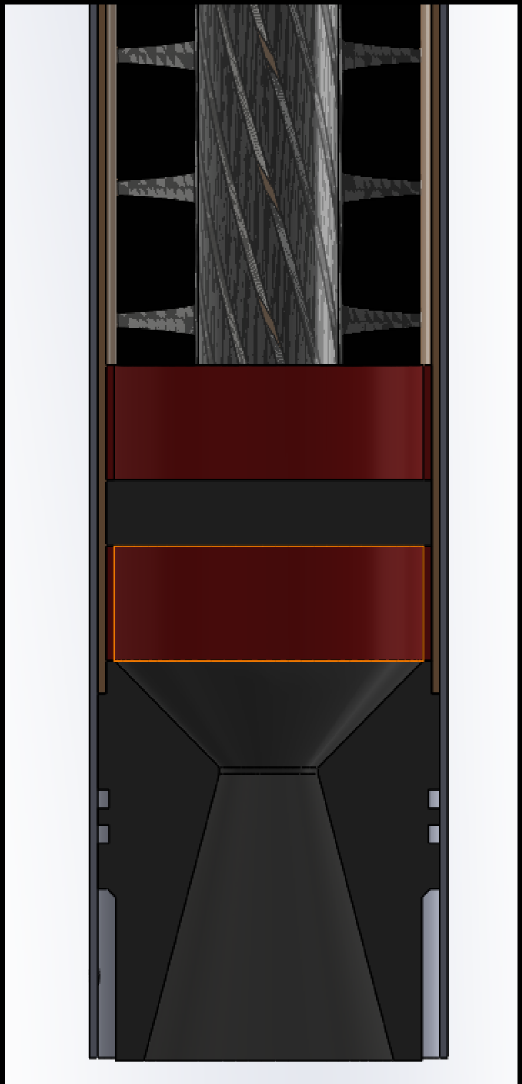
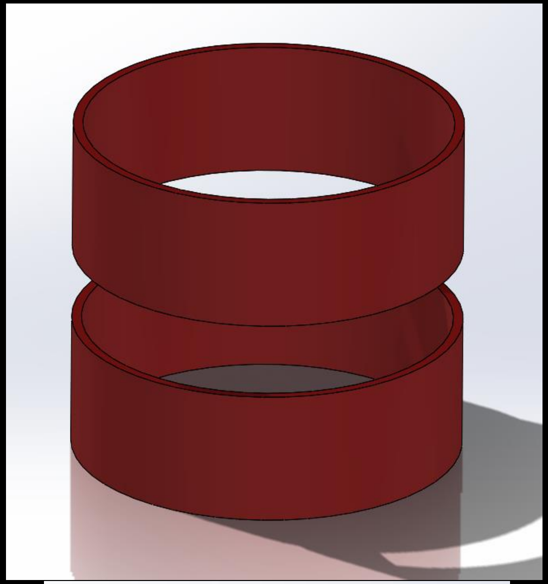
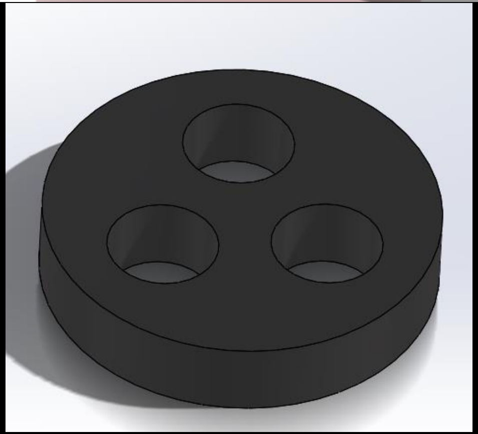
Post-Combustion Chamber and Mixing Plate

- Propellants allowed to fully mix
- Ideal length-to-diameter ratio of 1
- Ideal post–pre chamber length ratio 2
- Actual length 4.467" including 1" mixing plate
- Additional thermal liner layers
- Graphite mixing plate further mixes propellants
- TPMs
  - Post-combustion chamber pressure and temperature
  - Post-combustion chamber dimensions and thickness







KNIGHTS EXPERIMENTAL ROCKETRY

Pre- and Post- Combustion Chambers

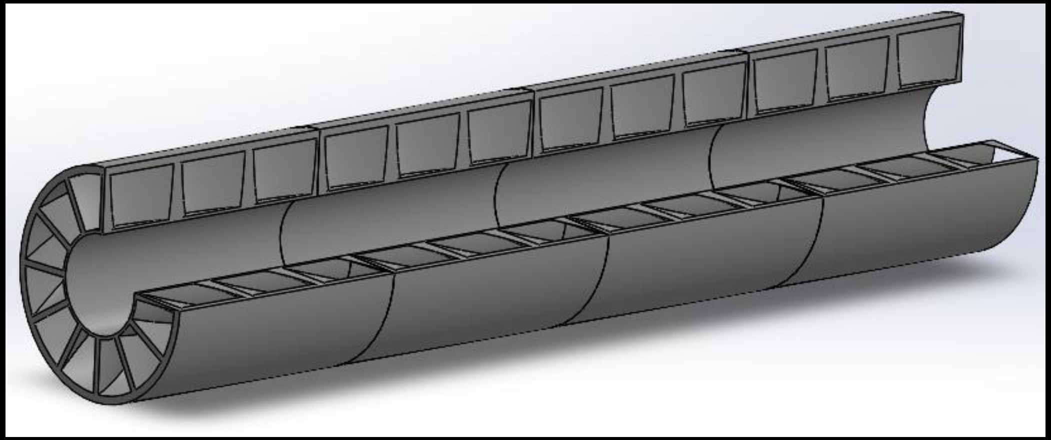
- Considered a design without these features
  - Decided implementation would increase efficiency
- Considered different mixing plate geometries
  - Current geometry suggests highest combustion efficiency
- Failure modes
  - Burn through liners
  - Introduction or strengthening of pressure oscillations

Table 1: All simulated post-combustion chamber devices with resulting c^* efficiency (ideal c^* = 1520 m/s)

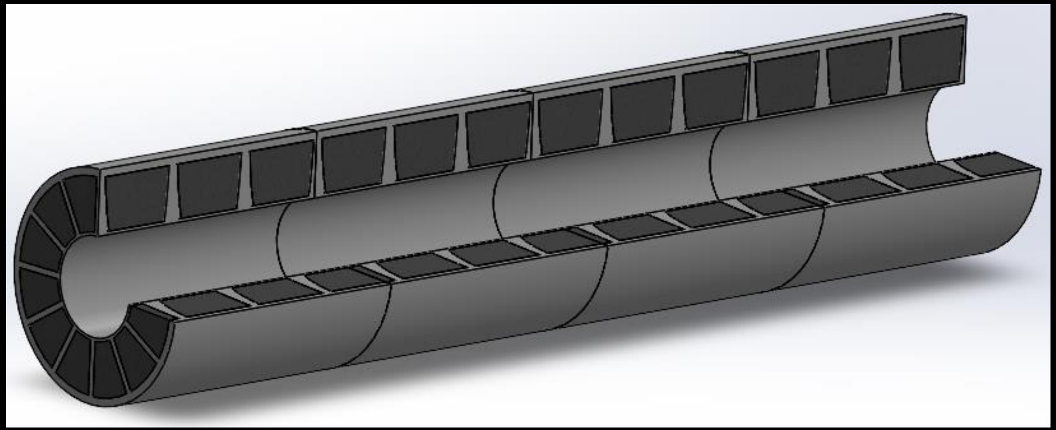
ID	Shape	η_{comb} achieved
1	no mixer	87.2 %
2		79.1 %
3		84.0 %
4		87.3 %
5		87.6 %
6		91.4 %
7		92.4 %

Fuel Grain Geometry

- Nested helical port geometry



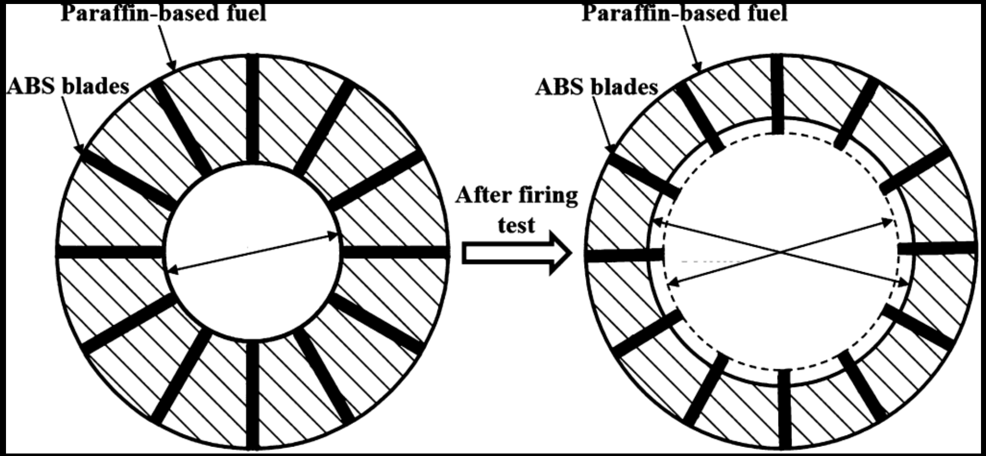
Helical ABS matrix

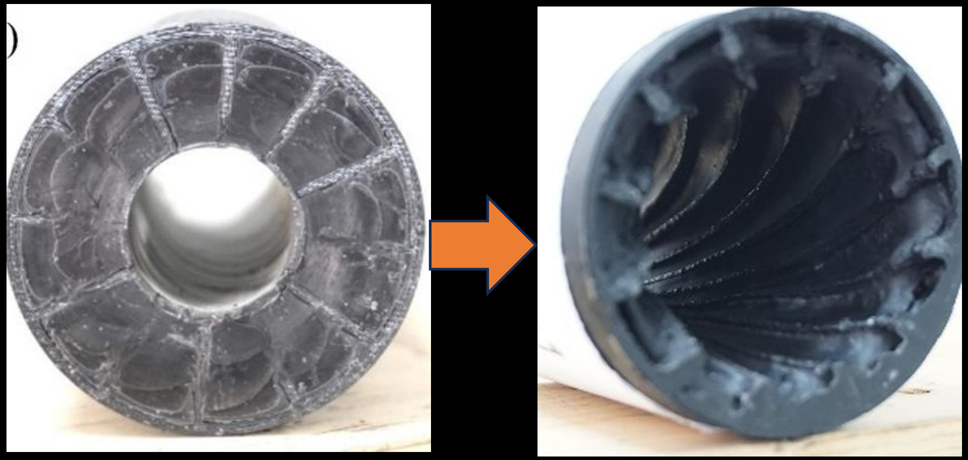


ABS matrix + paraffin based fuel

Grain Specs:
- OD: 5 in
- ID: 2.15 in
- Length: 24 in

Regression behavior of nested helical grain





Test-firing results of nested helical grain

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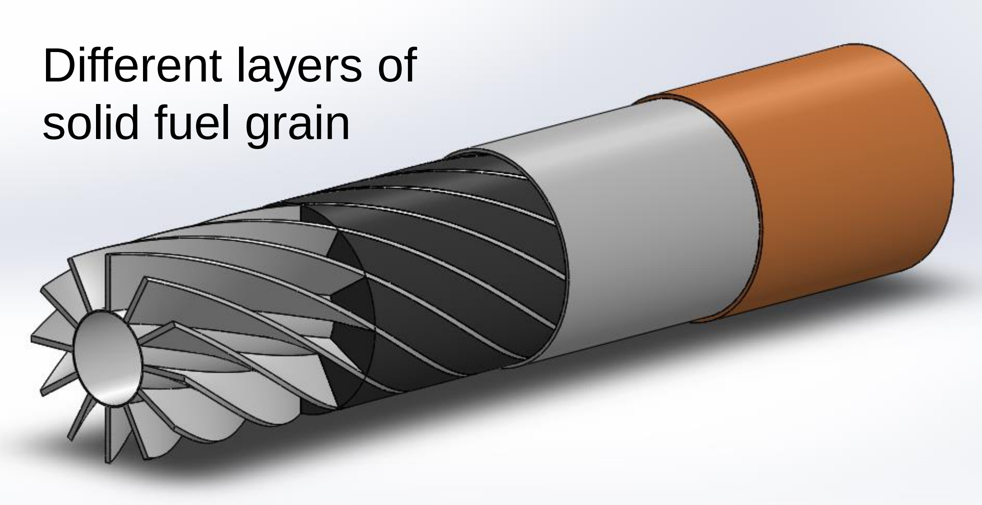
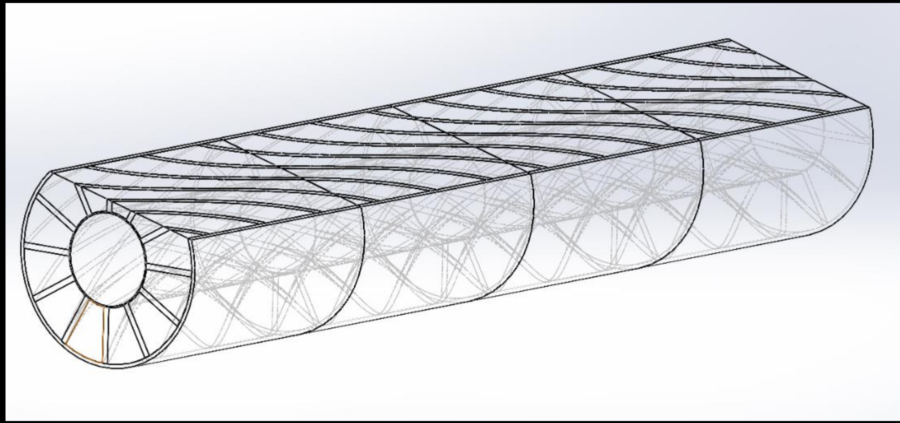
Fuel Grain Geometry

Benefits of nested helical geometry

- Increase in structural integrity of the grain
- Turbulence due to blade vortices formed in the recirculation zone
- Maintains angular momentum of NOx along the grain
- Longer NOx residence time in the chamber
- Higher instantaneous burning surface area
- Ideal web fraction & volumetric loading efficiency
- Benefits increase over time due to difference in regression rates between ABS and paraffin





Transparent cross-sectional view of solid fuel grain

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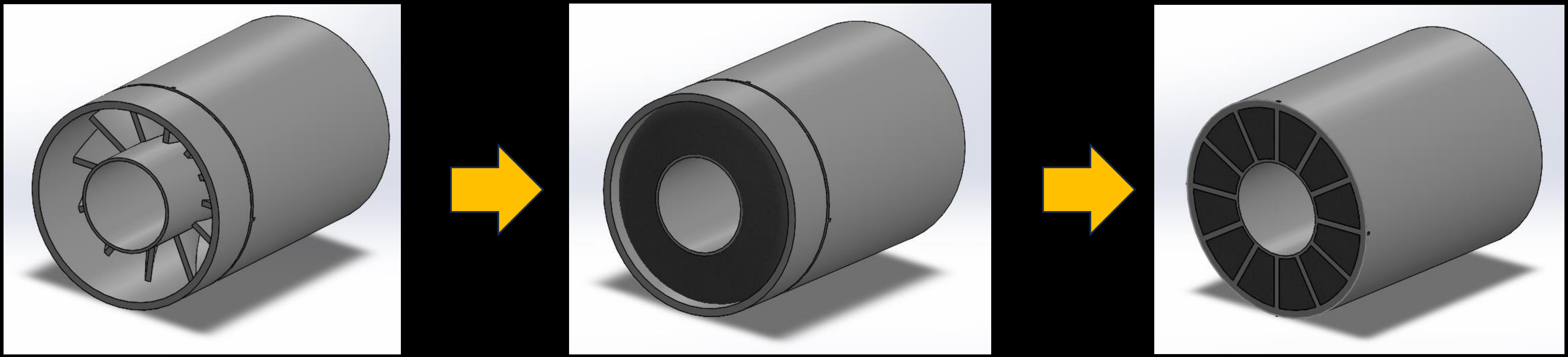
Fuel Grain Geometry

- ABS matrix manufacturing technique
  - Matrix made using additive manufacturing (3D printing) w/ thermoplastic ABS
    - Matrix will serve as mold for paraffin-based fuel which will be poured into negative space between adjacent fins
    - After paraffin wax has cooled, grain will be cut down to 6 inches along the pictured groove to create a flush surface



Fuel Grain Geometry

- General specs chart (see right)
- Modes of failure
  - Grain loses structural integrity and breaks up
  - Grain does not ignite
  - Grain ignites poorly and causes sputtering start
  - Grain causes uneven burn (burn-through occurs)
  - Grain structure impedes NOx flow

Fuel Grain Dimension	Expected value
Initial inner port diameter (ID)	2.15 in
Outer grain diameter (OD)	5 in
ABS Fin Width	0.143 in
Outer ABS Layer Width	0.179 in
Inner ABS Layer Width	0.0717 in
Fuel Grain Length	24 in (four 6-in segments)
Pitch of Helical Fins	24 in (one full 360-degree rotation)
Total Initial Grain Thickness	1.425 in
Total Grain Volume	384.08 in^3
Total Grain Weight	15.8 pounds

Fuel Grain Composition

- Previously consisted of sorbitol and paraffin; with a mixture ratio of ~4:1
- With the novel fuel grain geometry, this year's fuel grain mixture ratio will consist of a ~3:2 ratio due to the nested helical providing more structural support to the fuel grain.

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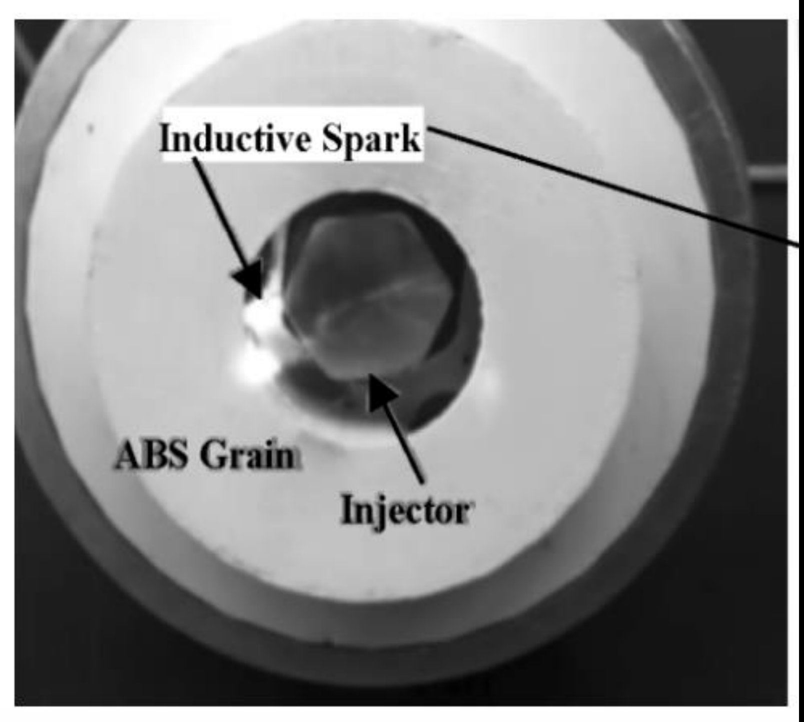
Fuel Grain Composition

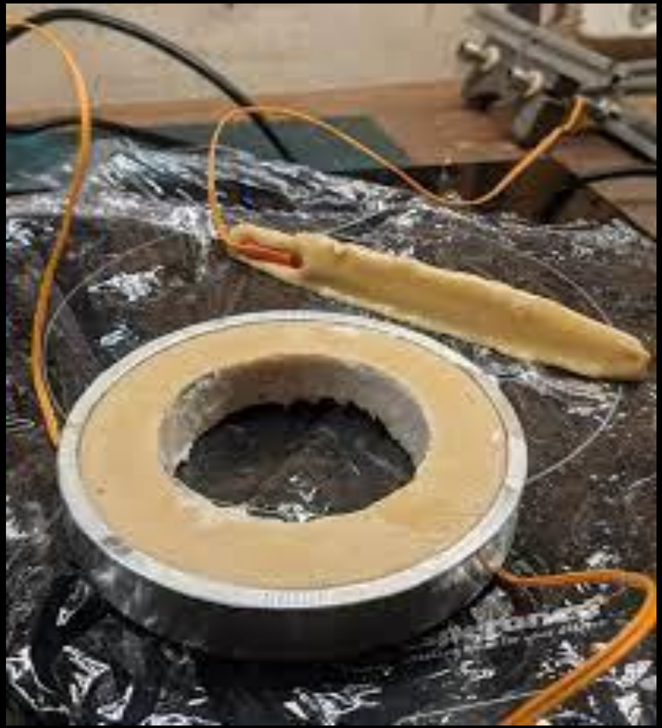
Chemical	%weight
Sorbitol	55
Paraffin	35
Aluminum Powder	10

- This year we will be looking into potential additives to create better combustion characteristics.
- Some potential additives include: Metallic Boride Powders, Carbon Powders, and other metal powders.

Ignition Mechanism



The ignition mechanism is positioned within the ABS Matrix for efficient fuel heating – this image shows interaction of the spark with the grain.



The design of the ignition mechanism is a "puck" shape, modified to assimilate with the fuel grain geometry.

