Raytheon

Test Readiness 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

Overview

Project Statement & Motivation

REPTAR

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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.

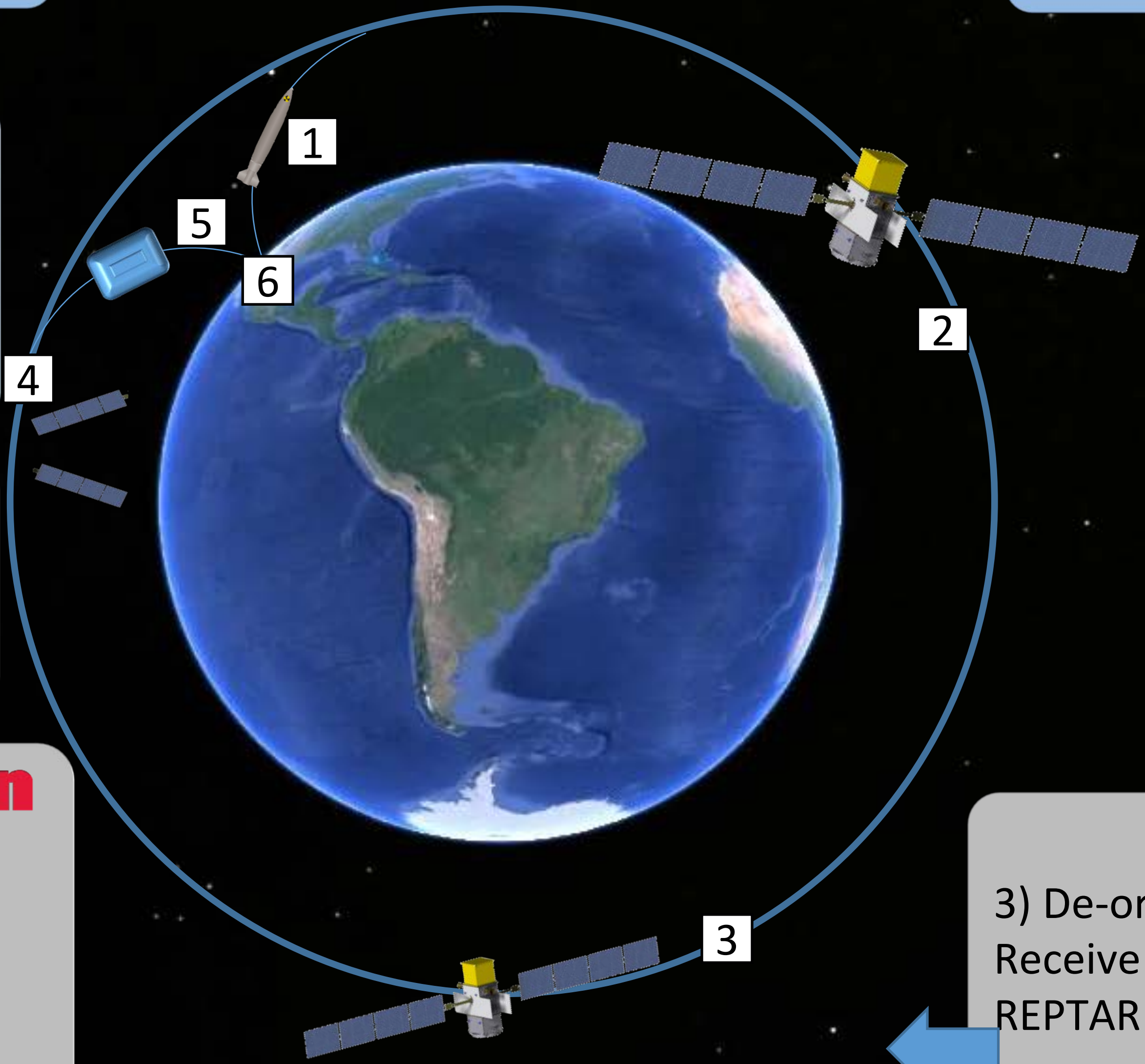
Recovery of payload enables:

- 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

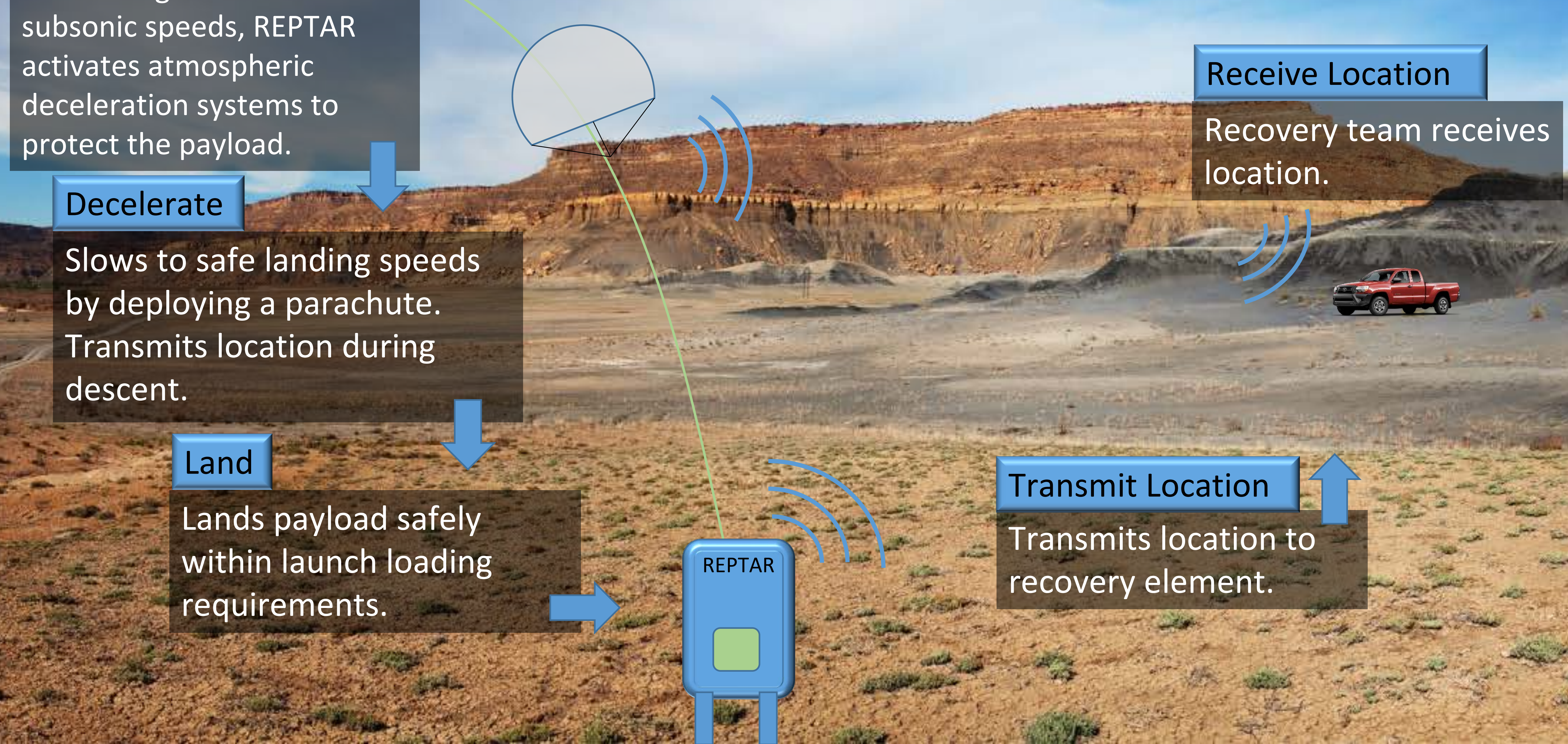
3) De-orbit — Raytheon
Receive command from bus to power REPTAR systems. Re-entry burn.

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

5) Deceleration — Raytheon
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)



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

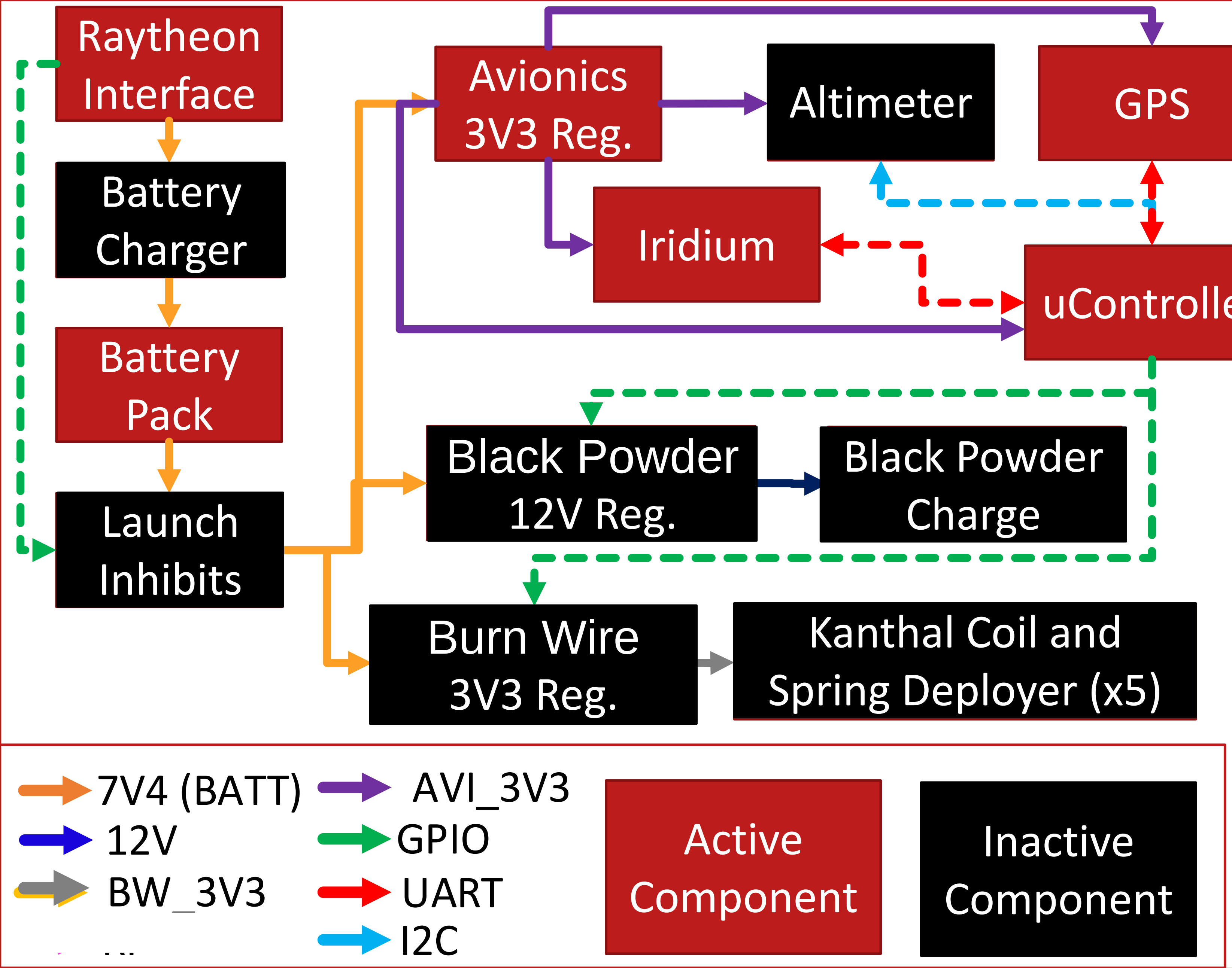
Recovery team receives location.

Levels of Success

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

Mission Timeline and FBD

REPTAR



On-Orbit Standby

- Maintain battery charge

Descent

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

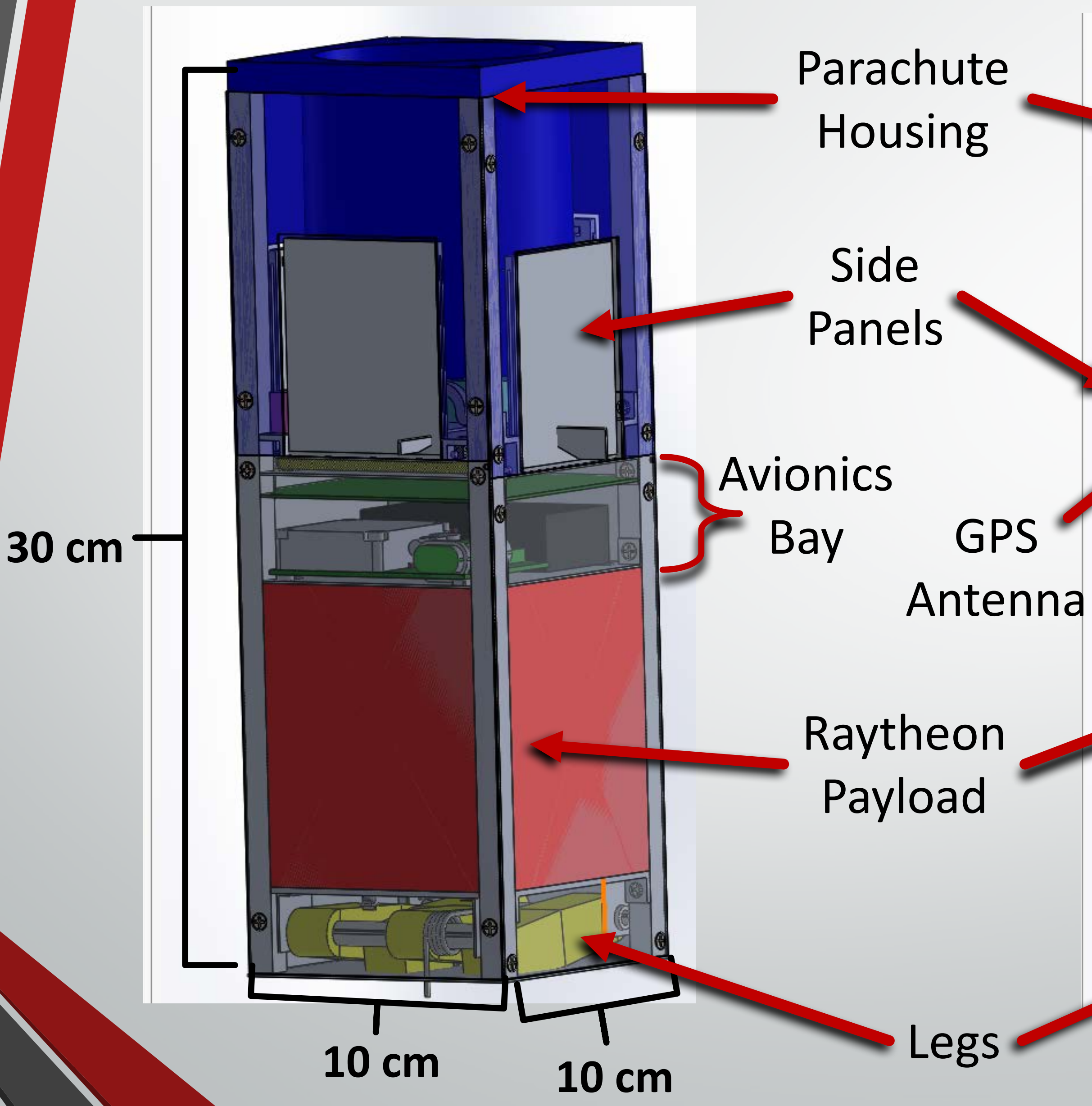
Deceleration [3,500 m]

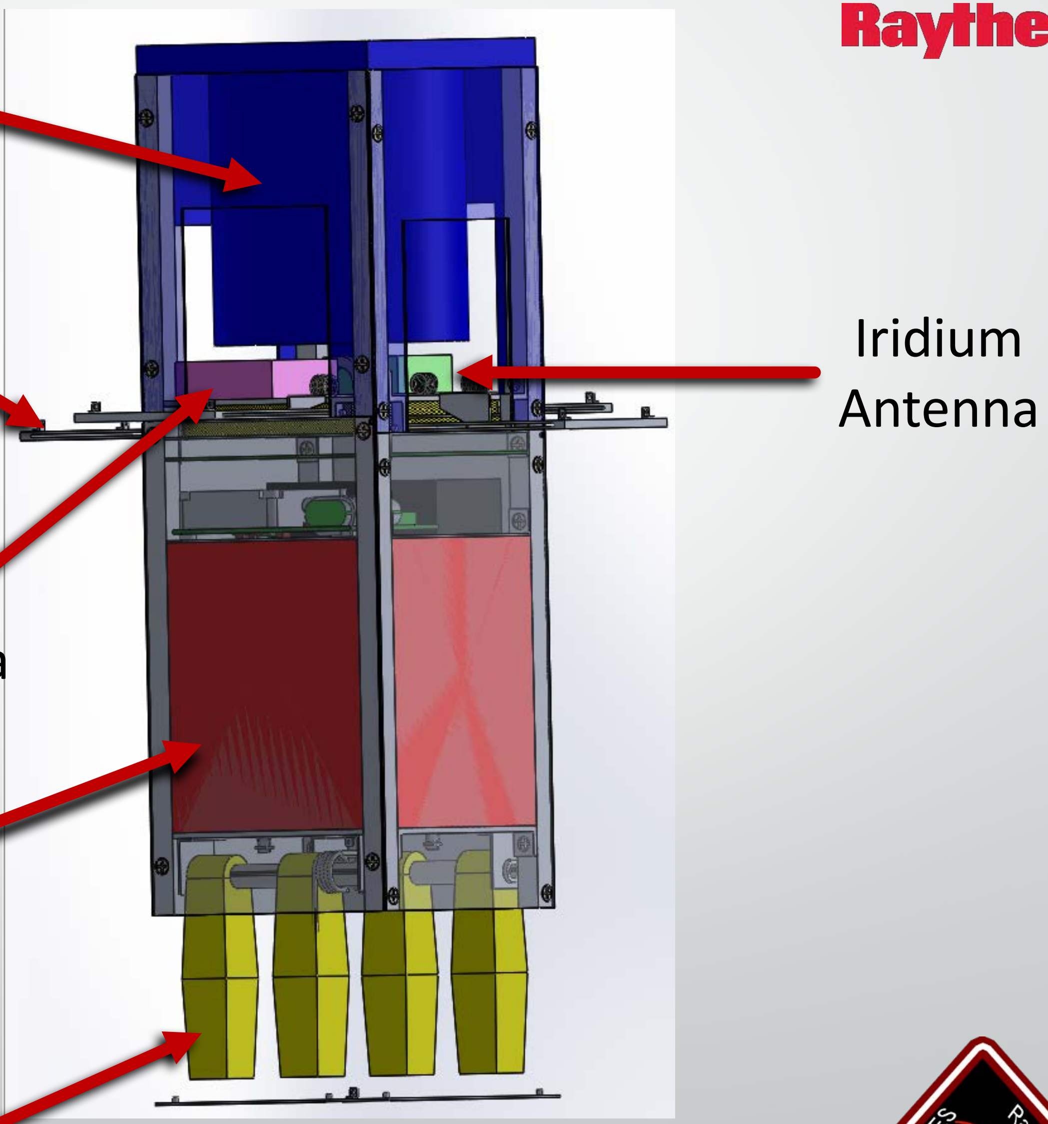
- Triggered by parachute deployment altitude being reached
- Deploy parachute, bottom panel, and side panels.

