Balloon Deployment System

Critical Design Review

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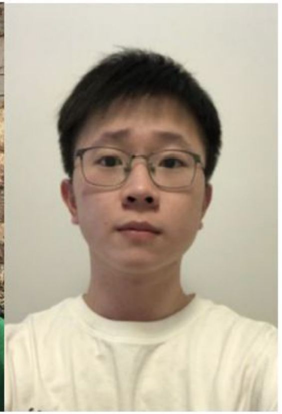


Chenshuo Yang
Structural Designer

Presentation Overview

- Project Purpose and Objectives
- Design Solution
- Critical Project Elements
- Design Requirements and their Satisfaction
- Project Risks
- Verification and Validation
- Project Planning

Project Purpose and Objectives

Project Purpose and Objectives

Mission Statement

The team shall design, build and test a high altitude balloon launcher for use in heavy winds supporting the Hypersonic Flight in the Turbulent Stratosphere (HYFLITS) program. The launcher will stand 3m high when fully extended, pose no risk for balloon puncture, be operable by a single user hands free and be easy to set up and transport.

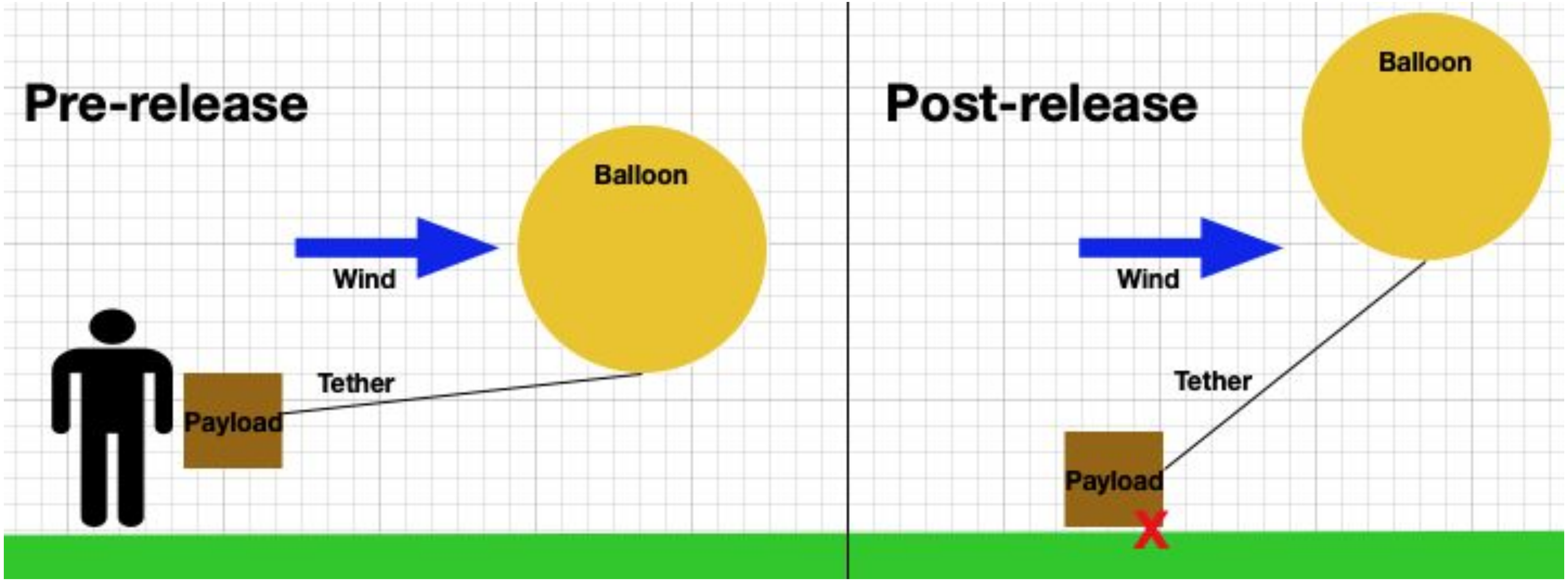
Project Purpose and Objectives

Current Process

Project Purpose and Objectives

Current Problem

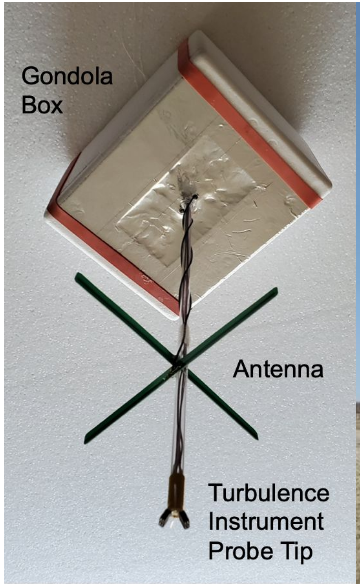
- Instrument payload hits ground



Project Purpose and Objectives

- Need: High wind weather balloon launching system
- Program: Hypersonic Flight in the Turbulent Stratosphere (HYFLITS) program
    - Study how future hypersonic vehicles can account for turbulence and particles in stratosphere
    - U of Colorado, Embry-Riddle, U of Minnesota
- Customer: Professor Dale Lawrence at CU-Boulder Smead Aerospace Engineering

Payload:



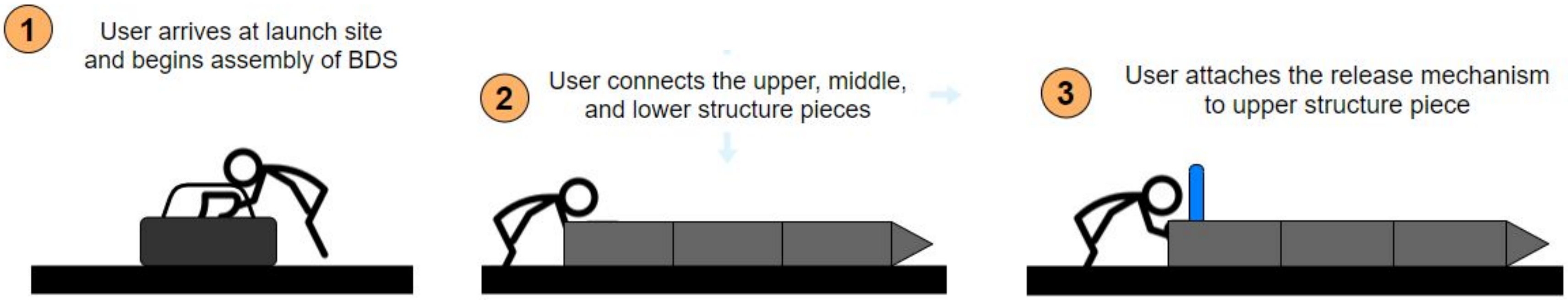
Balloon:

Project Purpose and Objectives
Customer's Requirements

- 3m tall balloon launching structure
  - Allow balloon more time to rise before payload release
- Stable launch in 10-20 m/s winds
- 1 or 2 balloon rigging with single payload
- Does not pose puncture risk to balloon
- User control of release is hands free
- Sub 50 lbs, fits in 1m x .25m case
- Sub $1000 mfg cost

