KNIGHTS EXPERIMENTAL ROCKETRY
at UCF

November 29th, 2023
FAR10k Basilisk Vehicle
Critical Design Review

Critical Design Purpose

Demonstrate that the design is appropriate to proceed with the fabrication phase

Determine that technical progress is on track to complete mission requirements within cost and schedule restraints

Approve “build-to” baseline design plans

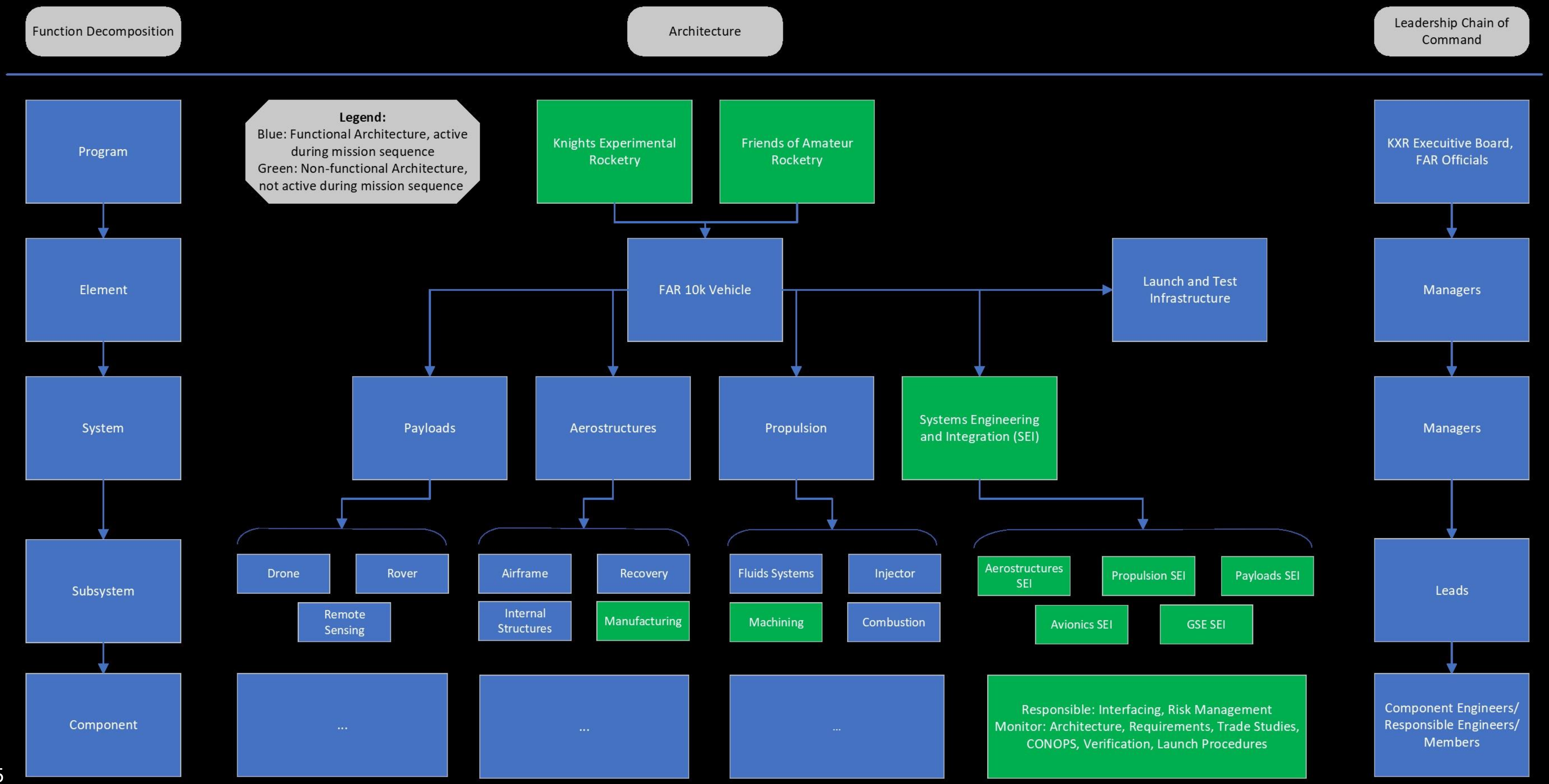
Concept Definition: The Mission

- FAR51025 Contest
  - Point Based Competition
  - Mojave, California
  - May 31st
- DPF 2023
  - Dynamic Piston Liquid Bi-Propellant to ~5,000ft
- FAR 2022
  - 1st, 2nd, 3rd place
  - ~5,000ft solid motors with deployable payloads

Stakeholder Definition

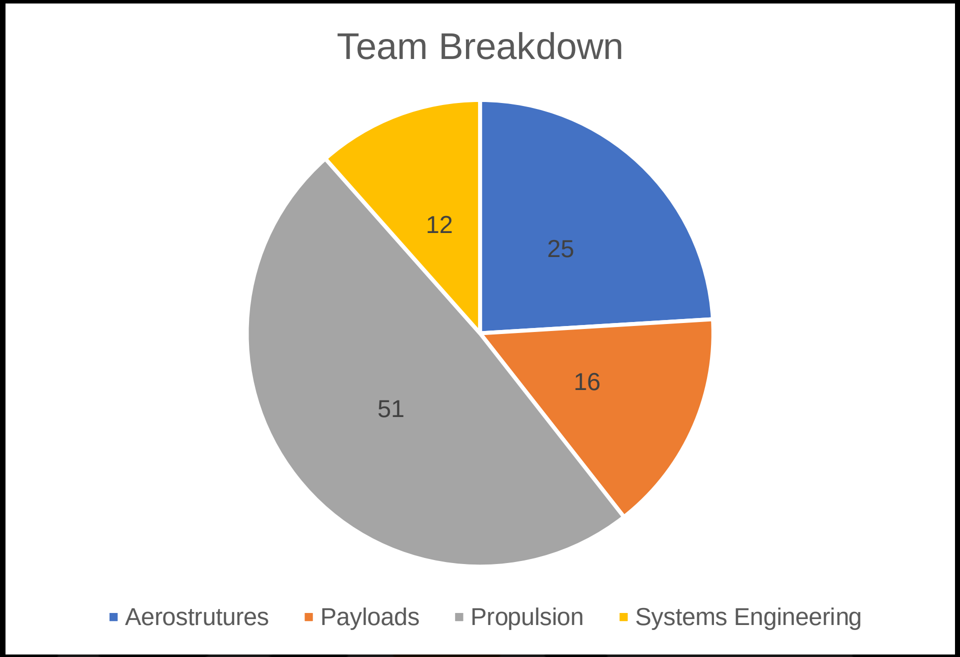
	The members of our team	- Cultivate a passion for science, technology, and space exploration - Develop skills that prepare students for the professional industry
	Friends of Amateur Rocketry Officials	- Point scoring system and rules
	KXR Executive Board	- Funding - Outreach - Misc. Support

Organization Chart

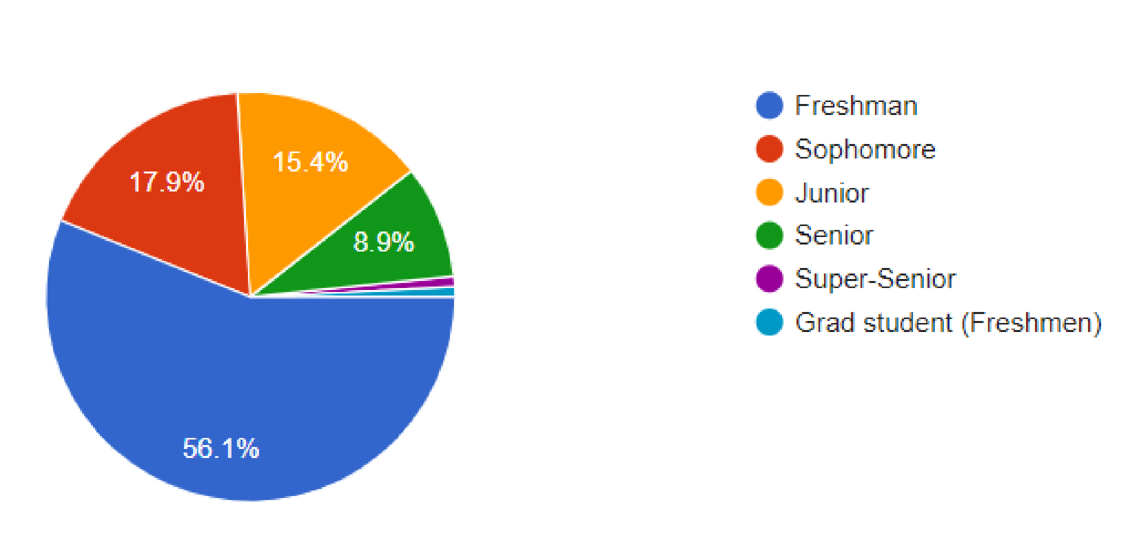


Team Demographics

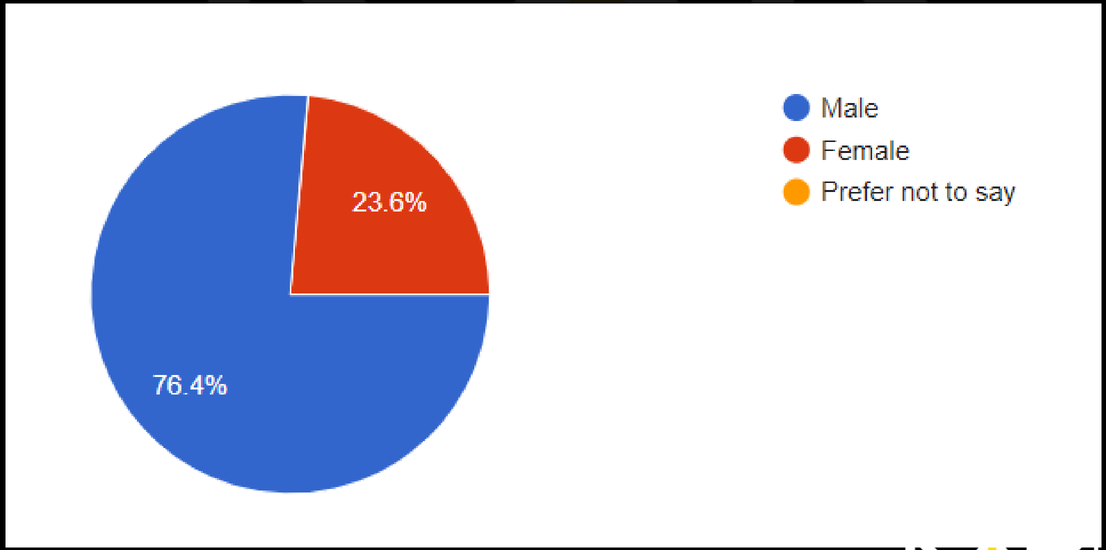
- Team: 96 students
- Managers: 4
- Leads: 20
- Component REs: ~50



Year in College



Gender



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Basilisk: Vehicle Overview

- Launch to 10k feet
- Recover in refight condition
- Deploy rover and drone
- Interface with LTI

Performance Measures	
Altitude	10,900 ft
Impulse	20,893, Ns 4,697 lbfs
Velocity	Mach 0.72
Max Acceleration	4 g
Stability	3.82 cal
Mass	168 lbs
Thrust to Weight	3.15
Length	18 ft
Diameter	6.2 in

Score Guide

FAR 51025 Scoring This will aid teams in how the scoring works for the competition.

Altitude: a point is awarded for every foot of altitude reached up to the target of the division entered. A point is deducted for every foot of altitude over the division target. Example, a rocket entered in the 10,000' division that reaches 9,500' would receive 9500 points and a rocket that reaches 10,500' would receive 9,500 points to their score. New Unlimited, team picks target altitude (different scoring metrix)

Motor type: Acknowledging the increased difficulty of experimental motor design, construction, and testing, additional points are added for their use in the rocket Changes for 2023: *experimenta*l solid motors an additional (10% of altitude reached) points added to the score, *experimental* hybrids an additional (20% of altitude reached) points and *experimental* liquids (30% of altitude reached) points. Commercial hybrids or liquids will receive 500 points.

2-stage rocket: An additional 1,000 points are given for teams competing in the 25,000' division that does so with a 2-stage rocket.

Water ballast nose cone: Many people use heavy materials for ballast to stabilize rocket flight. An additional 1,000 points are given to any team demonstrating the successful use of a nose cone containing 500 mL of water for ballast and safely releasing the water into the air at or near apogee.

Build video or photos: 500 points will be added to the team score for a 2 minute video of the team's build or 25 photographs and submitted Change for 2023: one week prior to arrival at the FAR facility.

Payload options, changes for 2023, points award for successful mission completion
1000-points: Remotely Radio-Controlled Rover. Changes for 2023: Rocket must deploy a rover that leaves the rocket and travels a minimum of 10-feet after touchdown with live video on the ground from the rover to the receiving station till. Rover can be deployed separately from the rocket in the air on a parachute or after landing.
3000-points: Autonomous rover: A rover that returns autonomously to FAR designated area with live video. New for 2023: 2,000 points if memory card used instead of live video.
1000-points: Remote Sensing. Changes for 2023: After landing, a remote video camera will record the landing surroundings in a 360-degree horizontal panorama for transmission to launch control.
1000-points: Reconnaissance. Glider deployment below 400' on rocket descent with live video transmission. New for 2023: 1,000 points for memory card video instead of live video if glider returns to FAR designated landing area for memory card retrieval.
2000-points: Reconnaissance Return. Release of drone below 400' altitude or after landing with live video during drone return to a FAR designated location by autonomous or remote control. New for 2023: 1,000 points if video memory card used instead of live video.
500-points: Remote Sensing. Rocket must transmit live video from liftoff to touch down. Live video must be seen by judges and or recorded by the ground launch area receiving station for later viewing.

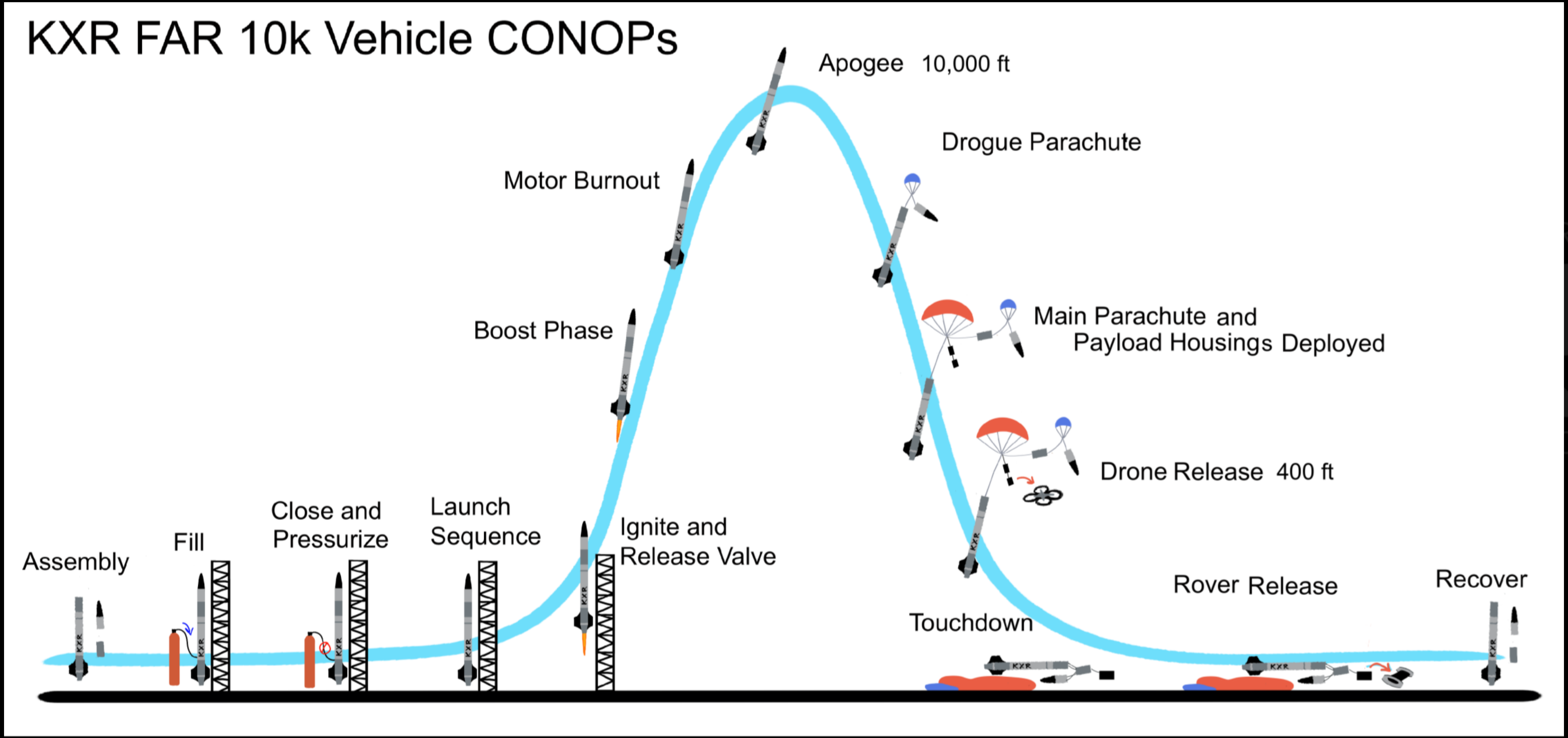
500 additional points New changes for 2023: for a user defined scientific payload that is contained in a 0.5 to 3 U CubeSat, Pocket Cube (5cm*3) or CanSat form factor. Prior approval required.

New for 2023: points for on board video source recorded to a memory card during the flight must be received by judges or downloaded the day of the flight to rocketrycontest@gmail.com

Live video must be witnessed by a judge and recorded at the ground launch area receiving station. Ground station recording of live video can be done on memory card or cell phone video of screen.
Points are awarded for successful payload mission completion.

Challenge Selected	Points Possible
10,000 ft Altitude	10,000
SRAD Liquid Propulsion	3,000
Water Ballast	1,000
Build Video	500
Remotely Controlled Rover	1,000
Reconnaissance Return Drone	2,000
Remote Sensing Camera	500
Total Points	18,000
Max Possible Points	23,500

Vehicle CONOPS



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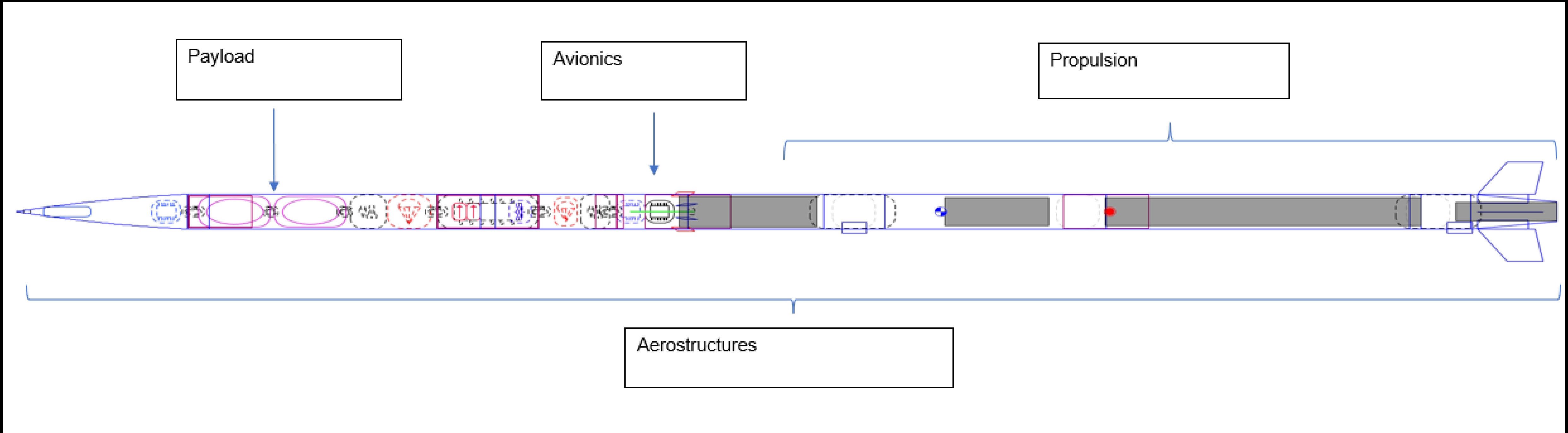
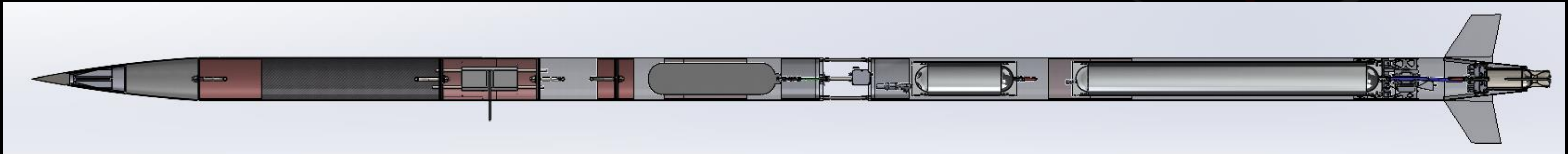
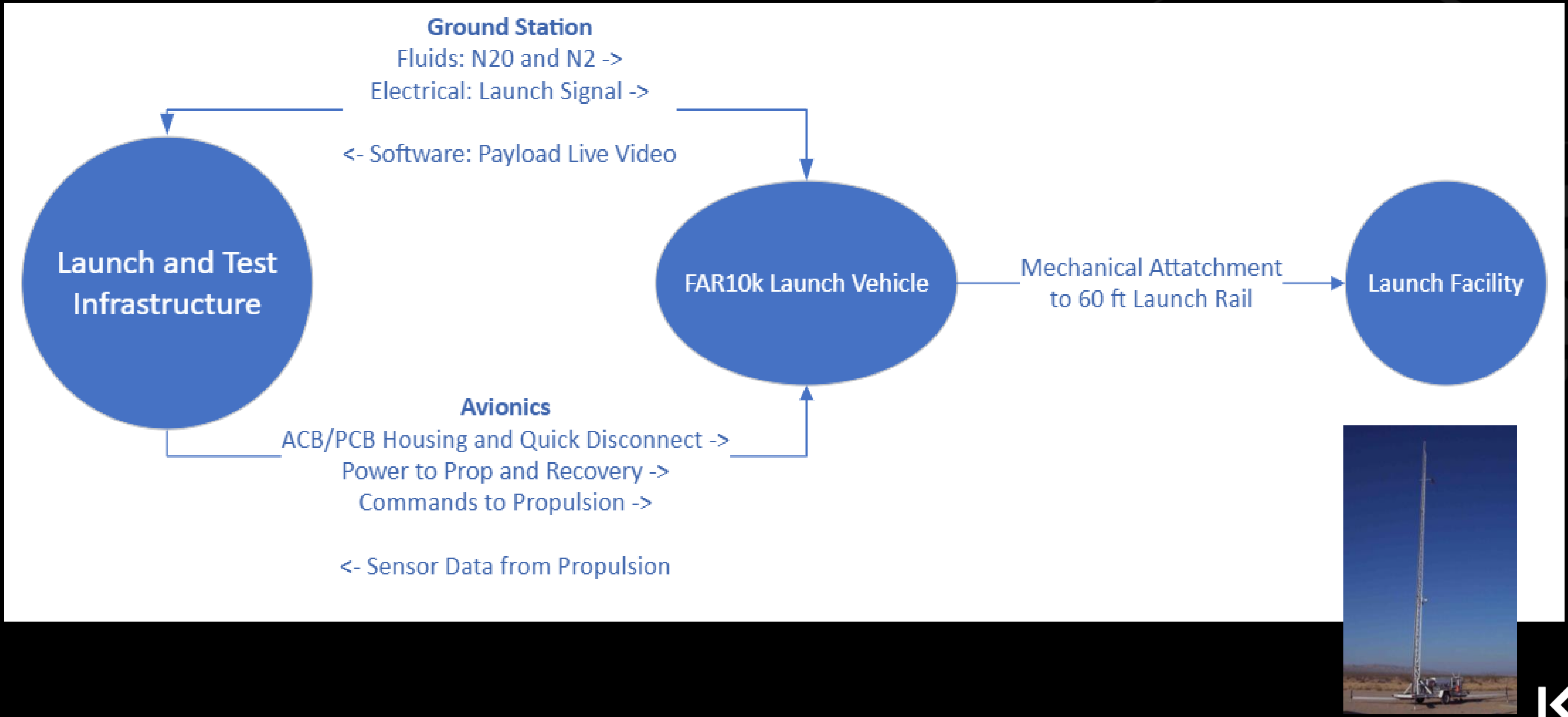
Vehicle Level Architecture



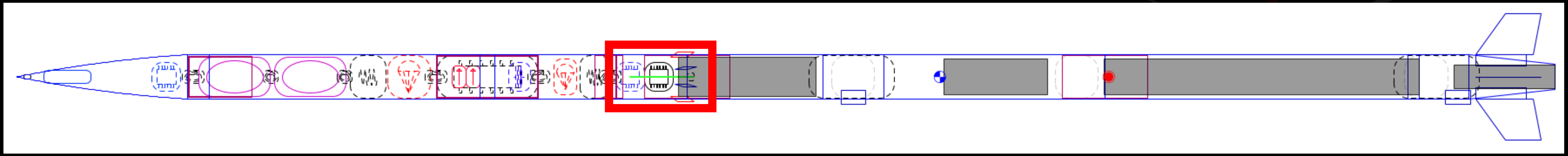


Vehicle Interface Diagram



Launch and Test Infrastructure Cont.

Avionics Control Board (ACB)	Propulsion Control Board (PCB^2)	Ground Station
Provides Power to Cameras	Provides Power to Propulsion	Fills Nitrogen and Nitrous Oxide
Transmits Data to Ground Station	Sends launch commands	Receives data from Avionics (ACB)
Collects Telemetry Data	Wired connection to Ground statation	Receives Live Video from Drone/Rover
Stores Data locally	Stores data locally	Sends wired commands to PCB^2 and ACB



Costs

Total Vehicle Budget: $13,000

Estimated System Breakdown

- Propulsion: $4,500 / $6,000
- Aerostructures: $5,000 / $4,500
- Payloads: $2,500 / $2,500

Sources of Funding

- UCF SG: $5,000
- KXR UCF: $5,000
- FSGC: $3,000
- Lockheed Martin *
- Daytona Speedway *
- Northrop Grumman *
- Agile Space *

Schedule: 9 Months

PI-1: Concept Dev and Design **September – December** **3 months**	Explore Concepts, Develop Team Structure, Create the final design Concept Exploration, Design Phase, PDR, SRR, and CDR, approve budget
PI-2: Procurement and Manufacturing **December – March** **3 months**	Procure throughout winter break Manufacturing, Simulation Verification, Machining, Assembly, and travel
PI-3: Testing and Launch **March – June** **3.5 months**	Begin Testing campaign, integration of systems, small changes and integration Travel to Mojave and Launch

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Schedule: PI 1

PI-1: Concept Development and Design (August – December)

- Preplanning……………………………………………………………………(Aug. 1st –31st)
- Vehicle Concepts Design…………………………………………….………...(Aug. 15th - 31st)
- Concept Development and Learning Phase…………………………………...(Sprint 1,2)
- **System Requirements Review……………………………………….…….(Oct. 2nd)**
- Preliminary Design…………………………………………………………..(Oct: Sprint 3,4,5,6)
- **Preliminary Design Review……………………….……………………….(*Oct. 23th*)**
- Detailed Design……………………………………………………….(Oct-Nov: Sprint 4,5,6)
- Sub-System/Component Requirements Review…...……………………………..(Mid-Nov.)
- Critical Design Review…………………………………………………………(End of Nov.)
- Begin Procurement……………………..…………………………………(Dec: Sprint 7)
- End of PI-1…………………………………...…………………………………..(December)

More details in SEMP

Verification Plans

1. System Verification Testing
2. Vehicle Dry Fit Test
    1. Geometrical fits and tolerances
    2. System Interfaces
    3. System functions
    4. Vehicle Level Testing
3. Wet Dress Rehearsal
    1. Launch Facility integration
    2. LTI Interfacing
    3. Element Level Testing
4. Launch Day Verification testing
    1. Repeat of 3 and 4
5. Flight Demonstration

Systems Engineering Processes

- Concept Dev. and Trade Studies (25) – Complete
- Design Descriptions (350+ pages) – Complete
- Requirements and Verification VCRM – Baseline
- Interface Control Documents – Baseline
- Concept of Operations CONOPS – Baseline
- Architecture – Baseline

Next Steps

- Approve long lead time and high priority items for purchase
- Begin Procurement
- Complete a “Delta CDR” in PI2 for unfinished designs

Questions?

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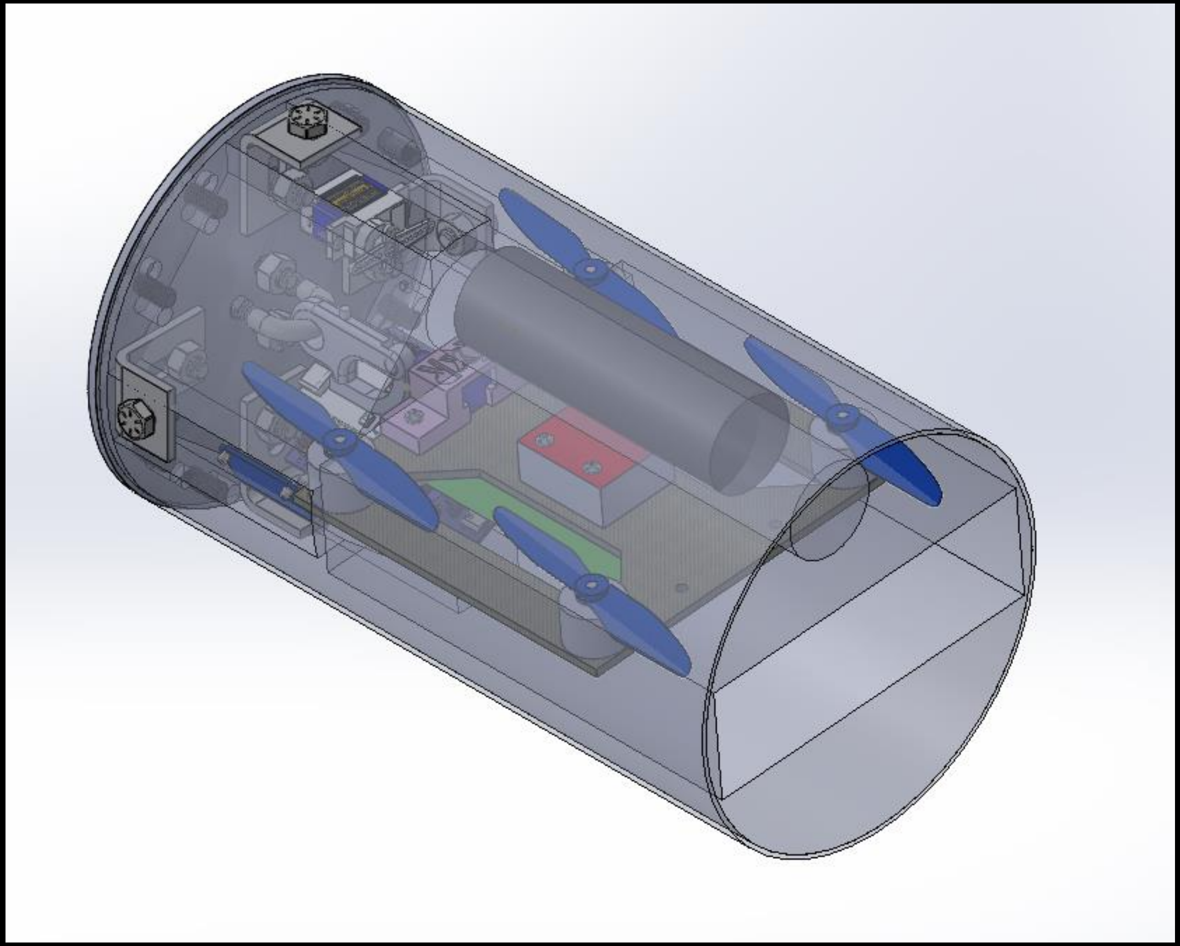
at UCF

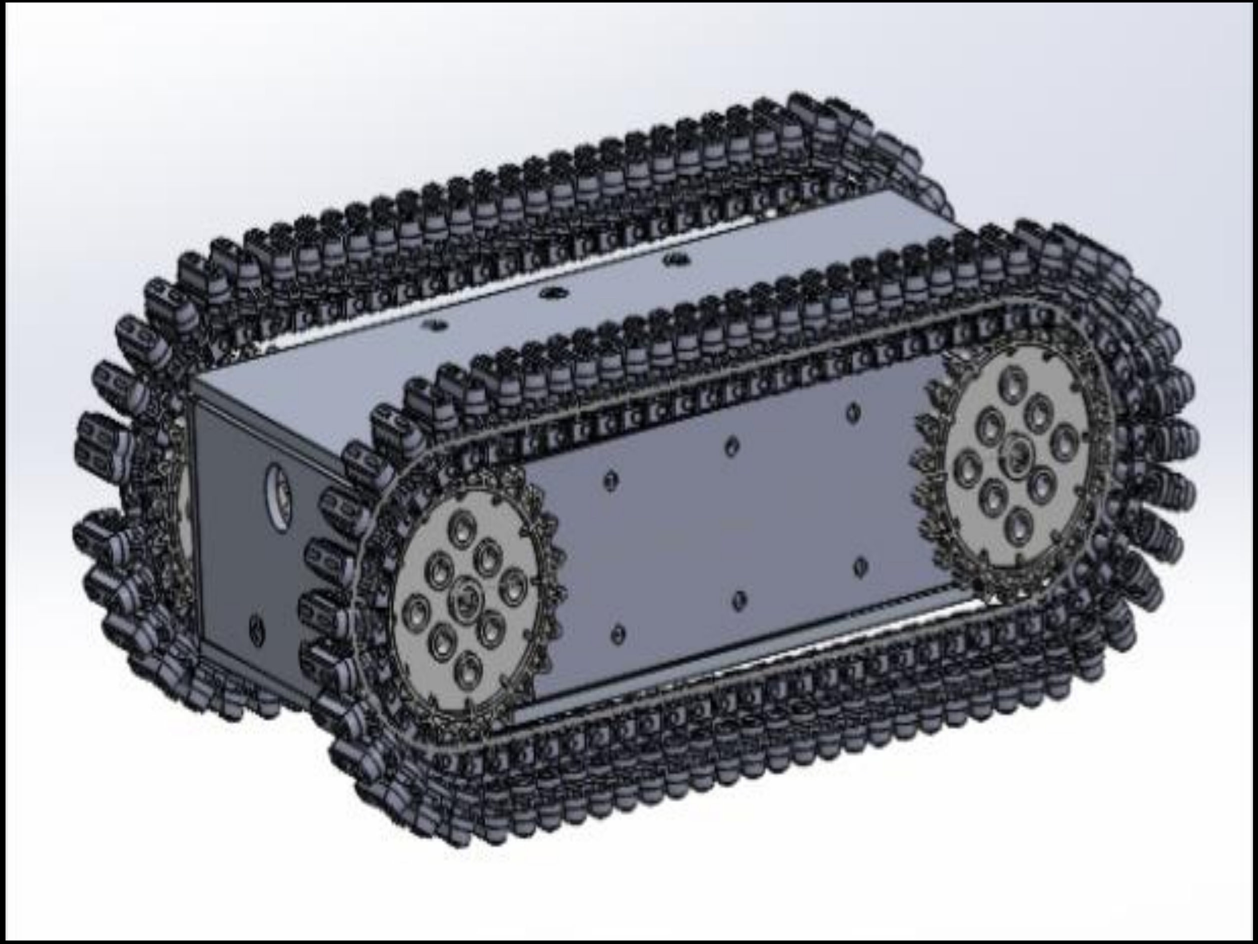
Payload CDR FAR10k Basilisk

Payload Mission Objectives

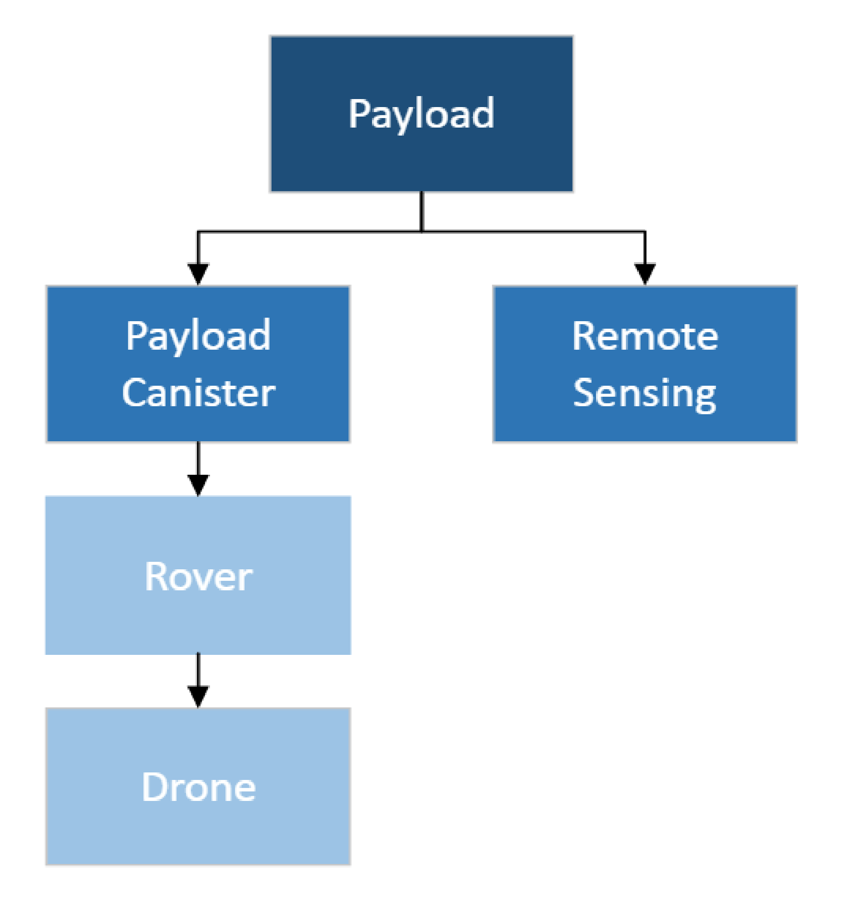
- **Remote-Controlled Rover (2000pts)**
  - Must travel 10ft while transmitting live video during those 10ft
- **Remote-Controlled Drone (2000pts)**
  - Must release drone below 400' or after touchdown
  - Drone must travel back to a designated drop-off zone
- **Remote Sensing – Live Video (500pts)**
  - Must transmit live video from liftoff to touchdown
- **Remote Sensing – Local Save (500pts)**
  - Must save live video from flight to an SD card

Payloads System

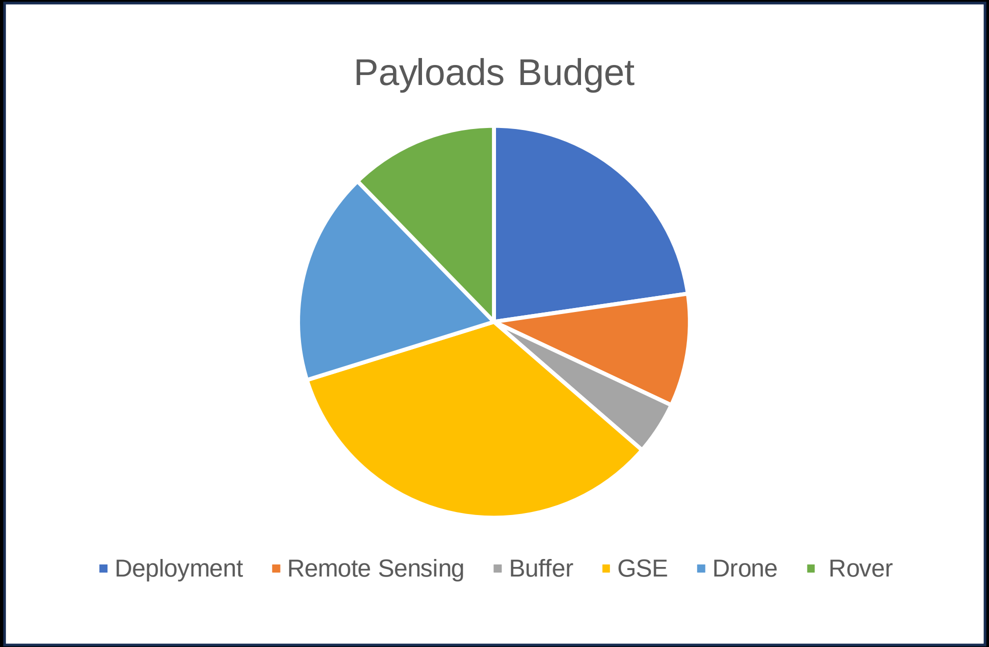




Payloads System Architecture

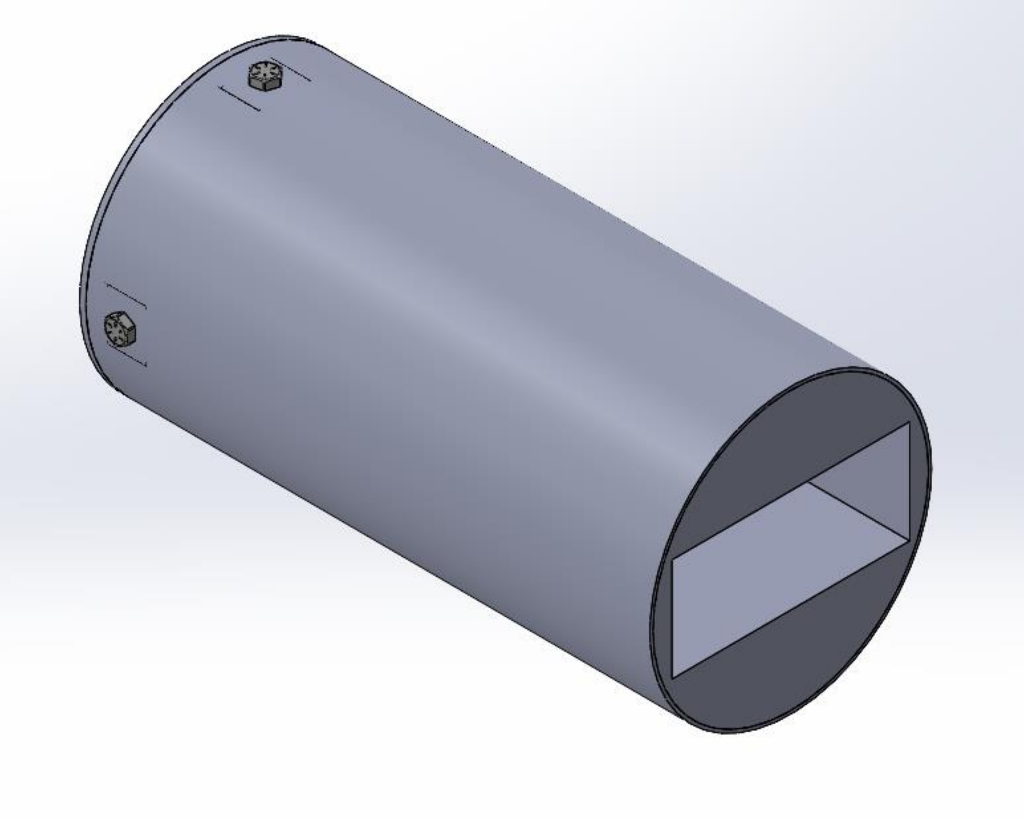


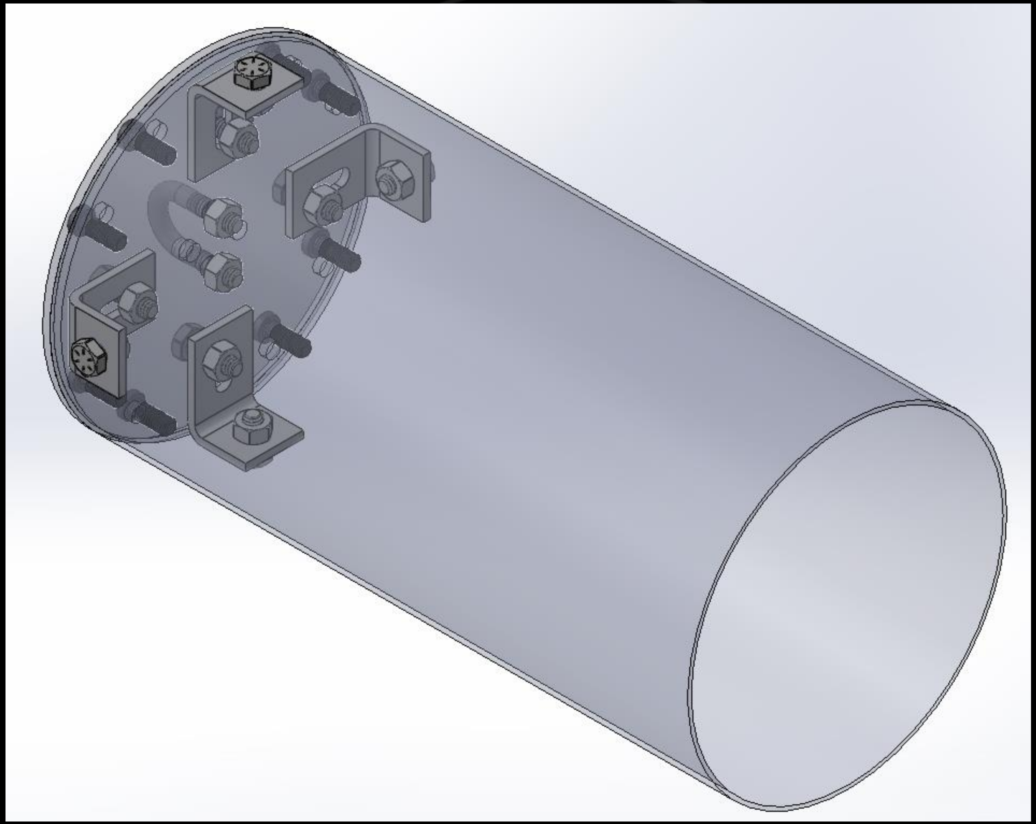
Payload Cost



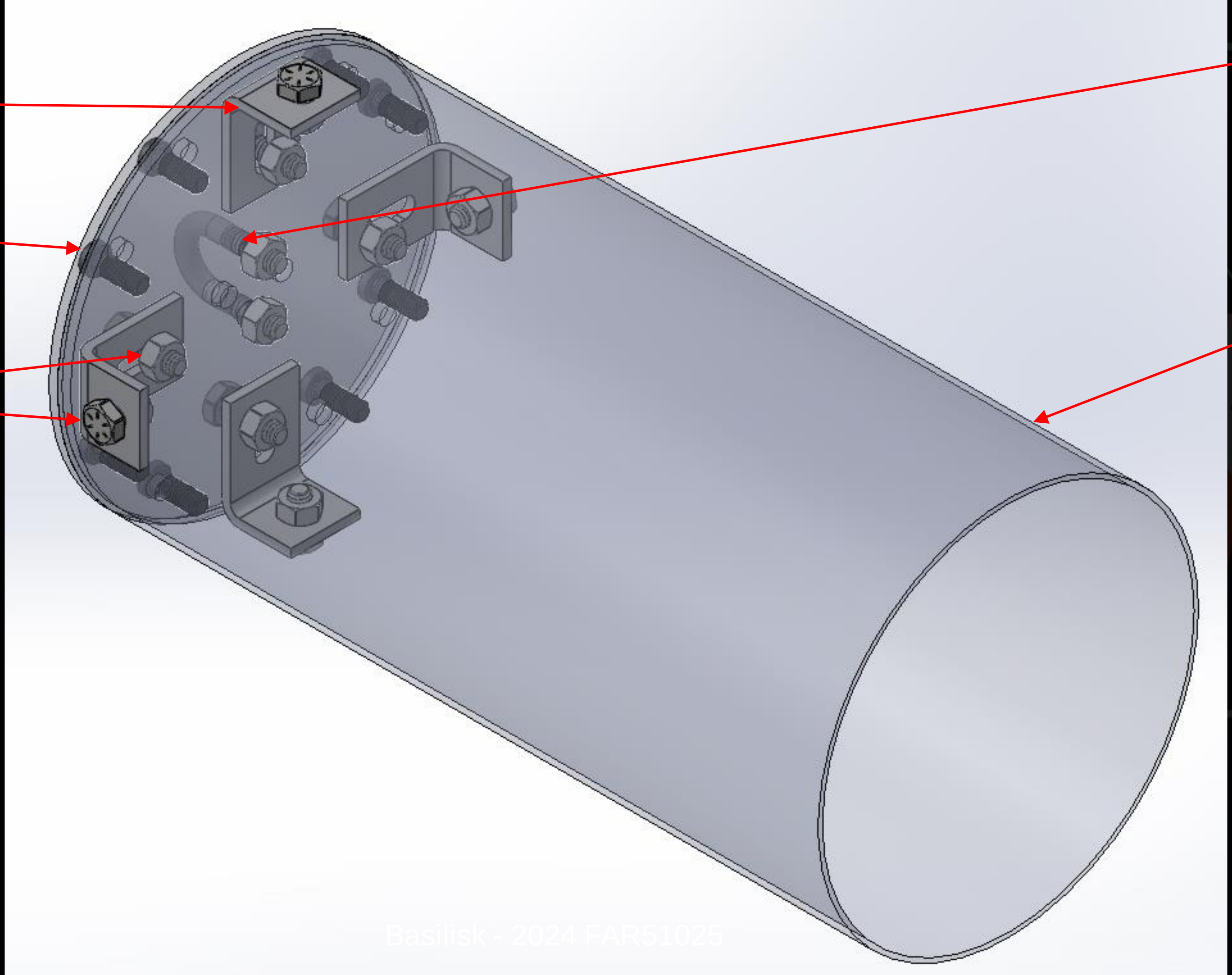
Payload	Cost
Deployment	$[567.65]
Rover	$[306.56]
Drone	$[438.48]
Remote Sensing	$[232.16]
GSE	$[845.90]
Buffer	$[109.25]
Total	**$[2500]**

Payload Canister



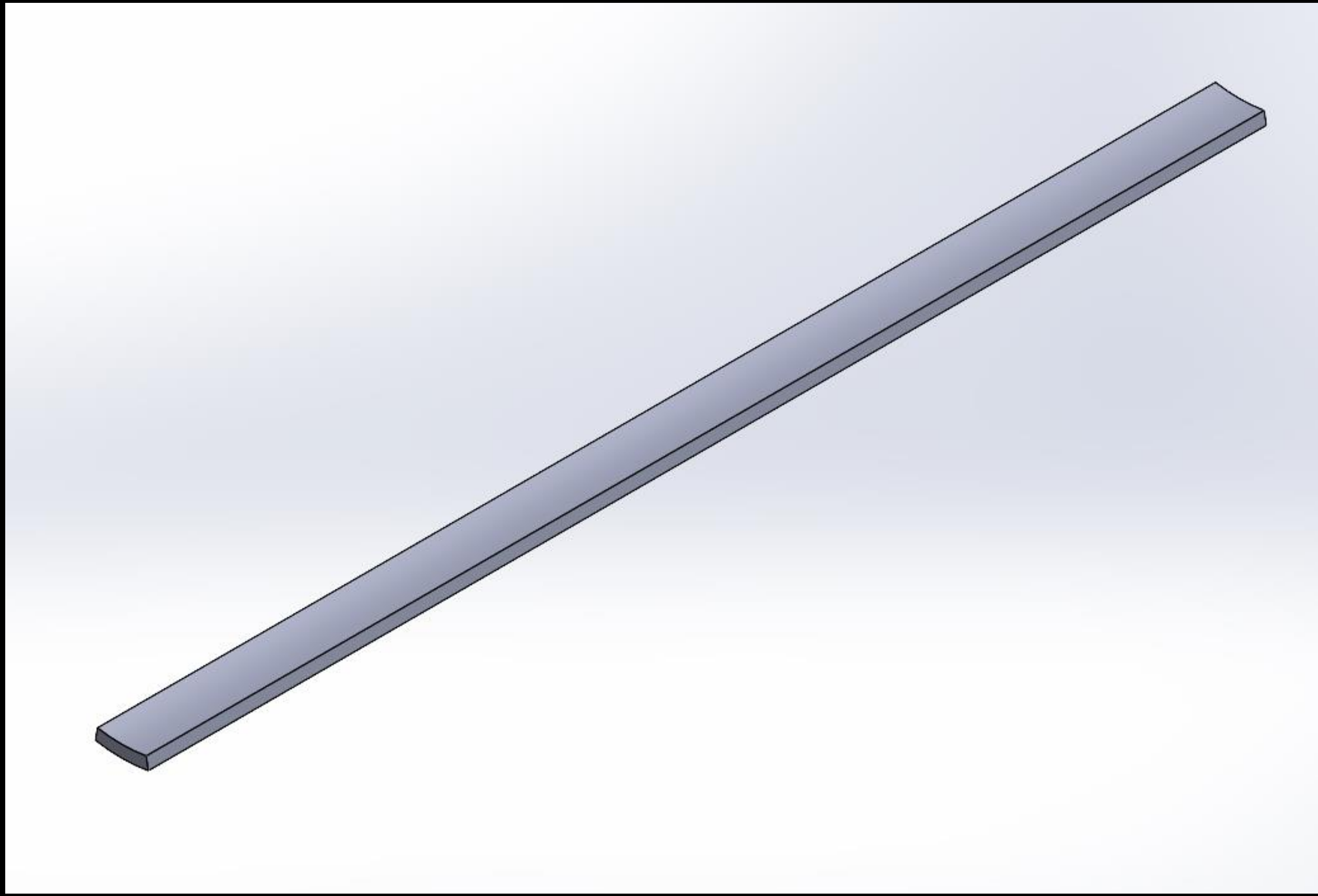


Payload Canister (Hardware)



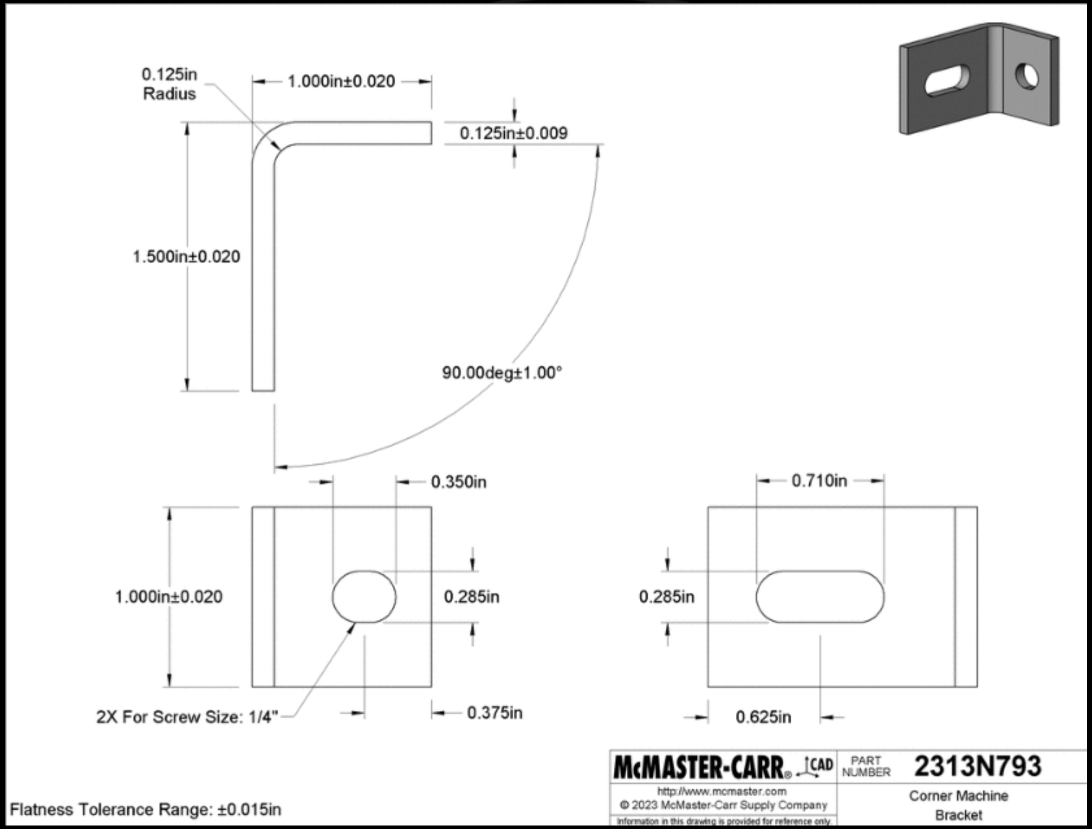
Mechanical Components

- Used to guide Payload Canister out of upper body tube
- 3 will be housed inside upper body tube
- Length: 22in
- Curved to fit ID of body tube and OD of payload canister



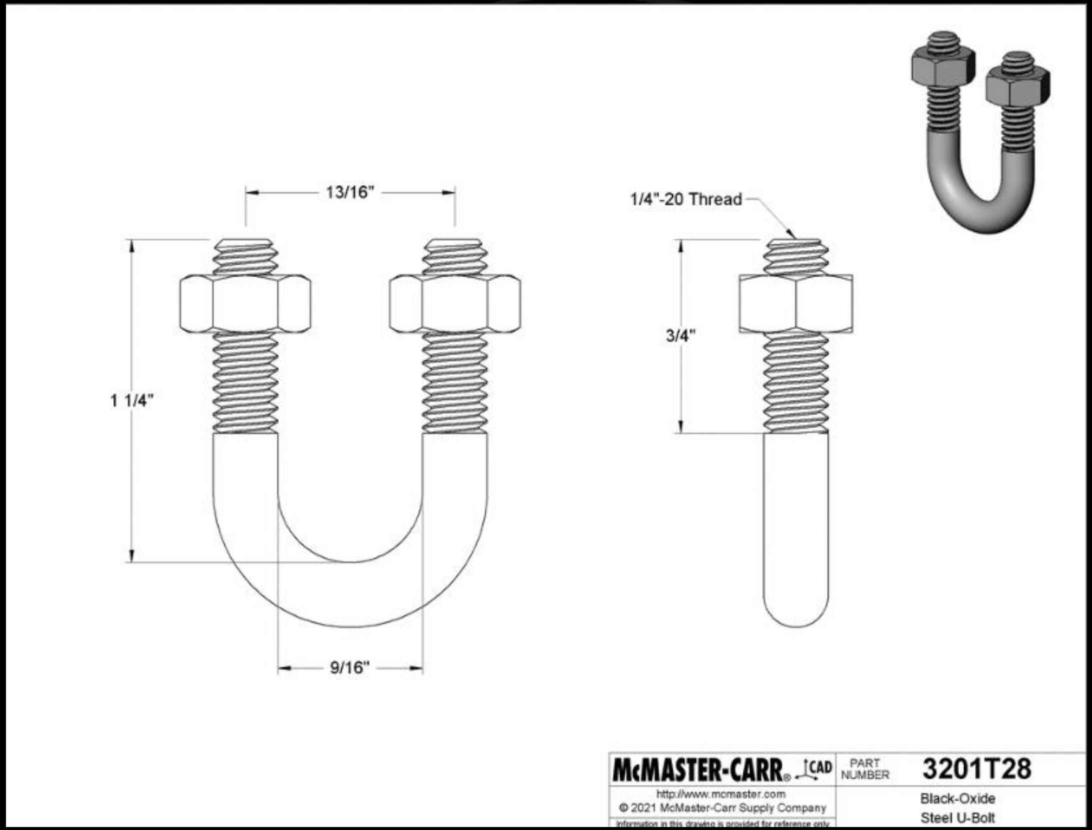
Mechanical Components

- Angle Brackets
  - 6061 Aluminum
  - Used to hold bulkhead to canister tube
  - Held with ¼-20 bolts



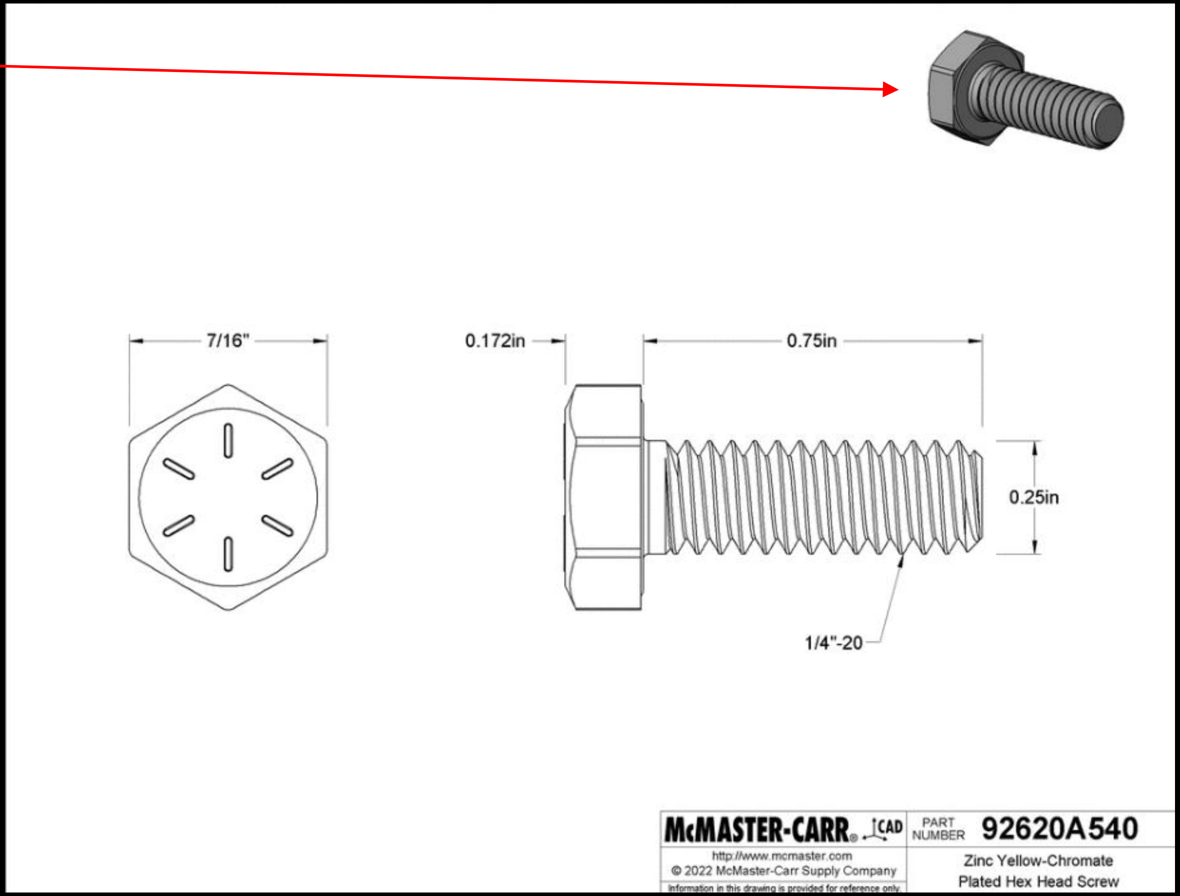
Mechanical Components

- U-bolt
  - Black Oxide
  - ¼-20 thread
  - Capacity: 425lbs
  - Unaffected by snatch force



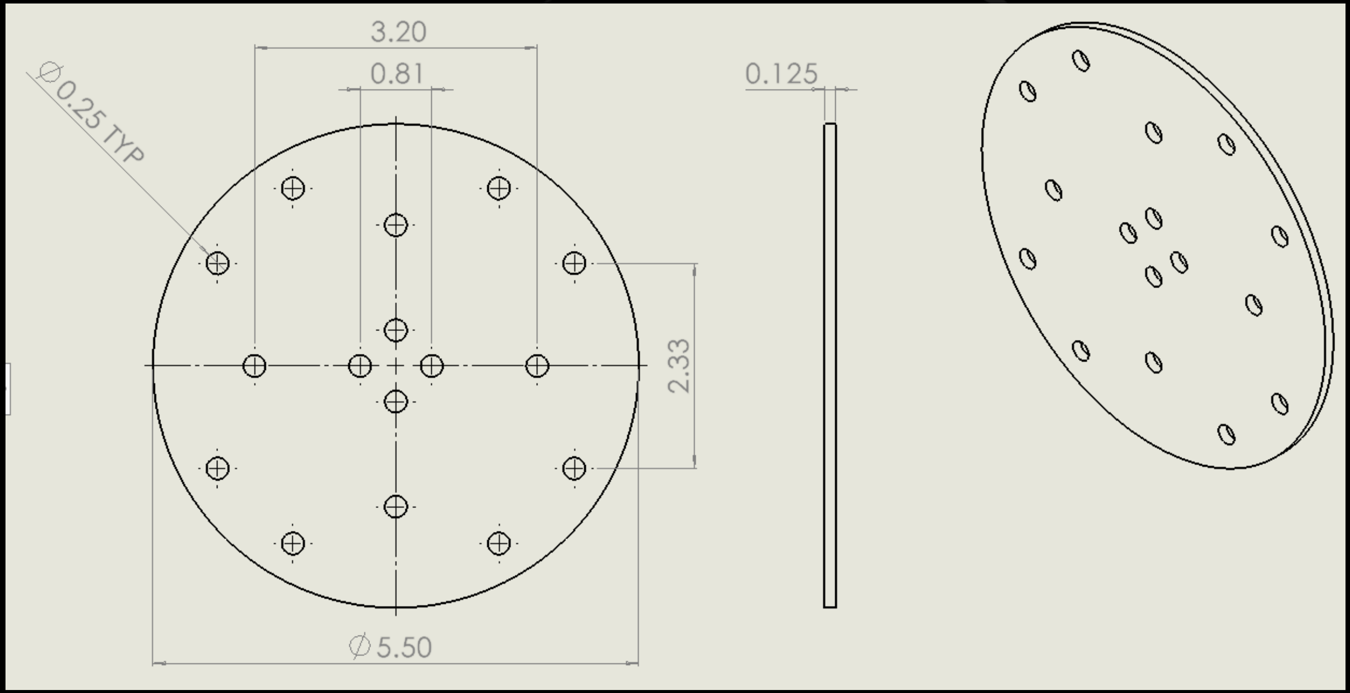
Mechanical Components

- Angle Bracket Bolts
  - McMaster Carr ¼-20
  - 0.75 Thread Length
- 3D Print Bolts
  - ¼-20
  - 5/8 Thread Length



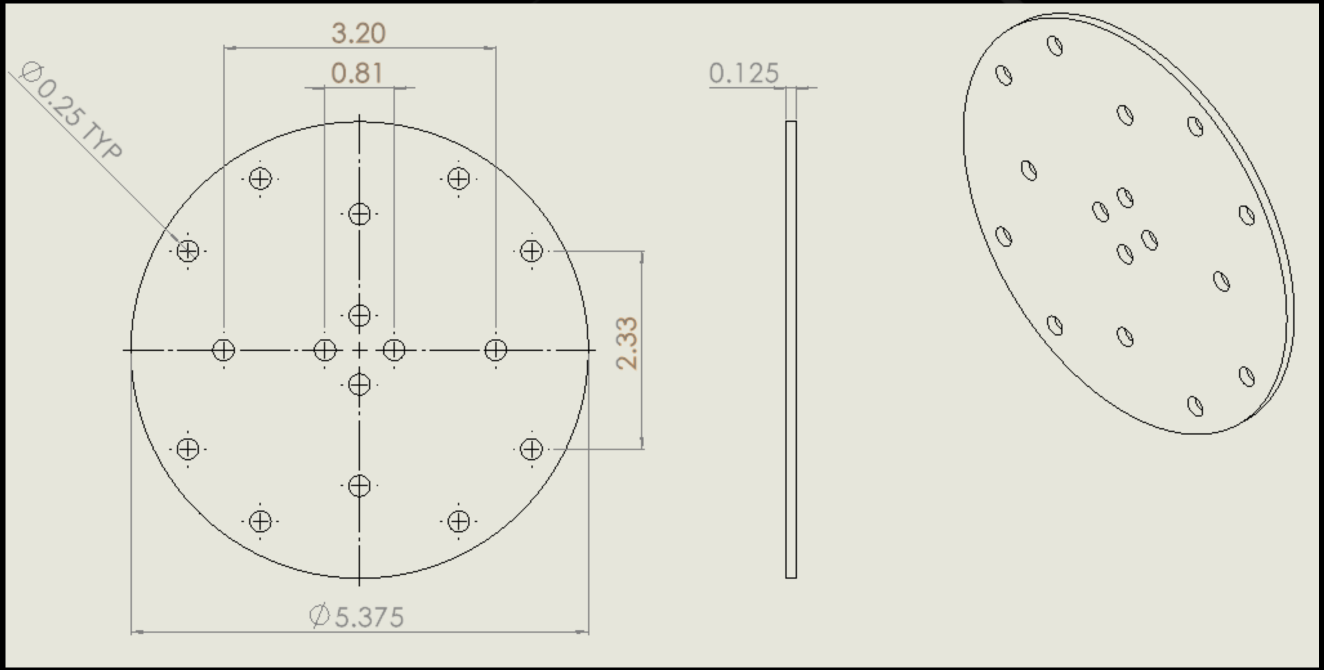
Bulkheads

- Outer Bulkhead
  - Made from CNCed G10 Fiberglass
  - Diameter = 5.5"
  - ¼-20 for all holes