Transmission

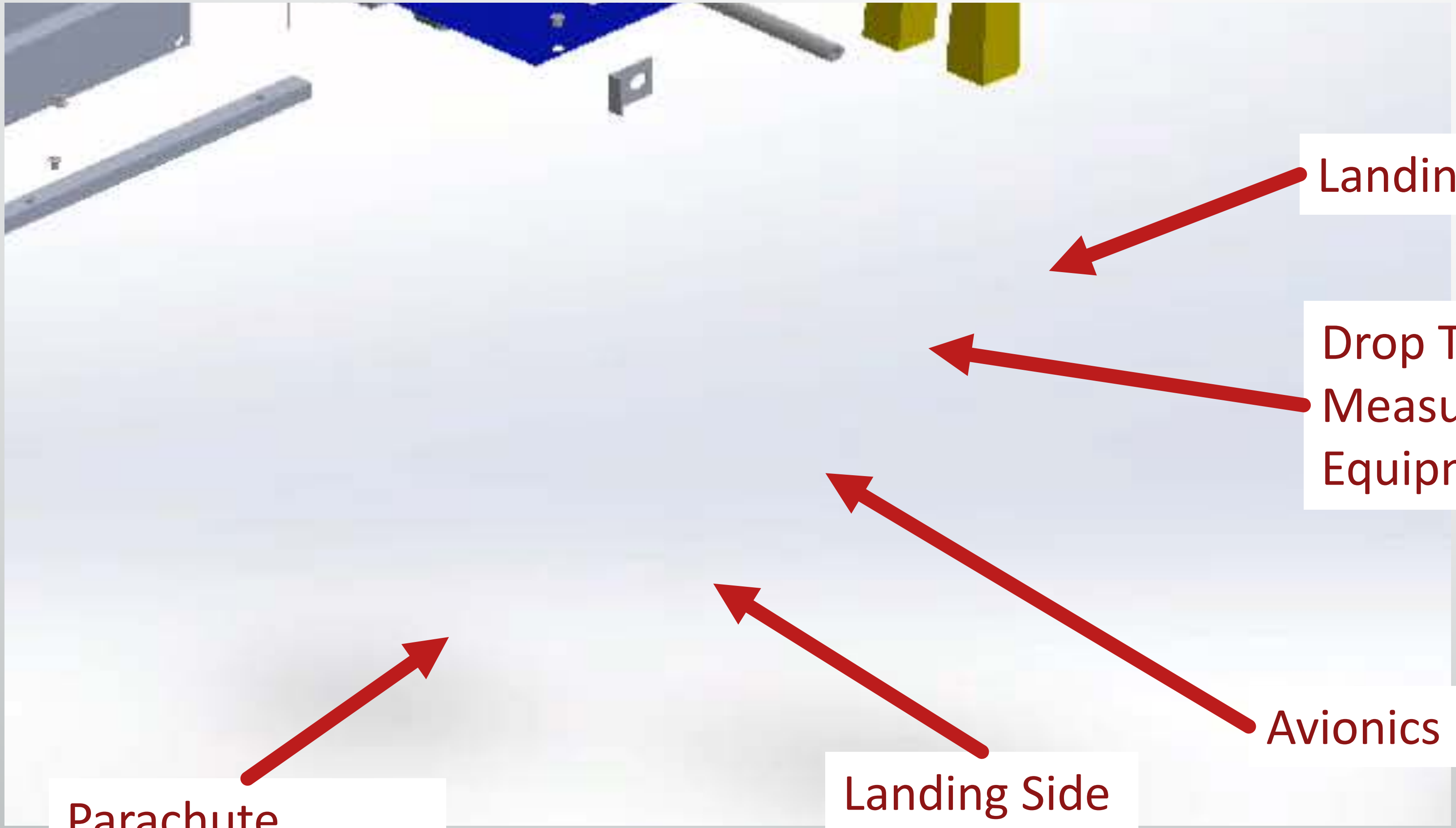
- Triggered by deployments
- Transmit Location

Key Components





Assembly Animation



Critical Project Elements

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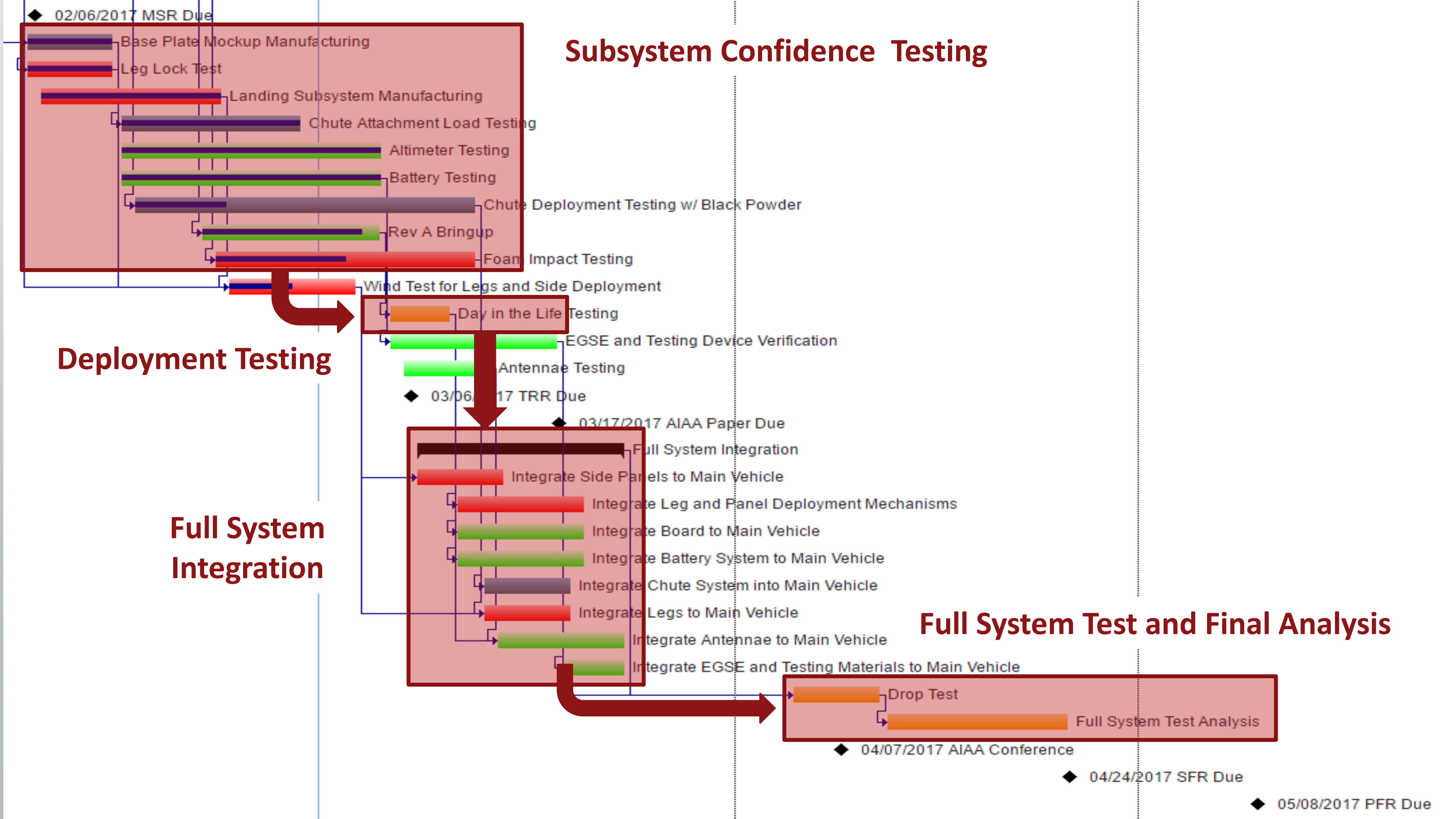
Subsystem	CPE	Explanation
Descent	Parachute Deployment	If the parachute does not deploy and act properly, it will be nearly impossible to achieve any of the mission requirements.
Landing	Leg Deployment	The legs lower the maximum G loading the vehicle experiences. Without successful leg deployment, safe landing will not be satisfied.
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	Subsystem Interaction	Ensuring that the avionics integrate with the other subsystems will be crucial to success of the mission.

Executive Summary

- **Changes since MSR:**
  - Vibration test has been removed from schedule
    - Current system structure not fully representative of the final system
      - Thermal Protection System
      - Payload
  - Aluminum cover removed from parachute housing
    - TPS is required to protect REPTAR on-orbit
- **Schedule:**
  - 11 days of margin incorporated before drop test
- **Budget:**
  - All materials in-house or ordered
  - Drop Test is only remaining major expense
  - $622.62 margin – no overall concerns

Schedule



02/06/2017 MSR Due
Base Plate Mockup Manufacturing
Leg Lock Test
Landing Subsystem Manufacturing
Chute Attachment Load Testing
Altimeter Testing
Battery Testing
Chute Deployment Testing w/ Black Powder
Rev A Bringup
Foam Impact Testing
Wind Test for Legs and Side Deployment
Day in the Life Testing
EGSE and Testing Device Verification
Antennae Testing
03/06/2017 TRR Due
03/17/2017 AIAA Paper Due
Full System Integration
Integrate Side Panels to Main Vehicle
Integrate Leg and Panel Deployment Mechanisms
Integrate Board to Main Vehicle
Integrate Battery System to Main Vehicle
Integrate Chute System into Main Vehicle
Integrate Legs to Main Vehicle
Integrate Antennae to Main Vehicle
Integrate EGSE and Testing Materials to Main Vehicle
Drop Test
Full System Test Analysis
04/07/2017 AIAA Conference
04/24/2017 SFR Due
05/08/2017 PFR Due
Subsystem Confidence Testing
Deployment Testing
Full System Integration
Full System Test and Final Analysis

TRR to Drop Test

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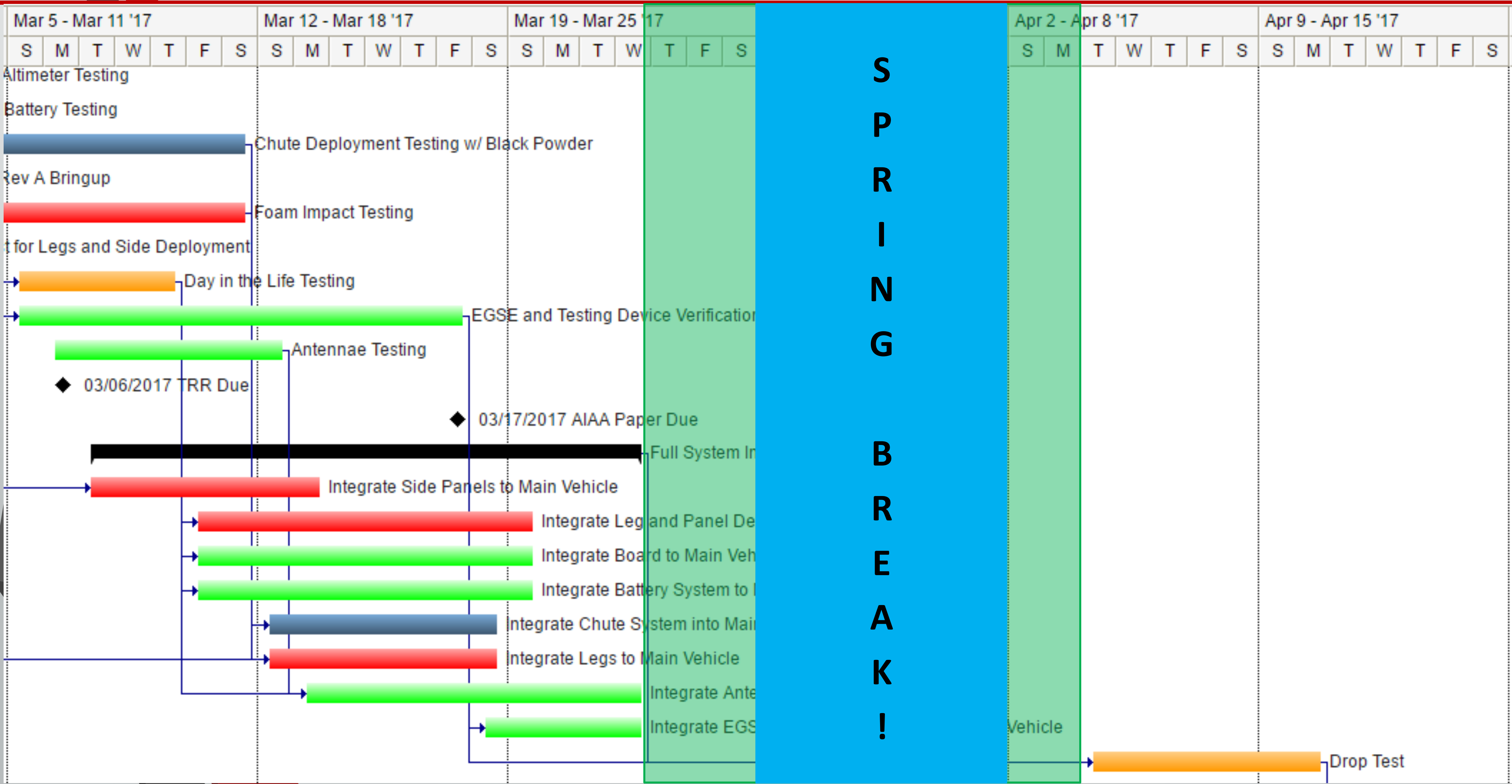
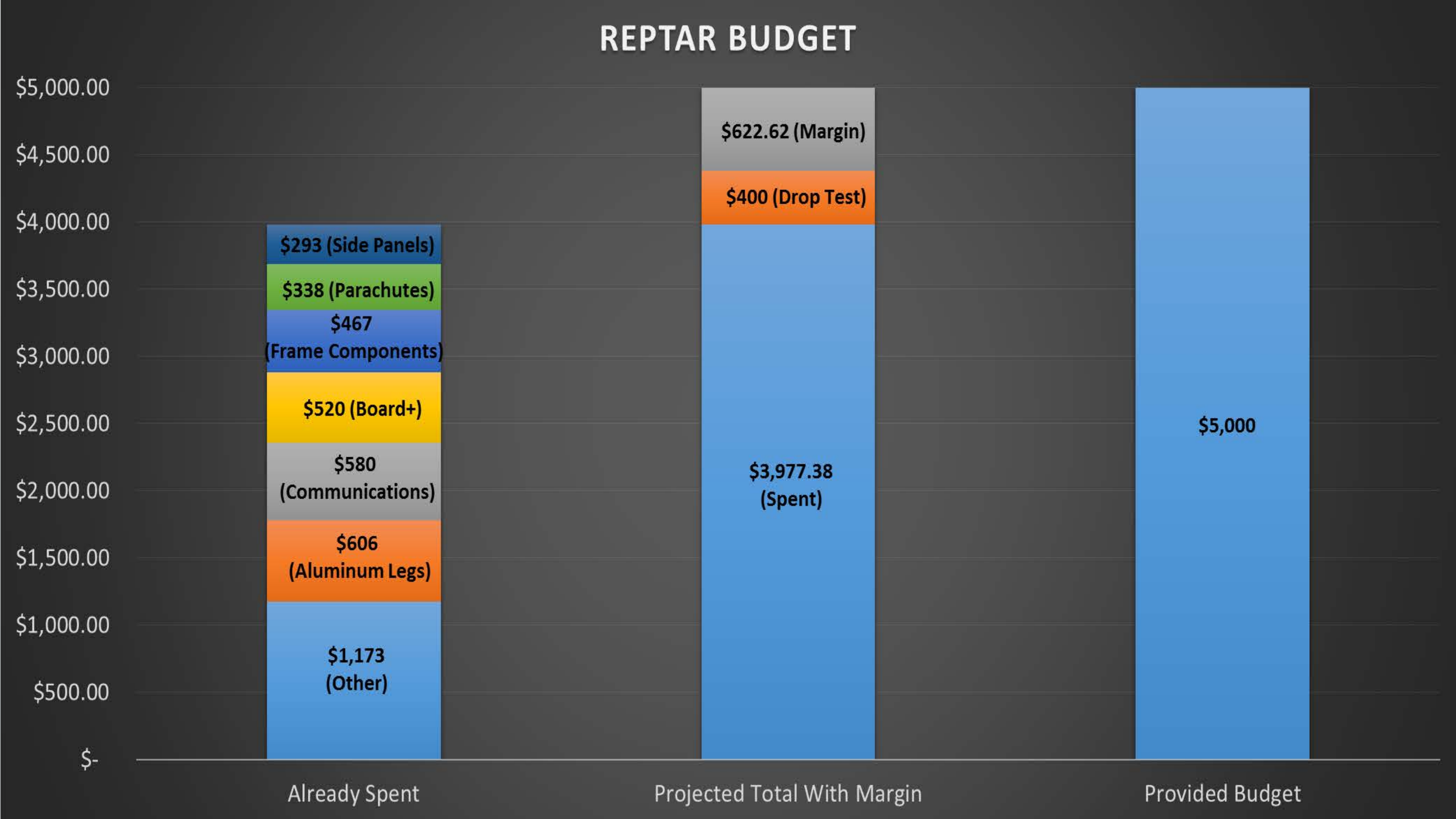