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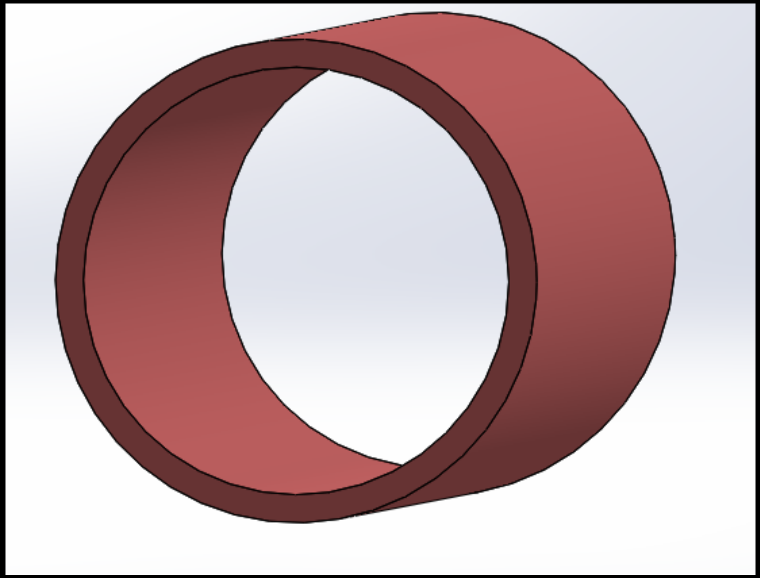
Ignition Mechanism



Structural representation of igniter

Material Test Cases

Fuel	Oxidizer	Additive
Sucrose	Potassium Nitrate	Epoxy
Thermite (Al & Fe)	Potassium Perchlorate	Iron Oxide (rust)

Nozzle

Design Sheet - MathCAD

Chamber Pressure: $P_c := 500\ psi$

Oxidizer Tank Pressure: $P_{tank} := 800\ psi$

$\rho := 589.4\ \frac{kg}{m^3}$

Head-Loss Coefficient: $K := 1.7$

Pressure Drop: $\Delta P := P_c \cdot 20\%$

Hole Count: $N := 35$

O/F Ratio: $OF := 5$

Specific Impulse: $I_{sp} := 200\ s$

Throat Temperature: $T_T := \frac{T_c}{\left(1 + \frac{k-1}{2}\right)} = (2.014 \cdot 10^3)\ K$

Throat Area: $A_T := \frac{m_{dot}}{P_T}\left(\sqrt{\frac{R \cdot T_T}{M_{mol} \cdot k}}\right) = 1.808\ in^2$

Mach Number at Exit: $M_{exit} := \sqrt[2]{\left(\frac{2}{k-1}\right) \cdot \left(\left(\frac{P_c}{P_a}\right)^{\frac{k-1}{k}} - 1\right)} = 2.901$

Throat Radius: $r_T := \sqrt[2]{\frac{A_T}{\pi}} = 0.759\ in$

Exit Area: $A_e := \left(\frac{A_T}{M_{exit}}\right) \cdot \left(\frac{1 + \left(\frac{k-1}{2}\right) \cdot (M_{exit})^2}{\frac{k+1}{2}}\right)^{\left(\frac{k+1}{2k-2}\right)} = 11.586\ in^2$

Area Ratio: $\varepsilon := \frac{A_e}{A_T} = 6.41$

Exit Radius: $r_e := \sqrt[2]{\frac{A_e}{\pi}} = 1.92\ in$

Thrust: $F_{thrust} := TWR \cdot M_{total} \cdot g = (6.672 \cdot 10^3)\ N$

Mass Flow Rate: $m_{dot} := \frac{F_{thrust}}{I_{sp} \cdot g} = 3.402\ \frac{kg}{s}$

Oxidizer Mass Flow Rate: $m_{dot\_ox} := m_{dot} \cdot \left(\frac{OF}{OF+1}\right) = 6.25\ \frac{lb}{s}$

Gas Constant: $R := 8.31\ \frac{J}{mol \cdot K}$

Chamber Temperature: $T_c := 2184.73\ K$

Atmospheric Pressure: $P_a := 12.2\ psi$

Specific Heat Ratio (for exhaust): $k := 1.17$

Throat Pressure: $P_T := P_c \cdot \left(1 + \frac{k-1}{2}\right)^{-\left(\frac{k}{k-1}\right)} = (1.966 \cdot 10^6)\ Pa$

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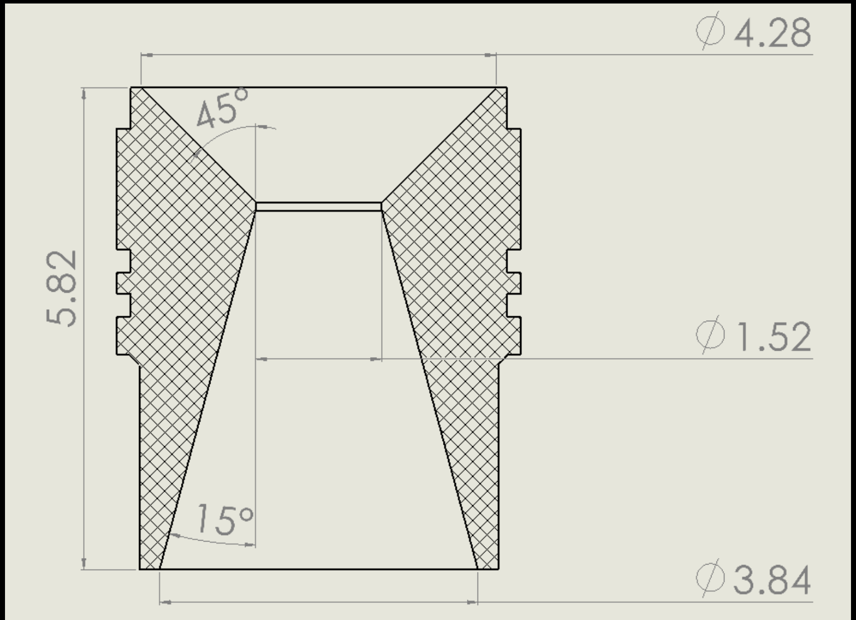
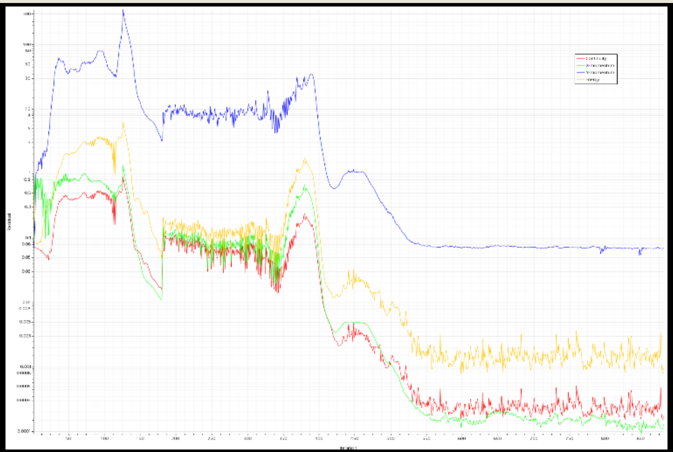
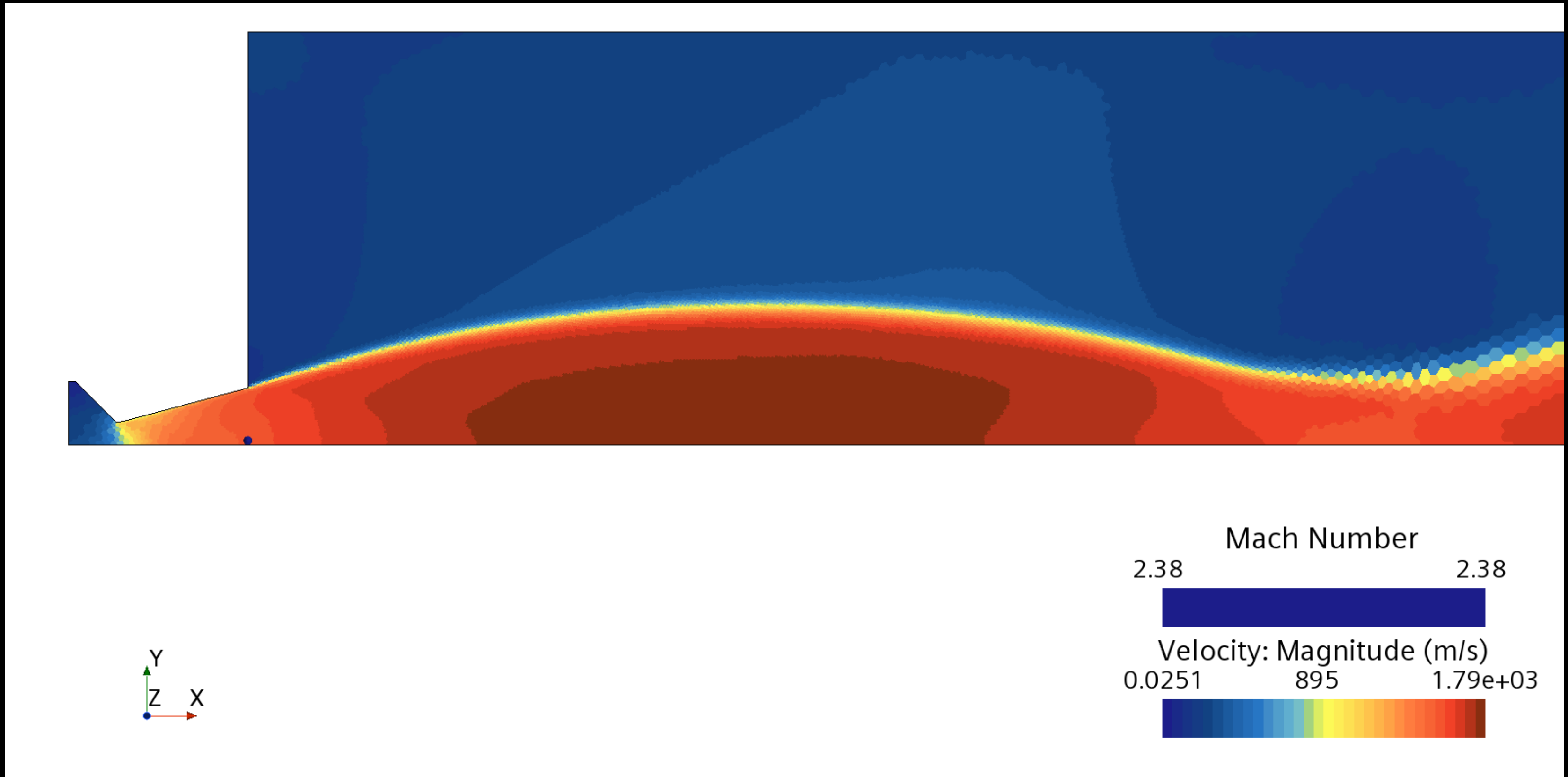
Nozzle

ANSYS Fluent Verification







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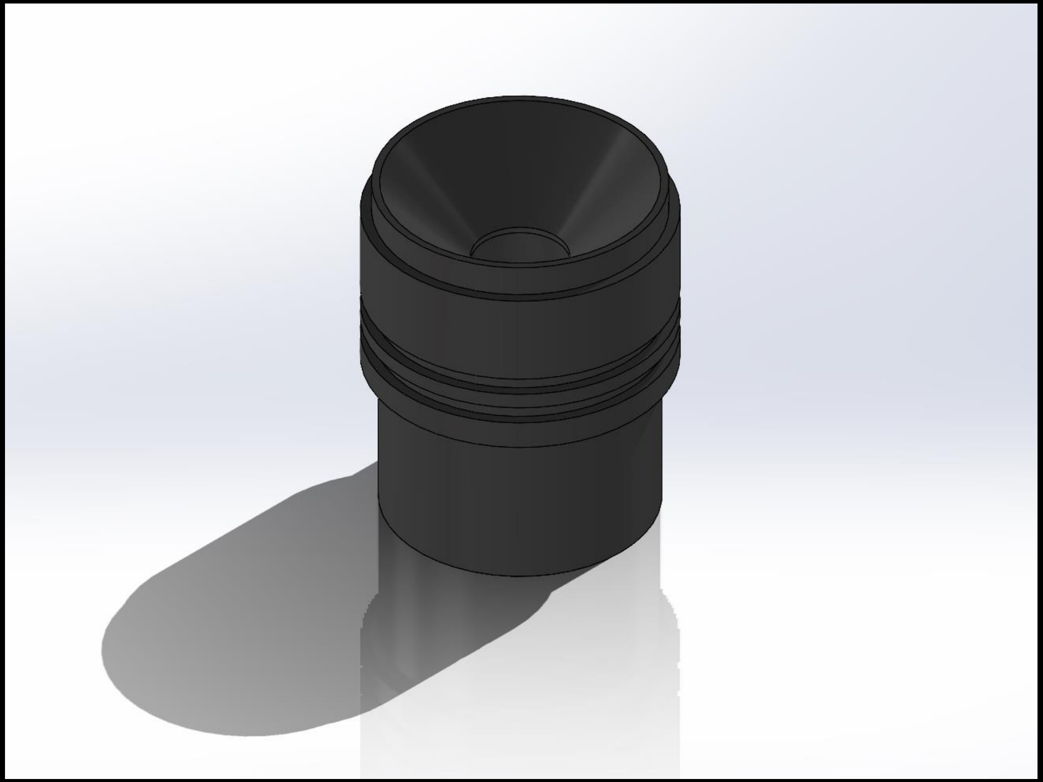
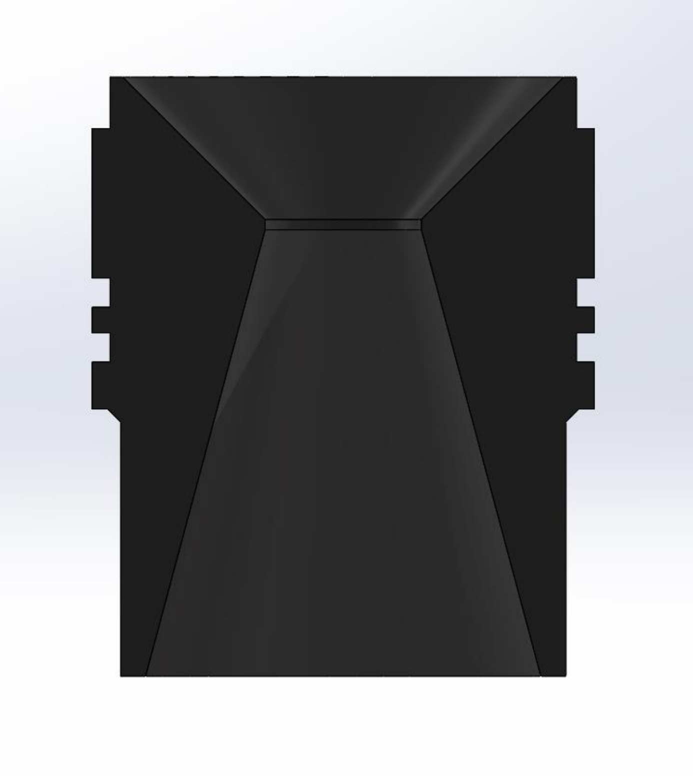
Nozzle

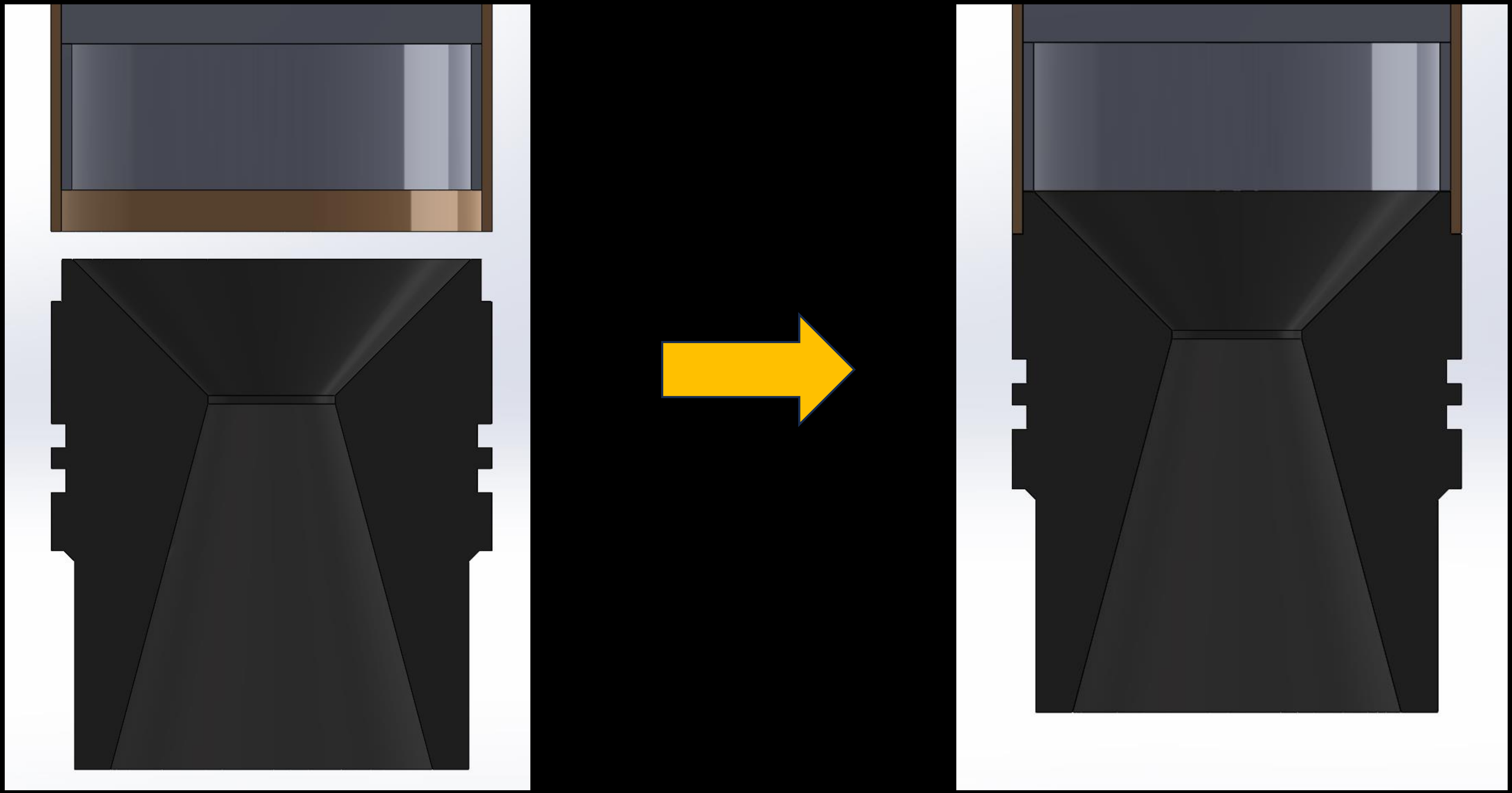
Visual Representations





Nozzle

Interfacing



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Nozzle

Implementation Plans

- COTS
- Graphite Nozzle

Estimated Cost

- 2 Nozzles - $ 350 each

Schedule

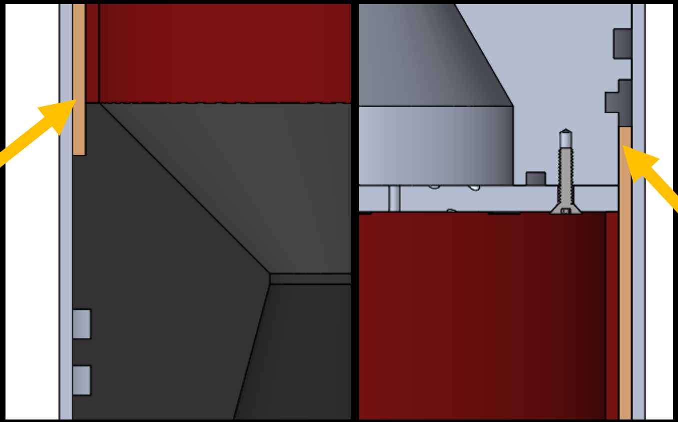
- Two+ weeks from order to delivery, material lead time may extend timeline

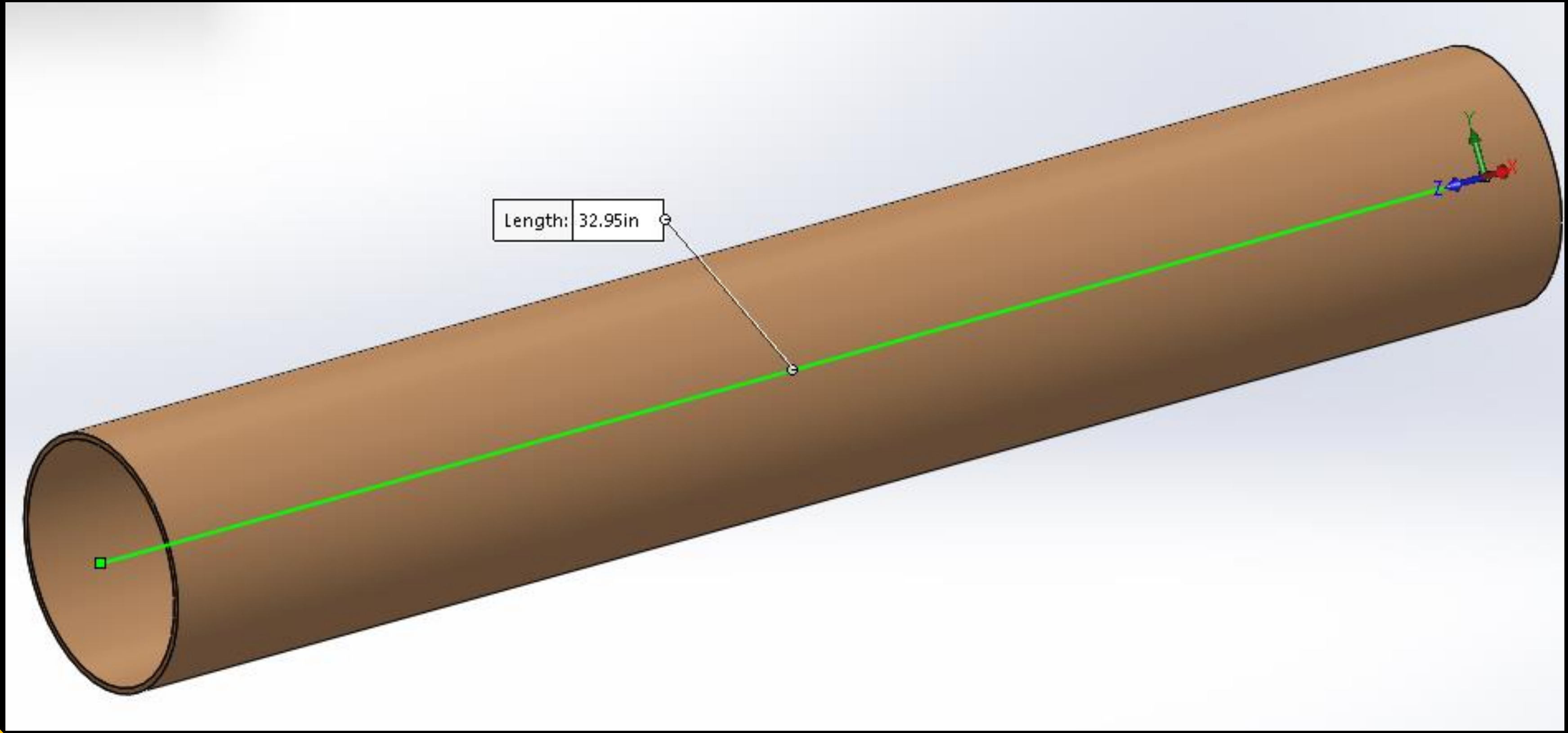
KNIGHTS EXPERIMENTAL ROCKETRY

Ablative Thermal Liner

Approach

- SRAD Phenolic Fiberglass
- ~33 inches long, subject to change
- ~0.125” thick
- Integrates with nozzle and injector to contain combustion





KNIGHTS EXPERIMENTAL ROCKETRY

Ablative Thermal Liner

Options Considered

- G-10
- Fibrous Refractory Composite Insulation (FRCI)
- Lamitex XX
- Lamitex CE

Notes

- G-10, XX, and CE share same manufacturer and 94HB Flammability Rating
- Lamitex prices through quotes

Option Information

Product	Type of Material	Tensile Strength	Highest Rated Temp.
G-10	Fiberglass	38000-65000	140C (284F)
Fibrous Refractory Composite Insulation (FRCI)	Ceramic Composite	876 PSI (Flexural)	1540C (2804F)
Lamitex XX	Phenolic Paper Composite	18850 PSI (Flexural)	140C (284F)
Lamitex C	Cotton Phenolic Composite	13500 PSI (Flexural)	125C (257F)

KNIGHTS EXPERIMENTAL ROCKETRY

Ablative Thermal Liner

Strength Information for 0.125" Sheets

Product	Flexural	Tensile	Compressive
G-10	LW: 55 kpsi CW: 45 kpsi	LW: 40 kpsi CW: 32 kpsi	FW: 68 kpsi EW: 35 kpsi
Lamitex XX	LW: 15 kpsi CW: 14 kpsi	LW: 16 kpsi CW: 13 kpsi	FW: 34 kpsi
Lamitex CE	(.062") LW: 17.5 kpsi CW: 15.5 kpsi	(0.125") LW: 11 kpsi CW: 9 kpsi	(.5") FW: 34 kpsi

LW: Lengthwise, CW: Crosswise, FW: Flatwise, EW: Edgewise

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Questions?