Bulkheads

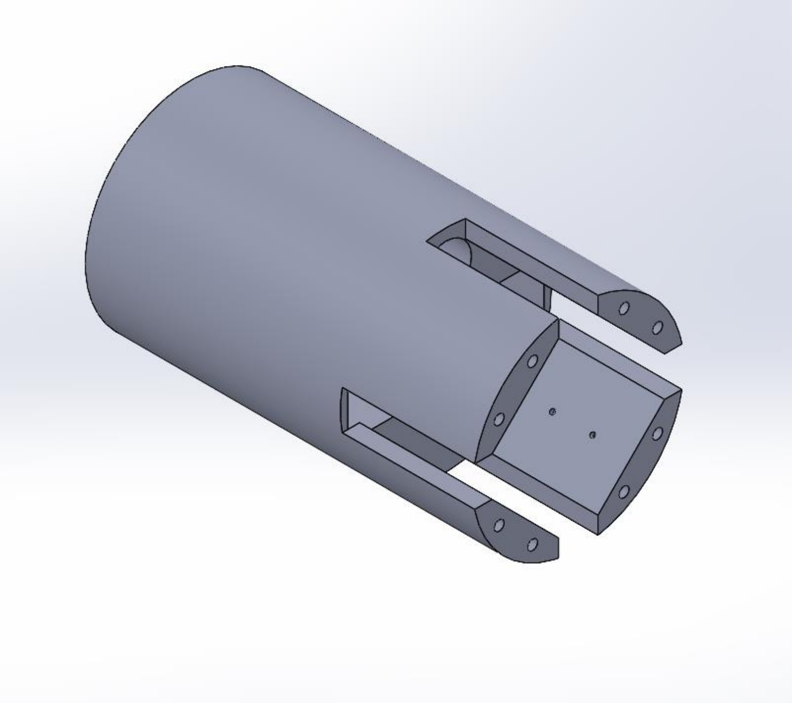
- Inner Bulkhead
  - Made from CNCed G10 Fiberglass
  - Diameter = 5.375"
  - ¼-20 for all holes



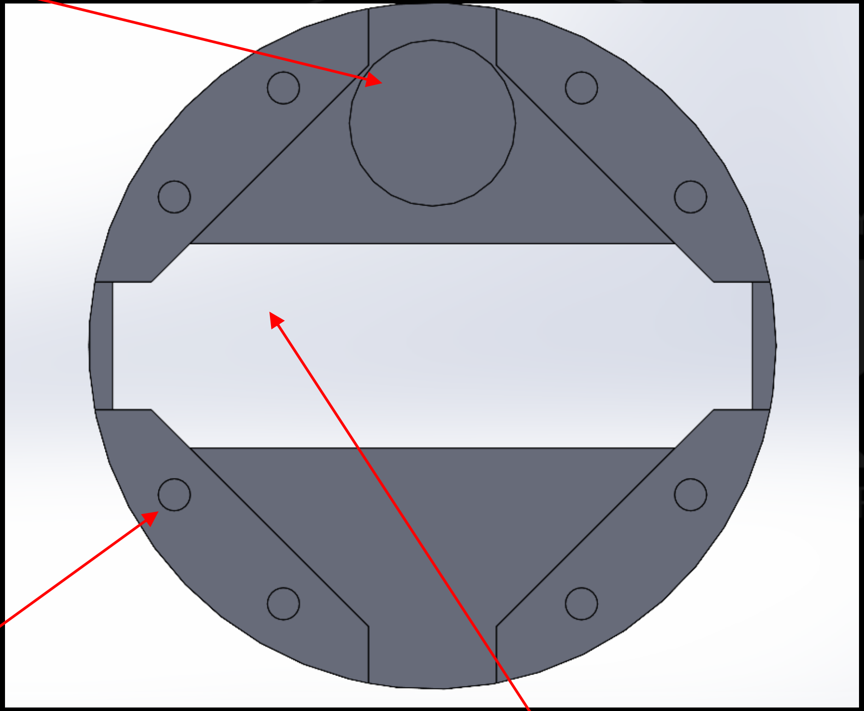
Canister Tube

- Canister Tube
  - Made from woven G12 fiberglass
  - OD = 5.525"
  - ID = 5.375"
  - Rover Tube
    - Length = 10.5in
  - Drone Tube
    - Length = 10in

3D Print Outs



Battery Cabin



¼-20 Threaded Inserts

Dimensions of Rover/Drone

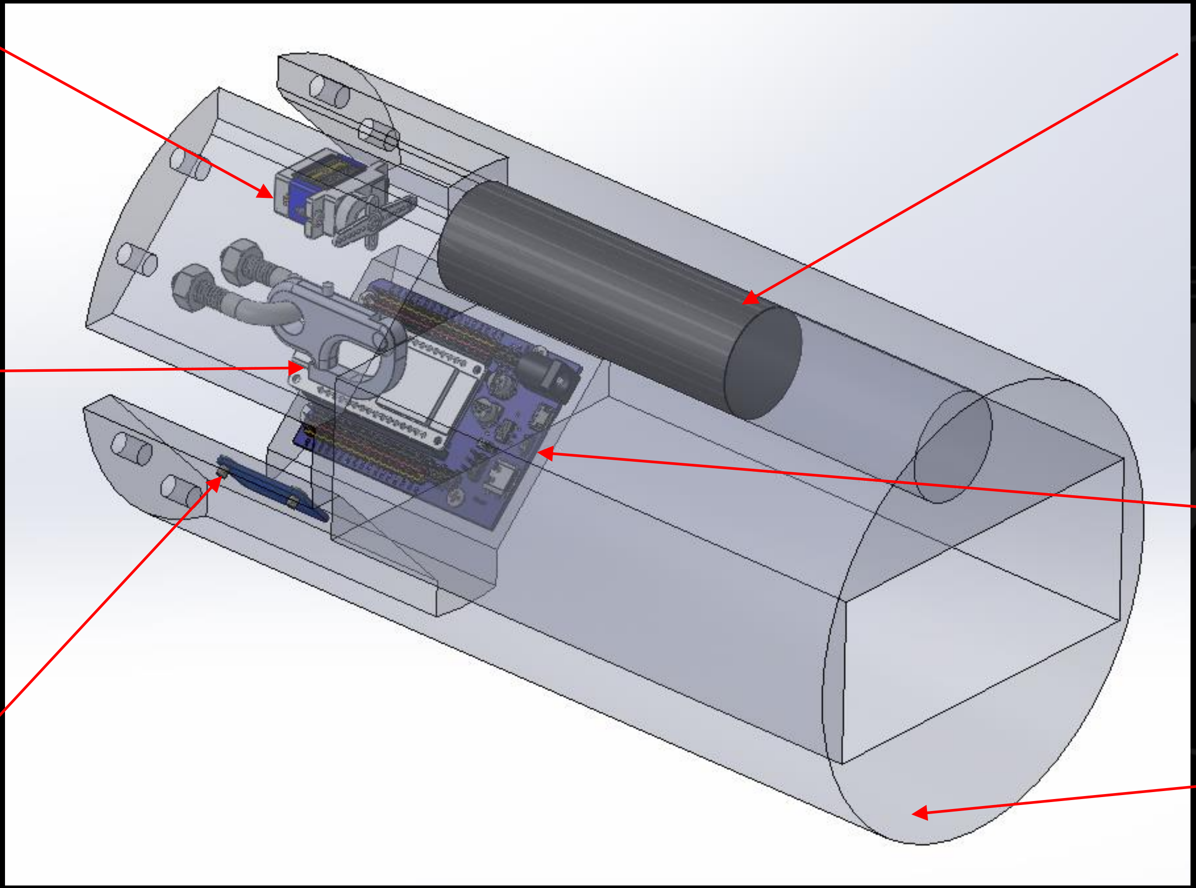
*Dimensions are the Same Length as the inner space of the Canister Tube

Payload Canister (Quick Release Mechanism)

Servo

Portable Battery

Quick Release

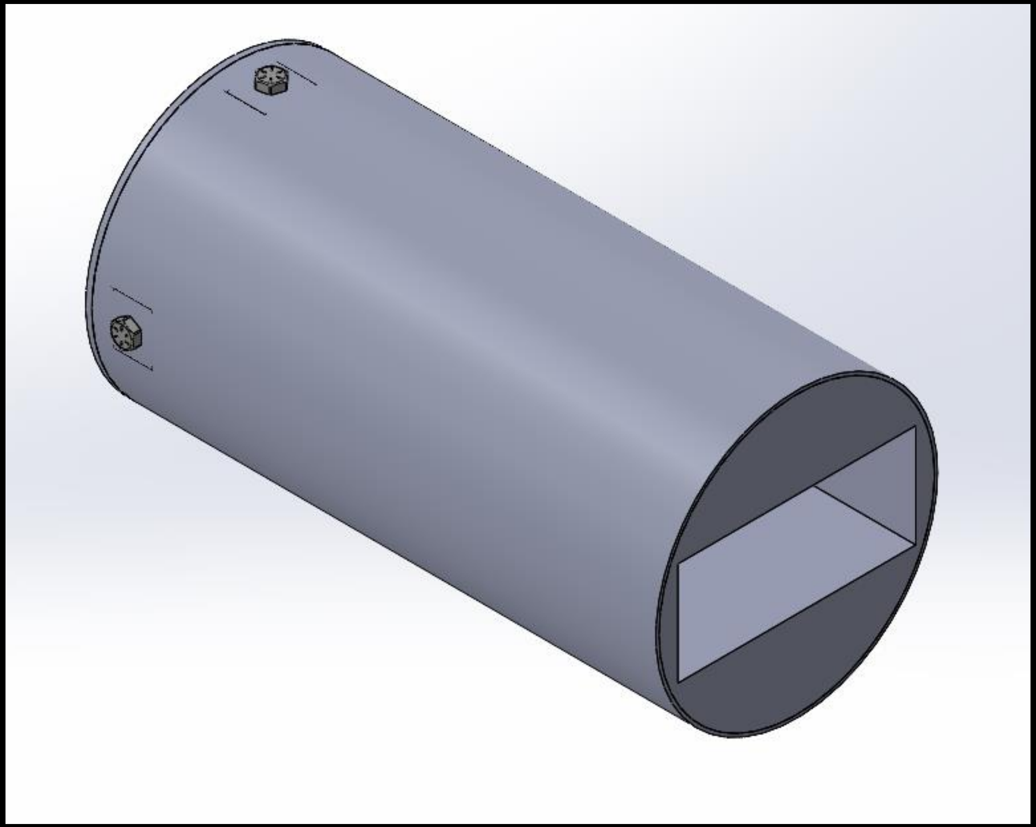


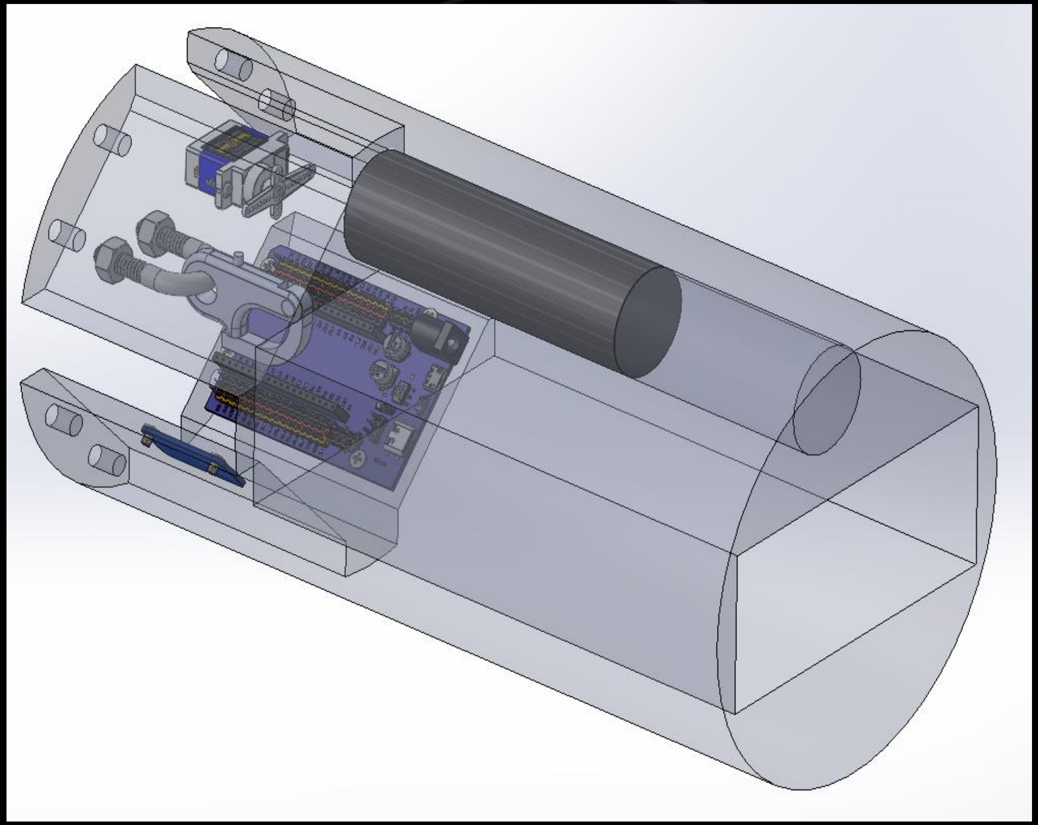
Esp32/Breakout Board

3D Printed Filler

BMP390
(Pressure Sensor)

Payload Canister



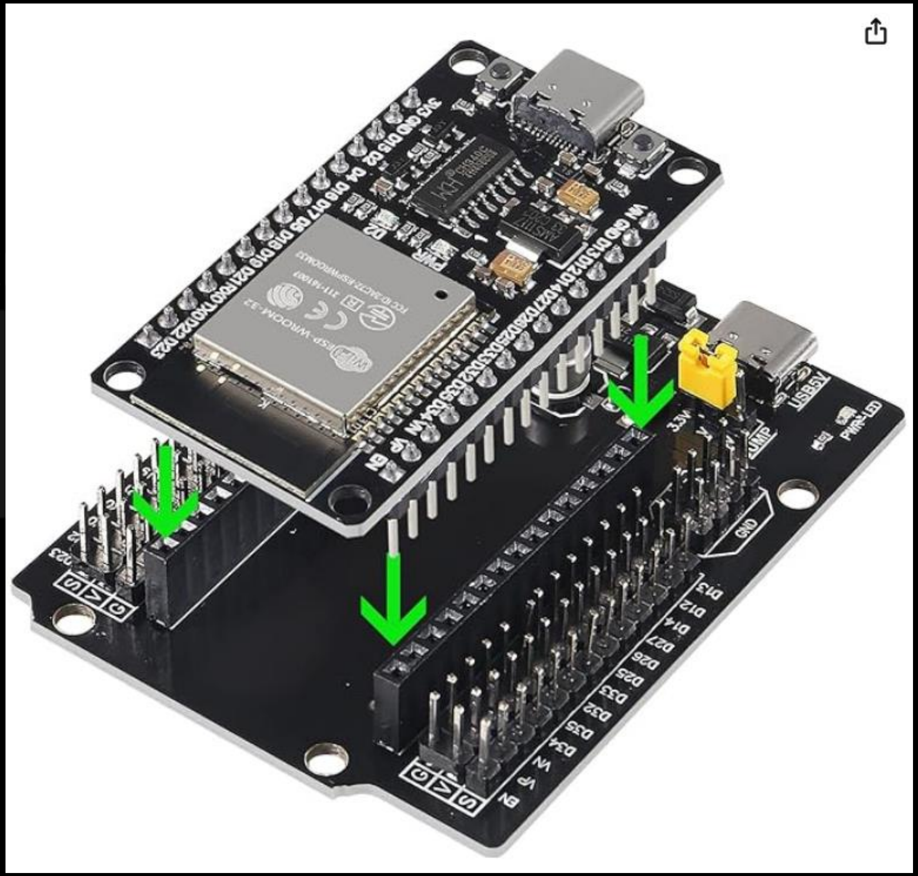


Electrical Components

- Portable Battery
  - 5V supplied
  - 5000mAh
  - Built in voltage regulator

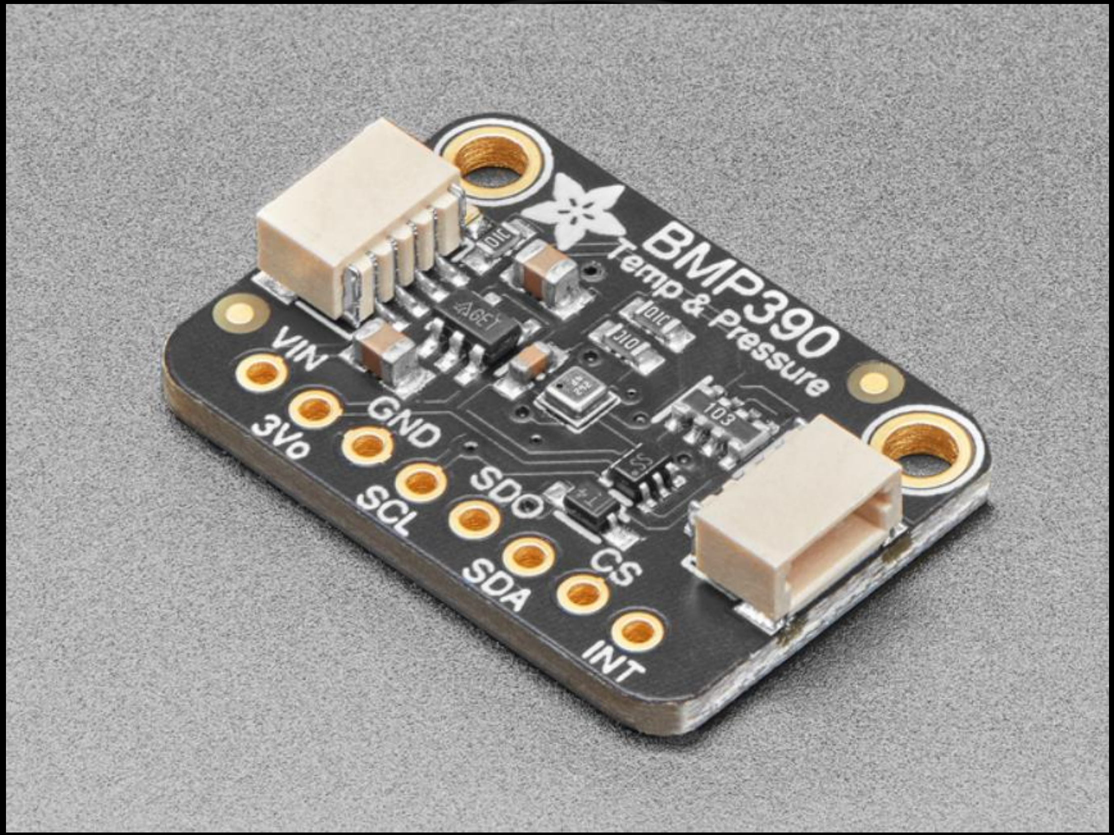
Electrical Components

- ESP32 w/ Breakout Board
  - Used as a microcontroller to handle actuation of servo
  - Common and Well Known



Electrical Components

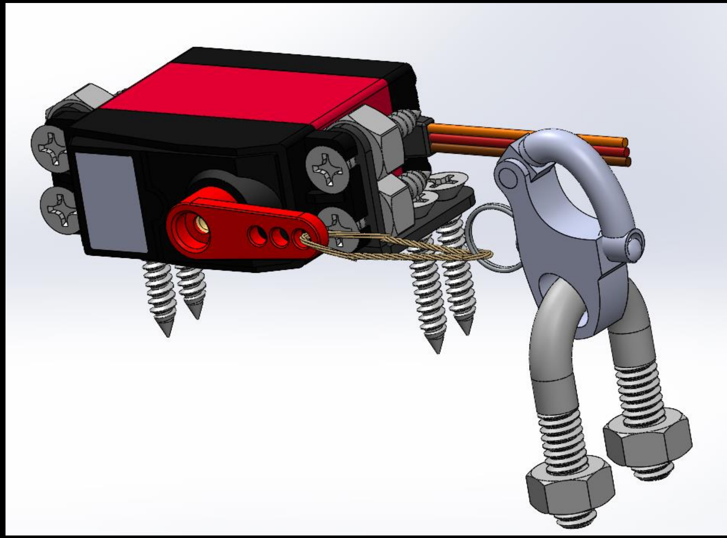
- BMP390 Pressure Sensor
  - Used to measure altitude based on pressure
- Servo
  - Used to pull release mechanism pin

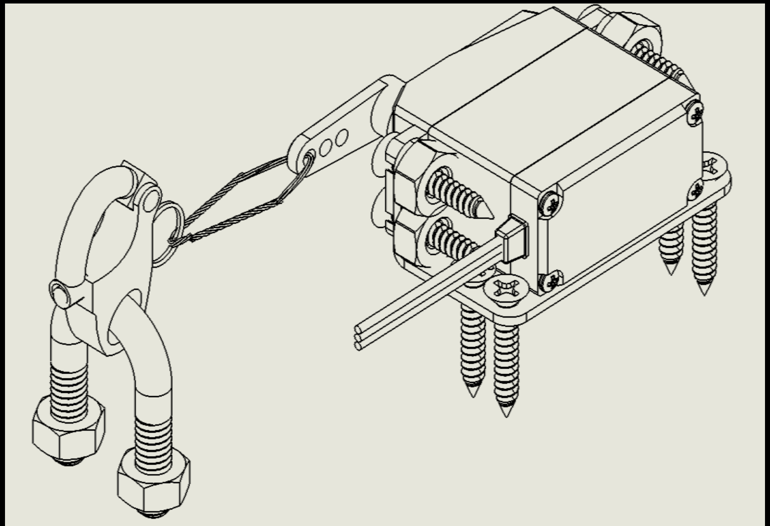


Quick Release

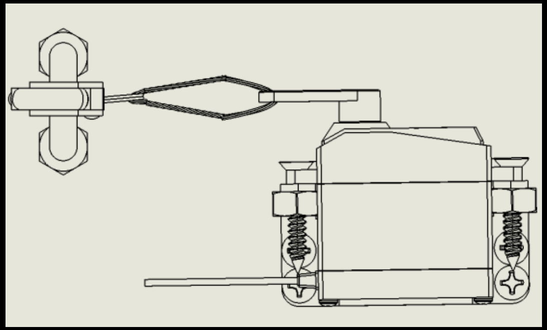
- Kong Quick Release 520
  - Made from Stainless Steel
  - Dimensions (1.3"x0.8"x0.05")
  - Maximum load: 881 lb
  - Weight: 10.4 g

Quick Release System





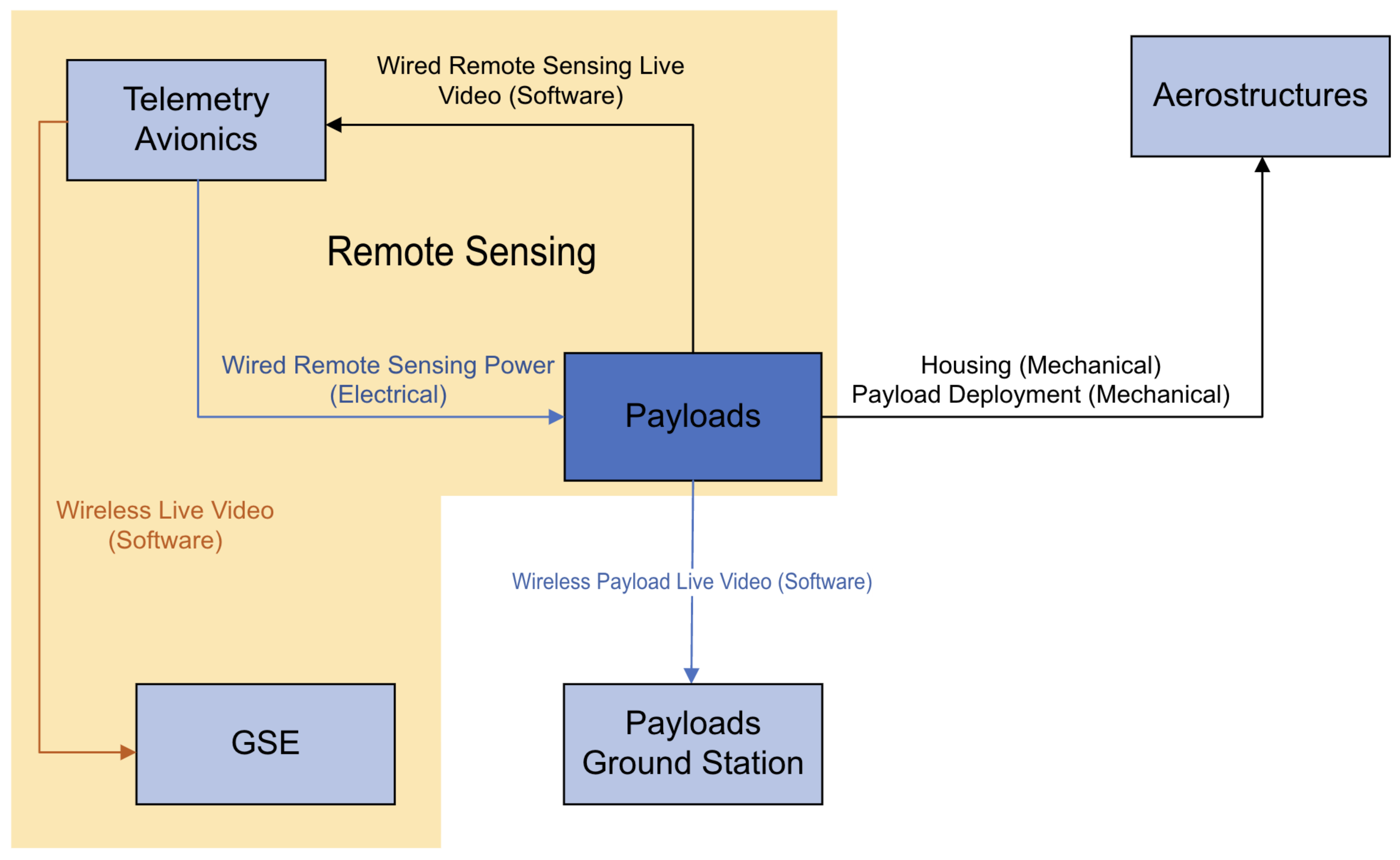
- Responsible for holding and releasing the rover and the drone.
  - 20KG RC Servo
  - Kong Quick Release 520
  - 12in of Rope
  - Mini U-Bolt
  - 8# x1" Screws
  - Hex Nuts
  - Horn Steering Arm
  - Servo Bracket



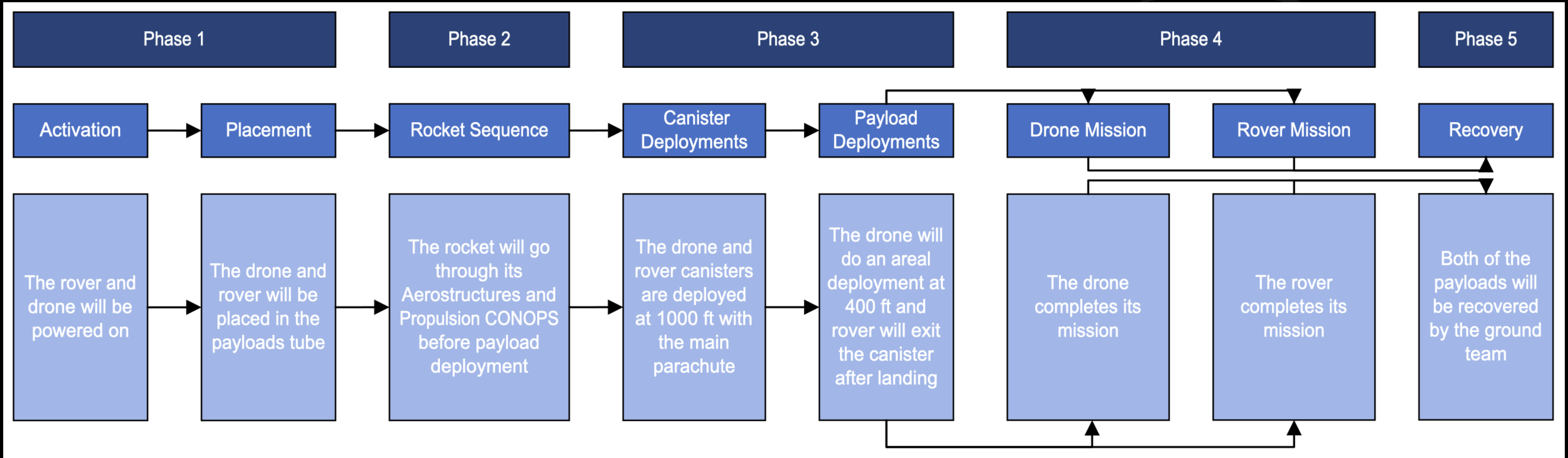
Functional and Performance Requirements	Verification Methods
The Quick Release **shall** Function	Demonstration
The Quick Release **shall** Attach/Detach to and from the Rover and the Drone	Demonstration

The quick release system will be comprised of a quick release latch made open by the servo's action to pull the rope that is connected to the keyring that is holding the quick release latch in place.

Payload Interface Diagram



Payload CONOPS



Payload System Verification Plans

- **Payload Canister Test Campaign**
  - Finite Element Analysis (Analysis)
  - Continuity Test (Testing)
  - Pressure Sensor Test (Testing)
  - Quick Release Test (Testing)
  - Payload Canister Drop Test (Testing)
  - Payload Canister Deployment Flight Test (Demonstration)
  - Payload Demonstration (Demonstration)

Payload System Verification Plans

- **Rover Test Campaign**
  - Finite Element Analysis (Analysis)
  - Continuity Test (Testing)
  - Transmission Test (Testing)
  - Piloting Test (Testing)
  - Rover Drop Test (Testing)
  - Payload Demonstration (Demonstration)

Payload System Verification Plans

- **Drone Test Campaign**
  - Continuity Test (Testing)
  - Transmission Test (Testing)
  - Auto Stabilization Test (Testing)
  - Piloting Test (Testing)
  - Payload Demonstration (Demonstration)

Payload System Verification Plans

- **Remote Sensing Test Campaign**
  - Continuity Test (Testing)
  - Transmission Test (Testing)
  - Local Save (Testing)
  - Payload Demonstration (Demonstration)

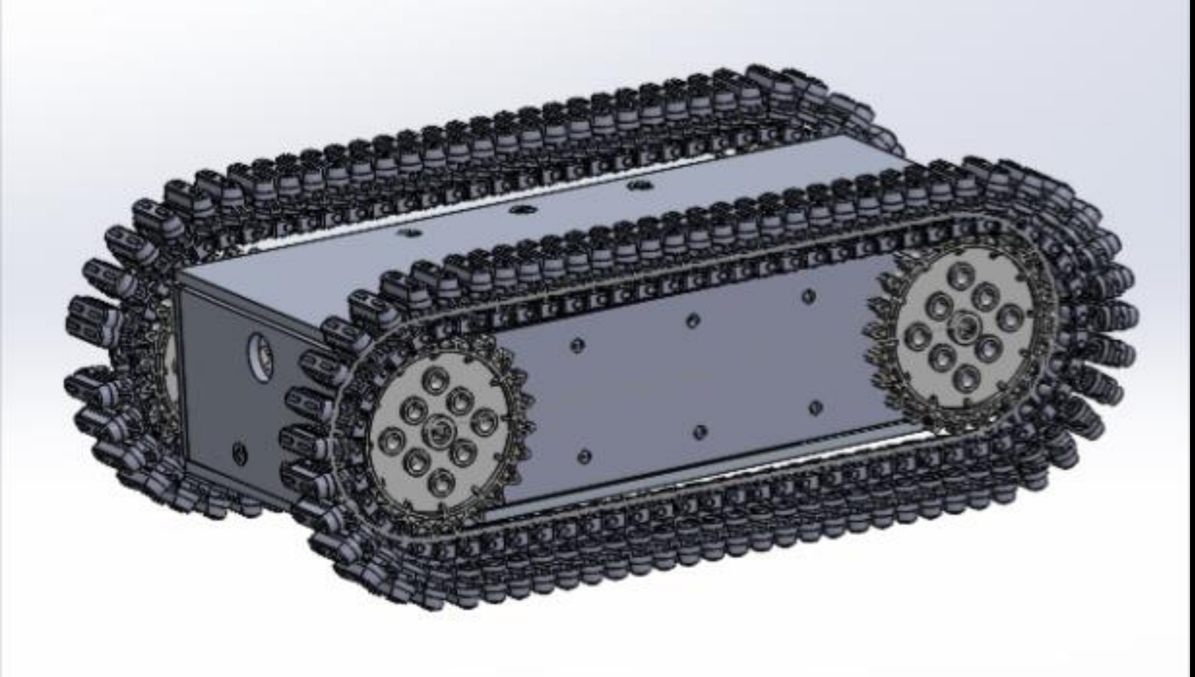
Payload Deployment System FMECA

Part	Failure	Criticality	Effect	Mitigation
Payload Canister	Quick Release	High	Mission Failure	Testing, Demonstration
Payload Canister	Barometric Sensor Delay	Low	Released at different height than specified	Testing, Demonstration
Payload Canister	Servo Failure	High	Quick Release Failure; Mission Failure	Testing, Demonstration
Payload Canister	Mechanical Failure	Medium	Canister Breaks on Impact Possibly Affecting Mission	Analysis, Testing, Demonstration
Drone	Auto-Stabilization	High	Mission Failure	Testing, Demonstration
Rover	Mechanical Failure	High	Rover Breaks on Impact	Testing, Demonstration

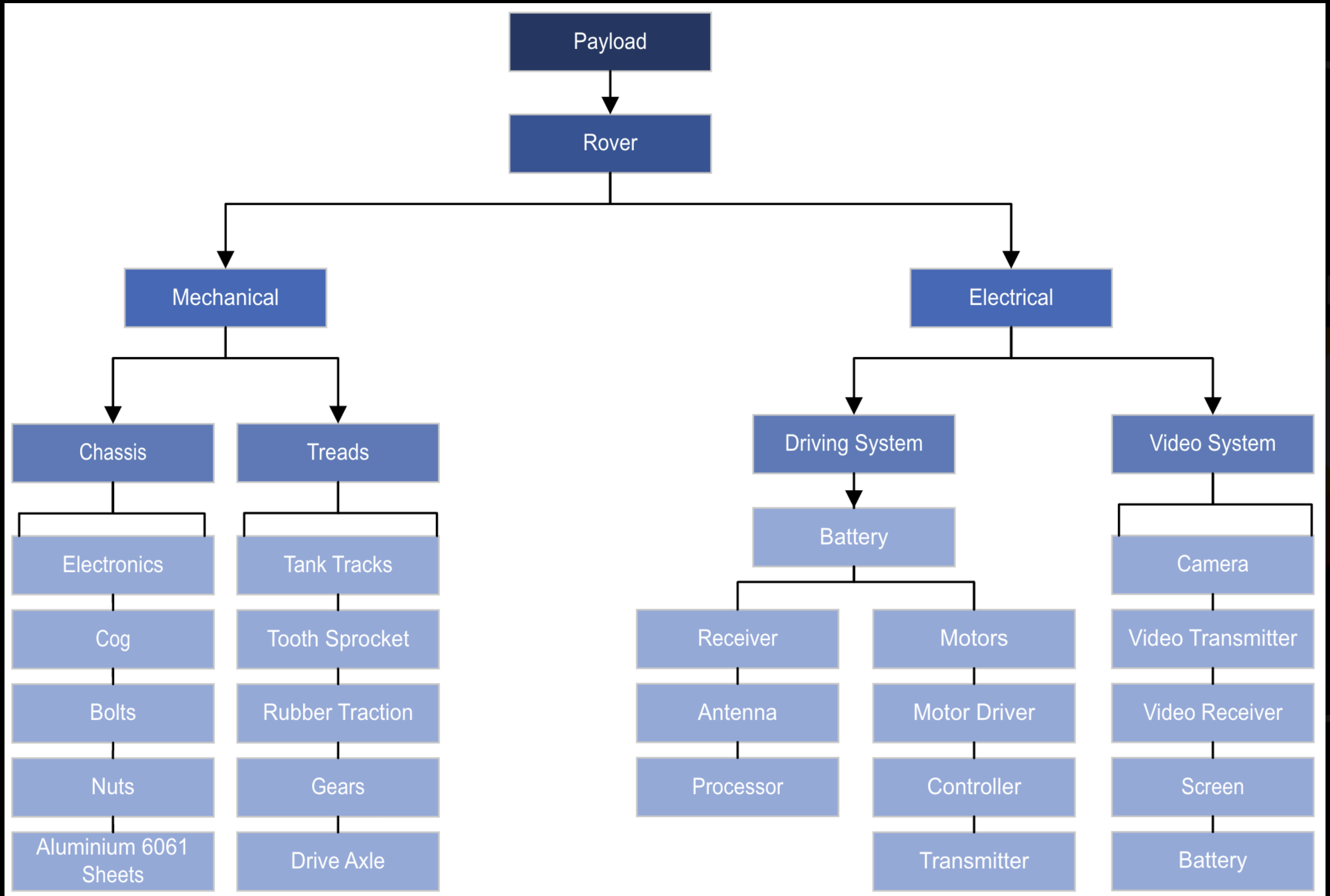
Rover Subsystem

TPMs

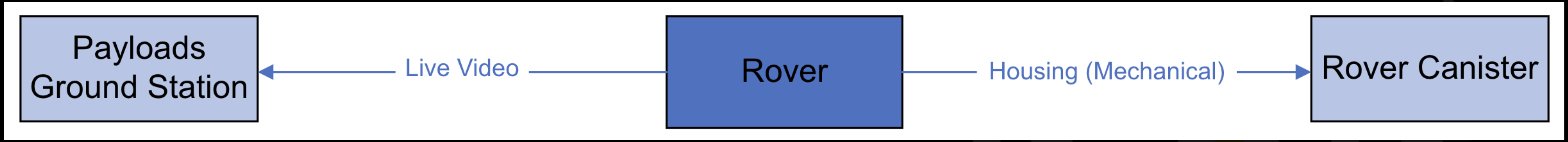
Measures	TPM Value	Units	Verification Method
Dimensions	7” x 5.31” x 3.3”	in	Inspection
Weight	1.54	lbs	Inspection
Operating Time	1.03-1.6	hr	Analysis, Testing, Demonstration
Passive Power Draw	1405-2165	mA	Analysis, Testing, Demonstration



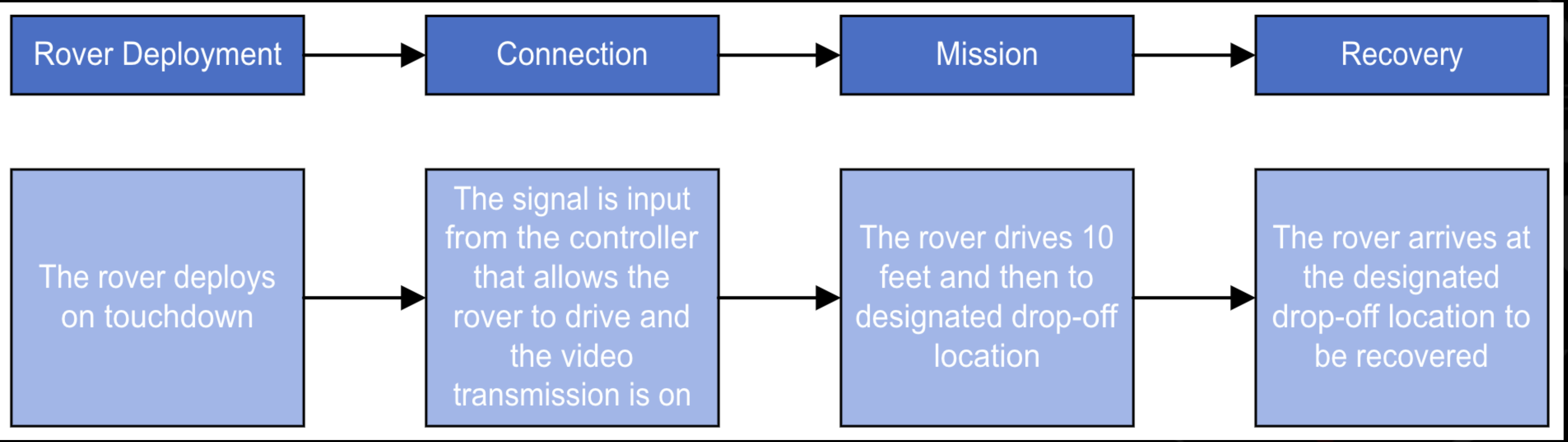
Rover Component Breakdown (Architecture)



Rover Interface Diagram



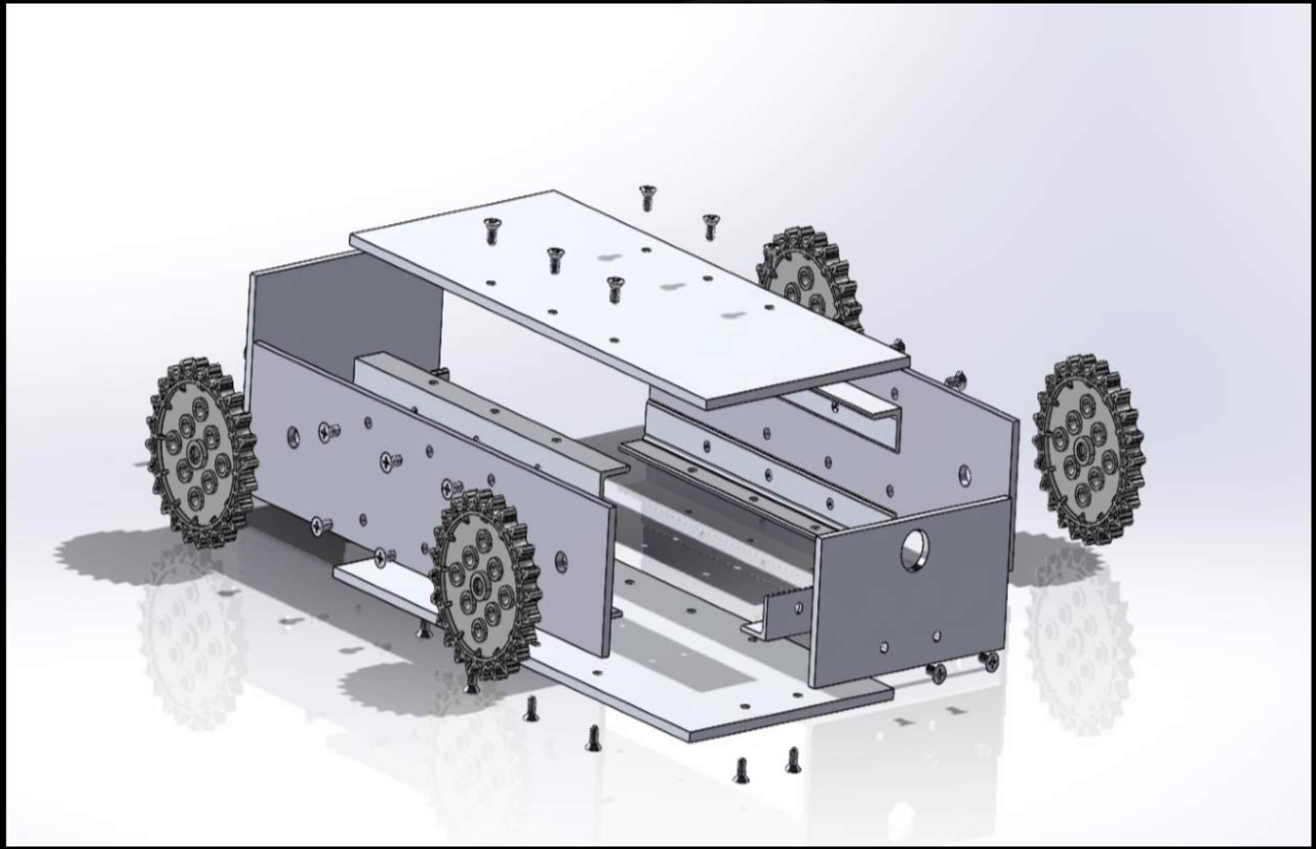
Rover CONOPS



Chassis

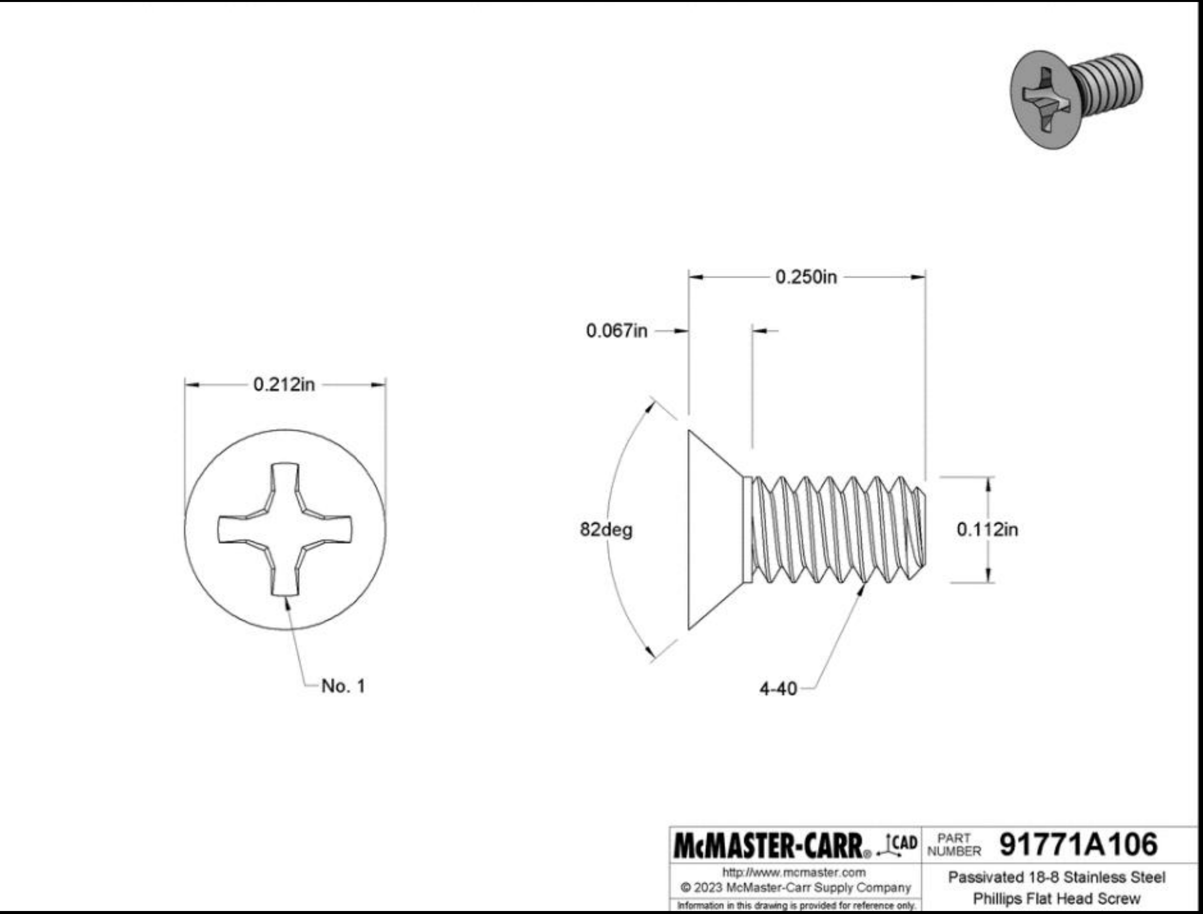
- COTS Chassis constructed of (6061-Aluminum Sheets)
- Aluminum sheets bolted
  - 4"x3.64"x2"
  - Electrical components screwed into place inside
  - 4-40 Stainless Steels Bolts

Exploded View



Chassis Bolts

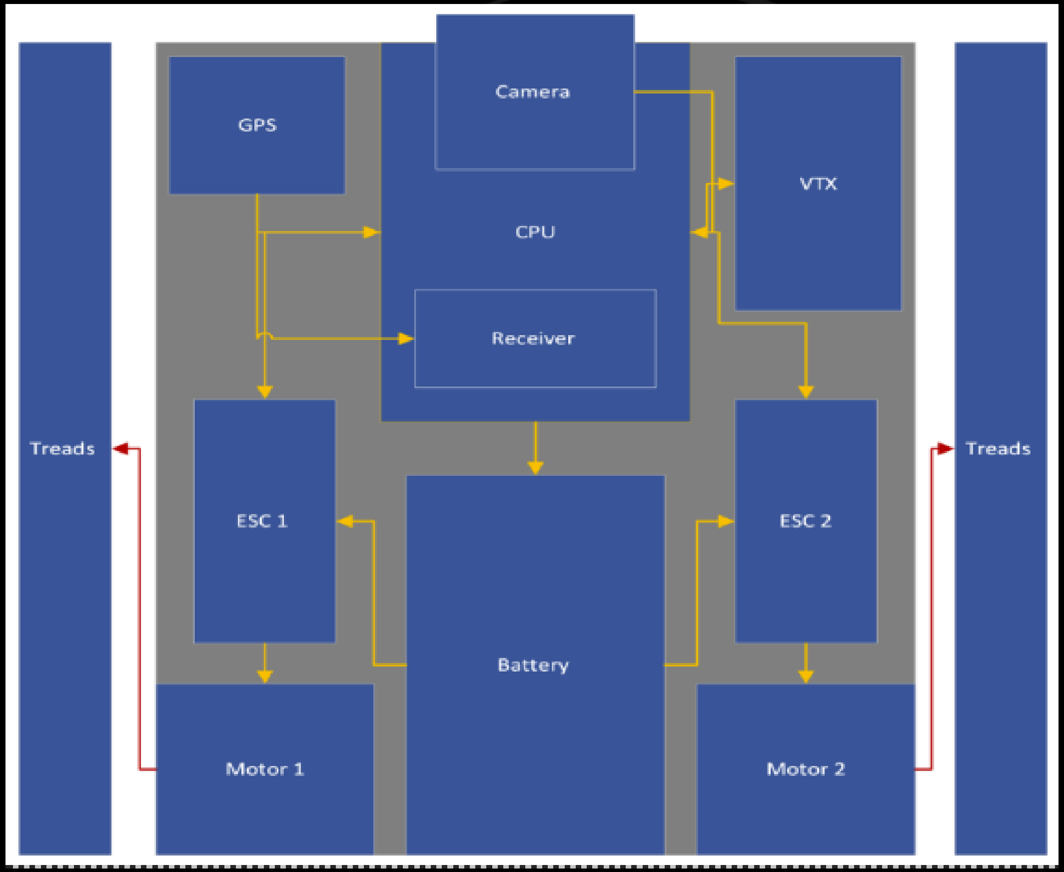
- Bolts
  - 4-40
  - Stainless steel
  - Common to work with



Rover Mechanical Electrical Layout

- Layout of electrical components within the chassis of the rover
  - Screwed into place
  - Based on effectivity to reduce failure points

Top View



Rover Mechanical FMECA

Part	Failure	Criticality	Effect	Mitigation
Tread Chains	May snap if a high impact is sustained	High	Loss of rover mobility	Testing, Demonstration
Tread Chains	May slip off if an object is forced in between the gears and tread chain	High	Loss of rover mobility	Testing, Demonstration
Rover Gear	Mechanical Failure on Impact	High	Loss of rover mobility	Testing, Demonstration
Drive axles	Mechanical Failure on Impact	High	High degree of impairment / Loss of rover mobility	Testing, Demonstration
Chassis	Mechanical Failure of Bolts on Impact	Medium	Reduced Protection / Efficiency of Chassis	Mechanical and Finite Element Analysis, Testing, Demonstration

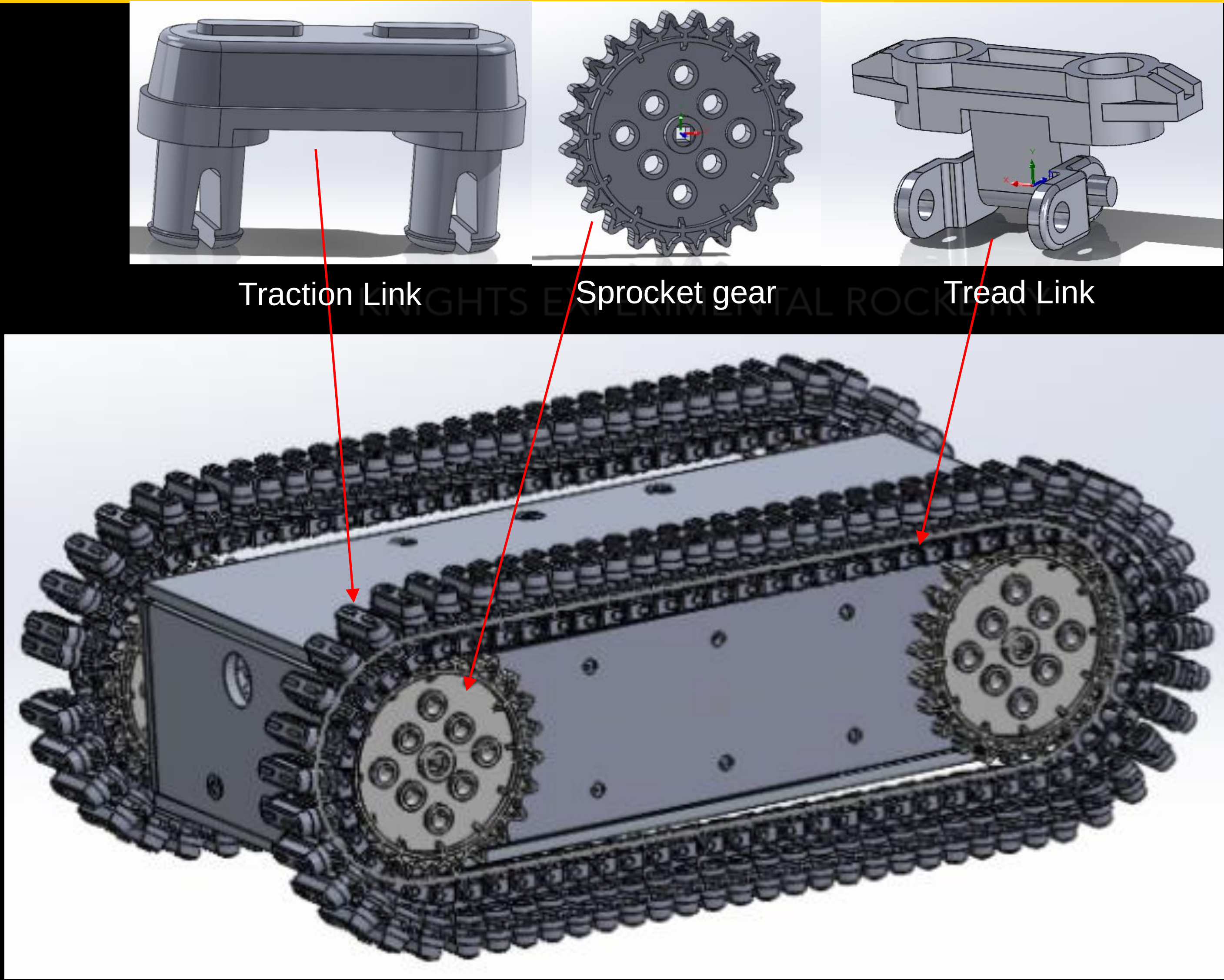
Traversal Mechanism

The Traversal System (or "Treads") provides propulsion to the rover, and consists of:

- VEX Tank Tracks
- 2 DC Motors

Sizing Specifications:

- Gear ID: 1.79 in
- Tread Link Length: 0.244 in
- Total Tread Dimensions: 2.16 x 1 x 7.85 in



Rover Electrical Systems Breakdown

- Driving System:
  - Map control signals with 14V power. (port open and close)
- Processor System:
  - Convert signal from radio to drive commands for motor functionality.
- Control System:
  - Capture and transmit control signals from radio to rover.
- Video System:
  - Capture and transmit live video to ground station.
- Receiving System:
  - Receive and display live video captured from rover.

Rover Driving System: Overview

- Components:
  - Processor subsystem:
    - Receiver: Sologood 915MHz ELRS Nano (stock antenna)
    - Processor: Teyleten ESP32 Microcontroller
  - Motor subsystem:
    - Motors: TAM54393 Type 380 Brushed Motor
    - Motor Driver: Qunqi L298N Motor Driver

Rover Driving System: Battery

- CNHL 2200mAh 4s 14.8V LiPo
  - 42 minutes mission lifetime with full activation of both motors. This does not account for work based on terrain.
  - All power and ground supplied via PDB
  - Charge Rate: 40C
  - Equipped with a XT60 power connector.

Processor Subsystem

- Processor:
  - Responsible for converting receiver signals to the L298N motor driver. (Will not interface with video system)
  - ESP32 will only handle 2 receiver channels respective to CH1 and CH2 from the radio
  - Logic:
    - Signal from CH1 will turn rover clockwise
    - Signal from CH2 will turn rover counterclockwise
    - Signal from CH1 + CH2 will drive rover forward

Rover Driving System Code Logic

- 2 defined functions:
  - Left Motor power
  - Right Motor power

- ESP Will read Channel PWM from receiver
  - Signal from ESP will be sent to L298N Motor Driver activating the motor (all or nothing)
    - GPIO will be respective to each channel for simplicity
    - Only value being passed will be 1 or 0 (open or close).

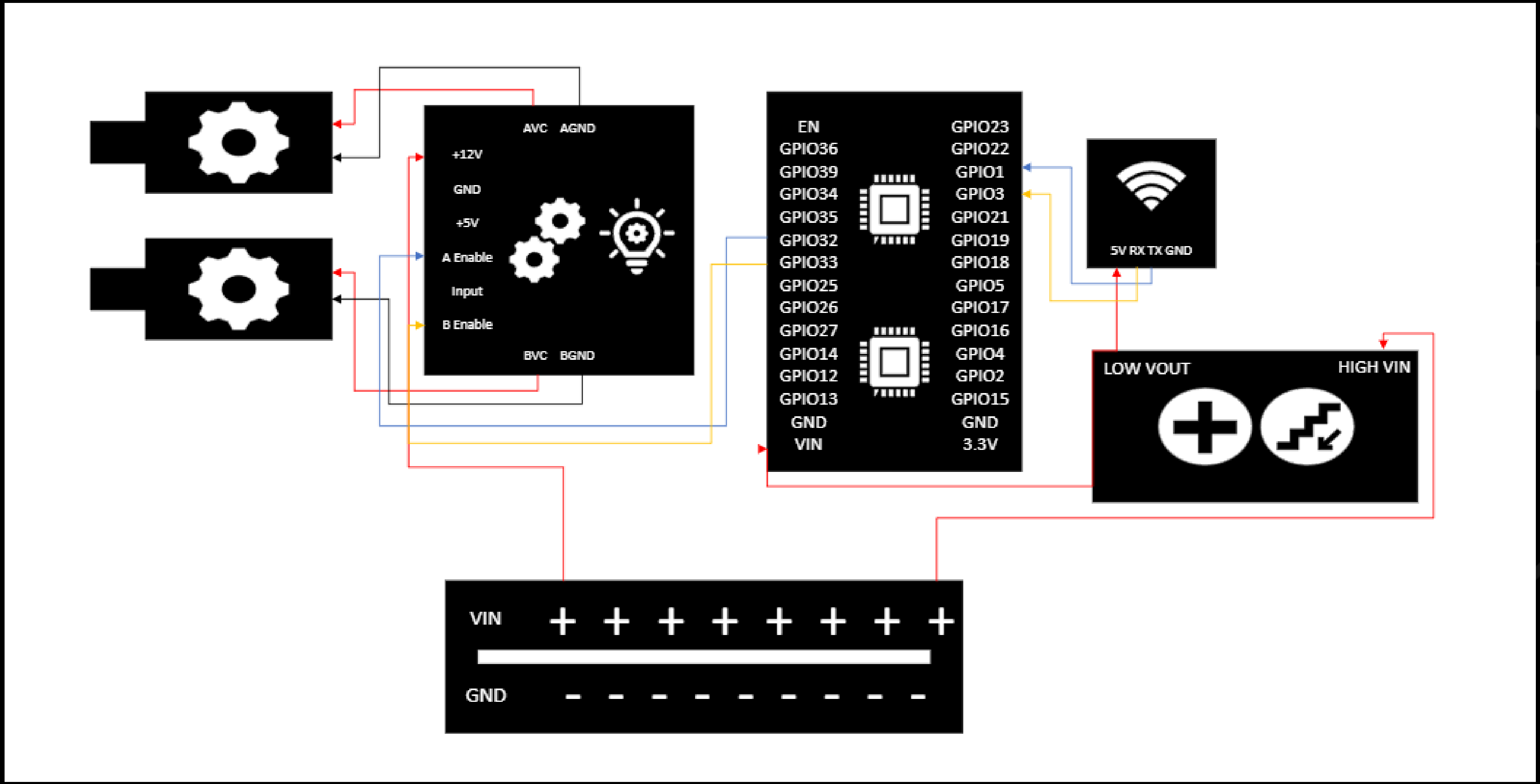
Receiver sends PWM output to ESP32	
ESP32 Converts receiver PWM signals into CH1 and CH2	
CH1 is opened	CH2 is opened

Rover Driving System: Controller

- Controller: Radiomaster TX12 Radio (Mode 1)
- Transmitter: Happymodel Micro TX900 ELRS Transmitter (same configuration for drone)

- Notes:
    - Only 2 channels are to be used for the rover. Channel 1 and Channel 2 will control left motor and right motor respectively. There are no other functions carried out by the controller (8 extra available channels)

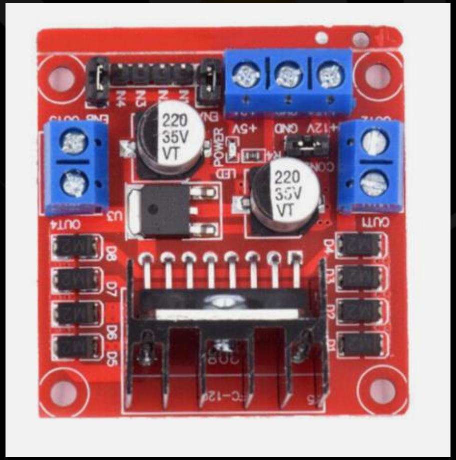
Rover Driving System: Visual Representation



Rover Driving System: Visual Representation

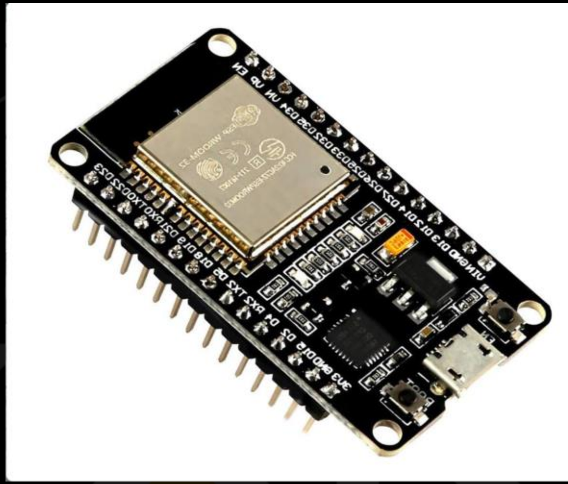
- TAM5493 Type 380 Motor

- Qunqi L298N Motor Driver



Rover Driving System: Visual Representation

- ESP32 Microcontroller



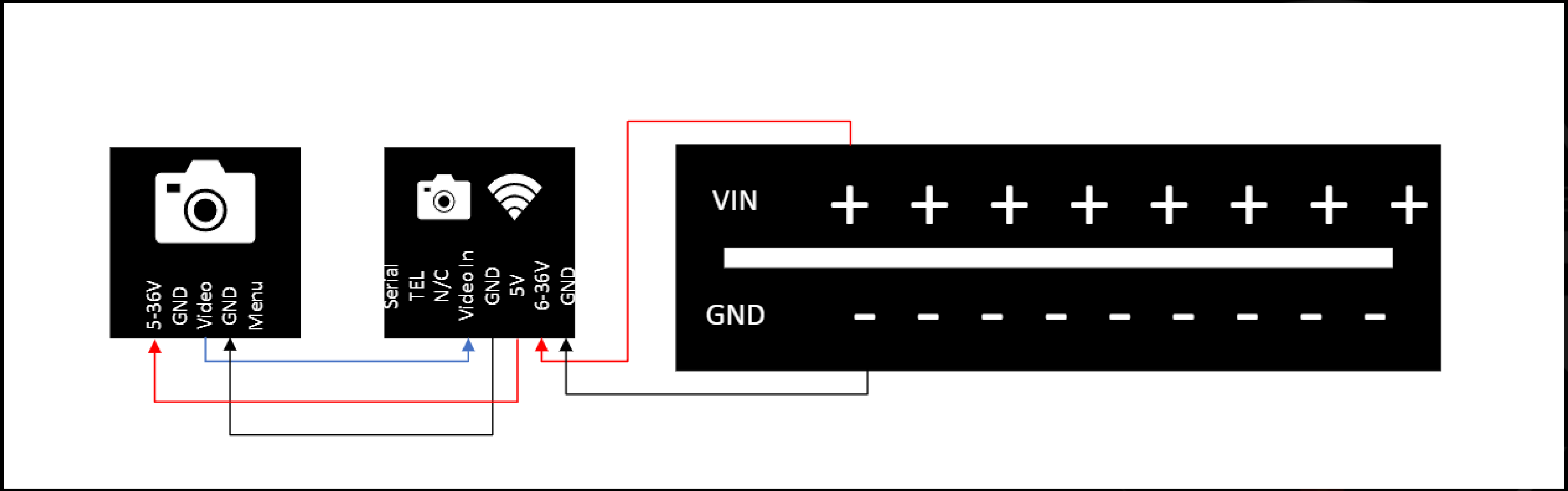
- Sologood 915mHz ELRS receiver

Rover Video System: Overview

- Camera: Runcam Nano 2
- VTX: 1.3GHz Dual Channel Video Transmitter
  - 200mw @ 150mA | 800mw @ 250mA (350mA drain total)

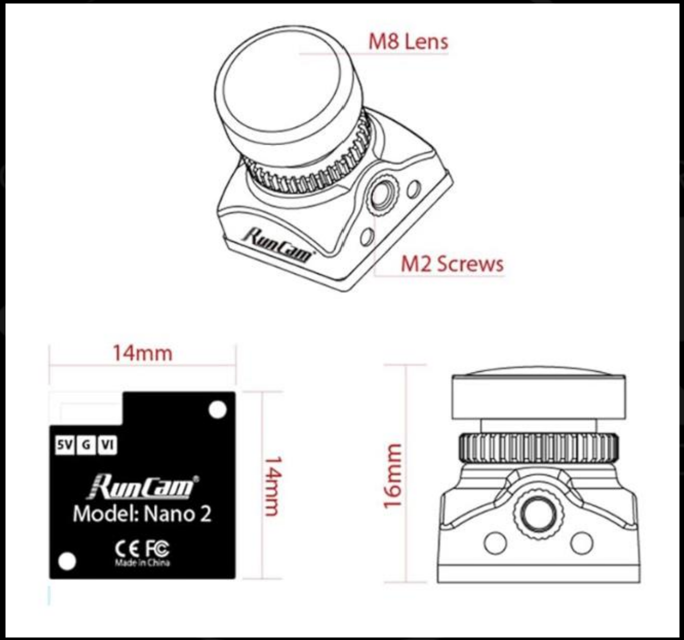
- Camera is to be powered through the VTX through 5V out pad.
- Video System DOES NOT interface with processing system

Rover Video System: Visual Representation



Demonstration of power supplied directly from PDB
to VTX then CAM
(No interfacing with processing system)

Visual Representation of Video System



Rover Video System: Receiving

- Video Receiver: ReadyMadeRC 900MHz – 1.3GHz VRX
  - Antenna: TrueRC Line Air 1.3GHz Directional Antenna
- Screen: Fat Shark Scout Goggles (AV Cable configuration)
- Battery: RDQ 11.1V 3s 2200mAh (~7 hours mission lifetime at 300mA drain)
- Notes:
  - The receiver and battery (powering only the receiver) will be attached via Velcro. From the receiver an AV cable will transfer video from the receiver to the goggles. This is done to avoid issues of regulating a 5.8GHz receiver to 1.3GHz. This is a direct manual conversion without using a repeater (local interference).

