Test Readiness Review: High Altitude Lifting Orbiter (HALO)

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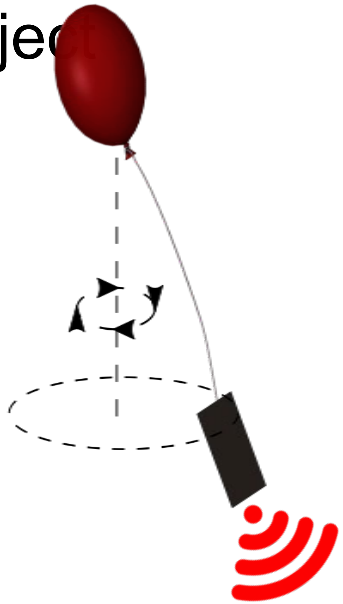
Customer: Professor Lawrence
Advisor: Matt Rhode

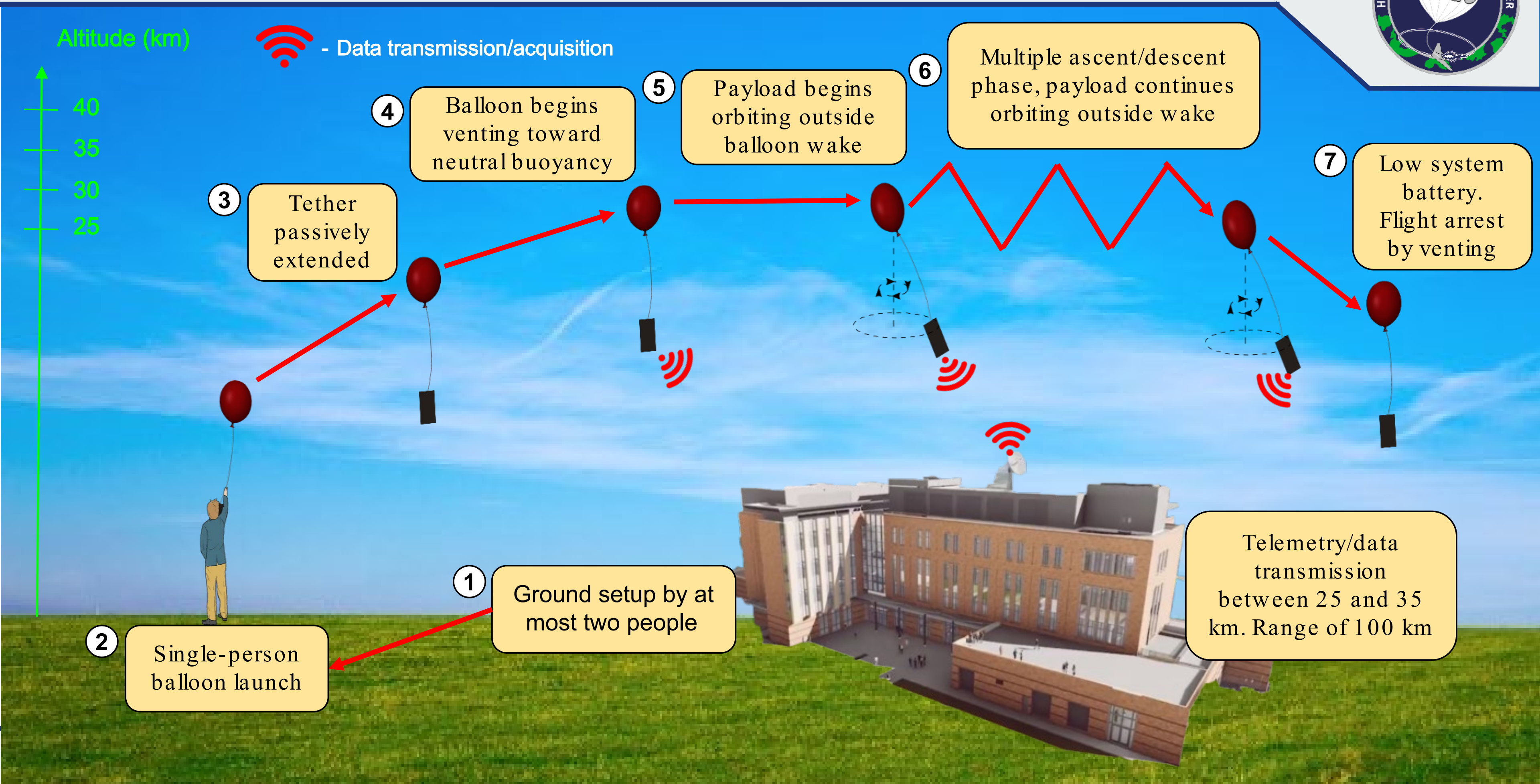
Mission Statement

The High Altitude Lifting Orbiter (HALO) project will improve collection of turbulence data in the stratosphere.

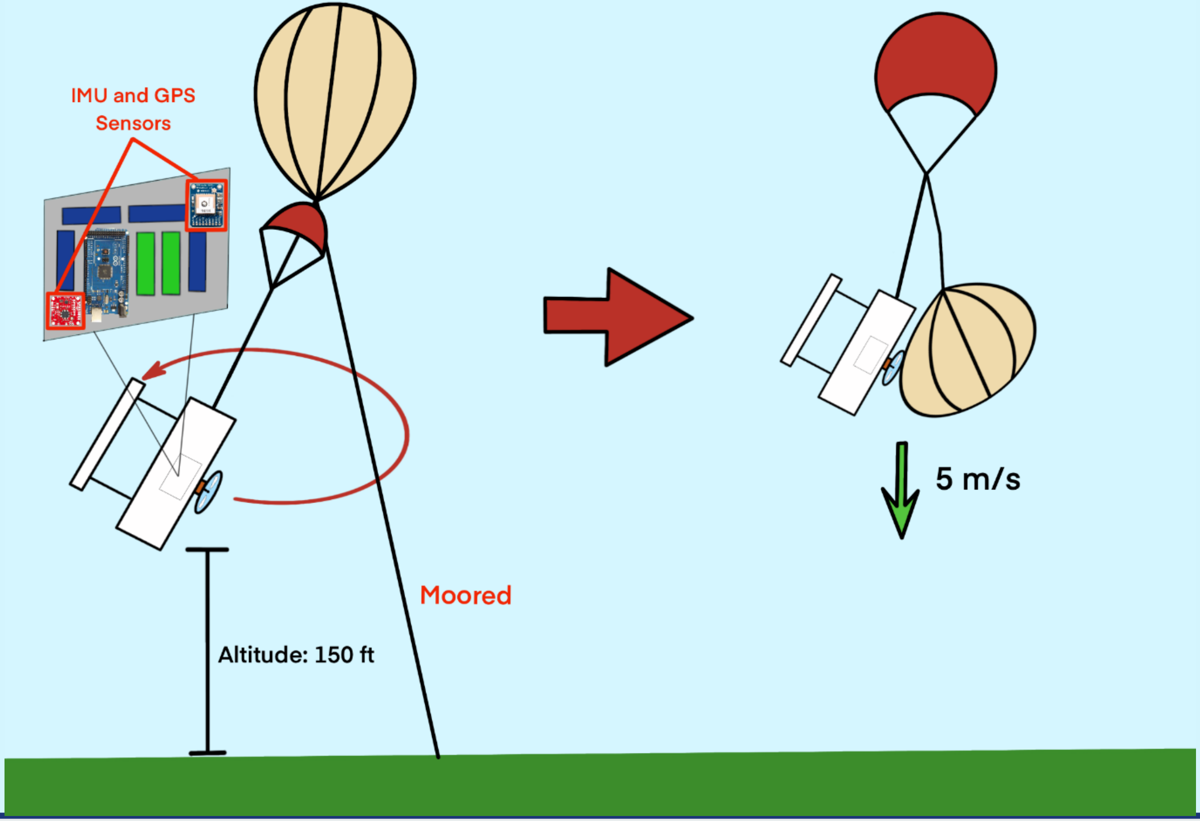
HALO will create an autonomous tethered payload system capable of orbiting outside a balloon's wake. A control surface will be used to induce altitude oscillations