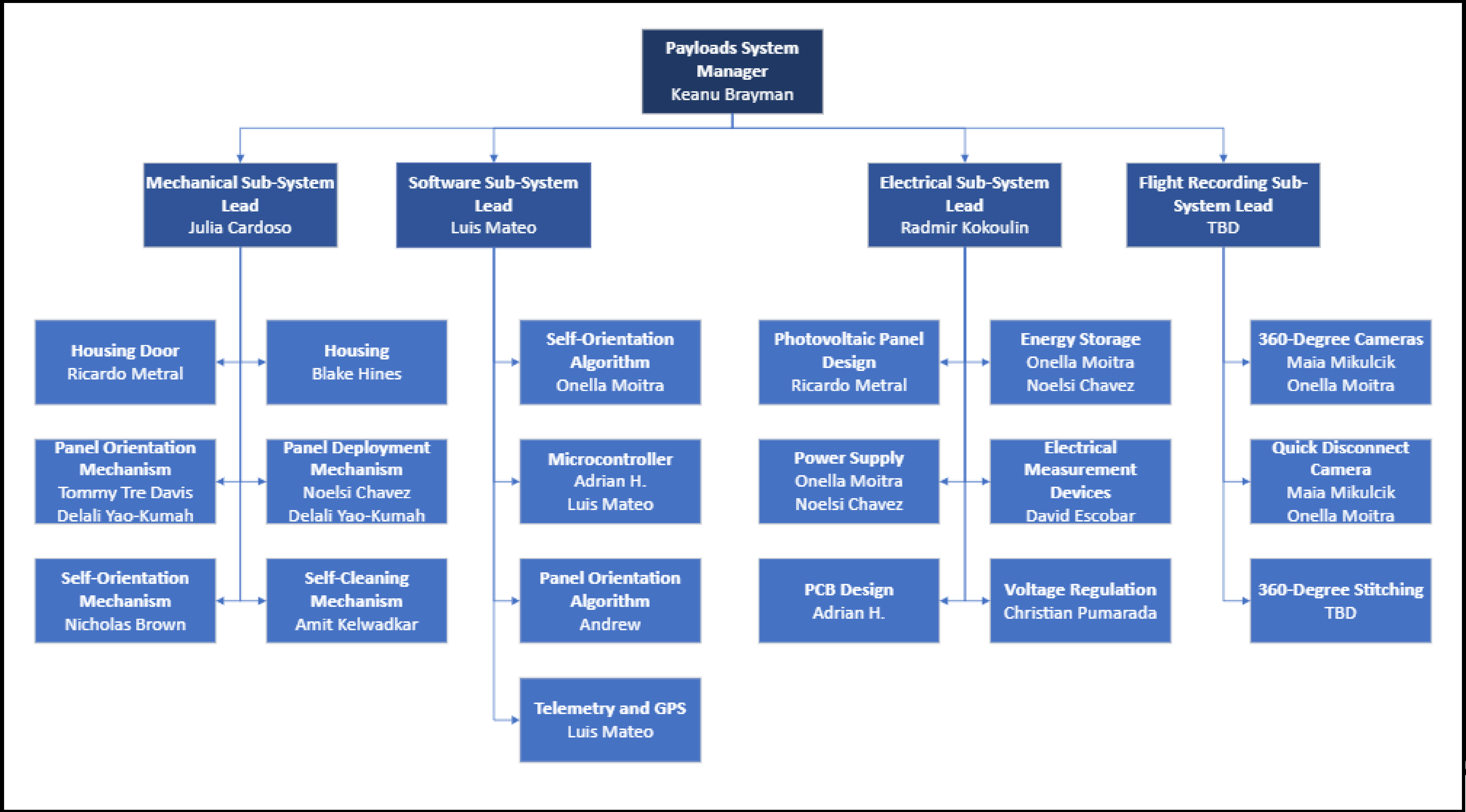
Payloads System Concept Review

Spaceport America Cup 2024

IREC 30k SRAD Hybrid Engine, Experimental Payloads, and Airframe

10/30/23

Payloads System Organization Chart



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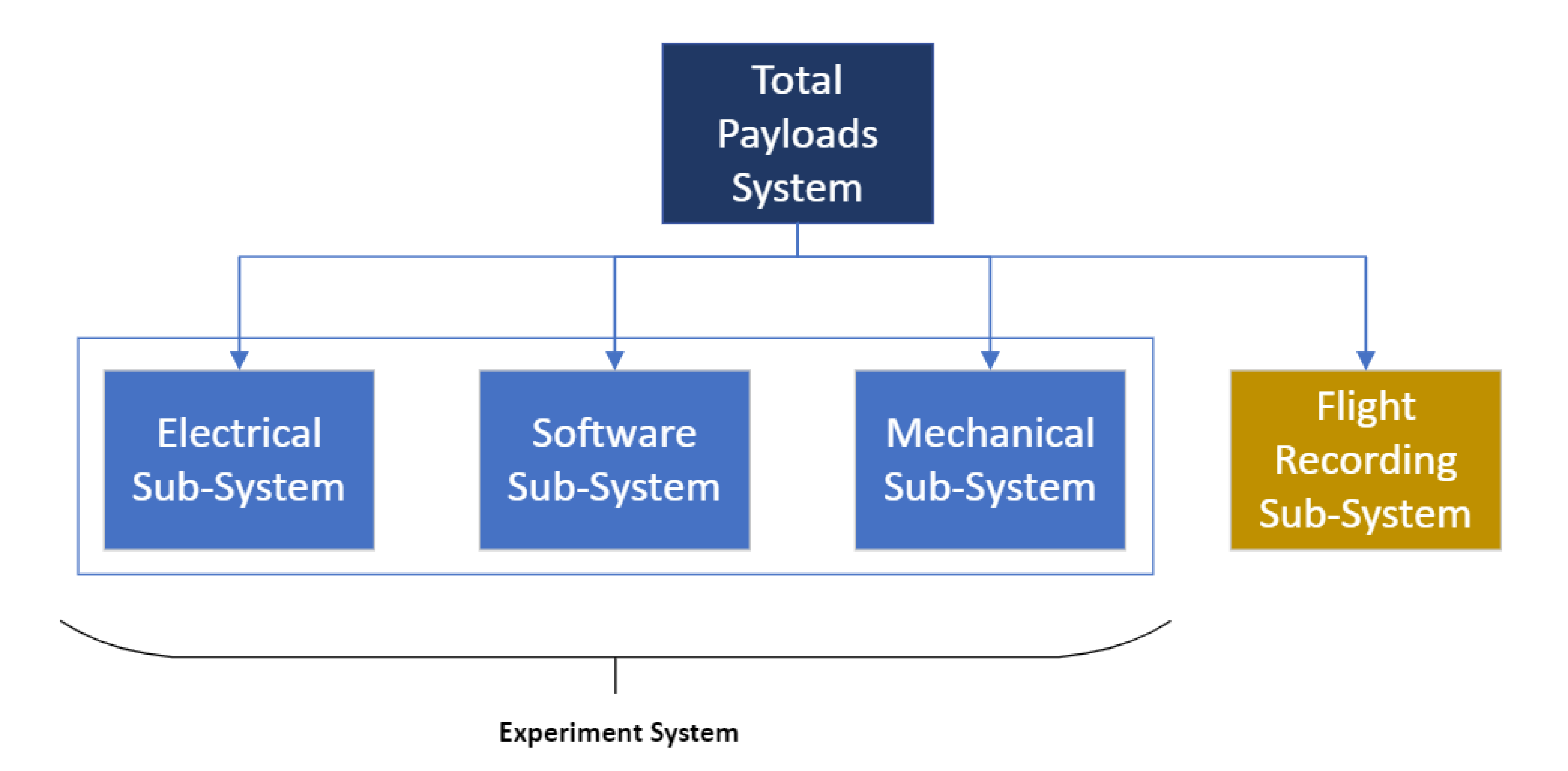
Payloads System Breakdown



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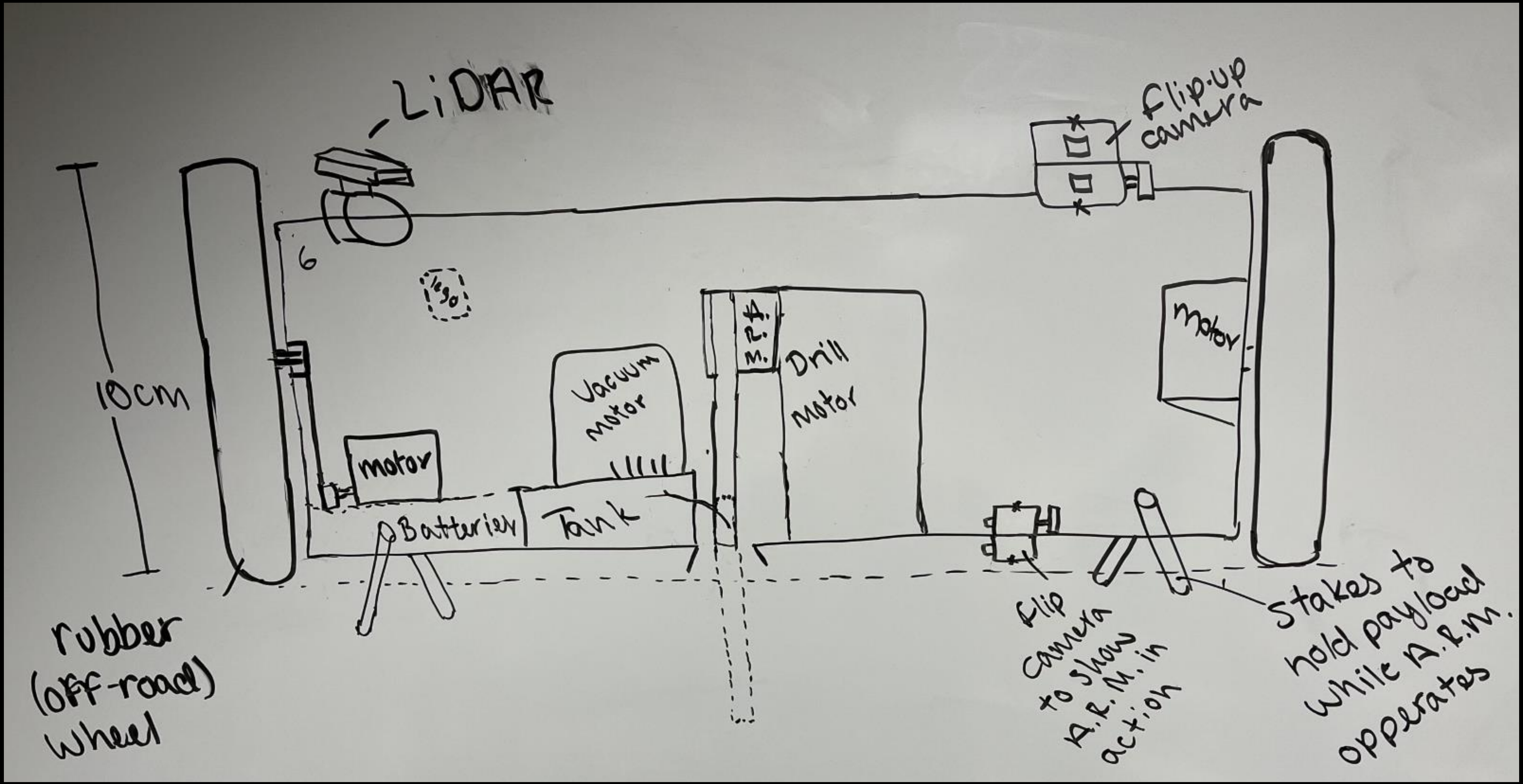
Proposal Solicitation

Concept #1: Ground Sampling Rover



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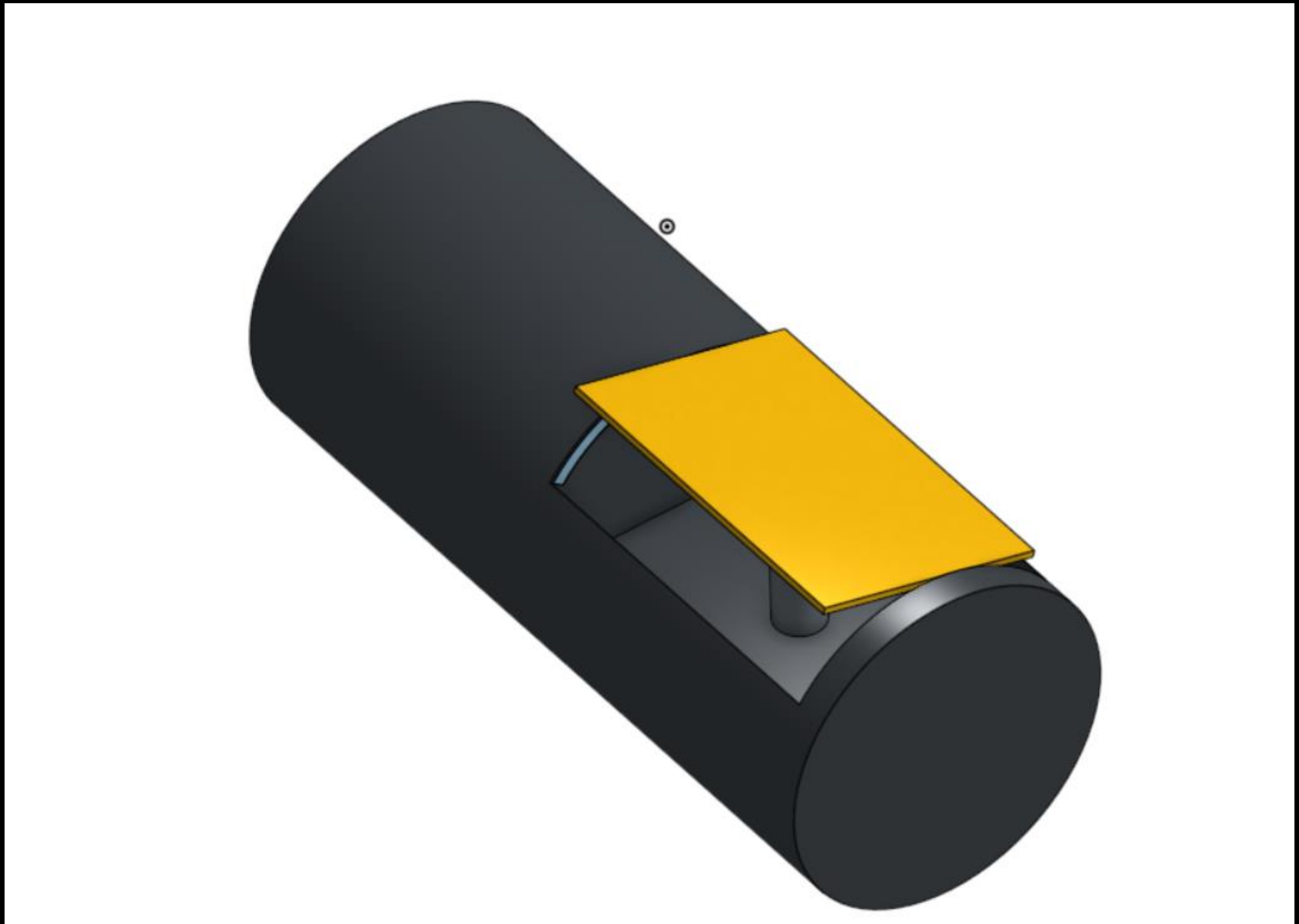
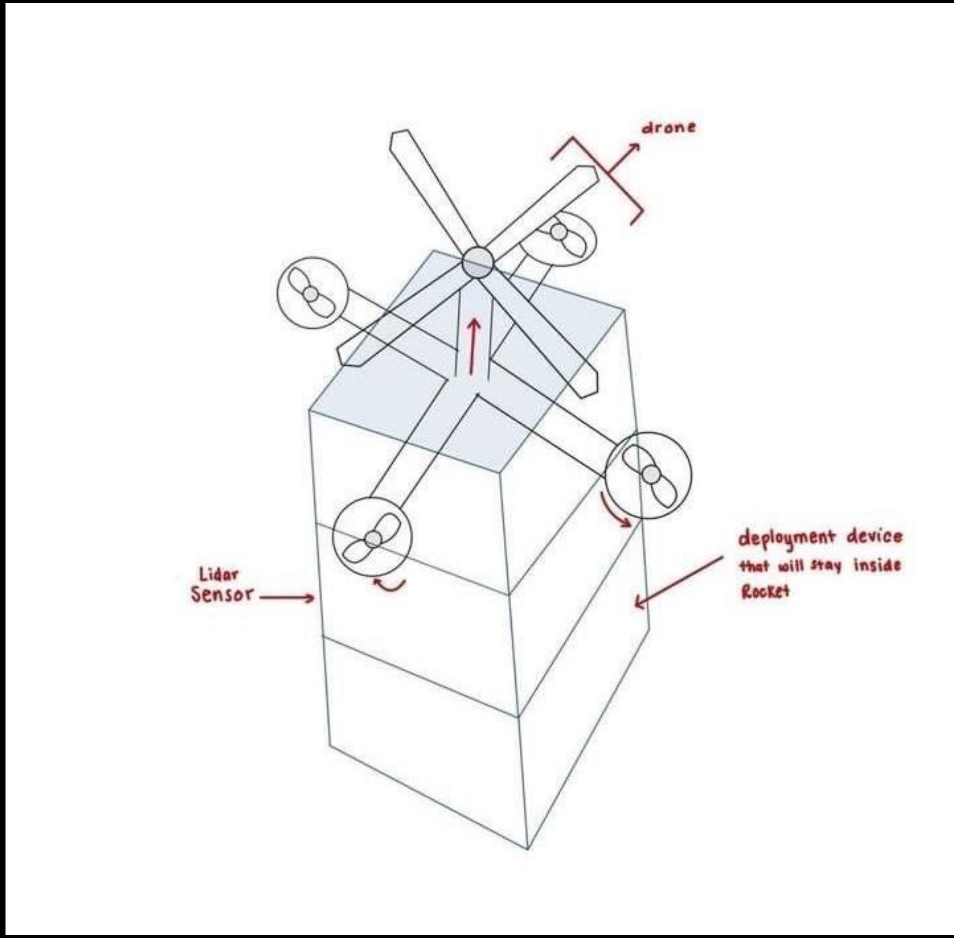
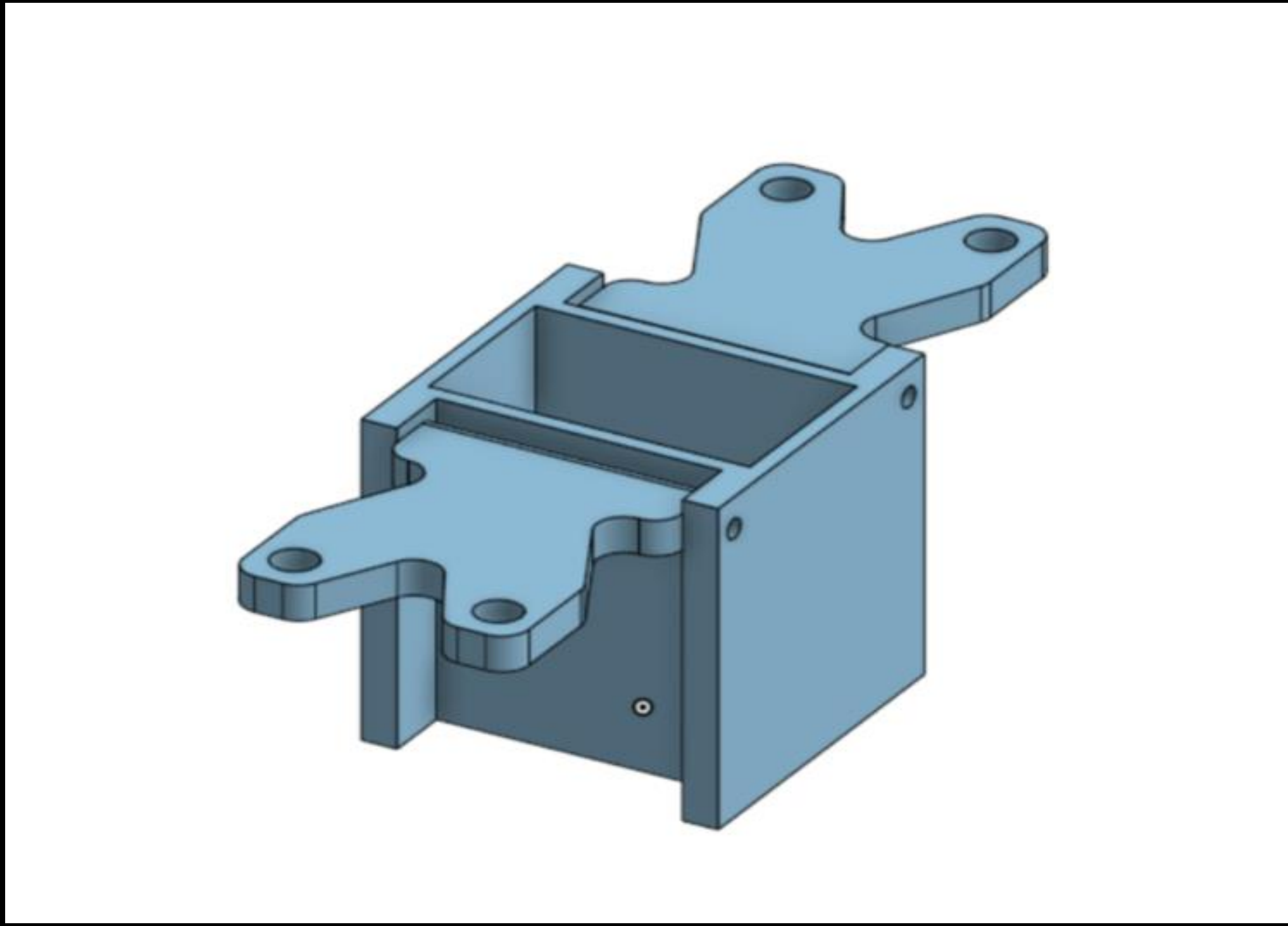
Concept #2: Deployable Solar Panel



