Raytheon

Manufacturing Status Review

REPTAR

REcoverable ProTection After Reentry

Team: Calvin Buechler, Kevin Faggiano, Dustin Fishelman, Cody Gondek, Lee Huynh, Aaron McCusker, William Sear, Himanshi Singhal, Craig Wenkheimer, Nathan Yeo

Customer: Steve Thilker, Collin Baukol, Cody Humbargar, Jason Latimer (Raytheon)

Advisor: Dr. Brian Argrow

University of Colorado Boulder

10/3/17

Overview

Project Statement & Motivation

REPTAR

Raytheon

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

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

Descent

After being decelerated to subsonic speeds, REPTAR activates atmospheric deceleration systems to protect the payload.

Decelerate

Slows to safe landing speeds by deploying a parachute. Transmits location during descent.

Land

Lands payload safely within launch loading requirements.

Transmit Location

Transmits location to recovery element.

Receive Location

Recovery team receives location.

Levels of Success

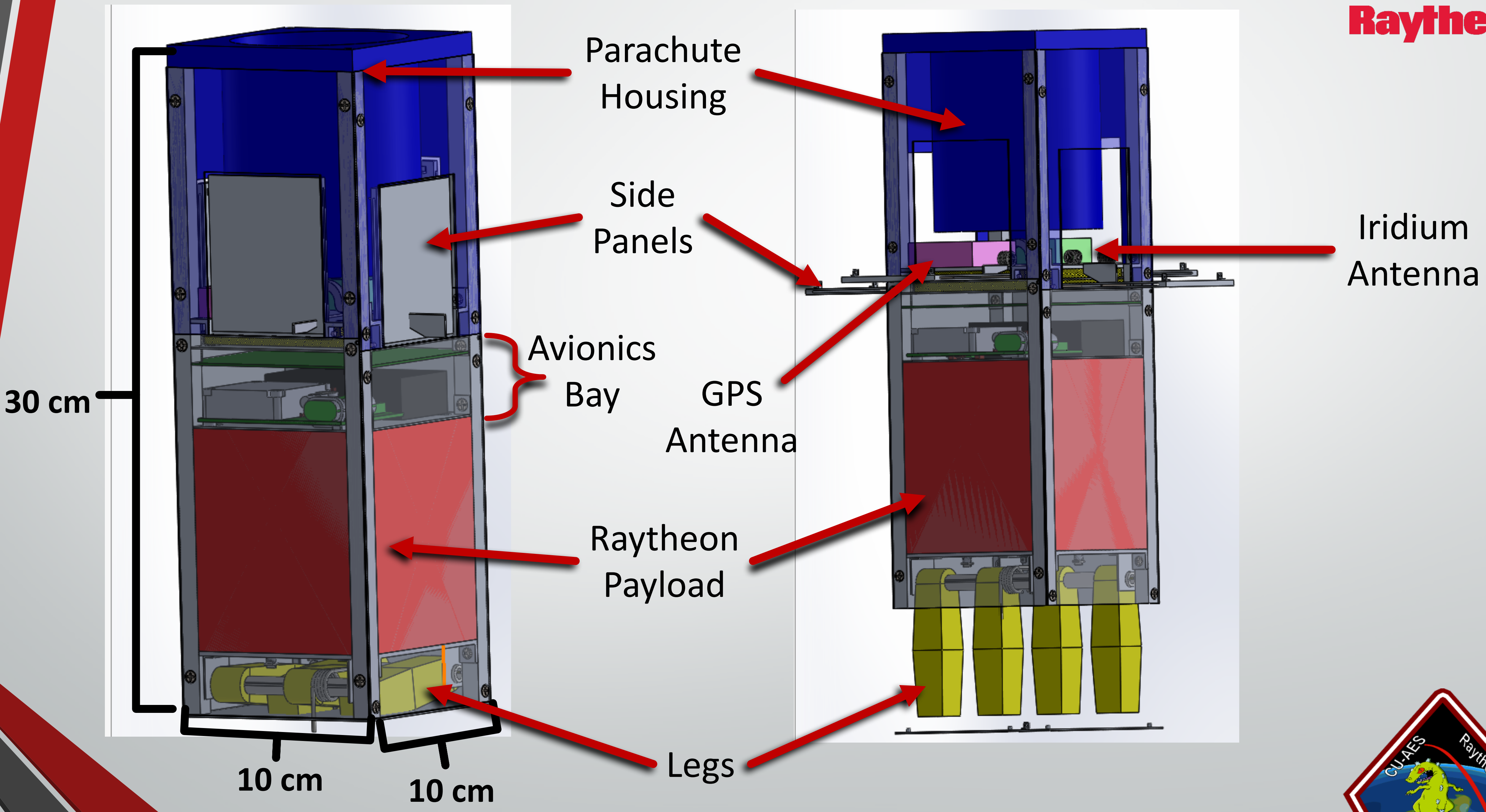
REPTAR

Criteria	Volume	Instantaneous G-Loading	Communication
Level 1	The volume of REPTAR including payload shall not exceed a maximum of 6U Standard	The payload shall endure a maximum instantaneous G-loading of less than 40 G's	REPTAR shall beacon its location over a range of 20 miles
Level 2	The volume of REPTAR including payload shall not exceed a maximum of 4U Standard	--	REPTAR shall beacon its location over a range of 30 miles
Level 3	The volume of REPTAR including payload shall not exceed a maximum of 3U Standard	--	REPTAR shall beacon its location over a range of 45 miles

Key Components

REPTAR

Raytheon

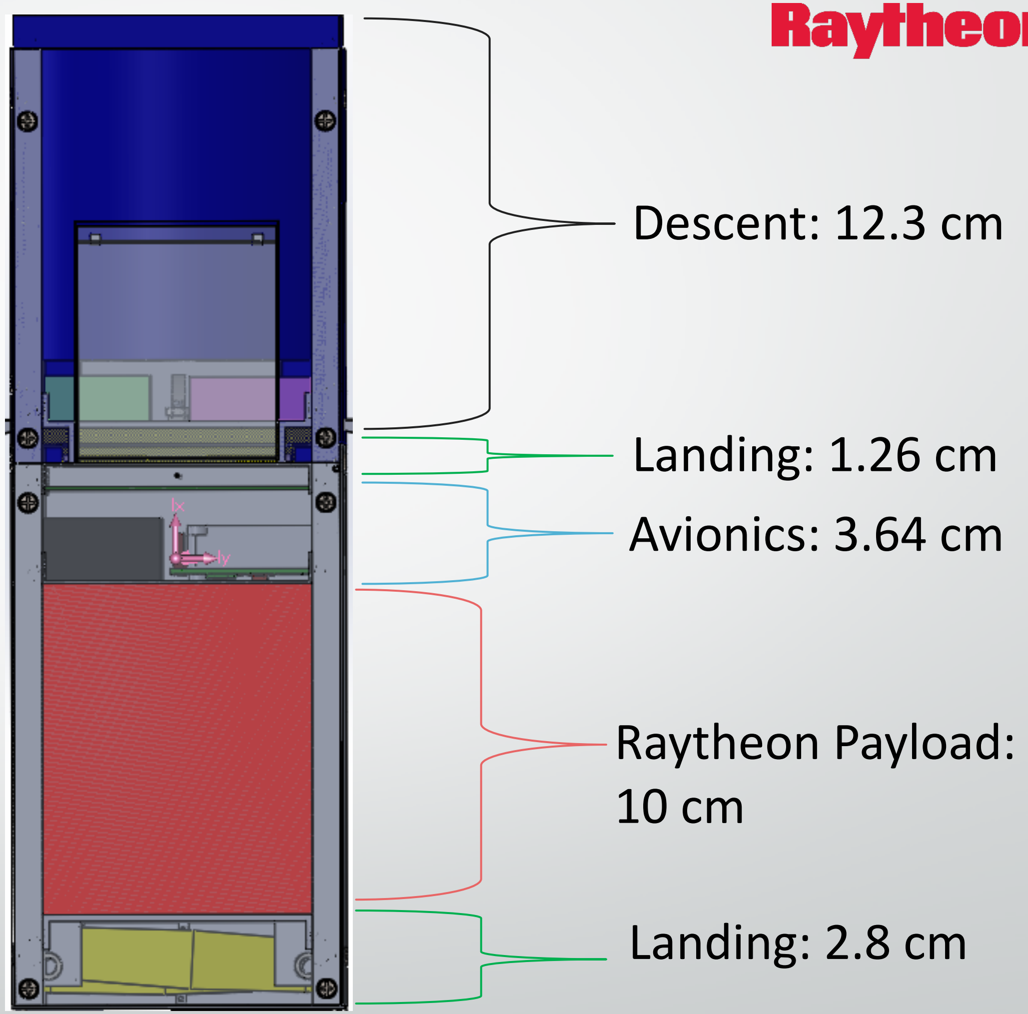


Total Mass & Volume Budget

REPTAR

Raytheon

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**	**-**



Critical Project Elements

REPTAR

Raytheon

Subsystem	CPE	Explanation
Descent	Parachute Deployment	If the parachute does not deploy and act properly, it will be nearly impossible to achieve any of the mission requirements.
Landing	Leg Deployment	The legs lower the maximum G loading the vehicle experiences. Without successful leg deployment, a mission requirement cannot be met.
Landing	Side Panel Deployment	The side panels assist in lowering the maximum G loading in the case of windy weather where the vehicle will have a horizontal velocity
Avionics	MainBoard Bringup	The mainboard is critical for all flight actions as it controls deployments and the GPS-Iridium interface.
Avionics	Battery Testing	Verification of the battery is critical for personal and hardware safety.
Avionics	Antenna Pattern Testing	In order to determine and transmit our location we need to be able to make link with the GPS and Iridium constellations.

Schedule

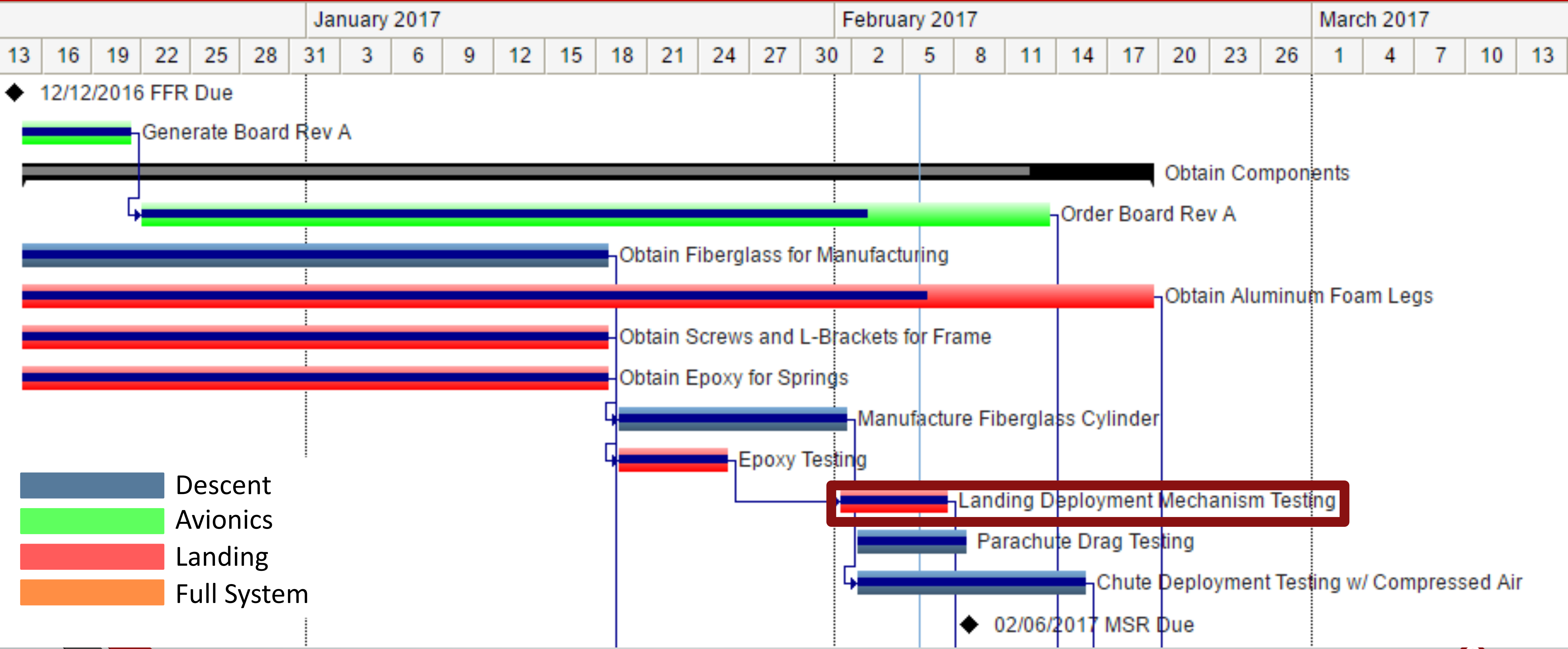
Critical Subsystem Tests

REPTAR

Subsystem	Test	Reasoning
Descent	Black Powder Deployment	Verifies chute deployment
Descent	Parachute Deployment Loading Test	Verifies base plate is strong enough to hold chute
Landing	Leg and Panel Deployment	Verifies legs and side panels deployment
Landing	Foam Impact	Verifies foam's structural properties and behavior
Avionics	Antennae Testing	Verifies antennae perform as expected
Avionics	Battery Testing	Verifies batteries function safely and properly
Avionics	Day in the Life	Verifies all avionics components cooperate when combined