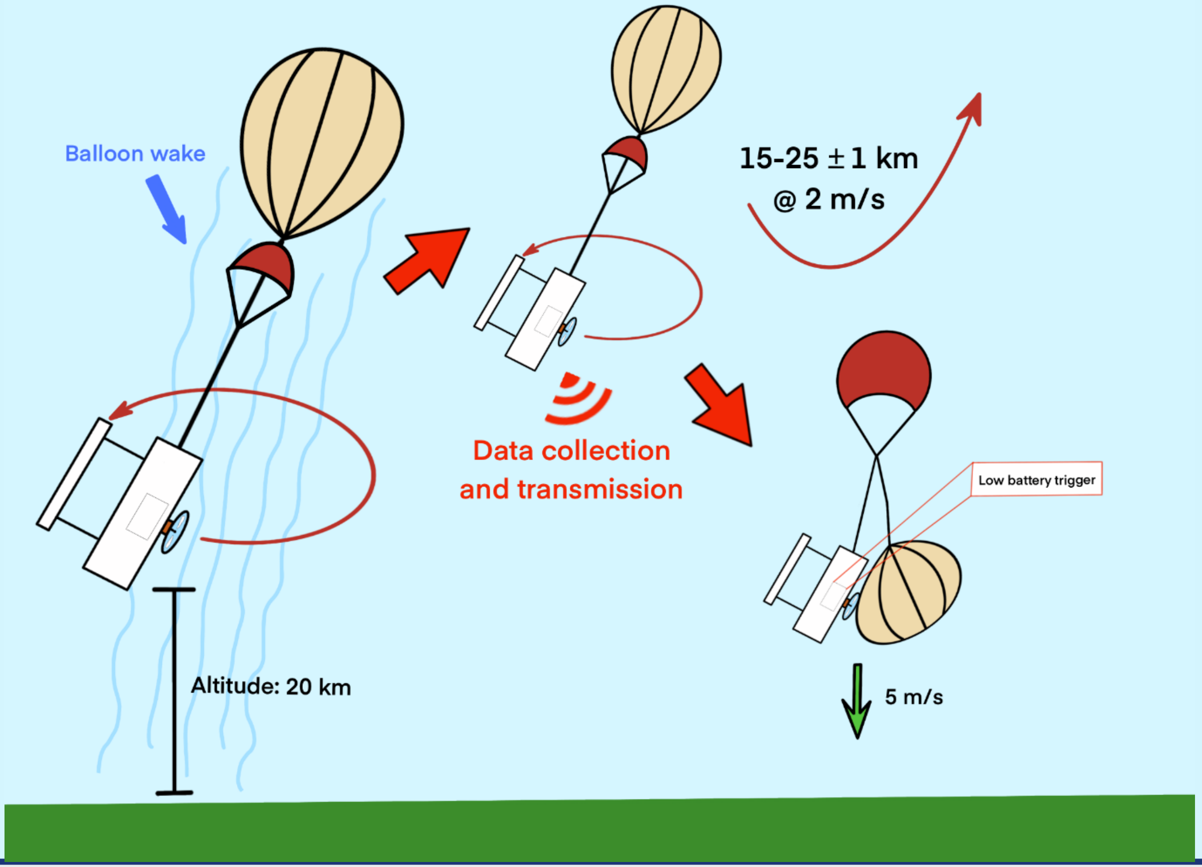
Concept of Operations



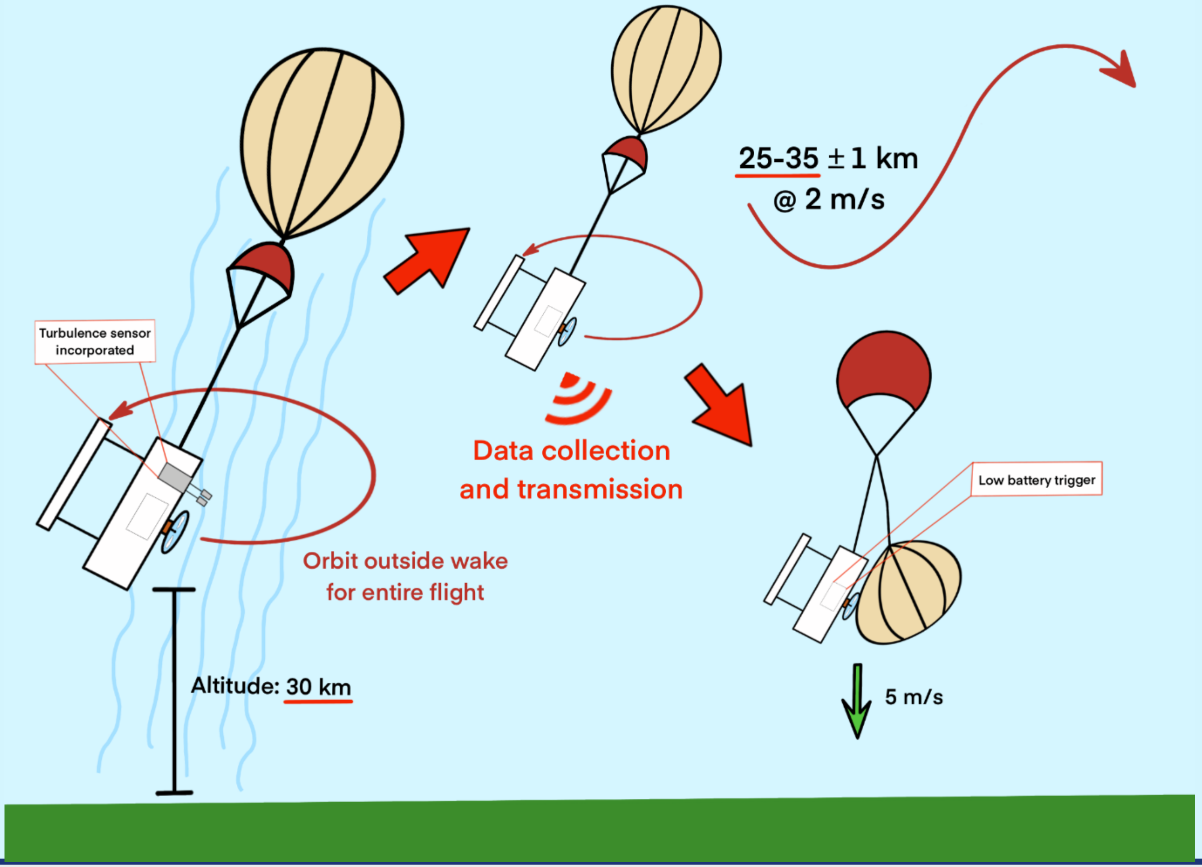
Levels of Success - Level 1



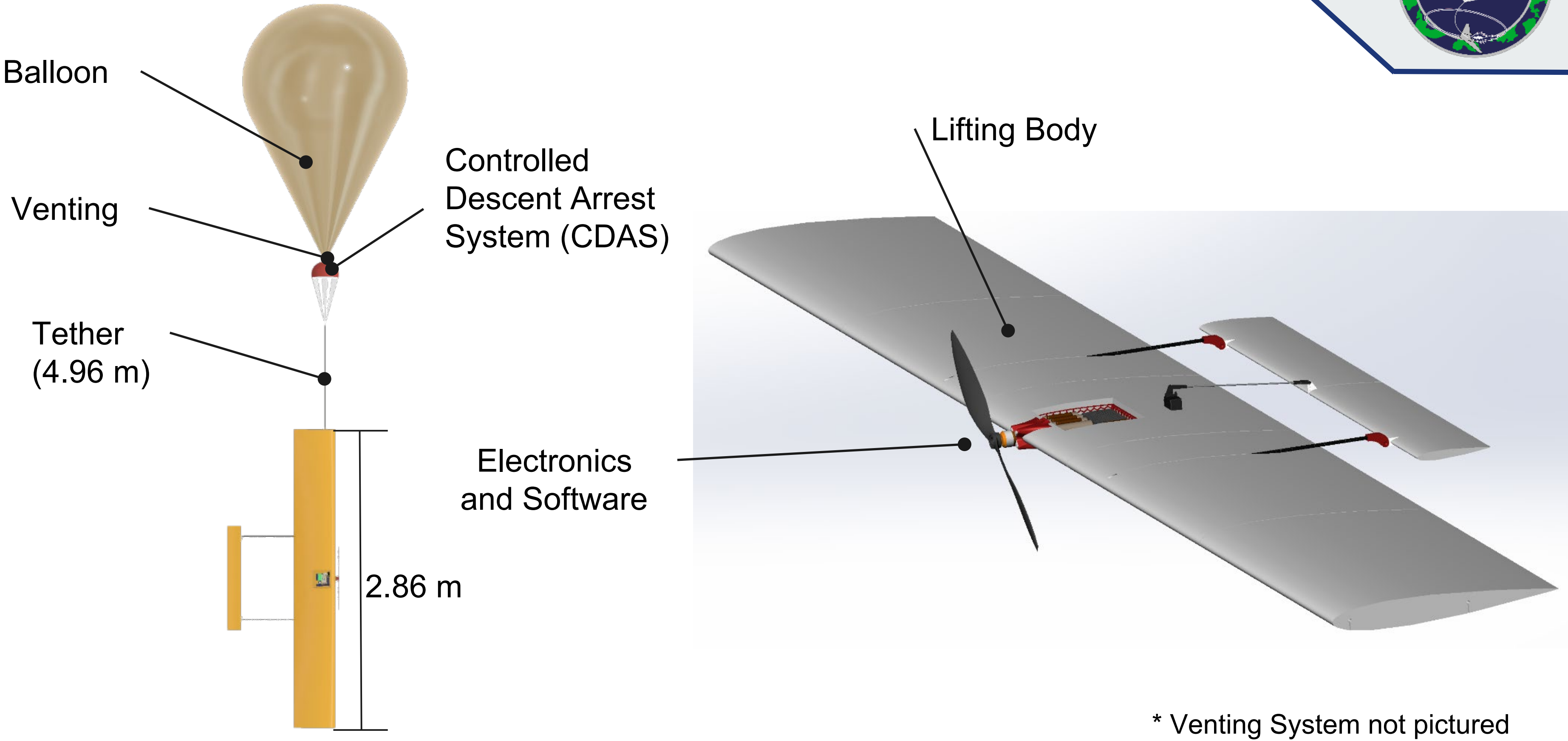
Levels of Success - Level 2



Levels of Success - Level 3

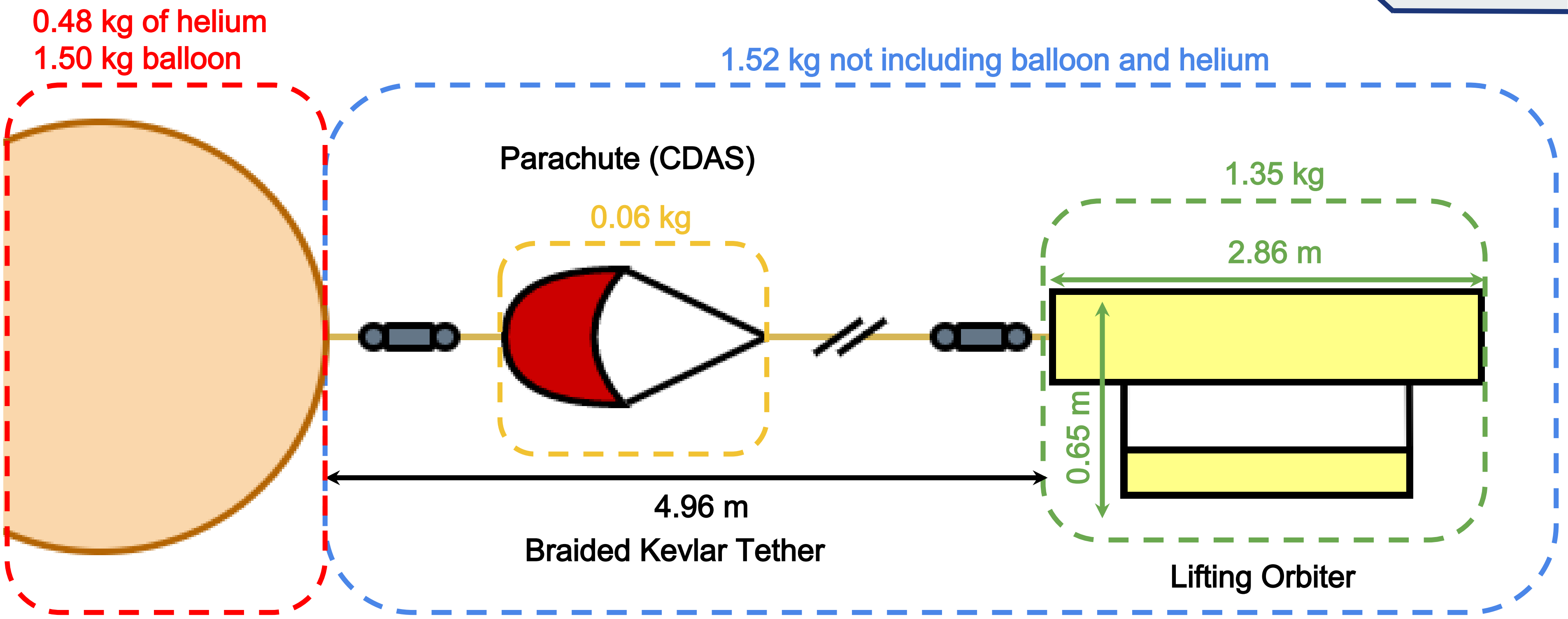


System Breakdown: CPE's



* Venting System not pictured

System Breakdown

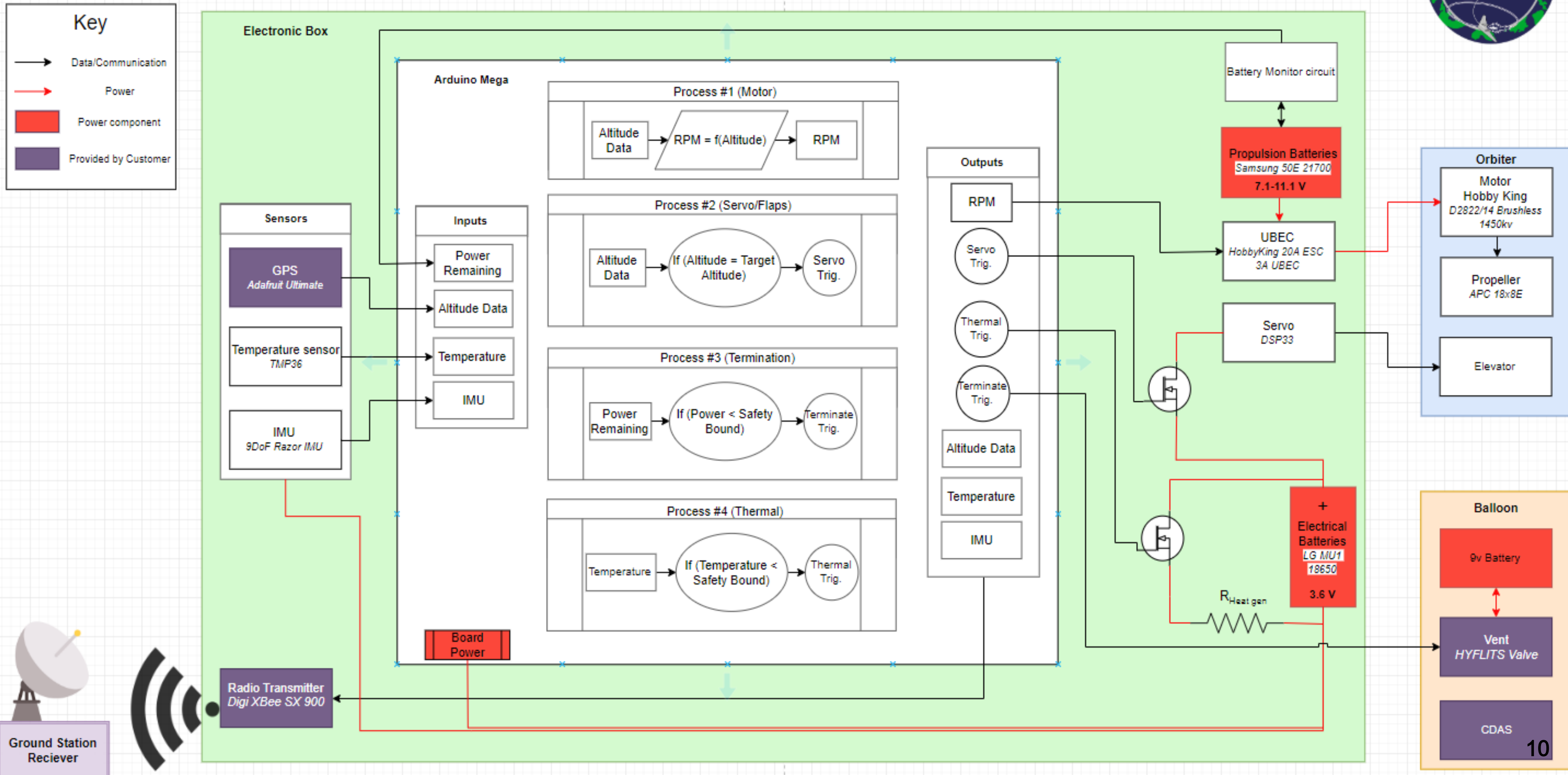


Critical Project Elements

CPE	Why it is Critical?
Balloon	Must be able to reach the target altitude without bursting and handle the stresses on the neck due to the tether and payload.
Venting	Must be able to ensure venting can achieve neutral buoyancy, as well as act as a method to terminate flight.
Tether	Must have a launching tether design that will allow a maximum of 2 people to deploy (preferably 1 person), as well as have a tether that breaks under a 50 lbf (222.4 impulsive force.
Lifting Body	Must be able to maintain the sensor package outside of the balloon wake while orbiting at a maximum speed of 20 m/s. This system will then be able to induce an average ascent and descent speed of the entire system of 2.0 ±20% m/s.
CDAS	Must have a method to ensure a safe descent of the payload in case of catastrophic failure in order to not harm person or property.
Electronics	Must keep electronics in operating temperature range and ensure that there is enough power for the duration of the entire mission.
Software	Must be able to account for altitude changes and actuate commands in order to initiate control surfaces, maintain the flight and terminate the flight.

Team **HALO**

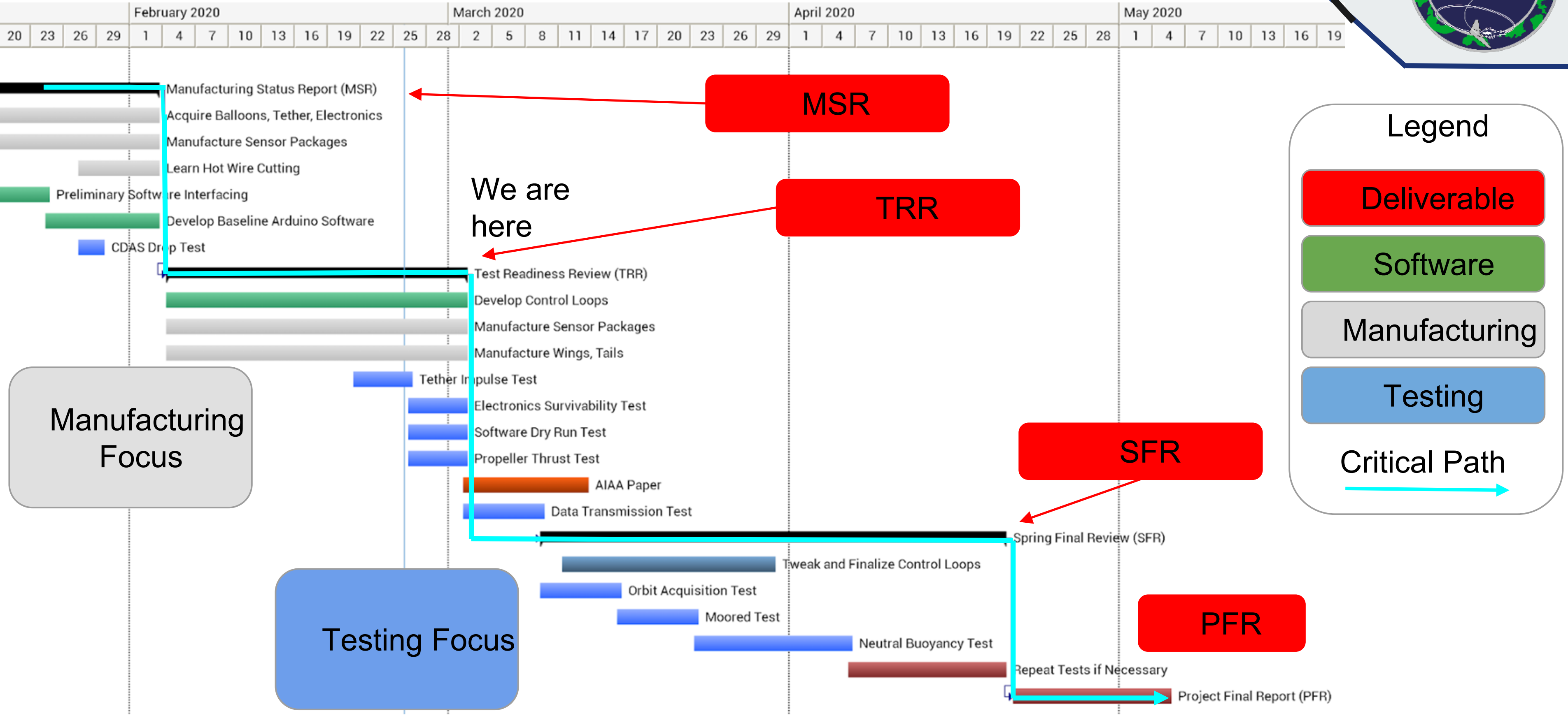
High **A**ltitude **L**ifting **O**rbiter
Test Flight Design
FBD Rev. 3



FAA Update

- CU administration is requiring an FAA waiver to conduct final systems test
  - Potential for airship classification
  - Waiting on official response from FAA
- Cannot conduct untethered flight until further notice
  - Likely will not hear back in time to conduct flight test

Updated Work Plan



Work Breakdown Structure

Deliverables	Manufacturing	Software	Testing
CDR	Assemble orbit acquisition test wing	Outline control system pseudocodes	Orbit acquisition test
FFR	Acquire components for 3 wings	Preliminary Software Interfacing	CDAS drop test
MSR	Assemble each wing	Develop data transmission automation	Tether breakage test
TRR	Assemble Electronics Package	Develop propulsion control system	Electronics survivability test
AIAA Paper	Assemble deployment stand	Develop control surface automation	Software dry run tests
SFR	Assemble flight test system	Develop venting control system	Propeller thrust test
Project Final Report			Data transmission test
			Orbit Acquisition Test
			Moored Test
			Neutral Buoyancy test

Legend

- Complete
- In Progress
- Incomplete

Updated Test Plan

Test	Location	Special Equipment	Planned Date
CDAS Drop Test	CU Aerospace Building	Parachute	1/29/20
Tether Impulse Test	CU Aerospace Building	Tether, Force Scale, Masses	2/23/20
Electronics Survivability Te	CU Aerospace Building	Electronics Package, Pressure Chamber, Dry Ice	3/4/20
Software Dry Run Test	CU Aerospace Building	Electronics Package, Wing, Tail, Servo	3/8/20
Propeller Thrust Test	CU Aerospace Building	Propeller, Force Scale	3/8/20
Data Transmission Test	Surrounding Area	Transmitter, Receiver, Electronics Package	3/8/20
Orbit Acquisition Test	CU Aerospace Building	Scaled Lifting Orbiter, Tether, Crane / Open area	3/15/20
Moored Test	CU Boulder South	Tether, Lifting Orbiter, Balloon	3/22/20
Neutral Buoyancy Test	Marshall Mesa Site	Balloon, Receiving Antenna	3/29/20

Legend
- Completed
- Incomplete
- Added

Testing Breakdown

Orbit Acquisition	Descent Arrest	Lift Generation
Neutral Buoyancy	Data Transmission	Survivability

Testing Breakdown

Orbit Acquisition

- Orbit Acquisition Test
- Moored Test

Descent Arrest

Lift Generation

Neutral Buoyancy

Data Transmission

Survivability

Testing Breakdown

Orbit Acquisition

- Orbit Acquisition Test
- Moored Test

Descent Arrest

- CDAS Drop Test

Lift Generation

Neutral Buoyancy

Data Transmission

Survivability

Testing Breakdown

Orbit Acquisition	Descent Arrest	Lift Generation
• Orbit Acquisition Test • Moored Test	• CDAS Drop Test	• Software Dry Run Test • Propeller Thrust Test
Neutral Buoyancy	Data Transmission	Survivability

Testing Breakdown

Orbit Acquisition
- Orbit Acquisition Test
- Moored Test

Descent Arrest
- CDAS Drop Test

Lift Generation
- Software Dry Run Test
- Propeller Thrust Test

Neutral Buoyancy
- Neutral Buoyancy Test

Data Transmission

Survivability

Testing Breakdown

Orbit Acquisition	Descent Arrest	Lift Generation
• Orbit Acquisition Test • Moored Test	• CDAS Drop Test	• Software Dry Run Test • Propeller Thrust Test

Neutral Buoyancy	Data Transmission	Survivability
• Neutral Buoyancy Test	• Data Transmission Test	

Testing Breakdown

Orbit Acquisition
- Orbit Acquisition Test
- Moored Test

Descent Arrest
- CDAS Drop Test

Lift Generation
- Software Dry Run Test
- Propeller Thrust Test

Neutral Buoyancy
- Neutral Buoyancy Test

Data Transmission
- Data Transmission Test

Survivability
- Tether Impulse Test
- Electronics Survivability Test

Testing Breakdown

Orbit Acquisition
- Orbit Acquisition Test
- Moored Test

Descent Arrest

Lift Generation
- Propeller Thrust Test

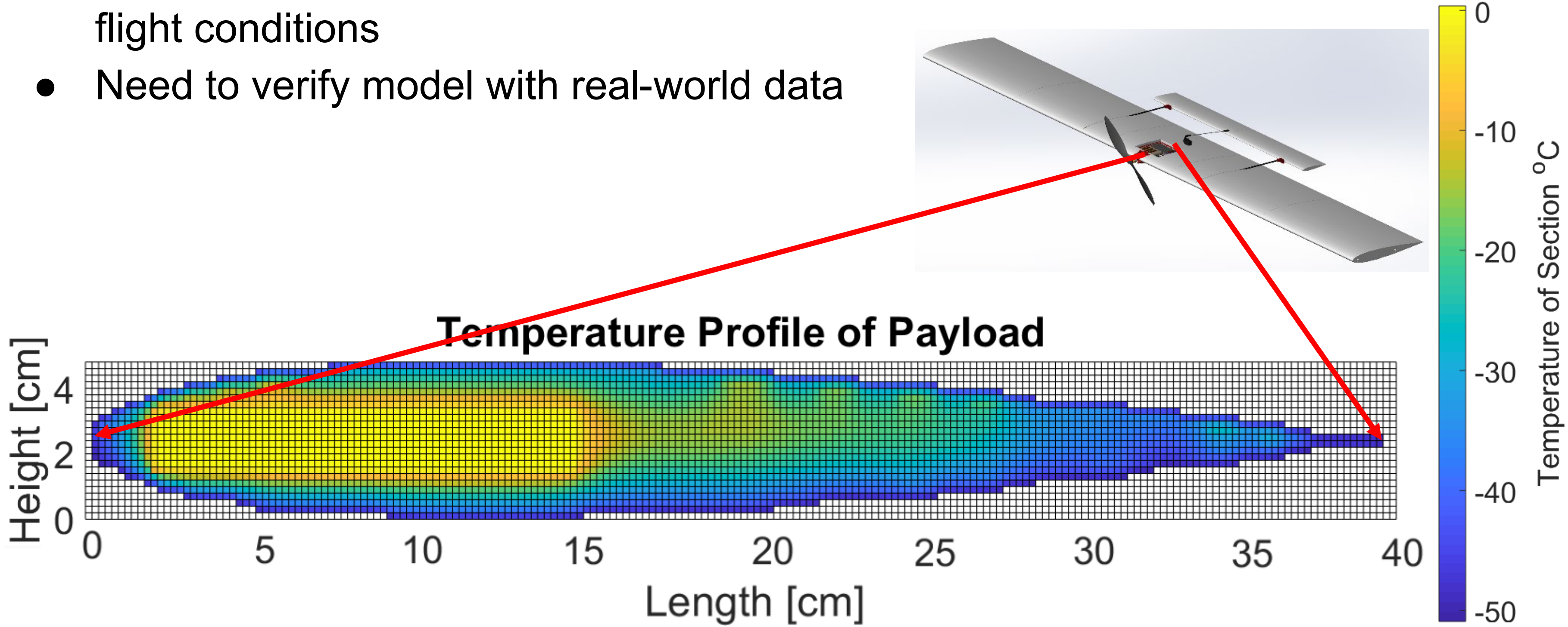
Neutral Buoyancy
- Neutral Buoyancy Test

Data Transmission

Survivability
- Electronics Survivability Test

Thermal Model: Overview

- Model results indicate electronic survival at flight conditions
- Need to verify model with real-world data



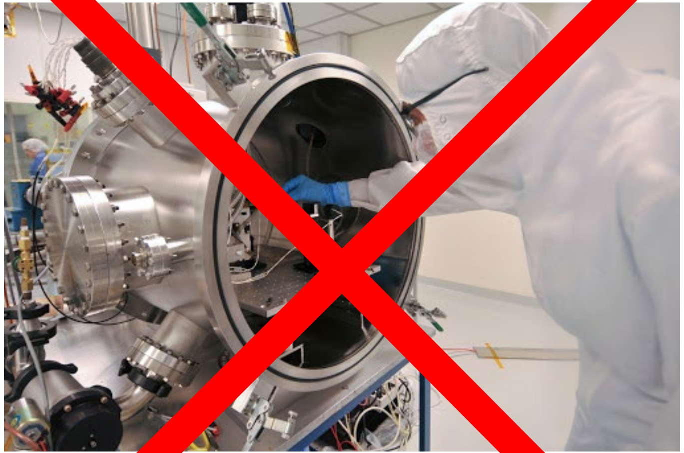
Thermal Model: Types of Verification

- Need to mimic environmental flight conditions
  1. Very cold (-69.70 °C)
  2. Very low air density (0.9145% sea level)

Mimic Cold Conditions:
- <u>Thermal Chamber Test</u>
- Dry Ice(-78.5 degrees°C)

Mimic Pressure Conditions:
- <u>Hypobaric Chamber Test</u>
- Will resistors still dissipate heat?

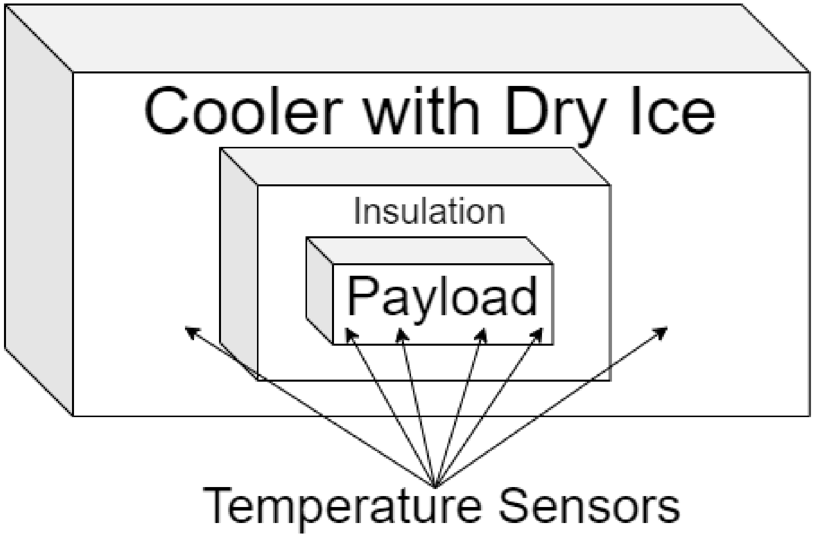
Thermal Vacuum Chamber?