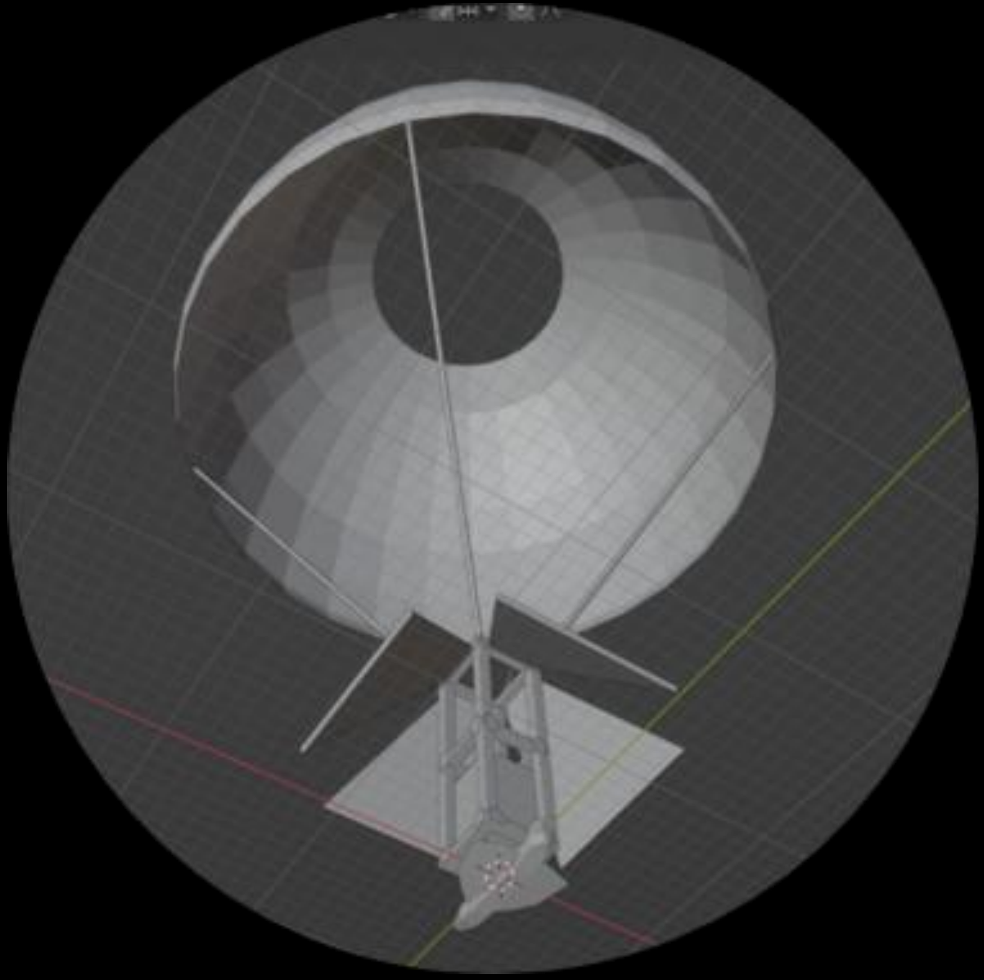
Concept #3: Topographic Mapping Drone

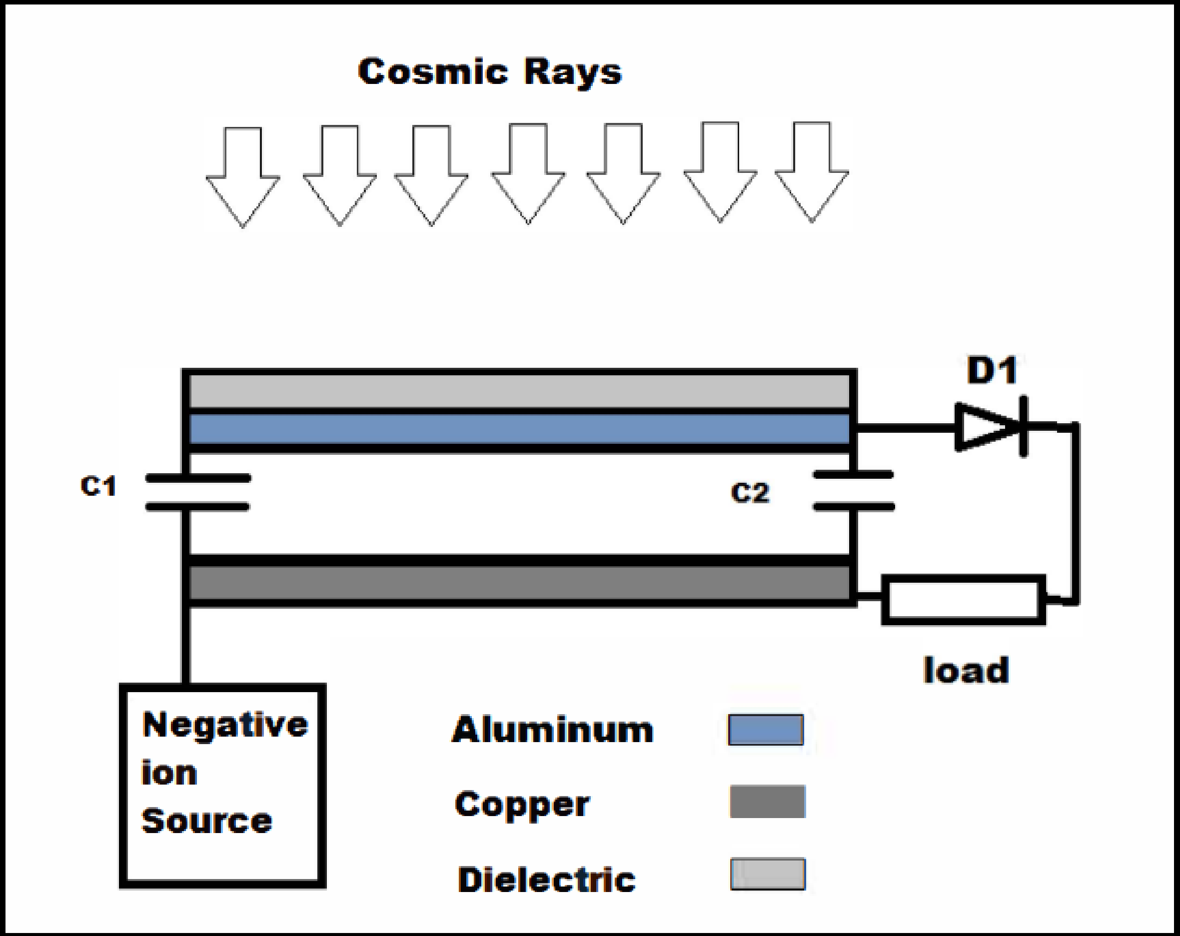


Concept #4: Advanced Research and Exploration Systems



Concept #5: Plasmon Resonance Powered Drone





Evaluation Criteria

The following criteria were used to evaluate each proposal concept

Each criterion was assigned a 0–5-point value

- Difficulty (15%)
- Cost (25%)
- Presentability (20%)
- Functionality (25%)
- Schedule (15%)
- Regulations (Pass/Fail)

Point Value
5
3
1
0

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Proposal Selection Decision Matrix

Criteria	Weight	Team 1	Team 2	Team 3	Team 4	Team 5
Difficulty	0.15	1	3	3	1	2
Cost	0.25	1	4	2	0.5	5
Presentability	0.2	4	3	3	5	5
Functionality	0.25	3	3	1.5	1	3
Schedule	0.15	1	5	3	0	1
Regulations	Pass/Fail	Pass	Pass	Pass?	Pass?	Pass
Weighted Score		2.1	3.55	2.375	1.525	3.45

Proposal #2 was selected as the IREC 2024 payload

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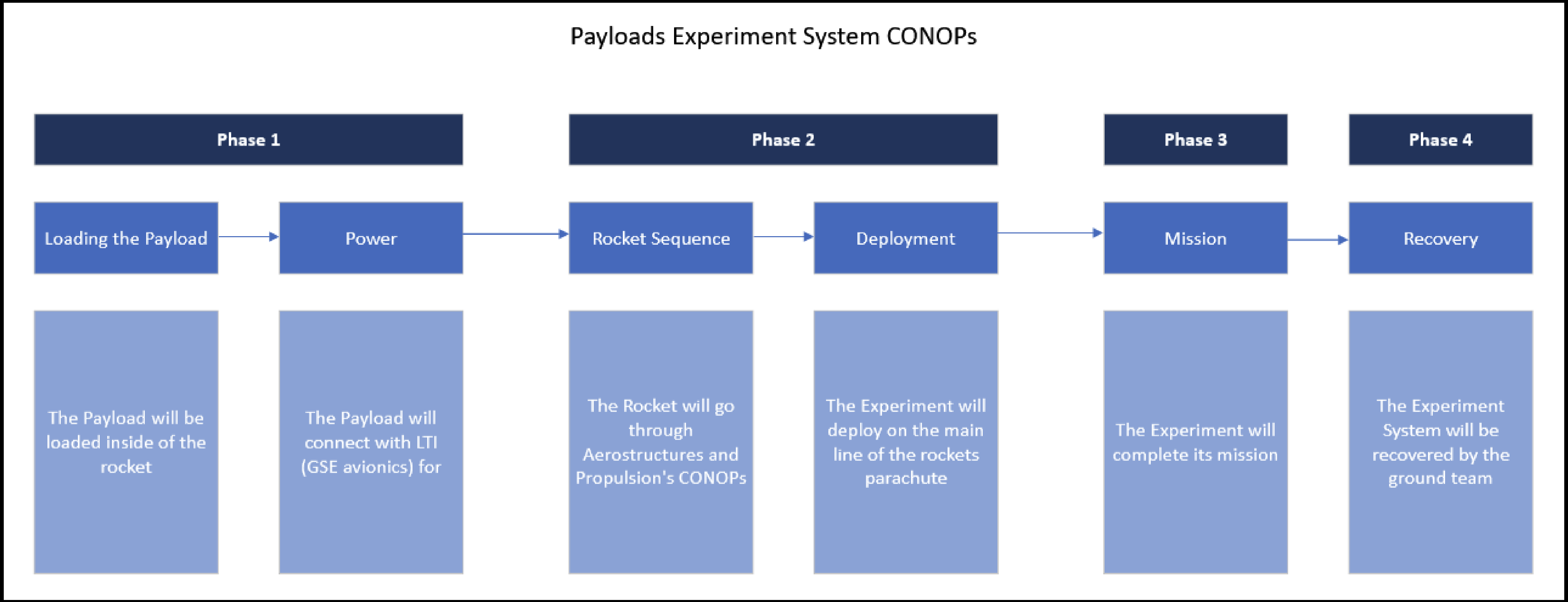
Payloads System CONOPS



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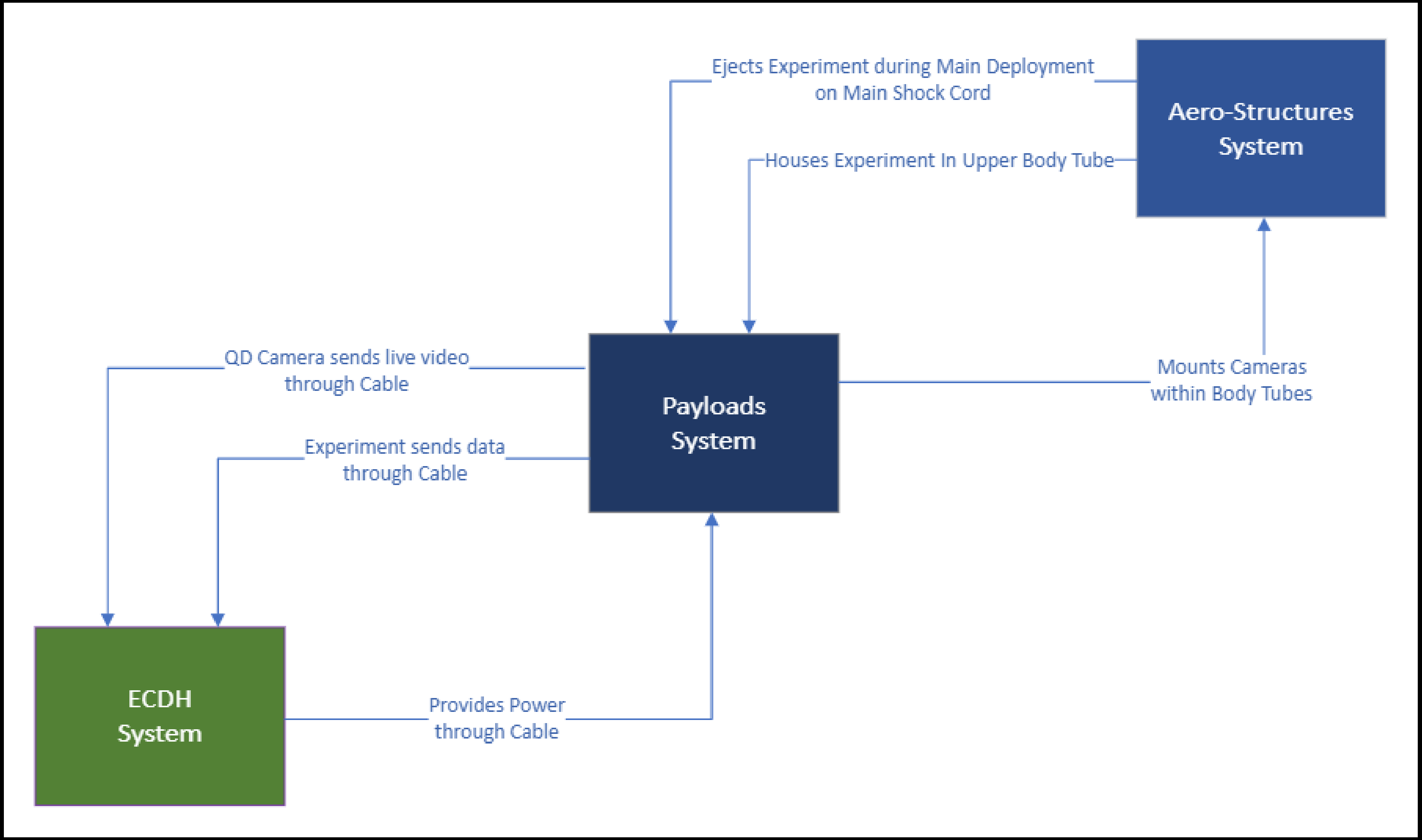
Payloads System Interface Diagram



KNIGHTS EXPERIMENTAL ROCKETRY

Total Payloads System Requirements

Requirement	Verification Method
The Total Payloads System **shall** consist of an Experiment System and a separate Flight Recording Sub-System.	Inspecion
The Total Payloads System **shall** fully fit inside the Aero-Structures System.	Inspection
The Total Payloads System **shall** be fully designed by the first week of February 2024.	Inspection
The Total Payloads System **shall** be entirely procured by the last week of February 2024.	Inspection
The Total Payloads System **shall** have been fully verified through testing by the last week of April 2024.	Inspection
The Total Payloads System **shall** be designed, manufactured, tested, and validated within a budget of [$1,600.]	Inspection
The Total Payloads System **shall** reserve [$400] for overhead and emergency purchases.	Inspection
The Total Payloads System **shall** be safely operable.	Demonstration
The Total Payloads System **shall** be designed and integrated such that it does not jeopardize the overall Vehicle's safety.	Demonstration
The Total Payloads System **shall** operate in temperatures above [-47.2 °C] and below [110 °C].	Demonstration
The Total Payloads System shall survive [11 Gs] of acceleration.	Demonstration

KNIGHTS EXPERIMENTAL ROCKETRY

Experiment System Requirements

Requirement	Verification Method
The Experiment System **shall** consist of Mechanical, Electrical, and Software Sub-Systems.	Inspection
The Experiment System **shall** have a weight of [9] lbs.	Inspection
The Experiment System **shall** have a CubeSat factor of [4U].	Inspection
The Experiment System **shall** have dimensions of [10 cm] diameter by [41.32 cm].	Inspection
The Experiment System **shall** remain independently powered for [1 hour].	Test
The Experiment System **shall** interface with the Aero-Structures system.	Inspection
The Experiment System **shall** withstand impact with the ground at [30] ft/s.	Test
The Experiment System **shall** be easily removeable from Aero-Structures System for inspection by ESRA judges.	Demonstration
The Experiment System **shall** fit inside [16.3] inches of the Airframe Upper Body Tube.	inspection
The Experiment System **shall** be deployed adjacent on the Main Parachute's Shock Cord.	Demonstration
The Experiment System **shall** be powered via cable connection by the Avionics Service System until Main Parachute Deployment event.	Test
The Experiment System **shall** send data via cable connection to the Avionics Service System until Main Parachute Deployment event.	Test
The Experiment System **shall** receive data via cable connection from the Avionics Service System until Main Parachute Deployment event.	Test
The Experiment System **shall** separate from the harnessing of the Avionics Service System upon Main Parachute Deployment event.	Demonstration
The Experiment System **shall** collect and store solar energy in a separate dedicated battery bank.	Demonstration
The Experiment System **shall** collect and store a solar energy amount of [TBD Watts].	Test
The Experiment System **shall** be designed, manufactured, tested, and validated within a budget of [$1,200].	Inspection
The Experiment System **shall** orient the Solar Panel within [5] degrees towards the Sun's direction.	Test
The Experiment System **shall** be deployed in such a way that it does not put spectators in direct harm.	Demonstration

Payloads Systems Technical Performance Measures

Measure	TPM Value	Units	Verification Method
Experiment Weight	[9 lbs]	Pounds	Inspection
Volume	[4 U]	CubeSat Units	Inspection
Length	[16.3 in]	Inches	Inspection
Min Temp	[-47.2 °C]	Fahrenheit	Demonstration
Max Temp	[110 °C]	Fahrenheit	Demonstration
Max Impact Speed	[30 ft/sec]	Feet per Second	Demonstration

Payloads Systems Cost

Subsystem	Estimated Cost
Mechanical	$600
Electrical	$300
Software	$300
Flight Recording	$400
Overhead	$400
Total	$2000

Payloads Systems Verification Plans

- Inspection on Machined Parts
- FEA on Payload Housing
- Battery Longevity
- Solar Panel power generation test
- Software-In-The-Loop for all Systems
- Camera Stitching occurs AFTER launch
- Hardware-In-The-Loop for all Systems (with Avionics)
- MQD testing
- Drop Test
- Snatch Force Test
- Payload Dry Fit
- Weight Inspection
- Shock and Vibration Testing*
- Temperature Test

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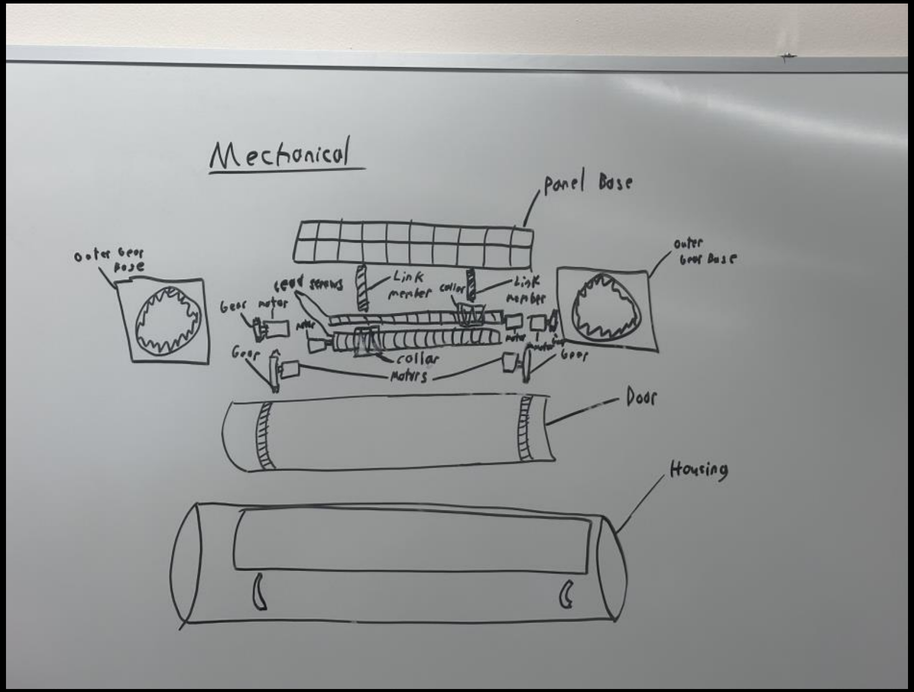
Mechanical Sub-System

A prototype of the outer housing



Exploded view drawing of
the entire mechanical system

KNIGHTS EXPERIMENTAL ROCKETRY

Mechanical Requirements

Requirement	Verification Method
The mechanical subsystem **shall** weigh [8.8 lbs]	Inspection
The mechanical subsystem **shall** have a [sliding door] to protect the solar panel during launch and during adverse weather	Demonstration
The mechanical subsystem **shall** have a self-orientation system with square ends and a rotating middle section in order to stay stabilized upon landing	Inspection
The mechanical subsystem **shall** have an offset weight to initially orient the housing	Inspection

Requirement	Verification Method
The mechanical subsystem **shall** have a [system of lead screws] to get the solar panel outside of the main body after landing as well as orient solar panel for tracking the sun	Test
The mechanical subsystem **shall** have a motor driven orientation system that rotates the inner cylinder to ensure correct positioning for operation	Test
The mechanical subsystem **shall** have a self-cleaning system to clean off the solar panel	Demonstration

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Mechanical TPMs

Measure	TPM Value	Units	Verification Method
Mass	[TBD]	lbs	Inspection
Length	[40]	cm	Inspection
Volume	[4000]	cm^3	Inspection
Power Draw	[12]	Volts	Testing

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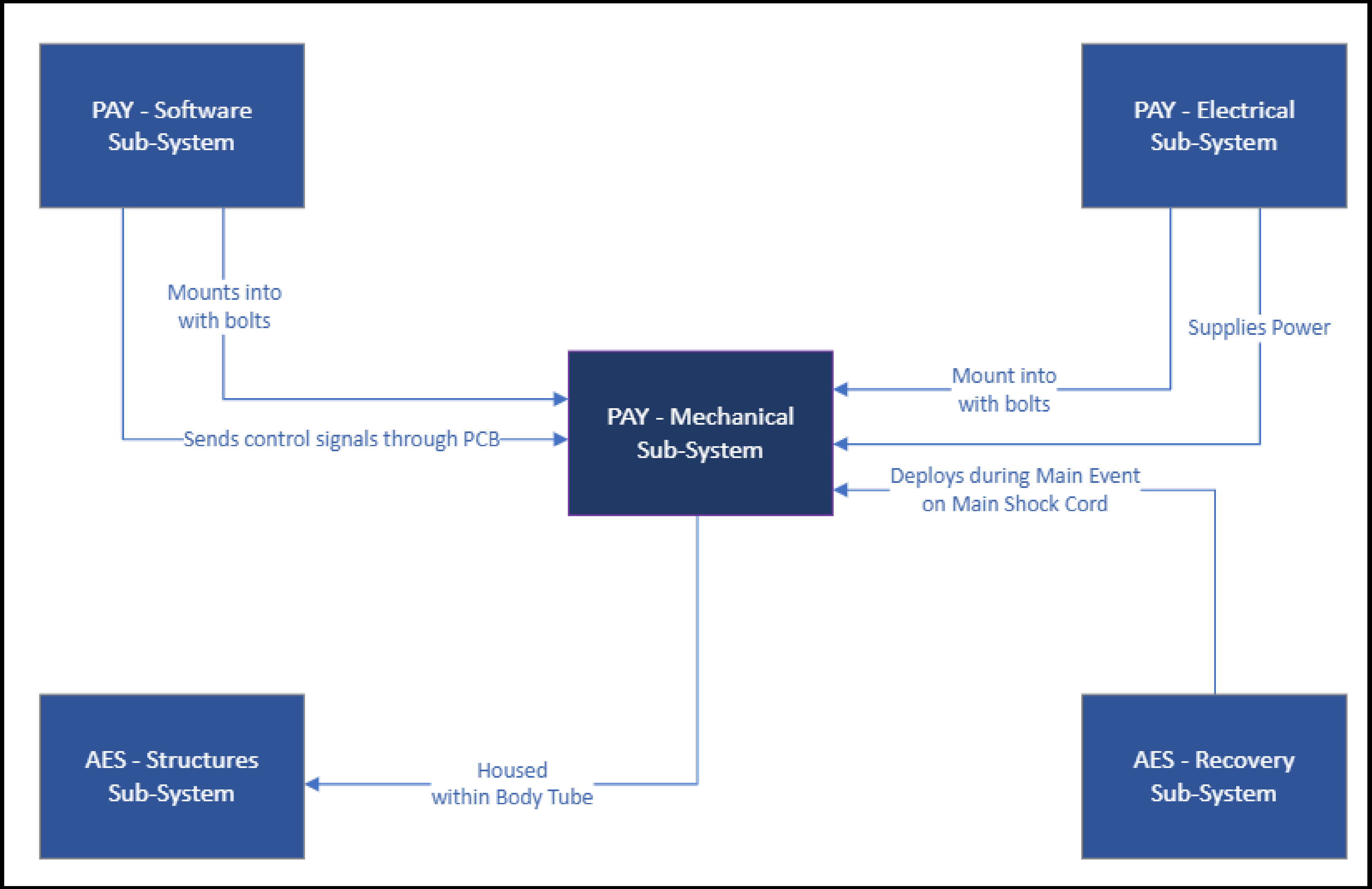
Mechanical Interface Diagram