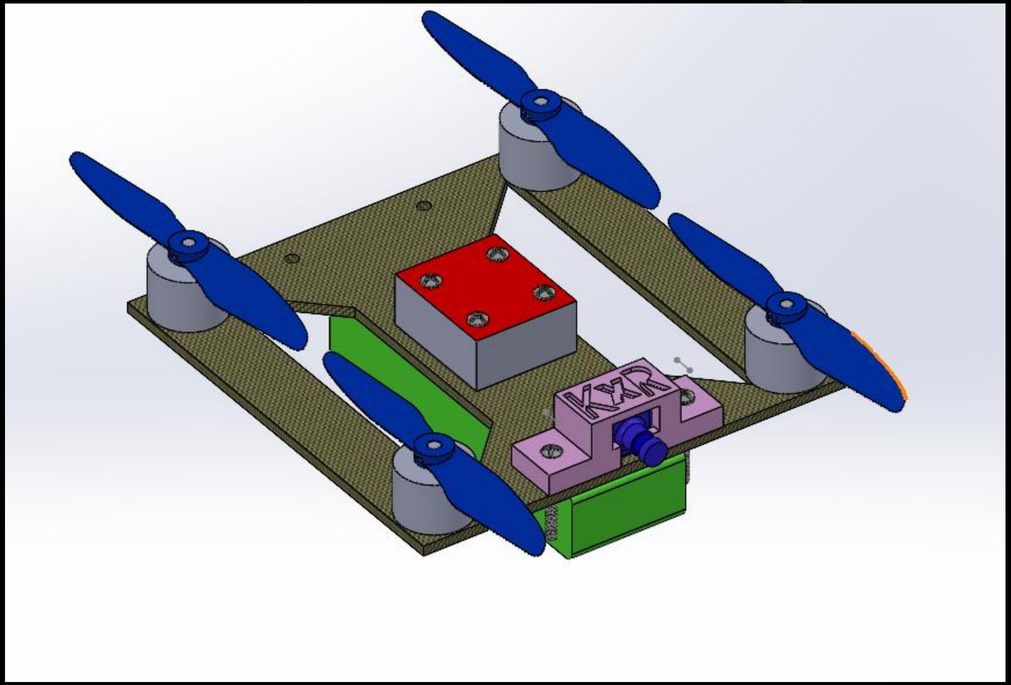
Rover Electrical FMECA

Part	Failure	Criticality	Effect	Mitigation
ESP	Electrical disconnect	High	Disconnect of any Electronic Component, Possible Mission Failure	Testing, Demonstration, Wrap wire around screw
ALL PARTS	Assembly Damage	Medium	Malfunctioning / Damaged System	Mechanical Testing, Demonstration
VTX	Overheating	Low	Reduced Efficiency of Transmission	Testing, Demonstration
Receiver	Out of transmission range	High	Mission Failure / Failure to Contact Payload	Analysis through Calculation, Testing, Demonstration
Battery	Overheating / Overcharging	High	Possible Combustion / Explosion / Off Gassing	Testing, Demonstration
PDB	Short Circuit	High	Complete Rover Shutdown	Analysis through Calculation, Testing, Demonstration

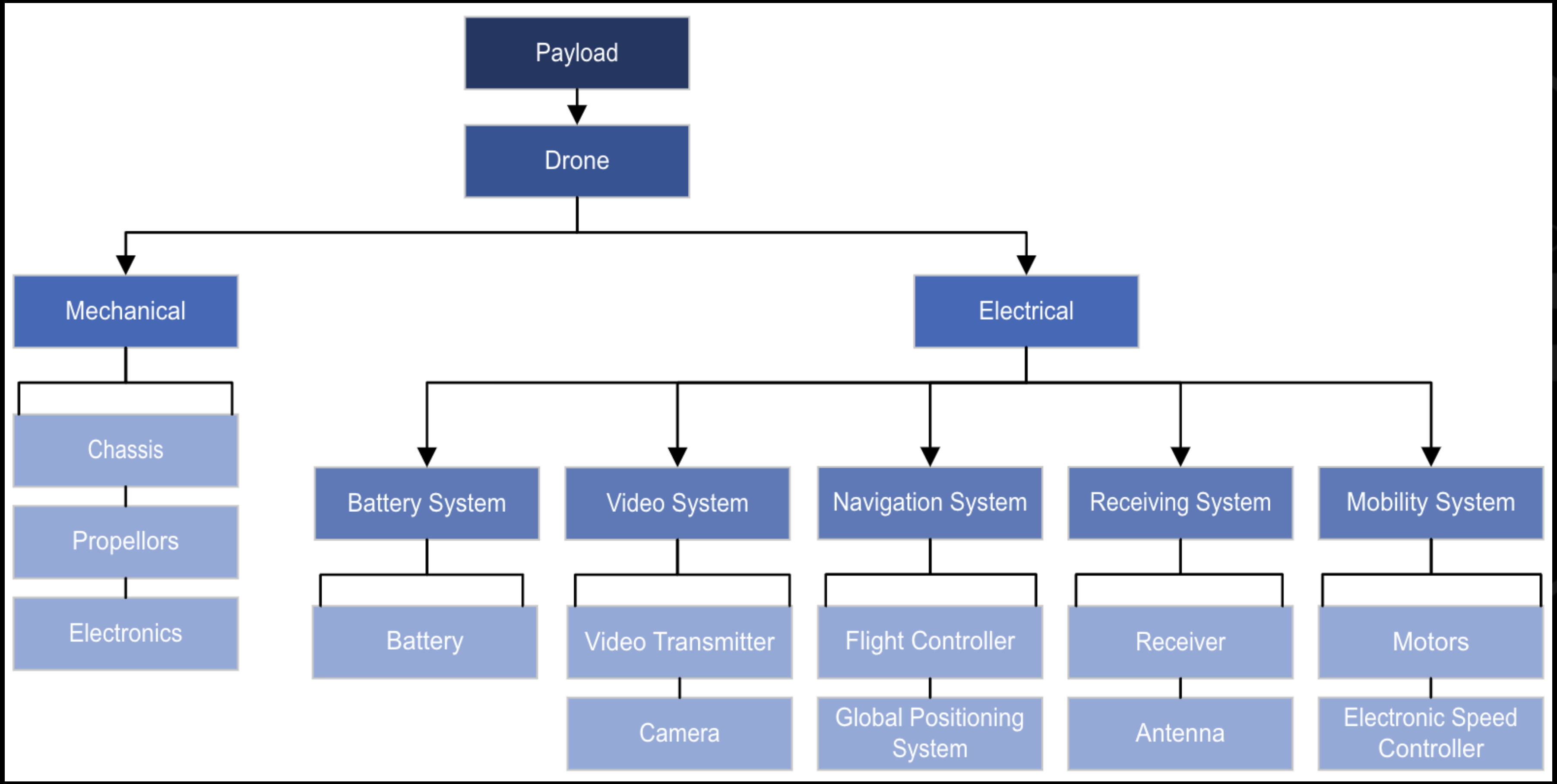
Drone Subsystem

TPMs

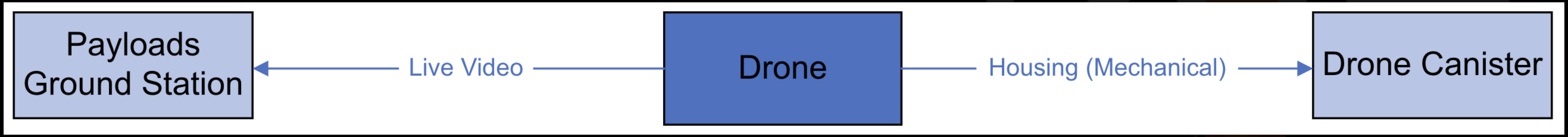
Measures	TPM Value	Units	Verification Method
Dimensions	8” x 5” x 1.6”	in	Inspection
Weight	1	lbs	Inspection
Operating Time	0.32-0.33	hr	Analysis, Testing, Demonstration
Passive Power Draw	4300-5125	mA	Analysis, Testing, Demonstration



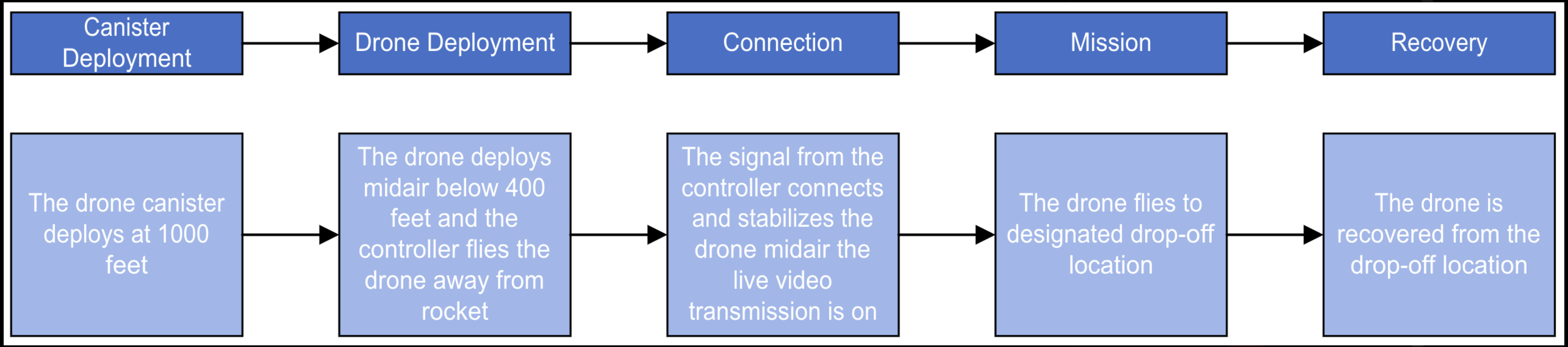
Drone Component Breakdown (Architecture)



Drone Interface Diagram



Drone CONOPS

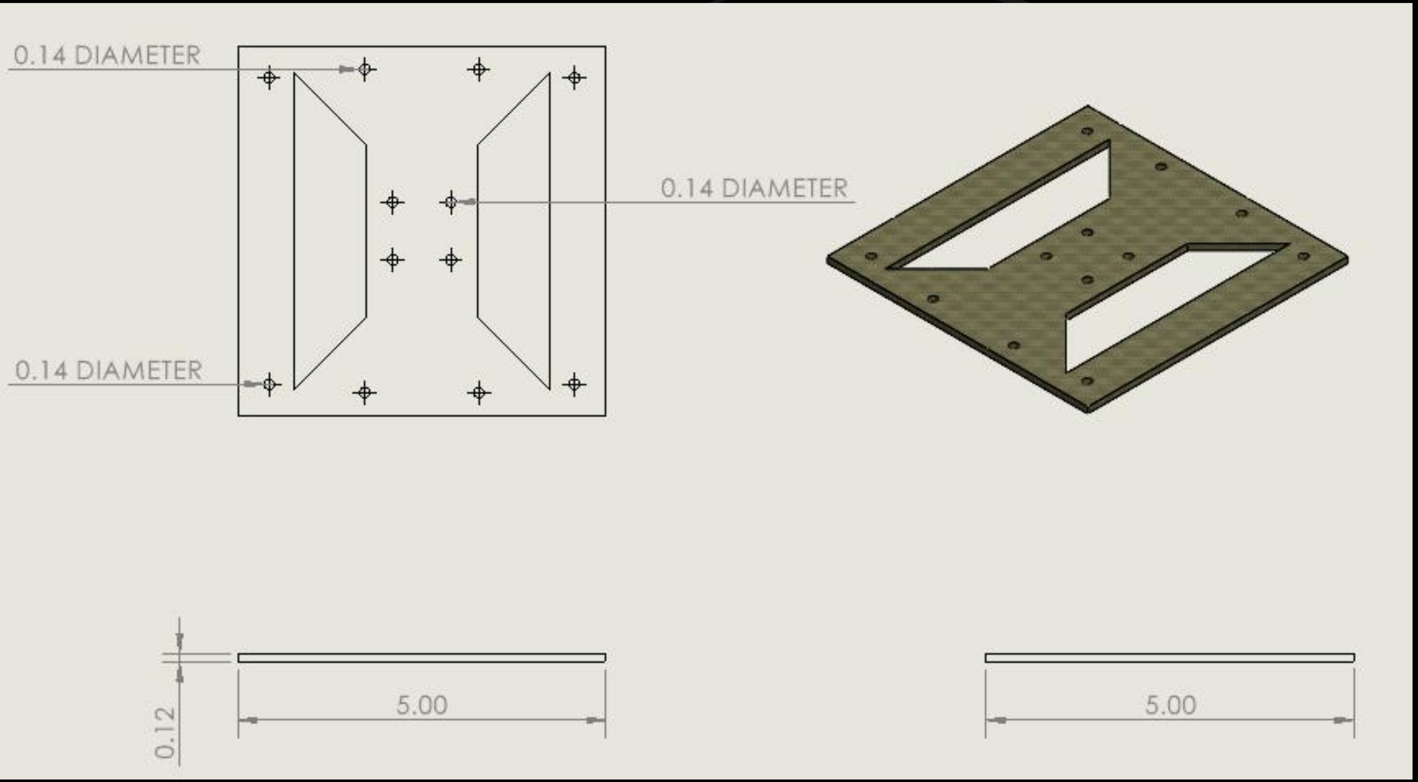


Mechanical Components

- Propellors
  - HQ Prop ETHIX P3B 5.1x3x2 Bi-Blade 5" Prop 4 Pack - Peanut Butter & Jelly
  - COTS for simplicity

Mechanical Components

- Chassis
  - Manufactured out of CNCed 0.12in Carbon Fiber Sheets (3mm)
  - Frame is 5" by 5"
  - Holes added for extra airflow to electronics
  - All Screw holes are for M3 screws for electronic components

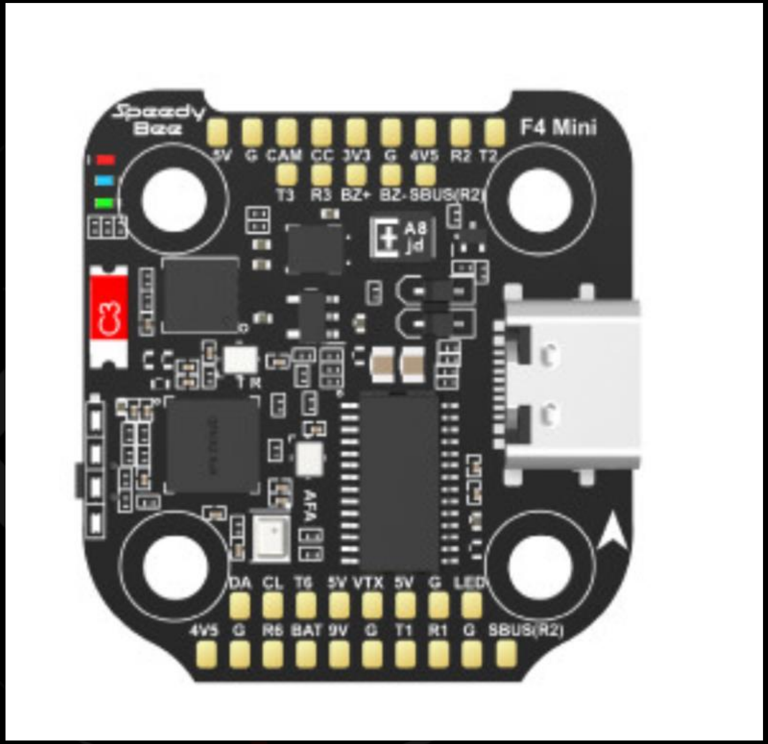


Drone Mechanical FMECA

Part	Failure	Criticality	Effect	Mitigation
Propellors	Mechanical Failure	High	Unstable Flight / Mission Failure	Testing, Demonstration
Chassis	Mechanical Failure	High	Chassis Failure / Mission Failure	Testing, Demonstration

Drone Electrical System

- Centralized through SpeedyBee F405 Mini FC/ESC combo
  - There are no subsystems respective to the drone electrical system due to the bottleneck design.
  - BETAflight to be used to generate LUA scripts for power-saving functionality
  - Expected mission lifetime: ~.45 hours full throttle. (27.1 minutes)
    - ~3.7 hours idle time.



Drone Electrical System: Motors

- Motors: Diatone Momba Toka 1404 3000Kv Brushed Motors
  - 1.1 A power draw per each at full power (4.4A drain total)
    - Change from PDR:
      - Turn rate (Kv) was lowered to increase torque, allowing for the drone to use larger props and become more efficient than the previous design.

Drone Electrical System: Navigation

- GPS Failsafe:
  - During rocket setup, GPS coordinates will be saved and locked by Flight Controller (arming process). In case of disconnect from radio controller and drone. Return to Sender (RTS) protocol will be enabled.
- Controller (TX12) GPS failsafe:
  - If radio inputs are cutting in and out (connection issue), controller GPS will be sent to drone and RTS will be enabled until user disables (any controller input)

Drone Electrical System: Video

- VTX: ImmersionRC Ghost Hybrid VTX
  - Frequency: 5.8GHz (Up to 10km range)
  - Power Drain and Output Power (outside of pit mode): 600MW at 200mA drain
- Camera: Runcam Phoenix Nano 2
- Notes:
  - BetaFlight Script will be used to enable VTX upon descent, saving battery power. If the script is faulty, Channel 10 of the TX12 radio will be used to manually switch the VTX out of pit mode into max operating power.

Drone Electrical System: Receiving Video

- Receiver + Goggle Combination: Fat Shark Scout 5.8GHz VRX
  - Antenna: Lumenier AXII Directional Patch 5.8GHZ RHP
- Notes: This is identical to a traditional FPV drone setup. The VTX/VRX combination was suggested and tested by FPV Knights, allowing up to 10km video transmission range from ground.

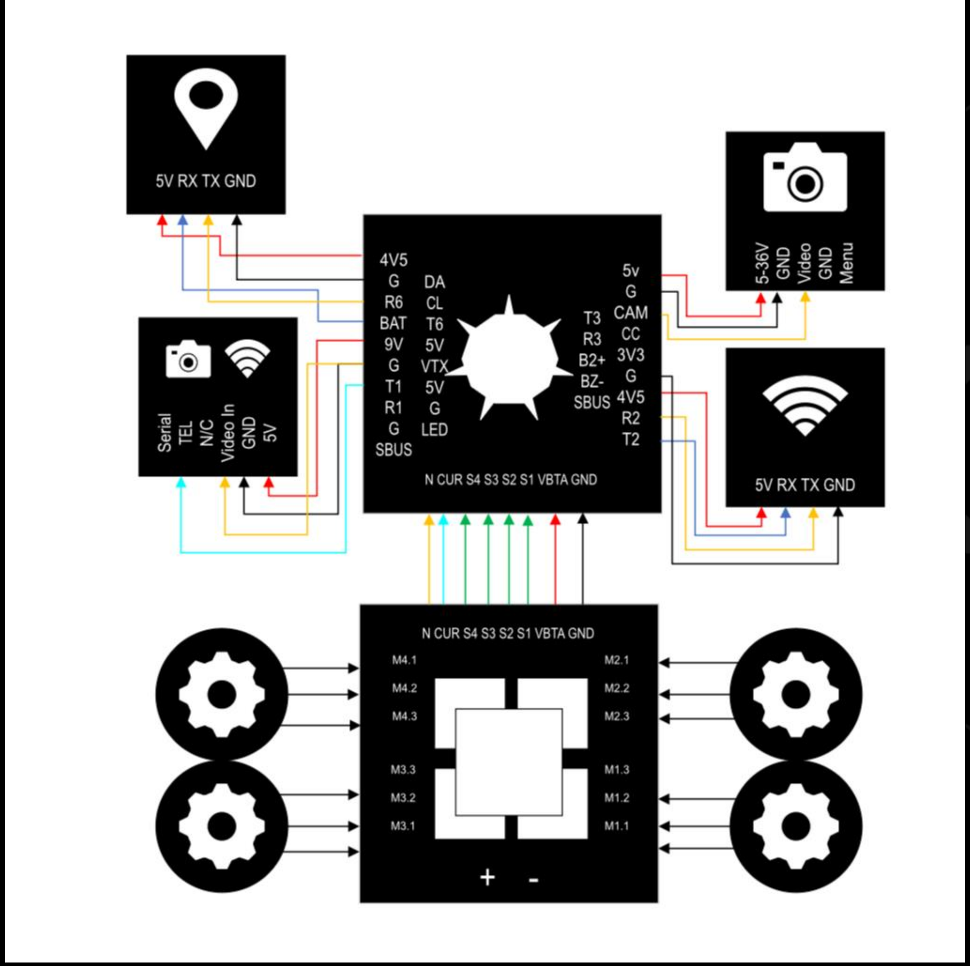
Drone Electrical System: Prelaunch

- Drone Armed:
  - Before rocket launch, drone is armed.
    - Coordinates of drone are locked. (gps failsafe)
    - VTX is put into pit mode. (battery consumption)
    - ELRS receiver is put to sleep. (battery consumption)
- VTX Configured to PIT mode:
  - Besides the motors, the VTX is expected to drain the most power from battery. Putting the VTX into PIT mode will reduce it to a 25mA power drain.

Drone Electrical System: Mission Active

- VTX Power Change:
  - Betaflight script will be using the Flight Controller altimeter to carry out specific actions upon descent.
    - 800ft: ELRS Receiver is powered on
    - 700ft: VTX is switched to max power. (600mW)
- Altitude Lock:
  - To avoid the drone crashing if no signal from radio, upon descent (after released from canister), the drone will hover at 200ft using the onboard altimeter. (this will be disabled if radio control is linked)

Drone Electrical System: Visual Representation

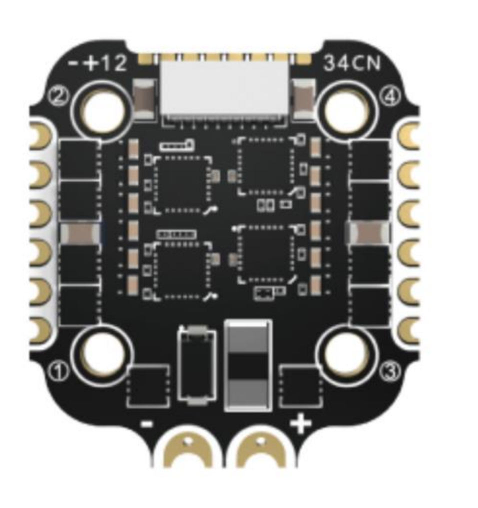


Drone Electrical System: Controller

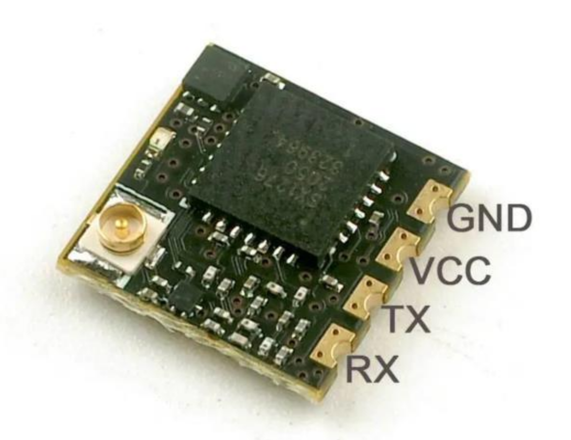
- Controller: Radiomaster TX12 (Mode 1)
- Transmitter: Happymodel Micro 900RX ELRS
  - This is the exact same setup as rover.
    - Each controller must be flashed to respective receiver to avoid mis-match (will be done during assembly phase).
  - Radiomaster TX12 can be programmed using Betaflight, and luascripts will be written and passed through Betaflight (Channel 10 for VTX manual control).

Drone Electrical System Visual Representation

- F405 Electronic Speed Controller



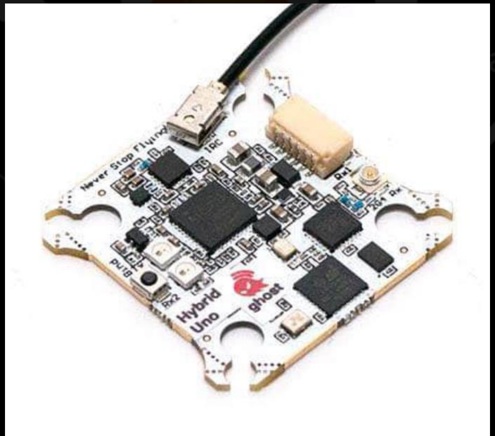
- Happymodel ES900RX



Drone Electrical System: Visual Representation

- GOKU Mini GPS:

- ImmersionRC Ghost Hybrid VTX:



Drone Electrical System: Battery

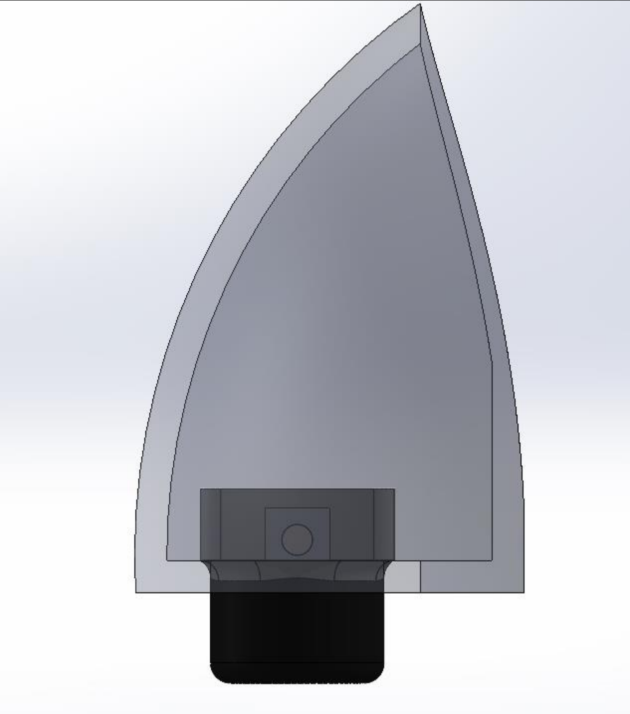
- RDQ Series 2200mAh 3s 11.1V LiPo
  - 20 minutes mission lifetime with full activation of Motors.
  - All power and ground supplied via FC/ESC.
  - Charge Rate: 80C
  - Equipped with a XT60 power connector.

Drone Electrical FMECA

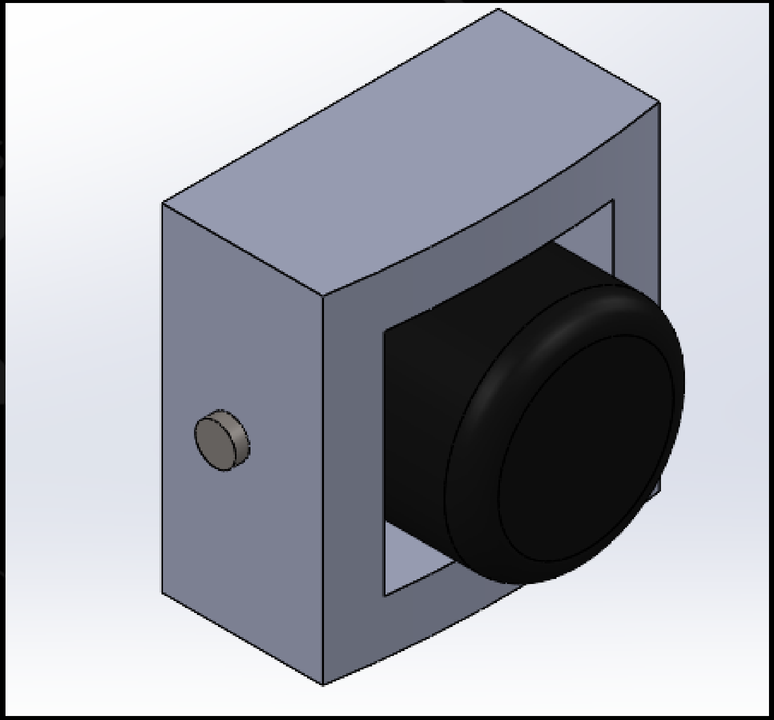
Part	Failure	Criticality	Effect	Mitigation
FC/ESC	Wire Disconnect / incorrect Installation	High	Possible Damage / Component Failure	Careful Assembly, Testing
ALL PARTS	Assembly Damage	Medium	Malfunctioning /Damaged System	Mechanical Testing, Demonstration
VTX	Overheating	Low	Reduced Efficiency of Transmission	Testing, Demonstration
Battery	Overheating / Overcharging	High	Possible Combustion/ Explosion / Off Gassing	Testing, Demonstration

Remote Sensing Subsystem

Measures	TPM Value	Units	Verification Method
Fin Dimensions	3” x 1.5” x 2.3”	in	Inspection
Horizon Dimensions	0.98” x 0.51” x ”0.98	in	Inspection
Total Weight	1	lb	Inspection
Operating Time	3	hr	Analysis, Testing, Demonstration
Video Storage	16	hr	Analysis, Testing, Demonstration

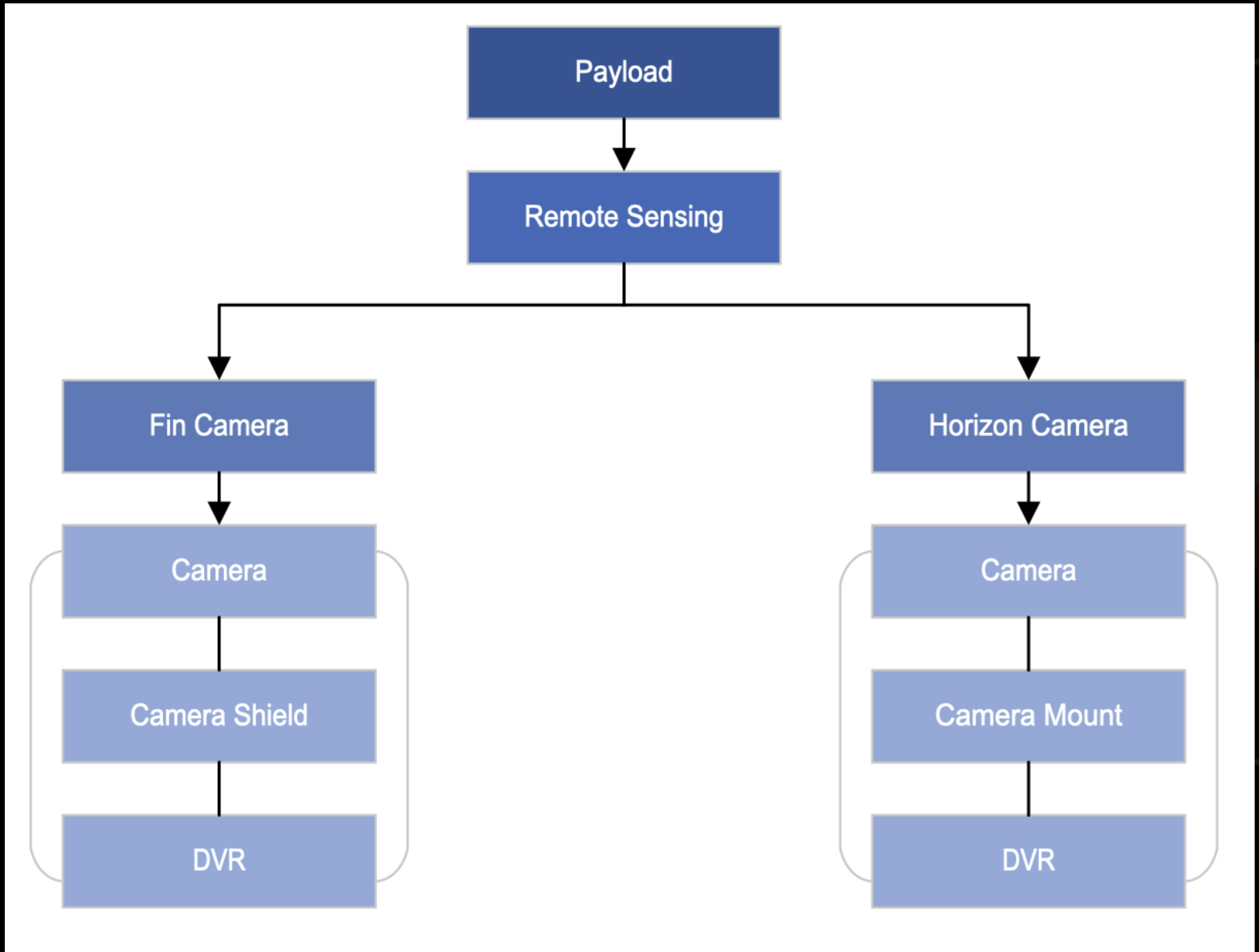


Fin Camera

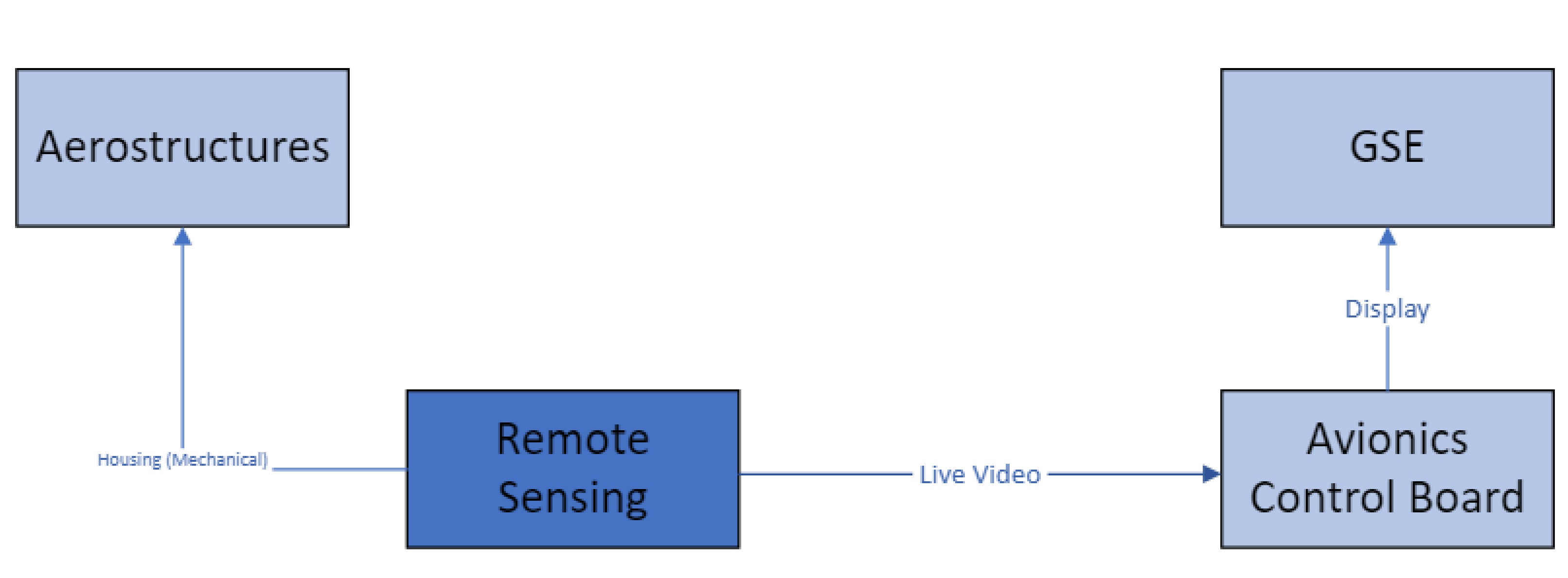


Horizon Camera

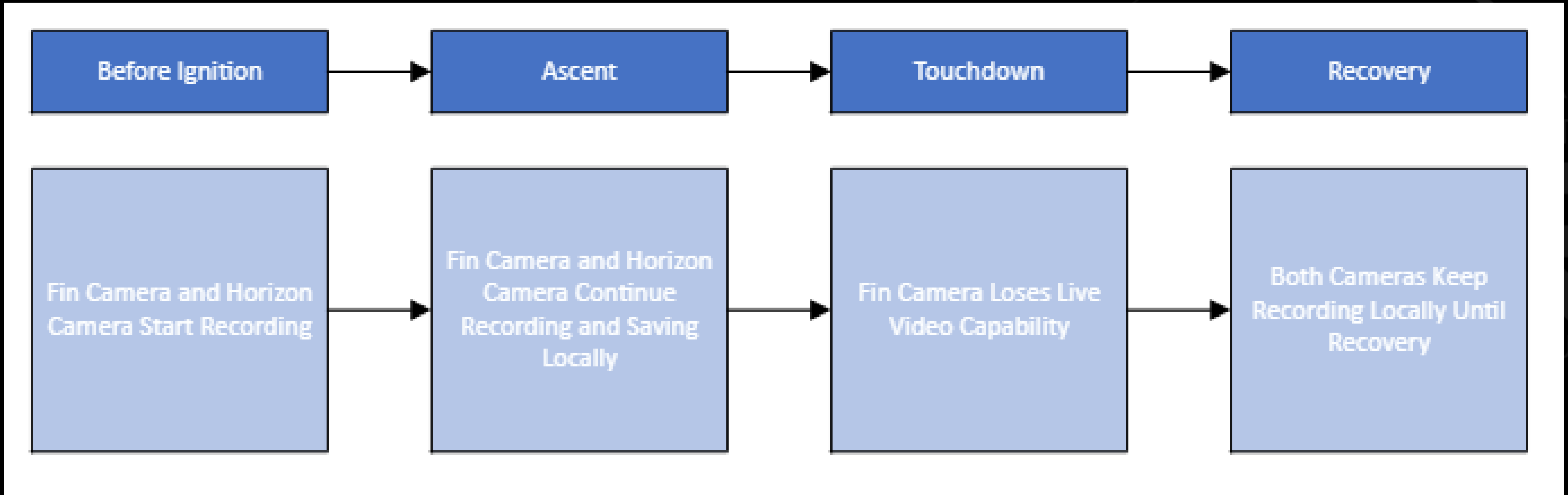
Remote Sensing (Architecture)



Remote Sensing Interface Diagram

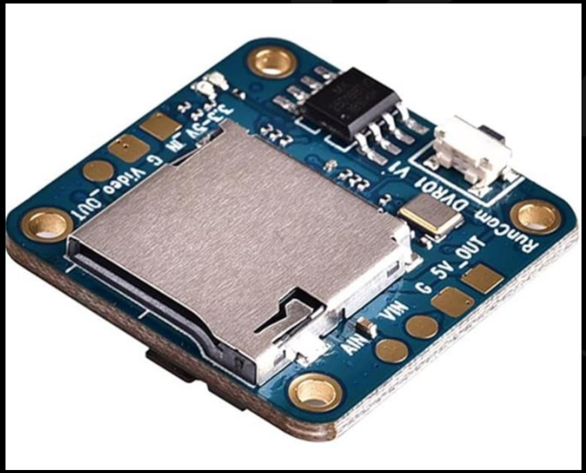


Remote Sensing CONOPS



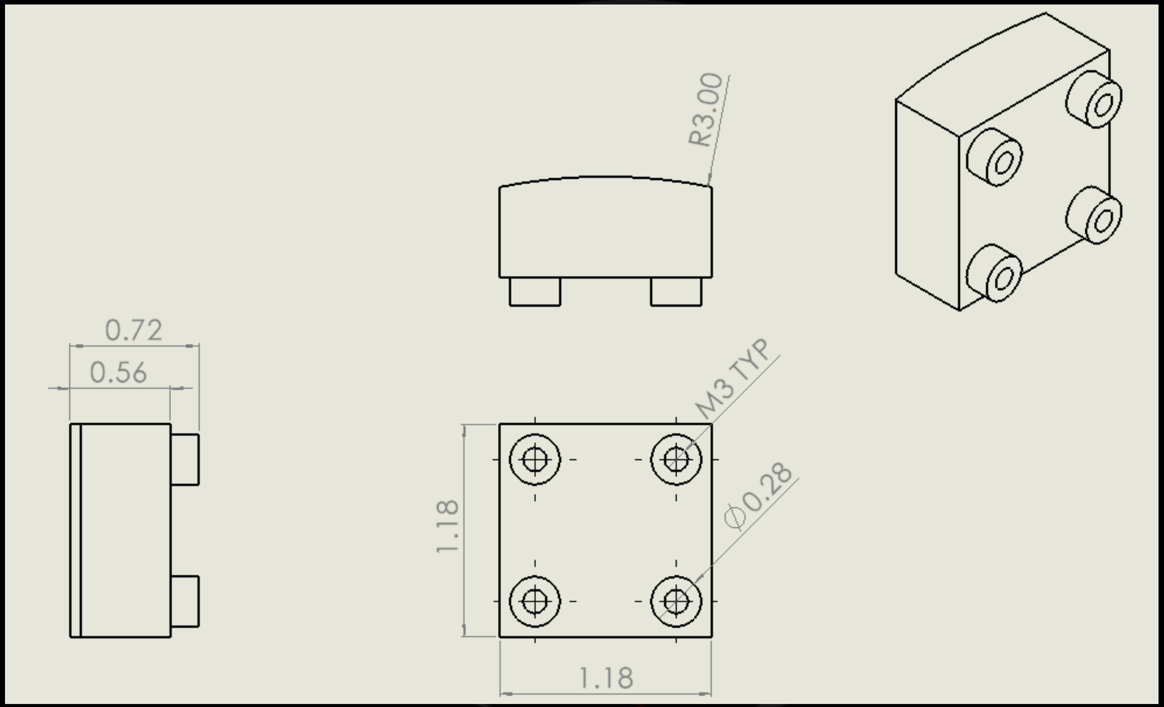
Remote Sensing Components

- Camera
  - Phoenix 2 Run Cam
  - 1000 TVL ~ 720p Camera
  - 2.0 Aperture ~ Less Blur and Noise
- DVR
  - Using 32Gb Sd Card
  - 2Gb ~ 1hr of Video
  - Local Saves Video Every 5 Minutes



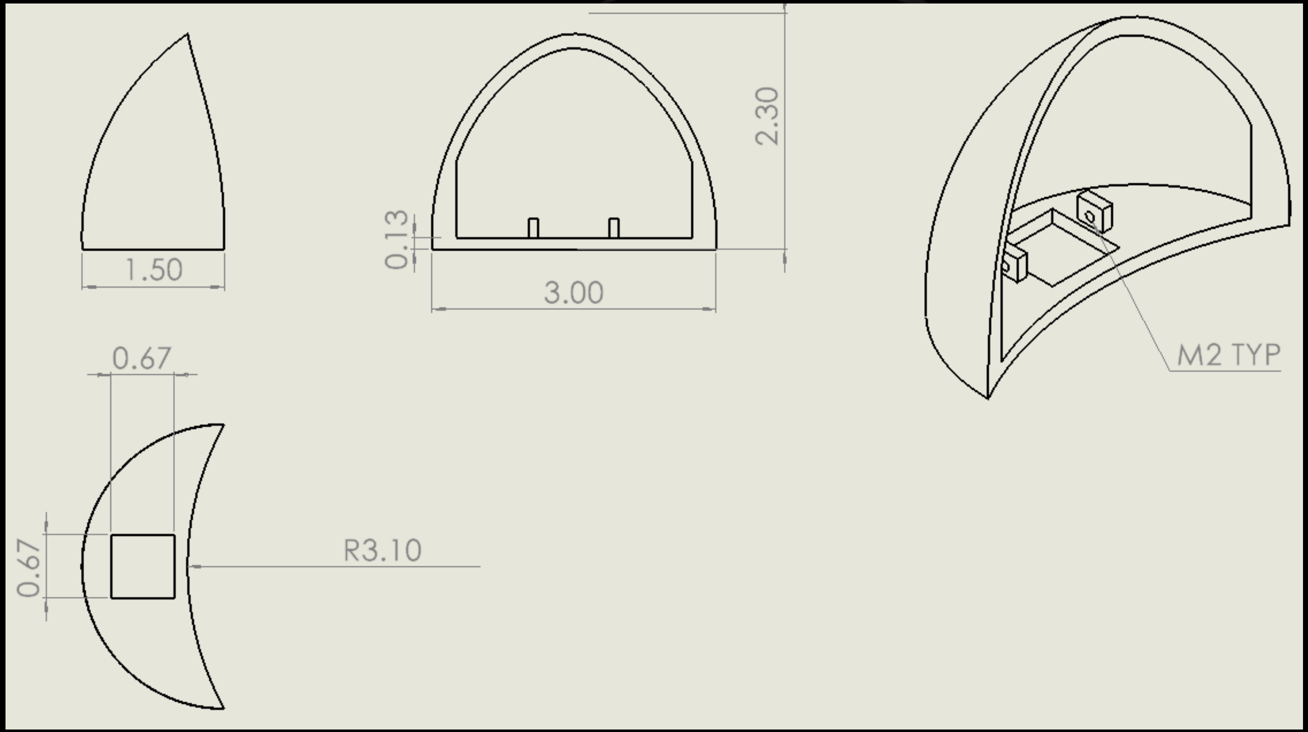
DVR Mount

- DVR Mount
  - Epoxied on the inside of the airframe
  - Allows for DVR to be mounted and increase stability of the system
  - Allows for heat set threaded inserts for mounting



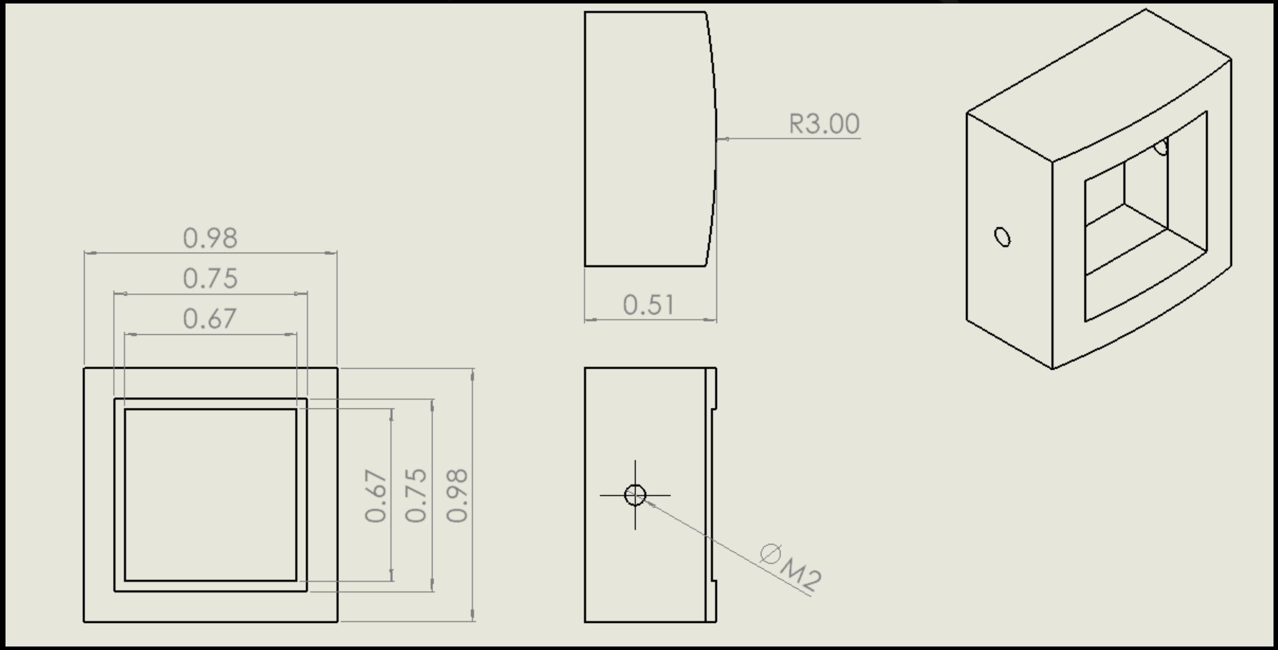
Remote Sensing Components

- Fin Camera Shield
  - Made of Polycarbonate Filament
  - Curved to be epoxied outside of the airframe
  - Built-in Camera Mount
  - Small hole in airframe needed for wires



Remote Sensing Components

- Horizon Camera Mount
  - Made of Polycarbonate Filament
  - Curved to fit to be epoxied to the inside of the airframe
  - Only a 12mm hole needed in airframe for lens



Remote Sensing FMECA

Part	Failure	Criticality	Effect	Mitigation
Camera	Electrical Disconnect	Medium	Loss of Video; Possible Mission Failure	Wrap Wire around screw, Testing, Demonstration
DVR	Electrical Disconnect	Medium	Loss of Video; Possible Mission Failure	Wrap Wire around screw, Testing, Demonstration
Camera Mount	Mechanical Failure	Low	Video Stabilization is Decreased; Possible Loss of Video	Testing, Demonstration

Questions?

Thank You for Listening!

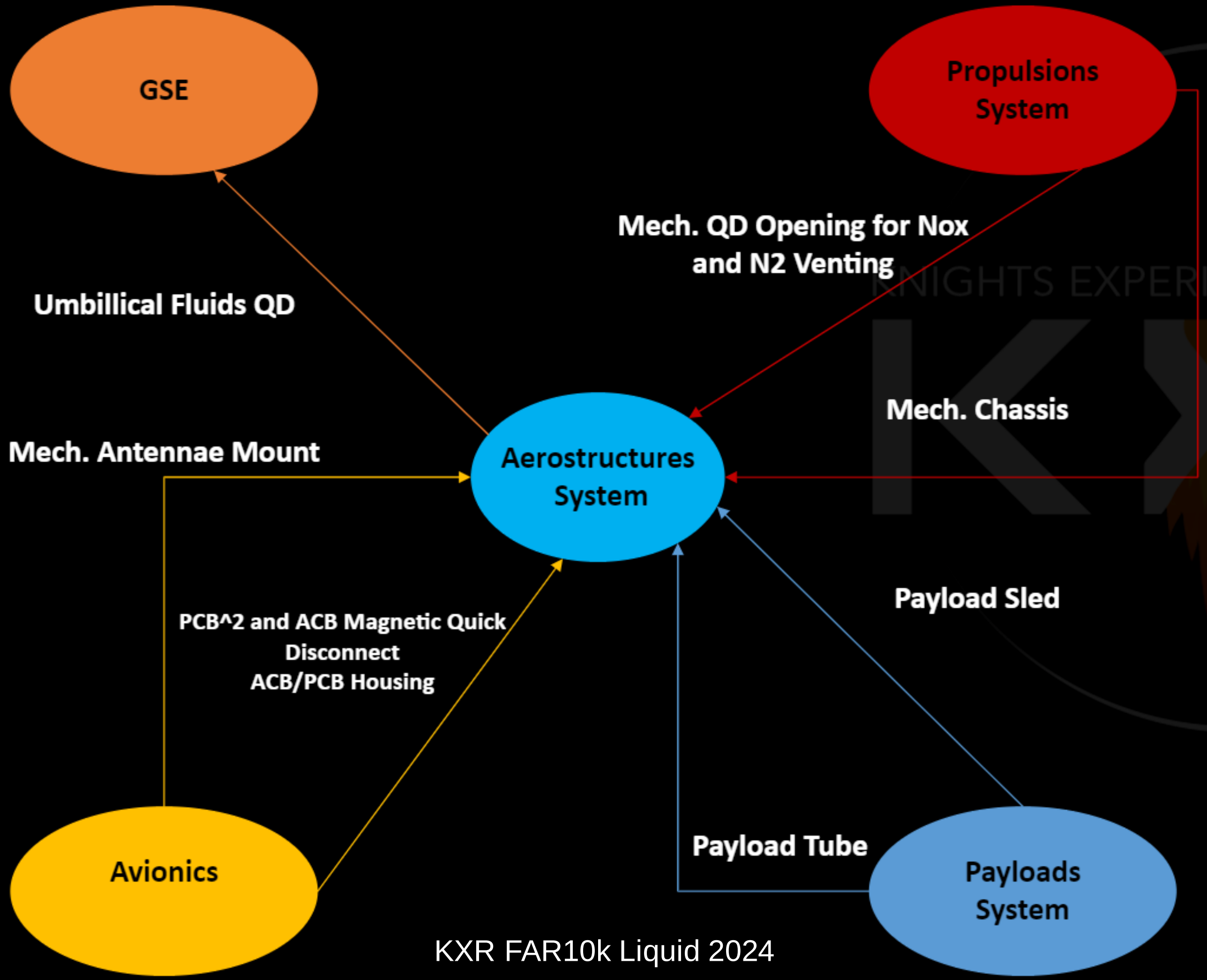
KNIGHTS EXPERIMENTAL ROCKETRY
KXR
at UCF

Aerostructures CDR
FAR10k Basilisk

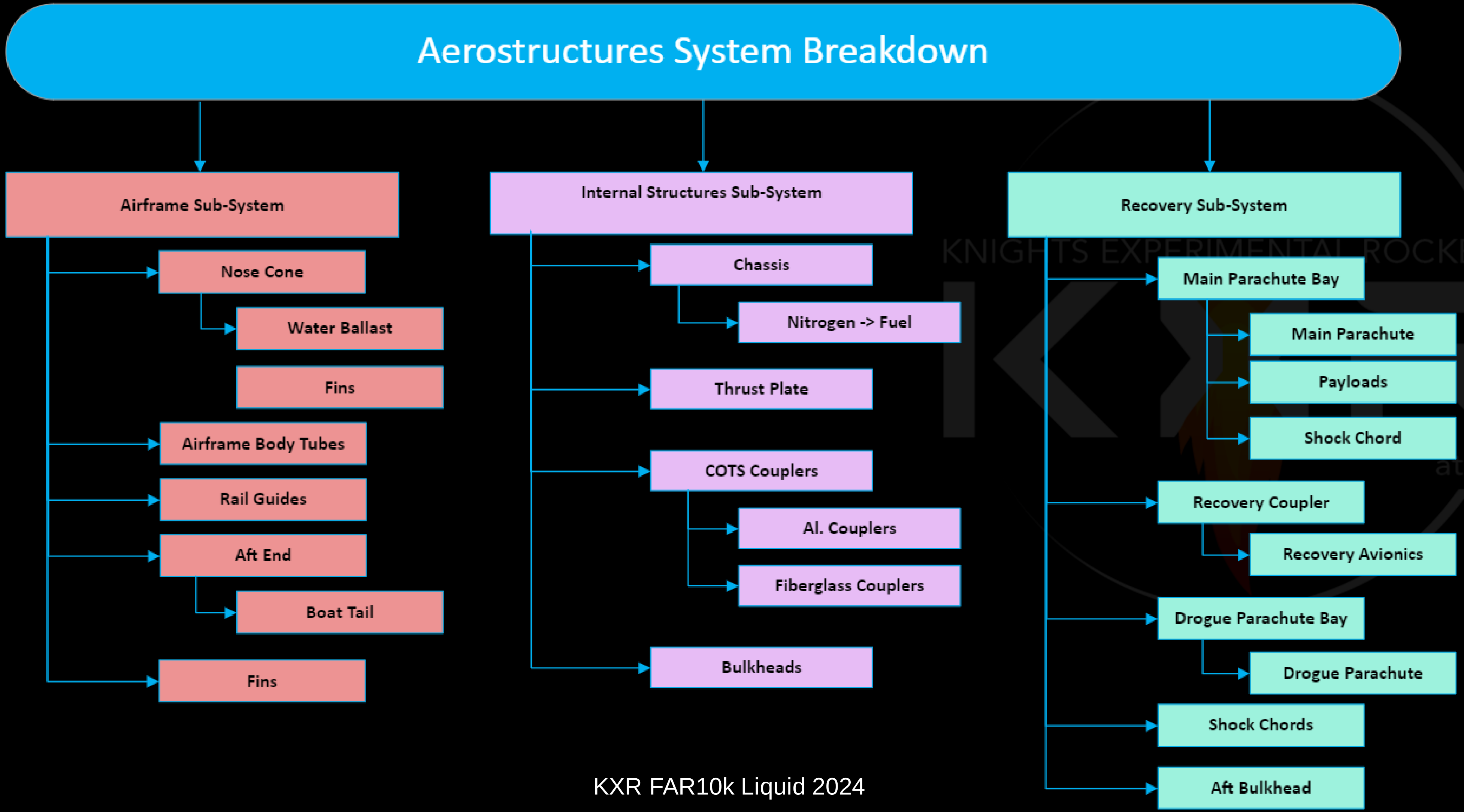
Aerostructures System

CAD and Open Rocket

Aerostructures Interface Diagram



Aerostructures Architecture



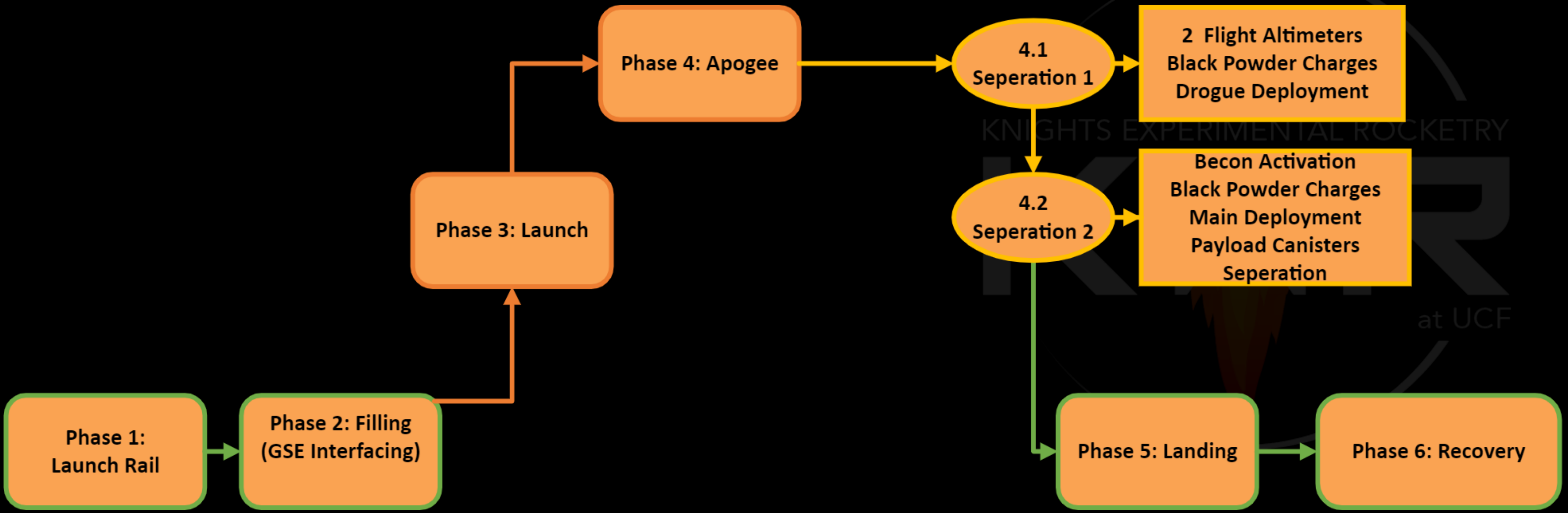
Aerostructures Function

- Package all vehicle systems into a:
  - Flyable
  - Light Weight
  - Aerodynamic Structure
- Main interface for all systems of the vehicle

Aerostructures System Verification Plans

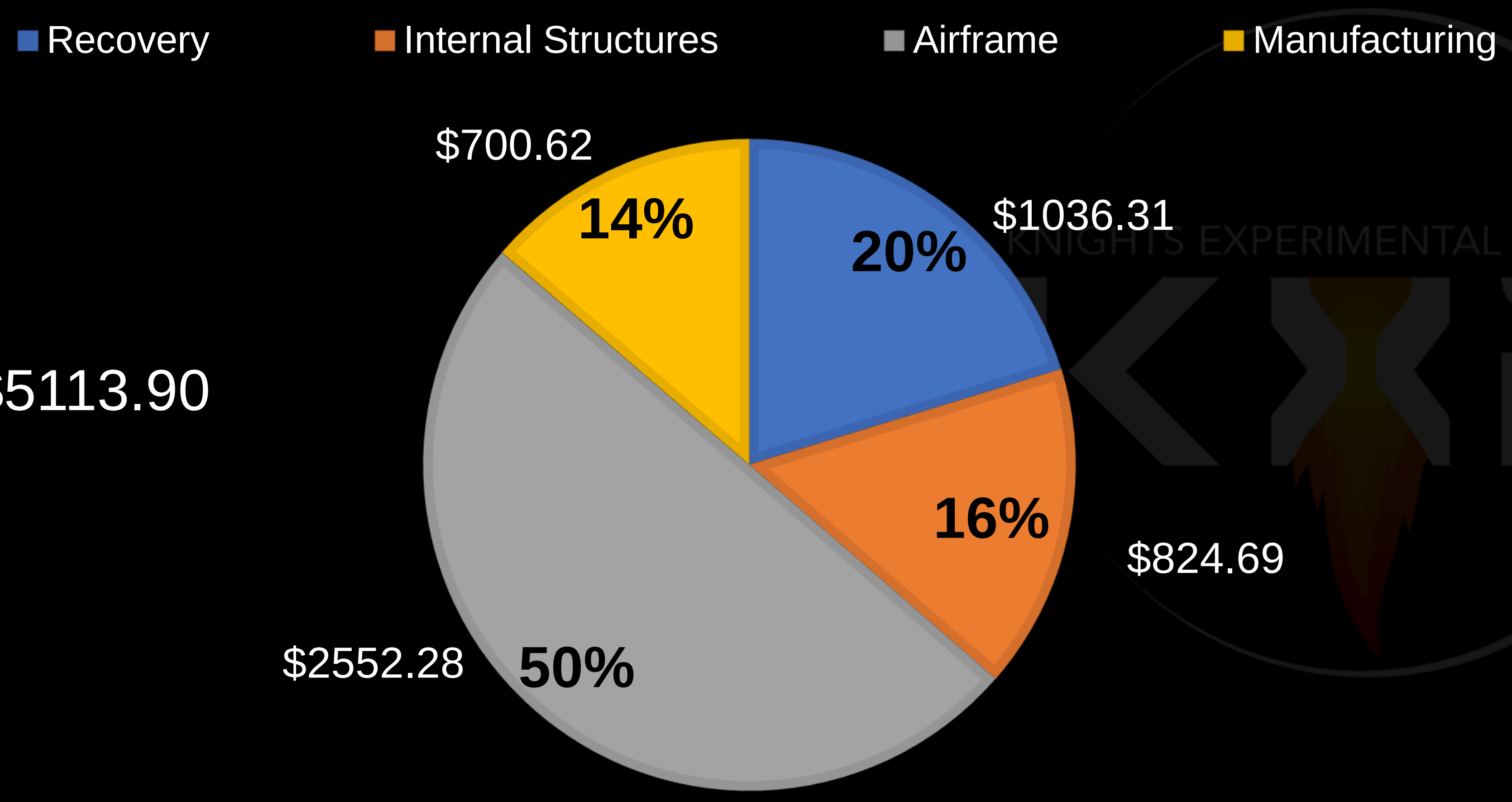
- Visual/Digital Inspection of System Interfaces
  - Accurate CAD Assembly
- FEA and ANSYS Component Load Analysis (Analysis)
- Test Article
  - Airframe and Fin Test Coupons Tested In UTM
- Dry Fitting Components (Demonstration)
- Confirmation of Dimensions and Mass (Inspection)
- Dual Deploy Recovery System Test (Test)
  - Black Powder and Shear Pin Tests

Aerostructures CONOPS



Aerostructures System Cost

Total: $5113.90



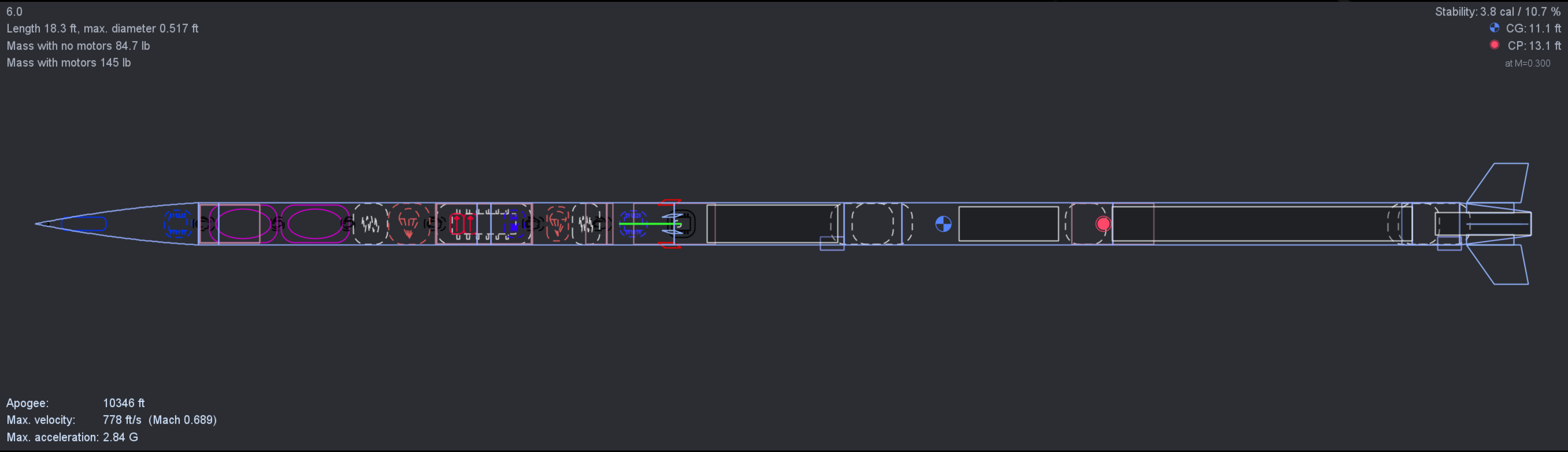
Aerostructures TPM's

Measure	TPM Value	Units	Verification Method
Snatch Force	1954	lbf	Demonstration
Max Bending Moment	7173	lb-in	Analysis
Max Compressive Load	21309	lbf	Analysis
Lateral Shear	122	lbf	Analysis
Drag Coefficient	0.75	n/a	Analysis

Aero TPMS Cont. (Dimensions)

Measure	TPM Value	Units	Verification Method
Total Length	18.3	Ft	Inspection
Inner Diameter	6	in	Inspection
Total Wet Mass	145	lbf	Inspection
Dry Mass	66	lbf	Inspection
Stability	12% (3.8)	CAL	Simulation

Aerostructures TPM's

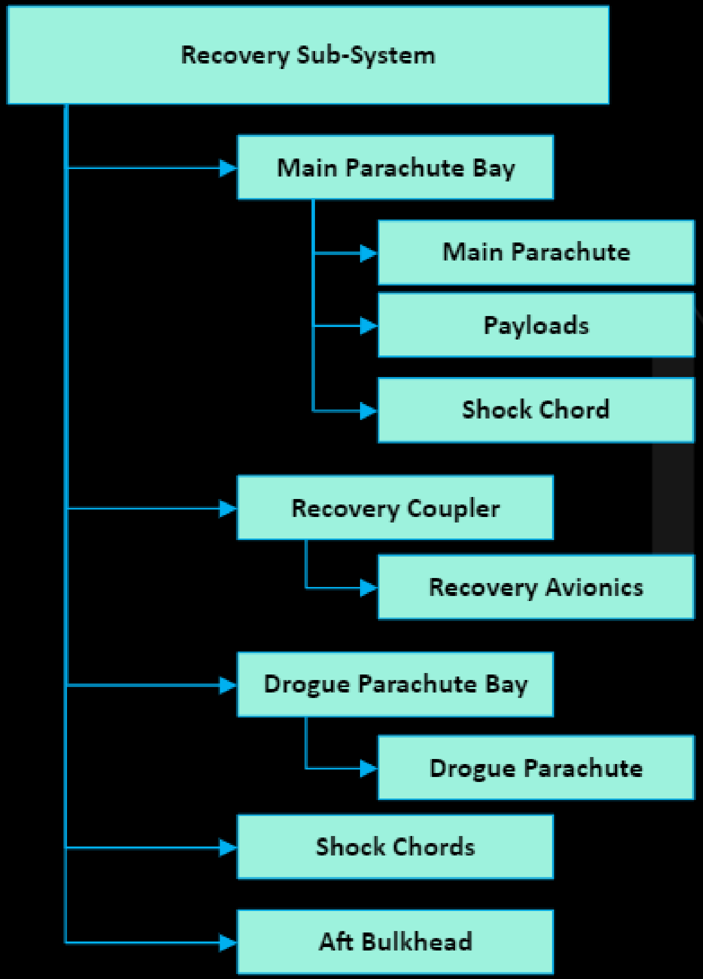


KXR UCF

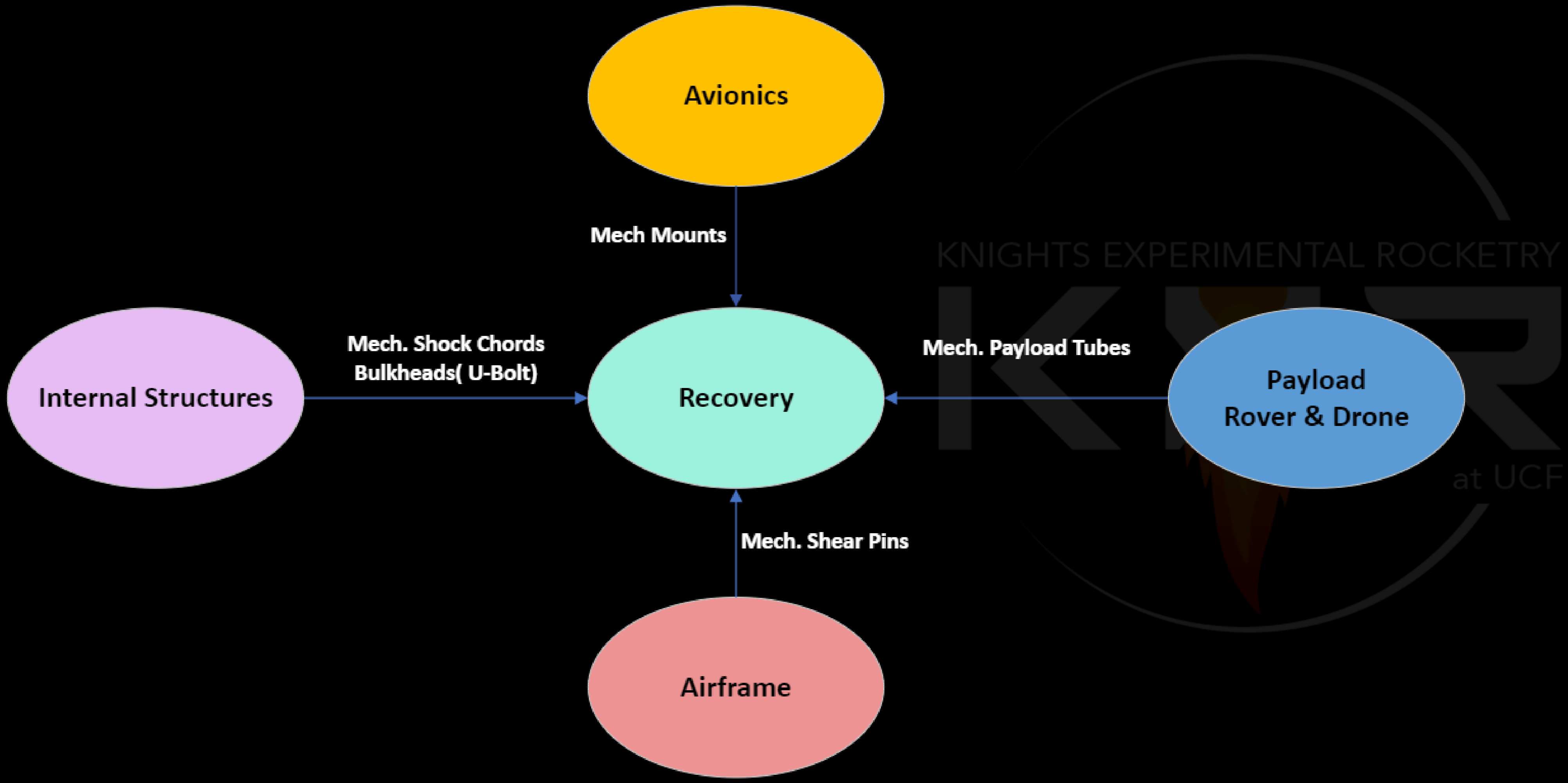
Aerostructures System FMECA

Sub-System	Failure	Criticality	Effect	Mitigation
Recovery	Failure to Recover	Medium	Failure to Deploy Parachutes and Payload	Testing Campaign and Designed Redundancy
Internal / External	Structural Failure During Flight	High	Rapid Unscheduled Disassembly	FEA and Hand Calculations. Coupon Testing
Flight Dynamics	Instability During Flight	Medium	Rocket Becomes Instable During Flight	Design and Testing of Fin Coupons

Recovery Component Breakdown



Recovery Interface Diagram



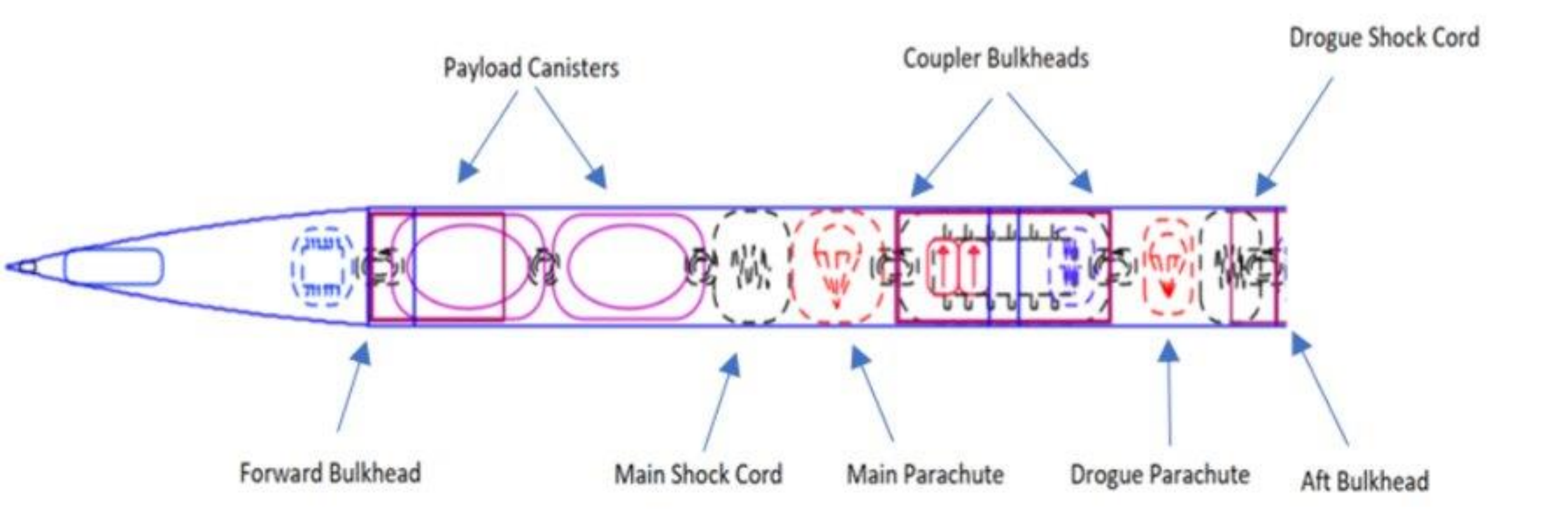
Recovery Functional Requirements

Requirement	Requirement Type	Verification Method
The Recovery System **shall** have redundancy	Functional	Demonstration
The Recovery System **shall** be visible during descent	Functional	Demonstration
The Recovery System **shall** have a dual-deploy system	Functional	Inspection
The Recovery System **will** create a safe controlled descent for the vehicle	Functional	Demonstration

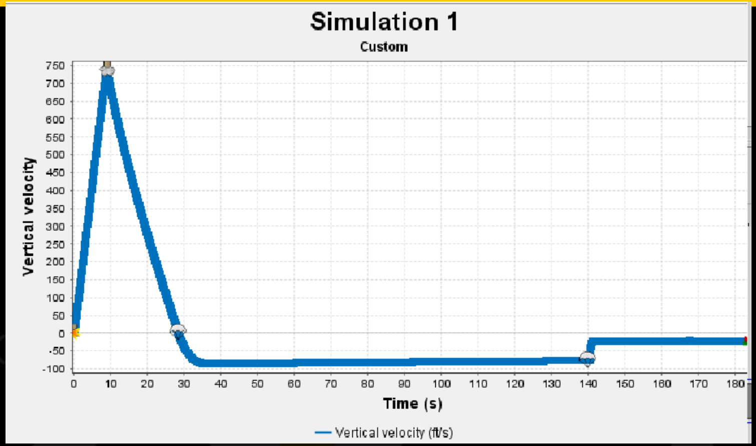
Recovery TPM's

Measure	TPM Value	Units	Verification Method
Snatch Force	1953.439059	Lbs.	Demonstration
Size of Recovery compartment	36” main+11” drogue	in	Inspection
Packing Length of Chutes	199.9	cu. in.	Inspection
Descent Rate	D: [75] M: [20]	Ft/s	Test
Shock Chord Length	1345	In	Inspection

Recovery Breakdown



Main Chute



- We are using a Skyangle Classic Cert 3 XXL as our main parachute
  - Uses 4 shroud lines
  - CD of 2.92, which gives us a final descent speed at 21.4 ftps
  - Deploys at 800ft
  - Total flight time of 220s (3 minutes 40 seconds)
  - Used OpenRocket to validate, using coordinates of the launch site, 100 degree ambient temperature and up-to-date vehicle characteristics
- We are attack the parachutes with fisherman knots and quick links
- We are using DB-XXL Main Deployment Bag as our fire blanket
- Deploy velocity at 76ftps

Drogue

We are also looking at reusing a parachute from another project as our main to save costs; final decision is pending on our final cost vs budget and discussions with the other projects.