Budget


REPTAR BUDGET
$5,000.00
$4,500.00
$4,000.00
$3,500.00
$3,000.00
$2,500.00
$2,000.00
$1,500.00
$1,000.00
$500.00
$-
$293 (Side Panels)
$338 (Parachutes)
$467 (Frame Components)
$520 (Board+)
$580 (Communications)
$606 (Aluminum Legs)
$1,173 (Other)
$622.62 (Margin)
$400 (Drop Test)
$3,977.38 (Spent)
$5,000
Already Spent
Projected Total With Margin
Provided Budget

Test Readiness

Past Testing – Descent Subsystem

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Test	Measurement Sought	Requirement Validation	Test Takeaway
Plate Load	Deformation due to chute deployment	Verifies structural integrity of base plate	Plate is strong enough to withstand the force of chute deployment
Drag	C_d of Parachute	Validate landing speed	C_d for undamaged parachute is within threshold, C_d for damaged parachute is not
BP Ignition	Amount of black powder needed to eject chute from housing	Proves chute can be deployed using black powder	Parachute ejected properly 10 times out of 11 in chosen configuration

Past Testing – Landing Subsystem

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Test	Measurement Sought	Requirement Validation	Test Takeaway
Leg and Side Panel Deployment	Percentage of time that legs and side panels deploy in 6 m/s winds	Validates reliability of deployables	Little concern about proper deployment of legs and panels
Leg Locking	Amount of torque needed to overcome leg locking mechanism	Higher torque required to overcome leg locking mechanism means lower likelihood legs fold when they impact ground	Torque at break was ~0.165Nm causing a screw-in design to be created for a higher tolerance
Foam Impact	Determine crushing characteristics of aluminum foam legs	Verify vehicle can be slowed to a stop while staying below 40 G's	Legs compressed almost exactly as anticipated

Avionics Status Dashboard

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Flight Components

Altimeter
- Int. 3V3 Reg.
- Resolution
- Accuracy
- Algorithm

Deployments
- 12V Power Stability
- 3V3 Power Stability
- 12V Power Monitor
- 3V3 Power Monitor
- Algorithm

Location D/T
- Iridium UART
- GPS UART
- Antenna Pattern
- Algorithm

Integration Testing
- Battery Testing
- Battery Manager
- Inhibits
- Day-In-the-Life (DITL)

Drop Test Components

Accelerometer
- Measured Accuracy

COTS Integration
- Battery
- Camera

Flight Integration
- I2C to MSP430
- Inhibit Control

STATUS
- Complete- Success
- In Progress
- To Conduct
- In Rework
- Failure – No Recovery

Day-In-The-Life (DITL) – Flight Dress Rehearsal

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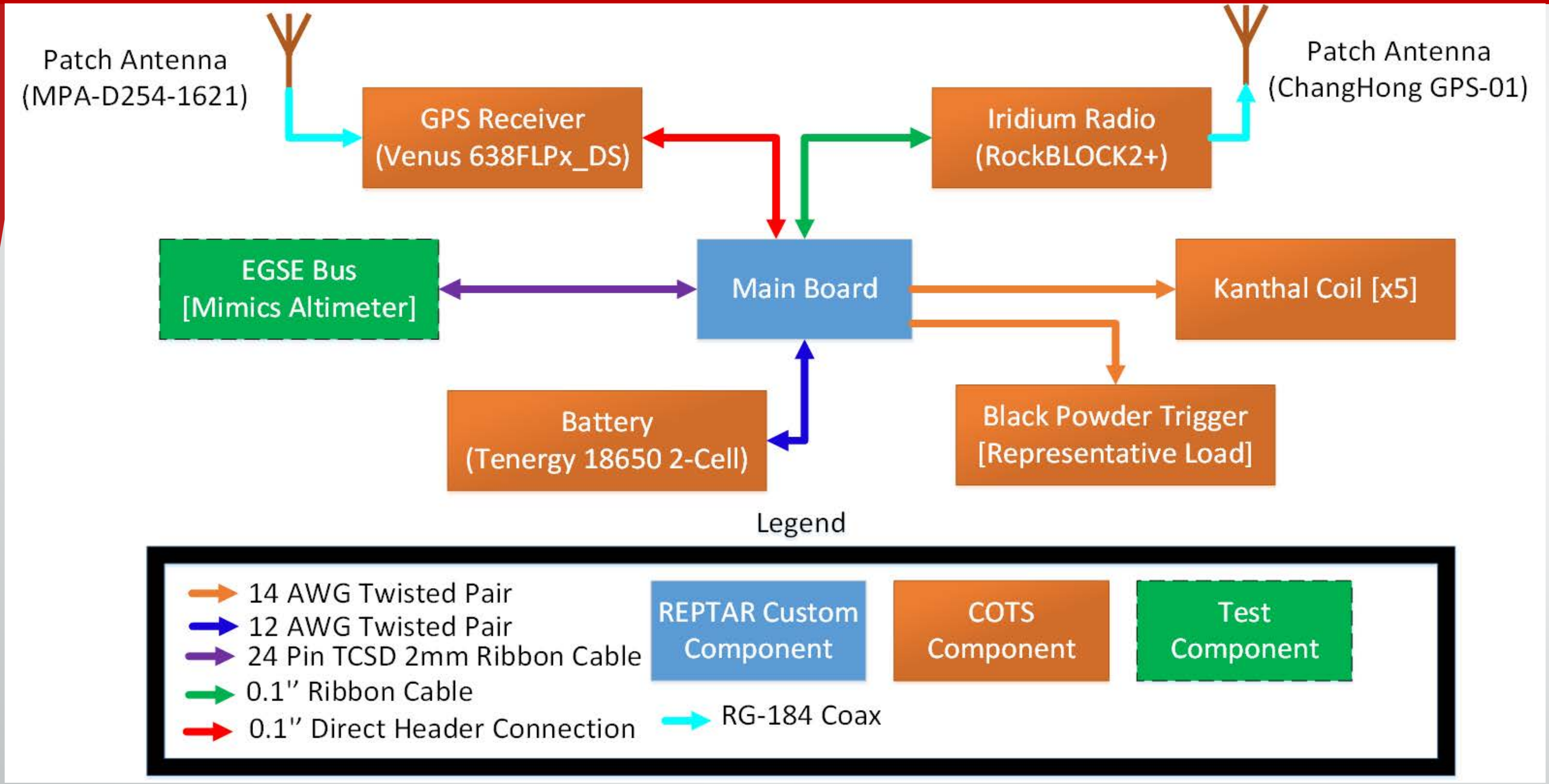

Purpose:

To verify the integrated performance of the Avionics Hardware and Software.

Deviations from Test Flight:

- Black Powder Trigger will be representative load
- Altimeter Readings from EGSE

Parachute Deployment

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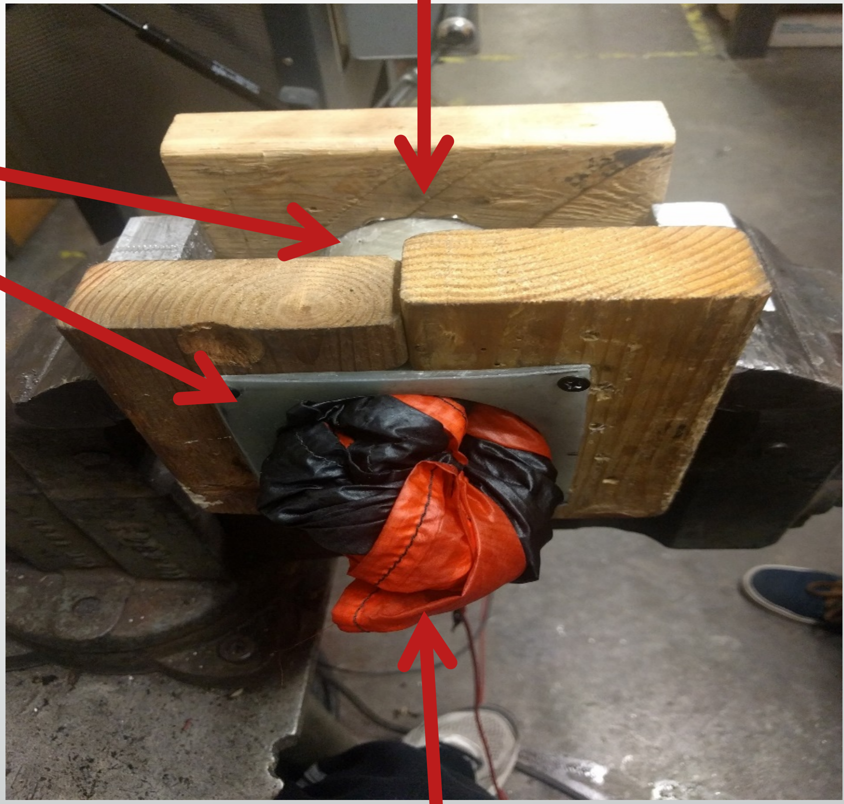
- Setup Details:
  - Very similar to flight article
- Repeatability:
  - Follow Checklist Procedure
- Risk Reduction:
  - Increases confidence that chute will deploy
- Expected Results:
  - 0.4 g of Black Powder to Eject Chute
- Actual Results:
  - Successful Ejection: 10/11 = 90.9%
  - Successful Canisters: 34/36 = 94.4%
  - Overall Confidence of Deployment: 85.8%

U-bolt

Parachute Housing



Parachute

Parachute Deployment

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Full System Drop Test

Full System Drop Test

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Scope	Drop REPTAR from airplane in controlled environment	• Requires aircraft, large drop zone
Rationale	Full system drop test is the culminating test that provides proof of concept and full integration testing	• Testing high speed parachute deployment • Location determination during descent • G loading profile
Risk Reduction	Reduces risk by validating in-flight performance before real flight with expensive payload	

Drop Test Logistics

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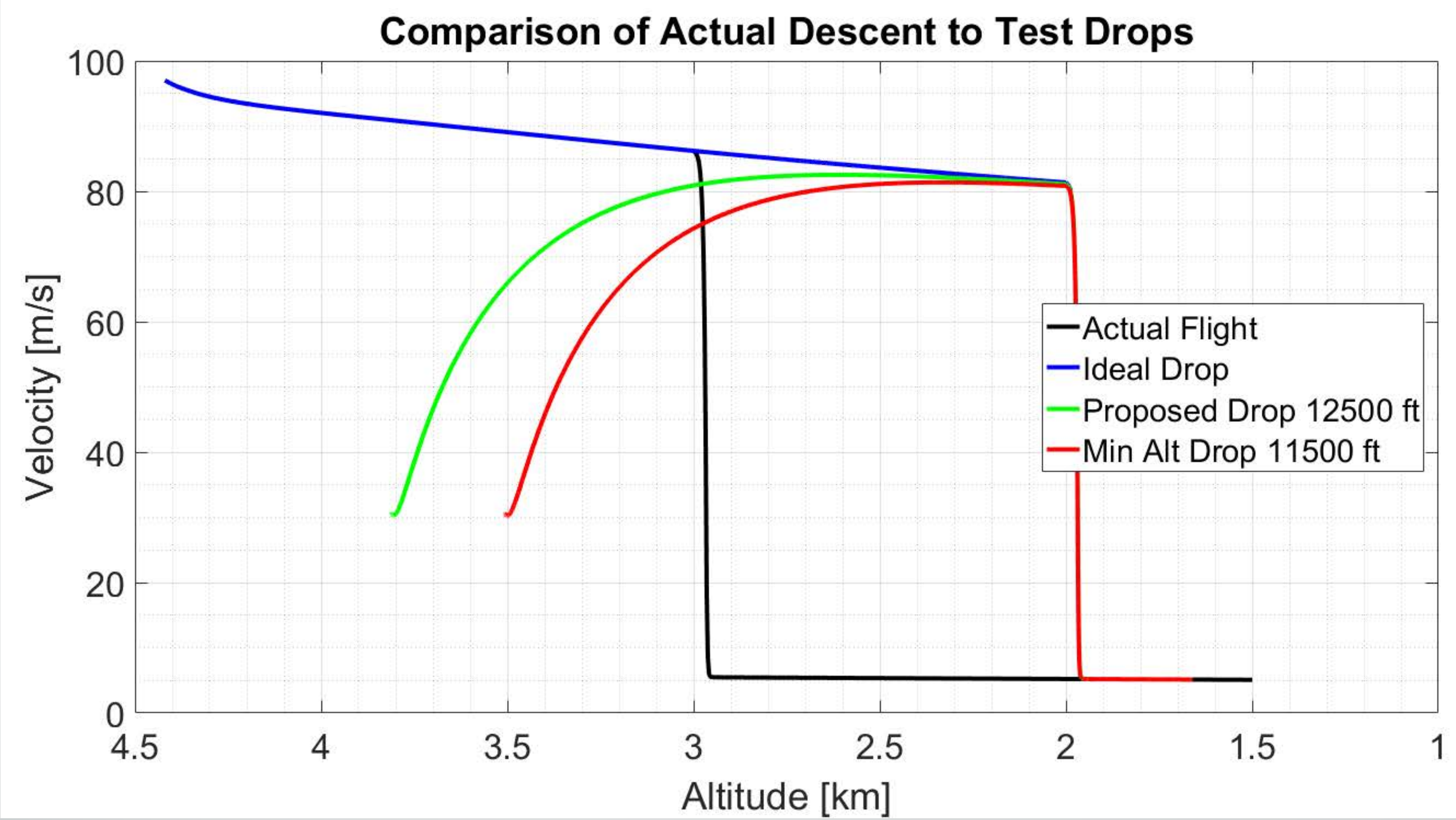
FR.3 - Keep safe during descent and landing
FR.4 - locatable after landing



FAA Rules and Regulations: Skydive Colorado

- April 4th (primary date) and April 11th (backup date)
- No-go days: Surface wind of more than 30 knots (34.5 mph) or cloud clearance of less than 1000 ft from the desired drop altitude