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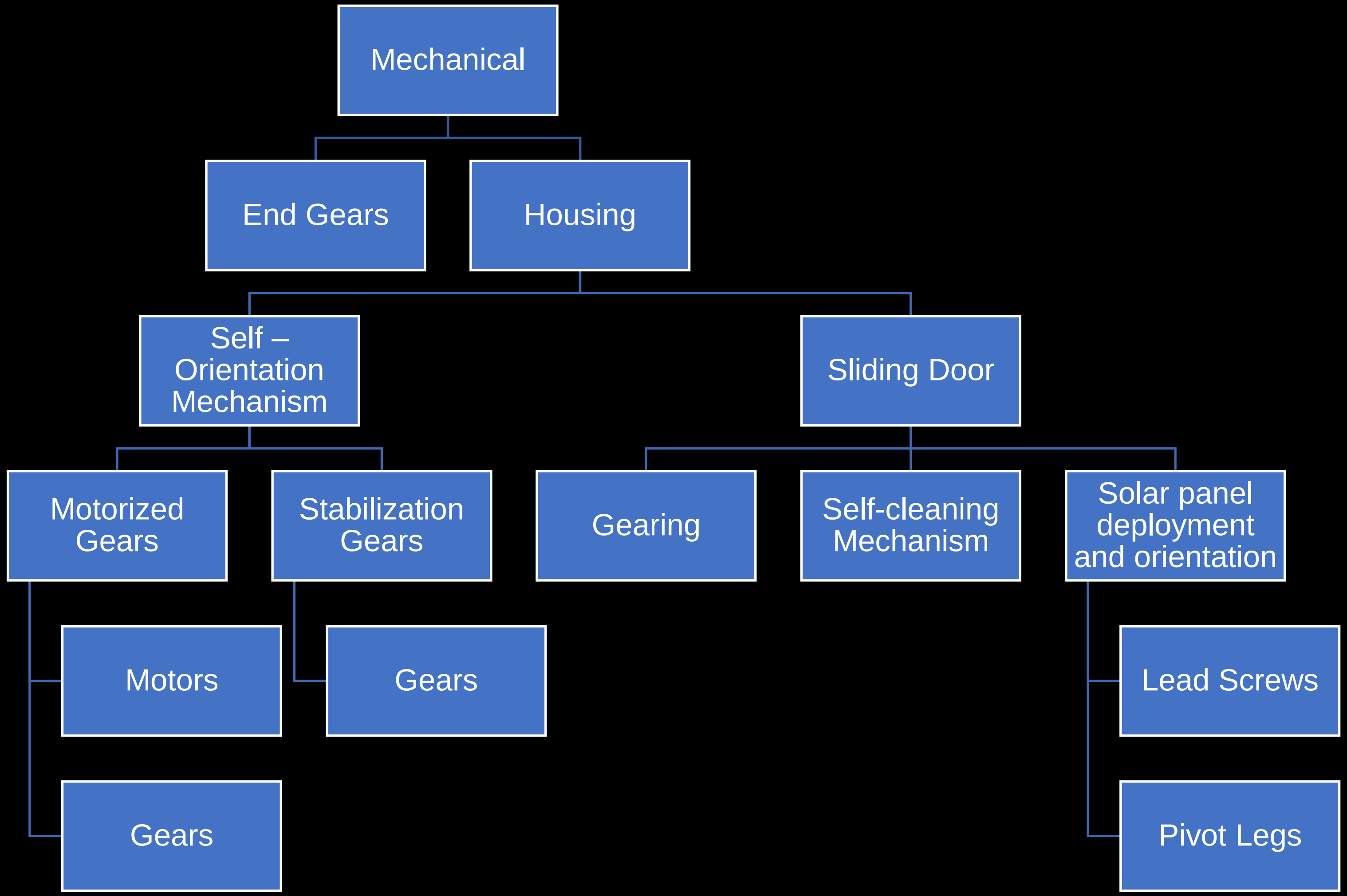
Mechanical Component Breakdown



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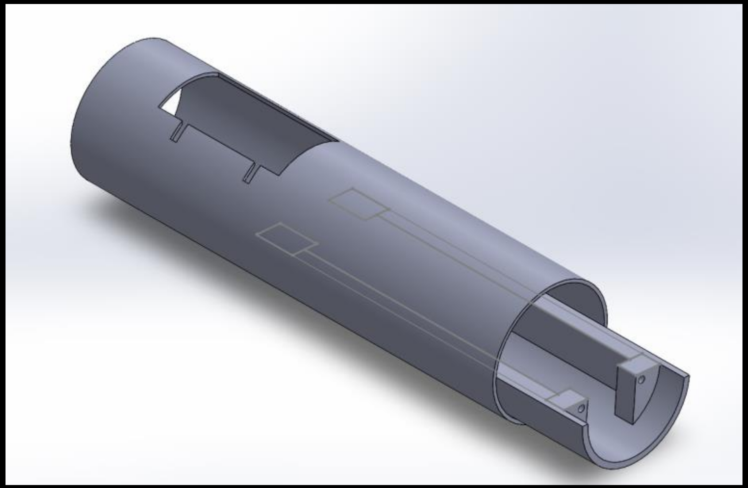
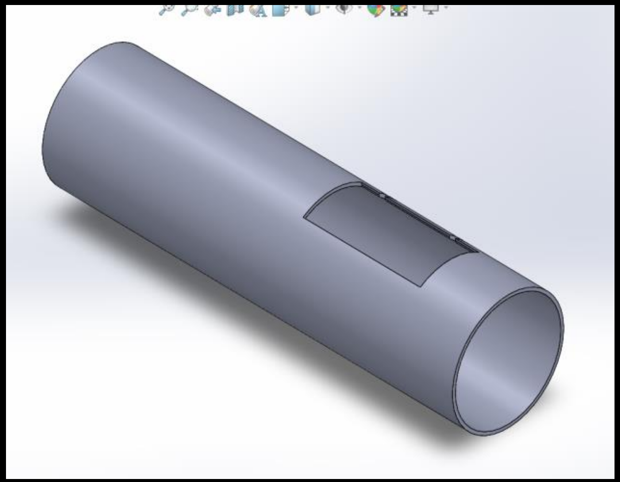
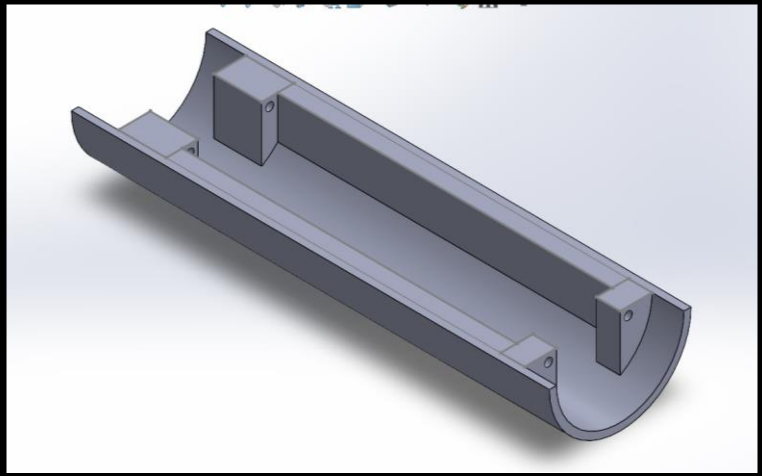
Housing

Exterior shell for the experiment which shall house all components

Possible Points of Failure

- Housing breaks upon impact
- Housing breaks upon receiving force from shock cord connection
- Housing breaks mid-flight

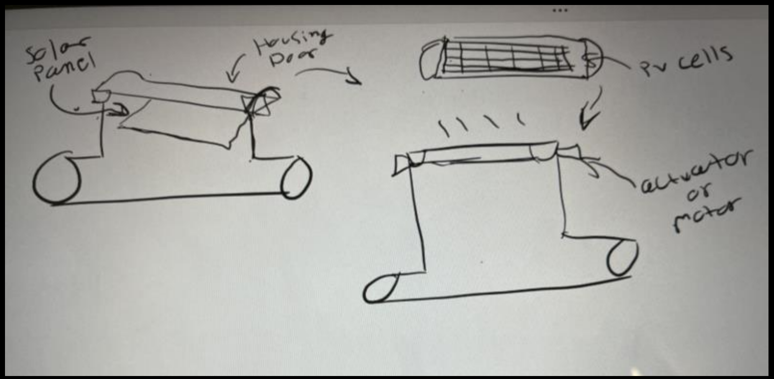
Housing

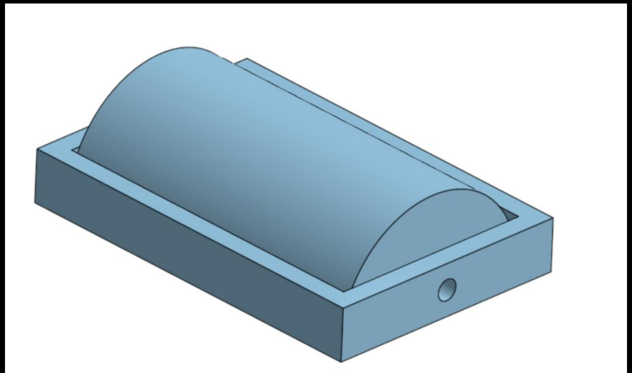
Requirement	Verification Method
The body **shall** be able to endure [TBD lbs] of impact	Test
The housing **shall** be assembled out of [TBD material]	Inspection
The housing **shall** have a footprint of [9 cm] diameter by [30 cm]	Inspection

Measure	TPM Value	Units	Verification Method
length	!	cm	Measurement
diameter	[9]	cm	Measurement

Housing Door

- Materials currently being considered for the door are:
  - Polyamide
  - Acrylonitrile Butadiene Styrene(ABS)
  - Polyethylene terephthalate glycol(PET-G)
  - Aluminum

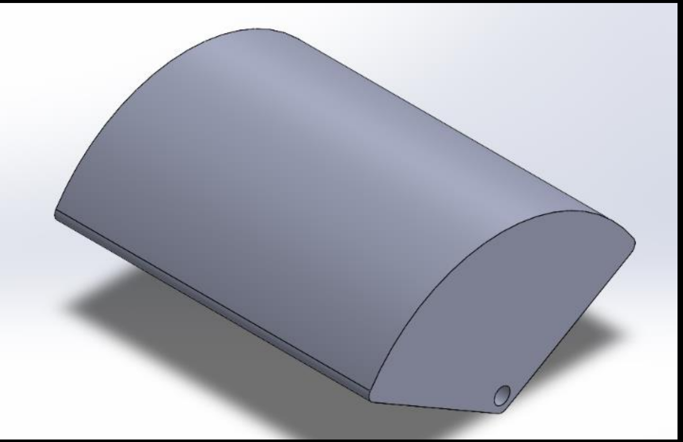


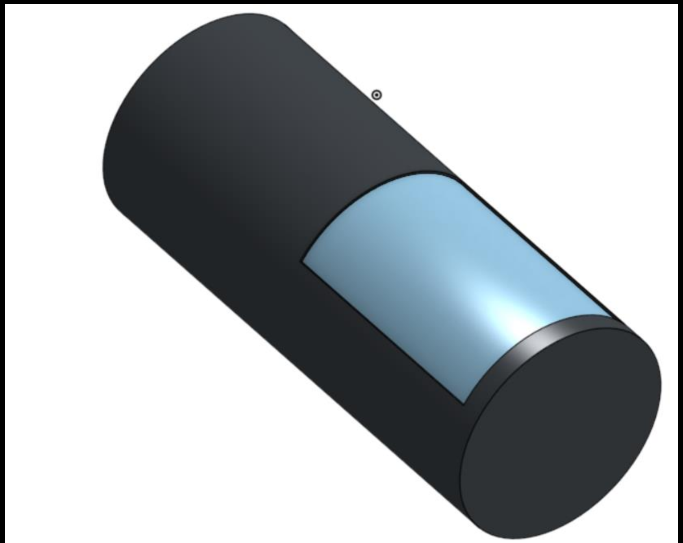


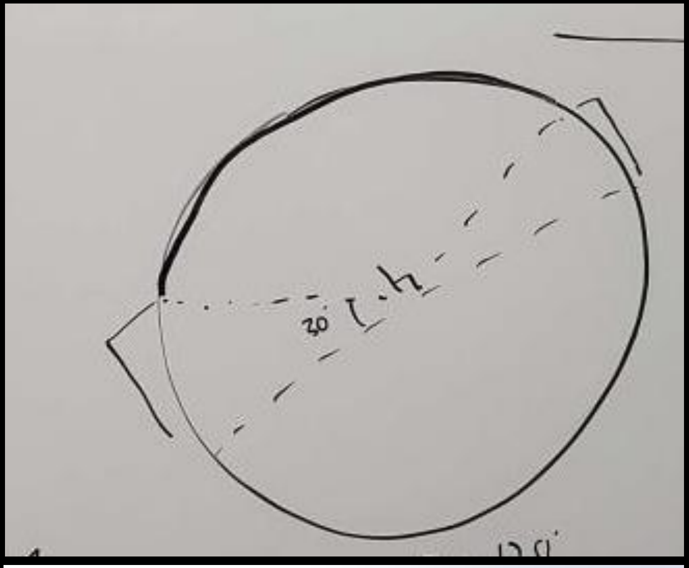
Requirements
The housing door **shall** be able to protect the payload components during landing
The housing door **shall** be able to open and close easily to protect the components during adverse weather
The housing door **shall** minimize debris entering the payload
The housing door **shall** be able to provide clearance for the panel to deploy once landed
The housing door **shall** stay open while panel is deployed
The housing door **shall** be [40 cm] long and have an arc length of [4 cm]
The housing door **shall** weigh [1 lb]

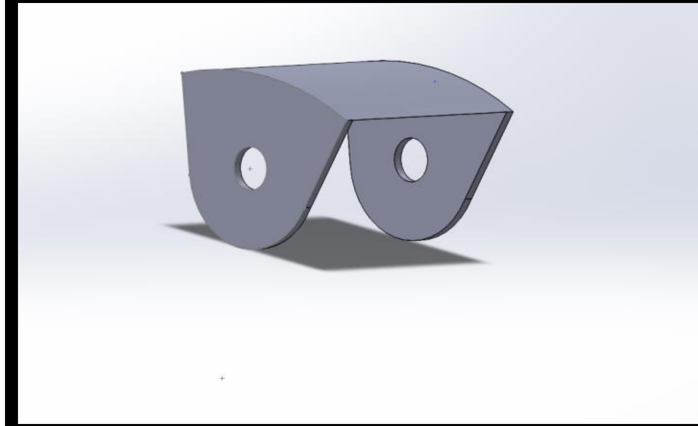
Housing Door

Before our final design these were some options considered:



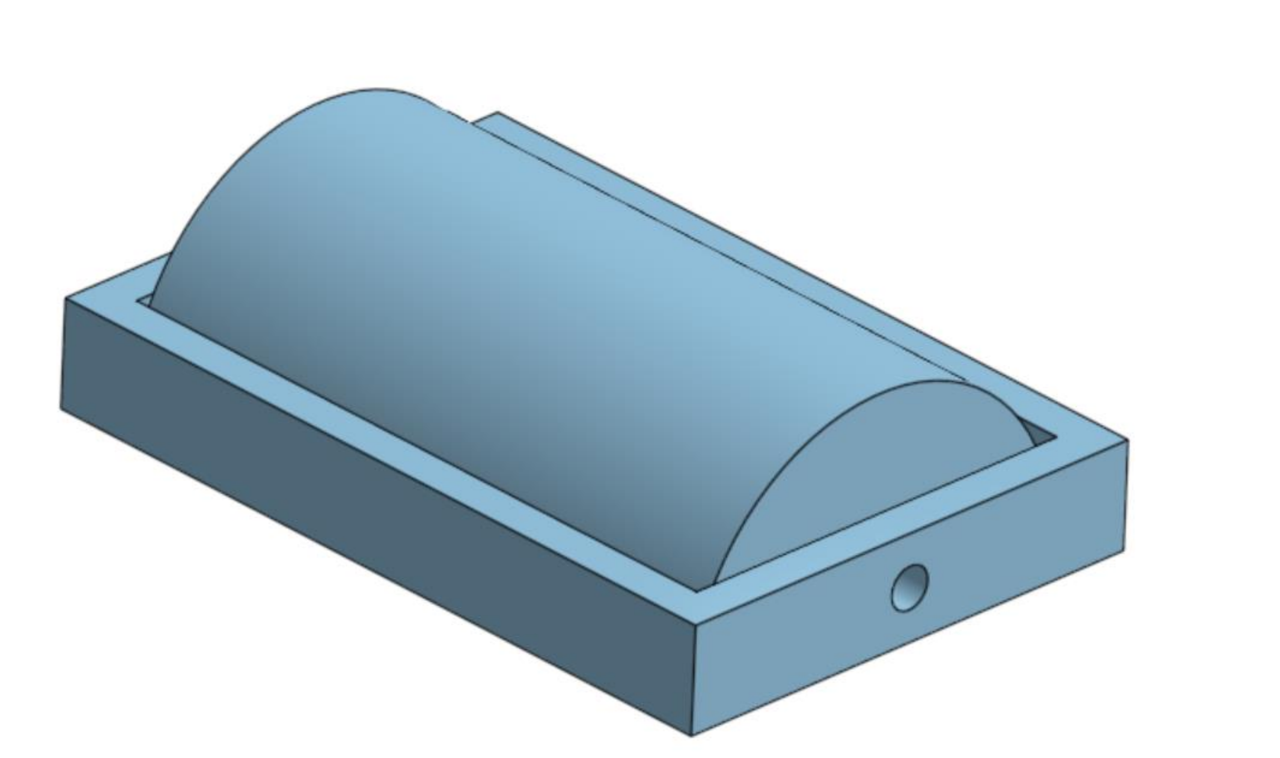






Housing Door

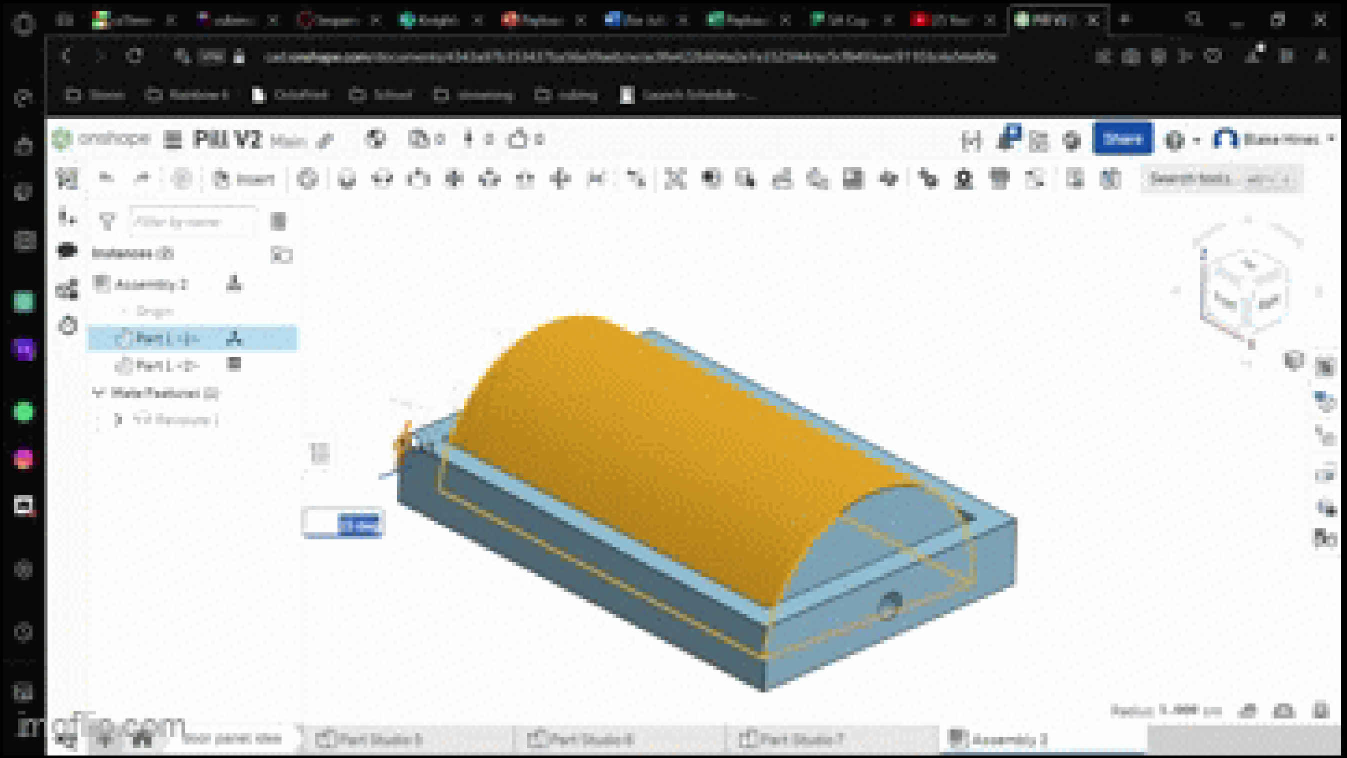
Design we went with adds another degree of freedom upon the payload's rotation by putting the panel on the flat side of the door



Housing Door

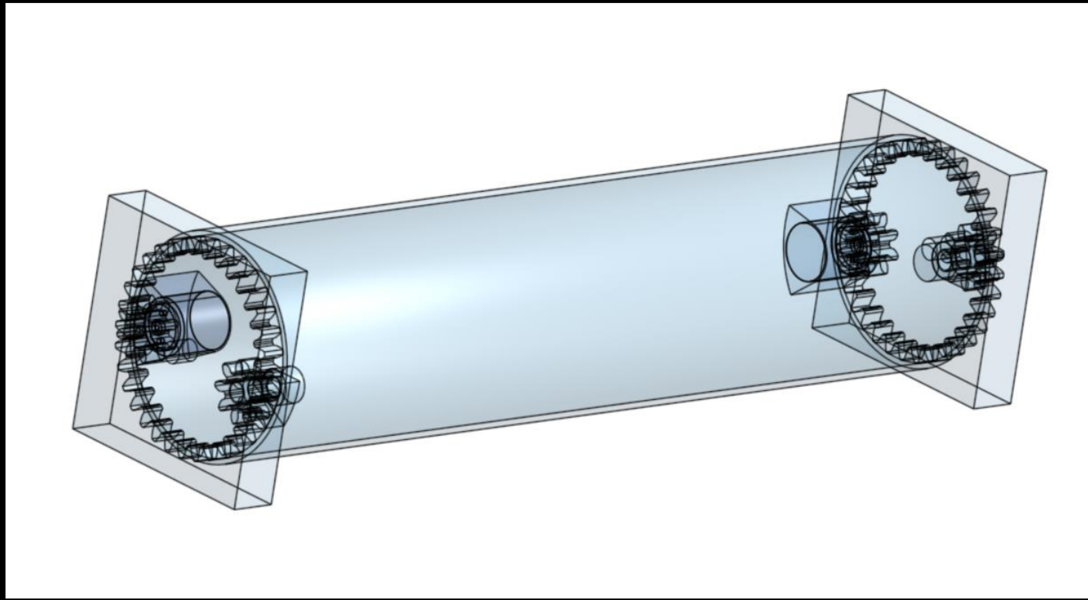
Possible Points of Failure:

- Damage upon landing impact
- Failure in motor to provide enough torque to rotate door and expose panel
- Weight of the top side of the door throws off motor calculations and doesn't align towards the sun.



