Test Readiness Review: High Altitude Lifting Orbiter (HALO)

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Customer: Professor Lawrence
Advisor: Matt Rhode
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**

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**

Altitude (km):
- **40**
- **35**
- **30**
- **25**

- **Data transmission/acquisition**

Telemetry/data transmission between 25 and 35 km. Range of 100 km
Levels of Success - Level 1

- Altitude: 150 ft
- Moored
- IMU and GPS Sensors
- 5 m/s
Levels of Success - Level 2

- Balloon wake
- Data collection and transmission
- Altitude: 20 km
- 15-25 ± 1 km @ 2 m/s
- Low battery trigger
- 5 m/s
Levels of Success - Level 3

- Altitude: 30 km
- Turbulence sensor incorporated
- Orbit outside wake for entire flight
- Data collection and transmission
- 25-35 ± 1 km @ 2 m/s
- Low battery trigger
- 5 m/s
System Breakdown: CPE’s

- Balloon
- Venting
- Tether (4.96 m)
- Controlled Descent Arrest System (CDAS)
- Lifting Body
- Electronics and Software

* Venting System not pictured
System Breakdown

- 0.48 kg of helium
- 1.50 kg balloon
- 1.52 kg not including balloon and helium

Diagram:
- Lifting Orbiter
- Braided Kevlar Tether: 4.96 m
- Parachute (CDAS): 2.86 m
- Weights:
  - 0.06 kg
  - 1.35 kg
Critical Project Elements

<table>
<thead>
<tr>
<th>CPE</th>
<th>Why it is Critical?</th>
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</thead>
<tbody>
<tr>
<td>Balloon</td>
<td>Must be able to reach the target altitude without bursting and handle the stresses on the neck due to the tether and payload.</td>
</tr>
<tr>
<td>Venting</td>
<td>Must be able to ensure venting can achieve neutral buoyancy, as well as act as a method to terminate flight.</td>
</tr>
<tr>
<td>Tether</td>
<td>Must have a launching tether design that will allow a maximum of 2 people to deploy (preferably 1 person), as well as having a tether that breaks under a 50 lbf (222.4 impulsive force.</td>
</tr>
<tr>
<td>Lifting Body</td>
<td>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 m/s.</td>
</tr>
<tr>
<td>CDAS</td>
<td>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.</td>
</tr>
<tr>
<td>Electronics</td>
<td>Must keep electronics in operating temperature range and ensure that there is enough power for the duration of the entire mission.</td>
</tr>
<tr>
<td>Software</td>
<td>Must be able to account for altitude changes and actuate commands in order to initiate control surfaces, transmit data, and terminate the flight.</td>
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</tbody>
</table>
● 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

Overview

Schedule

Test Readiness

Budget

Backups

Legend

Deliverable

Software

Manufacturing

Testing

Critical Path

Manufacturing Focus

Testing Focus

We are here

MSR

TRR

SFR

PFR

February 2020

March 2020

April 2020

May 2020

Manufacturing Status Report (MSR)

Acquire Balloons, Tether, Electronics

Manufacture Sensor Packages

Learn Hot Wire Cutting

Preliminary Software Interfacing

Develop Baseline Arduino Software

CDAS Drop Test

Test Readiness Review (TRR)

Develop Control Loops

Manufacture Sensor Packages

Manufacture Wings, Tails

Tether Impulse Test

Electronics Survivability Test

Software Dry Run Test

Propeller Thrust Test

AIAA Paper

Data Transmission Test

Tweak and Finalize Control Loops

Orbit Acquisition Test

Moored Test

Neutral Buoyancy Test

Repeat Tests if Necessary

Project Final Report (PFR)
Overview

Schedule

Test Readiness

Budget

Backups

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Work Breakdown Structure

**Deliverables**
- CDR
- FFR
- MSR
- TRR
- AIAA Paper
- SFR
- Project Final Report

**Manufacturing**
- Assemble orbit acquisition test wing
- Acquire components for 3 wings
- Assemble each wing
- Assemble Electronics Package
- Assemble deployment stand
- Assemble flight test system