Drop Test Measurement Unit

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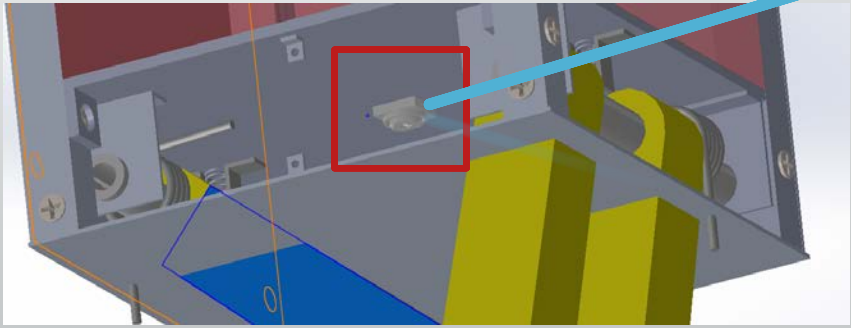
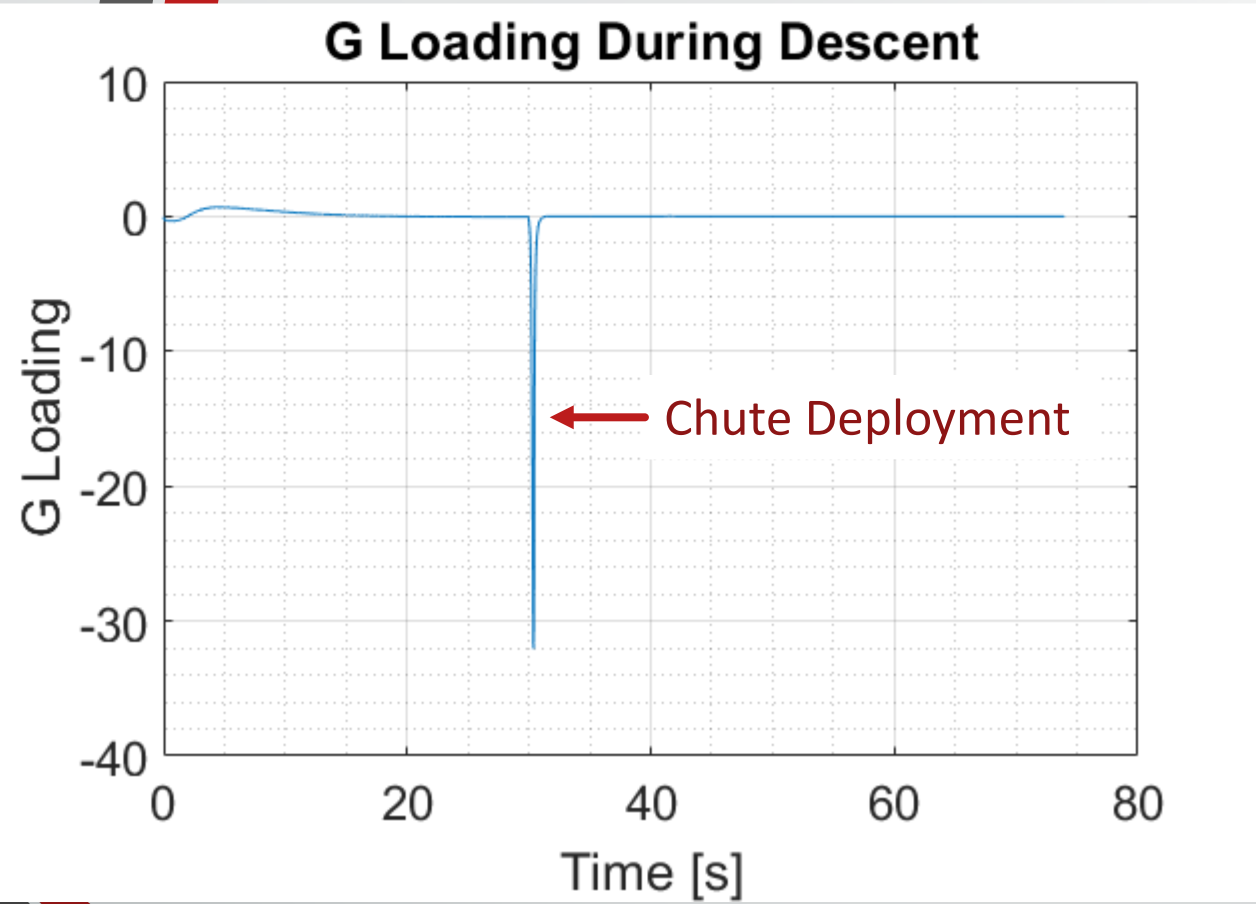
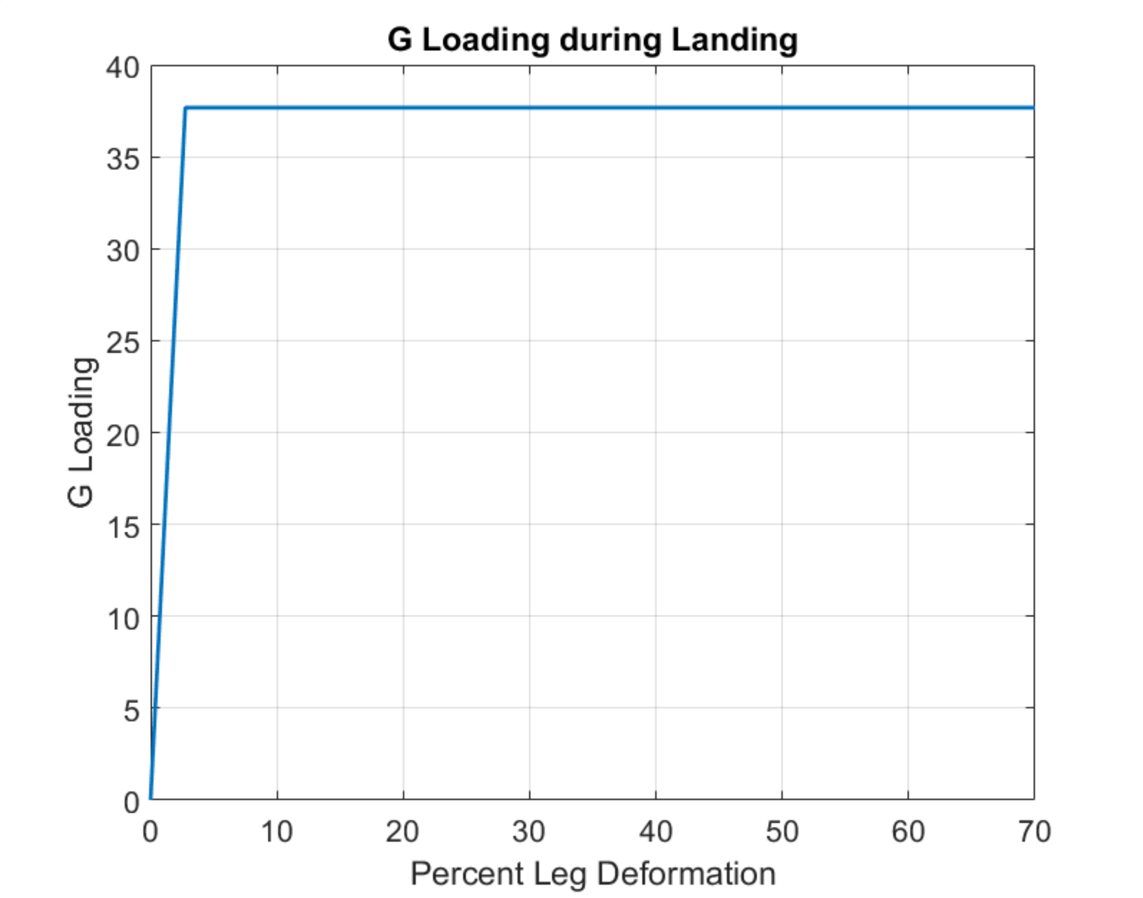
- Where?
  - Housed where Raytheon Payload would be stored in actual mission
- How?
  - Accelerometer (ADXL377, +/- 200G with an error of 1G)
  - Raspberry Pi Camera
- Quantities from the main avionics:
  - Altitude (Altimeter)
  - Location (GPS)
- Mass and Volume
  - Mass: 177 g of instruments + 1157 g of ballast
  - Volume: 1U
- <u>Additional Measurements will be taken from the plane</u>



Expected G-Model





Drift Zone and Recovery

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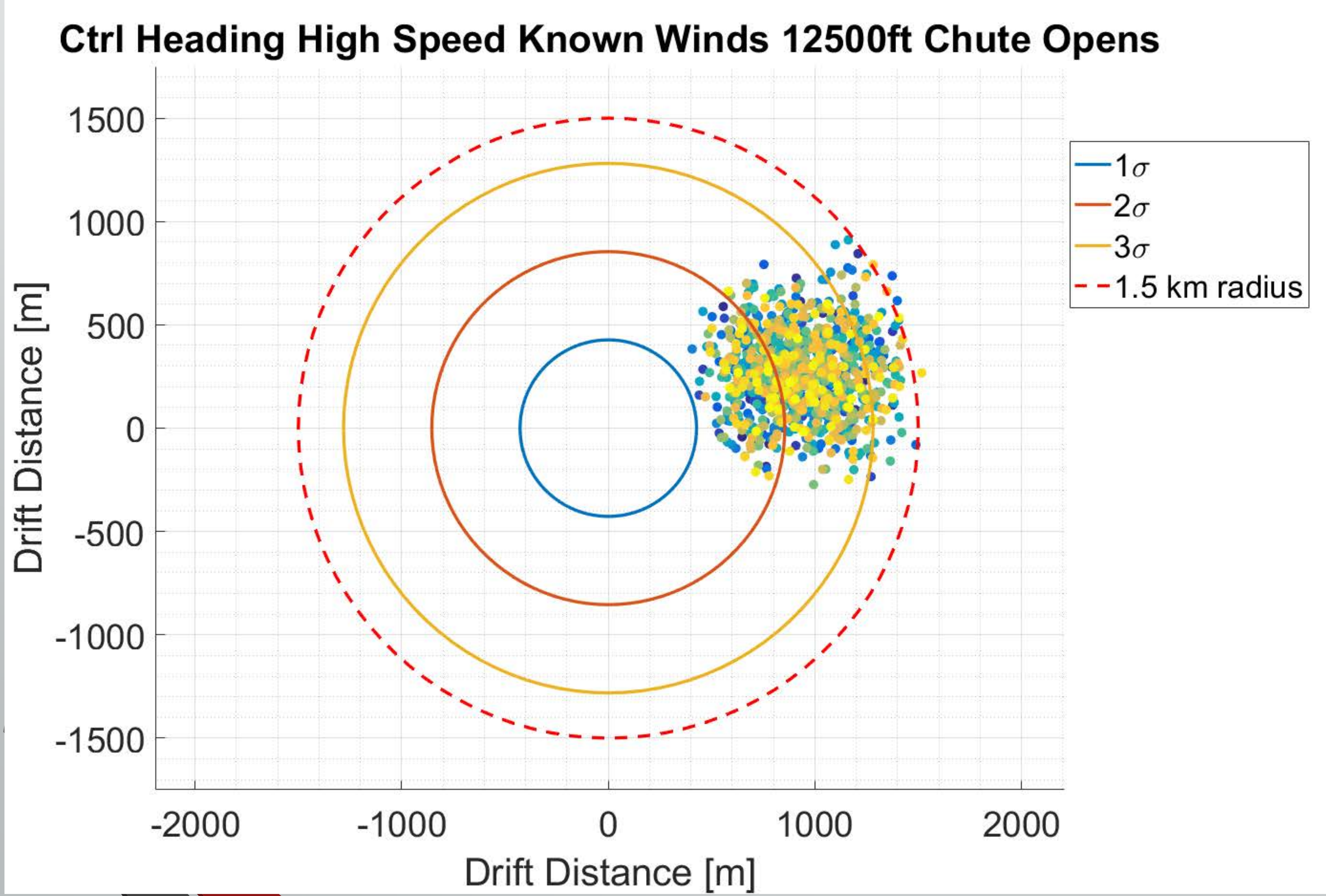

Monte Carlo Parameters

Initial Velocity = 32.0 [m/s]
Initial Velocity Variance = 5.0 [m/s]
Min Alt = 12500 [ft], Alt Variance = 200 [ft]
Heading Range = 20 [deg]
Pos. Variance (x) = 500 [m]
Pos. Variance (y) = 500 [m]
Pos. Shift (x) = -250 [m]
Pos. Shift (y) = -250 [m]
Wind Vel. min = 5 [kts]
Wind Vel. Variance = 5 [kts]
Wind Dir. min = 230 [deg]
Wind Dir. Variance = 40 [deg]
Chute Open Alt Min = 1900 [m]
Chute Open Variance = 200 [m]
Standard Deviation = 213.5 [m]
Known Winds 2520 2530 2540 2545

Drop Zone

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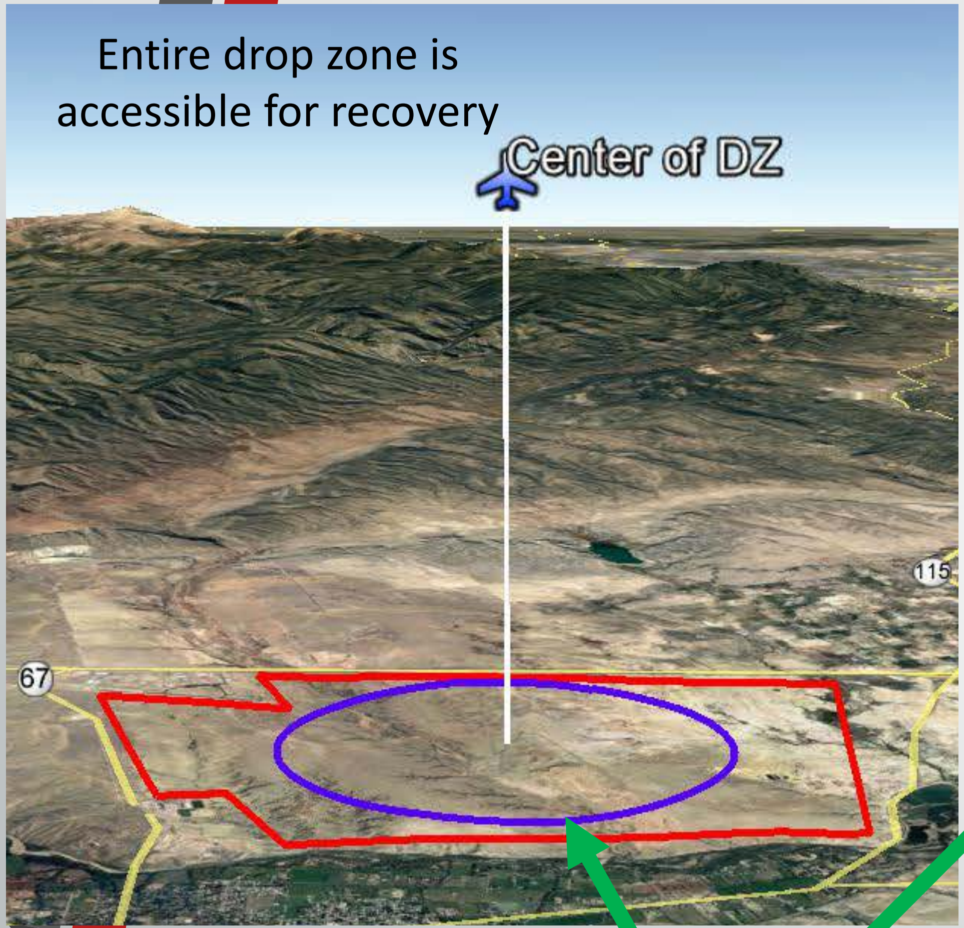

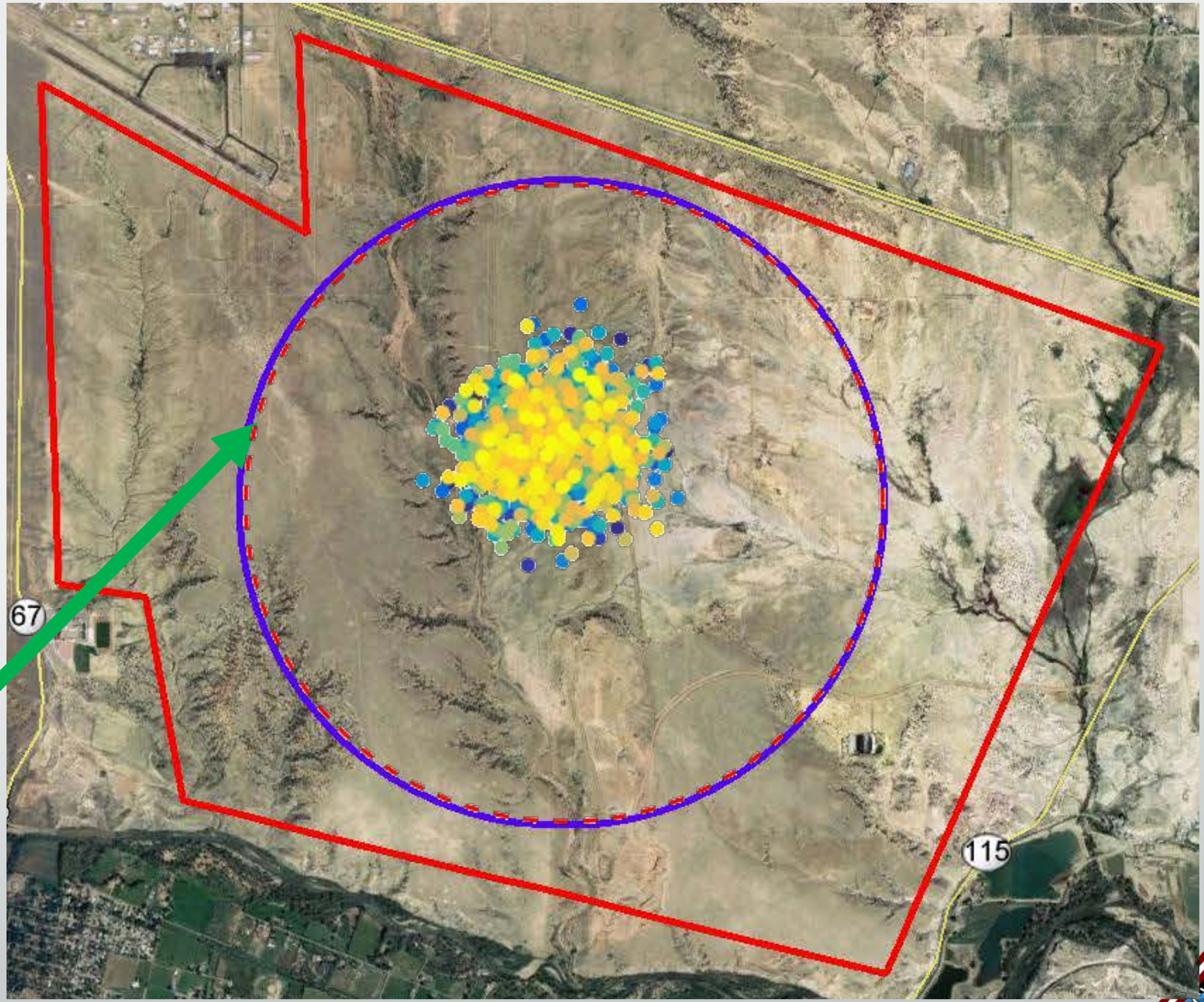

1.5km radius Reference Circle

Consequences Table

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Quantities	All golden!	Location Transmission Fails	Landing Fails	Parachute Fails	All fail
G's experienced	37	37	52	840	840
Location Determined?	Yes	No	Likely	No	No
Time to Land (s)	~86 s	~86 s	~86 s	~32 s	~32 s
Data survived	Yes	Yes	Yes	Likely	Likely

Post Flight Analysis

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Compare:

- G-loading experienced during flight
- Expected drift vs actual drift
- Expected time to land vs actual time to land

Review:

- Leg deployment footage

Summary of Confidence for Drop Test

- Descent System:
  - 85% confidence of parachute deployment
- Landing System:
  - High confidence that legs and side panels will properly deploy
  - 95% confidence towards aluminum foam landing characteristics
  - Concerns towards uncontrollable landing environment
- Avionics System:
  - High confidence in avionics system as designed
  - Flight environment can introduce issues in communication
- Overall:
  - Current: 81% confidence that full system will perform successfully in drop test
  - Further testing to reduce variance

Questions?

