Raytheon

Critical Design Review

REPTAR

REcoverable ProTection After Reentry

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Project Statement & Motivation

REPTAR shall assist in the recovery of a de-orbited 1U Raytheon Payload. The mission begins once the SmallSat has re-entered the atmosphere and has reached subsonic velocity. REPTAR shall facilitate the subsonic deceleration, landing, location determination, and location transmission portions of the mission.

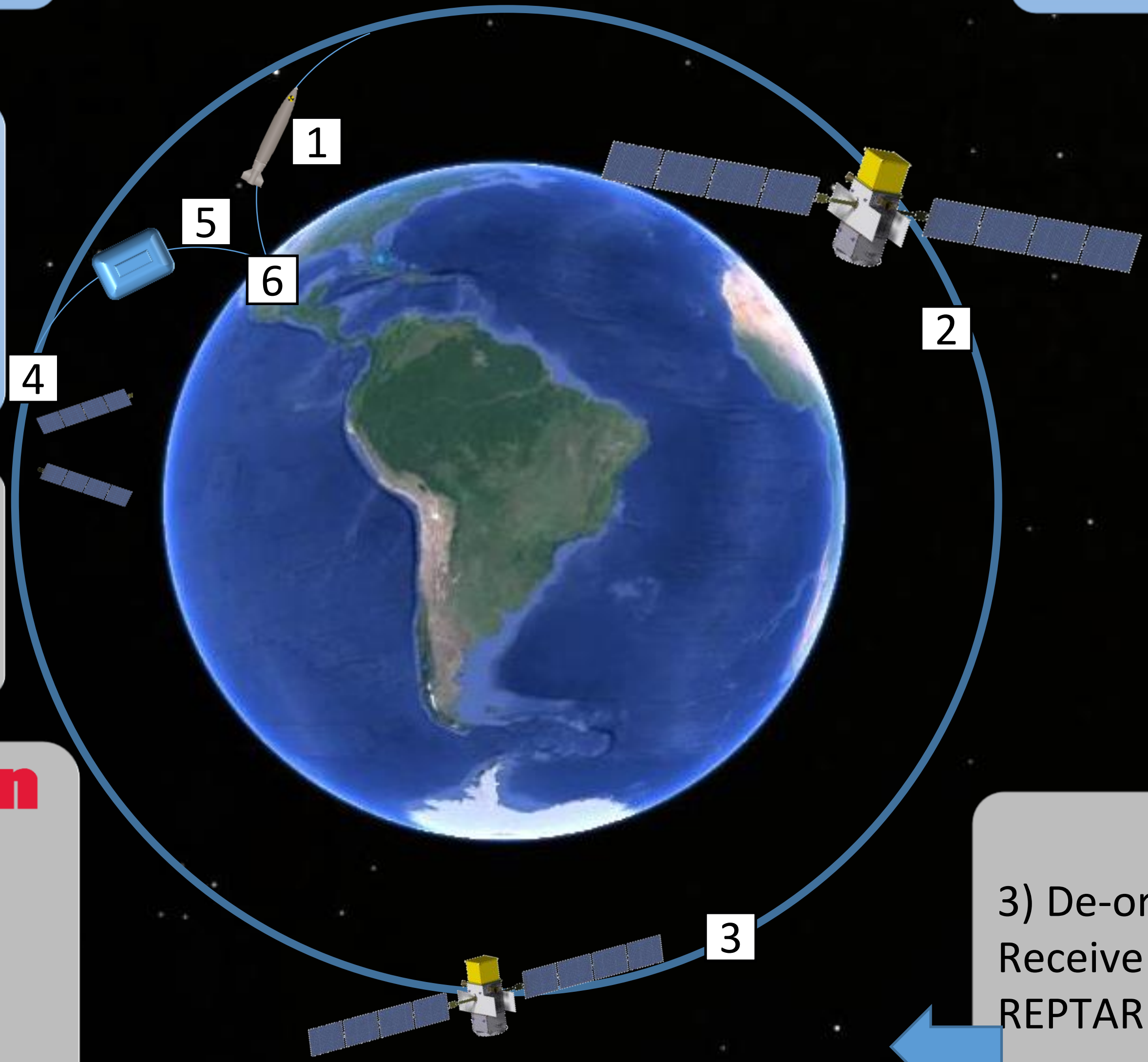
Recovery of payload enables:

- Lower mission costs by re-using the payload
- Obtain samples collected by payload on-board

Mission Concept of Operations

1) Launch
REPTAR components survive launch conditions as payload attached to a bus.

2) Orbit/Standby
REPTAR Components survive on orbit conditions. Batteries charged by bus.



Legend

REPTAR Solution

Raytheon Solution

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3) De-orbit
Receive command from bus to power REPTAR systems. Re-entry burn.

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4) Re-entry
Receive command from bus to power REPTAR systems. REPTAR separation from bus. Re-entry completed by Raytheon System.

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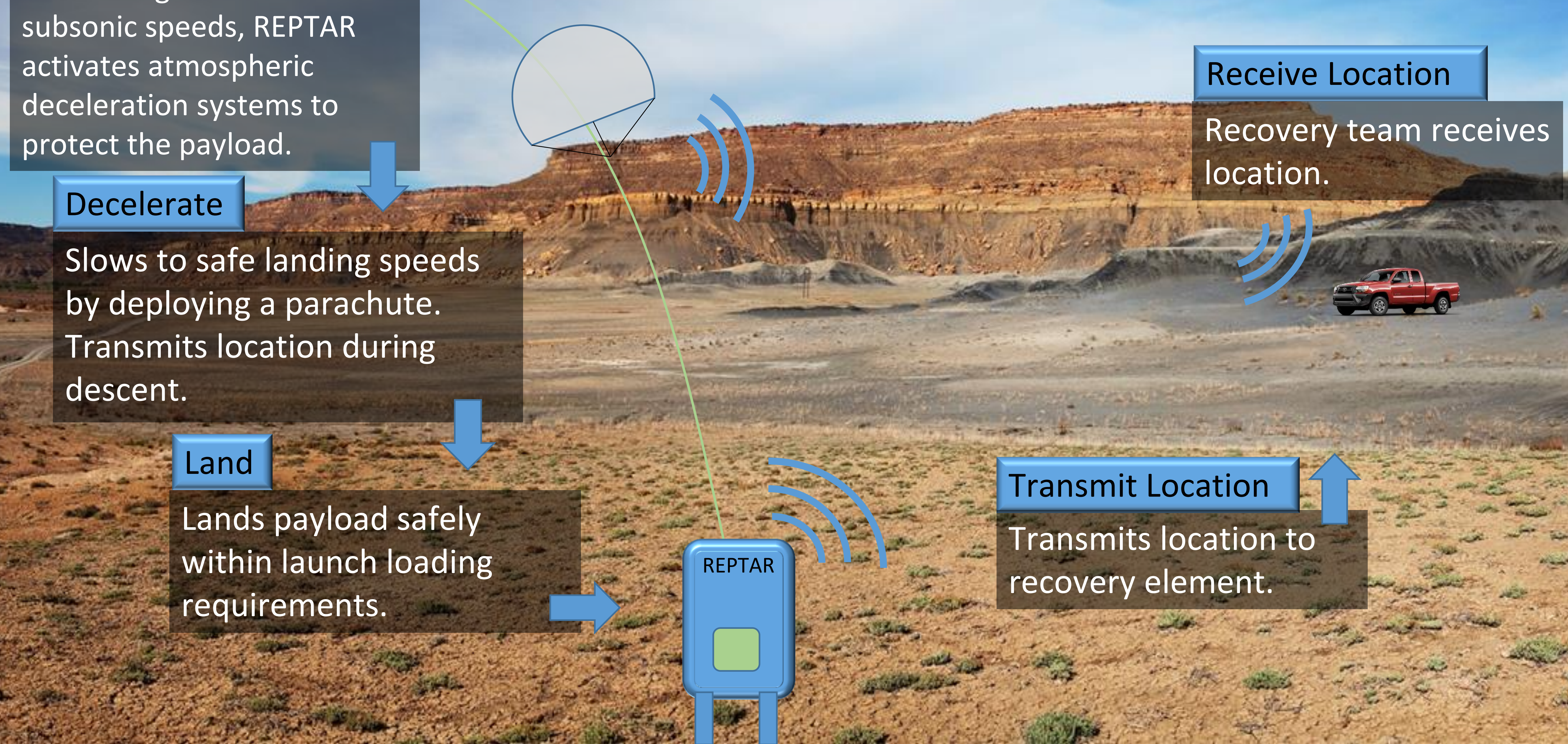
5) Deceleration
Decelerate to subsonic speeds.

6) Land and Recovery
REPTAR protects payload during ground contact and transmit location.

REcoverable ProTection After Reentry (REPTAR) Concept of Operations(CONOPS)



Driving Design Requirements

Requirement	Description	Motivation
DR 2.1	REPTAR shall be 3U in size	REPTAR must conform to industry CubeSat standards
DR 2.3	REPTAR shall be less than 4 kg in mass	REPTAR must conform to industry CubeSat standards
DR 3.1	REPTAR shall survive an instantaneous G loading of 40 G's	REPTAR is expected to protect a 1U payload that is designed to MIL-STD-810G standards
DR 4.1	REPTAR shall communicate its location over a radius greater than or equal to 45 miles	A search team must be able to find and recover the 1U Raytheon payload

Design Solution

Mission Timeline and FBD

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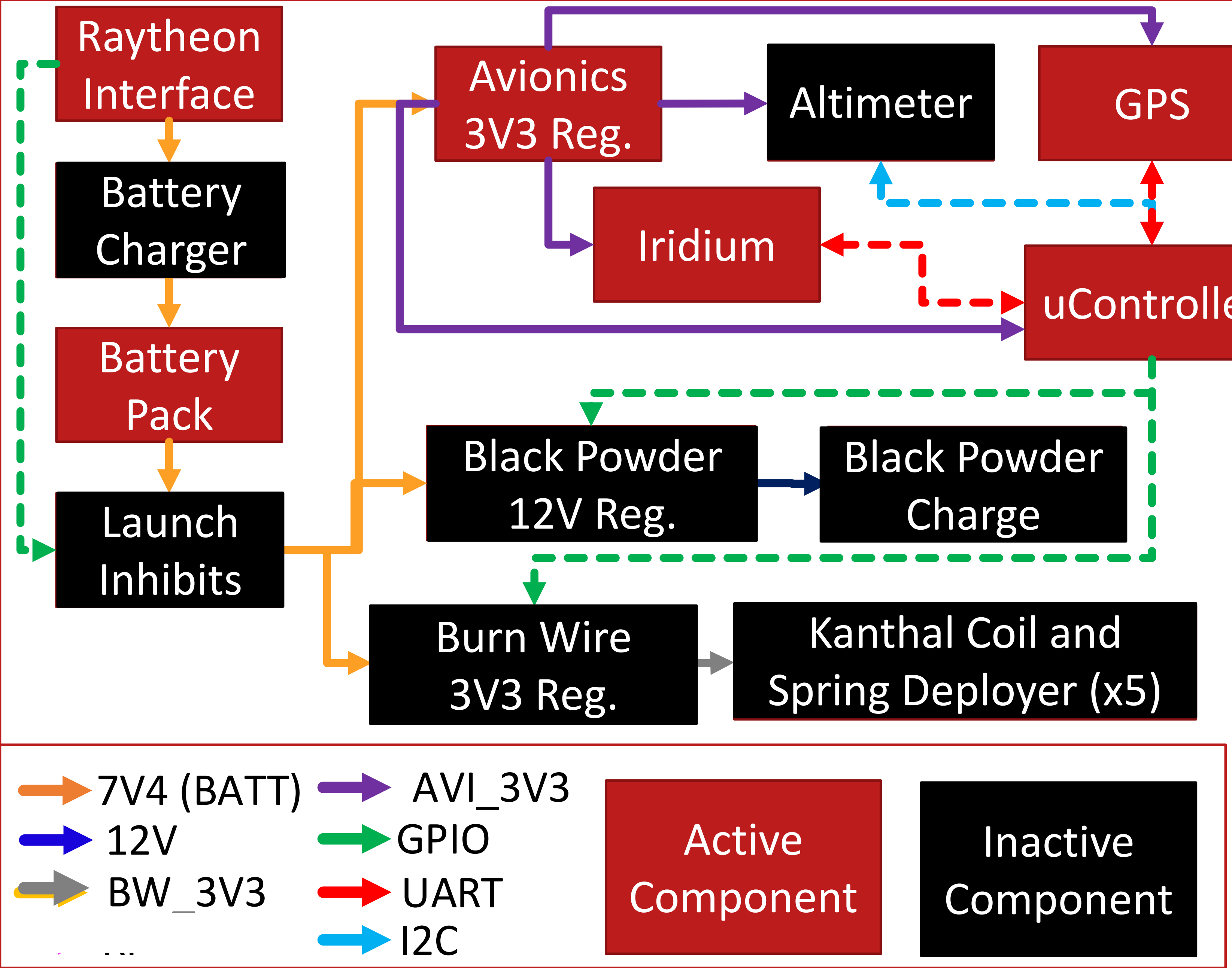

On-Orbit Standby

- Maintain battery charge

Descent

- Triggered by bus signal
- Determine altitude
- Attain GPS lock

Deceleration [3,500 m]

- Triggered by parachute deployment altitude being reached
- Deploy parachute, bottom panel, and side panels.

Transmission

- Triggered by deployments
- Transmit Location

Parachute Deployment Sequence

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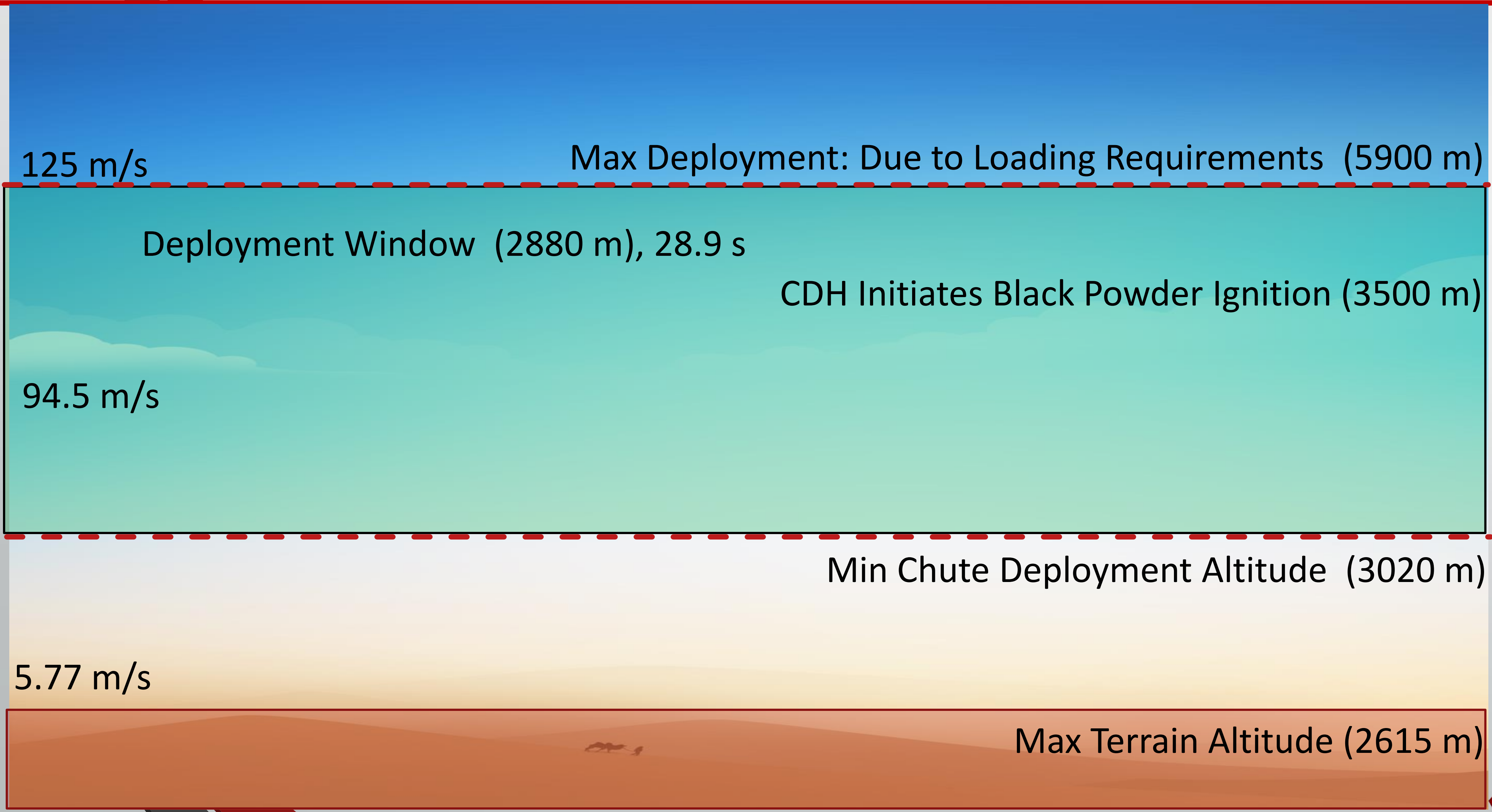

Key Components

DR.2.1
DR.2.3

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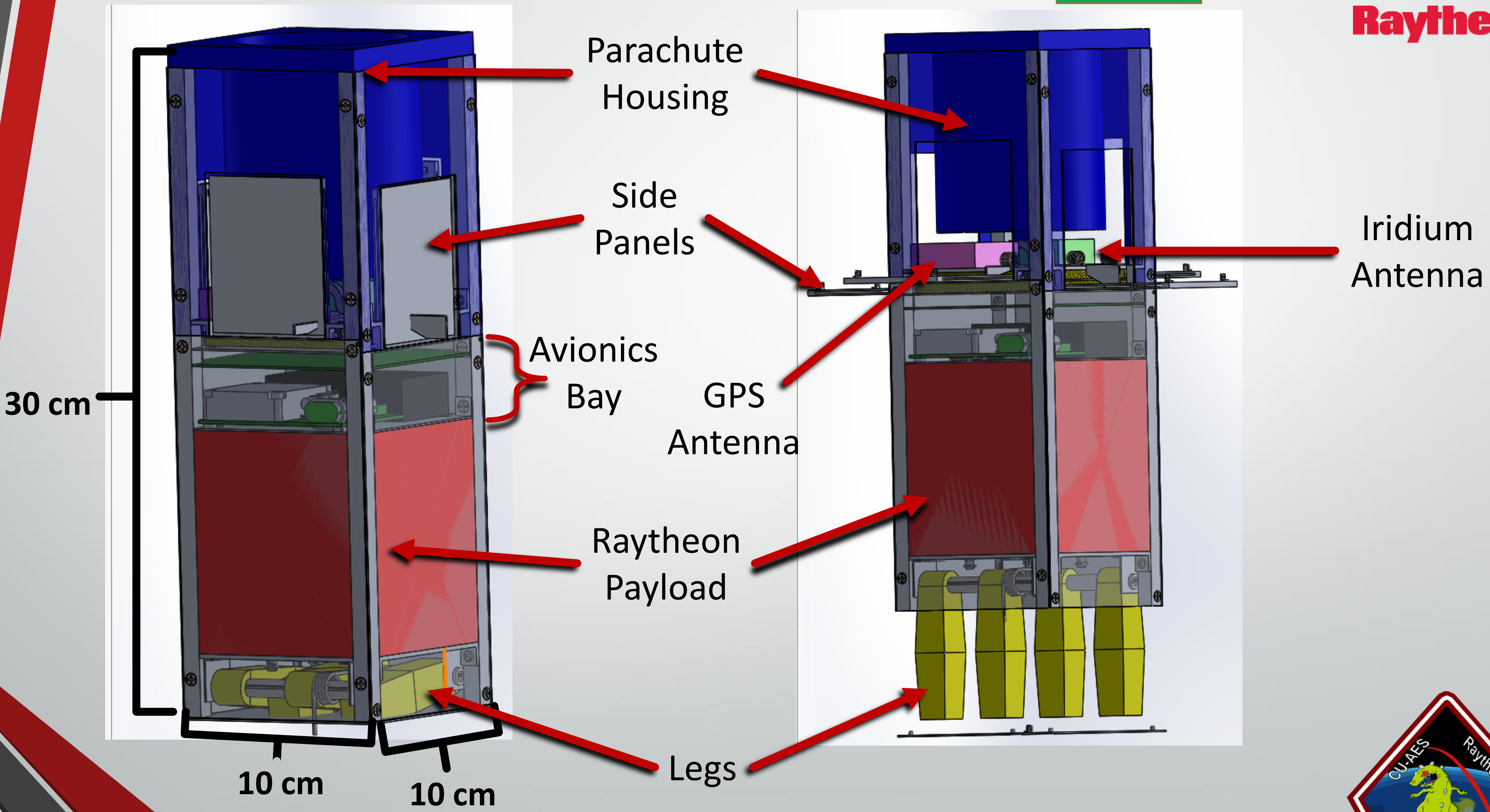
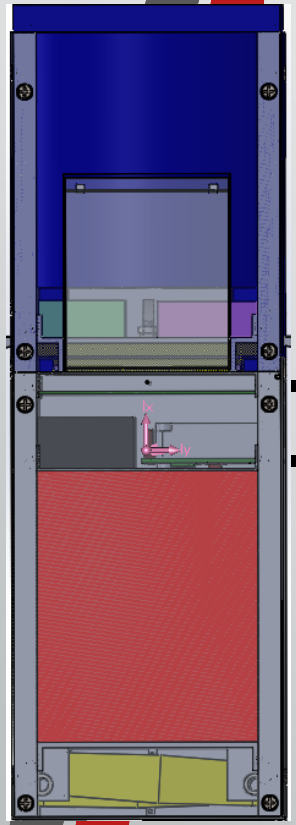
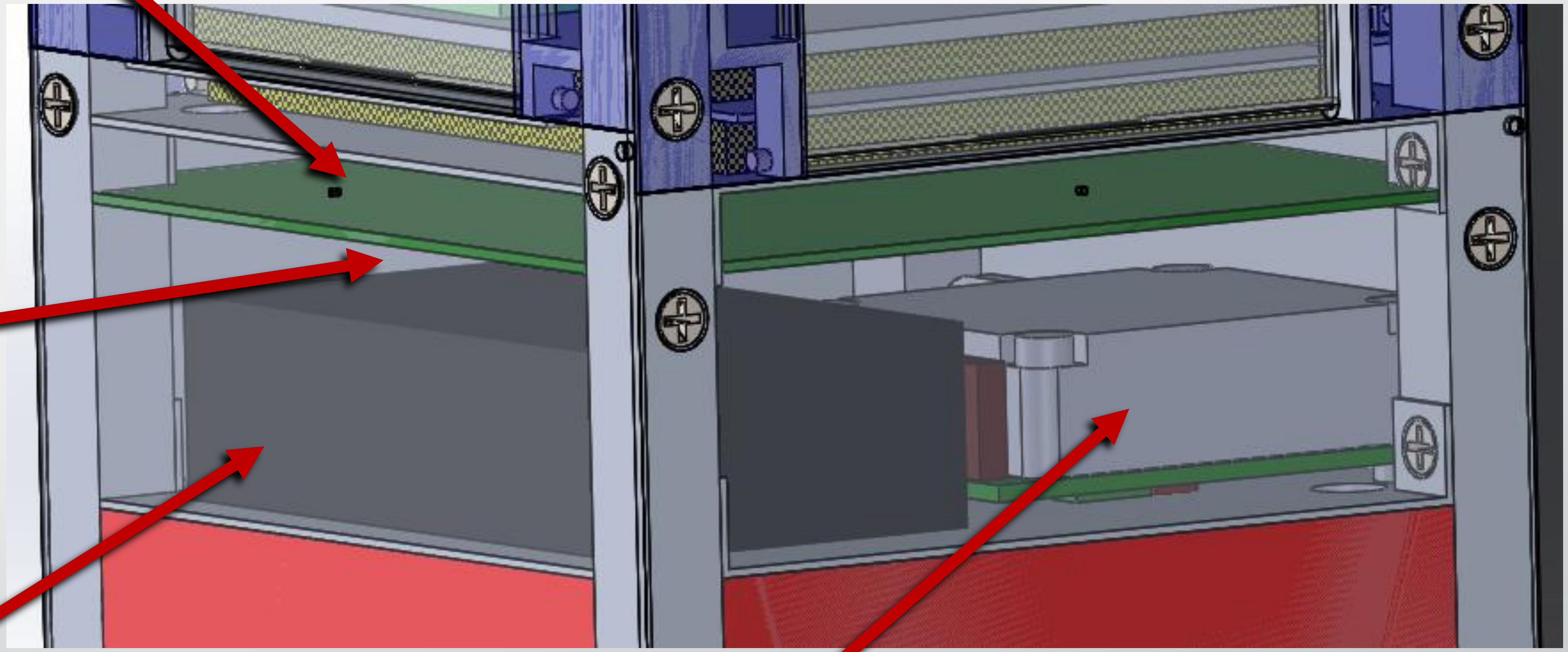


Avionics Bay Key Components





Total Mass & Volume Budget

DR.2.1
DR.2.3

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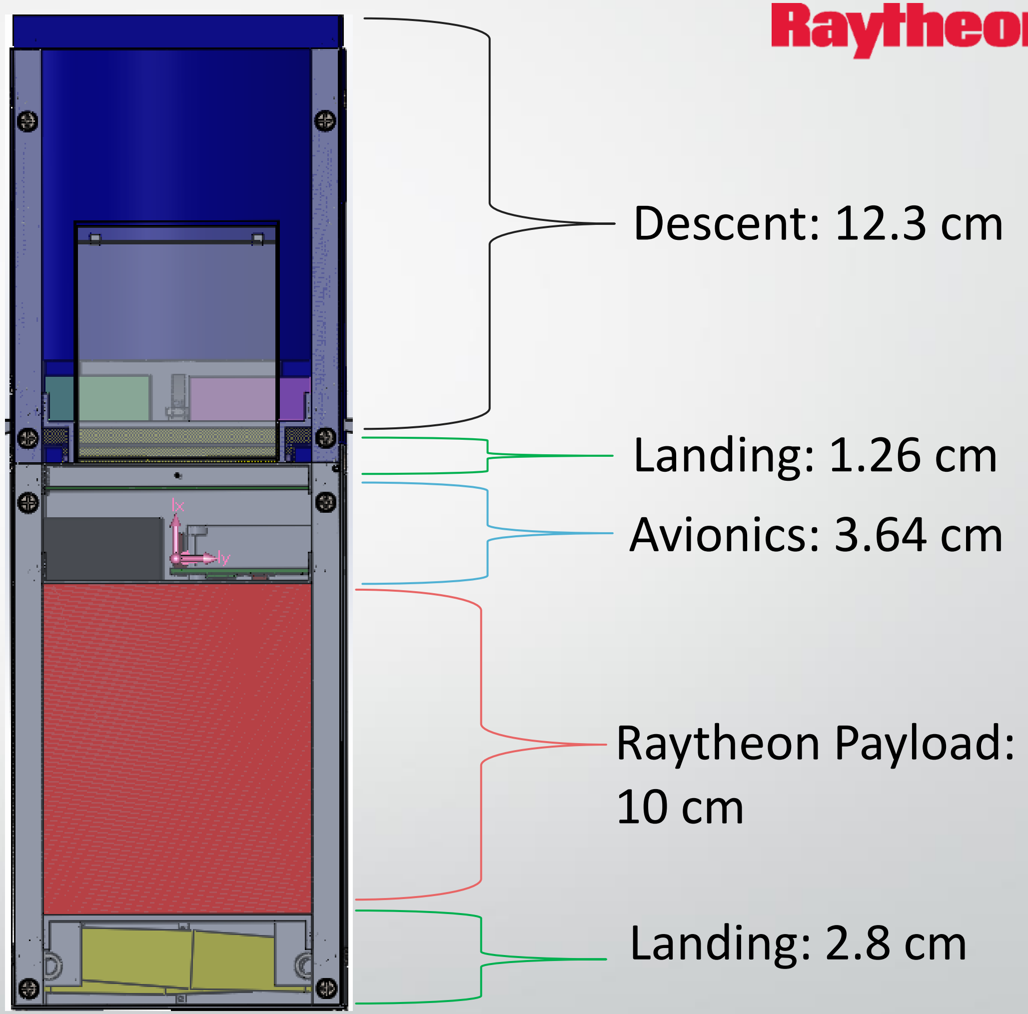
Item	Mass (g)	Volume (U)
Descent Subsystem	383	1.23
Landing Subsystem	395	0.41
Avionics Subsystem	518	0.36
Frame	437	-
Raytheon Payload (Provided and Unchanging)	1330	1.00
SYSTEM TOTAL	**3063**	**3.00**
SYSTEM MAX	**4000**	**3.00**
Margin	**937**	**-**

*All proceeding analysis assumes 4 kg system mass



Critical Project Elements

Critical Project Elements

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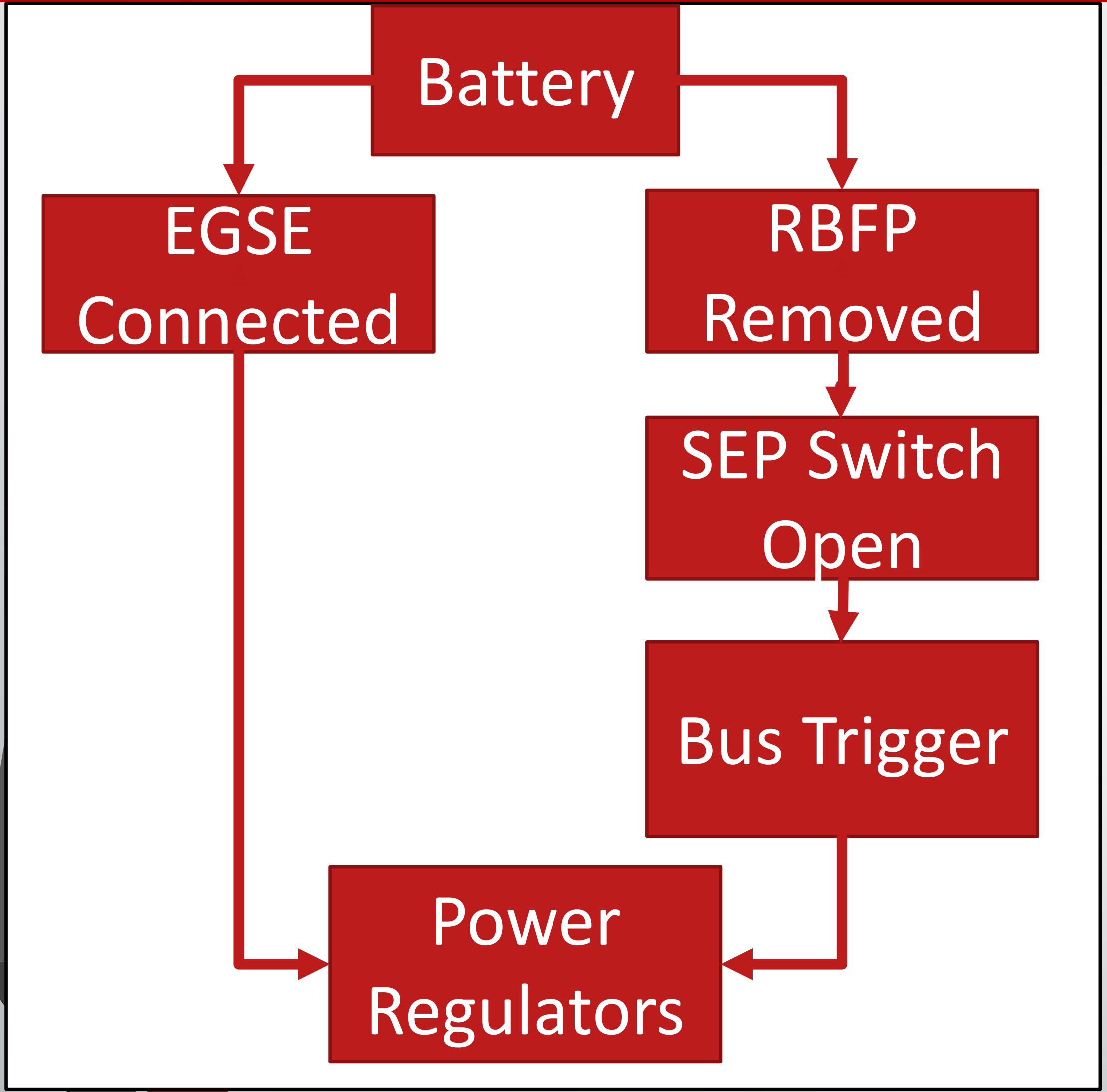
System	Critical Elements
Descent	• Parachute Deployment
Landing	• Leg and Side Panel Deployment
Avionics	• Deployment Interfacing • Antennae Pattern • Altimeter Accuracy
Full System	• Manufacturing • Full System Testing

Design Requirements

Launch Inhibit Considerations



- **CPE**:
  - Interfacing to Deployment Mechanisms
- **Requirements**:
  - FR1: REPTAR shall survive launch and standby phase in space
  - FR2: REPTAR shall conform to industry CubeSat standards
- **Concerns:**
  - None at this time

Altimeter Considerations

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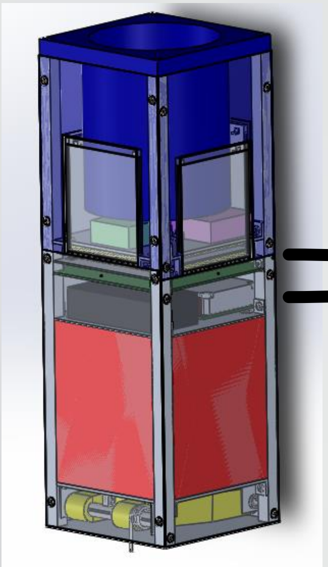

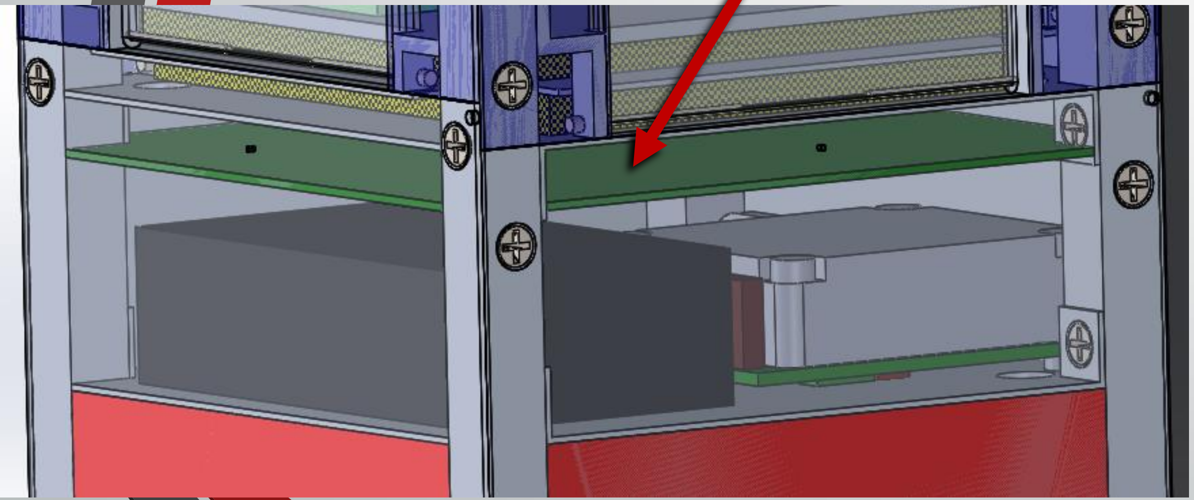

- **CPE**:
  - Altimeter Accuracy
- **Requirements**:
  - DR 3.1: REPTAR shall survive an instantaneous G loading of 40 G's
- **Concerns**:
  - Errors – Inherent inaccuracies in CDH subsystem
  - Delays – CDH tasks that take time, during which REPTAR has traveled some distance

CDH Error Stackup

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Delay Source	Description	Altitude [m]
Update Delay	Distance traveled between measurement samples	0.8
Transmission Delay	Distance traveled during the transmission from Altimeter to Microcontroller	order of millimeters
Calculation Delay	Distance traveled during a computation cycle of the flight code	0.9
Equilibrium Delay	Distance traveled during the time taken to equilibrate the ambient and internal pressures	1.3
Parachute Delay	Distance traveled during the parachute deployment	1.0
Total		**4.0**

Error Source	Description	Altitude [m]
Altimeter Error	Smallest altitude reading resolved by the altimeter	0.7
Calculation Error	Interpolation error in standard atmosphere lookup tables	5.0
Total		**5.7**

$$h_{margin} = 2\sum h_{delay} + \sum h_{error} = \boxed{\mathbf{13.7\ m}}$$

Key Altitudes

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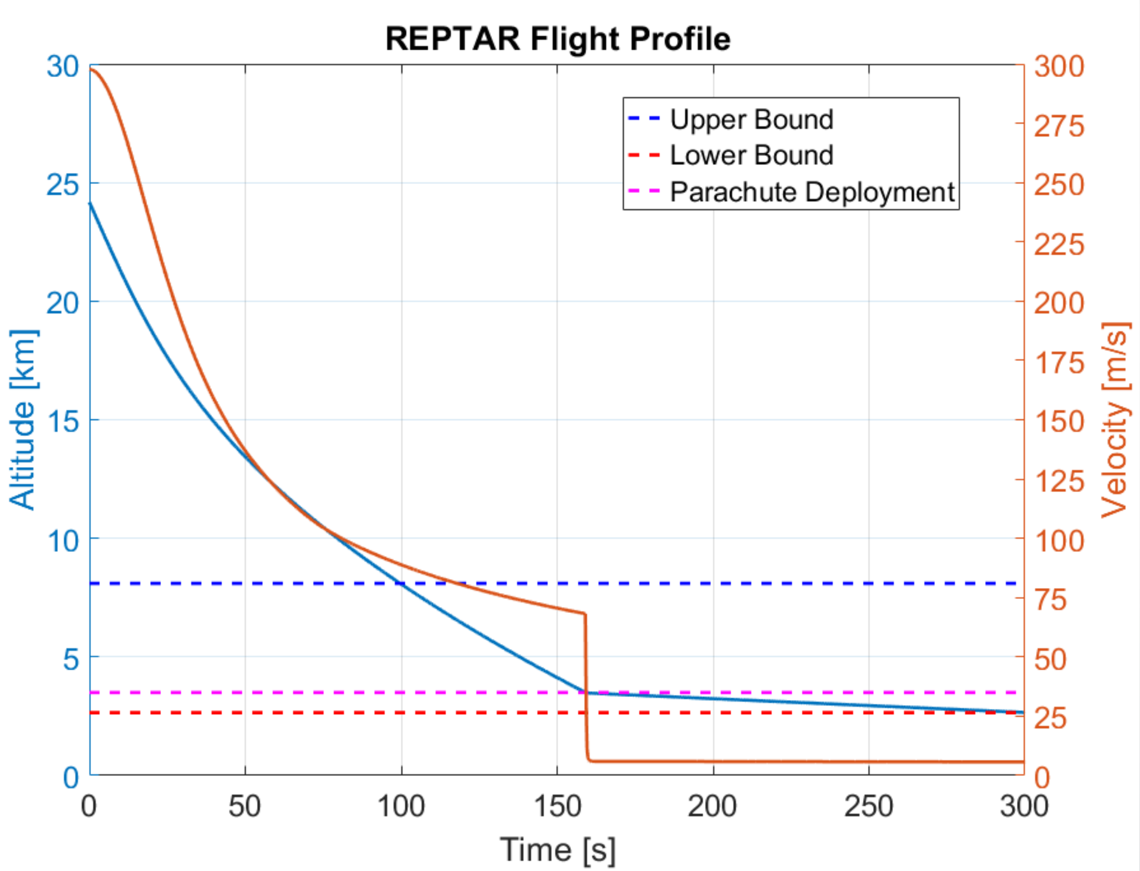
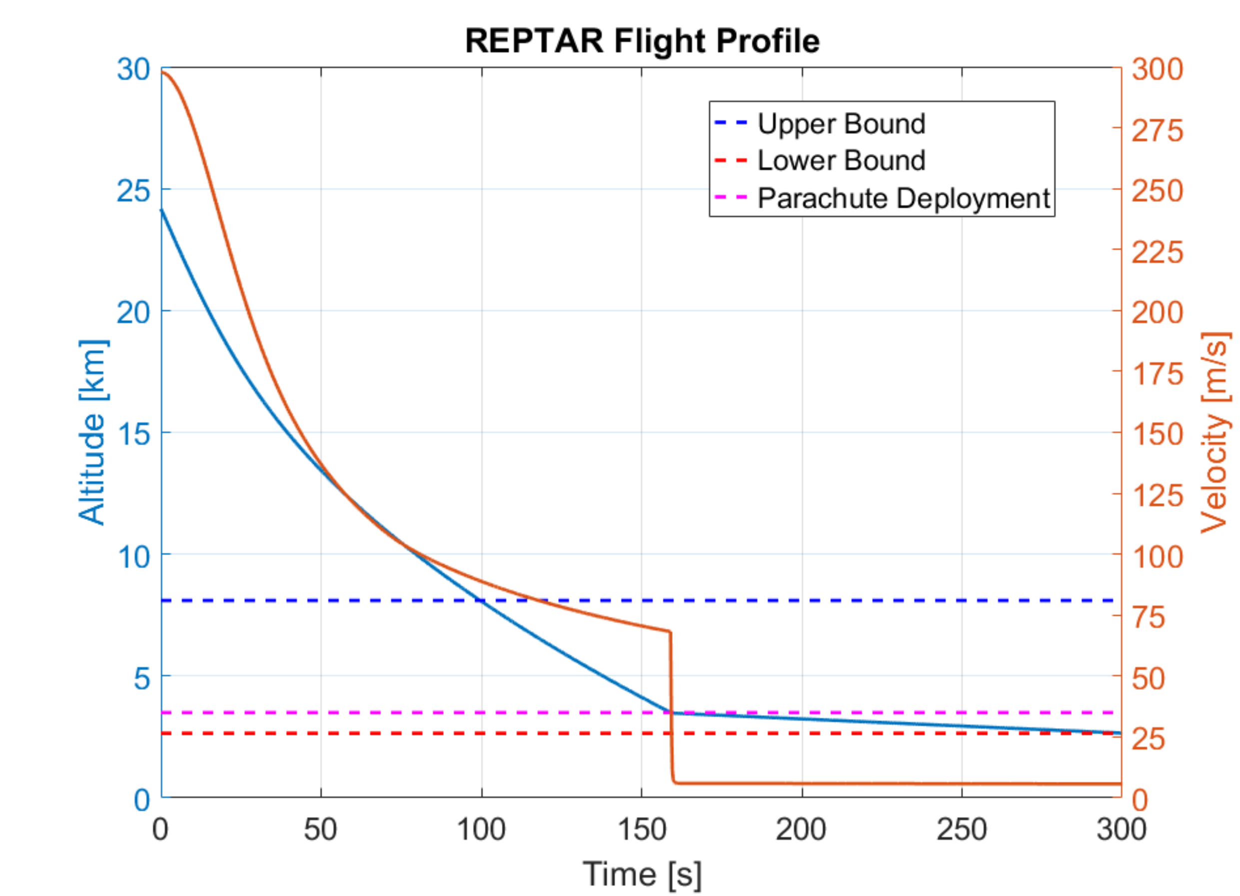
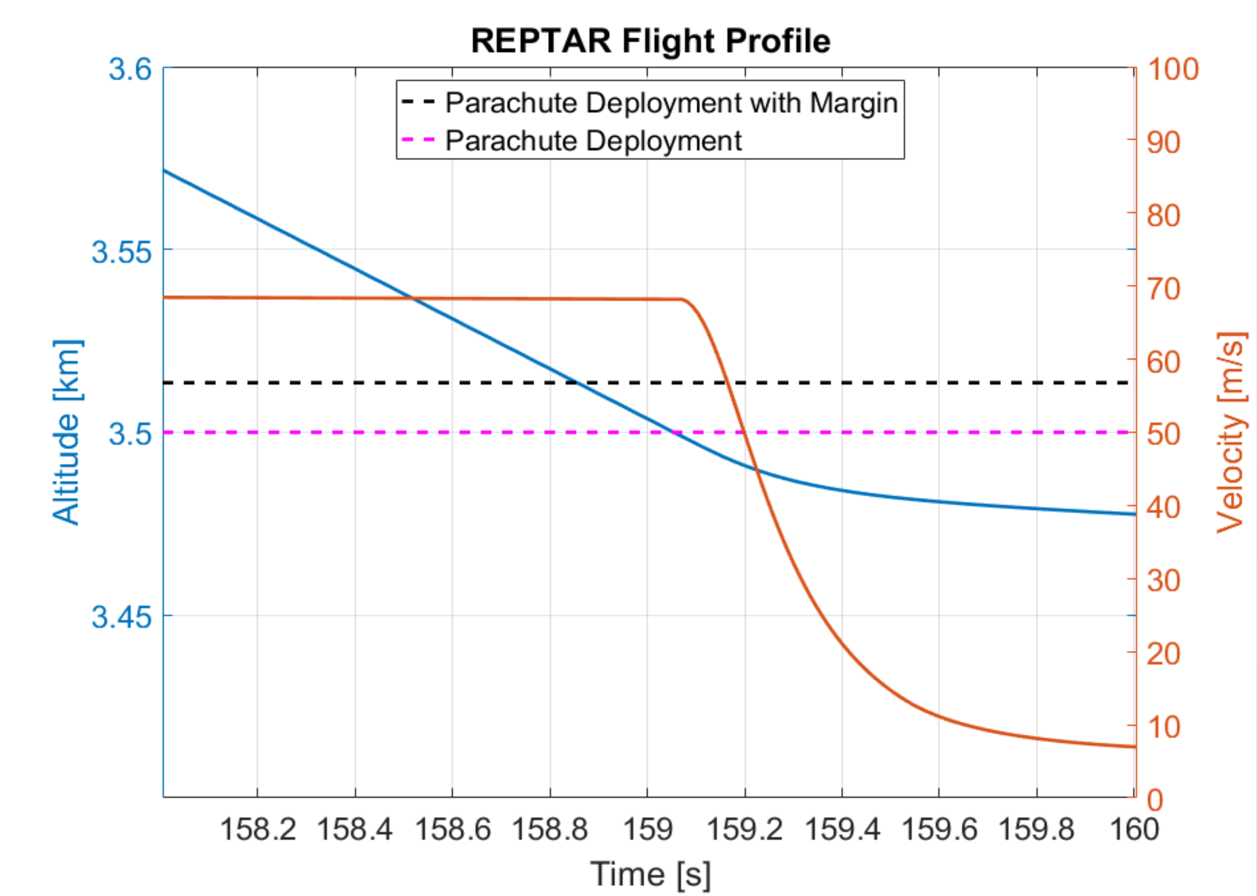


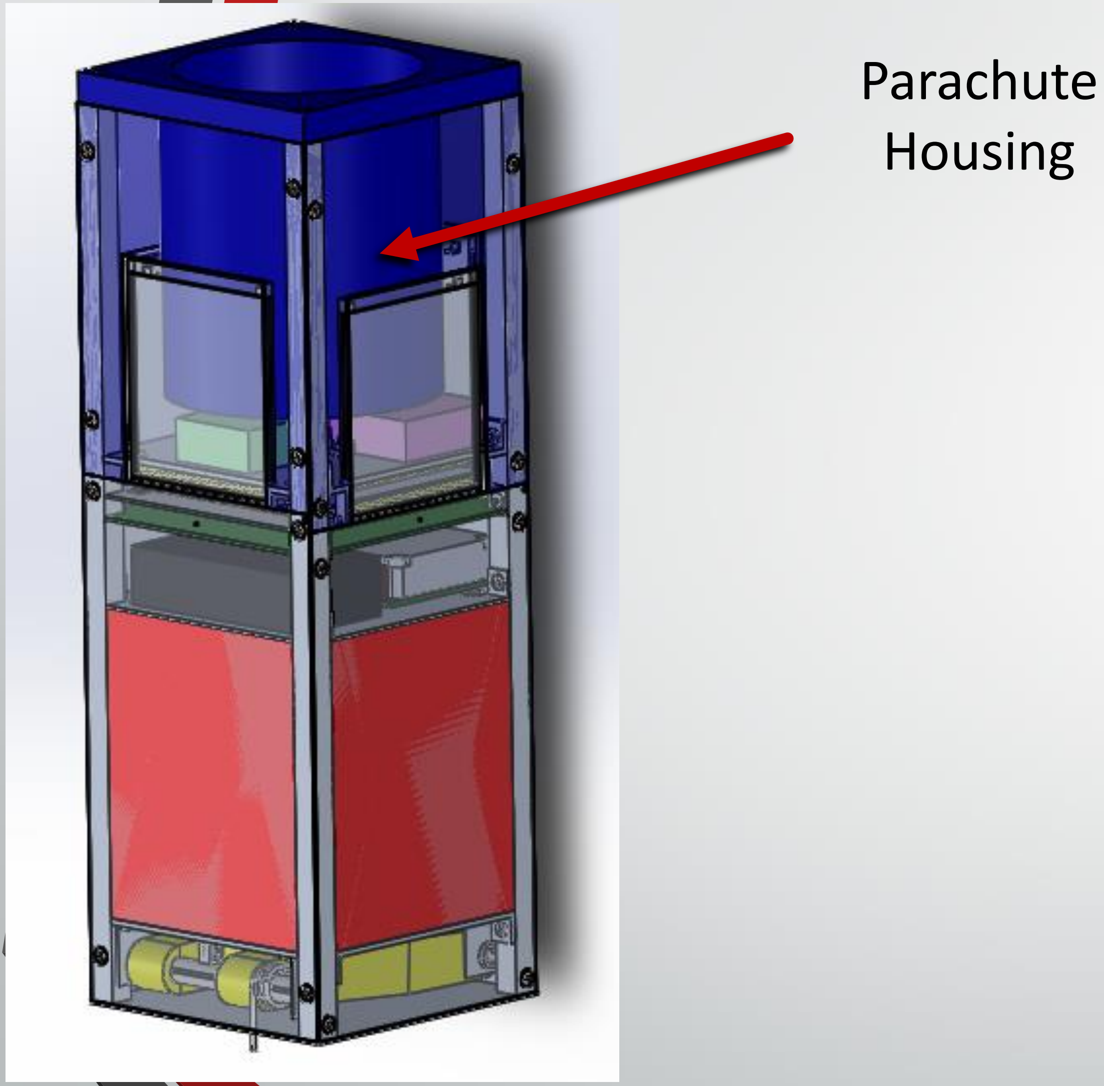
Altitude [m]	Description	Driver
TPS Jettison	Begin altitude sensing	REPTAR terminal velocity becomes subsonic
5900	Upper Bound for parachute deployment	Parachute deployment at higher altitudes induces greater than 40 G's
3513.7	CDH target for parachute deployment	Builds in margin from CDH error stackup
3500	Target for parachute deployment	Factor of safety for deceleration and deployments
3050	Lower Bound for parachute deployment	Not enough time for deceleration or deployments