- ❑ Descent speed of 75fps
- ❑ Coefficient of Drag 1.87
- ❑ Deploys at apogee
- ❑ Nominal deploy velocity at 0 ftps, horizontal velocity expected to be below 100 fpts, will depend on angle off the rail and wind

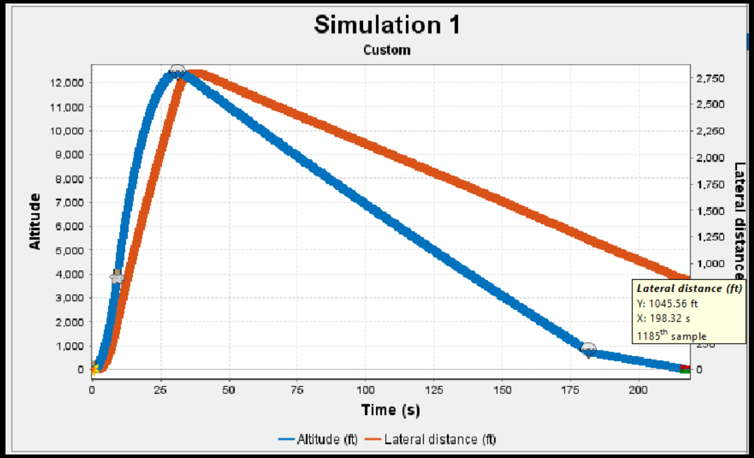
- ❑ Used OpenRocket to find a parachute in acceptable price range with a descent speed of 75ftps
- ❑ We attach the Drogue shroud lines to the quick link through Alpine Butterfly Loop
- ❑ We are using Medium SkyAngle Deployment Bag as our fire blanket.

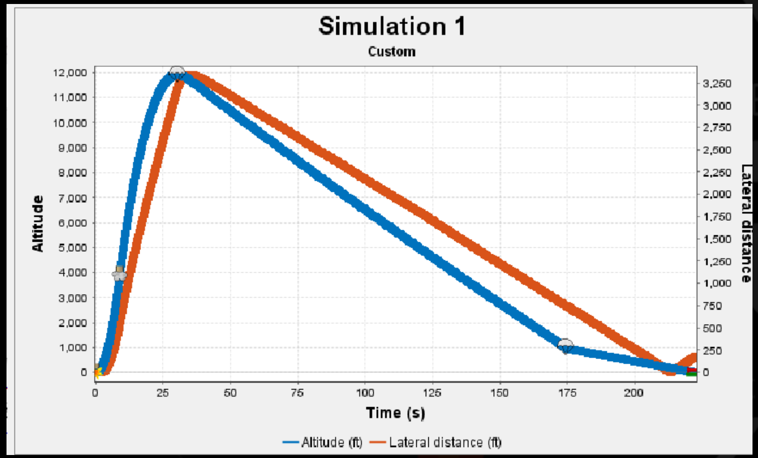
Parachute Drift Analysis

According to National Oceanic and Atmospheric Association, for **Mojave, CA:**

- Max Windspeed 13mph
- Average Windspeed 7mph

Both drift simulations take weathercocking into account with a 90* launch angle, the real radius will depend on launch angle of the rail and if the rocket remains straight off the rail



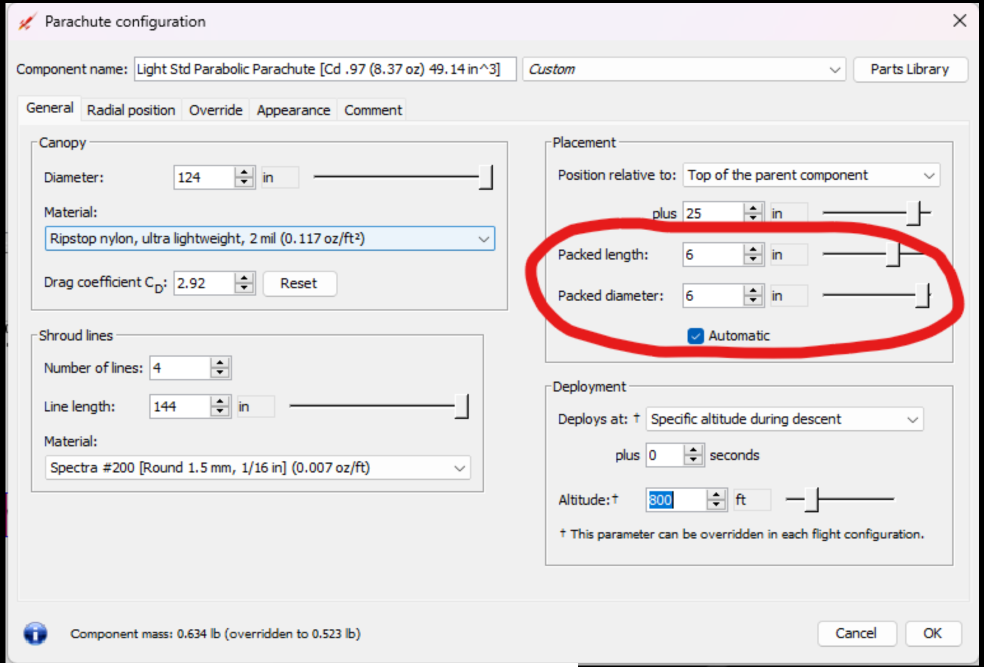


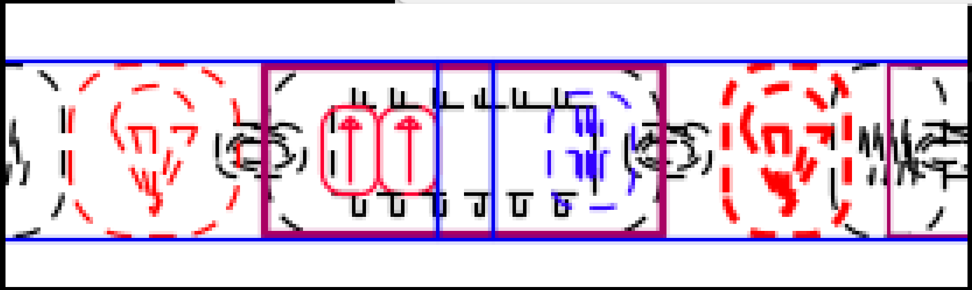
Average Windspeed:
Expected drift radius of under 1000 ft with wind conditions of 7.5mph

Peak Windspeed:
Expected drift radius of under 500 ft with wind conditions of 13mph

Parachute Packing lengths

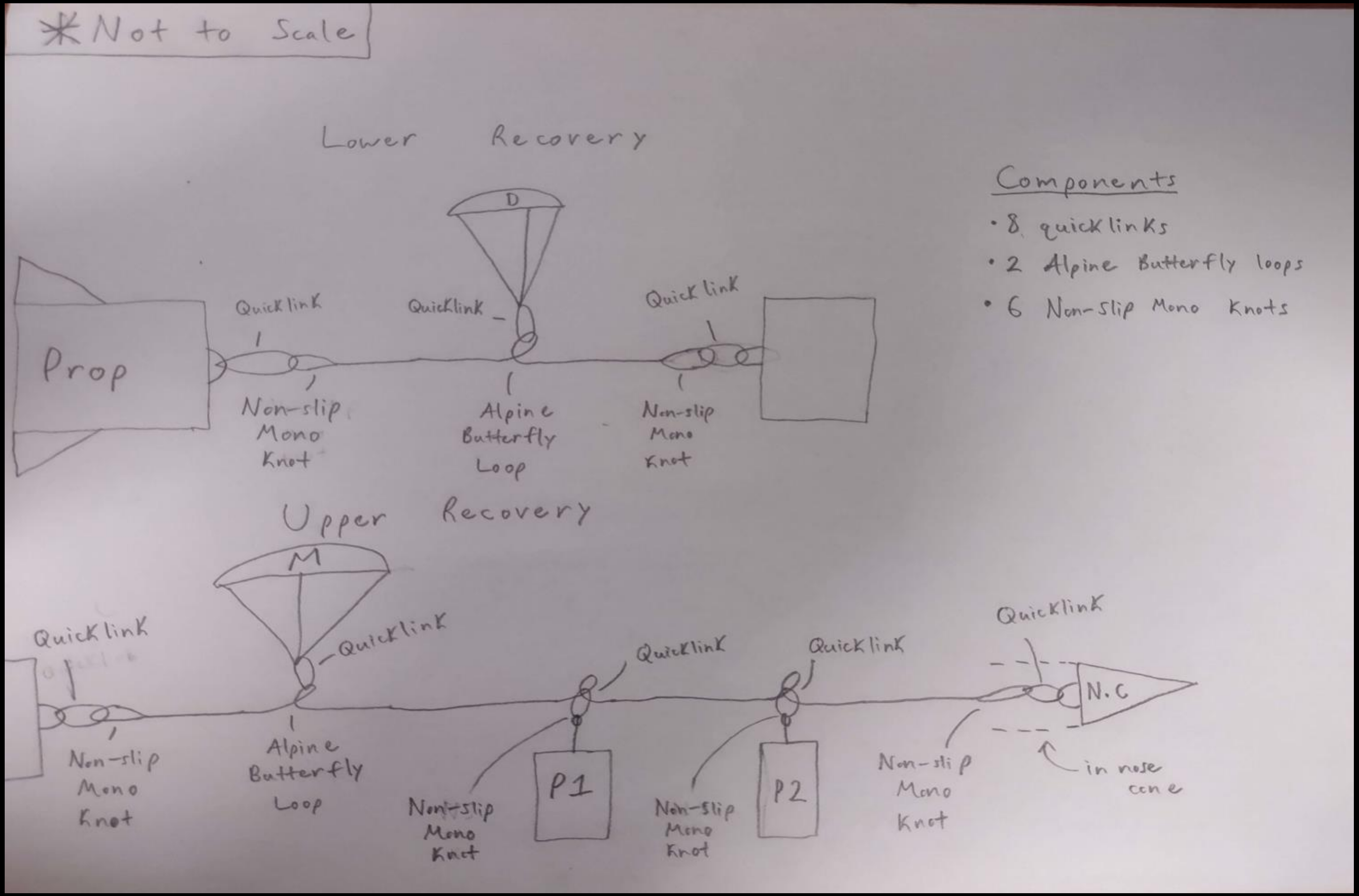
Drogue chute packing volume:
Under 3 inches in length in a 6" airframe





Main chute packing volume:
6 inches in length in a 6" airframe

Shock Cords



The recovery system will contain:

- 117 ft of ¼ " Kevlar shock cord
- 8 quick links
- 4 Alpine Butterfly Loops
- 4 Non-slip Mono Knots

Each knot will be epoxied for extra strength.

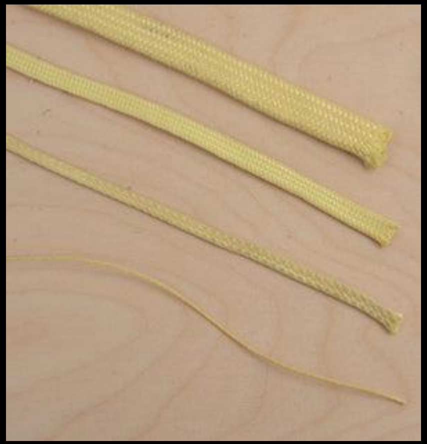
These components will provide the best chance of the system working as intended and not failing during execution.

Shock Cords

- We are using quick links and two types of fisherman knots to prevent tangling of the payloads.
- There will be rails developed by payloads inside to prevent tube knocking.
- We will have a beacon in the main compartment, but we are waiting on LTI for dimensions.

Material	Safety Factor
¼" Kevlar shock cord	1.5
½" Quick link	1.69

¼" Kevlar shock cord
Max Load 3000 lbs
Price: $143.52 (144 yards)



1/2 in. Zinc-Plated Quick Link
Max Load 3,300 lbs
Price: $50.16 (8)

Non-Slip Mono Knot

Alpine Butterfly Loop

- Order of hitting the ground: The bottom of the rocket (prop), coupler, nose cone, payloads

Shock Cords

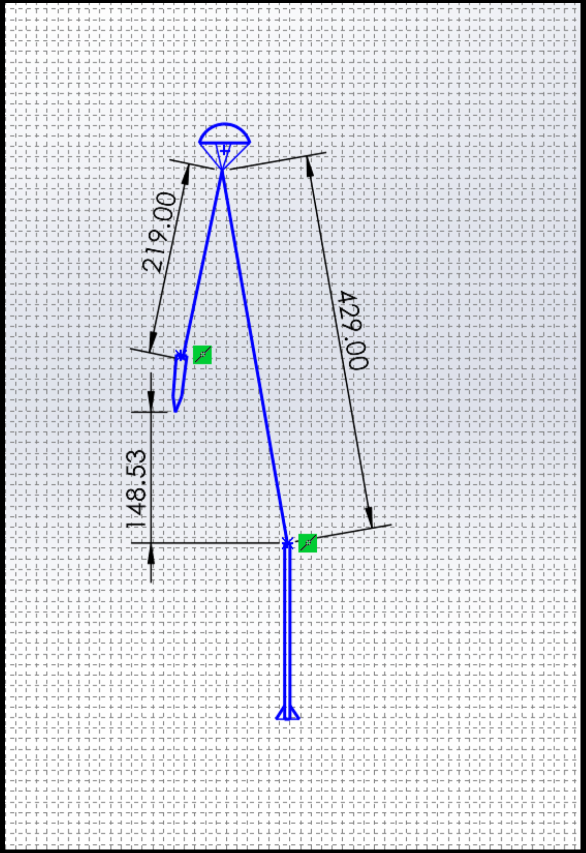
Drogue:
Total Shock cord length (3 x length of Rocket): 648"

Drogue to upper body: 219"

Drogue to lower body: 429"

Clearance from upper body to lower body: 140" (Safety Factor of 2)

Rocket length: 216"



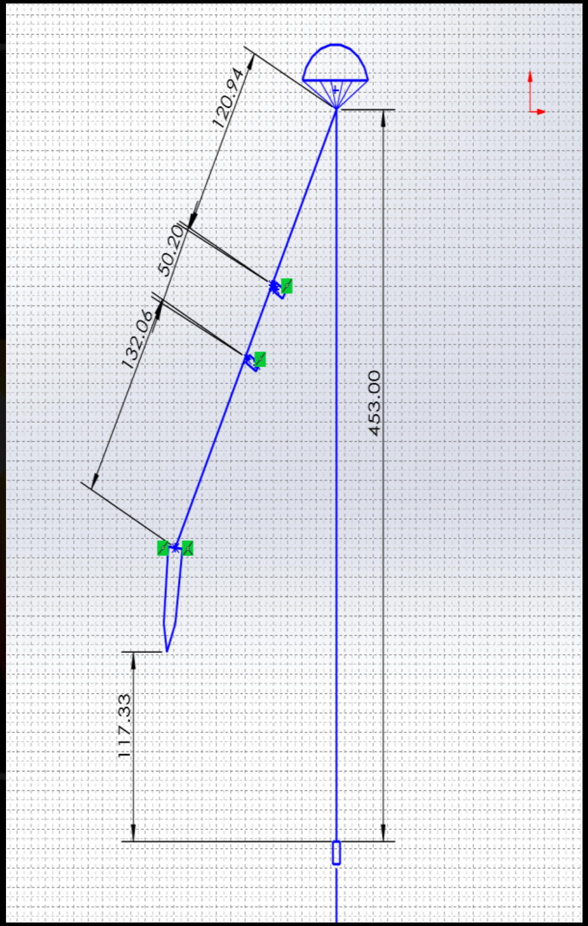
Main:
Total Shock cord length (3.5 x length of Rocket): 756"

Parachute to Payload 128"

Distance between payloads: 50" Sf(3)

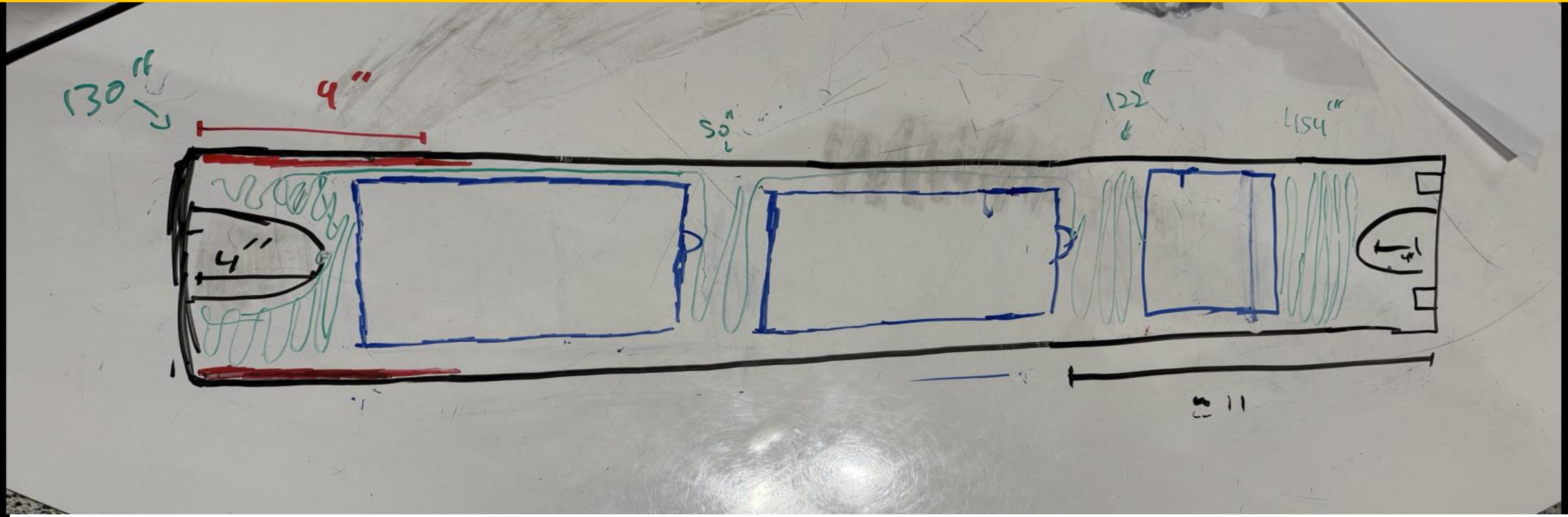
Payload to Nosecone: 113" Sf(1.5)

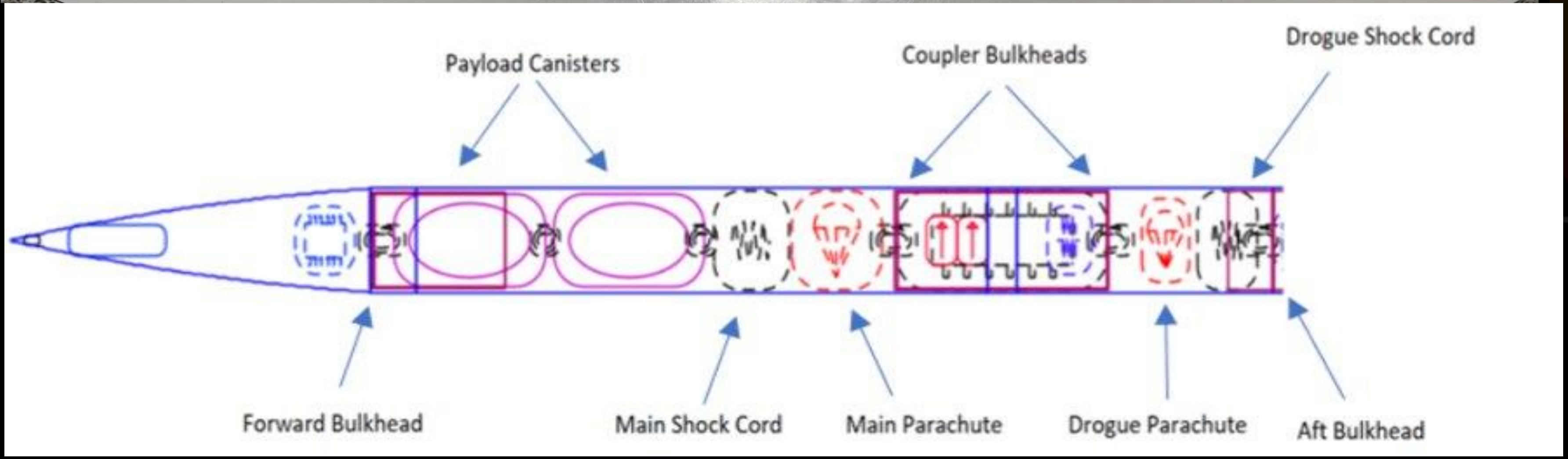
Nosecone to Coupler: 176" Sf(1.7)



KXR UCF

Recovery and Payloads Interface





Payload dimensions
- 5.5" Diameter
- Rover Canister: 11" length
- Drone Canister: 11"

Recovery Dimensions
- 6" Diameter
- 36" Length

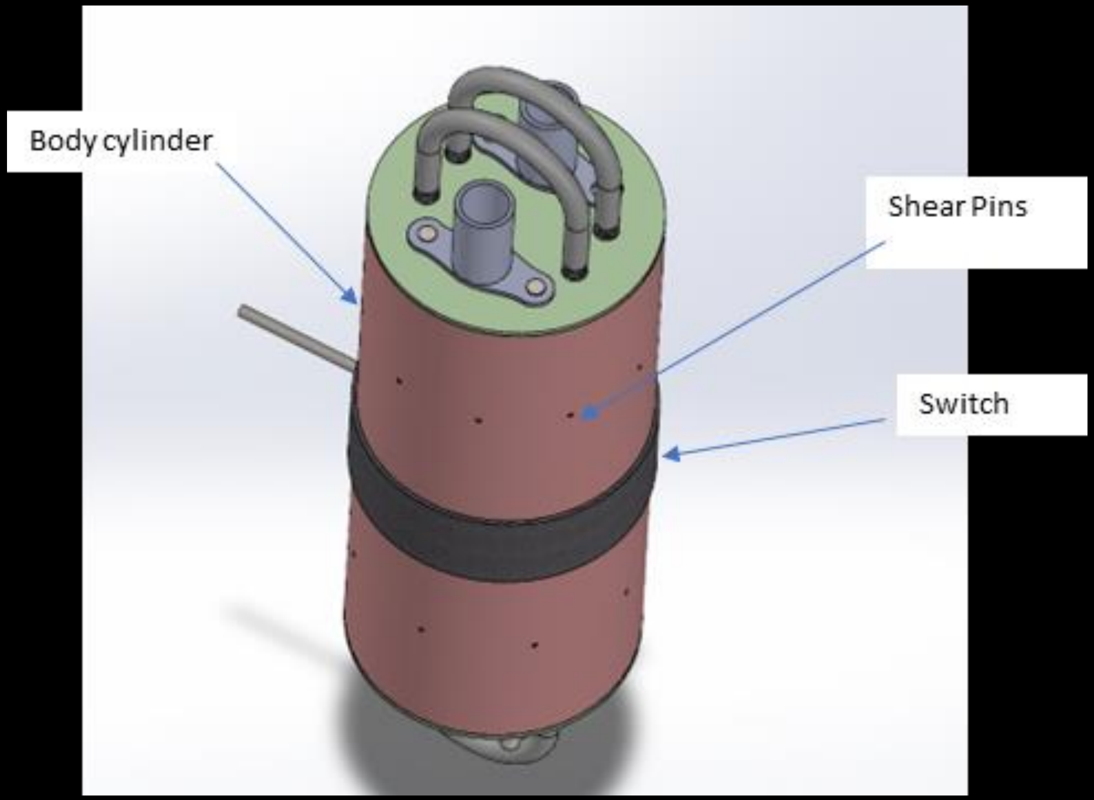
Shock Cord Length
- 117 ft of ¼ " Kevlar shock cord

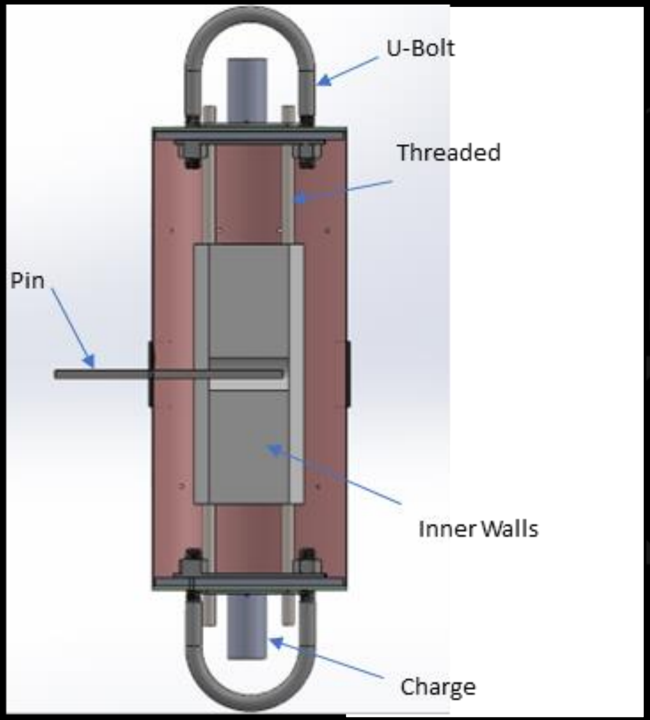
Available space for Recovery after Payloads:
14" length

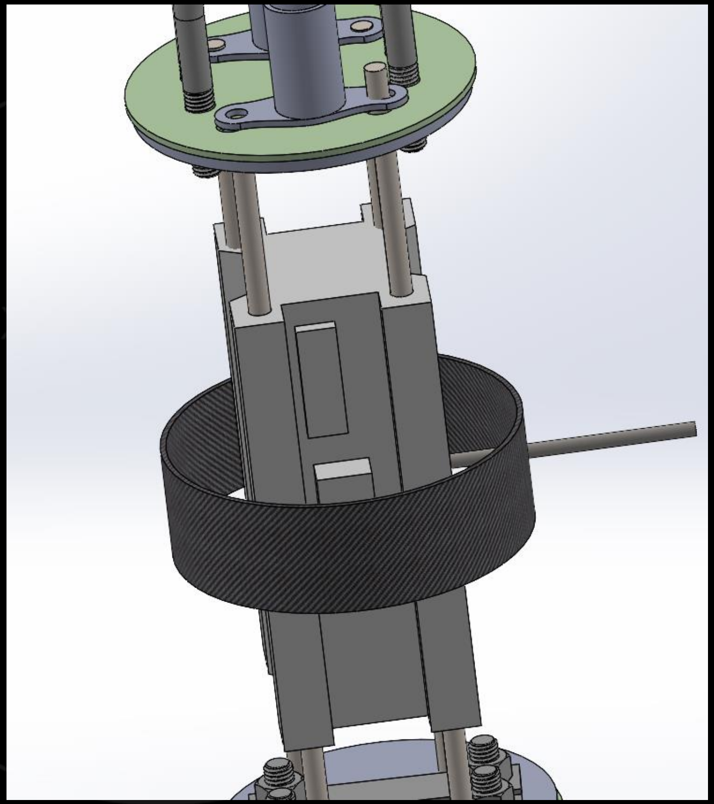
FMECA

Part	Failure	Criticality	Effect	Mitigation
Shock Chords	Snap	High	No Controlled Descent	Apply Safety Factor
Quick Links	Snap	High	No Controlled Descent	Apply Safety Factor
Shock Chords	Snap due to stress caused by heat	High	No Controlled Descent	Kevlar Shock Cord (heat resistant)
Shock Chords	Tangling With Payloads	High	Damage to the Rocket	Rail System for Payload
Shock Chords	Improper Shock Cord Lengths	Medium	Damage to the Rocket	Verify Lengths via Testing prototype

Recovery Coupler







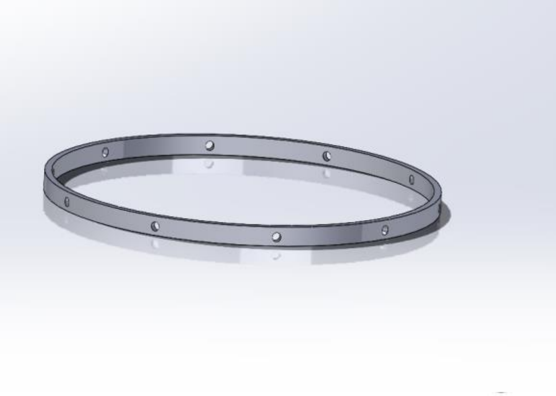
Dimensions
- Outer Diameter 5.998"; Inner Diameter 5.820"
- 14 inch length

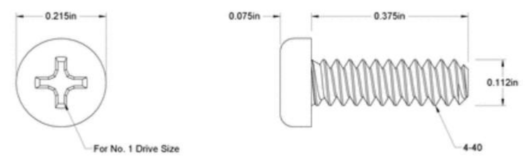
Coupler Costs

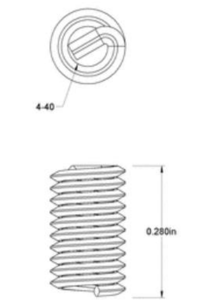
Material	Dimensions	Cost
G12 Fiberglass tube	Outer Diameter 5.998"; Inner Diameter 5.820"	$99.00 madcowrocketry.com
4 Zinc-Plated Threaded Rod	3/8 in.-16 tpi x 24 in. Zinc-Plated Threaded Rod	$3.47 Home depot
High-Strength Steel Nylon-Insert Locknut (20 pack)	Grade 8, 3/8"-16 Thread Size	$4.50 Mcmaster.com
18-8 Stainless Steel Washer (100 pack)	3/8" Screw Size, 0.406" ID, 0.875" OD	$7.33 Mcmaster.com
PVC Pipe	3/8 in. x 5 ft. White PEX-B Pipe	$2.97 Homedepot
Shearpins (100 pack)	Nylon Pan Head Screws Phillips, 4-40 Thread, 1/2" Long (100 pack)	$8.97 Mcmaster.com
Helical Insert (10 pack)	18-8 Stainless Steel Helical Insert, 4-40 Right-Hand Thread, 0.280" Long (10 pack)	$4.71 Mcmaster.com
	Total	

Recovery Coupler

- Shear pins
- 10 Nylon Pan Head Screws Phillips for Main parachute deployment
- 8 Nylon Pan Head Screws Phillips for Drogue parachute deployment
- Helical inserts to prevent thread stripping







Bolt Selector (select yellow box for dropdown)

	Bolt Type	Max Force (lbs)	Min Force (lbs)	MinorA (in^2)	Max Stress (psi)	Min Stress (psi)
Drogue	#4-40	76	50	0.005191238	14640.05201	9631.613167
Main	#4-40	76	50	0.005191238	14640.05201	9631.613167

Inputs

Rocket ID (drogue) (in)	Rocket ID (main) (in)	Empty Length (drogue) (in)	Empty Length (main) (in)	Launchpad Height (ft)	Rocket Apogee (ft)
6	6	11	30	2762	16000

Calculated Outputs

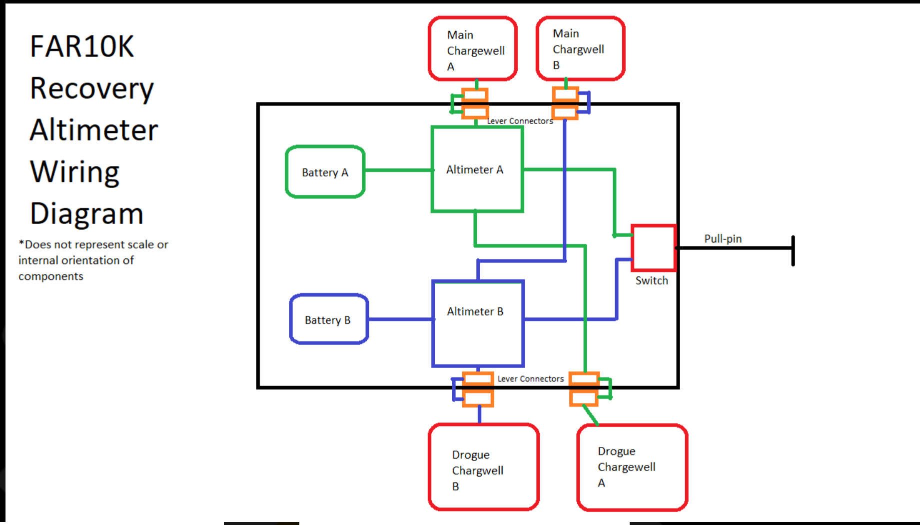
Temperature1 (F)	Temperature2 (F)	Atm. Pressure1 (psi)	Atm. Pressure2 (psi)	Ref Area Drogue (in^2)	Ref. Area Main (in^2)	
49.16728	-7.79272	13.30169173	7.127427439	28.27433388	28.27433388	< Temp/Pressure equations work up to 36152ft above sea lvl

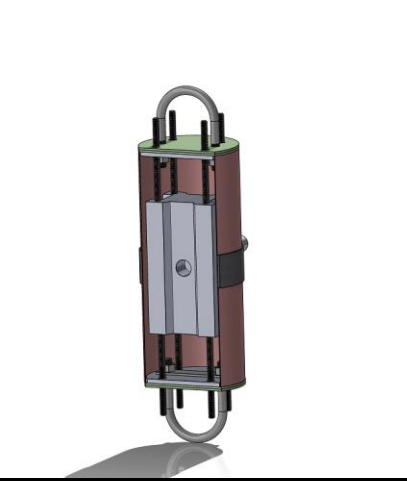
Drogue	
Drag Top (lbs)	66.49
Drag Bottom (lbs)	105.81
Delta Drag (lbs)	39.31984546
Sep. Force (lbs)	174.57321
Bolt Safety Factor	1.5
Bolts	4.277861109
Bolts (rounded w/ SF)	**8**
Black Powder Safety Factor	2
Black Powder (grams)	3.448608579
Black Powder (SF) (grams)	**6.9**

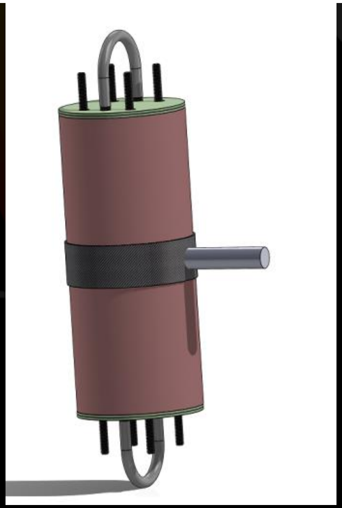
Main		
Drag Top (lbs)	49.67	< Add up drag below and above separation point (where it shears) to find your drag diff.
Drag Bottom (lbs)	105.81	
Delta Drag (lbs)	56.13761346	
Sep. Force (lbs)	174.57321	
Hanging Section Weight (lbs)	20	< Weight of section being held by main shear bolts after drogue deployment
Bolt Safety Factor	2	
Bolts	4.614216469	
Bolts (rounded w/ SF)	**10**	
Black Powder Safety Factor	1.8	
Black Powder (grams)	11.75662016	
Black Powder (SF) (grams)	**21.2**	

Recovery Avionics General Architecture

- Recovery system will use a fully dual redundant avionics system to deploy parachutes
- Both altimeters are fully able to deploy both parachutes
- Both powered by 9v batteries
- Nominal powered-on period of over 15 hours
- Avionics sit on a sled within the recovery coupler
- A pull-pin will activate the avionics system before flight, accessible from outside of the coupler; through vent hole

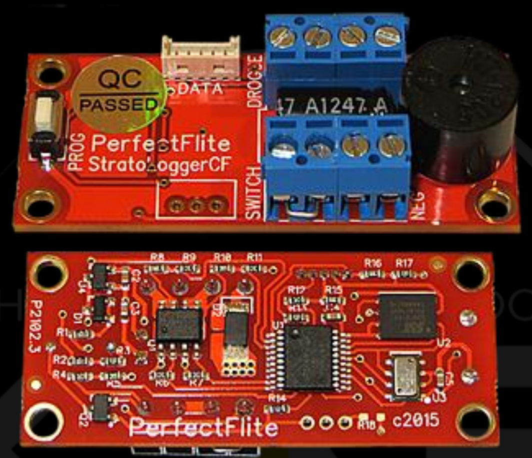






Recovery Avionics - Altimeters

- ❑ Stratologger CF – Already owned by KXR
    - ❑ 1.5mah consumption, over 100 hours of nominal life
    - ❑ Samples atmosphere 20 times per second
    - ❑ Dual-Deploy computer
- ❑ Missileworks RRC2+ - Already owned by KXR
    - ❑ 35mah consumption, 15 hours of nominal life
    - ❑ Dual-Deploy computer
- ❑ Back-up: Stratologger



FMECA

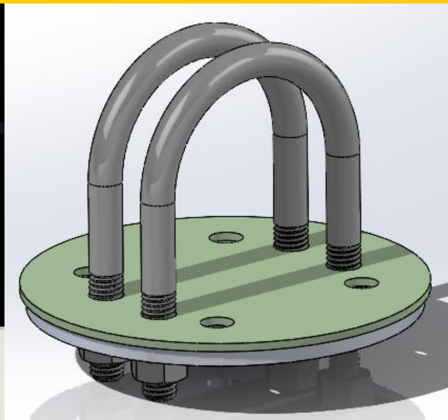
Part	Failure	Criticality	Effect	Mitigation
Threaded Rods	Shearing	High	Coupler Failure	PVC Piping to cover the rods, stronger nuts to withstand snatch force.
Altimeters	Detonating charges late	High	Parachute(s) deploy at high velocity or too late	Ground testing of altimeters
Altimeters	Does not detonate charges	High	Parachute(s) do not deploy	Ground testing of altimeters
Parachute	Parachute failure (rip, does not unfold)	High	Unsafe descent	Proper packing procedure, analysis of velocity at deployment

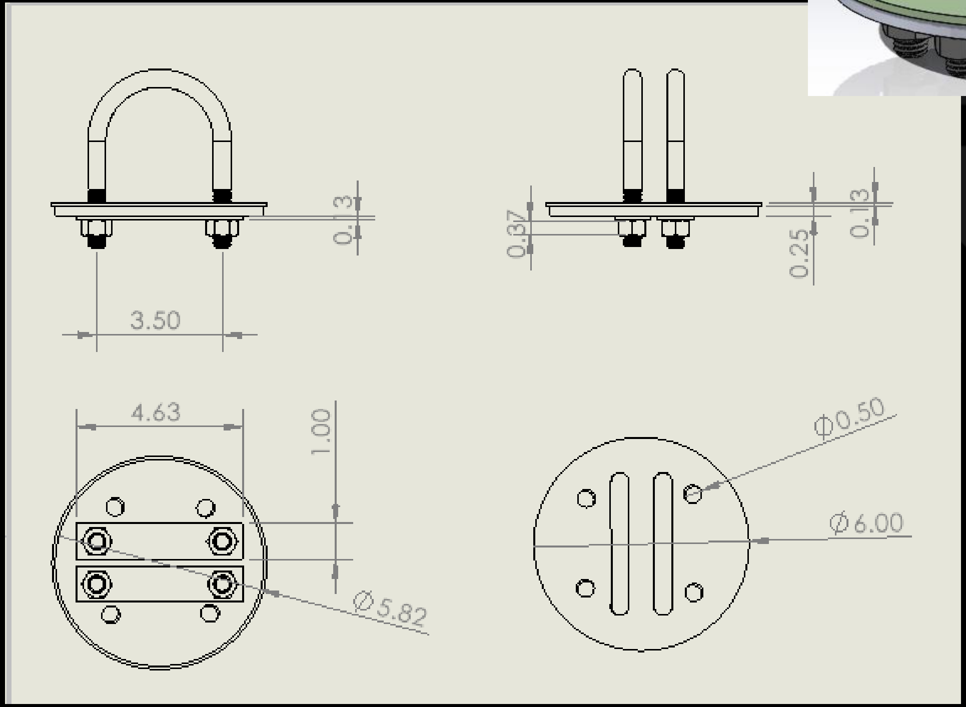
Recovery Bulkheads

- Materials: G10 (FR4) Fiber glass plate, Black Oxidized Steel U-bolts, ½ " nuts and washers, wire quick connect, and wood Bulkhead lip
- Safety factors:
  - U-bolt- 1.02 - Excel calculated
  - Bulkhead Plate: 13.7 - Excel calculated
  - Shear force per bolt: 211 – Excel calculated
- Due to the low SF there will be 2 U-bolts to counteract it
- With 2 U-bolts the force will be distributed over a larger surface area
- Forces: Snatch - Bolt shear (1389 PSI), Shear Force per bolt (14.27 PSI)

$$F = 0.5 * r * v_d^2 * C_d * A_m$$

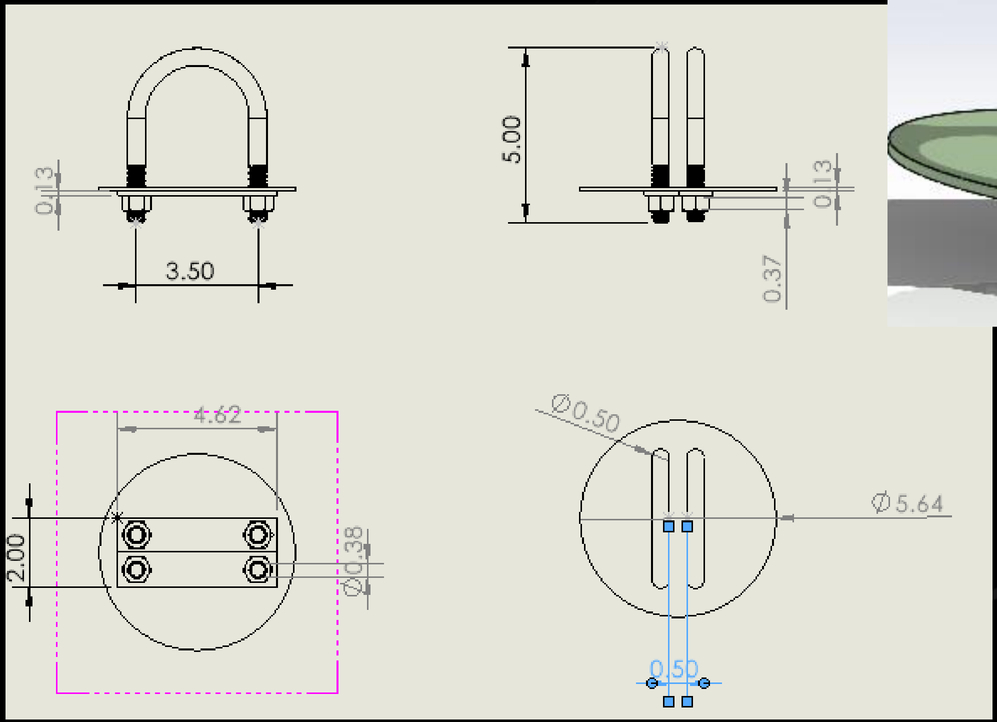
Snatch Force (N)	Snatch Force (lbs)	SF	Focre*SF (lbs)
5606.019256	1260.283264	1.55	1953.439059

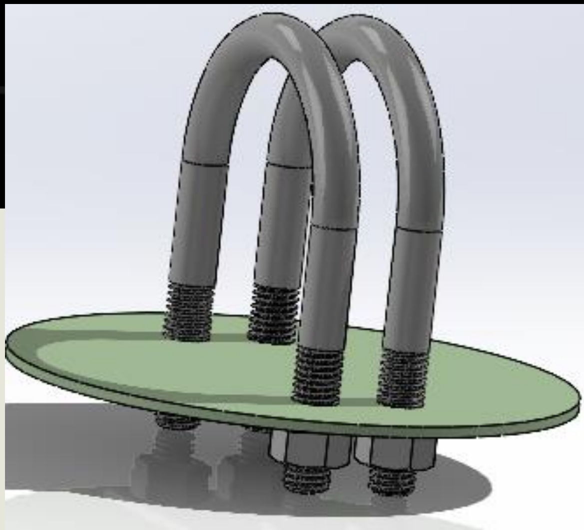




Recovery Bulkheads

- Attachments:
  - Recovery Coupler – 3/8" rods with lock nuts to secure
  - Body Bulkheads – secured in place by G12 couplers in body sections
- Verifications – Excell calculators and physical tests
  - Using values from open rocket, other calculators, and manufacturers
  - Physical Test
- Forces applied:
  - Main areas: U-bolt, threads, and bulkhead plate
  - Transfer of Forces: Quick link > U-Bolt > back plate > Lip > BH Plate





FMECA

Part	Failure	Criticality	Effect	Mitigation
U-bolt	Snaps	High	Vehicle Disassembly	The U-bolt has a Safety factor 1.02 thus 2 U-bolts are being used
Bulkhead Plate	Bolt Tear	High	Vehicle Disassembly	13.7 Safety Factor on the Bulkhead

Bulkhead Cost

Part	Quantity	Cost
U-bolt/nuts(2)/back plate	8	$46.53
G10(FR4)	1x0.125” x 12” x 24” sheet	$42.11
Nuts ½ in	16	$11.04
Washers ½ in	16	$11.04
Wire quick connect	2	$12.99
Hardpoint wood	1 2ft x 4ft plank	$5.15

Black Powder

- Calculated Black powder by using values from open rocket (Fin height root chord Tip Chord & Pressure Base and Friction Coefficient) plugging into the aerodynamics forces we get drag top and bottom for drogue and main.
- Then we use drag top and bottom and use the black powder calculator
  - We used black powder safety values of 2 for drogue and 1.8 for main
  - Bolt safety of 1.5 for drogue and 2 for main.
  - We also got Rocket ID, length and hanging sections weight from Open rocket
- We will be using 6.9 Grams of black powder for the drogue and 21.2 grams of black powder for the Main

Bolt Selector (select yellow box for dropdown)

	Bolt Type	Max Force (lbs)	Min Force (lbs)	MinorA (in^2)	Max Stress (psi)	Min Stress (psi)
Drogue	#4 40	76	50	0.005191238	14640.05201	9631.613167
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49.16728	7.79272	13.30169173	7.127427439	28.27433388	28.27433388

< Temp/Pressure equations work up to 36152ft above sea lvl

Drogue

Drag Top (lbs)	66.49
Drag Bottom (lbs)	105.81
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Sep. Force (lbs)	174.57321
Bolt Safety Factor	1.5
Bolts	4.277861109
Bolts (rounded w/ SF)	8
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Bolts (rounded w/ SF)	10
Black Powder Safety Factor	1.8
Black Powder (grams)	11.75662016
Black Powder (SF) (grams)	21.2

< Add up drag below and above separation point (where it shears) to find your drag diff.

< Weight of section being held by main shear bolts after drogue deployment

Coefficient Inputs

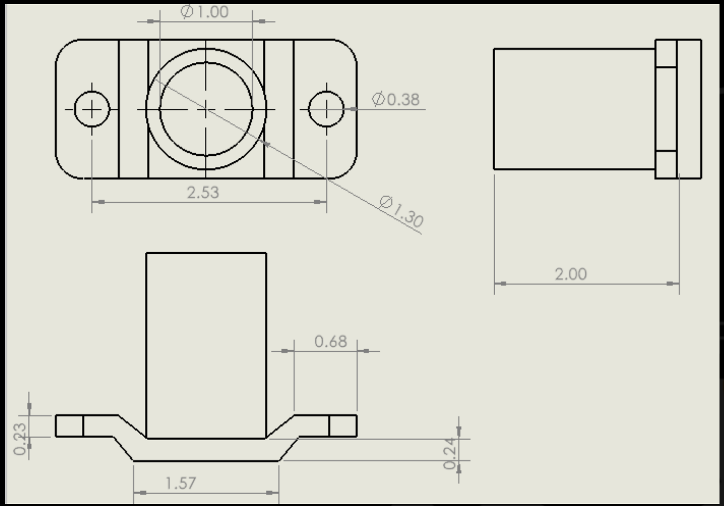
Componen	Pressure C	Base C	Friction C	Total C	Drag (lbf	Cn α	Cn	Lift (lbf
Nose Cone	0.04	0.00	0.03	0.07	26.20	0.00	0.00	0.00
nose cone shoulde	0.00	0.00	0.01	0.01	1.96	0.00	0.00	0.00
payload body tube	0.00	0.00	0.06	0.06	21.51	0.00	0.00	0.00
ecovery switch rin	0.00	0.00	0.01	0.01	1.96	0.00	0.00	0.00
ower recovery tub	0.00	0.00	0.04	0.04	14.86	0.00	0.00	0.00
n mount	0.00	0.00	0.03	0.03	13.30	0.00	0.00	0.00
trogen valves mou	0.00	0.00	0.02	0.02	6.26	0.00	0.00	0.00
fuel tube	0.00	0.00	0.02	0.02	7.04	0.00	0.00	0.00
fuel valves mount	0.00	0.00	0.02	0.02	6.26	0.00	0.00	0.00
ox tube	0.00	0.00	0.06	0.06	21.51	0.00	0.00	0.00
cc mount	0.00	0.00	0.02	0.02	6.26	0.00	0.00	0.00
trapezodial fin set	0.02	0.00	0.01	0.03	9.78	0.00	0.00	0.00
boat tail	0.00	0.07	0.02	0.09	20.55	0.00	0.00	0.00
Total	0.05	0.07	0.31	0.44	157.44	0.00	0.00	0.00

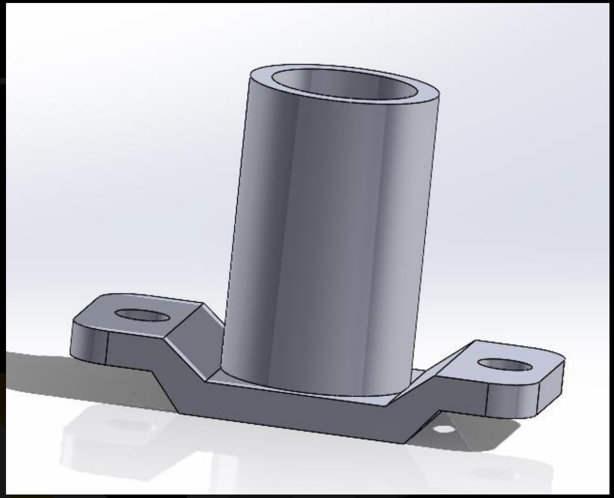
Constant Inputs

Density of air at sea level	Max velocity	outer diameter	Cross-sectional Area	α (angle of attack)	Fin Area	g	Fin Root Chord	Fin Tip Chord	Fin Height
slugs/ft^3	ft/s	ft	ft^2	degrees	ft^2	ft/s^2	ft	ft	ft
0.00238	1001.00000	0.51667	0.32844	0.00000	0.18960	32.17405	0.58	0.38	0.40

Charge Wells

- 3D printed charge wells, Wing nuts 3/8", electrical tape, E-match, quick connect, and Wiring
- Charges will be packaged in fingers of gloves
- Then be placed in in well with electrical tape to secure it to the E-match and prevent any movement
- Igniting the charge – the wires from the altimeter will be run through a quick connect to a small hole in the bottom of charge well





	PM(g)	BD(g/cm^3)	PV (cm^3)	PV(in)	Actual Volume
	21.1	1.7	12.4117647	0.757412	1.570796327
					0.964367295
	2.356194				

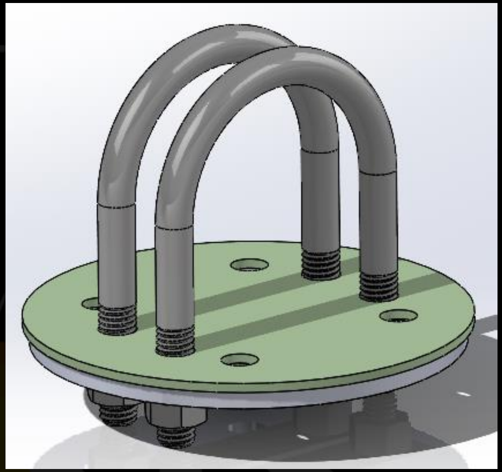
PV = PM / BD P V = PM /B D Where PV is the Powder Volume (m^3) PM is the powder mass (g) BD is the bulk density (g/m^3) To calculate the powder volume, divide the powder mass by the bulk density.