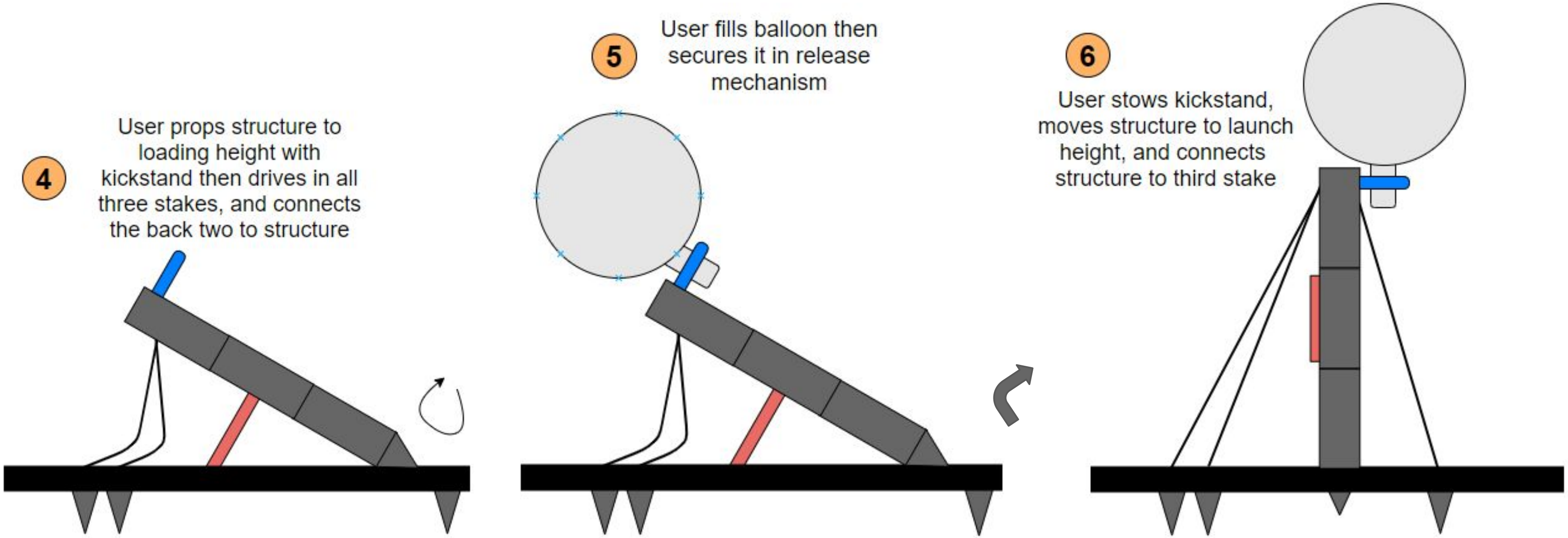
Project Purpose and Objectives

CONOPS



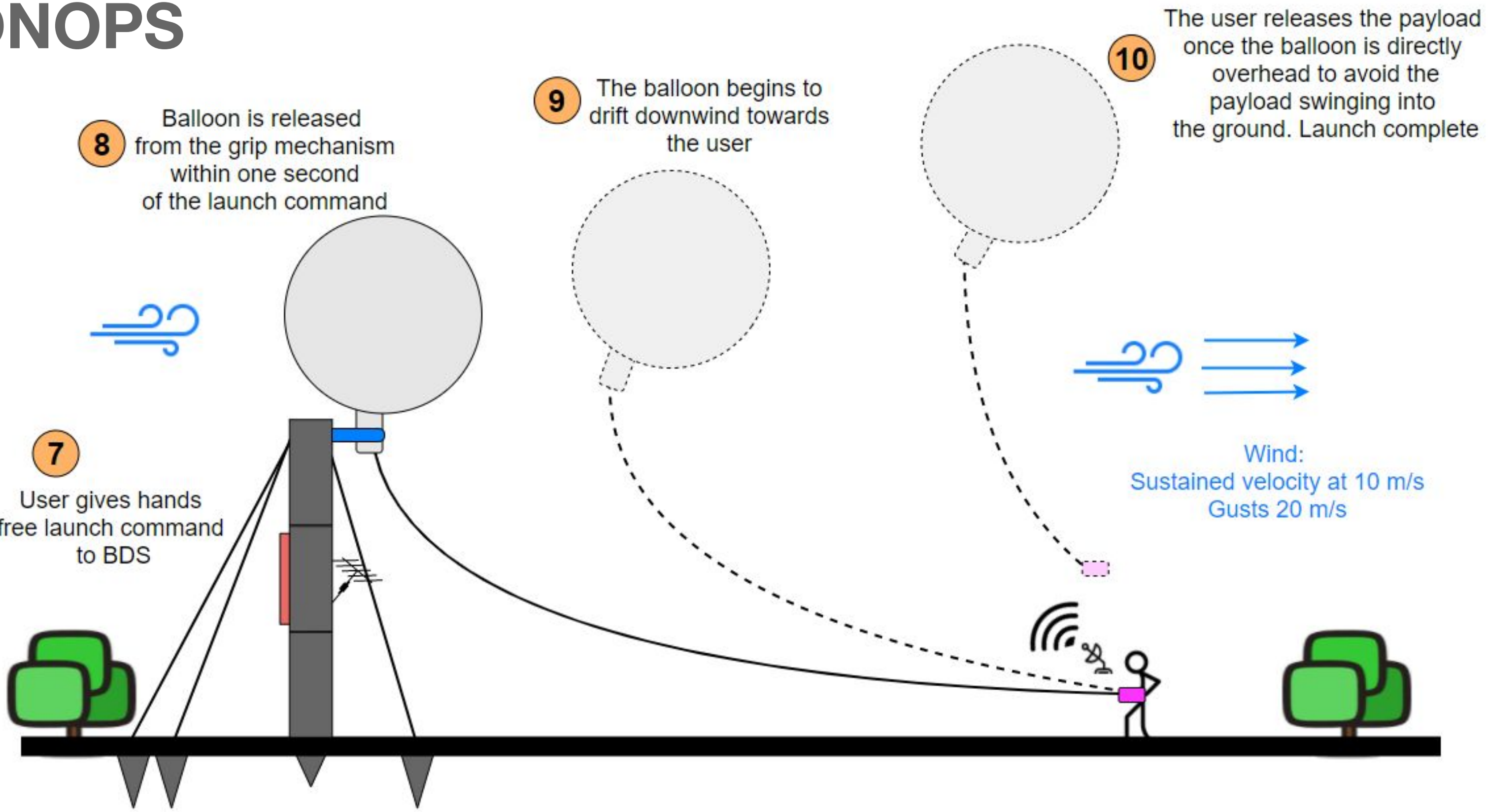
Project Purpose and Objectives

CONOPS



Project Purpose and Objectives

CONOPS



Project Purpose and Objectives

CONOPS

11 After confirmation of a successful launch, the user disassembles BDS and stores the system in the carrying case for departure

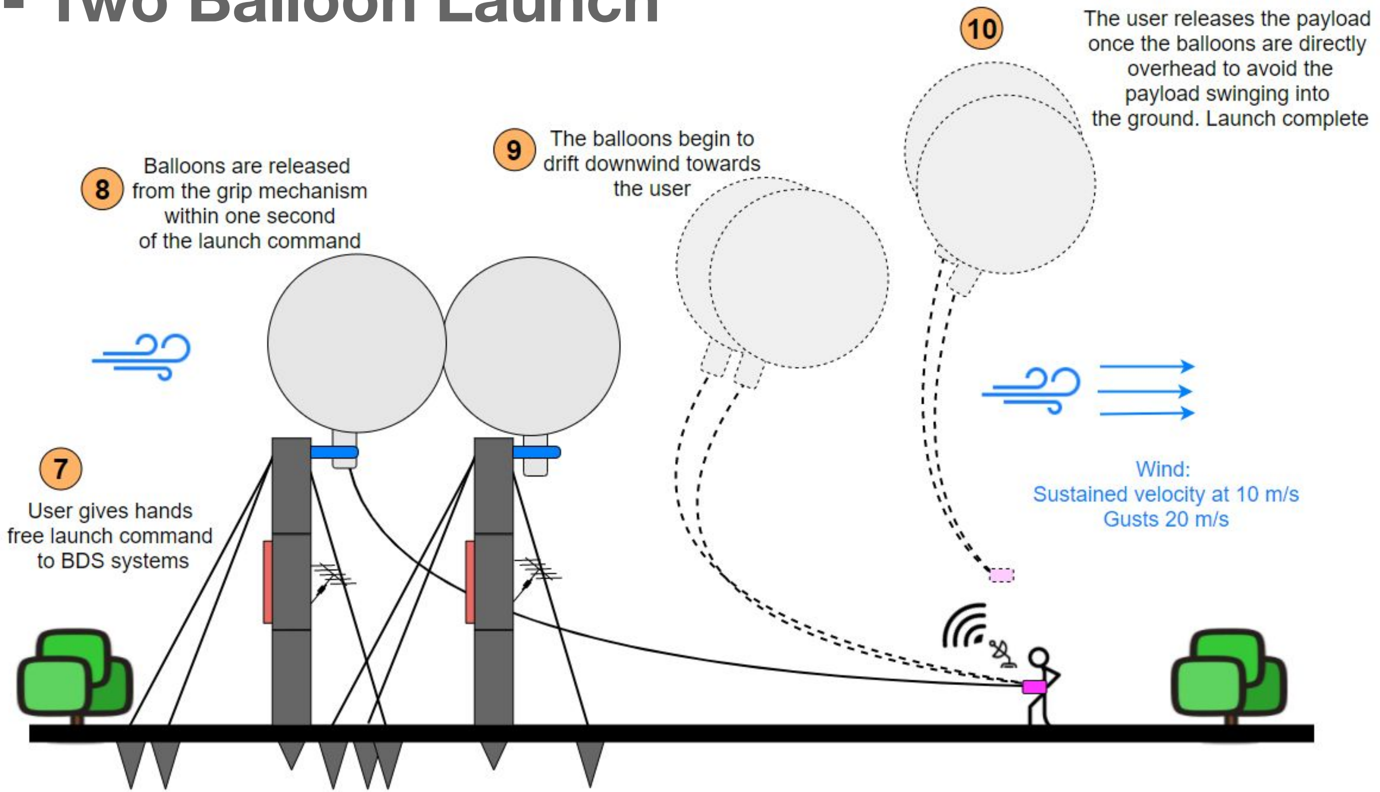
12 The user departs the launch site and is able to repeat this process for another launch when needed

Project Purpose and Objectives

CONOPS - Two Balloon Launch

1 – 6

Same steps as previous CONOPS except with two separate structure + balloon systems