Key Altitudes





Parachute Deployment



- **CPE:**
  - Parachute Deployment
  - Antenna Pattern
  - Manufacturing
- **Requirements:**
  - DR 3.1: REPTAR shall survive an instantaneous G loading of 40 G's
- **Concerns:**
  - Black powder ignition provides sufficient pressure to break thin aluminum plate

CDR Parachute Deployment

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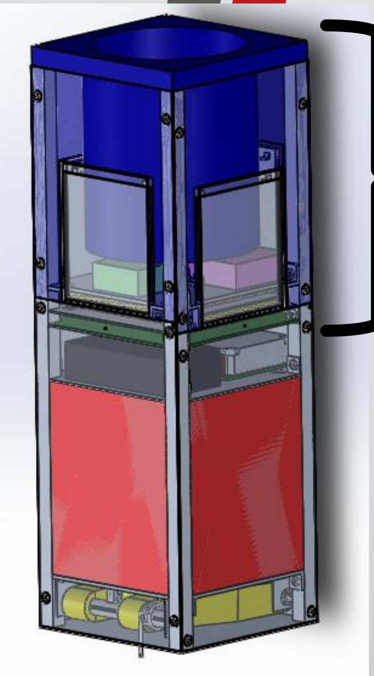

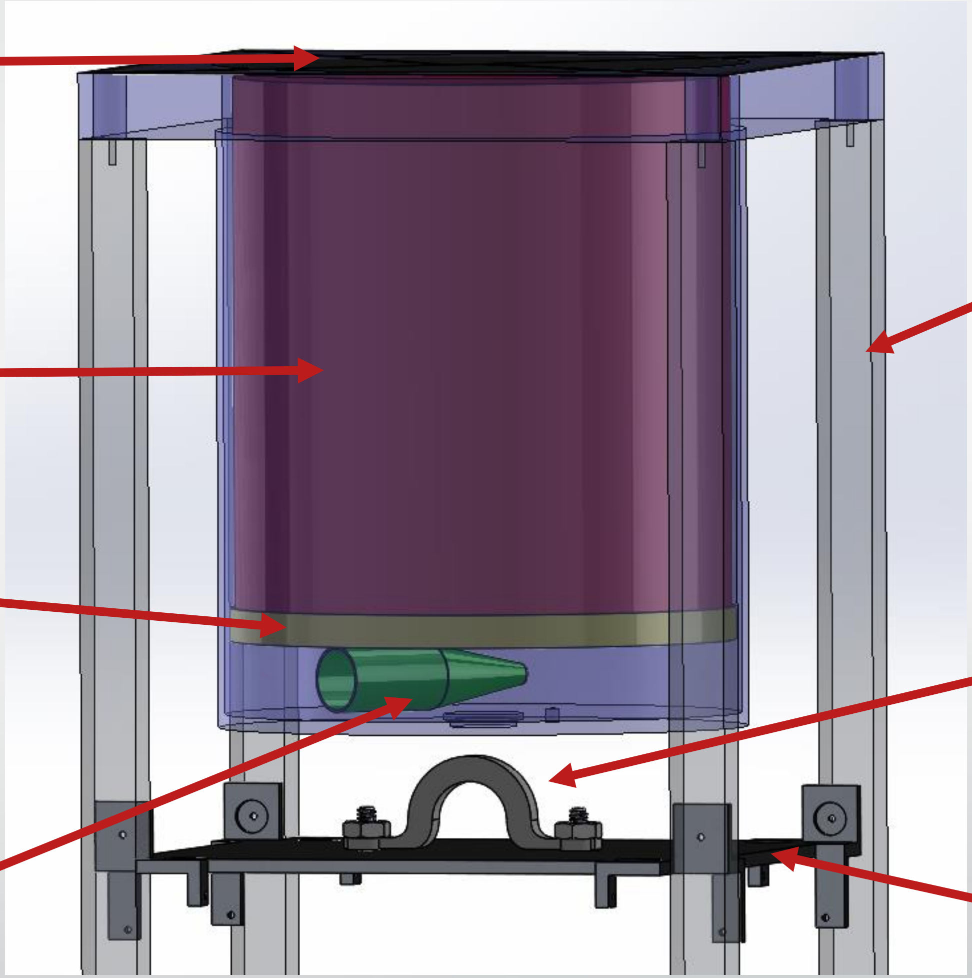

Black Powder Ignition Test

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- Computer Model
  - 20 PSI
  - 0.3 g Black Powder
  - 18 G's on REPTAR from Ignition
  - 34 G's from Parachute Inflation
  - 5.5 m/s Landing Velocity
- Results
  - Recorded Pressure: 24 PSI
- Sources of Error
  - Mols of Air
  - Ignition Temperature
- Conclusion
  - 20% Deviation from Computer Model

Landing Legs

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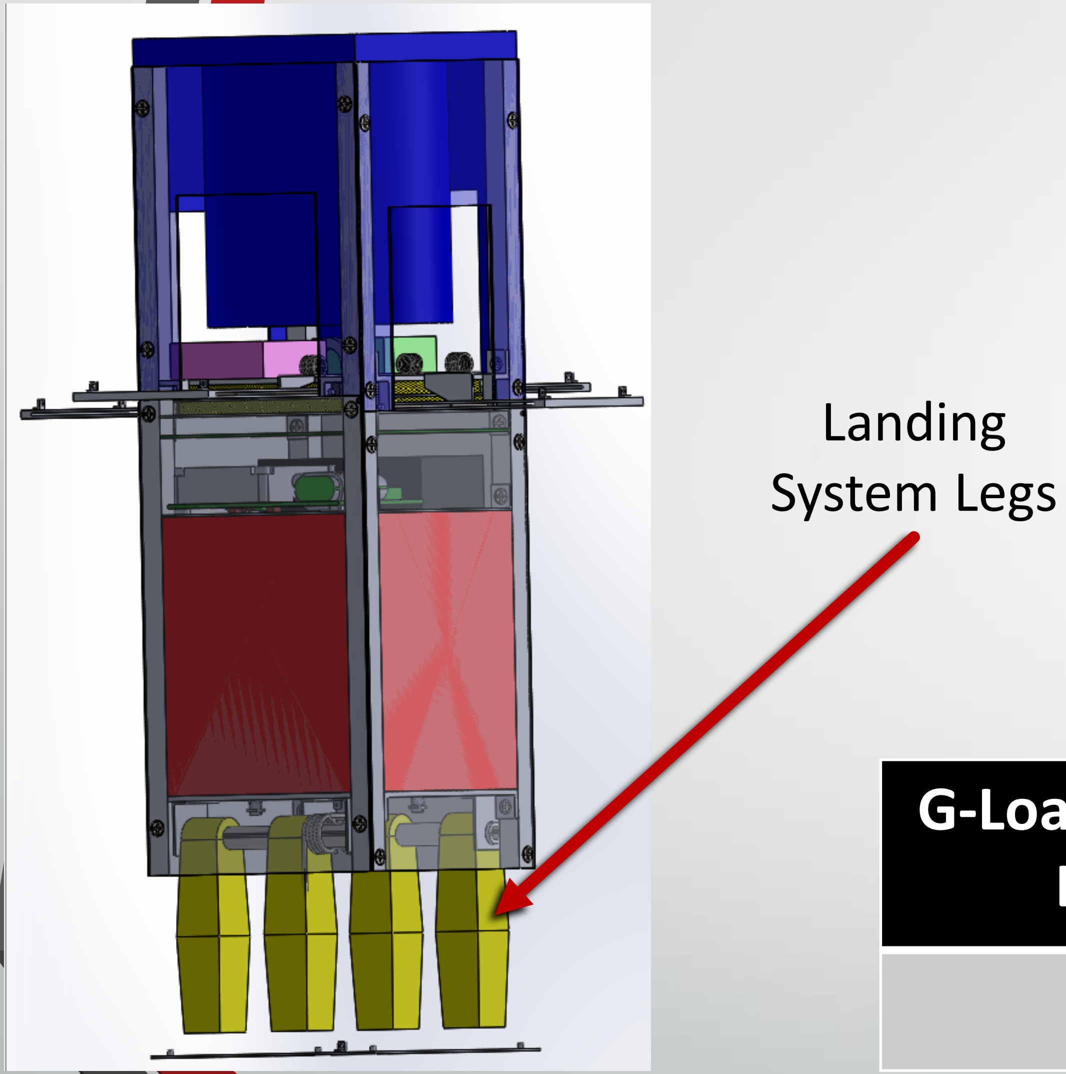
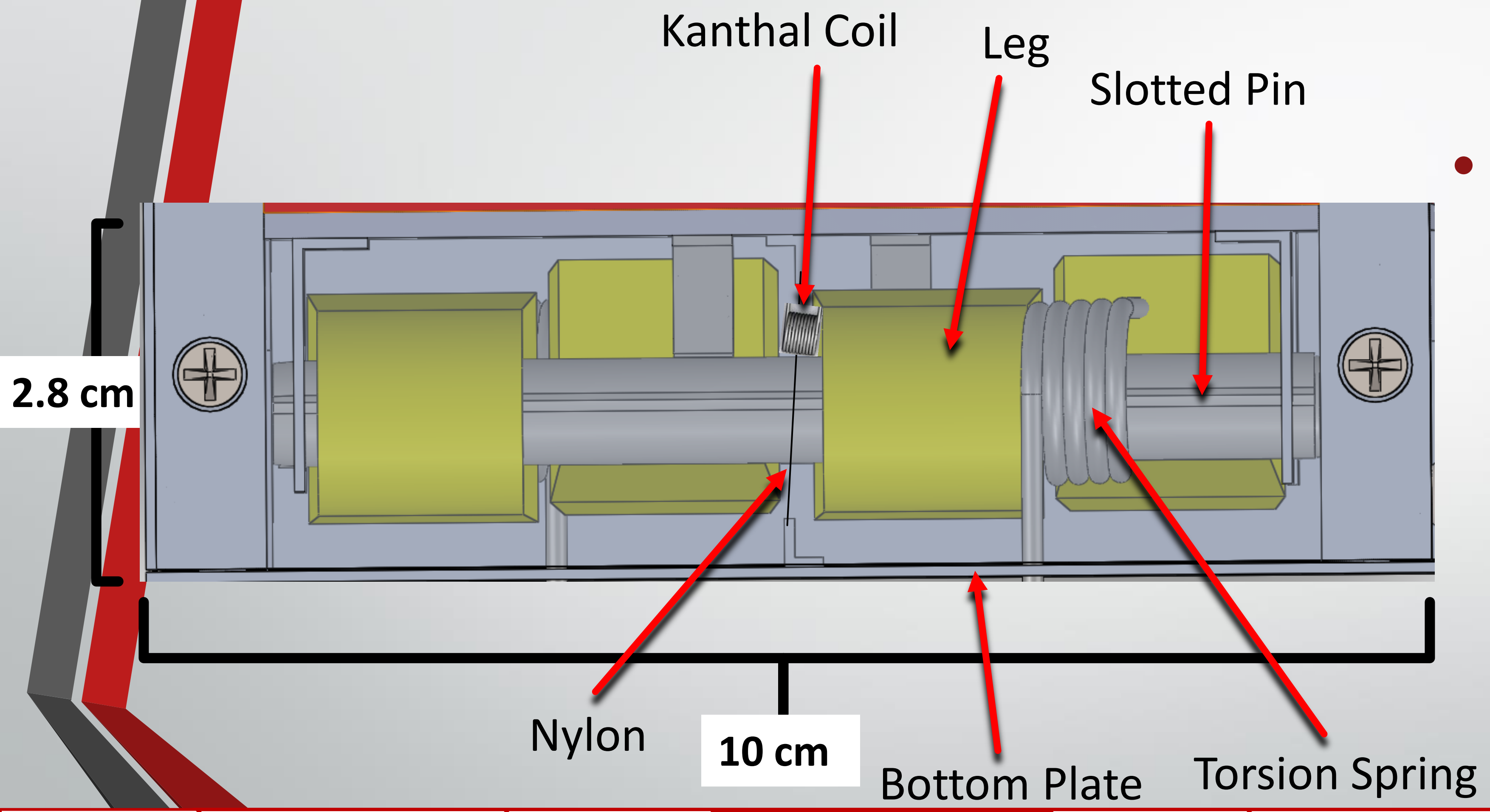


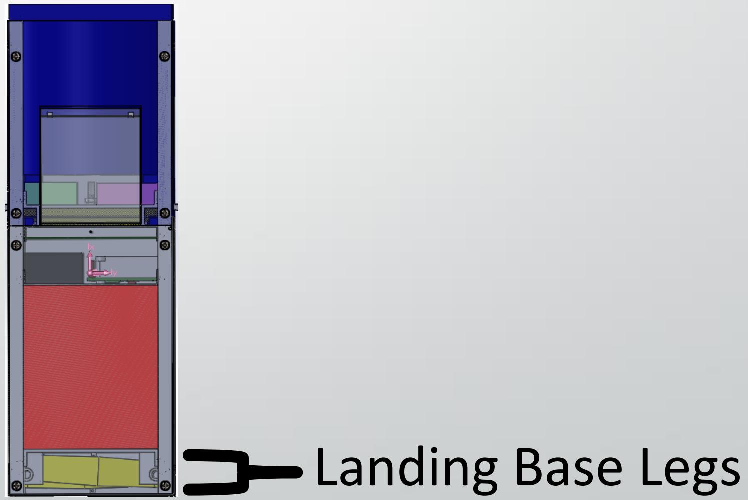
- **CPE:**
  - Base Leg Deployment and Locking
- **Requirements:**
  - DR 3.1: REPTAR shall survive an instantaneous G loading of 40 G's
- **Concerns:**
  - Buckling of legs upon impact

G-Loading w/o Legs	G-Loading w/Legs	Max Allowable G-Loading	Margin
51	34	40	5.7

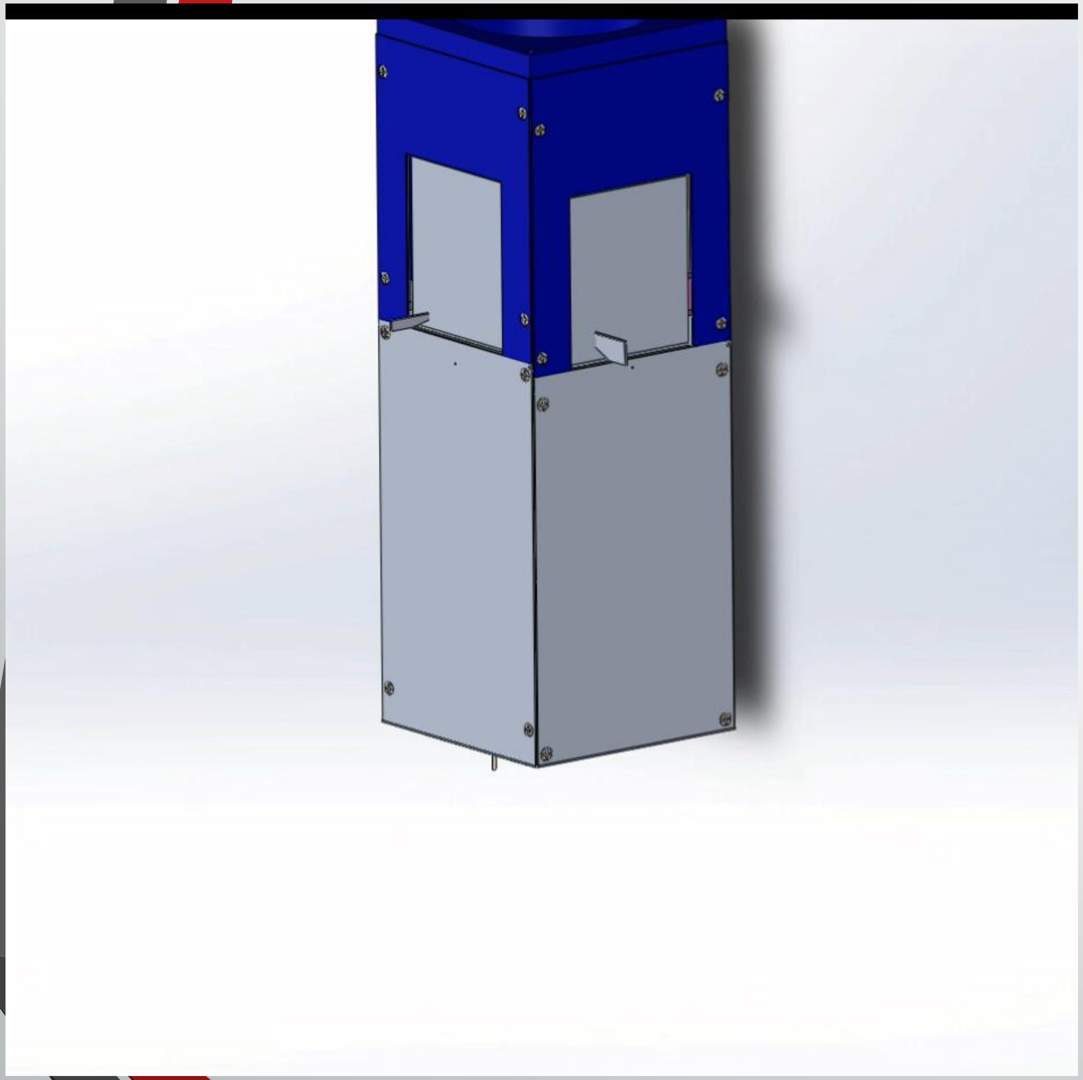
Landing Base Plate Deployment



- Prior to deployment, the base plate will be held to the system by 10 lb-test nylon
- Power will be sent to each Kanthal coil to cut the line with heat for deployment



Landing Legs



- Legs deploy as pairs instead of four individual legs
- Legs deploy utilizing torsion springs
- Moment due to drag: 8.3×10^{-3} N-m

Landing Leg Locking

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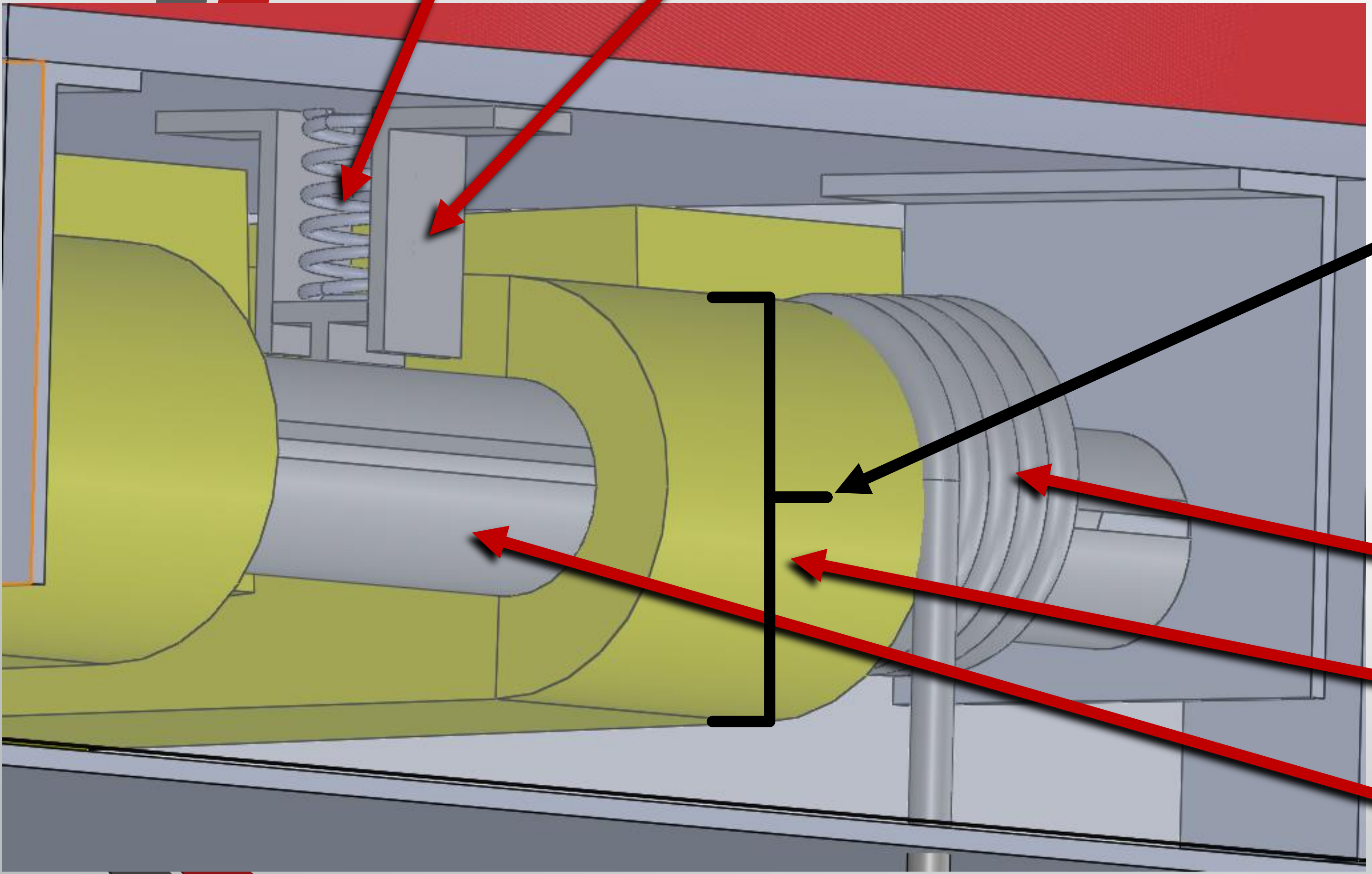
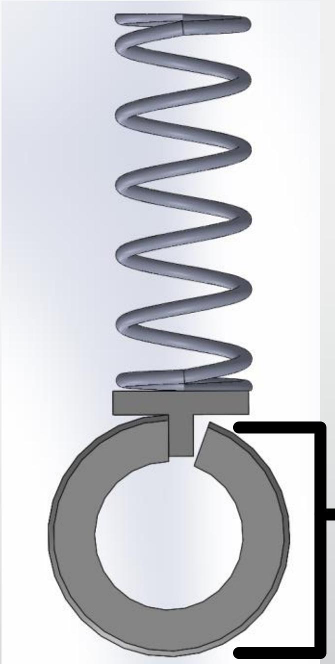
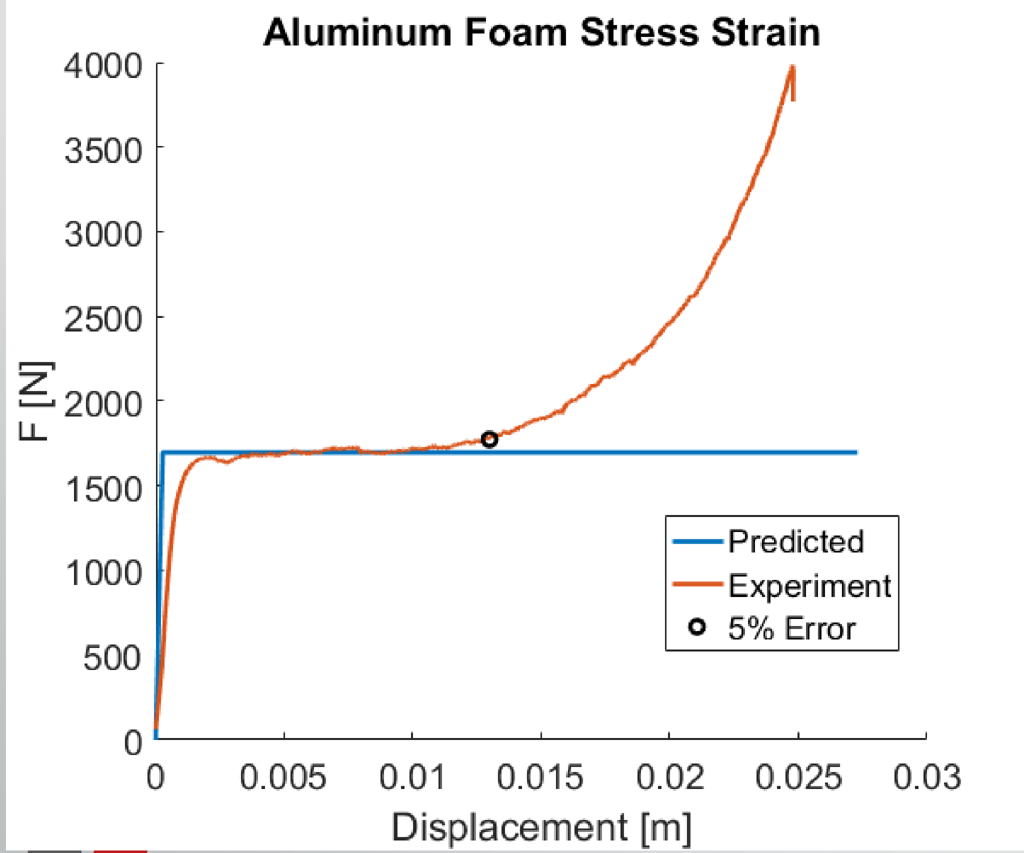
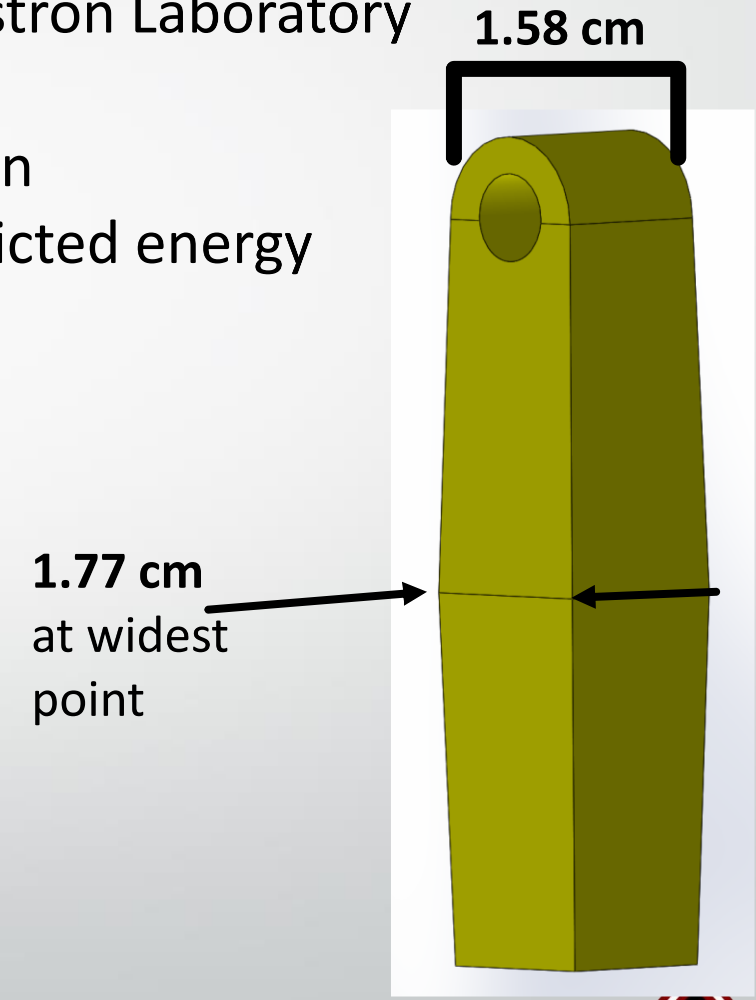




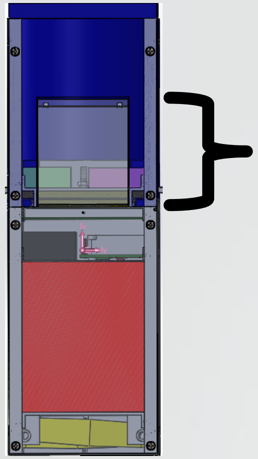
Aluminum Foam Test



- Performed in the Instron Laboratory in the ITLL
- 51.94 % Compression
- 4.72 % Error in predicted energy absorption

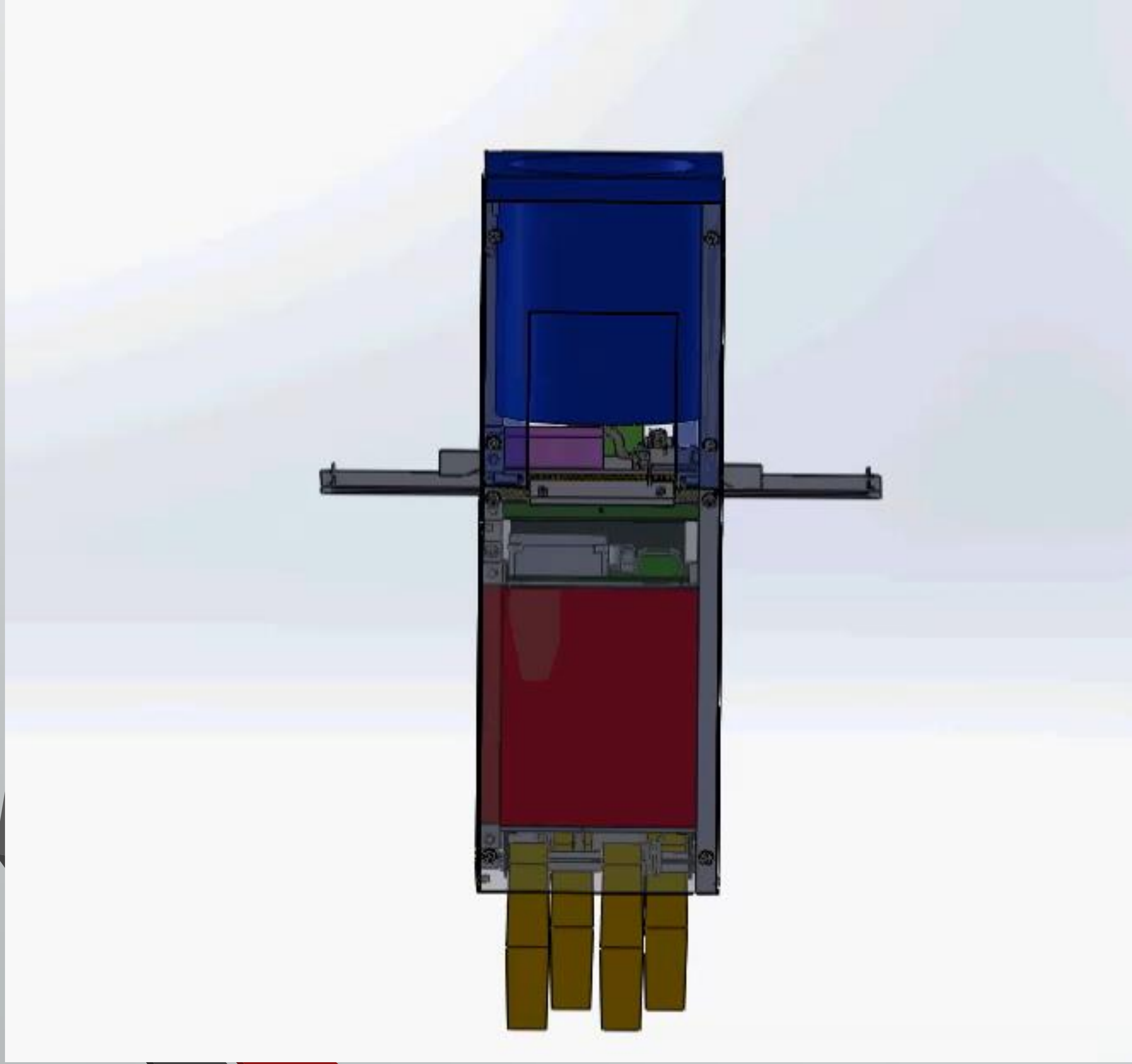


Landing Side Panels



- **CPE:**
  - Side Panel Deployment and Locking
- **Requirements**
  - DR 3.1: REPTAR shall survive an instantaneous G loading of 40 G's
- **Concerns**
  - Orientation of side panels

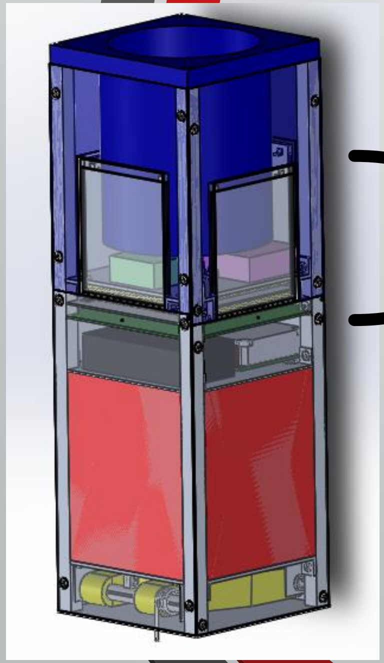
Side Panel Operation



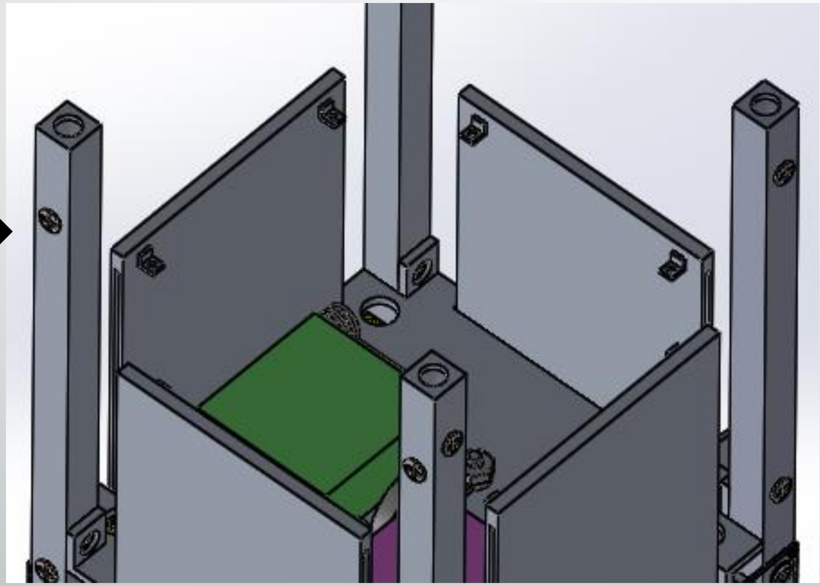
- Following deployment, the side panel inserts into the center foam structure of the system
- Acts as energy absorber, like the legs

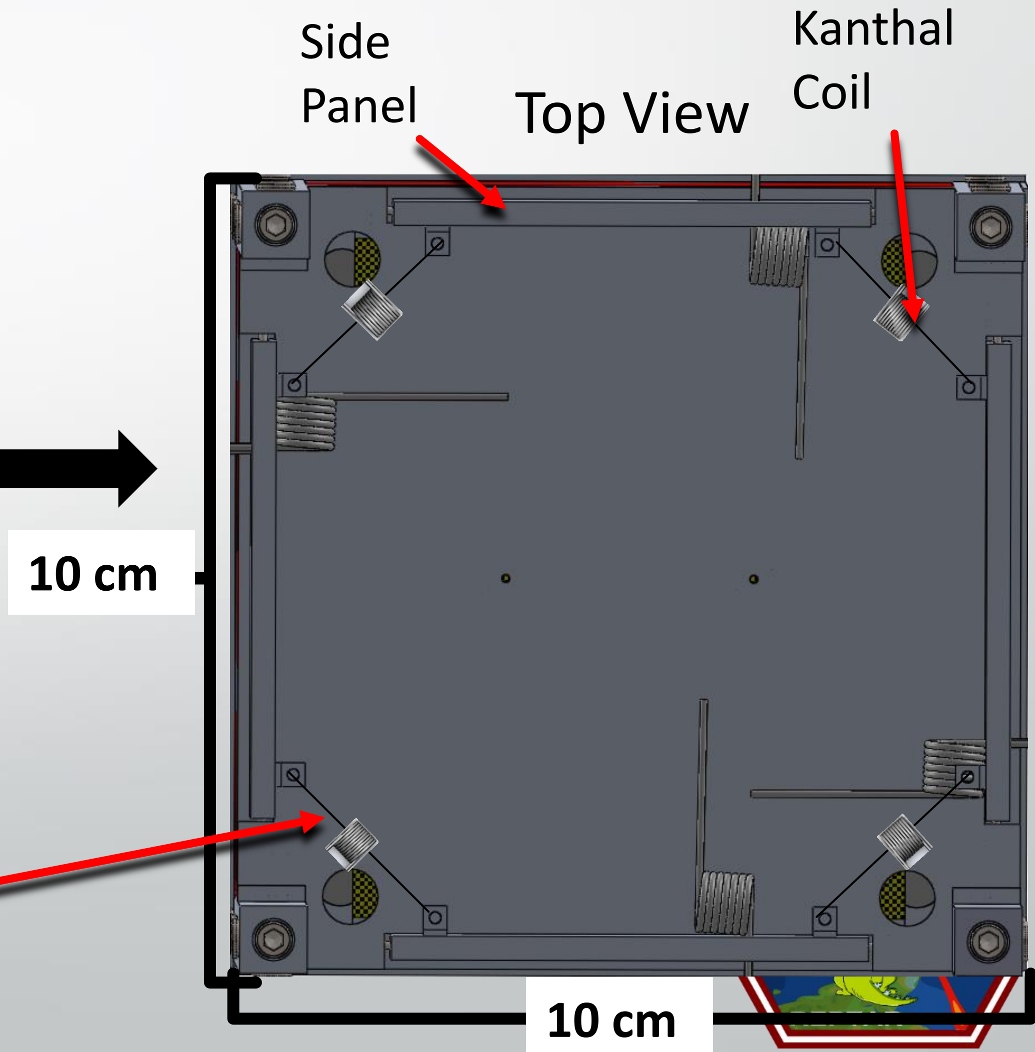
Landing Side Panel Deployments

- Prior to deployment, side panels will be held to each other by 10 lb-test nylon
- Cut the same way as the bottom plate, releasing the side panels

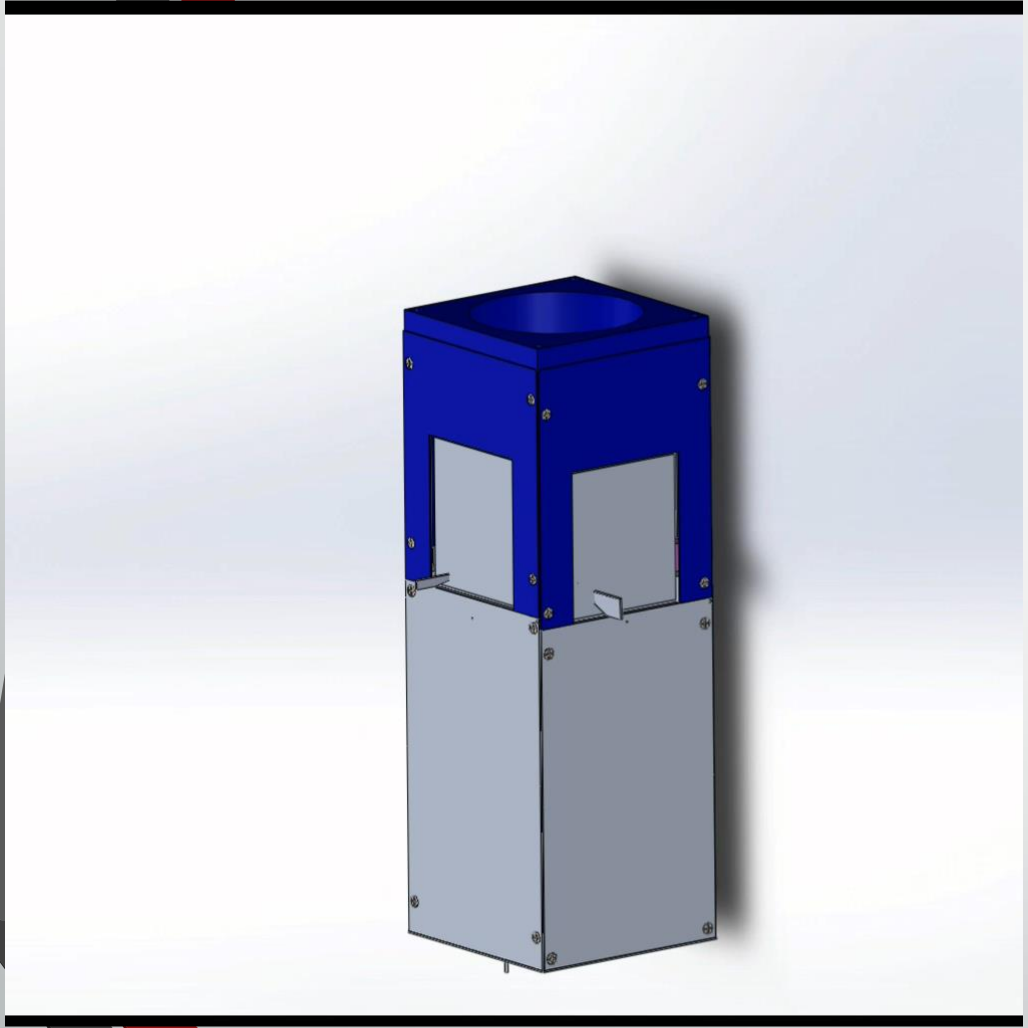


Focusing on Landing Side Panels



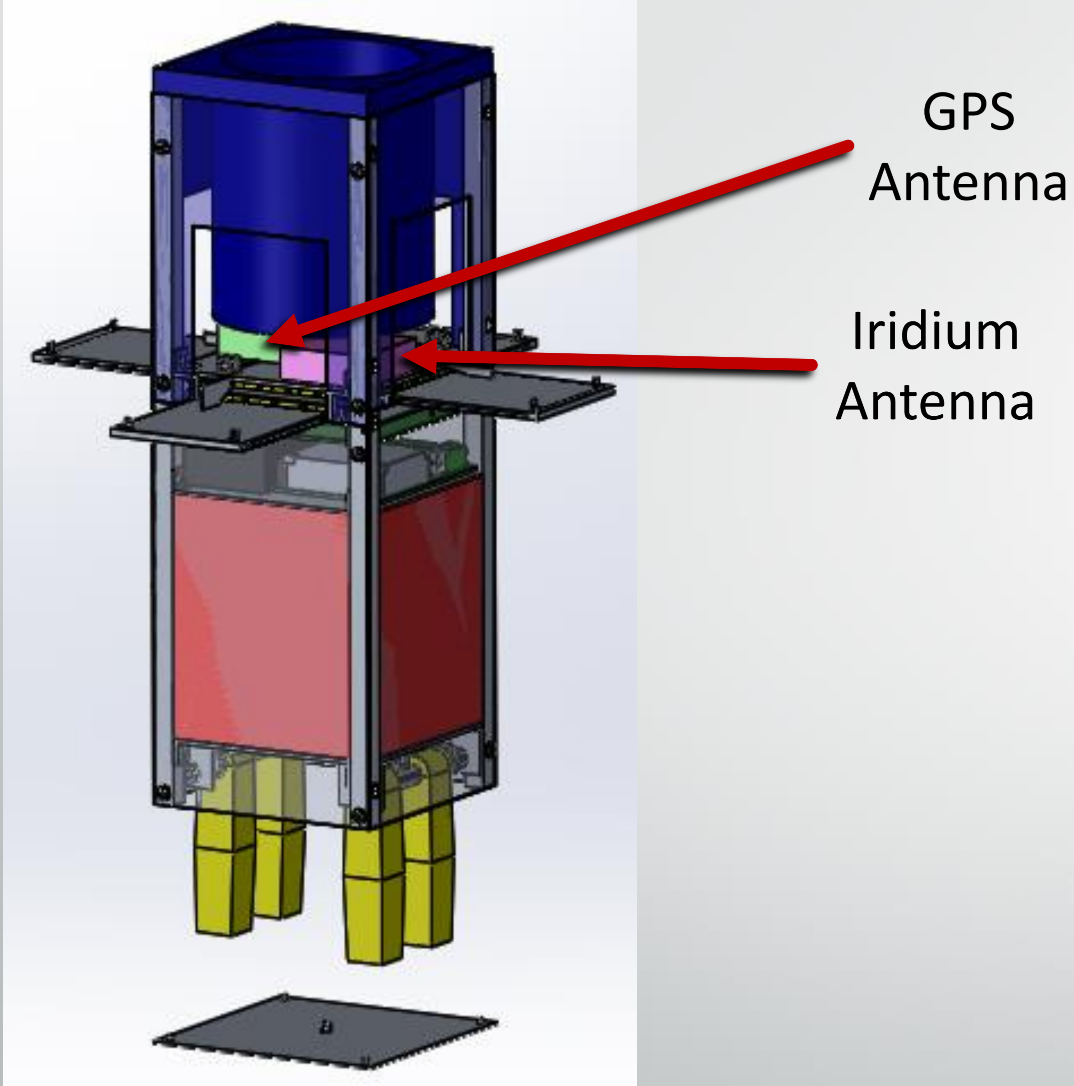


Landing Side Panel Deployment and Locking



- Side panels deployed by torsion springs
- Drag force calculations: 0.012 N-m to be overcome by springs during deployment (7 cm long panel)
- Side panels locked by torque provided by torsion springs and offset of side panels from walls
- The material properties of aluminum allow for proper orientation

Antenna Considerations



- **CPE:**
  - Antenna Performance
- **Requirements:**
  - DR 4.1: REPTAR shall communicate its location over a radius greater than or equal to 45 miles
- **Concerns:**
  - Antenna Pattern inside REPTAR Structure
  - Location of Iridium Communication Satellites relative to REPTAR