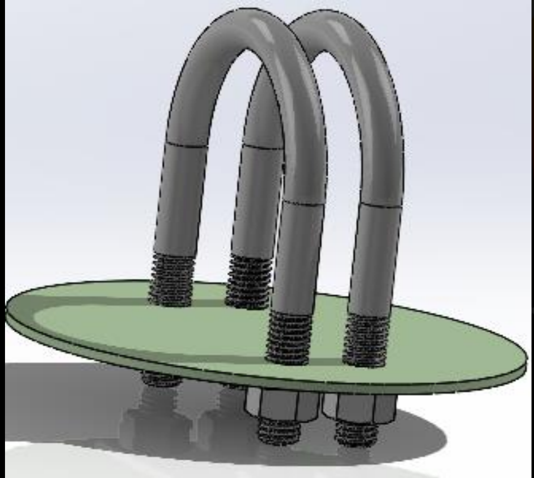
FMECA

Part	Failure	Criticality	Effect	Mitigation
BP Fuse	Fails to ignite	High	Separation fails	Proper wiring
BP Amount	Too much BP	High	Separation fails	BP testing
BP Amount	Too little BP	High	Separation fails	BP testing

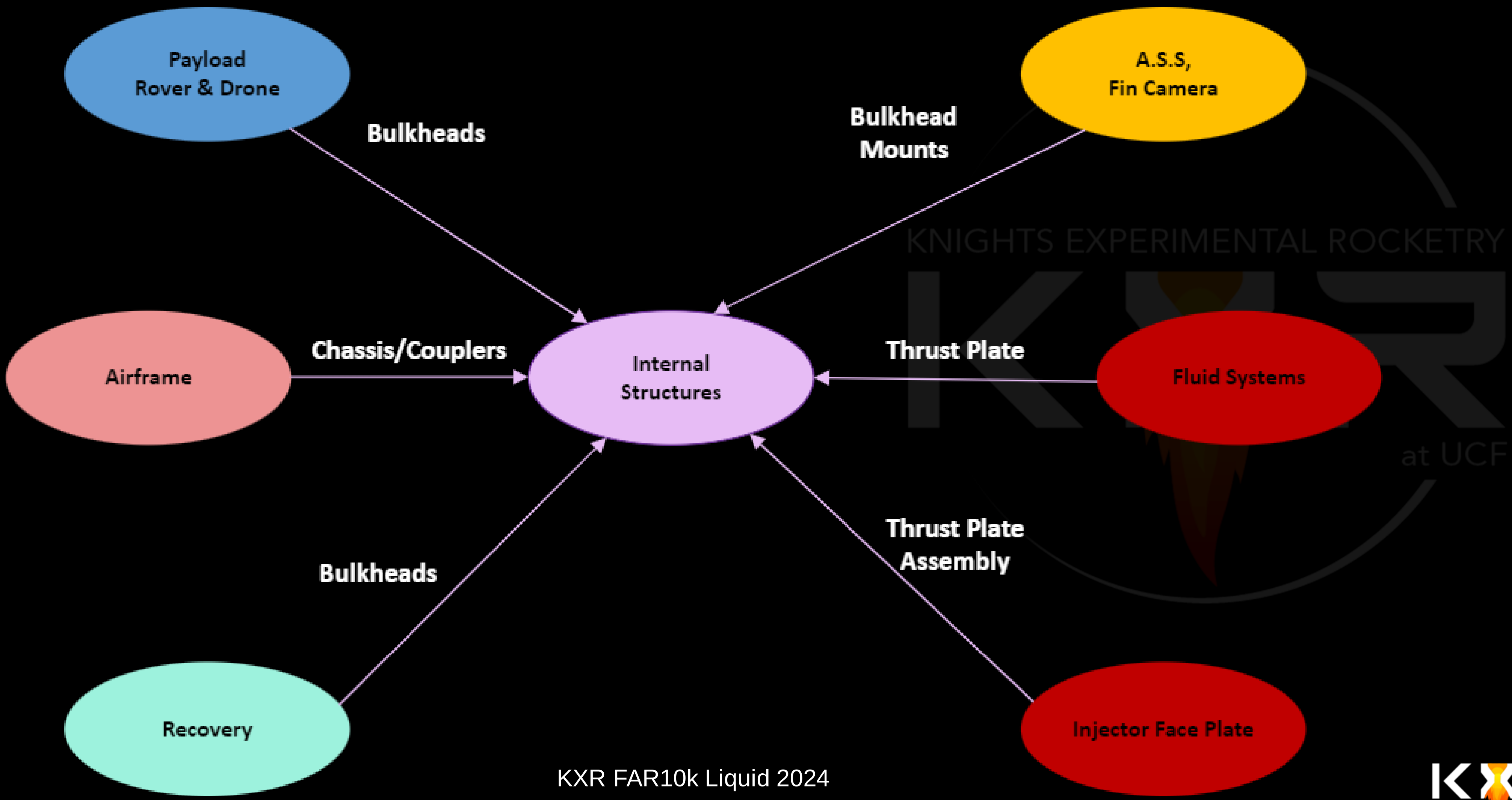
Recovery System Manufacturing

- Bulkheads
  - Made from G10 fiberglass
  - Bulkheads will be designed through CAD
    - The drawing file will be sent to a fabrication center to be laser cut
  - U-bolts will be bought from McMaster
- Switchbands
  - Made from carbon fiber pre-preg
  - The 2" band will be cut from the lower recovery tube and the nitrogen tank tube
    - These tubes can be manufactured longer than needed to allow the switchbands to be cut from them





Internal Structures Interface Diagram



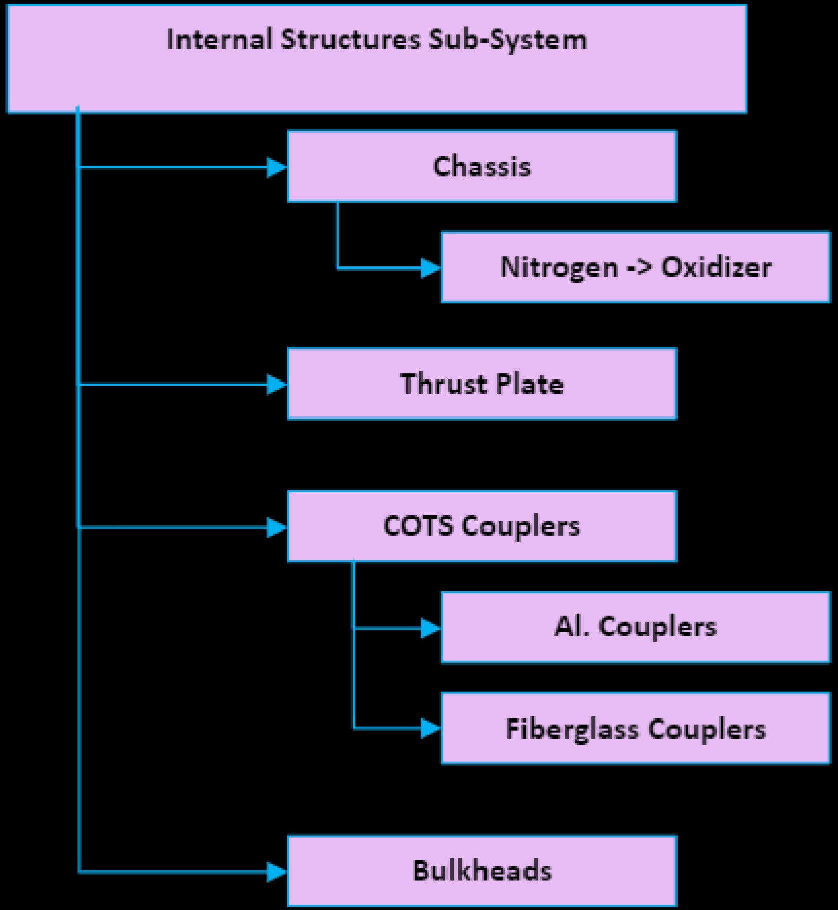
Internal Structures Functional Requirements

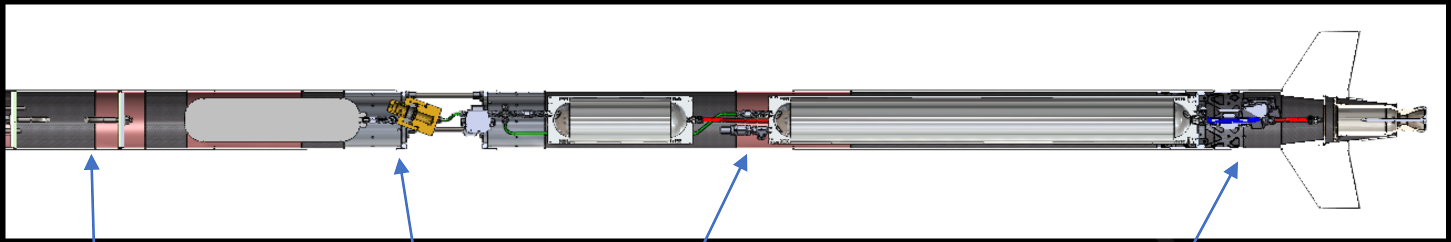
Requirement	Requirement Type	Verification Method
The Internal Structures sub-system **shall** support and protect the **Propulsion** and **Payload** systems	Functional	Analysis
The internal Structures sub-system **shall** withstand the loads and vibrations acting on the rocket	Functional	Analysis
The Internal Structures sub-system **shall** house and provide access to the internal components of the vehicle	Functional	Inspection
The Internal Structures sub-system **shall** allow separation between motor, payload and recovery section of the vehicle.	Functional	Inspection
The Internal Structures sub-system **shall** withstand the weight of the propulsion system [64 lbs] and the payloads [10 lbs]	Functional	Analysis

Internal Structures Technical Performance Measures

Measure	TPM Value	Units	Verification Methods
Total Compression Loads	16,941.311	psi	Force Calculator (Aero Loads)
Snatch Force	1,260.283 (No S.F) 1,953.439 (S.F 1.55)	lbf	Force Calculator (Snatch Force)
M1 Bending Max M2 Bending Max	-3,726.961 5,742.241	psi	Far Force Calculator (Aero Forces)
G Force	2.84	G's	Open Rocket
Shear Force (V1) Shear Force (V2)	67.690 221.527	lbf	Force Calculator (Aero Force Loads)
Bearing Stress (Tensile) Bearing Stress (Compression)	2,367.805 68,105.684	psi	Force Calculator (bolt sizing)

Internal Structures Component Breakdown





Chassis Technical Performance Measures

Measure	TPM Value	Units	Verification Methods
Total Compression Loads	16,941.311	psi	Force Calculator (Aero Loads)
Snatch Force	1,260.283 (No S.F) 1,953.439 (S.F 1.55)	lbf	Force Calculator (Snatch Force)
M1 Bending Max M2 Bending Max	-3,726.961 5,742.241	psi	Far Force Calculator (Aero Forces)
G Force	4.24	G's	Open Rocket
Shear Force (V1) Shear Force (V2)	67.690 221.527	lbf	Force Calculator (Aero Force Loads)
Bearing Stress (Tensile) Bearing Stress (Compression)	2,367.805 68,105.684	psi	Force Calculator (bolt sizing)

Airframe Shear Stress

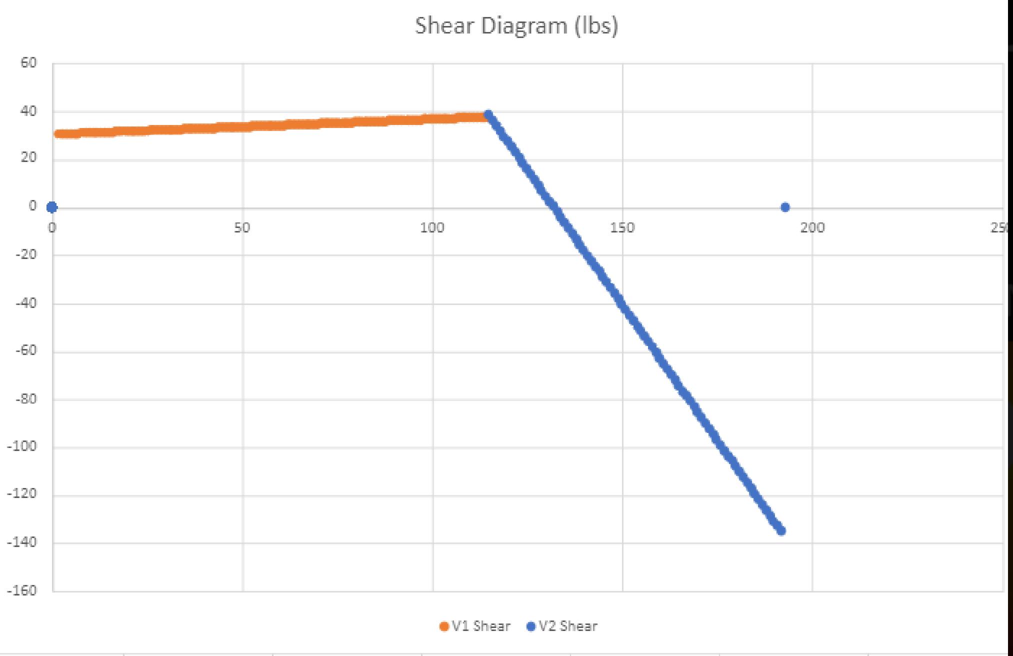
Equations from Nakka rocketry assume a distributed load acting on the body during flight.

$$w_2 = \frac{N_F(2x_2 + x_1) - N_N\, x_1}{x_2^2 + x_1\, x_2}$$

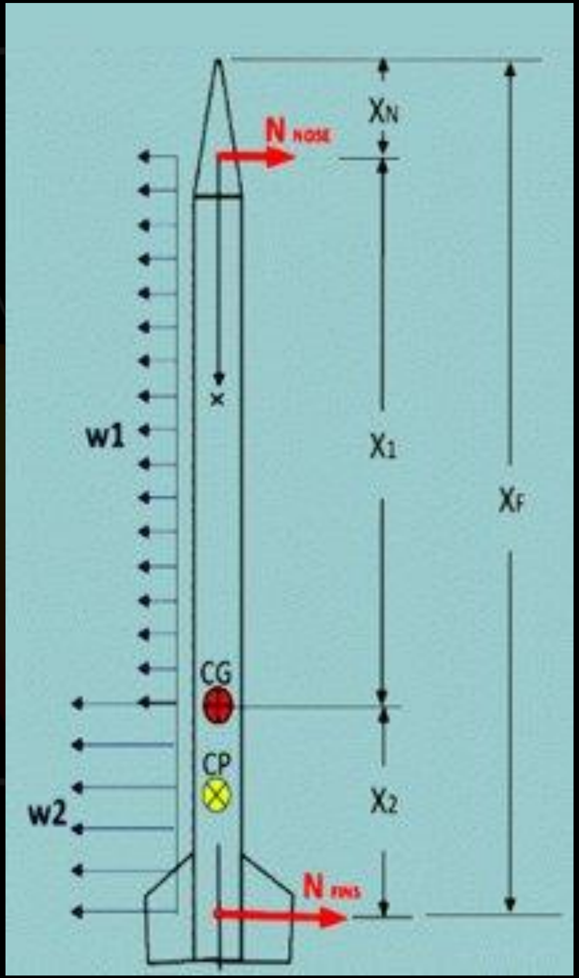
$$w_1 = \frac{N_N + N_F - w_2\, x_2}{x_1}$$

$$V(x) = N_N - w_1\, x \qquad 0 \le x \le x1$$

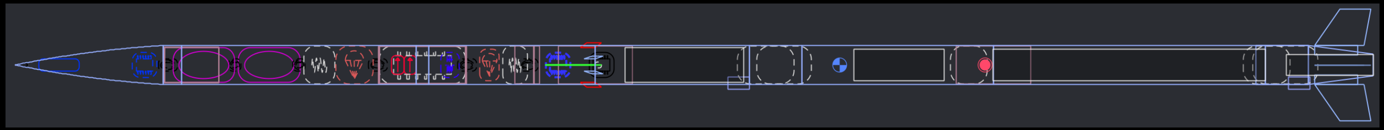
$$V(x) = V_1 - w_2(x - x_1) \qquad x1 < x \le L$$



Body Tube Loads			
Distributed load W1 (lb/in)	Distributed load W2 (lb/in)	Lateral Shear V1 (lbf)	Lateral Shear V2 (lbf)
-0.064303376	2.256670282	37.79152609	121.91



Airframe Bending Stress

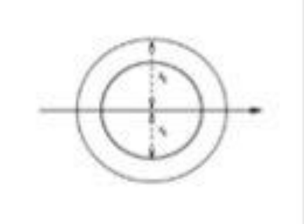


The **bending moment (M)** as a function of x is given by:

$$M(x) = N_N\, x - w_1 \frac{x^2}{2} \qquad 0 \le x \le x1$$

$$M(x) = V_1\, x + w_2\left(x_1\, x + \tfrac{1}{2}L^2 - \tfrac{1}{2}x^2\right) - L(V_1 + w_2\, x_1) \qquad x1 < x \le L$$

$$f_{b\,max} = \frac{M}{Z}$$



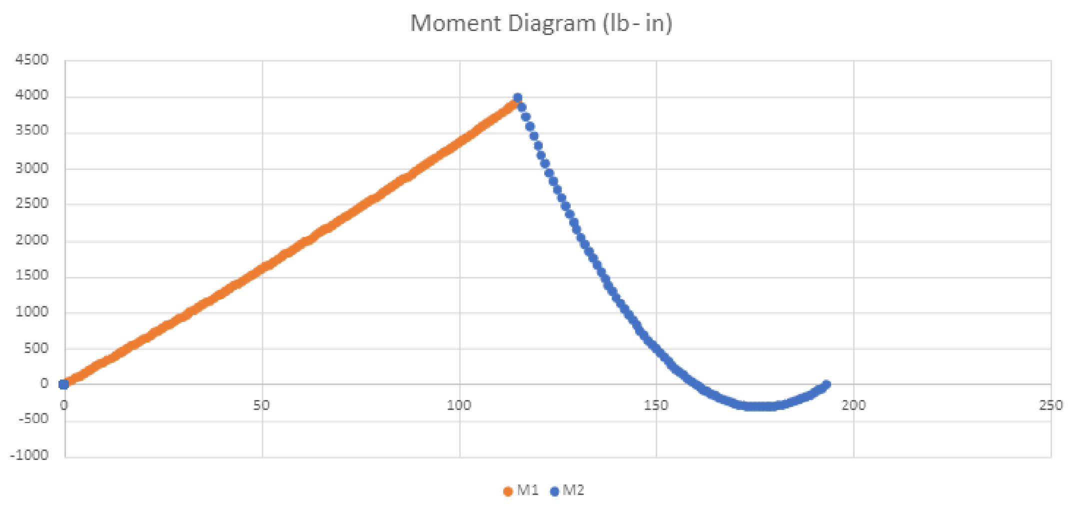
$$S = \frac{\pi(r_2^4 - r_1^4)}{4r_2} = \frac{\pi(d_2^4 - d_1^4)}{32 d_2}$$

Calculator:

Section Modulus Hollow Round Center Neutral Axis Calculator

NA indicates neutral axis

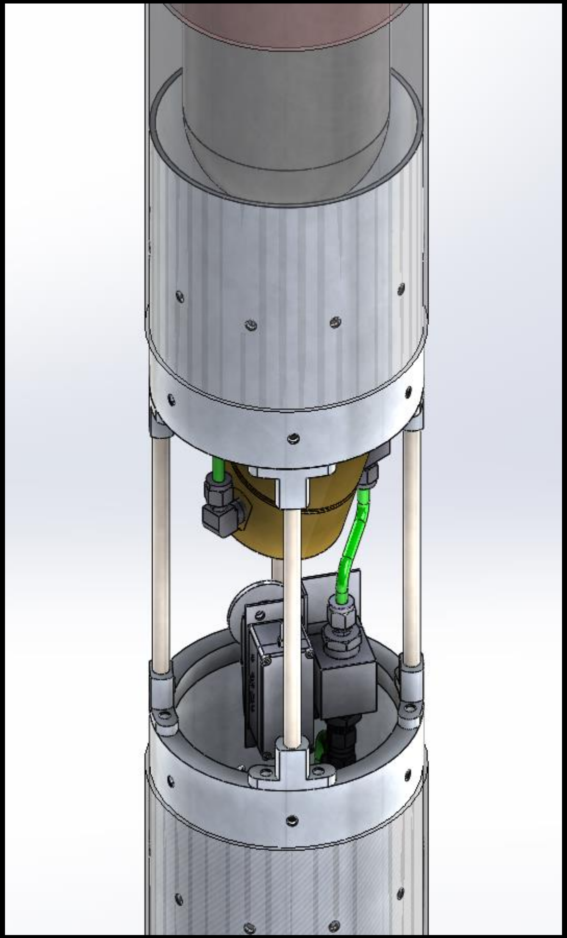
Max Bending Stress on Body (PSI)	
M1 Bending Max	-2493.867483
M2 Bending Max	1927.620763



Forward Moment/Bending Moment		
M1 Max Moment (lb in)	Max Forward Bending Moment (lb in)	Location of Max Forward Bending (in)
3917.964997	-7172.619099	115.00

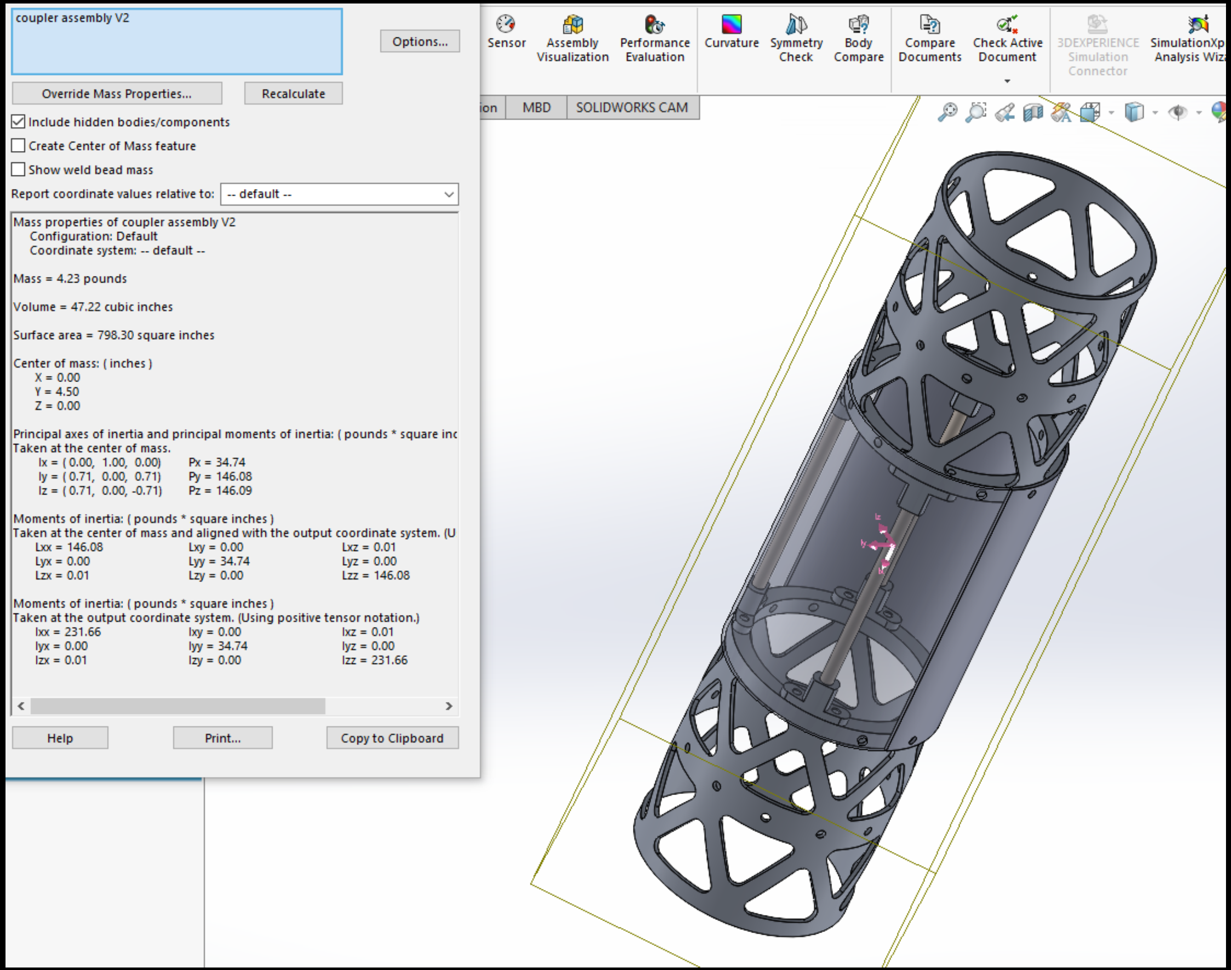
Aft Moment/Bending Moment		
M2 Max Moment (lb in)	Max Aft Bending Moment (lb in)	Location of Max Aft Bending (in)
3986.169714	5544.035357	115

Chassis



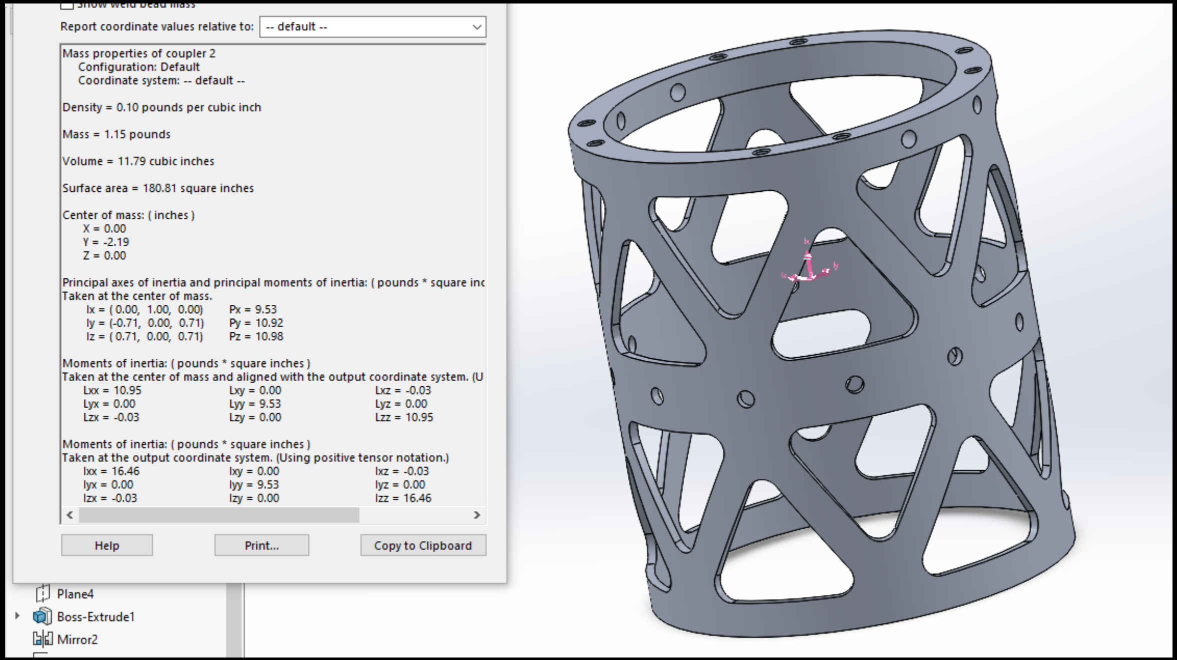
- Aluminum Coupling Section goes between the nitrogen tank and the fuel tank
- 8" long steel threaded rods provide an opening for access to regulator to avoid moving the entire tube and wearing out threads
- Aero panels can cover up the exposed plumbing and take little load during flight
- The panels will be made out of 3D printed polycarbonate

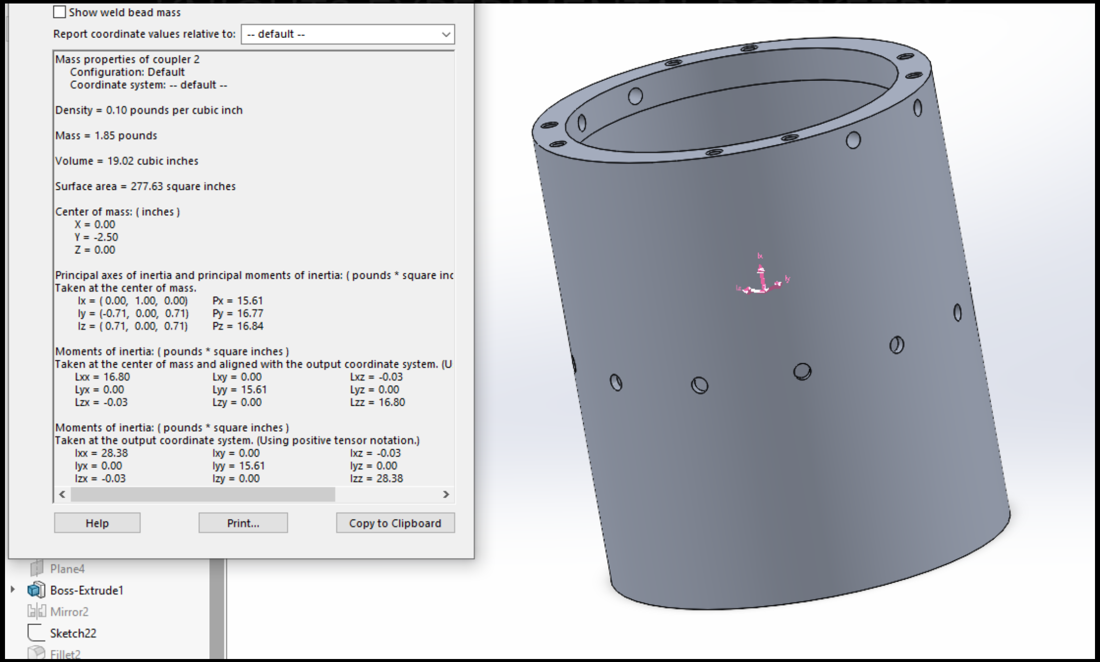
Design Evolution



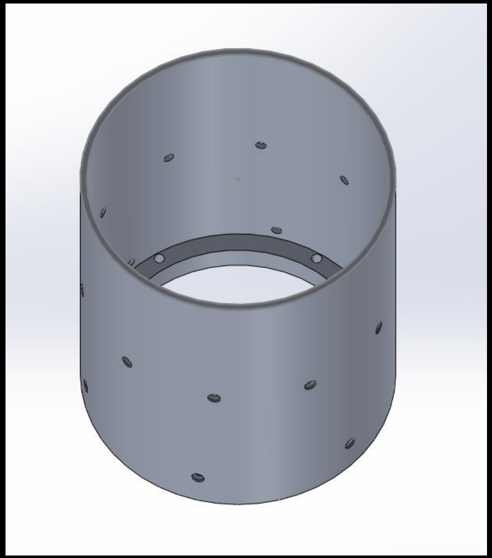
Weight Loss

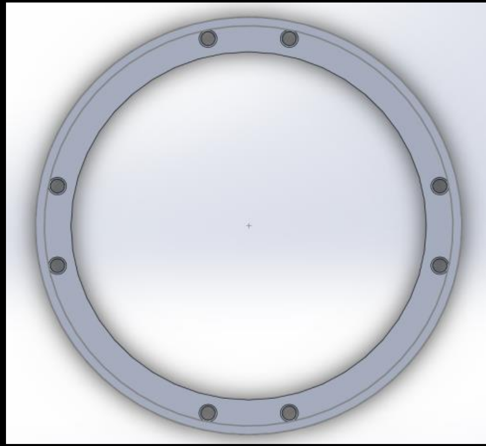
- Original: 1.85 lbs
- Lightened: 1.15 lbs
- Weight loss of 0.7 lbs per coupler, or 40%
- Adds up to almost 3 lbs across all couplers



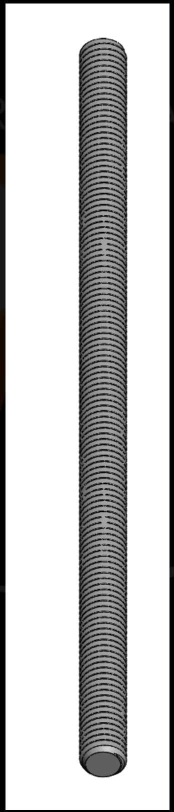


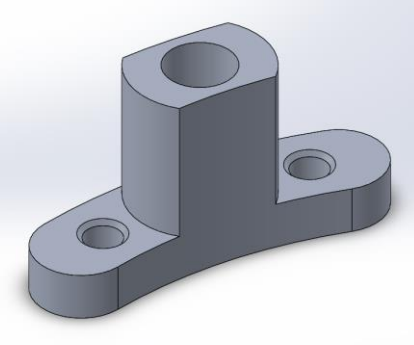
Chassis





Item	Material	Stock and Machining Costs	Quantity	Total	Resource
Chassis	6061 T6 Aluminum	$75 for stock 3 hours per coupler $35 hourly	1	Estimated $360	Quotes provided by UCF Machine Shop
3/8" threaded rods	Steel	$4.24	4	Estimated $18	https://www.homedepot.com/p/5-8-in-11-tpi-x-12-in-Zinc-Plated-Threaded-Rod-802017/204274006





FMECA

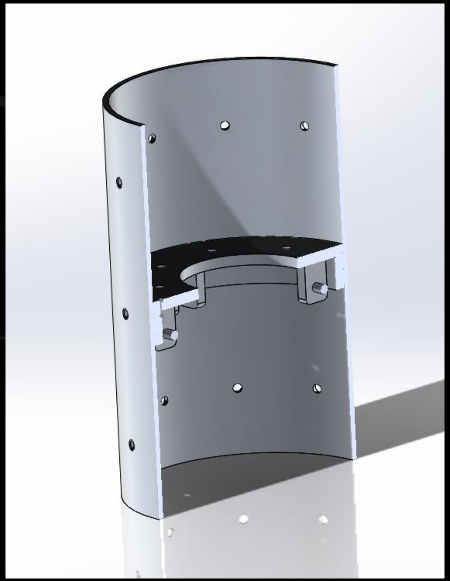
Part	Failure	Criticality	Effect	Mitigation
Coupler Tube	Bolt tear out	High	Joined sections of the airframe come apart during flight	6" shoulder length on carbon tubes
Coupler Tube	Bearing Stress	High	Bolt connections become loose during flight	Bigger bolts and better material for those bolts
Threaded Rods	Buckling	High	Component bends and fails during flight	Using different strut geometry, increasing the number of threaded rods or the diameter
All	Galvanic corrosion	High	Oxidizes the Aluminum	We will apply a coat to the Aluminum to stop the corrosion

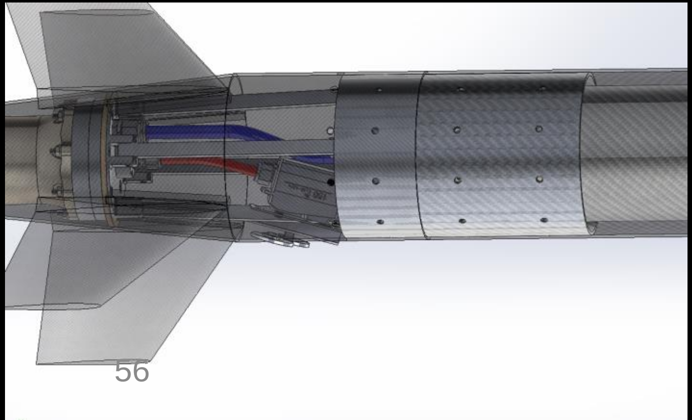
Thrust Plate TPMs

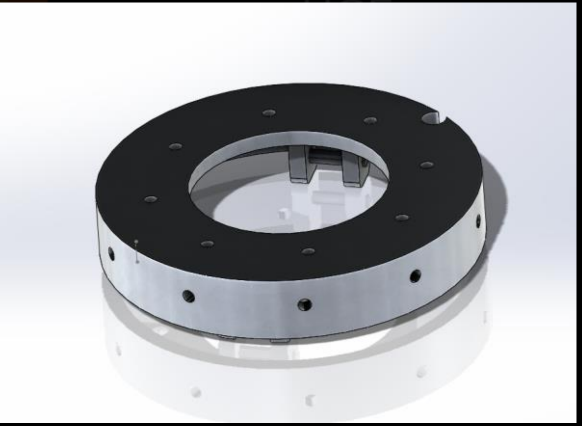
Measure	TPM Value	Units	Verification Methods
Total Compression Loads	16,941.311	psi	Force Calculator (Aero Loads)
Snatch Force	1,260.283 (No S.F) 1,953.439 (S.F 1.55)	lbf	Force Calculator (Snatch Force)
G Force	2.84	G's	Open Rocket
Thrust Force	539.991	lbf	Force Calculator (Aero Force Loads)
Bearing Stress (Tensile) Bearing Stress (Compression)	2,367.805 68.105.684	psi	Force Calculator (bolt sizing)
Shear Stress (Tensile) Shear Stress (Compression)	1,396.641 15,234.508	psi	Force Calculator (bolt sizing)

Thrust Plate

- Thrust Plate interfaces with aluminum struts coming from the injector
- Aluminum coupler tube attaches to the thrust plate in the middle to allow for attachment of the boat tail and one of the main body tubes
- The oxidizer bulkhead is attached, flushed with the thrust plate
- An indent of 3/8" is made to allow the fuel line to pass through







Thrust Plate Cost Breakdown

Part	Material	Stock and/or Machining Costs or	Quantity	Total	Link (not hyperlink)
Thrust Plate	6061 T6 Aluminum	Estimation of 20-35 dollars for stock 3.5 to 4 hours of machining time Hourly Machine Charges of 35 dollars	1	Estimated $170 dollars	Quotes from UCF machine shop
Aluminum Tube (6x.125x5.75)	6061 T6 Aluminum	$44.37	1	$44.37	https://www.metalsdepot.com/aluminum-products/aluminum-round-tube

Compression and Tensile Stresses

Thrust Force (lb)	Tube Cross-sectional Area (in^2)	Engine Thrust Compression (PSI)
539.9910813	1.257755468	429.3291462

Force Drag (lb)	Tube Cross-sectional Area (in^2)	Compressive Drag (PSI)
429.0488383	1.257755468	341.1226181

Mass (lb)	Max Gs	Tube Cross-sectional Area (in^2)	Mass inertia compression (PSI)
145	2.84	1.257755468	14243.23844

Engine Thrust Compression (PSI)	Max Bending Stress on Body (PSI)	Compressive Drag (PSI)	Mass inertia compression (PSI)	Total Compressive (PSI)
429.3291462	1927.620763	341.1226181	14243.23844	16941.31097

Main

Snatch Force (N)	Snatch Force (lbs)	SF	Focre*SF (lbs)
5606.019256	1260.283264	1.55	1953.439059

Drouge

Snatch Force (N)	Snatch Force (lbs)	SF	Focre*SF (lbs)
347.5449334	78.13120915	1.5	117.1968137

- Compression Loads are calculated using equations from Nakka Rocket

$$f_{cm} = \frac{m\, g\, (1 + G_{max})}{A_c}$$

- Compressive stress due to mass inertia

$$f_{ca} = \frac{F_D}{A_c} \qquad \text{[Equation 11]}$$

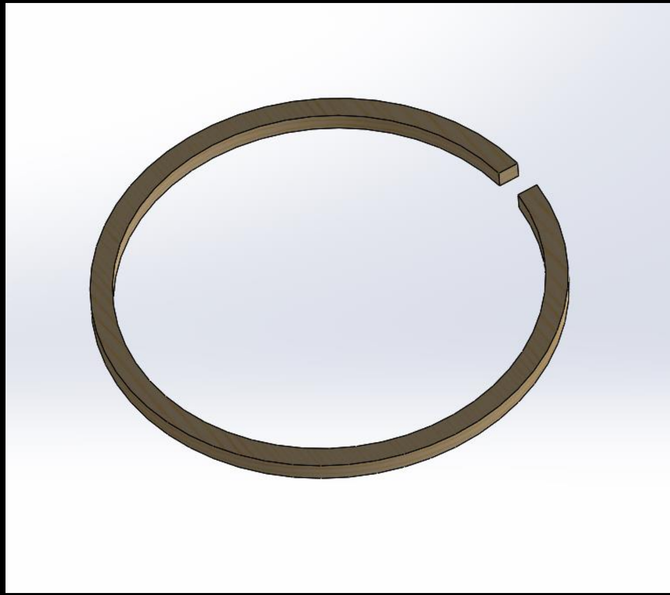
- Compressive stress due to drag force

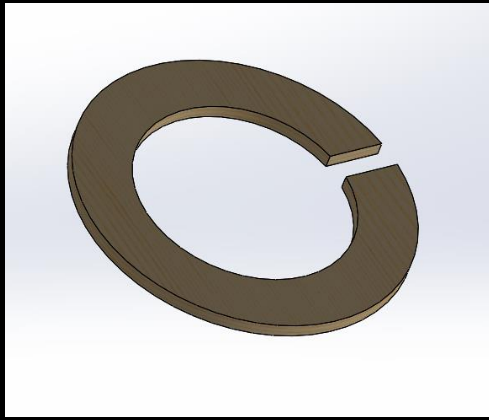
- Tensile stress from snatch force during recovery

FMECA

Part	Failure	Criticality	Effect	Mitigation
Coupler Tube	Bolt Shear	High	Thrust Plate and or joined sections of the airframe come apart	6" shoulder length on body tubes 3" of shoulder length into the boat tail
Coupler Tube	Bearing Stress	High	Bolt connections become loose	Bigger bolt diameter or stronger material
Thrust Plate	Bolt shear	High	Propulsion system connections become loose during flight	Using bigger bolt diameter and stronger material
Thrust Plate	Deformation	High	Propulsion system could collapse into the airframe	Adding thickness to the thrust plate or changing material

Centering Rings





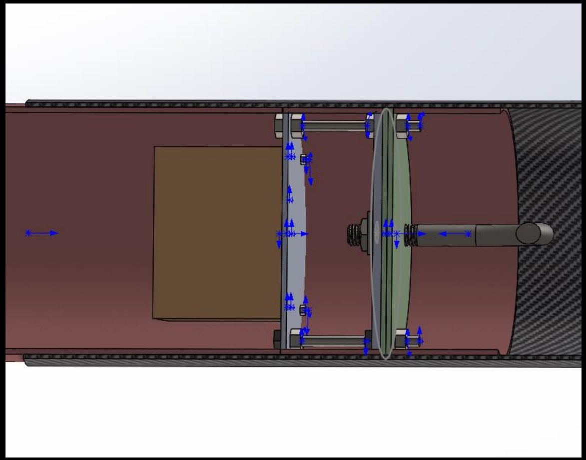
- To prevent translation of the tanks and the combustion chamber centering rings will be placed around the propulsion system.

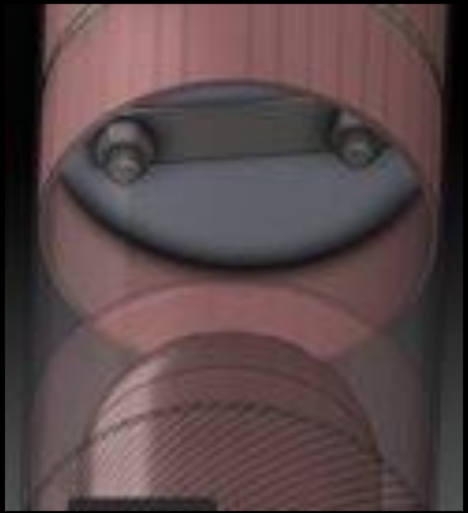
- Centering rings will be placed around the combustion chamber as well as the fuel and oxidizer tank.

- Will be cut out of plywood

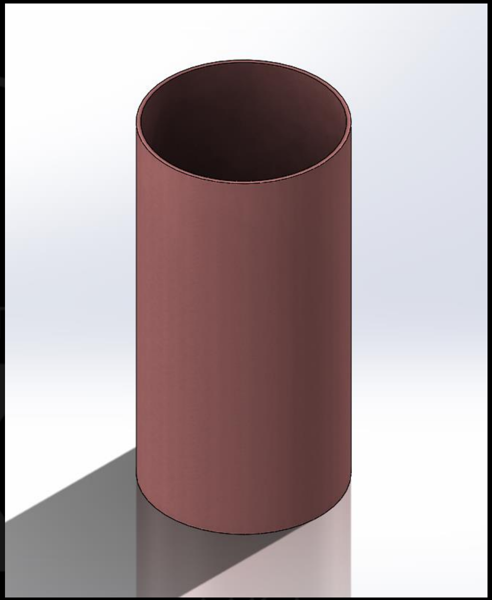
- Cost: $40 for a sheet of plywood

COTS Couplers/ Bulkheads





- Sections that won't require a chassis near the propulsion system will be joined together using fiberglass couplers
- Above the nitrogen tank, two bulkheads will secure the PCB and the ACB using fiberglass couplers and G10 plates
- These bulkheads will also be used to secure two cameras providing a horizon view during flight and a camera pointing down towards the fins



Item	Full Item Description	Cost	Quantity	Total	Link (not hyperlink)
G12 Fiberglass coupler tube	6” fiberglass tube	$60.00 each	2	$120.00	https://www.compositewarehouse.com/index.php?route=product/product&product_id=125

FMECA

Part	Failure	Criticality	Effect	Mitigation
Centering Rings	Cracking or disassembly	Medium	Risks the propulsion system sloshing inside the airframe	Multiple centering rings and/or thicker wood
Bulkeads	Cracking or disassembly	Medium	PCB, ACB, and cameras could risk collapsing inside the airframe	Using larger bolts to support the bulkhead

Bolt Bearing Stress

Compressive Loads Aluminium	
Bearing Stress (psi)	Saftey Factor
68185.68485	0.527970058

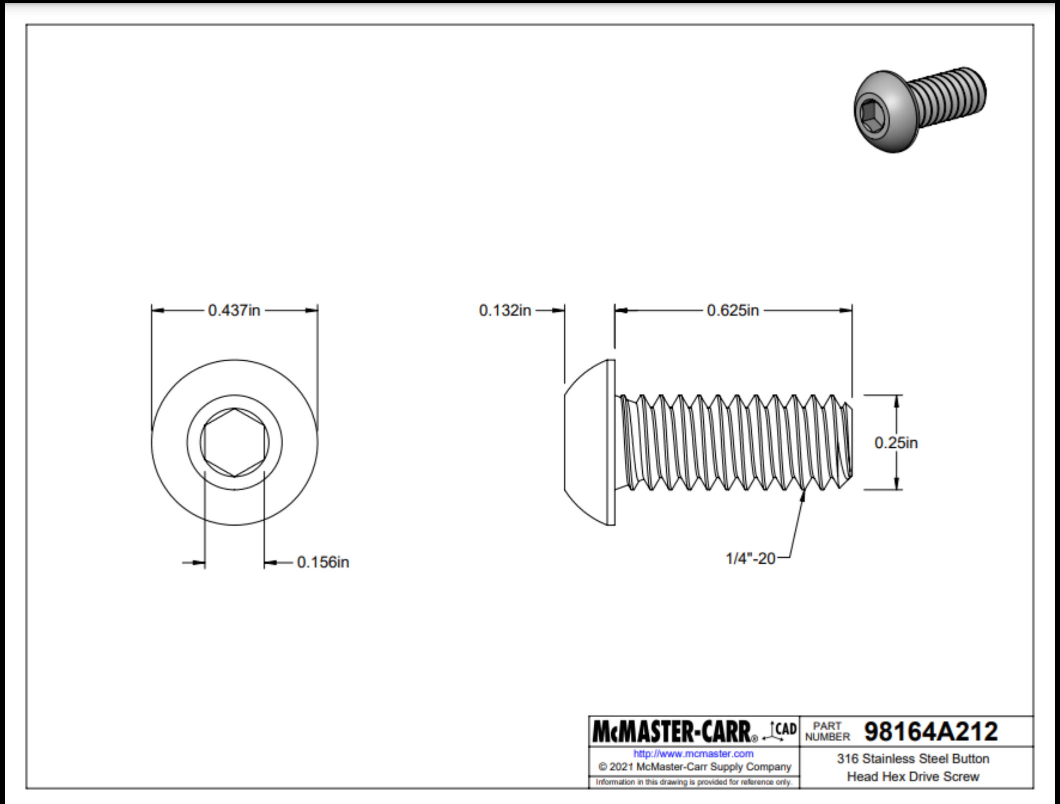
Tensile Loads Aluminium	
Bearing Stress (psi)	Saftey Factor
2367.80492	15.20395523

Bolt Sizing		
Bolt Type	Wall thickness (in)	SF of Bolts
1/4 - 20	0.2	1.75

Airframe will be secured using 10 ¼-20 steel bolts at all jointing sections.

$$f_{br} \leq \frac{S_{br}}{S.F.}$$

$$f_{br} = \frac{F_s}{D_m t}$$



Bolt Tear Out

Bolt Diameter (in)	Edge distance (in)
0.25	0.5

Bolt Diameter (in)	Minimum Edge distance (in)
0.25	0.375

- Minimum Edge distance was calculated for aluminum couplers on the chassis and on the aft end

Compressive Loads Bolts

Number of Bolts	Num Bolts With SF	Num of Bolts to even Number
6.165516932	10.78965463	10

Shear Stress Per Bolt (PSI)	Shear Force per Bolt (lb)	SF of Bolts
15234.50842	2130.802652	1.62192402

$$F_{max} = f\frac{M}{D}$$

$f = 2/5$ for ten fasteners

Shear Stress Average = Applied Force / Area
or
Shear Stress ave.= $F/(\pi r^2)$
or
Shear Stress ave.= $4F/(\pi d^2)$

Where:

Tensile Loads Bolts

Number of Bolts	Num Bolts With SF	Num of Bolts to even Number
0.565231209	0.989154616	1

Shear Stress Per Bolt (PSI)	Shear Force per Bolt (lb)	SF of Bolts
1396.641954	195.3439059	17.69187518

Max # of bolts: $n_{bolts} = \frac{F_{bulk}}{F^{max}_{bolt}} =$

Max Force one bolt can take: $F^{max}_{bolt} = \tau_u \cdot A_{bolt}$

Edge Distance

$$E \geq 2 \times d^{major}_{bolt}$$

$$E \geq 2 \times 0.25$$

$$E = 0.5$$

Minimum Distance from Edge

$$E_{min} = E - \frac{d^{major}_{bolt}}{2}$$

$$E_{min} = 0.5 - \frac{0.25}{2}$$

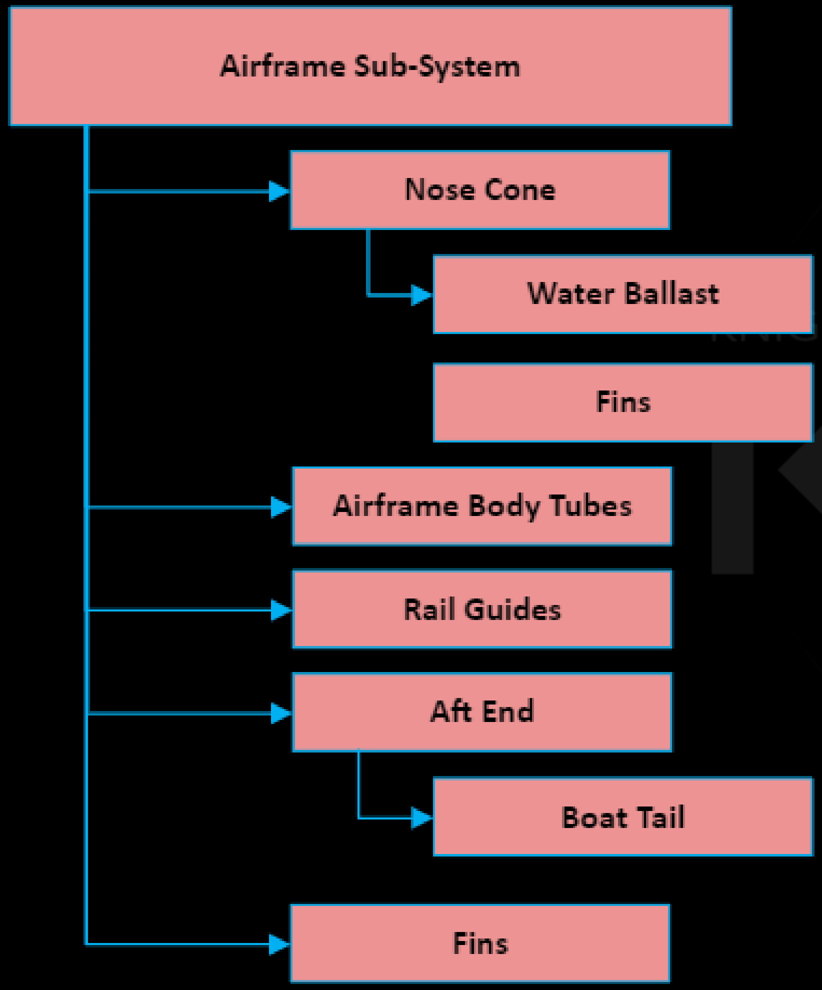
$$E_{min} = 0.5 - 0.125$$

$$E_{min} = 0.375in$$

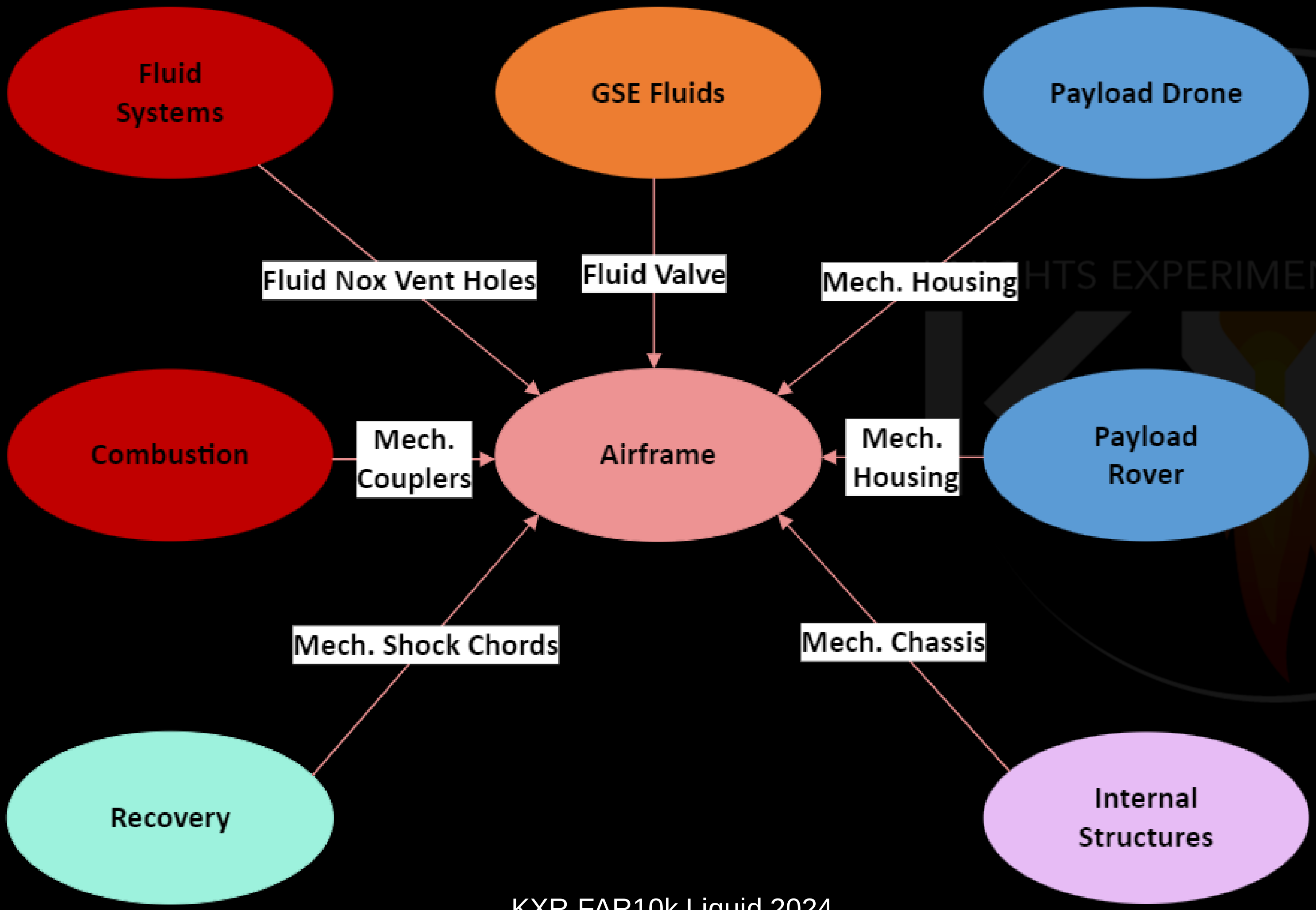
Internal Manufacturing

- Chassis
  - Will purchase stainless steel threaded rods, which we will cut to specified lengths
  - The coupler adapter ("feet") of the struts will be machined out of 6061 aluminum in the machine shop
  - 6 hours to machine
  - 8 pieces in total
- Thrust Plates
  - Will be machined out of 6061 aluminum in the machine shop
- Bulkhead Rings
  - Will be made from COTS G12 couplers
    - We will cut the rings from the coupler and post-process as necessary

Airframe Component Breakdown



Airframe Interface Diagram



Airframe Functional Requirements

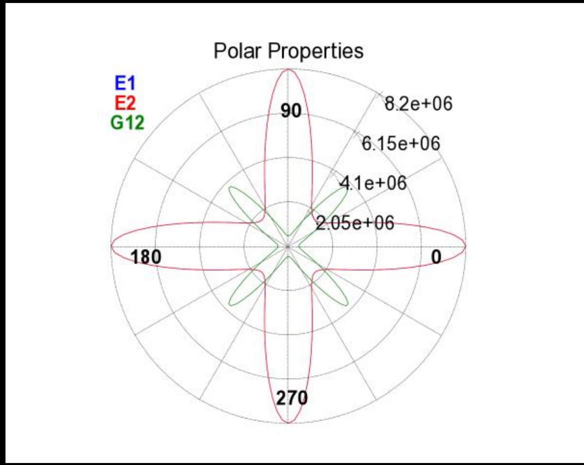
Requirement	Requirement Type	Verification Method
The Airframe Sub-system **will** be optimized for transonic speeds	Functional	Analysis
The Airframe Sub-system **will** provide stability in flight	Functional	Analysis
The Airframe Sub-system **will** withstand flight loads	Functional	Analysis

Airframe TPMS

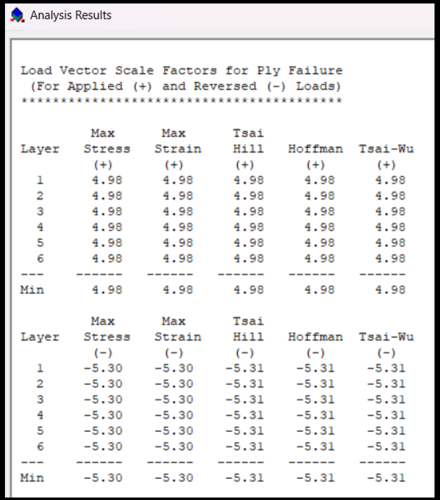
Measure	TPM Value	Units	Verification Method
Snatch Force	1954	lbf	Demonstration
Max Bending Moment	7173	lb-in	Analysis
Max Compressive Load	21309	lbf	Analysis
Lateral Shear	122	lbf	Analysis
Drag Coefficient	0.75	n/a	Analysis
Vibrations (Flutter)	3120	ft/s	Test/Analysis

External Structures Lay-Up

- Body Tubes, Boat Tail & Fins: 3K 2x2 twill weave prepreg carbon fiber
- Nose Cone: Wet-Lay Fiberglass Sleeves
- Methods of calculations : The Laminator, Classical lamination theory, Force Calculator
- Simulation: Ansys ACP



Polar Material Properties



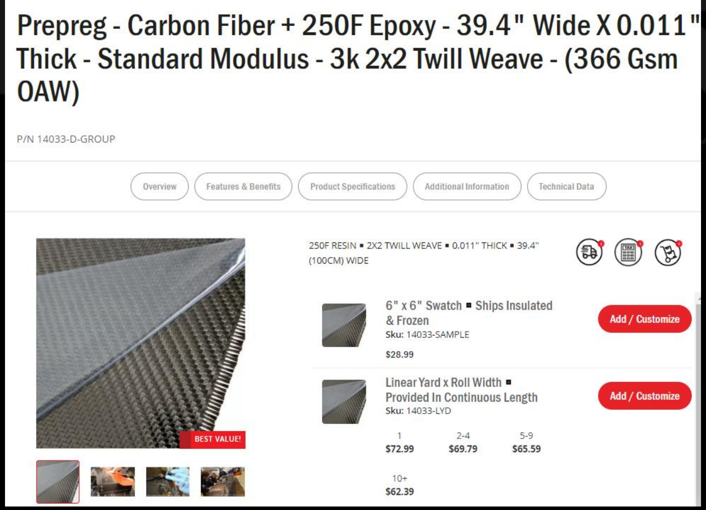
Analysis Results

Load Vector Scale Factors for Ply Failure
(For Applied (+) and Reversed (-) Loads)

Layer	Max Stress (+)	Max Strain (+)	Tsai Hill (+)	Hoffman (+)	Tsai-Wu (+)
1	4.98	4.98	4.98	4.98	4.98
2	4.98	4.98	4.98	4.98	4.98
3	4.98	4.98	4.98	4.98	4.98
4	4.98	4.98	4.98	4.98	4.98
5	4.98	4.98	4.98	4.98	4.98
6	4.98	4.98	4.98	4.98	4.98
Min	4.98	4.98	4.98	4.98	4.98

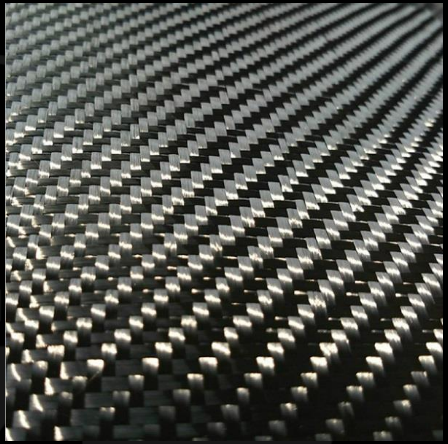
Layer	Max Stress (-)	Max Strain (-)	Tsai Hill (-)	Hoffman (-)	Tsai-Wu (-)
1	-5.30	-5.30	-5.31	-5.31	-5.31
2	-5.30	-5.30	-5.31	-5.31	-5.31
3	-5.30	-5.30	-5.31	-5.31	-5.31
4	-5.30	-5.30	-5.31	-5.31	-5.31
5	-5.30	-5.30	-5.31	-5.31	-5.31
6	-5.30	-5.30	-5.31	-5.31	-5.31
Min	-5.30	-5.30	-5.31	-5.31	-5.31

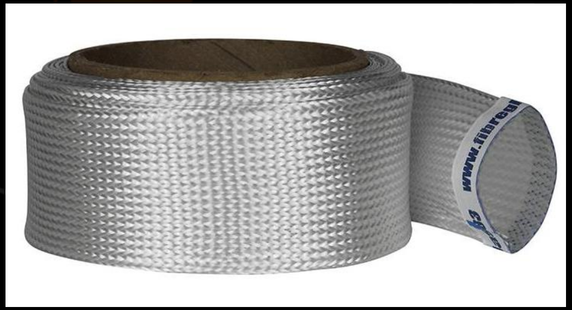
The laminator F.S

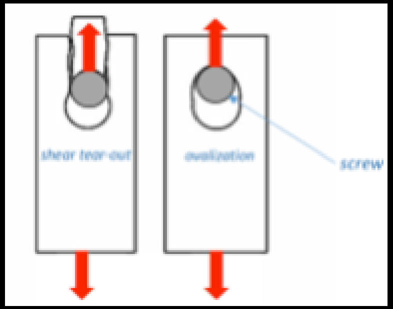


External Structures Lay-Up

Item	Number of Plies	Ply Orientation	Method	Raw Composites Cost
Body Tubes	6	0	Rolling	$1277
Coupler Aero covers "skins"	2	0	Rolling	(integrated in Body tubes)
Nose Cone	6	45/45	Sleeves	$74.9
Boat Tail	8	0	Rolling	$234
Fins	24	0	Hand Laying	$399
Total (+ Tax & Handling)	-	-	-	$2310

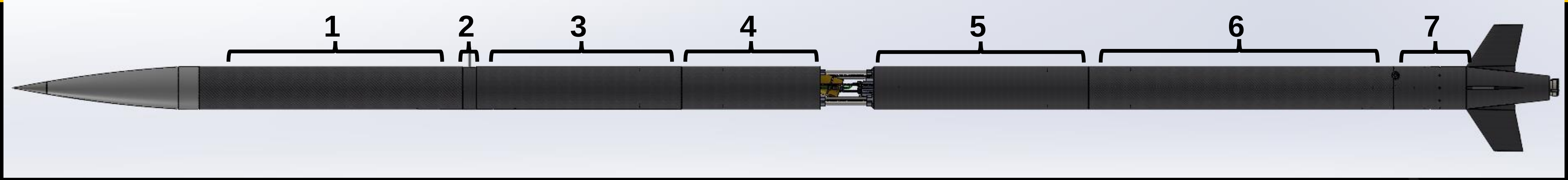

3k 2x2 Twill CF


Bi-Axial FG Sleeve



Edge Distance S.F:
= Distance / Minimum Safe distance
= 3in / 0.375in = 8

Body Tubes / Design



1 Payload Body Tube	2 Recovery Switch Ring	3 Drogue Body Tube	4 Nitrogen Tank Tube	5 Fuel Tank Tube	6 Oxidizer Tank	7 Boat Tail

Body Tube FMECA

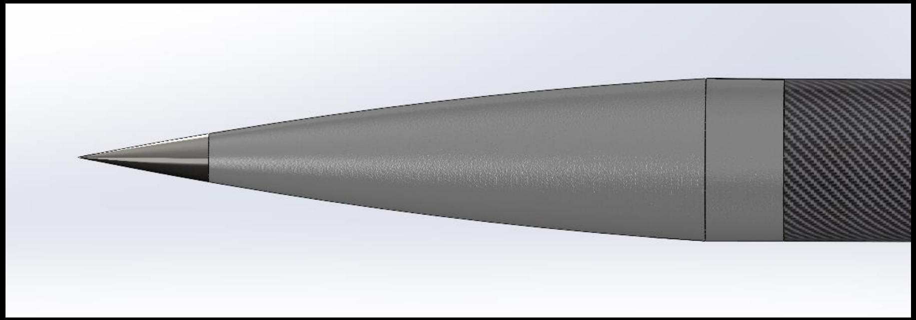
Part	Failure	Criticality	Effect	Mitigation
Body Tubes/Nose Cone/ Boat tail/ fins	Structural Failure	**High**	Complete Mission Failure	Verify Layup and add SF as well as coupon testing
Body Tubes / Nose Cone / Boat Tail	Bolt Shear/ Tear out	**High**	Complete Mission Failure	Optimize the bolt locations

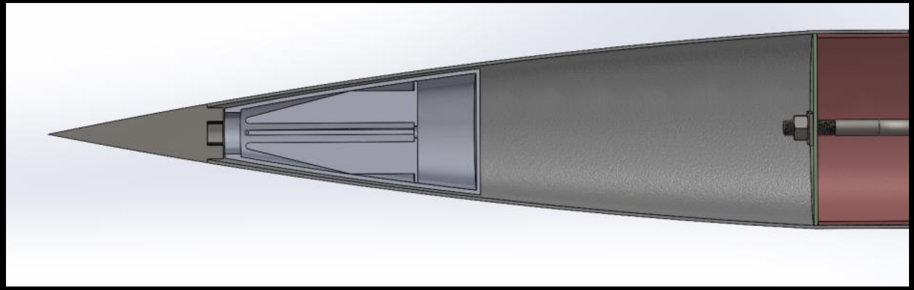
Nose Cone

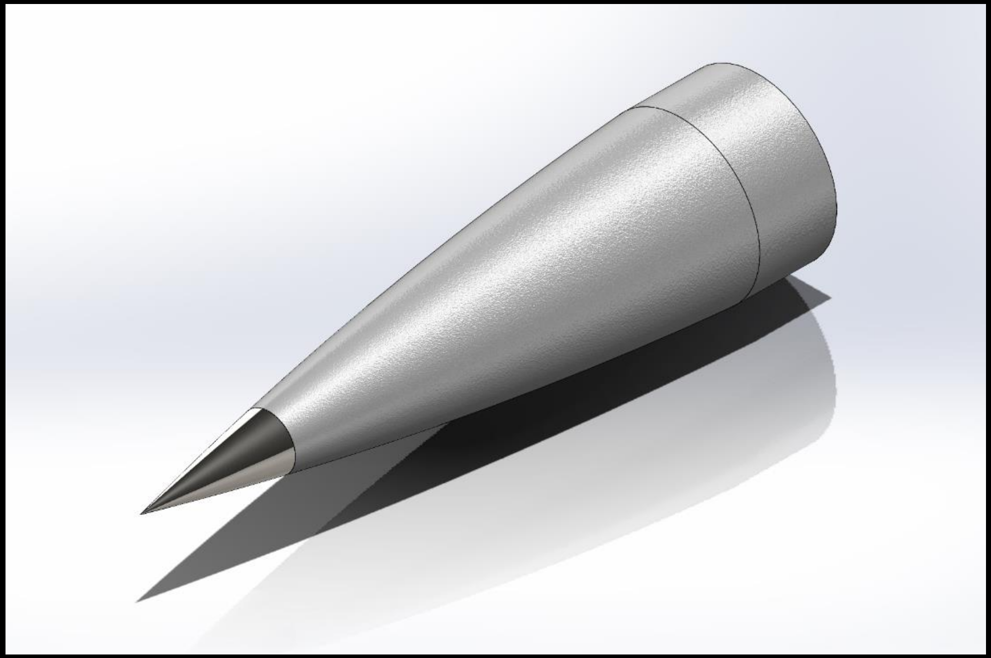
- Parabolic Nose Cone
  - Achieved lowest coefficient of drag between Fluent & OpenRocket with K = 0.7
- Steel Tip
  - Higher density than aluminum adds more stability
  - 1.56 lb

For $0 \leq K' \leq 1 : y = R\left(\frac{2\left(\frac{x}{L}\right) - K'\left(\frac{x}{L}\right)^2}{2 - K'}\right)$

R = 3.1 in
L = 24 in
K = 0.7







Nose Cone TPM

Measure	TPM Value	Unit	Verification Method
Dynamic Pressure	4.1	psi	Force Calculator
Normal Force	30.37	lbf	Force Calculator
Total Drag	96.45	lbf	Force Calculator / ANSYS
Bolt Tear Out (Min-Safe-Distance)	2	in	Force Calculator
Total Compressive Force	371	lbf	Force Calculator

$$Q = \frac{1}{2} * Rho * V^2{}_{Max}$$

$$N_{NOSE} = q\, A\, \alpha\, (C_{N\,\alpha})_N$$

$$D = \frac{1}{2} C_D \rho v^2 A_{ref}$$

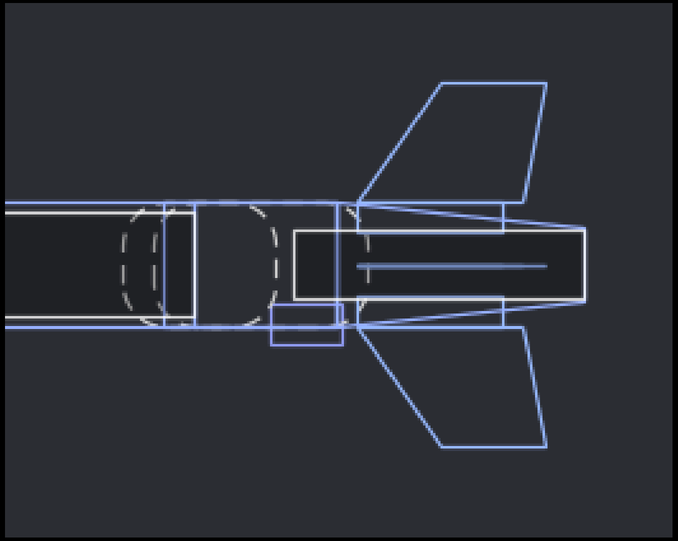
Nose Cone FMECA

Part	Failure	Criticality	Effect	Mitigation
Nose Cone	Fail to reduce drag	Low	Rocket doesn't reach estimated apogee	Keep iterating to produce the most optimized nose cone shape
Nose Cone	Crumples due to compressive load	High	Rockets drag is significantly increased	Design thickness according to calculations with a safety factor
Nose Cone	Breaks on landing impact	Medium	No more re-flyability (Point loss)	Design it to withstand impact with a safety factor

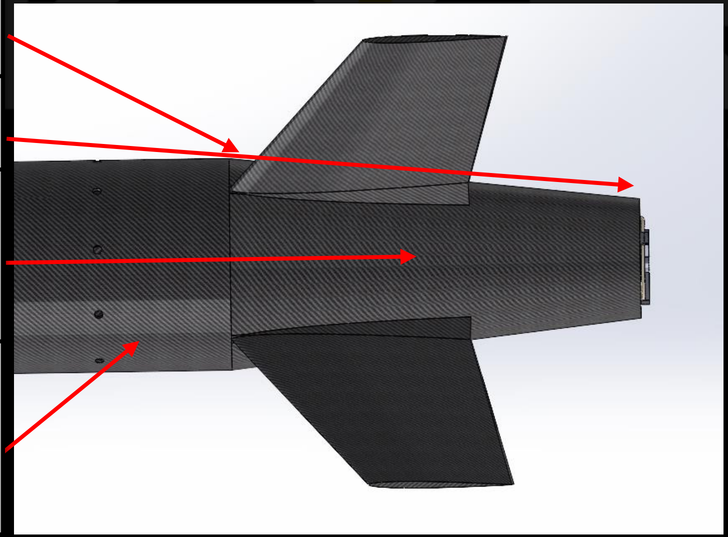
Boat Tail

- Lowest drag coefficient out of all three possible geometries.
  - The boat tail decreases our drag coefficient by 0.095.

Flat Aft	0 (0%)	0.132 (0%)	0.025 (0%)	**0.157 (0%)**
Boat Tail	0 (0%)	0.042 (0%)	0.02 (0%)	**0.062 (0%)**



Fore Radius	6.2 Inches
Aft Radius	3.5 Inches
Length of Taper section	12 Inches
Length of straight section	10.5 Inches



FMECA

Part	Failure	Criticality	Effect	Mitigation
Boat Tail	Fail to reduce drag	Low	Rocket doesn't reach estimated apogee	Keep iterating to produce the most optimized aft end shape
Boat Tail	Breaks upon ground impact	Medium	Rocket no longer has re-flyability (Point Loss)	Design to withstand ground impact with safety factor

Water Ballast

Function/ Performance:

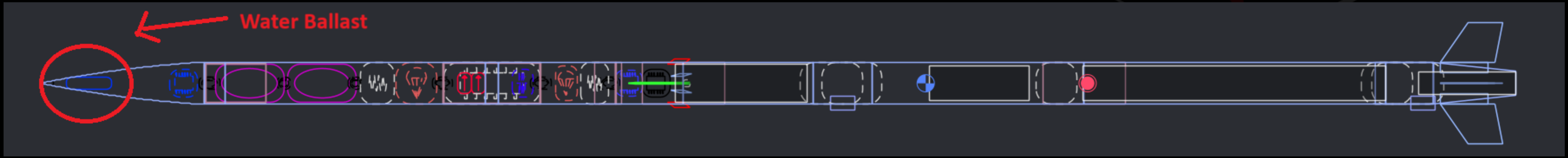
- Add weight for ascent
- Removed at descent or apogee
- Gain 1000 points
- Threaded Rod should sustain snatch force

Characteristics – TPM values:

- 500ml of water (1.1 lbs)
- Nose Cone Tip Weight (~1.6 lbs)

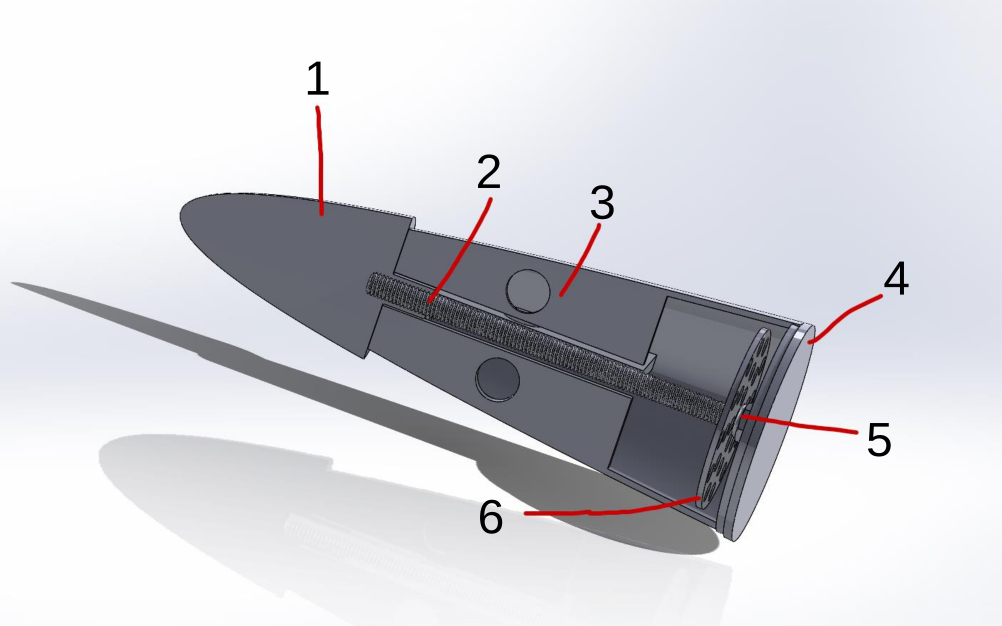
Geometry

- We're pursuing a trans-sonic and subsonic design until we get our actual values.