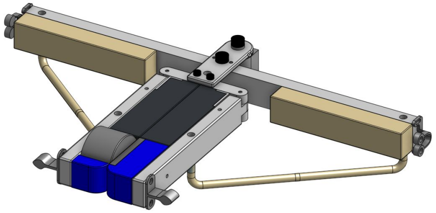


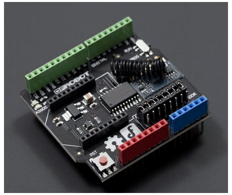
Design Solution

Design Solution

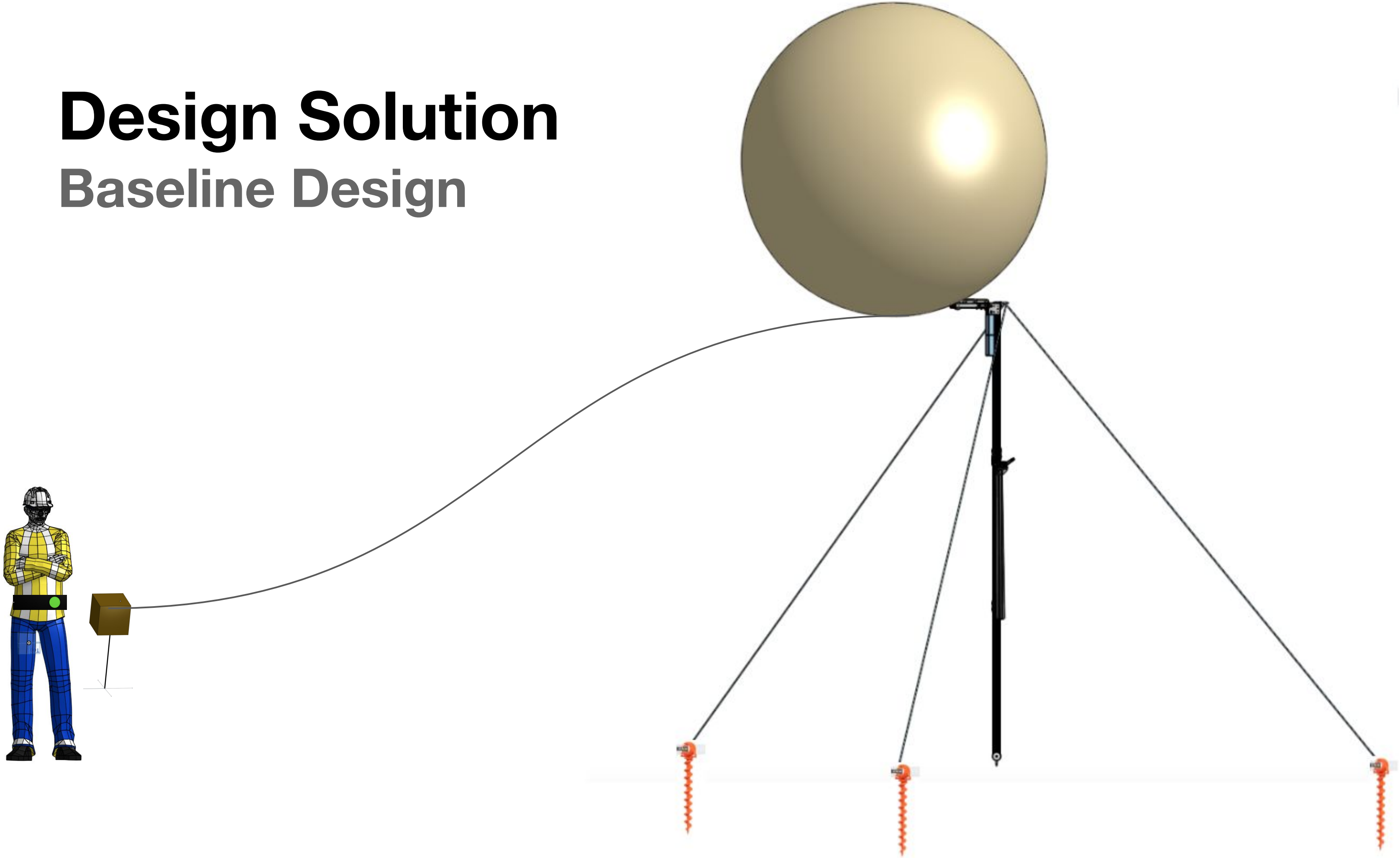
BDS Subsystems

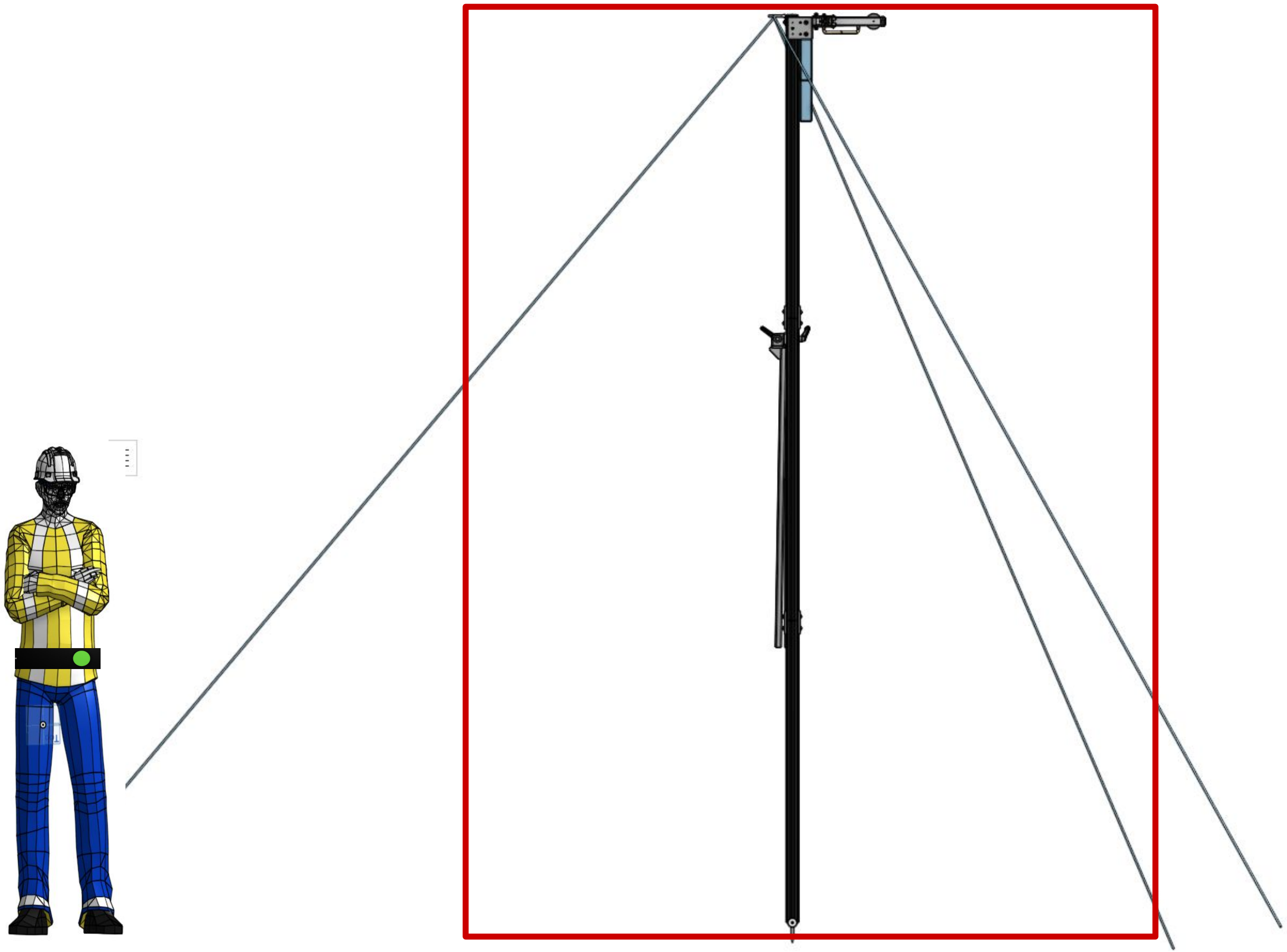
- Balloon Deployment System
  - Support Structure
    - Base
    - Extension
  - Release Mechanism
  - Command & Control
    - Transmitter
    - Receiver





Design Solution
Baseline Design



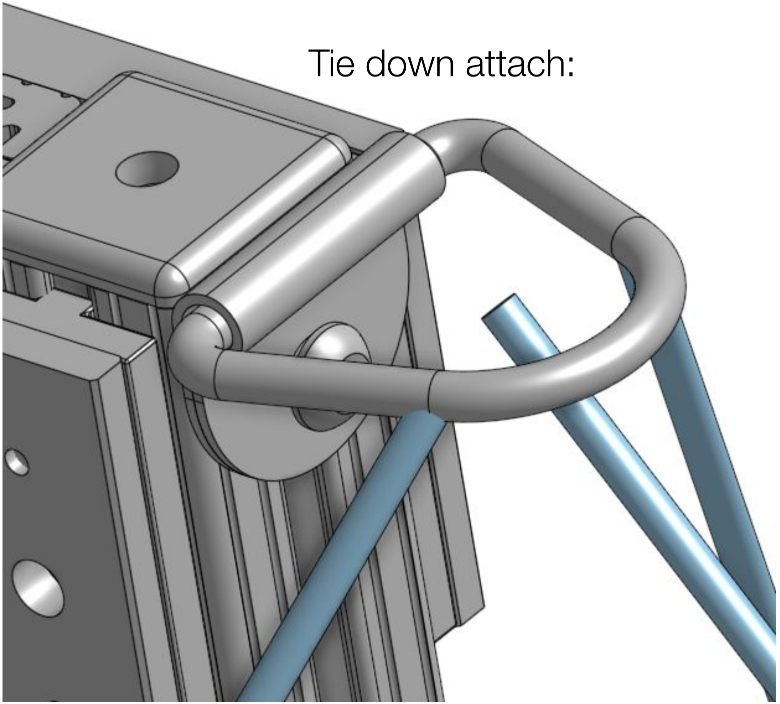


Design Solution
Structure

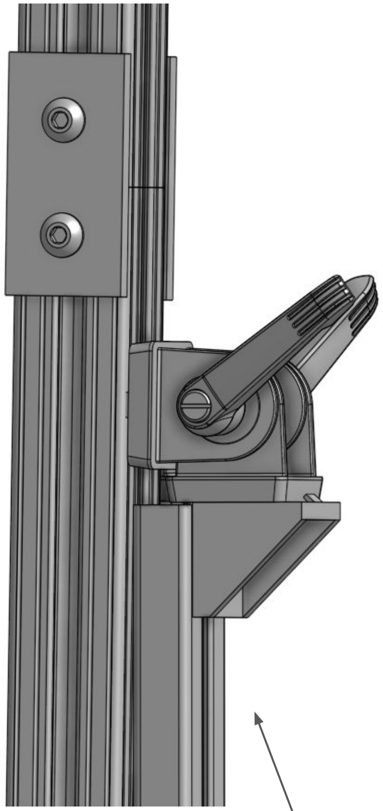
- 3 sections of T-frame Al bars form tower
    - Al brackets with through bolt/wing-nut
- Tower staked with 3 ground anchors
    - Screw in anchors
    - Adjustable tie down strap support lines
- Dimension:
    - Tower: 3m x 3.8cm x 3.8cm
    - Footprint: 3 stakes 2.64m from tower @ 120°
- Weight: 29 lbs

Design Solution
Structure

Tie down attach:

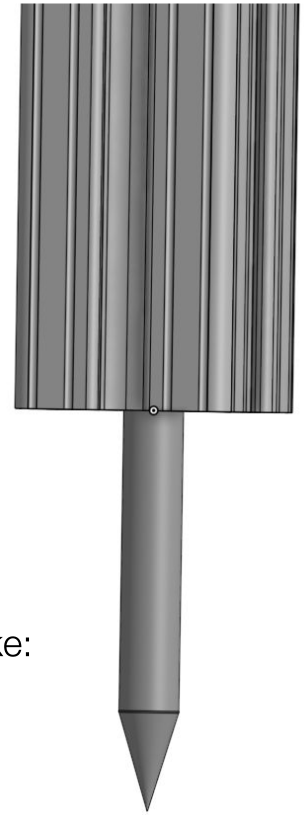


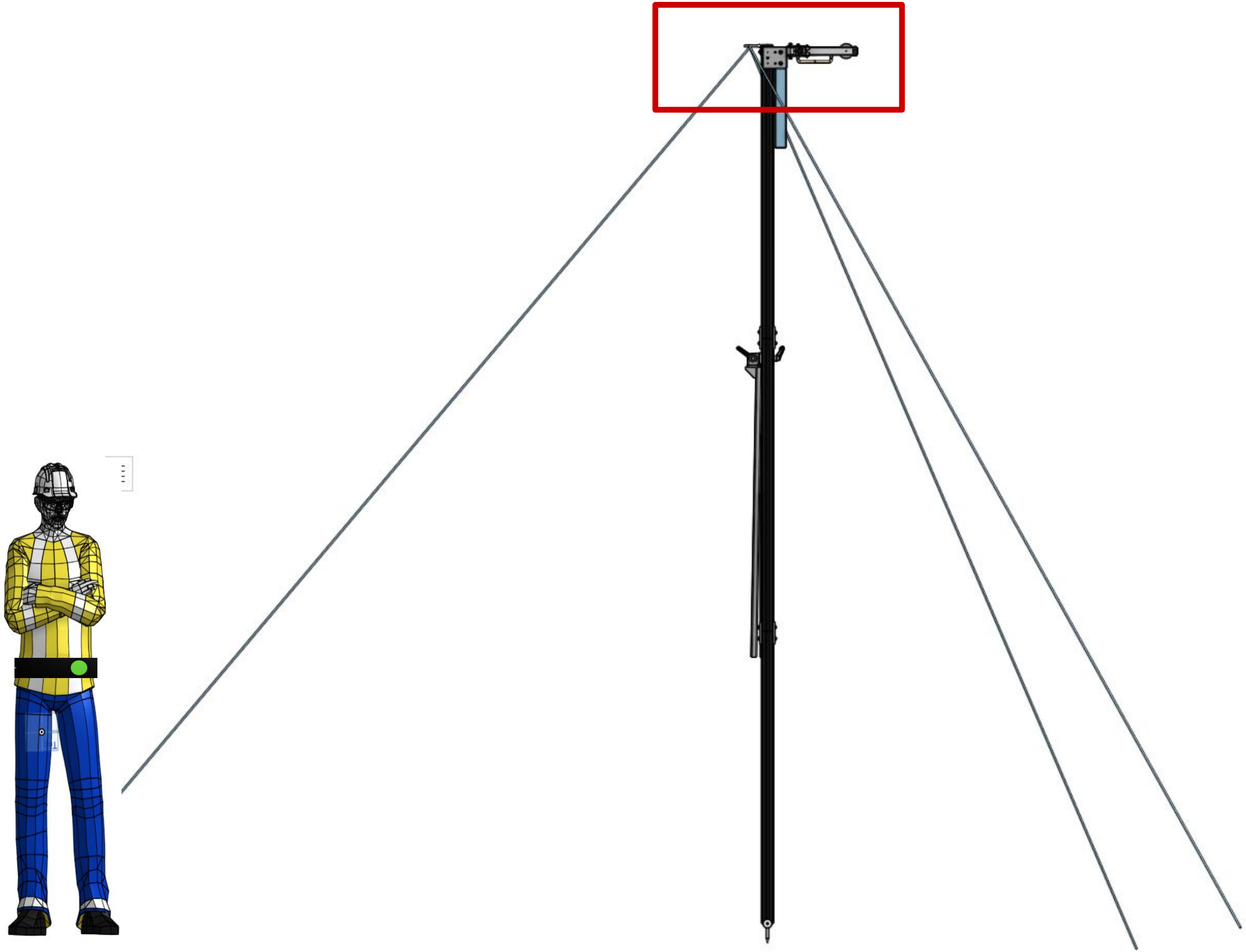
Bar joint:



Folding kick-stand:

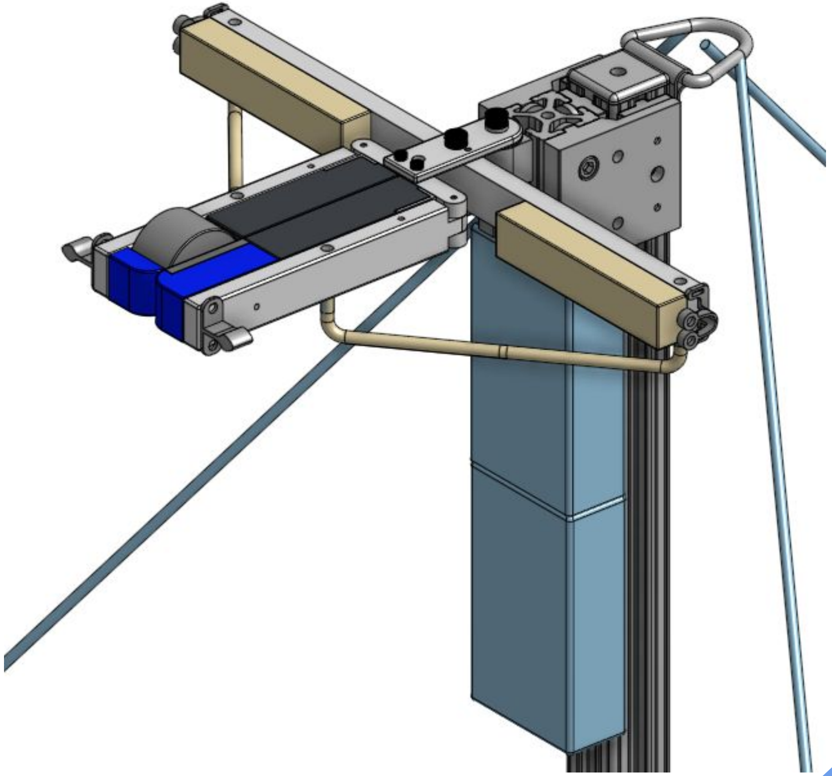
Stake:





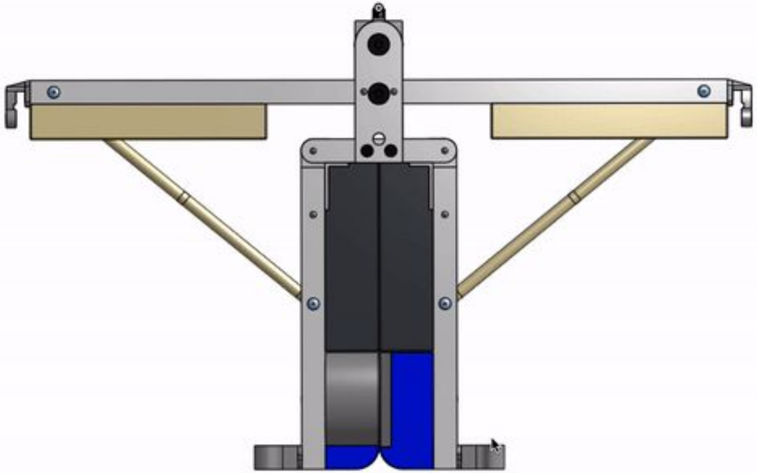
Design Solution

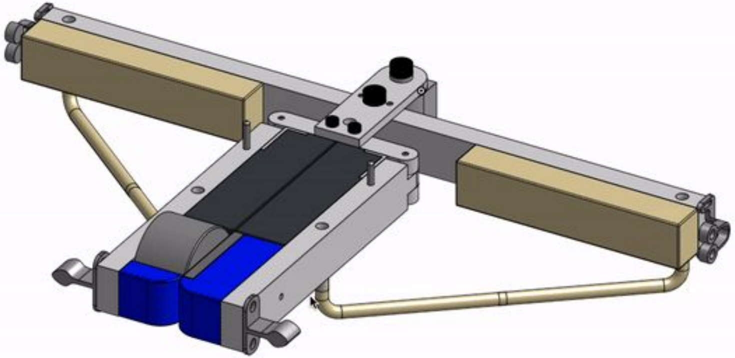
Release Mechanism



Design Solution

Release Mechanism - DOF

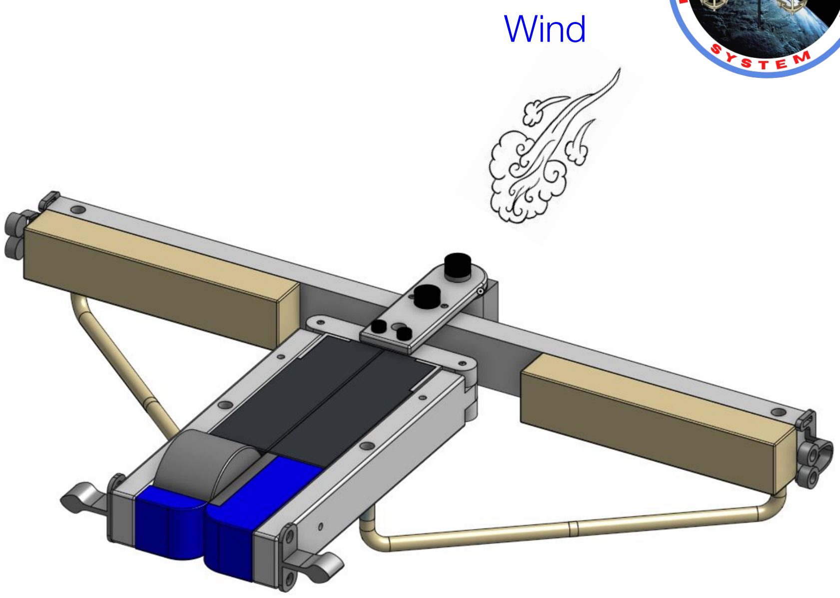




Note: This motion is stopped by locking pin until structure is risen and secure

Design Solution
Release Mechanism - Armed

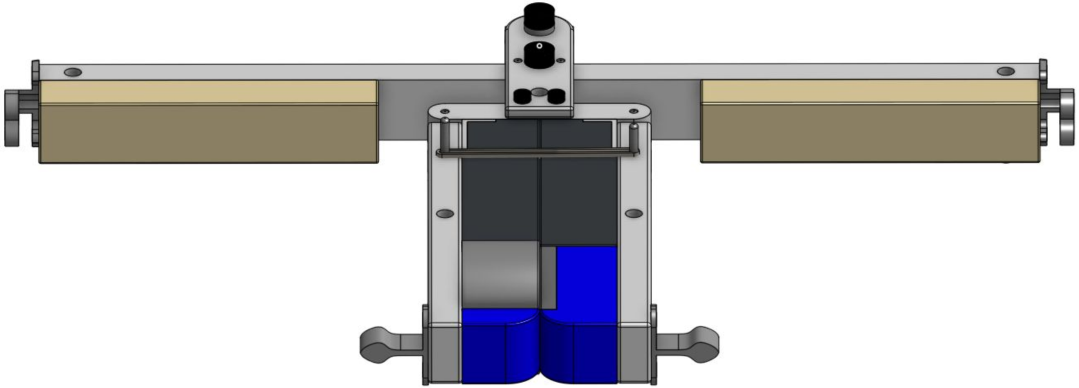
- Permanent Electromagnet latches with ferromagnetic steel
- Surgical tubing mounted to pins
  - Slip fit to swinging arms
  - Friction fit to back-plate
- Polyethylene foam gripping balloon
  - Adhesive spray to secure
- Polyurethane foam backstop coupled with 7lb pull-force cabinet latches



Design Solution

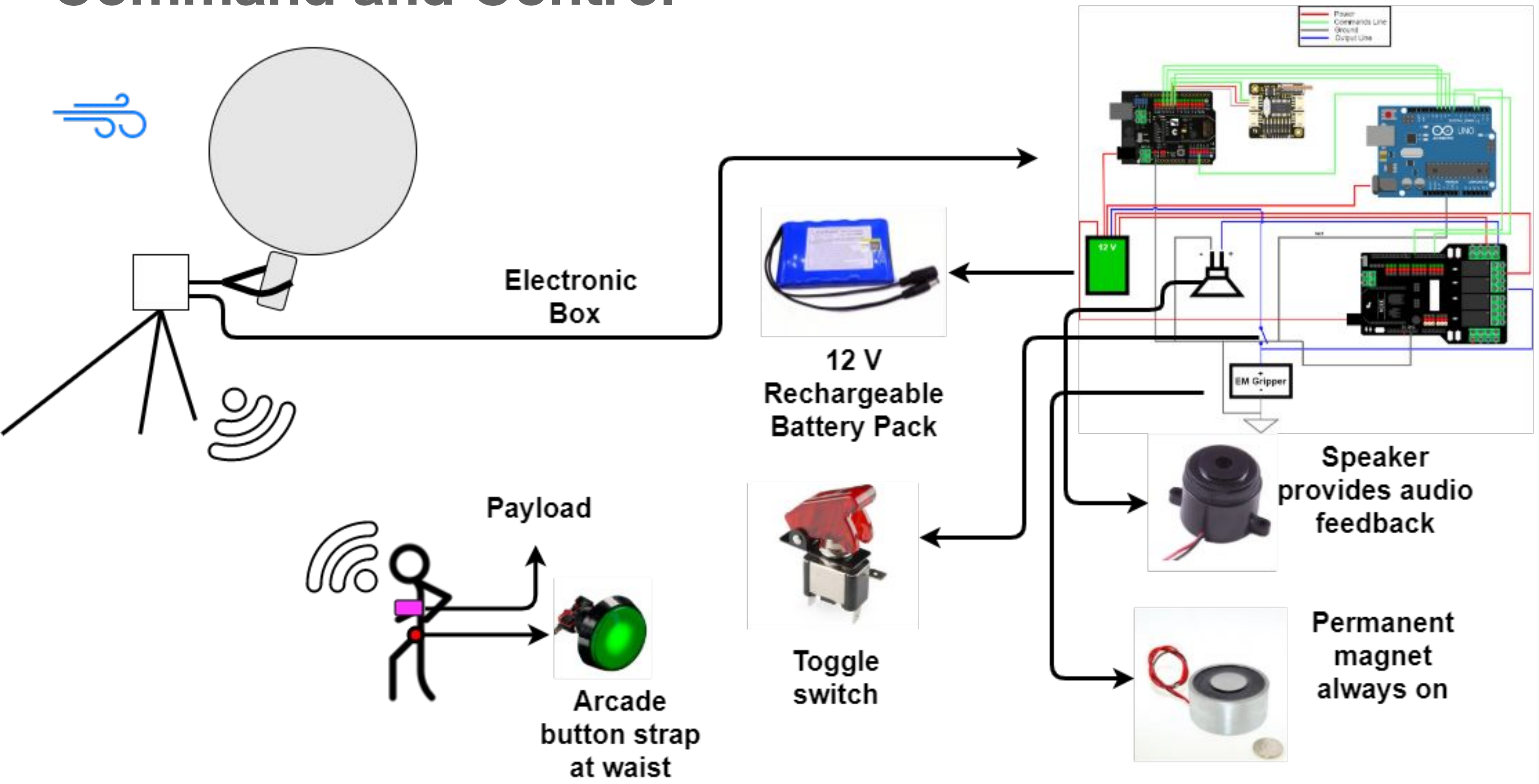
Release Mechanism - Loading

- 5 in. rubber band for loading resistance
  - Removable slip-fit pins
- 108° freedom in mounting swivel
  - Removable locking pin
- Rounded PLA inserts around electromagnet and steel
- Dimensions
  - Swinging Arms: 7 in.
  - Backstop: 14.75 in.
  - Arm-to-arm parallel distance: 3.3 in
- Weight: 7.5 lbm