Descent Iridium Antenna Pattern Performance REPTAR

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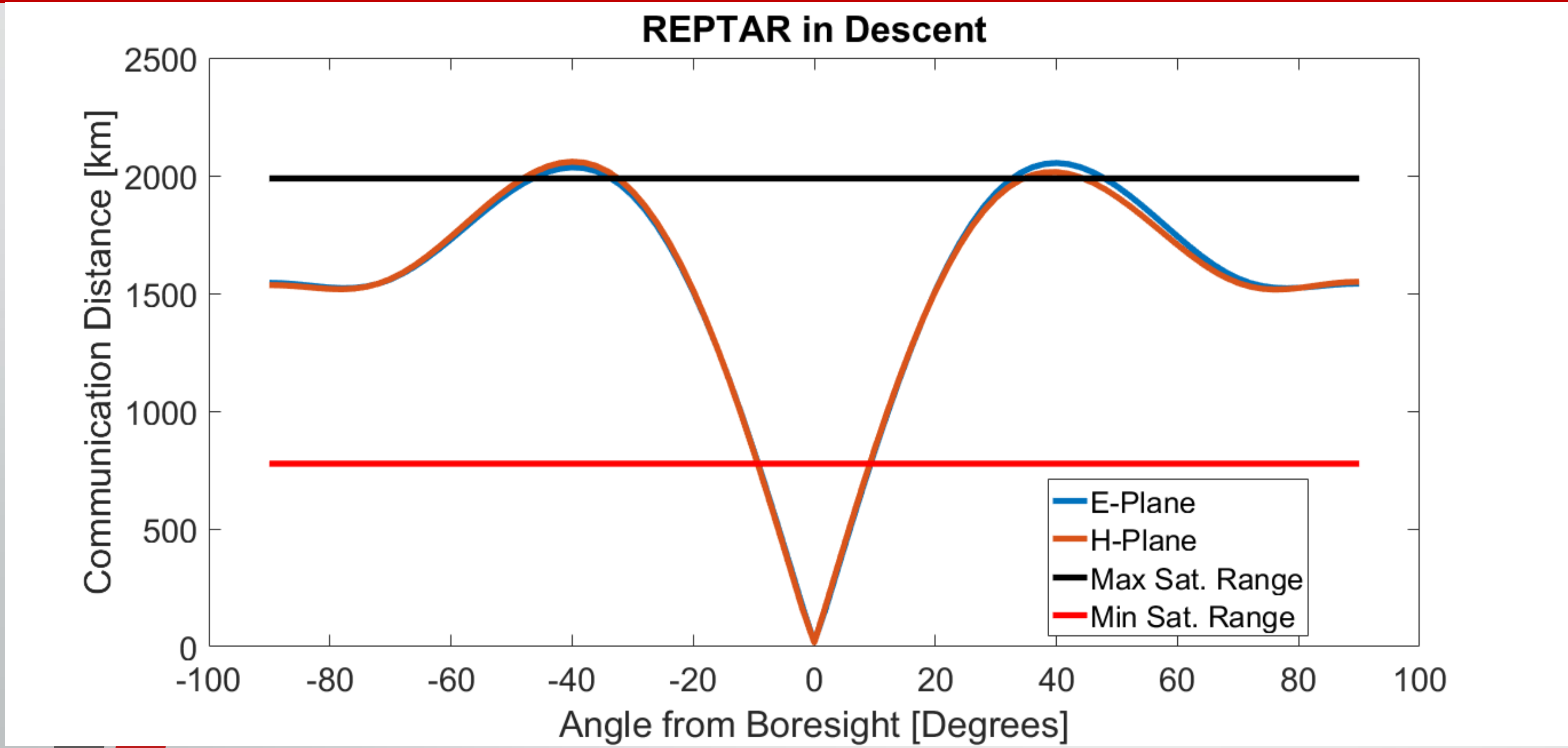
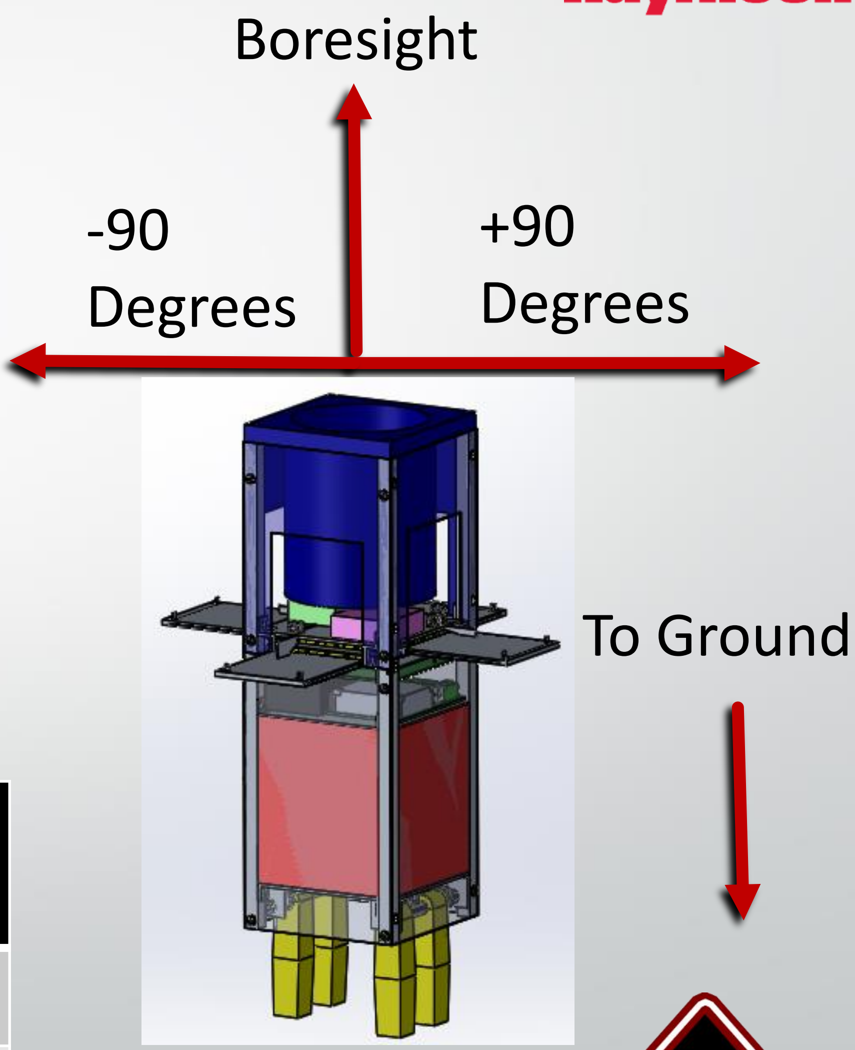
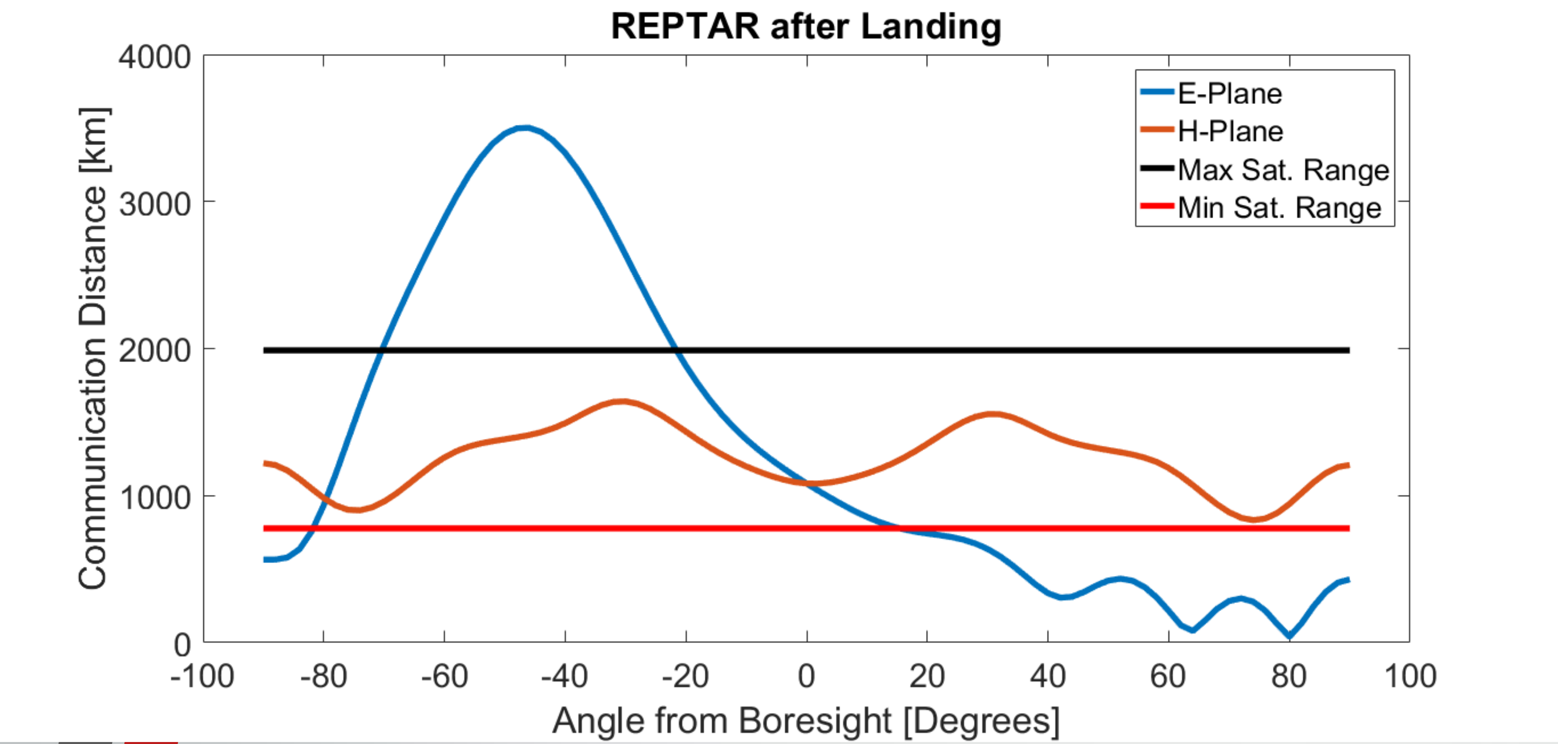
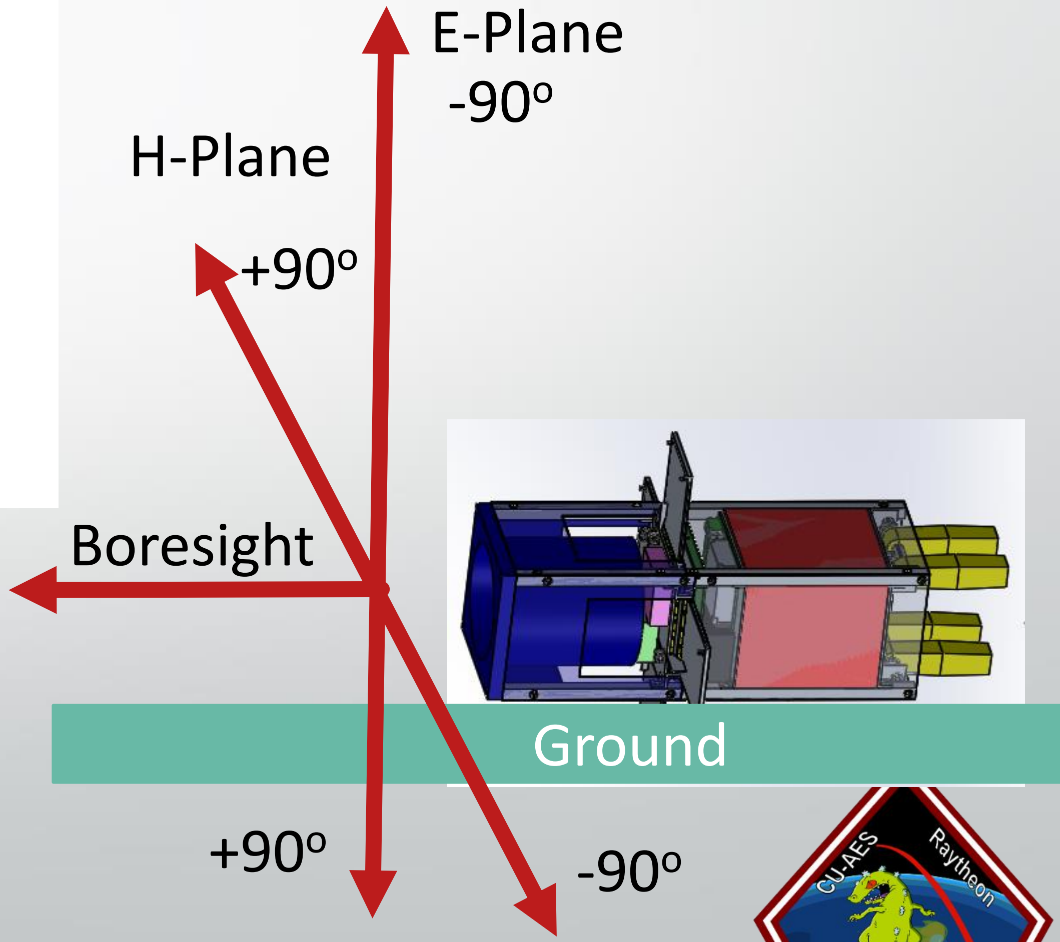




Iridium Parameter	Power [dBm]
Transmitted Power	32.0
Minimum Receive Sensitivity	-127.6

Landed Iridium Antenna Pattern Performance





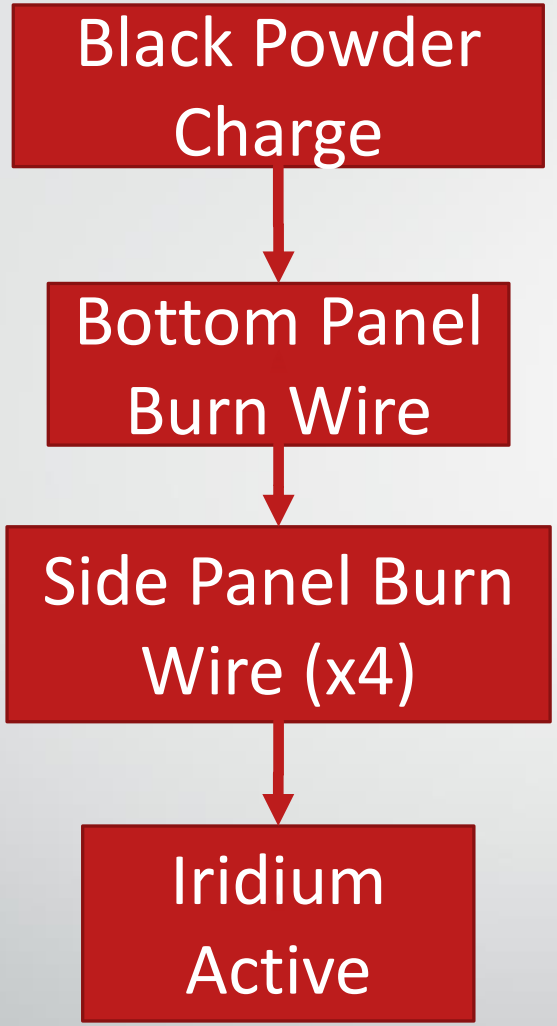
Iridium Parameter	Power [dBm]
Transmitted Power	32.0
Minimum Receive Sensitivity	-127.6

Iridium Orbit Path

STK Descent Model (1km Elevation)
4 Hour Period

- Iridium Orbit:
  - 100 Hour Orbital Period
  - 86 Active Satellites
  - 100% Earth Antenna Coverage
- STK Model in Descent:
  - 100% Coverage
- STK Model after Landing
  - Worst Case: 10 Minute Passes with 2 Minute Spacing

Avionics Deployment Considerations



- **CPE:**
  - Avionics Interface
- **Requirements:**
  - DR 3.1: REPTAR shall survive an instantaneous G loading of 40 G's
  - DR 4.1: REPTAR shall communicate its location over a radius greater than or equal to 45 miles
- **Concerns**
  - Physical Interface and Sensors
  - Power Budget
  - Avionics Thermal Budget

Deployment Triggering and Monitoring

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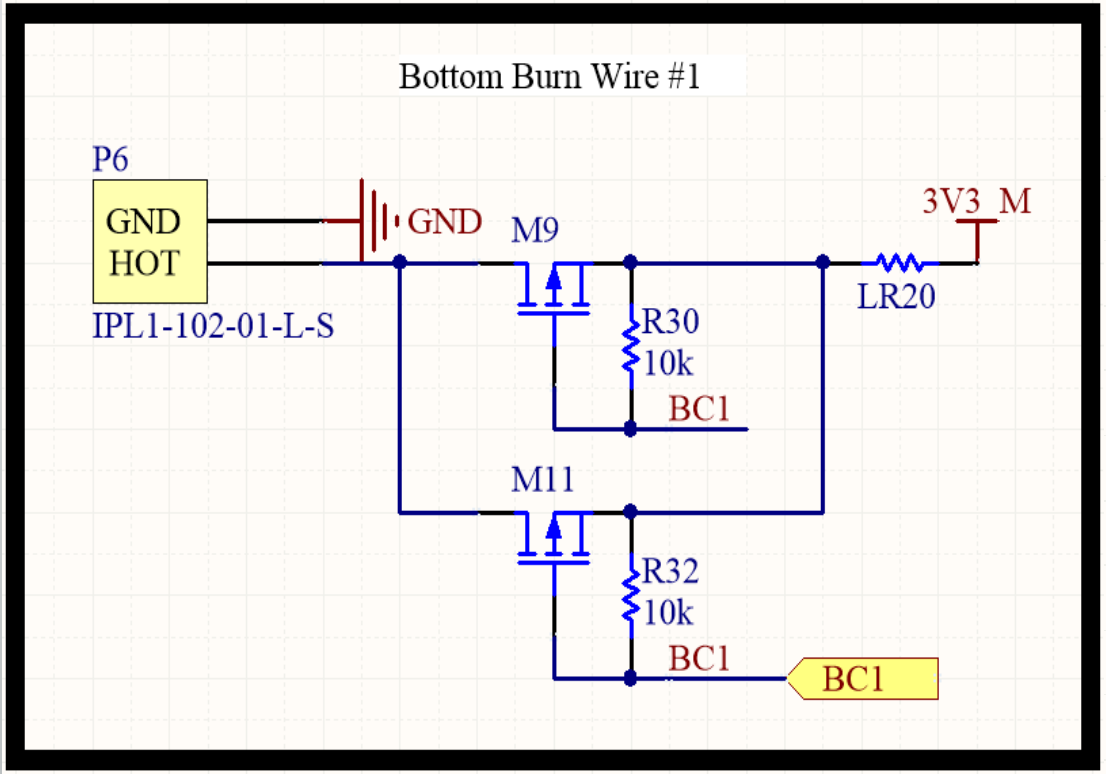

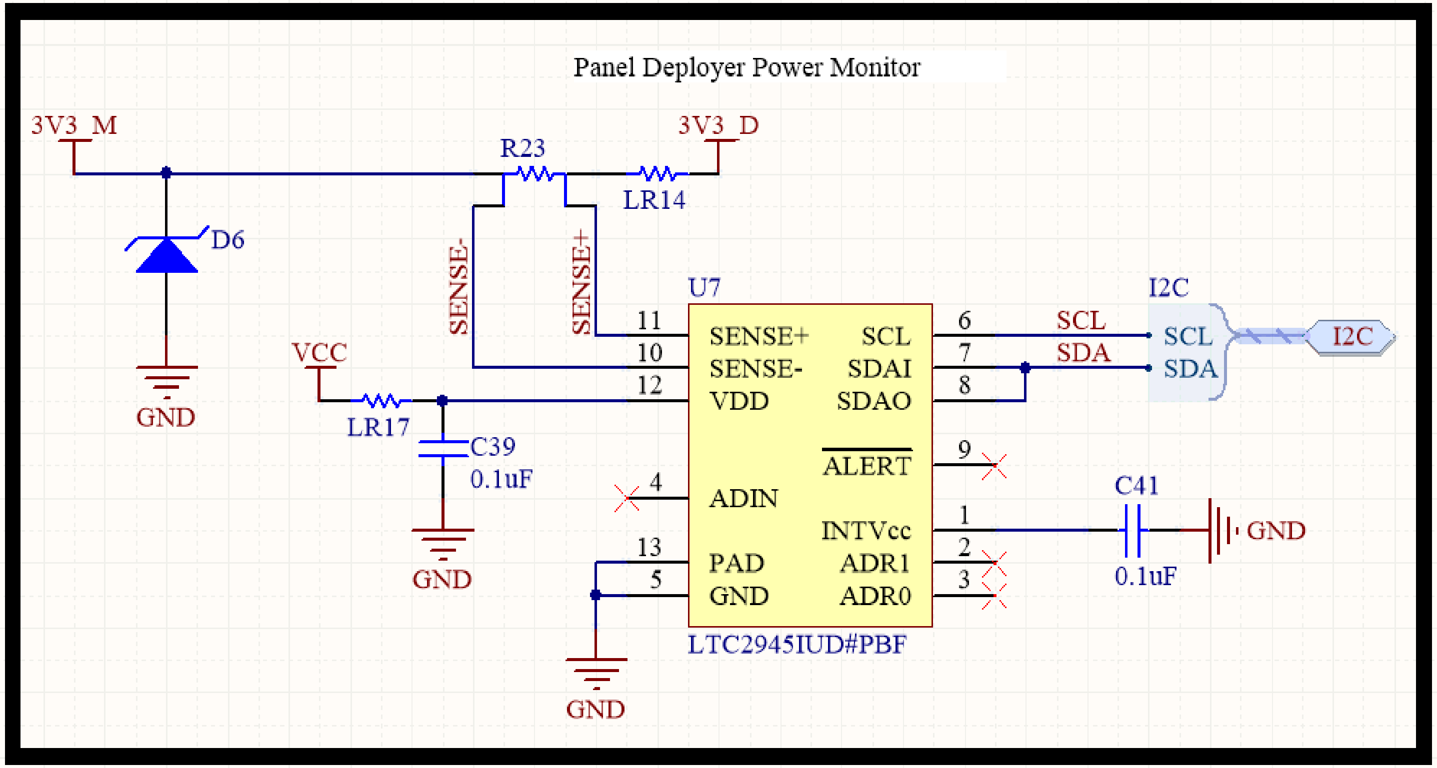

- FET Controlled Burn Wire Interface Connector to AWG 14 Wire (29 Amp. Max)
- Power Monitor capable of “snapshotting” 1 second periods and determining power transfer.

Battery and Regulator Statistics

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Parameter	Battery
Pack Configuration	2 Panasonic NCR18650BF cells in series
Pack Voltage	7.2 V (3.6V per cell)
Max Discharge	10 A
Internal Resistance	154 mOhm (77 mOhm per cell)
Capacity	3350 mAHr

Parameter	3V3 Avionics	3V3 Deployer	12V Deployer
Efficiency	80%	93%	92%
Max Current	1.2 A	8 A	10 A
Junction Temperature Max	100 C	125 C	120 C
Part Number	MCP1632	LTC1775	LTC3786

Battery and Regulator Performance

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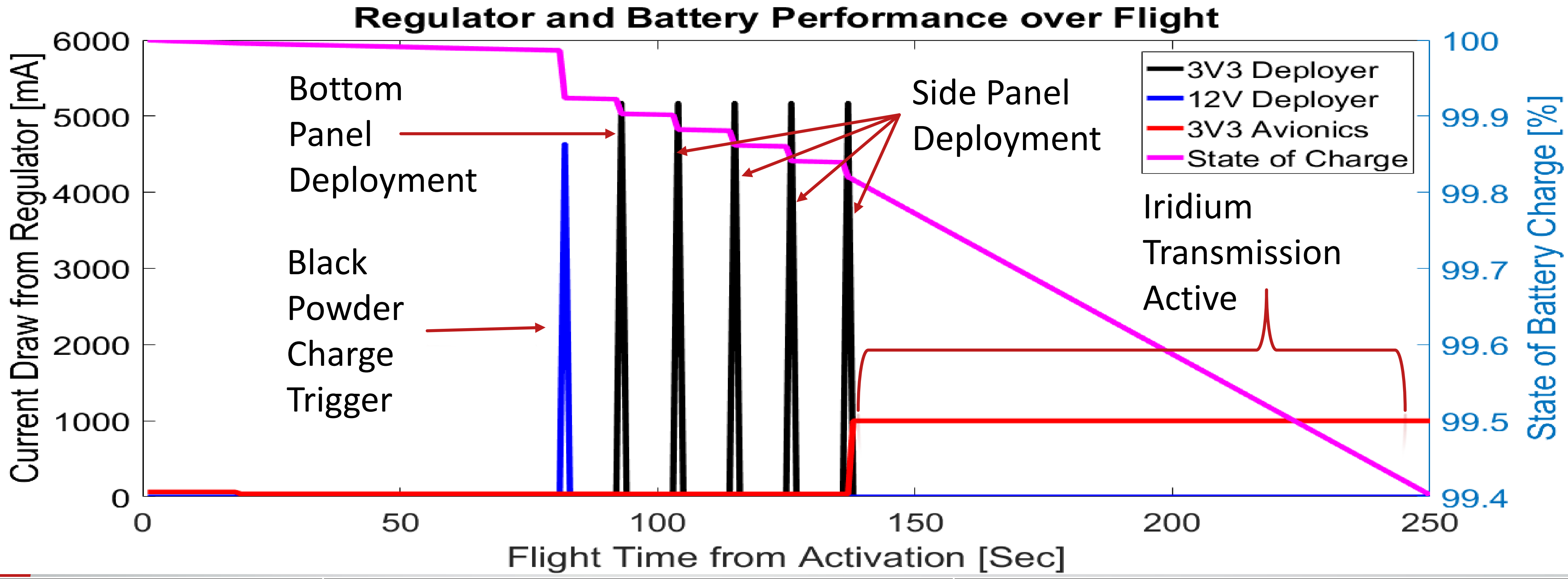
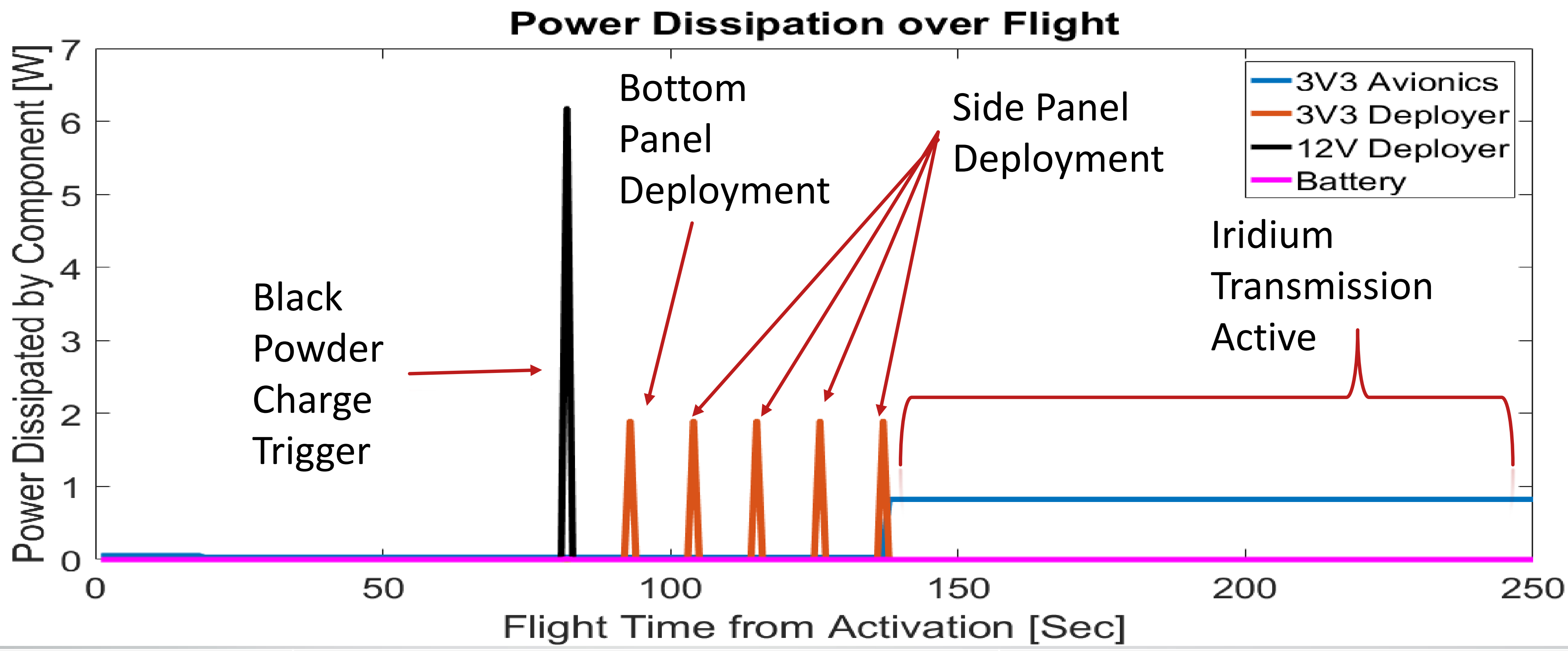


Regulator	Max Rated Current Draw [mA]	Max Modelled Current Draw [mA]
3V3 Avionics	1,200	920
3V3 Burn Wire	8,000	5,560
12V Black Powder	10,000	4,670

Battery and Regulator Performance

REPTAR



Regulator	Max Rated Junction Temp. [C]	Max Modelled Junction Temp. [C]
3V3 Avionics	125	85
3V3 Burn Wire	125	100
12V Black Powder	125	120

Project Risks

Risk Introduction

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Likelihood	Rating
1	Very Low (0% – 20%)
2	Low (20%-40%)
3	Moderate (40%-60%)
4	High (60%-80%)
5	Very High (80%-100%)

Severity	Rating
1	No effect on cost or schedule
2	Schedule slip < 1 week Cost slip < $200
3	Schedule slip < 3 weeks Cost slip < $500
4	Schedule slip > 3 weeks Cost slip > $500 Some requirements not met
5	Project failure, most requirements not met

Pre-Mitigation Risk Assessment

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Risk	Description
RD1: Black Powder Ignition	Black Powder fails to ignite properly
RD2: Insufficient Top Break	Top fails to allow chute to properly eject from canister
RL1: Bottom Leg Locking	Bottom legs fail to lock after deployment
RL2: Side Panels Orientation	Side panels do not properly orient before ground impact
RA1: Antennae Failure	Antennae do not send or receive data properly
RA2: Regulator / Battery Overdraw	Regulator or Battery overheat and fail due to current overdraw

		Severity				
		1	2	3	4	5
Likelihood	5 (Very High)					
	4 (High)			RA2	RA1	RD1
	3 (Moderate)					RD2,RL1,RL2
	2 (Low)					
	1 (Very Low)					

Post-Mitigation Risk Assessment

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Risk	Mitigation
RD1: Black Powder Ignition	Packing BP canister, testing
RD2: Insufficient Top Break	Perforation in top plate, Increase black powder, Testing
RL1: Bottom Leg Locking	Compression springs lock a slotted pin
RL2: Side Panels Orientation	Torsion springs that exceed expected Drag Force
RA1: Antennae Failure	Antenna placement on the deck has been optimized
RA2: Regulator / Battery Overdraw	All regulators include heat sinks and expanded ground planes

		Severity				
		1	2	3	4	5
Likelihood	5 (Very High)					
	4 (High)			RA2	RA1	RD1
	3 (Moderate)					RD2,RL1,RL2
	2 (Low)					
	1 (Very Low)					

Post-Mitigation Risk Assessment

REPTAR

Risk	Mitigation
RD1: Black Powder Ignition	Packing BP canister, testing
RD2: Insufficient Top Break	Perforation in top plate, Increase black powder, Testing
RL1: Bottom Leg Fails to Lock	Compression springs lock a slotted pin
RL2: Side Panels Fail to Orient	Torsion springs that exceed expected Drag Force
RA1: Antennae Failure	Antenna placement on the deck has been optimized
RA2: Regulator / Battery Overdraw	All regulators include heat sinks and expanded ground planes

		Severity				
		1	2	3	4	5
Likelihood	5 (Very High)					
	4 (High)					
	3 (Moderate)					
	2 (Low)				RA1	RL2
	1 (Very Low)			RA2		RD1,RD2,RL1

Verification and Validation

Launch Survivability Vibration Test

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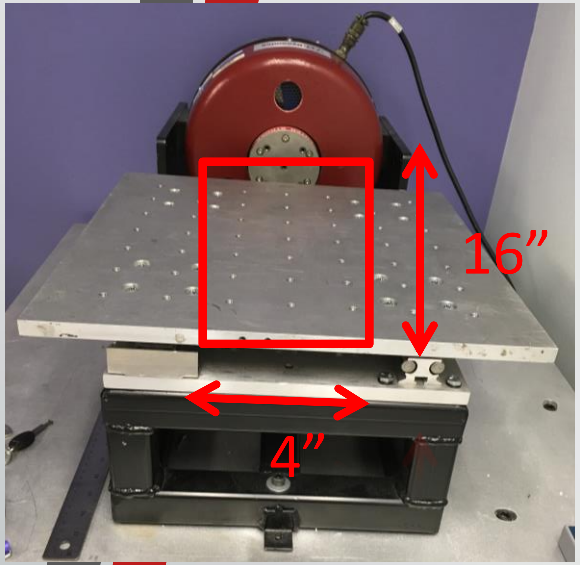

Motivation:

- Acquire data on mode shapes
- Validate launch survival environment

Logistics:

- Facility: ITLL Vibration Table
- Tentative Week: 03/20/17 - 03/24/17
- LabView: Currently exists (Spacecraft Control LabView)

Vibration Profile of Delta IV:

Axis	Frequency (Hz)	Acceptance Test Levels	Sweep Rate
Thrust	5 to 6.2 6.2 to 100	1.27 cm (0.5 in.) double amplitude 1.0 g (zero to peak)	4 octaves/min
Lateral	5 to 100	0.7 g (zero to peak)	4 octaves/min

0000593.2

Figure 3-54. Sinusoidal Vibration Acceptance Test Levels

Launch Survivability Vibration Test

REPTAR

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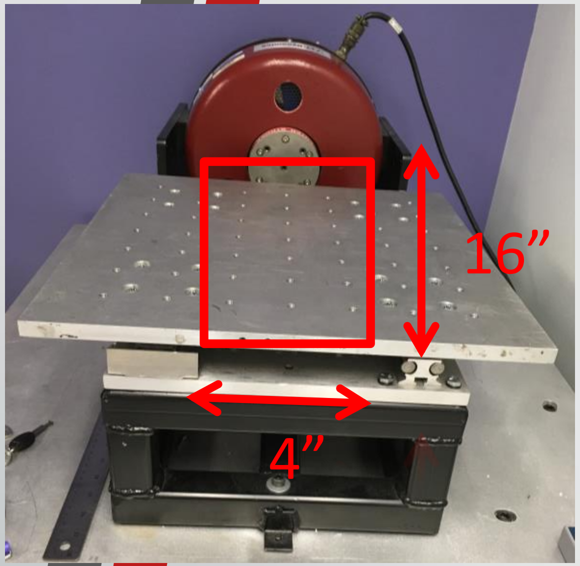


Parameters	Required	Facility(ITLL)
Dimensions	14”x4”x4”	16“x16”
Weight	10lbs	25lbs(vertical), 50lbs(horizontal)
Frequency Sweep	5-100Hz	0-200Hz

Mounting

LabView1

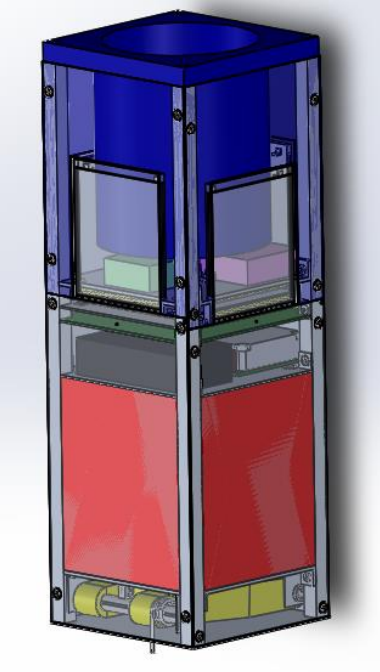
LabView2

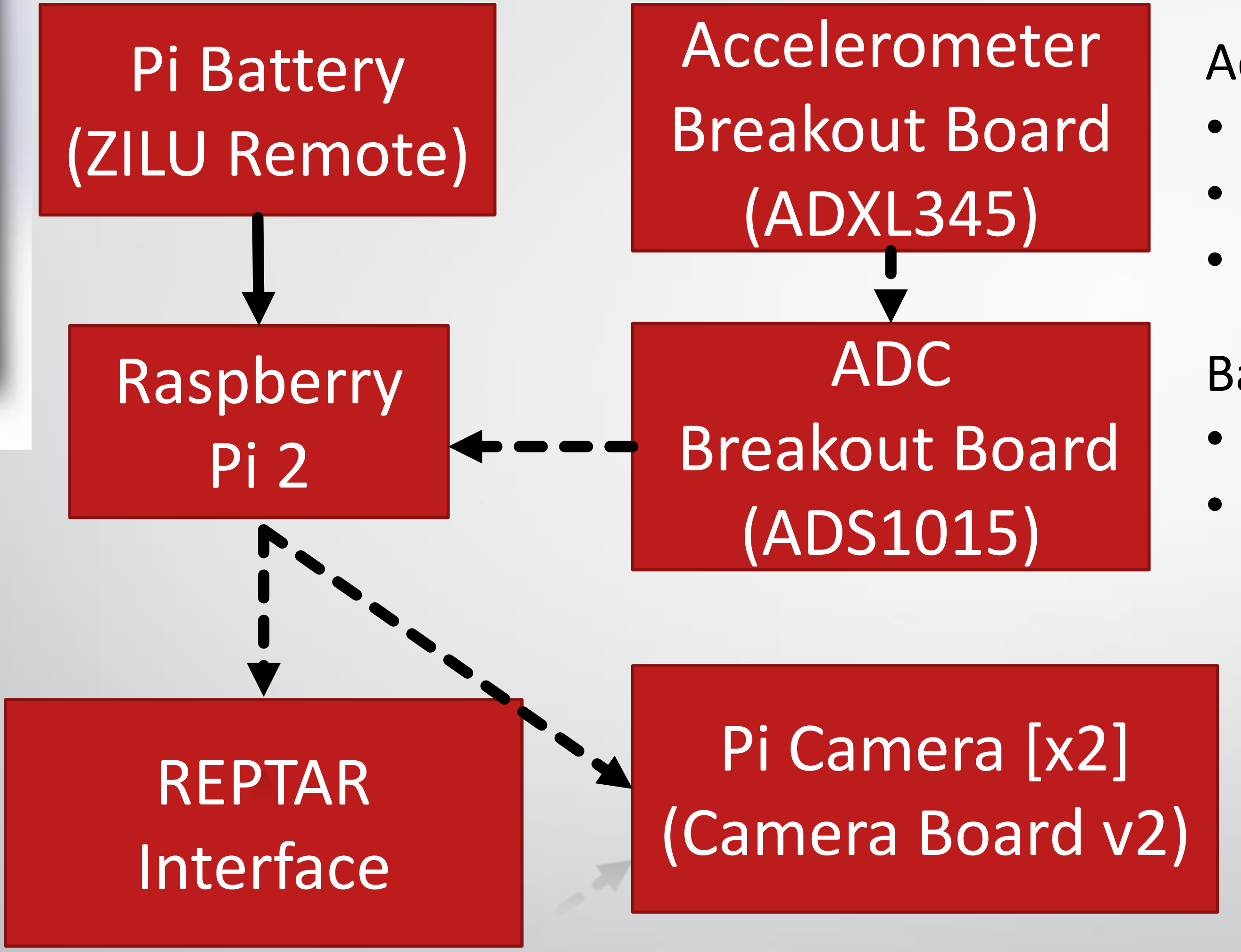
- **Modal Sweep:** Frequency Sweep of 5-100Hz with a loading of 0.25G (Safety Factor of 4)
- **Post test assessment:** Compare frequency response from Sine sweep with 0.25G and 1G
  - Failure Criteria: ≥±10% modal shift indicative of structural failure/alteration

Full System Drop Test

- Motivation:
  - System level validation
  - Acquire data for system G-loading model validation.
    - Tentative onboard sensors : Accelerometer, 2 cameras (for visual data)
- Logistics:
  - Company Name: SkyDive Colorado, Fremont County Airport, Canon City, CO. http://skydiveco.com/
  - POC – Nate Morgan, and Mat Clark (owner).
  - Tentative Week: April 1st week (04/03/17-04/07/17)
  - Cost: $200-300

Drop Test Measurement Equipment





Accelerometer and ADC Statistics

- +/- 200 G Range
- 0.1 G Accuracy
- 3.3KHz Update Rate

Battery Statistics

- 4400 mAhr Capacity
- 2 Hour Expected Lifespan in Test

Pi Camera

- 8 Megapixels
- 3280 x 2464 Resolution
- 25mm x 23mm x 9mm

Full System Drop Test

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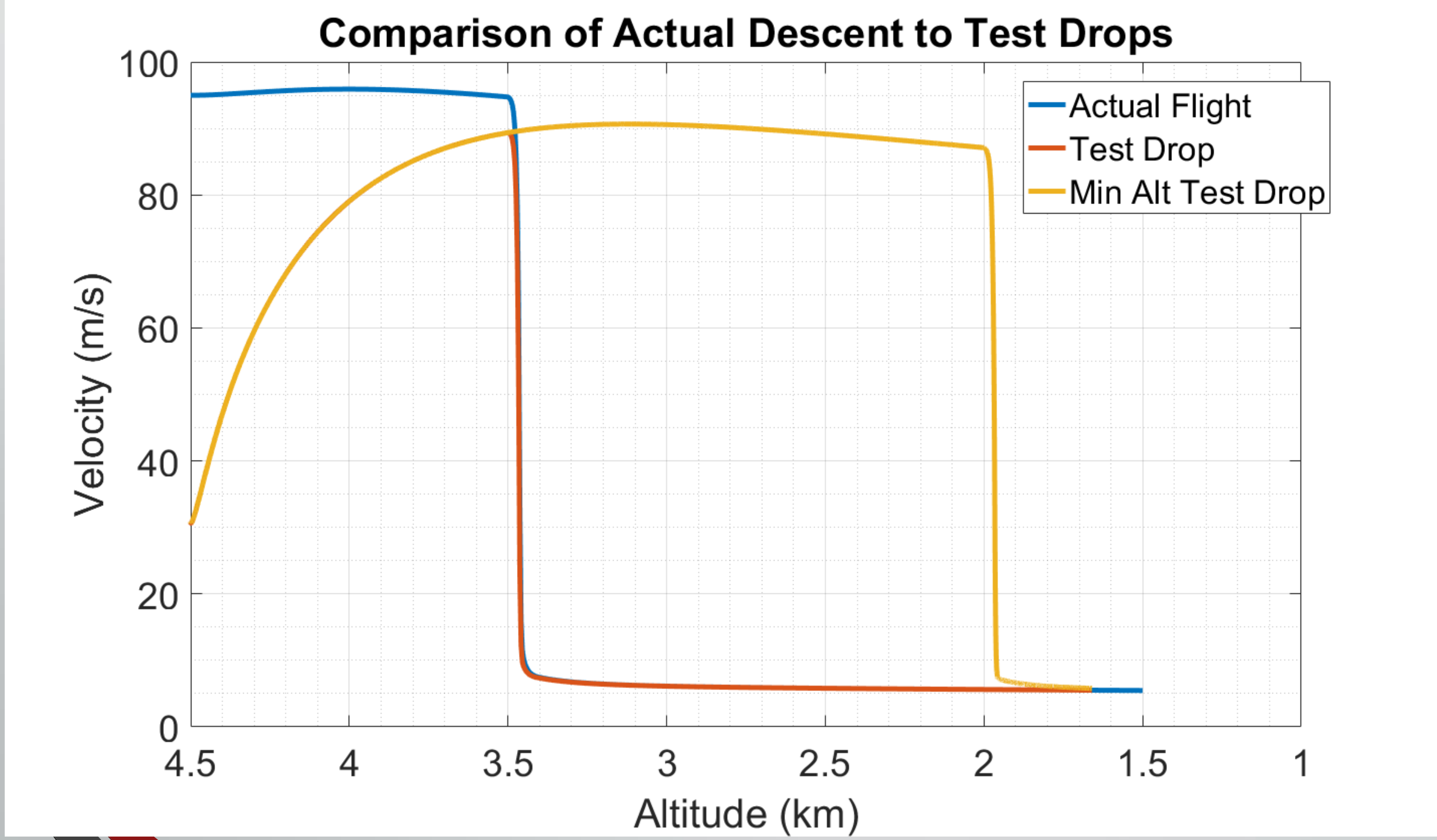

- At a 14,500 ft test drop, system will be within 5 m/s of terminal velocity
- Drop zone location is in altitude range of UTTR
- Minimum altitude drop test can be used to minimize wind drift

Full System Drop Test: FAA Regulations

www.ecfr.gov

e-CFR data is current as of November 14, 2016

Title 14 → Chapter I → Subchapter F → Part 91 → Subpart A → §91.15

Browse Previous | Browse Next

Title 14: Aeronautics and Space
PART 91—GENERAL OPERATING AND FLIGHT RULES
Subpart A—General

§91.15 Dropping objects.

No pilot in command of a civil aircraft may allow any object to be dropped from that aircraft in flight that creates a hazard to persons or property. However, this section does not prohibit the dropping of any object if reasonable precautions are taken to avoid injury or damage to persons or property.

Project Planning

Organizational Chart

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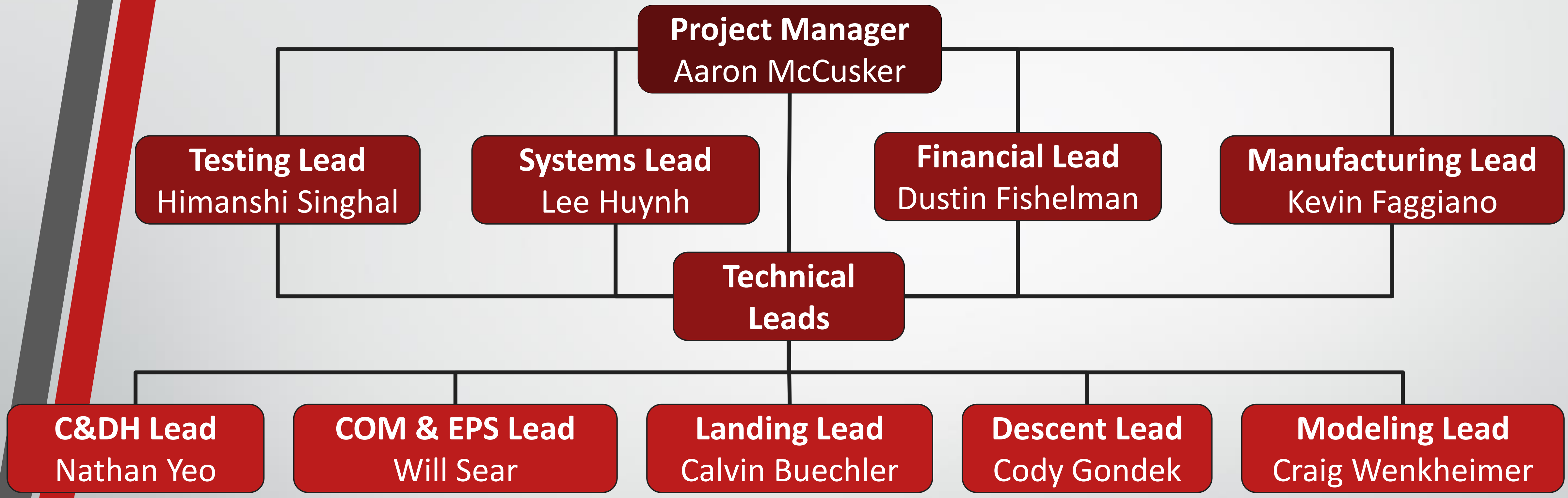

Work Breakdown Structure

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- **Descent**
  - Aerodynamic and Force Models
  - Order Material
  - Chute Cylinder
  - Black Powder Mass Calibration
  - Chute Attachment to Frame
- **Landing**
  - Force and Impact Models
  - Order Parts
  - Aluminum Parts
  - Mounting Devices
  - Deployment Devices
- **Avionics**
  - Antennae Pattern Models
  - CDH Timing
  - Board Schematic Creation
  - Order Components
  - PCB Rev A
  - PCB Rev B
- **Testing**
  - Foam Structure
  - Chute Deployment
  - Antennae Field Test
  - Avionics “Day in the Life”
  - Descent Subsystem Drop
  - Landing Subsystem Impact
  - Vibration Test
  - Final Drop Test
- **Deliverables**
  - CDR
  - MRR
  - TRR
  - AIAA
  - AIS
  - SFR
  - PFR

Key

- Completed
- Future Work

Completed (red boxes): Aerodynamic and Force Models; Force and Impact Models; Antennae Pattern Models; CDH Timing; Board Schematic Creation; Foam Structure; Chute Deployment; CDR.