Water Ballast (cont'd)

Parts:
1 – Nose Cone Tip
2 – Threaded Rod
3 - Baffles
4 - Lid
5 – Lock Nut
6 – Mesh Plate



Materials: Polycarbonate 3d print for Water containment portion

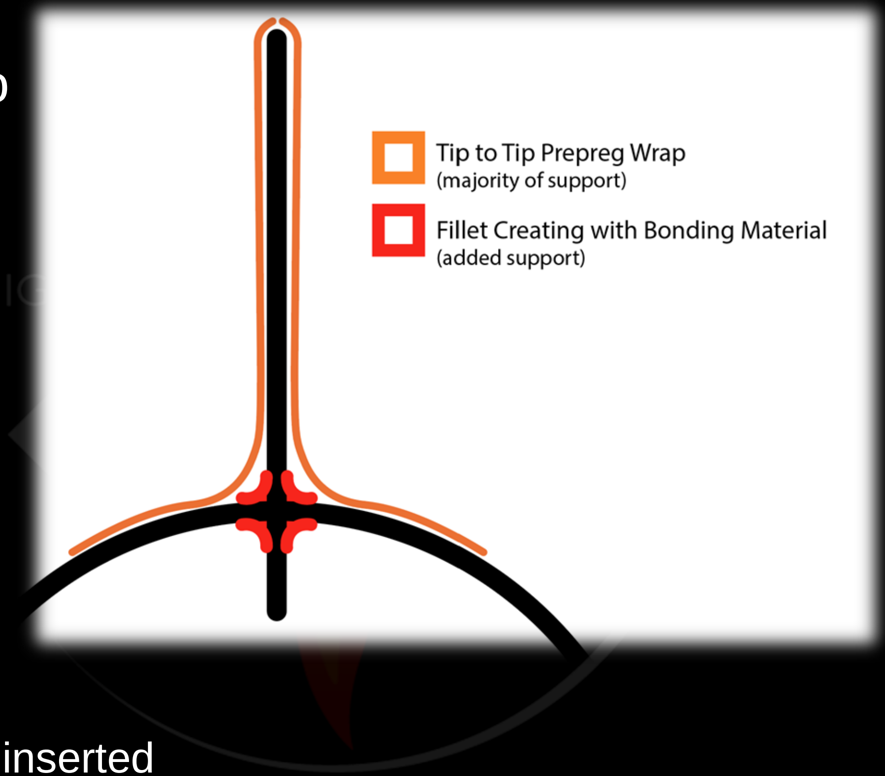
- Threaded rod
- Lock nut
- Nose cone tip made of steel

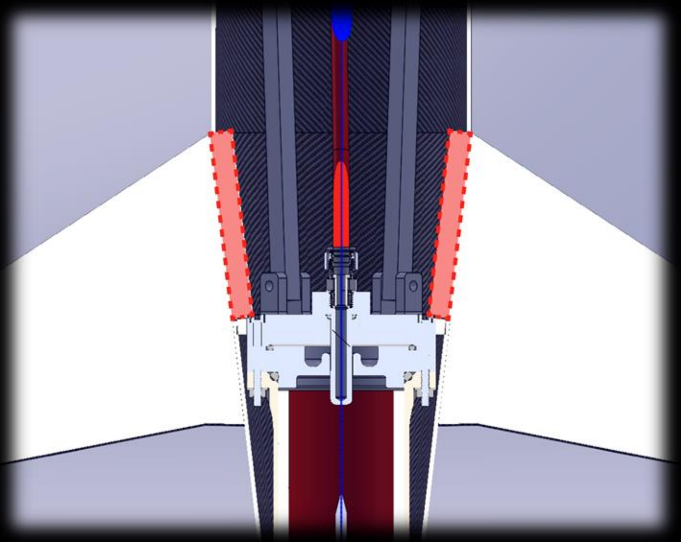
Water Ballast FMECA

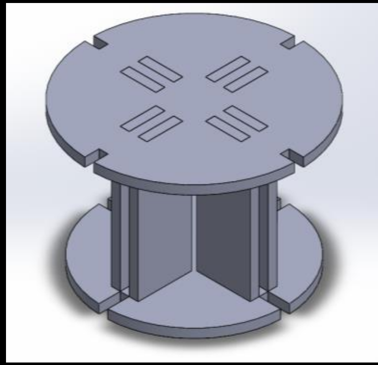
Part	Failure	Criticality	Effect	Mitigation
Nose Cone Tip	Fails to Detach	Low	Water fails to release	Tolerance between nose cone tip and water ballast is increased
Baffles	Threaded Rod crushes baffles	Low	Baffles are damaged	Baffle Width is increased
Lid	Fails to seal water	Low	Chance of damaging electronics	Epoxy is used to seal the Water Containment
Mesh	Mesh breaks	High	The nose cone tip can separate from the main rocket creating a safety problem	Mesh becomes thicker.

Fin Cage Component Breakdown

- Our rocket will alternatively use fillets on each corner of contact for the fin tabs, as well as tip to tip pre preg wrap to support each fin
- This decision was made for the sake of simpler integration with the CC and thrust plate
- A support will be made and laser cut for holding the fins in place while they cure, then will be removed.







Fin tabs are inserted into an internal and external centering jig for manufacturing

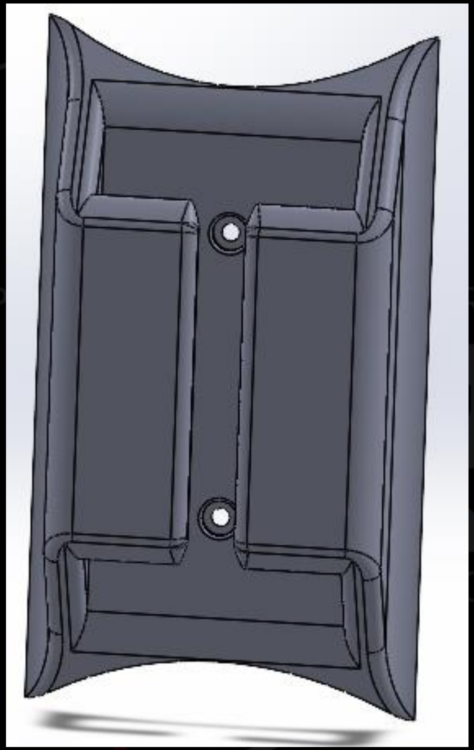
Rail Guides Component Breakdown

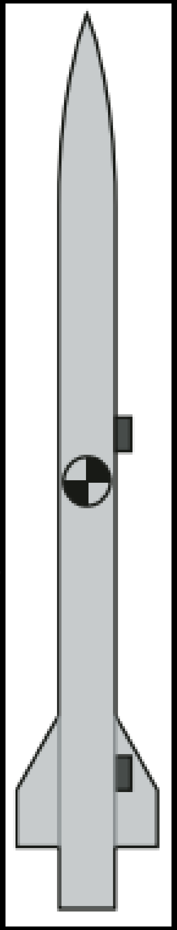
Function/ Performance:

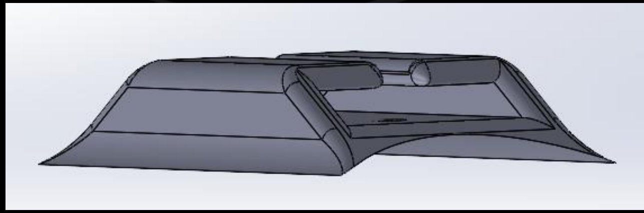
- Hold rocket to rail
  - Supports rocket so stability can effectively develop
  - Prevents any misalignment of trajectory during launch
- Permanent feature, now a part of rocket and influences flight character

- Upstream guide: ~115 inches from the nose tip
- Downstream guide: ~205 inches from the nose tip

Item	Full Item Description	Cost	Quantity	Total	Link (not hyperlink)
Polycarbonate filament	Black PC Filament 1.75 mm 3D Printer Filament 1 KG Spool 2.2LBS Dimensional Accuracy +/- 0.05mm 3D Printing Polycarbonate Material	$25	2	$50	CC3D global
Screws	Alloy steel socket head screws.1-72. Item number 91251A068	$7.23	1	$7.23	McMaster-Carr
nuts	High strength steel hex nuts. Item number 94895A815	$10.92	1	10.92	McMaster-Carr
Graphene powder	Lucky Line 4.5 Grams of Dry Lock Lubricant Graphite Powder for Pin Tumbler Locks, 1 Tube (95001)	$3	2	$6	Lucky Line







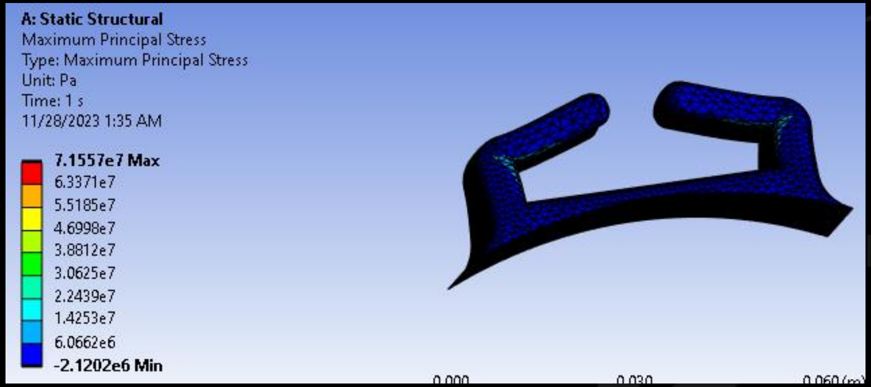
Rail Guides Component Breakdown

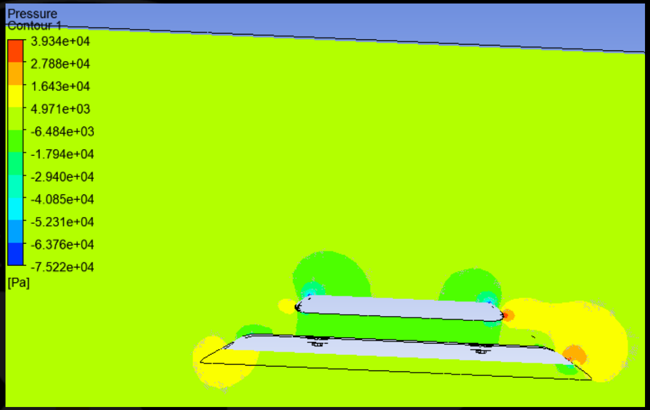
Designed and evaluated at 600lbs

Estimated Factor of Safety of 2.78

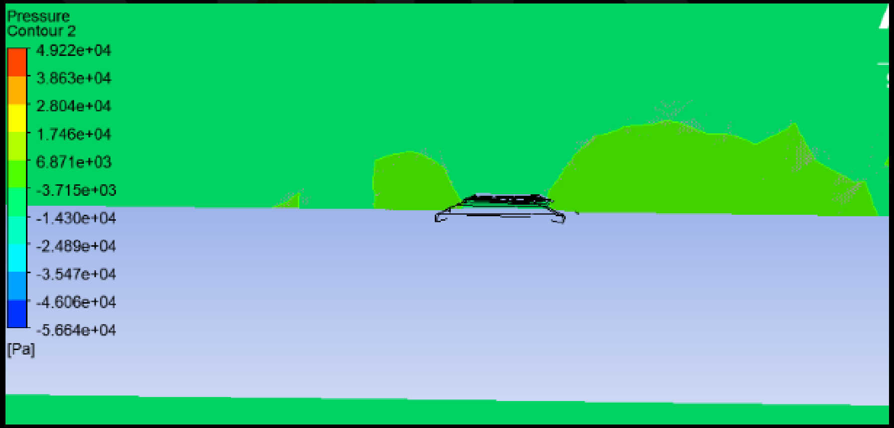
$$P_f L_f + P_a L_a - \mu \left| P_f + P_a \right| R_T = 0$$

- Back plate will be utilized





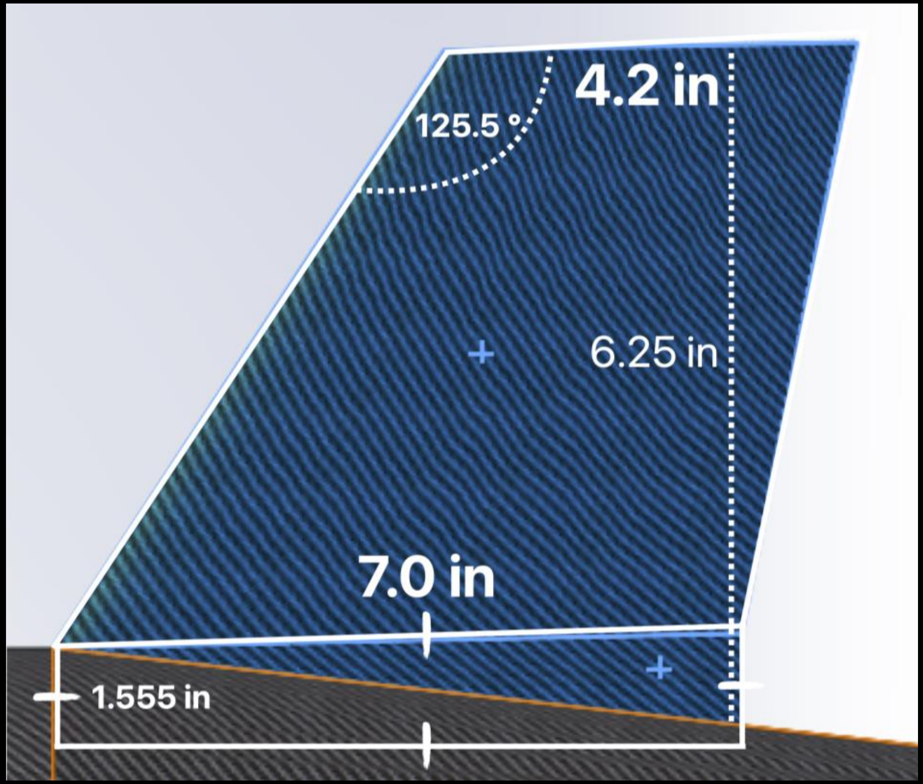
Measure	TPM Value	Units	Verification Method
Resisted launch force	600	lbf	Testing
Mount length	4	inches	Demonstration
Mount height	1	inches	Demonstration
Drag from mount	4000	Pa	Analysis



FMECA

Part	Failure	Criticality	Effect	Mitigation
Bolt	Bolt tear out	High	Rail guides shear off, rocket fails to develop stability. Launch failure	Choose bolts with high strengths, design guides to be thick on face with rocket. Employ back plate
Rail guides	Flange failure	High	Rail flanges tear off, rocket fails to develop stability. Launch failure	Thicken flanges to withstand high safety factor

Fins

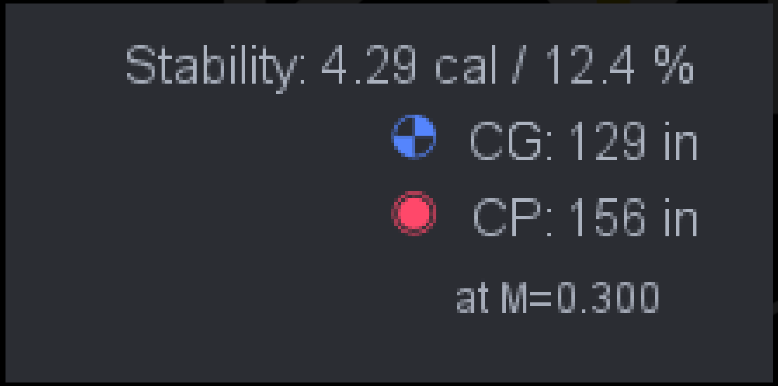


Function/ Performance:

- Shall resist all loads and vibrations experienced in flight.
- The fins shall provide passive stability to the vehicle.

Characteristics – TPM values:

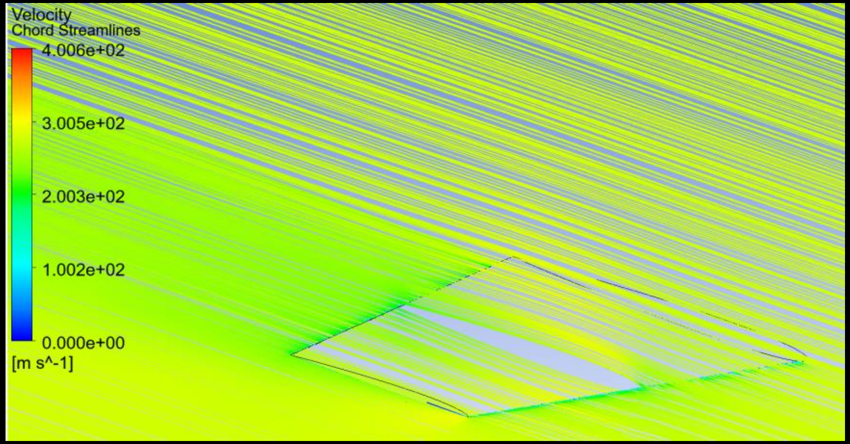
- Pressure [11.66 psi]
- Fin flutter velocity [3055 ft/s] - safety factor of [3.92]

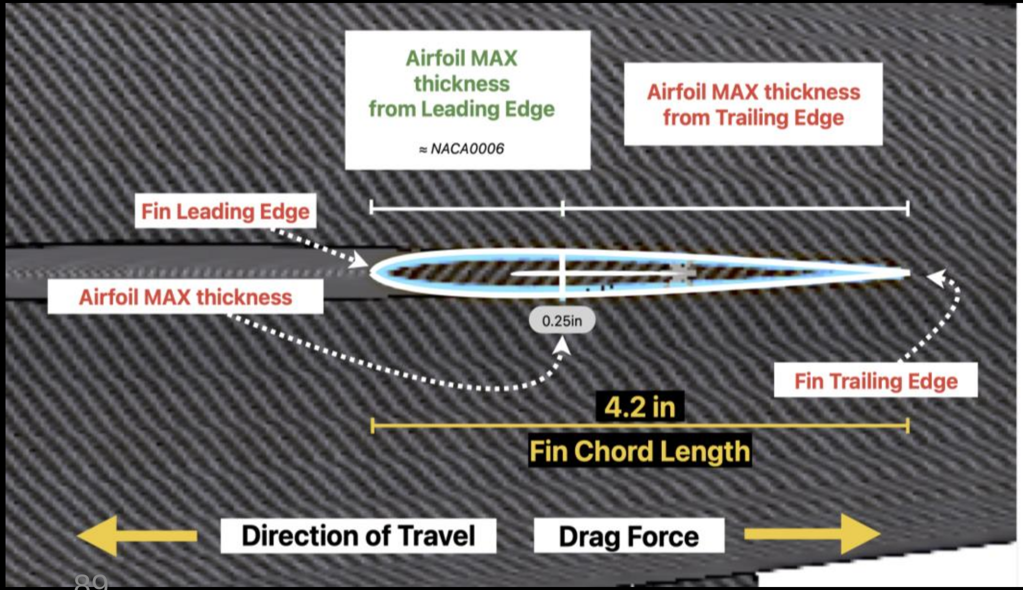


Fins

Part	Failure	Criticality	Effect	Mitigation
Fin	Flutter	High	Vibration	Make thicker/Shorter
Fin	Drag	Low	Decreased Apogee	Airfoil
Airfoil	Manufacturing	Medium	Time/Budget	Tolerance

Airfoil





Function/ Performance:

- Airfoil should minimize the aerodynamic forces acting on the vehicle.

Characteristics – TPM values:

- Pressure [11.66 psi]
- Fin flutter velocity [3055 ft/s] - safety factor of [3.92]

Drag coefficient	Value
Pressure Cd	1.15E-04
Viscous Cd	1.51E-04
Total (drag) Cd	2.66E-04

$$y_t = 5t\left[0.2969\sqrt{x} - 0.1260x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4\right],$$ [5][6]

where:

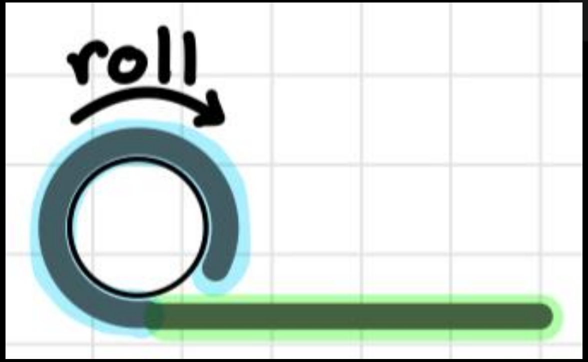
x is the position along the chord from 0 to 1.00 (0 to 100%),

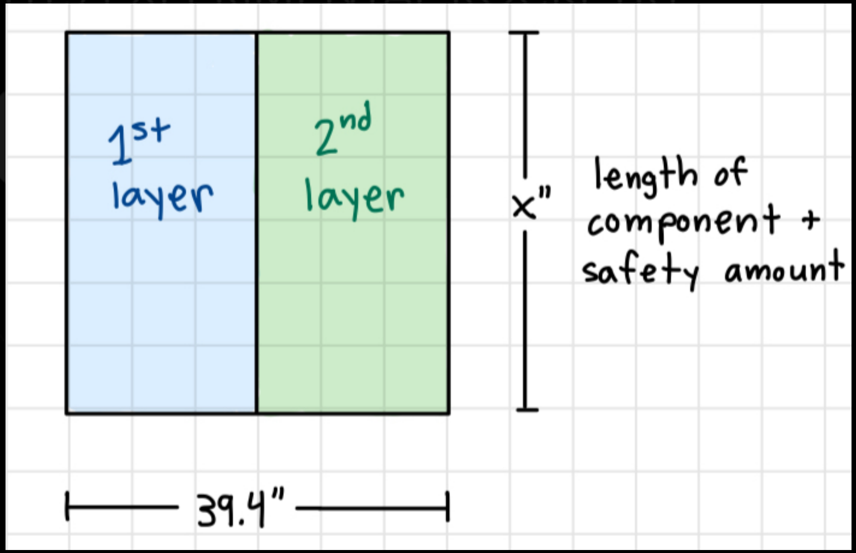
y_t is the half thickness at a given value of x (centerline to surface),

t is the maximum thickness as a fraction of the chord (so t gives the last two digits in the NACA 4-digit denomination divided by 100).

Airframe Manufacturing

- Tubes
  - Made of 3k 2x2 twill weave prepreg carbon fiber
  - Roll the prepreg around a 6 in. metal mandril to build up layers and form the tube
    - Width of pre-preg is 39.4 in, which is twice the circumference, so one sheet will have 2 layers
    - Roll 3 sheets in total to make 6 plys
  - Cure tube in autoclave and post-process as necessary
  - Will need to manufacture 5 separate tubes*
    - Payload body tube: 38 inches
    - Recovery switch band: 2 inches
    - Lower recovery tube: 27 inches
    - N tank tube: 19 inches
    - Fuel tube: 31 inches
    - OX tube: 44 inches

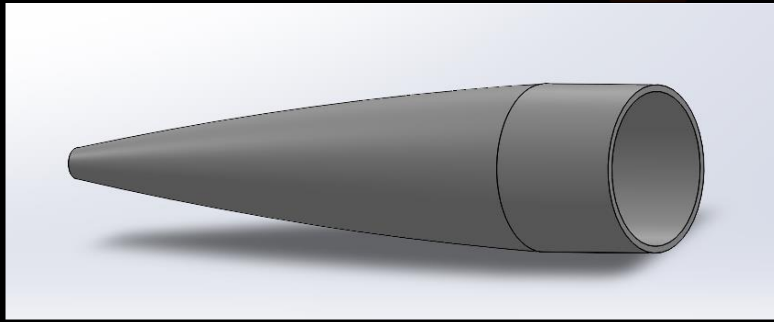




*the recovery switch band (length/material) will be added and cut from the lower recovery tube piece

Airframe Manufacturing Contd.

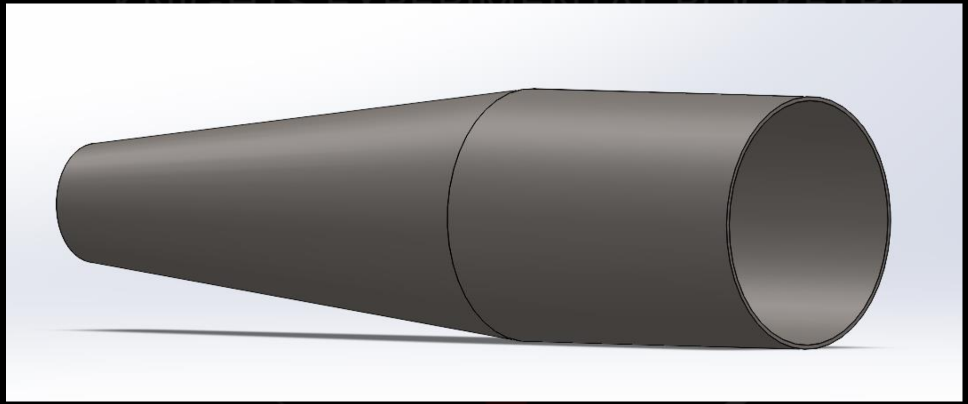
- Nose Cone
  - Mold: Male mold; 3D-printed out of PLA plastic with extra length on ends as safety factor for material
    - Will take about 5 days to print
    - Will be printed in separate sections due to the size constraints of the 3D printer
      - These will be glued together, most likely with E6000
  - Wet-lay fiberglass sleeves over the 3D-printed male mold, according to lay-up schedule
  - Composite will be vacuumed and sealed in Autoclave
- Tip machined from 2 in. diameter steel rod
    - Will take 1-2 days to machine



- Water Ballast
  - 3D printed out of PLA
    - Will take only a few hours to print
  - The COTS threaded rod will be cut to size by us

Airframe Manufacturing contd.

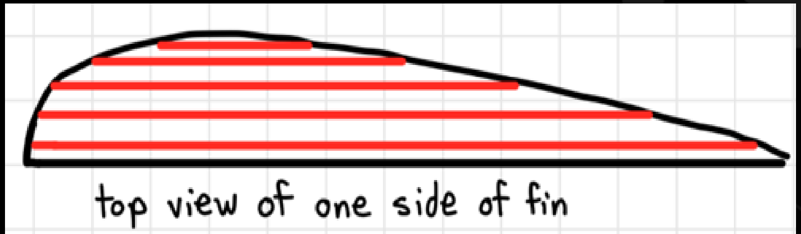
- Boat Tail
  - Made from carbon fiber pre-preg
    - Will 3D print a male mold out of polycarbonate plastic (PCP)
      - It will be 3D printed in separate sections due to size constraints of the 3D printer, glued together most likely with a high temp. epoxy
  - Will need to apply 8 layers of prepreg
    - Cure composite in the autoclave
  - Then, insert the fins with epoxy and fillet them to the tail cone
    - May need a high temp epoxy/glue

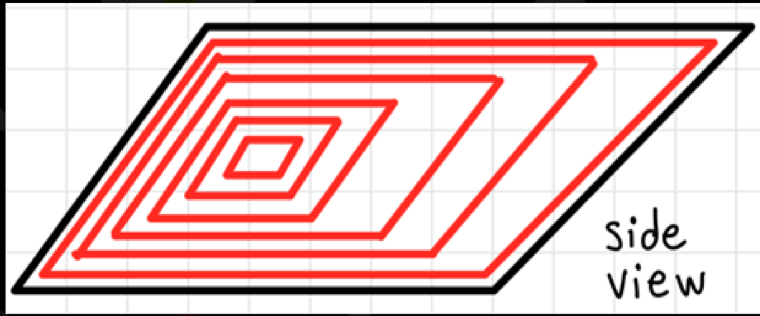


  - Then the tail cone will go back into the autoclave and cure to cement the fins in place

Airframe Manufacturing Contd.

- Fin Cage
  - The material will be G10 fiberglass
    - The parts will be laser cut at a fabrication center and then assembled by us
- Fins
  - Will be tapered, swept, trapezoidal and made from layered pre-preg
    - There will be a total of four fins.
    - The measurements are as follows:
      - Root chord – 7.5in
      - Tip chord – 5in
      - Height – 5in
      - Swept length – 2.5in
      - Sweep angle – 26.5in

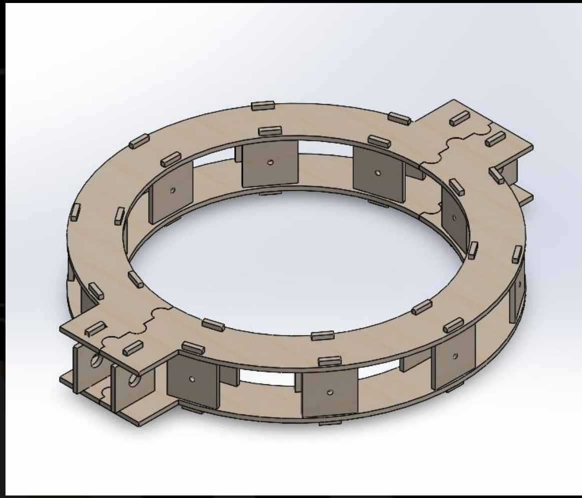


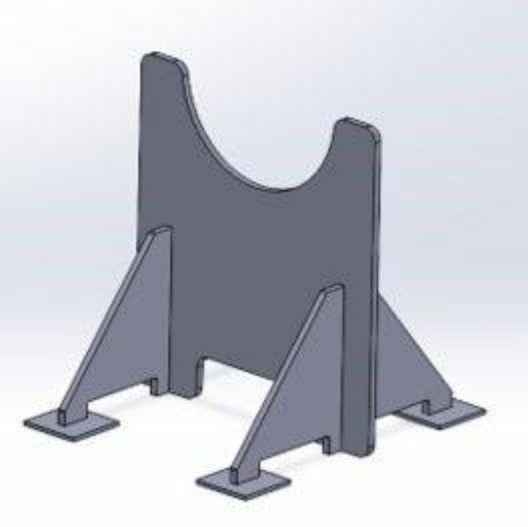


  - The airfoil will be NACA0006
  - The pre-preg will be cut to different lengths and shapes which will be stacked up to form the airfoil
    - This layering technique will be done for each side of the fin

Airframe Manufacturing Contd.

- Holes
  - We will be using the drilling collar to make our holes even spaced and the correct size
- Jigs
  - For drilling we have a drilling collar made from plywood
  - The drilling collar will double as our cutting collar
  - The rocket stands will be made from plywood and cut with the laser cutter in the TI Lab
- Rail Guides
  - 3D printed out of polycarbonate plastic





Manufacturing Process Plan (MPP)

Mix Epoxy/Resin for Layer 1	4	Epoxy/ Resin components are mixed to the proper ratio	Read the instructions on the Epoxy/Resin label to find the proper mixing ratios. Follow the instructions to a tee to ensure best results. Mix your Epoxy/Resin **ONE LAYER AT A TIME.** eg. mix epoxy for layer 1, lay fiberglass+epoxy for layer 1. Then mix and lay for layer 2, etc.	gloves, goggles,respirator, popsicle sticks, Epoxy/Resin, mixing cups	DO NOT MIX the resin and hardner until you are ready to lay. Be ready to work quickly from this point on, the Epoxy/Resin will cure quickly so be sure to have your fiberglass and mold ready to rock.
Seal Mold	5	Seal mold with layer of resin	Apply a layer of resin to the mold to seal any tiny pores or gaps in the material before laying fiberglass.	gloves, goggles, respirator, mixed Epoxy/Resin, paint brush	Especially necessary if chosen mold is wood.
Lay First Layer of Material	6	Material is oriented correct, no bubbles	Lay material on top of first resin coat, ensure it's laid in the correct direction, smooth out the material with gloved hands	1st layer of fiberglass, gloves	
Apply Epoxy/Resin Mix	7	Even layer coats entire surface of material	Use paint brushes to evenly coat the material with the resin mixture.	epoxy/resin mix, gloves, paint brushes	The exoxy/resin mix should be a specific amount proportional to the amount of material being covered. Use expocy calcultor to calculate amount of mix
Repeat steps 10-11	8		Repeat steps 10-11 until all layers are complete		

Steps 4 - 8 of Fiberglass Coupon for nose cone

Apply Carbon Fiber Prepreg	4	6 plys of carbon fiber prepreg must be applied	Apply each layer in the same direction	PrePreg Carbon Fiber, Scissors, Gloves	If carbon fiber bubbles or wrinkles, remove said ply and start again
Apply release film over carbon fiber	5	1 layer of release film must be evenly placed on carbon fiber surfaces	Must be even and wrinkle free	Release film, scissors	
Apply breather cloth over	6	Wrap liberal amount of breather cloth over composite surface	Must cover entirty of the mandrel	Breather cloth, scissors	
Vaccum Bag entire mandrel	7	Create an envelope bag with gum tape and insert test coupon	Bag must be totally sealed	Vacuum bag, vacuum sealent tape, scissors	
Insert Vacuum Connector	8	Place vacuum connector through bag	Bag must be totally sealed	Vacuum connector, Scissors	
Pull Vacuum in Autoclave	9	Pull 1 atmosphere of vacuum pressure	Ensure vacuum holds	Autoclave	
Cure tube in Autoclave	10	Run cure cycle	Cure for 1 hour at 250F	Autoclave	
Remove Vacuum supplies	11	Cut test coupon out of vacuum bag	Ensure all breather cloth and vacuum supplies are removed	Scissors	

Steps 4 – 11 of Carbon Fiber prepreg coupons for tubes and tail cone

- All the test coupon MPPs are finished, except for the fins' coupon, which is still being fleshed out. These MMPs include:
  - Body tube test coupon
  - Tail Cone test coupon
  - Nose Cone test coupon
  - Fin test coupon

Machine Costs and Printing Times

- Nose Cone
  - Mold: 5 days to 3D print*
  - Water Ballast: a few hours to 3D print*
  - Nose Cone Tip: 2-3 hours to machine, the material is free. Total cost is < $100.
- Tail Cone
  - Mold will take 4 days to 3D print*
- Chassis
  - 10 hours to machine
  - Material cost $150
  - Total cost to manufacture is $500
- Thrust Plate
  - 3.5 hours to machine
  - Will cost $158

*only cost is for filament, between $30-40

Manufacturing Schedule

- Largely dependent on when materials arrive
  - Best case Jan. – Apr., worst case Jan. – May.

1 – 5 Jan:
Make test coupons and send out to lab for testing

8 – 12 Jan:
Review test data
Prepare to make first tube (finalize body tube MPP, repair mandrel)

Jan. 14:
Drawings finished for machined parts (all except nose cone tip)

Jan 15 – Feb 16:
Submit drawings to machine shop.
Make pre-preg body tubes.

Feb 19 – Mar 1:
Finalize molds + start printing them
Start fins

Mar 4 – 8:
Finish fins

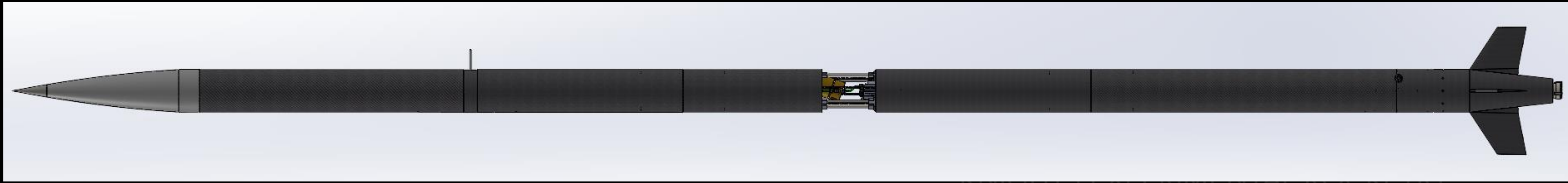
Mar 11 – 15:
Make tail cone

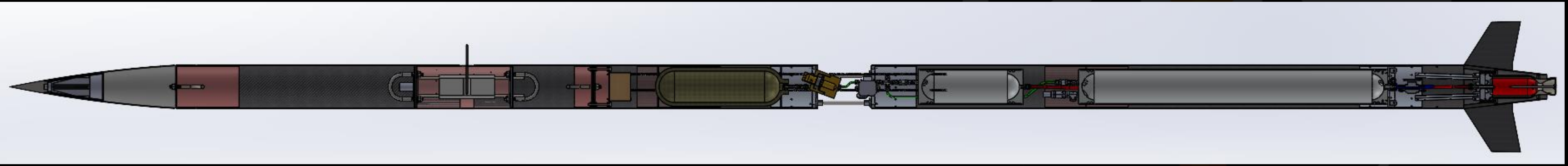
Mar 18 – 22: spring break
Start nose cone (if possible)

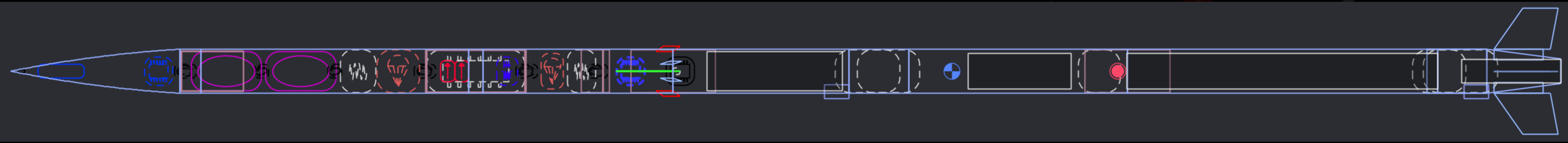
Mar 25 – 29:
Finish nose cone
Print water ballast
Machine nose cone tip

Month of April:
Post-processing, assembly

Questions?







CAD and Open Rocket

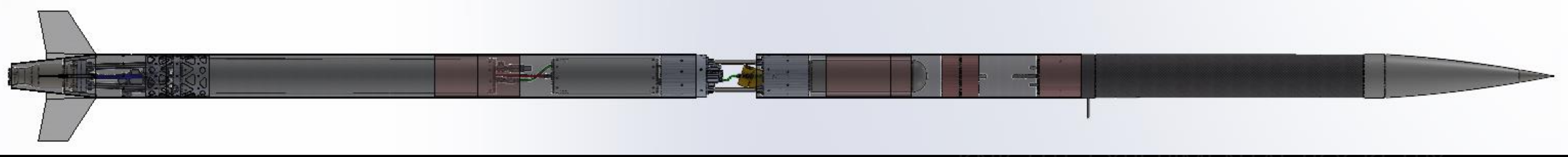
KNIGHTS EXPERIMENTAL ROCKETRY

KXR

at UCF

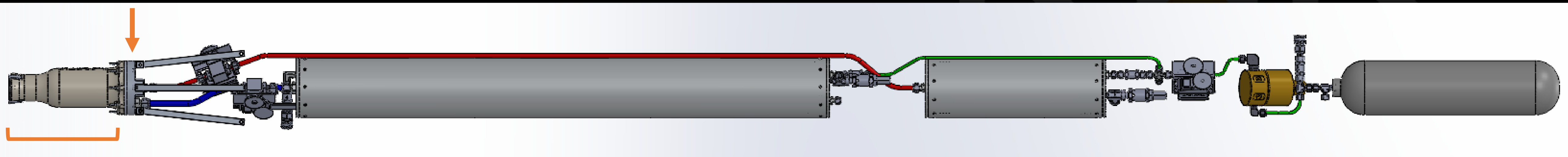
FAR 10k Propulsion CDR

Propulsion System



Fluids Subsystem

Injector



Combustion Chamber

Oxidizer Tank

Fuel Tank

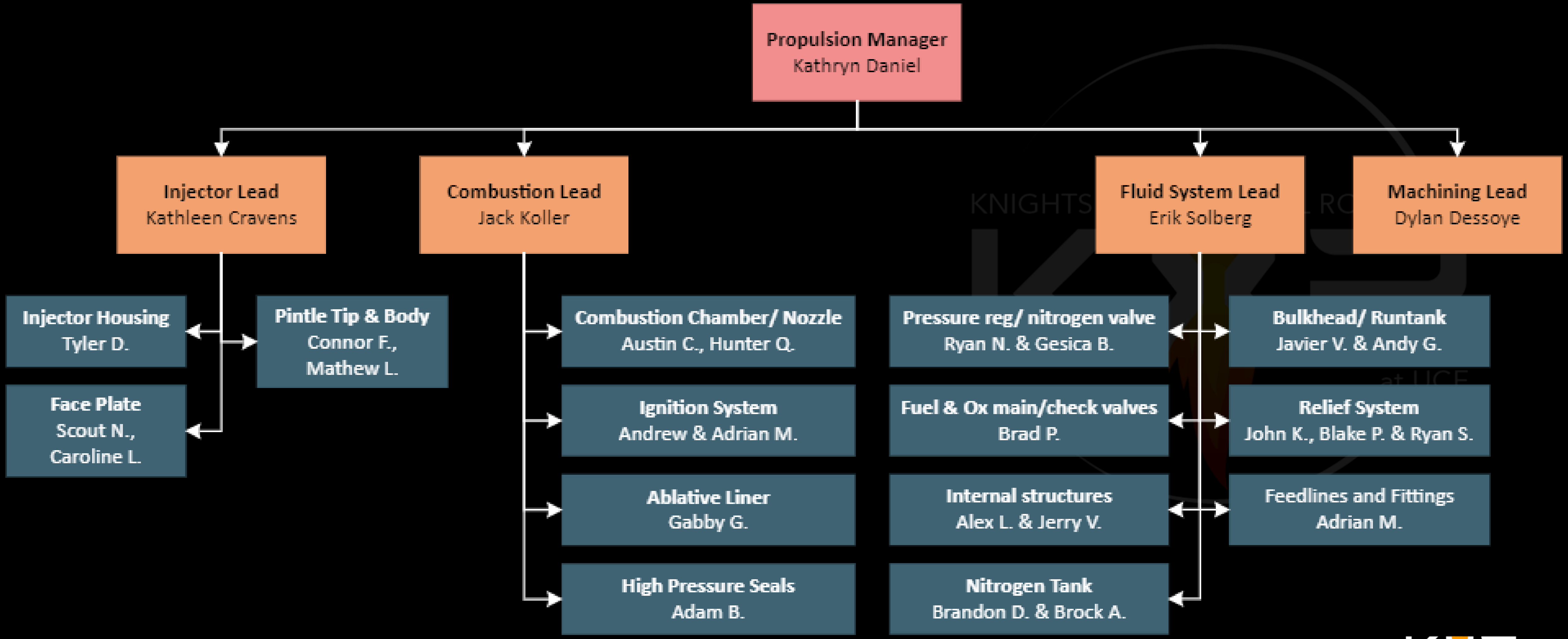
Nitrogen Tank

Propulsion System Overview

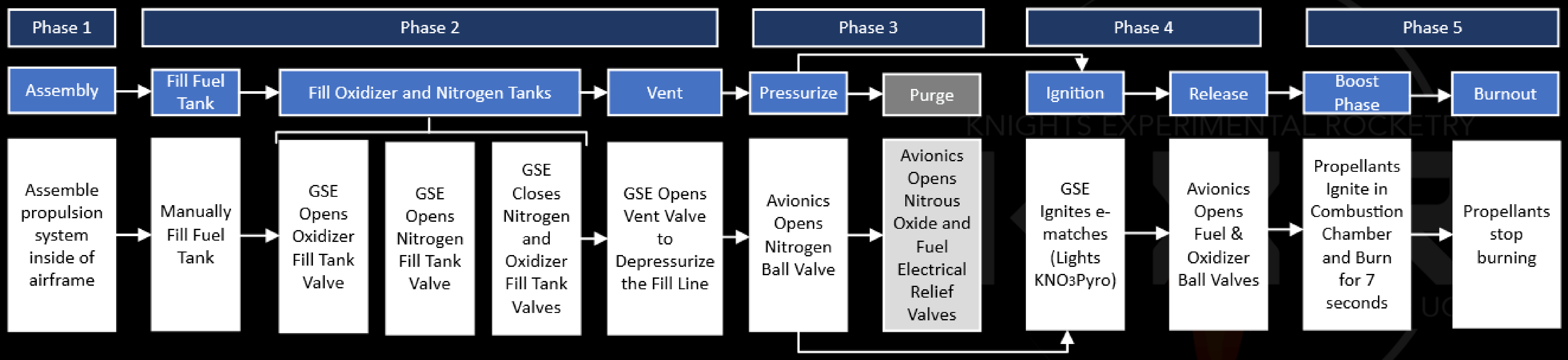
Propulsion Functions

- Remotely controlled
- Generates thrust
- Stores and deliver propellants and pressurant throughout the system
- Indicates tank capacities
- Safely pressurizes and depressurizes the run tank

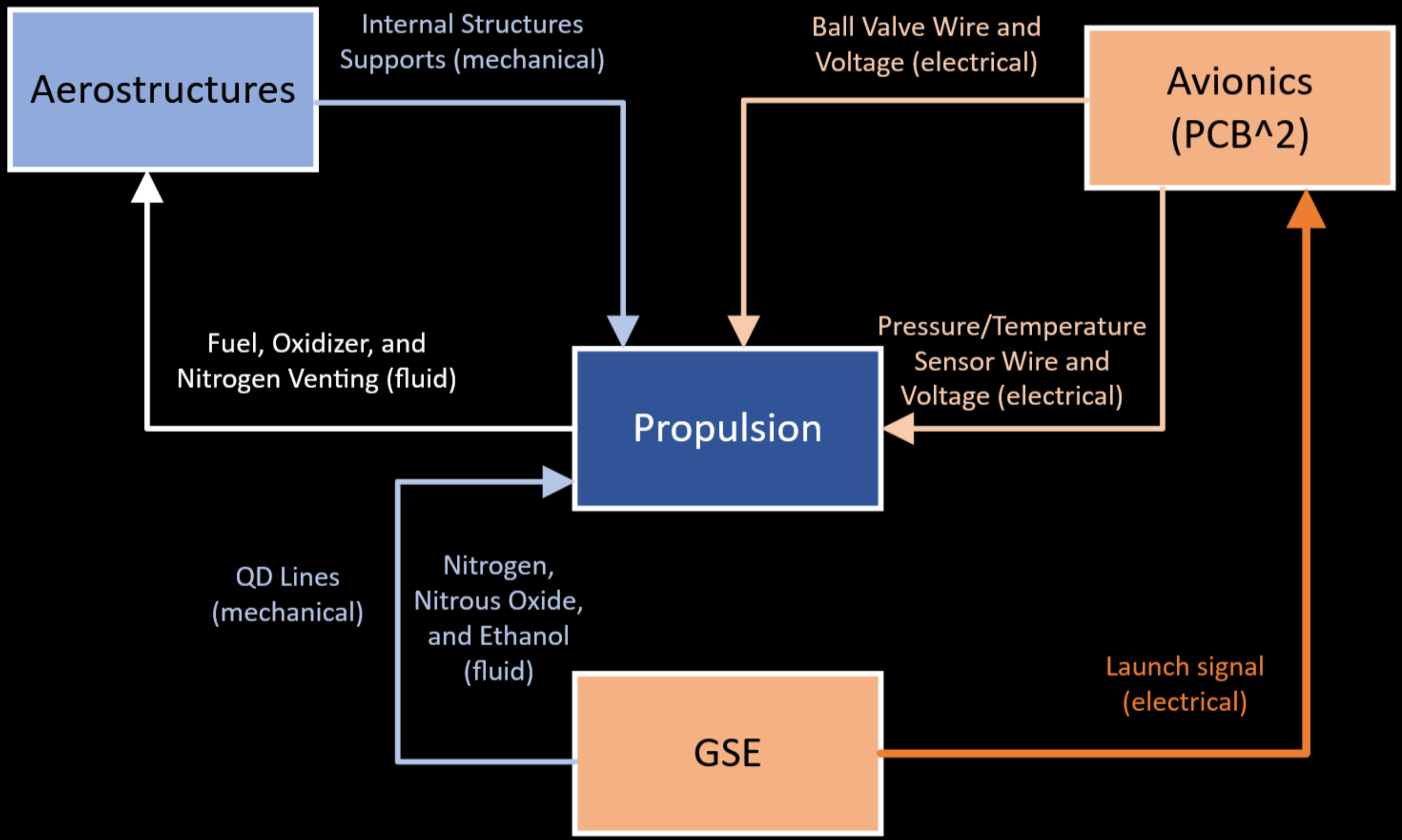
Propulsion Org Chart



Propulsion CONOPS



Propulsion Interface Diagram



Propulsion System TPMs

Technical Performance Measure	Value	Unit	Verification Method
Total Dry Mass	59.6	lbs	Inspection
Total Wet Mass	83.879	lbs	Test
Total Propellant Mass	24.279	lbs	Test
Total Length	10.83	ft	Inspection
Burn Time	9	s	Test
Total Mass Flow Rate	2.5	lb/s	Analysis
Oxidizer/Fuel Ratio	3:01		Analysis
Maximum Thrust	550	lbs	Test
Specific Impulse	212.6	s	Test
Delta V	324.3326	m/s	Test
Target Apogee	10,000	ft	Test

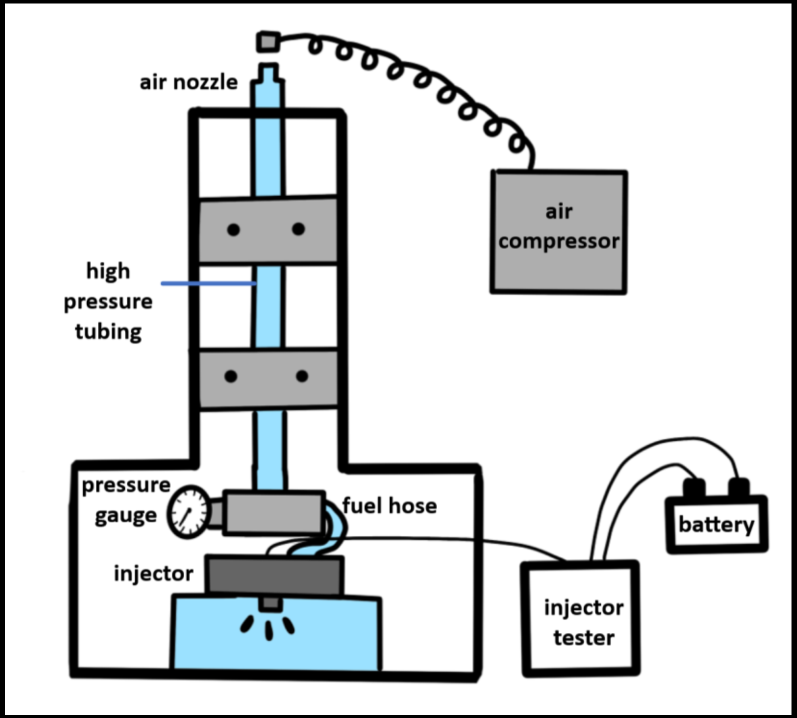
Propulsion System Verification Methods

Pneumatic Injector Test

- Pressurizes water through injector to simulate propellant mixing

Verifies:

- Injector withstands injection pressures



Hydrostatic Test

- Pressurizes the run tanks using water to measure leaks and deformation

Verifies:

- Fluids system withstands hoop stress and bolt shear and maintains pressures without leaks

Propulsion System Verification Methods

Cold Flow Test

- Full setup of fluids system and injector using nitrous oxide and isopropyl alcohol

Verifies:

- Fluids system maintains pressures without leaks
- interfaces correctly with avionics and GSE
- provides sufficient propellants for duration of the burn time
- Injector withstands injector pressures and mixes pressurants

Static Fire

- Full setup and ignition of propulsion system

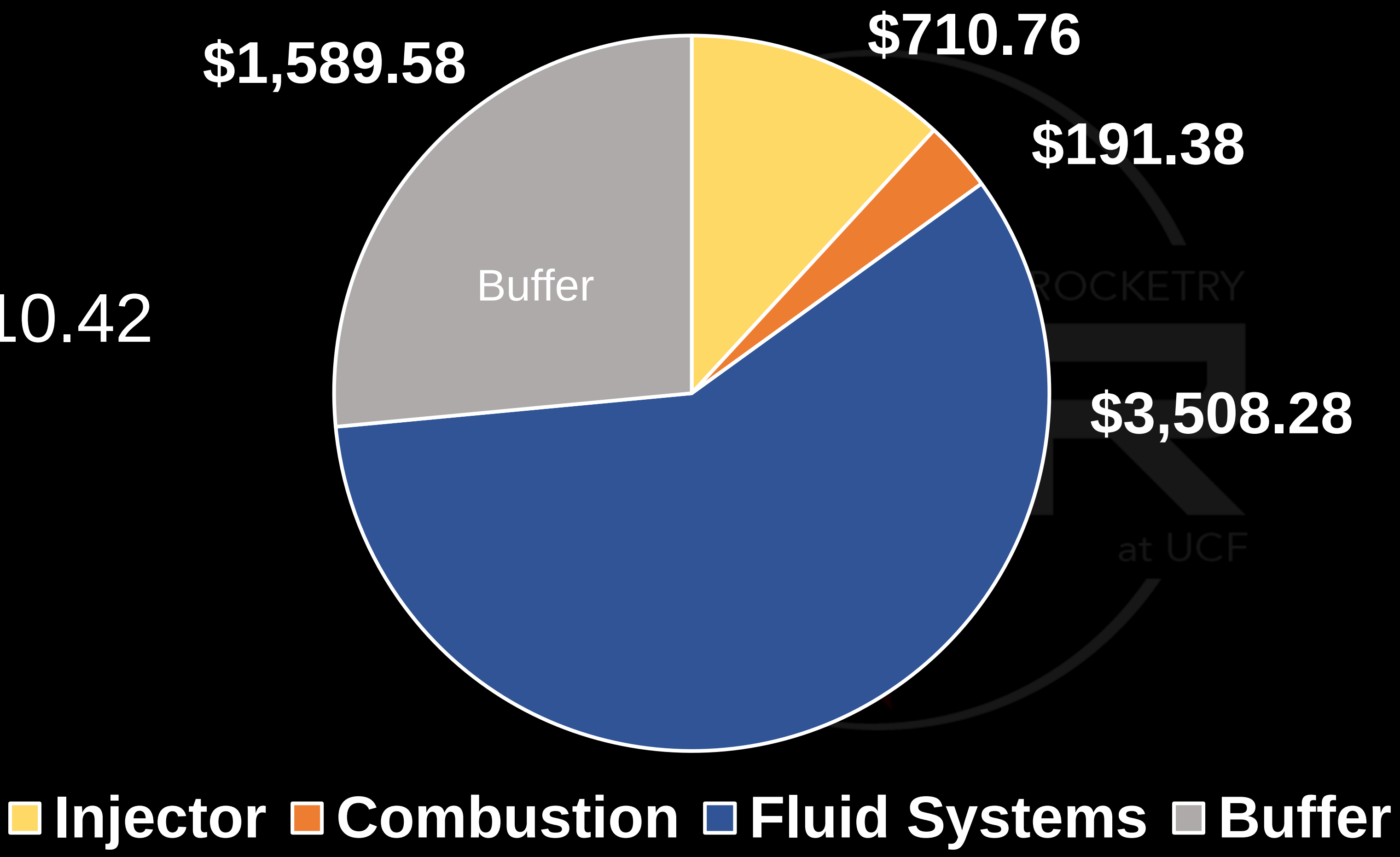
Verifies:

- Thrust data, from GSE
- Propulsion system is reusable
- Fluids system interfaces with avionics and GSE

Propulsion Cost

Budgeted ~ $6,000

Propulsion total used ~ $4,410.42

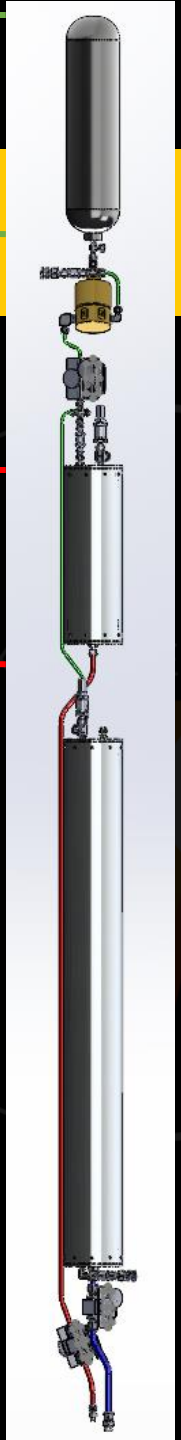


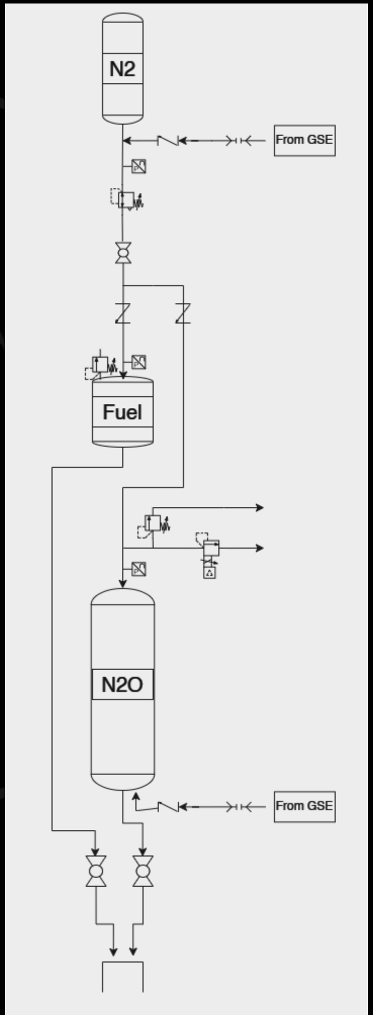
Propulsion System FMECA

System	Failure	Effect	Criticality	Mitigation
Propulsion	Low Initial Thrust	Low initial thrust can cause the rocket to have a low velocity off the rail resulting in instability and a poor flight profile	Medium	Static fire engine and analyze thrust profile, minimize weight of the rocket in order to achieve higher velocity off the rail
Propulsion	Exceeding weight requirement	Exceeding the weight requirement will severely impact the stability and therefore apogee of the rocket, or cause schedule delays in redesign	High	Regularly analyze the and update the wight of the design in CAD, communicate with aerostructures whenever the weight is updated. Select components and design for minimum possible weight.
Propulsion	Procurement Delays	Ordering and shipping delays will negatively impact the schedule and prevent the successful machining of components in a timely maner	Medium	Order all stock metal and long lead items before December 8th. Submit machining jobs through UCF machine shop as early as possible.
Propulsion	Machining Delays	Delays in the machining shedule will shorten the amount of time set aside for testing and verification processes.	Medium	Communicate effectively with the UCF machine shop about our schedule. Assemble a drawing book for the entire engine along with assembly drawings for each assembly and subassembly. Submit machining jobs before the senior design rush.

Fluids Subsystem

- **Blowdown Fed**
  - Blowdown has an initial pressure that starts to decrease over time
  - Performance loss over time
  - More propellant mass to make up for performance loss
- **Regulated Pressure Fed**
  - Constant pressure feeding the propellants
  - Minimal performance loss over time
  - Less propellant mass than a blowdown
  - Nitrogen supply a part of the propulsion system





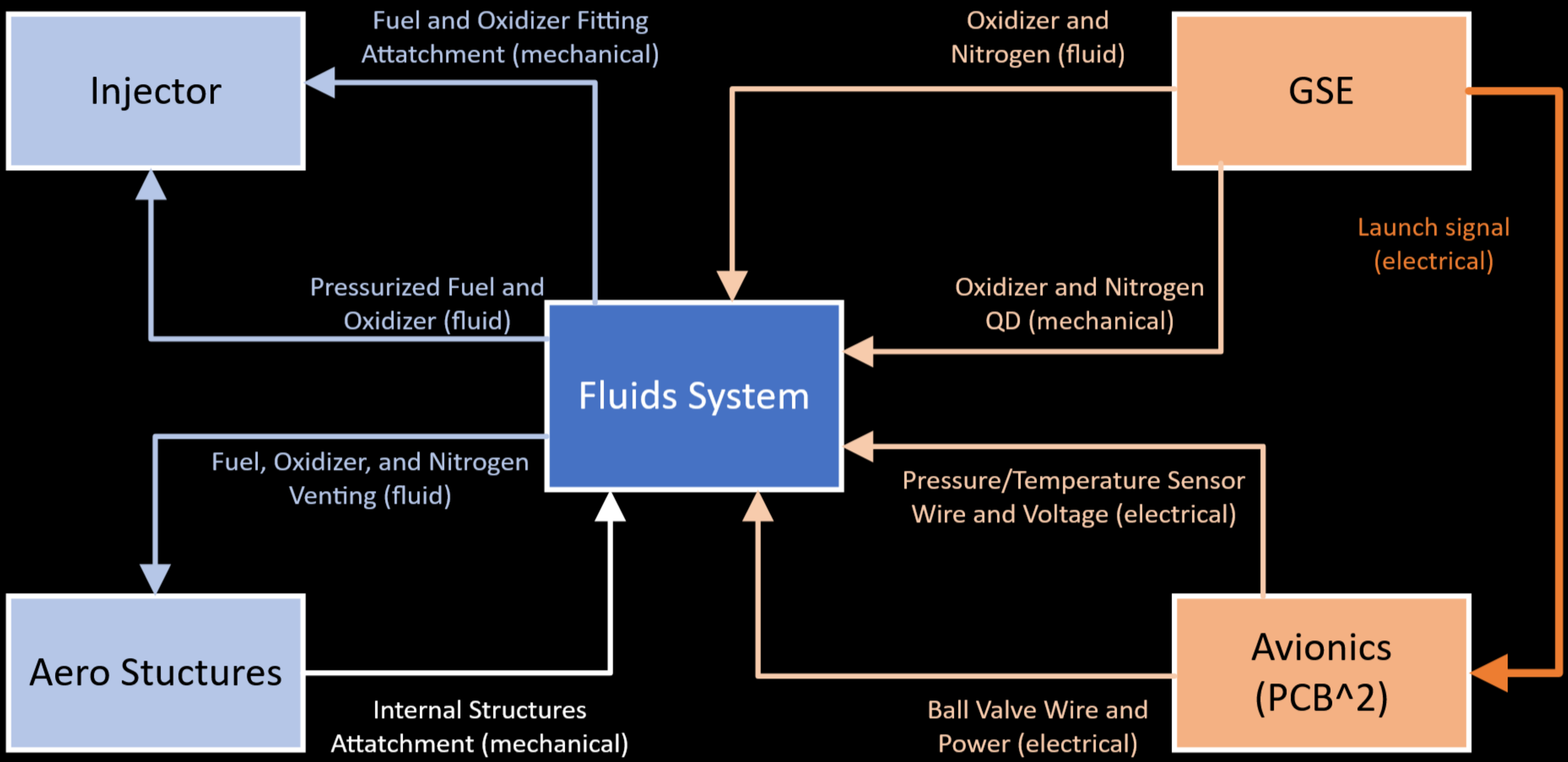
Fluids Requirements

Functional Requirement	Verification Method
The Fluids Subsystem shall restrict/enable fluid flow throughout the propulsion system.	Demonstration
The Fluids Subsystem shall report Fuel tank pressure.	Demonstration
The Fluids Subsystem shall report Fuel tank fill volume.	Demonstration
The Fluids Subsystem shall report Oxidixer tank pressure.	Demonstration
The Fluids Subsystem shall report Oxidizer tank fill volume.	Demonstration
The Fluids Subsystem shall report Nitrogen tank pressure.	Demonstration
The Fluids Subsystem shall report Nitrogen tank fill volume.	Demonstration

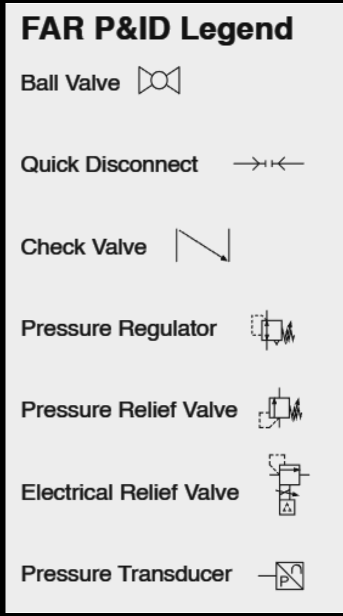
Fluids TPMs

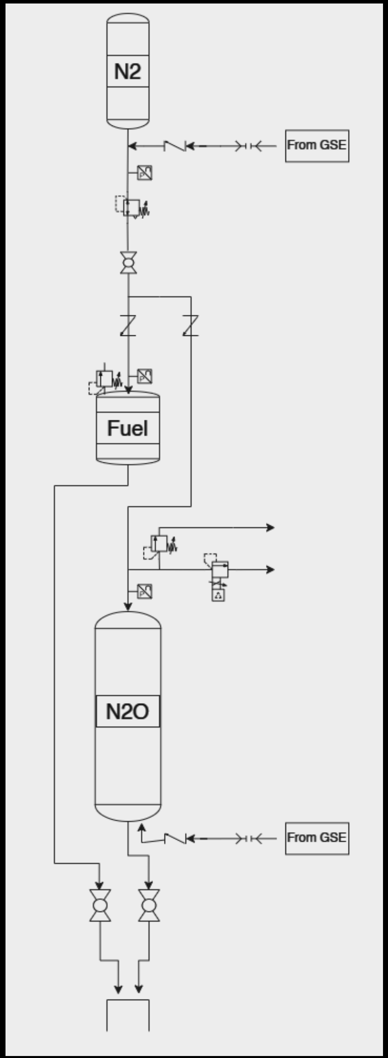
Technical Performance Measure	Value	Units	Verification Method
Operating Pressure	800	PSI	Test
Total Delivered Mass Flow	2.5	Lb/s	Test
Delivered Fuel Mass Flow	0.625	Lb/s	Test
Delivered Oxidizer Mass Flow	1.875	Lb/s	Test
Nitrous Oxide Total Weight	16.875	Lbs	Demonstrate
Ethanol Total Weight	5.625	Lbs	Demonstrate
Nitrogen Total Weight	1.779	Lbs	Demonstrate
Dry Mass	40	Lbs	Inspection
Wet Mass	62.5	Lbs	Inspection
Total Height	10	Feet	Inspection

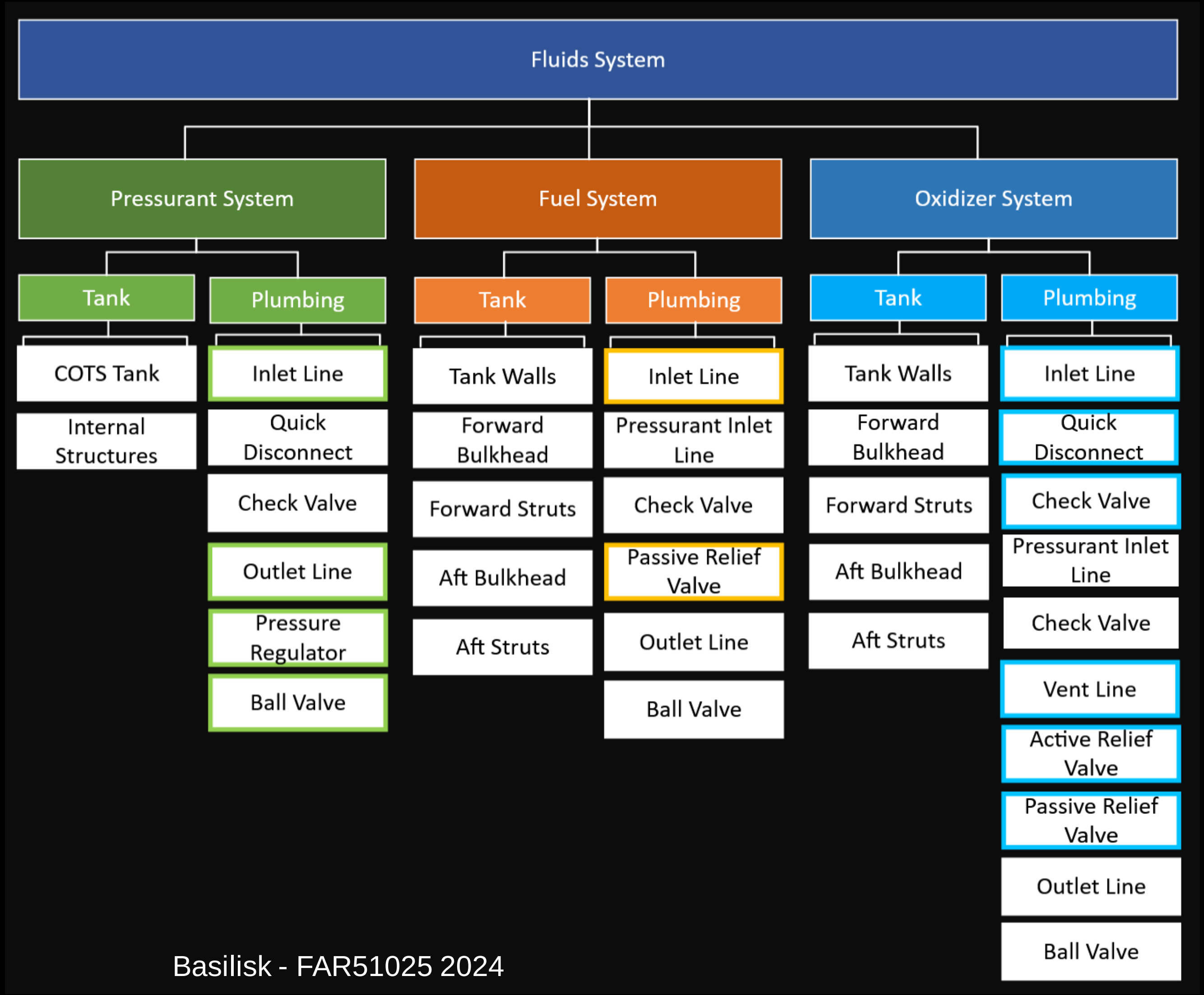
Fluids Interface Diagram



Fluids Component Breakdown







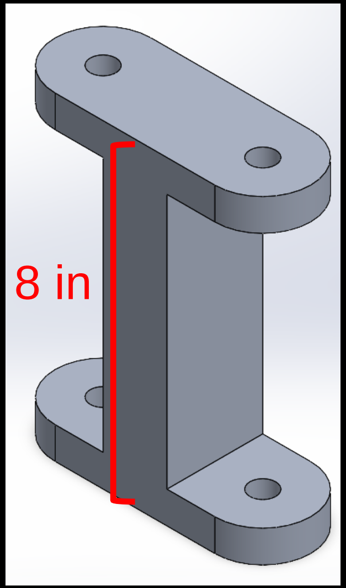
Propellant Tanks

Components List:

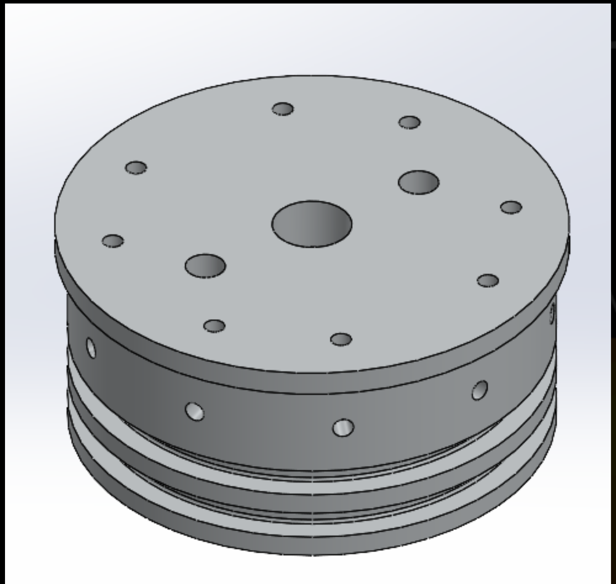
- 4 struts
- 4 bulkheads
- 2 tanks (Fuel and Oxidizer)

- Other Materials:
  - 8 O-ring
  - 76 Stainless Steel Bottom Head Hex Drive Screws (¼-20 thread size, ½ length)

- Stock Lead times:
  - All our materials has less than 15 days for delivering.