Self-Orientation

Requirement	Verification Method
The self-orientation mechanism **shall** have a stationary outside while rotating the inner components with a [type of motor]	Inspection
The self-orientation mechanism **will** be able to track the sun along a rotating axis to aid with the solar orientation	Test
The self-orientation mechanism **shall** be driven by [TBD] motors	Inspection



Self-Orientation

Possible Points of Failure:

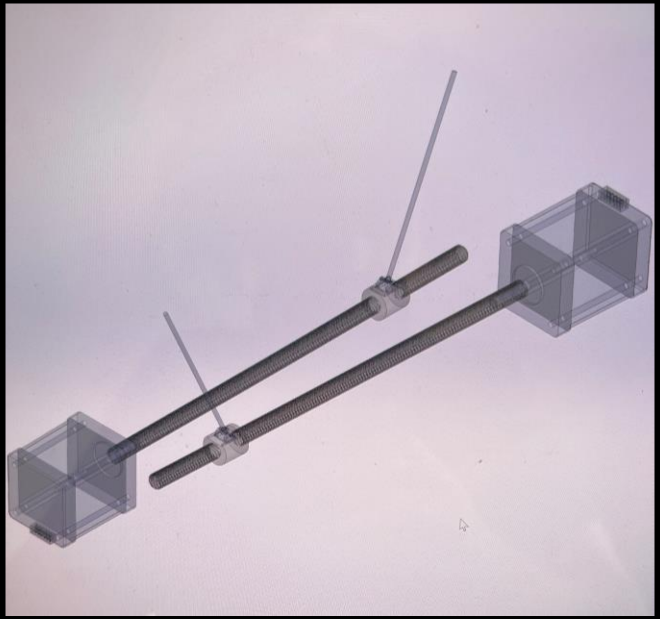
- Misalignment of internal gear system upon landing
- Failure of motor to apply enough torque to rotate payload
- Self-orientation subassembly causes Panel Orientation subassembly to fail because of unaccounted for rotation.

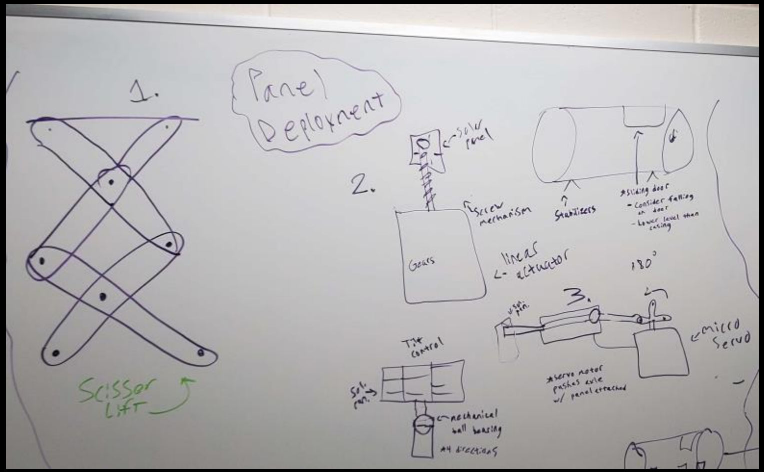
Measure	TPM Value	Units	Verification Method
Torque	77.571	lb-ft	Analysis
Angle of Rotation	90	degrees	Demonstration

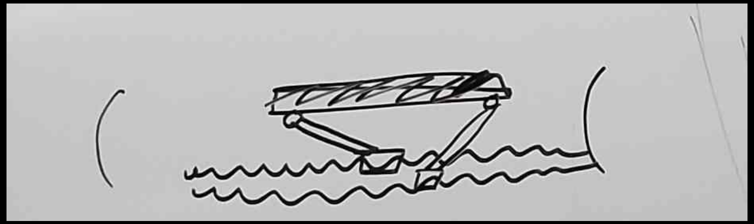
Solar Panel Deployment and Orientation

We considered a few designs such as
- Scissor Lift
- Linear Actuator
- Mechanical Arm with Ball Joint

We decided to use a lead screw system that would double as a deployment mechanism and an orientation mechanism through pivoting



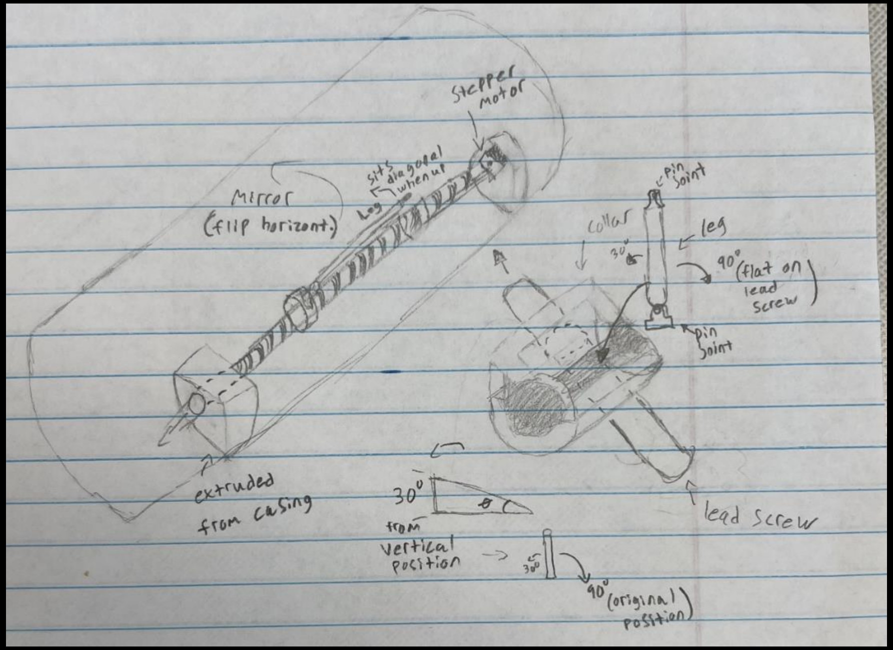




Solar Panel Deployment and Orientation

Possible points of failures:

- Not fully extending upon deployment
- Rotation in the pivot legs
- Incorrect movement in the stepper motor
- Not orienting correctly



Requirements	Verification Method
The solar orientation assembly **shall** be able to move the panel toward any given direction	Inspection
The deployment mechanism **shall** have a [TBD] base that accounts for the solar panel	Inspection
The deployment mechanism **shall** have 2 leadscrews running in parallel to allow the panel to lift and tilt along an axis	Inspection
The solar panel deployment and orientation mechanism **will** drive lead screws with [2 Stepper] motors	Inspection

Solar Deployment and Orientation

Measure	TPM Value	Units	Verification Method
Length of connecting rod (*l*)	[11.811]	in	Inspection
Length of solar panel (l_{sp})	[7.874]	in	Inspection
Screw lead (*k*)	[0.495]	in/rad	Inspection
Mass	[TBD]	lbs	Analysis
Torque	[9.63]	lbs/in	Analysis

$$y = \sqrt{\ell^2 + (k\theta)^2}$$

$$\theta_n = \tan^{-1}\left(\frac{\ell_{sp}}{|y_2 - y_1|}\right)$$

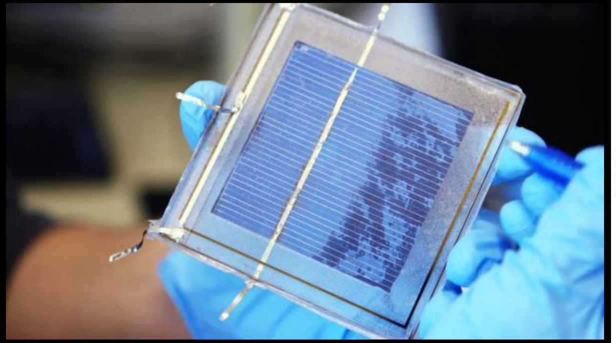
$$\theta_n = \tan^{-1}\left(\frac{\ell_{sp}}{\sqrt{\ell^2 + (k\theta_2)^2} - \sqrt{\ell^2 + (k\theta_1)^2}}\right)$$

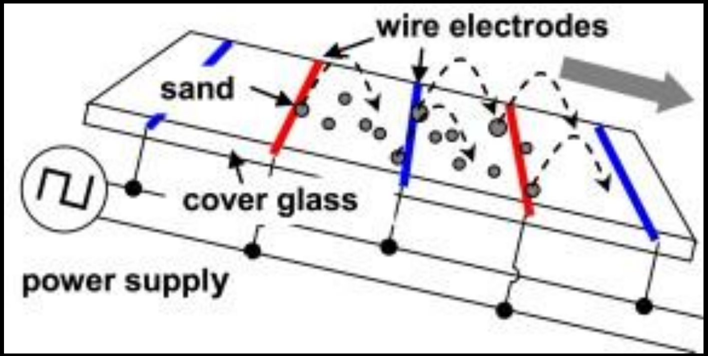
$$\ell_{window} = \ell_{sp} \cdot \sin(\theta_n)$$

Self-Cleaning Mechanism

- The solar panel will have some form of cleaning itself to theoretically survive long missions without maintenance

- The most prospective manner to do so currently, is through electrostatic discharge



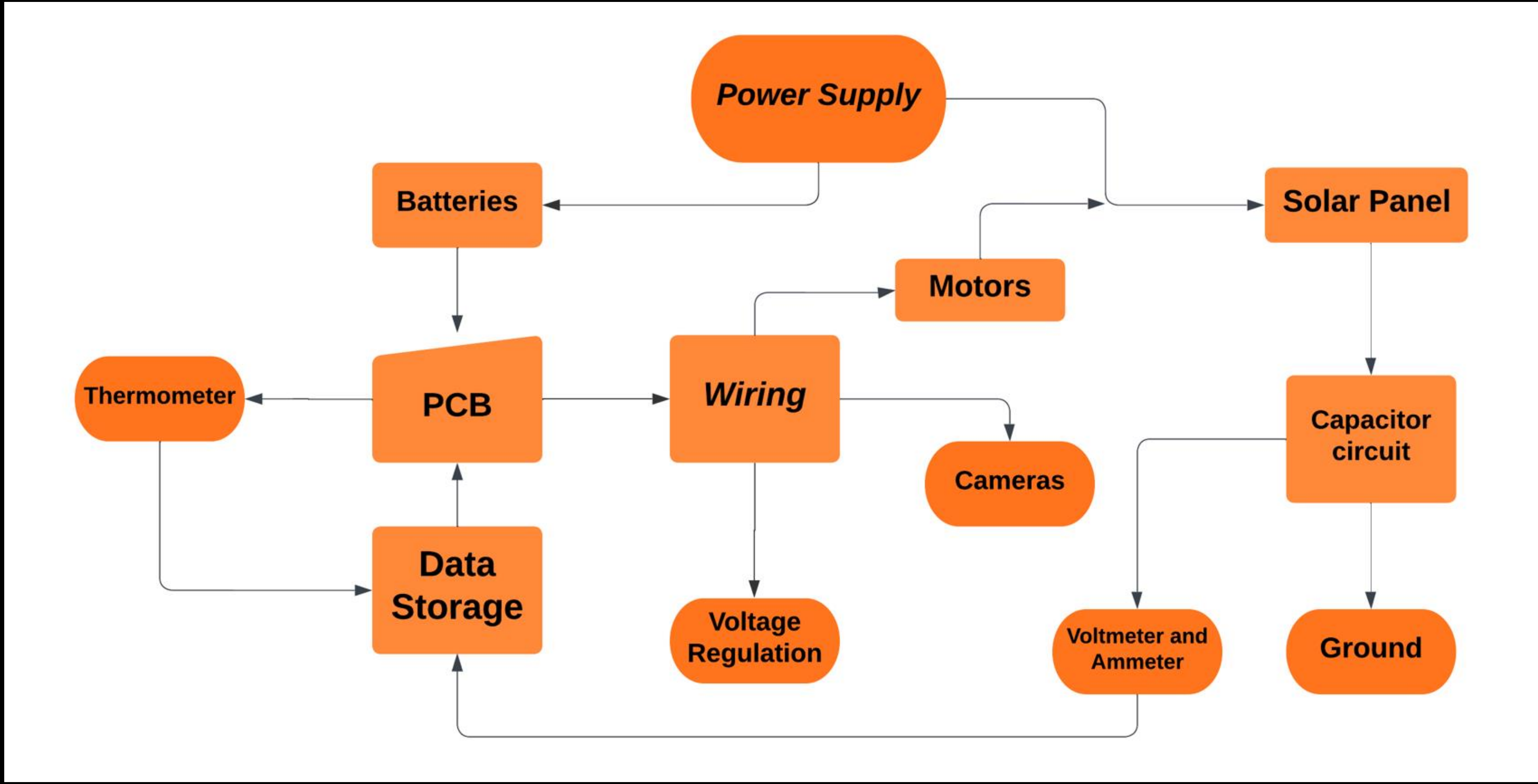


Requirements
The self-cleaning mechanism **shall** be able to remove debris from the solar panel using [electrostatic discharge]
The self-cleaning mechanism **shall** use three different, repeating electrodes to remove debris
The self-cleaning mechanism **shall** function at any given time
The self-cleaning mechanism **should** not decrease panel energy generation
The self-cleaning mechanism **shall** use [dielectric film coating] to protect the electrodes
The self-cleaning mechanism **shall** minimize power usage
The self-cleaning mechanism **should** not require maintenance to retain function

Mechanical Path Forward

- ***Making the full CAD***
- ***Test further prototypes***
- ***Finalize the designs***

Electrical Sub-System



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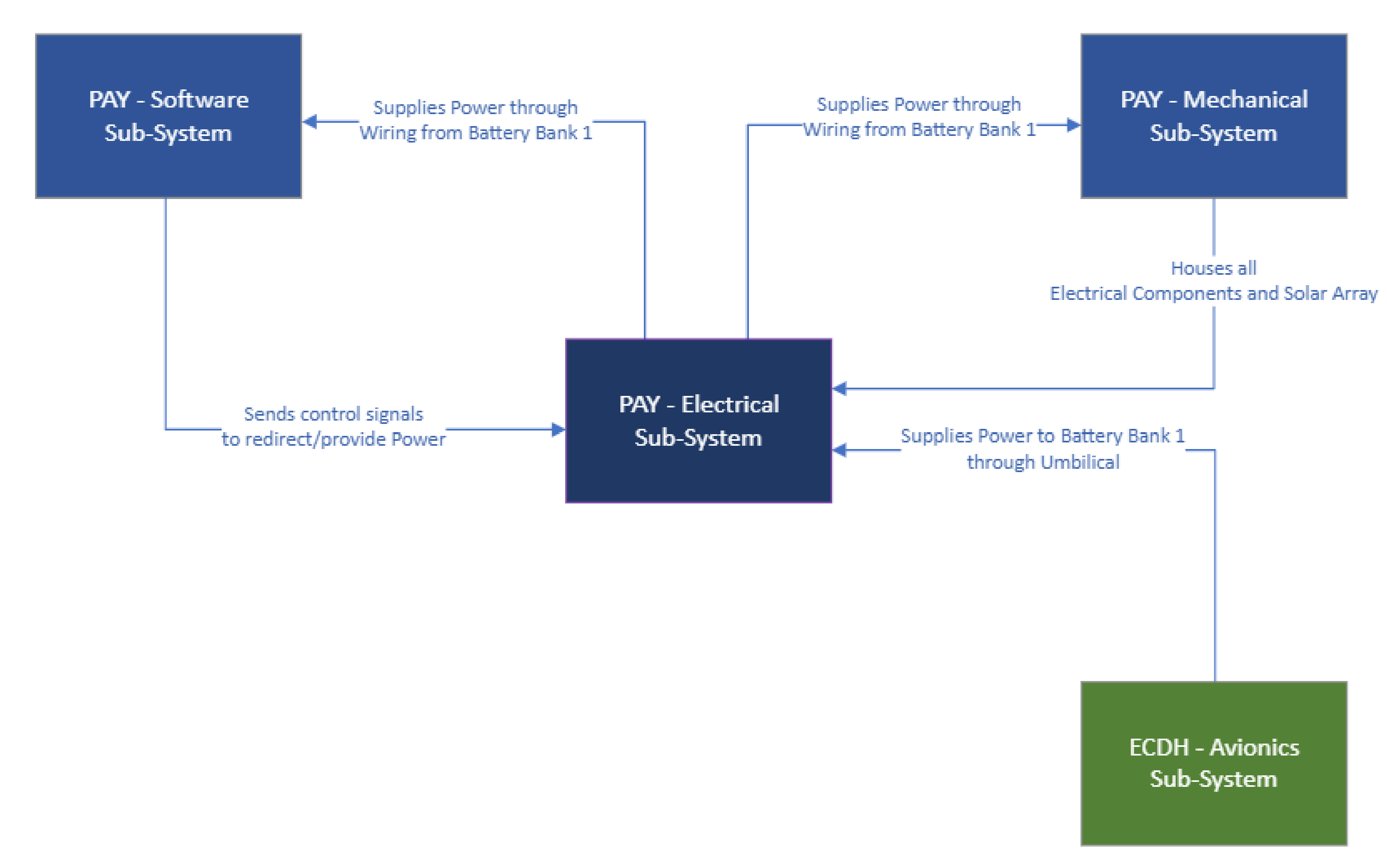
Electrical Functional Requirements

Requirement	Verification Method
The electrical subsystem **shall** have a power source independent of the photovoltaic panel and battery experiments that will supply power to the payload	Demonstration
The electrical subsystem **shall** include a circuit connected to the photovoltaic panel with a voltmeter, ammeter, and an empty dischargeable capacitor that will act as energy storage	Demonstration
The electrical subsystem **shall** facilitate the exchange of data between all components of the payload	Demonstration
The electrical subsystem **shall** have a system of voltage regulation	Test

Electrical Interface Diagram



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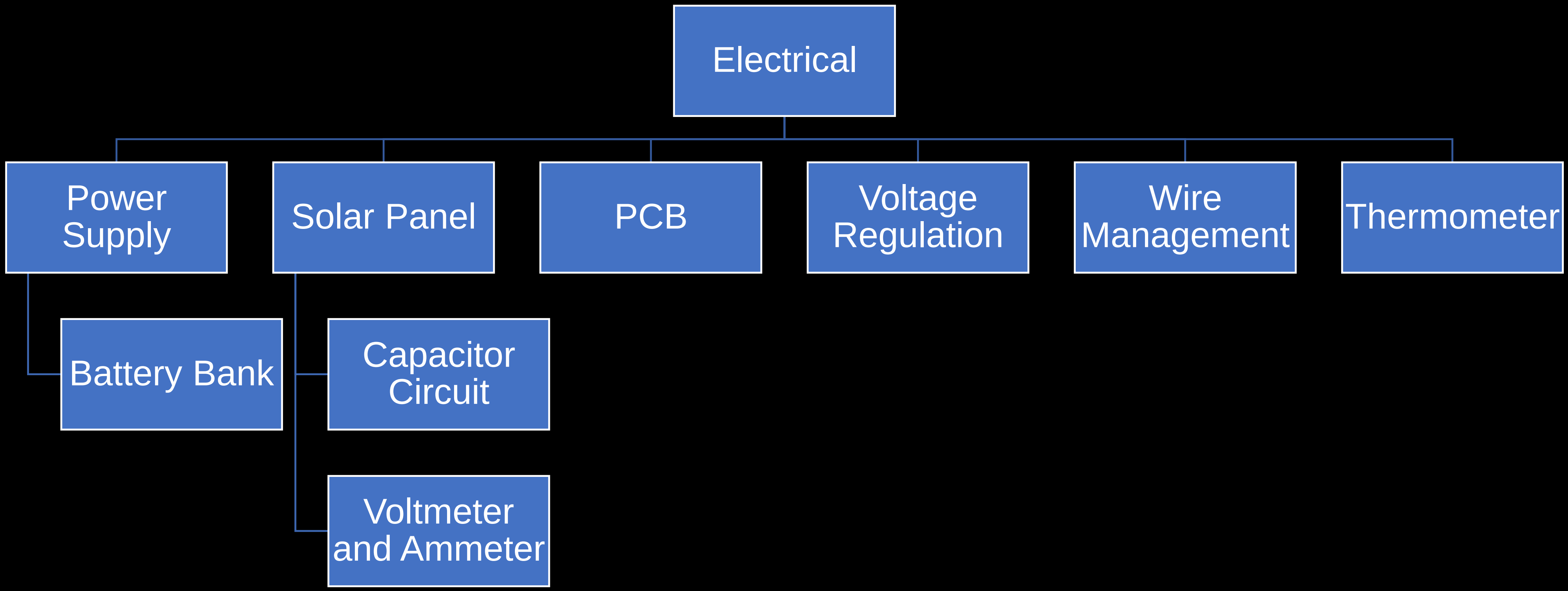
Electrical Component Breakdown



Electrical Component Requirements

Solar Panel Requirements	Verification Method
The solar panel **shall** be stored and released from within the payload	Demonstration
The solar panel **shall** produce [TBD] amount of energy	Demonstration
The solar panel **shall** cost a maximum of [TBD] dollars	Inspection
The solar panel **shall** follow the sun's path throughout the day	Test
The solar panel **should** have a self-cleaning function	Test
Battery Requirements	**Verification Method**
The batteries **shall** be stored within the payload	Demonstration
The power supply **shall** produce [TBD] amount of energy	Test
The power supply **shall** cost a maximum of [TBD] dollars	Inspection

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Solar Panel Trade Study

Criteria	Weight	Monocryst. Silicon	Polycryst. Silicon	Amorphous Silicon	CdTe	CIGs
Cost	.25	2	3	5	5	4
Schedule	.25	4	4	4	4	4
Risk	.25	4	4	2	1	1
Performance	.25	5	4	1	3	2
Weighted Scores		3.75	3.5	3	3.25	2.75

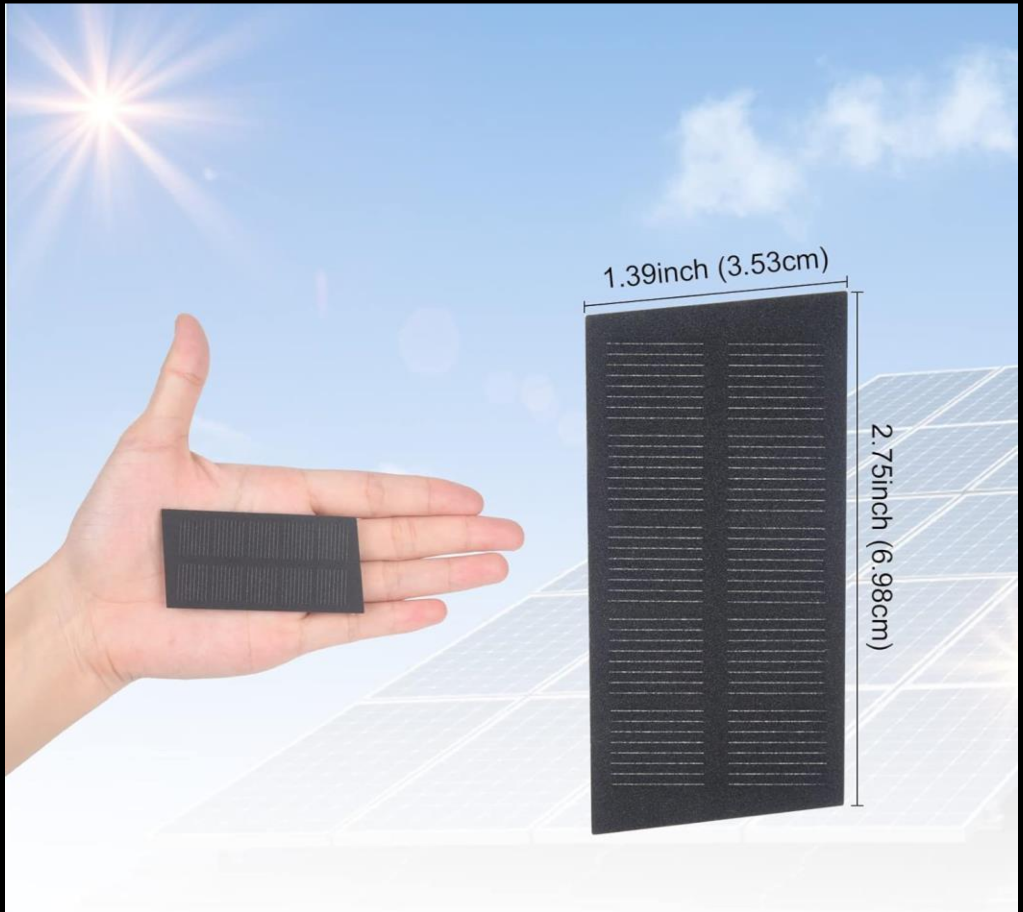
- Researched Monocrystalline and Polycrystalline Panels, Cadmium Telluride, Amorphous silicon, and Copper Indium Gallium Selenide panels
- Our final choice was to use Monocrystalline Panels