Cost Plan

Component or Service	Cost
Parachute (x3)	$510
Fiberglass Tubing	$130
Ejection Canister (x5)	$100
Aluminum Sheets	$190
Side Panel Manufacturing	$600
Aluminum Foam	$400
Iridium RockBlock2+	$250
Populated Boards	$300
Circuit Board Revisions (x3)	$200
Aircraft Rental	$250
Shipping and Other	$470
Total	**$3,400**
Maximum	**$5,000**
Margin	**$1,600**

Test Plan

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Dates	Plan	Key Dates
Pre-Semester (Dec 1 – Jan 16)	Epoxy Testing, Landing Deployment Mechanism Testing	
Weeks 1 – 2 (Jan 16 – Jan 29)	Avionics Rev A Bringup, Parachute Drop Test	
Weeks 3 – 4 (Jan 30 – Feb 12)	Chute Attachment Load Testing, Field Testing, Chute Deployment w/ Compressed Air	**MSR** – Feb 6
Weeks 5 – 6 (Feb 13 – Feb 26)	Chute Deployment w/ Black Powder, Avionics Rev B Bringup,Foam Impact Testing	
Weeks 7 – 8 (Feb 27 – Mar 12)	Landing Subsystem Drop Test, Avionics "Day in the Life", Chute inflation testing	**TRR** – Mar 6
Weeks 9 – 10 (Mar 13 – Mar 26)	Vibration Test	Last Machining Day – Mar 24
Weeks 11 – 13 (Apr 3 – Apr 23)	Full System Drop Test	**SFR** – Apr 24

Gantt

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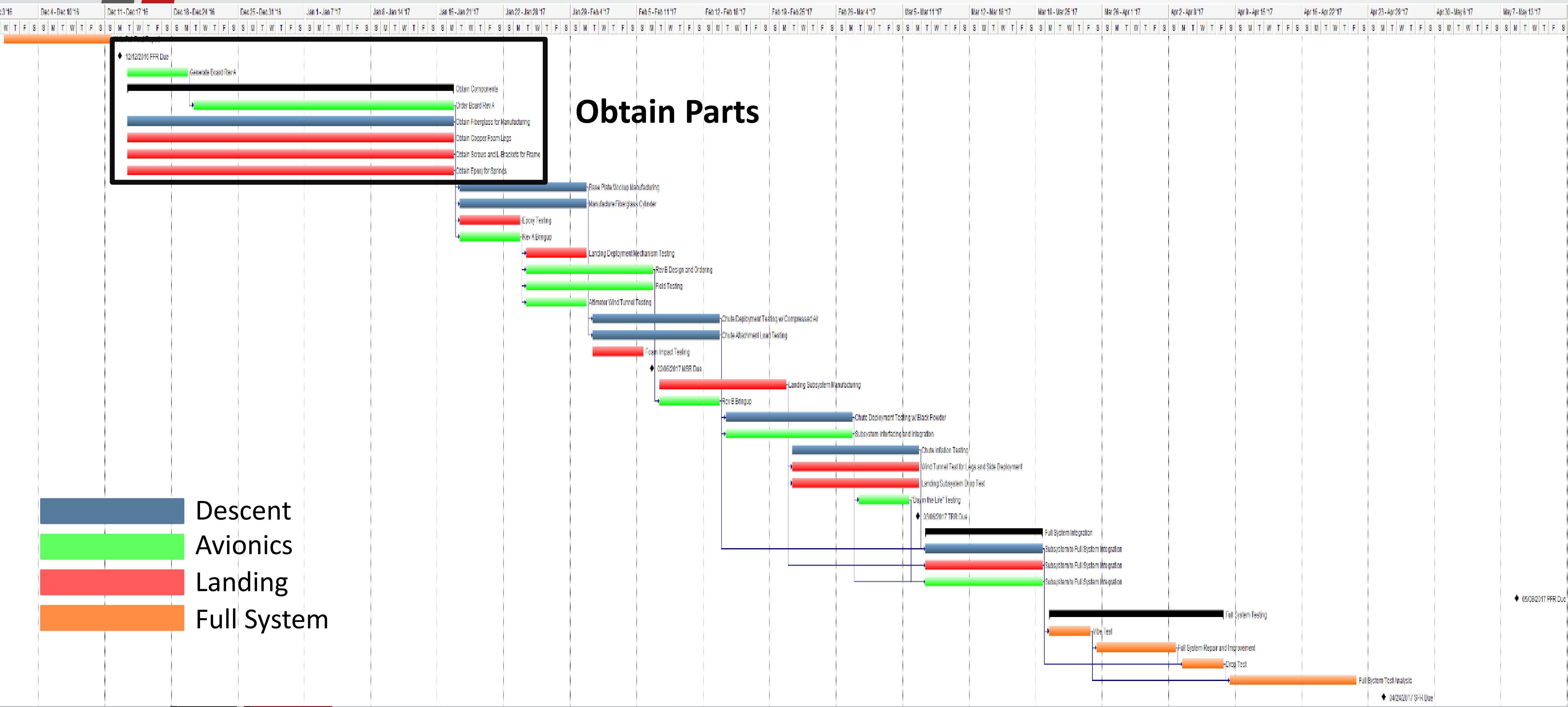

Obtain Parts

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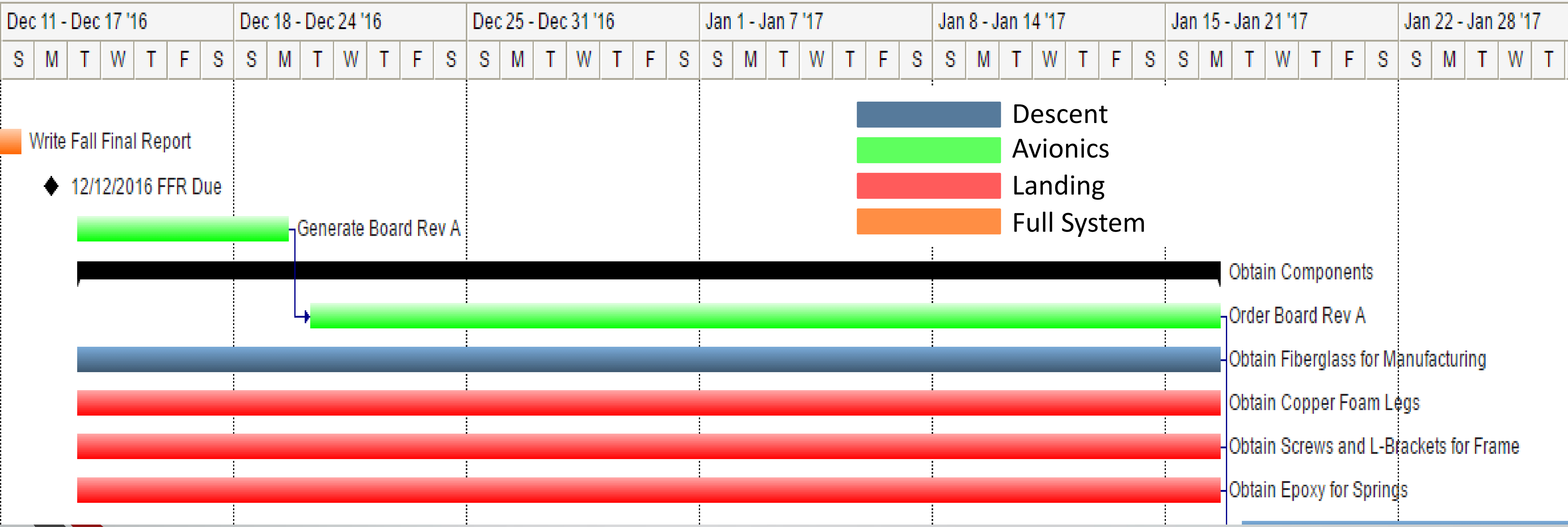

Gantt Chart

REPTAR

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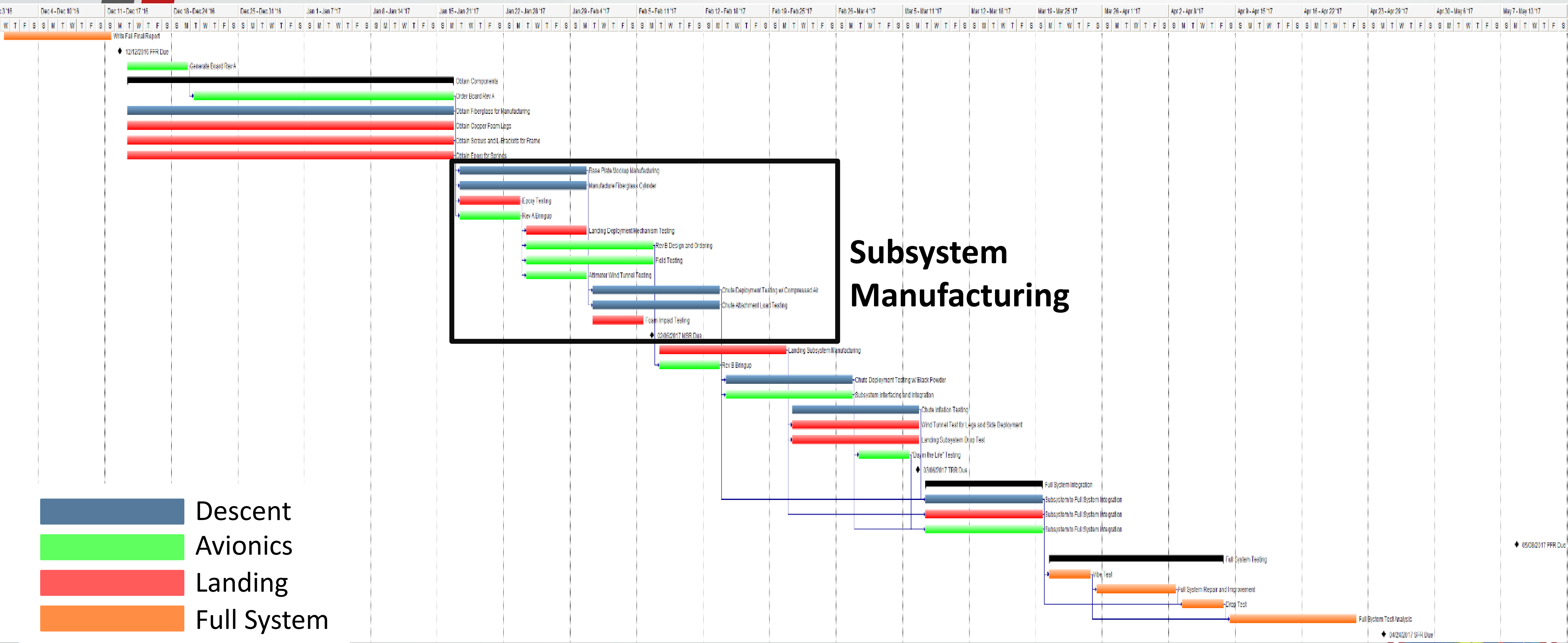

Subsystem Manufacturing

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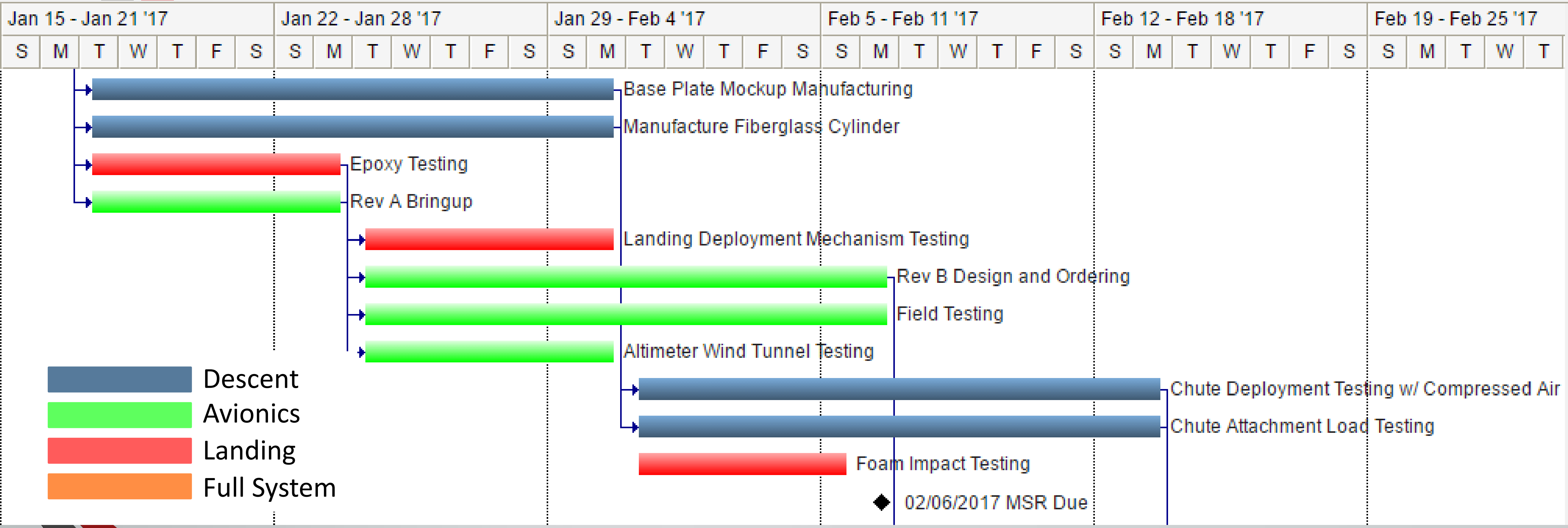
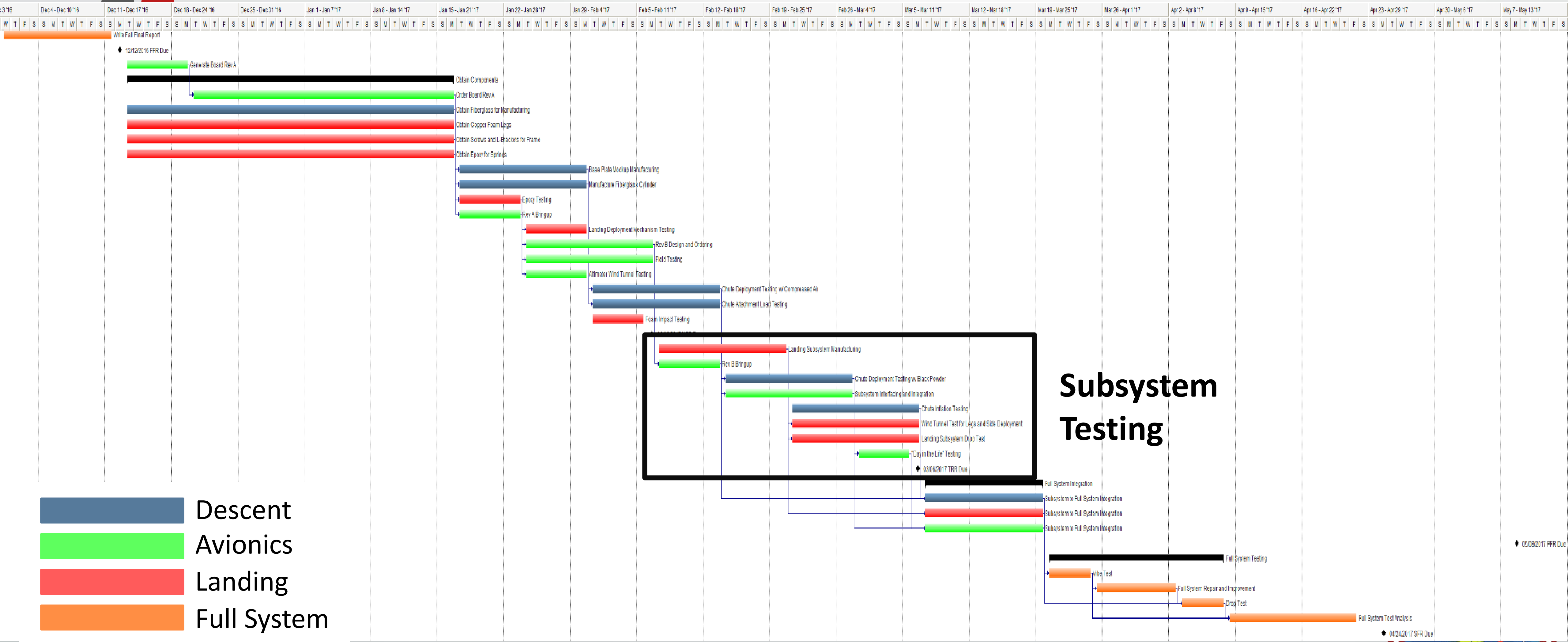


Gantt Chart

REPTAR

Raytheon



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Subsystem Testing

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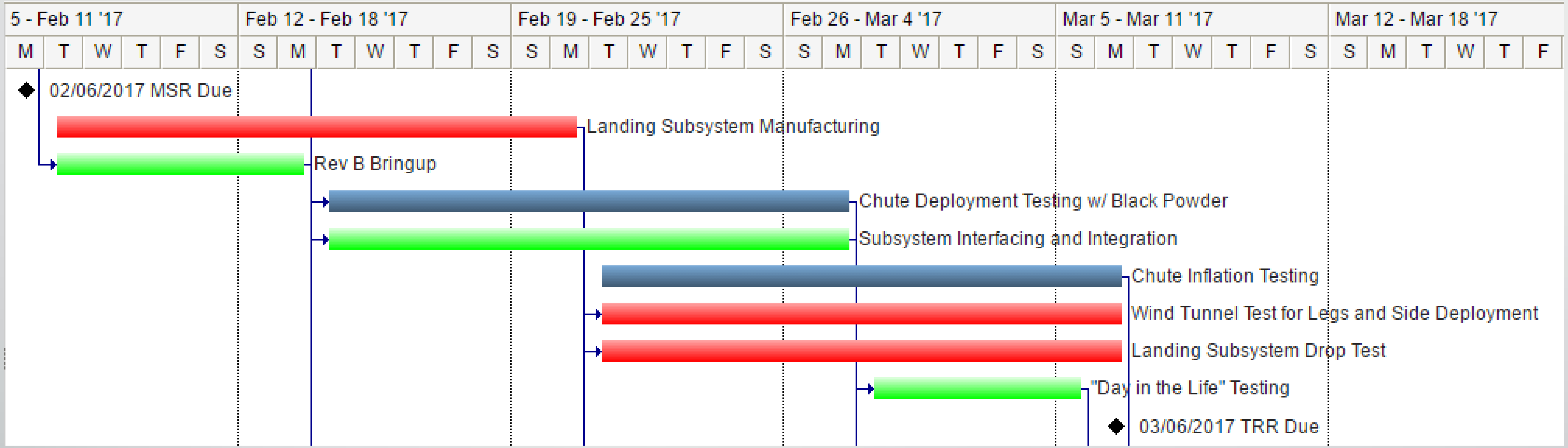

Descent
Avionics
Landing
Full System

CU-AES Raytheon REPTAR

Gantt Chart

REPTAR

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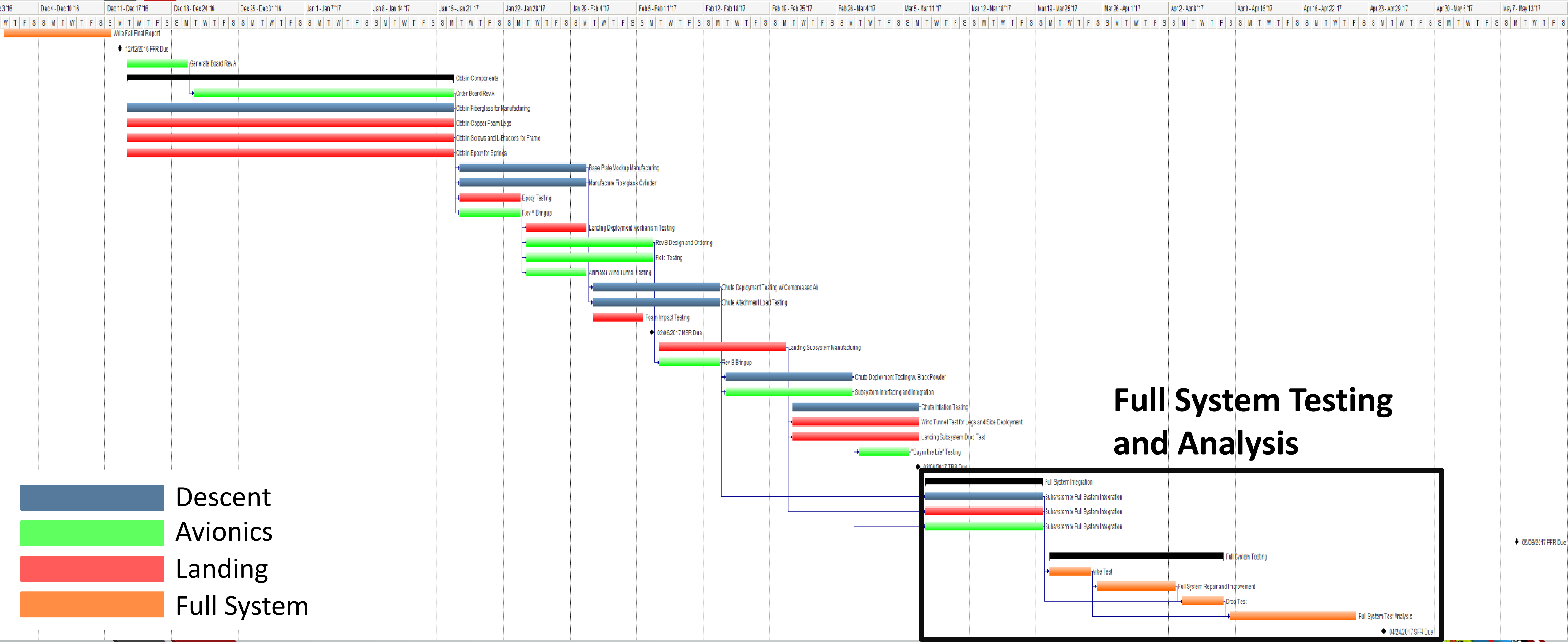

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Full System Testing and Analysis

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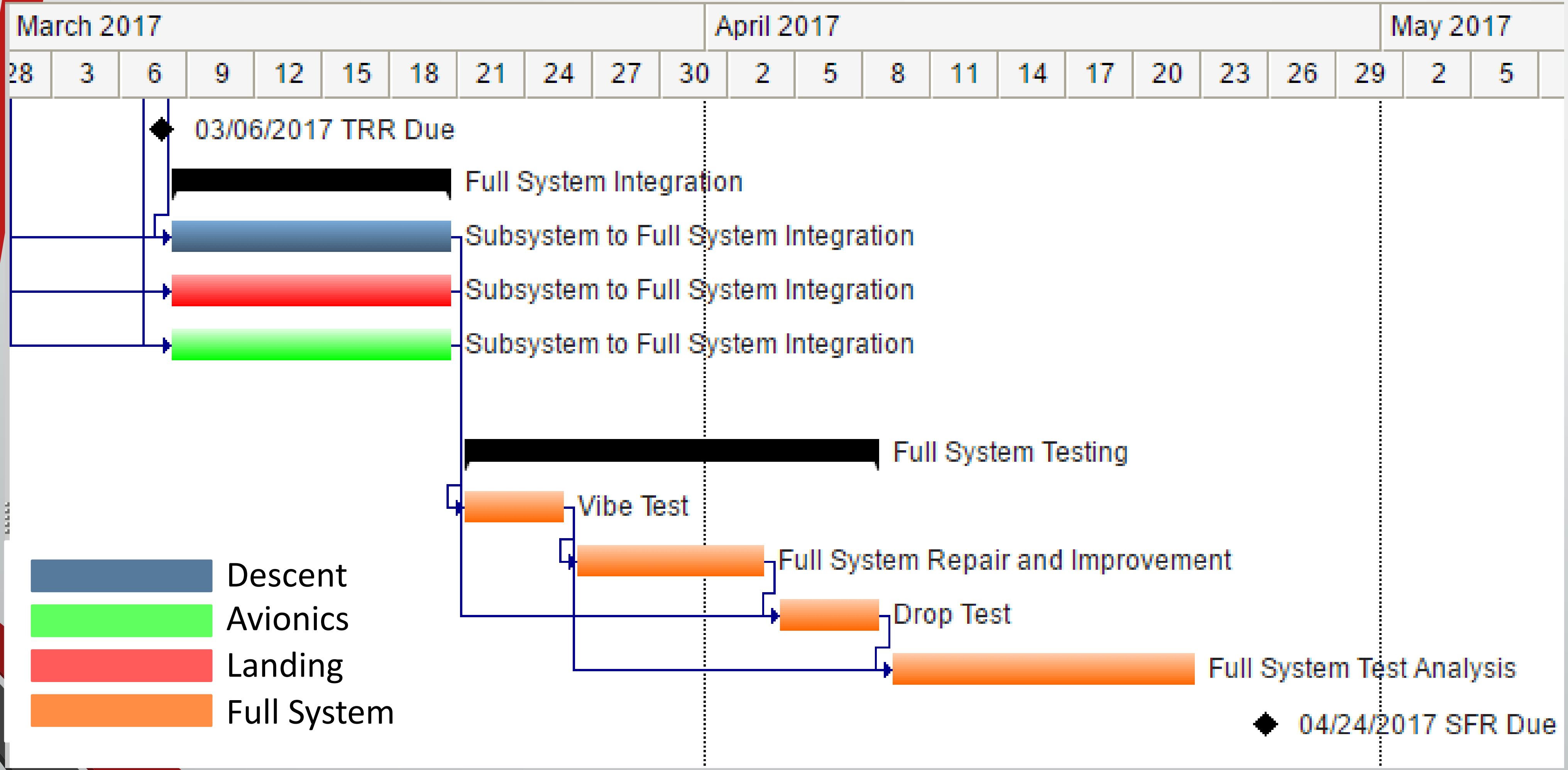

Gantt Chart Critical Path

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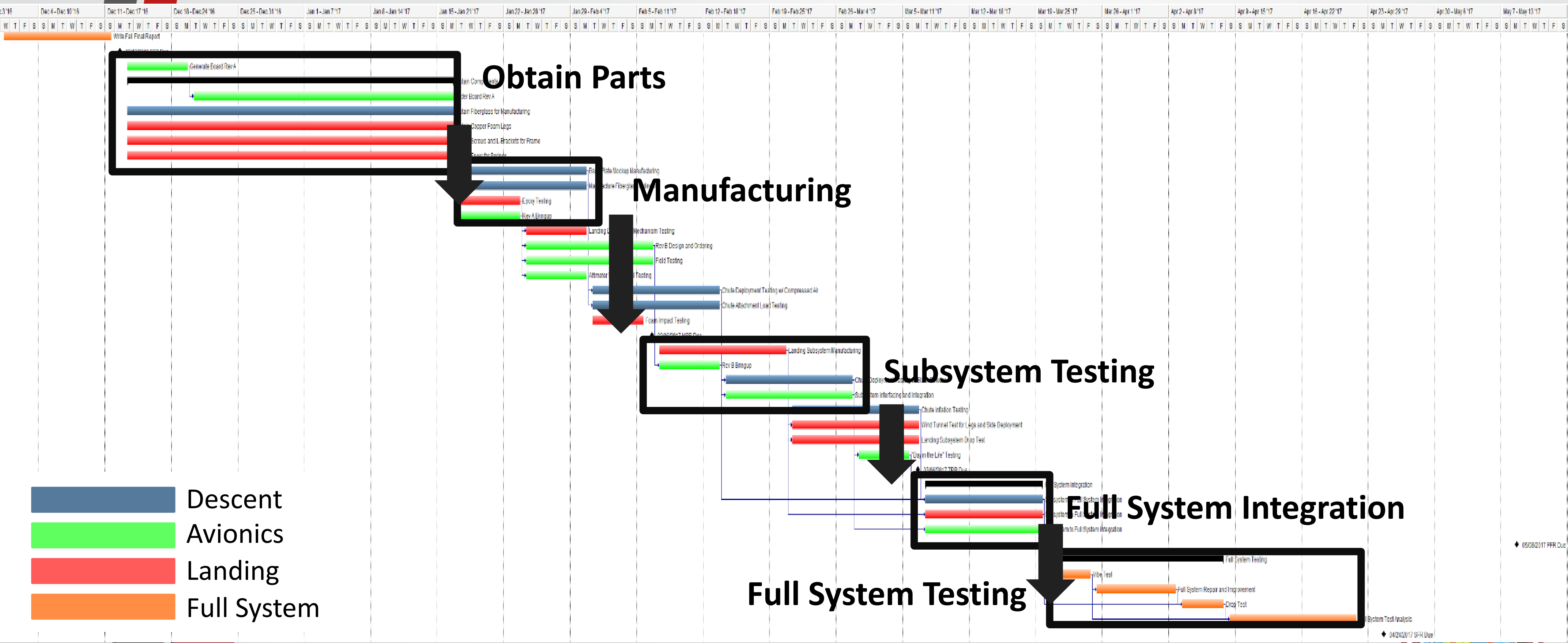

Questions?

Avionics Layout

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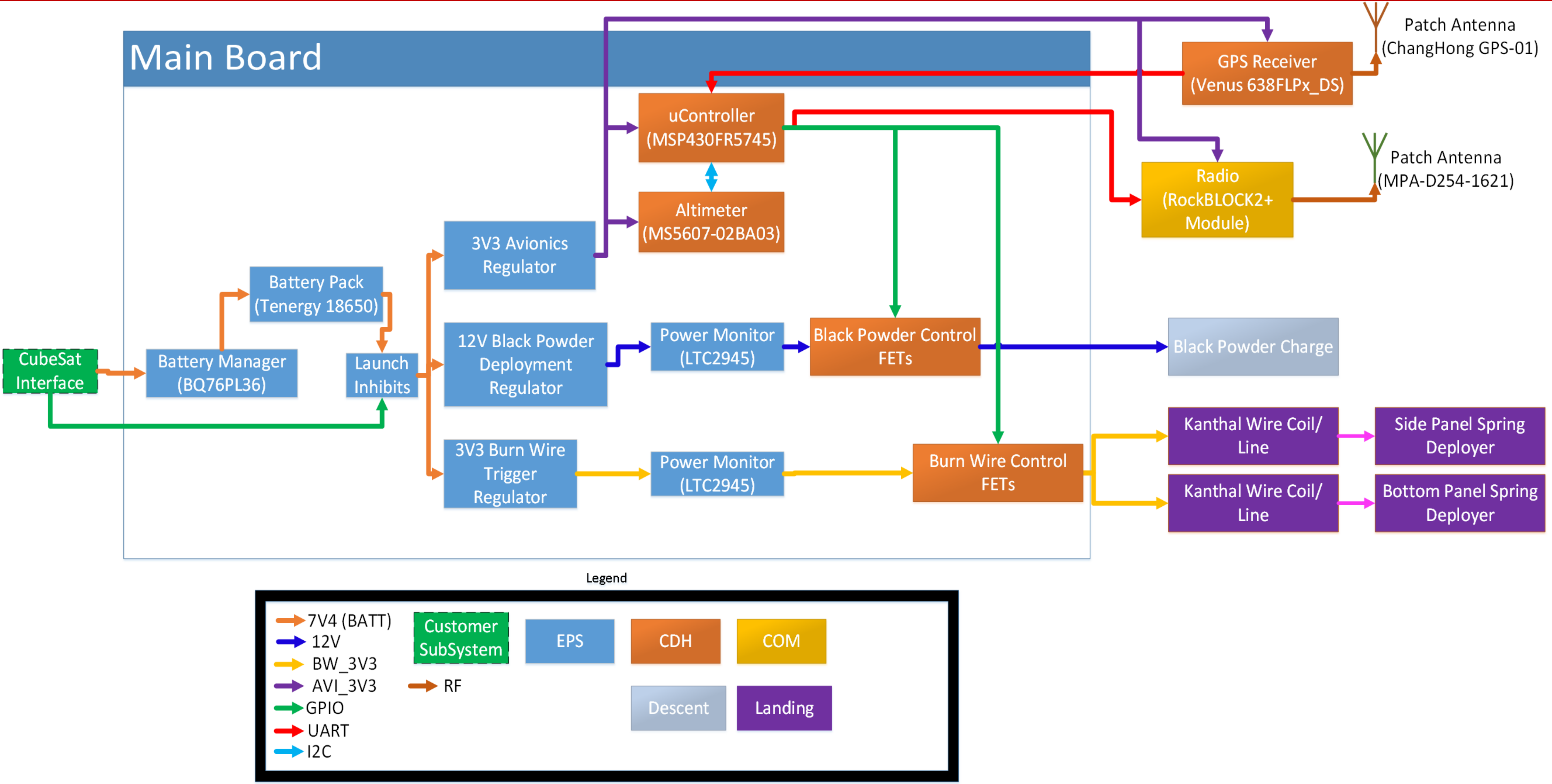

Critical Project Elements

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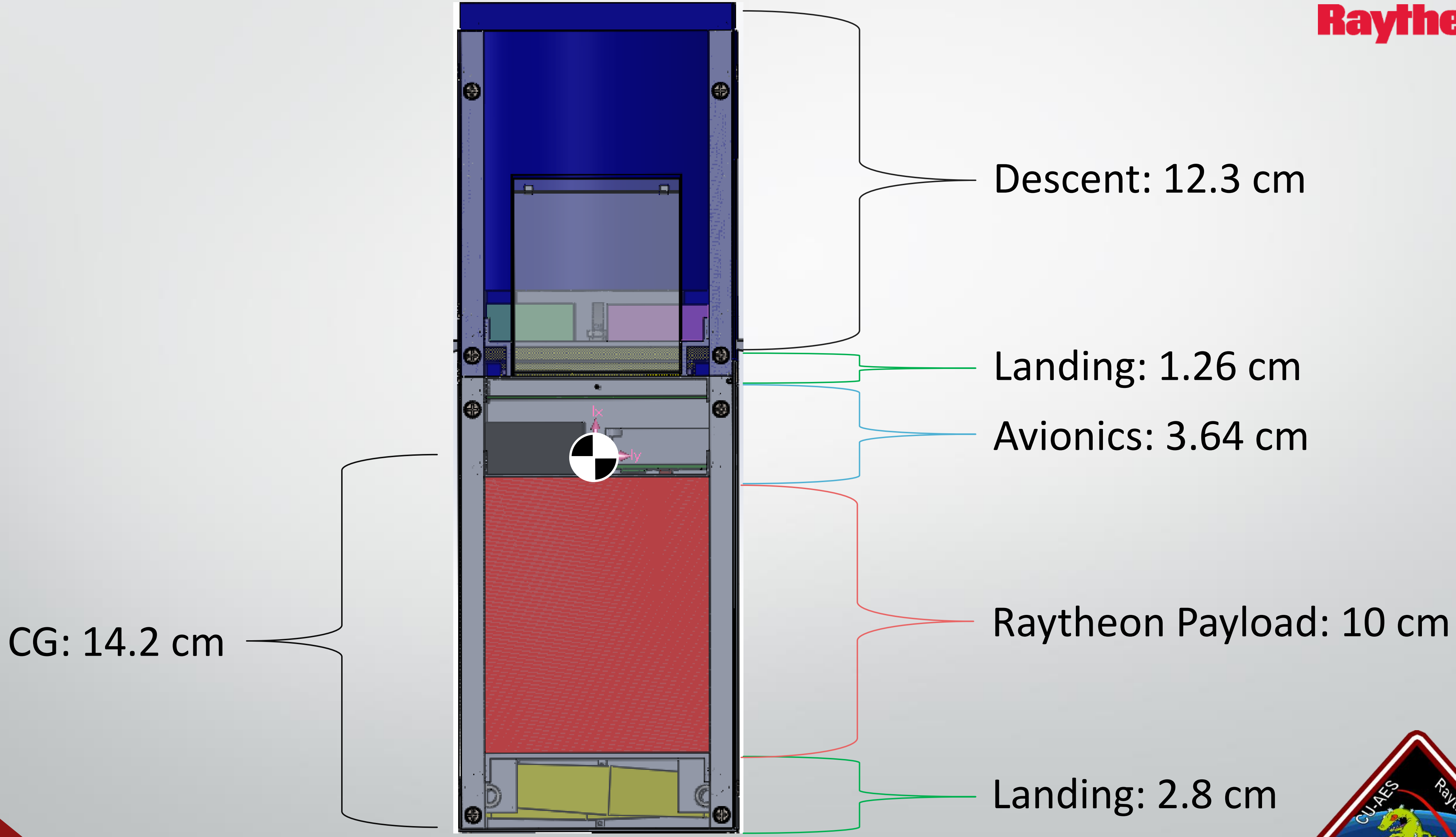
CPE	Explanation
Parachute Deployment	Proper deployment of parachute required for safe landing without structural damage
Leg and Side Panel Deployment	The base legs and side panels deploy to mitigate the landing G-Loadings experienced and the G-Loadings upon falling over onto a side
Interfacing Deployment Mechanisms	Deployment mechanisms require high current draw from battery. Battery will require cooldown time between deployments
Antennae Pattern	Aluminum portions of the structure may cause the antennae signal to change polarity and be unable to communicate
Altimeter Accuracy	Significant error in altimeter readings can cause structural damage due to improper deployment timings
Manufacturing	Manufacturing is expected to take a significant amount of time
Full System Testing	Full system tests are high risk, damaging components would cause project delays and added expense

CG Location


Descent: 12.3 cm
Landing: 1.26 cm
Avionics: 3.64 cm
Raytheon Payload: 10 cm
Landing: 2.8 cm
CG: 14.2 cm

Background

DR 1.5 & DR 1.6

- Temperature in space tends to stay between 2 and 5 K
- There may be a requirement for the satellite, or at least specific components, to be kept warm through the use of a heater
- Investigating whether a heater, which would take up space, is necessary

Requirements

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DR 1.5 & DR 1.6

- The electronics must be kept between 218 and 298 K
- The nylon parachute must be kept between 233 and 353 K (Professional Plastics)

Assumptions

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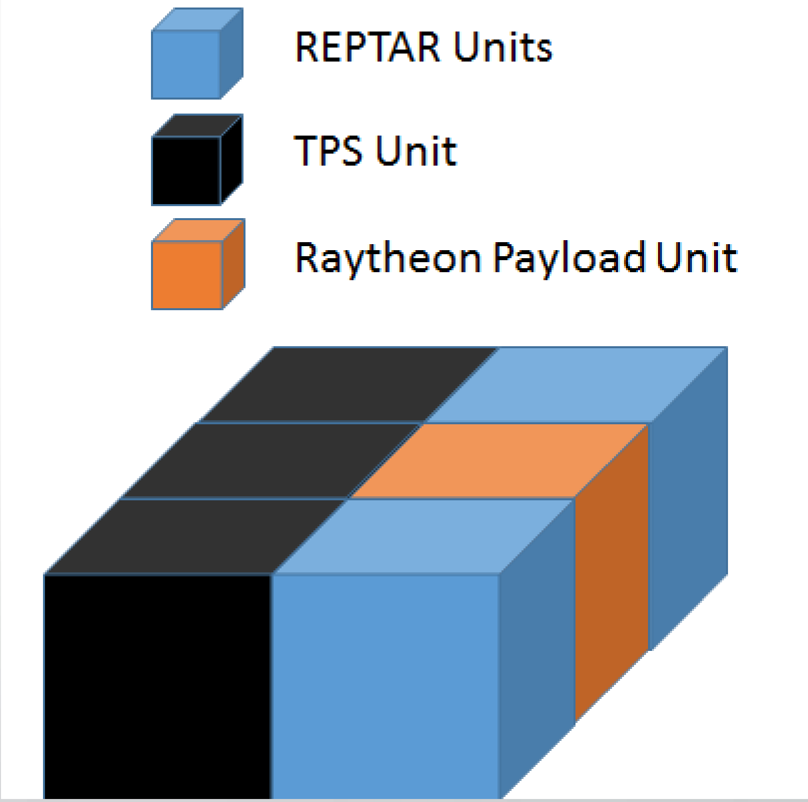
DR 1.5 & DR 1.6

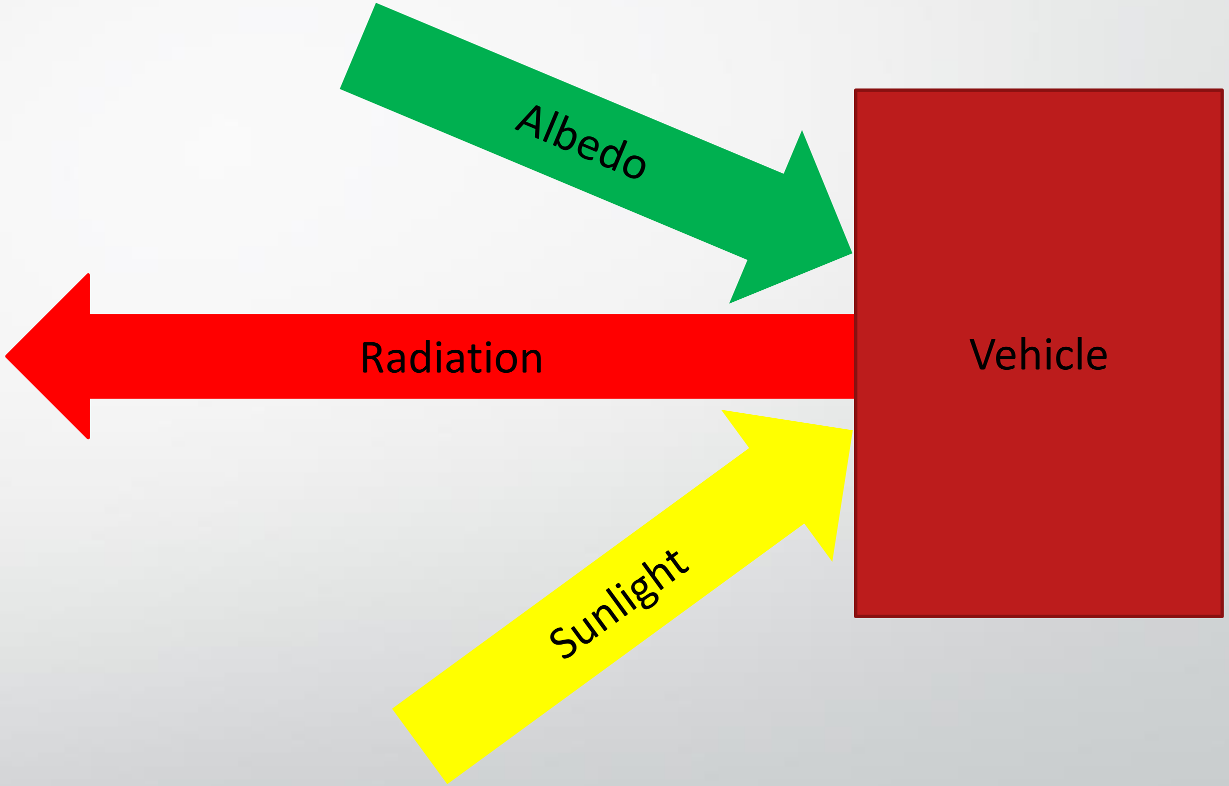
- Satellite is in a circular, 400 km altitude, 92.5 minute period orbit
- The satellite is a black body
- The satellite is composed entirely of aluminum
- The TPS is covering one long face of the satellite
- The payload does not generate heat while operational
- The only sources of heat addition are the sun and albedo
- The only source of heat loss is emission from the surface of the satellite



Analysis

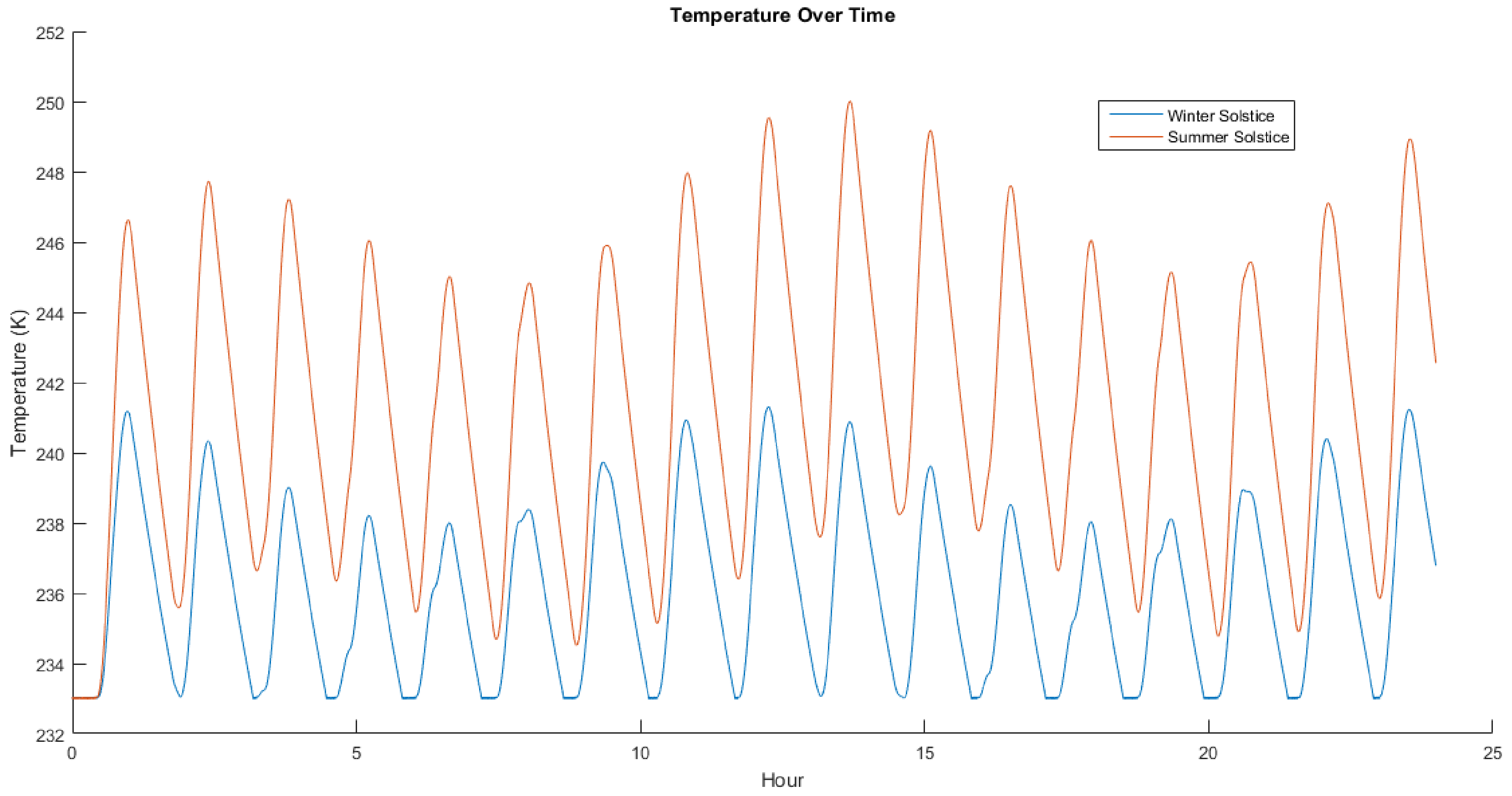
DR 1.5 & DR 1.6

- As the satellite orbits the earth, it will rotate and different faces will receive sunlight
- Earth's albedo also causes the satellite to increase in temperature
- Throughout the orbit, all exposed sides of the satellite will be radiating heat away from the satellite



Variation in Temperature

DR 1.5 & DR 1.6



Descent Mass Budget

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Item	Mass (g)
Parachute	122
Parachute Container	251
Tie Down	7.3
Tie Down Bolts x2	0.4
Chute Cylinder Screws x4	0.2
Aluminum Foil Top	1

Item	Mass (g)
DESCENT SYSTEM TOTAL	**382.9**

Pre-Mitigation Risk Assessment

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Risk	Description
RD1: Black Powder Ignition	Black powder must be in contact with electrodes in order to ignite
RD2: Insufficient Break in Top Plate	The parachute may not break the thin aluminum plate after black powder ignition due to lack of force
RD3: Parachute Burned during Canister Ignition	Burning the parachute as a result of igniting the black powder could lead to holes in the parachute and ultimately landing too fast
RD4: Partial Chute Opening	The parachute only partially opening due to strings being tangled
RD5: Destruction of Parachute Cylinder	Igniting the black powder creates an increase of pressure in the cylinder which could lead to a rupture in the fiberglass

Pre-Mitigation Risk Assessment

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		Severity				
		1	2	3	4	5
Likelihood	5 (Very High)		RD3			
	4 (High)					RD1
	3 (Moderate)				RD4	RD2
	2 (Low)		RD5			
	1 (Very Low)					

Post-Mitigation Risk Assessment

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Risk	Mitigation
RD1: Parachute Burned during Canister Ignition	Use of recovery wadding
RD2: Partial Chute Opening	Testing, Increase PSI
RD3: Black Powder Ignition	Packing canister, Using more black powder
RD4: Insufficient Break in Top Plate	Perforations, Increase PSI, Testing
RD5: Destruction of Parachute Cylinder	Pressure testing, Back up cylinder

Post-Mitigation Risk Assessment

		Severity				
		1	2	3	4	5
Likelihood	5 (Very High)					
	4 (High)					
	3 (Moderate)					
	2 (Low)	RD3				
	1 (Very Low)		RD5		RD4	RD1, RD2

RD1. Black Powder Ignition

- Severity: 5 Likelihood: 4 Total: 20
- Black powder must be in contact with electrodes in order to ignite after signal from altimeter
- Source of Mitigation: Packing ejection canisters with recovery wadding/hot glue
- Before Mitigation:
  - Use minimum amount of black powder to eject parachute, moves freely in canister
- After Mitigation:
  - Recovery wadding keeps black powder near electrodes
- Post Mitigation Severity: 5 Likelihood: 1 Total: 5

RD2. Insufficient Break in Top Plate

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- Severity: 5 Likelihood: 3 Total: 15
- The parachute may not break the thin aluminum plate after black powder ignition
- Source of Mitigation: Increase PSI, Perforations in thin aluminum sheet, modeling and testing
- Before Mitigation:
  - Use typical model rocketry pressures to push parachute out of cylinder
- After Mitigation:
  - Using more black powder to create a higher force to burst through top plate weakened by perforations
- Post Mitigation Severity: 5 Likelihood: 1 Total: 5

RD3. Chute Burned during Canister Ignition

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- Severity: 2 Likelihood: 5 Total: 10
- Burning the parachute as a result of igniting the black powder could lead to holes in the parachute and ultimately too fast of a landing speed
- Source of Mitigation: Recovery wadding
- Before Mitigation:
  - Use minimum amount of black powder to eject parachute
- After Mitigation:
  - Recovery wadding receives burns from black powder ignition
- Post Mitigation Severity: 1 Likelihood: 2 Total: 2

RD4. Partial Parachute Opening

- Severity: 4 Likelihood: 3 Total: 12
- The parachute only partially opening due to strings being tangled
- Source of Mitigation: Testing chute packing options
- Before Mitigation:
  - Poor packing of the parachute potentially leads to tangled lines
- After Mitigation:
  - Testing to ensure proper packing as well as adequate pressure for parachute ejection validates complete parachute opening
- Post Mitigation Severity: 4 Likelihood: 1 Total: 4

RD5. Destruction of Parachute Cylinder

- Severity: 2 Likelihood: 2 Total: 4
- Igniting the black powder creates an increase of pressure in the cylinder which could lead to a rupture in the fiberglass
- Source of Mitigation: Pressure testing, Back up cylinder to prevent project timeline creep
- Before Mitigation:
  - Use required PSI to eject parachute quickly from the cylinder
- After Mitigation:
  - Decreasing PSI to ensure parachute ejection and safety of cylinder
- Post Mitigation Severity: 2 Likelihood: 1 Total: 2