Parachute Drag Test

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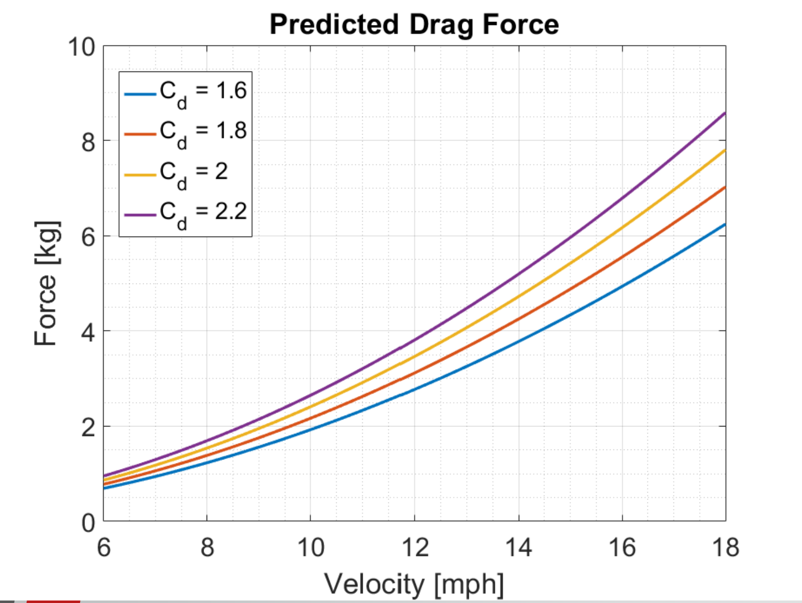
- Objective:
  - Determine the coefficient of drag of good and bad parachute
- Measurement Sought:
  - Force (lbs) and Wind (MPH)
- Expected Value:
  - Based on provided info from manufacturer –
    - Good parachute ~ 2.2
    - Bad parachute < 2.2
- How it Reduces Risk:
  - Higher coefficient, lower landing velocity, stay under 40 G's during landing
  - Too high of coefficient, go over 40 G's during deployment

Parachute Drag Test Cont.

- Results:
  - Good parachute n = 23, Avg = 2.42, Std = 0.529
  - Bad parachute n = 32, Avg = 2.09, Std = 0.553
- What This Means:
  - If parachute Cd is < 2.05, landing is over 40 G's
  - Bad parachute, less than 66% confident will be more than 2.05
  - Good parachute, slightly less than 66% confident will be more than 2.05

Parachute Drag Test

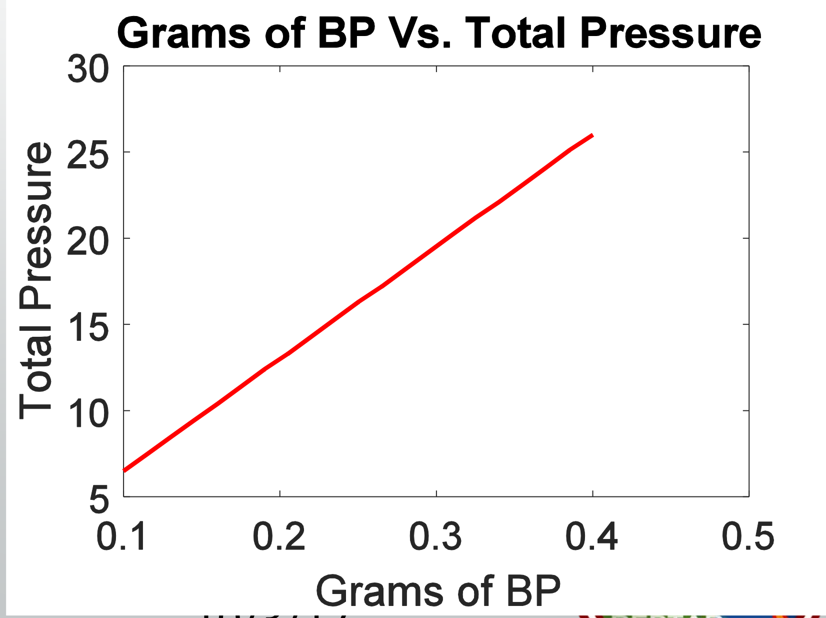


- Parachute shock chord will be attached to rope which will be attached to a digital scale with hook
- The digital scale will be attached to the rod of a headrest in a car
- The rope will be approximately 4 meters in length
- Team member will begin to accelerate car to 13 mph
- Team member in back seat 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

Black Powder Tests, No Parachute

REPTAR

- 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

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- 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 PVC Housing

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- Objective:
  - Determine if parachute will deploy from PVC housing
  - Determine amount of black powder needed to deploy
  - Determine if velocity of parachute is to high
- Measurement Sought:
  - Amount of black powder needed in grams to 2 decimals
  - Velocity of parachute does not put REPTAR over 40 G's
- Expected Value:
  - Amount of powder to be > 0.10 grams which is approximately 75 psi
    - 80 psi is what expelled parachute during compressor test
  - With 4kg REPTAR, velocity of parachute must be 80 m/s to go over 40 G's
- How it Reduces Risk:
  - Need parachute to deploy in order to be under 40 G's
  - Ensures REPTAR stays under 40 G's during deployment

Black Powder Tests With PVC Housing

- 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
  - From video, velocity calculated to be 3.29 – 4.83 m/s
- What This Means:
  - Parachute will not cause REPTAR to go over 40 G's
  - Need to conduct black powder test with fiberglass housing
  - 0.40 grams should be sufficient to expel parachute from housing
  - 99% confidence parachute will not cause REPTAR to go over 40 G's

Black Powder Tests With PVC Housing

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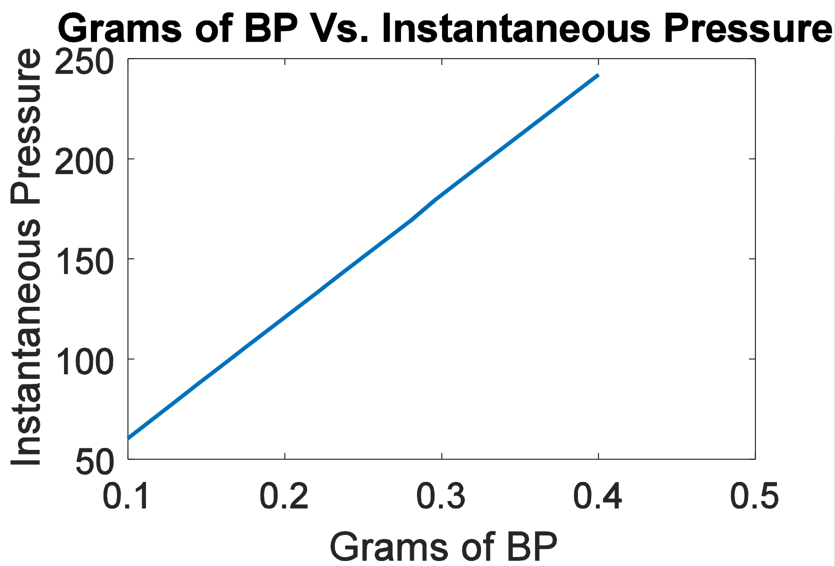
- PVC Housing with ejection canister inside
- Parachute shock chord attached to U-bolt
- Parachute folded inside of housing with recovery wadding between it and ejection canister
- Aluminum foil with small perforation in middle and taped down
- Canister attached to power supply with 12V and 5A
- Results:
  - .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



Black Powder Test Checklist

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1. Fill canister with 0.4g black powder and place recovery wadding inside
2. Wipe down inside with wet rag
3. Dry inside with dry towel
4. Light sanding of inside with 600 grit
5. Lube inside with Aerokroil
6. Place ejection canister
7. Feed parachute through bottom and connect to u-bolt
8. Screw housing to wood and place in vise facing 180 degrees
9. Tape holes on back of housing with electrical tape
10. 2.5 sheets of recovery wadding placed over ejection canister
11. Lube up sides of parachute
12. Twisting parachute fold and fit inside housing, push down to make sure parachute is flush with housing surface
13. Connect power lines to canister lines and check resistance on other side
14. Connect other side to power supply and turn on power for ignition

Drop Test

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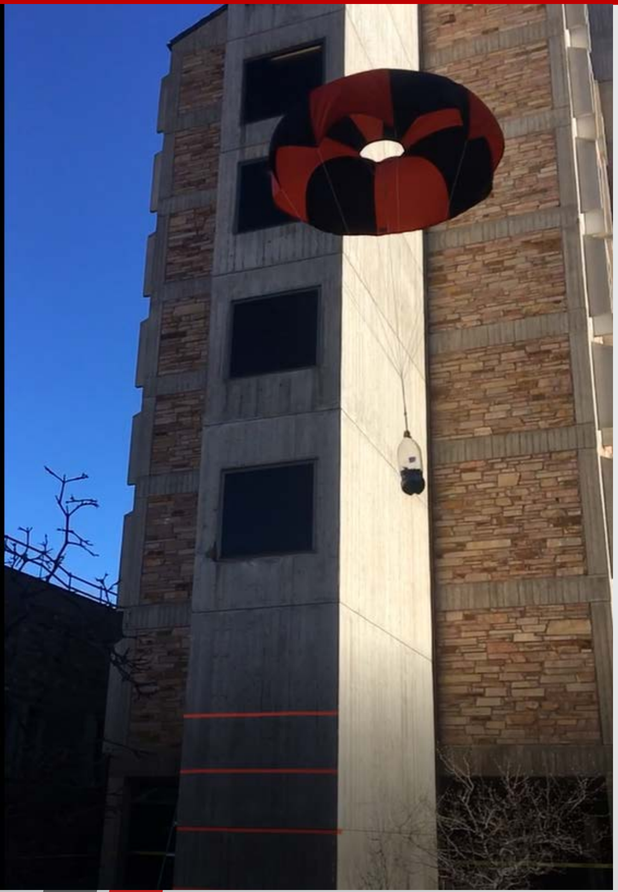
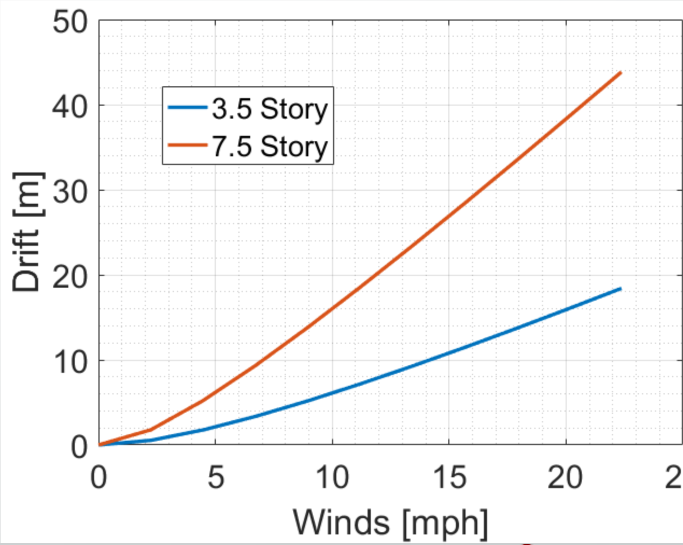


- Lines placed across ECOT to give measurements of distance
- High speed camera set up with two other team members filming
- Caution tape placed to cut off courtyard from bystanders
- Parachute was as inflated as possible before drop
- Dropped from 8th story window instead of 3rd due to difficulties
- 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



Aluminum Plate Load Test Explanation

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- Model:
  - MATLAB simulation to determine G-loading
  - Solidworks to compare deformation
- Purpose:
  - Show aluminum plate withstands impulse from parachute inflation
  - Verify model and simulations

Aluminum Plate Load Test

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- 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

Load Test: Measurements

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- What and how well?
  - Deformation: mm to two decimal places
  - Drop Height: in to nearest 1/16th
  - Mass of weight: kg to nearest g
- How?
  - Distance between straight edge going across plate to top of deformation with caliper
  - Tape measure in projects work shop
  - Scale from composites lab