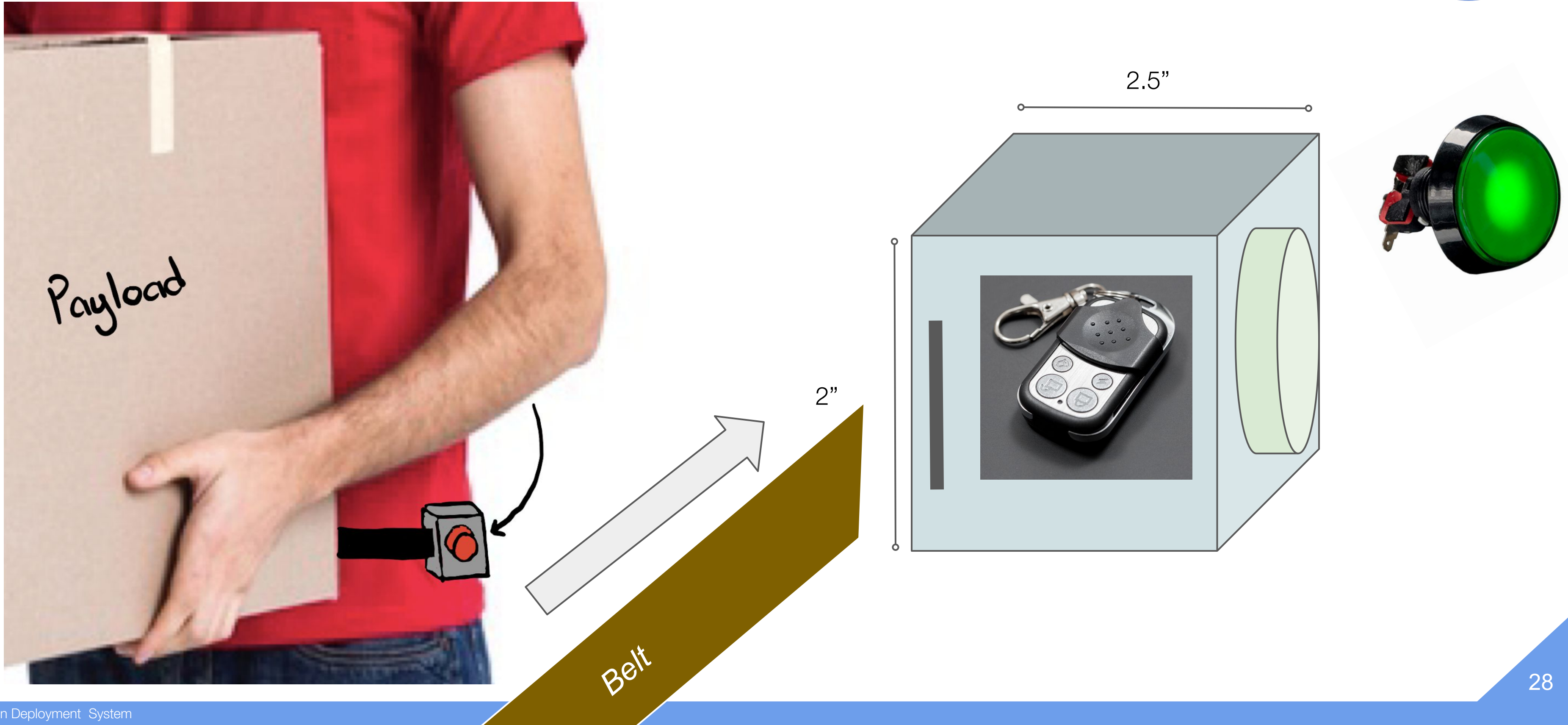


Design Solution

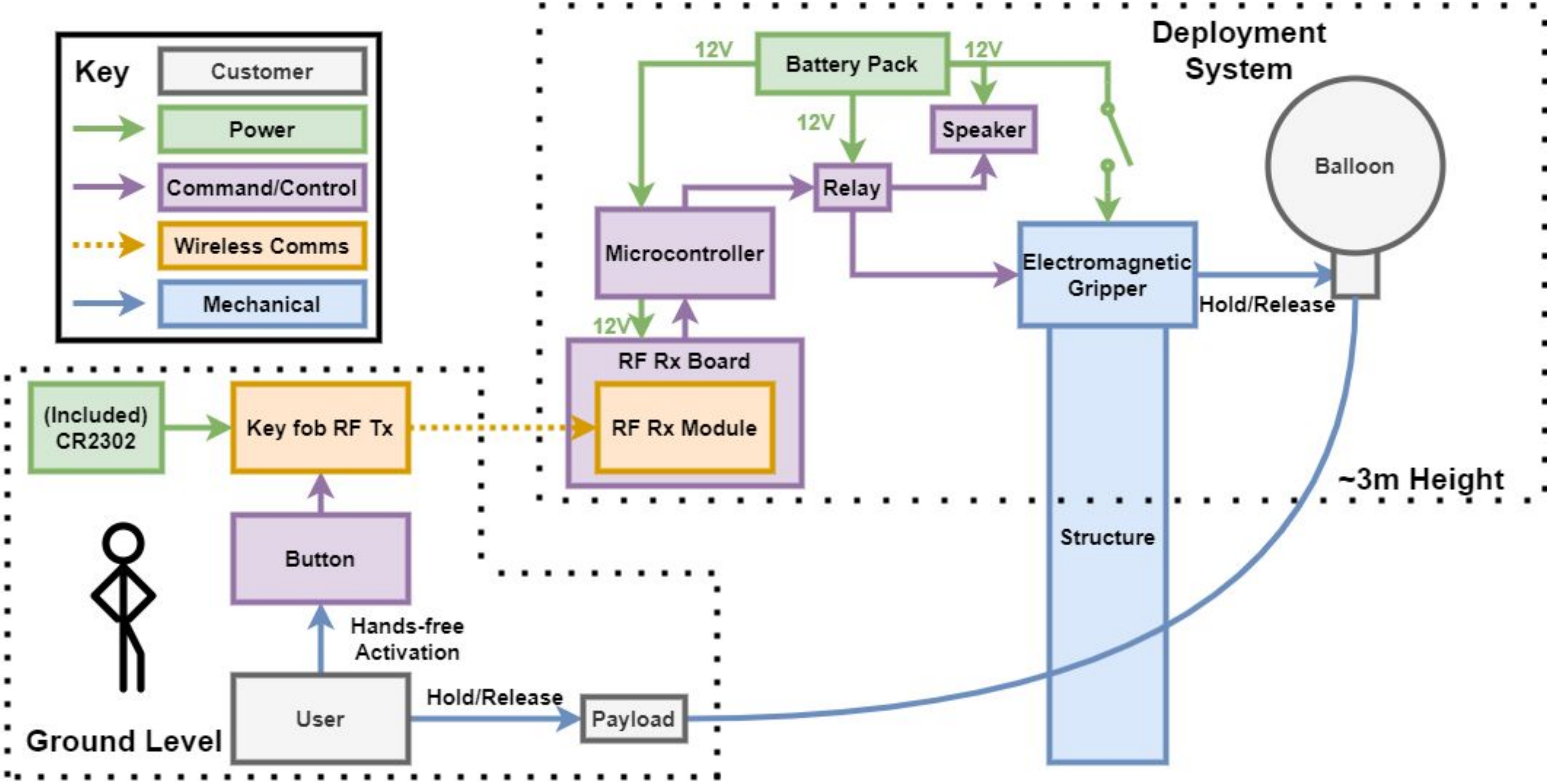
Command and Control



Design Solution
Command and Control



Design Solution
Command and Control - FBD



Critical Project Elements

Critical Project Elements

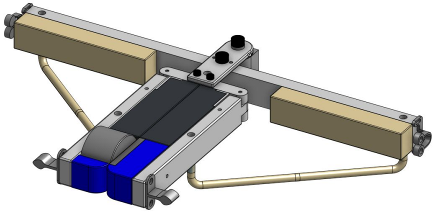
- Ease of set up/transport
  - Launch from multiple sites per HYFLITS need
- Stability in wind
  - Allow for launches in high wind conditions
- Internal structure strength
  - Survive high wind launch forces
- No balloon damage
- No premature release of balloon
- Hands free release command
  - Allow user to focus on payload safety and launch

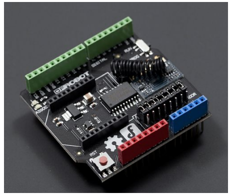
Design Requirements & Satisfaction

Design Requirements/ Satisfaction

BDS Subsystems

- Balloon Deployment System
  - Support Structure
    - Base
    - Extension
  - Release Mechanism
  - Command & Control
    - Transmitter
    - Receiver

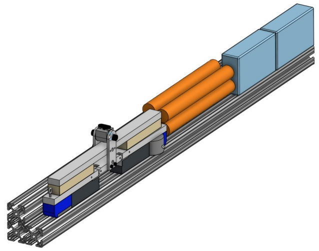




Design Requirements/Satisfaction

Ease of set-up/transport: 37 lbs and dimensions of 1.03m x.15m x .15m

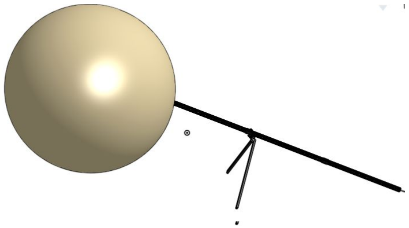
1) Unpack:



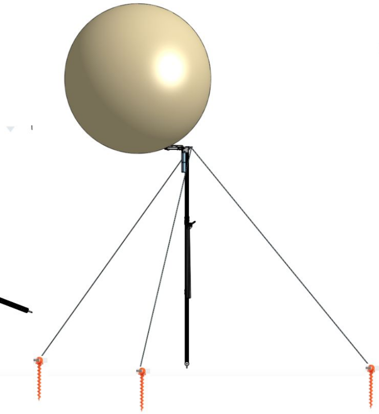
2) Assemble tower, measure/set anchors (check for buried lines-typical 24in deep):

3) Attach 2 tie downs

4) Load balloon w/ kickstand

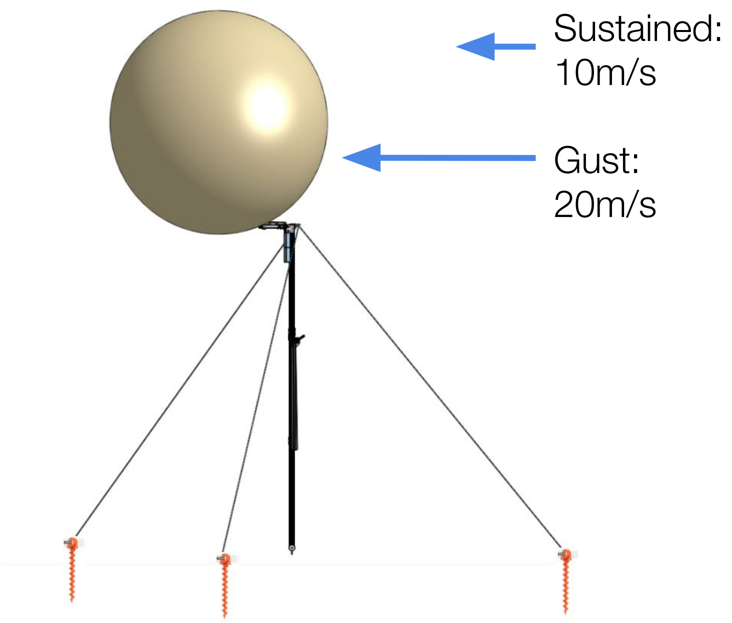


5) Raise, attach last tie down to final anchor



Design Requirements/ Satisfaction
Support Structure

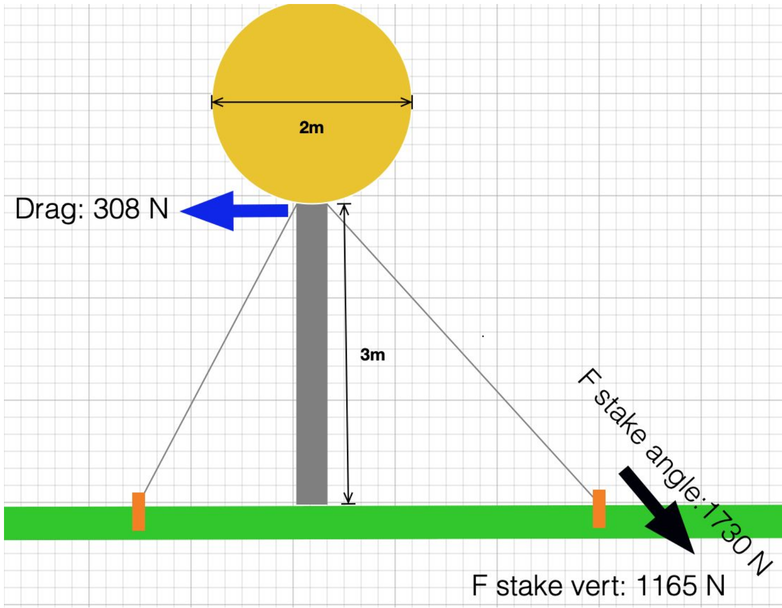
- Stability in Wind
  - Highest forces expected for subsequent modeling:
    - Max Wind Sustained
      - Max potential wind: 20m/s
      - Model balloon as sphere
      - Drag: 308N (upper bound)
    - Wind Gust Dynamic Load:
      - mass=3.689 kg (latex+helium)
      - Acceleration of wind 10m/s to 20m/s
        - Empirical data using gust factor
      - $F_{dynamic}$=184.5N (less than F_{drag}=308N)