Descent Design Decision

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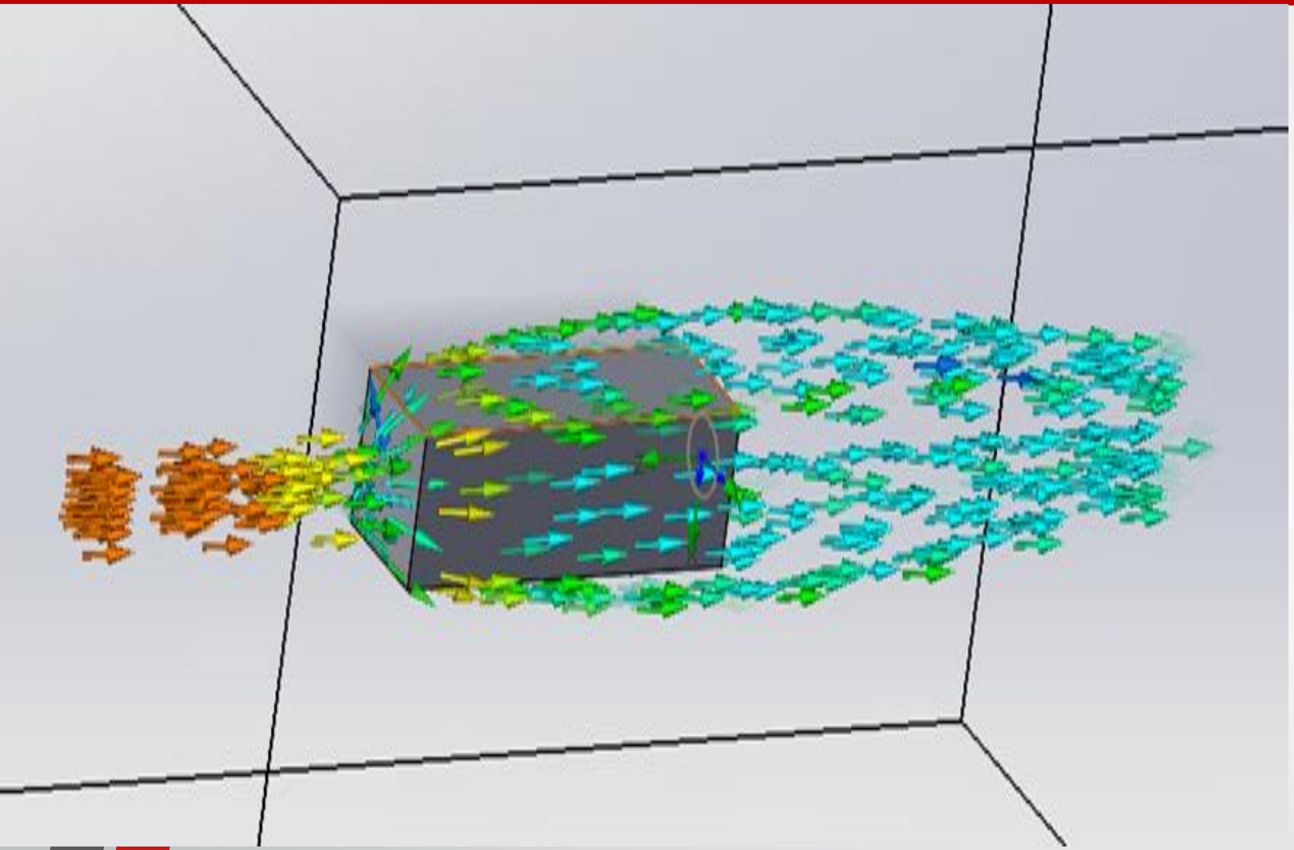
Item	COTS/Manufactured	Source/Facility	Details
Iris Ultra 122 cm Compact Parachute	COTS	Fruity Chutes	121.9 g , C_d = 2.20, Packing volume 428 cm^3
GOEX FFFFg Black Powder	COTS	Bass Pro Shop	0.300 g per canister
Parachute Containment Cylinder	Manufactured	ITLL/Aero Shop	Manufactured from fiber glass
Ejections Canisters	COTS	Pratt Hobbies	Tested for 9 and 12 VDC
Recovery Wadding	COTS	McGuckins Hardware	Thermal protection for parachutes

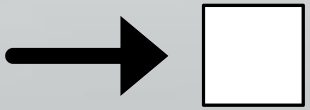
Coefficient of Drag



- Global Force in SolidWorks Flow Simulation
- $C_d = \frac{F}{0.5*\rho*v^2*S}$
    - C_d = 1.135 @ 15,000 m
    - C_d = 1.095 @ 6,000 m
    - C_d = 0.978 @ 3,000 m
    - Average C_d = 1.069

- Reynolds Number and Coefficient of Drag
    - $R_e = \frac{v*L}{\mu/\rho}$
        - V = velocity at altitude
        - L = length of object
        - μ = dynamic viscosity of air
        - ρ = density of air at altitude
    - R_e = 3.96 x 10^5 @ 20,000 m
    - R_e = 9.07 x 10^5 @ 10,000 m
    - R_e = 1.15 x 10^6 @ 5,000 m
    - Average R_e = 8.18 x 10^5

- Shames, Irving Herman. "Chapter 12: Boundary-Layer Theory." *Mechanics of Fluids*. Fourth ed. New York: McGraw-Hill, 1962. 674. Print.
    - Drag Coefficient of Cube = 1.05
    - For Reynolds Number ≈ 10^5



Black Powder Calculation

- Products of Combustion:
  - 56% Solid Products, 43% Gaseous Products, 1% Water
- Energy Density = 3 MJ/kg
- 75% Potassium Nitrate, 15% Charcoal, 10% Sulfur
- $10KNO_3 + 8C + 3S \rightarrow 2K_2CO_3 + 3K_2SO_4 + 6CO_2 + 5N_2$
  - (101.1*0.75) + (12*0.15) + (32.1*0.10) = 80.8 g/mol

Black Powder Calculation

- Ideal Gas Law: PV = nRT
  - n = $\frac{PV}{RT}$
    - P_2 = 20 psi = 137,900 Pa
    - $V_2 = 9cm*\pi*(4cm)^2 = 452.4\ cm^3 = 4.52*10^{-4}\ m^3$
    - R = 8.314 J/mol*K
    - T = 1837.2 K
  - n = 4.08×10^{-3} mol
  - 80.8 g/mol * 4.08×10^{-3} mol = 0.330 g
  - Tests found 0.318 g produce 24 psi
  - http://www.vernk.com/EjectionChargeSizing.htm

Black Powder Burn Time

- Sources indicate burn velocity of GOEX Black Powder = 0.47 in/sec
- Other sources indicate burn velocity of Black Powder = 0.197 in/sec
- From testing this burn time was almost instantaneous
- Worst cases range from 1.5 sec to 3.5 sec
  - Height of black powder is 0.67 inches
- http://www.ctmuzzleloaders.com/ctml_experiments/bp_burning/bp_burning.html
- http://www.dtic.mil/dtic/tr/fulltext/u2/a129087.pdf

Fiberglass Cylinder Burst Pressure

- $P = \frac{2St}{(OD)(SF)}$
- P = Fluid Pressure (PSI) = 20
- t = Wall Thickness (in) = 0.157
- OD = Outer Diameter (in) = 3.46
- SF = Safety Factor = 1 (Burst Pressure)
- S = Ultimate Tensile Strength (PSI) = 7900 PSI

- Burst Pressure for Fiberglass Cylinder = 717 PSI

http://www.engineersedge.com/calculators/pipe_bust_calc.htm

Force of Parachute Vs. Aluminum Foil

- Perforated (1/8” hole, centered) foil failed at approximately 25.7 kPa
- Non-perforated foil failed under approximately 258 kPa pressurized air
  - Parachute did not deploy. Pressure was gradually increased, so assumption that chute is acting like a piston fails without near-instantaneous pressure increase from below chute
  - Foil failed at 5 psi below maximum chamber pressure for instantaneous loading limits

Parachute Cylinder Pressure

- Limitations on pressure due to MIL-SPEC 11ms 40G loading
- $F = P_{max} \cdot A - f = ma$
- f includes pressure differences, losses, friction, gravity, and dynamic pressure, which may allow higher pressure to overcome
- Assuming ideal situation, $f = 0$, solving for maximum chamber pressure P_{max} yields:

$$P_{max} = \frac{mGg}{A} = 302.7\ kPa\ (43.91\ psig)$$

$m = 3.82\ kg$

$a = Gg$

$g = 9.81\ m/s^2$

$G = 40$

$A = .005\ \mathrm{m}^2$

Parachute Cylinder Pressure Losses

- Parachute Friction – modeled as $P \cdot A \cdot \mu$, which determines friction force as function of chute position.
- Ambient pressure difference – higher ambient pressure requires more pressure increase from
- Energy lost in pushing through top plot
- Pressure lost through top plate, wire or chute line holes
- Dynamic pressure from top-down descent

Parachute Time to Deploy

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- $S_0 = 232\ ft^2$
- $D_0 = \sqrt{\frac{4 * S_0}{\pi}}$
- $n = 8$
- $t_{deploy} = \frac{n * D_0}{v_{term}}$ = 0.455 s
- $G's = (\frac{Diff(V)}{t_{step}})/9.81 m/s^2$
- $t_{step} = 0.011\,\text{sec} \rightarrow milspec\ standard$

***Mohaghegh, F., and Jahannama, M. R., "Parachute Filling Time: A Criterion to Classify Parachute Types," pp. 1–13.**

Force on Strings of Parachute

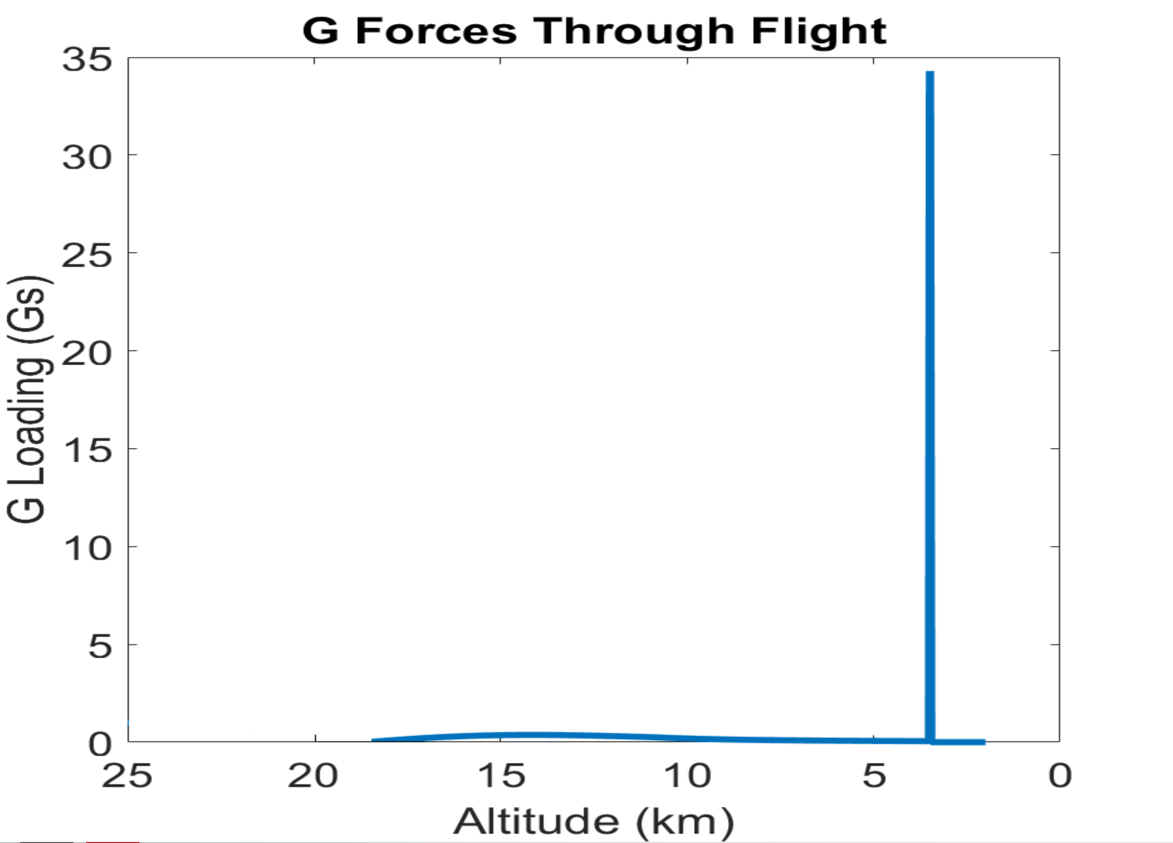
- Maximum Instant G Loading = 34.3 G's
- 34.3 G's * $9.81 m/s^2$ = $336.5 m/s^2$
- F = ma = 3.99kg * $336.5 m/s^2$ = 1343 N
- 1343 N= 301.9 lbf
- 301.9 lbf / 8 strings = 38 lbf per string
- Each line is #400 Spectra, which means 400 lbf per string
- Factor of Safety of 10.53

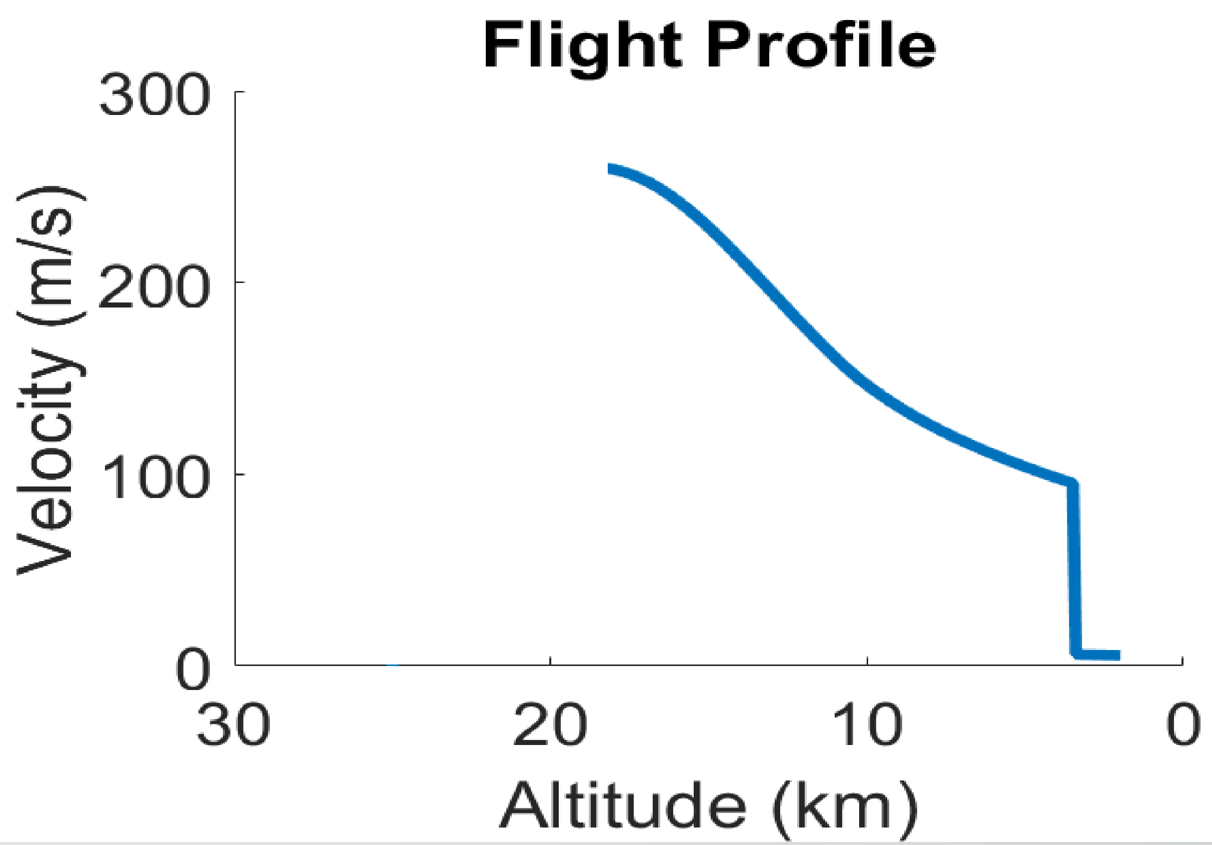
Parachute Drop Test

- Drop deployed parachute attached to 4 kg at 15m above ground
- Use high speed camera at 120 fps to measure trajectory
  - Verify C_d of parachute
  - Verify landing velocity model
  - Verify wind trajectory model

Design Feasibility

REPTAR





- Minimum time required: 0.46 sec
  - G Load of 34.3 G's (DR 1.3)
- Sustained < 1.2 G's (DR 1.2)

- Maximum deployment height: 8,000 m MSL
- Minimum deployment height: 3,182 m MSL
  - Landing Velocity = 5.5 m/s
- UTTR Ranges 1,500-2,600 m MSL
  - Deploying at 3,500 m MSL

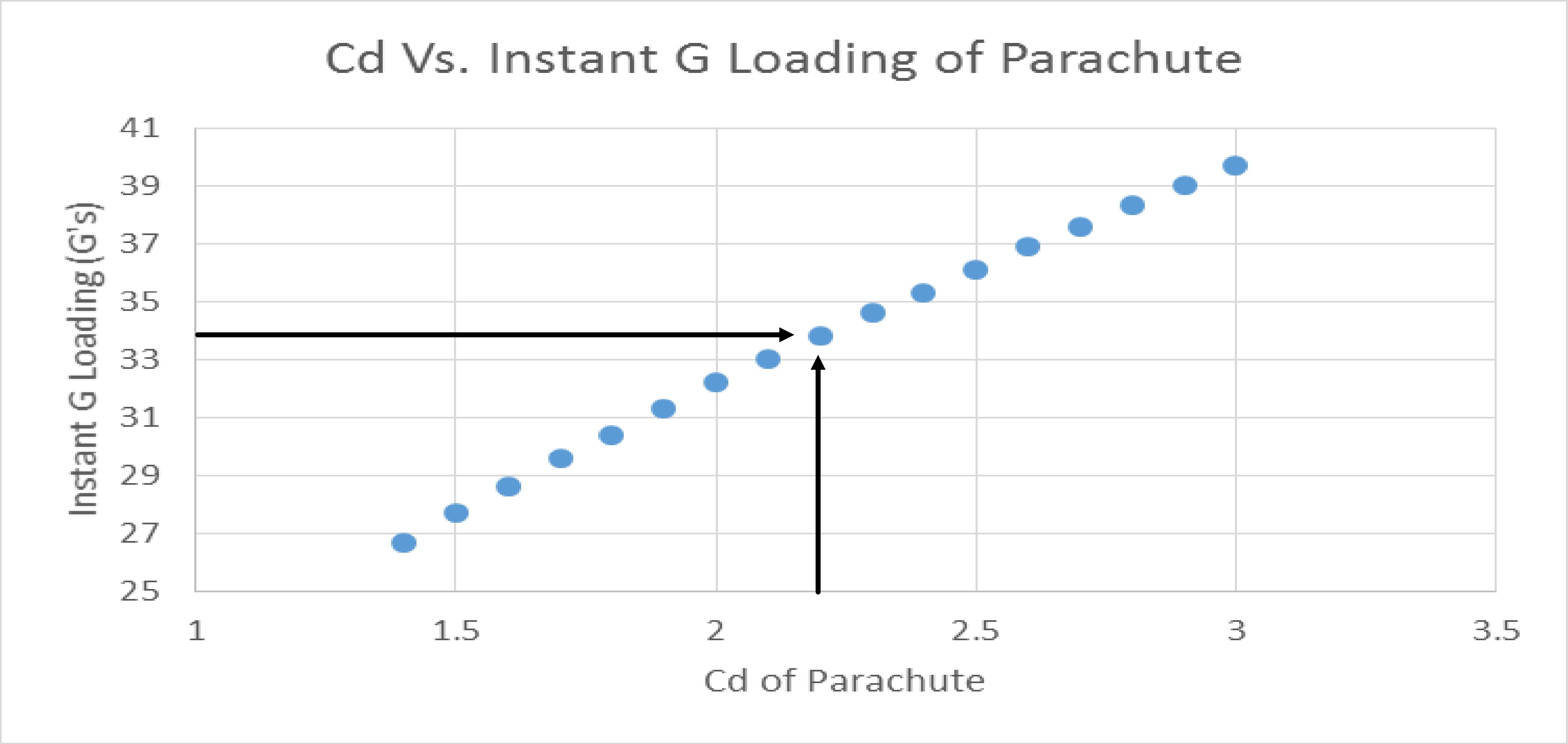
C_d of Parachute Sensitivity

Assumptions:

- Area = 1.13 m^2
- Open Time = 0.46 Sec
- Chute Deploy = 3500 m MSL

Baseline:

- Cd = 2.20



Projected Area of Parachute Sensitivity

REPTAR

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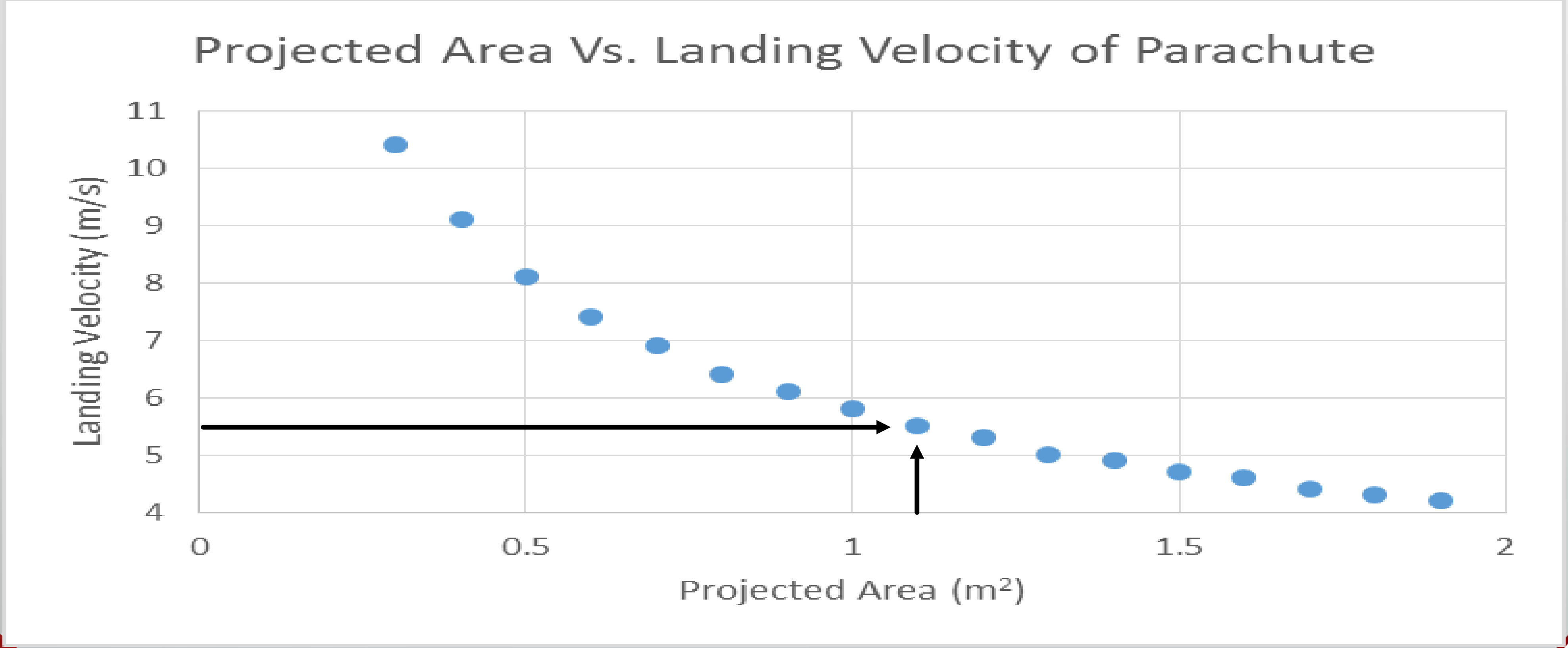
Assumptions:

- Cd = 2.20
- Open Time = 0.46 Sec
- Chute Deploy = 3500 m MSL

Baseline:

- Area = 1.13 m^2



Time to Open Parachute Sensitivity

REPTAR

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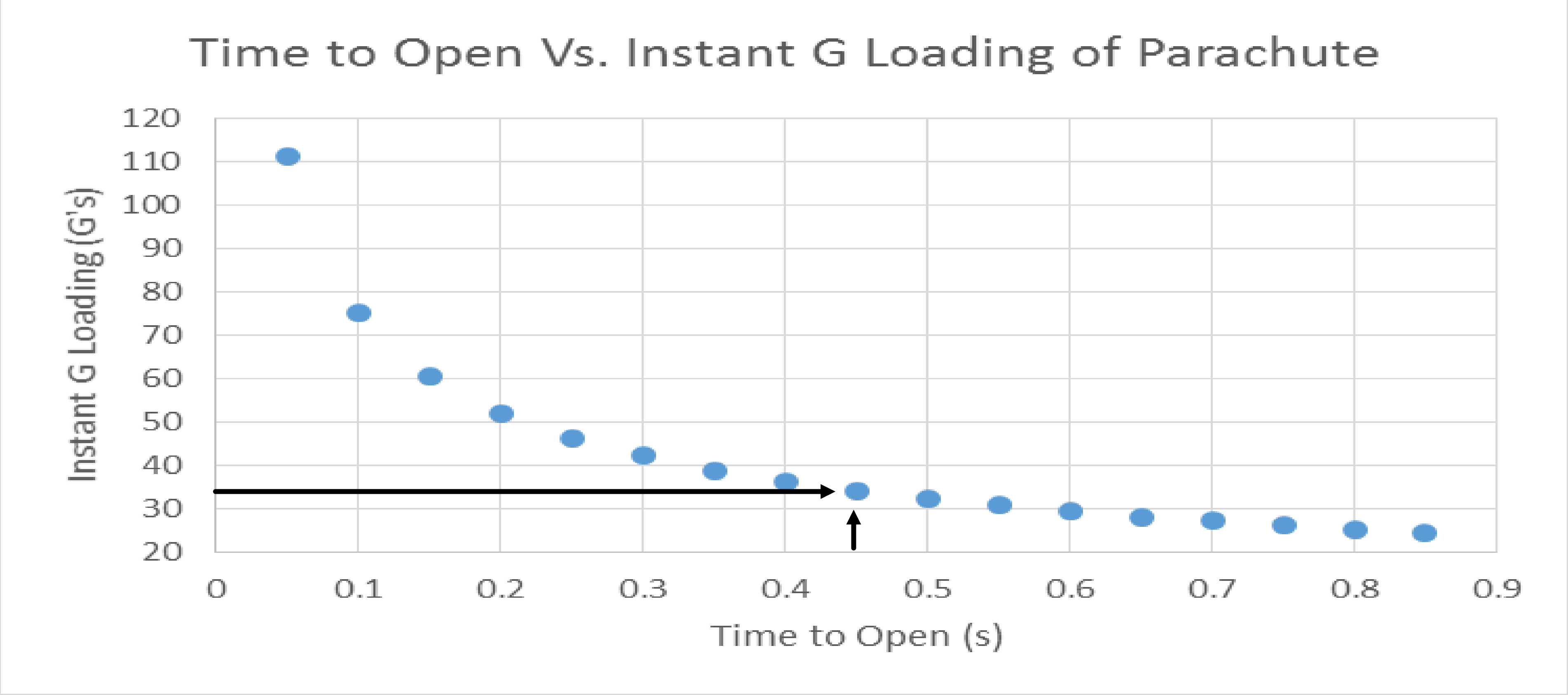
Assumptions:

- Cd = 2.20
- Area = 1.13 m^2
- Chute Deploy = 3500 m MSL

Baseline:

- Open Time = 0.46 sec



Altitude of Deployment of Parachute Sensitivity

REPTAR

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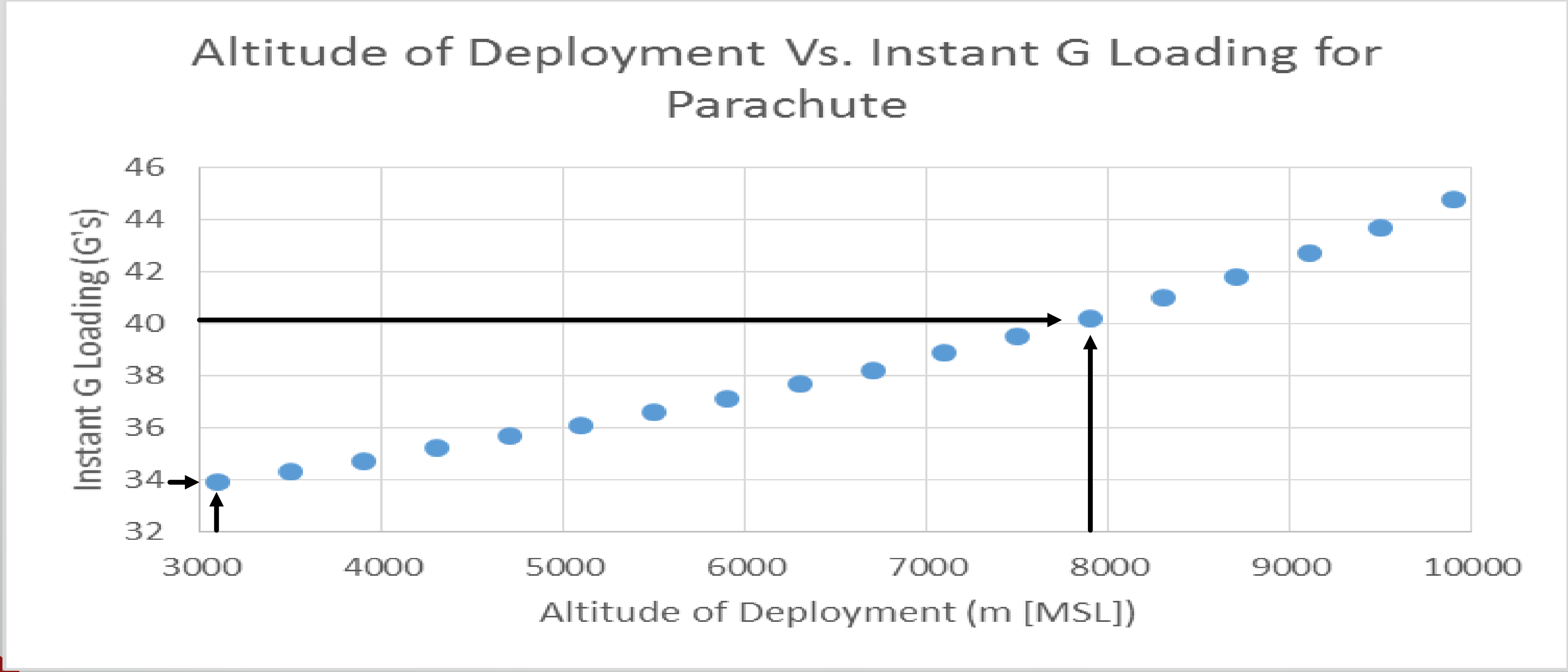
Assumptions:

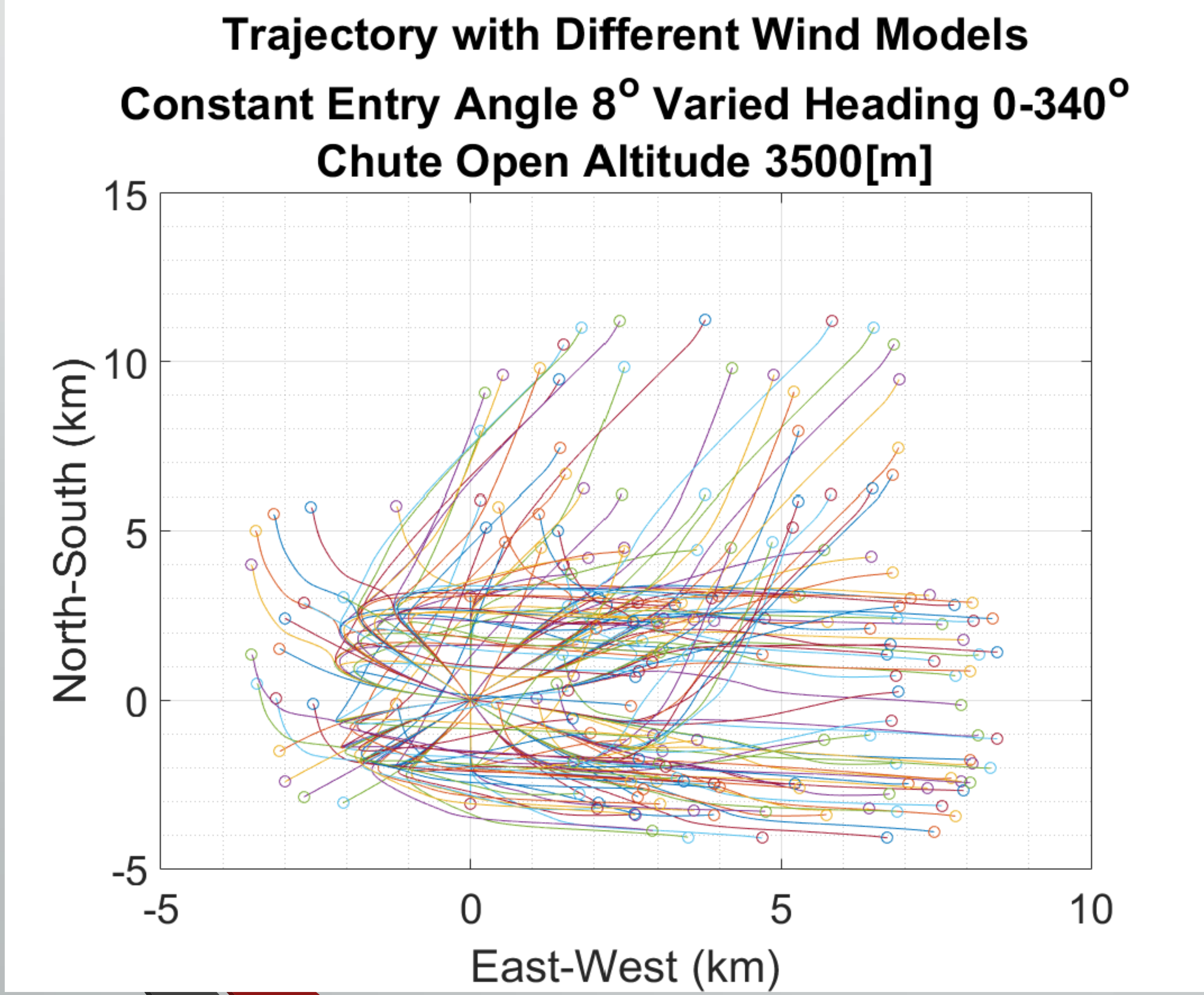
- Cd = 2.20
- Area = 1.13 m^2
- Open Time = 0.46 sec

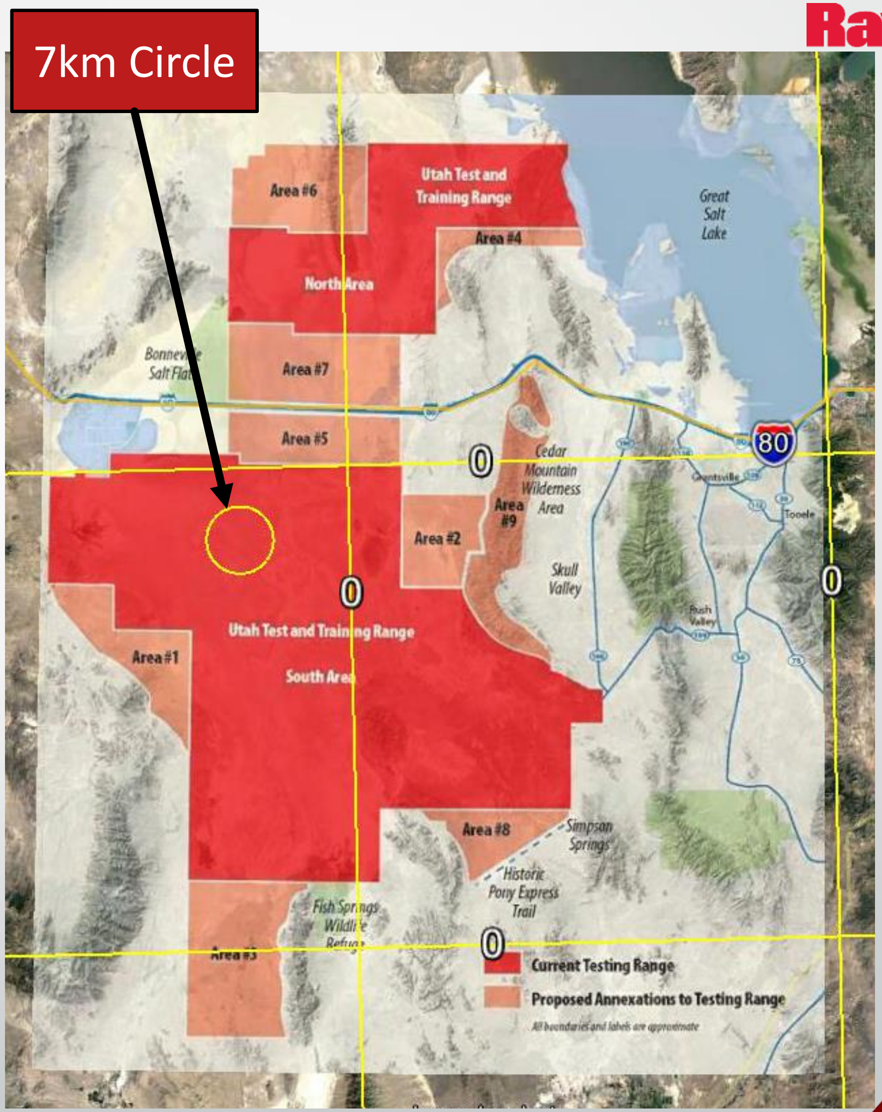
Baseline:

- Maximum deployment height: 8,000 m MSL
- Minimum deployment height: 3,020 m MSL



Wind Influence on Trajectory





Surface Wing Analysis by Hour

REPTAR

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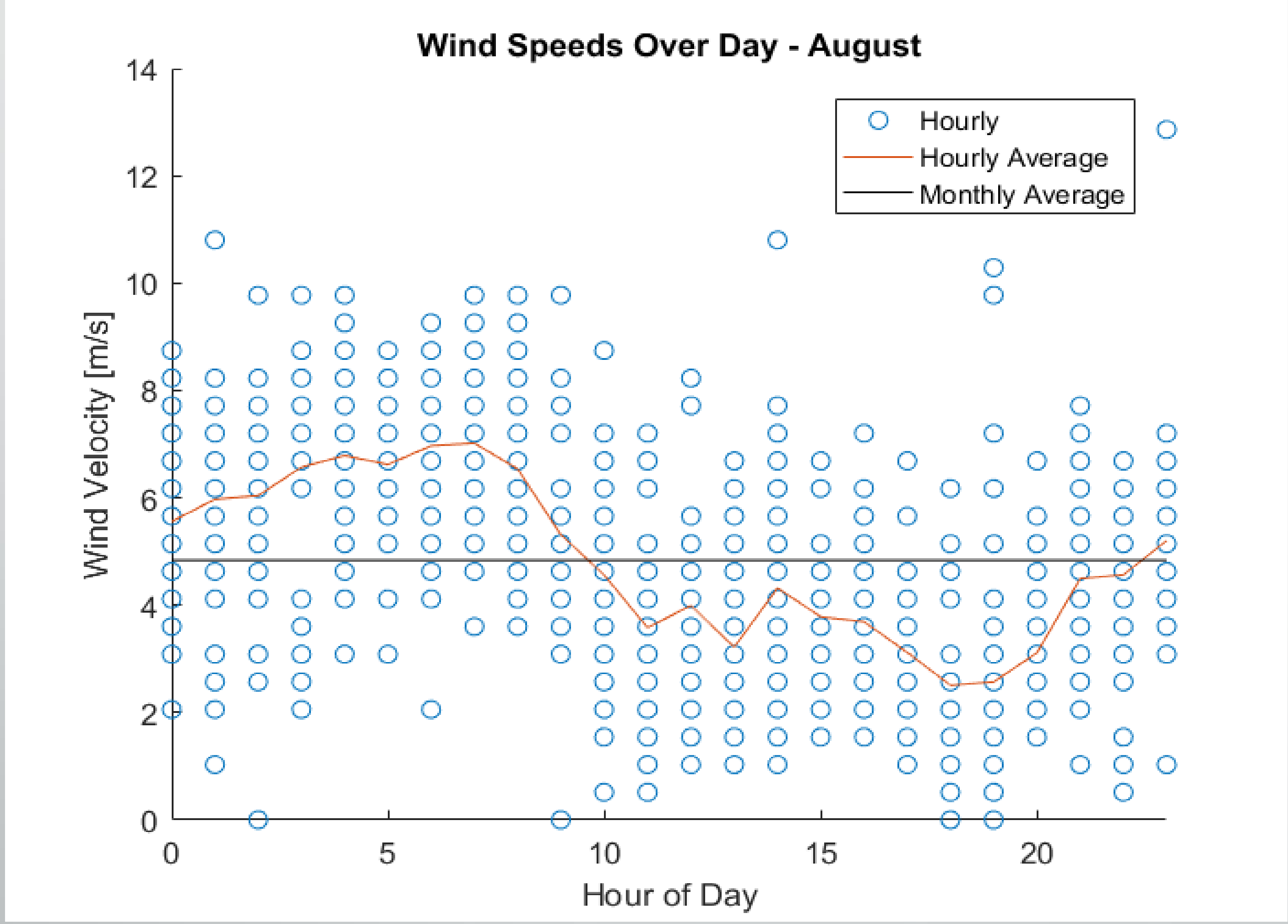

- Windiest Month – August
- Average wind speed for August 2016: 4.74 m/s.
- Max daily average wind speed for August 2016: 7.02 m/s.

Effect of Parachute Deployment Altitude

REPTAR

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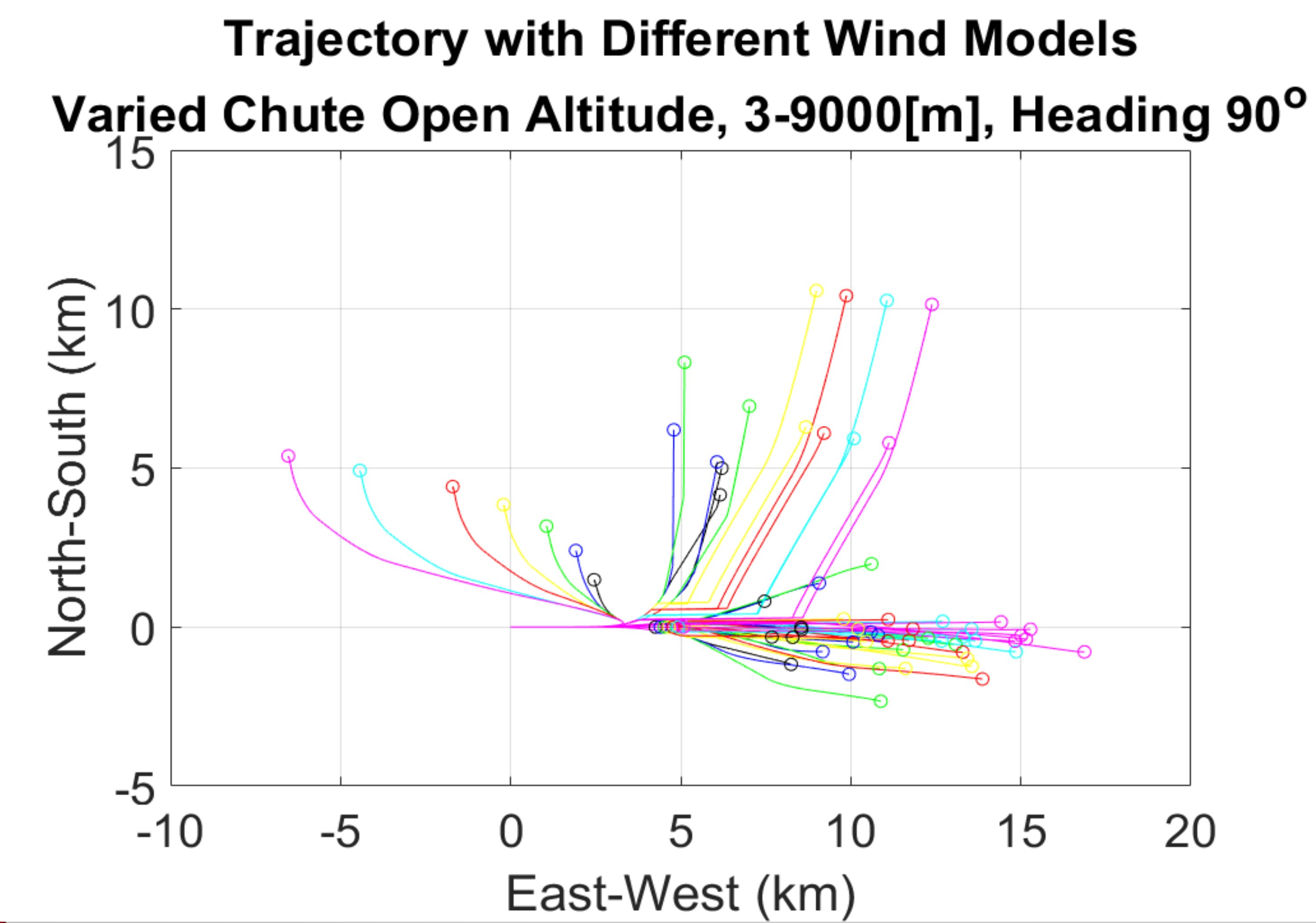
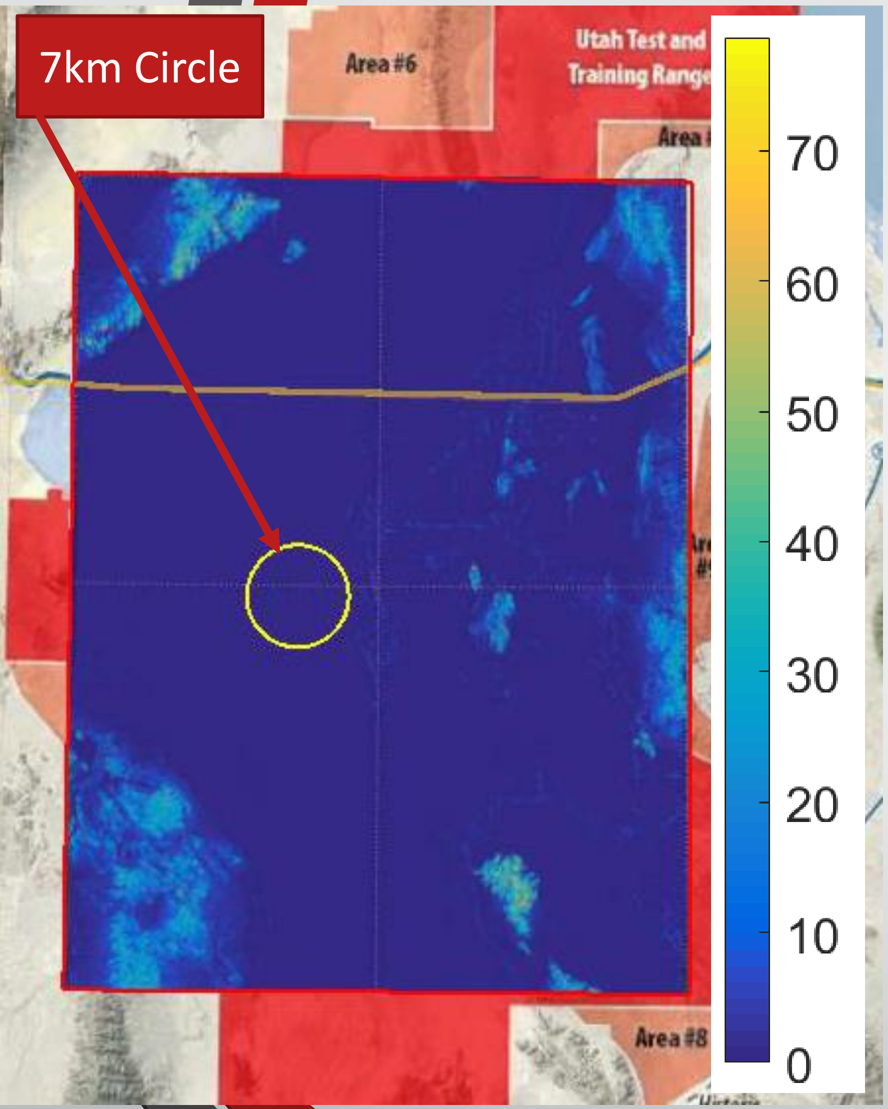