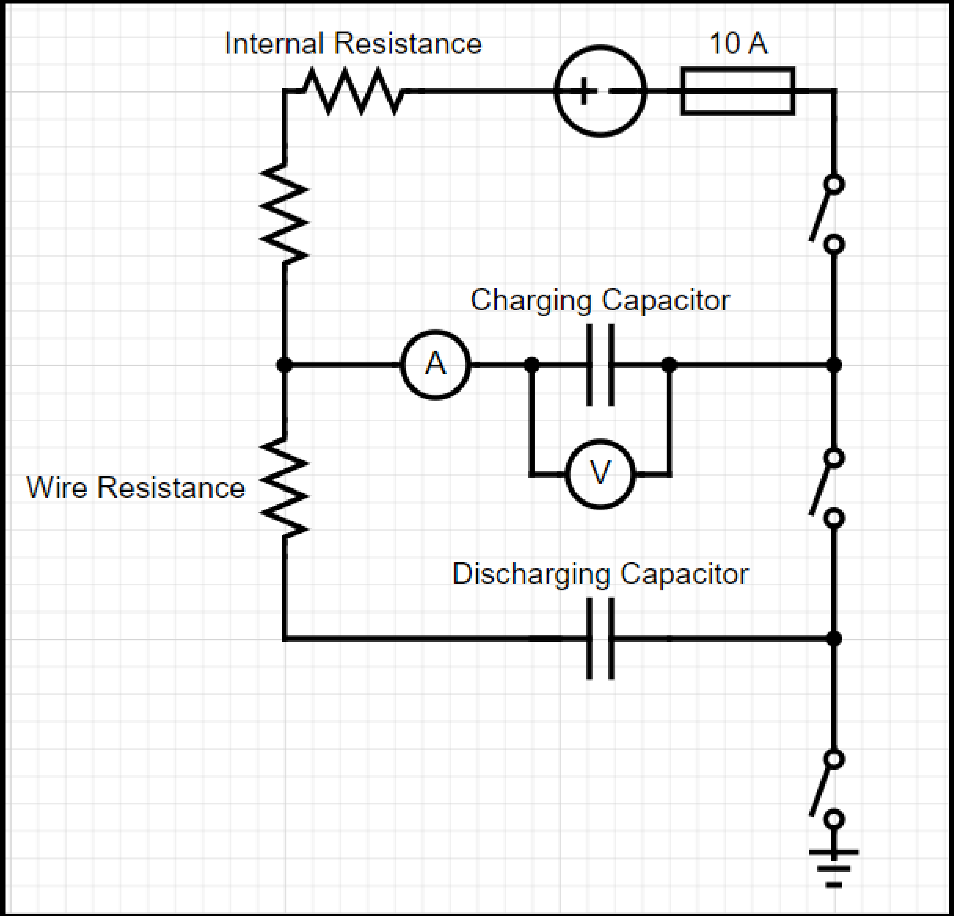
Battery Trade Study Decision Matrix

Criteria and Weights		Options and Scores			
Criteria	Weight	LFP	NiMH	Lead Acid	Alkaline
Cost	0.25	3	5	5	5
Schedule	0.25	5	3	5	5
Risk	0.25	3	3	3	1
Performance	0.25	5	3	3	1
Weighted Scores		**4**	**3.5**	**4**	**3**

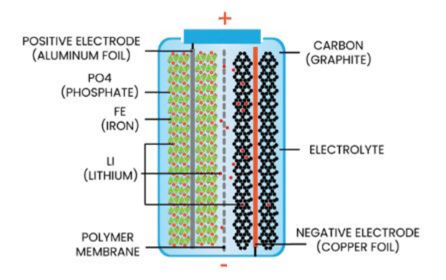
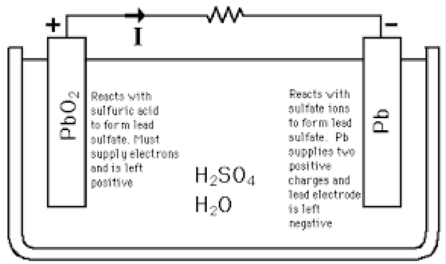
Top two choices from decision matrix were the Lithium-ion Phosphate Batteries (LiFePO4 or LFP) and the Lead Acid Batteries. Lead Acid Batteries were forbidden by ESRA, so LiFePO4 Batteries were the final choice.

Preliminary Solar Panel Circuit Design





Lithium-Ion Phosphate Battery

Type of Battery	Pros	Cons	Pictures
LiFePO4	• Expected cycle life of 3000 – 10,000 cycles • 98% efficient (when you put 100 AH into an LFP battery, you get about 98 Ah back out) • Short absorb time • Operates between 32ºF and 120ºF, with little degradation • Very lightweight	• Will cost about twice as much as an equivalent high quality AGM battery • Will have a very small reserve capacity (about 20%) designed into the bank • Subject to damage if over or under charged	 

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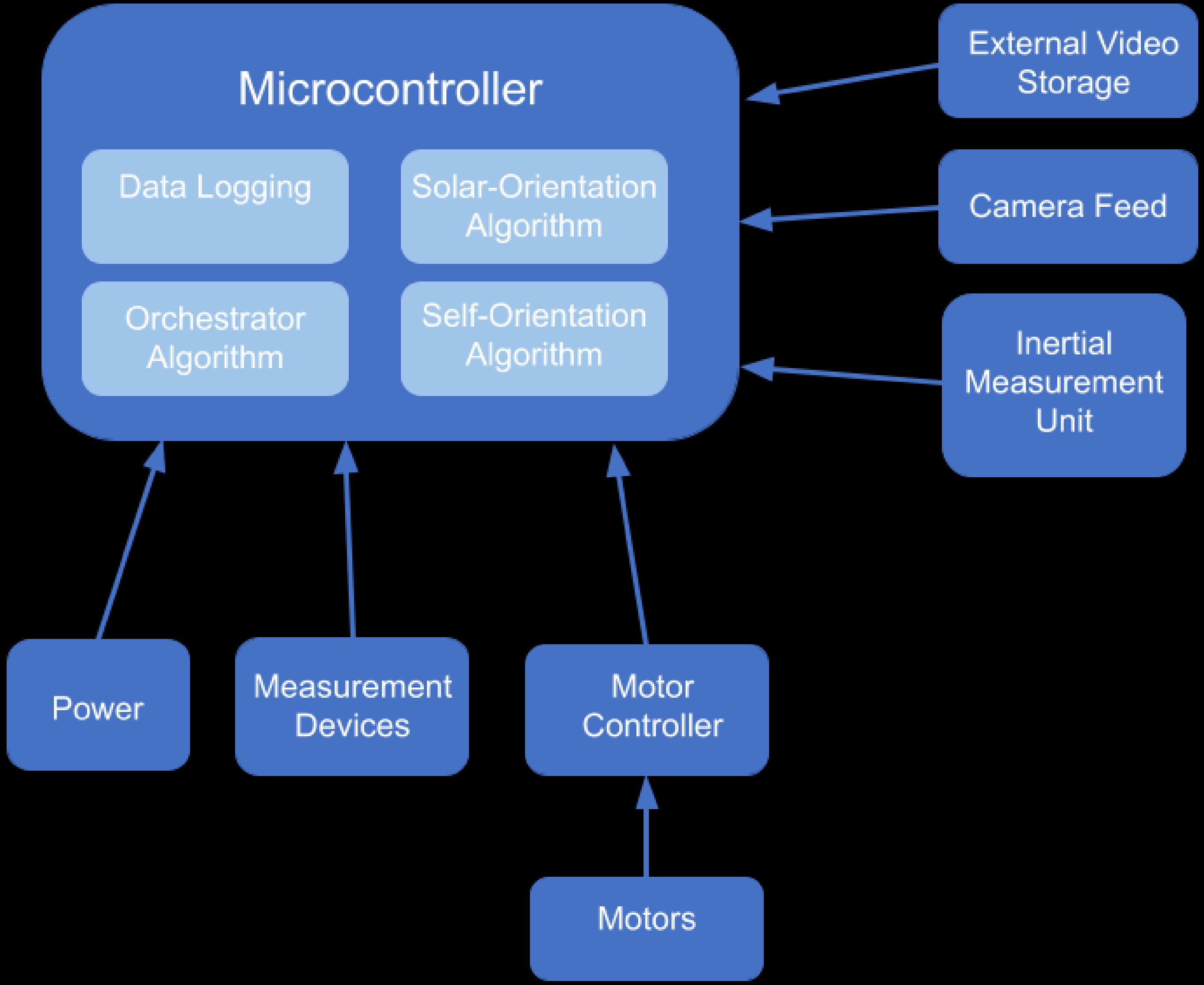
Electrical Path Forward

- ***Determine exact voltage and current specifications for the power supply***
- ***Create a detailed circuit schematic for the entire payload***
- ***Decide on specific components to purchase***

Software Sub-System



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Software Requirements

Requirement	Verification Method
The software subsystem **shall** interface correctly with other subsystems	Inspection
The software subsystem **shall** orchestrate the mission to completion	Test
The software subsystem **shall** track the sun in the sky	Test
The software subsystem **shall** orient the payload upright	Test
The software subsystem **shall** record experimental data starting from launch	Test
The software subsystem **shall** track the payload after launch time	Test

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Software TPMs

Measure	TPM Value	Units	Verification Method
Solar panel orientation	[5°]	Degrees	Test
GPS position accuracy	[5%]	Percent	Test
IMU accuracy	[5%]	Percent	Test
Execution speed	[240MHz]	MHz	Inspection

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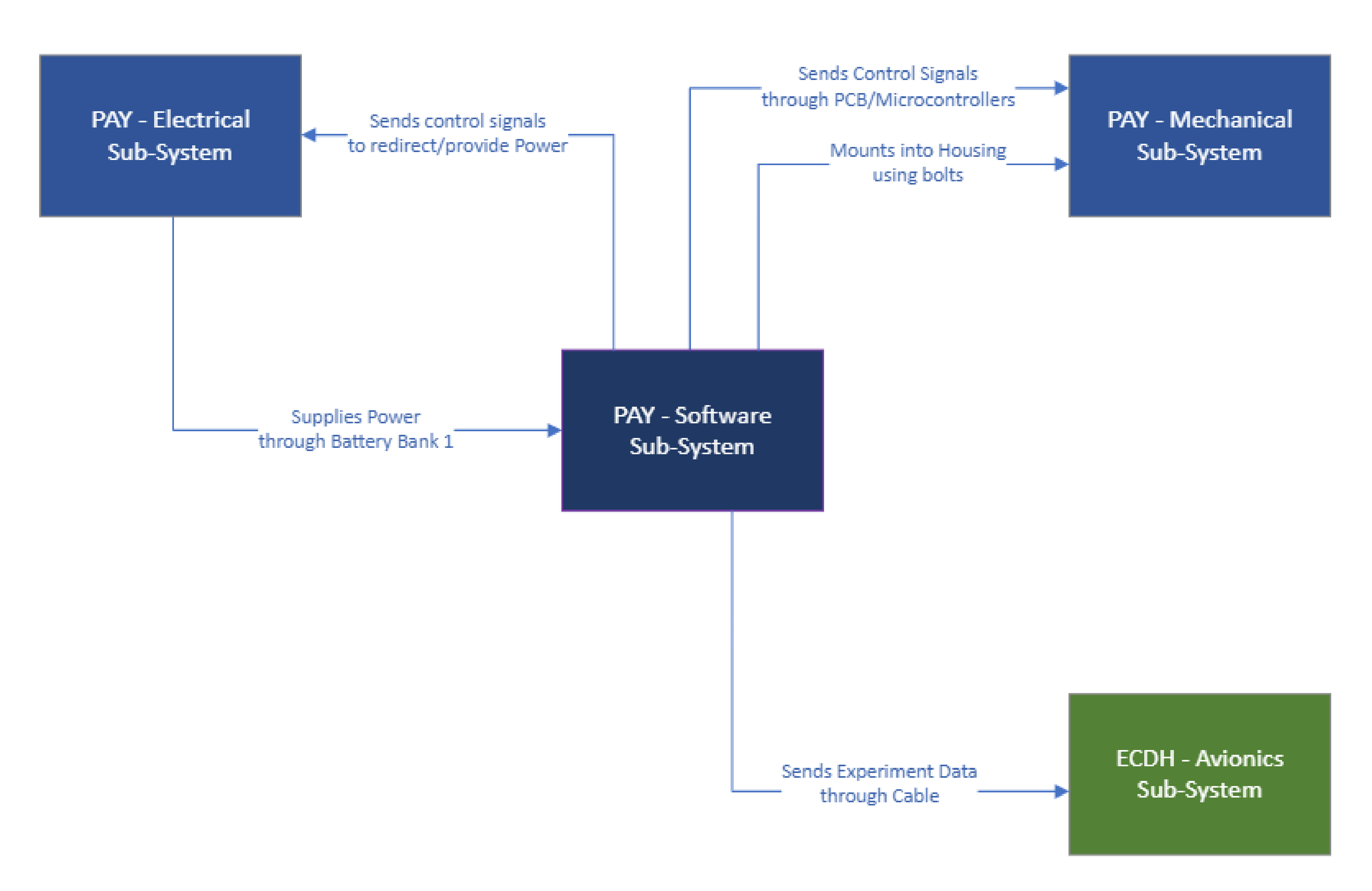
Software Interface Diagram



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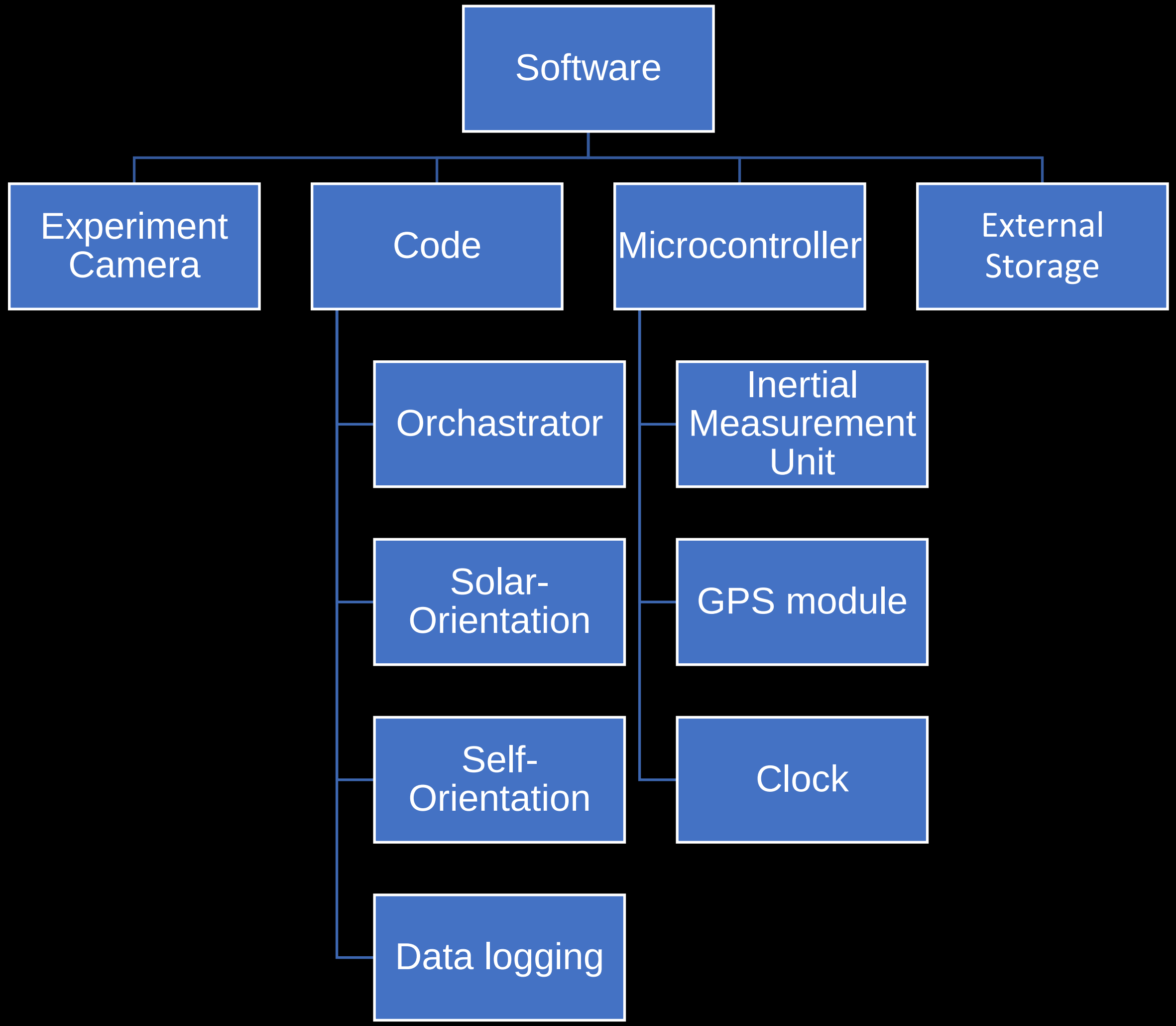
Software Component Breakdown



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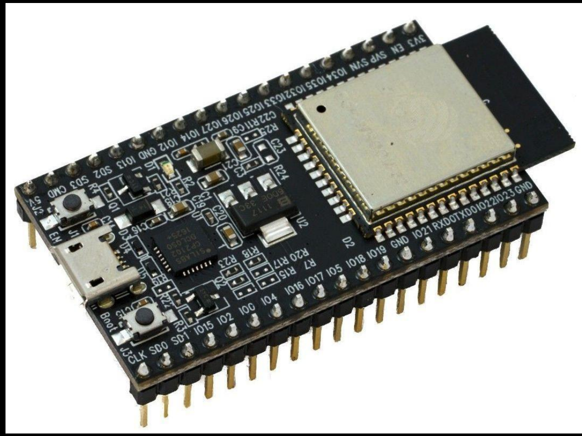
Microcontrollers Trade Study

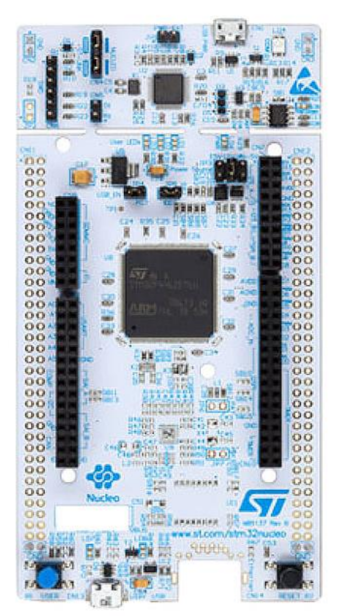
A study on which microcontroller family was to be used for the software system paired with an MPU9250 inertial measurement unit and possible long-range transmission.

Options considered:

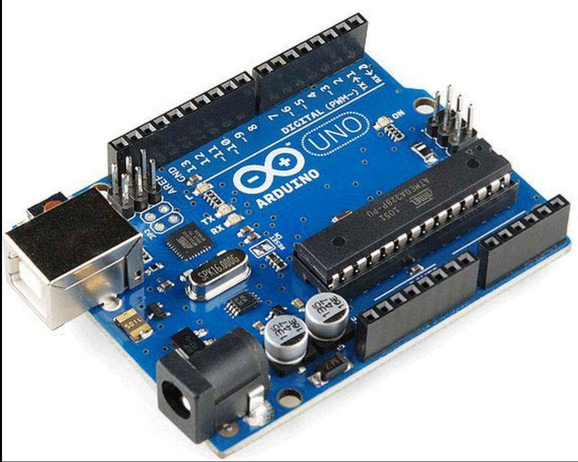
ESP32



STM32



Arduino



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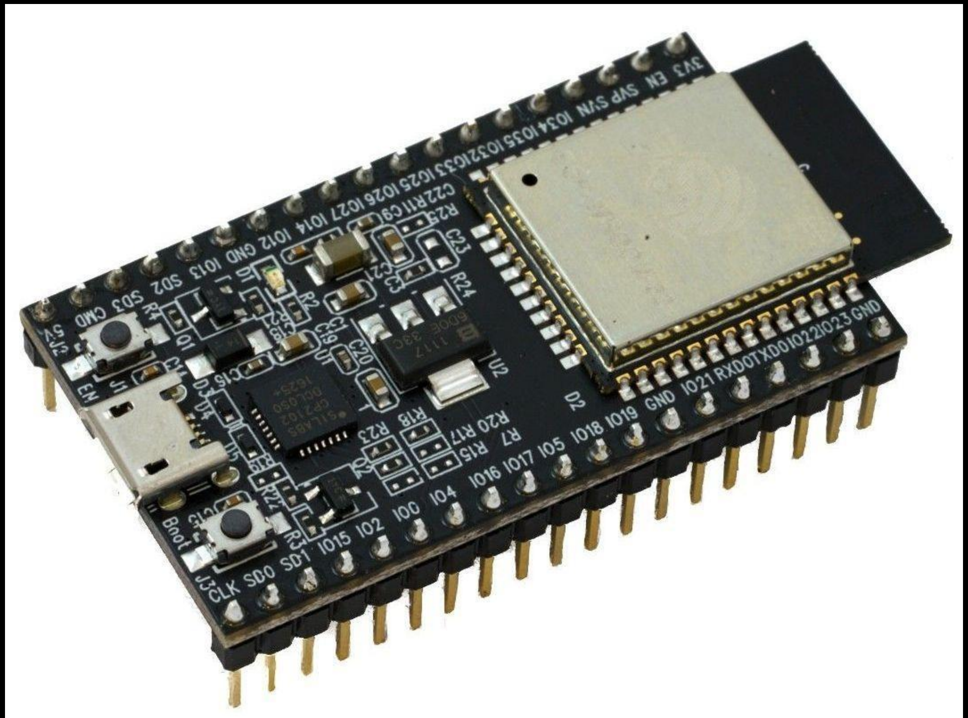
Microcontrollers Trade Study

Option 1: ESP32

Pros	Cons
Wireless	
Can act as a server	
Extendable internet connection (1km unobstructed through 802.11LR mode)	
Not IDE specific	
Widely Used	
Bluetooth	



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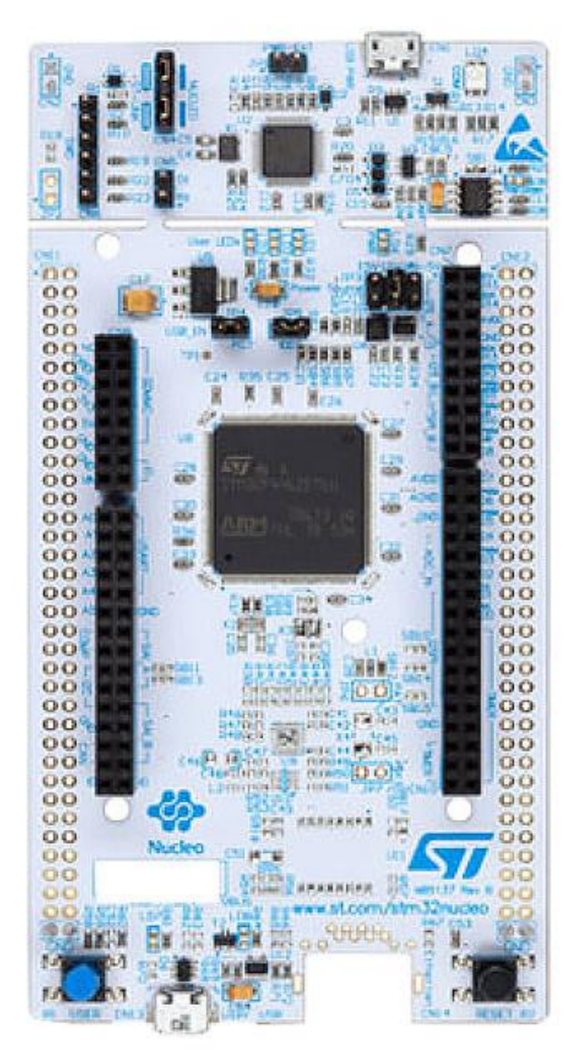
Microcontrollers Trade Study