**Software**
- Outline control system pseudocodes
- Preliminary Software Interfacing
- Develop data transmission automation
- Develop propulsion control system
- Develop control surface automation
- Develop venting control system

**Testing**
- Orbit acquisition test
- CDAS drop test
- Tether breakage test
- Electronics survivability test
- Software dry run tests
- Propeller thrust test
- Data transmission test
- Orbit Acquisition Test
- Moored Test
- Neutral Buoyancy test

**Legend**
- Complete
- In Progress
- Incomplete
## Updated Test Plan

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

- Orbit Acquisition
- Descent Arrest
- Lift Generation
- Neutral Buoyancy
- Data Transmission
- Survivability

Overview  Schedule  Test Readiness  Budget  Backups
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
- Orbit Acquisition Test
- Moored Test

Descent Arrest
- CDAS Drop Test

Lift Generation
- 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**
  - 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**

---

**Overview**  **Schedule**  **Test Readiness**  **Budget**  **Backups**
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

Temperature Profile of Payload
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:
- Thermal Chamber Test
- Dry Ice (-78.5 degrees °C)

Mimic Pressure Conditions:
- Hypobaric Chamber Test
- Will resistors still dissipate heat?

Thermal Vacuum Chamber?

- Expensive
- Hard to acquire access
- 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**

---

**Cooler with Dry Ice**

- **Insulation**
- **Payload**
- **Temperature Sensors**

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 select 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
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

\[ D_o = T_{prop} \]

\[ \tau = 0.65r \times D_p \]

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

V_p = 0.65\omega r
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

- **Rescheduled for March 8th**
Orbit Model

Beta vs Tangential Velocity

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

\[
\sum F_y : L \cos \beta + T \sin \beta = W
\]

\[
\sum F_z : D = F
\]
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)
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

Overview Schedule Test Readiness Budget Backups
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

![Balloon Ascent Velocity](image1)

![Balloon Altitude](image2)
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 3m³ 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
HALO Budget Overview

HALO BUDGET MARCH UPDATE

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

- **Margin:** 42.7%
- **$2,137.03**
- **Electronics:** 20.2%
- **$1,011.22**
- **Flight Train:** 17.8%
- **$887.88**
- **Miscellaneous:** 19.3%
- **$963.87**
CUSTOMER BUDGET MARCH UPDATE

- Labor: 34.5% ($455.00)
- Electronics: 37.3% ($491.00)
- Flight Components: 28.2% ($372.00)
Questions?

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

- Data transmission/acquisition

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 3.8 sec.
Parachute Deployment Test - Results

- Results discussion

**Height vs. Time**

- **Vertical Axis:** Height (m)
- **Horizontal Axis:** Time (s)