1. Expensive
2. Hard to acquire acces
3. Size requirement

Thermal Chamber Test

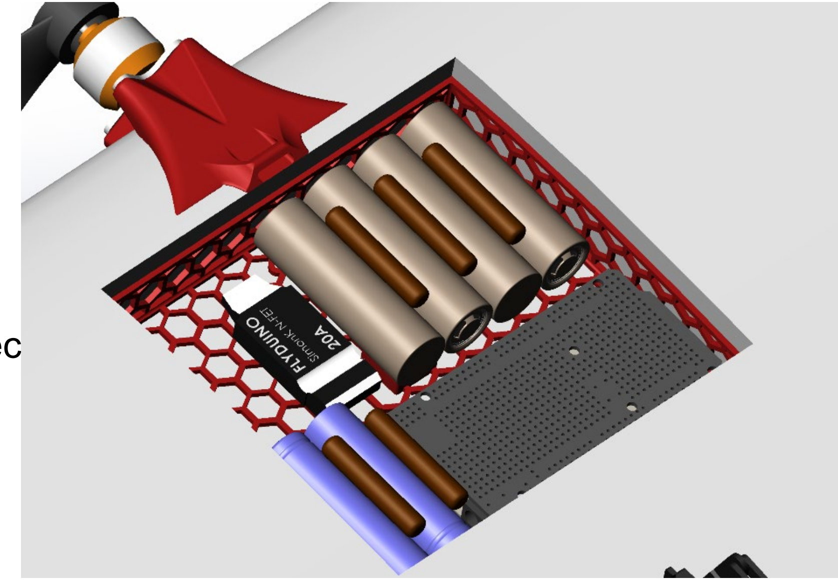
- Testing
  - FR 3.0: The payload must be able to survive the conditions presented throughout the entirety of the mission
    - Risks Mitigated: electronics failure, over/under heating
- Procedure
  - Place foam box with insulation width similar to the airfoil in cooler with dry ice
  - Put all components where they would be for a real flight
  - Use the temperature sensors to monitor the temperatures in the dry ice cooler and payload
  - Data saved via SD card
- Re-Scheduled for March 4th



Status: 1 Week Behind

Hypobaric Chamber Test

- Testing
  - FR 3.0: The payload must be able to survive the conditions presented throughout the entirety of the mission
    - Risks Mitigated: electronics failure, over/under heating
  - Ability of heaters to dissipate heat to payload given low pressure (low density) conditions
- Procedure
  - Place the electronics housing package with selec components active in pressure chamber
  - Use temperature sensors to monitor the heat conduction/convection in payload air
  - Data saved via SD card
- Conducted on March 1st



Status: On track

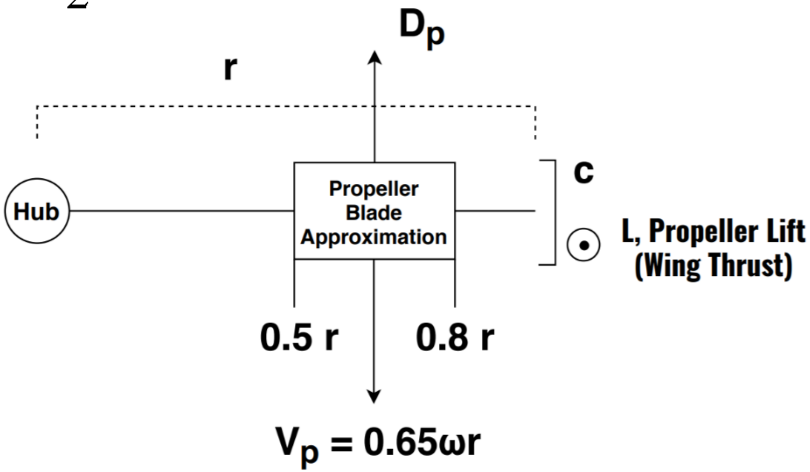
Propeller Thrust Model

- Thrust model must be verified to gain confidence we have the required thrust to orbit at altitude
- Blade element theory
- Propeller thrust must equal orbiter drag
- Most propeller thrust is generated from middle of blade section

$$D_o = T_{prop}$$

$$\tau = 0.65r \times D_p$$

$$D_o = \frac{1}{2}\rho V_p^2 S_p C_{L,p} n$$

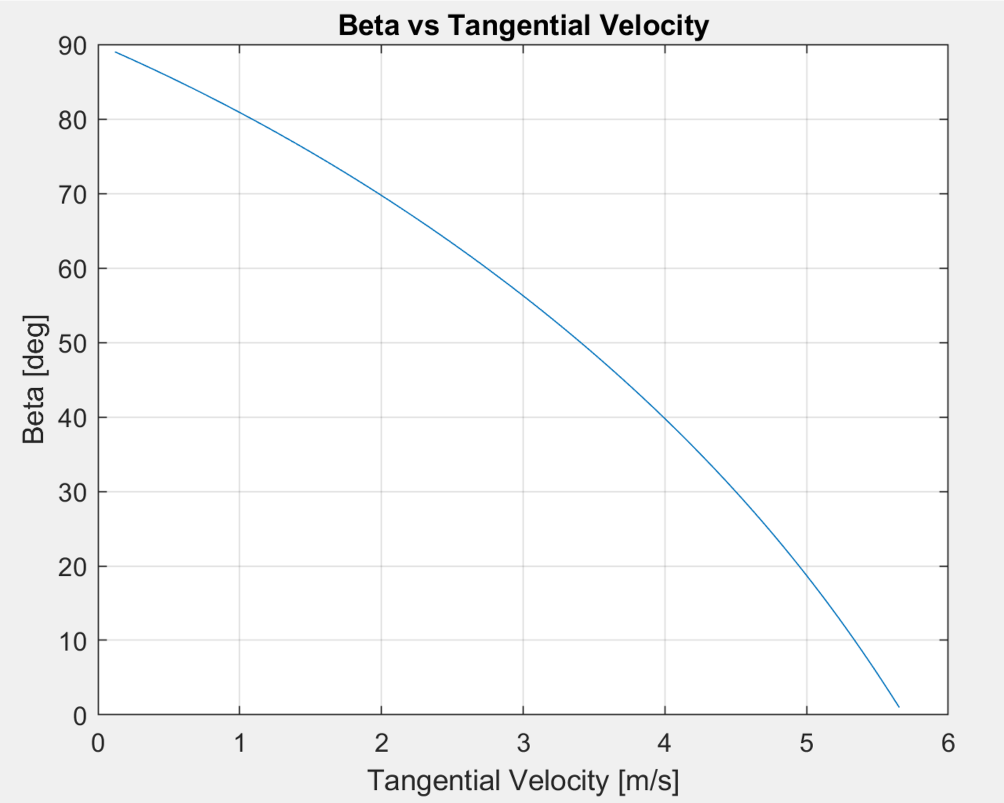


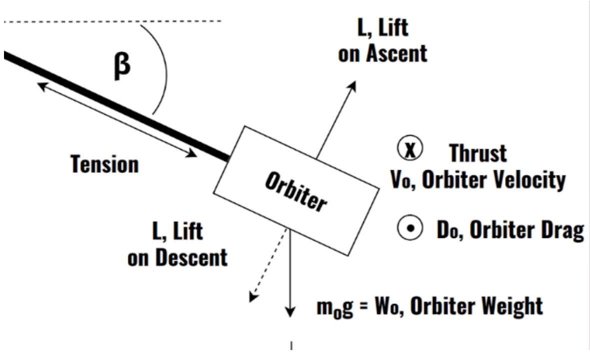
Propeller Thrust Test

- Testing
  - FR 2.0: The payload must be capable of orbiting beneath the balloon
    - Risks Mitigated: not producing enough lift, not inducing predicted orbit
  - Ability to change motor speeds
- Procedure
  - Attach motor to thrust sensor mount
  - Vary throttle
  - Obtain thrust data through a wired connection
- Rescheduledfor March 8th

Status: 1 Week Behind

Orbit Model





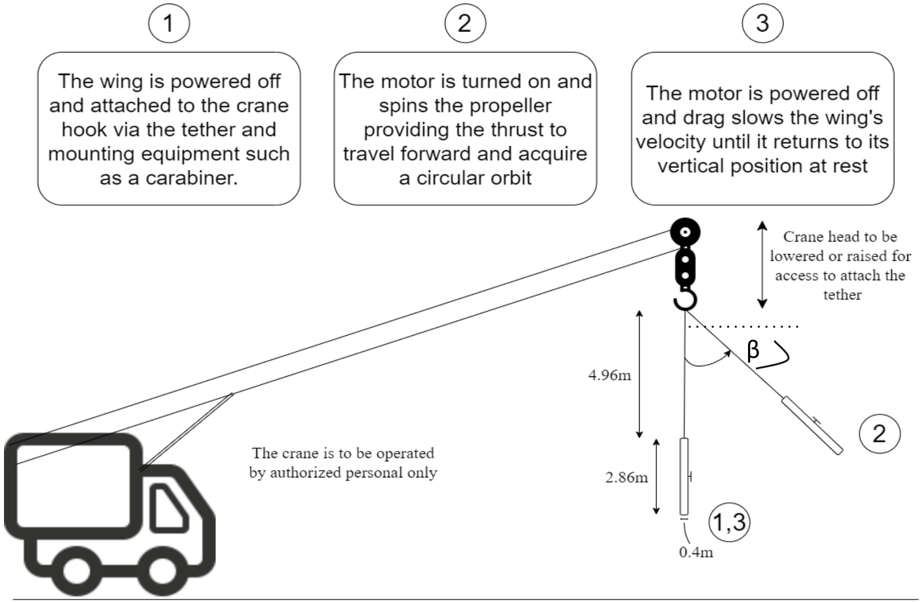
$$\rightarrow \sum F_x : T\cos\beta - L\sin\beta = \frac{mV^2}{r}$$

$$\uparrow \sum F_y : L\cos\beta + T\sin\beta = W$$

$$\odot \sum F_z : D = F$$

Orbit Acquisition Test

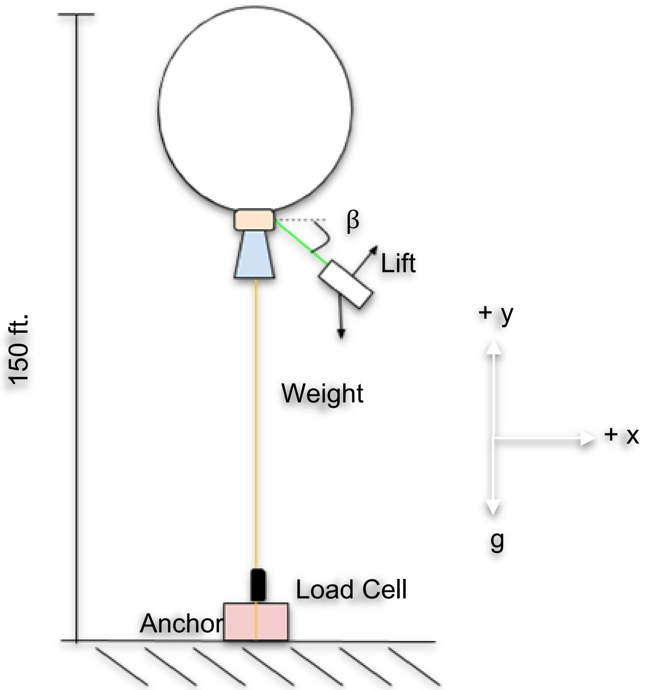
- Testing
  - FR 2.0: The payload must be capable of orbiting beneath the balloon
    - Risks Mitigated: not acquiring orbit, no orbit stability
  - Ability to obtain orbit from vertical rest position
  - Further check the beta angle measurement
  - Test that the wing maintains the correct angle
  - Test the stability of the wing
  - Validate lift and drag coefficients
- Scheduled for March 15th
  - Pending crane availability (currently in process)



Status: On track

Moored Test

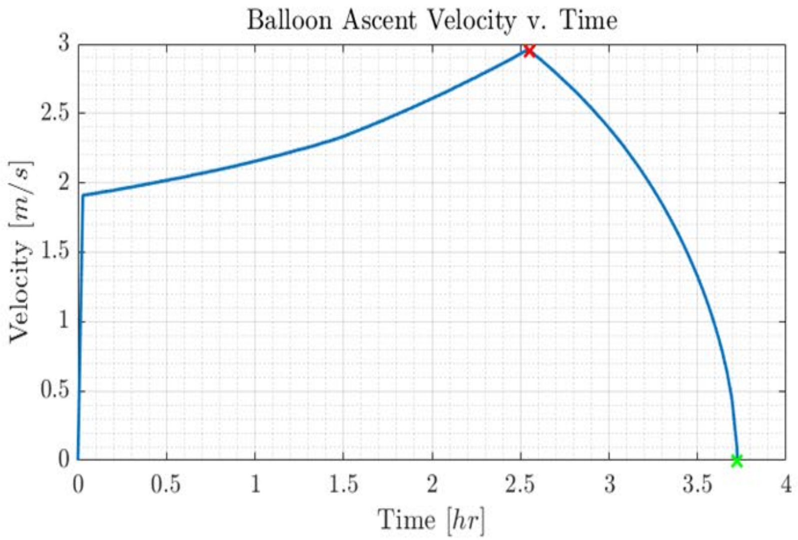
- Testing
  - FR 1.0: There will be a method of controlling the altitude of the balloon and payload
    - Risks Mitigated: can't control altitude as predicted
  - Full functionality of all components
  - Ability to actuate tail to increase/decrease lift
- Procedure
  - Moor the balloon and payload to the ground with a cable less than 150 ft and an anchor
  - Inflate the balloon with helium
  - Throttle the motor and reach a stable beta angle
  - Actuate the tail servos and measure changes in lift
- Scheduled for March 22nd

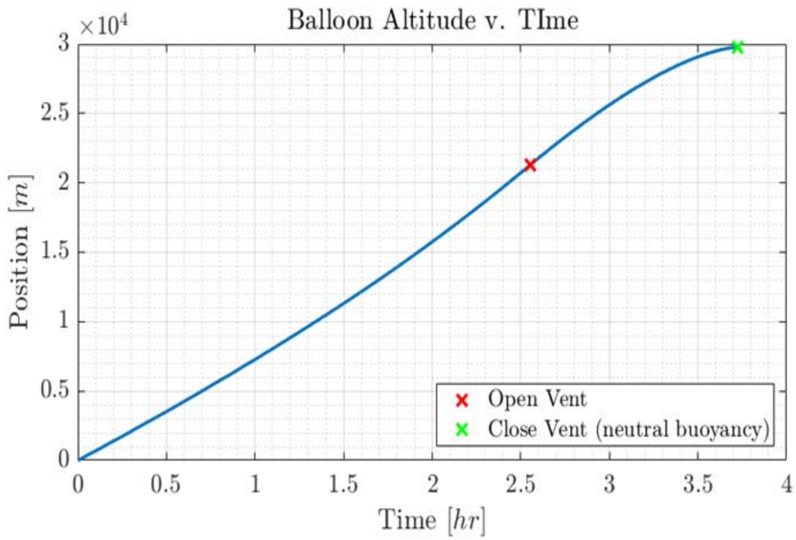


Status: On track

Neutral Buoyancy Model

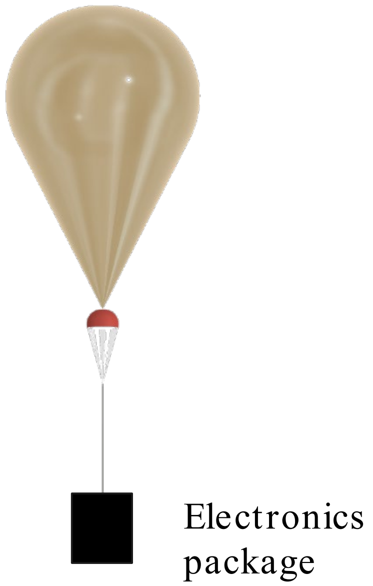
- We need to verify that we can vent to neutral buoyancy at a desired altitude of 30 km
  - Allows for orbiter to control system altitude





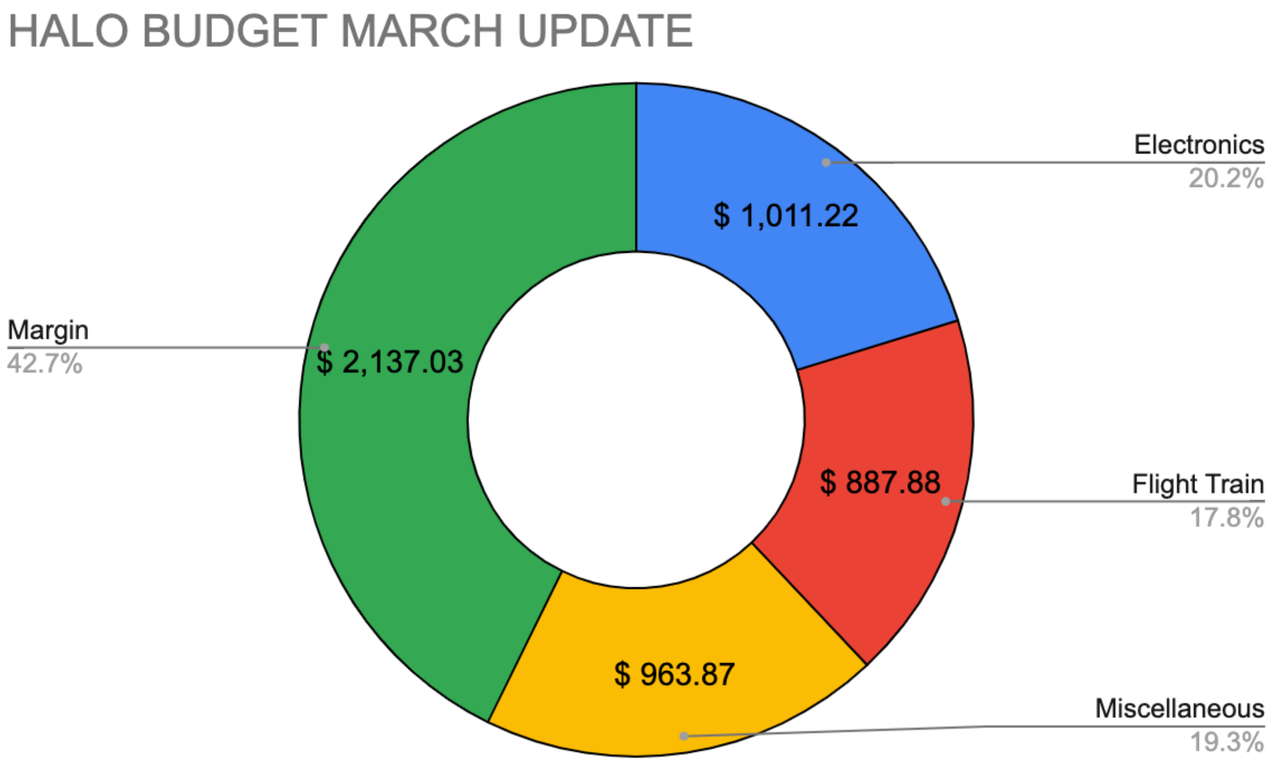
Neutral Buoyancy Test

- Testing
  - FR 1.0: There will be a method of controlling the altitude of the balloon and payload
    - Risks Mitigated: can't achieve neutral buoyancy
  - Vent and data transmission operates successfully
- Procedure
  - Fill balloon with $3m^3$ of helium
  - Attach electronics package with insulation for total mass equal to wing mass
  - Continuously record/transmit altitude data with GPS
  - Vent balloon to neutral buoyancy at 30km
  - Monitor balloon altitude to verify neutral buoyancy
  - Actuate vent until negatively buoyant (-2 m/s) to ensure safe system descent
- Scheduled for March 29th