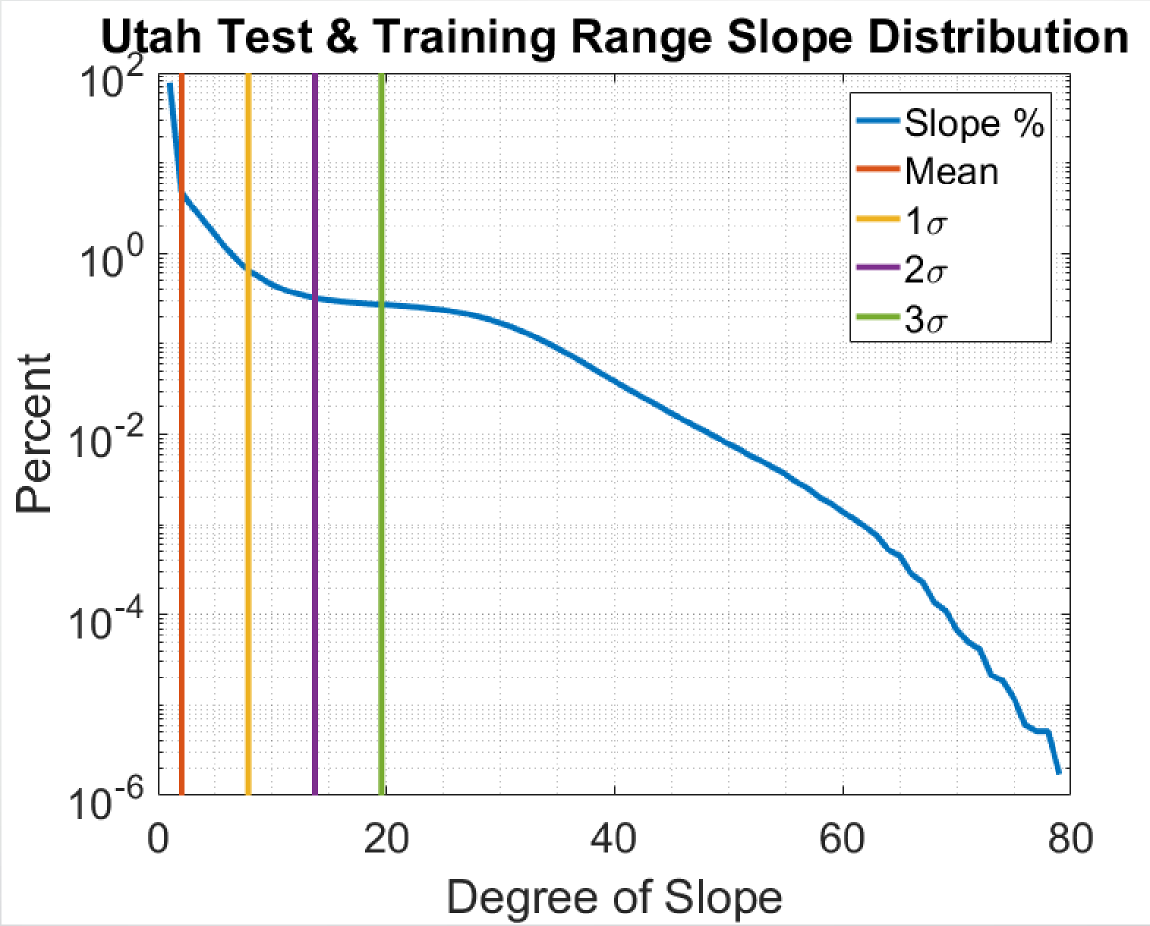
- Parachute deployment altitude significantly increases wind-drift spread due to high velocity winds at high altitudes

Utah Test and Training Range Slope Data

REPTAR

Raytheon





- 99.0% of terrain in UTTR below 10°
- 99.7% of terrain in UTTR below 20°

Parachute Release

REPTAR

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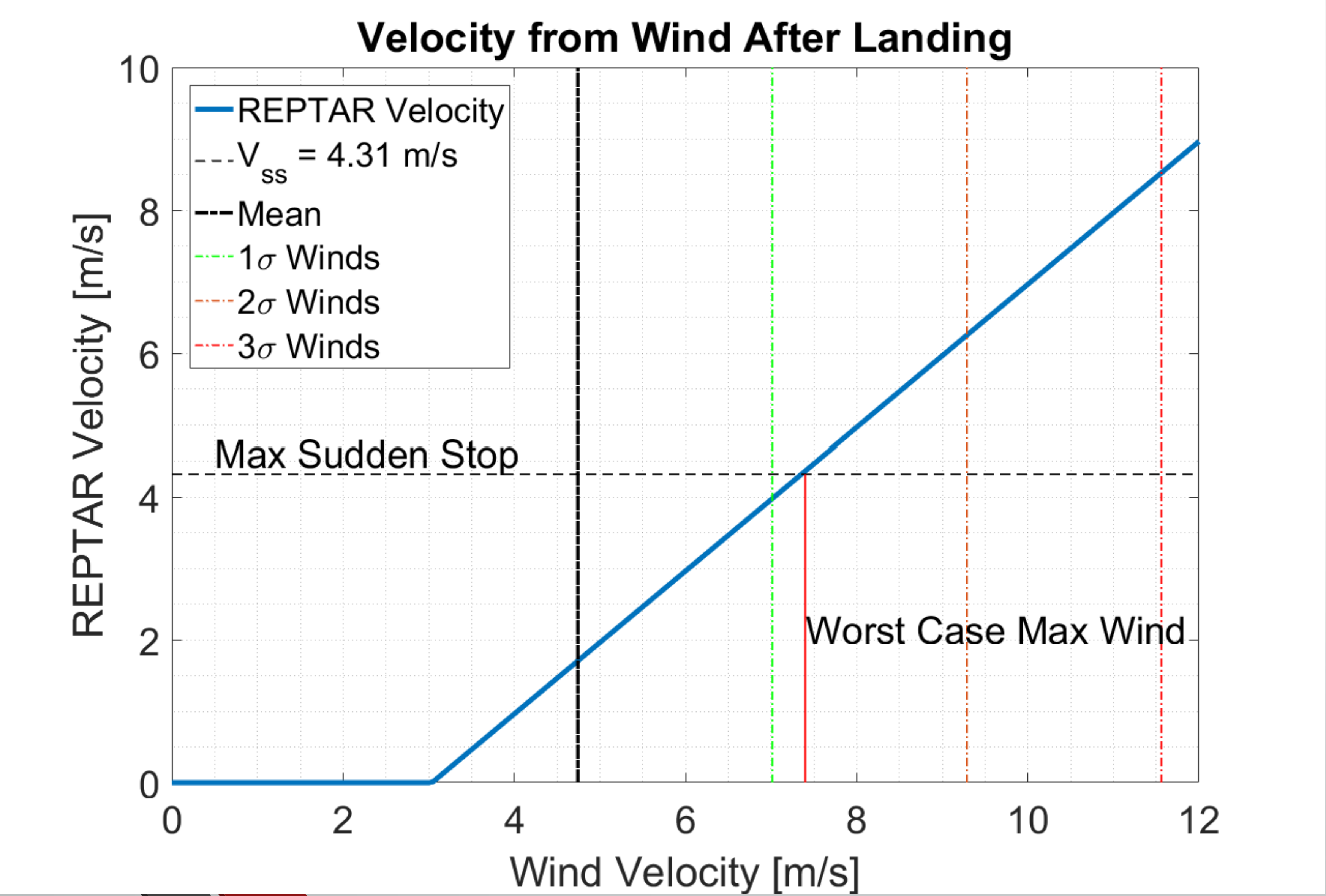


Coefficient of friction assumed: $\mu = 0.3$

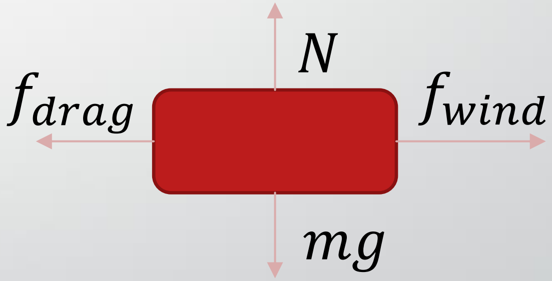
V_w Wind Velocity

V_b REPTAR Velocity

Chute

$$f_{drag} = \mu N$$

$$f_{wind} = .5\rho C_d A(V_w - V_b)^2$$

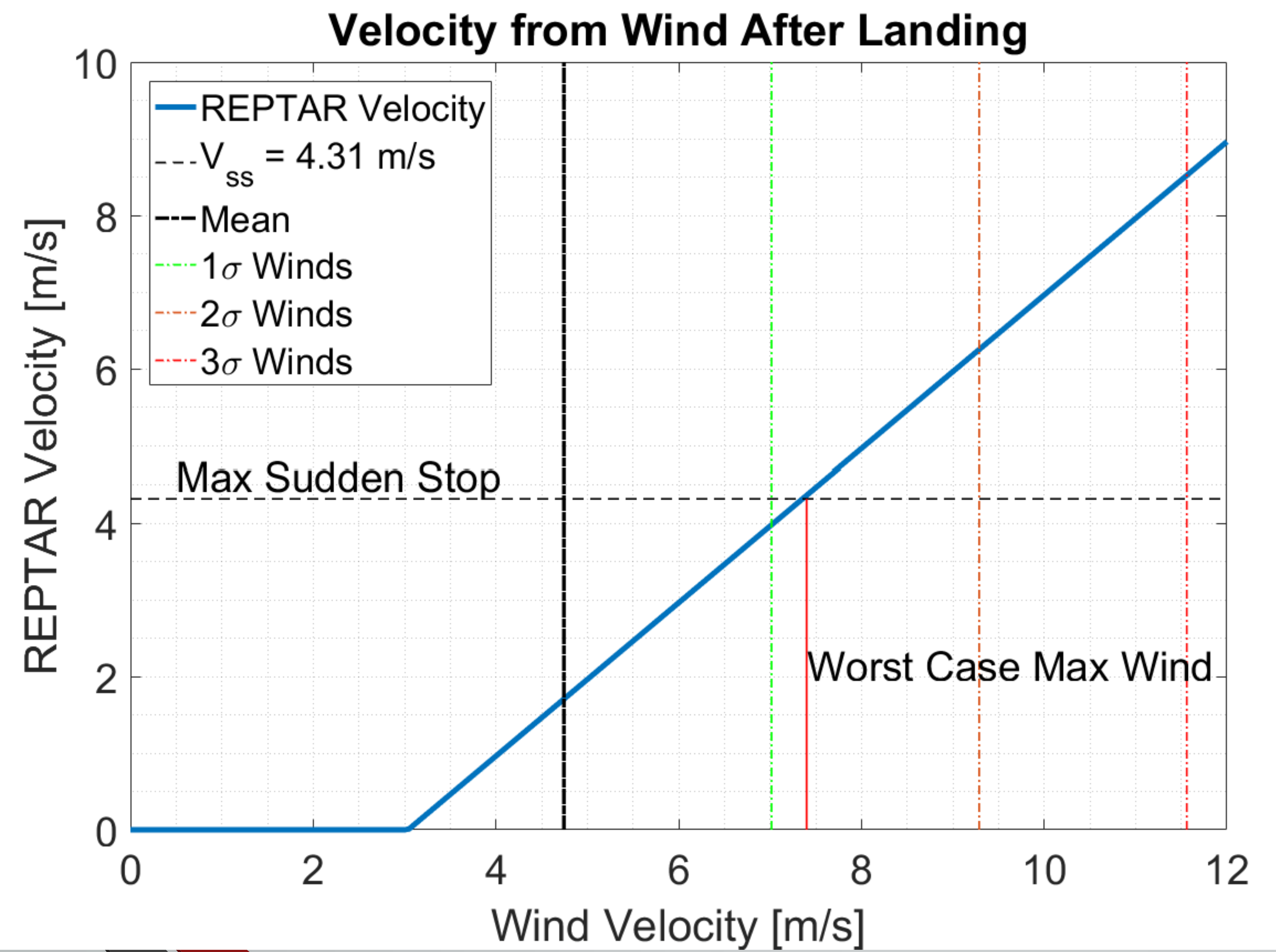


$$V_{w,max} = \sqrt{\frac{2f_{drag}}{C_d A\rho}} + V_{b,max}$$

Removal of Parachute Release Requirement

REPTAR

Raytheon



- Assumptions:
  - $\mu = 0.3$ Sudden stop means full deceleration in 0.011s.
  - Fully inflated chute
  - All horizontal force components
- Rationale:
  - Unlikely to accelerate consistently to reach sudden stop speed.
  - Added complexity in design, power, mass, volume constraints
  - More than 70% of wind measurements less than theoretical maximum

Landing Pre-Mitigation Risk Assessment

REPTAR

Risk	Description
RL1: Deployment Timing	Early plate deployment can harm parachute while late deployment may not allow landing system to be deployed in time
RL2: Bottom Leg Locking	If legs are not locked into position they may fold upon impact reducing absorption capabilities
RL3: Side Panel Orientation	If panels are not oriented properly absorption capabilities are reduced or lost

		Severity				
		1	2	3	4	5
Likelihood	5 (Very High)					
	4 (High)					
	3 (Moderate)					RL2,RL3
	2 (Low)					RL1
	1 (Very Low)					

Landing Post-Mitigation Risk Assessment

REPTAR

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Risk	Mitigation
RL1: Deployment Timing	CDH does not allow deployment before chute deployment. Redundant/excessive behavior. Contact sensors
RL2: Bottom Leg Locking	Compression springs lock a slotted pin
RL3: Side Panel Orientation	Torsion springs that exceed expected Drag Force

		Severity				
		1	2	3	4	5
Likelihood	5 (Very High)					
	4 (High)					
	3 (Moderate)					
	2 (Low)					RL3
	1 (Very Low)					RL1,RL2

1. Deployment Timing

- Severity: 5 Likelihood: 2 Total: 10
- Early plate deployment can harm parachute while late deployment may not allow landing system to be deployed in time
- Source of Mitigation: CDH Timing Sequence
- After Mitigation:
  - CDH does not allow deployment before chute deployment. Redundant/excessive behavior. Contact sensors
- Post Mitigation Severity: 5 Likelihood: 1 Total: 5

2. Bottom Leg Locking

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- Severity: 5 Likelihood: 3 Total: 15
- After deploying, and upon impact, the legs may fold, reducing impact absorption capabilities
- Source of Mitigation: Compression Spring System
- Before Mitigation:
  - Use torsion spring with large enough torsion to overcome horizontal drag forces
- After Mitigation:
  - Using compression springs and slotted pins for rotation, compression springs will insert into pins for a redundant locking mechanism
- Post Mitigation Severity: 5 Likelihood: 1 Total: 5

3. Side Panel Orientation

- Severity: 5 Likelihood: 3 Total: 15
- After deployment, the walls may over rotate or under rotate to not impact the aluminum foam directly causing higher G-Loadings not under requirements
- Source of Mitigation: Torsion Springs/Lip Outside Panel
- After Mitigation:
  - Torsion spring will push panel into the lip created from manufacturing to orient the panel perpendicular to the side walls of the system
- Post Mitigation Severity: 5 Likelihood: 2 Total: 10

Torsion Spring Calculations

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- Torque required to deploy the base legs and the side panels is calculated using the Drag Force from the descent through the atmosphere
- Force of Drag, $F_d = \frac{1}{2}\rho V^2 A C_d$
- Moment, $M = F_d \times l$ where l is the length dimension of the legs (7.3 cm) and side panels (12.5)
- $c_d = 2.02$, used as a worst case scenario for a flat plat straight into the wind
- $A_{Base\ Leg} = 7.3\ cm \times 1.2\ cm$ for undeployed legs into direct velocity
- $A_{Side\ Panel} = 12.5\ cm \times 6.14\ cm$ for fully deployed panels into direct velocity
- $\rho = 0.8191, 0.8543, 1.0065, 1.112\ kg/m^3$ for altitudes of 4000, 3600, 2000, and 1000 m, respectively
- $V = 100, 90, 6.3\ (with\ chute)\ m/s$ for various terminal velocities at altitudes as well as expected landing speeds reached following chute deployment

Torsion Spring Calculations (cont'd)

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- From Drag Force calculations:
  - Moment required for base legs to deploy:
    - $M(4000\,m) = 1.058\,N\,m = 9.36\,in\,lbs$
    - $M(3600\,m) = 0.894\,N\,m = 7.92\,in\,lbs$
    - $M(2000\,m)_{\frac{w}{o}chute} = 1.054\,N\,m = 9.32\,in\,lbs$
    - $M(2000\,m)_{w/chute} = 0.0056\,N\,m = 0.04\,in\,lbs$
  - Moment required for side panels to deploy:
    - $M(4000\,m) = 7.446\,N\,m = 65.90\,in\,lbs$
    - $M(3600\,m) = 6.290\,N\,m = 55.67\,in\,lbs$
    - $M(2000\,m)_{w/o\,chute} = 7.411\,N\,m = 65.59\,in\,lbs$
    - $M(2000\,m)_{w/chute} = 0.036\,N\,m = 0.343\,in\,lbs$

Torsion Spring Selections

- McMaster Carr Torsion Springs:

Item	Deflection Angle	Outside Diameter	Leg Length	Max Rod OD	Torque (in-lbs.)	Torque (in-lbs.) w/cut down legs
Base Leg Springs	90°	0.560”	2.000”	0.343”	5.518	1.9313 (0.7” legs)
Side Panel Springs	180°	0.304”	1.25”	N/A	1.070	0.642 (0.75” legs)

Epoxy Data for Mounting (Landing)

- Torr Seal Vacuum Epoxy
  - ThorLabs, Inc.
    - Price: $84.70 for 2.9 oz resin and 1.3 oz hardener
    - Total Mass Loss (TML): 0.63%
    - Collected Volatile Condensable Material (CVCM): 0.01%
  - NASA Standards for Outgassing
    - TML ≤ 1.0%
    - CVCM ≤ 0.1%

Landing Mounting Interfaces

- Aluminum and Steel cannot be welded together
- Due to shape of spring legs, pinning down is subject to sliding
- Due to these interface problems, an epoxy will be used for mounting of system components that aren’t screwed in or those that need to remain inert
- Torr Seal Vacuum Epoxy
  - ThorLabs, Inc.

Heated Kanthal Coil Test: Increasing Voltage

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- For this test, the voltage was increase until the coil heated enough to cut the nylon line. The Voltage and Current at which this occurred was recorded.
- This was a proof of concept test, high accuracy was not needed, rather the gather voltage and current proves the concept will work for the chosen battery.

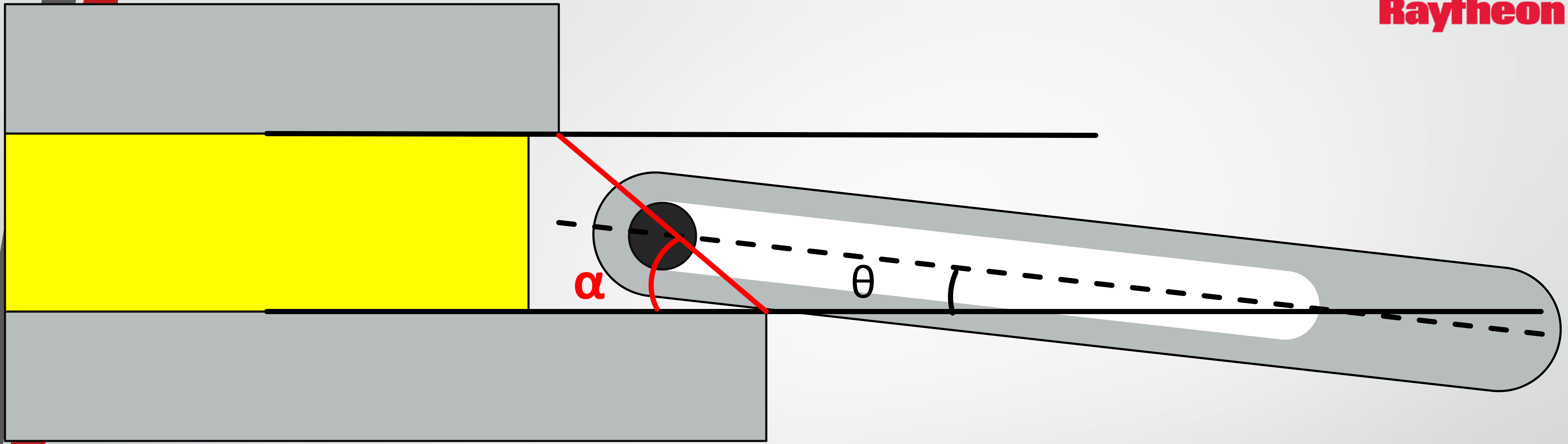
	Cold Resistance (Ohms)	Voltage at Break (V)	Current at Break (amps)
Coil 1	.20	1.8	2.5
Coil 2	.82	2.1	2.2

Heated Kanthal Coil Test: Constant Voltage

- For this test, the voltage was made constant at 3.3 volts. The time and current at which the nylon broke were recorded.
- This was a proof of concept test, high accuracy was not needed, rather the time and current recorded, proves the concept will work for the chosen battery and will occur in a timely manner compatible with REPTAR

	Voltage (V)	Current at Break (amps)	Time (sec)
Coil 1	3.3	4.7	<1
Coil 2	3.3	3.7	<1

Side Panel Orientation Verification



- $\theta \leq \alpha$, this process allows for proper insertion of the aluminum side panel into the foam without impacting the frame components directly
- Becomes a tolerance of manufacturing and pin placements
- Through trigonometry pin must be placed within 0.1 mm accuracy

Landing Volume Budget

REPTAR

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Item	Volume (cm^3)
Leg Pins x2	2.47 ea.
Leg Springs x2	0.42 ea.
Base Locking x2	0.036 ea.
Base Legs x4	20.17 ea.
Base L-Brackets x8	0.28 ea.
Base Mounting Plate	19.27
Base Deployment Plate	8.05
Spring Attachment x2	0.18 ea.

Item	Volume (cm^3)
Side Panel Springs x4	0.12 ea.
Side Panel Pins x8	0.02 ea.
Side Panels x4	8.47 ea.
Side Panel Foam x2	29.04 ea.
Foam Divider Plate x2	6.57 ea.
Wire L-Brackets x10	0.013 ea.
Center Mounting Plate	17.70
Small Spring Attachment x2	0.07 ea.

Item	Volume(cm^3)
LANDING SYSTEM TOTAL	**239.84**

Screws are internal so do not take up volume, just mass

Landing Mass Budget

REPTAR

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Item	Mass (g)
Leg Pins x2	19.03 ea.
Leg Springs x2	3.31 ea.
Base Locking x2	0.17 ea.
Base Legs x4	16.25 ea.
Base L-Brackets x8	0.95 ea.
Base Mounting Plate	52.22
Base Deployment Plate	21.82
Spring Attachment x2	0.49 ea.
Steel Screws x12	0.2 ea.

Item	Mass (g)
Side Panel Springs x4	0.92 ea.
Side Panel Pins x8	0.18 ea.
Side Panels x4	22.94 ea.
Side Panel Foam x2	9.44 ea.
Foam Divider Plate x2	17.82 ea.
Wire L-Brackets x10	0.04 ea.
Center Mounting Plate	47.70
Small Spring Attachment x2	0.19 ea.

Item	Mass (g)
LANDING SYSTEM TOTAL	**394.92**

Landing Cost Budget

REPTAR

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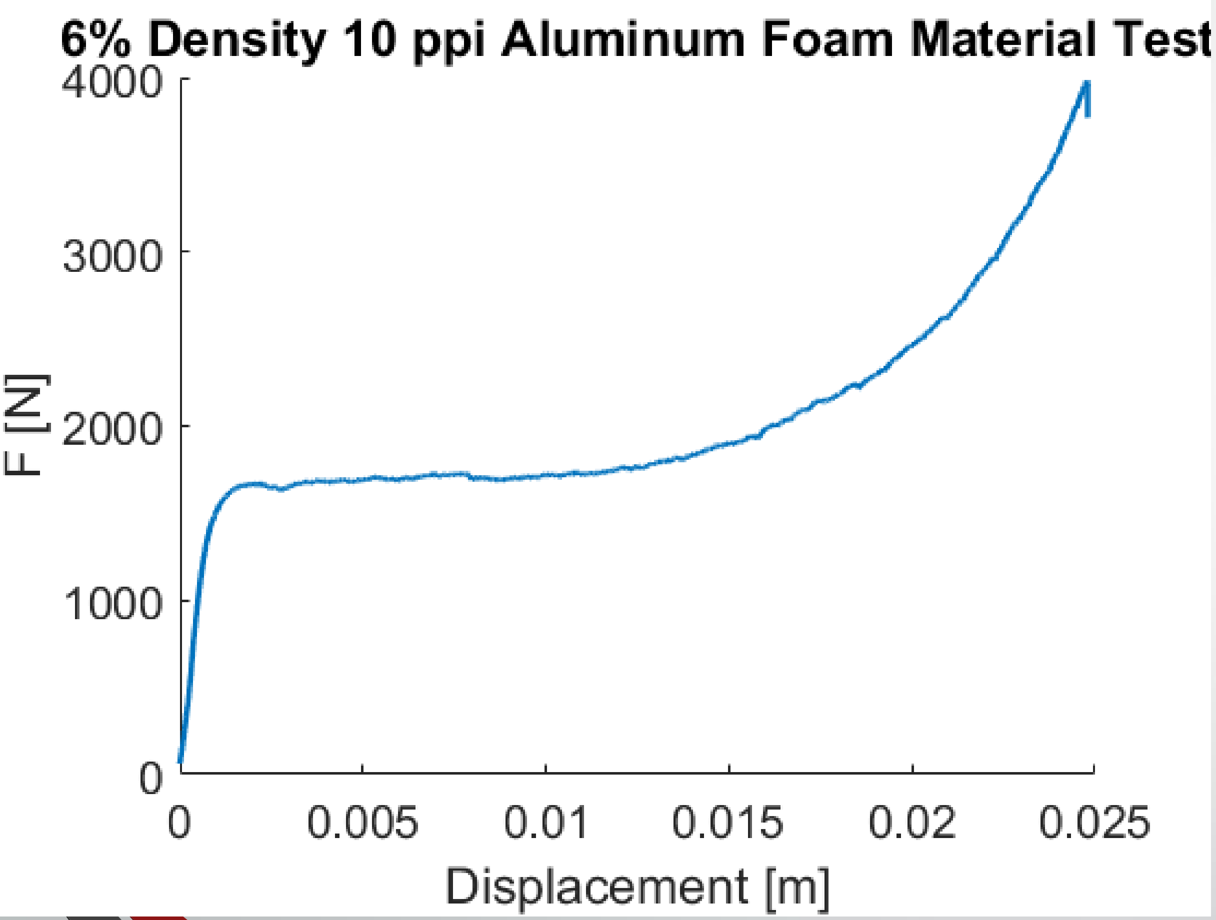
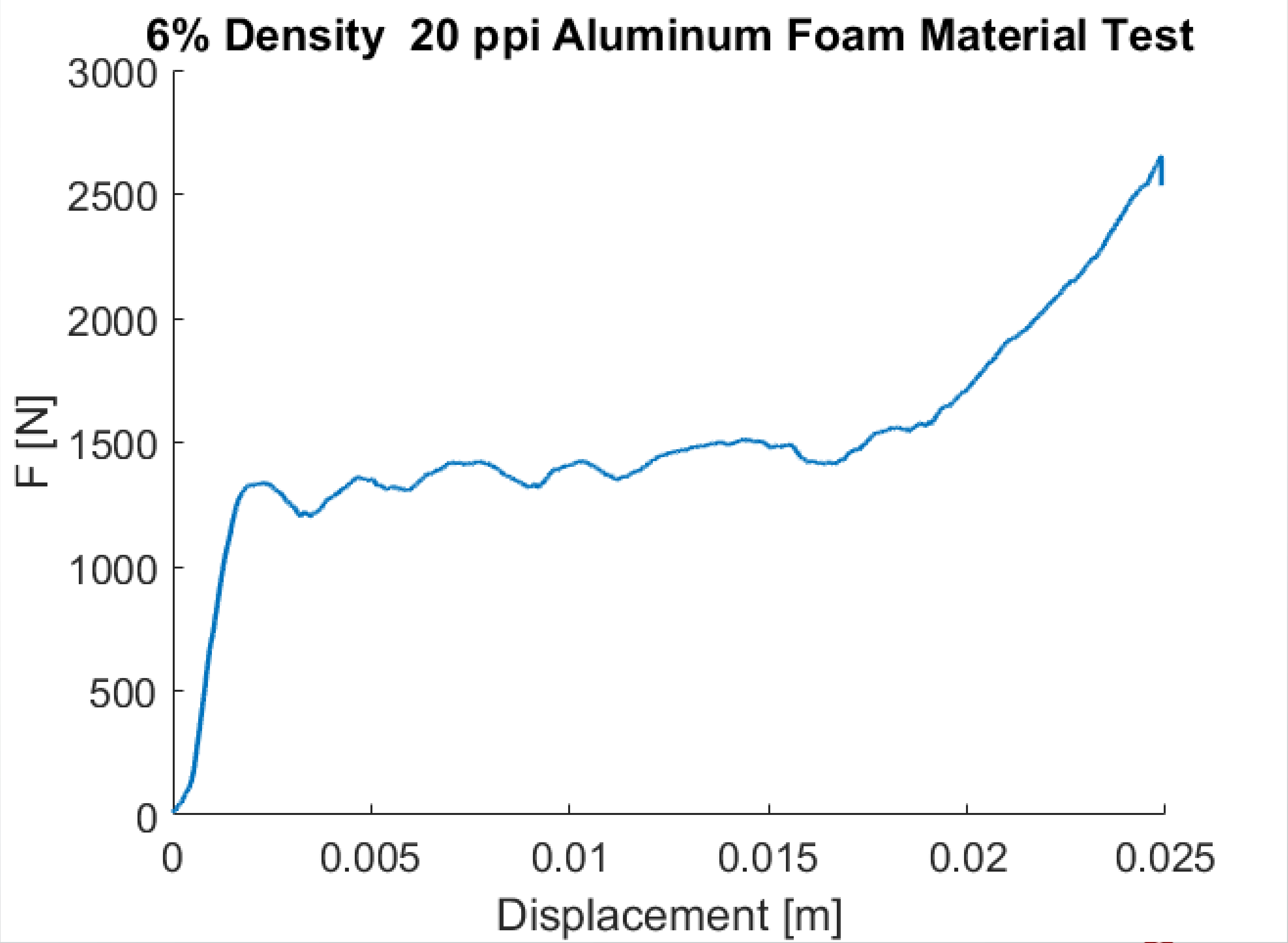
Item	Pkg. Qty. (if specified)	Number of Pkgs. needed	Part Number	Pkg. Price	Total Price
McMaster Carr					
Slotted Spring Pin	10	1	92383A777	$8.97	$8.97
Flat Headed Pin	1	16	98378A211	$4.97	$79.52
Base Leg Torsion Spring	6	2	9271K620	$7.81	$15.62
Side Panel Torsion Spring	6	2	9271K603	$5.01	$10.02
Base Leg Compression Spring	3	2	9001T15	$5.03	$10.06
ThorLabs, Inc.					
Vacuum Epoxy	1	1	TS10	$84.70	$84.70

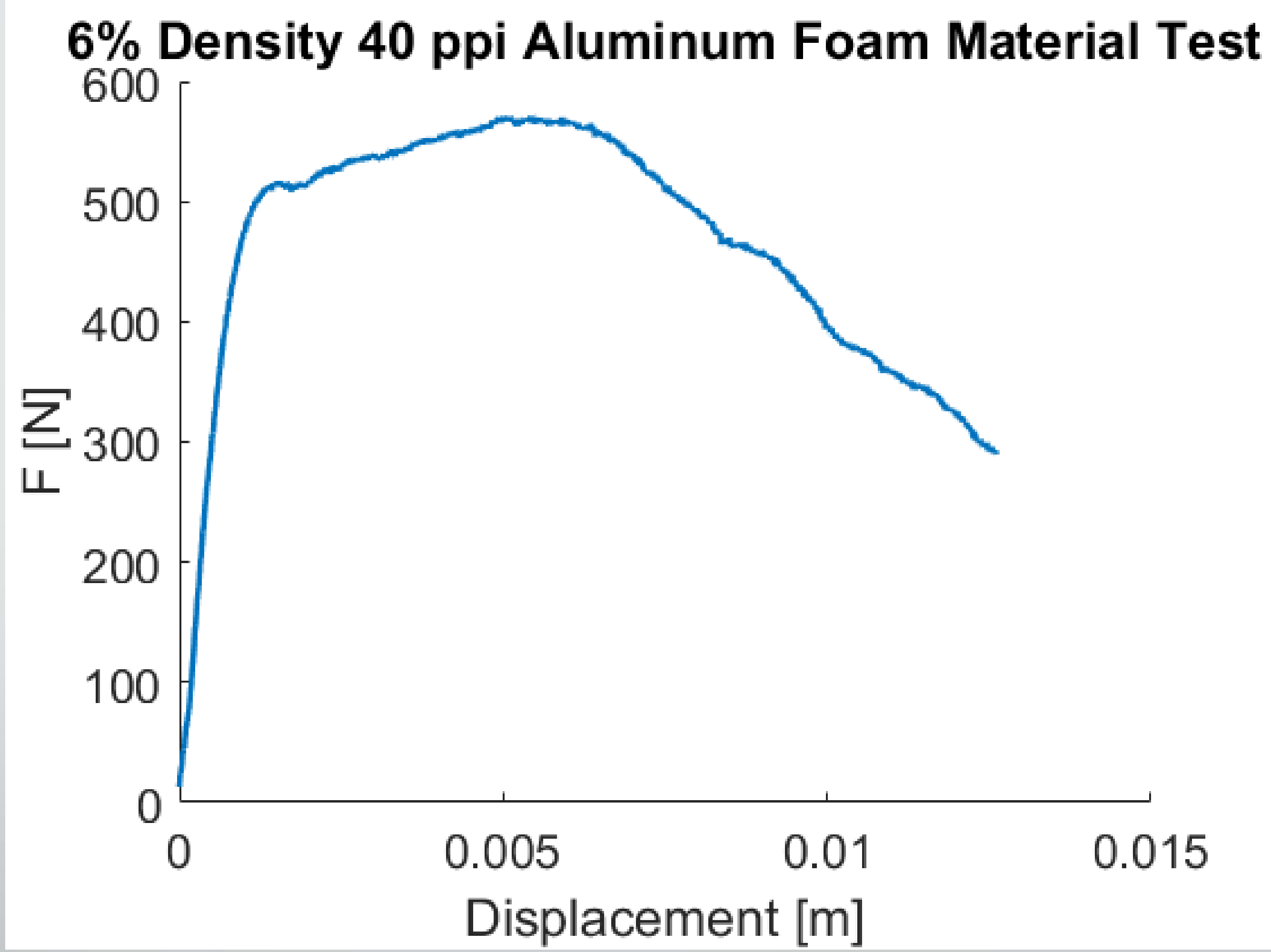
Aluminum Foam Test





Aluminum Foam Test

REPTAR
Raytheon



Base Leg Material Change

- Change from Duocel Aluminum Foam → Duocel Copper Foam
- Duocel Aluminum Foam Compression Strength: 2.07 MPa

Material Characteristic	Value	Expected Upon Landing	Margin
Relative Density	9%	-	-
Compression Strength	1.08 MPa	-	-
Energy Absorbed	61.06 J	58.3 J	2.76 J
Max Loading	34.3 G's	40 G's Max	5.7 G's

- Allows for more surface area to be utilized to make the legs larger

Avionics Mass Budget

Item	Mass (g)
GPS Antenna	80
Iridium Antenna	80
Battery	200
RockBlock	76
Aluminum Base Plate	20.82
Custom Board	60
Screws x4	0.2

Item	Mass (g)
AVIONICS SYSTEM TOTAL	**517.62**

CDH Error Stackup

REPTAR

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Calculate temperature compensated pressure						
OFF	Offset at actual temperature [3] $OFF = OFF_{T1} + TCO * dT = C2 * 2^{17} + (C4 * dT) / 2^6$	signed int 64	41	-17179344900	25769410560	5764707214
SENS	Sensitivity at actual temperature [4] $SENS = SENS_{T1} + TCS * dT = C1 * 2^{16} + (C3 * dT) / 2^7$	signed int 64	41	-8589672450	12884705280	3039050829
P	Temperature compensated pressure (10…1200mbar with 0.01mbar resolution) $P = D1 * SENS - OFF = (D1 * SENS / 2^{21} - OFF) / 2^{15}$	signed int 32	58	1000	120000	110002 = 1100.02 mbar

Resolution RMS	OSR	4096		0.024		mbar
		2048		0.036		
		1024		0.054		
		512		0.084		
		256		0.130		

$$p_{res} = (0.01 + 0.024)\text{ mbar} = 3.4\text{ Pa}$$

Standard Atmosphere Model

$$h_{res} = 0.6679\text{ m} \approx 0.7\text{ m}$$

CDH Error Stackup

ANALOG DIGITAL CONVERTER (ADC)

Parameter	Symbol	Conditions		Min.	Typ.	Max	Unit
Output Word					24		bit
Conversion time	t_c	OSR	4096	7.40	8.22	9.04	ms
			2048	3.72	4.13	4.54	
			1024	1.88	2.08	2.28	
			512	0.95	1.06	1.17	
			256	0.48	0.54	0.60	

$$h_{update} = t_{sample}V_{max} = (9.04 \times 10^{-3})(89) = 0.8046\text{ m} \approx 0.8\text{ m}$$

CDH Error Stackup

Parameter	Symbol	Conditions	Min.	Typ.	Max	Unit
Serial data clock	SCLK	SPI protocol			20	MHz
		I^2C protocol			400	KHz

$$h_{trans} = \frac{1}{f_{I^2C}} V_{max} = (2.5 \times 10^{-6})(89) = 2.2 \times 10^{-4}\text{m} \approx 0$$

CDH Error Stackup

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Step	Calculations	Cycles	Time [ms]
Read Pressure	N/A	N/A	0
Read Temperature	N/A	N/A	0
Calculate Temperature	3 Multiplication 3 Addition	321 Multiplication 12 Addition	2.07
Calculate Comp. Pressure	10 Multiplication 7 Addition	1070 Multiplication 28 Addition	6.8
Store Result	N/A	N/A	0
Calculate Altitude	2 Multiplication 2 Addition	114 Multiplication 8 Addition	0.76
Operation Cycles	Addition: 4	Multiplication: 107	N/A
Clock Frequency	14 MHz	N/A	N/A
Clock Period	6.2 ns	N/A	N/A
Total	N/A	N/A	9.63

$$h_{calc} = t_{calc}V_{max} = (9.63 \times 10^{-3})(89) = 0.8572\ \text{m} \approx 0.9\text{m}$$

CDH Error Stackup

2.1.4 Calculate and Display the Altitude (inside the loop)

Calculating the altitude h using directly the formula

$$h = \frac{288.15}{0.0065} \cdot \left(1 - \left(\frac{p}{101325}\right)^{0.0065 \cdot \frac{R}{g}}\right)$$

is too complicated for a 4 or 8 Bit microcontroller, because it would require extensive floating point calculation. Instead Intersema has developed a simple formula based on a linear piecewise approximation which will give a maximum error of +/- 5 meters between –700 and 9000 meters, and a maximum error of +/- 10m between 9000 and 16000 meters. The idea of this formula is to build the two models of the troposphere and the stratosphere out of linear segments with coefficients allowing calculations without floating

Pre-Mitigation Risk Assessment

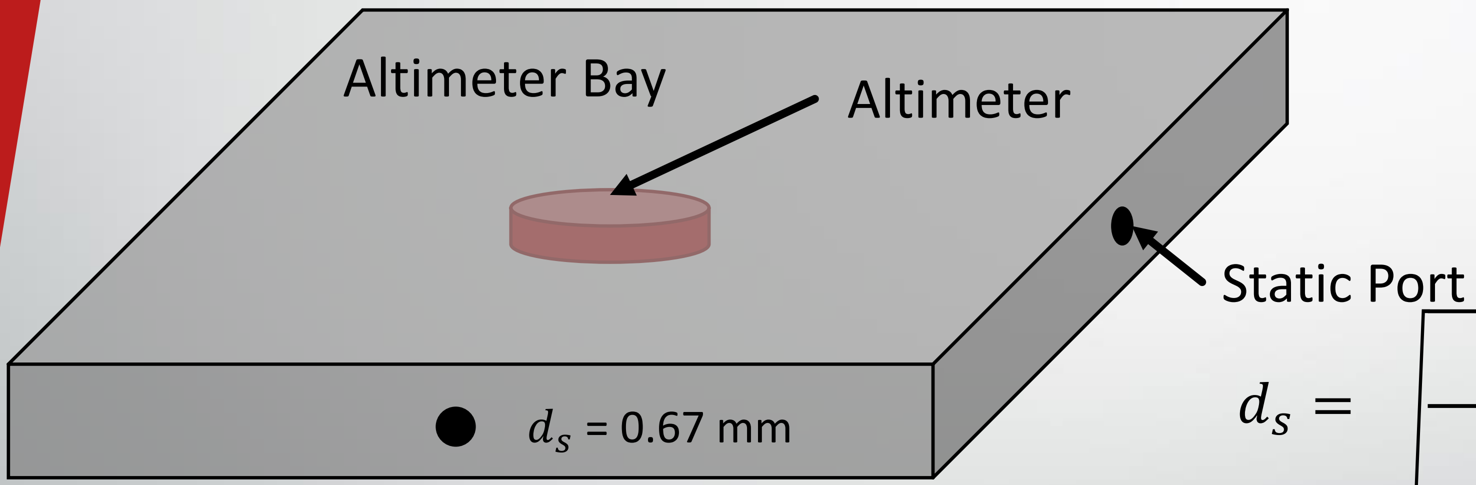
Risk	Description
RA1: CDH Lockup	CDH will have operation flags to ensure proper sequencing. If conditions are not detected properly operations will not be performed
RA2: Mounting and Interfacing	Avionics must interface with all deployments
RA3: Antenna Placing	Antennas must be mounted to ensure communication
RA4: Altimeter Error	Due to speed of travel dynamic pressure error can arise
RA5: Battery Management	Make sure it does not blow up

Altimeter Bay Static Port Sizing

Design ports to allow altimeter bay to equilibrate with ambient pressure for accurate altimeter readings. Minimize large currents and dynamics pressure effects

$$V = l \cdot w \cdot h$$
$$n = 4$$

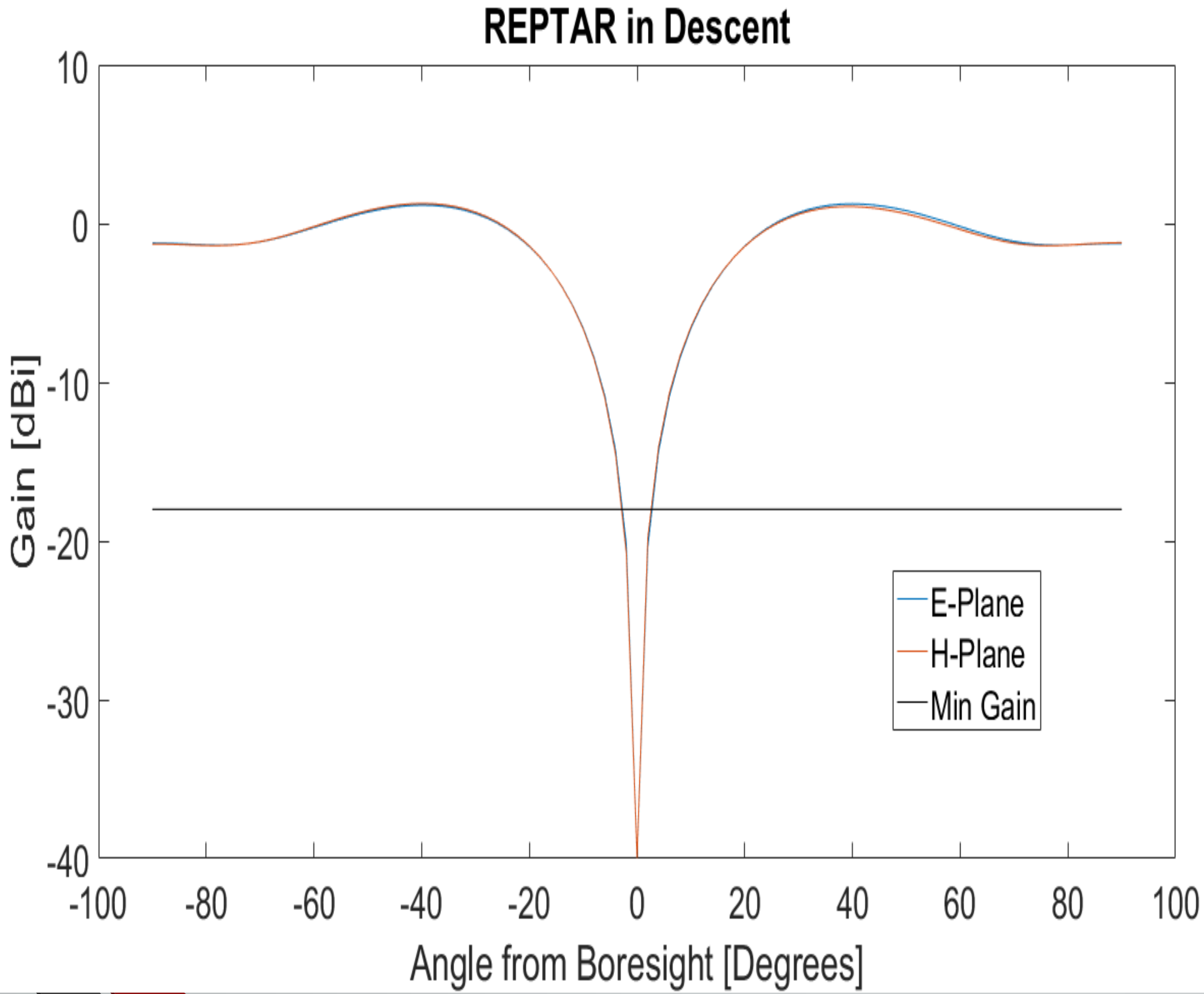
$c = 0.62$, discharge coefficient for sharp-edged orifices in thin plates



$$\dot{m} = \frac{V\rho\left(\frac{P-P_A}{P}\right)}{t}$$

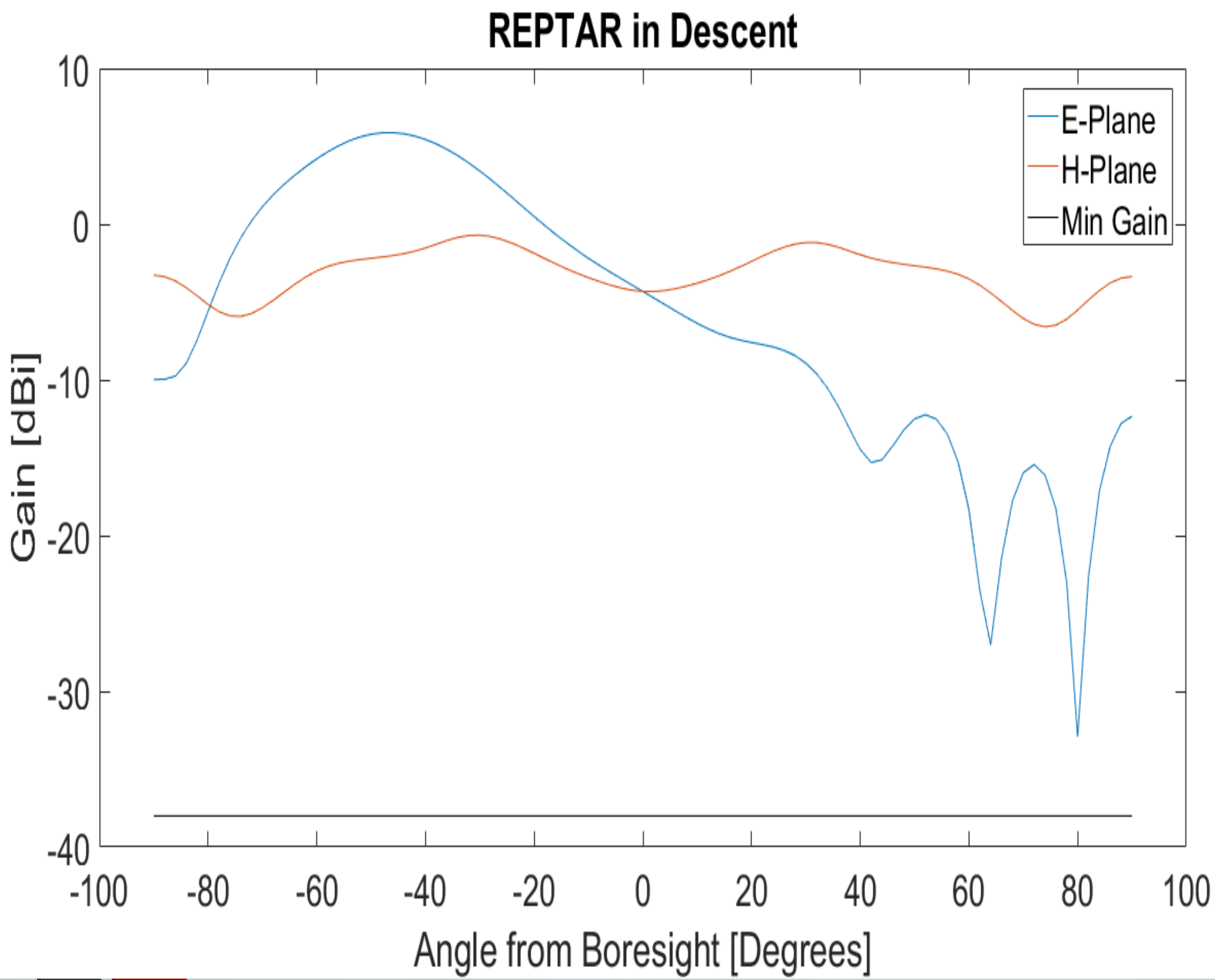
$$d_s = \sqrt{\frac{4\dot{m}}{\pi n c\sqrt{2\rho\left(\frac{\gamma}{\gamma-1}\right)\left[\left(\frac{P_A}{P}\right)^{\frac{2}{\gamma}} - \left(\frac{P_A}{P}\right)^{\frac{\gamma+1}{\gamma}}\right]}}}$$

GPS Acquisition



	Signal Strength
Worst Case Incident Signal	-155 dBm
LNA Gain	28 dB
Receiver Minimum Acquisition Power	-145 dBm
Minimum Antenna Gain	-18 dBi

GPS Tracking



	Signal Strength
Worst Case Incident Signal	-155 dBm
LNA Gain	28 dB
Receiver Minimum Tracking Power	-165 dBm
Minimum Antenna Gain	-38 dBi

Regulator Power Issues

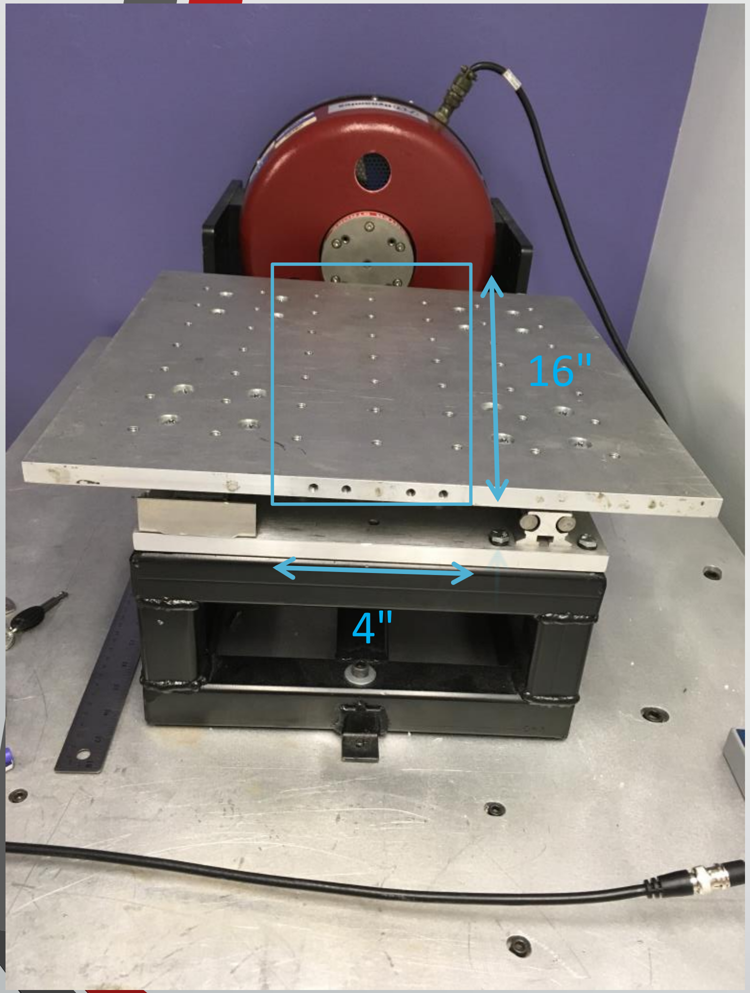
REPTAR

Regulator	Max Rated Junction Temp. [C]	Max Modelled Junction Temp. With Heatsink [C]	Thermal Resistance Without Heatsink [C/W]	Thermal Resistance With Heatsink [C/W]
3V3 Avionics	125	85	80	65
3V3 Burn Wire	125	100	45	36
12V Black Powder	125	115	50	16

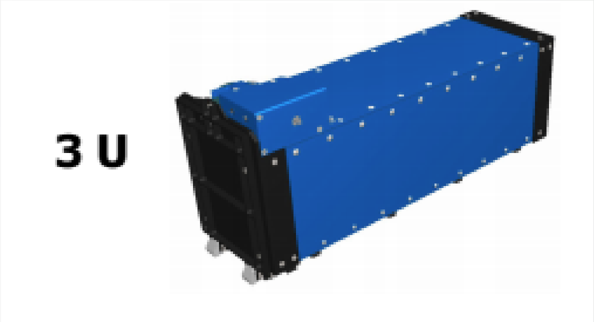
Assumptions

- FR4 4-Layer Board with 86 cm^2 Area
- 2 cm separation between regulators
- Dissipating 1 Watt in 3V3 Deployer Regulator takes 5 seconds (LT App Note for Regulator)

Launch Survivability Vibration Test Mounting



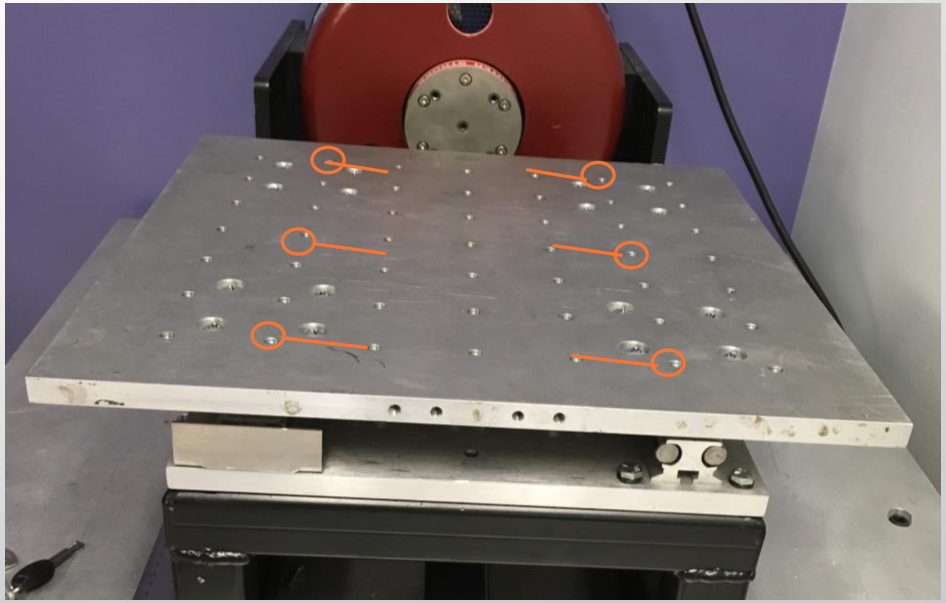
Mounting:
P-pod satellite interface: Mechanical interface with CubeSats by means of guiderails



Shaker:
3 L shaped brackets on each side.