Plan to MSR

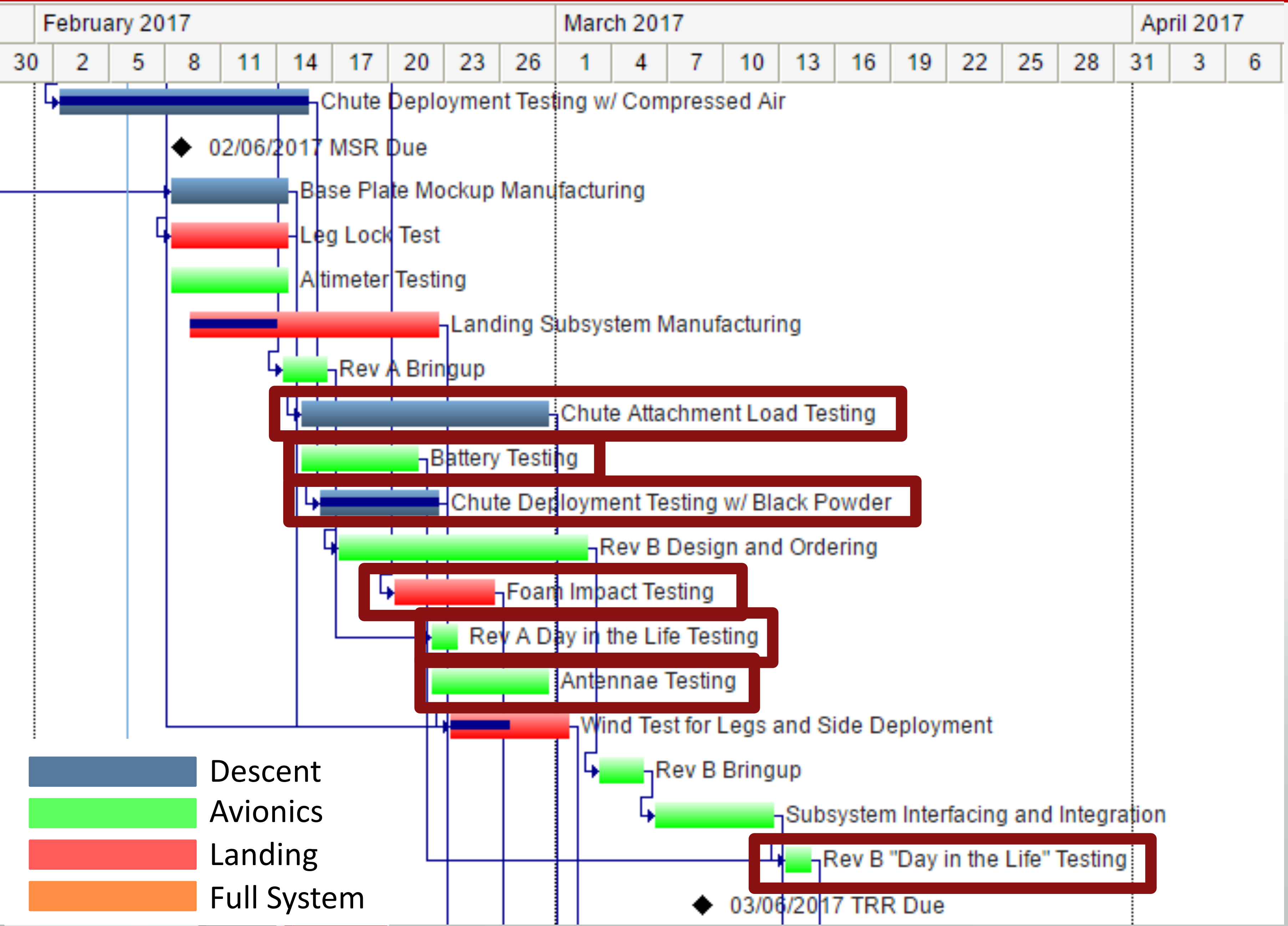
REPTAR



Plan from MSR to TRR

REPTAR

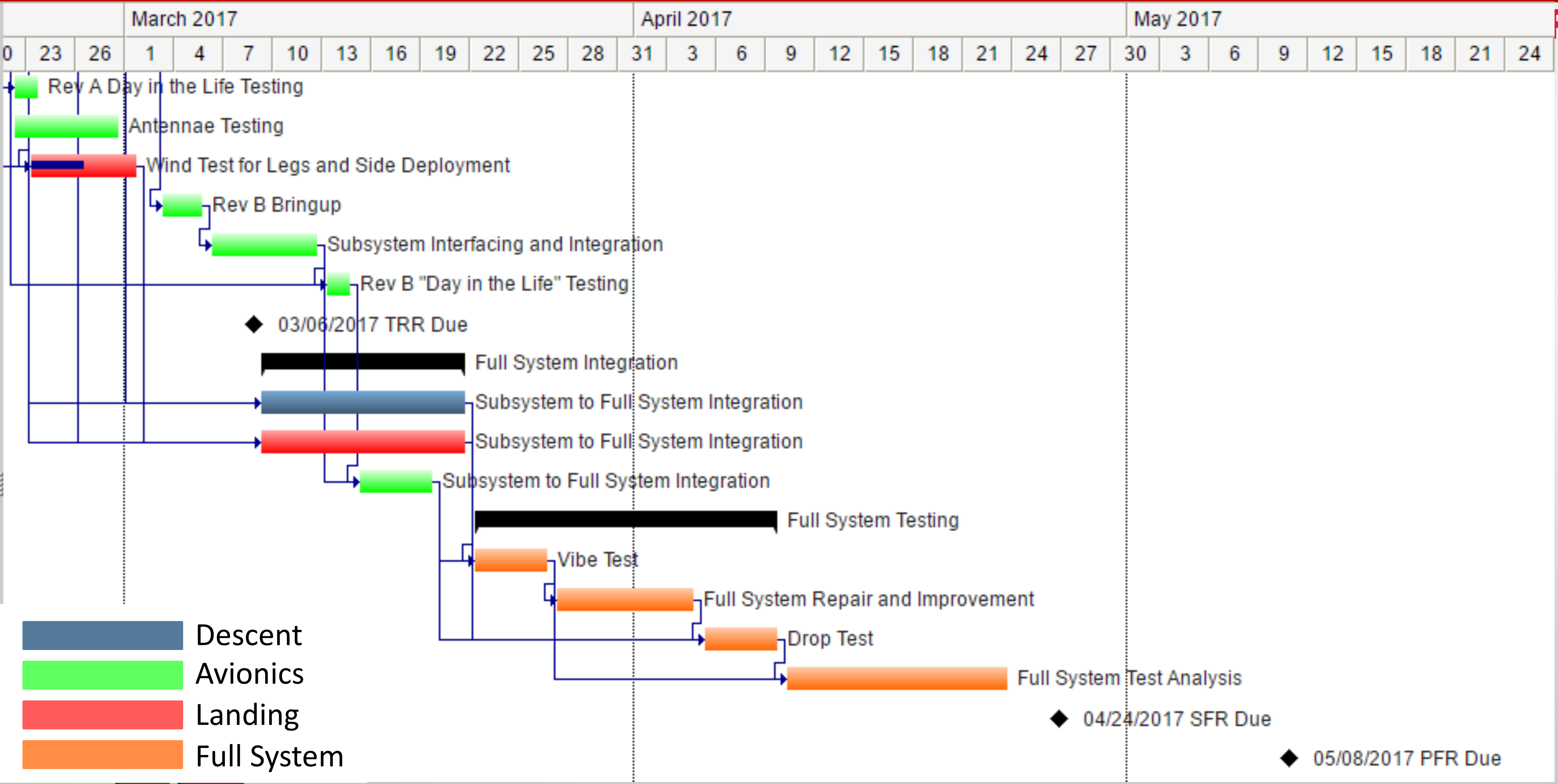
Raytheon



Plan from TRR to End of Semester

REPTAR

Raytheon



Manufacturing

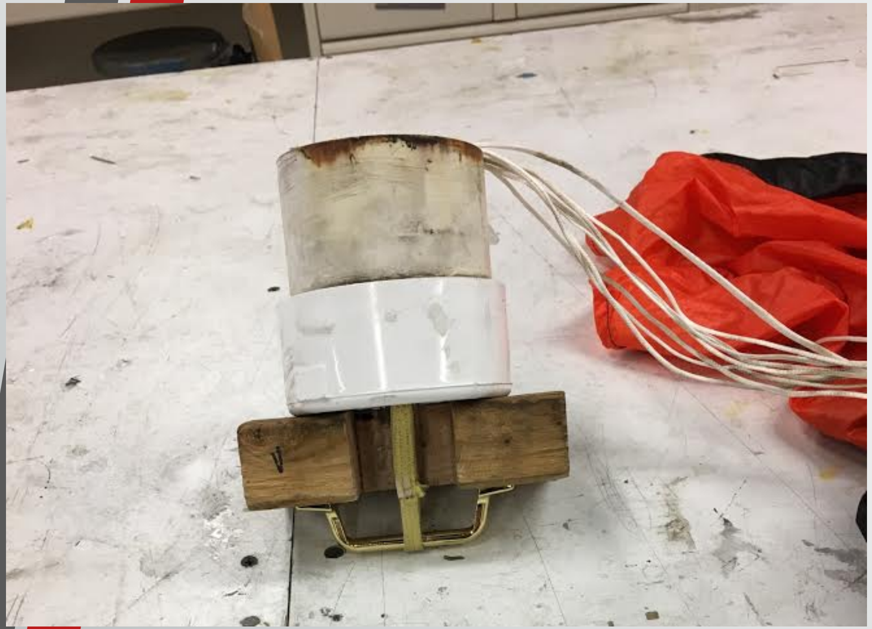
CPE: Parachute Deployment

Descent Subsystem

Past Manufacturing

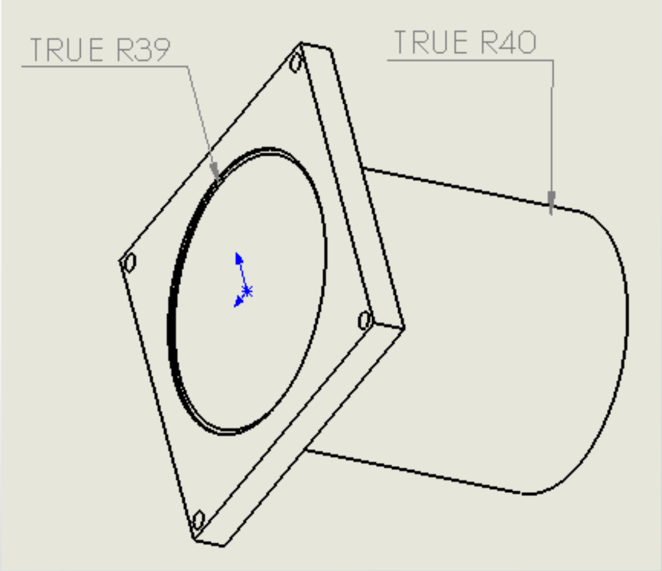
PVC Housing

~ 4.5 Man Hours



Fiberglass Housing

~ 15 Man Hours



Past Testing

REPTAR

Raytheon

Test	Purpose	Results
Black Powder Tests, No Parachute	Quantify the amount of equilibrium pressure in housing with various amounts of powder, compare with pressure model	Successful, ~ 24 psi equilibrium vs. 20 psi predicted
Air Compressor Test	Quantify the pressure needed to expel the parachute from housing	Successful, ~ 80 psi instantaneous with perforation
Black Powder Tests, with Parachute	Validate that parachute is expelled from housing due to instantaneous pressure from powder ignition	Somewhat Successful, expelled from housing, but burnt parachute
Drop Test	Validate the coefficient of drag of parachute, validate drift model accuracy	Unsuccessful, too much drift
Parachute Drag Test	Validate coefficient of drag of parachute	Successful, Cd ~ 2.15

Parachute Ejection with Black Powder

- Purpose
  - Validate that parachute is ejected
- Model
  - 0.4 grams, ~248 psi instantaneous pressure
- Results
  - Ejected but some burns presents

Future Testing

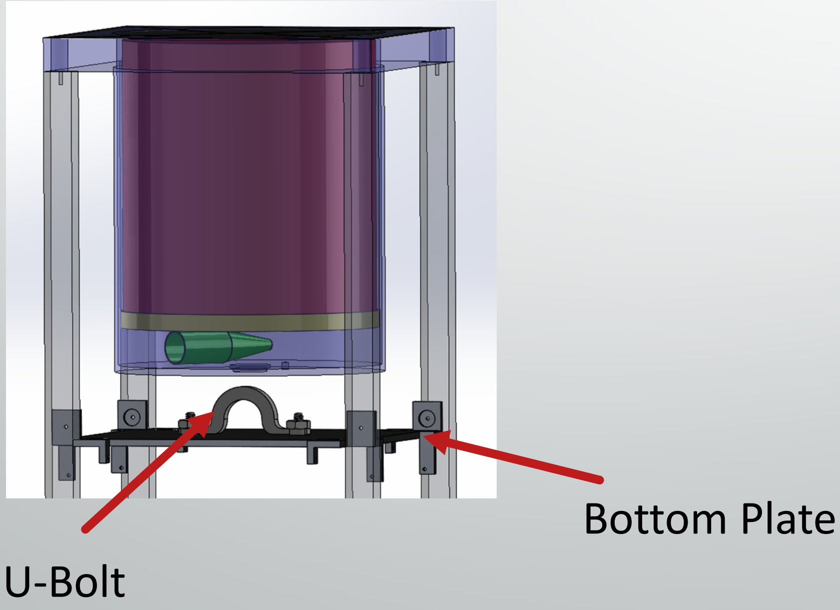
Test	Purpose	Possible Off-Ramps
Parachute Deployment Load Test	Validate that aluminum plate attached to parachute chord can withstand instant force of 353 lbf	Increase thickness, reinforce point of weakness
Fiberglass Housing Pressure Test	Validate fiberglass housing can withstand minimum 248 psi instantaneously	Increase thickness of fiberglass, carbon fiber housing
Black Powder Quantity Tests	Determine minimum amount of black powder needed to expel parachute from housing without damage to parachute	More perforations, parachute bag, more layers of protective paper

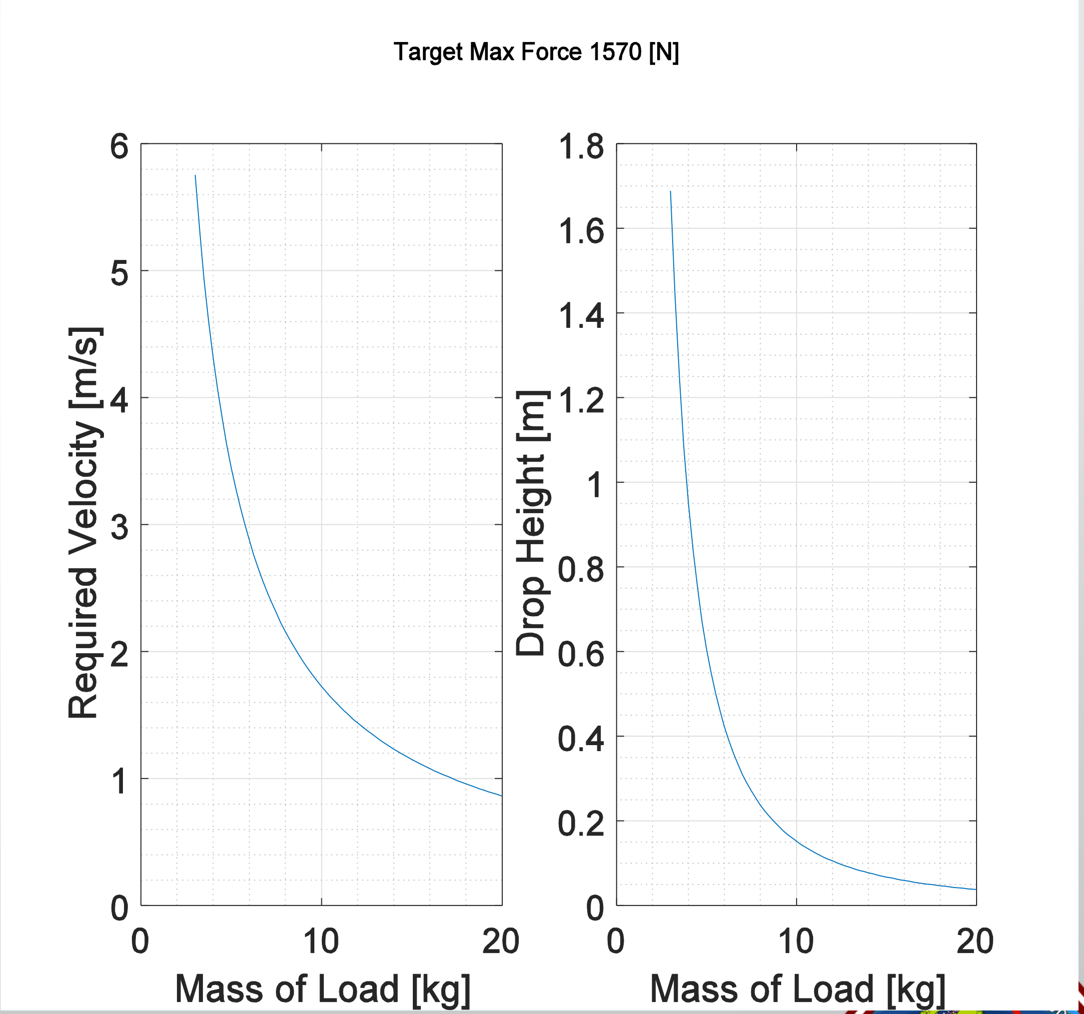
Parachute Deployment Load Testing

REPTAR

Raytheon

- Purpose
  - Verify plate can withstand 353 lbf instantaneous force
- Model
  - Drop 4 kilograms a distance of 1 meter





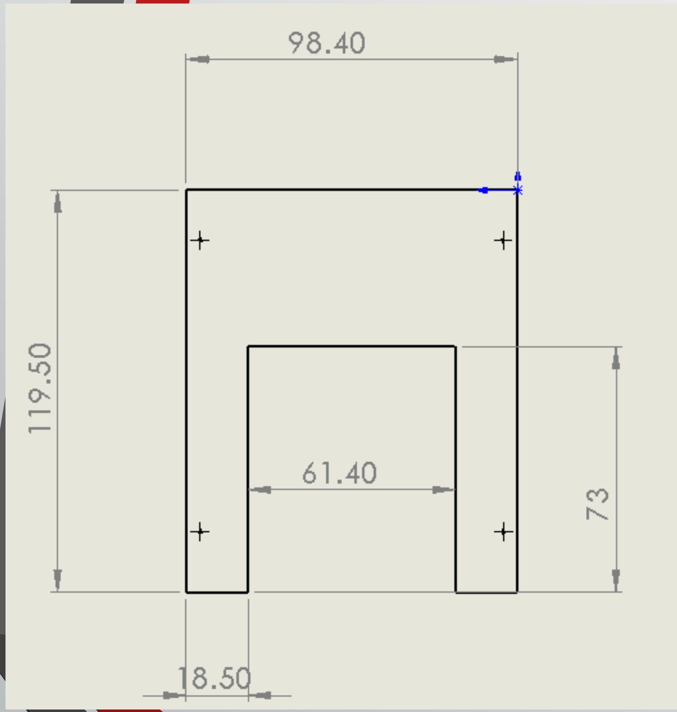
Future Manufacturing

REPTAR

Raytheon

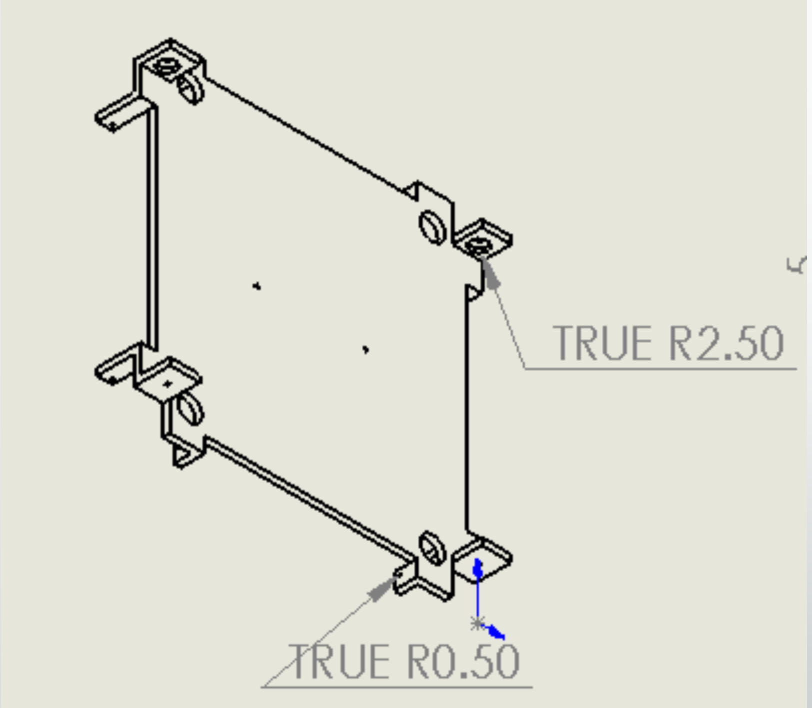
Side Wall

~4 Man Hours



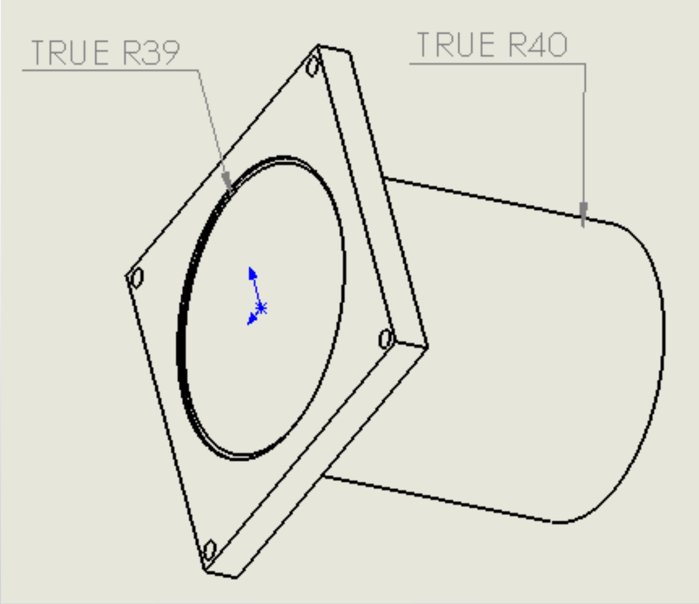
Bottom Plate

~5 Man Hours



Fiberglass Housing

~10 Man Hours



* All units in mm

Current and Future Orders

- Parachute x2 – Arrived
- Ejection Canisters – Arrived
- Black Powder – Arrived
- Fiberglass Tube – Arrived
- Fiberglass Cloth – Arrived
- Epoxy – Arrived
- Fiberglass Top Plate – Arrived
- Fiberglass Side Walls – Material needs to be ordered