Aluminum Plate Load Test SolidWorks

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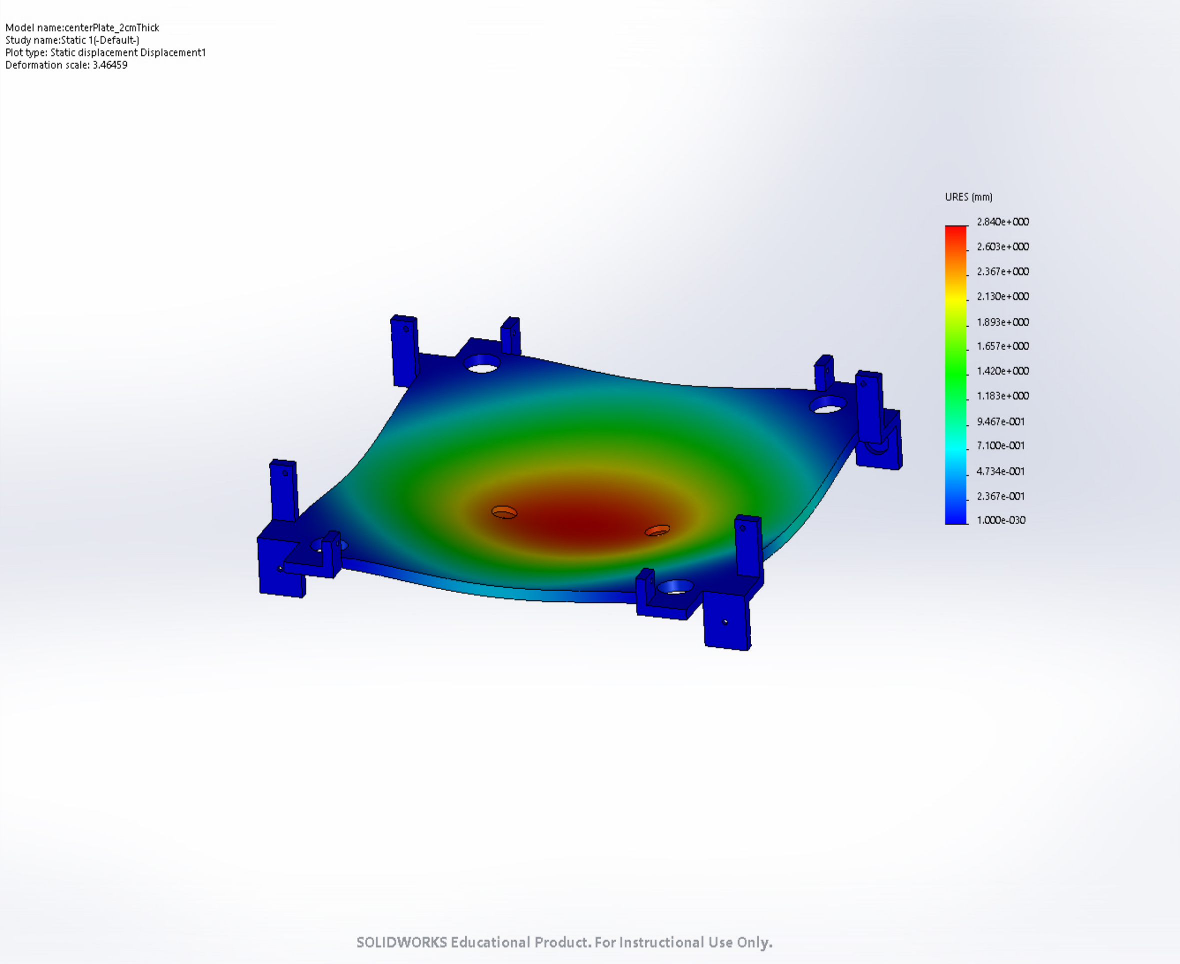
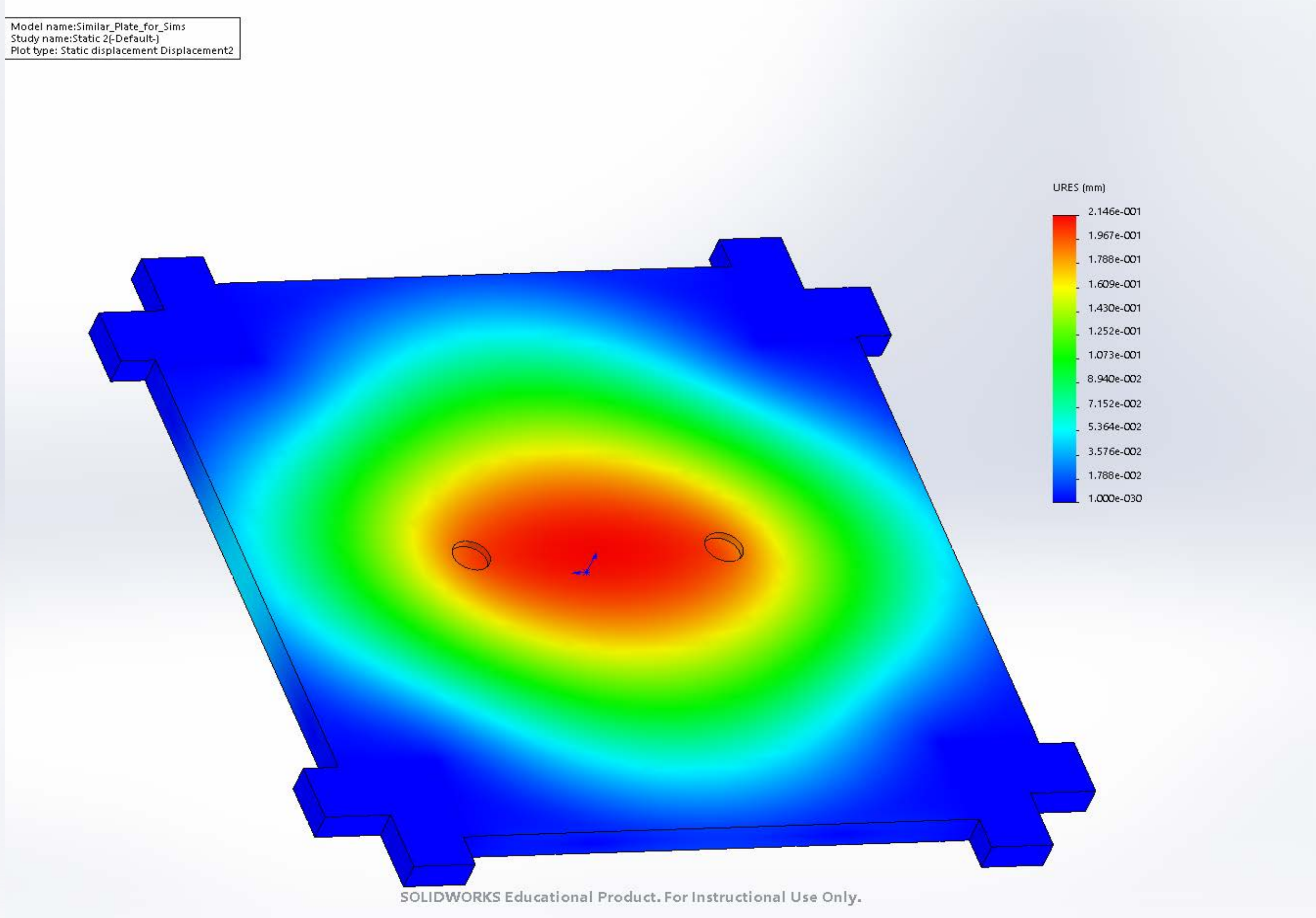




48 G’s Impulse
2” thick plate - 2.84 mm Displacement

48 G’s Impulse
4” thick plate - 2.15 mm Displacement

Aluminum Plate Load Test

- Objective:
  - Determine deformation of aluminum plate due to instantaneous force from parachute becoming taut
- Measurement Sought:
  - Deformation in mm to two decimal places
- Expected Value:
  - From SolidWorks simulations, deformation is 2.80mm
- How it Reduces Risk:
  - Ensures aluminum plate and/or U-bolt does not fracture
  - Minimizes deformation that could affect antennas

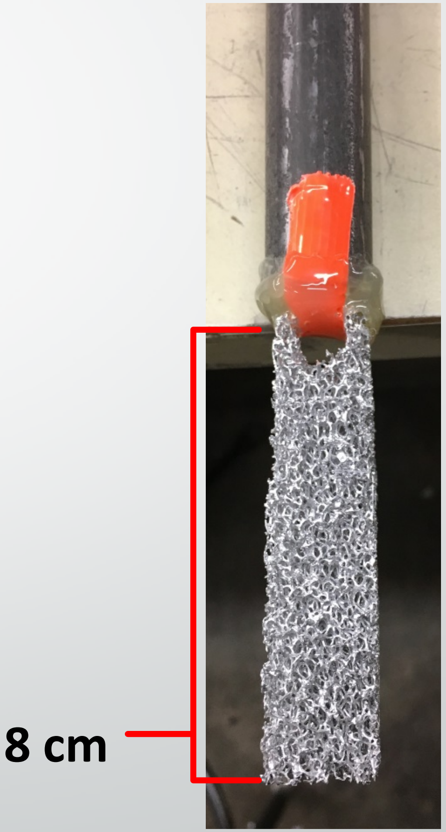
Aluminum Plate Load Test

- Results:
  - Measured deformation to be 2.43mm
  - Error could exist in method of measuring due to human error
  - Error from caliper used
- What This Means:
  - Increased thickness to minimize deformation
  - Antennas have chance of being slightly angled
  - Aluminum plate will not fracture and parachute lost
  - 99% confidence aluminum plate and/or U-bolt will fracture

Landing Backup

Foam Leg Drop Test

- Objective
  - To achieve landing velocities to determine crushing characteristics of a one leg setup as well as G-loading in a one leg scenario at a 5.7 m/s landing velocity
  - Requirement DR 3.2 The payload shall not experience instantaneous loading exceeding 40 G's
- Measurement Sought
  - Deformation of foam leg in the compressive direction as well as G-Load upon impact
- Expected value
  - Expected to deform for validation of ERG Aerospace's projected value of 70%+ compression
  - G-Loading of 11.8 G's
- How it reduces risk
  - Provides verification of design to reduce G-loading below the 40 G limit requirement



Foam Leg Drop Test

- Results
  - Dropped at 1.66 m ± 0.05 m
  - Initial Leg Length: 8.00 ± 0.05 cm
  - Initial Leg Width: 1.80 ± 0.05 cm
  - Final Leg Length: 2.35 ± 0.05 cm
  - Final Leg Width: 3.60 ± 0.05 cm
  - G-Loading experienced: 29.2 G's

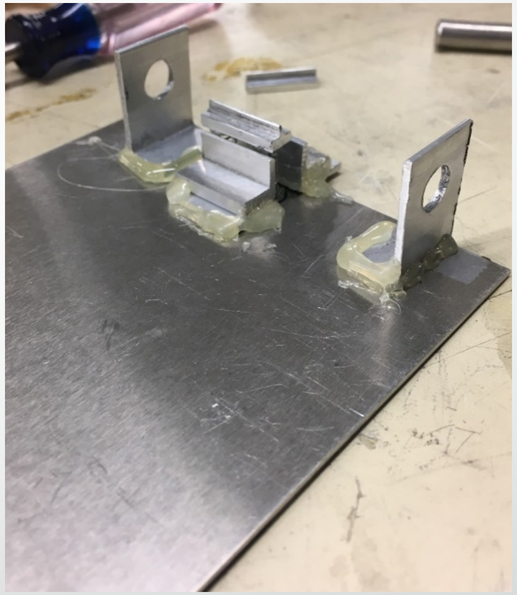
- What this means for our project
  - This shows that the assumption of a 65% deformation during calculations for areas and lengths required for the leg design can be upped to 70% deformation following the validation of ERG Aerospace's claim
  - 98% due to the performance meeting expectations of foam, and increasing area would lower G-Loading experienced

Foam Leg Drop Test

- Using kinematics the proper height to drop was found
  - V = V_0 + at = 0 + 9.81t
  - X = X_0 + V_0t + ½at^2
  - V = 5.7 m/s
  - Solving for X the leg must drop 1.66 m to achieve the proper impact velocity

Leg Locking Testing

- Objective
  - To determine the point of breakage for the leg locking mechanism
  - Requirement DR 3.2 The payload shall not experience instantaneous loading exceeding 40 G's
- Measurement Sought
  - Amount of torque held by locking mechanism housing walls
- How it reduces risk
  - By verifying the load required to break, the design can be altered to not allow rotation upon landing following the locking of the mechanism



Leg Locking Testing

REPTAR

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- Results
  - The setup broke following a 0.6 kg load applied at the end of a 16.5 cm vice grip equating to a 0.165 N load
- What this means for our project
  - This caused a redesign to involve a thicker housing wall and a screw-in setup for the housing walls
  - By changing the design it upped the confidence to 99%

Leg Deployment Testing

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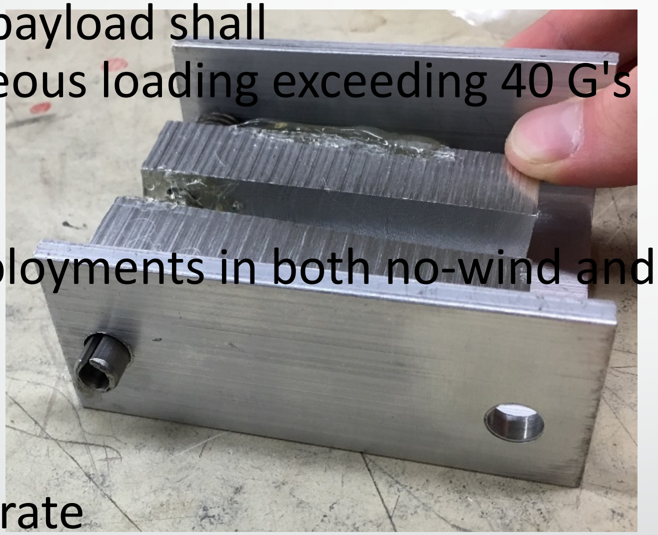
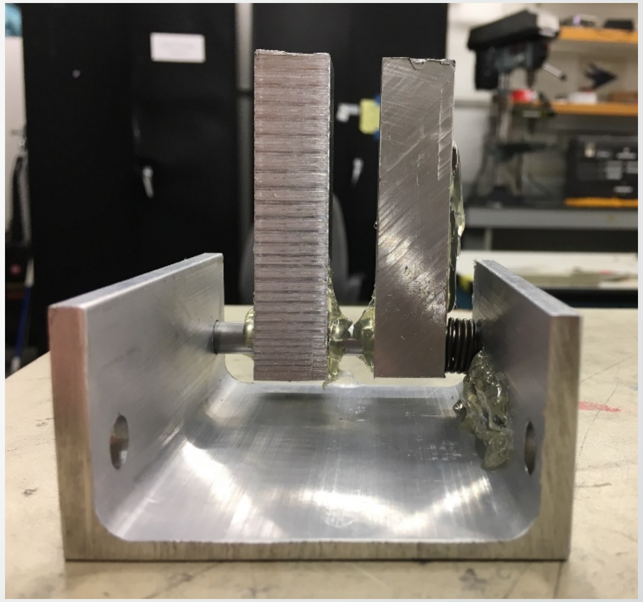
- Objective
  - To achieve reliability numbers for deployment of the aluminum foam legs
  - Requirement DR 3.2 The payload shall not experience instantaneous loading exceeding 40 G's
- Measurement Sought
  - Number of successful deployments in both no-wind and 6 m/s wind scenarios
- Expected value
  - 95% deployment success rate
- How it reduces risk
  - Indicates the reliability of these deployments following extensive testing for their on mission deployment probability





Leg Deployment Testing

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- Results
  - The setup was tested 40 times in both the no-wind and 6 m/s wind scenarios and successfully deployed in all cases
- What this means for our project
  - This verified the design of utilizing torsion springs and epoxy for deployment purposes while the legs are attached to a slotted pin
  - This result provided a confidence level of 99%

Side Panel Deployment Testing

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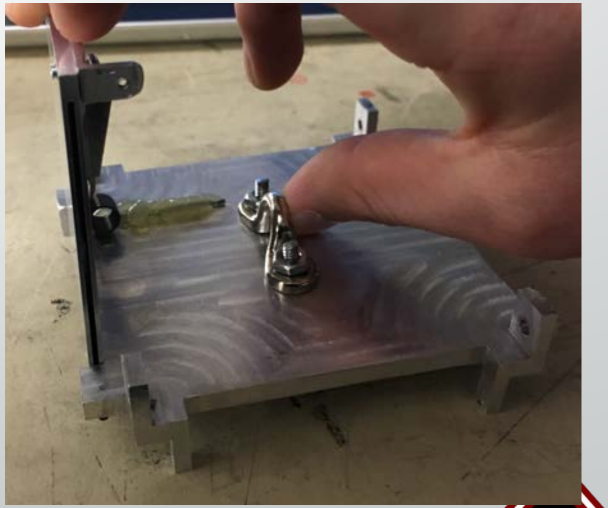
- Objective
  - To achieve reliability numbers for deployment of the machined aluminum side panels
  - Requirement DR 3.2 The payload shall not experience instantaneous loading exceeding 40 G's
- Measurement Sought
  - Number of successful deployments in both no-wind and 6 m/s wind scenarios
- Expected value
  - 95% deployment success rate
- How it reduces risk
  - Indicates the reliability of these deployments following extensive testing for their on mission deployment probability

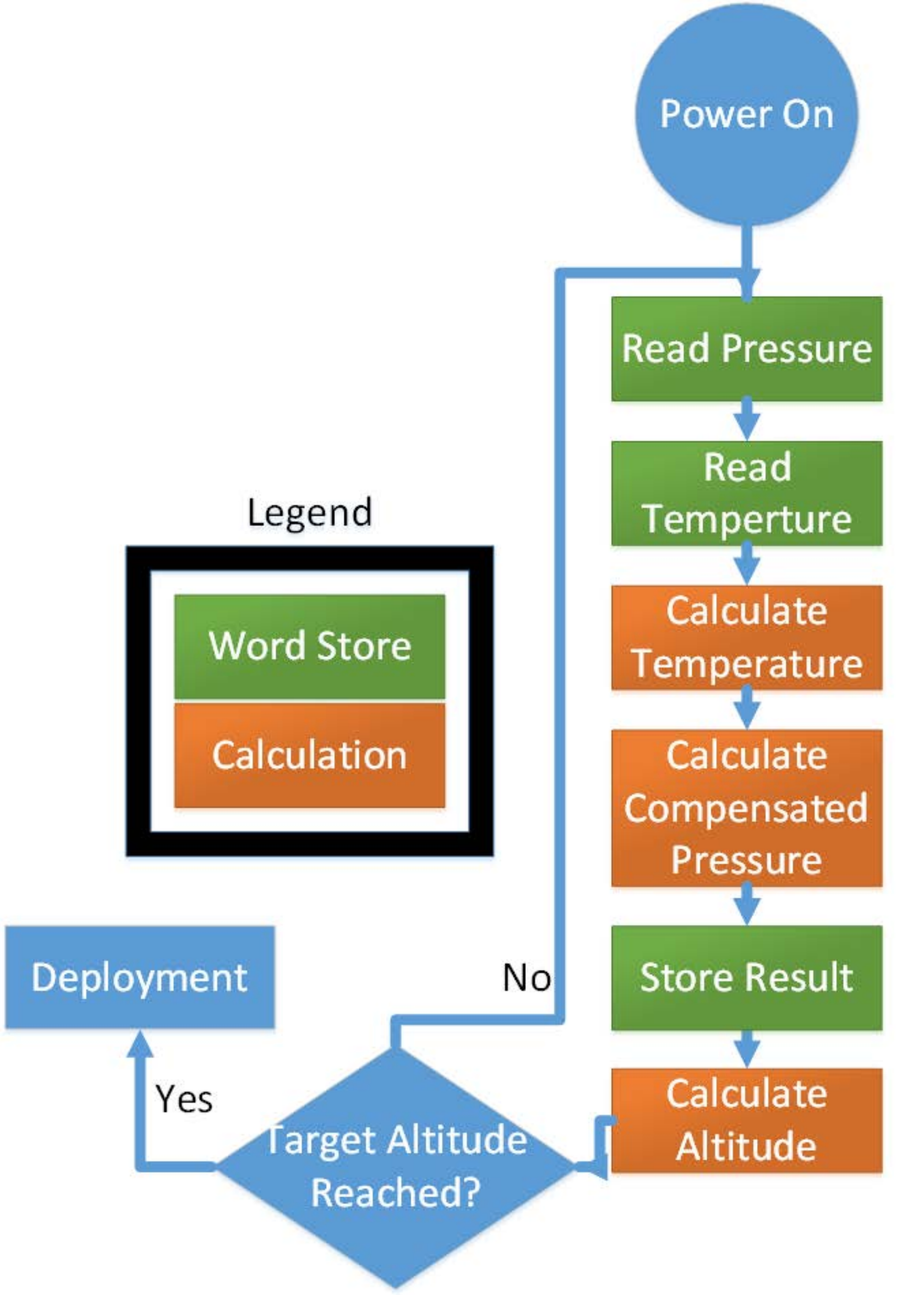


Side Panel Deployment Testing

- Results
  - The setup was tested 40 times in both the no-wind and 6 m/s wind scenarios and successfully deployed in all cases
- What this means for our project
  - This verified the design of utilizing torsion springs and epoxy for deployment purposes while the side panels are attached with steel pins
  - This result provided a confidence level of 99%