Design Requirements/ Satisfaction

Support Structure

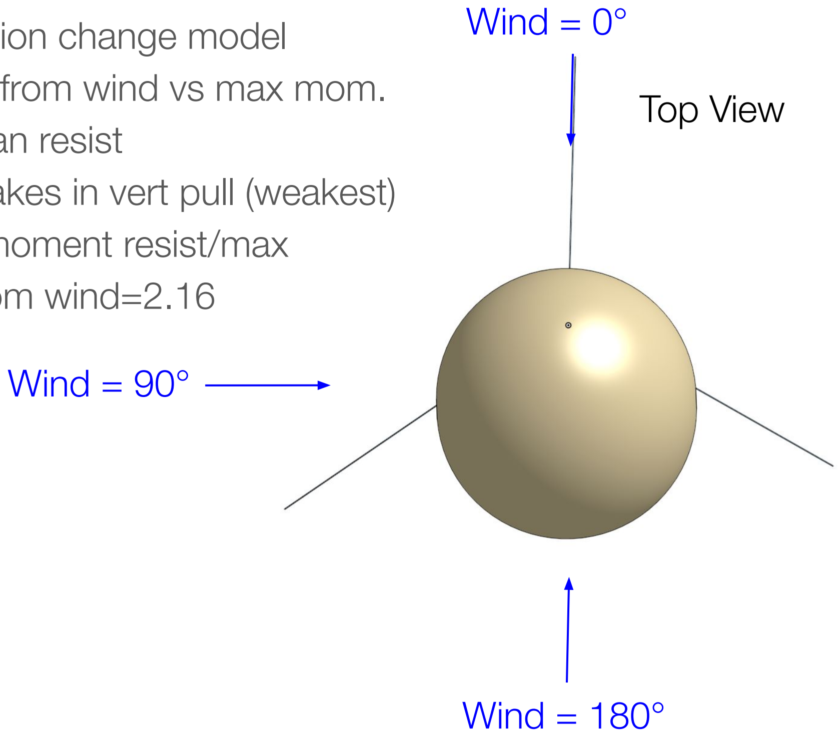
- Stability in Wind
  - Large moment to resist:
    - Wind Speed: 20 m/s
    - Drag: 308 N (model as sphere, upper bound)
    - Height: 3m
    - $Moment_{wind}$=924 N*m
  - Moment solution:
    - $F_{tie\text{-}down}$=2225N
    - $F_{stake\ @45}$=1730N
    - $F_{stake\ @vert}$=1165N (unlikely)
    - $F_{support}$=466N (wind coming directly on support)
    - $F_{support}$=537N (wind coming @ 30° off support)
      - F required in cable and anchor
    - FOS=1165N/537N=2.16

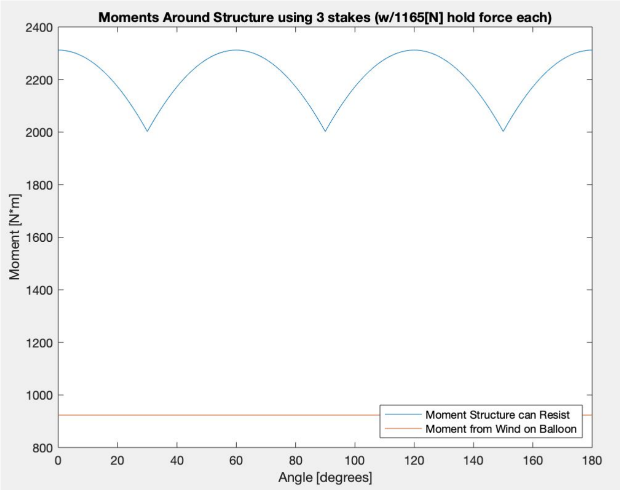


Design Requirements/ Satisfaction

Support Structure

- Stability in Wind
  - Wind direction change model
  - Max mom. from wind vs max mom. structure can resist
  - Assume stakes in vert pull (weakest)
  - FOS=min moment resist/max moment from wind=2.16



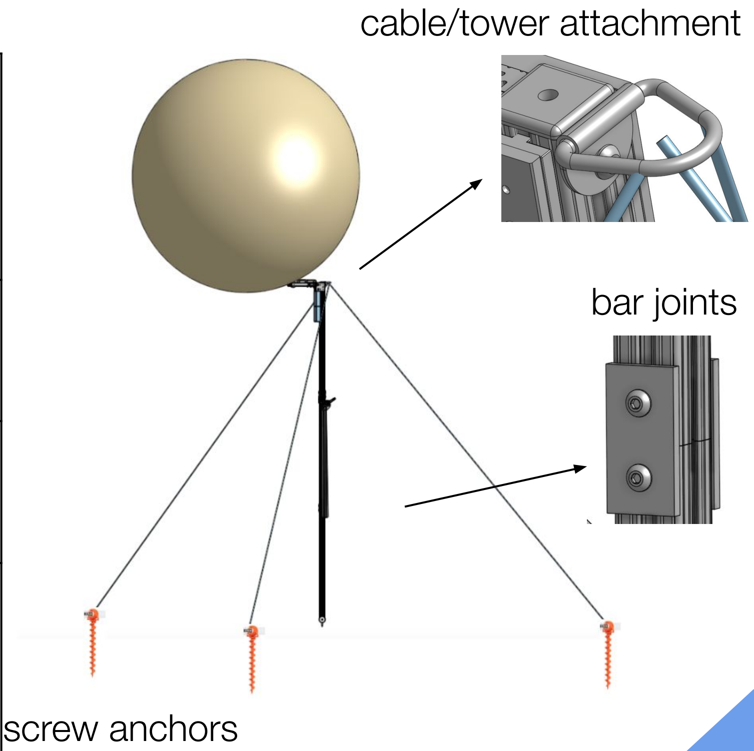


Design Requirements/ Satisfaction

Support Structure

- Internal Structure Strength:

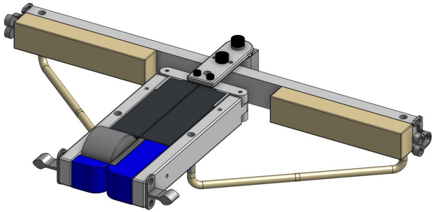
Internal Structure Strength:	**Factor of Safety** **(1.5-2 for aerospace)**
Cable/Tower Attach: Steel D-ring	4.14 (max rated tension)
Screw Anchors: Polycarbonate	2.17 (max rated tension)
Bar Joints: 6061 Al Bar Fasteners: Steel	127 (shear stress) 44 (shear stress)

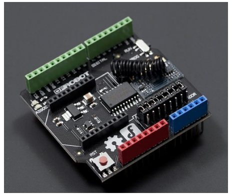


Design Requirements/ Satisfaction

BDS Subsystems

- Balloon Deployment System
  - Support Structure
    - Base
    - Extension
  - Release Mechanism
  - Command & Control
    - Transmitter
    - Receiver