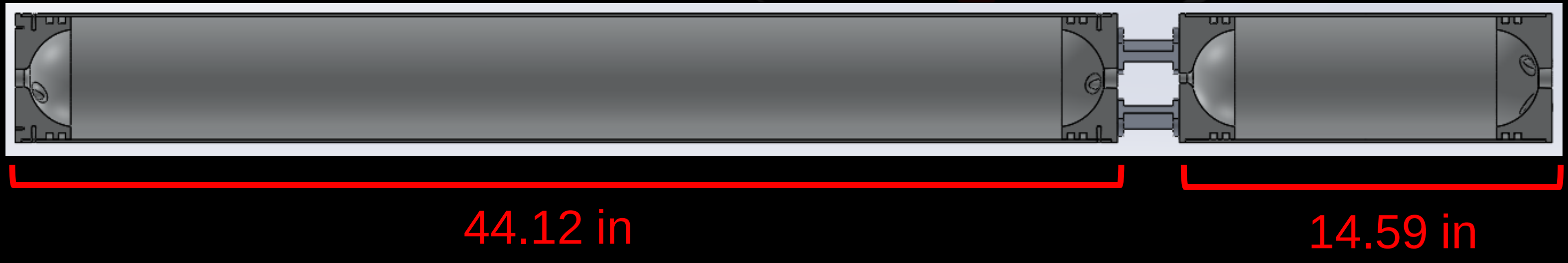


Strut

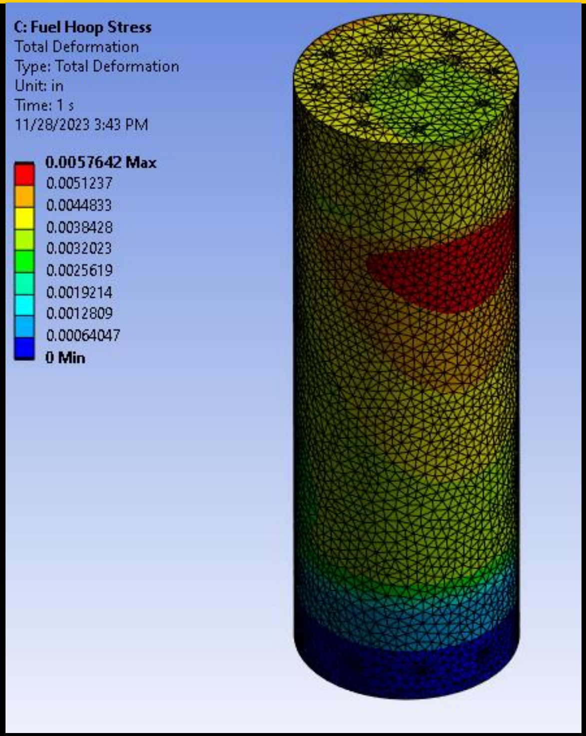


Bulkhead

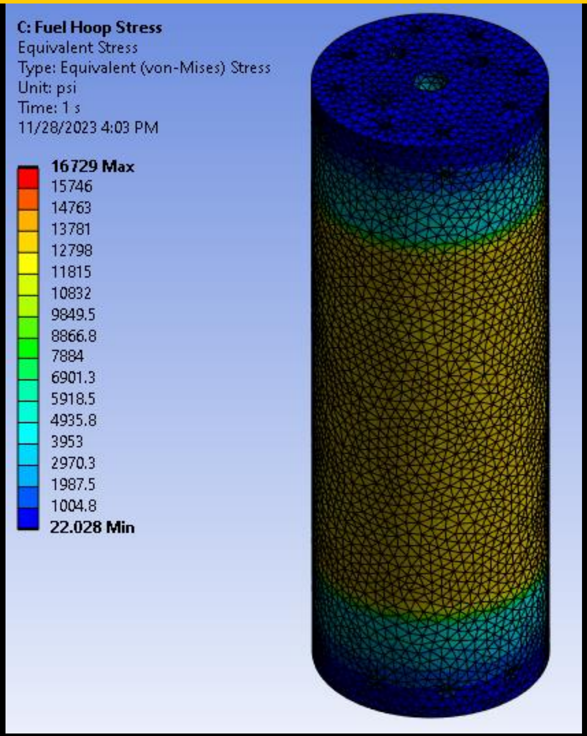
Fuel & Oxidizer Tanks



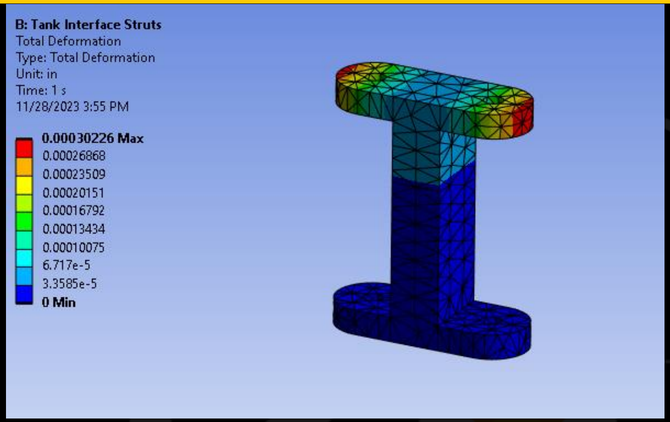
Propellant Tanks



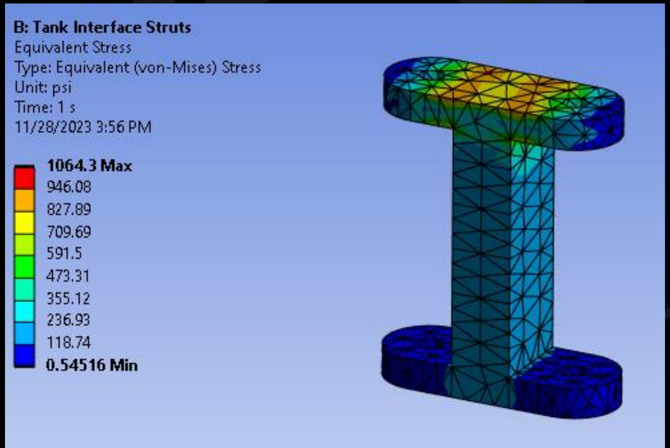
Fuel Tank Total Deformation



Fuel Tank Hoop Stress



Tank Interface Struts Total Deformation



Tank Interface Struts Compression Loading (Due to Launch)

Propellant Tanks

- Updates from PDR
  - 9s burn time
  - Increase in volume
  - Increase in height
- Used a Safety Factor of 2 for all calculations
- 20% Oxidizer & 10% Fuel tank volume dedicated to Ullage
- MEOP 800 psi (CC 750psi MEOP + SF)
- Total Weight of Fuel, Oxidizer and Nitrogen tanks (Dry) (including plumbing)= 52.9lb
- Full-Assemble tanks (Wet) = 75.6lb (total weight of the Propellant system)

Initial Conditions:	Value
Total Mass Flow (lb/s)	2.5
O/F	3
Burn Time (s)	9

Oxidizer	Value
Mass Flow (lb/s)	1.875
Mass (lb)	16.875
Volume (in^3)	620.360
Volume with Ullage	744.431
Height of Tank (in)	44.118

Fuel	Value
Mass Flow (lb/s)	0.625
Mass (lb)	5.625
Volume (in^3)	201.159
Volume with Ullage	221.275
Height of Tank (in)	14.595

Force of Bulkhead

$$F_{bulk} = \left(\frac{\pi}{4}(D_i)^2 \times MEOP\right)$$

Minimum Number of Bolts

$$n_{bolts} = \frac{F_{bulk}}{F_{bolt}^{max}}$$

Bolt Shear

$$\sigma_{bolt\ shear} = \frac{\left(\frac{\pi}{4}(D_i)^2 \times MEOP\right)}{\left(\frac{\pi}{4}(d_{bolt})^2 \times n\right)}$$

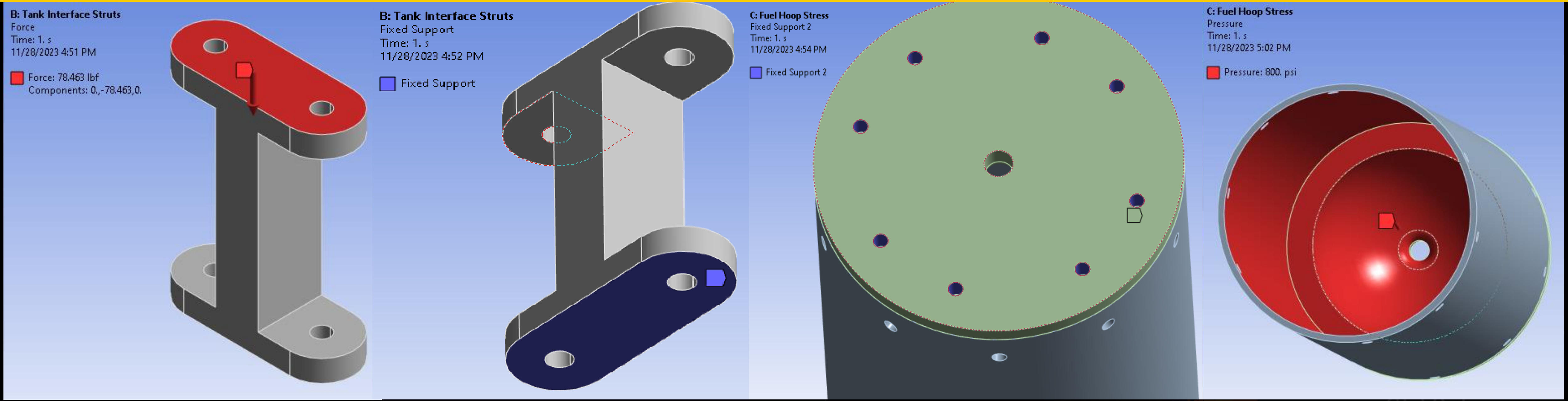
Bulkhead ID	F_bulk	Bolt Diameter	Bolt Area	Bolt Ultimate Stress	Max Bolt Force	Min # Bolts	Recommended # Bolts	Bolt Shear
4.75	14176.437	0.25	0.049	72000	3528	4.018	10	28931.5
in	lbs	in	in^2	psi	lbs	#	#	psi

Bolt Ultimate Stress	Max Bolt Force	Min # Bolts	Recommended # Bolts	Bolt Shear	Safety Factor Bolt Shear
72000	3534.2917	4.0111	10	28880	2
psi	lbs	#	#	psi	

MEOP	Tank ID	Tank Wall Thickness	Target SF	Estimated Hoop Stress	Max Shear Stress Aluminum	SF Calculated
800	4.75	0.125	2	15200	30000	1.974
psi	in	in		psi	psi	

KXR UCF

Propellant Tanks



Struts:

- Tested with largest loading expected (5Gs)
- Fixed face selected for compression sim

Tanks:

- Tested with MEOP of 800psi
- Tanks will be constrained by ¼"-20 x 0.5 bolts

Propellant Tanks

FMECA

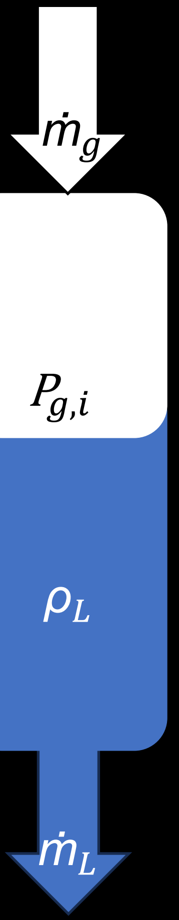
Failure	Criticality	Effect	Mitigation
Structural Failure	High	Tanks rupture or explode	FEA and Hydrostatic test
Vibration and Shock	Medium	Excessive vibration can lead to fatigue failure	An internal structure support that will miligate the vibration
Seal Failure	Medium	Pressure or fluid leaks between tanks and bulkheads	Proper O-Ring sizing and optional High Vacuum Grease
Overpressurization	High	Tanks rupture or explode	A proper Relief System
Manufacturing Defects	Low	Flaws during manufacturing process may cause weak points	Buying materials from approved vendor
Electrostatic Discharge	High	Propellants ignite and tanks explode	ECD rated PPE should be used when handling

Sizing Nitrogen Tank

- Related the volumetric flow rates of the pressurant entering and the propellant leaving to derive this equation
  - $\dot{m}_g = \frac{\dot{m}_L P_{g,i}}{\rho_{L,i} R_g T_{g,i}}$
  - $m_g = \dot{m}_g * Burn\ Time$
  - $V_g = \frac{m_g R_g T_g}{P_g}$

Propellant	Tank Operating Pressure (psi)	Density of Propellant (lb/ft^3)	Specific Gas Constant (N2)	Nitrogen Temperature (K)
Ethanol	800	773.990	296.8	310
Nitrous Oxide	800	752.926	296.8	310

Propellant	Nitrogen Mass Flow Rate (lb/s)	Nitrogen Mass Required (lb)	Nitrogen Volume Required (Gallons)
Ethanol	0.048	0.436	0.196
Nitrous Oxide	0.149	1.344	0.604
Total	0.198	1.779	0.800



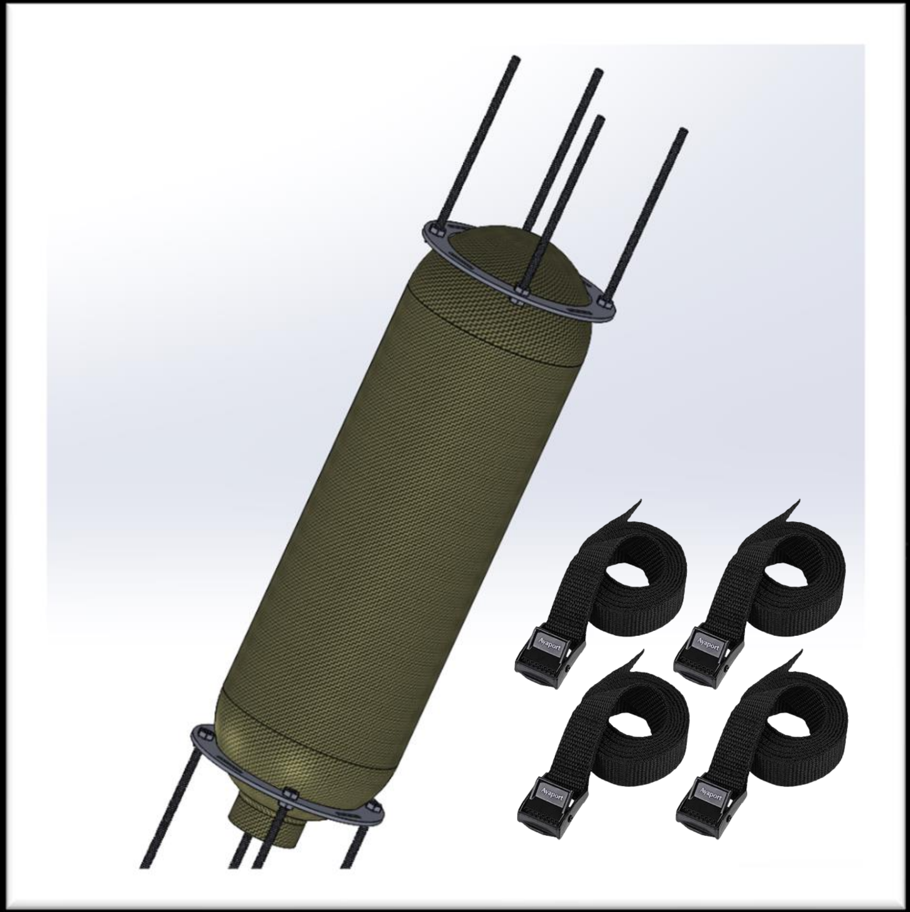
KXR UCF

Nitrogen Tank

- Aluminum tank overlayed with carbon fiber
- Commercial off the Shelf (COTS)
- Cost of $325
- Total Volume of 4.67 L ~ 1.2 Gallons
- Weight of 3.5kg ~ 7.7 lb
- 4500 psi Maximum Operating Pressure
- CGA 347 thread
- Clamping bulkhead system for propulsion system interface
- Nitrogen is easier to obtain than helium

Nitrogen Tank Interface

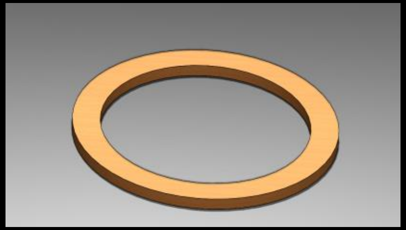
- Nitrogen Tank stabilized within the airframe
    - Threaded rod connects nitrogen tank to the top bulkhead and the electronics bay
    - Crowns held in place by straps
- Avionics PCB^2 sits on top of Nitrogen Tank

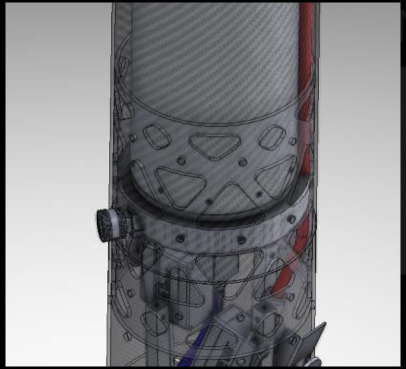


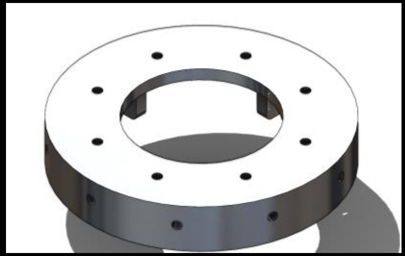
Internal Structures

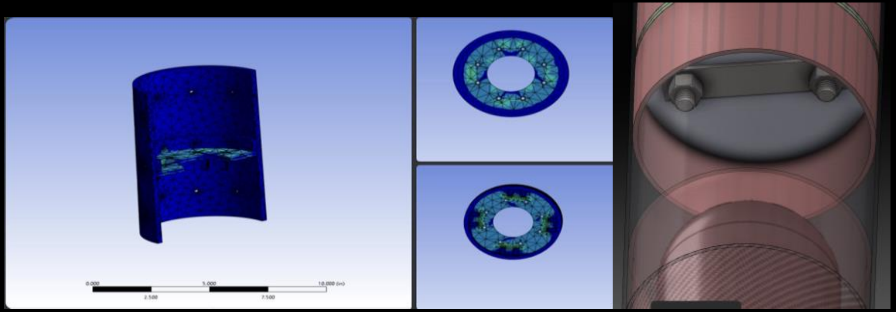
Fluid Systems Mechanical Interfaces:

- Centering (plywood) rings --> pressure vessels
- System via lower bulkhead --> Flush with shoulder/thrust plate
- Fuel and OX --> Inter-tank Struts
- Nitrogen Tank --> Top of Fuel bulkhead
- Nitrogen Tank --> Underside of drogue bulkhead
- Nitrogen Tank --> Avionics Enclosure (PCB^2)

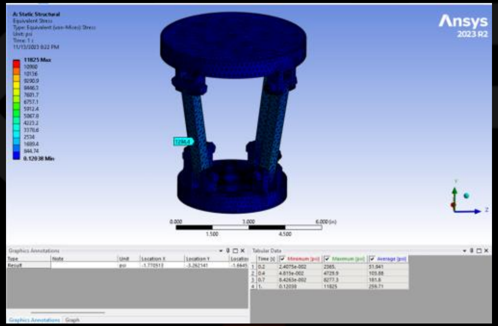








with 1/2" 6061 rectangular tube



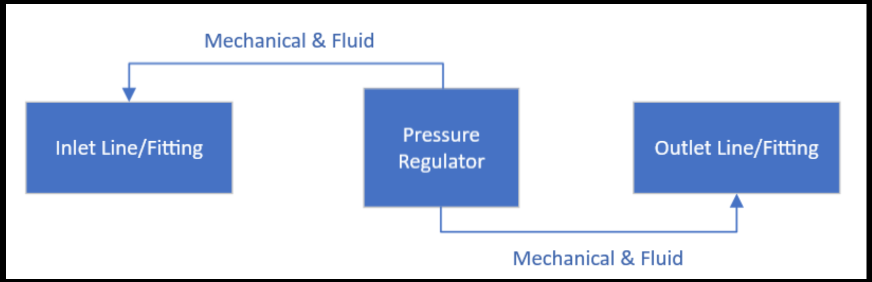
Inputs	Value	Units
Expected peak thrust	550	lbf
Strut cross sectional area	0.1094	in^2
Strut angle (from vertical)	14.042	deg
Number of struts	4	
Strut yield strength	35000	psi

Outputs	Value	Units
Strut stress	1295.6	psi
Factor of safety	27.015	

Stress Heatmap

Pressure Regulator

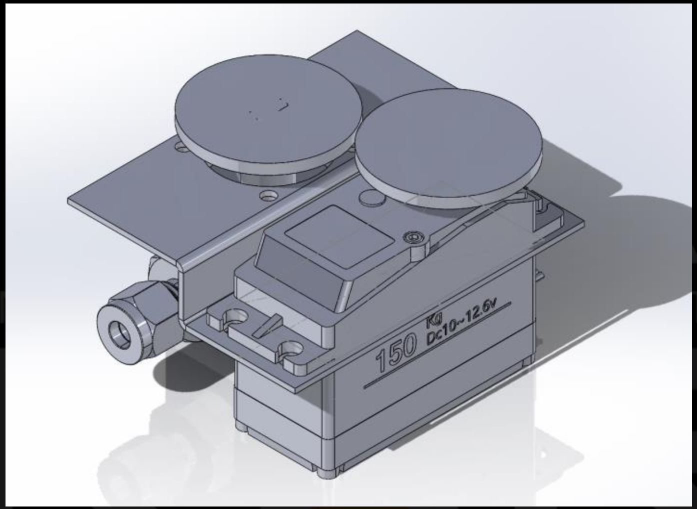
- Spring-loaded high-flow pressure regulator
- Rated to 6000 psi inlet pressure and 1500 psi outlet pressure (Safety factor of two)
- Cost: $348
- Temperature rating: – 60 F
- Cv 0.8
- Weight 2.75 lb   Length: 6.5 in   Diameter: 3 in
- Inlet Pressure: 3000 psi   Outlet Pressure: 800 psi
- Inlet NPT fitting of 0.25 in   Outlet NPT fitting of 0.5 in

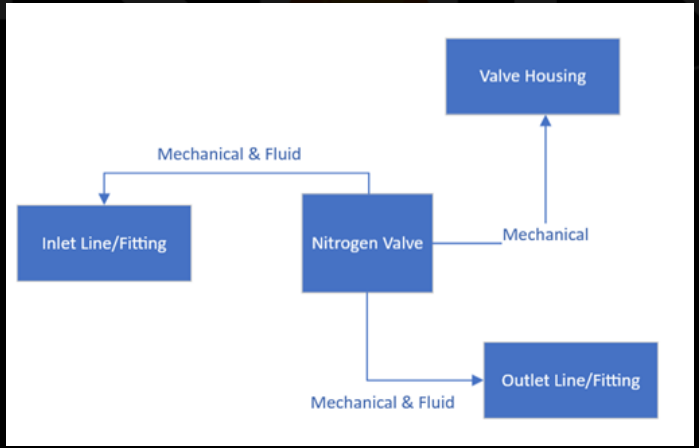


Aqua Environment 873

Nitrogen Ball Valve

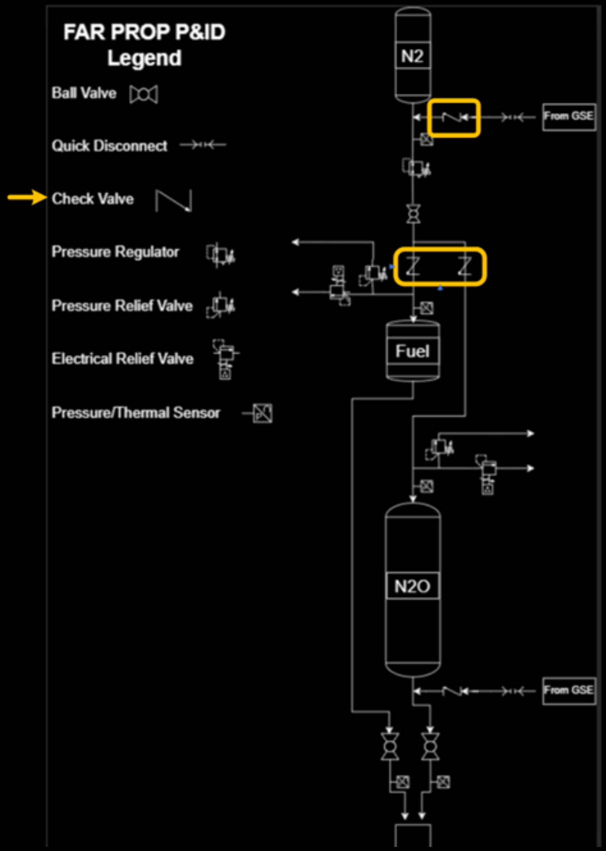
- Hy-Lok 105 series 0.25 inch tube compression fitting
- Placed after pressure regulator
- Servo-actuated using gears
- Torque requirements: 28.4 inch-pounds
- Torque: 52 inch-pounds servo
- Max power draw: 24.6W
- Gears will be machined for free by KXR
- Temperature rating: -65 F
- Pressure rating: 10,000 psi
- Cv of 1.2
- Cost $139





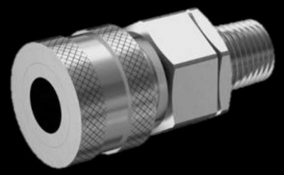
Nitrogen Check Valves

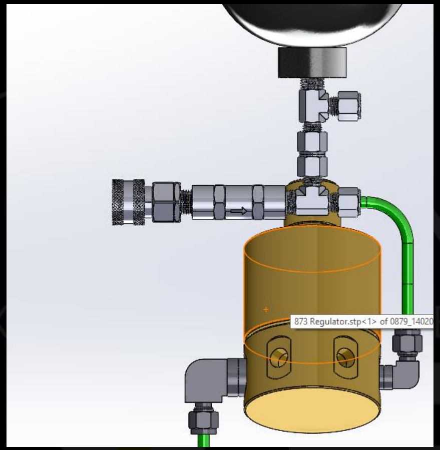
- Hy-Lok 700 series
- Size: 0.25 inch compression fitting
- Two are placed after nitrogen feed line splits to prevent intermixing of propellants
- Cv: 0.67
- 316 Stainless Steel
- Pressure rating 6000 psi
- Cost: $38 each



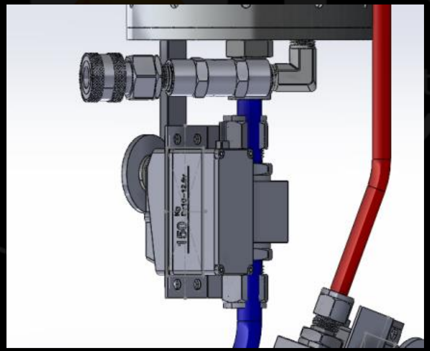
Nitrogen/Oxidizer Fill Check Valves

- Hy-Lok 700 series check valve
- Has Female NPT inlet and outlet
  - Interfaces with LTI quick disconnect
- Cv of 0.67
- Used for both Nitrogen and Nitrous Oxide Fill
  - Keeps fluids from flowing back into the supply bottles
- 316 Stainless Steel
- Pressure rating 6000 psi





Nitrogen Fill

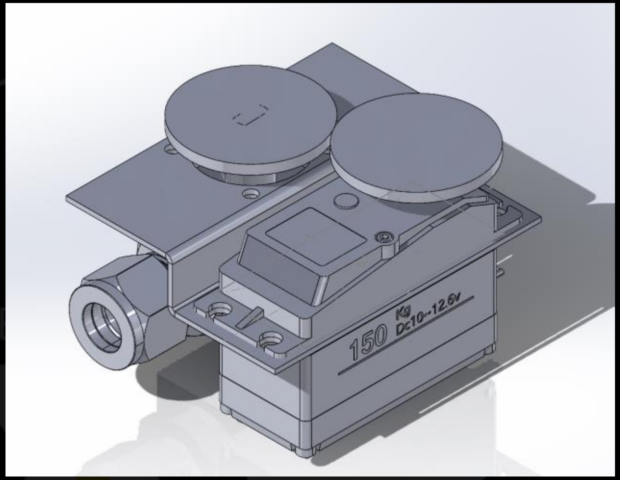


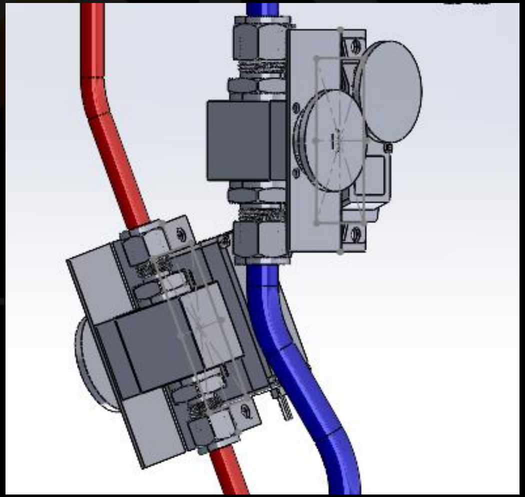
N2O Fill

Fuel and Oxidizer Ball Valves

- Hy-Lok 105 Series Ball Valves with Panel Mount
- 3/8” Tube Compression Fitting for Fuel
  - Cv of 3.7
  - Flow Rate = 5.834 GPM
  - Ethanol Specific Gravity = 0.788
  - Pressure Drop ~ 2 psi
- 1/2” Tube Compression Fitting for Oxidizer
  - Cv of 7.5
  - Flow Rate = 17.953 GPM
  - N2O Specific Gravity = 0.754
  - Pressure Drop ~ 4 psi
- Same servo mounting plate as the nitrogen ball valve
- Torque Requirements
  - Ethanol = 12.4 inch-pounds
  - N2O = 18.6 inch-pounds
- Temperature rating: -65 F
- Pressure rating: 10,000 psi

$$\Delta P = G \cdot \frac{Q_l^2}{C_v^2}$$

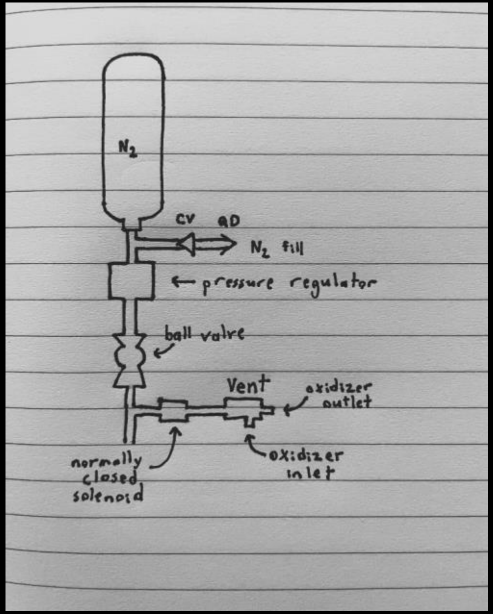




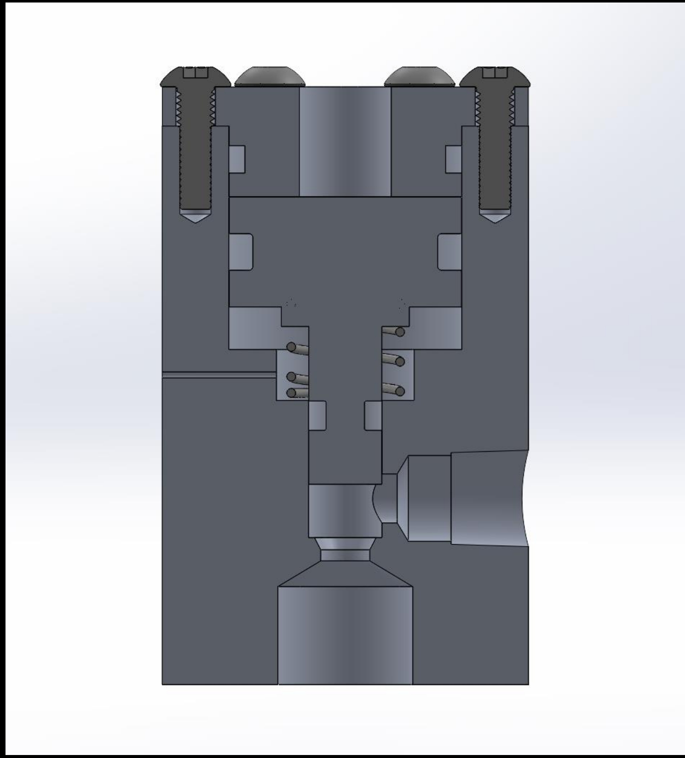
Active Relief System

Normally-Open Vent Valve

- NC Solenoid Controls Pressure – 7 Watts, 24VDC
- Manufactured and designed here at UCF
- Tees off from the Nitrogen tank
- Controlled by PCB^2 through PTs
- 1x for the Nitrous Tank



Vent P&ID

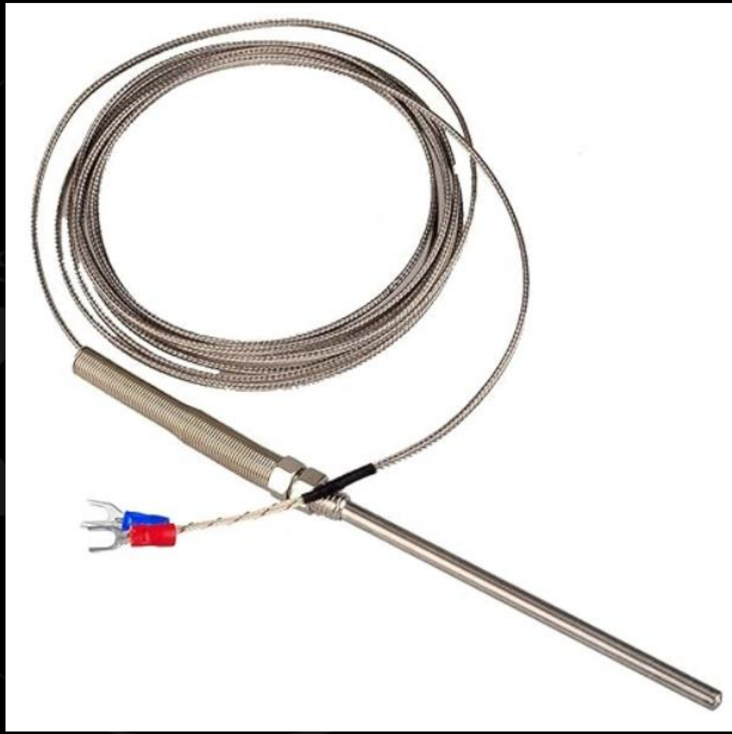


GEMS Solenoid

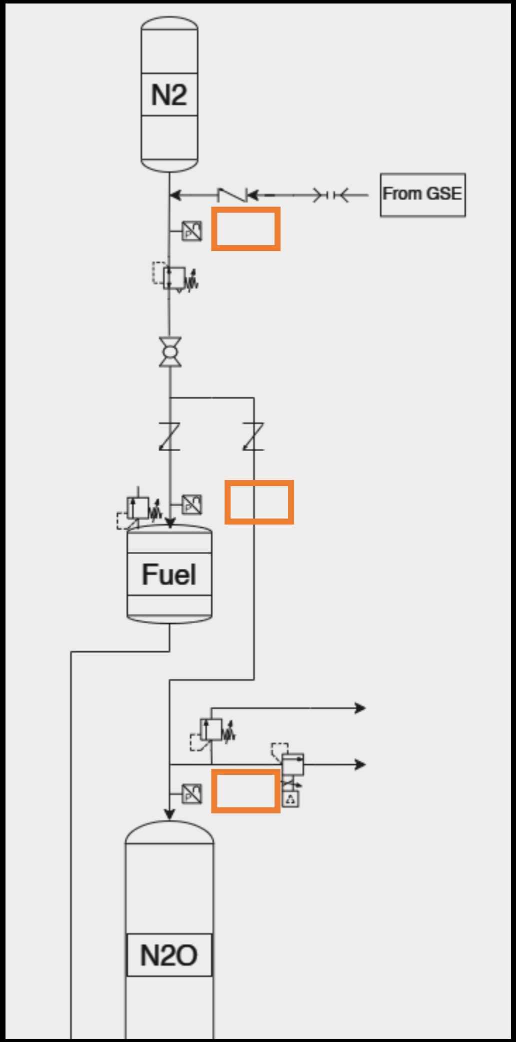
Thermocouples

- Purpose: Verify fill of the oxidizer tank
- Operating Temperature:

  173.15 to 1523.15 K
- Probe Diameter: 1/5 inch
- Probe length: 4 inches



Pressure Transducers



- Pressure Range:
  0 to 3000 psi
- Operating Temperature:
  233.15 to 398.15 K
- Supply Voltage: 24 VDC
- Electrical Connection: 9.4 mini DIN
- Output: 4-20 mA

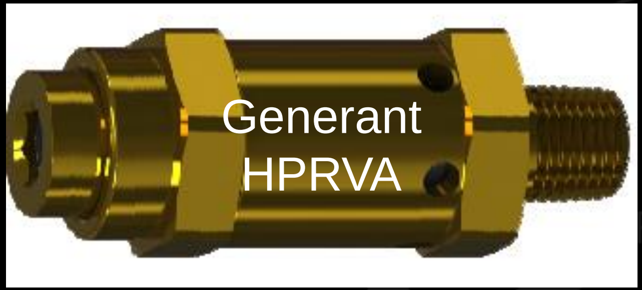
Passive Relief System

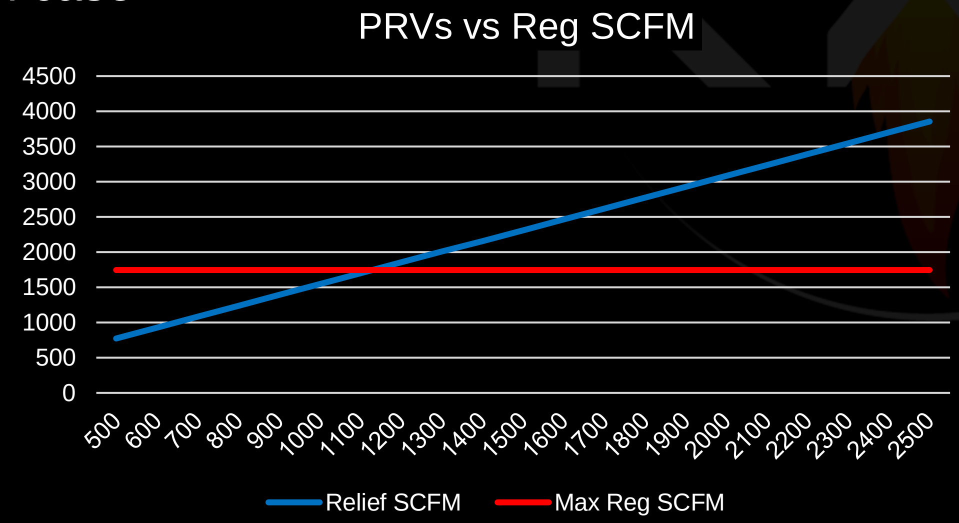
COTS Generant Relief Valve

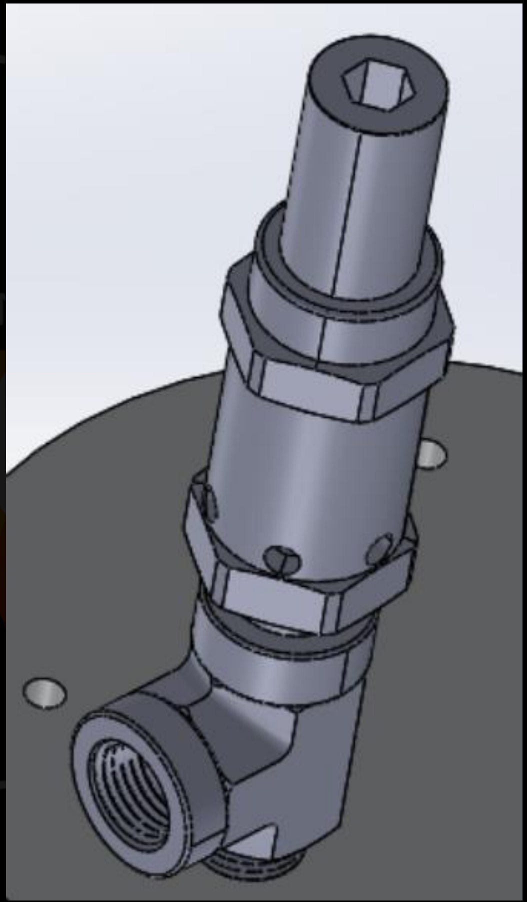
- Set pressure by manufacturer
- Only actuates in high-pressure fail cases
- Vents directly into airframe
- ¼" NPT – Has dedicated NPT port on bulkhead
- 1x per tank

Burst Disk

- Rated to open at 1500 PSI to vent system in case of RV failure
- COTS NPT fitting attachment







$$Q_s = P_u d_o^2 \frac{C\pi}{4\rho_s}\sqrt{\frac{k\,M}{Z\,RT}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}\,60$$

$$Q_s = K\,P_u\,d_o^2$$

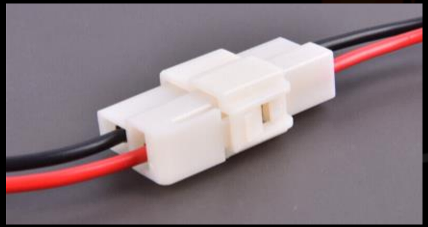
Formula for flow when flow is choked

Power and Data Wire Bundling

- Braided Sleeving
  - Bundles wires from servos, thermocouples, pressure transducers, solenoids and PCB, reducing vibration
  - Allows wires to be easily split-off from main bundle
- Heat Shrink Tubing
  - Prevents braided sleeving from splitting and reduces wire vibration
- JST PH Connector Plugs
  - Connect propulsion electronics bundle to PCB wire bundle
  - Enables quick separation of Nitrogen and propellent assemblies
  - Allows for easy assembly, test setup, launch prep and repair
- Zip Ties and Wax String
  - Secure all wire bundles to chassis, reducing shifting, vibration and strain

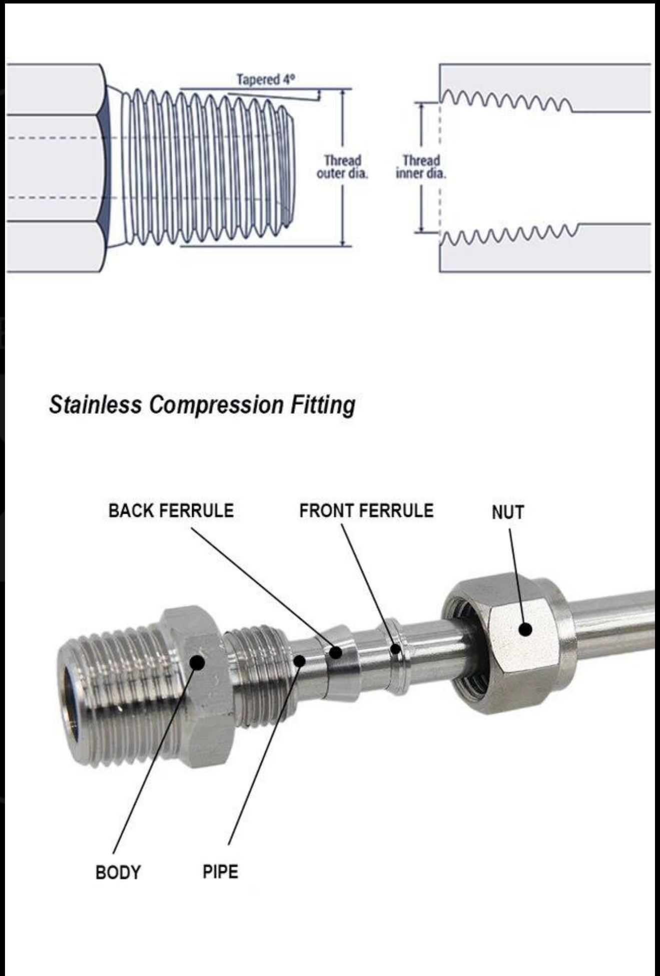

Braided Sleeving + Bundle Splitting


Heat Shrink + Connector Plugs


JST PH Connector Plug

Feedlines & Fittings

- Fittings
  - Primarily compression fittings for ease of assembly
    - Hy-lok
  - NPT $\frac{1}{4}$” used to connect to relief system
  - Cost ~ $400
- Feedlines
  - $\frac{1}{4}$“ OD, .18” ID, and 30” length for pressurant line
  - $\frac{1}{2}$" OD, .402” ID and 11” length for oxidizer line
  - $\frac{3}{8}$” OD, .326” ID and 64” length for fuel line



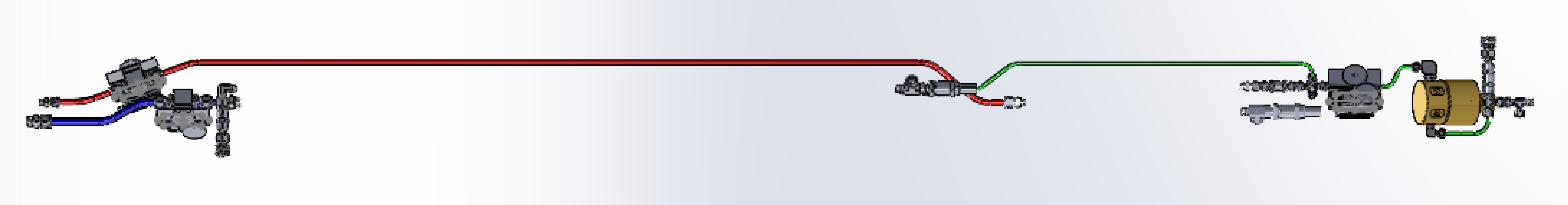
Feedlines & Fittings

- Pressure drop for ethanol line: 12 psi
- Pressure drop for Nitrogen line: > 1 psi
- Pressure drop for Nitrous Oxide line: > 5 psi

$$\dot{m} = \rho v A$$

$$\dot{m} = \frac{A p_t}{\sqrt{T_t}} \sqrt{\frac{\gamma}{R}} M \left(1 + \frac{\gamma - 1}{2} M^2\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$$

$$\Delta p = f \frac{L}{D} \frac{\rho V^2}{2}$$



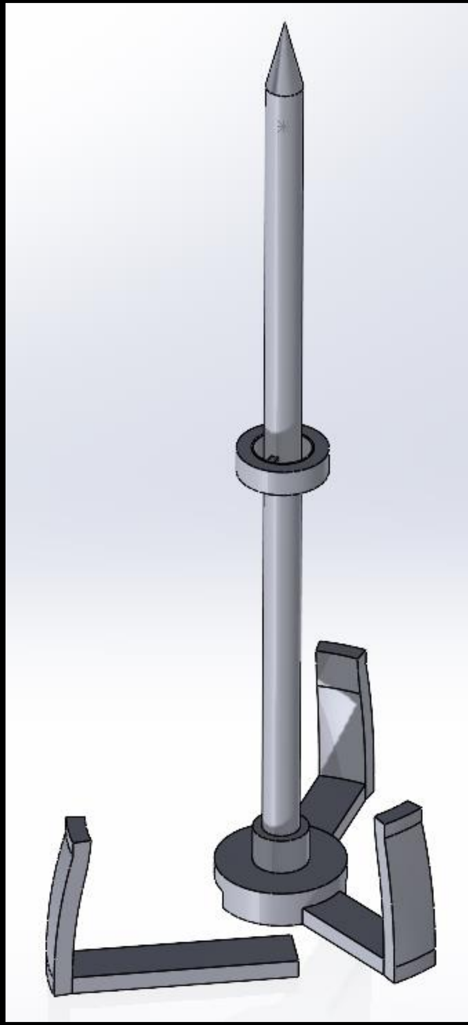
Fluids Systems FMECA

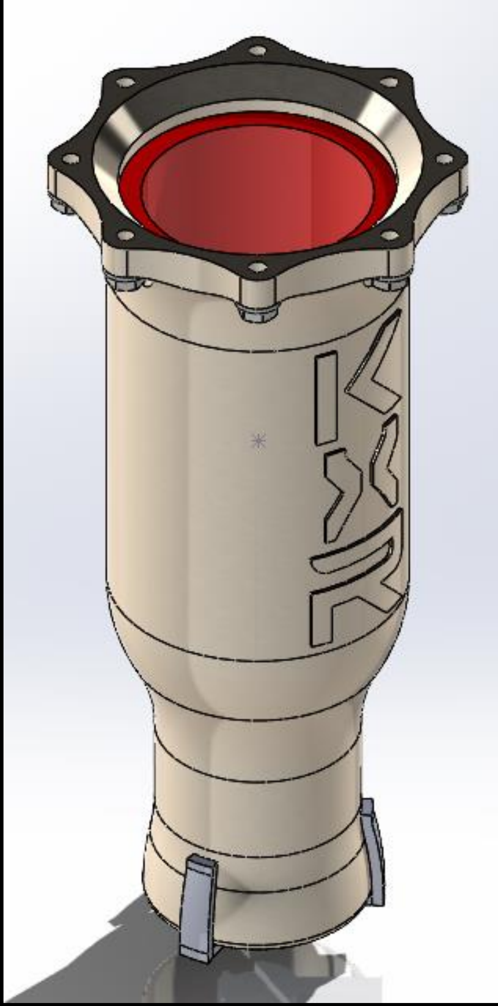
Part	Failure	Criticality	Effect	Mitigation
Run valves	Freeze	High	No propellant going to injector; no thrust	Verify that valves can handle anticipated temperatures
Run valves	Power loss	High	No propellant going to injector; no thrust	Backup power system/source
GSE interface	Not disconnecting	High	Drag GSE equipment with rocket; possible rocket travel in wrong direction	Verify with testing that GSE interface will separate
Relief Solenoid	Power loss	Medium	No active pressure relief on vehicle	Backup power system/source
Nitrogen Regulator	Freeze up	Medium	Chance of regulator freezing in full open or close poisitions	Mitigate by making sure nitrogen in tank is warm enough
Nitrogen Regulator	Leak	Medium	More pressure allowed through system than desired; possible other component failure	Ensure selected regulator meets anticipated temperatures
Relief solenoid	Freeze	Medium	No active/constant pressure relief (depends on state when frozen)	Verify solenoid can handle anticipated temperatures
Relief Solenoid	Leak	Medium	Constant loss of pressure; possible expend all pressurant and decrease operating pressure	Verify valve can handle anticipated pressures and temperatures. Keep piping free of particulate matter
Nitrogen Regulator	FOD causing damage to sealing surface	Low	Slow leak	Filter in pressure regulator and filter in nitrogen fill lines

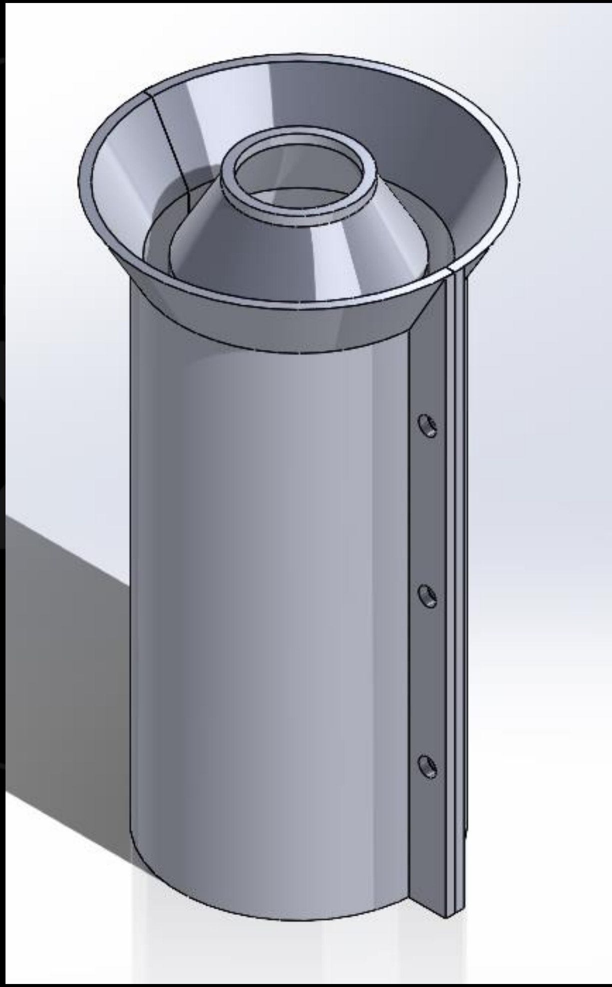
Fluid Systems Manufacturing

- Bulkheads
  - Material for 4 aluminum 6061-T6 bulkheads ~ $100 in stock
- Tank Walls
  - Aluminum 6061-T6 tube stock ~ $80 in stock
    - May need to turn ends depending on tube stocks "roundness"
- Load Bearing Struts
  - Milled out of billet aluminum 6061-T6
- Feed Lines
  - All stainless-steel feed lines will be bent by our team using bending jigs
  - Hy-Lok fittings and flares will be done by our team
- All aluminum components will be machined by the UCF machine shop with rough quoting as follows
  - Per Bulkhead ~ 4 Hours at $35 an hour
  - Per Tank Wall ~ 1 Hours at $35 an hour
  - Per Strut ~ 1 Hours at $35 an hour
- Rough total of around $1200 for all machining and stock not including hardware

Combustion Subsystem







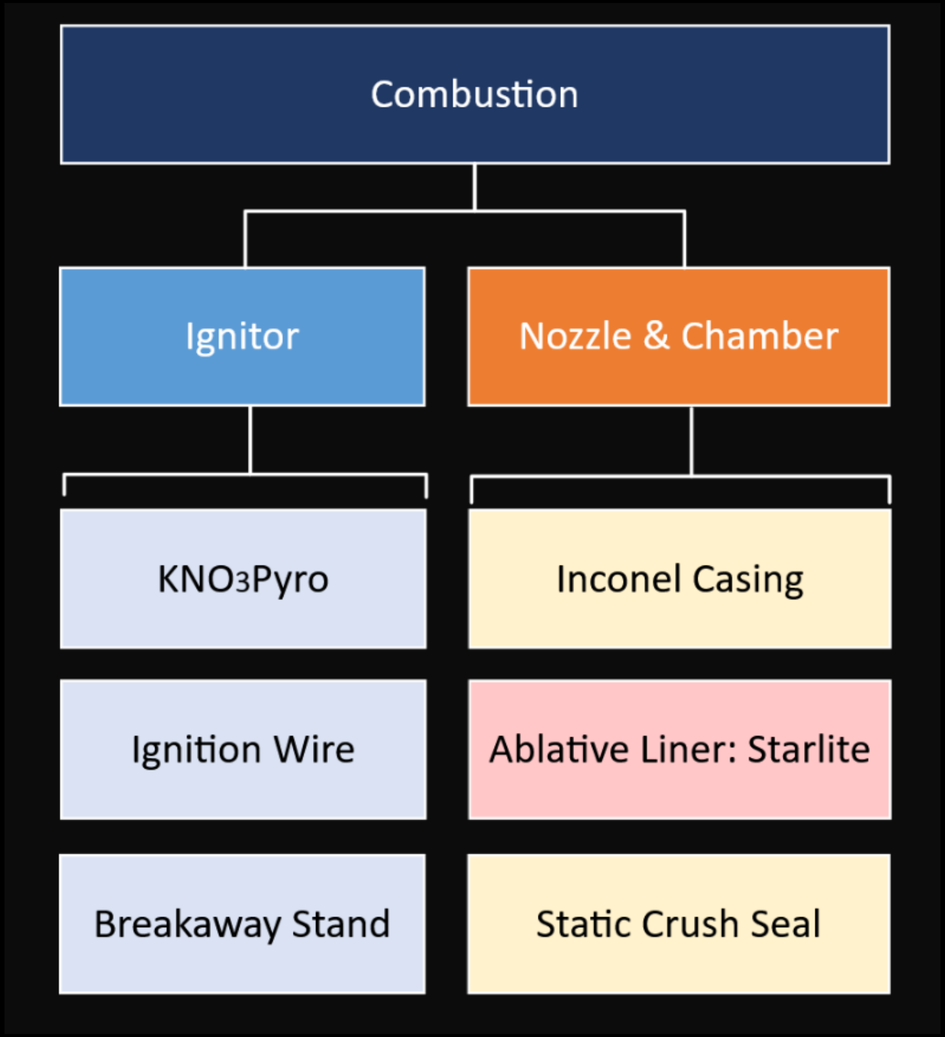
Combustion System Requirements

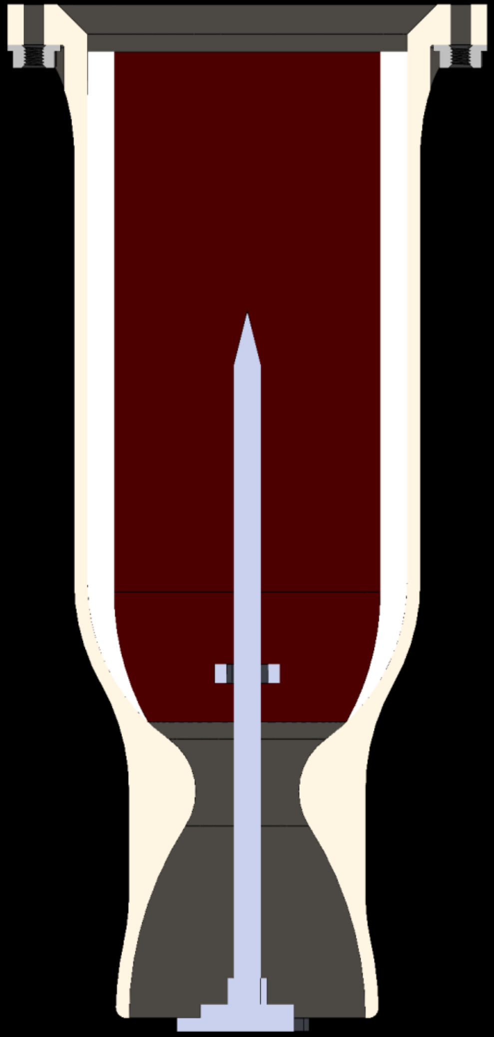
Functional Requirement	Verification Method
The Combustion Subsystem shall ignite the propellants.	Demonstration
The Combustion chamber shall withstand ignition temperatures.	Demonstration
The Combustion chamber shall withstand burn temperatures.	Demonstration
The Combustion chamber shall withstand burn pressure.	Analysis
The Combustion chamber shall seal all pressure.	Demonstration
The Combustion chamber shall direct the flow of the propellant flame toward the aft end of the vehicle.	Demonstration

Combustion System TPMs

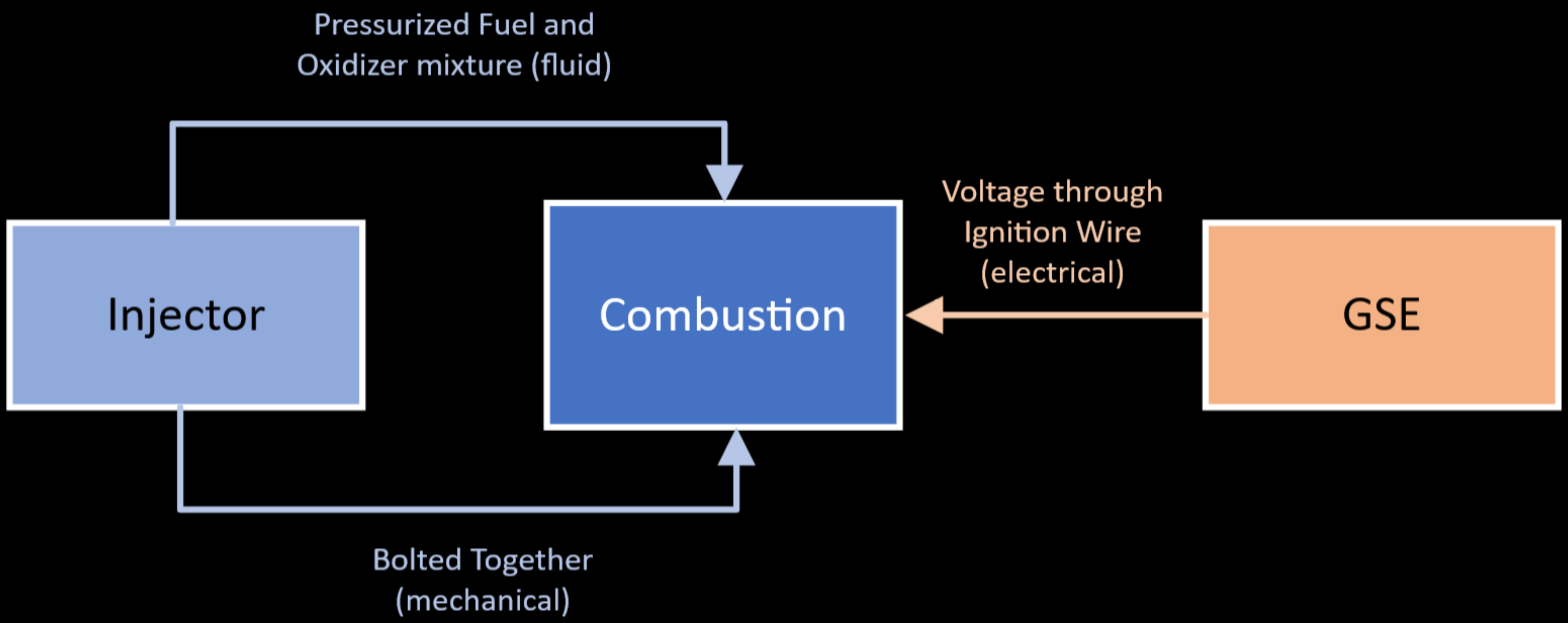
Technical Performance Measure	Value	Units	Verification Method
Chamber weight	4.73	lbs	Inspection
Chamber Length	9.5	in	Inspection
Chamber Maximium Outer Diameter Injector End	4.5	in	Inspection
Chamber Maximium Outer Diameter Aft End	3.25	in	Inspection
Maximum Chamber Pressure	500	psi	Analysis
Maximum Chamber Temperature	2550	K	Analysis
Burn Time	9	sec	Test

Combustion Component Breakdown





Combustion Interface Diagram

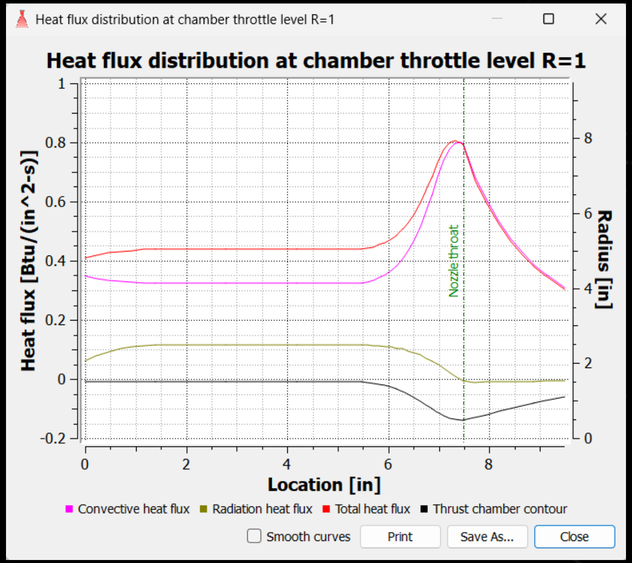


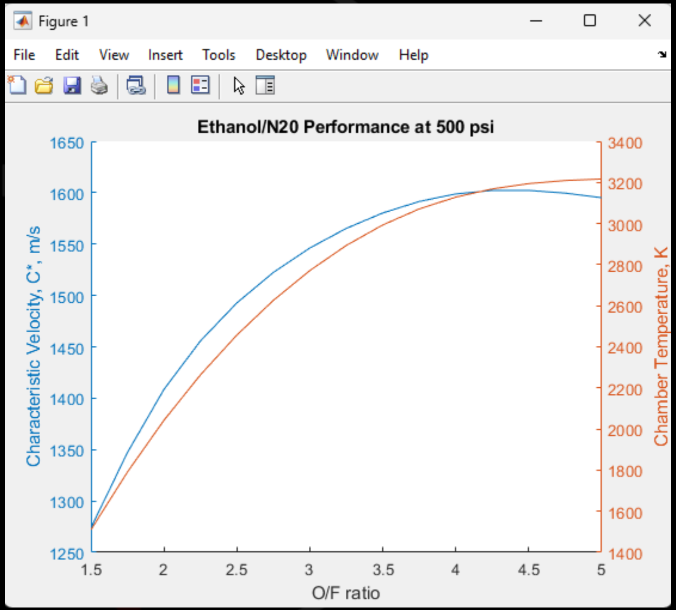
Combustion Chamber and Nozzle

- Constructed as a single component out of printed inconel 718
  - Manufacturing and assembly benefits to printing geometry
- Length: 9.5 inches
- Chamber outer diameter: 3.25 inches
- Chamber flange outer diameter: 4.5 inches
- Mass: 4.73 lbm

Combustion Chamber Thermochemistry

- Various O/F ratios plotted at a constant chamber pressure of 500 psi
- Characteristic velocities (C*) and combustion temperatures generated by NASA CEA
- Peak C* occurs at an O/F ratio of ~4
- O/F ratio of 3 selected for engine to minimize combustion chamber temperatures while maintaining good characteristic velocity
- Estimated chamber temperatures at 95% combustion efficiency is ~2550 K
- Estimated specific impulse at 95% combustion efficiency is 212.6 seconds





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Chamber Sizing and Nozzle Performance

- Initial expansion ratios and C* values found using NASA CEA
- Design values found using Rocket Propulsion Analysis (RPA) with following parameters:
  - Chamber pressure: 500 psi
  - O/F: 3
  - ṁ: 2.5 lbm/s
  - L*: 63 in
    - Yields higher combustion efficiencies
  - Contraction ratio: 9.64
    - Assumes liner thickness of 1/8" to simulate mid-burn conditions
  - Expansion ratio: 5.28
    - Assumes nozzle exit condition of 13 psi
- Resulting thrust at optimal expansion is 531.5 lbf
- Chamber hoop stress calculated at room temperature and worst-case scenario material temperature (liner burn-through)

```
Thrust and mass flow rates
------------------------------------------
   Chamber thrust (opt):  531.46950    lbf
 Specific impulse (vac):  233.23208      s
   Chamber thrust (vac):  583.08021    lbf
 Specific impulse (opt):  212.58780      s
   Total mass flow rate:    2.50000  lbm/s
Oxidizer mass flow rate:    1.87500  lbm/s
    Fuel mass flow rate:    0.62500  lbm/s

Geometry of thrust chamber with parabolic nozzle
------------------------------------------
    Dc =     3.00  in         b =   40.00 deg
    R2 =     1.81  in        R1 =    0.72  in
    L* =    63.00  in
    Lc =     7.49  in     Lcyl =    5.35  in
    Dt =     0.97  in
    Rn =     0.18  in        Tn =   19.38 deg
    Le =     2.00  in        Te =   15.28 deg
    De =     2.22  in
 Ae/At =     5.28
 Le/Dt =     2.07
Le/c15   =    84.71 % (relative to length of cone nozzle with Te=15 deg)
```