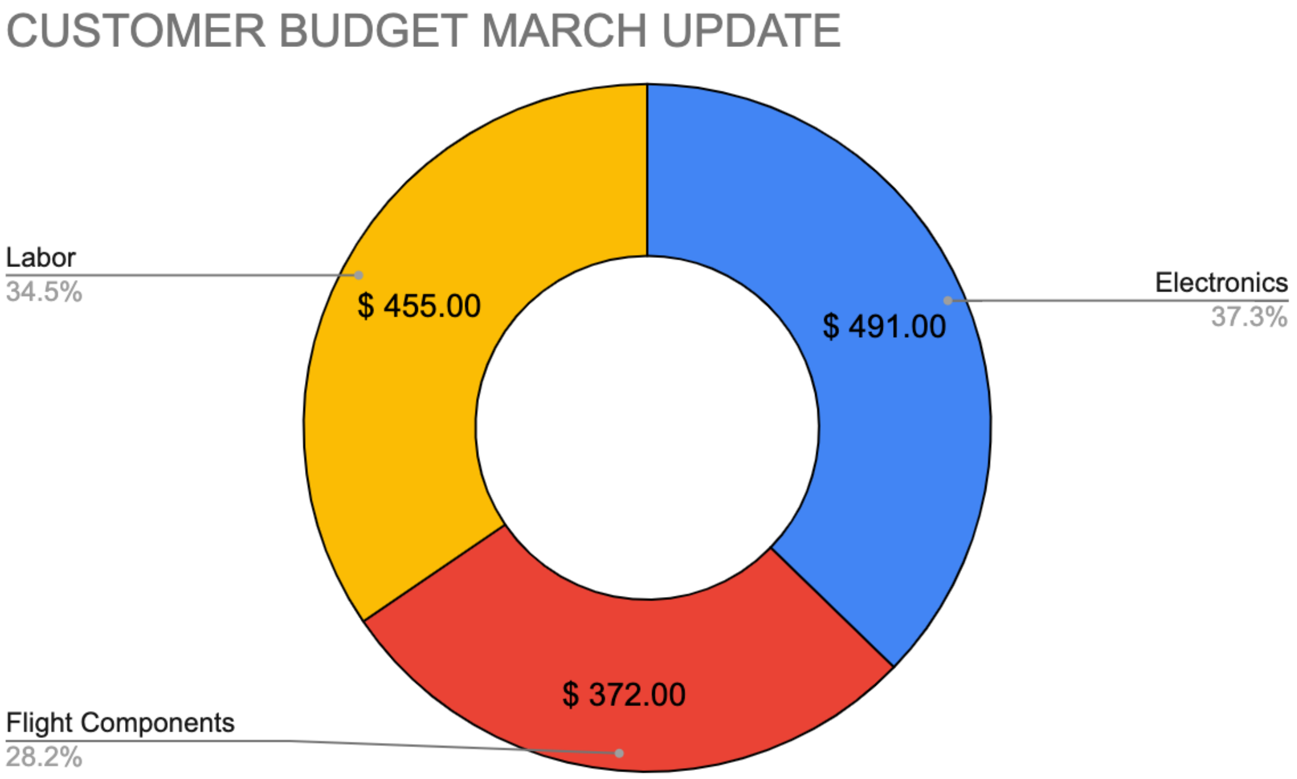
Status: On track

HALO Budget Overview

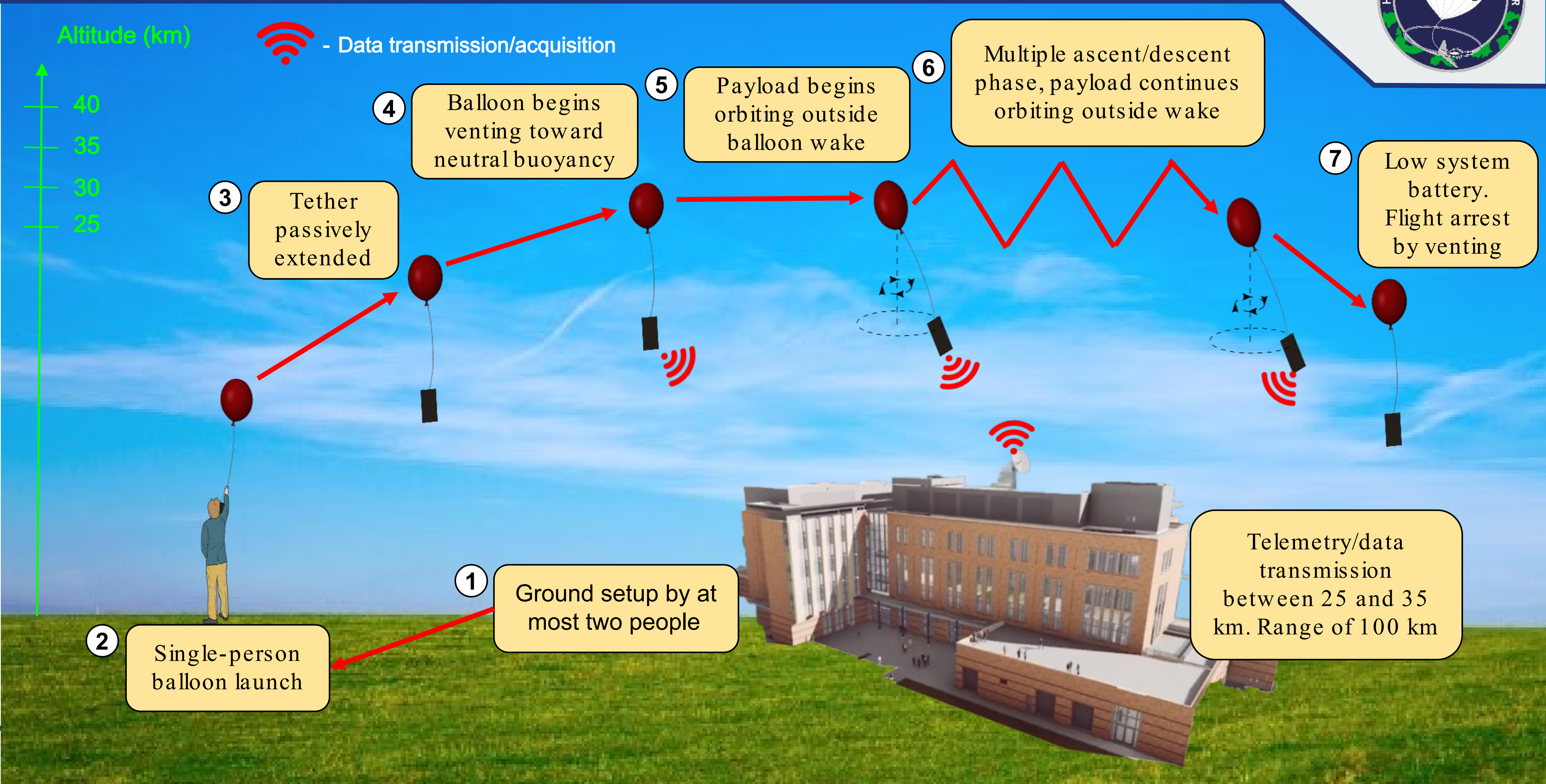


Total spent: $2,862.97
Total margin: $2,137.03

Customer Budget



Questions?



Altitude (km)
40
35
30
25
- Data transmission/acquisition
HIGH-ALTITUDE LIFTING ORBITER
HALO
1 Ground setup by at most two people
2 Single-person balloon launch
3 Tether passively extended
4 Balloon begins venting toward neutral buoyancy
5 Payload begins orbiting outside balloon wake
6 Multiple ascent/descent phase, payload continues orbiting outside wake
7 Low system battery. Flight arrest by venting
Telemetry/data transmission between 25 and 35 km. Range of 100 km

Backup Slides

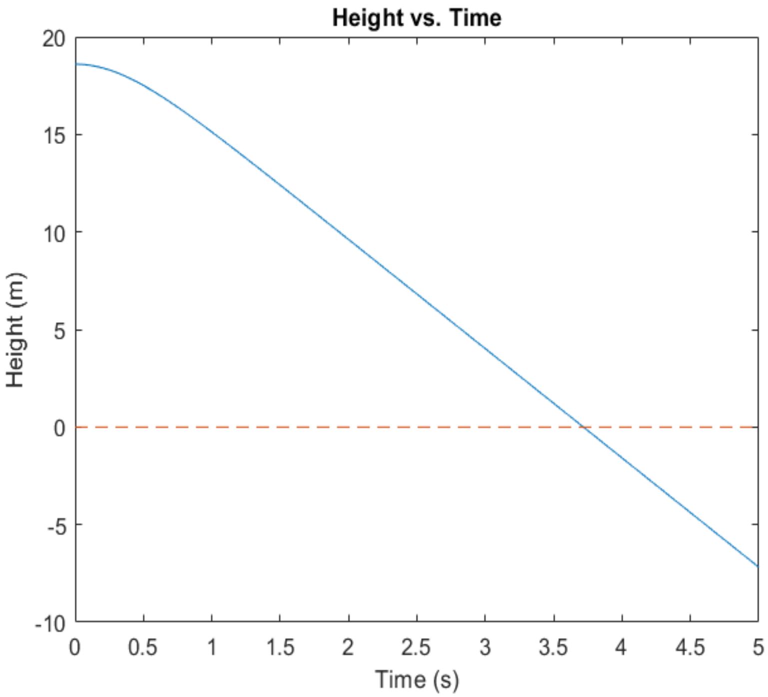
Testing Backup Slides

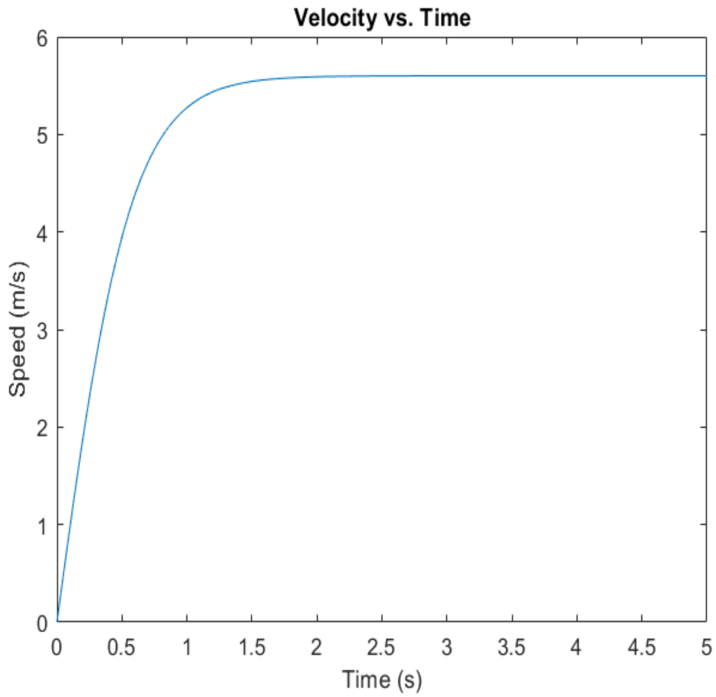
Parachute Deployment Test

- Testing
  - FR 7.0:As specified by the customer, the balloon must contain a controlled descent arrest system (CDAS) to prevent harm to property or person upon balloon burst.
  - Successful deployment of the parachute
  - Successful arresting of descent speed
- Procedure
  - Parachute tied to bottle mass
  - Thrown off roof
  - Radios for communication
  - Timed descent of about 3.8sec.

Parachute Deployment Test - Results

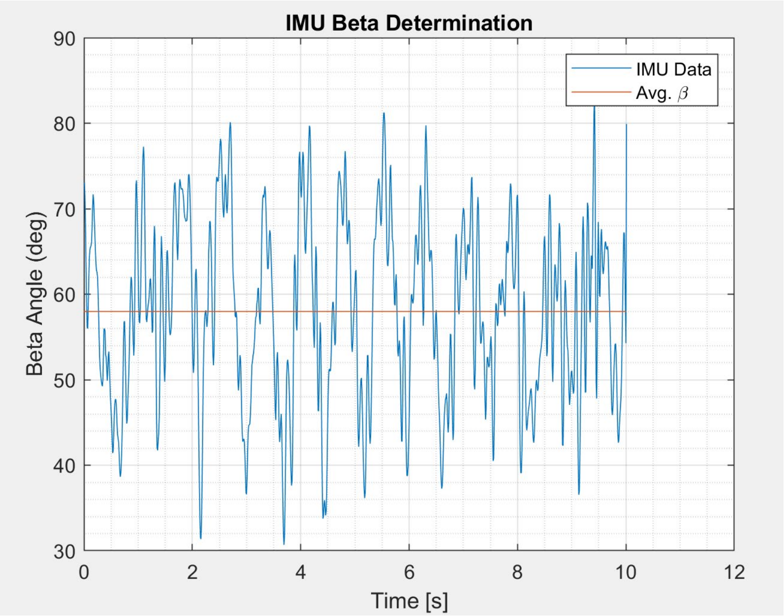
- Results discussion





IMU - Beta Angle Test

- Testing
  - FR 1.0:There will be a method of controlling the altitude of the balloon and payload.
  - Successful measure of angle
- Procedure
  - IMU was connected to a computer outputting to serial the angular rate
  - It was then spun in circles and collected data
  - The actual angle was found by taking a video and using similar triangles
- Results
  - 3 degree deviation between the video and IMU



Tether Strength Test

- Testing
  - FR 5.0:Balloon and its payload must meet all FAA guidelines, including those subjecting the balloon and its payload to designation as an unregulated balloon. In addition, Balloon and payload shall meet specifications set forth by customer.
  - The tether breaks under a 50lbf impulse
- Procedure
  - Cut and configured shortened tethers
  - Used an analog loading device
  - Dropped 50lb of weights connected to tethers
  - Used a slow-motion camera to measure the breaking force