Accelerometers Tentative Positon:

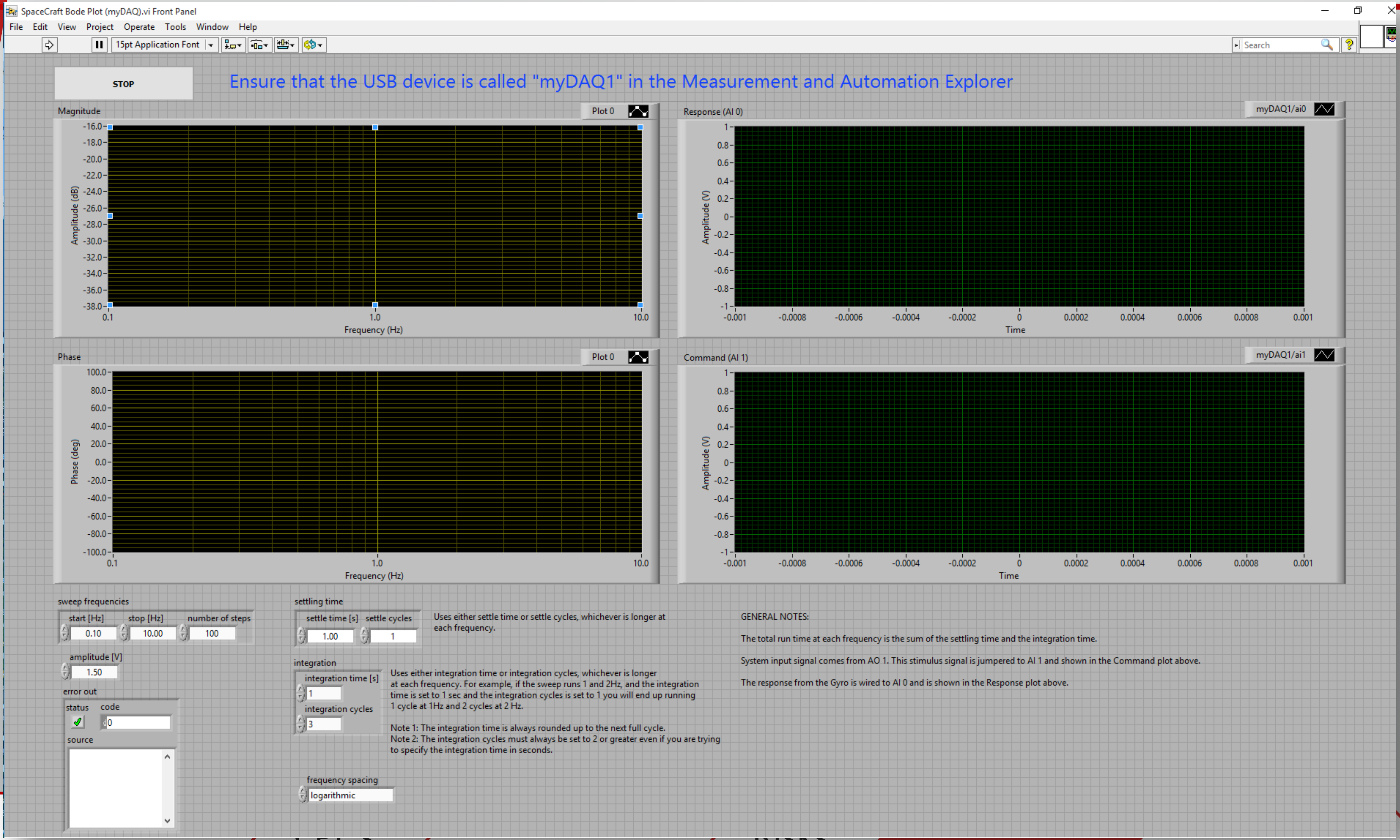
1. Initial
   - On the shaker table
   - On both ends of the CubeSat
2. Later (Initial + more)
   - Near the side panels
   - Near parachute canister



Launch Survivability Vibration Test LabView

REPTAR

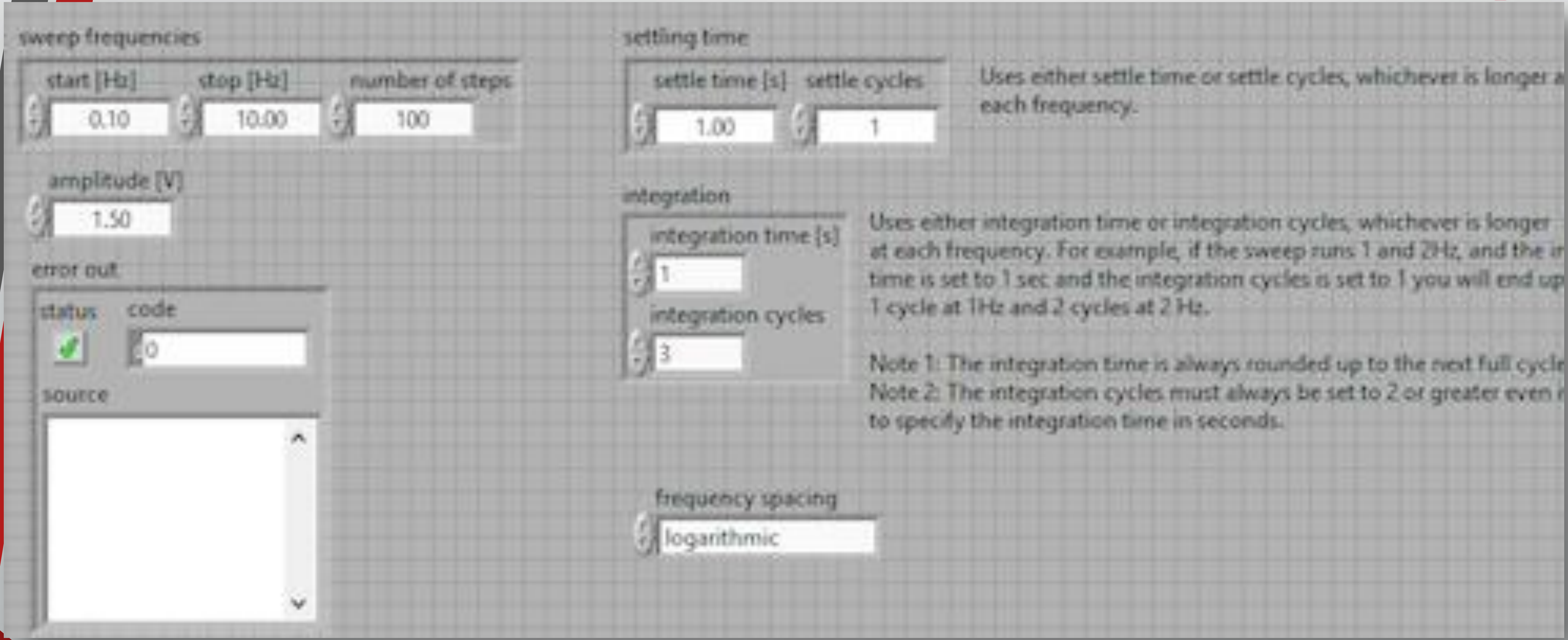
Raytheon



Launch Survivability Vibration Test LabView

REPTAR

Raytheon



Frame Mass Budget

REPTAR

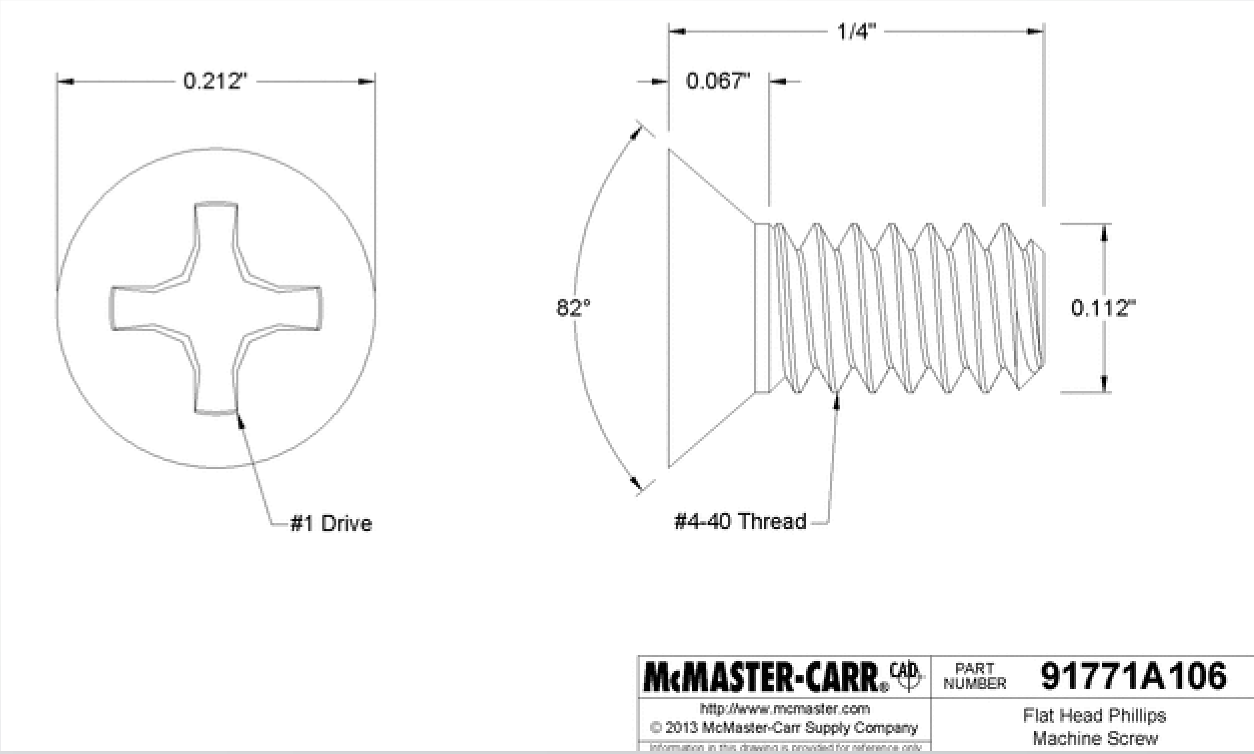
Raytheon

Item	Mass (g)
Rails x4	55.8
Short Side Panels x2	33.4
Long Side Panels x2	32.2
Short Upper Panel x2	18.4
Long Upper Panel x2	19.6
Screws x32	0.2

Item	Mass (g)
FRAME SYSTEM TOTAL	**436.8**

Screw Specifications

- 18-8 Stainless Steal Flat Head Phillips Screw
- #4-40, ¼ inch
- Can be purchased from McMASTER-CARR
- $3.75 for pack of 100

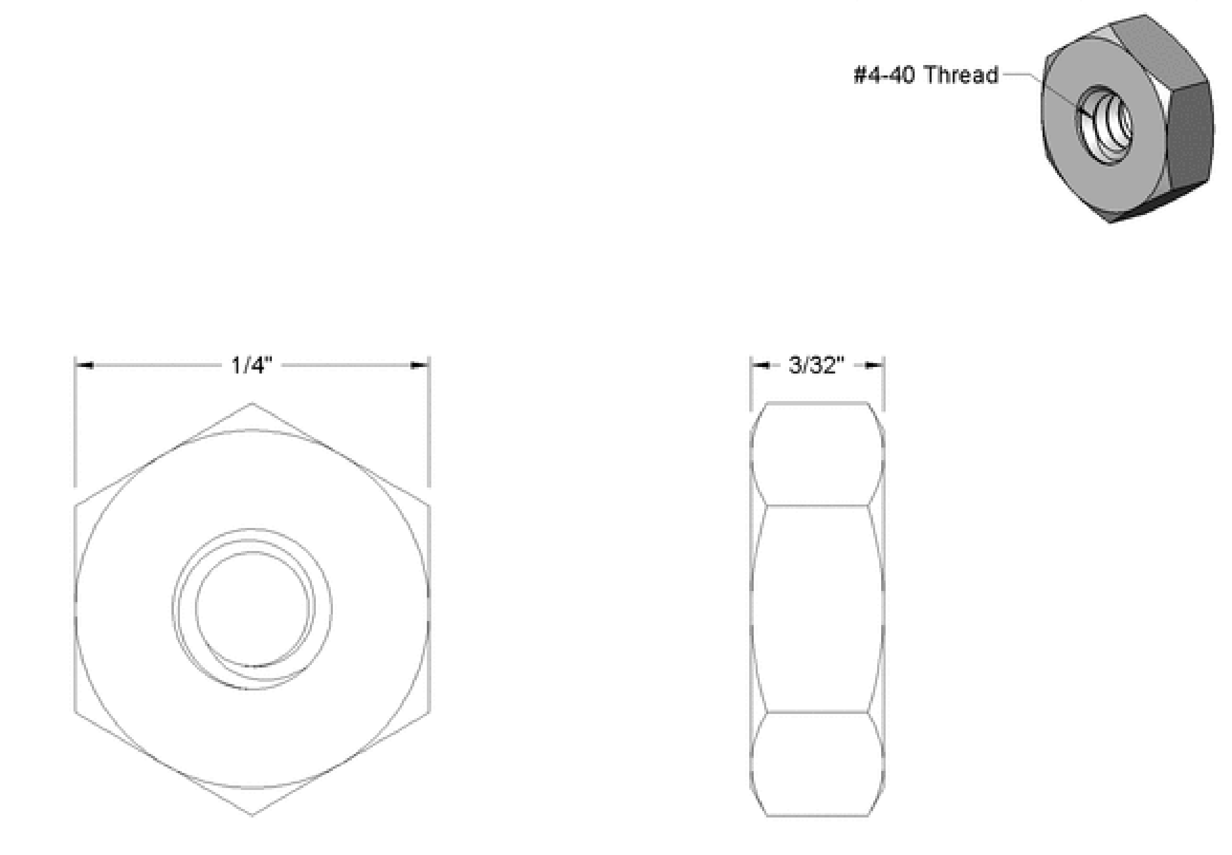


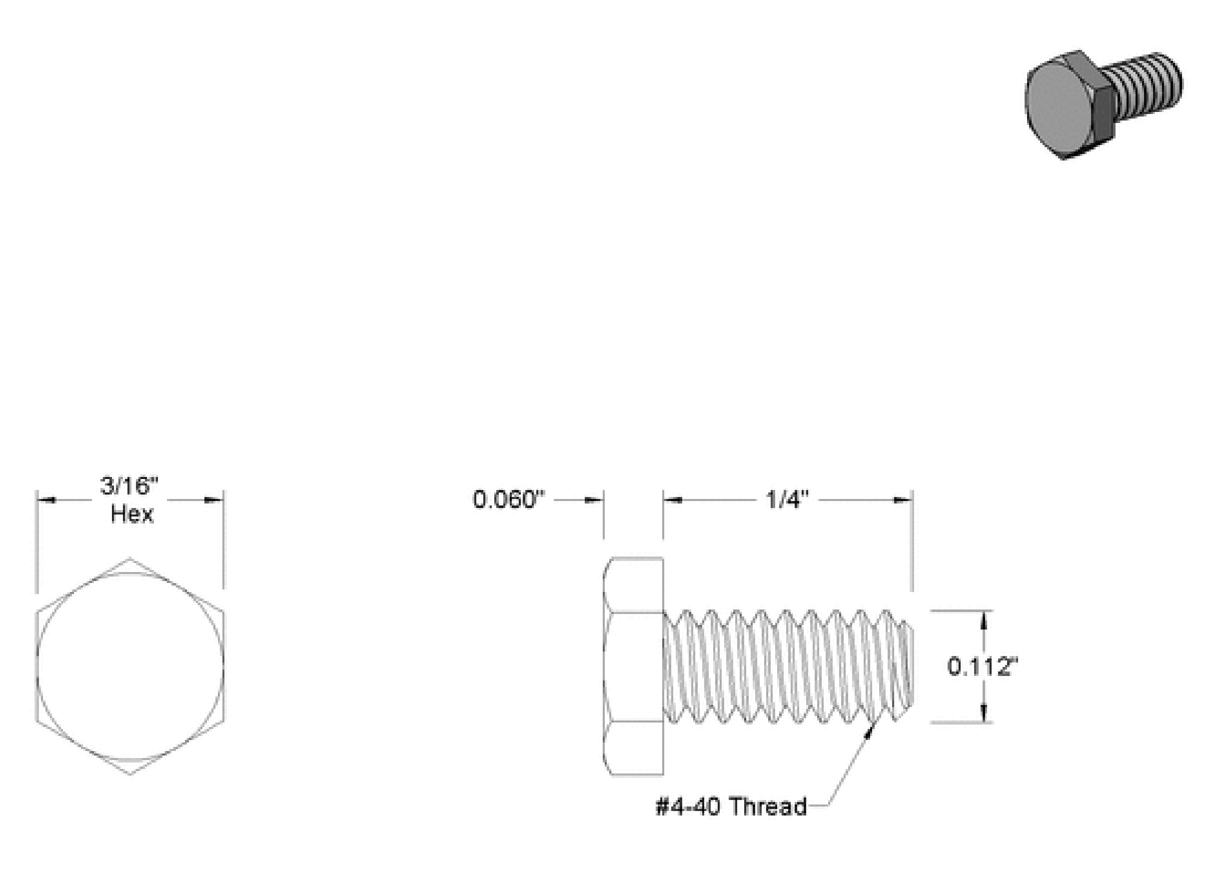
U-bolt Screw and Nut Selection

REPTAR

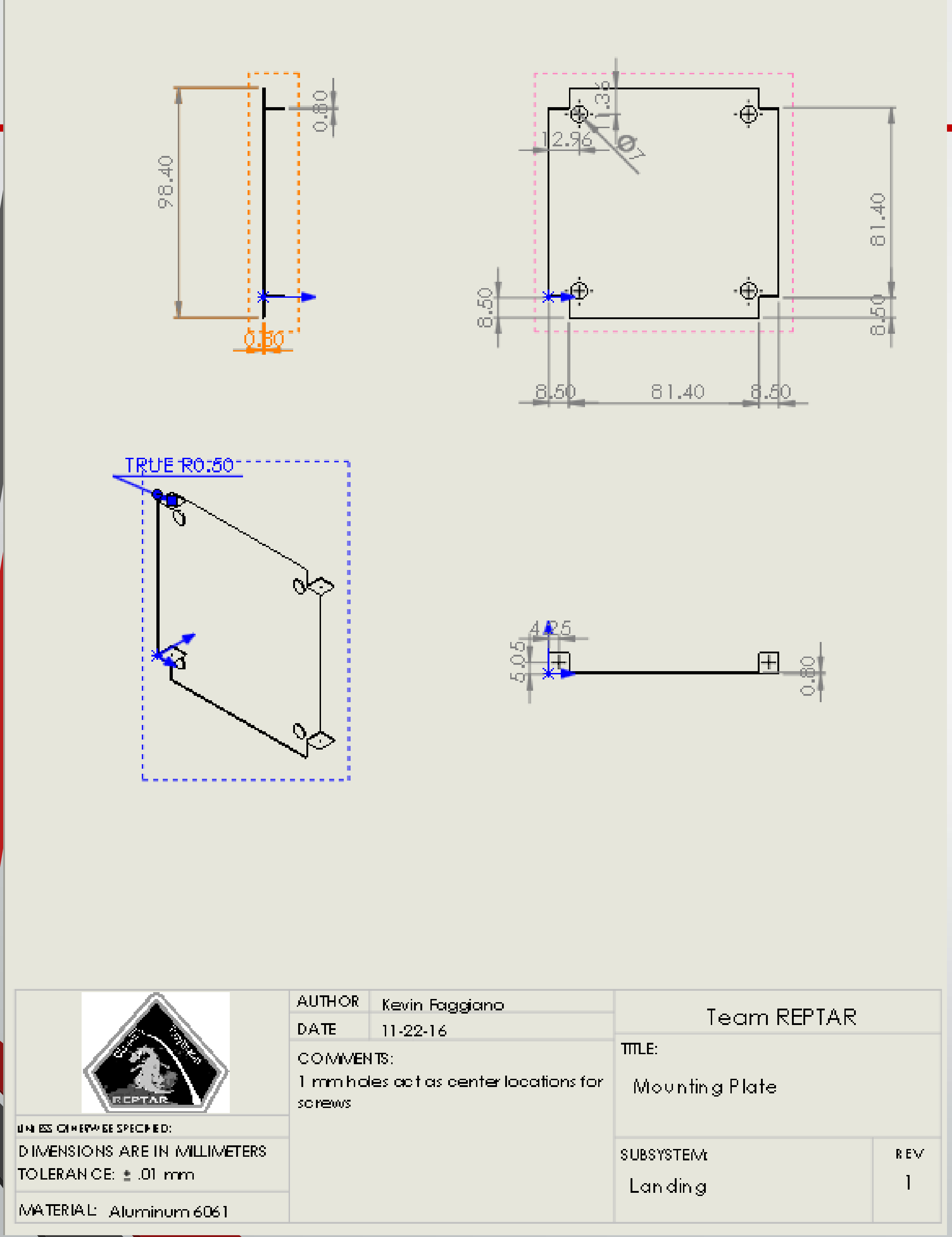
Raytheon

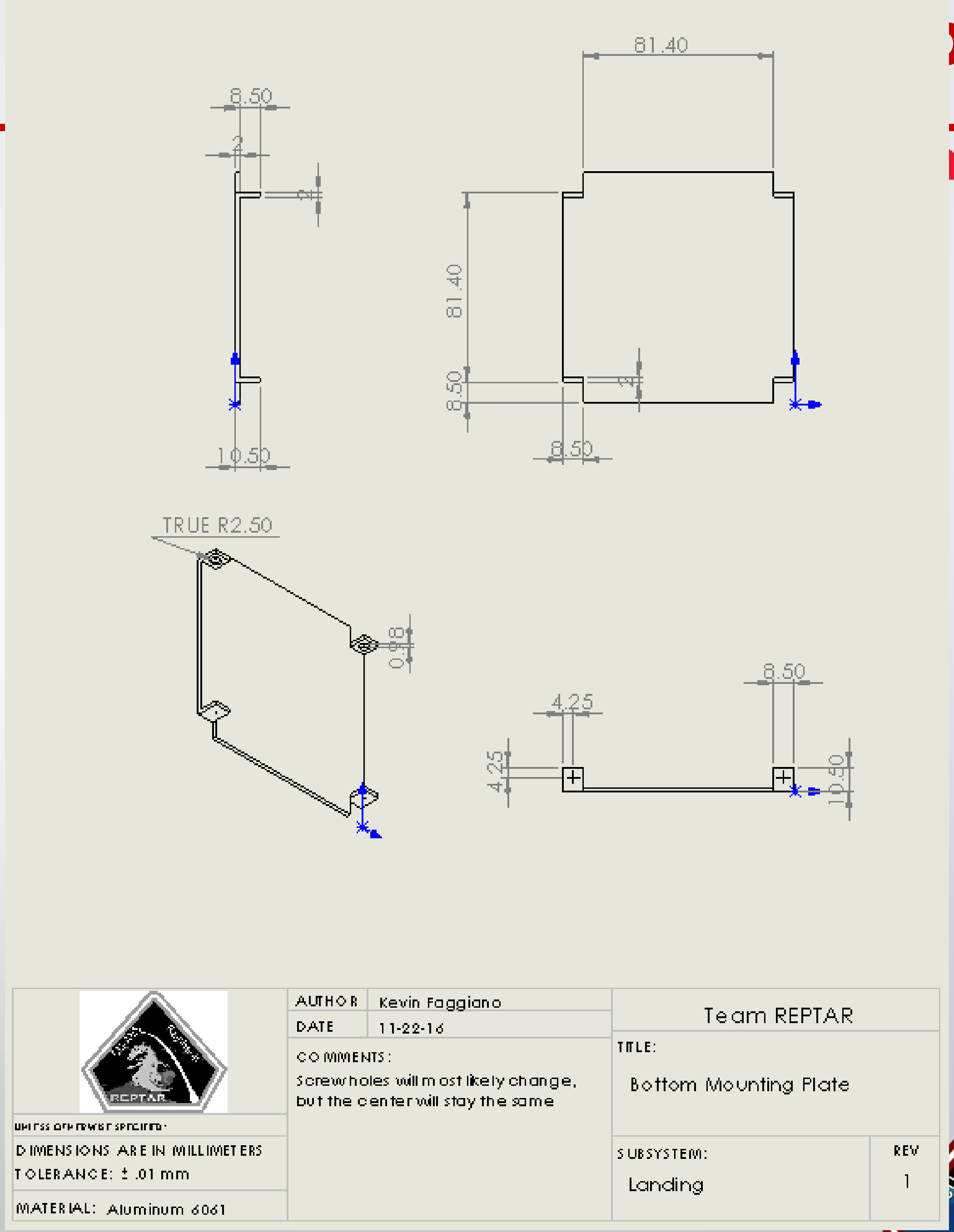
- 4-40, ¼ inch long screw
- .06 inch/1.5 mm head height allows it to fit in counterbore of 2mm plate

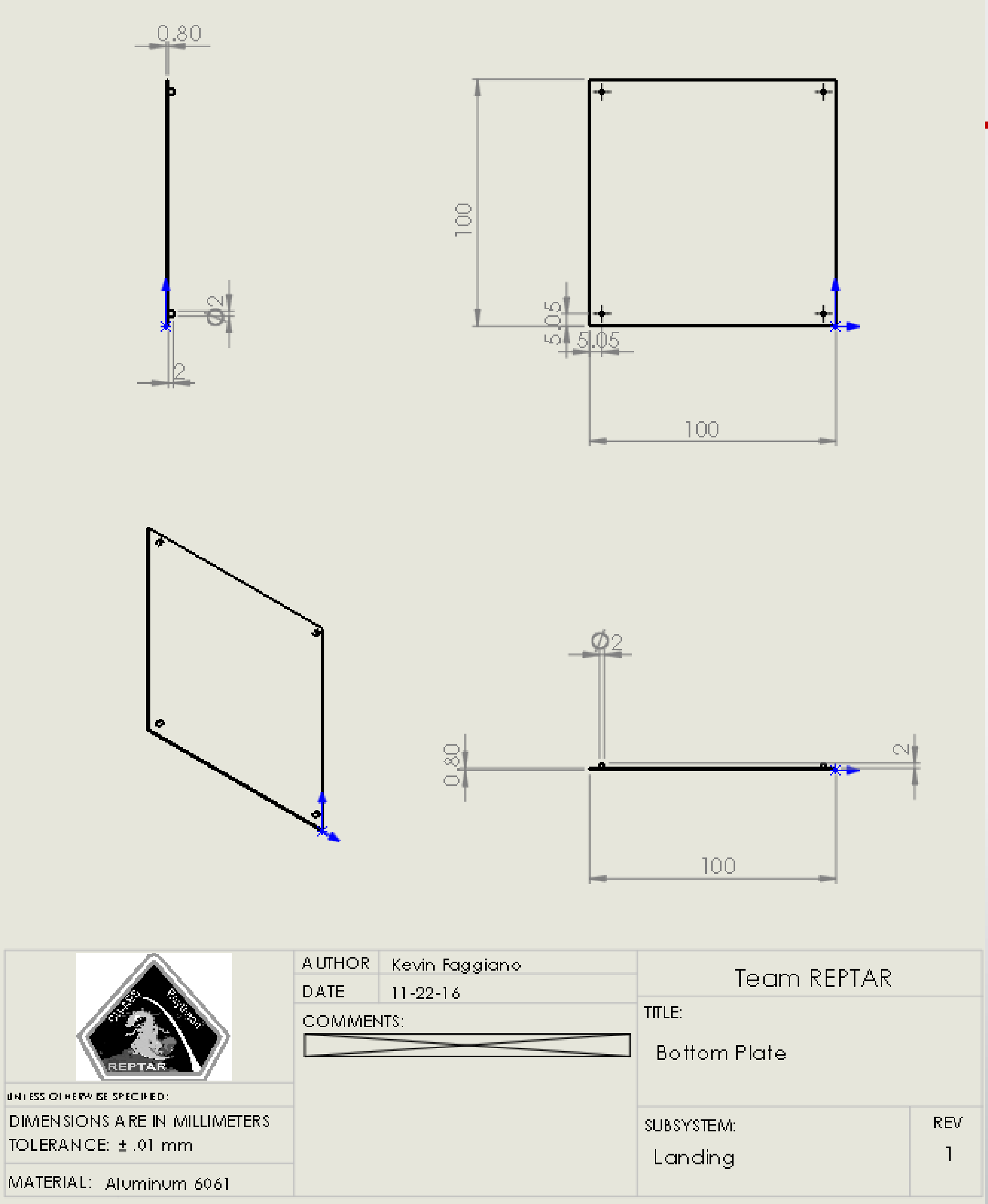


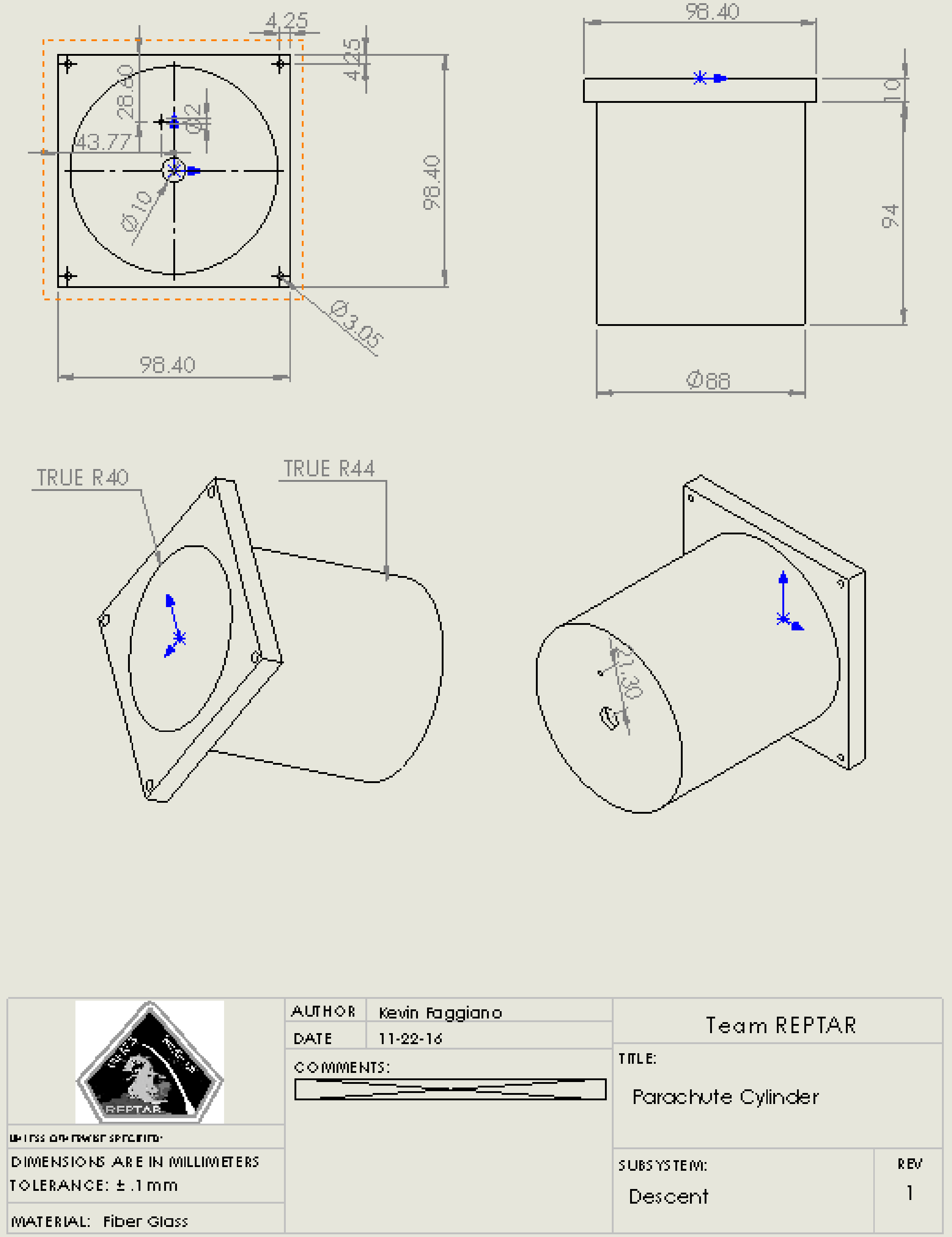


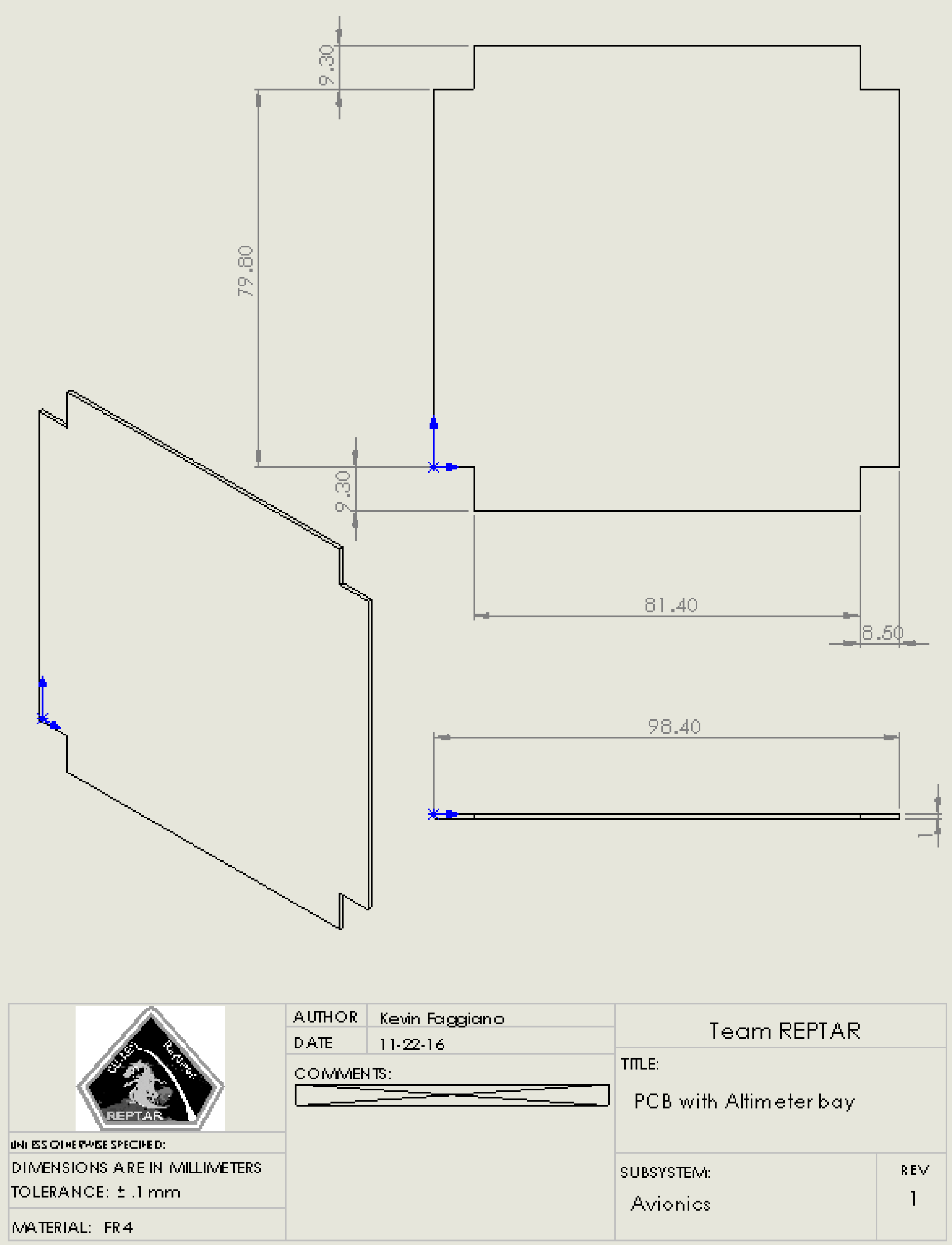
Solidworks Drawings

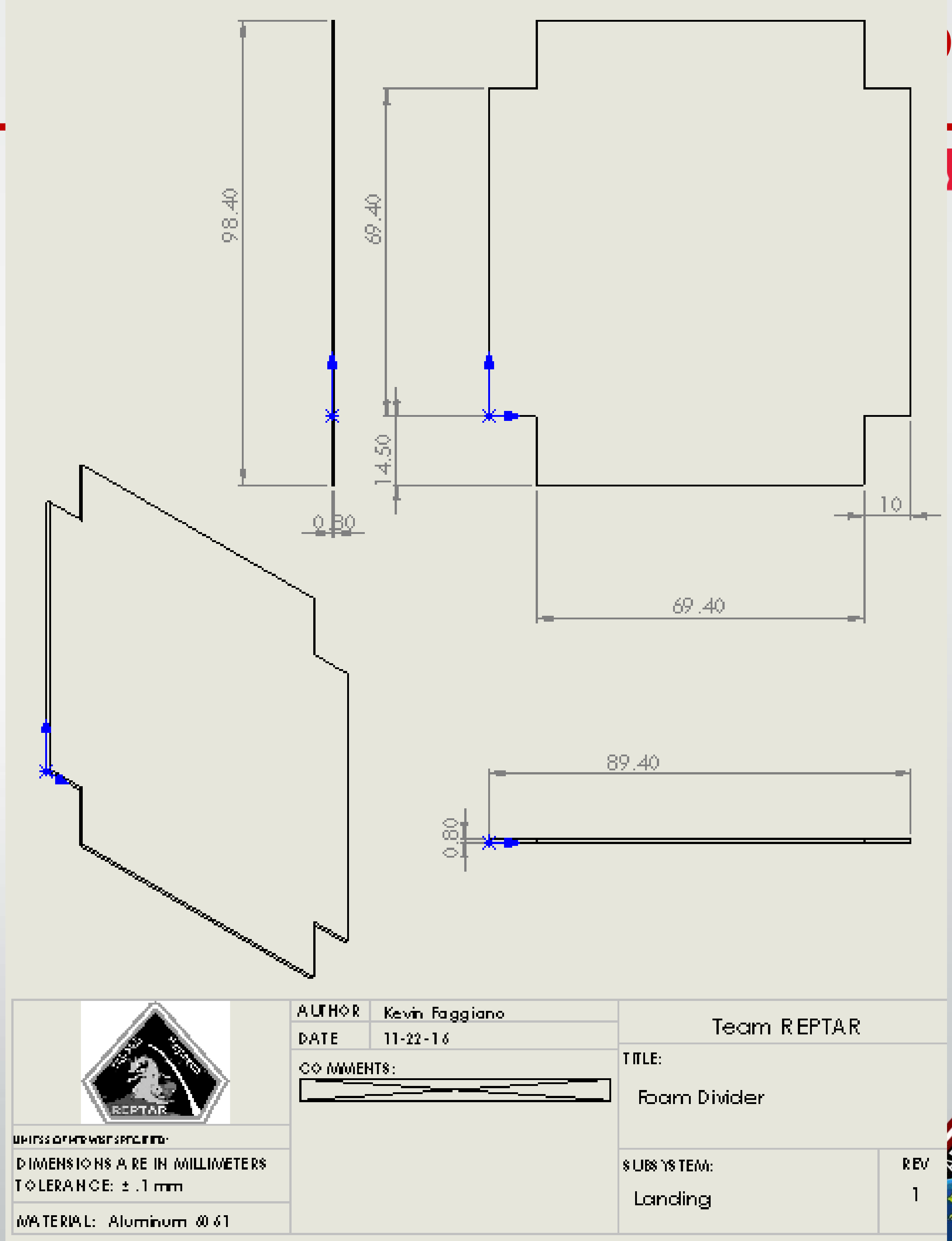

0.80
98.40
0.80
1.36
12.96
Ø7
81.40
8.50
8.50
8.50
81.40
8.50
TRUE R0.50
4.25
5.05
0.80
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
1 mm holes act as center locations for screws
Team REPTAR
TITLE:
Mounting Plate
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm
MATERIAL: Aluminum 6061
SUBSYSTEM:
Landing
REV
1

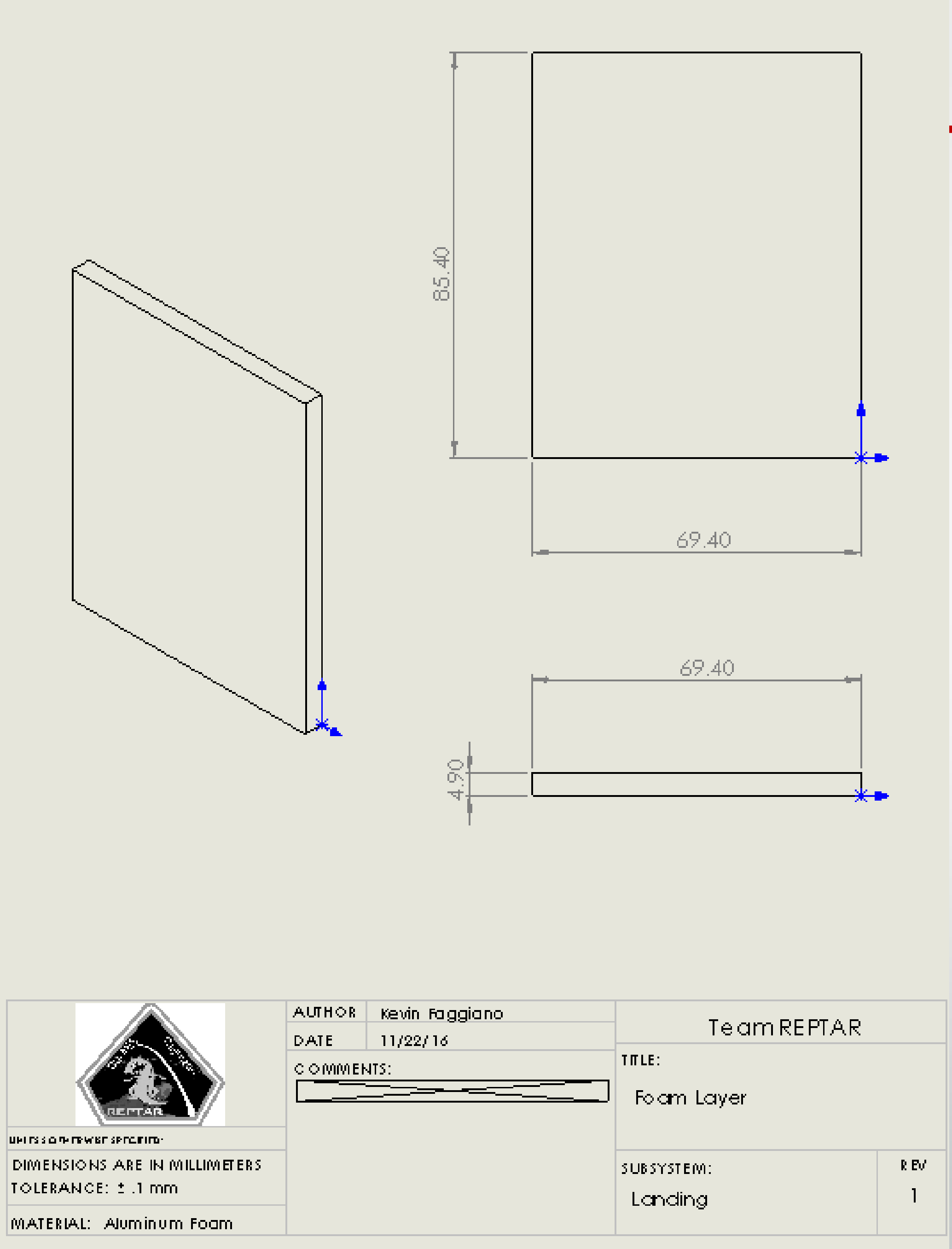

81.40
8.50
2
2
81.40
8.50
10.50
8.50
TRUE R2.50
0.98
4.25
8.50
4.25
10.50
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
Screw holes will most likely change, but the center will stay the same
Team REPTAR
TITLE:
Bottom Mounting Plate
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm
MATERIAL: Aluminum 6061
SUBSYSTEM:
Landing
REV
1