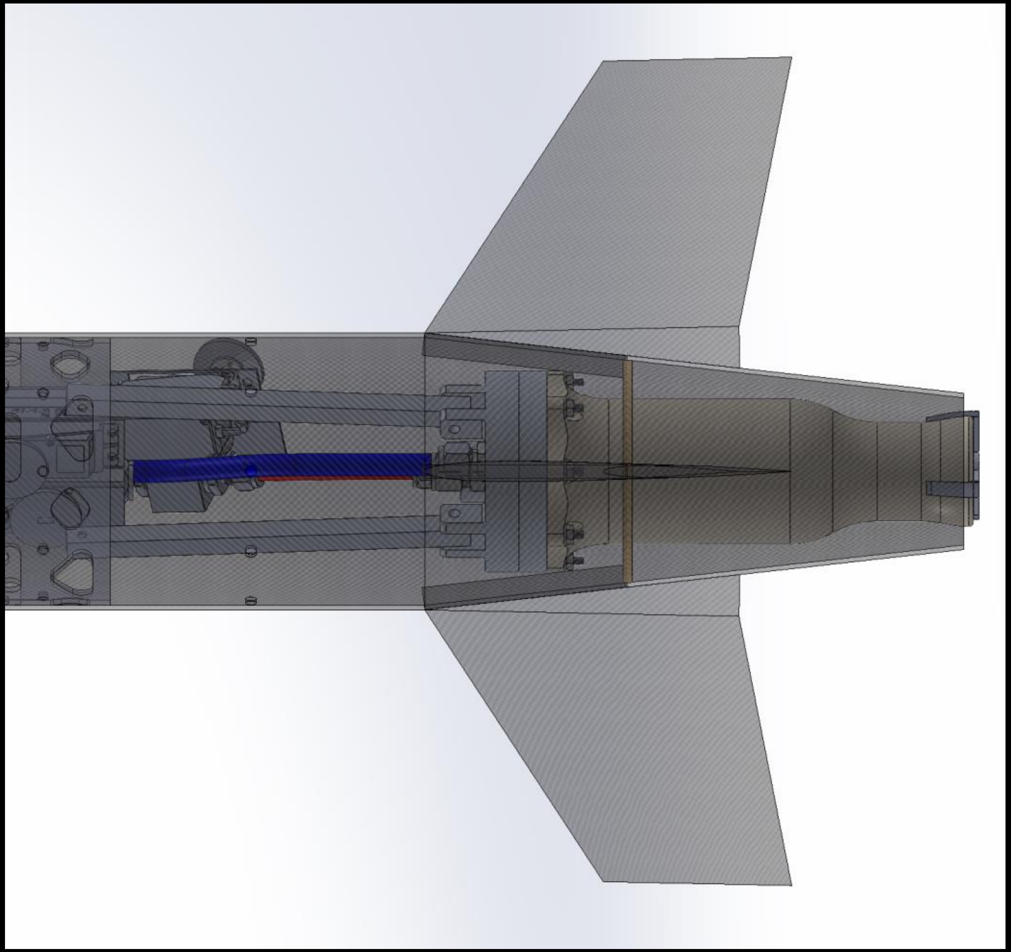
Inputs	Value	Units
Chamber pressure	500	psi
Combustion chamber wall thickness	0.125	in
Combustion chamber OD	3.25	in
Chamber material tensile stress	150000	psi
Chamber material tensile stress (at 800 C)	79770.8	psi

Outputs	Value	Units
Hoop stress	6500.0	psi
Factor of safety	23.077	
Factor of safety at operating temperature	12.272	

Combustion – Boat Tail and Fins Interface

Requirements given by Aerostructures:

- Maximum outer diameter at injector end: 4.5 inches
- Maximum outer diameter at aft end: 3.25 inches
- Satisfies clearance requirements for igniter installation and fin cage integration



KNO_3 Pyrotechnic

- Rocket Candy
  - 65% Potassium Nitrate (oxidizer)
  - 35% Sugar (fuel)
  - 75 grams total

- Cost
  - $2.20 Per Batch

- Extremely Reliable
  - Burn Time – 6 Seconds
  - Burn Temp – 1347 C

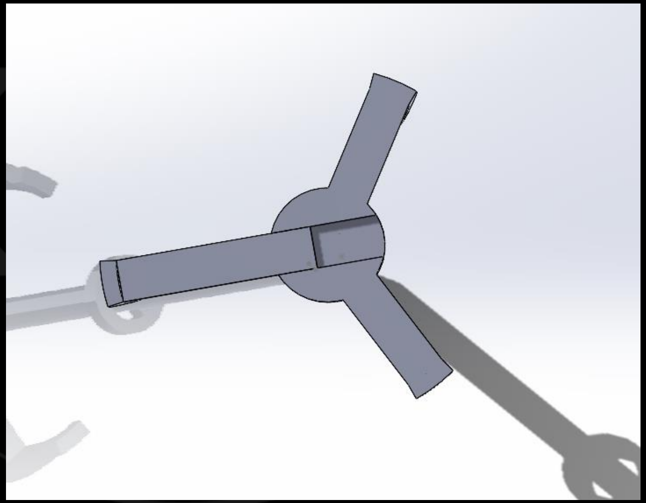
6 second burn time for 75 gram sample above

Ignition Stand

- Delivery
  - Nozzle inserted dowel
  - Easy installation and removal during testing
  - 2 attached legs, 1 free leg, tape to seal

- Cost – Free!
  - Ignition Stand created using sources of free PLA
  - Will be destroyed and expelled in Basilisks combustion

- Risk of blowout before ignition
  - Mitigated by 3 leg clamp system

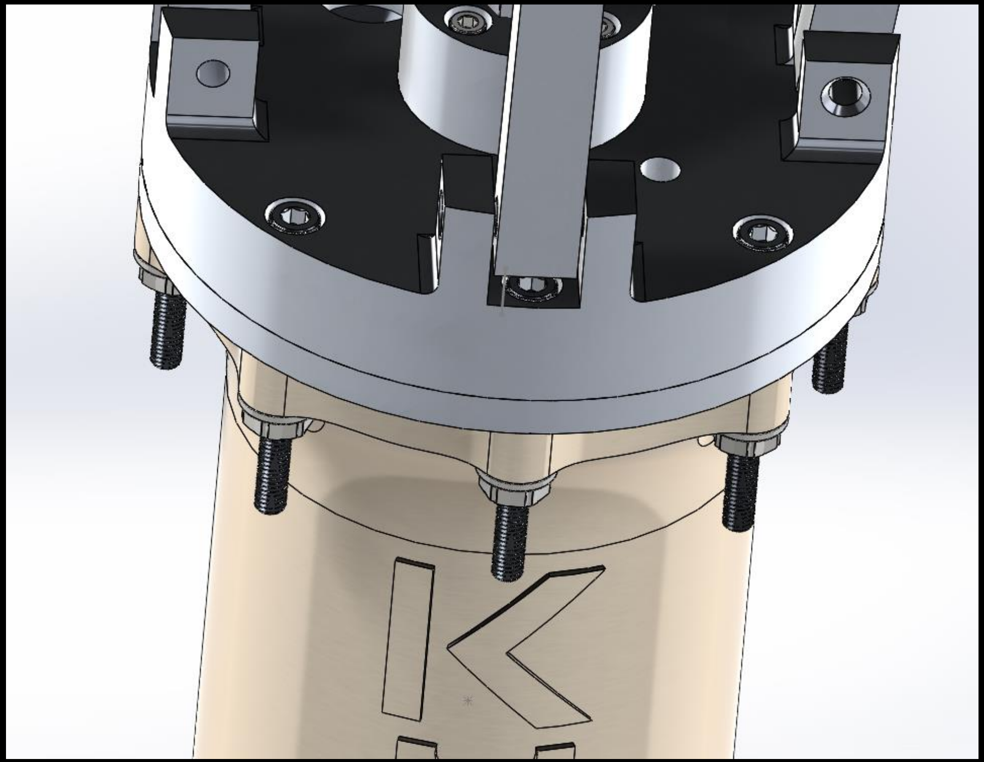


E-matches

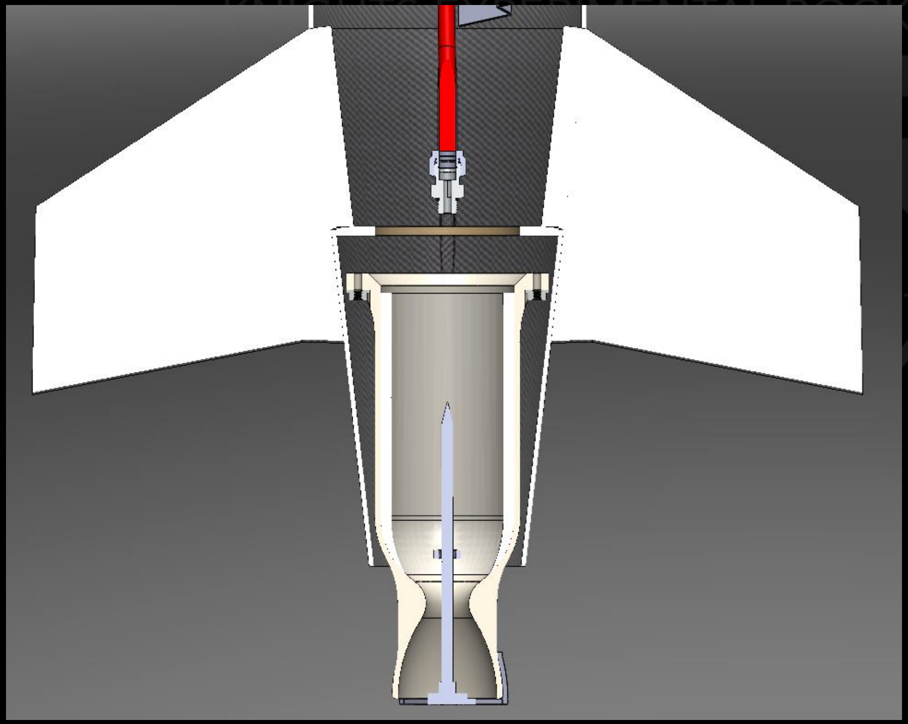
- 9v Initiator
- 3 for Redundancy
- Ignited through ground support to light KNO_3 Pyro
  - 2 Watts needed to ignite.
- Cost - $4.50 per attempt

Ignitor Interface – Lessons Learned

- Cannot remove the nozzle, only access through top
- If coating the liner (last year's delivery)
  - 12 bolts must be removed to paste
  - If static fire failed, 12 bolts must be removed to clean

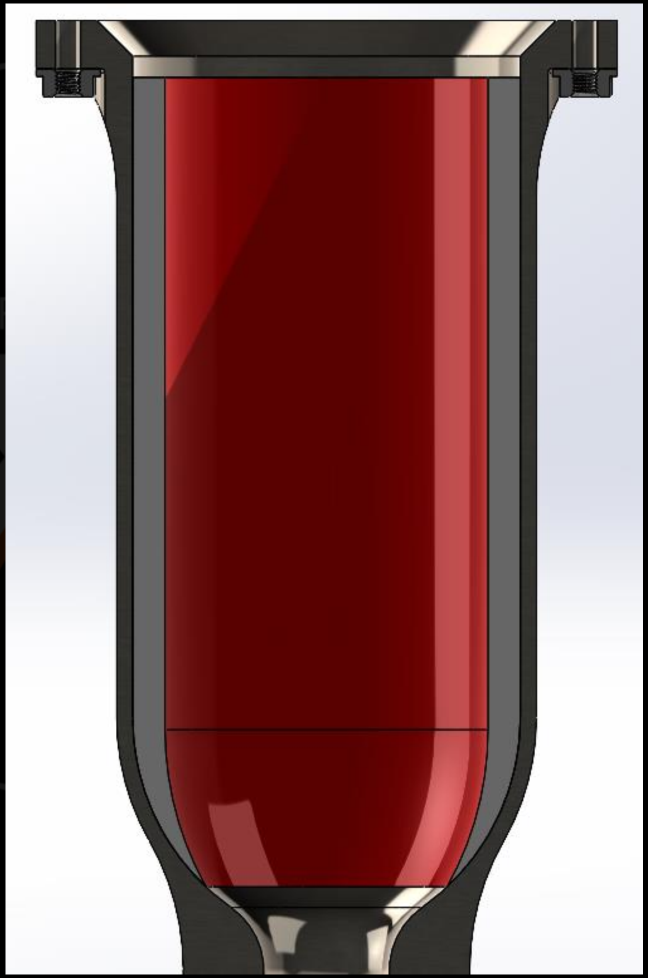


- Access from beneath rocket requires no disassembly.
- The flame will burn radially from the center providing faster ignition
- There will be no residue of the ignitor anywhere along the chamber walls after ignition.



Ablative Liner

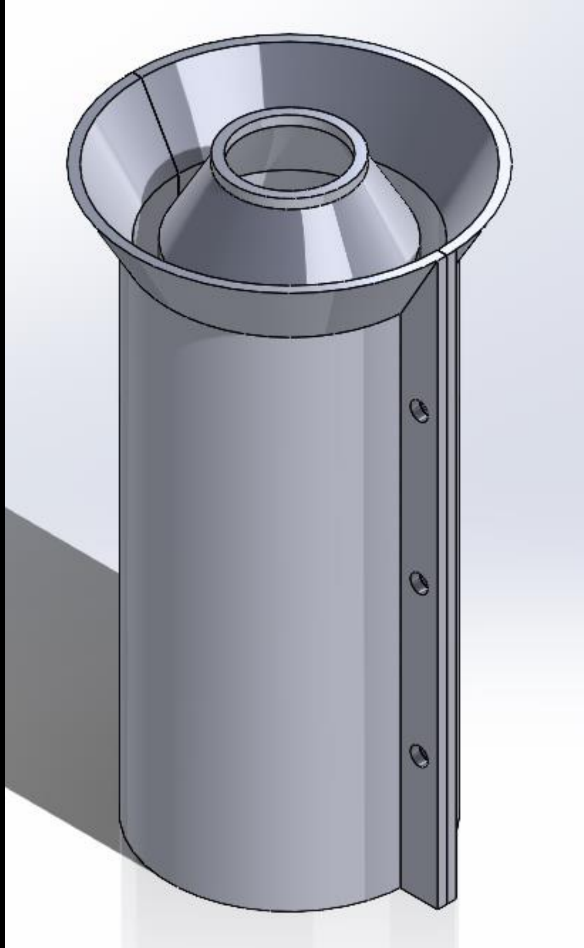
- Peak chamber temperatures of 2550 K
- Liner thickness increased to 1/4" to prevent cracking and reduce inconel erosion over the component lifetime
- Starlite
  - Great insulation and heat dispersion
  - Ease of manufacturing (epoxy, cornstarch, flour, sugar, baking soda, borax)
- Tapered up until the engine throat
  - Volume ~12 in^3
- $0.80 per liner using last year's epoxy

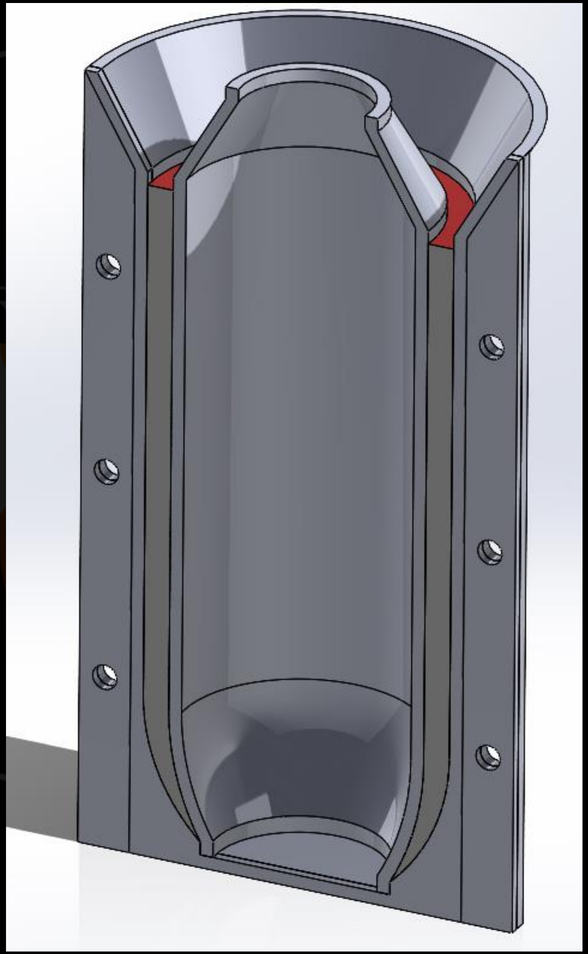


Hot Side: 823 K = 1022 F
Cold Side: 329 K = 133 F
(¼" Sample)

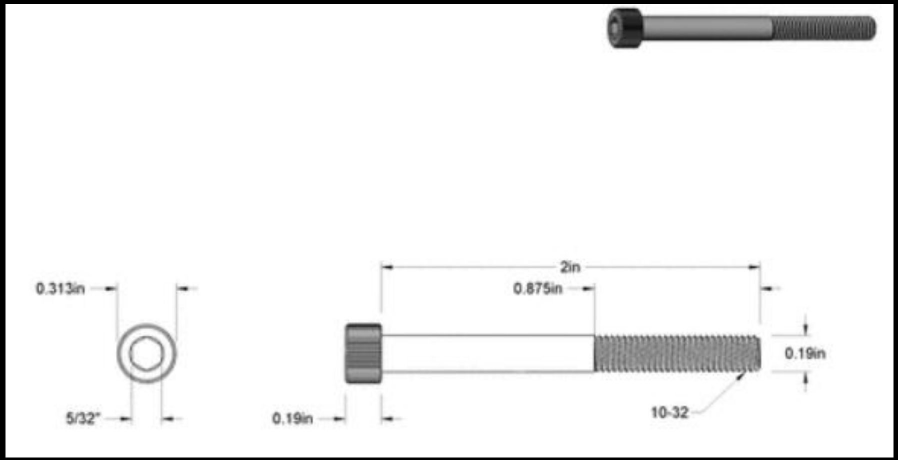
Ablative Liner Molding

- Based on last year's mold
- SLA printed
- Modified to allow for a taper
- M6 Screws and caulking to secure both halves together
- Hollow chamber to hold water to prevent thermal run away





Bolts and O-rings



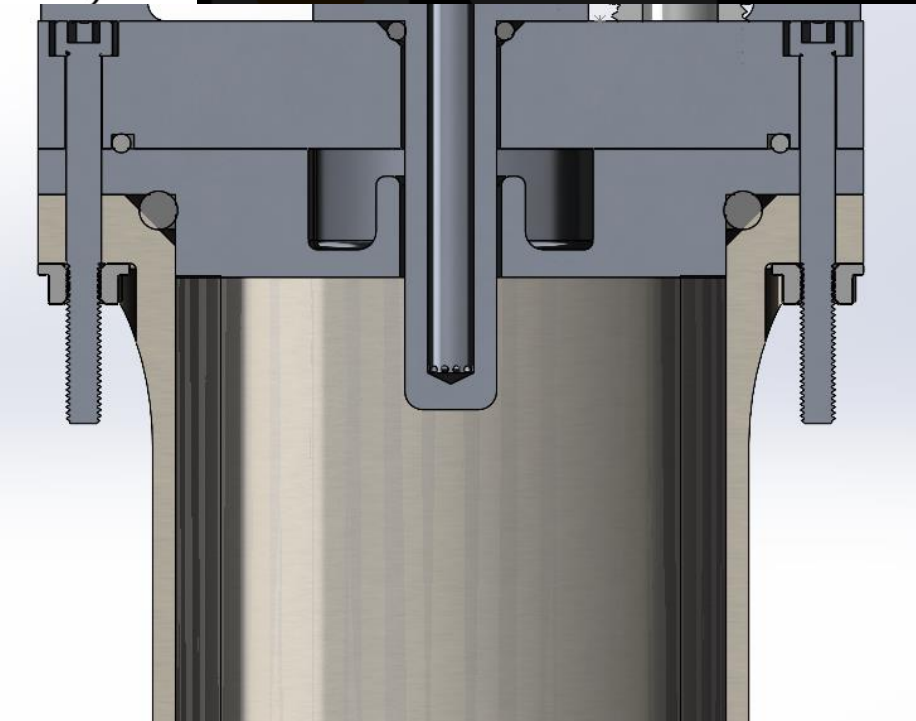
18-8 Stainless Steel Socket Head Screw

10-32 Thread Size, 2" Long, Partially Threaded

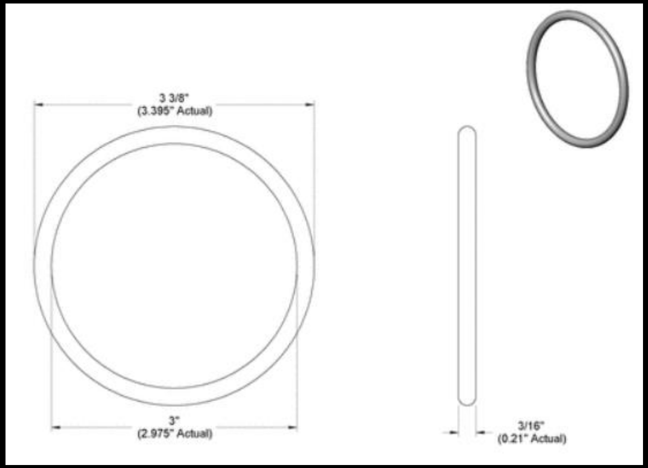
$$\sigma_{Bolt} = \frac{P_{Manifold} \times A_{Injector\ cavity\ surface}}{\left(\frac{n_{bolts} \times \pi \times (D_{Bolt\ minor}{}^{2})}{4}\right)}$$

$$\frac{70000}{22553.9} \times 100 \approx 310\%$$

- 8 Bolts
- Integration with injector
- 70,000 psi tensile strength
- Calculated bolt tensile stress of 22553.9 psi
- Safety factor of 3.1

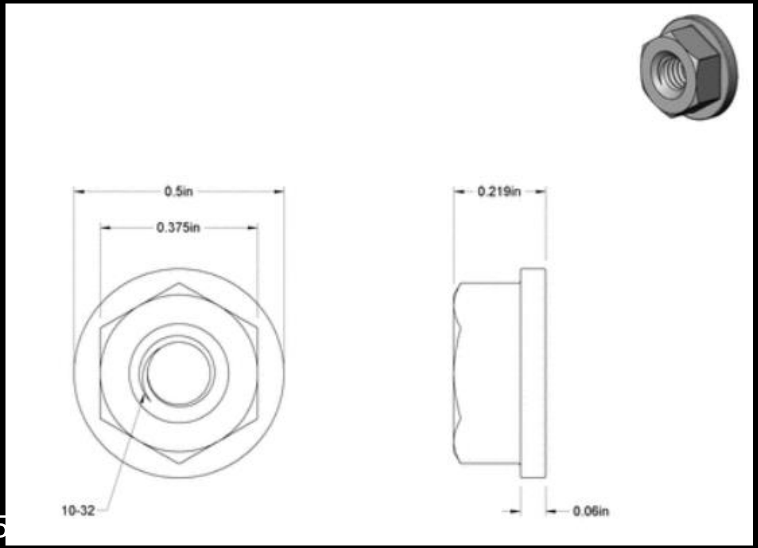


O-rings and Nuts



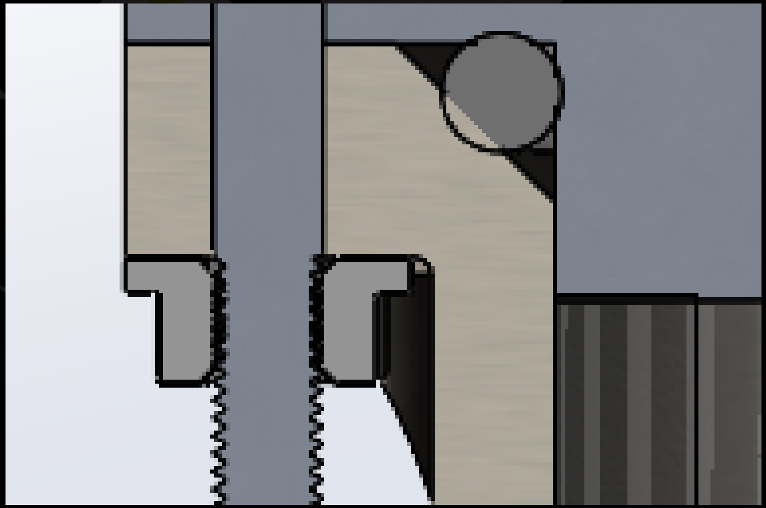
High-Temperature High-Purity Silicone O-Ring
3/16 Fractional Width, Dash Number 337

- Static Crush Gland Seal
- Rated to 477.59 kelvin



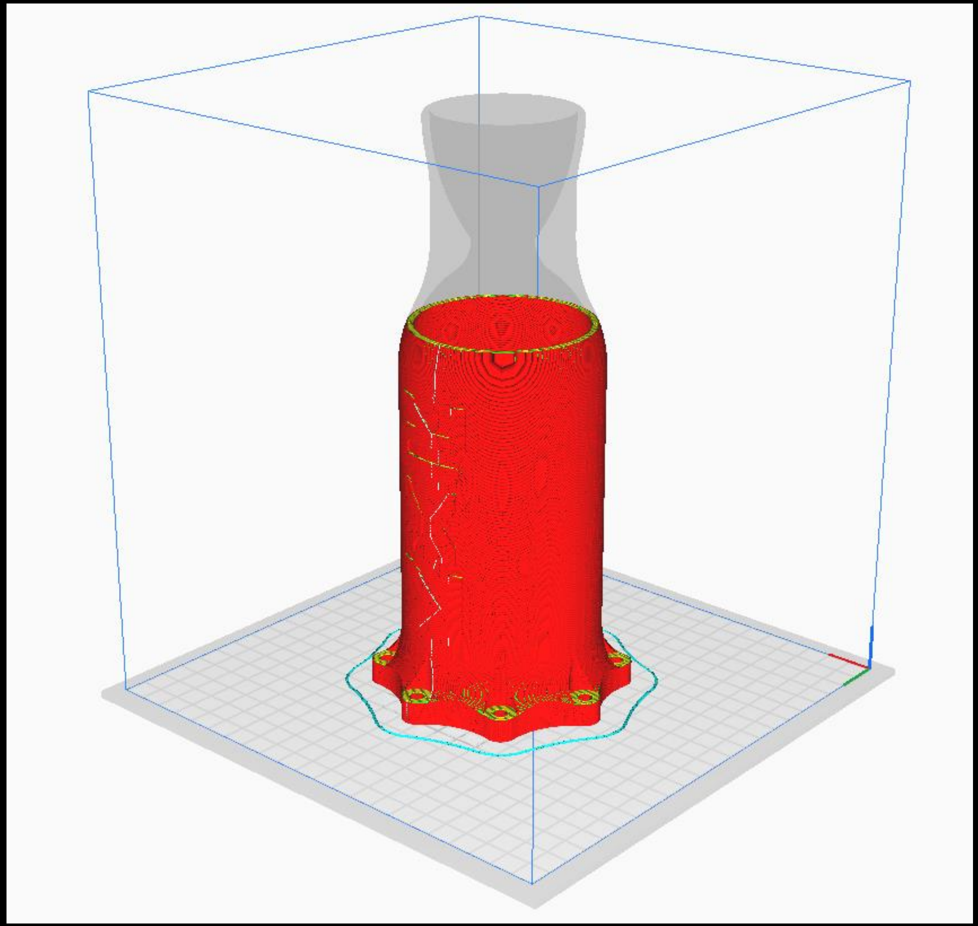
316 Stainless Steel Flange Nuts
Super-Corrosion-Resistant, 10-32 Thread Size

- 8 Nuts
- Same material as bolts



Combustion Manufacturing

- Combustion Chamber
  - DMLS Inconel 718
    - Printed axially for ease of post machining
    - Since part is so large, it will need a print pause to add more powder to the vat
  - Post machining needed for internal geometries
- Ablative Liner
  - SRAD mold for Starlite
    - 3D Printed ABS filament
  - Needs to be dried for rigidity
- Igniter Holder
  - FDM 3D printed PLA

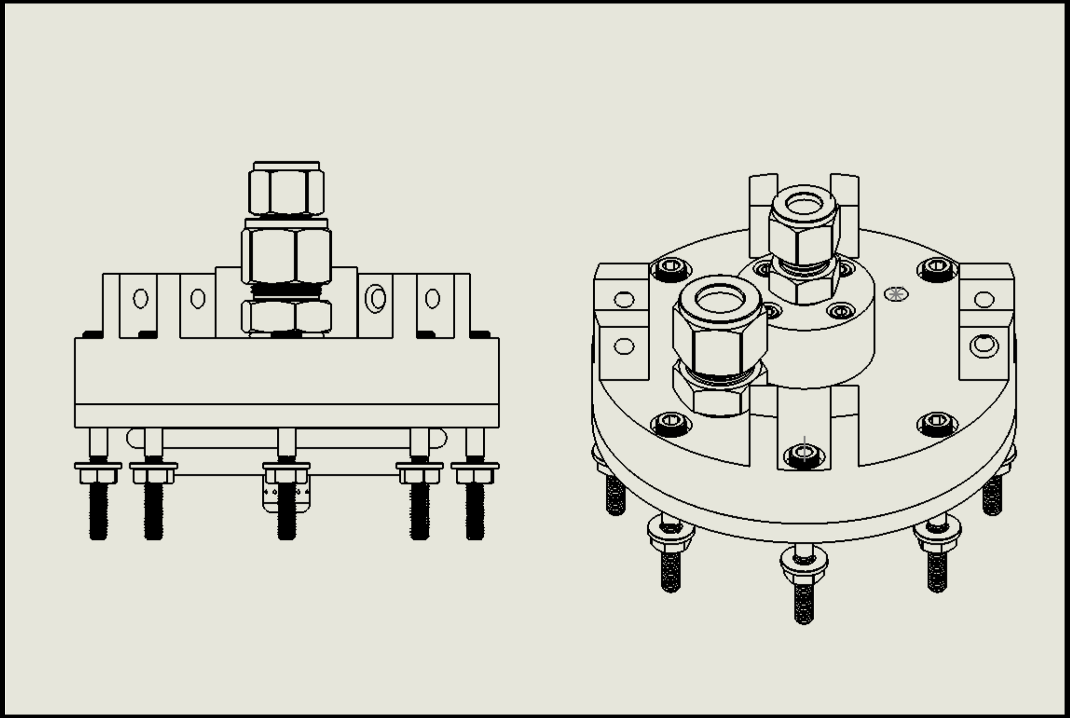


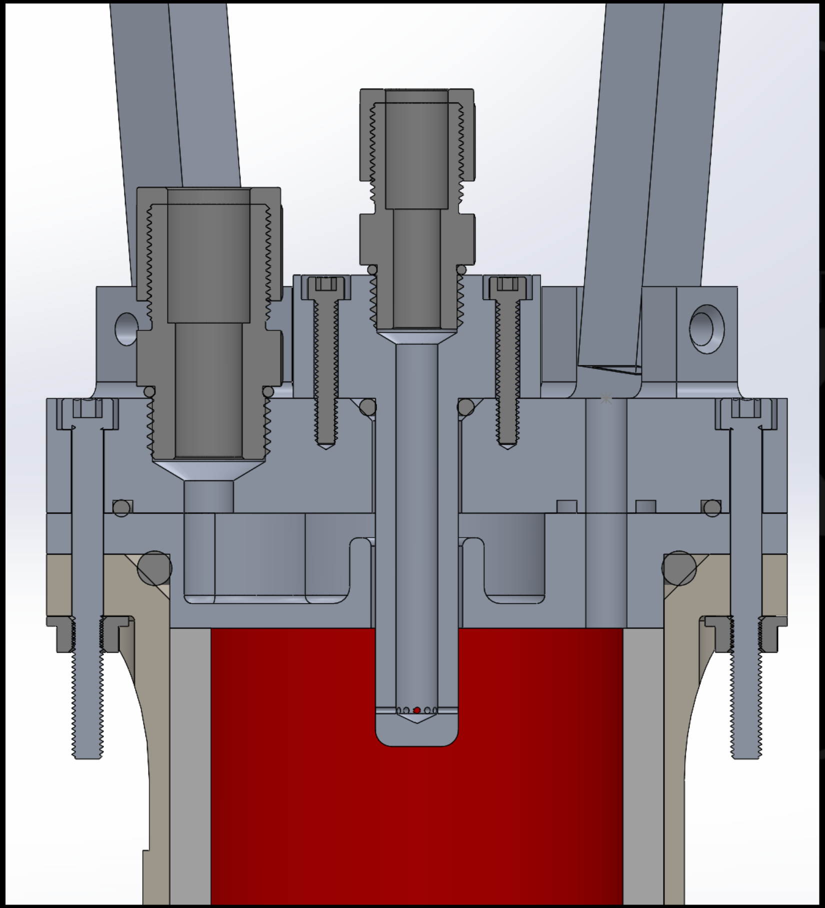
Preliminary combustion chamber cad in Cura slicer to show print orientation

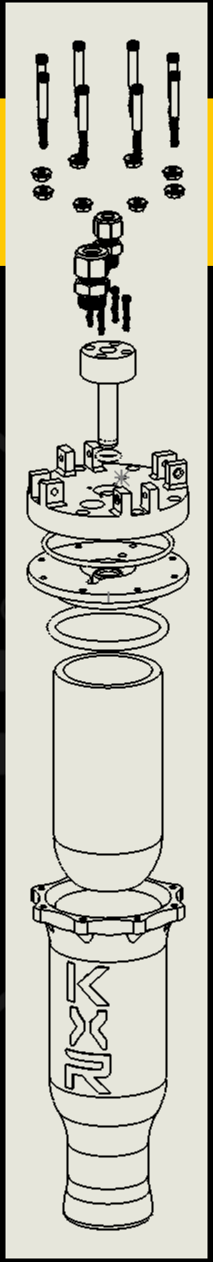
Combustion FMECA

Part	Failure	Criticality	Effect	Mitigation
Ignitor	E-match fails to ignite rocket candy	High	Propellants do not ignite, and rocket does not launch	Three e-matches for redundancy and e-match testing before launch.
Ignitor	Ignitor is unable to stay on the nozzle	High	Is unable to ignite propellants and rocket does not launch	Testing Ignitor during static tests and evaluating
High Pressure Seals	Chamber fails to completely seal to injector	High	Combustion Chamber breaks away from Basilisk	8 high tensile strength bolts are used
Ablative Liner	Ablative Liner fails to insulate the chamber from the heat of the engine	Low	Chance that chamber takes damage from burn	Testing Starlite against high temperature for conformation of insulation
Ablative Liner	Ablative liner fails to be removed from mold	Low	Ablative liner is unable to protect chamber	Testing Starlite in last year's mold, if it fails reassess how to design mold

Injector Subsystem







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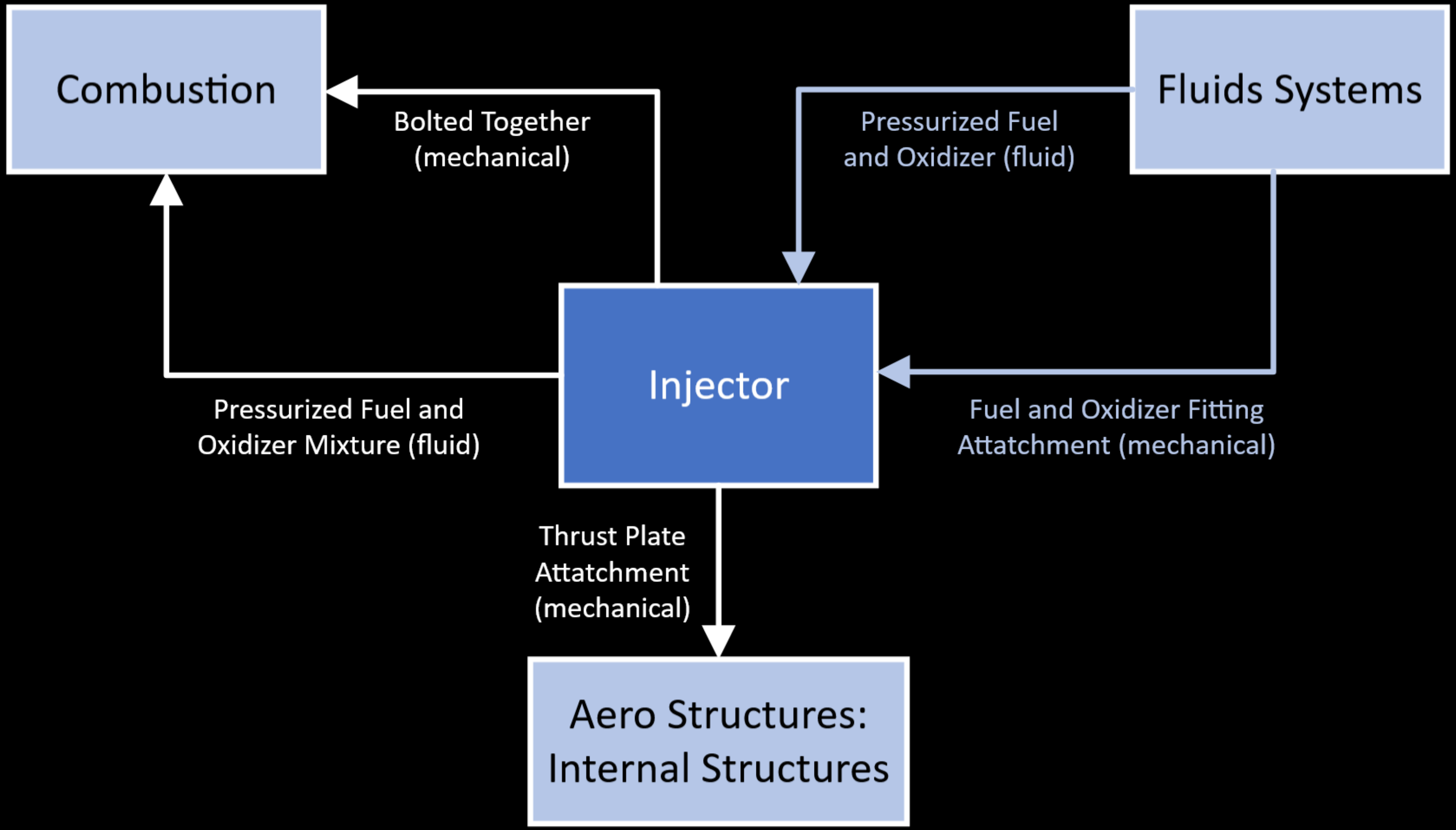
Injector Requirements

Requirement	Verification Method
The Injector shall be able to withstand ignition temperatures.	Test
The Injector shall be able to withstand burn temperatures.	Test
The Injector should be able to produce a combustion efficiency (C*) of at least 90 to 95%.	Analysis
The Injector should maintain an equivalence ratio of 3:1.	Analysis
The Injector shall be able to withstand pressurization stress.	Test
The injector shall mix the presssurized fuel and oxidizer.	Demonstration

Injector TPMs

Technical Performance Measure	Value	Units	Verification Method
Maximum Ignition Temperature	2550	K	Analysis
Ethanol Mass Flow Rate	0.625	lbm/s	Test
Nitrous Oxide Mass Flow Rate	1.875	lbm/s	Test
Minimum Pressure Drop from Inlet and Combustion Chamber	20	%	Test
Maximum Stress from Pressurization	7500	psi	Analysis

Injector Interface Diagram



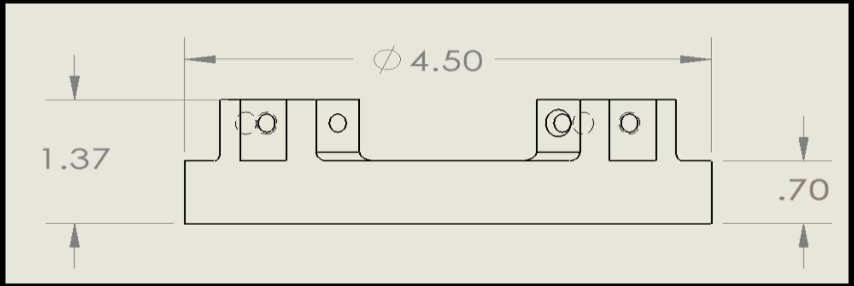
Injector Housing

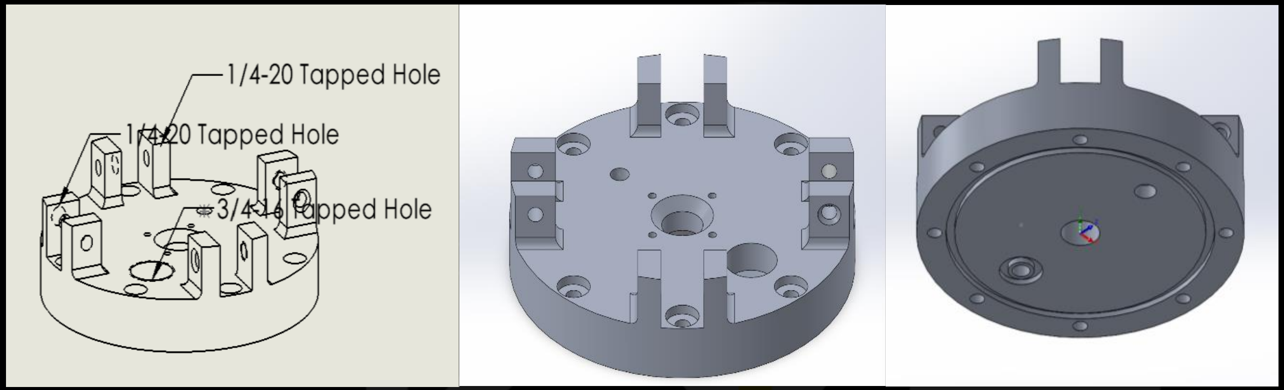
The Injector Housing takes in the oxidizer and is the main interface component between Injector and the rest of the airframe.

6061 Aluminum: Cost Effective and Reliable

Integration
- 8 Bolts on outer edges attach Injector and Combustion Chamber
    - 18-8 Stainless Steel Socket Head Screw, 10-32 Thread Size, 2" Long, Partially Threaded
- Strut supports integrate with the airframe (1/4-20 Bolt Interface)
- O-rings seal Face Plate and Pressure Transducer
- 4 Bolts secure pintle to Injector Housing (#6-32 Straight Tap)

- Design Considerations:
    - Pressure Transducer must read chamber pressure
    - Strut Bolts must withstand chamber thrust
    - All elements must fit within 4.5” OD





Functional and Performance Requirements	Verification Methods
The Injector Housing shall intake 750psi of oxidizer through an intake channel.	Demonstration
The Injector Housing shall maintain seal integrity with proper sealants.	Demonstration
The Injector Housing shall withstand the vibrations, shocks, and temperature/pressure fluctuations of a rocket launch and thrust from the combustion chamber	Inspection
The Injector Housing shall be able to evenly distribute the force of the engine evenly across the structure of the airframe	Demonstration

Pintle – Mechanical Design

Facilitates the flow of Ethanol fuel into the combustion chamber for atomization

Material
- Aluminum 6061-T6; cost-effective and dependable

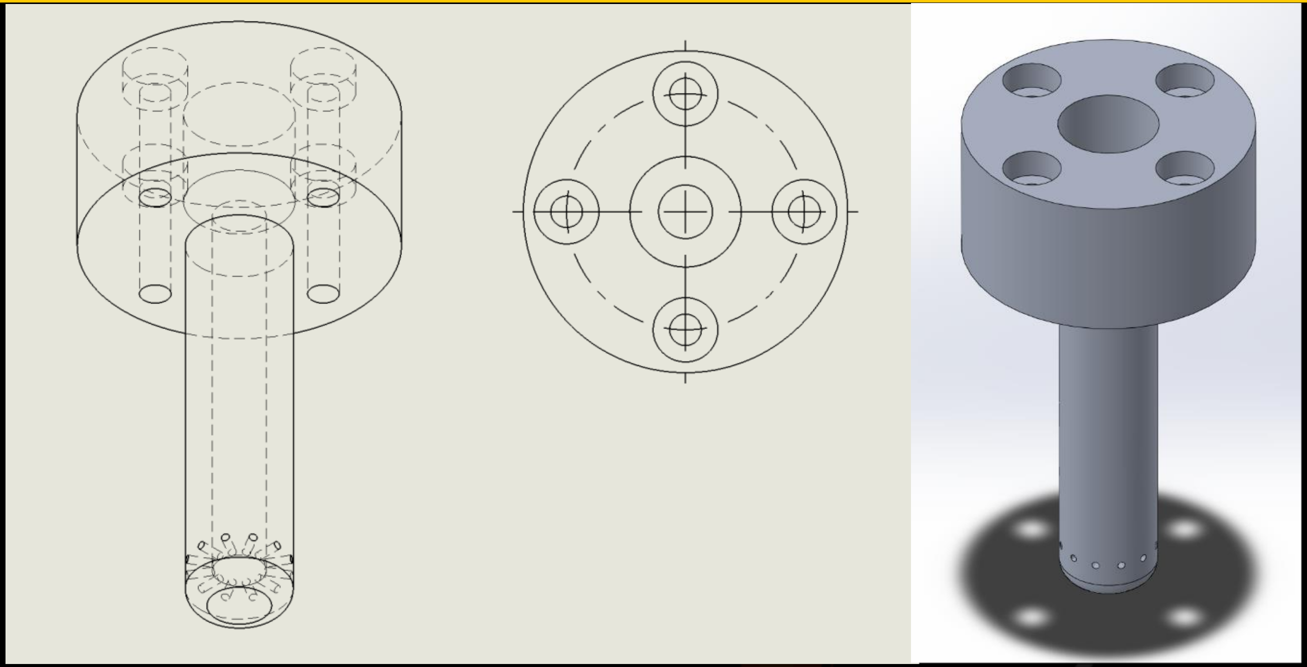
Fuel Orifice
- 12x 0.039" diameter orifices (#61 drill)

Pintle Body
- 2.87" overall length
- 0.25" Inner Diameter
- 0.5" Outer Diameter

Screw Holes
- Counterbored for #6-32 machine screws
- 4 Screw Holes

Fuel Inlet
- 9/16"-18 SAE Tapped Hole

Design considerations:
- Pintle tip heating within material spec for 9s burn time
    - Film Cooling of ox sheet
    - Cool ethanol fuel

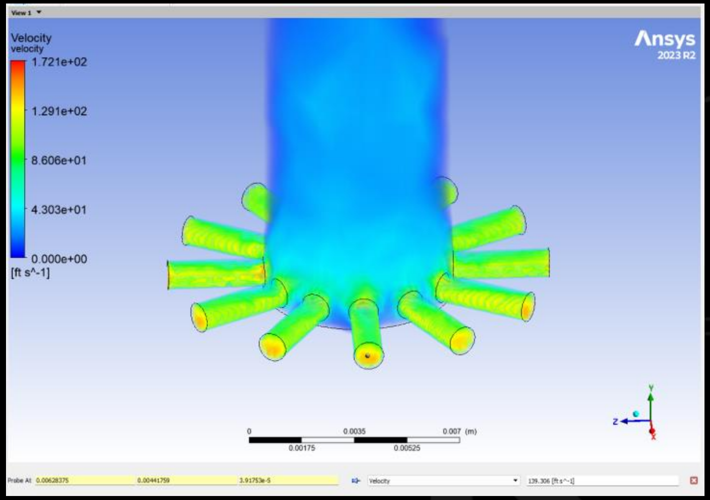


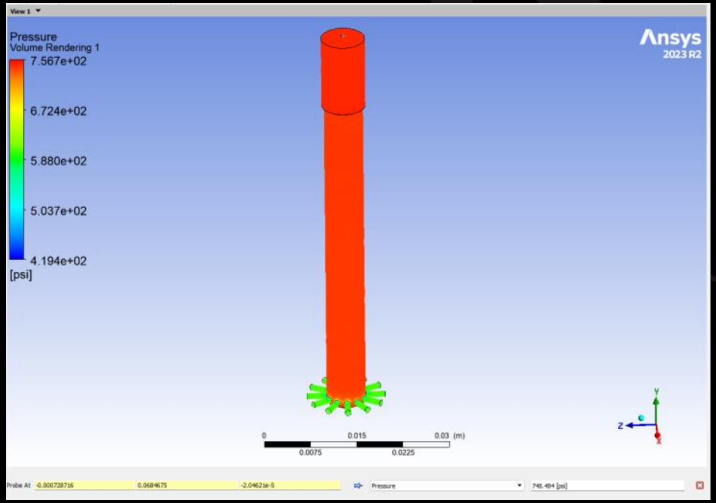
Functional and Performance Requirements	Verification Methods
The Pintle Body **shall** be able to withstand temperatures of 2600 Kelvin for 9 Seconds.	Test
The Pintle Tip **shall** withstand pressures of 750 psi for [9 Seconds	Test
The Pintle Tip **shall** generate combustion efficiencies of >95%	Analysis
The Pintle Body **shall** achieve an .625 lbs/s for the fuel.	Analysis
The pintle **shall** effectively facilitate the atomization of the ethanol with the annular nitrous oxide sheet.	Demonstration

KXR UCF

Pintle – Fluid Design

- Desired ethanol mass flow rate of 0.625 lbm/s
- Optimal pressure drop of 150 psi verified through Ansys Fluent to achieve desired mass flow
- Evenly distributed pressure and velocity gradients at orifices
- Orifices to be undersized at start of testing campaign, bored out as necessary as testing progresses
  - Accounts for Cd discrepancies or other unknown flow behaviors





Inputs	Value	Units
System Requirements		
O/F ratio	3	
Chamber pressure	500	psi
Total mass flow	2.5	lbm/s
Pressure drop across injector	30	%
Propellant 1 (annular)		
Density	42.58	lb/ft^3
Mass flow	1.875	lbm/s
Pressure drop, Δp	150	psi
Discharge coefficient (Cd)	0.8	
Pintle OD	0.5	in
Propellant 2 (radial)		
Density	48.4	lb/ft^3
Mass flow	0.625	lbm/s
Pressure drop, Δp	150	psi
Number of orifices	12	
Discharge coefficient (Cd)	0.77	

Outputs	Value	Units
Propellant 1 (annular)		
Orifice area	0.04385318	in^2
Orifice diameter	0.5530	in
Velocity at orifice exit	144.596	ft/s
Propellant 2 (radial)		
Orifice area	0.0142449	in^2
Orifice diameter	0.03888	in
Orifice diameter to 64th of an inch	2.49	1/64 in
Velocity at orifice exit	130.538	ft/s
Propellant Stream		
Total momentum ratio (TMR)	0.30092594	
Blockage factor (BF)	0.2970	
Spray angle (from vertical)	39.764	deg

Face Plate – Mechanical Design

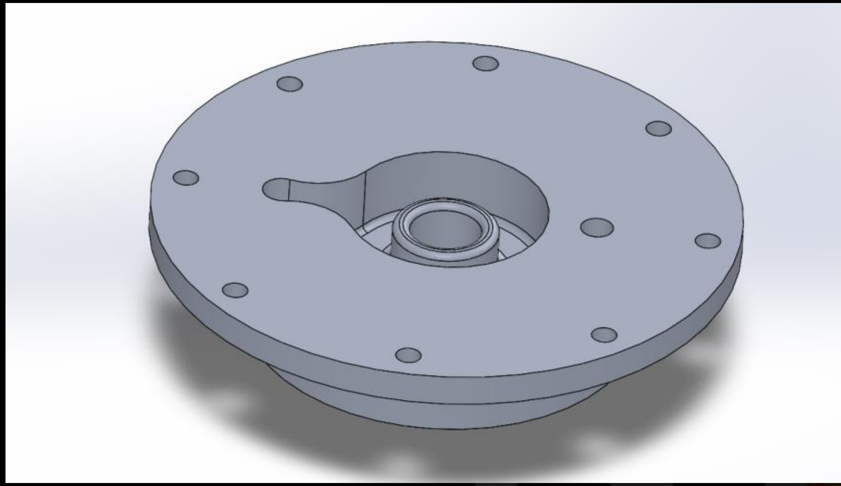
Material
- Aluminum 6061-T6

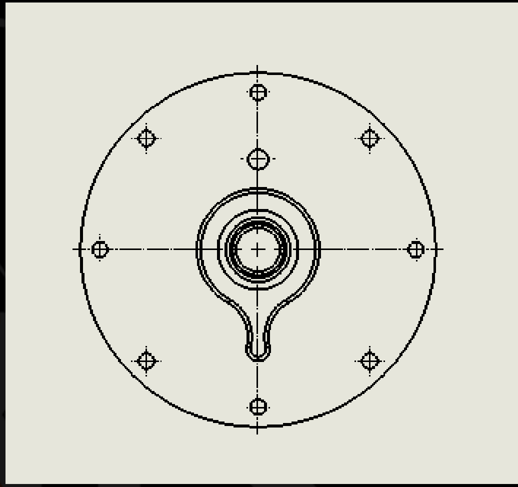
Oxidizer Orifice
- 1x 0.553" diameter
- Accounts for pintle OD

Faceplate
- 4.5" outer diameter
- 1.75" oxidizer cavity diameter
- 0.75" overall thickness

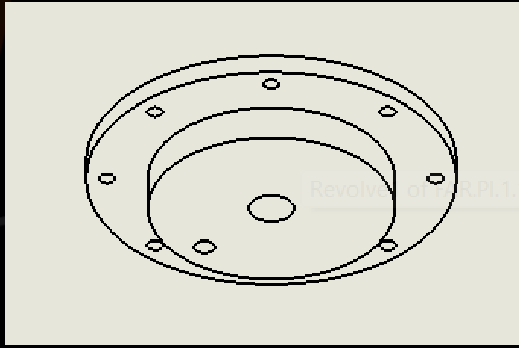
Oxidizer Inlet
- 3/4"-16 SAE Tapped Hole

Design Considerations:
- Central orifice height allowing for even distribution of oxidizer
- Pressure transducer hole location to correctly analyze and record chamber pressure



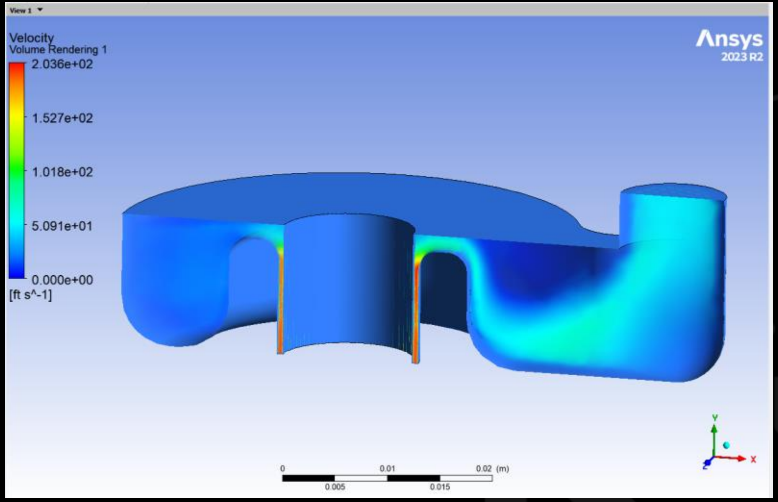


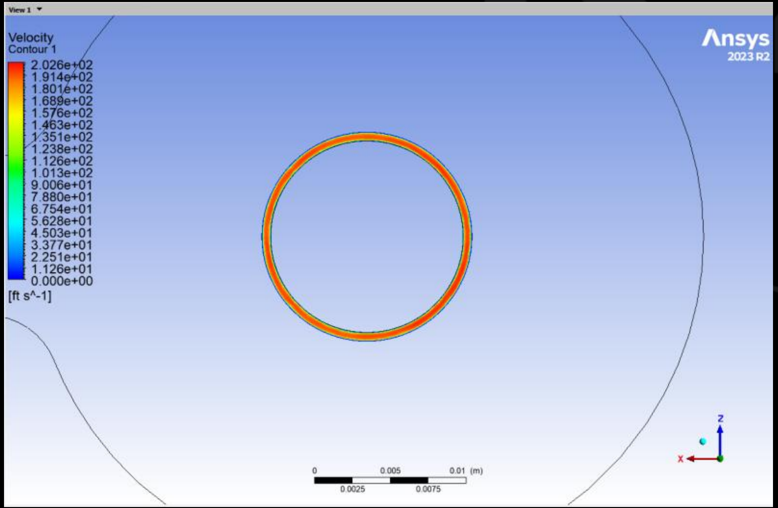
Functional and Performance Requirements	Verification Methods
The face plate shall evenly distribute oxidizer through central orifice	Demonstration
The face plate shall be able to withstand temperatures of 2600 Kelvin from combustion chamber	Test
The face plate shall be able to withstand pressures of 500 psi for 9 seconds.	Test
The face plate shall depressurize oxidizer to 500 psi	Test



Face Plate – Fluid Design

- Primary role of face plate/oxidizer cavity is to evenly distribute fluid before injection
  - 3/8" height wall was added to the oxidizer cavity to achieve this
- Desired nitrous oxidize mass flow of 1.875 lbm/s
- Simulated in Ansys Fluent using a fluid of similar density to nitrous oxide at 305 K (~44 lb/ft^3)
- Verified even flow distribution with velocity gradient at oxidizer orifice
- Achieves optimal pressure drop of 150 psi





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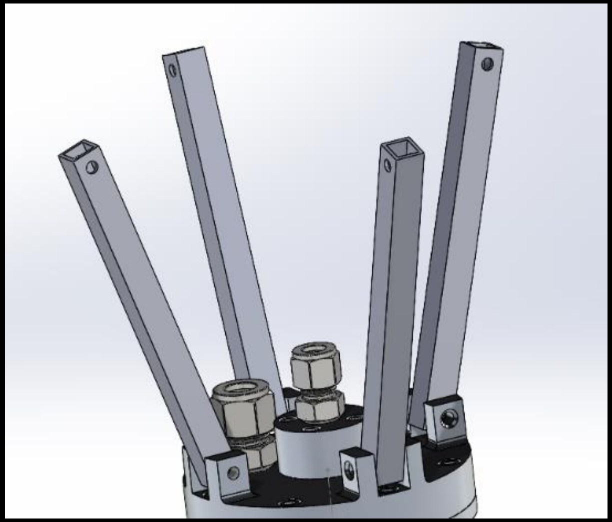
Thrust Structure

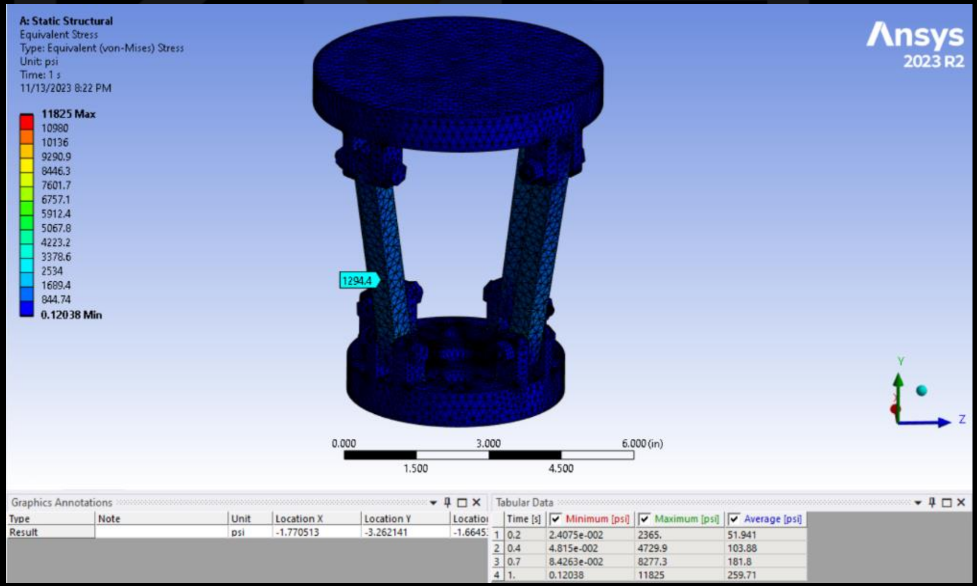
- Thrust structure and injector housing integrated as one component
- Struts constructed out of ½" 6061-T6 aluminum rectangular tube
- Fastened to structure with ¼"-20 18-8 stainless steel bolts
- Preliminary stress calculations found FoS to be 27.7, assuming peak thrust of 550 lbf
- Preliminary values verified through Ansys mechanical, minimal stresses and buckling

Inputs	Value	Units
Expected peak thrust	550	lbf
Strut cross sectional area	0.1094	in^2
Strut angle (from vertical)	5.5	deg
Number of struts	4	
6061-T6 tensile yield strength	35000	psi

Outputs	Value	Units
Strut stress	1262.7	psi
Factor of safety	27.719	

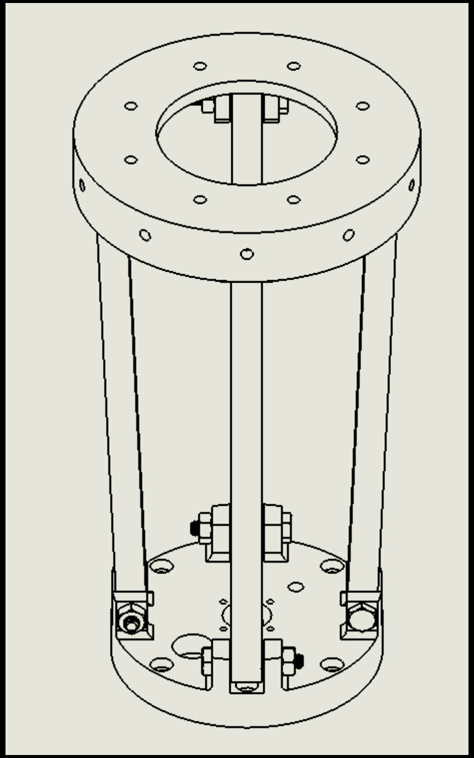
Functional and Performance Requirements	Verification Methods
The struts shall transfer 550 lbs. of thrust to from the injector housing to the thrust plate.	Demonstration
The struts shall structurally withstand 550 lbs. of force.	Analysis
The struts shall connect the propulsion system, aft of fluids, to aerostructures.	Inspection

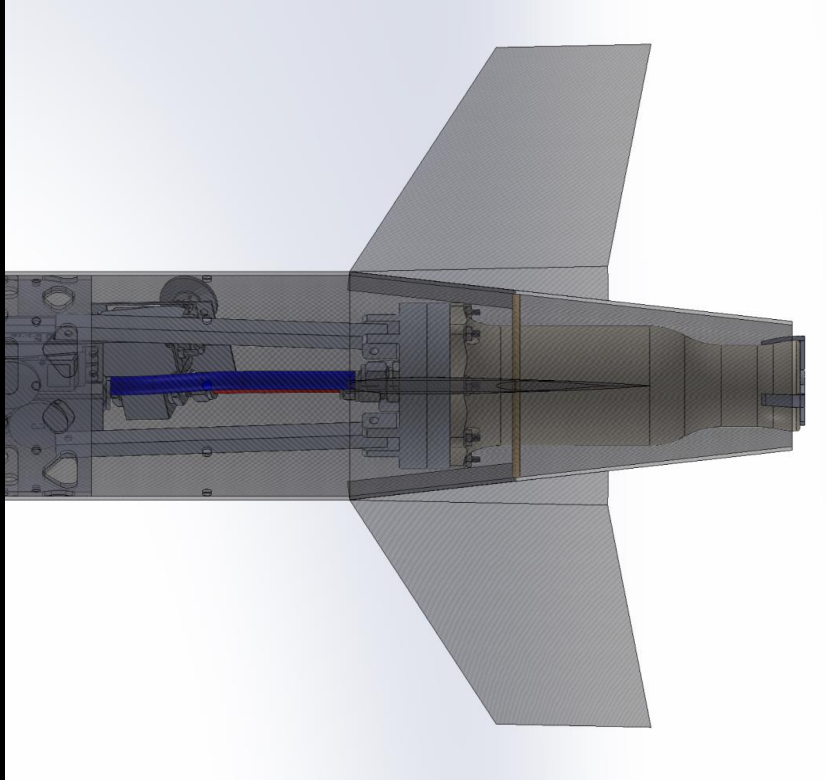


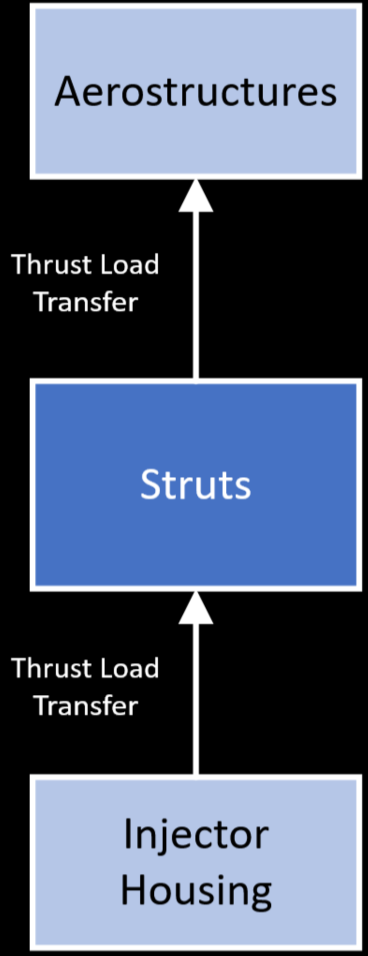


Injector Housing – Thrust Plate Interface

- Struts are the primary structural interface to the rest of the vehicle
- Transfers load into thrust plate, transfers to vehicle airframe
- Clearances between airframe and thrust structure are large enough to access plumbing, fittings, and fasteners

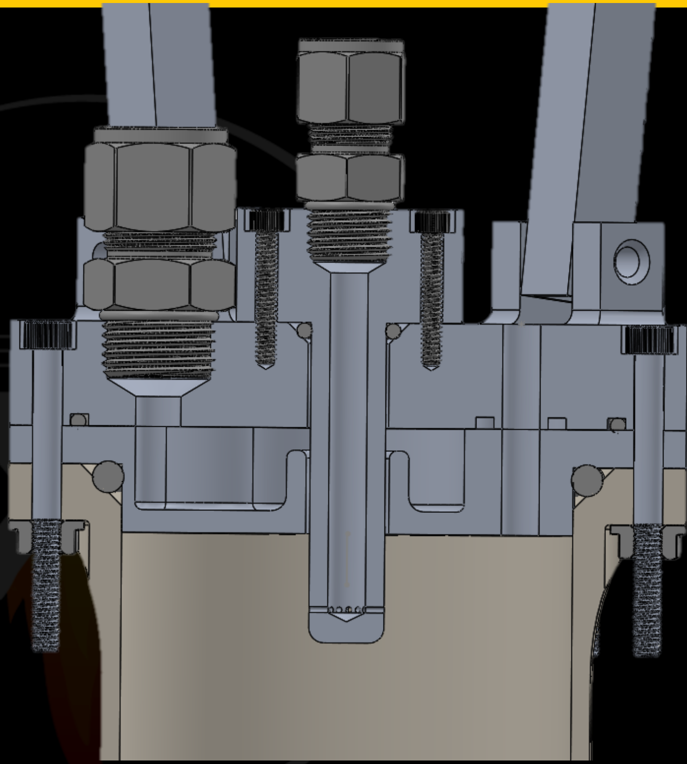






Injector Manufacturing

- Component materials
  - Aluminum 6061-T6
    - Injector body ~ $20 in stock
    - Pintle body ~ $12 in stock
    - Face plate ~ $20 in stock
  - Hardware and Fittings
    - Hy-Lok and Stainless-steel flange nuts and SHC Bolts
- All aluminum components will be machined by the UCF machine shop with rough quoting as follows
  - Injector body ~ 3 Hours at $35 an hour
  - Pintle body ~ 2 Hours at $35 an hour
  - Face plate ~ 3 Hours at $35 an hour
- Rough total of around $330 for all machining and stock not including hardware
- Surface Finish
  - Anodizing is an electrochemical process that converts the metal surface into a decorative, durable, corrosion-resistant, anodic oxide finish that can be up to 0.006" thick
  - The aluminum oxide layers melting point is 3,762°F compared to aluminums 1,221°F



Injector FMECA

Part	Failure	Risk	Effect	Mitigation
Injector Housing	The injector housing/thrust plate bolts shear	High	The injector housing gets shoved into the oxidizer tank and the rocket fails.	Stress testing during design to ensure the bolts are strong enough.
Injector Housing	Injector housing structurally fails	High	Loss of performance and possible loss of vehicle	Testing on stand and frequent inspection
Pintle	Overheating	High	Loss of propulsion / RUD	Testing on stand and frequent inspections
Face Plate	Overheating	High	Loss of propulsion / RUD	Testing on stand
Face Plate	Fails to maintain consistent pressure change across the anulus	Medium	Loss in performance and time / materials	CDF, testing on stand, and inspections
Struts	Structural failure	High	Loss of propulsion / RUD	Demonstration on test stand

Questions / Discussion