Tether Strength Test - Results

- 20 Samples Taken
  - Bootstrapping done to obtain simulated results
- After 5,000 iterations we obtain:
  - 95% Confidence Interval of (37.15 , 40.9)
- This is to say that a sample of data taken, no matter the size, the mean of the dataset will fall within the Confidence Interval 95% of the time

```
xbar = 39.15 . xbarstar = 39.15441
The 95% bootstrap pivot confidence interval for the mean is ( 37.15 , 40.9 )


        Shapiro-Wilk normality test

data:  breaks
W = 0.90878, p-value = 0.06042

The 95% confidence interval for the mean is ( 37.2514392708935 , 41.0485607291065 )
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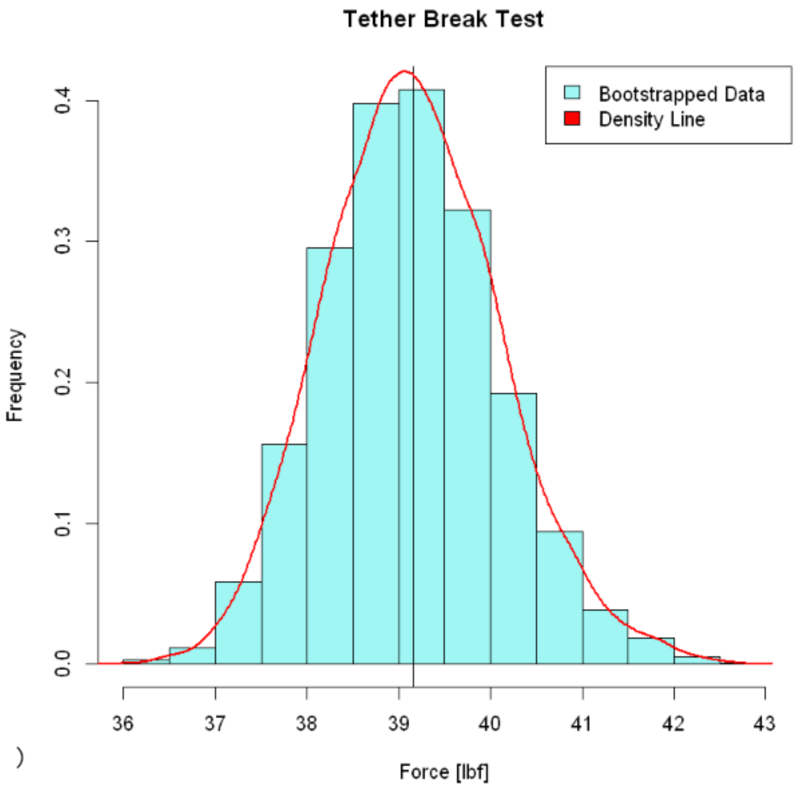


Data Communication Test

- Testing
  - FR 4.0: The payload will be able to transmit collected data to the ground receiver
  - Communication over long distances
- Procedure
  - Have two radios on the ground
  - Attenuate signal from transmitting radio
  - Calculate predicted range based on received signal strength
- Scheduled for March 8th

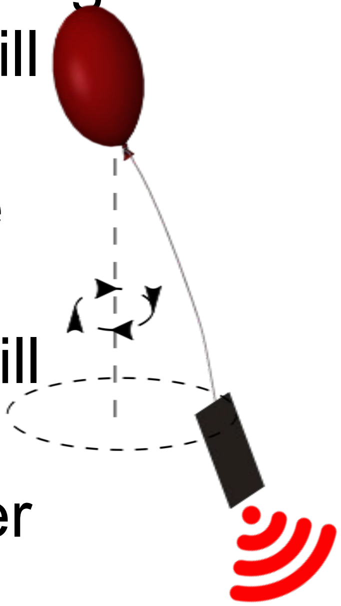
Software Dry Run Test

- Testing
  - FR: There will be a method of controlling the altitude of the balloon and payload
  - All software should be working correctly
- Procedure
  - Change servo angles
  - Change motor speeds
  - Actuate the vent
- Scheduled for March 1st

Overview Backup Slides

Mission Statement

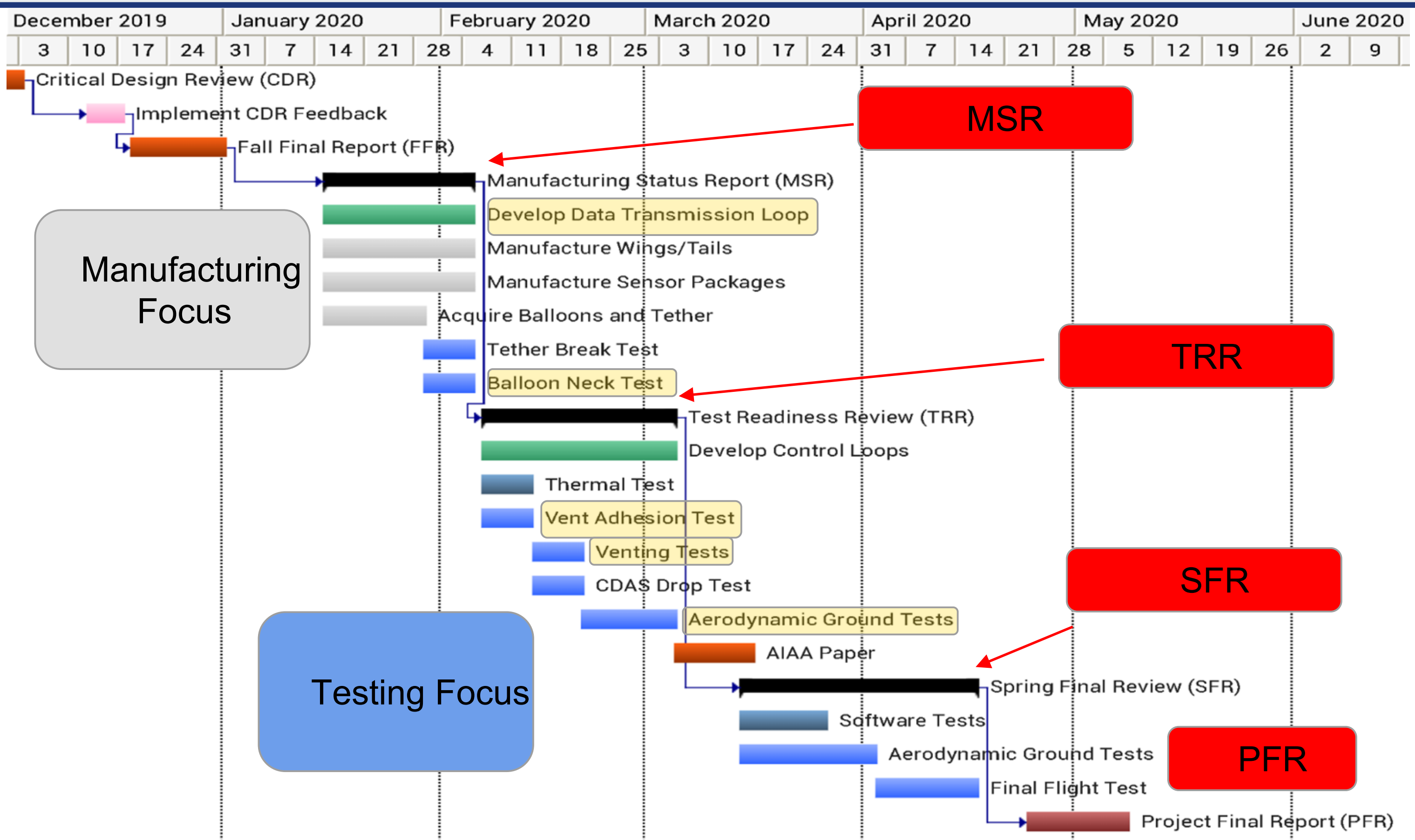
HALO aims to improve the process of collecting turbulence data in the stratosphere. This will be accomplished by designing a tethered payload system that will autonomously execute orbits outside of the balloon wake with the help of control surfaces. These surfaces will also help induce altitude oscillations, increasing the amount of data collection per flight.



Levels of Success

	Tethered Orbiter	Altitude	Data Collection	Descent Arrest
Level I	The payload shall orbit below the balloon. This orbit will be stable and periodic.	The balloon and payload will achieve a target altitude of 150 ft and be neutrally buoyant via Moored test. The balloon will remain at this altitude until termination.	The orbiting payload will contain ar and GPS to verify a successful orbiter trajectory. This data will will be transmitted to a receiving antenna throughout the Moored test.	System will include a fail-safe descent arresting device in the e of balloon burst. The payload wi then enter a controlled descent a maximum speed of 5 m/s.