Avionics Backup

Altitude Determination Algorithm



EGSE Testing Components:

- Altimeter Breakout Board
- Rasberry Pi 3 EGSE

Flight Testing Components:

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

Deployment Algorithm

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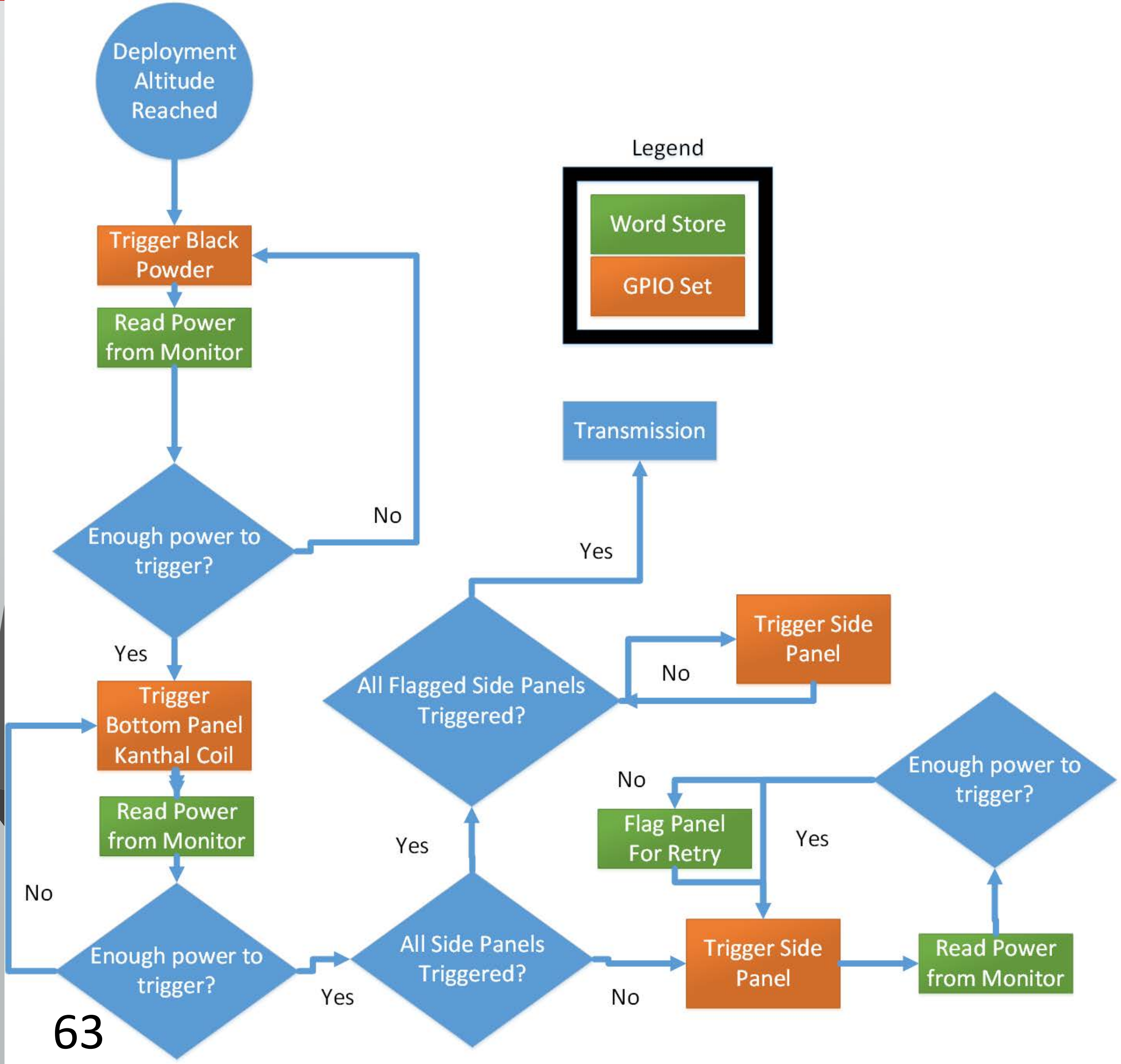


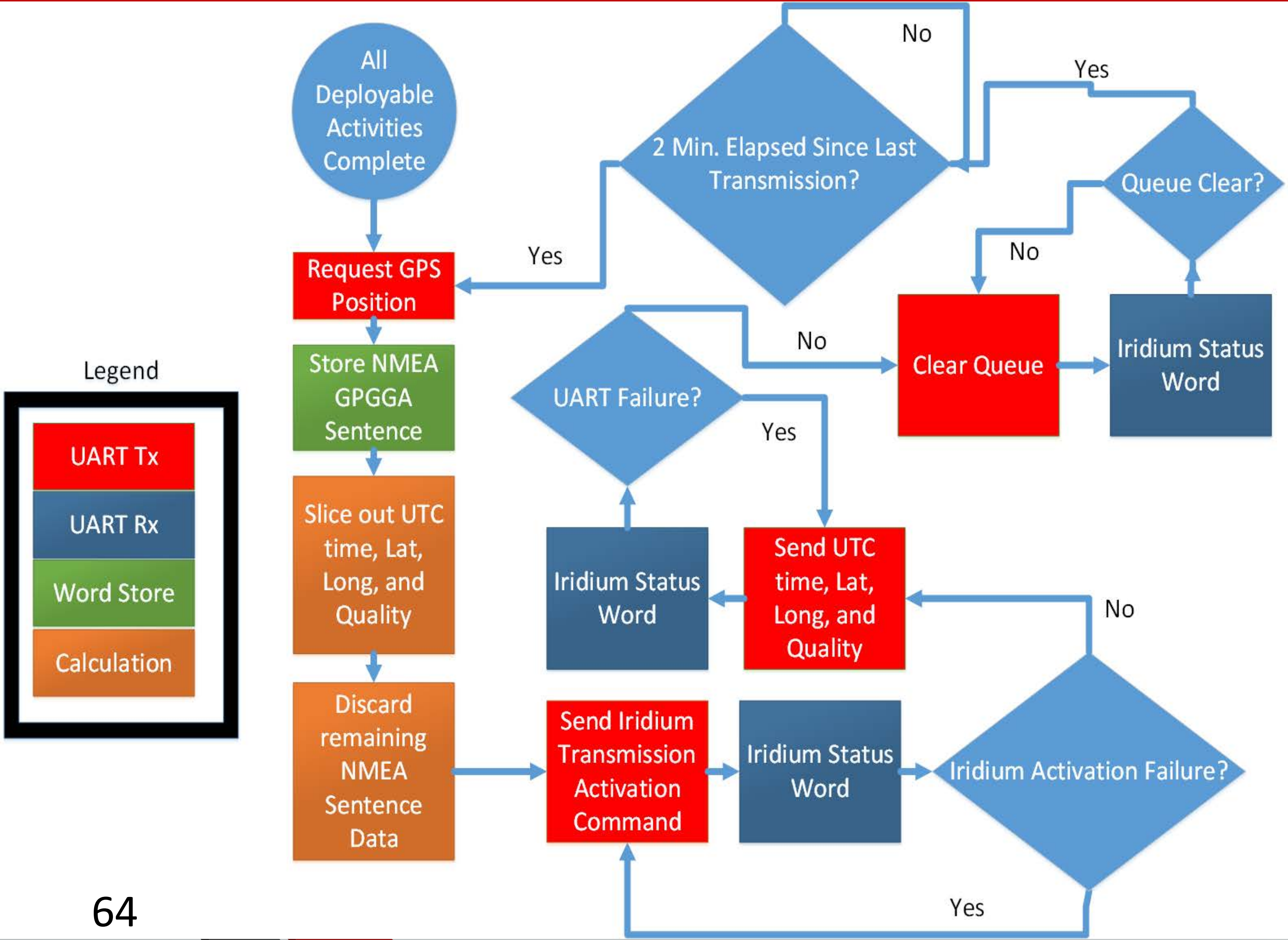
EGSE Testing Components:

- N/A

Flight Testing Components:

- MainBoard
- EGSE (if MSP430FR drivers fail)

Location Determination/Transmission Algorithm



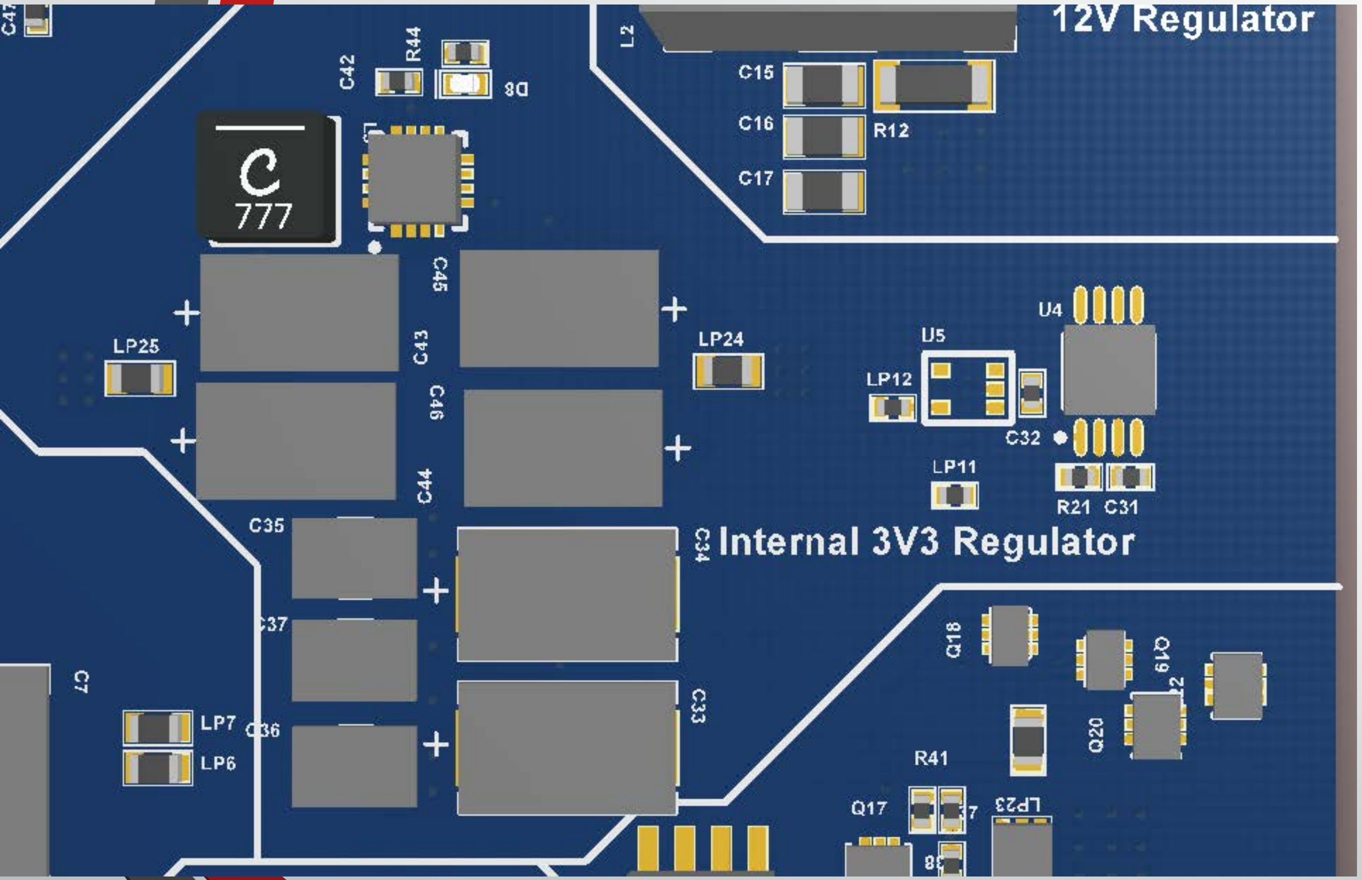
<u>EGSE Testing Components:</u>

- Iridium RockBlock
- Venus GPS
- Rasbperry Pi 3 EGSE

<u>Flight Testing Components:</u>

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

3V3 Internal Regulator



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)

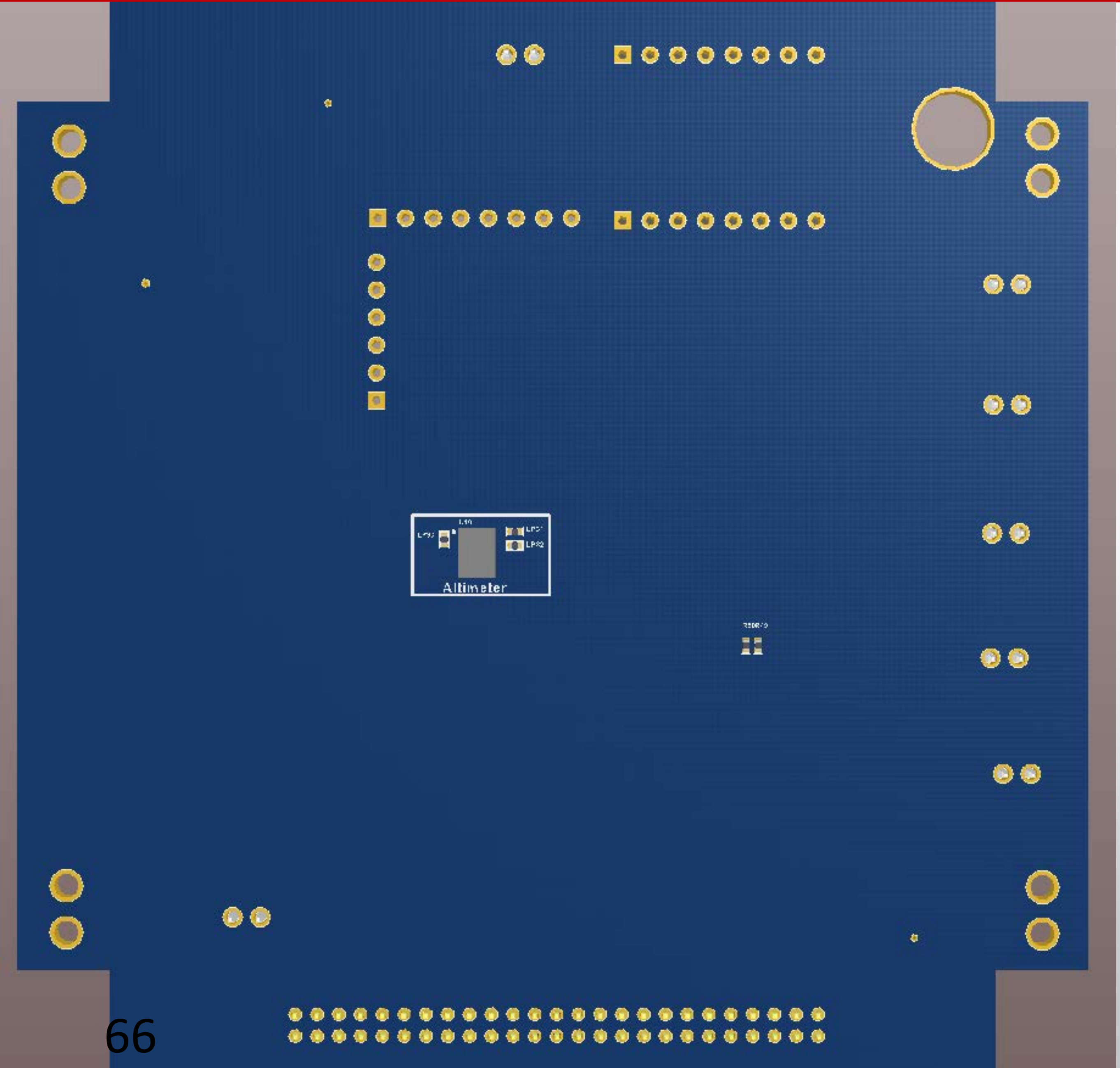
Software Tests:

- 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

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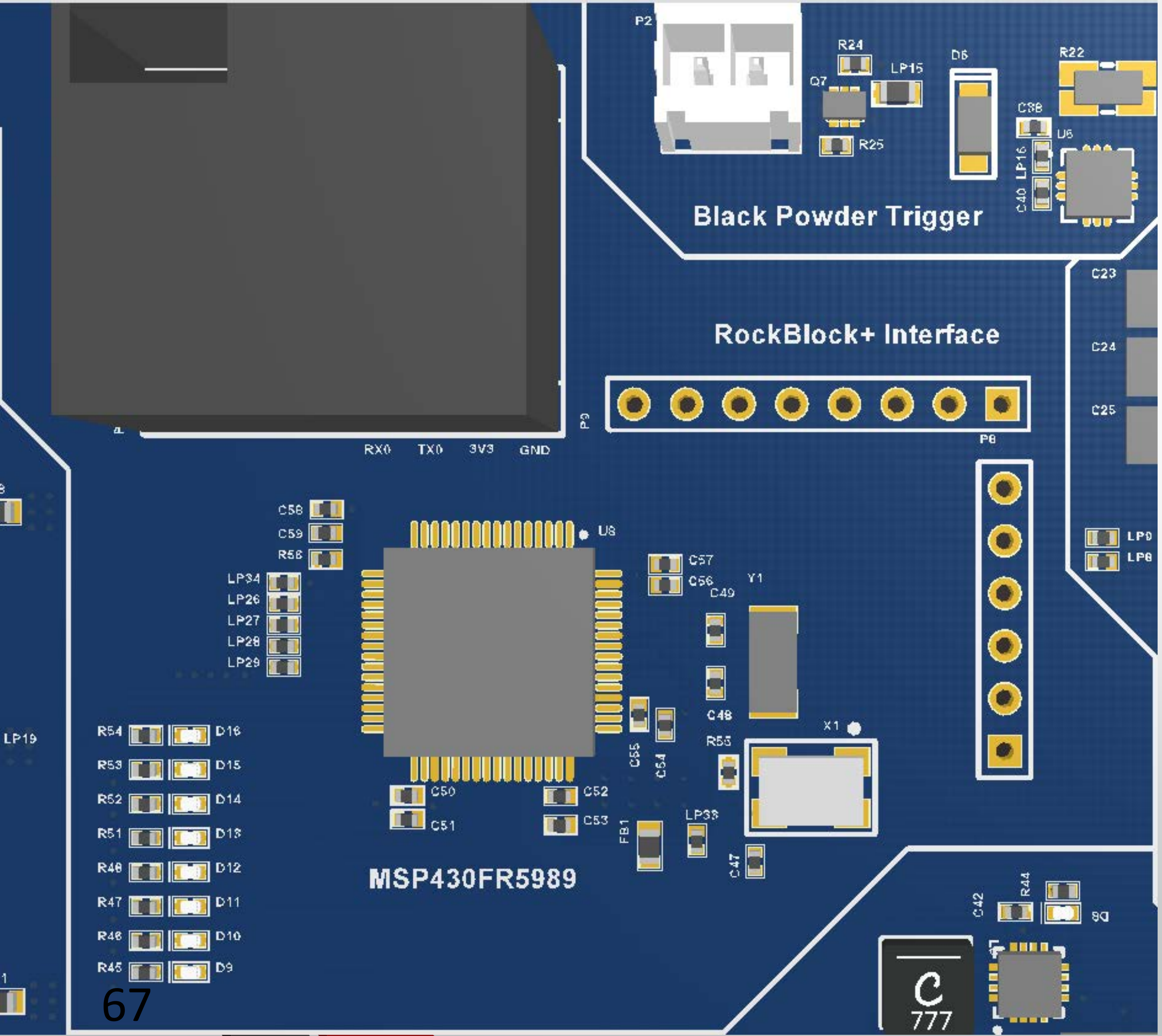

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Responsible For:

- 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

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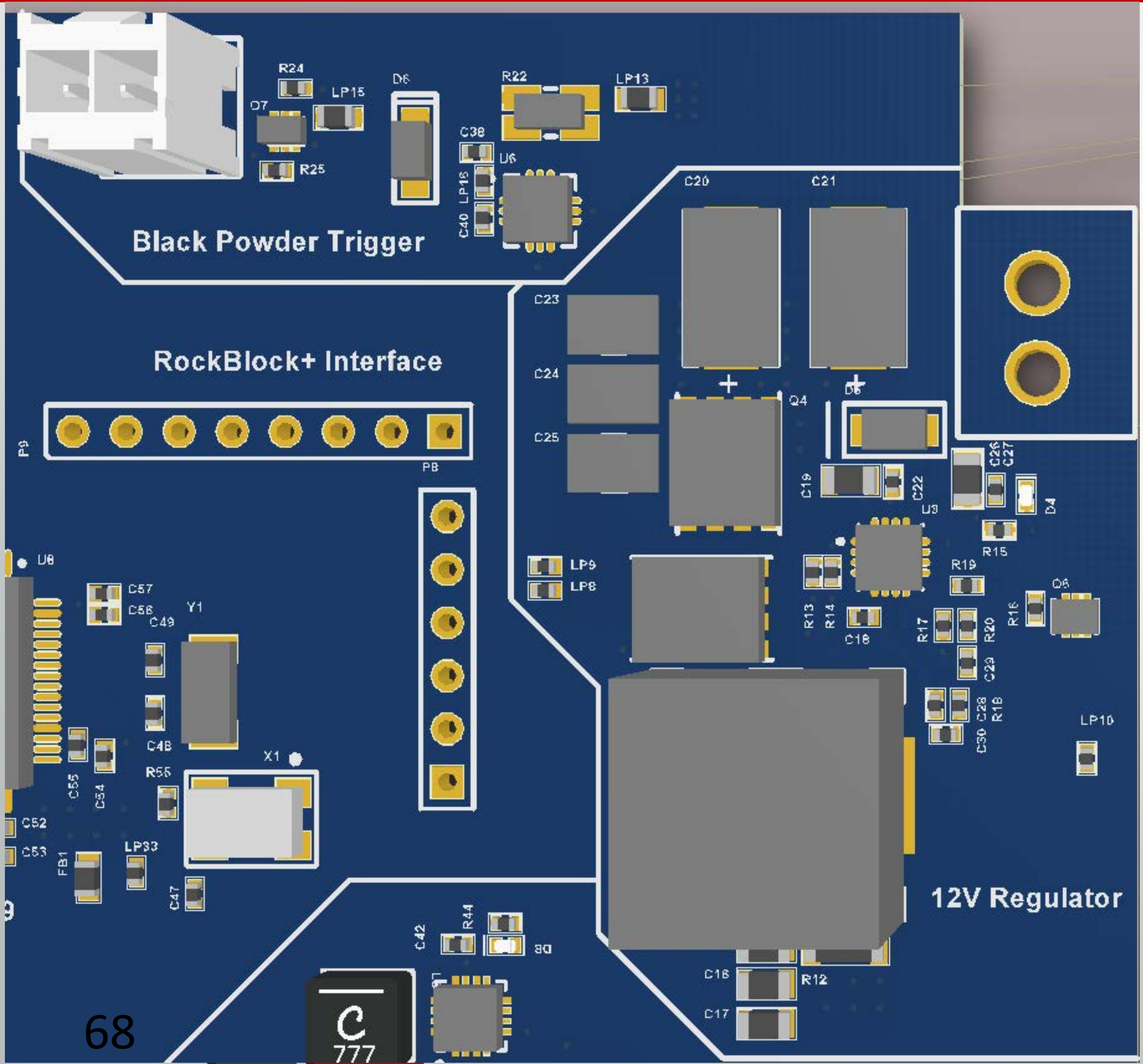

Responsible For:

- 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

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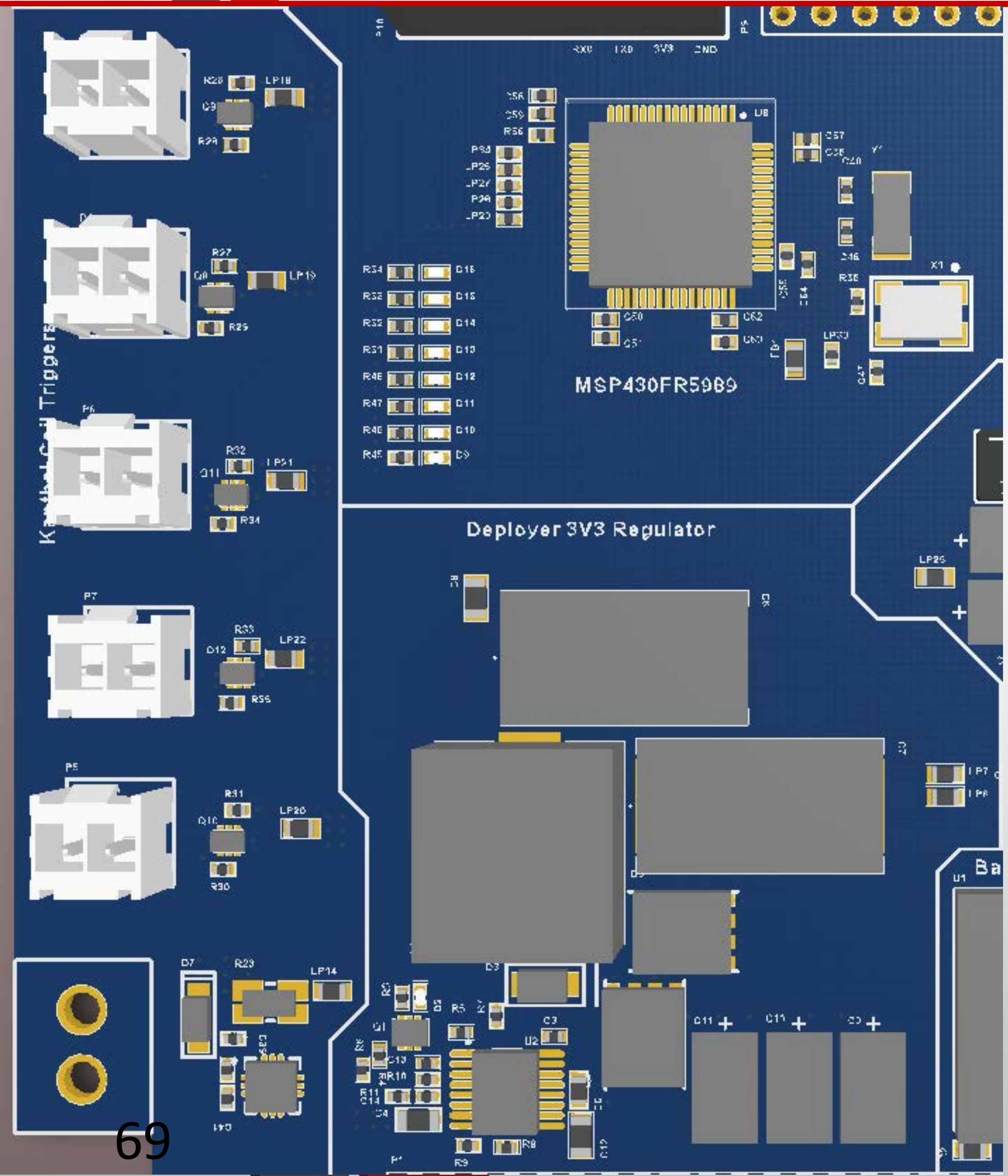

Responsible For:

- 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

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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

Work Completed:

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

Descent

Key Items Bought	Price
Parachute x2	$388
Black Powder	$30
Ejection Canisters	$108
Fiberglass Tube	$77
Fiberglass Cloth	$44
Fiberglass Sheets	$59
Epoxy	$112
Other	$134

Key Numbers	
Estimated Cost	$897.00
Total Cost	$951.90
Under/Over	-$54.90

Landing

Key Items Bought	Price
Side Panels	$293
Aluminum Legs	$606
Springs	$34
Pins	$92
Aluminum Foam	$92
Epoxy	$94
Aluminum	$166
Other	$67.15

Key Numbers	
Estimated Cost	$1,444.15
Total Cost	$1,418.93
Under/Over	$25.22

Avionics

Key Items Bought	Price
Rev A	$76
Altimeter Break	$39
Battery Recharger	$123
Iridium Antenna	$33
Raspberry Pi3	$40
Venus GPS SMA	$50
RockBlock	$294
Other	$951.45

Key Numbers	
Estimated Cost	$1,087.90
Total Cost	$1,606.45
Under/Over	-$518.55

Estimated Cost	Total Cost	Drop Test	Under/Over	Margin
$3,429.05	$3,977.38	$400.00	-$948.23	$622.62

In-plane measurements

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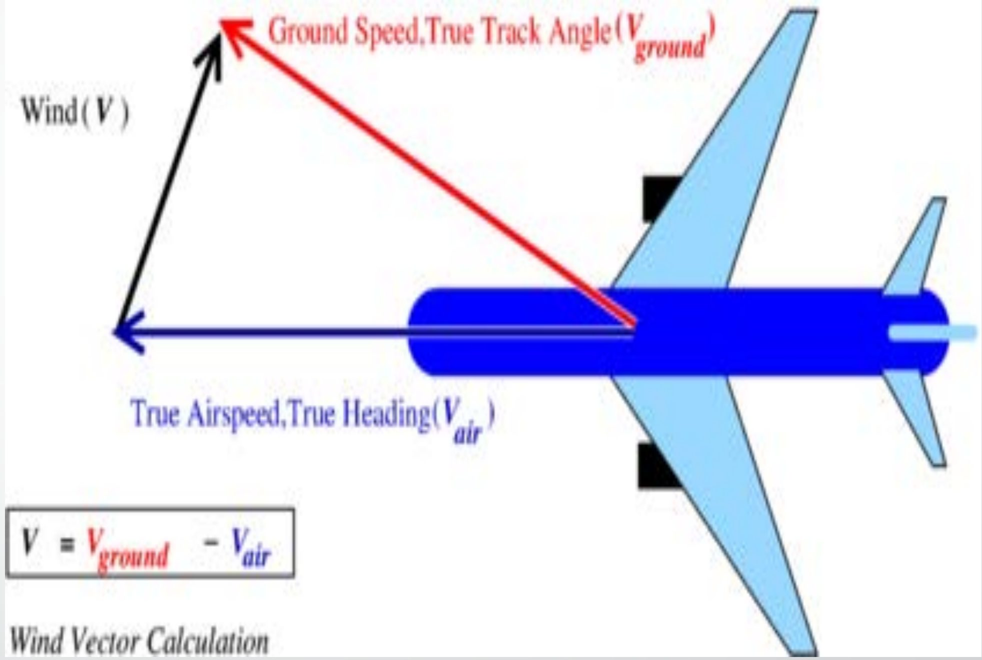
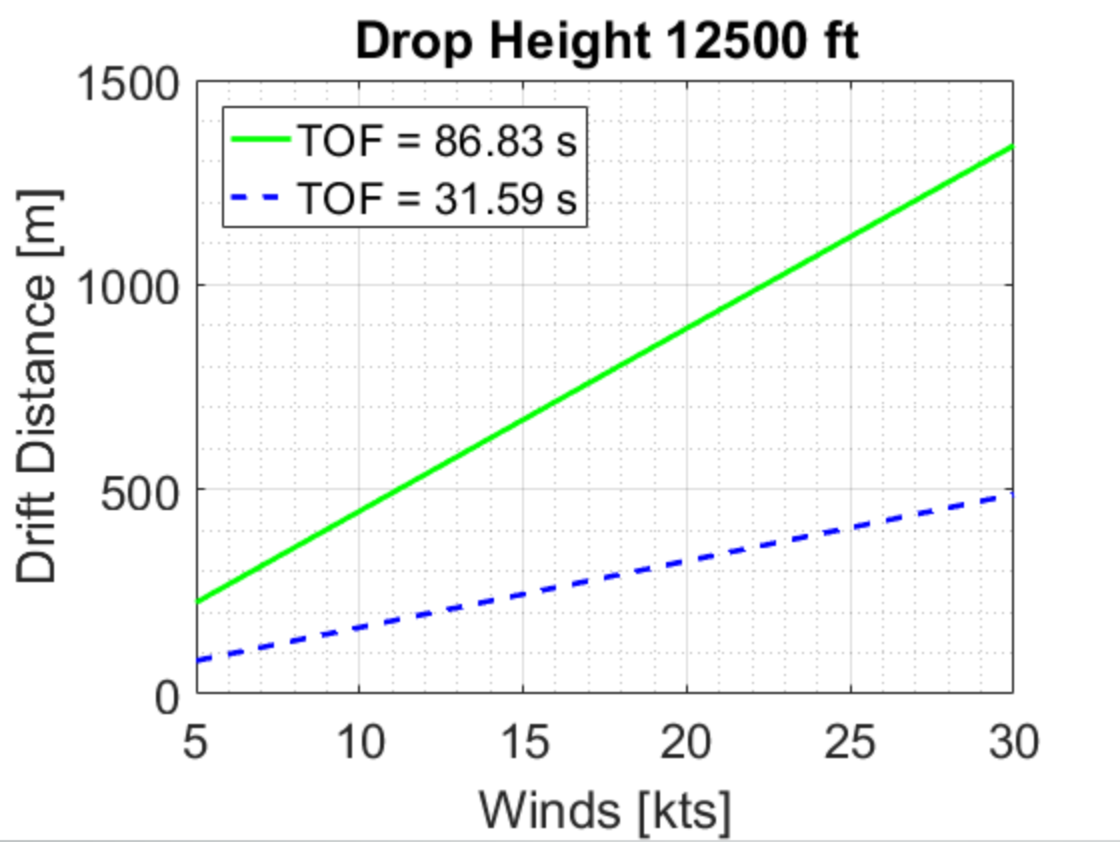
Quantity	How	Why
Coordinates and time of the point REPTAR is dropped	Drop a pin using a map app	To calculate final drift, assist recovery
Indicated airspeed	Plane instruments	To validate wind aloft model and predict drift
Outside Air Temperature	OAT Gauge	To calculate True Airspeed
Pressure Altitude	Plane altimeter	To calculate True Airspeed
Ground speed	GPS	Compare with True Airspeed for Winds Vector Calculation
Ground track vs heading	Magnetic compass	To validate wind aloft model and predict drift



Expected Drift Model



Drift Zone and Recovery

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