Option 2: STM32

Pros	Cons
Wireless support	No Long range wireless standard
Not IDE specific	Not compatible with HC-12 module
Bluetooth	Very limited long-range ecosystem
Widely used	Not widely used for long range



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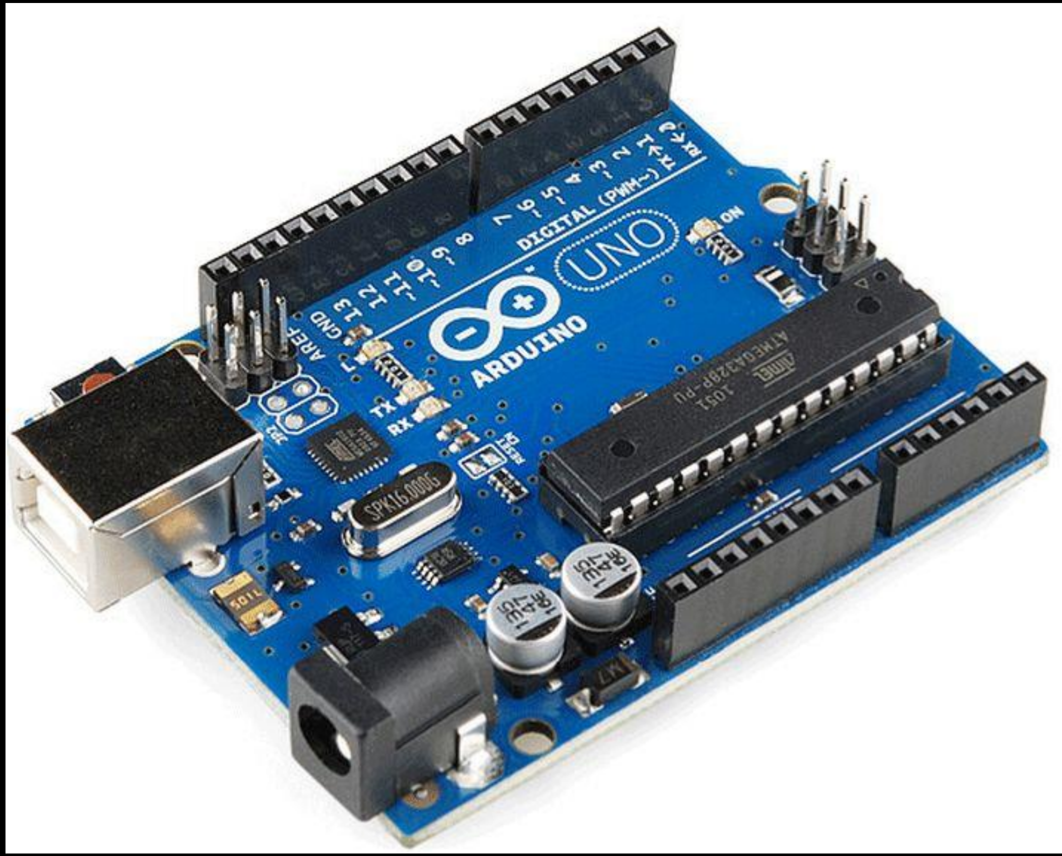
Microcontrollers Trade Study

Option 3: Arduino

Pros	Cons
Widely used	Arduino IDE required
RF module gives 1.8km	Hard wire connection to upload code
	Requires Long range RF module
	Questionable Antenna geometry



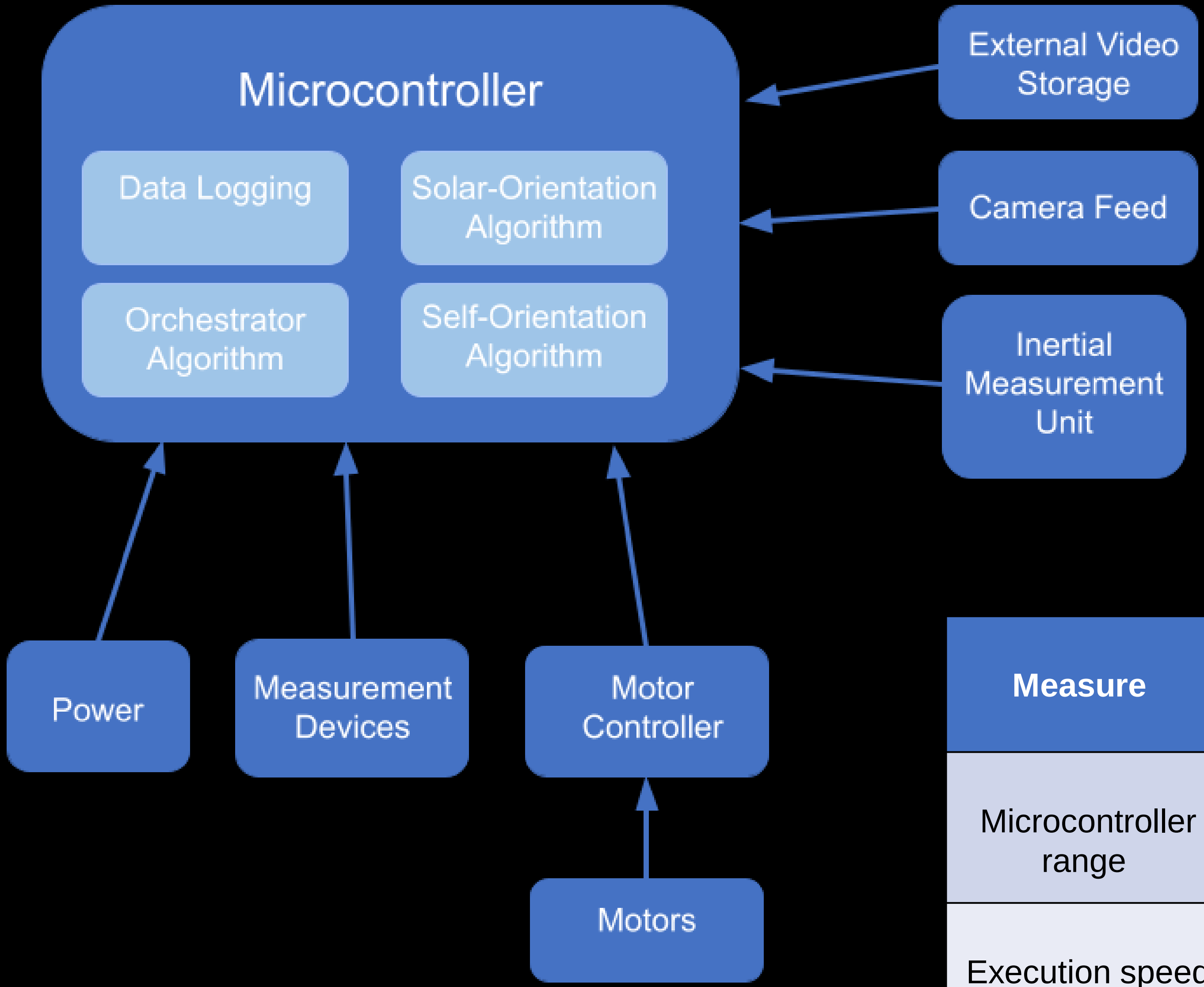
Microcontrollers Trade Study

Decision matrix

Criteria and Weights		Options and Scores		
Criteria	Weight	STM32	Arduino	ESP32
Cost	0.25	1	3	5
Schedule	0.25	5	5	5
Risk	0.25	5	5	5
Performance	0.25	1	3	5
Weighted Scores		**3**	**4**	**5**

The ESP32 paired with the MPU9250 Inertial Measurement Unit, and possible NEO-8M GPS module was decided.

Microcontroller Component PDR



Requirement	Verification Method
The payload **shall** have an IMU & GPS	Inspection
The microcontroller **shall** be able to transmit its status	Test
The microcontroller **shall** have a range of >600m	Test

Measure	TPM Value	Units	Verification Method
Microcontroller range	600m	meters	Test
Execution speed	[240MHz]	MHz	Inspection

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Microcontroller Component PDR

Microcontroller Failure Modes:

- Physical damage
  - Damage on impact could render communication issues between components or damage to components
- Possible component miscommunication
  - If an incorrect reading is given by the IMU the solar orientation algorithm will be wrong
  - If the Experimental Camera is wired incorrectly or returning the wrong data format that could corrupt all visual data storage/processing
  - If incorrect time is returned by the clock the solar orientation algorithm will be wrong

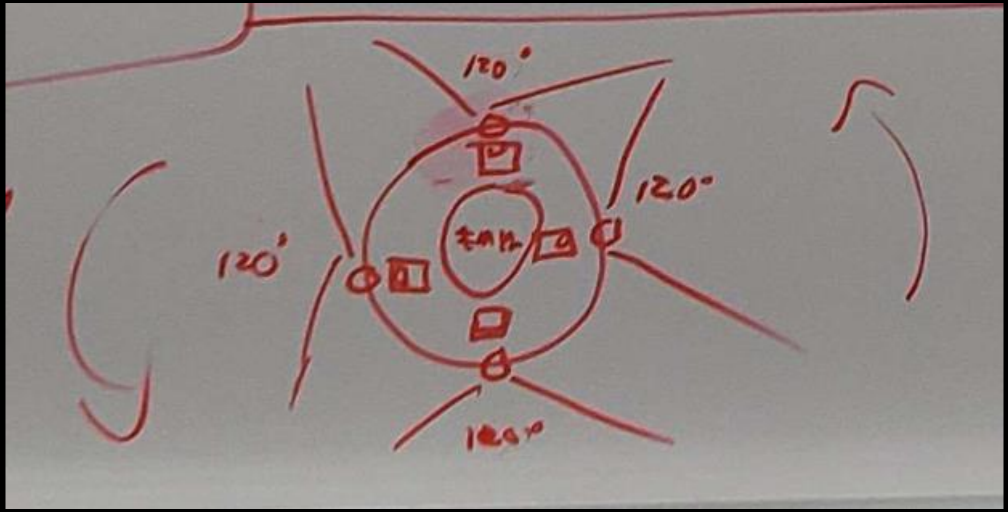
KNIGHTS EXPERIMENTAL ROCKETRY

Software Path Forward

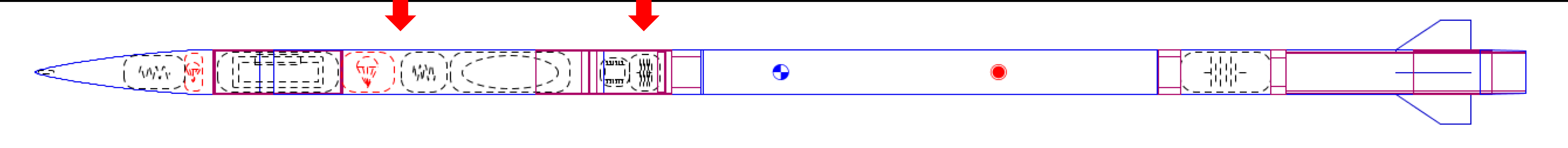
- ***Decide on exact components***
- ***Compile all documentation for components***
- ***Acquire a test-bed to start developing algorithms***

Flight Recording Sub-System

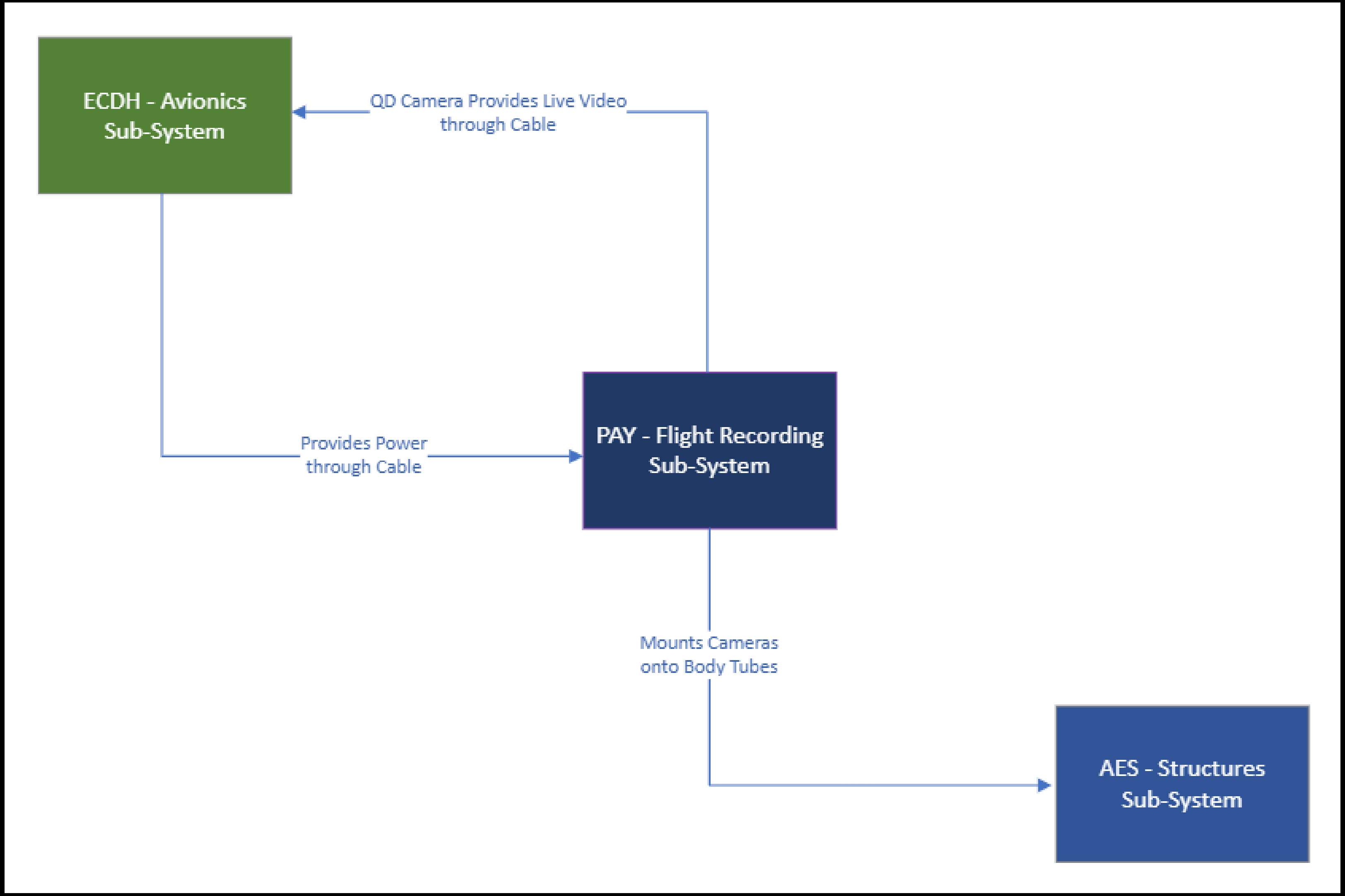
- 360 Camera System
- Quick Disconnect (QD) Real-Time Camera



QD CAM **360 CAM**



Flight Recording Interface Diagram



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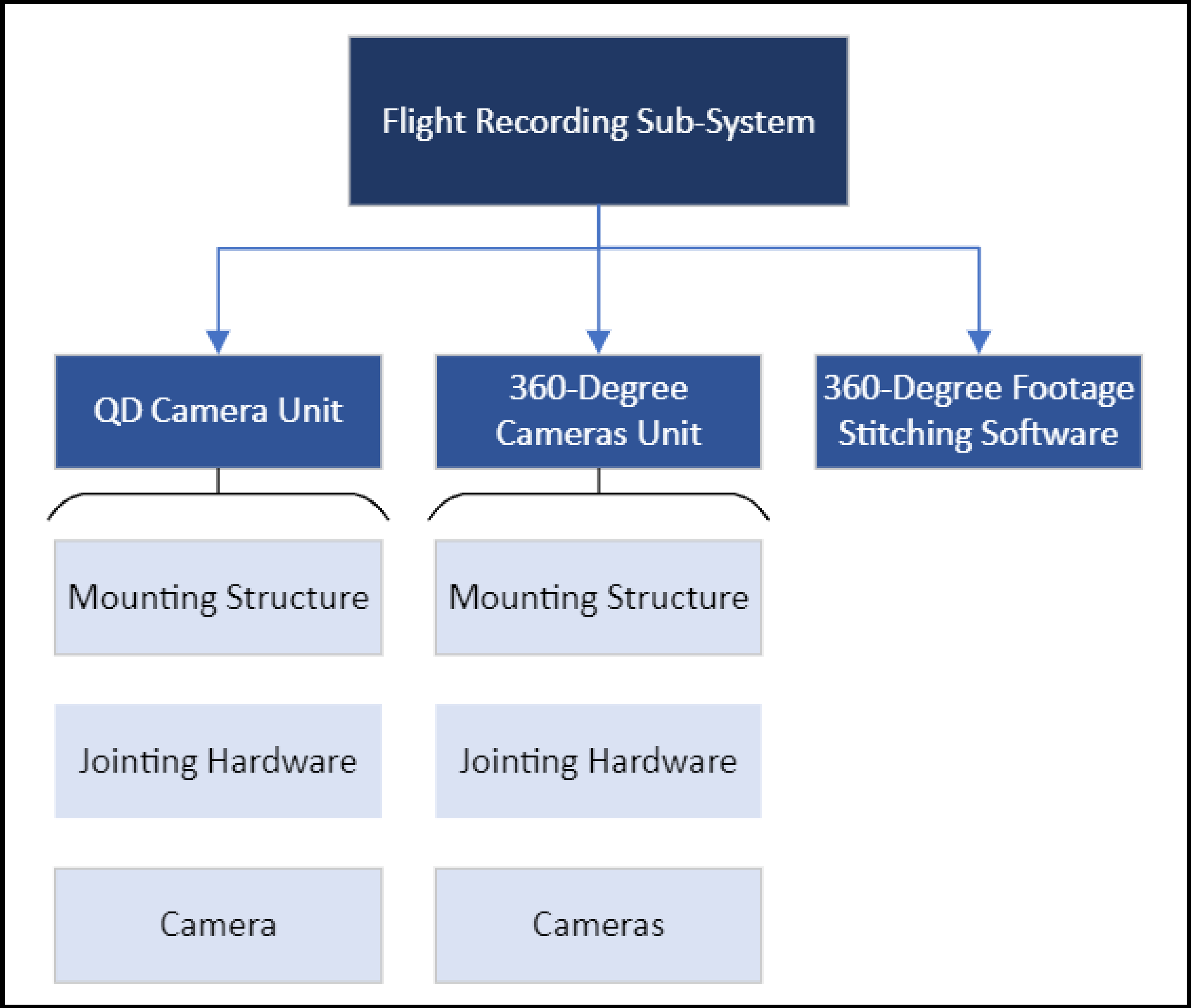
Flight Recording Component Breakdown



Flight Recording Requirements

Should be tables including requirements and verification methods

Requirement	Verification Method
The 360-degree camera system **shall** capture synchronized footage from [4] cameras	Demonstration
The QD camera **shall** capture and transmit live footage of the QD connector	Demonstration
The 360-degree camera system **shall** weigh [TBD lbs]	Inspection
The 360-degree camera system **shall** weigh [TBD lbs]	Inspection
Both camera systems **shall** interface with the aerostructures system	Inspection
Both camera systems **shall** withstand [10 G] of acceleration	Demonstration

Flight Recording TPMs

Measure	TPM Value	Units	Verification Method
Quick Disconnect Camera System			
Resolution	[1080p]	Pixels	Test
Framerate	[30fps]	Frames per second	Test
Field of View	[90°]	Degrees	Test
360-Degree Camera System			
Resolution	[1080p]	Pixels	Test
Framerate	[30fps]	Frames per second	Test
Field of View	[90°]	Degrees	Test

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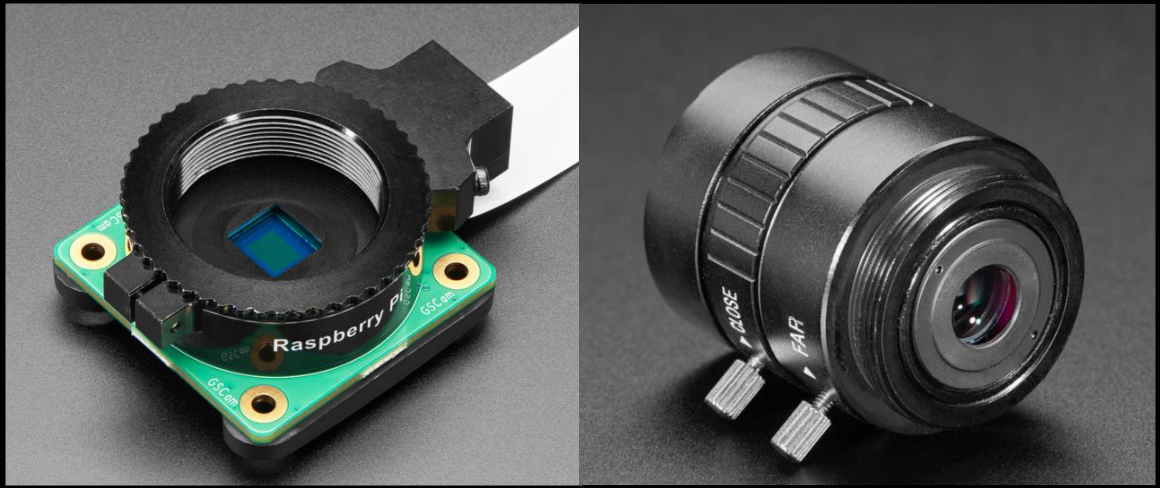
Camera Trade Study

The Top Two According to the decision Matrix were the Raspberry PI Cameras:

Arducam Camera for Raspberry Pi

Pros: Cheap, Field of View (120°(D)x88°(H)x55°(V)) , 1080p
Cons: Rolling Shutter, 30 fps

Raspberry Pi Global Shutter Camera + Wide Angle Lens



Pros: Global shutter, con record 1440 x 1080 pixels at 60 fps
Cons: 63 degree angle lens, more expensive

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Camera Trade Study

Looked at 6 different options: 4 stand-alone cameras & 2 Raspberry PI cameras

Criteria and Weights		Options and Scores					
Criteria	Weight	AKASO Action	Estes AstroCam	RunCam2	Mobius Pro Mini	Raspberry Pi	Global Shutter
Cost	0.35	3	5	3	3	5	3
Schedule	0.1	5	5	5	5	5	5
Risk	0.2	3	1	3	3	5	5
Performance	0.35	3	1	5	5	3	5
Weighted Scores		**3.2**	**2.8**	**3.9**	**3.9**	**4.3**	**4.3**

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Flight Recording Path Forward

- ***Make a final camera selection***
- ***Procure components and begin test-bedding both camera systems***
- ***Create CAD***

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