Level II	The payload will be in a stable orbit below the balloon, demonstrating the ability to remove itself from the wake. It will also generate enough lift or drag to bring the balloon and payload to a vel 2m/s +/- 20% in ascent and descent.	Controls will be implemented that will allow the tethered orbiter to change the balloon and payload altitude. The balloon will reach neutral buoyancy at 20 km, descend to 15 km, ascend to 25 km, and terminate. GPS measurements will be used to approximate the altitude of the balloon. These altitudes will be allowed an uncertainty of 1 km.	Temperature, GPS, and IMU data will be collected on the payload throughout its flight. This data will be transmitted to a receiving antenna during flight.	Controlled descent will be initiat autonomously as triggered by lo battery notification on board.
Level III	The stable payload orbit will remain fully outside the balloon wake for the entire flight, ignoring occasional perturbations due to wind gusting. It also must be capable of generating lift or drag to bring the balloon system to a velocity of 2 m/s +/- 20% during ascent or descent. Orbiter speed will not introduce turbulence measurement bias.	The payload will reach a target altitude of 30 km and then oscillate between 25 km to 35 km until power depletion. GPS measurements will approximate the altitude of the balloon. These altitudes will be allowed an uncertainty of 1 km.	Turbulence sensors will be incorporated	

Schedule: Old Work Plan



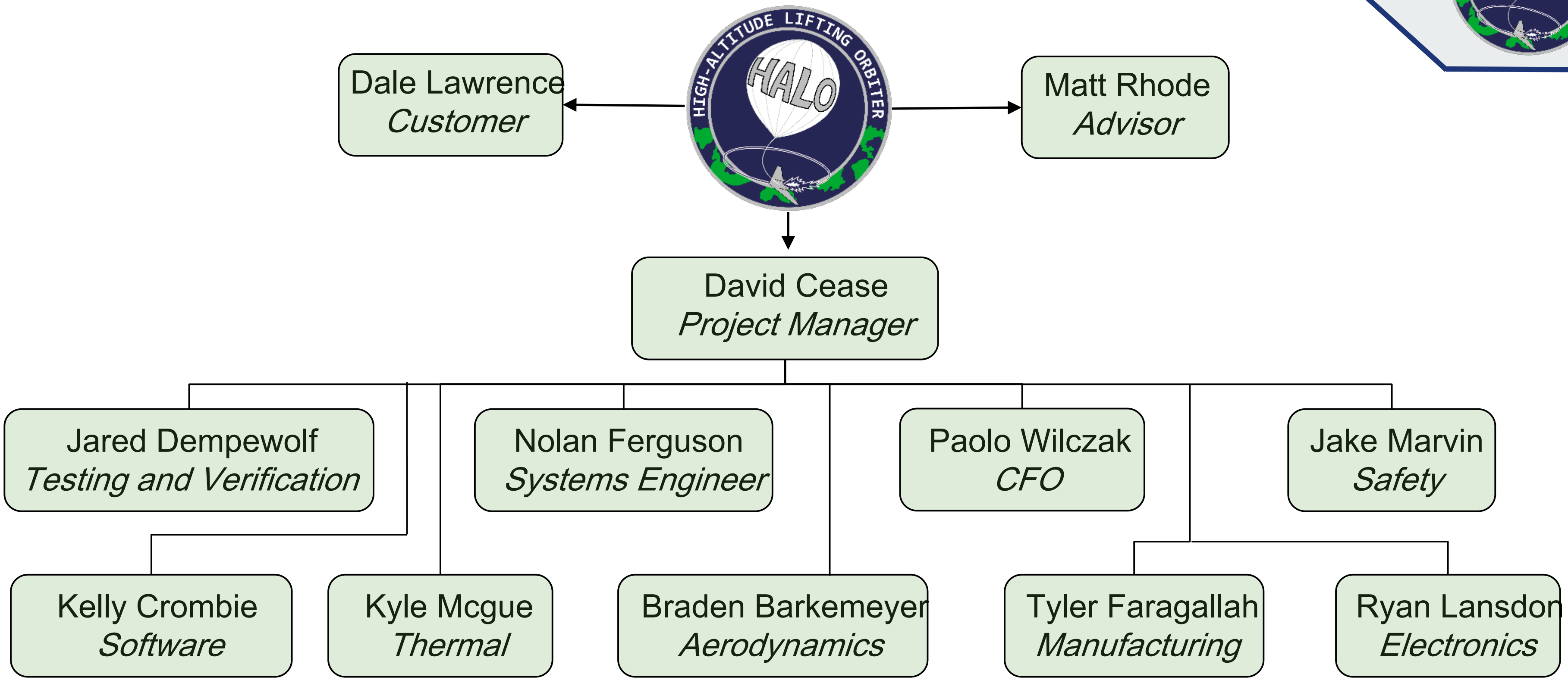
Legend

- Deliverable
- Management
- Software
- Manufacturing
- Testing

Critical Path

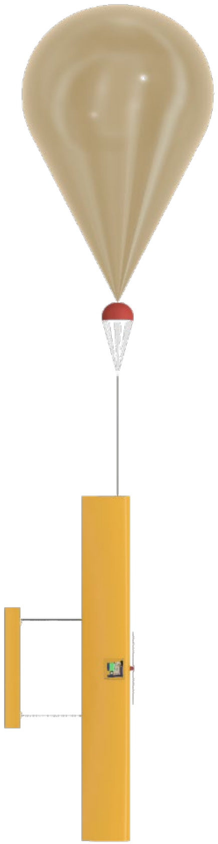
Altered Tasks

Organizational Chart



Manufacturing Backup Slides

Manufacturing Overview



Manufactured

Wings/Booms

Motor Mount

Safety-System Connections

Testing

Balloon Vent

Drop Test assembly

Tether/Force scale assembly

Software

Data Transmission Code

Orbit Acquisition Code

Motor Control Code

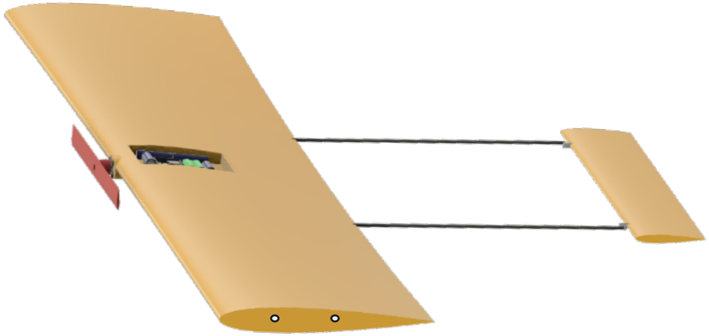
Tail Actuation Control Code

Venting Code

Thermal Control Code

Electronics Assembled

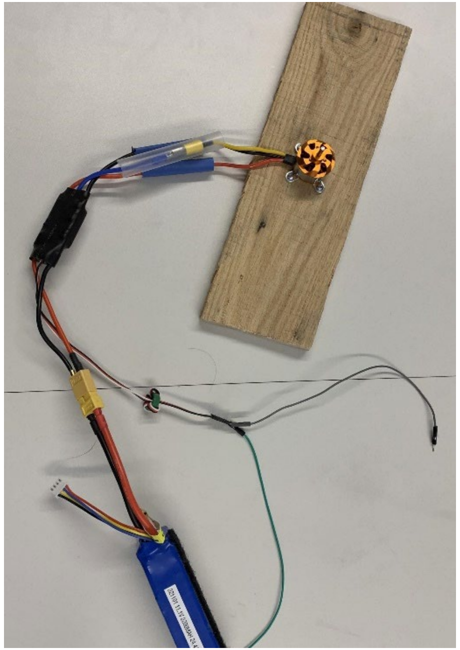
Electronics Bay



Lifting Orbiter

Purchased Components

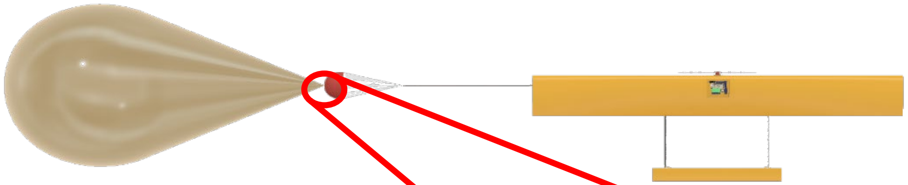
Hardware	Electronics
Foam	Battery
3D Printing Filament	ESC
Carbon Spars	Motor
Kevlar Tether	Arduino
Propeller	Servos
Balloon	Thermal Resistors
Swivels and Slip Rings	Relay Switch (pMOSFET)
Load Cell	IMU
Tether Deployment Spool	Transceivers

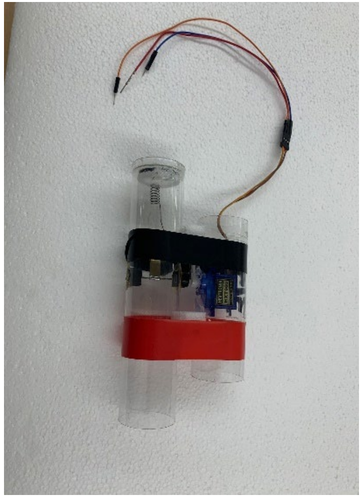


Motor Mount with ESC

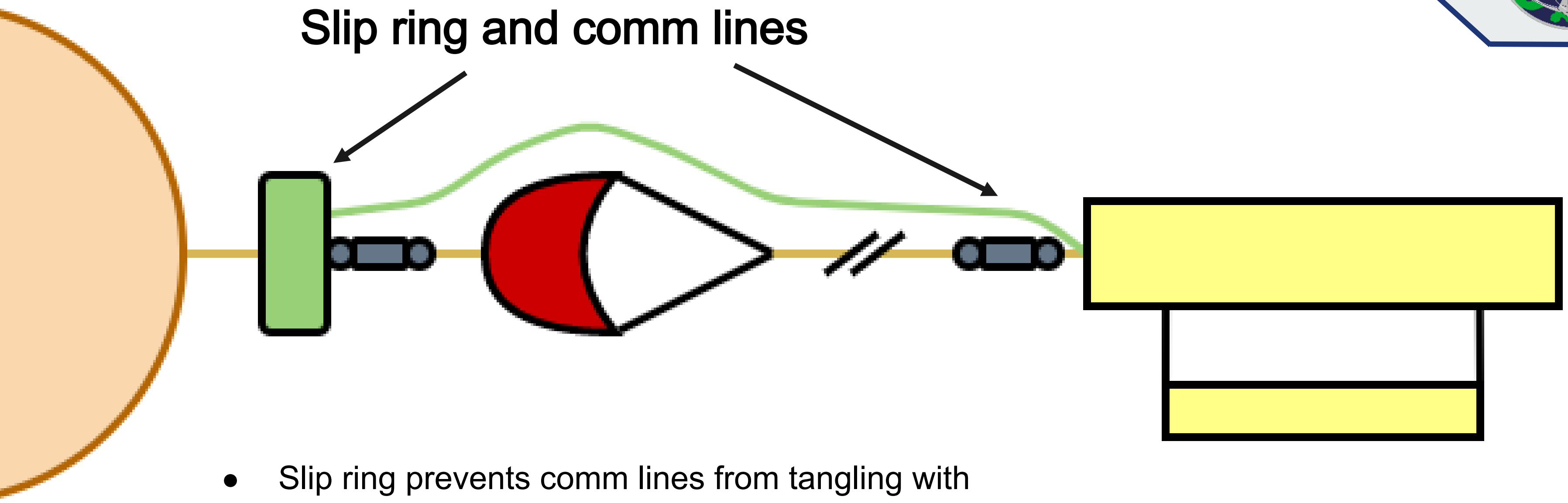
Vent for Balloon Neck

- Verified functional vent with improved servo actuation (24 Jan)
- Vent has flight heritage
  - Verified to work up to 32.5 km
- Vent affixed to balloon neck using fiber tape





Tether Connection



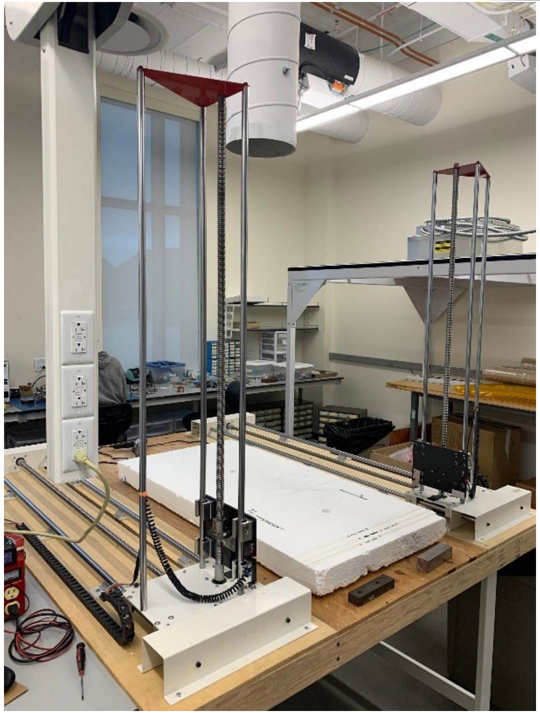