**Velocity vs. Time**

- **Vertical Axis:** Speed (m/s)
- **Horizontal Axis:** Time (s)
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 = 0.9087, p-value = 0.06042
```

The 95% confidence interval for the mean is (37.2514392708935, 41.0485607291065)
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
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 an IMU and GPS to verify a successful orbiter trajectory. This data will be transmitted to a receiving antenna throughout the Moored test. System will include a fail-safe descent arresting device in the event of balloon burst. The payload will then enter a controlled descent at 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 drag to bring the balloon and payload to a velocity of 2 m/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 initiated autonomously as triggered by low 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 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 and 35 km until power depletion. GPS measurements will be used to 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

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<td>26</td>
<td>2</td>
<td>9</td>
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</table>

**Legend**

- **Deliverable**
- **Management**
- **Software**
- **Manufacturing**
- **Testing**

**Critical Path**

- **Altered Tasks**

### Manufacturing Focus

- Implement CDR Feedback
- Fall Final Report (FFR)
- Manufacturing Status Report (MSR)
- Develop Data Transmission Loop
- Manufacture Wings/Tails
- Manufacture Sensor Packages
- Acquire Balloons and Tether
- Tether Break Test
- Balloon Neck Test
- Test Readiness Review (TRR)
- Develop Control Loops
- Thermal Test
- Vent Adhesion Test
- Venting Tests
- CDAS Drop Test
- Aerodynamic Ground Tests
- AIAA Paper

### Testing Focus

- Spring Final Review (SFR)
- Software Tests
- Aeroscopic Ground Tests
- Final Flight Test
- Project Final Report (PFR)
Manufacturing Backup Slides
Manufacturing Overview

Manufactured
- Wings/Booms
- Motor Mount
- Safety-System Connections

Software
- Data Transmission Code
- Orbit Acquisition Code
- Motor Control Code
- Tail Actuation Control Code
- Venting Code
- Thermal Control Code

Testing
- Balloon Vent
- Drop Test assembly
- Tether/Force scale assembly

Electronics Assembled
- Electronics Bay

Lifting Orbiter
## Purchased Components

### Hardware
- Foam
- 3D Printing Filament
- Carbon Spars
- Kevlar Tether
- Propeller
- Balloon
- Swivels and Slip Rings
- Load Cell
- Tether Deployment Spool

### Electronics
- Battery
- ESC
- Motor
- Arduino
- Servos
- Thermal Resistors
- Relay Switch (pMOSFET)
- IMU
- Transceivers

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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 hoseclamp
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)
Wings: Spar Alignment Sketch For Main Airfoil

- Carbon Fiber Spars

<table>
<thead>
<tr>
<th>Wing Section</th>
<th>95.5 cm</th>
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</thead>
<tbody>
<tr>
<td>Carbon Spars</td>
<td>91.5 cm</td>
</tr>
<tr>
<td>Payload</td>
<td></td>
</tr>
<tr>
<td>Carbon Spars</td>
<td>91.5 cm</td>
</tr>
</tbody>
</table>

21.5 cm
6.5 cm
4.8 cm
40 cm
Tail Boom: Spar Attachment Sketch

- Two carbon fiber rods
- Placed on either side of the electronics package
Tail Boom: Spar Attachment Sketch
Tail Boom: Spar Attachment CAD

Payload Bay

Tail control servo

Tail control horn

NOTE: Control link between servo and control horn not shown
3D Printing: Payload Bay

- 3D printed chassis to keep electronics aligned
## Software: Overview Status

<table>
<thead>
<tr>
<th>Electronics Component</th>
<th>Status</th>
<th>Next Step</th>
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</thead>
<tbody>
<tr>
<td>Arduino Mega</td>
<td>Completed Preliminary Interfacing</td>
<td>Integrate Main Functions</td>
</tr>
<tr>
<td>ESC</td>
<td>Completed Preliminary Interfacing</td>
<td>Develop Motor Control Loop</td>
</tr>
<tr>
<td>Motor</td>
<td>Completed Preliminary Interfacing</td>
<td>Develop Motor Control Loop</td>
</tr>
<tr>
<td>GPS</td>
<td>Completed Preliminary Interfacing</td>
<td>Data Transmission Test</td>
</tr>
<tr>
<td>IMU</td>
<td>Completed Preliminary Interfacing</td>
<td>Develop Angle Determination</td>