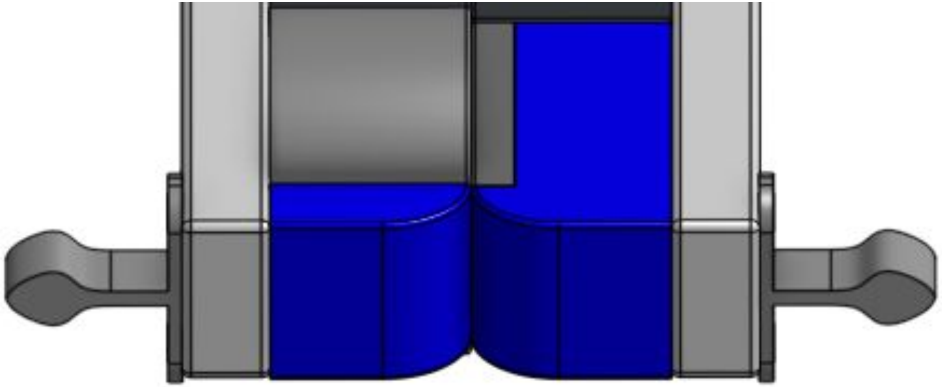


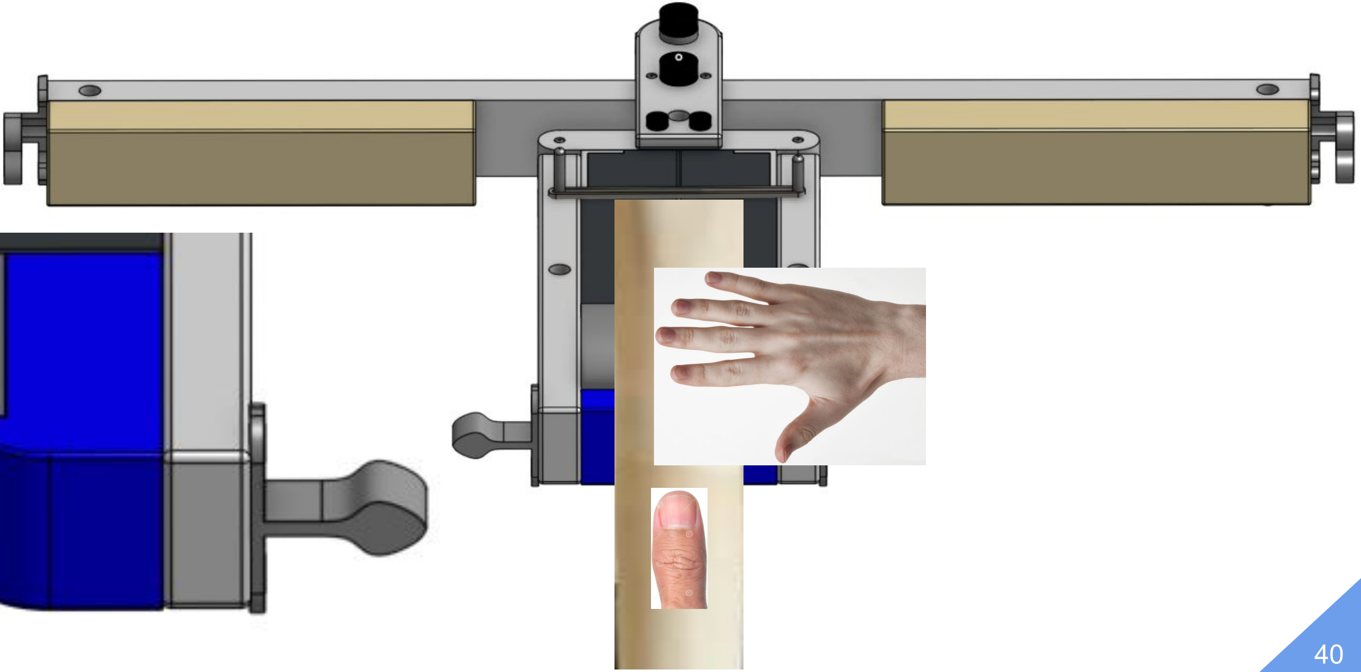


Design Requirements/ Satisfaction

Release Mechanism - Balloon Loading

- Balloon neck will be pushed through the blue 3D parts

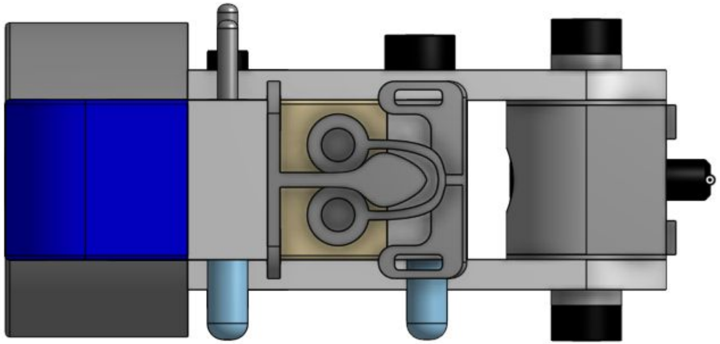


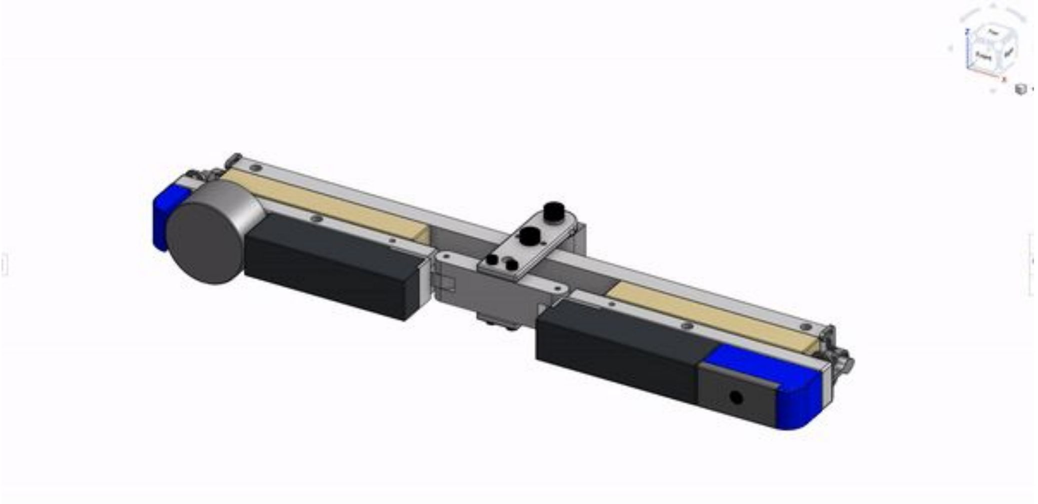


Design Requirements/ Satisfaction

Release Mechanism - Cleanly Closing

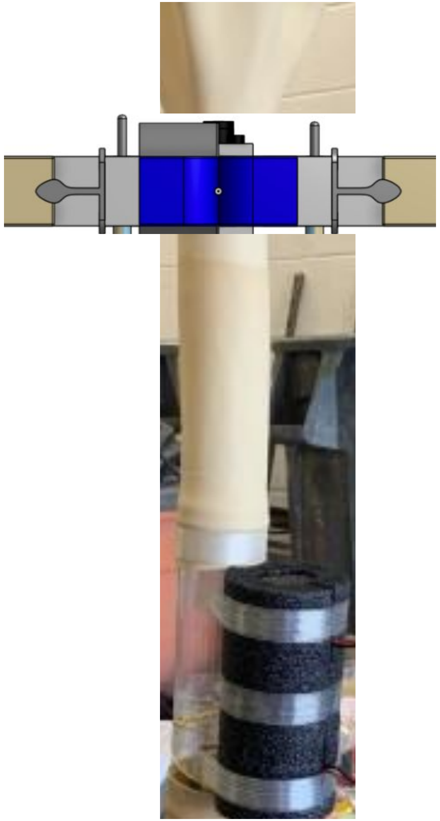
- Back plates will hit the polyurethane foam padding to decelerate the arm
- While the cabinet latch will catch the incoming arms of the release mechanism

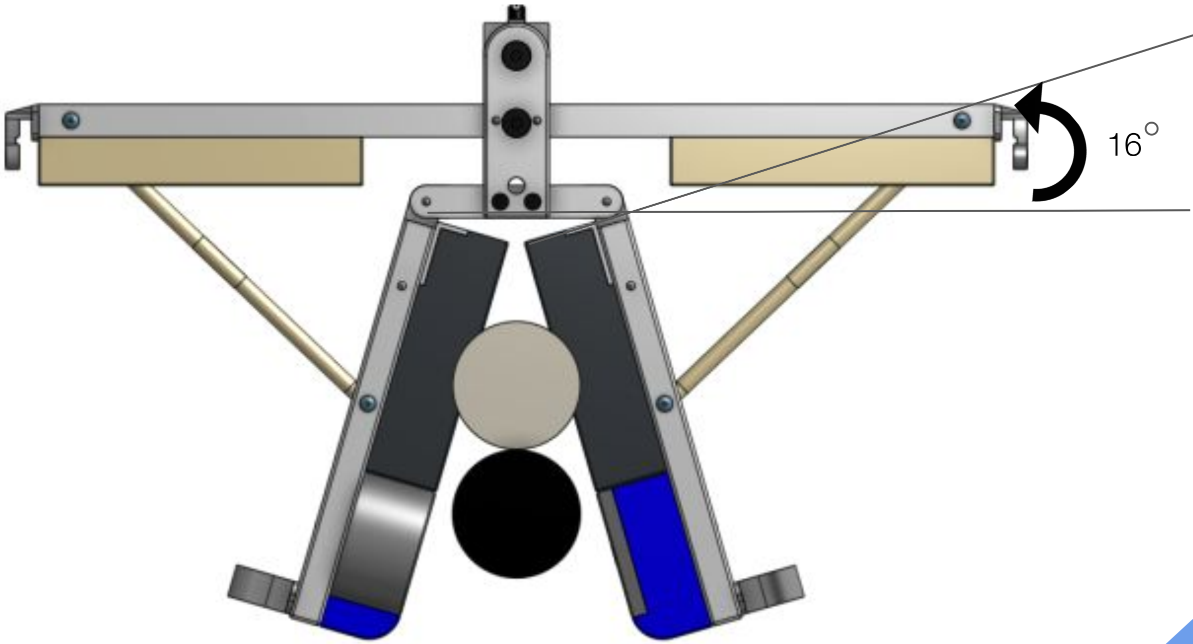




Design Requirements/ Satisfaction

Release Mech - Does the Venting Valve Get Caught?

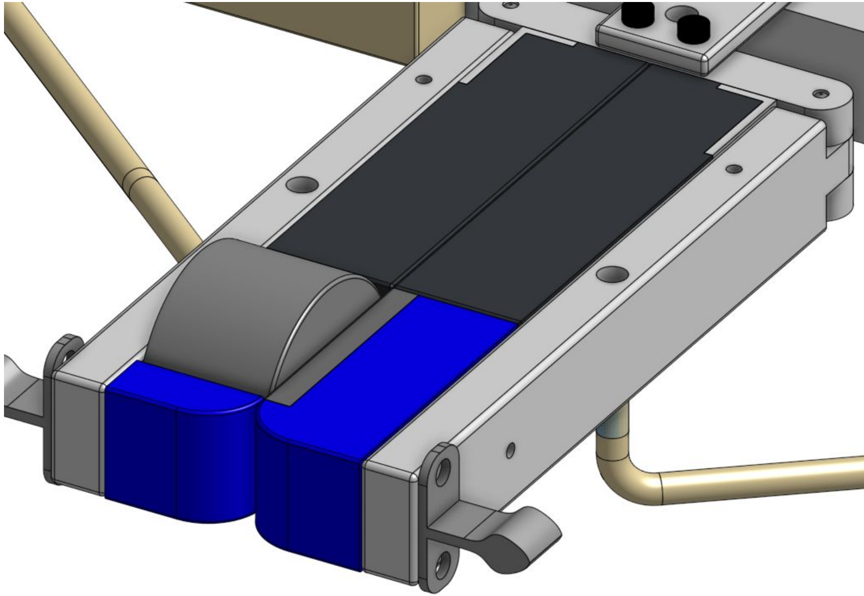




Design Requirements/ Satisfaction

Release Mech - Does the Balloon Get Damaged?

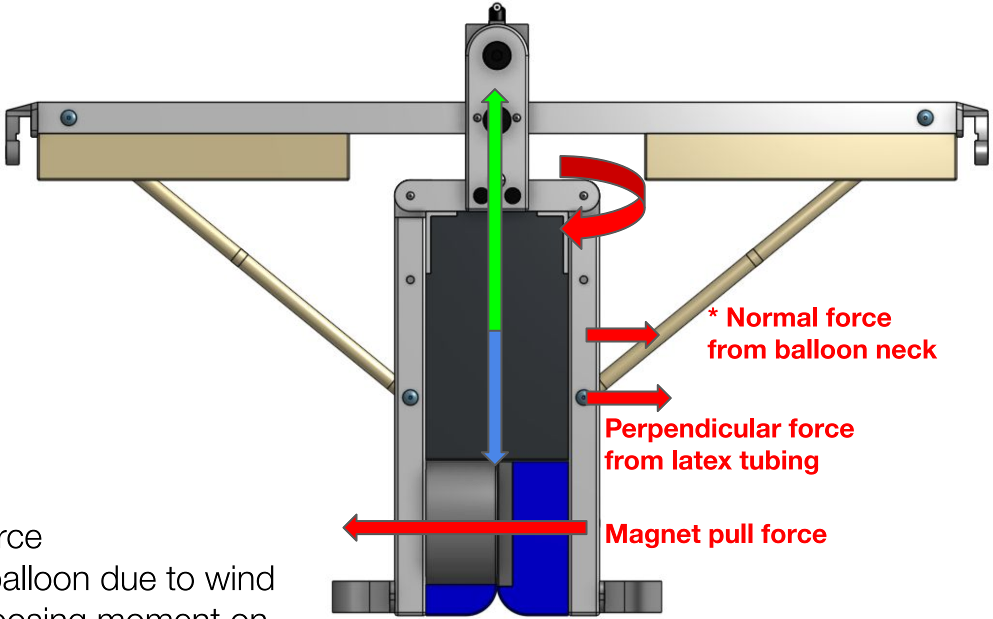
- Metal protrusions and edges will be chamfered and smoothed to prevent balloon damage



Design Requirements/ Satisfaction

Release Mech - Grip Strength

- Total Friction Force = $2F_N * \mu_s$
- Assuming μ_S between rubber and urethane.
- Total Grip Strength of 267 lbs
- Required Grip Strength of 70.5 lbs
- Factor of Safety = 3.79



Friction Force
Force on balloon due to wind
Forces imposing moment on simple beam model arm