- Slip ring prevents comm lines from tangling with tether
- Tether connected with fishing swivel
- Tether wraps around wing
- Tether attached to vent via hose clamp

Wings: Hot Wire Cutting

- Completed training with current student Operator (30 Jan)

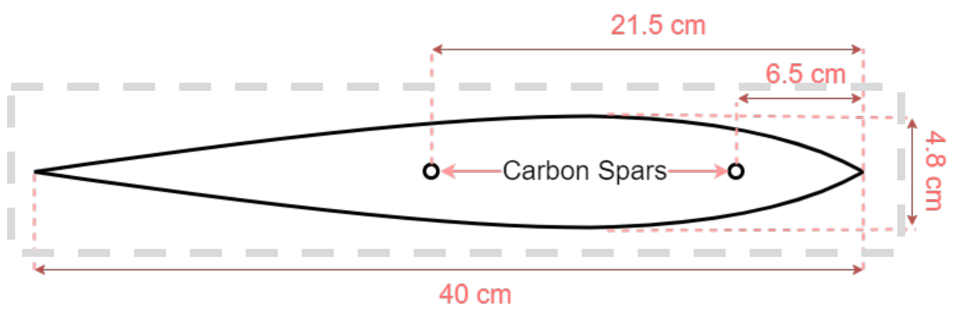
- Small test cuts completed on Monday (03 Feb)
  - Use Profili Pro 2 Program to create Gcode

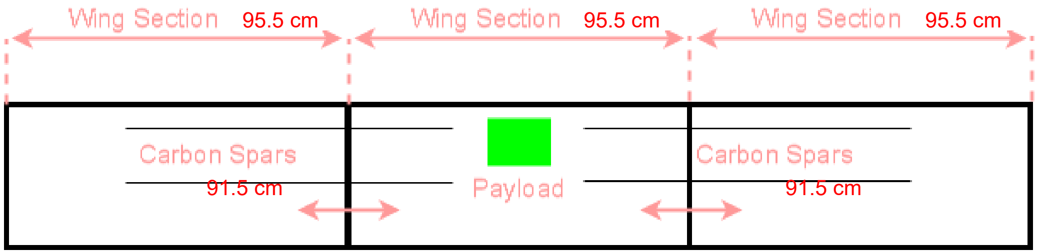
- Prototype airfoil section scheduled for Friday (07 Feb)

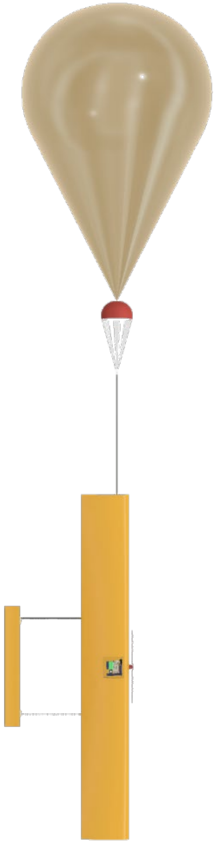


Hot Wire Cutting Station

Wings: Spar Alignment Sketch For Main Airfoil



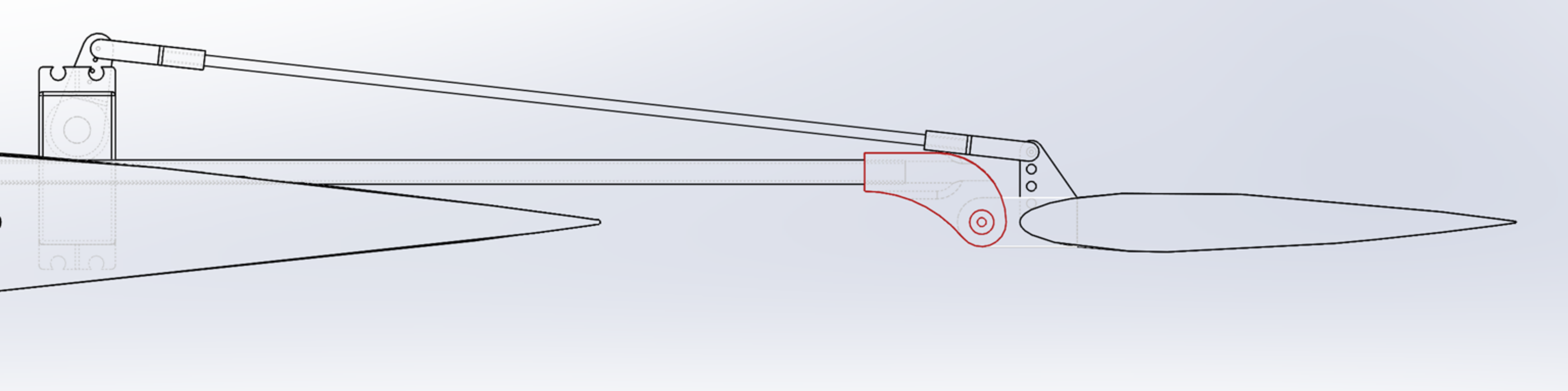




Carbon Fiber Spars

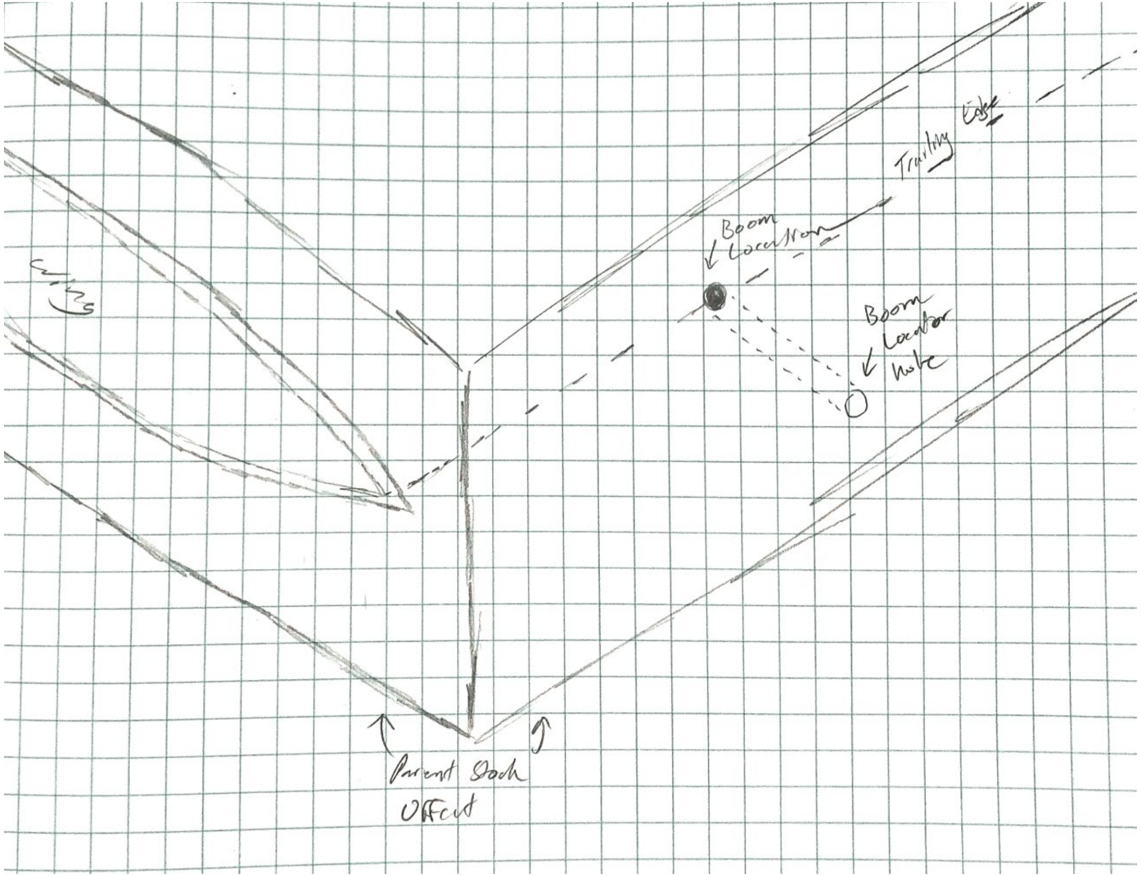
Tail Boom: Spar Attachment Sketch

- Two carbon fiber rods
- Placed on either side of the electronics package

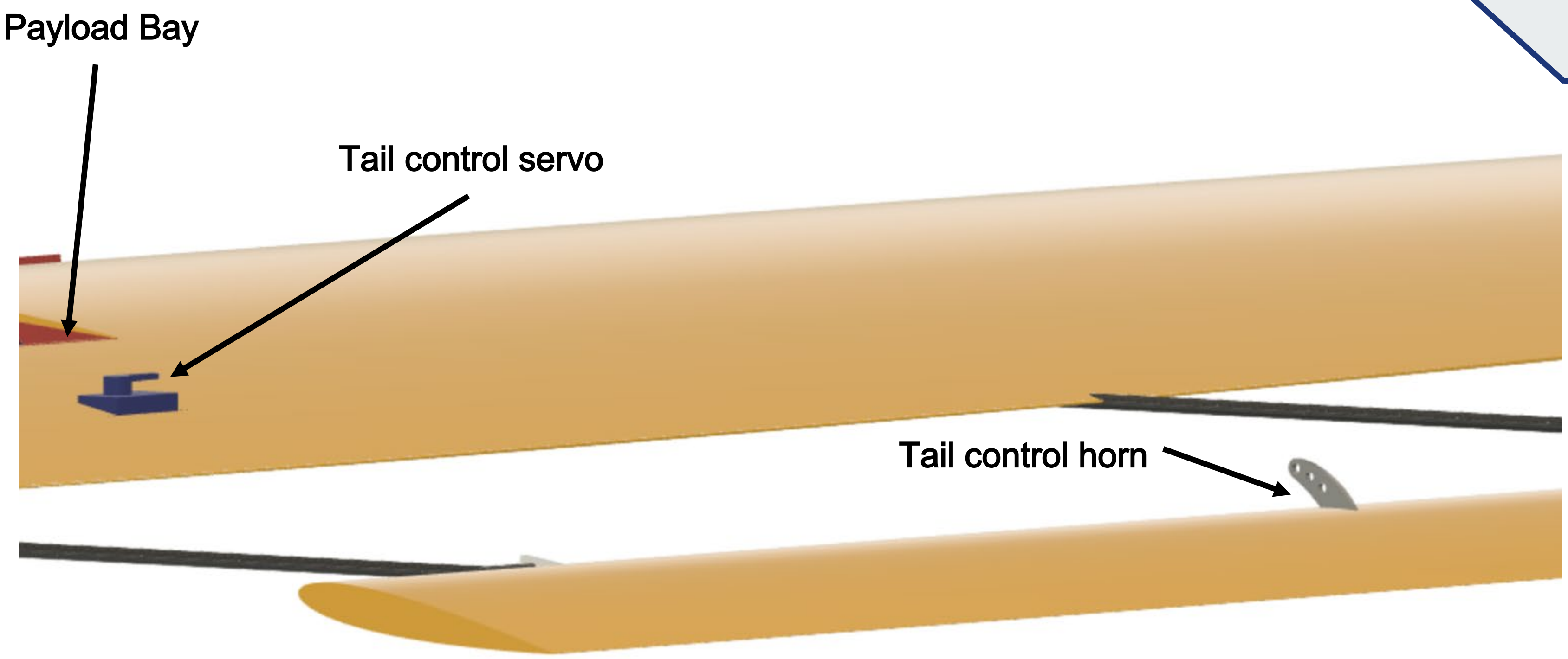


Spar Attachment

Tail Boom: Spar Attachment Sketch



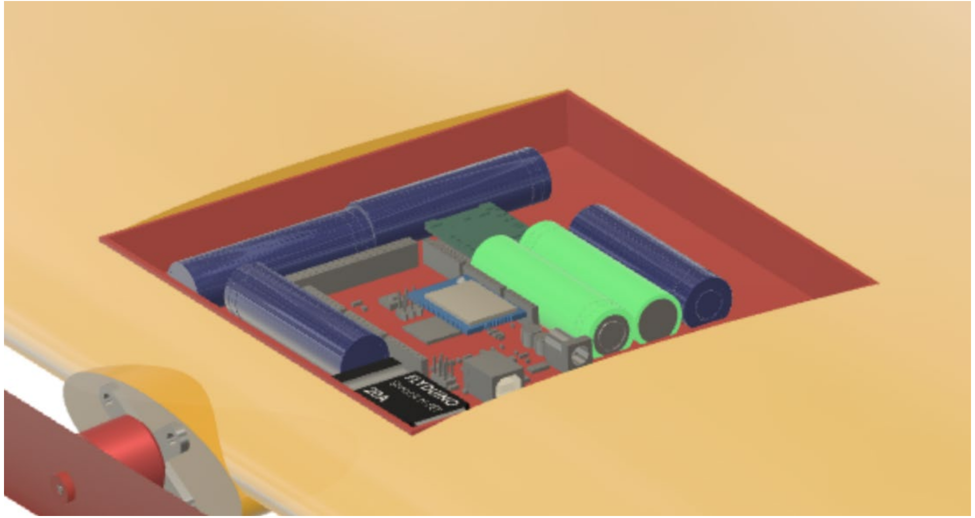
Tail Boom: Spar Attachment CAD



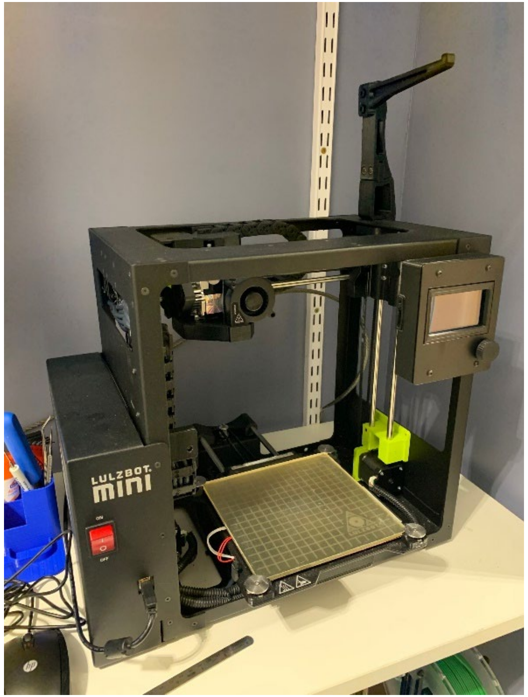
NOTE: Control link between servo and control horn not shown

3D Printing: Payload Bay

- 3D printed chassis to keep electronics aligned

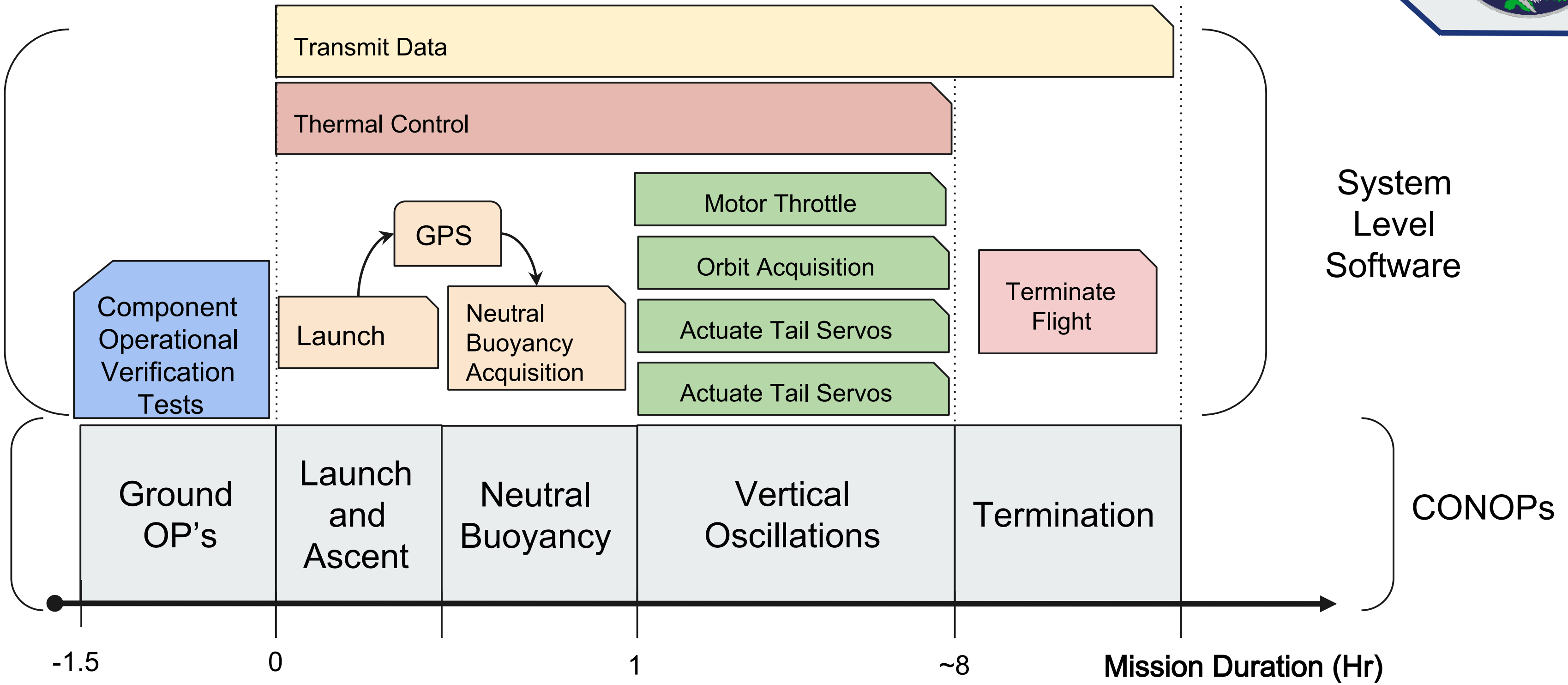


Electronics Bay



3D Printer

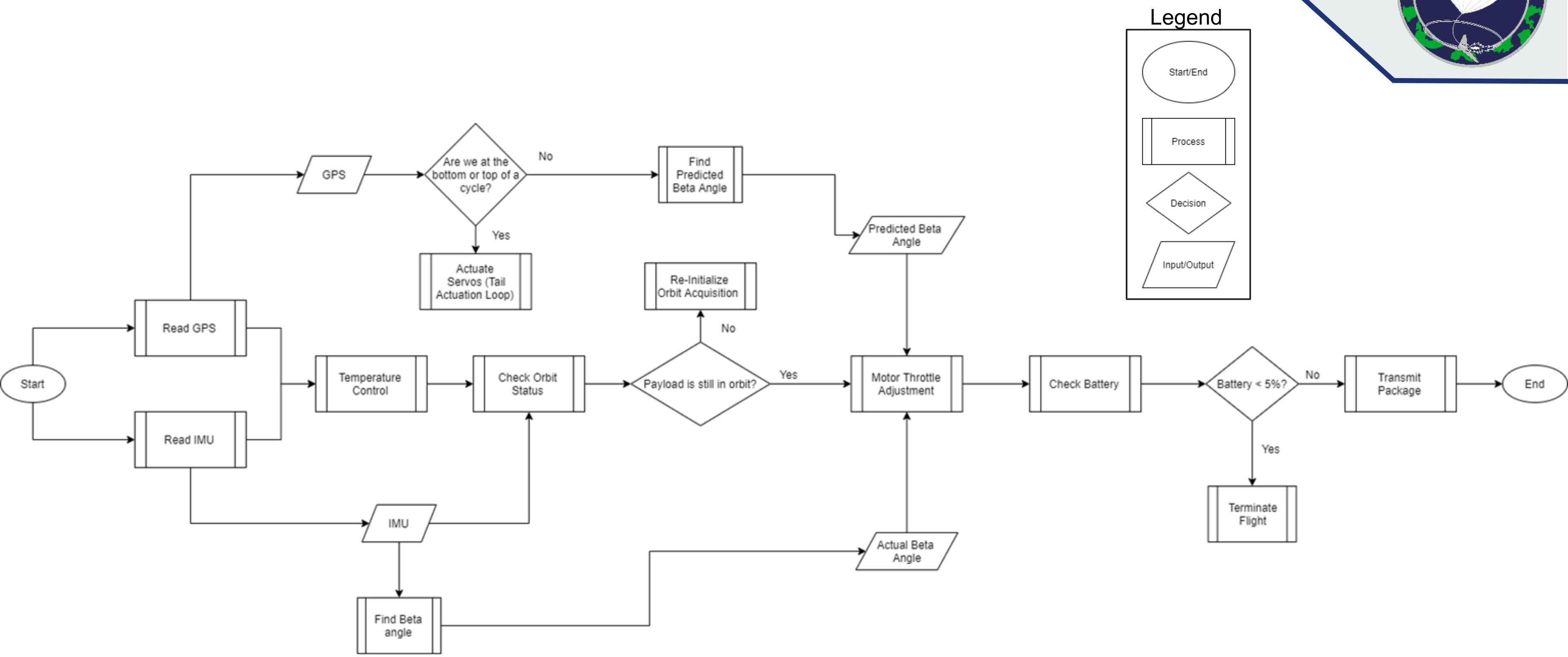
Software: Overview



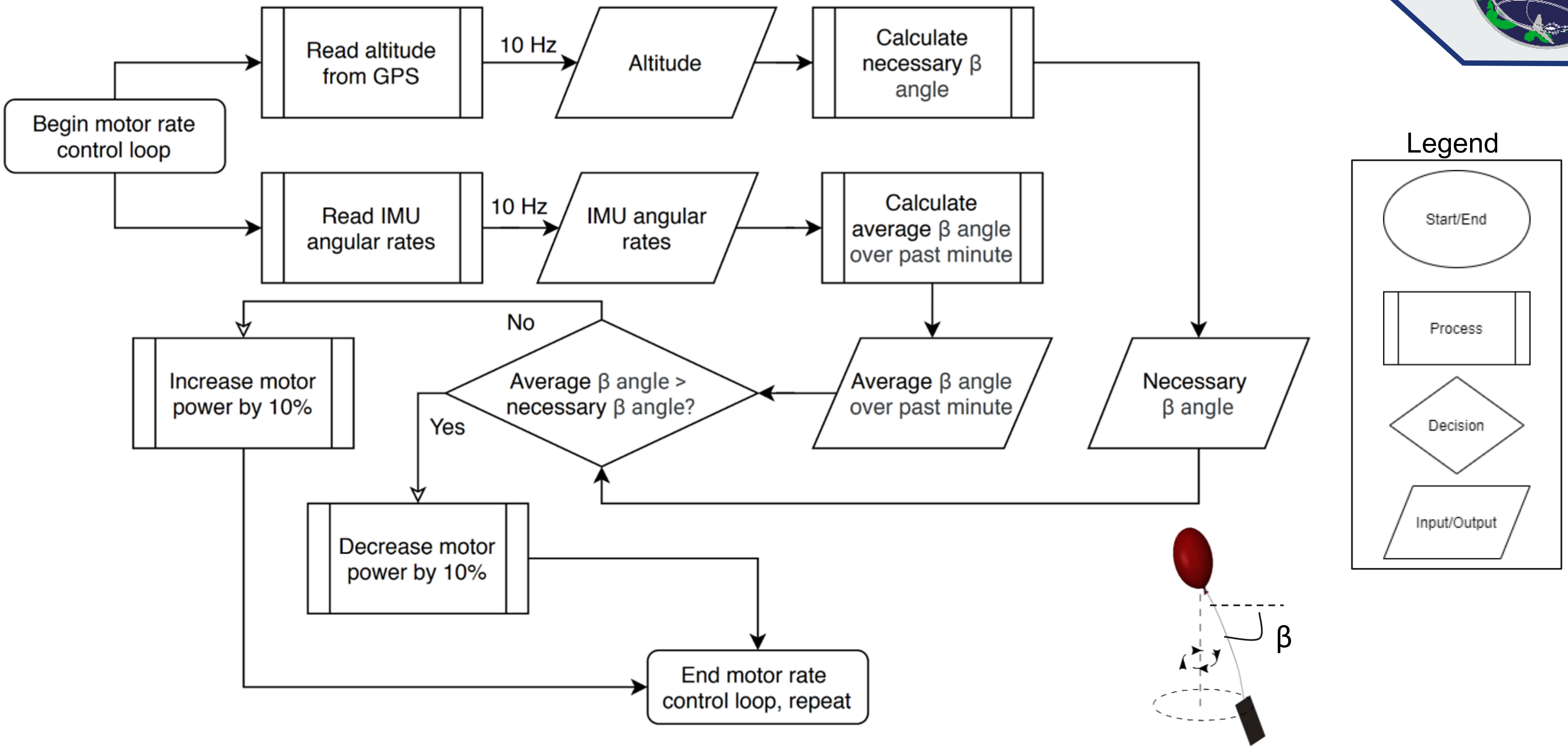
Software: Overview Status

Electronics Component	Status	Next Step
Arduino Mega	Completed Preliminary Interfacing	Integrate Main Functions
ESC	Completed Preliminary Interfacing	Develop Motor Control Loop
Motor	Completed Preliminary Interfacing	Develop Motor Control Loop
GPS	Completed Preliminary Interfacing	Data Transmission Test
IMU	Completed Preliminary Interfacing	Develop Angle Determination
Vent	Completed Preliminary Interfacing	Develop Vent Control Loop
Temperature Sensors	Basic Wiring Complete, No Interfacing	Preliminary Arduino Interfacing
XBee Transceiver	No Interfacing	Preliminary Arduino Interfacing and Data Transmission Test

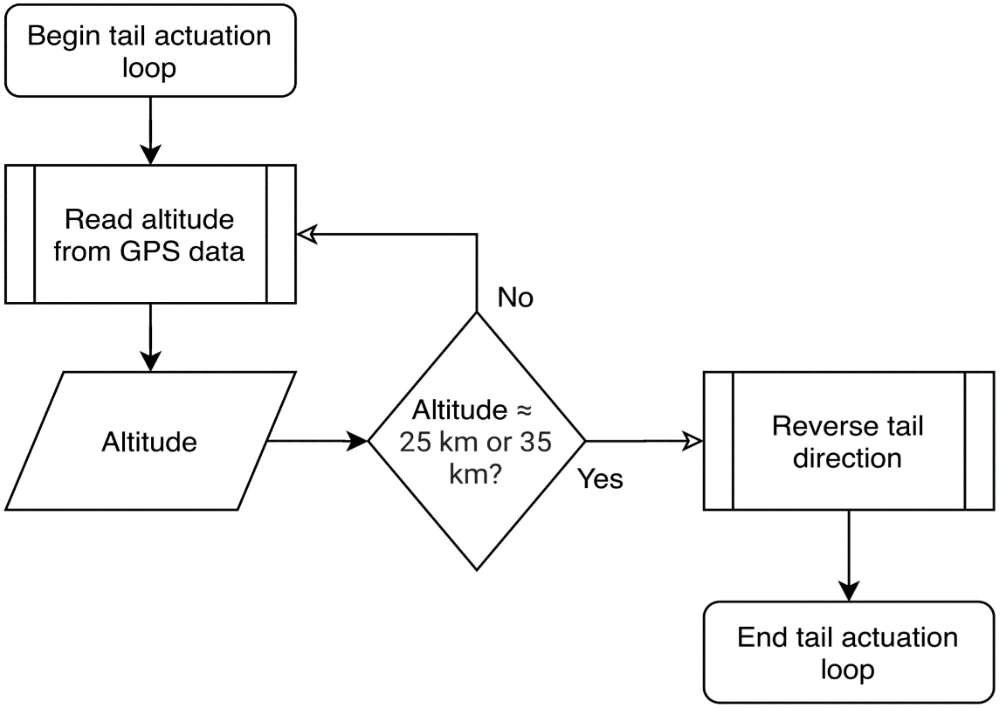
Software: Main Block

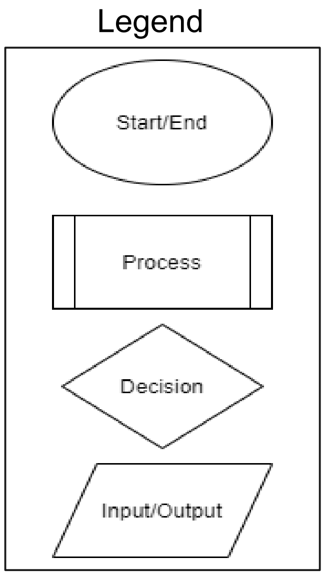


Software: Motor Control

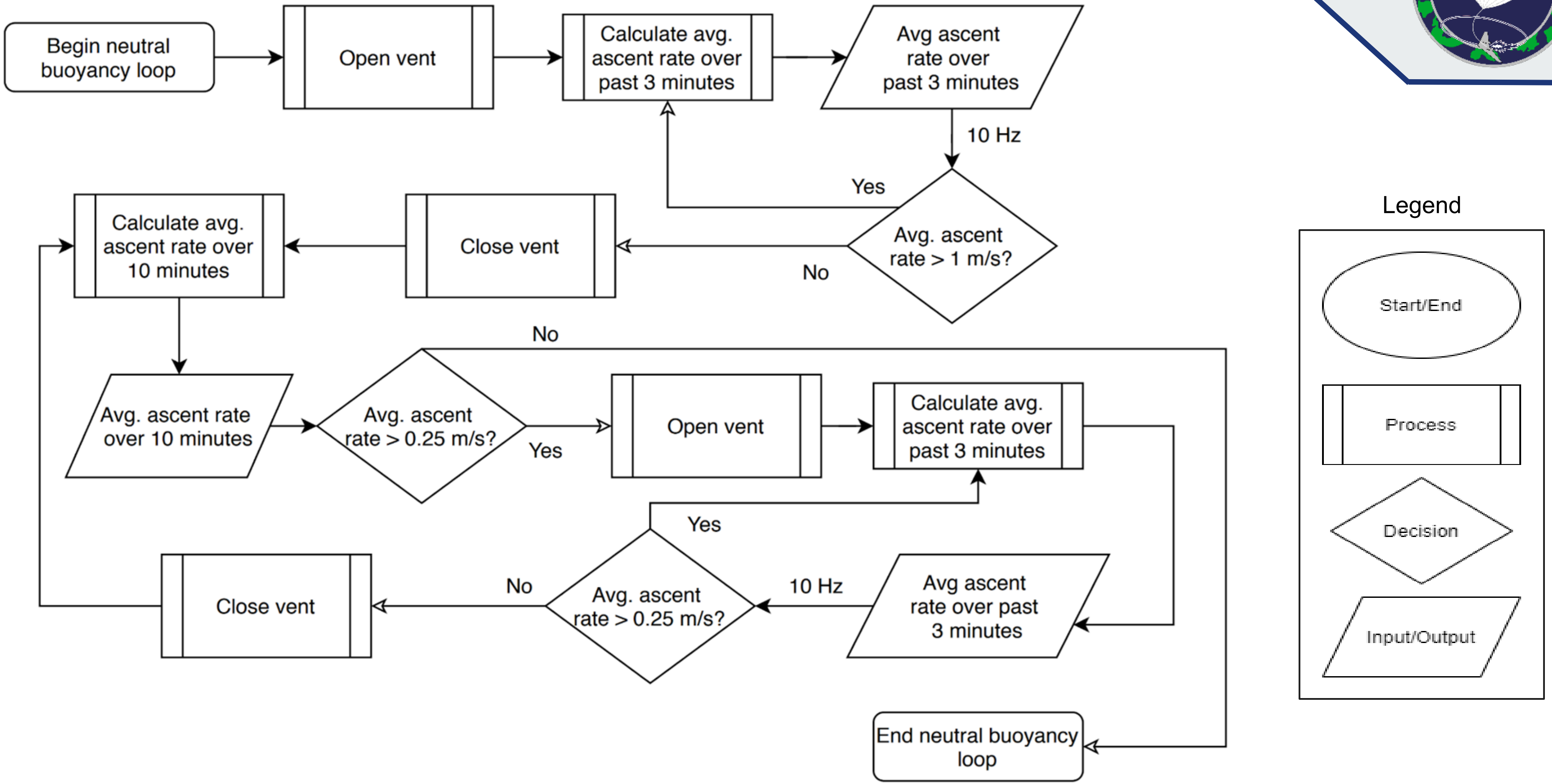


Software: Tail Actuation



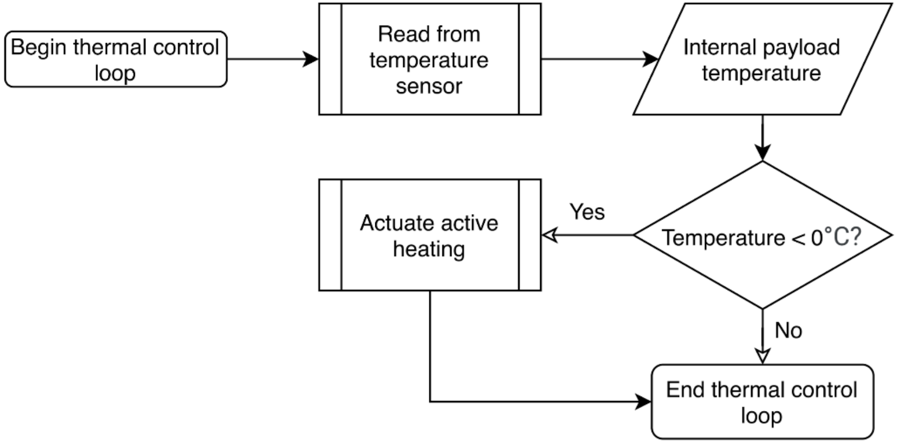


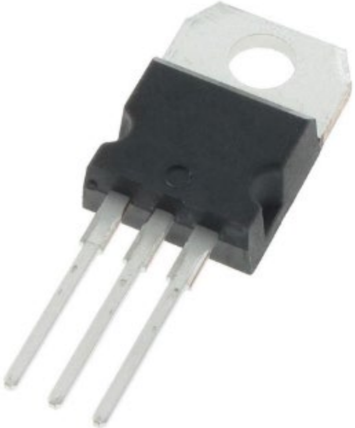
Software: Neutral Buoyancy Acquisition



Software: Thermal Control

- Using p-channel MOSFET as a relay switch
- On/off Arduino pin control
- Less than 0°C will result in "on" command from Arduino
- (1-1.5 W)





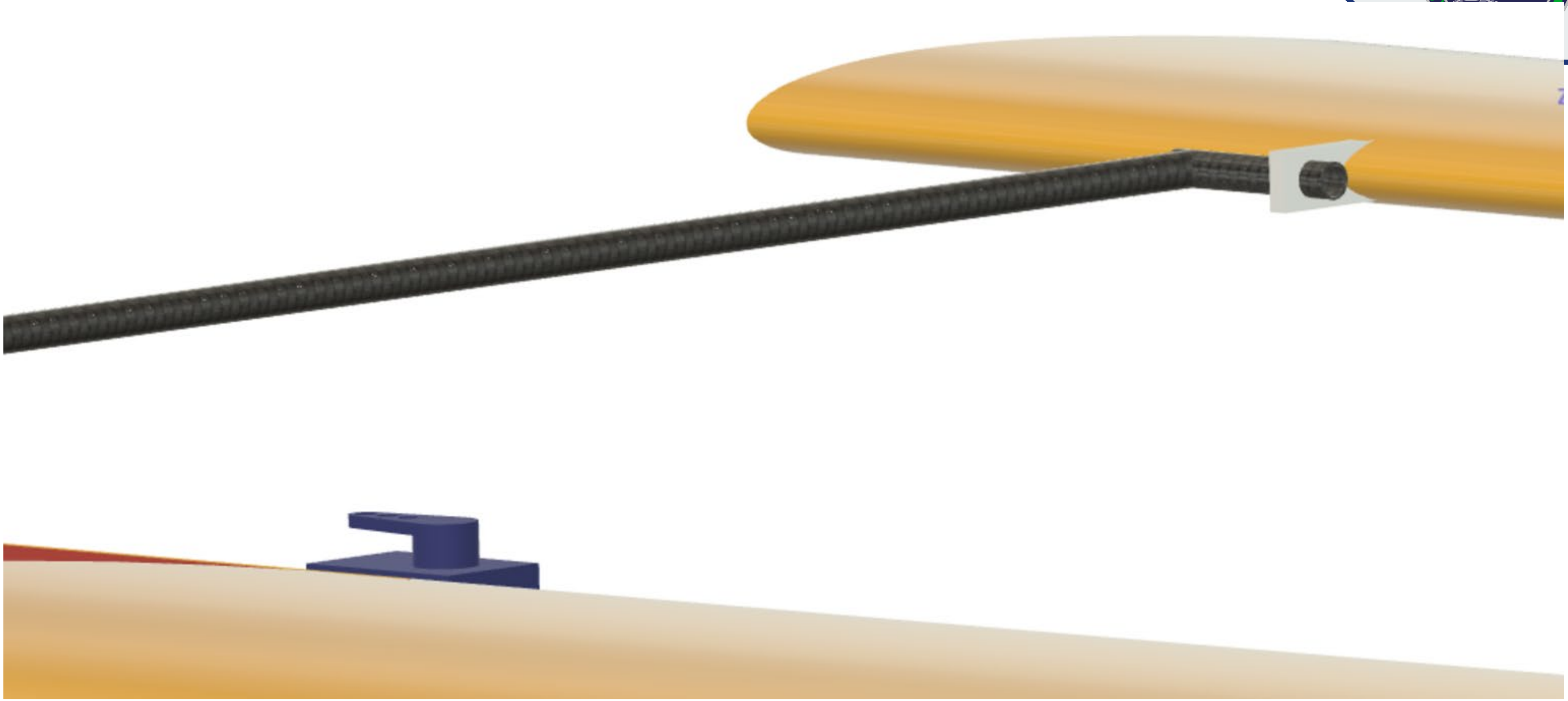
Drilling into Foam for Carbon Spar Mounting

Tools capable of drilling into foam for carbon spar mounting: Standard Spade Bit

Hot Wire Cutting G -Code