CPE: Software and Electronic Hardware

Avionics Subsystem

Avionics Status-at-a-Glance

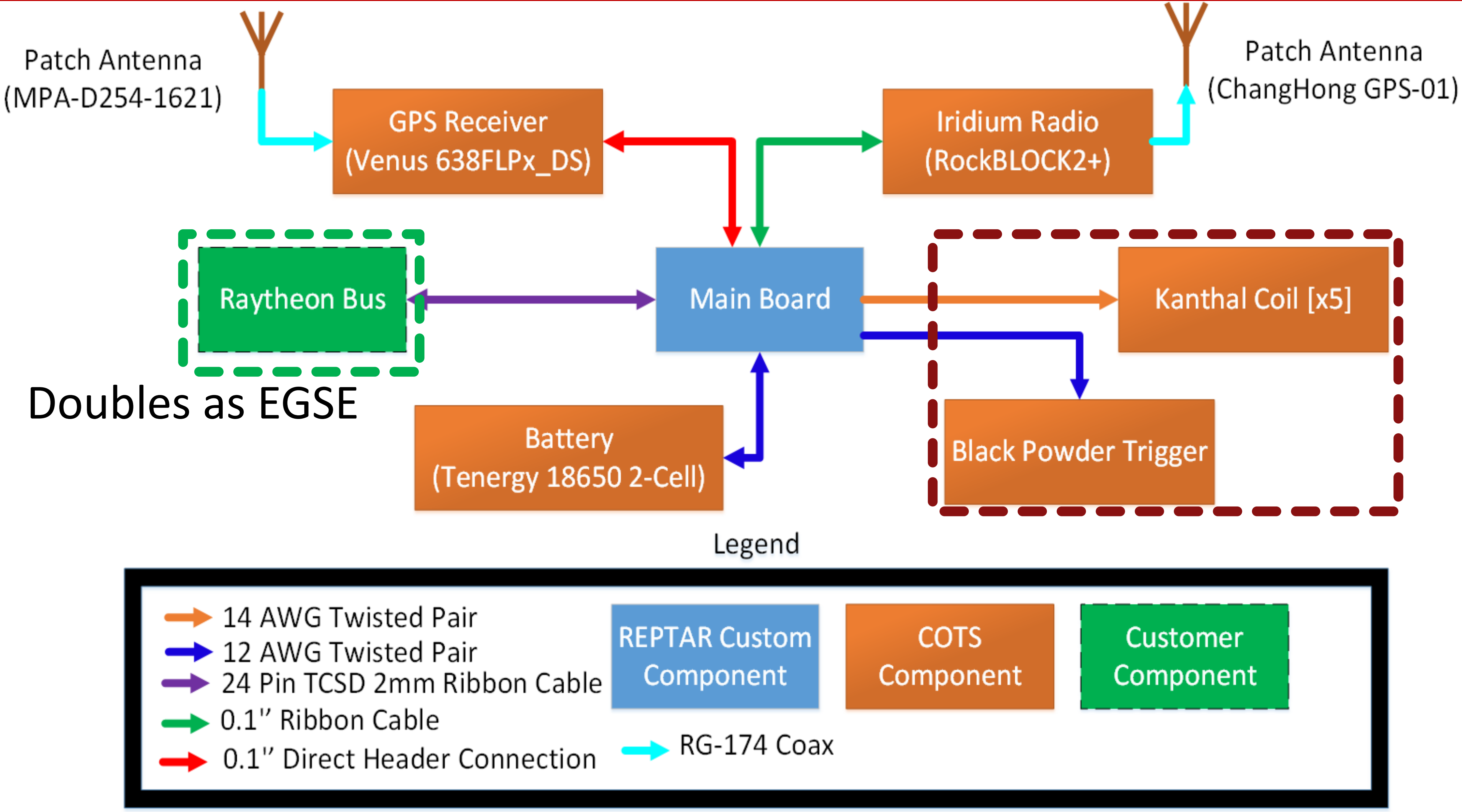
- No testing yet performed
- All components ordered

Task	Status	Comments
MainBoard Rev. A Design	113 Man Hours - Complete	Designed for simpler testing and mitigate regulator thermal Issues
Flight Software Development	7/30 Man Hours	Developed on Raspberry Pi 3 for simplicity and offramps
Bring Up Testing	0/20 Man Hours	Waiting on Rev A Board

Avionics System Breakdown

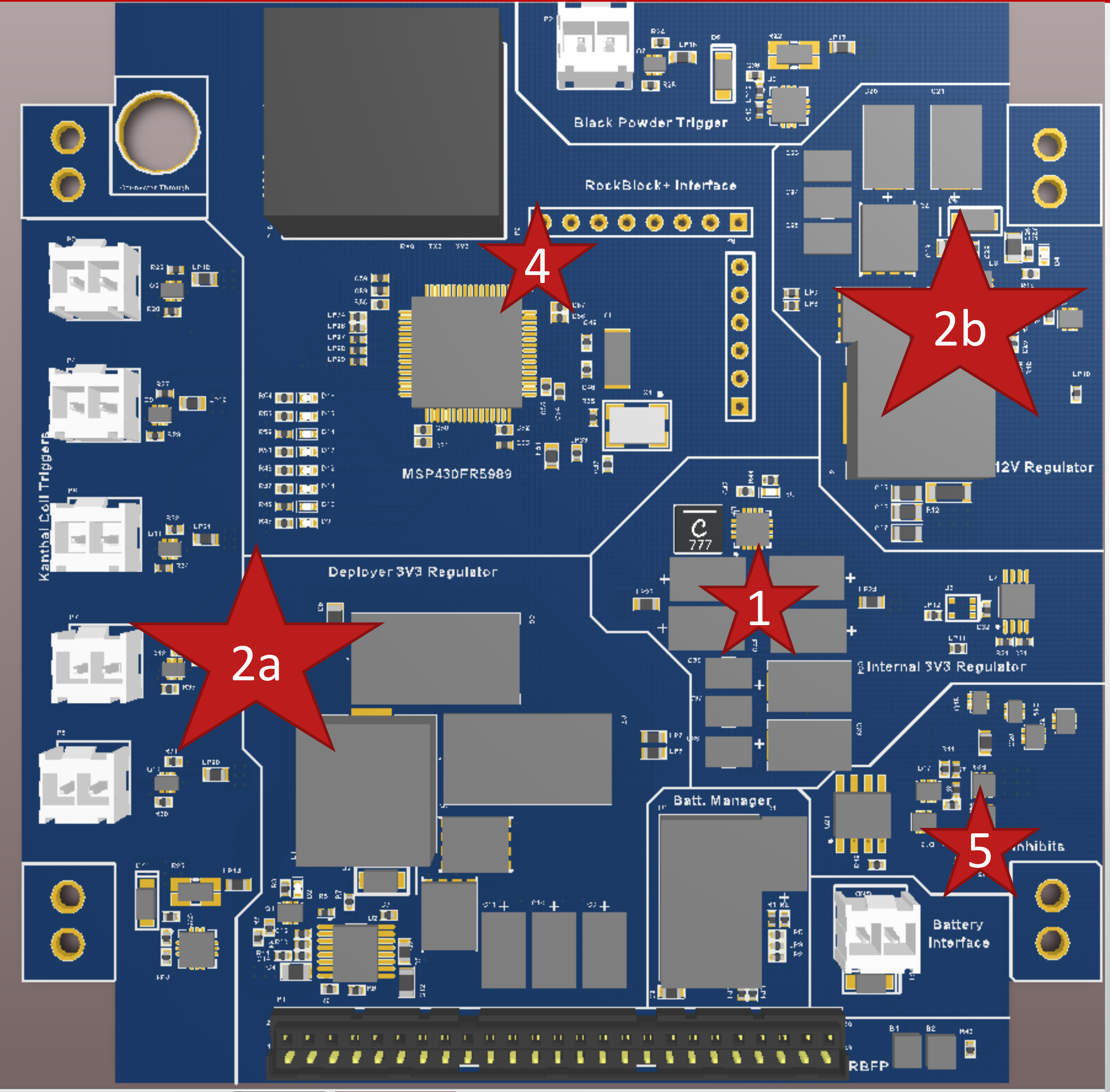
REPTAR

Raytheon



Future Hardware Testing

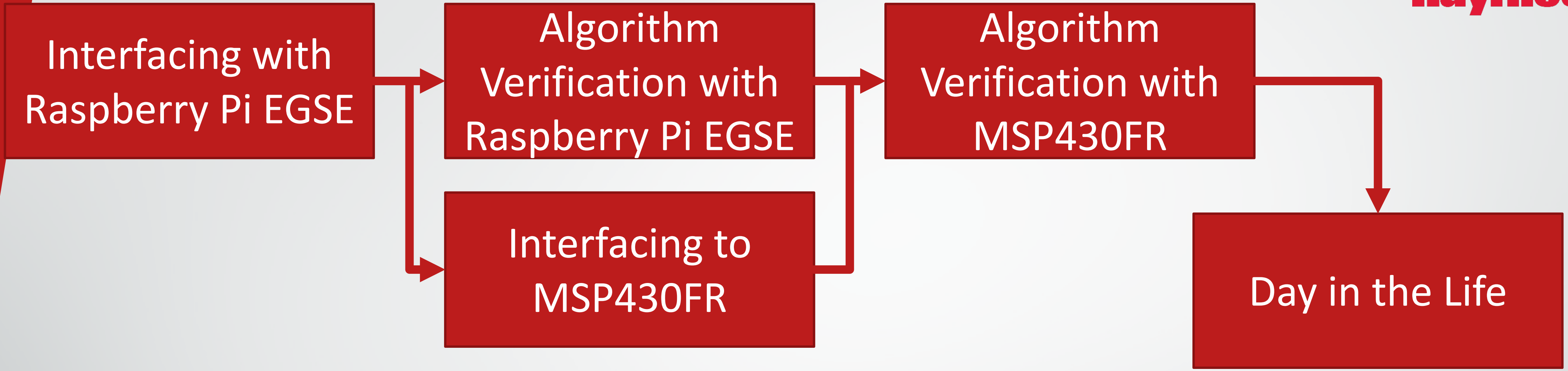
REPTAR



<u>MainBoard Bringup Tests:</u>

1. 3V3 Internal Regulator [2 MH]
    - Absolute Voltage, Ripple, and draw
2. 3V3 and 12V Deployment Regulator [8 MH]
    - Power Delivery
    - Trigger Logic
3. Altimeter [4 MH] (on Reverse)
    - Absolute Pressure Accuracy
4. GPS-Iridium Interface [4 MH]
    - Electrical Connection
5. Inhibits [2 MH]
    - Design logic

Software Testing Buildup

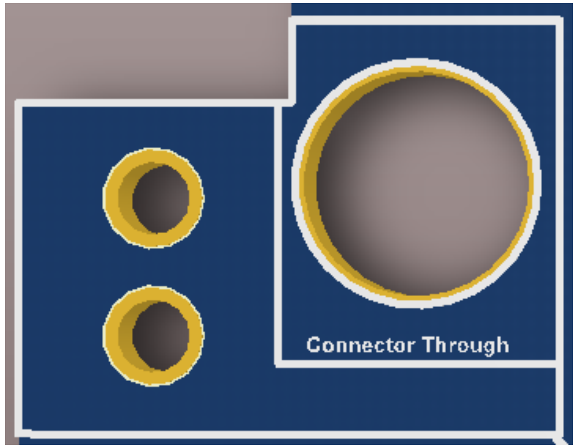


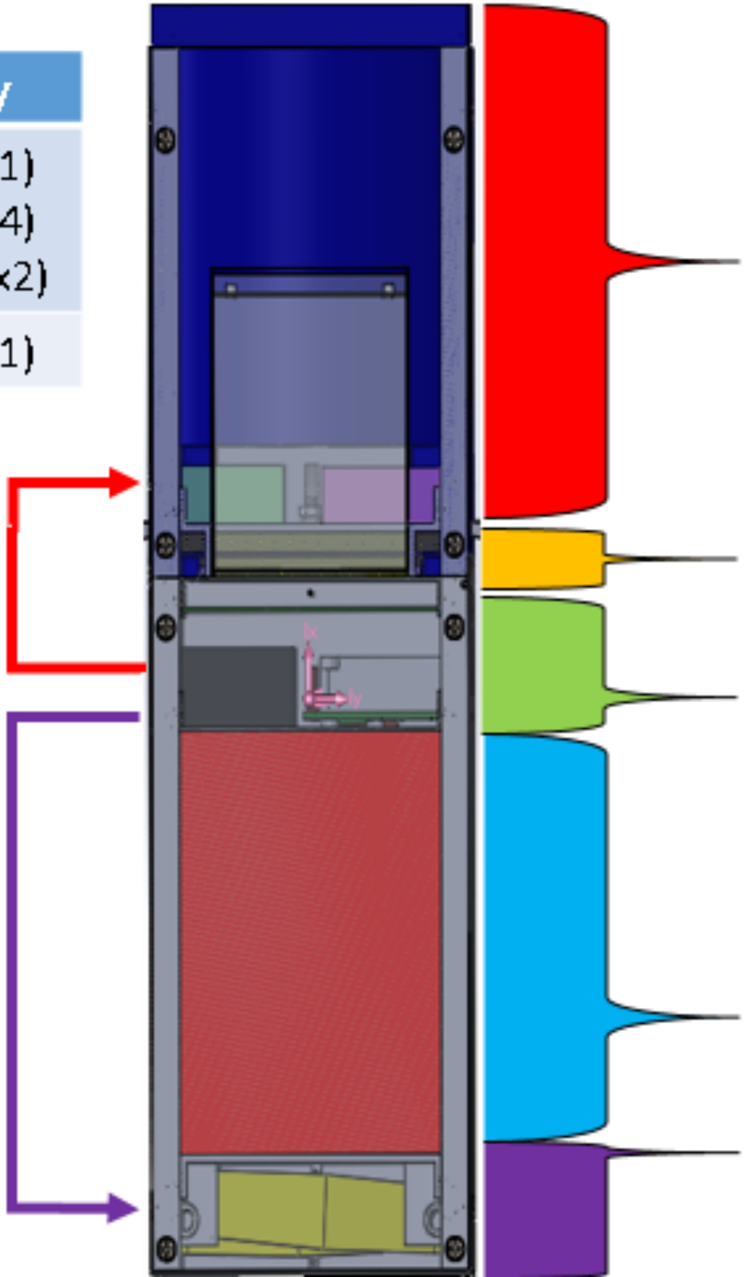
Mission Action	Time to Develop	Required Hardware
Altitude Determination	8 Man Hours	Altimeter
Deployment	5 Man Hours	Deployment Regulators
Location Determination and Transmission	15 Man Hours	Iridium Module & Antenna GPS Module & Antenna

Physical Interfaces

Path	Cables Outside of Avi. Bay
→ (red)	• AWG 12 Twisted Pair (x1) • AWG 14 Twisted Pair (x4) • RG-184 Coaxial Cable (x2)
→ (purple)	• AWG 14 Twisted Pair (x1)

Board Corner Connector Through:



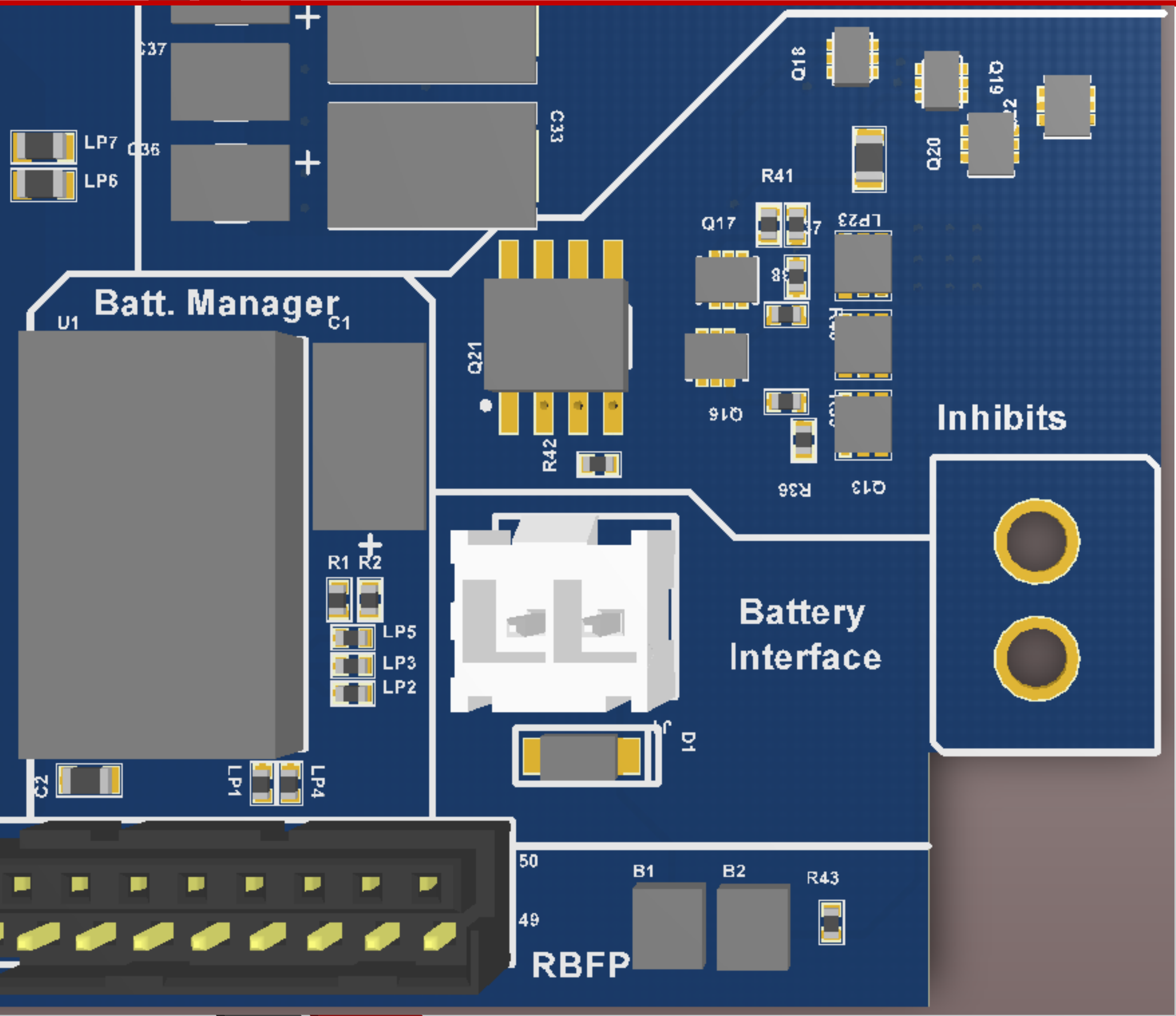


Section	Height [cm]	Avionics Components
Parachute Cavity	12.30	• Iridium Antenna • GPS Antenna • Black Powder Charge Trigger • Side Panel Burn wires (x4)
Side Panel Foam	1.26	-
Altimeter and Avionics Bay	3.64	• Main Board • Iridium Radio • GPS Receiver • Battery
Raytheon Payload	10.00	-
Landing Legs	2.80	• Bottom Panel Burn wire

Battery Interface and Inhibits

REPTAR

Raytheon



Responsible For:

- Providing Power to all Components

Hardware Tests:

- Battery Charge/Discharge
- Inhibit Logic Verification
- Battery Manager [If Time]

Software Tests:

- **None**

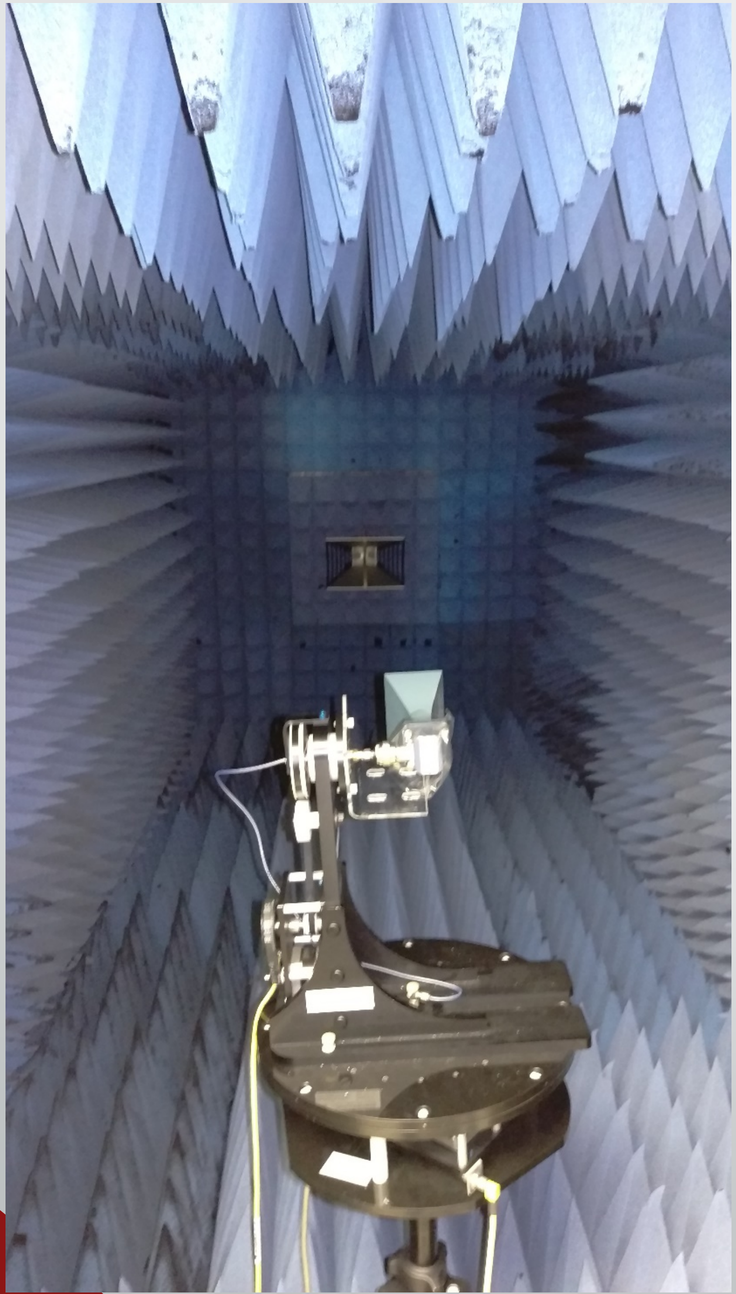
Off-ramps:

- EGSE

Antenna Testing

REPTAR

Raytheon



Responsible For:

- Location Determination and Transmission

Hardware Tests:

- Radiation Pattern Determination
  Requires Anechoic Test Chamber
  (currently booked in ECEE Department)

Software Tests:

- **None**

Offramps:

- External Antenna Mount

CPE: Landing Leg Deployment

Landing Leg Design Changes

- Changed **Copper Foam Legs** to **Aluminum Foam Legs**
  - Done by lowering density of aluminum foam
  - Delays caused in the changing process, will not cause further delays once ordered
- Will machine Aluminum foam to desired shape
  - Been tested in the machine shop with samples, proving viability of in house machining
  - Saves $500 and 3 weeks of time to receive material

Past Manufacturing

REPTAR

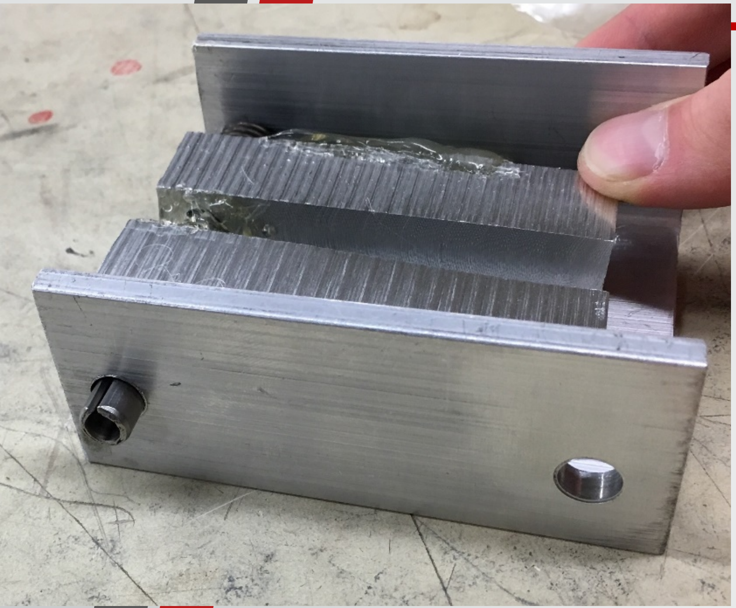
Raytheon

- Most parts for the landing subsystem are purchased parts
  - Torsional springs – Arrived
  - Compression springs – Arrived
  - Slotted pins – Arrived
  - Aluminum Foam Material for legs– Ordered (Expected Arrival: 2/19)
  - Epoxy for mounting – Arrived
- Leg locking mechanism attachment has been manufactured

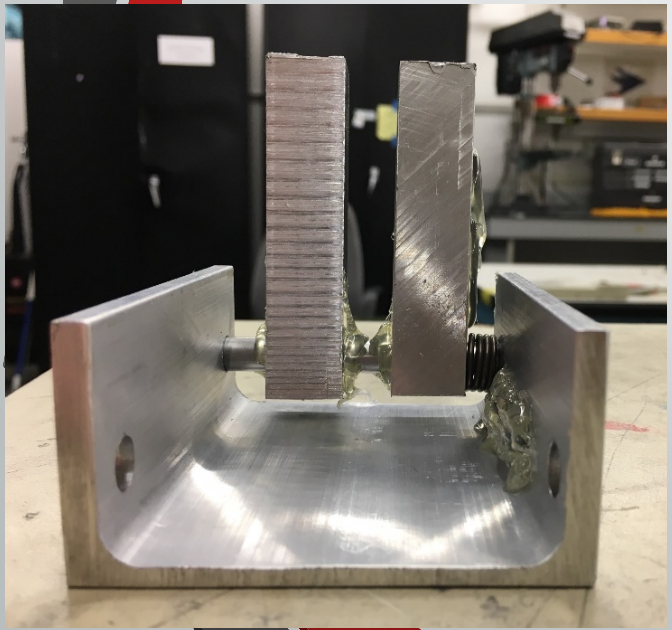
Past Testing

Test	Purpose	Results
Epoxy Testing	To test the adhesive capabilities of the NASA rated epoxy purchased	Successful, upwards of 49 N of applied force without breaking (needed 10 N)
Deployment Testing	Testing the reliability of the torsion springs in deploying a pair of legs	Successful, the provided torque is enough to overcome a wind of 5.5 m/s

Deployment Testing



- Purpose: Testing the reliability of the torsion springs in deploying a pair of legs
- Differences from actual setup
  - Use of hot glue instead of epoxy
  - Use of Aluminum legs instead of Al foam
- Key Results
  - Confirmation of system deployment with a single spring
  - Torque expectation has been met

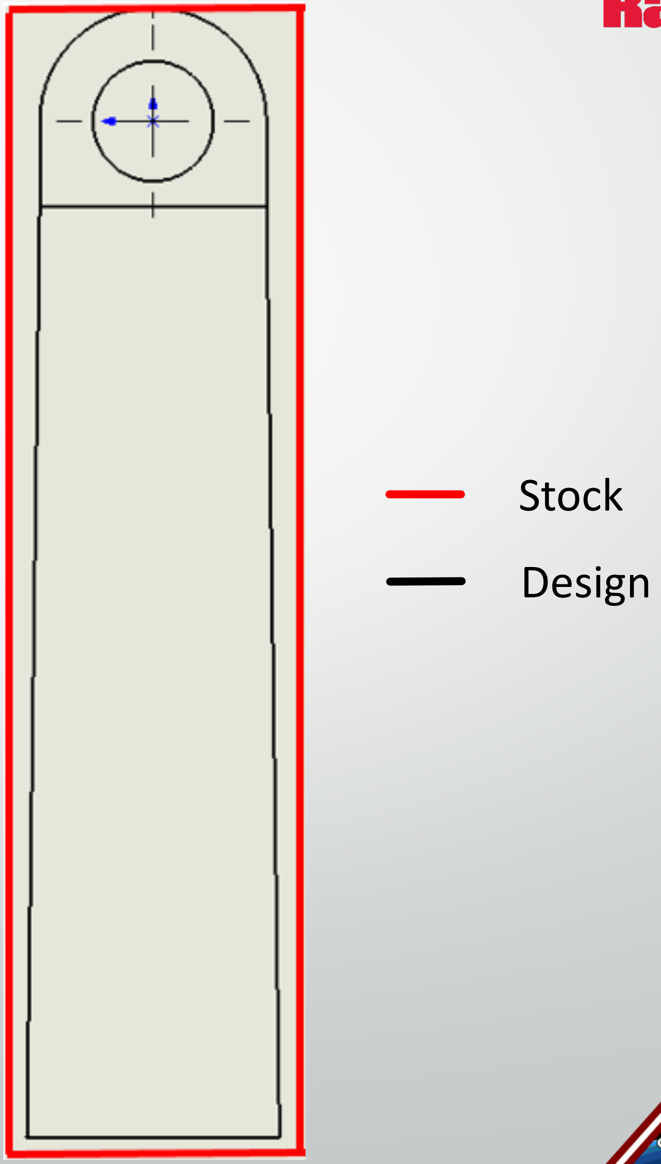


Future Testing

Test	Purpose	Possible Off-Ramps
Impact Loading Test	Verify energy absorbing properties by measuring deformation with known impact	Changing the taper ratio, lower system mass
Locking Mechanism Testing	Testing the locking mechanism for effectiveness and reliability of design	Alter the locking mechanism design, change in spring

Future Manufacturing

- Aluminum Foam Legs
  - Stock leg from ERG Aerospace
  - Needs to be machined to specifications in design
  - ~15 man hours



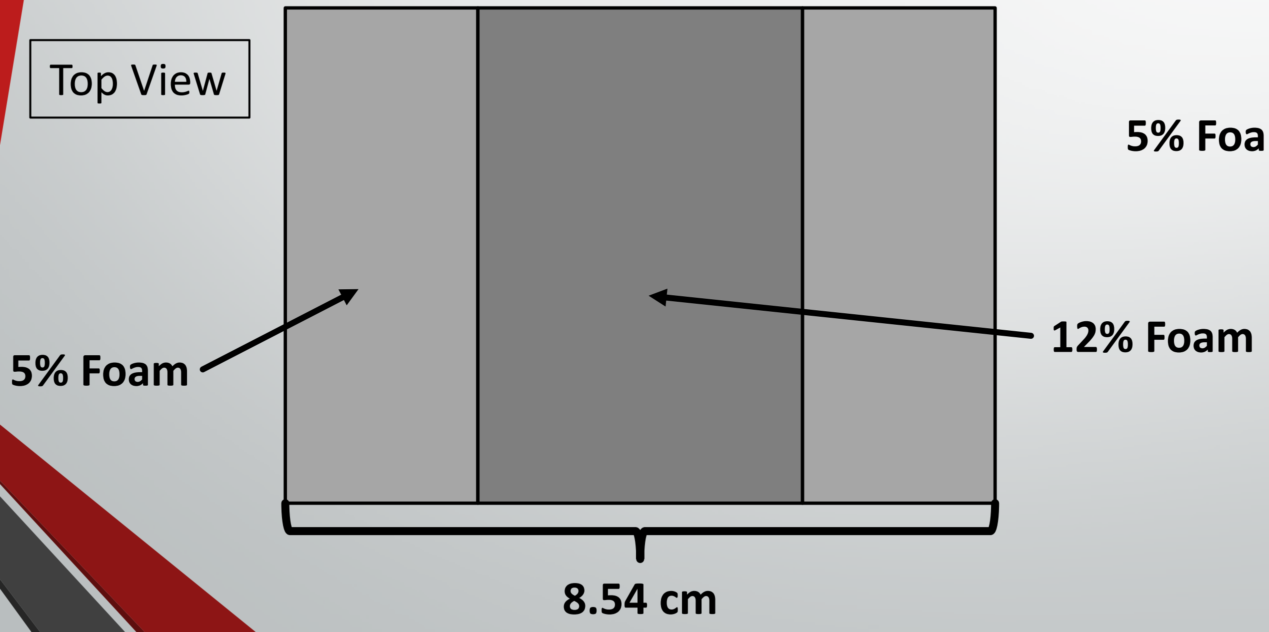
CPE: Landing Side Panel Deployment

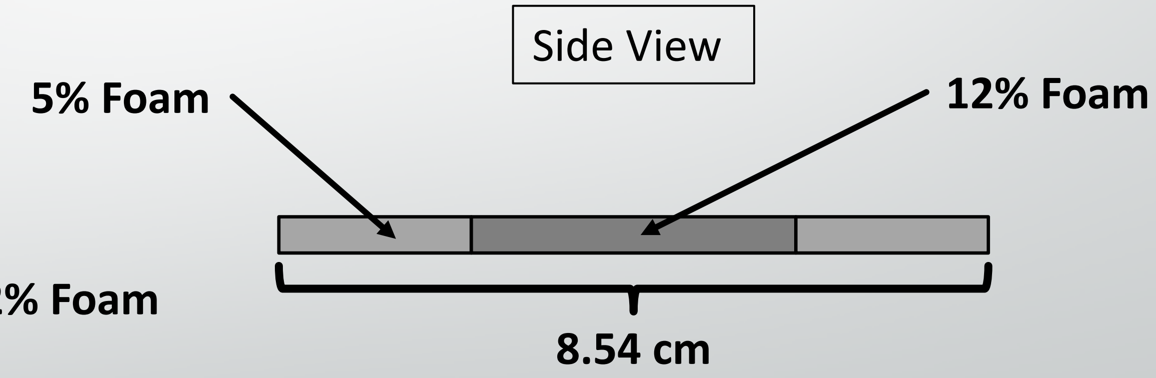
Landing Side Panel Design Changes

REPTAR

Raytheon

- Changed from a **Uniform Density** foam to a **Dual Densities Combination** of foam
  - This is done by obtaining a 12% density aluminum foam and a 5% density aluminum foam