</tr>
<tr>
<td>Vent</td>
<td>Completed Preliminary Interfacing</td>
<td>Develop Vent Control Loop</td>
</tr>
<tr>
<td>Temperature Sensors</td>
<td>Basic Wiring Complete, No Interfacing</td>
<td>Preliminary Arduino Interfacing</td>
</tr>
<tr>
<td>XBee Transceiver</td>
<td>No Interfacing</td>
<td>Preliminary Arduino Interfacing and Data Transmission Test</td>
</tr>
</tbody>
</table>
Software: Main Block

Legend

- **Start/End**
- **Process**
- **Decision**
- **Input/Output**

Flowchart:

1. **Start**
2. Read GPS
3. Check Orbit Status
4. Load Temperature Control
5. Find Predicted Beta Angle
6. Actuate Servos (Tail Actuation Loop)
7. Re-Initialize Orbit Acquisition
8. Motor Throttle Adjustment
9. Check Battery
10. Transmit Package

Decision Points:
- **Are we at the bottom or top of a cycle?**
- **Payload is still in orbit?**
- **Battery < 5%?**
- **Terminate Flight**
Software: Motor Control

Begin motor rate control loop

1. Read altitude from GPS
   - 10 Hz
   - Altitude

2. Read IMU angular rates
   - 10 Hz
   - IMU angular rates

3. Calculate average β angle over past minute
   - Necessary β angle

4. Decision: Average β angle > necessary β angle?
   - Yes: Decrease motor power by 10%
   - No: Increase motor power by 10%

5. End motor rate control loop, repeat

Legend:
- Start/End
- Process
- Decision
- Input/Output

65
Software: Tail Actuation

Begin tail actuation loop

Read altitude from GPS data

Altitude

Altitude ≈ 25 km or 35 km?

No

Yes

Reverse tail direction

End tail actuation loop

Legend

Start/End

Process

Decision

Input/Output
Software: Neutral Buoyancy Acquisition

Legend

- Start/End
- Process
- Decision
- Input/Output

1. Begin neutral buoyancy loop
2. Open vent
3. Calculate avg. ascent rate over past 3 minutes
4. Avg. ascent rate over past 3 minutes
   - Yes
   - 10 Hz
   - Avg. ascent rate > 1 m/s?
     - Yes
     - Calculate avg. ascent rate over past 3 minutes
     - Open vent
     - Calculate avg. ascent rate over past 3 minutes
8. Avg. ascent rate > 0.25 m/s?
   - Yes
   - End neutral buoyancy loop
   - Close vent
9. No
10. Close vent
11. Calculate avg. ascent rate over 10 minutes
12. Avg. ascent rate over 10 minutes
   - Yes
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
     - Yes
     - End neutral buoyancy loop
     - Close vent
   - No
   - Avg. ascent rate > 0.25 m/s?
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
- 4-6 50 Ω resistors will be supplied with 3.6 V (1-1.5 W)
Drilling into Foam for Carbon Spar Mounting

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

<table>
<thead>
<tr>
<th>Component</th>
<th>Chosen</th>
<th>Voltage [V]</th>
<th>Current [mA]</th>
<th>Mass [g]</th>
<th>Powered by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>Adafruit Ultimate</td>
<td>3.3</td>
<td>25</td>
<td>8.5</td>
<td>3.3V Arduino pin</td>
</tr>
<tr>
<td>Arduino</td>
<td>Arduino Mega</td>
<td>7.6</td>
<td>100</td>
<td>53</td>
<td>LG MU1 barrel connector</td>
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<tr>
<td>IMU</td>
<td>Sparkfun 9DoF Razor IM</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>5V Arduino pin</td>
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<tr>
<td>Radio Transceiver</td>
<td>Radio Transceiver</td>
<td>3.3</td>
<td>150</td>
<td>3</td>
<td>3.3V Arduino pin</td>
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<tr>
<td>Arduino Battery</td>
<td>2 x LG MU1 18650</td>
<td>7.6</td>
<td>NA</td>
<td>2 x 49 = 98</td>
<td>NA</td>
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<tr>
<td>Temperature Sensor</td>
<td>TMP36</td>
<td>3.3</td>
<td>5</td>
<td>1</td>
<td>3.3V Arduino pin</td>
</tr>
</tbody>
</table>
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 of 35 km
  - Burst altitude/diameter is the most significant factor to consider

- Balloon will be neutrally buoyant at 30 km
  - 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 remaining unregulated
  - FAA guidelines can be found in appendix

FR 5.0: Balloon and payload system must meet all FAA guidelines.
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-life, determined when battery has 5% remaining.
Venting Control System

- GPS, battery data fed into control 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.
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