```
This is our first attempt
G20
G17
G90
F18.000000
M3
G0A0.000000B0.000000X0.000000Y0.000000
G0A0.000000B1.500000X0.000000Y1.500000
G0A2.250000B1.500000X2.250000Y1.500000
G1A2.253789B1.500000X2.253789Y1.500000F18.000000
G1A2.644000B1.542064X2.644000Y1.542064
M0
G1A2.675740B1.546498X2.675740Y1.546498
G1A2.707480B1.550932X2.707480Y1.550932
G1A2.739223B1.555343X2.739223Y1.555343
G1A2.770967B1.559751X2.770967Y1.559751
G1A2.802711B1.564150X2.802711Y1.564150
G1A2.834457B1.568546X2.834457Y1.568546
G1A2.866202B1.572942X2.866202Y1.572942
G1A2.897947B1.577339X2.897947Y1.577339
```

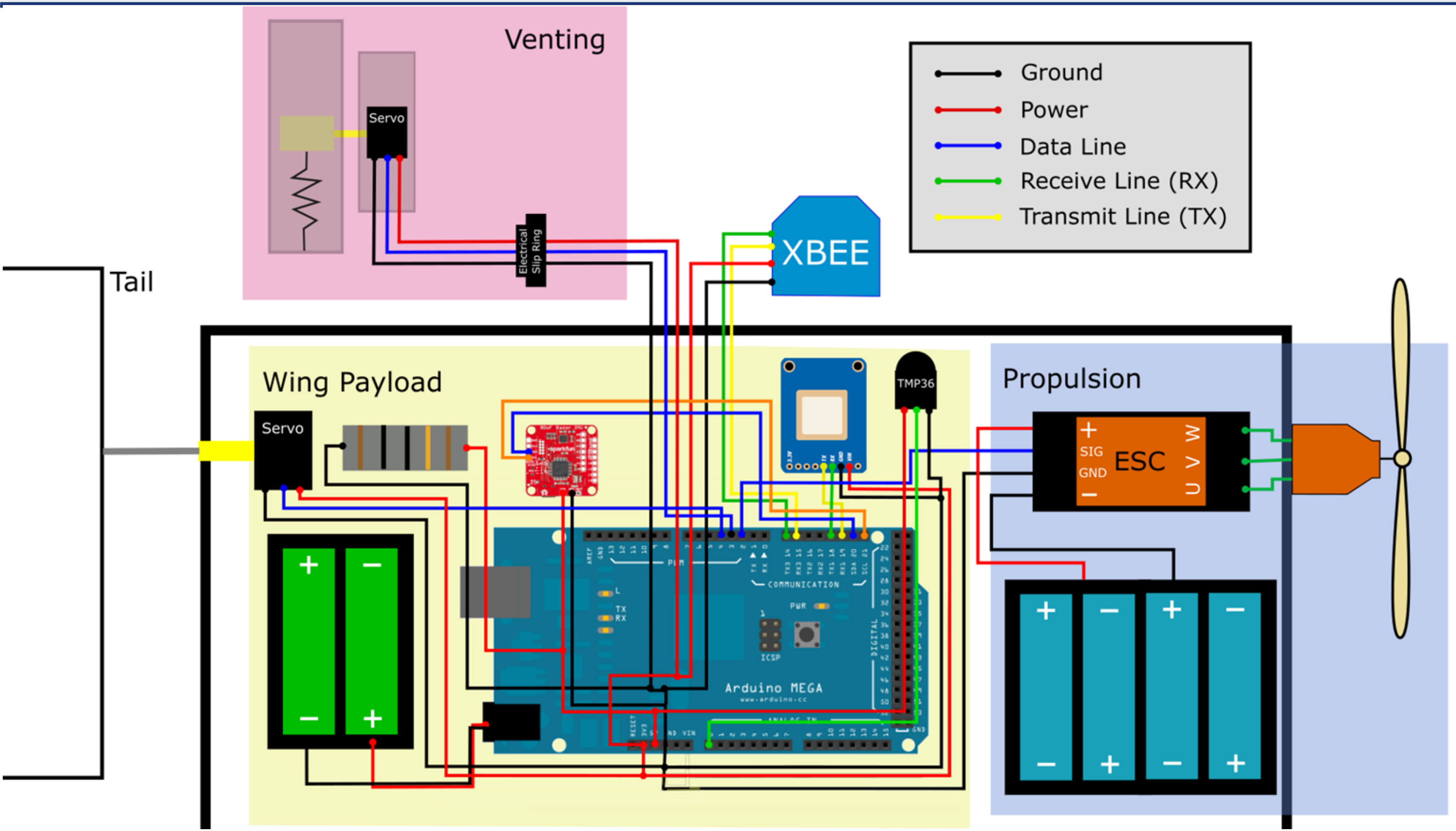
Servo Shot #2



Electronics

Component	Chosen	Voltage [V]	Current [mA]	Mass [g]	Powered by:
GPS	Adafruit Ultimate	3.3	25	8.5	3.3V Arduino pin
Arduino	Arduino Mega	7.6	100	53	LG MU1 barrel connector
IMU	Sparkfun 9DoF Razor IM	5	10	15	5V Arduino pin
Radio Transceiver	Radio Transceiver	3.3	150	3	3.3V Arduino pin
Arduino Battery	2 x LG MU1 18650	7.6	NA	2 x 49 = 98	NA
Temperature Sensor	TMP36	3.3	5	1	3.3V Arduino pin

Wiring Schematic



Software Backup Slides

Software: Data Transmission

- IMU, GPS, and temperature sensor measurements will be transmitted to ground receiver

- Data transmission test will be held 2/15 to determine data rate, transmission rate, and transmission range

Software: Orbit Acquisition

- Motor will be throttled to attain orbit
  - Throttle amount will be determined with scaled flight test
- If orbit is not acquired, motor will turn off and try again after a minute
- Motor has been successfully interfaced with Arduino Mega

Venting Backup Slides

Balloon Purpose

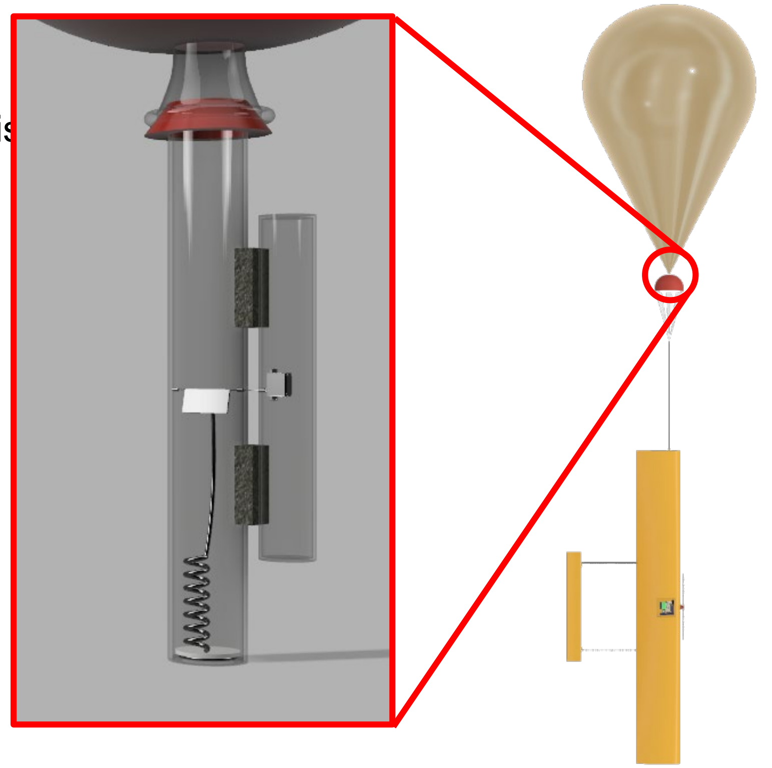
- Balloon will transport the payload to maximum altitude *km* of 35
  - Burst altitude/diameter is the most significant factor to consider
- Balloon will be neutrally buoyant at *km* 30
  - This will determine our mass budget
- Customer Requirements
  - Balloon and its payload must meet all FAA guidelines
    - Per customer request, balloon will meet FAA criteria for rem unregulated
    - FAA guidelines can be found in appendix

FR 5.0 Balloon and payload system must meet all FAA guidelines.

High Altitude Balloon

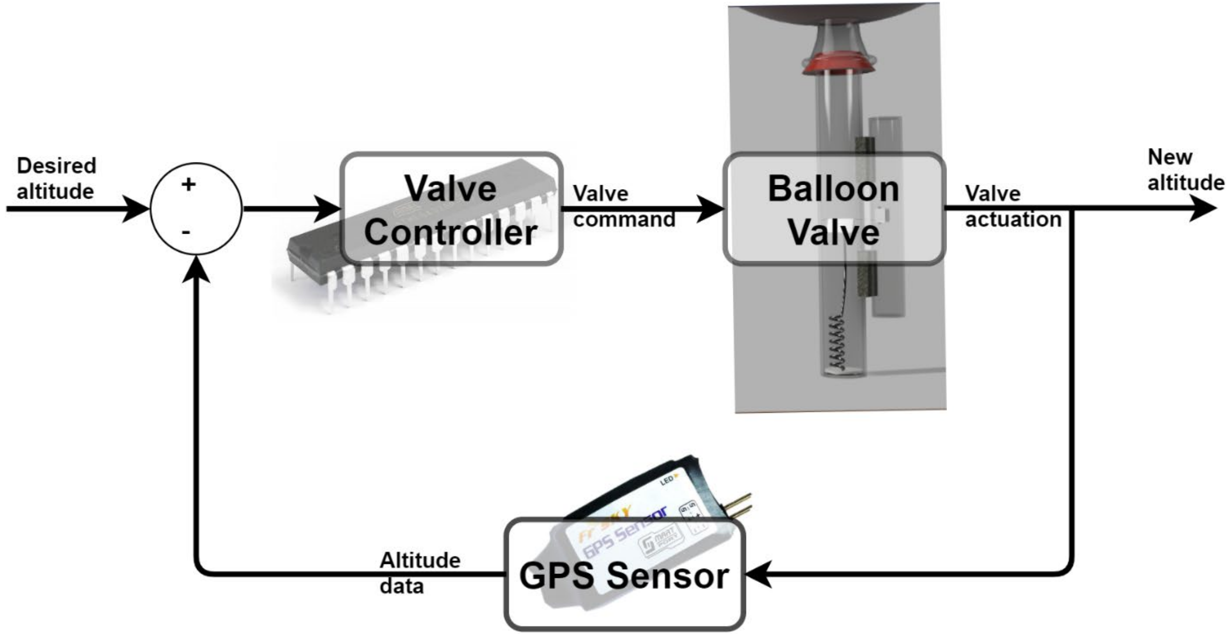
Venting Design

- Reusing venting system from HYFLITS mission
  - Verified to operate in atmospheric conditions
  - Can be sufficiently mounted to balloon
  - Venting has been experimentally modelled for this



FR 6.0: System must be capable of mission termination at end-of-life, determined when battery has 5% remaining.

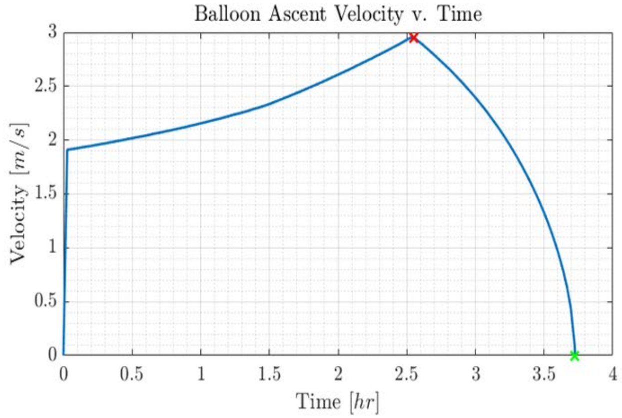
Venting Control System

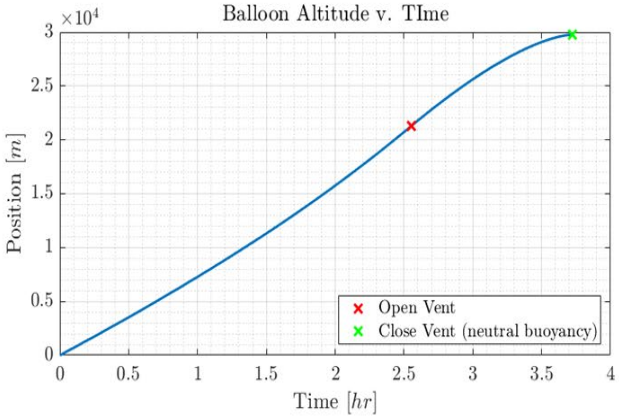


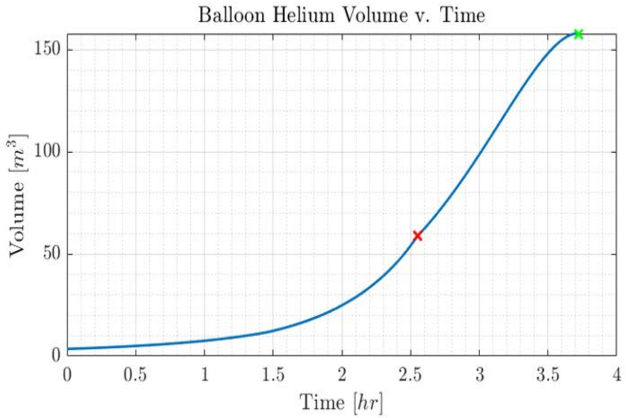
- GPS, battery data fed into cont system
- Vent until desired altitude is reached

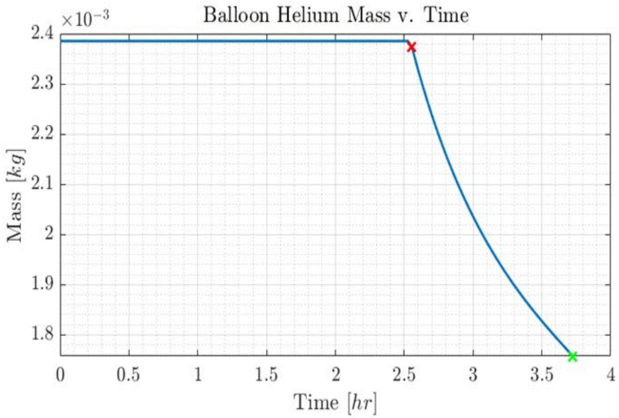
FR 6.0: System must be capable of mission termination at end-of-life, determined when battery has 5% remaining.

Venting Model





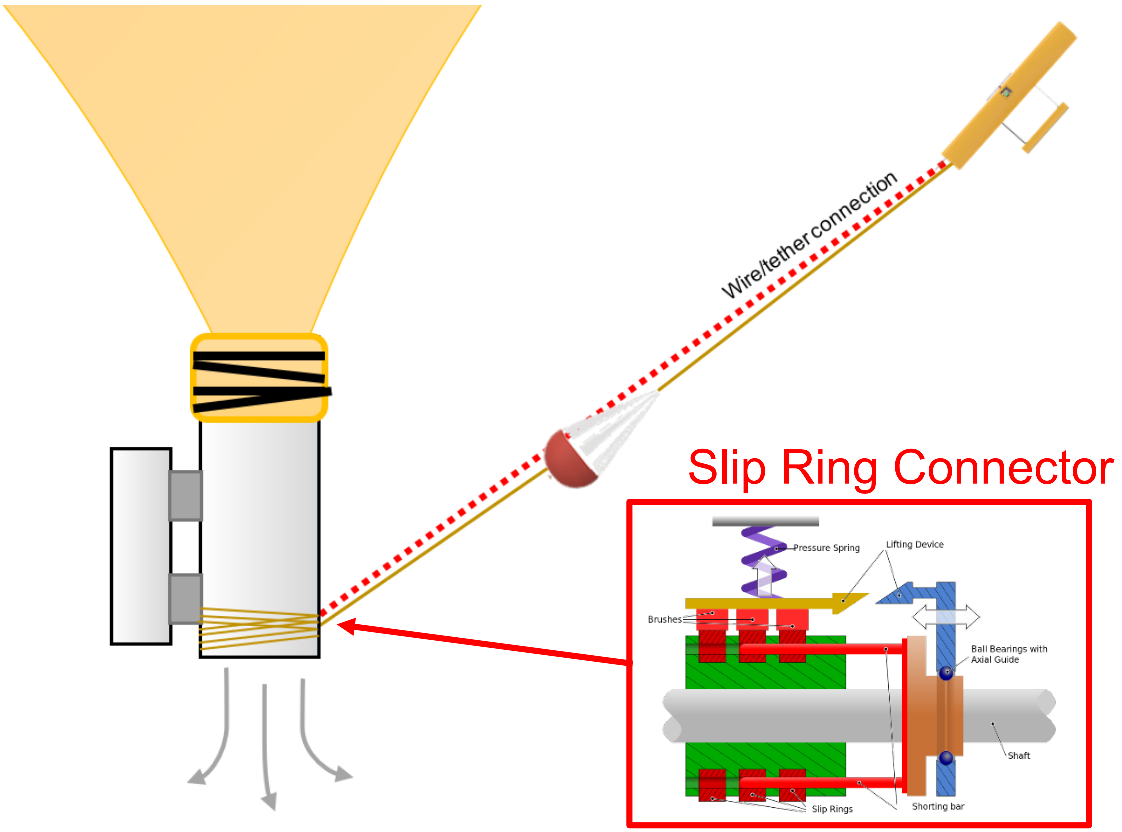




- Neutral buoyancy acquired after roughly 1 hour of venting

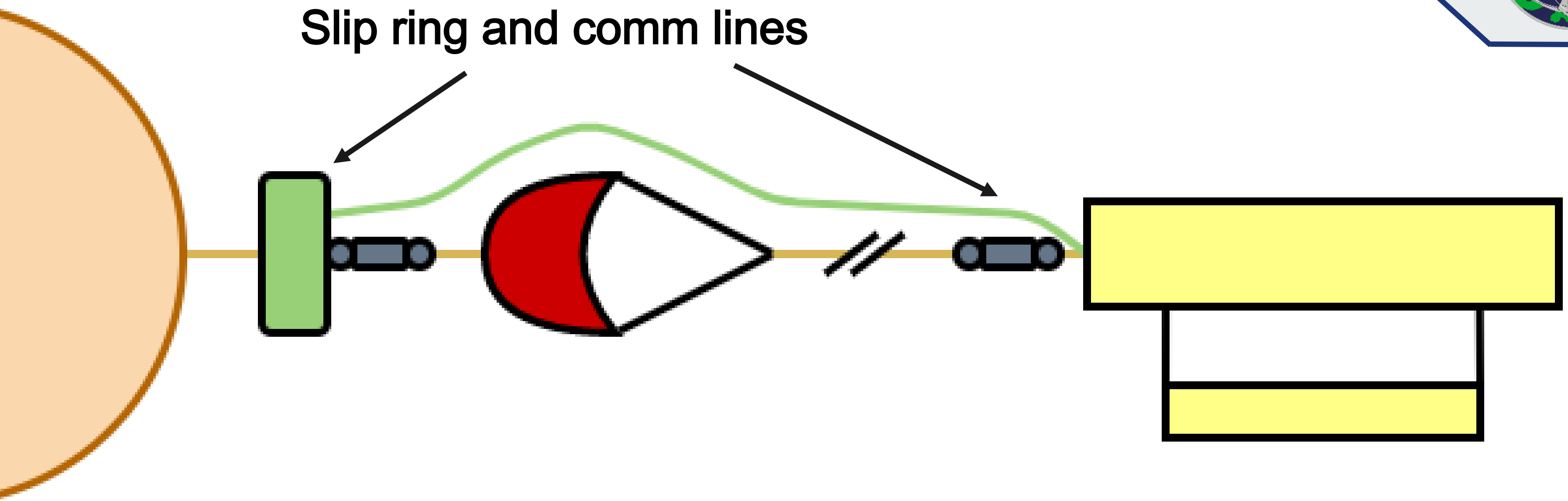
Tether Backup Slides

Venting Purpose and Concerns



- Need to vent gas to become neutrally buoyant
- Neutral buoyancy decreases force needed to lift balloon

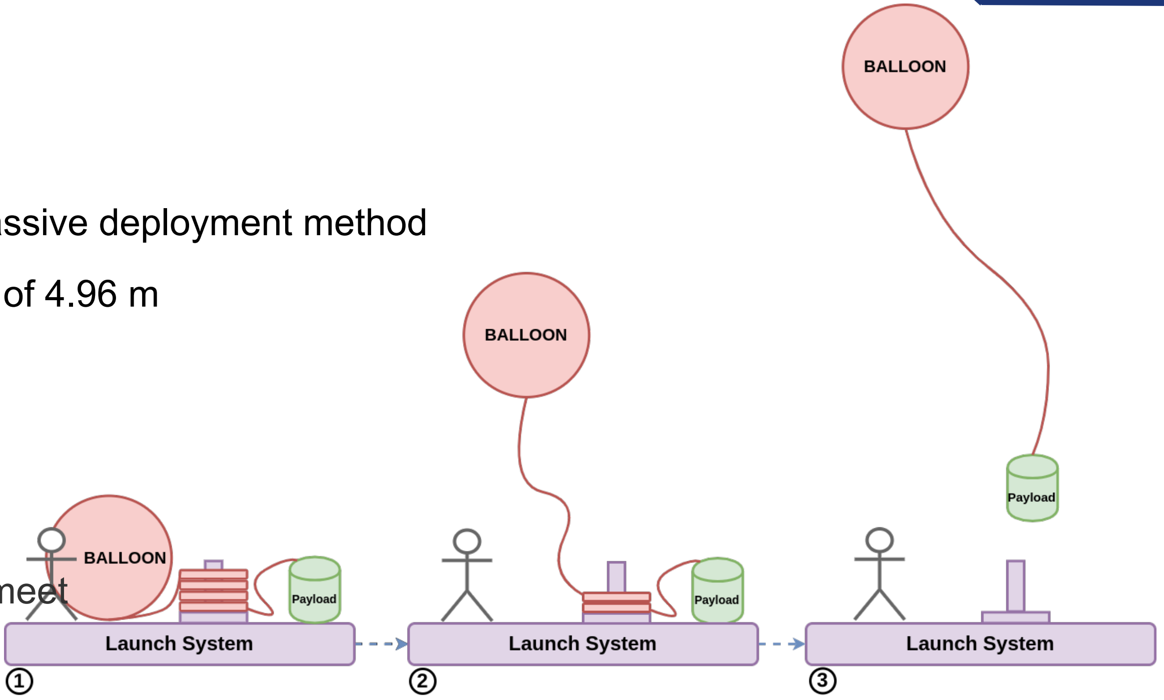
Tether Connection



FR 5.0: Balloon and payload system must meet all FAA guidelines.
FR 8.0: Launch setup must be able to be conducted by a maximum of two people, but ideally one person.

Tether Deployment Method

- Simple and reliable ground based passive deployment method
- Suitable due to our low tether length of 4.96 m



Tether Deployment System

FR 5.0: Balloon and payload system must meet all FAA guidelines.
FR 8.0: Launch setup must be able to be conducted by a maximum of two people, but ideally one person.

Alternate Tether Deployment Method

- Modelled after passive unspooling devices used in sounding balloon missions

  With a deployment rate slower than the ascent rate of the balloon there is an increased likelihood to clear obstacles in the launch zone

FR 5.0: Balloon and payload system must meet all FAA guidelines.
FR 8.0: Launch setup must be able to be conducted by a maximum of two people, but ideally one person.

Notable Risks to the Project Success - cont.

Risk	Mitigation Plan	PreMitigation Likelihood	PreMitigation Impact
Tether breaks	• Tensile testing • Impulse Generator	Severe	Improbable
Vent too much	• Pressure Tank Tests	major	High likely
Wing stalls	• Tetherball • Moored • CFD Analysis	minor	likely
Stability	• Tetherball • RECUV Flight Room Testing	major	likely
Software talk/initiate control surfaces	• Tetherball • Moored • Observational Studies	Severe	likely

Risk Backup Slides

Notable Risks to the Project Success

Risk	Mitigation Plan	PreMitigation Likelihood	PreMitigation Impact
Unable to do actual flight test due to external factors	• Conduct early and manufacture early to allow more time allotted for launching	Likely	Catastrophic
Ground tests not accurate or don't scale properly	• Compare results to CFD programs (such as XFLR, Fluent) • Compare results to hand computations	High Likely	Severe
Unable to initiate orbit at altitude	• Tetherball test • Moored test	Likely	Catastrophic
Data transmission error	• Will test reliability around mountainous surroundings of Boulder	Likely	Severe
Balloon burst	• Will purchase stronger balloon material (Totex) • Adding a Factor of Safety to max. height	Likely	Severe
CDAS Failure	• Conduct Drop tests	Likely	Major

Notable Risks to the Project Success - cont.

Risk	Mitigation Plan	PreMitigation Likelihood	PreMitigation Impact
Q_diss too hot/cold	• Tvac Testing • Dry Ice Testing	severe	Low likely
Propeller disturbances propagating to sensors	• Place further apart	severe	Low likely
Unit system costs	• Plan out material(s) bought prior to buying • Budget Plan	major	improbable
Wing being in wake	• Tetherball Test	severe	likely
Foam strength	• Torsion Tests	severe	Low likely

Testing Backup Slides

Schedule: Old Test Plan

Test	Location	Special Equipment	Planned Date
Tether Break	CU Aerospace Building	Tether, load cell	1/27/20
Balloon Neck	CU Aerospace Building	Balloon, tether, load cell	2/1/20
Thermal	CU Aerospace Building	Thermal Vacuum, electronic package	2/4/20
Vent Adhesion	CU Aerospace Building	Balloon, vent	2/8/20
Venting	CU Aerospace Building	Balloon, vent, pressure tank	2/11/20
CDAS	CU Aerospace Building	Balloon, tether, CDAS	2/15/20
Tetherball	CU Aerospace Building/Courtyar Boulder South	Tether, orbiter	2/18/20
Moored	CU Aerospace Courtyard, CU Bo South	Balloon, tether, orbiter	2/25/20
Final Flight Test	CU Aerospace Courtyard, CU Bo South	Full HALO System	4/10/20

Parachute Deployment Drop Test

Controlled Descent Arrest System (CDAS)

FAA Backup Slides

FAA Regulations - General

101.1 Applicability.

(a) This part prescribes rules governing the operation in the United States, of the following:

(1) Except as provided for in §101.7, any balloon that is moored to the surface of the earth or an object thereon and that has a diameter of more than 6 feet or a gas capacity of more than 115 cubic feet.

(2) Except as provided for in §101.7, any kite that weighs more than 5 pounds and is intended to be flown at the end of a rope or cable.

(3) Any unmanned rocket except:

(i) Aerial firework displays; and,

(ii) Model rockets:

(a) Using not more than four ounces of propellant;

(b) Using a slow-burning propellant;

(c) Made of paper, wood, or breakable plastic, containing no substantial metal parts and weighing not more than 16 ounces, including the propellant; and

(d) Operated in a manner that does not create a hazard to persons, property, or other aircraft.

(4) Except as provided for in §101.7, any unmanned free balloon that-

(i) Carries a payload package that weighs more than four pounds and has a weight/size ratio of more than three ounces per square inch on any surface of the package, determined by dividing the total weight in ounces of the payload package by the area in square inches of its smallest surface;

(ii) Carries a payload package that weighs more than six pounds;

(iii) Carries a payload, of two or more packages, that weighs more than 12 pounds; or

(iv) Uses a rope or other device for suspension of the payload that requires an impact force of more than 50 pounds to separate the suspended payload from the balloon.

(b) For the purposes of this part, a gyroglider attached to a vehicle on the surface of the earth is considered to be a kite.

[Doc. No. 1580, 28 FR 6721, June 29, 1963, as amended by Amdt. 101-1, 29 FR 46, Jan. 3, 1964; Amdt. 101-3, 35 FR 8213, May 26, 1970]

101.3 Waivers.

No person may conduct operations that require a deviation from this part except under a certificate of waiver issued by the Administrator.

[Doc. No. 1580, 28 FR 6721, June 29, 1963]

101.5 Operations in prohibited or restricted areas.

No person may operate a moored balloon, kite, unmanned rocket, or unmanned free balloon in a prohibited or restricted area unless he has permission from the using or controlling agency, as appropriate.

[Amdt. 101-1, 29 FR 46, Jan. 3, 1964]

101.7 Hazardous operations.

(a) No person may operate any moored balloon, kite, unmanned rocket, or unmanned free balloon in a manner that creates a hazard to other persons, or their property.

(b) No person operating any moored balloon, kite, unmanned rocket, or unmanned free balloon may allow an object to be dropped therefrom, if such action creates a hazard to other persons or their property.

(Sec. 6(c), Department of Transportation Act (49 U.S.C. 1655(c)))

[Doc. No. 12800, Amdt. 101-4, 39 FR 22252, June 21, 1974]

FAA Regulations - Moored Balloons and Kites

101.11 Applicability.

This subpart applies to the operation of moored balloons and kites. However, a person operating a moored balloon or kite within a restricted area must comply only with §101.19 and with additional limitations imposed by the using or controlling agency, as appropriate.

101.13 Operating limitations.

(a) Except as provided in paragraph (b) of this section, no person may operate a moored balloon or kite-

(1) Less than 500 feet from the base of any cloud;

(2) More than 500 feet above the surface of the earth;

(3) From an area where the ground visibility is less than three miles; or

(4) Within five miles of the boundary of any airport.

(b) Paragraph (a) of this section does not apply to the operation of a balloon or kite below the top of any structure and within 250 feet of it, if that shielded operation does not obscure any lighting on the structure.

101.15 Notice requirements.

No person may operate an unshielded moored balloon or kite more than 150 feet above the surface of the earth unless, at least 24 hours before beginning the operation, he gives the following information to the FAA ATC facility that is nearest to the place of intended operation:

(a) The names and addresses of the owners and operators.

(b) The size of the balloon or the size and weight of the kite.

(c) The location of the operation.

(d) The height above the surface of the earth at which the balloon or kite is to be operated.

(e) The date, time, and duration of the operation.

101.17 Lighting and marking requirements.

(a) No person may operate a moored balloon or kite, between sunset and sunrise unless the balloon or kite, and its mooring lines, are lighted so as to give a visual warning equal to that required for obstructions to air navigation in the FAA publication "Obstruction Marking and Lighting" .

(b) No person may operate a moored balloon or kite between sunrise and sunset unless its mooring lines have colored pennants or streamers attached at not more than 50 foot intervals beginning at 150 feet above the surface of the earth and visible for at least one mile.

(Sec. 6(c), Department of Transportation Act (49 U.S.C. 1655(c)))

[Doc. No. 1580, 28 FR 6722, June 29, 1963, as amended by Amdt. 101-4, 39 FR 22252, June 21, 1974]

101.19 Rapid deflation device.

No person may operate a moored balloon unless it has a device that will automatically and rapidly deflate the balloon if it escapes from its moorings. If the device does not function properly, the operator shall immediately notify the nearest ATC facility of the location and time of the escape and the estimated flight path of the balloon.

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