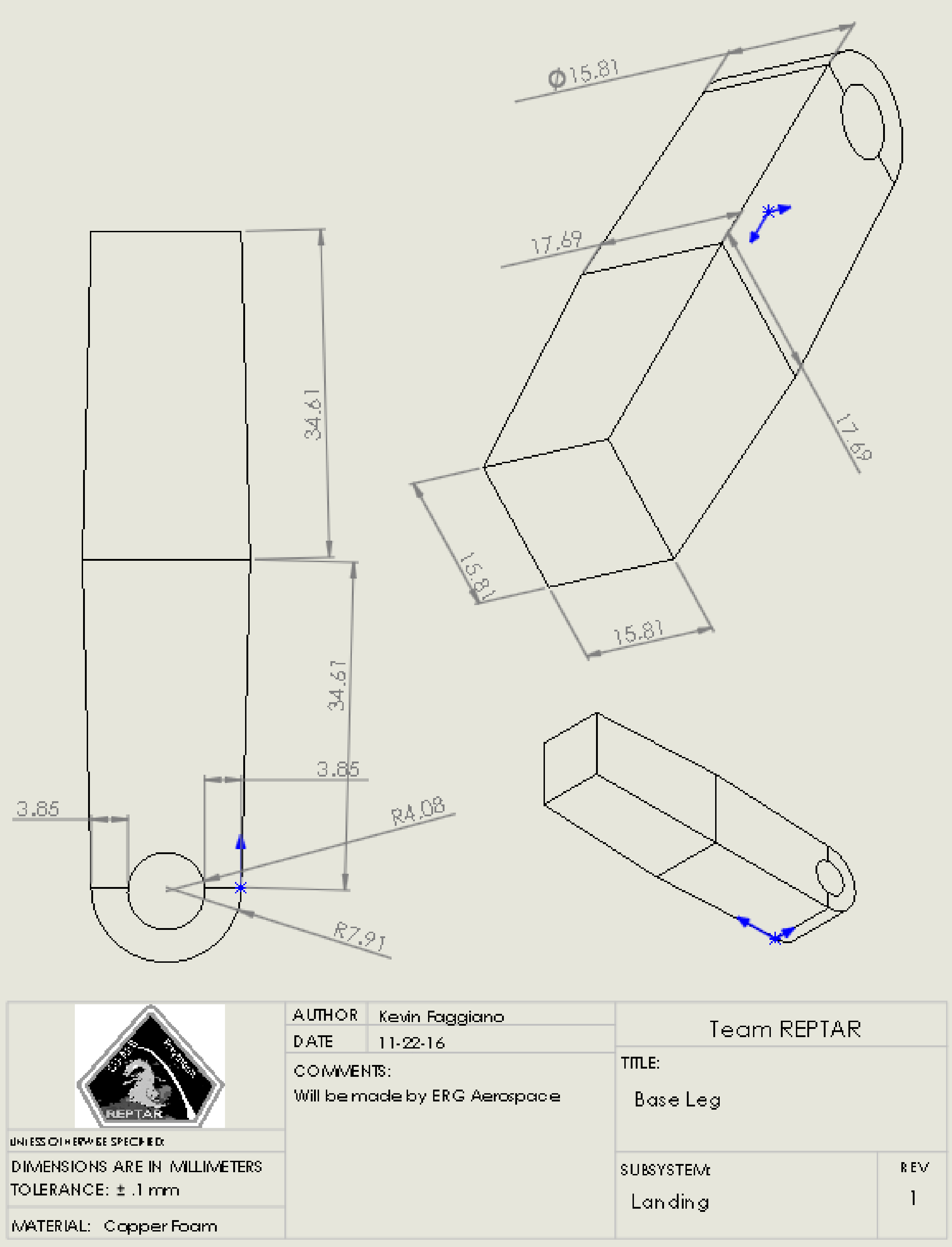

0.80
100
5.05
5
5.05
Ø2
2
100
Ø2
0.80
2
100
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
Team REPTAR
TITLE:
Bottom Plate
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm
MATERIAL: Aluminum 6061
SUBSYSTEM:
Landing
REV
1

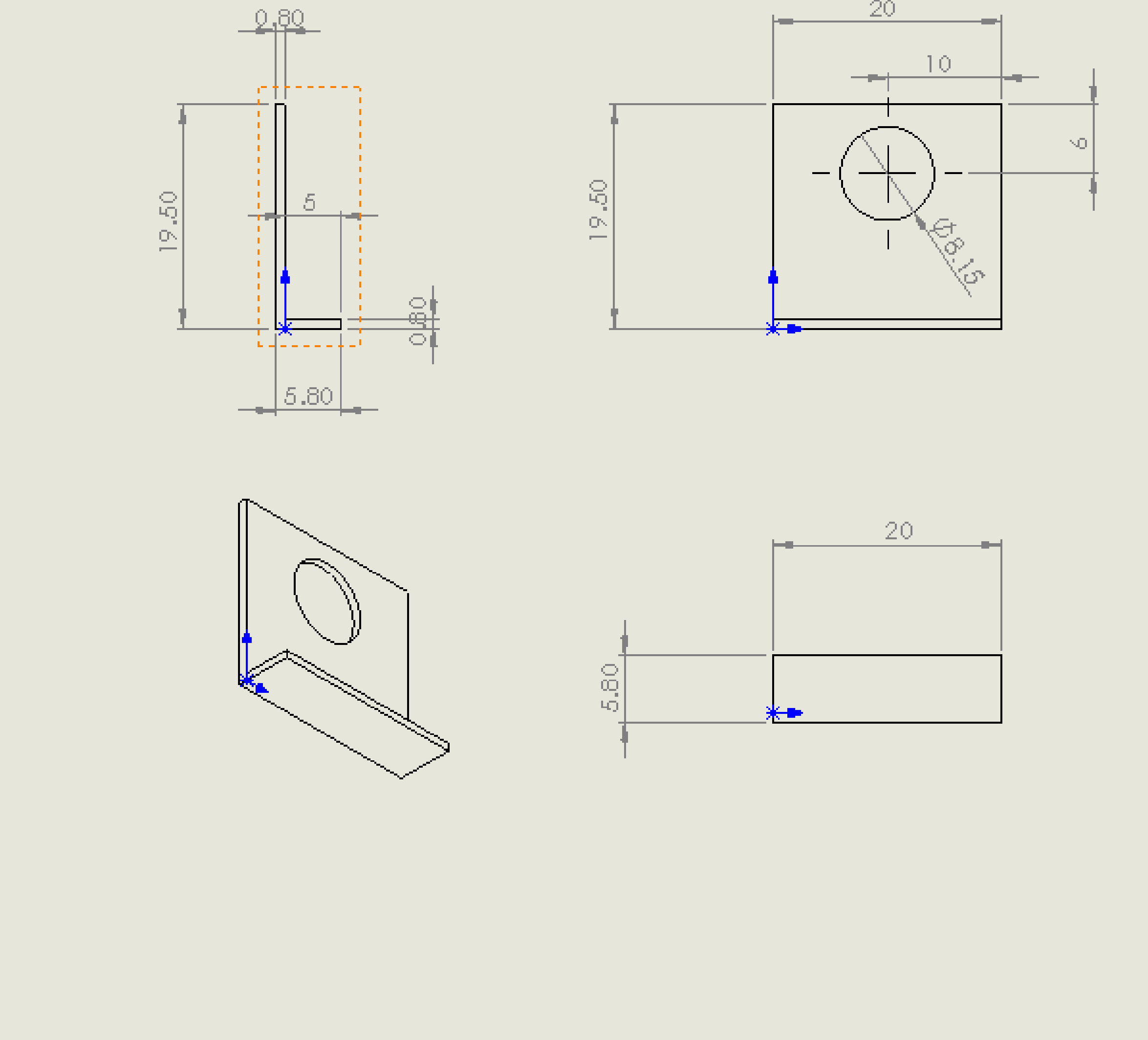

4.25
28.40
43.77
Ø2
Ø10
98.40
Ø3.05
98.40
98.40
10
94
Ø88
TRUE R40
TRUE R44
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
Team REPTAR
TITLE:
Parachute Cylinder
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .1 mm
MATERIAL: Fiber Glass
SUBSYSTEM:
Descent
REV
1


9.30
79.80
9.30
81.40
8.50
98.40
AUTHOR
Kevin Faggiano
DATE
11-22-16
COMMENTS:
Team REPTAR
TITLE:
PCB with Altimeter bay
SUBSYSTEM:
Avionics
REV
1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .1 mm
MATERIAL: FR4


98.40
69.40
14.50
0.80
10
69.40
89.40
0.80
AUTHOR
Kevin Faggiano
DATE
11-22-16
COMMENTS:
Team REPTAR
TITLE:
Foam Divider
SUBSYSTEM:
Landing
REV
1
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .1 mm
MATERIAL: Aluminum 6061


85.40
69.40
69.40
4.90
AUTHOR
Kevin Faggiano
DATE
11/22/16
COMMENTS:
Team REPTAR
TITLE:
Foam Layer
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .1 mm
MATERIAL: Aluminum Foam
SUBSYSTEM:
Landing
REV
1
REPTAR

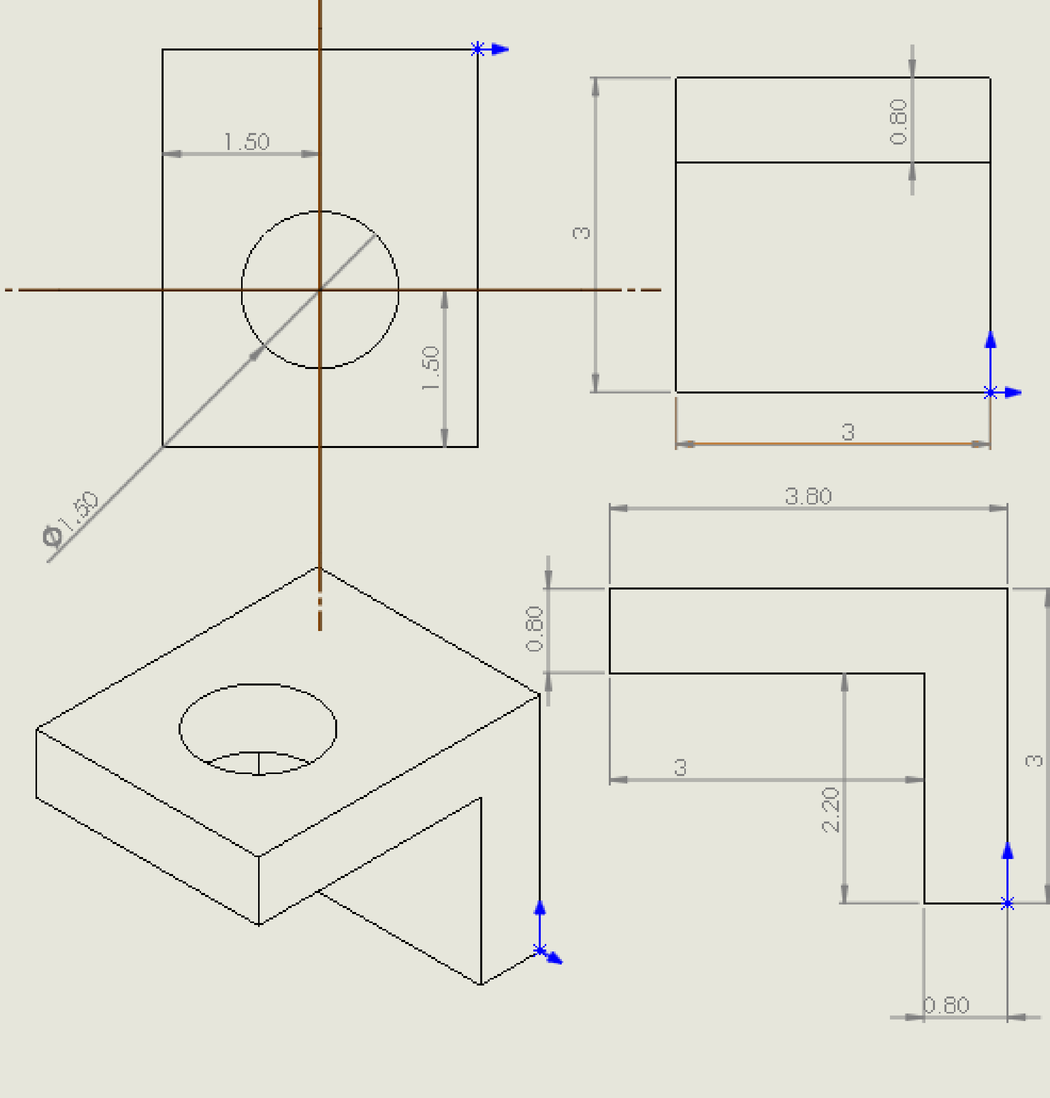

Φ15.81
17.69
17.69
15.81
15.81
34.61
34.61
3.85
3.85
R4.08
R7.91
AUTHOR
Kevin Faggiano
DATE
11-22-16
COMMENTS:
Will be made by ERG Aerospace
Team REPTAR
TITLE:
Base Leg
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .1 mm
MATERIAL: Copper Foam
SUBSYSTEM:
Landing
REV
1
REPTAR



AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:

Team REPTAR
TITLE: L-Bracket
SUBSYSTEM: Landing
REV 1

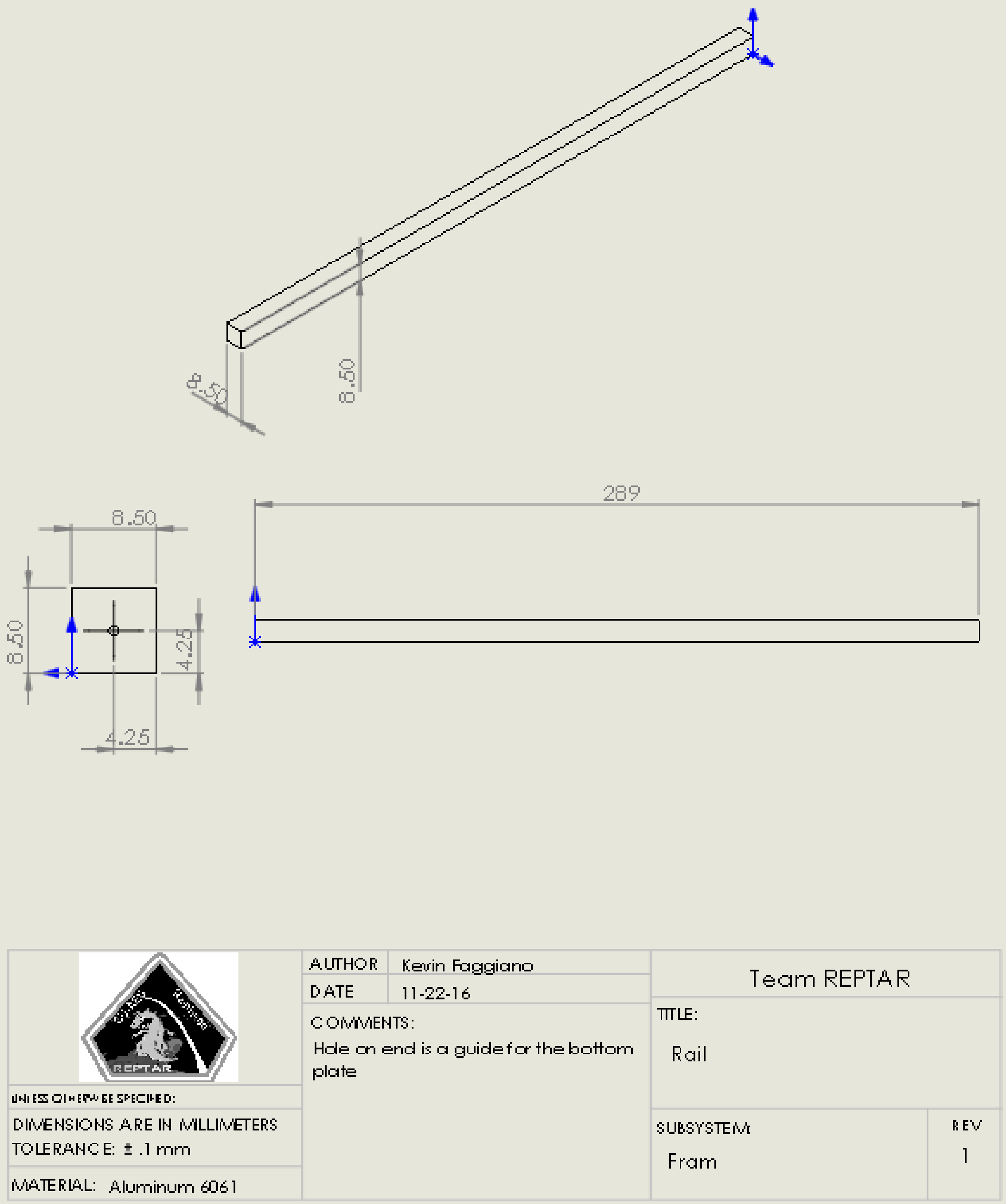
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm
MATERIAL: Aluminum 6061

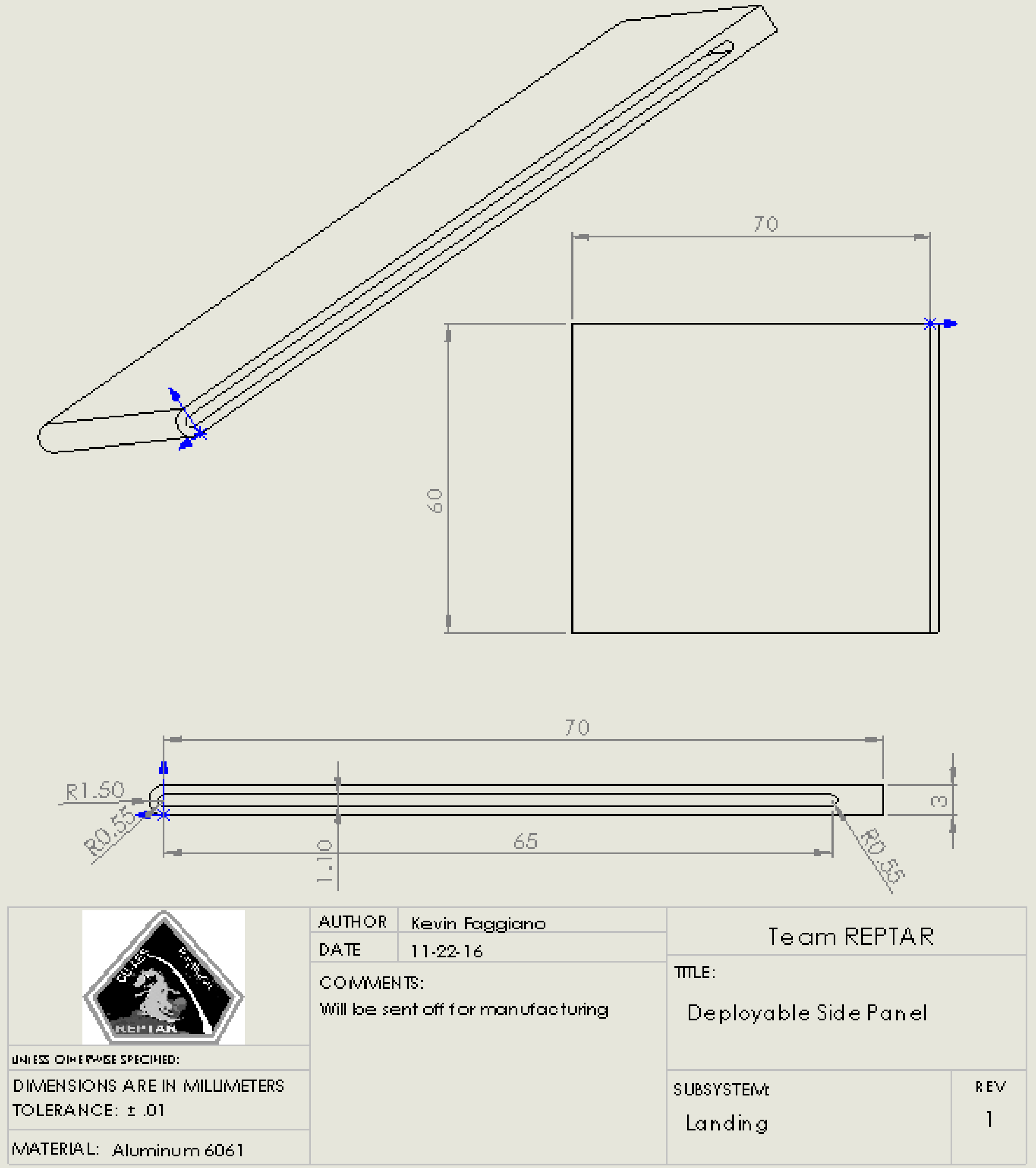


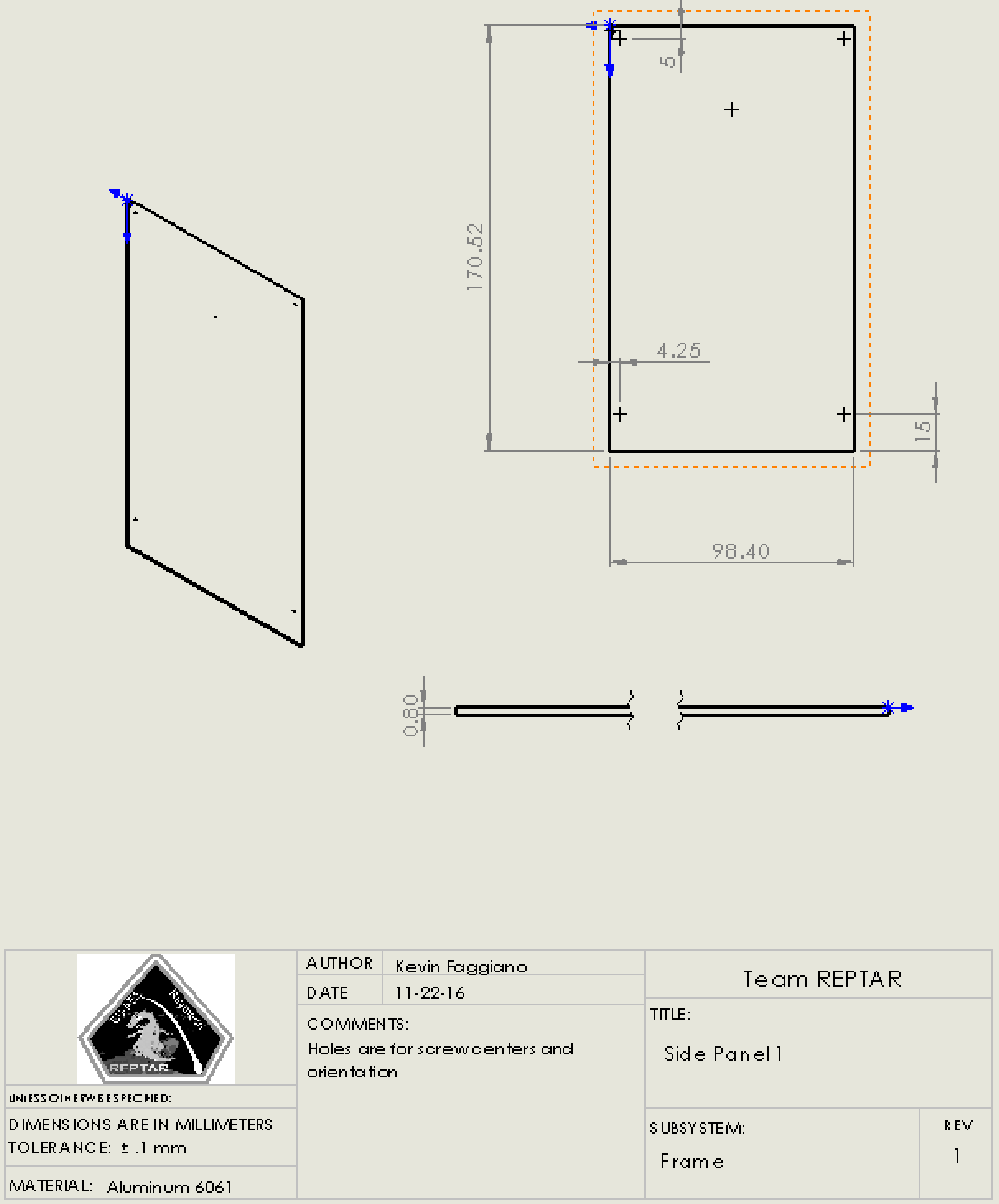
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:

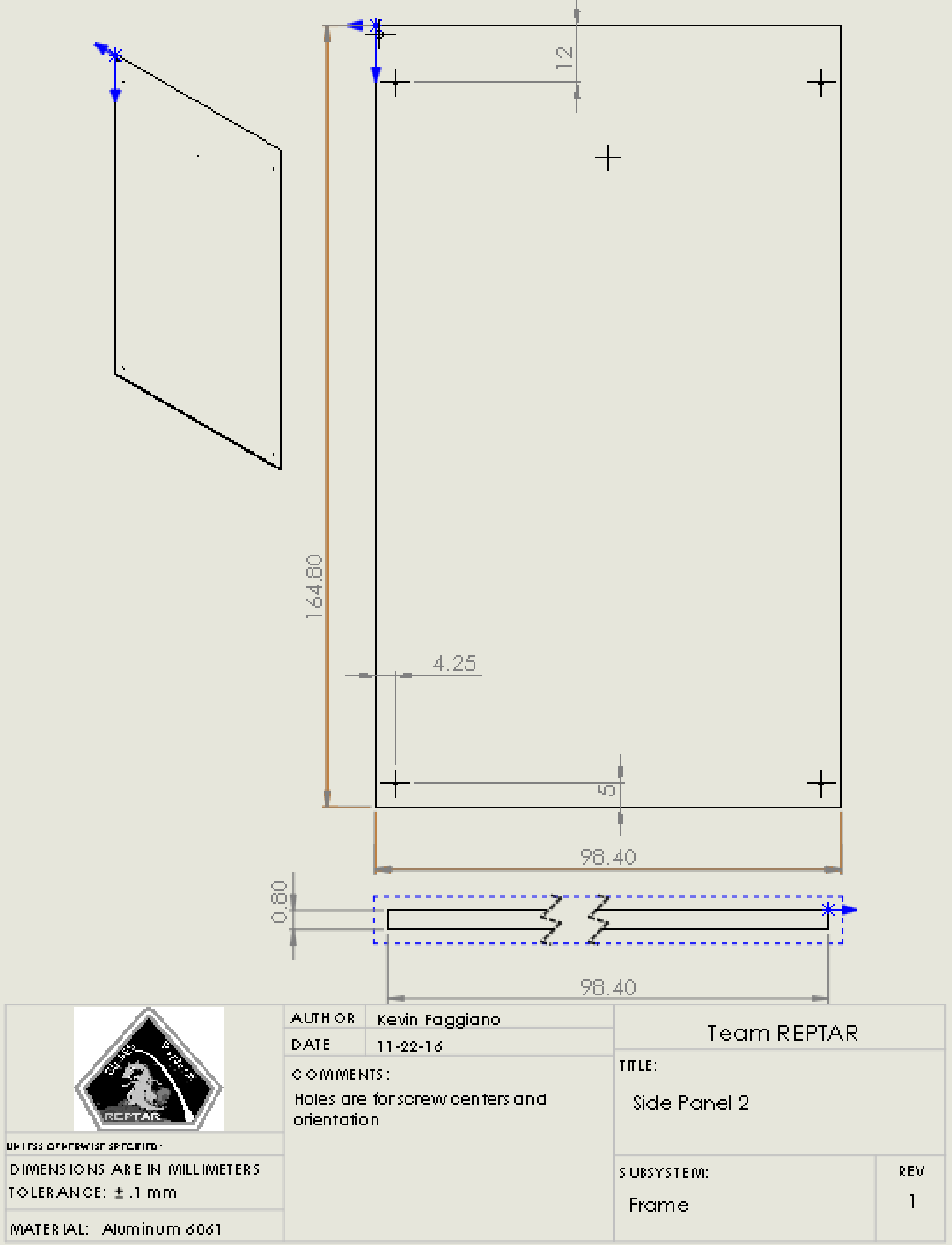
Team REPTAR
TITLE: Nylon Attachment
SUBSYSTEM: Landing
REV 1

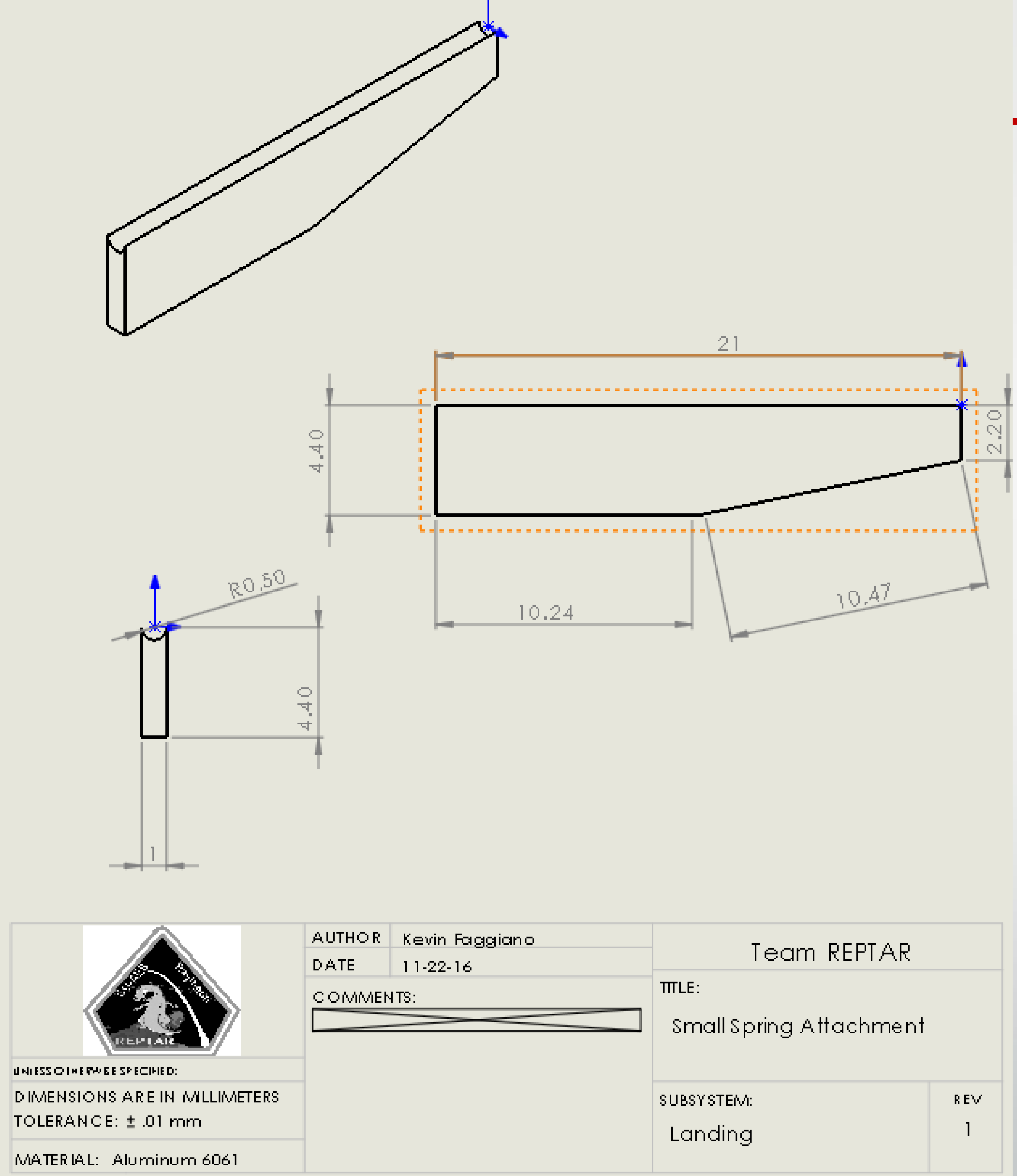
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .1 mm
MATERIAL: Aluminum 6061

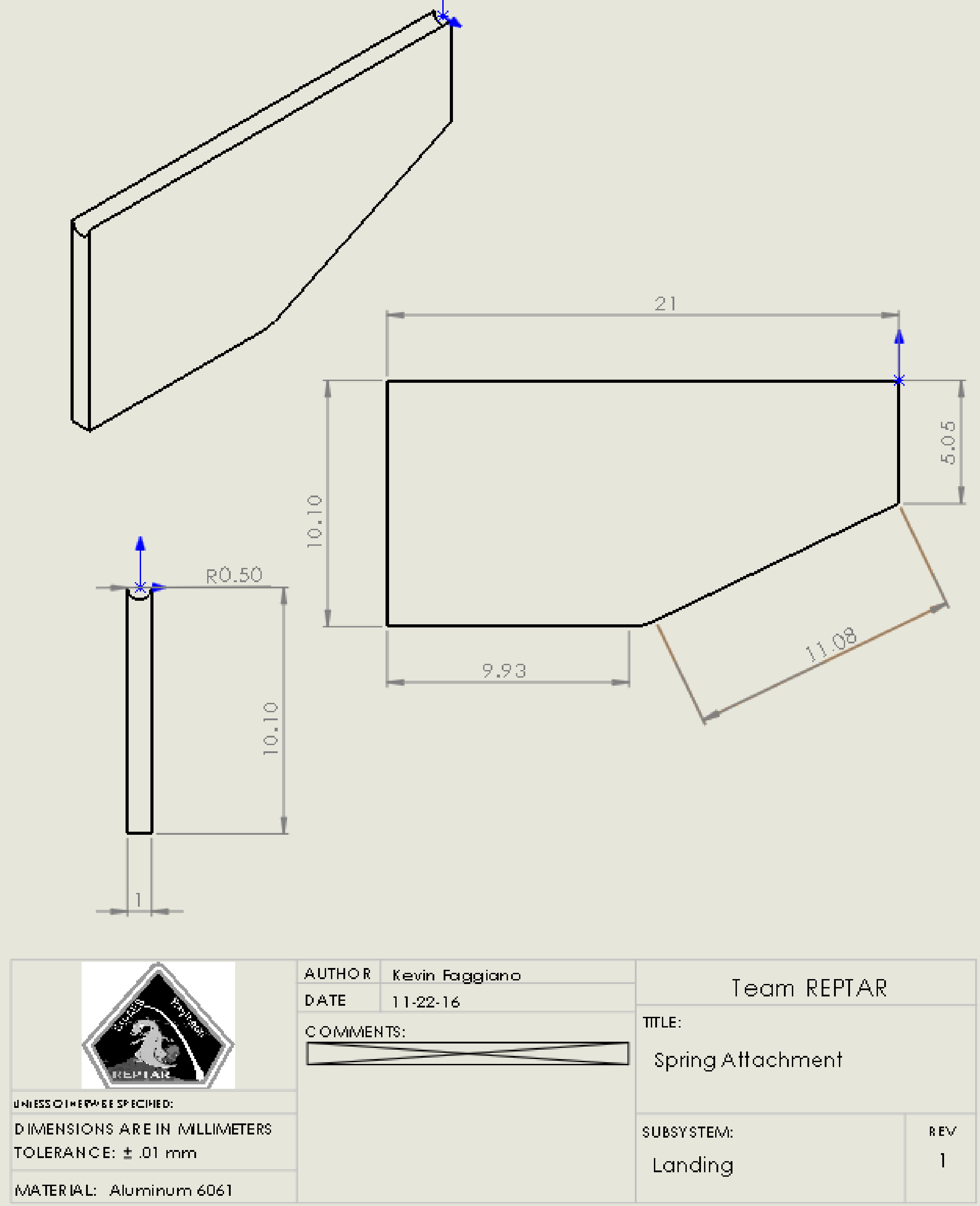

8.50
8.50
289
8.50
8.50
4.25
4.25
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
Hole on end is a guide for the bottom plate
Team REPTAR
TITLE:
Rail
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .1 mm
MATERIAL: Aluminum 6061
SUBSYSTEM
Fram
REV
1

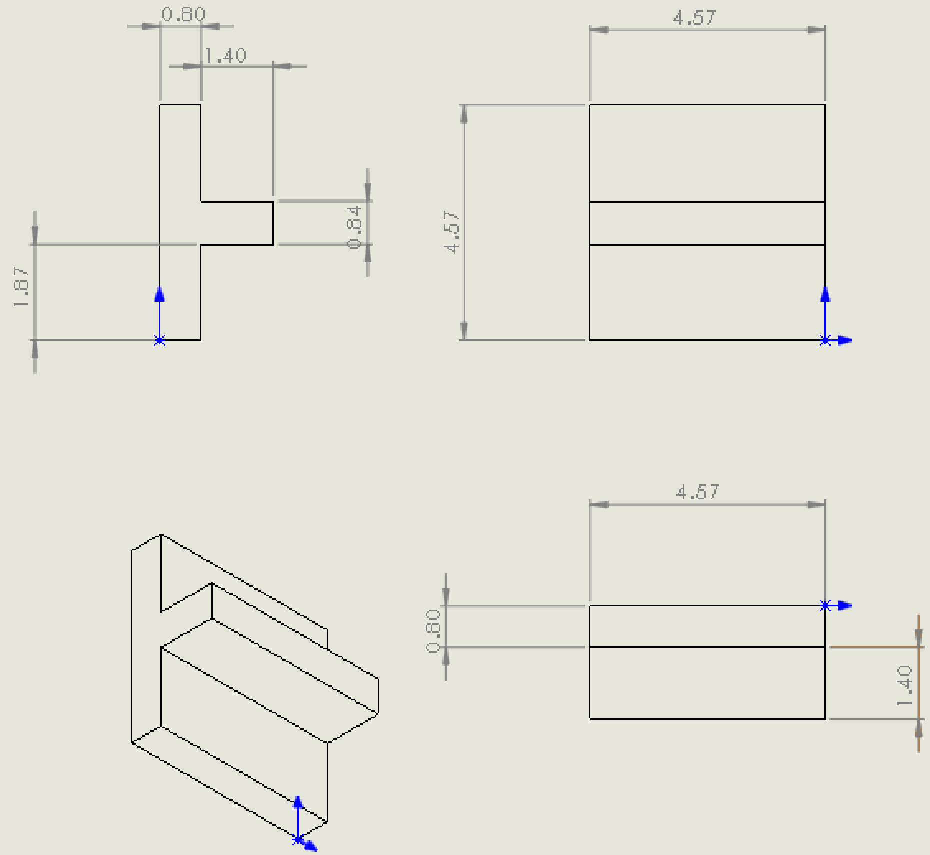

70
60
70
R1.50
R0.55
1.10
65
R0.55
3
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
Will be sent off for manufacturing
Team REPTAR
TITLE:
Deployable Side Panel
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01
MATERIAL: Aluminum 6061
SUBSYSTEM
Landing
REV
1


170.52
5
4.25
15
98.40
0.80
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
Holes are for screw centers and orientation
Team REPTAR
TITLE:
Side Panel 1
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .1 mm
MATERIAL: Aluminum 6061
SUBSYSTEM:
Frame
REV
1


12
164.80
4.25
5
98.40
0.80
98.40
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
Holes are for screw centers and orientation
Team REPTAR
TITLE:
Side Panel 2
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .1 mm
MATERIAL: Aluminum 6061
SUBSYSTEM:
Frame
REV
1


21
4.40
2.20
R0.50
10.24
10.47
4.40
1
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
Team REPTAR
TITLE:
Small Spring Attachment
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm
MATERIAL: Aluminum 6061
SUBSYSTEM:
Landing
REV
1


21
10.10
5.05
R0.50
9.93
11.08
10.10
1
AUTHOR Kevin Faggiano
DATE 11-22-16
COMMENTS:
Team REPTAR
TITLE:
Spring Attachment
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm
MATERIAL: Aluminum 6061
SUBSYSTEM:
Landing
REV
1



AUTHOR	Kevin Faggiano
DATE	11-22-16

COMMENTS:
This could change after actually getting parts and testing

Team REPTAR

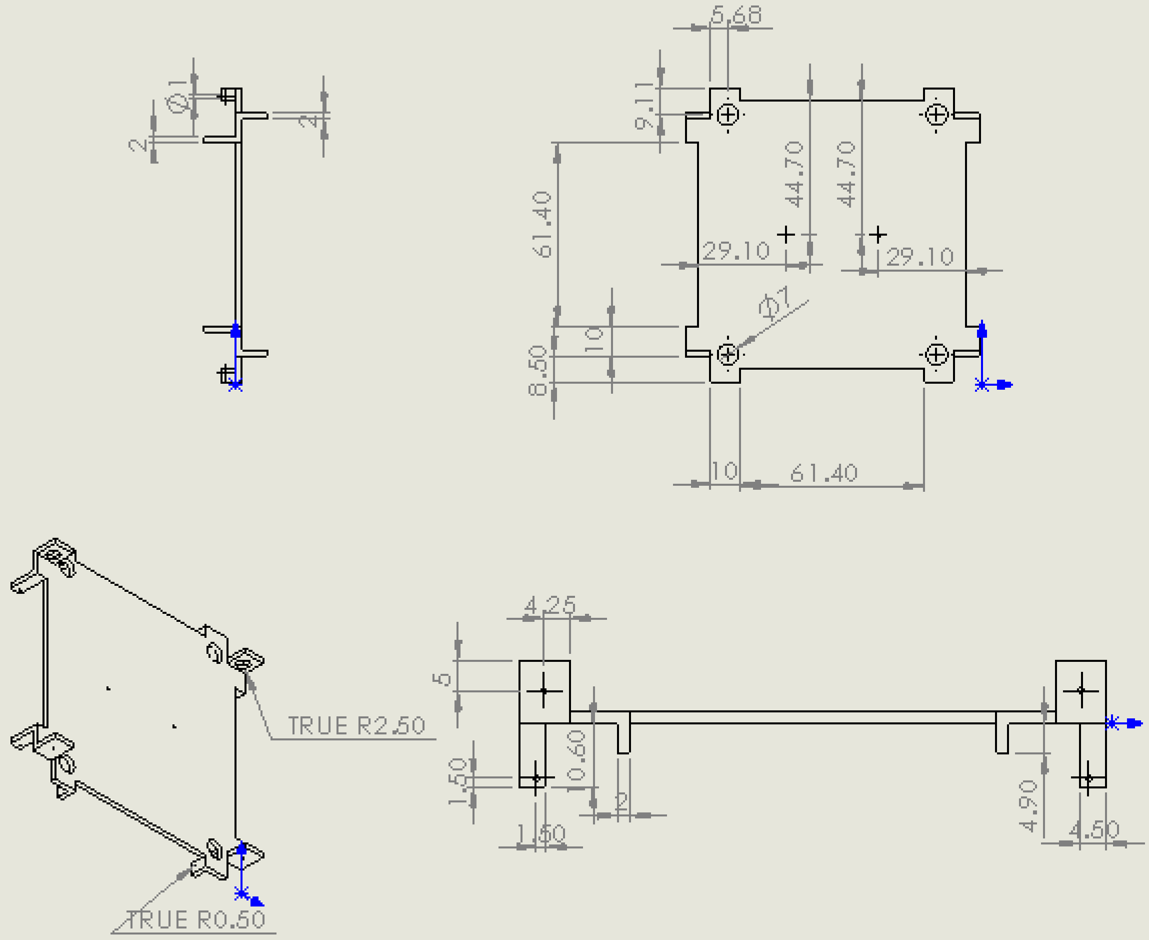
TITLE:
Spring Top

SUBSYSTEM: Landing

REV 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm

MATERIAL: Aluminum 6061



AUTHOR	Kevin Faggiano
DATE	11-22-16

COMMENTS:
1 mm holes are pin holes, or just for screw placement in the assembly, larger screw holes will be added

Team REPTAR

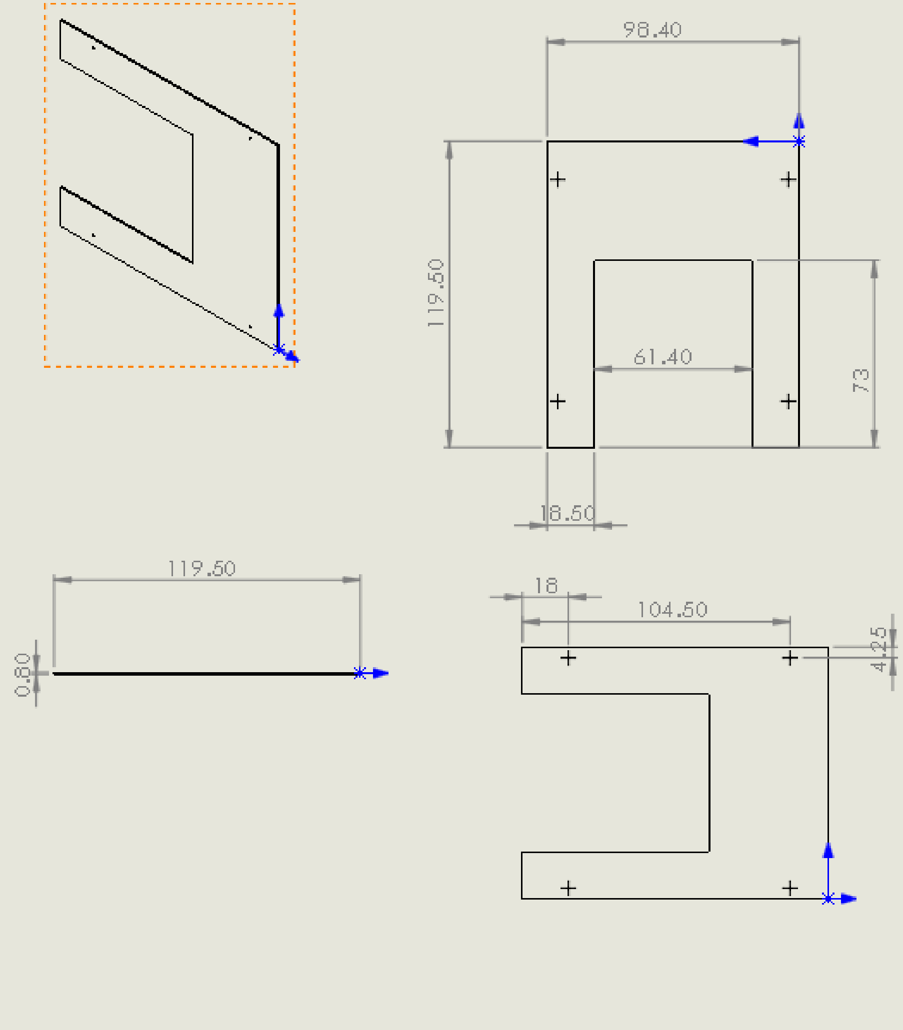
TITLE:
Upper Level Mounting Plate

SUBSYSTEM: Landing

REV 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm

MATERIAL: Aluminum 6061



AUTHOR: Kevin Faggiano
DATE: 11 - 22- 16
COMMENTS: Holes are for screw locations

Team REPTAR

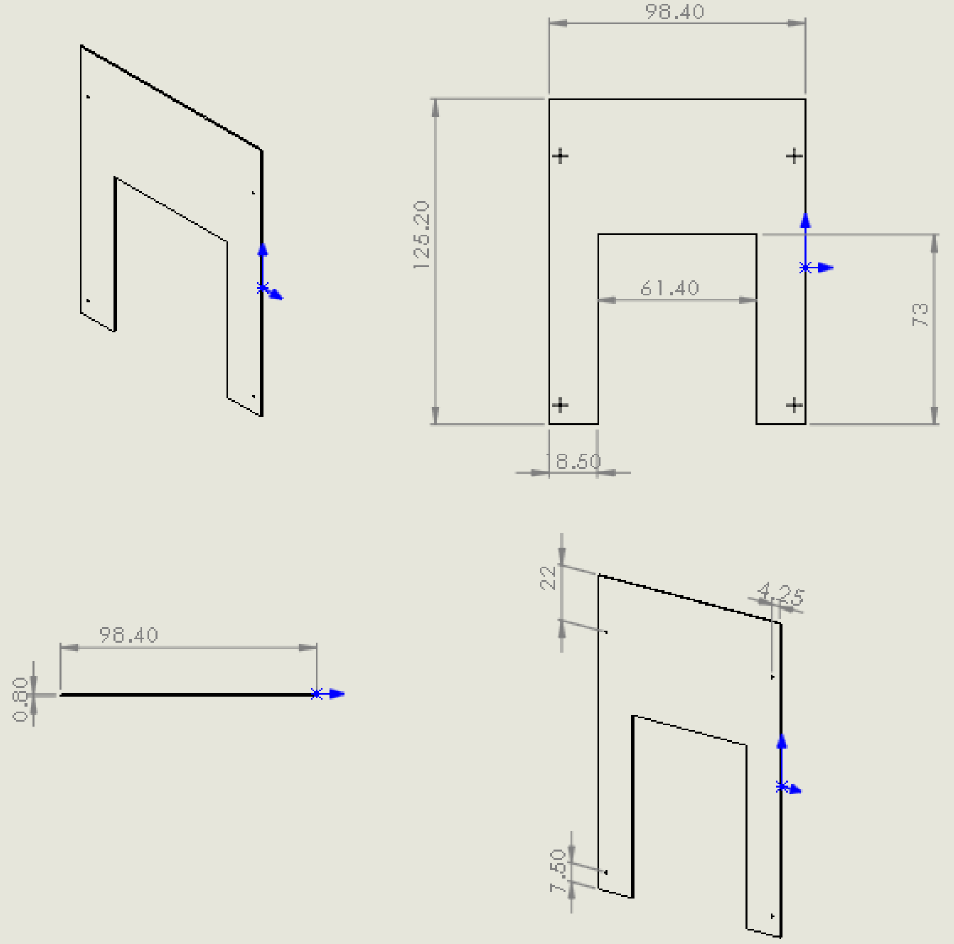
TITLE: Drawing Title: Upper Panel 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm

MATERIAL: Fiber Glass

SUBSYSTEM: Frame

REV: 1



AUTHOR: Kevin Faggiano
DATE: 11-22-16
COMMENTS: Holes are for screw locations

Team REPTAR

TITLE: Upper Panel 2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE: ± .01 mm

MATERIAL: Fiber Glass

SUBSYSTEM: Frame

REV: 1