Past Manufacturing

- Most parts for the landing subsystem are purchased parts
  - Torsional springs – Arrived
  - Side panel pins – Arrived
  - CNC Side Panels – Ordered (Expected Arrival: 2/18)
  - Aluminum Foam for center panels – Arrived
  - Kanthal coil wire – Arrived

Future Testing

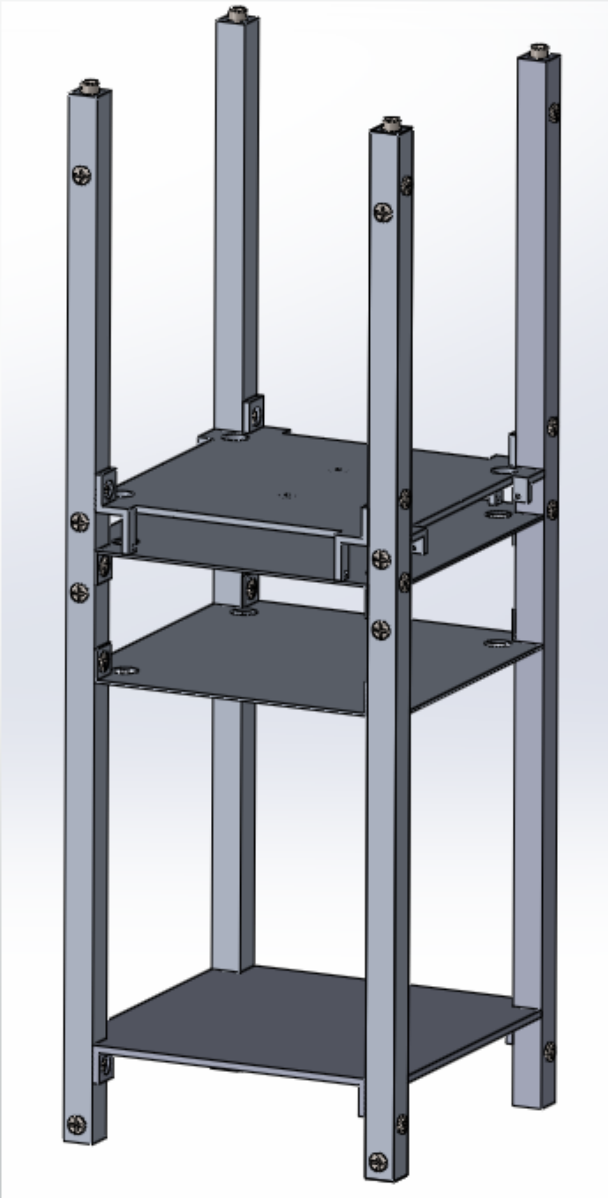
Test	Purpose
Deployment Testing	Testing the reliability of the torsion springs and locking mechanisms for a side panel

Future Manufacturing

REPTAR

Raytheon

- 4 Center Plates that connect to the rails and provide structure and deployment surfaces
  - ~25 man hours



Landing Manufacturing Summary

Work Completed:

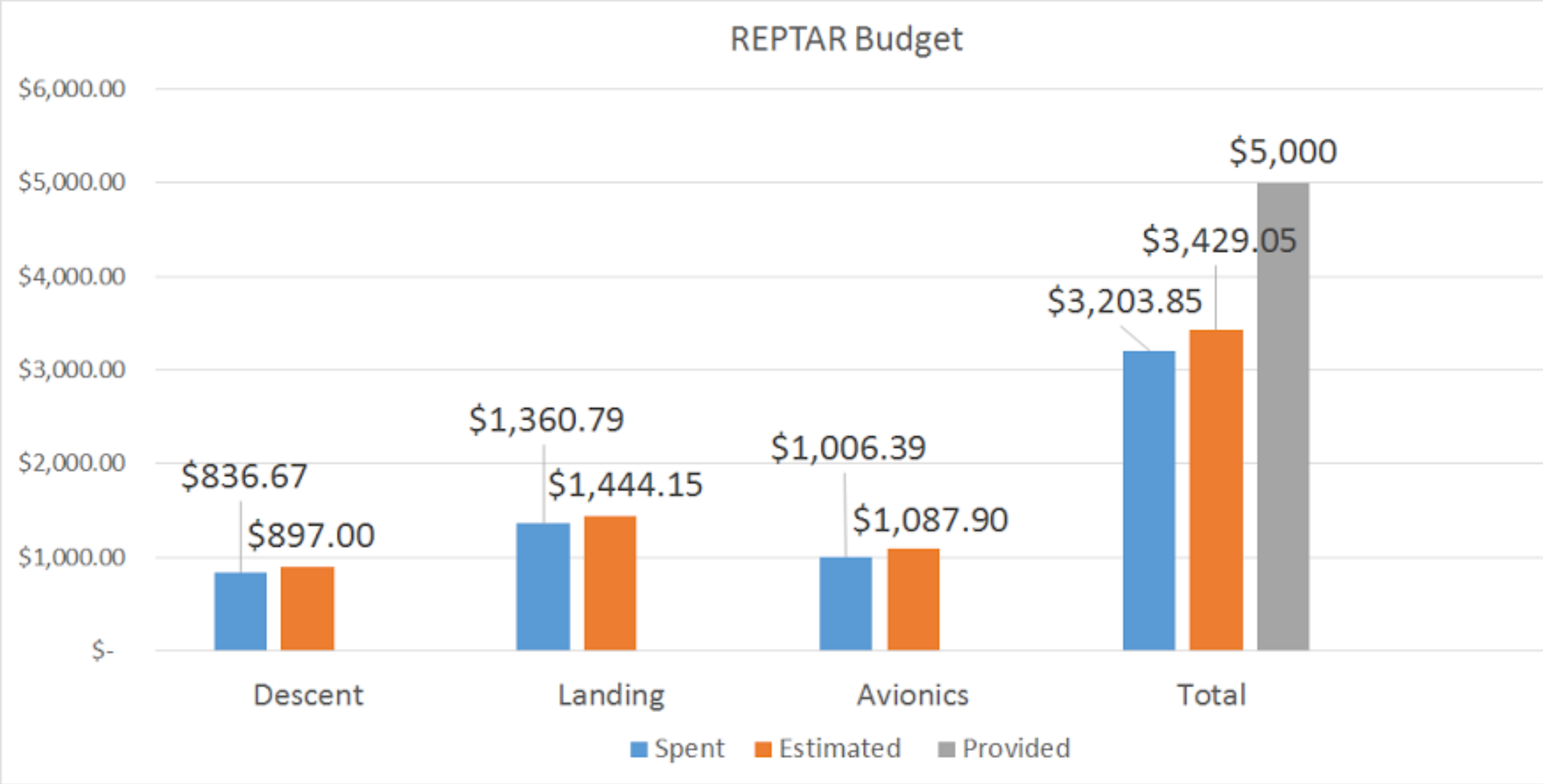
- Side rails constructed
- Leg locking mechanism constructed
- Outer Panels constructed

Future Work:

- Manufacture remaining parts (~8 man hours)
- Integration of Side Panels (4-6 man hours)
- Integration of Aluminum Foam Legs (4-6 man hours)

Budget

Budget

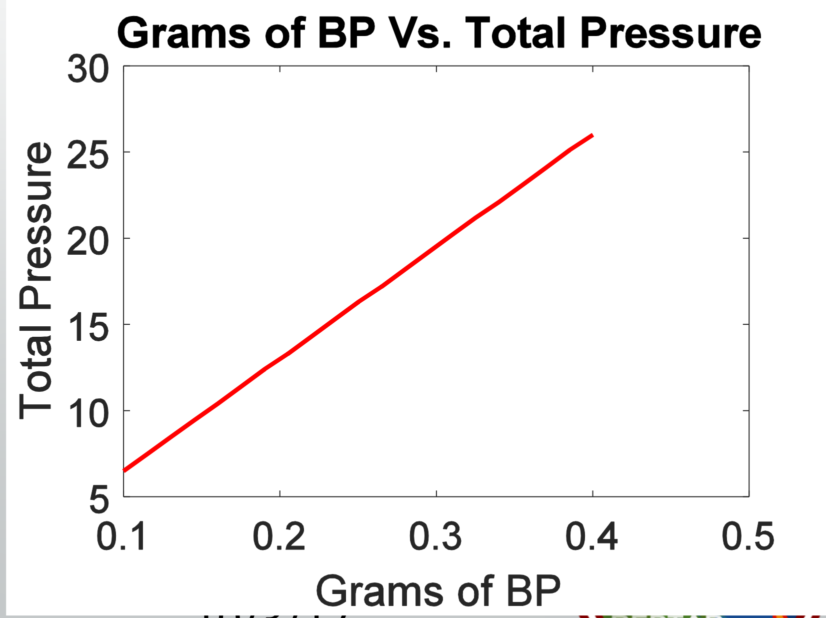

REPTAR Budget
$6,000.00
$5,000.00
$4,000.00
$3,000.00
$2,000.00
$1,000.00
$-
$836.67
$897.00
$1,360.79
$1,444.15
$1,006.39
$1,087.90
$3,203.85
$3,429.05
$5,000
Descent
Landing
Avionics
Total
Spent
Estimated
Provided

Backup

Descent Backup

Black Powder Tests, No Parachute

- PVC Housing created to hold ejection canister
- Pressure gauge attached to bottom of PVC Housing
- High speed camera placed on gauge
- Canister connected to 12V, 5A power supply
- Top of PVC sealed down to prevent leaks
- From Model to create 20 psi equilibrium, 0.128 g of powder needed
- Results:
  - High speed camera showed equilibrium pressure of 24 psi
  - ~17% difference in experiment and model



Air Compressor Test

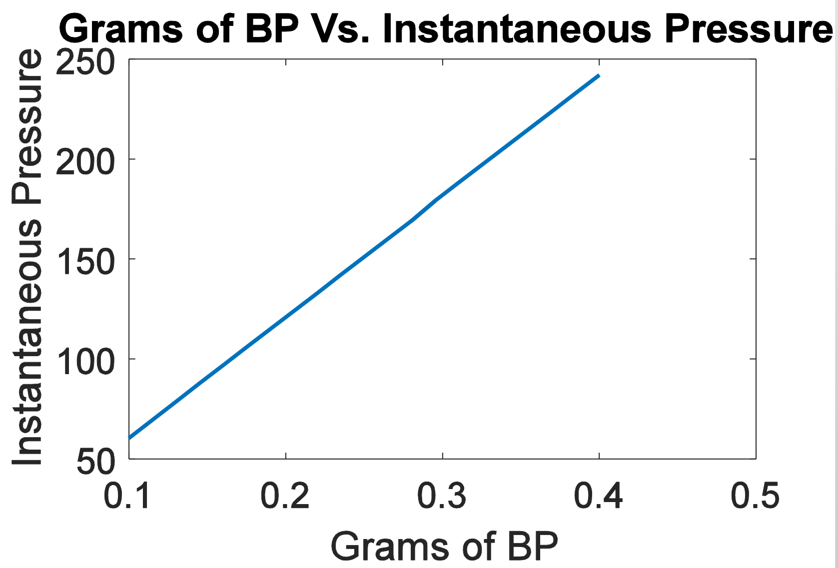
- Pressure gauge removed
- U-bolt attached to bottom of housing
- Shock chord of parachute fed through housing and attached to U-bolt
- Parachute folded inside PVC housing
- Air compressor attached to hole where ejection canister would be
- Aluminum foil taped over top
- Some parts of experiment had small perforation in middle of foil
- Results:
  - 40 psi – slight emergence of parachute through middle
  - 50 psi – slight emergence of parachute through side of foil
  - 50 psi w/ perforation – good emergence of parachute through middle
  - 80 psi – very good emergence through middle
  - 80 psi w/ perforation – fully deployed through middle

Black Powder Tests, With Parachute

REPTAR

Raytheon

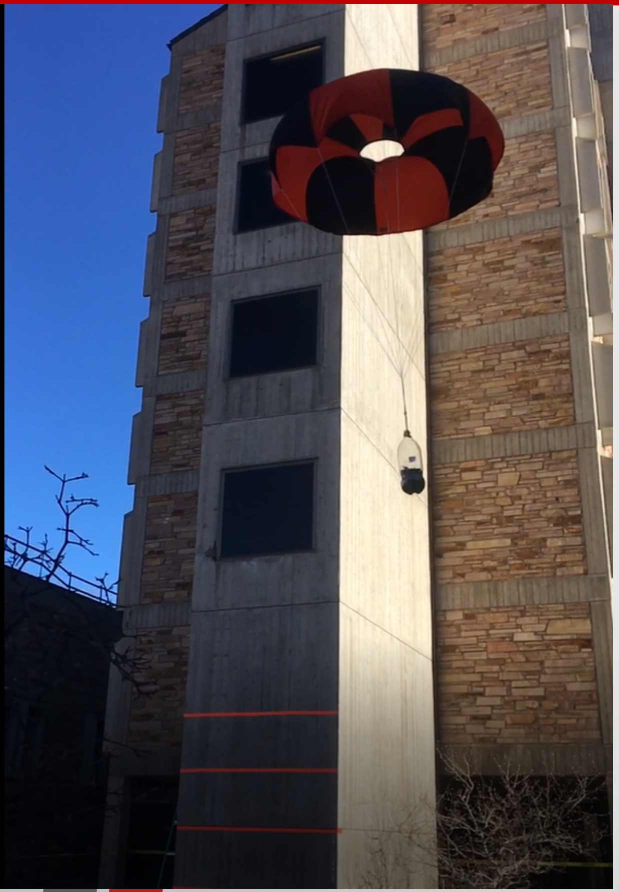
- PVC Housing with ejection canister inside
- Parachute shock chord attached to U-bolt
- Parachute folded inside of housing with recovery wadding between it and ejection canister
- Aluminum foil with small perforation in middle and taped down
- Canister attached to power supply with 12V and 5A
- Results:
  - .1 grams powder predicted to be ~75 psi instantaneous pressure
    - Did not hear ignition go off and no movement of parachute
  - .4 grams powder predicted to be ~248 psi instantaneous pressure
    - Parachute left housing, video recorded, burnt parachute
  - Could lower grams and probably still deploy



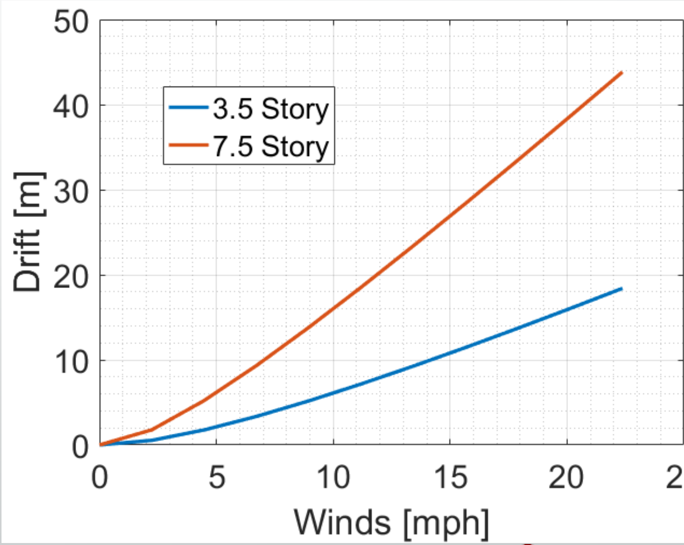
Drop Test

REPTAR

Raytheon



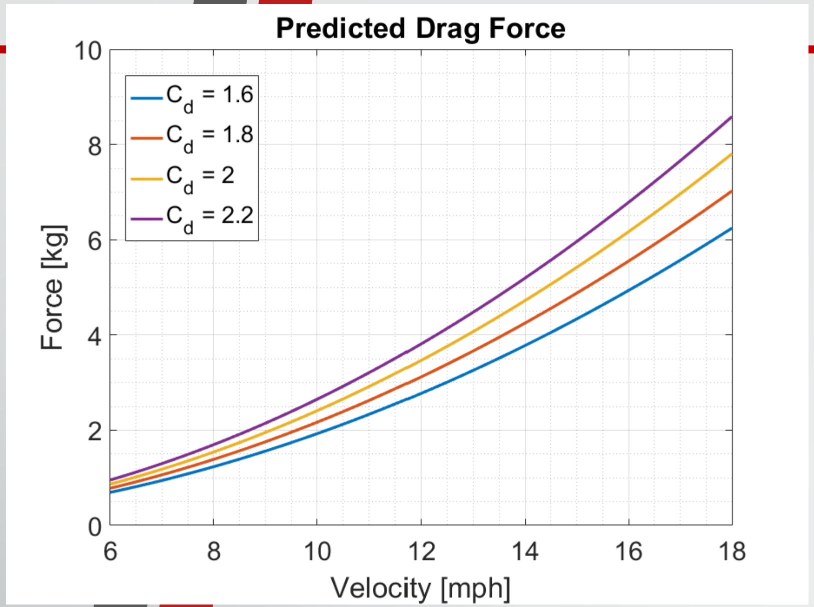
- Lines placed across ECOT to give measurements of distance
- High speed camera set up with two other team members filming
- Caution tape placed to cut off courtyard from bystanders
- Parachute was as inflated as possible before drop
- Dropped from 8th story window instead of 3rd due to difficulties
- Anemometer on ground gave maximum reading of 2.2 mph
- Drift model stated 2.2 mph would provide 4 meter maximum drift
- Trouble communicating and ensuring safety of bystanders
- Once dropped, accelerated to wind speed and moved away from tower
- Minimal good data was acquired