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.
● Simple and reliable ground based passive deployment method
● Suitable due to our low tether length of 4.96 m

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.
<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation Plan</th>
<th>PreMitigation Likelihood</th>
<th>PreMitigation Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tether breaks</td>
<td>● Tensile testing</td>
<td>Severe</td>
<td>Improbable</td>
</tr>
<tr>
<td></td>
<td>● Impulse Generator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vent too much</td>
<td>● Pressure Tank Tests</td>
<td>major</td>
<td>High likely</td>
</tr>
<tr>
<td>Wing stalls</td>
<td>● Tetherball</td>
<td>minor</td>
<td>likely</td>
</tr>
<tr>
<td></td>
<td>● Moored</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>● CFD Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td>● Tetherball</td>
<td>major</td>
<td>likely</td>
</tr>
<tr>
<td></td>
<td>● RICUV Hight Room Testing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software talk/initiate control surfaces</td>
<td>● Tetherball</td>
<td>Severe</td>
<td>likely</td>
</tr>
<tr>
<td></td>
<td>● Moored</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Observational Studies</td>
<td></td>
<td></td>
</tr>
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</table>
Risk Backup Slides
### Notable Risks to the Project Success

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

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

---

**Overview**

- **Schedule**
- **Test Readiness**
- **Budget**
- **Backups**
Testing Backup Slides
## Schedule: Old Test Plan

<table>
<thead>
<tr>
<th>Test</th>
<th>Location</th>
<th>Special Equipment</th>
<th>Planned Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tether Break</td>
<td>CU Aerospace Building</td>
<td>Tether, load cell</td>
<td>1/27/20</td>
</tr>
<tr>
<td>Balloon Neck</td>
<td>CU Aerospace Building</td>
<td>Balloon, tether, load cell</td>
<td>2/1/20</td>
</tr>
<tr>
<td>Thermal</td>
<td>CU Aerospace Building</td>
<td>Thermal Vacuum, electronic package</td>
<td>2/4/20</td>
</tr>
<tr>
<td>Vent Adhesion</td>
<td>CU Aerospace Building</td>
<td>Balloon, vent</td>
<td>2/8/20</td>
</tr>
<tr>
<td>Venting</td>
<td>CU Aerospace Building</td>
<td>Balloon, vent, pressure tank</td>
<td>2/11/20</td>
</tr>
<tr>
<td>CDAS</td>
<td>CU Aerospace Building</td>
<td>Balloon, tether, CDAS</td>
<td>2/15/20</td>
</tr>
<tr>
<td>Tetherball</td>
<td>CU Aerospace Building/Courtyard Boulder South</td>
<td>Tether, orbiter</td>
<td>2/18/20</td>
</tr>
<tr>
<td>Moored</td>
<td>CU Aerospace Courtyard, CU Boulder South</td>
<td>Balloon, tether, orbiter</td>
<td>2/25/20</td>
</tr>
<tr>
<td>Final Flight Test</td>
<td>CU Aerospace Courtyard, CU Boulder South</td>
<td>Full HALO System</td>
<td>4/10/20</td>
</tr>
</tbody>
</table>
Parachute Deployment Drop Test

Controlled Descent Arrest System (CDAS)
FAA Backup Slides
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 40 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.

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.

[Amendment 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, Amendment 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 §101.10 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))


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.
References
References


[7] Grainger, 'Open Cell, Foam Sheet, Polyurethane', Retrieved August 29, 2019, from https://www.grainger.com/product/5GC4U4gc1Id=Cj0KcQyww7HsBRdKARIsAARsIT45lm5vDpt0pM_np7cVeeRBe4-N8p7qvgswEB84g1AM6G7cWKOAOQAaAocyNEAlw_wcB6cm_mmc=P+mC=+GooSp+PLA+of_Id=Cj0KcQyww7HsBRdKARIsAARsIT45lm5vDpt0pM_np7cVeeRBe4-N8p7qvgswEB84g1AM6G7cWKOAOQAaAocyNEAlw_wcB6G:sk=skwcid=AL12986131!249559163841!ig=437270349819!


References


[16] Solenoid Valve, from https://www.omega.co.uk/prodinfo/solenoid-valve.html


[28] Hobby King Orbiting Body https://hobbyking.com/en_us/aero-modelling-foam-board-10mm-x-500mm.html?countrycode=US&gclid=CjwKCAjvdHsBRaoElWAd0yJybFj98EK4Gi-nxVUNEFP7HMIjkogAYgp0Hak0-IlKXKyrs-uPoCgTzhlCtMQUAV0d_Bw

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[34] Full Battery 14 AH Batteries [https://fullbattery.com/collections/18650-cells/products/ncr18650ga]