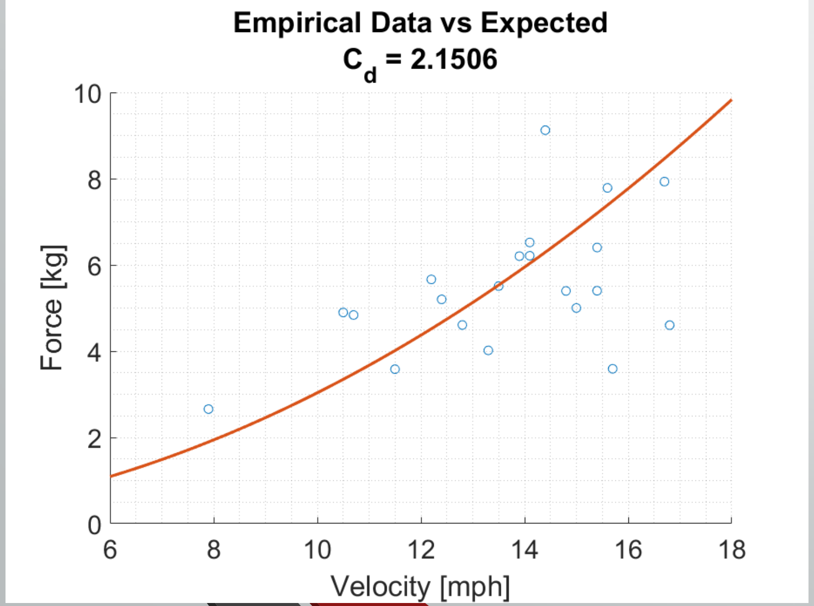


Parachute Drag Test

REPTAR

Raytheon





- Parachute shock chord will be attached to rope which will be attached to a digital scale with hook
- The digital scale will be attached to the rod of a headrest in a car
- The rope will be approximately 4 meters in length
- Team member will begin to accelerate car to 13 mph
- Team member in back seat will slowly release line of rope as parachute gets taut
- Car will stay at 13 mph, team member in back will record different values of force from scale
- Third team member will hold anemometer out window and record wind data as backseat member records force
- Comparing the velocity and force will allow calculation of the coefficient of drag of parachute
- Important because if coefficient is off, landing team must prepare for different landing speed

Aluminum Plate Load Test

- Aluminum plate will be attached to railings of CubeSat
- U-bolt will be placed in center and screwed into plate
- Shock chord of parachute will be attached to U-bolt
- When parachute deploys and becomes taut it will cause approximately 40 G’s or 353 lbs of force on the aluminum plate
- Test is to ensure plate will not fracture/buckle
- Plate with railings will be suspended upside down
- A chain will be attached to U-bolt and other end will hold a ten pound plate
- Chain will be 1 meter in length
- Ten pound plate will be held against aluminum plate and dropped vertically
- If aluminum plate breaks it will need to be reinforced. If not test is a success

Fiberglass Housing Pressure Test

REPTAR

Raytheon

- Prior tests showed that 0.4 grams expels parachute
- 0.4 grams equates to 248 psi instantaneous pressure
- Actual amount used for project will be less than this
- If fiberglass housing can withstand an ignition of 0.4 grams it will not break during testing
- Model calculates burst pressure of fiberglass cylinder to be 717 psi
- Creates a FOS of 2.89

$$P = \frac{2St}{(OD)(SF)}$$

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

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

Black Powder Quantity Tests

REPTAR

Raytheon

- Purpose
  - Determine minimum amount of black powder needed to expel parachute without damage to parachute
- Possible Off-Ramps
  - More perforations
  - Parachute bag
  - More recovery wadding

Fiberglass Housing Manufacturing

- COTS 8cm diameter fiberglass tube and 0.030" fiberglass sheets cut to 10cm square.
- Fiberglass cloth to join flat sheets to tube. Fiberglass cloth and resin between the plates to create a thicker, plied panel with factory finish.
- Cut circular plate matching OD of 8cm tube and adhere using resin and fiberglass "stitches."
- Cut/grind out hole in top plates
- Sand
- Drill mounting holes and holes for chute line and cartridge.

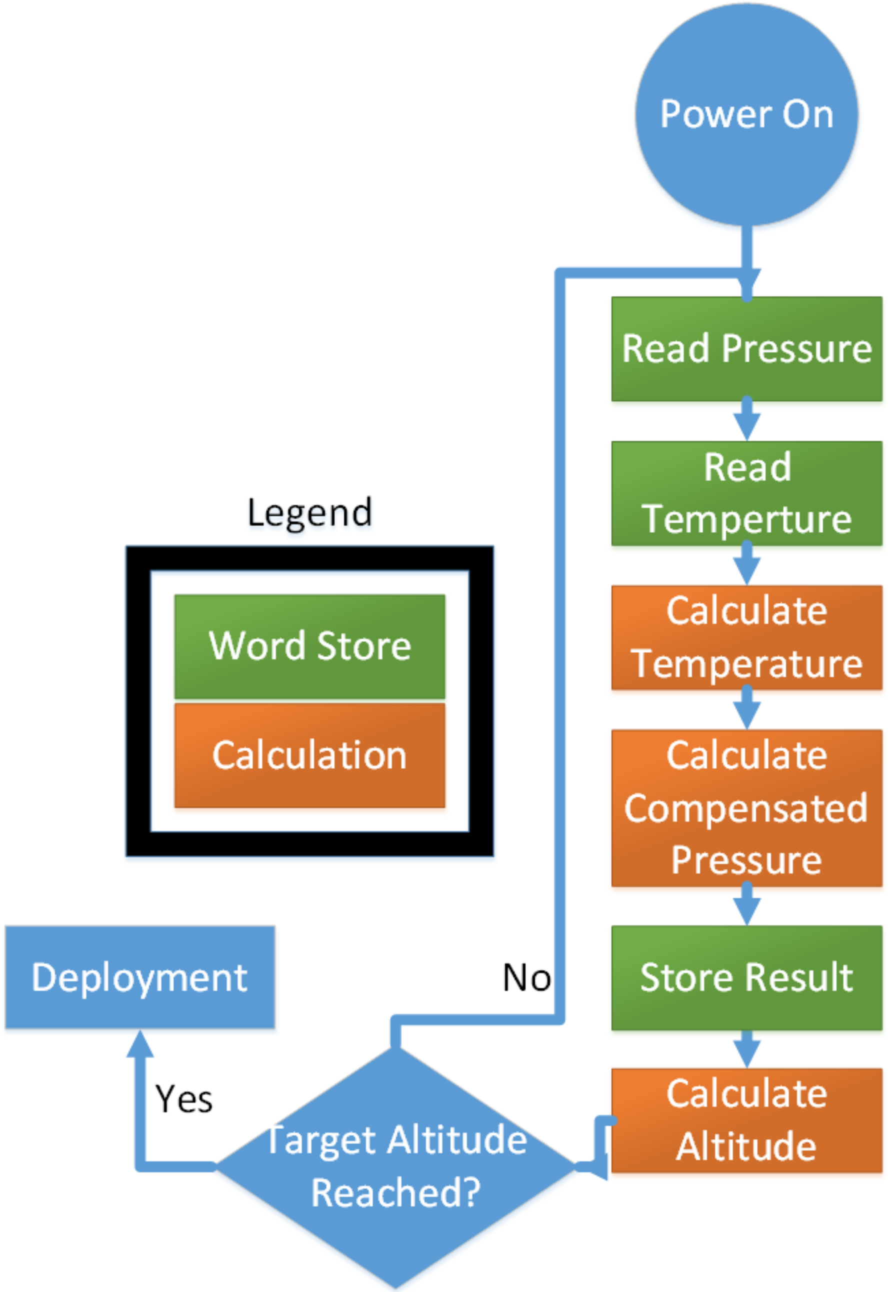
- Side panels are cut from .030" sheet and mounted with screws.

Avionics Backup

Altitude Determination Algorithm

REPTAR

Raytheon



EGSE Testing Components:

- Altimeter Breakout Board
- Rasberry Pi 3 EGSE

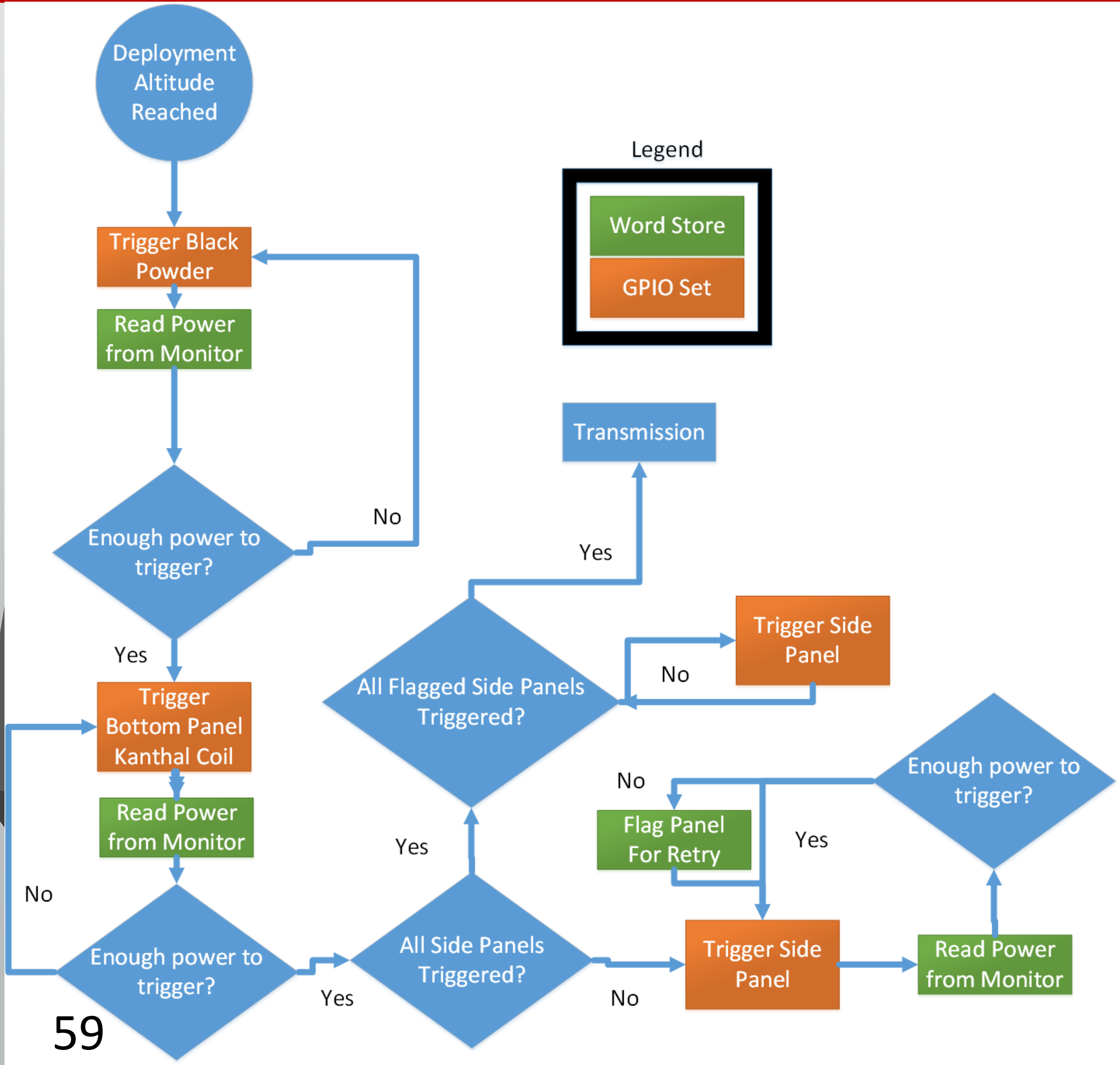
Flight Testing Components:

- MainBoard
- Raspberry Pi 3 EGSE (if MSP430FR drivers fail)

Deployment Algorithm

REPTAR

Raytheon



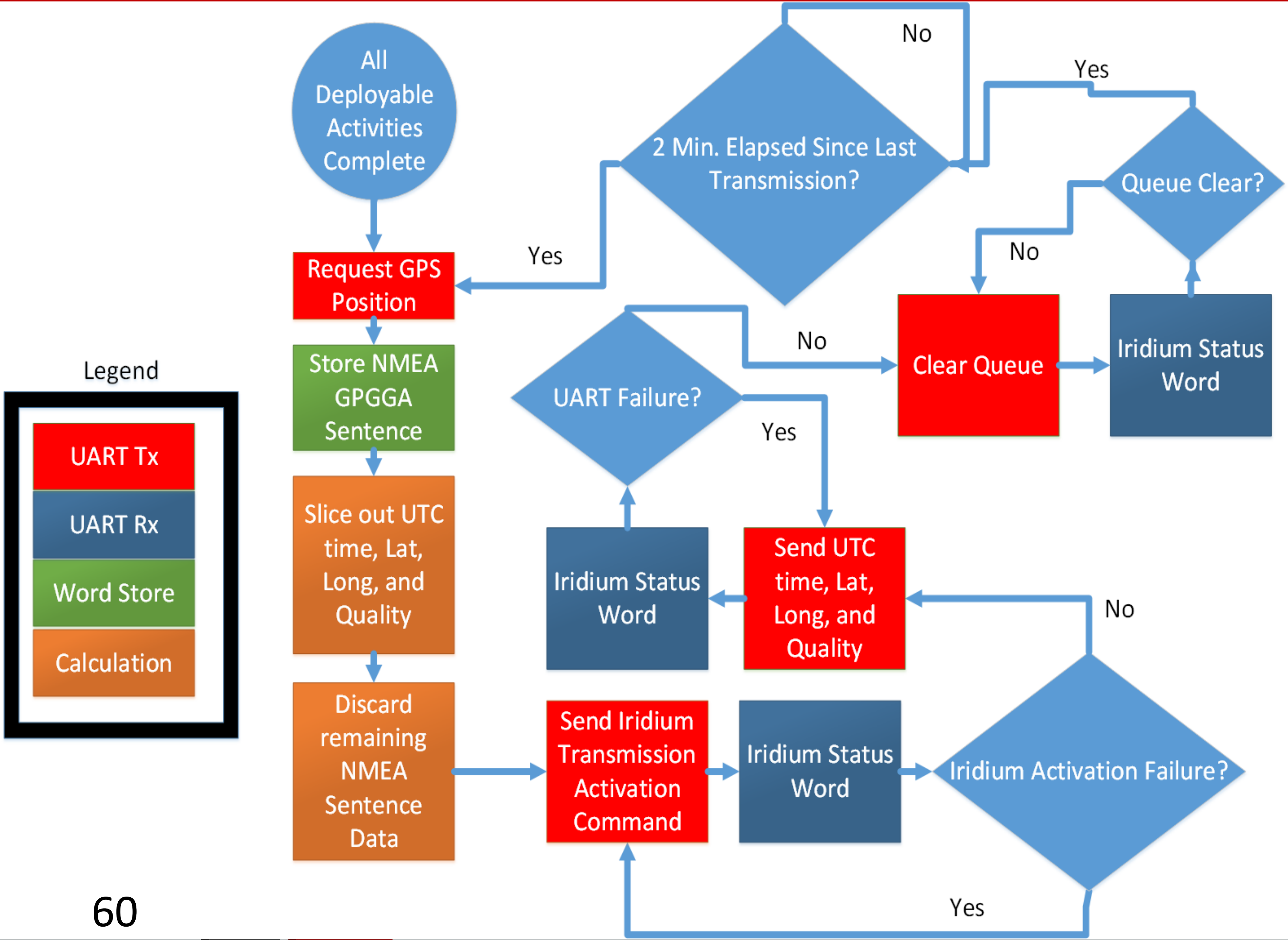
EGSE Testing Components:

- N/A

Flight Testing Components:

- MainBoard
- EGSE (if MSP430FR drivers fail)

Location Determination/Transmission Algorithm



Raytheon

EGSE Testing Components:

- Iridium RockBlock
- Venus GPS
- Rasbperry Pi 3 EGSE

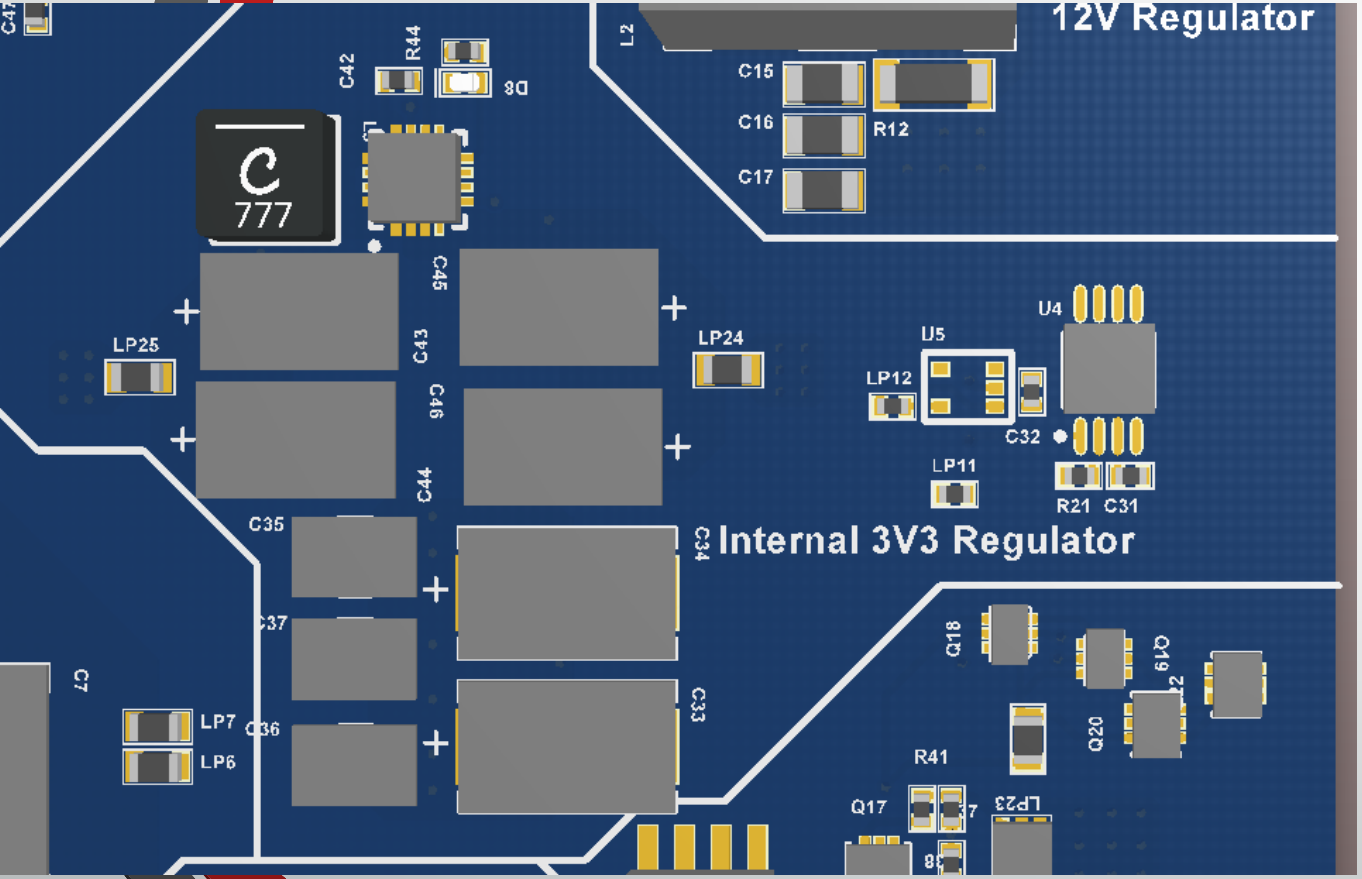
Flight Testing Components:

- MainBoard
- Rasberry Pi 3 EGSE (if MSP430FR drivers fail)

3V3 Internal Regulator

REPTAR

Raytheon



Responsible For:

- Providing power to GPS, Iridium, and MSP430FR

Hardware Tests:

- Verify Absolute Voltage Accuracy (+-5%)
- Verify Voltage Ripple (<300mV)
- Verify Current Draw (2A Max)

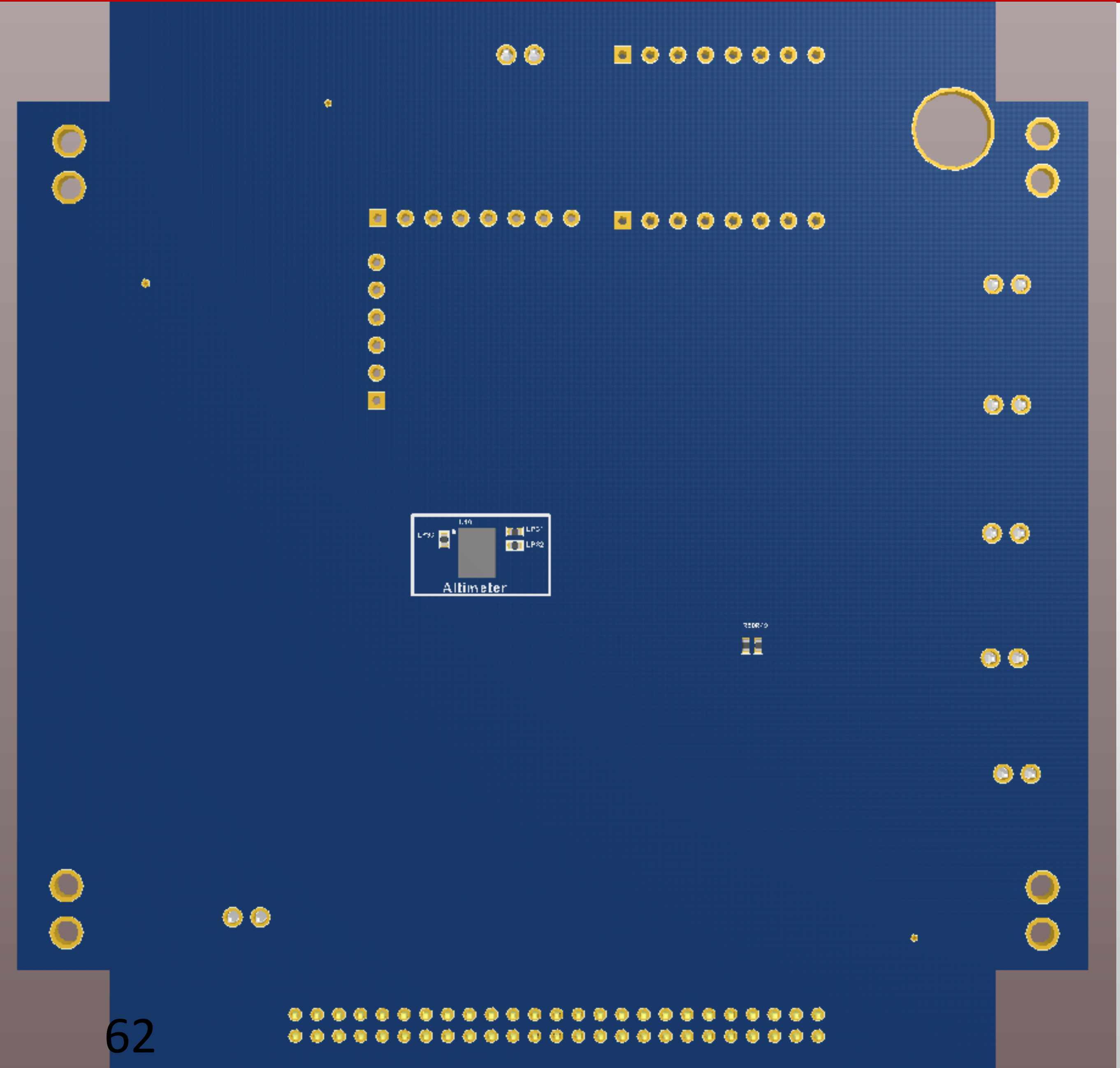
Software Tests:

- N/A

Off-ramps:

- Hardware: COTS Dev. Board

Altimeter



Responsible For:

- Altitude Determination with MSP430FR

Hardware Tests:

- Altimeter Correctly Mounted
- Verify Altimeter Accuracy via comparison to known standard barometer

Software Tests:

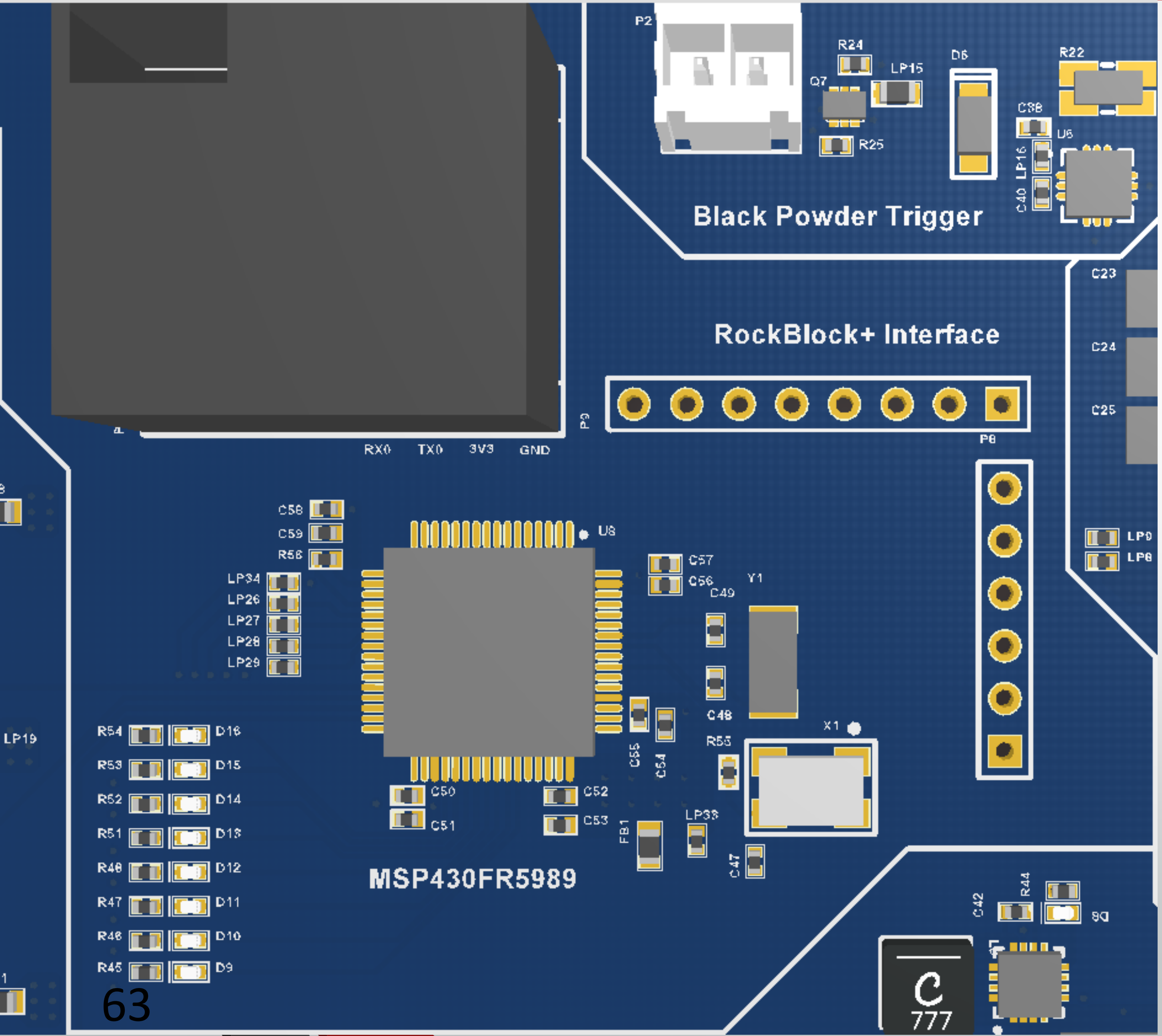
- Verify I2C Interface
- Verify Altitude Calculation (MSP430FR)
- Flight Test

Off-ramps:

- Hardware: COTS Dev. Board
- Software: Raspberry Pi 2 EGSE

GPS-Iridium Interface

REPTAR



Responsible For:

- Determining and Transmitting Location

Hardware Tests:

- Correct Electrical Connections
- Internal 3V3 Regulator Testing

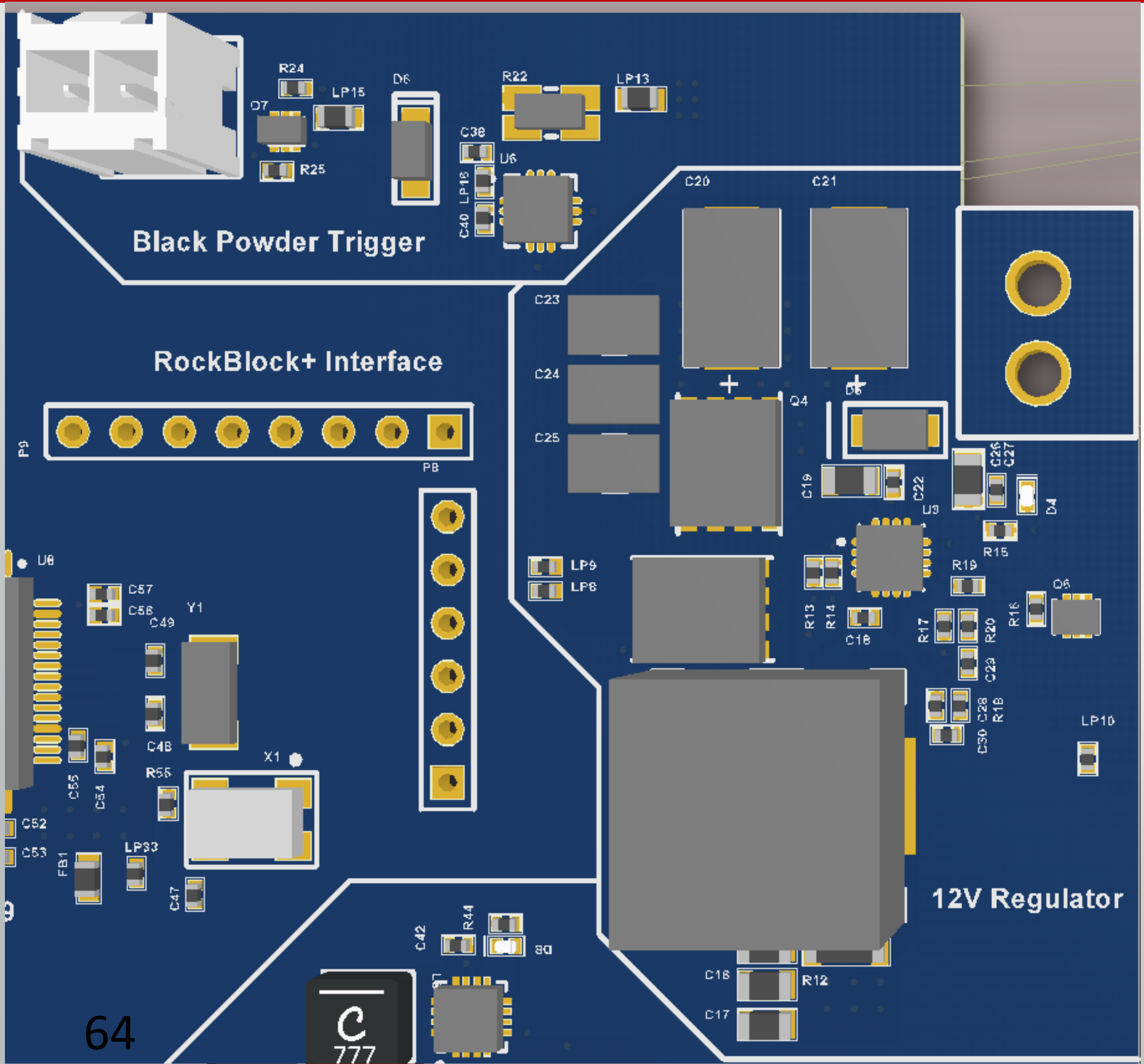
Software Tests:

- Verify UART Communication to each
- Verify Parsing Code
- Flight Test

Off-ramps:

- Hardware/Software: Raspberry Pi 2 EGSE

Black Powder Trigger



Responsible For:

- Parachute Deployment

Hardware Tests:

- Power Sensor Verification via known Standard
- Trigger Logic Verification
- 12V Regulator Power Verification

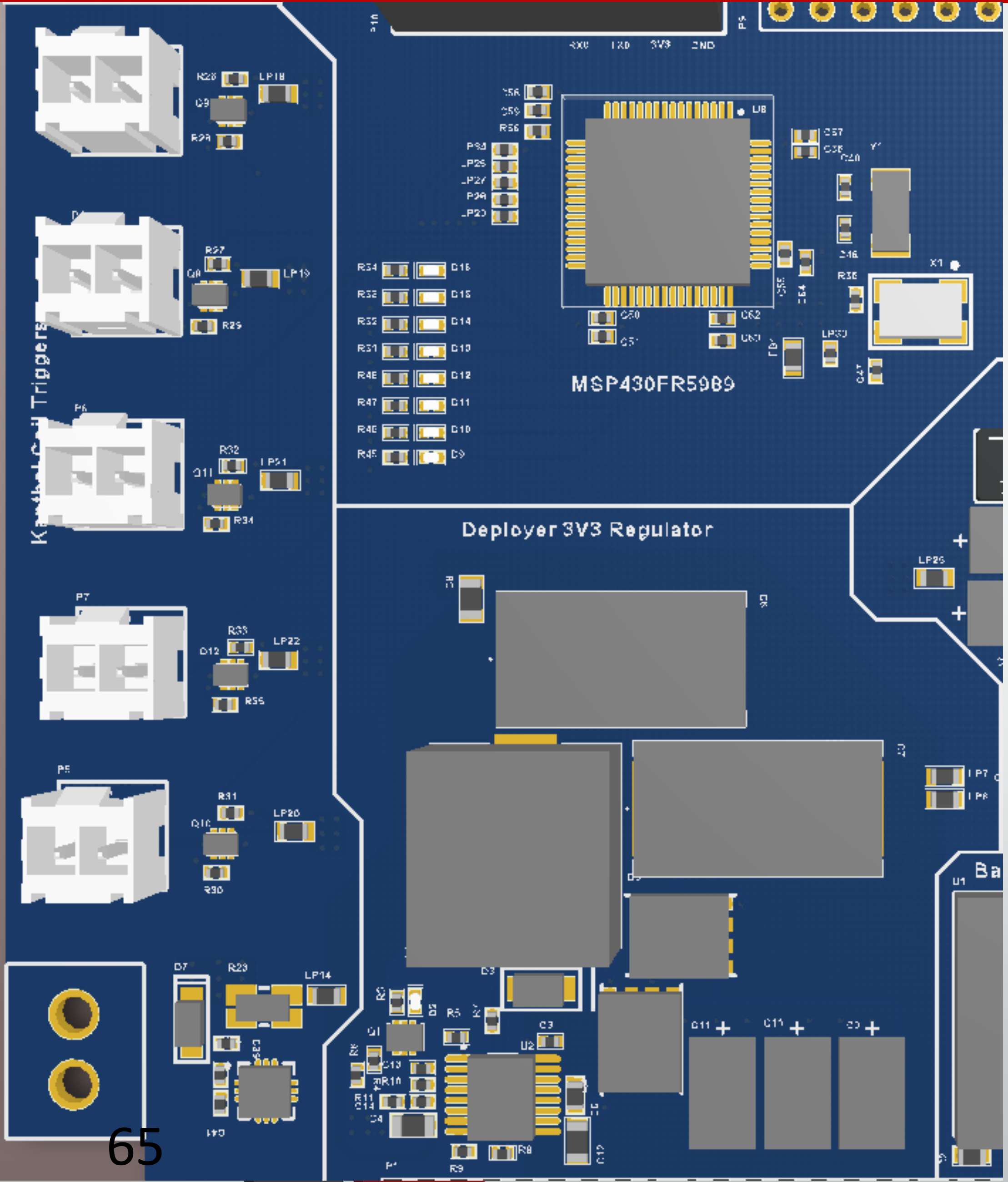
Software Tests:

- Trigger logic Verification

Off-ramps:

- Raspberry Pi 3 EGSE

Kanthal Coil Triggers



Responsible For:

- Side and Bottom Panel Deployment

Critical Hardware Tests:

- Power Sensor Verification via known Standard
- Trigger Logic Verification
- 3V3 Regulator Power Verification

Critical Software Tests:

- Trigger logic Verification

Off-ramps:

- Raspberry Pi 3 EGSE

Avionics Design Changes

- Trimmed down complexity of Main Board Revision A

Avionics Development Approach

- Separate Hardware and Software Testing
- Make all testable components independently testable
- Provide as many proven offramps as reasonably possible

- EGSE can interface the Raspberry Pi 2 to all Components
- Raspberry Pi 3 is first step for software testing always
- Extensive Design work on Mainboard to separate testable elements

Manufacturing Summary

REPTAR

Raytheon

Work Completed:

- Revision A designed and (ordered/received/not ordered)

Future Work:

- (Solder any additional components?)
- Validate Revision A and decide if a Revision B is necessary
- Continue down Test Paths for subsystem validation
- Integrate Main Board in REPTAR structure

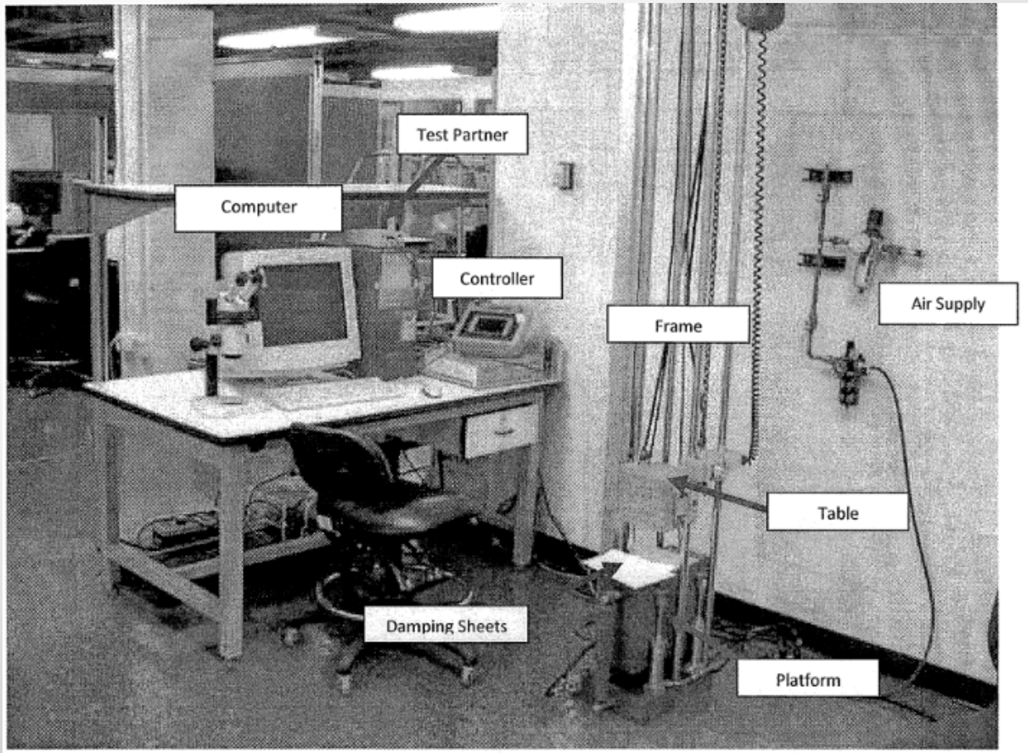
Landing Backup

Impact Loading Test

REPTAR

Raytheon

- Facility: Idea Forge Impact Loading Machine
- Process: Mount the legs to the hole pattern and drop it with a velocity of approximately 5.5 m/s from a calculated height to mimic the landing forces
- Mounting: Mount onto the hole pattern using screws to mimic the forces experienced as being part of the satellite
- Measurements: Will measure the force experienced on the load cell upon impact as well as deformation of the aluminum foam

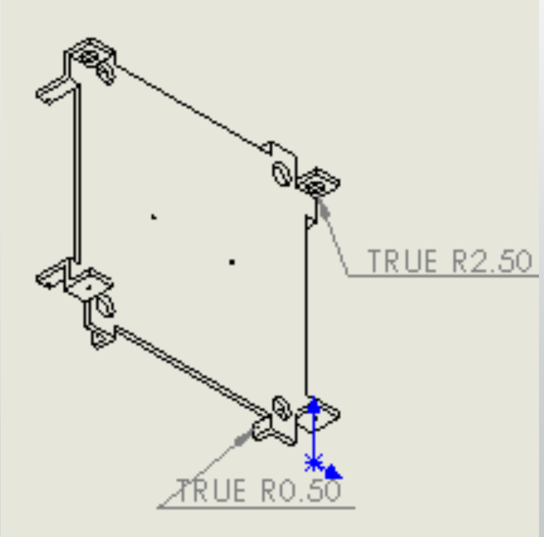


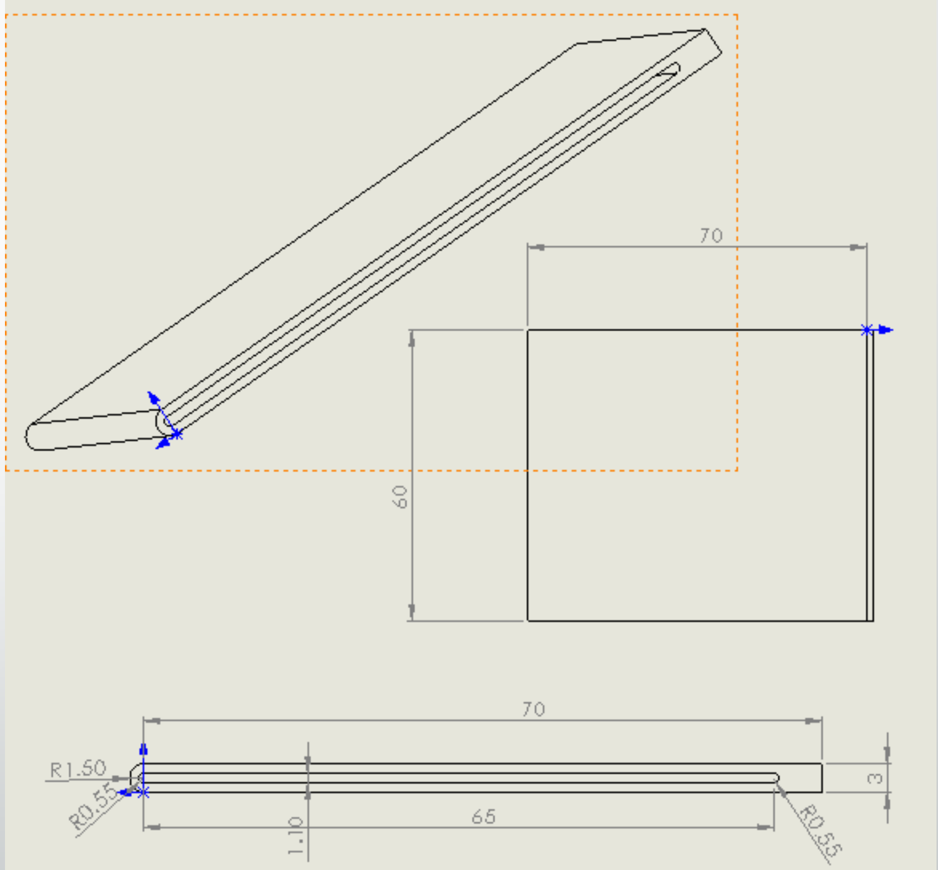
Side Panel Deployment Test

REPTAR

Raytheon

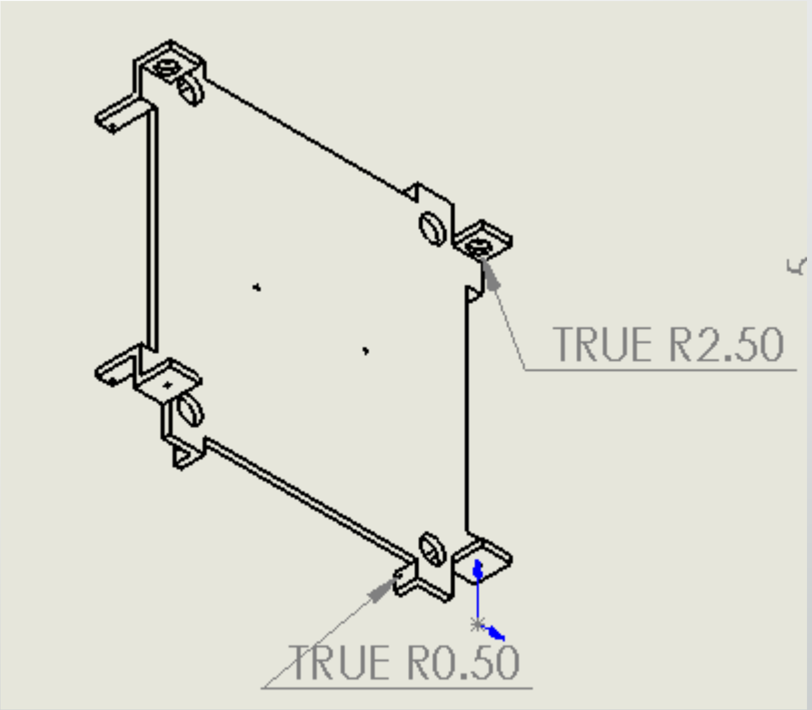
- Similar to Leg Deployment Testing
- Mounting with hot glue
- Test spring deployment repeatedly for reliability in fan, reaching landing velocities





Center Plate Manufacturing

- COTS Aluminum from McMaster 0.5 in x 4 in x 24 in
- CNC Machine in AES Machine Shop
- Drill mounting holes for side panels and rails

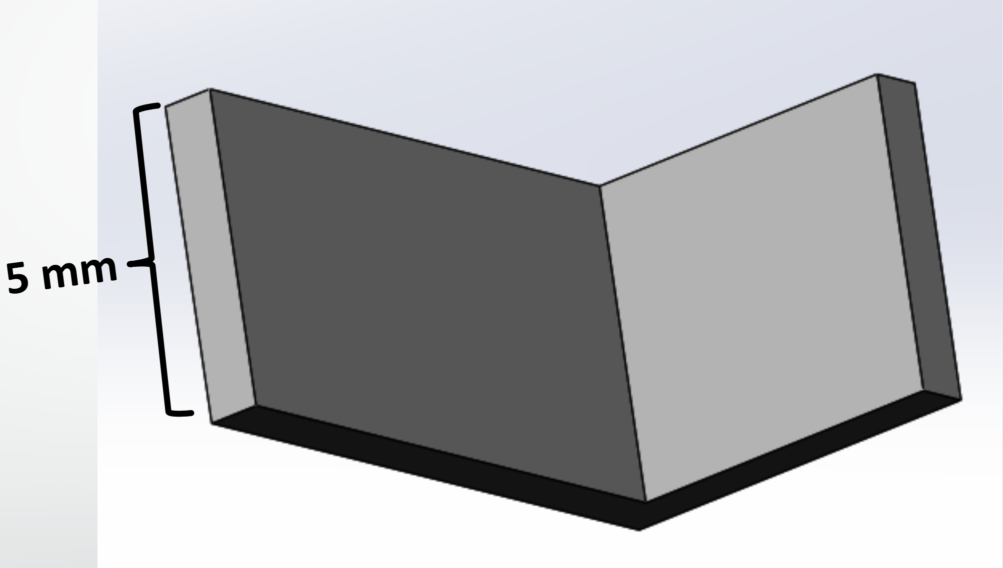


Locking Housing Manufacturing

REPTAR

Raytheon

- COTS Aluminum from McMaster
- Machined in AES Machine Shop

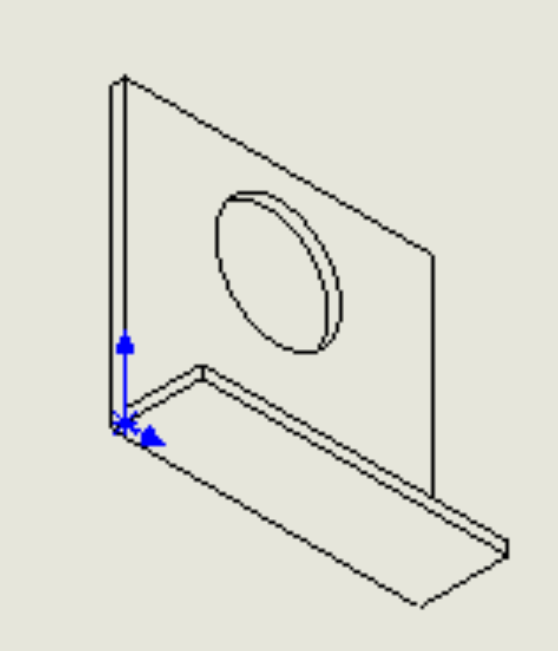


L-Bracket Manufacturing

REPTAR

Raytheon

- COTS Aluminum from McMaster 1 in x 1 in L frame, x 12 in long
- Machine in AES Machine Shop to correct length
- Drill mounting holes

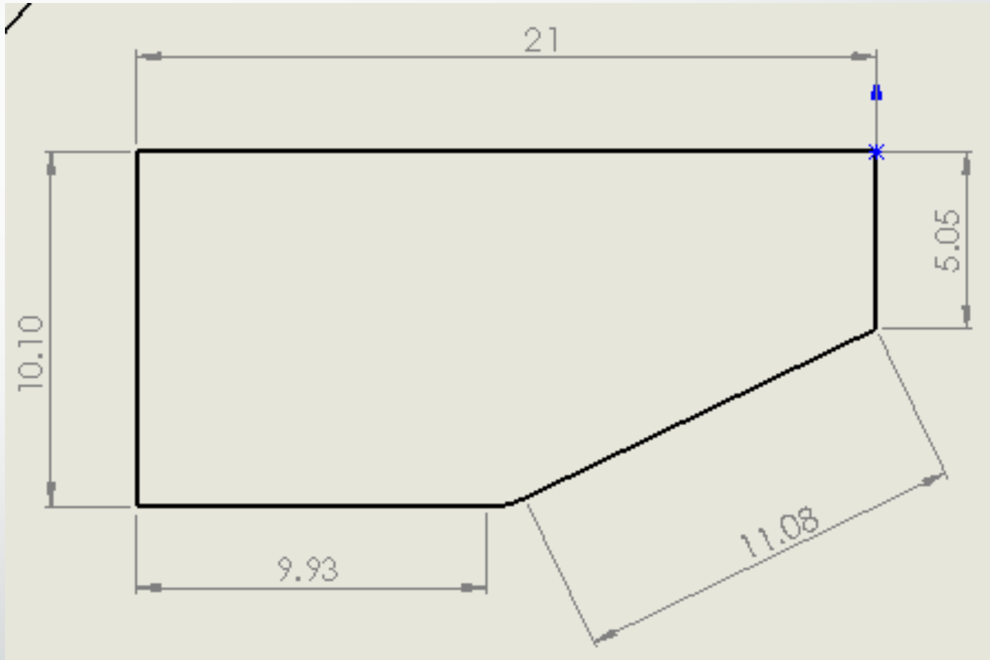


Spring Attachment Manufacturing

REPTAR

Raytheon

- COTS Aluminum from McMaster
- Machined in house in AES Machine Shop



Budget Backup

Descent		Landing		Avionics	
Key Items Bought	**Price**	**Key Items Bought**	**Price**	**Key Items Bought**	**Price**
Parachute x2	$388	Side Panels	$293	Rev A	$300
Black Powder	$30	Aluminum Legs	$578	Antenna GPS	$18
Ejection Canisters	$44	Torsional Springs	$13	Smart Charger	$26
Fiberglass Tube	$77	Compression Springs	$21	Battery Recharger	$123
Fiberglass Cloth	$44	Slotted Pins	$12	Iridium Antenna	$33
Fiberglass Sheet	$28	Side Panel Pins	$66	Raspberry Pi3	$40
Epoxy	$112	Epoxy	$94	Venus GPS SMA	$50
		Aluminum	$151	Altimeter Break	$30
				RockBlock	$294

Key Points		Key Points		Key Points	
Estimated Cost	$897.00	Estimated Cost	$1,444.15	Estimated Cost	$1,087.90
Total Cost	$836.67	Total Cost	$1,360.79	Total Cost	$1,006.39
Under/Over	$60.33	Under/Over	$83.36	Under/Over	$81.51

Total Budget Breakdown

Key Points	
Already Purchased	$3,203.85
Estimated Cost	$3,429.05
Under/Over	$225.20

Key Points	
Already Purchased	$3,203.85
Drop Test and Equipment	$700
Other Test Equipment	$200
Other Manufacturing	$250
Final Margin	$646.15