Design Requirements/ Satisfaction

BDS Subsystems

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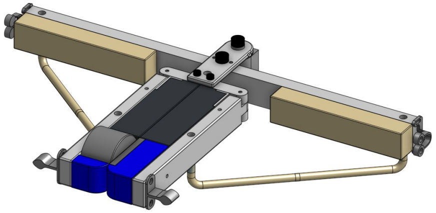
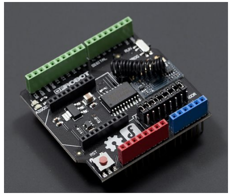




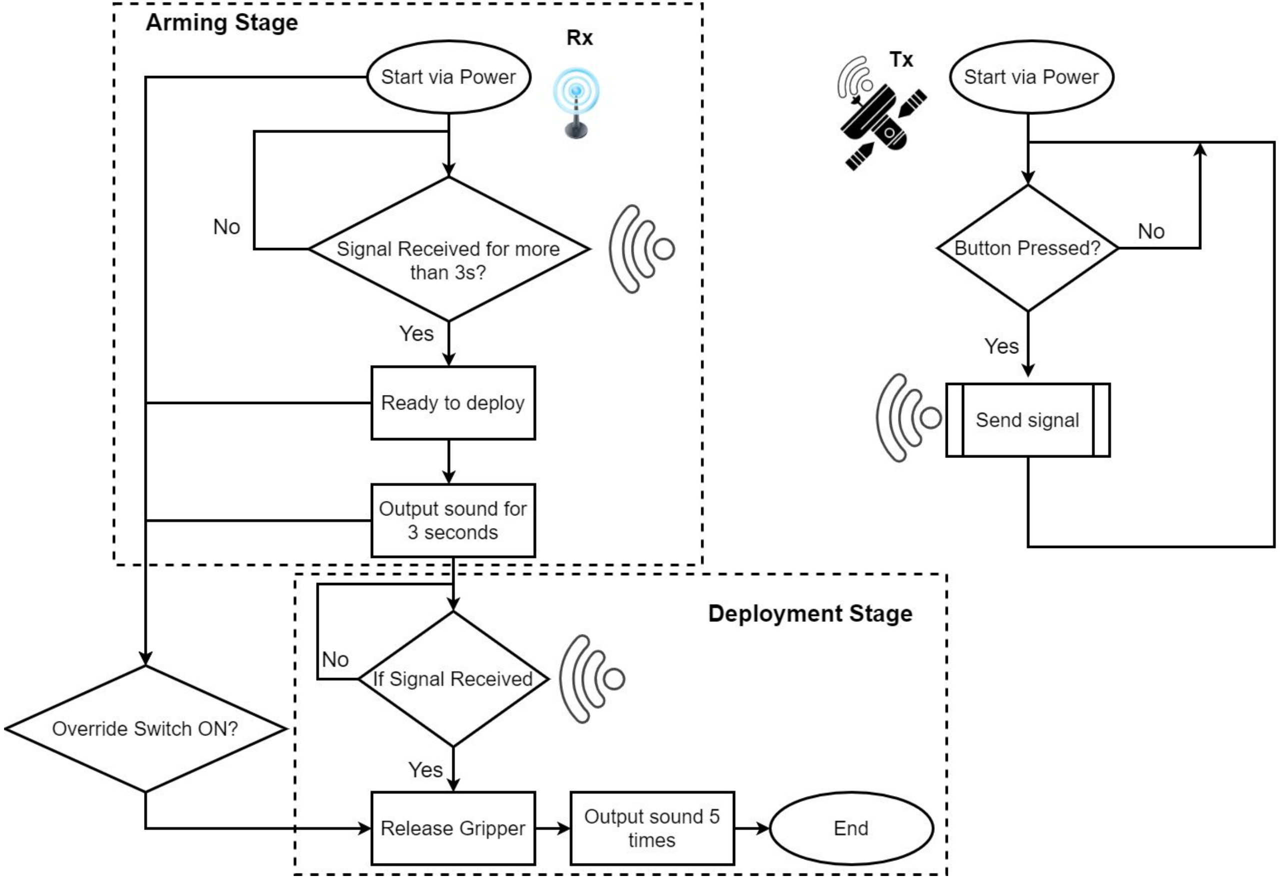
Design Requirements/ Satisfaction

Command and Control - Hands-free Operation

- Pressed with elbow to send signal when ready
- Freedom of motion
- Easily adjustable

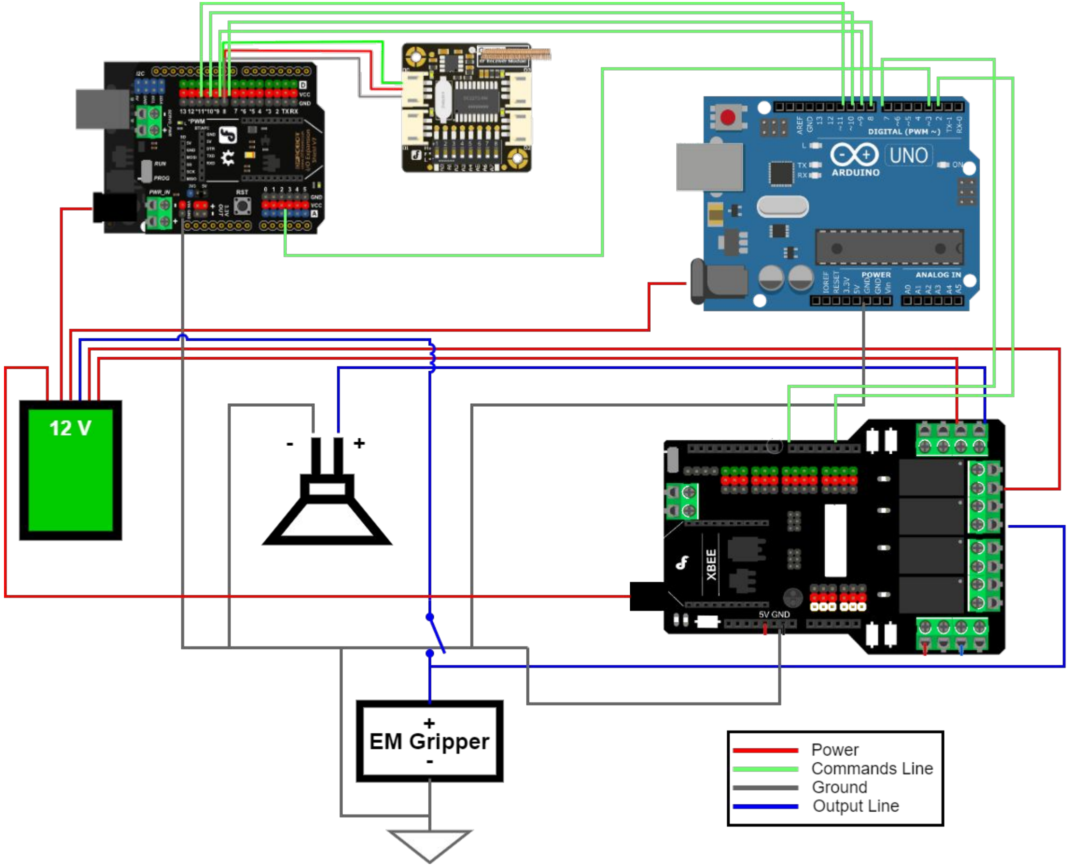
Design Requirements/ Satisfaction

Command and Control - Software



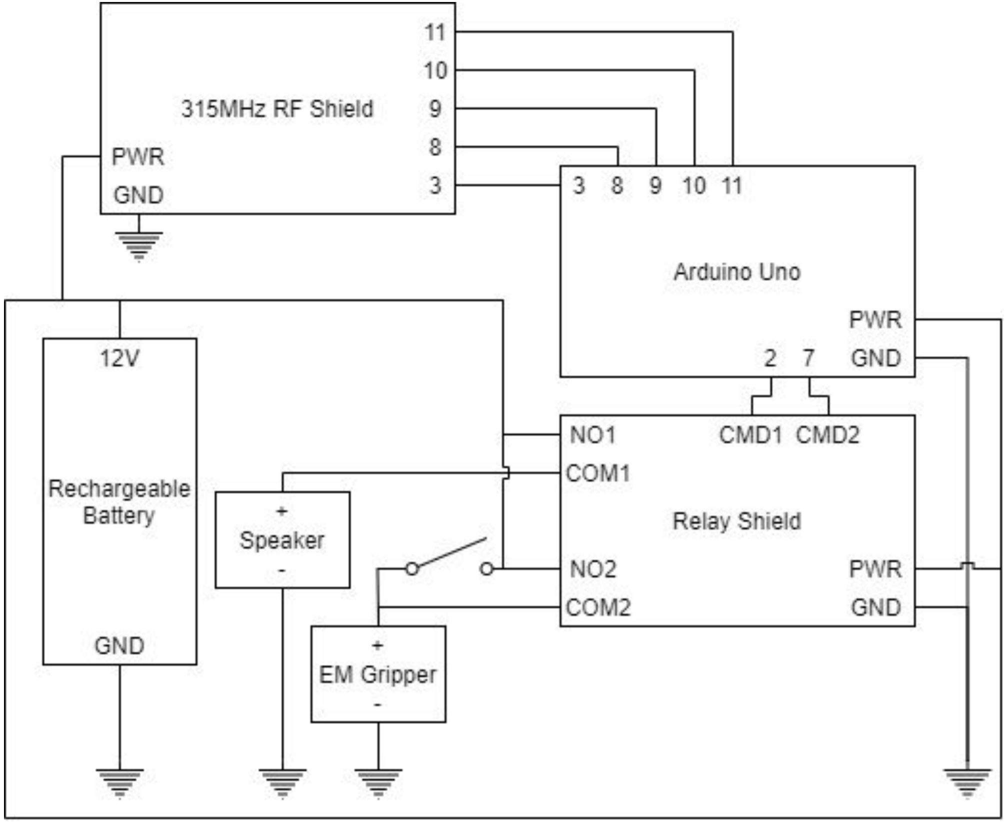
Design Requirements/ Satisfaction

Command and Control - Electrical Schematic



Design Requirements/ Satisfaction

Command and Control - Electrical Design



Component	Voltage (V)	Current (A)	Power (Watts)	Time On (Minutes)	Charge (A-Hr)	Number of Launches
Receiver:						
Arduino Uno	12	0.2	2.4	5	0.017	
Electromagnet Gripper	12	3.25	39	0.01666	0.001	
RF Board	5	0.01	0.05	5	0.001	
RF Rx	5	0.01	0.05	5	0.001	
1 Speaker with 12V Battery	12	0.01	0.12	0.5	0.000	
4 Channel Relay Shield for Arduino	12	5	90	5	0.417	
Rx Total					0.436	15.597
User:						
Remote Wireless Key Fob	3	0.04	0.12	0.5	0.000	630.000
Power:						
Rechargeable Battery Pack	12	6.8			6.800	15.597
CR2302 (Tx)	3	0.2			0.210	630.000

Design Requirements/ Satisfaction

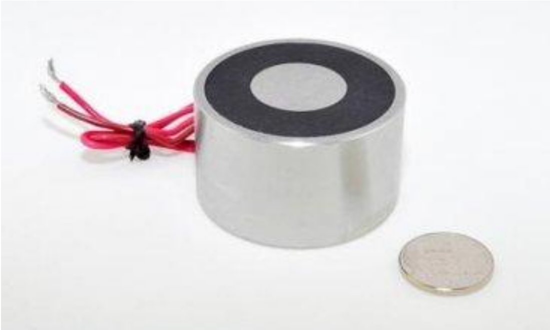
C&C - Magnet Trade-Offs (Electromagnet)

- Always off except when a 12v current is applied
- Consider very safe for user when loading the balloon
- More concerned with balloon safety
- More power intensive

Design Requirements/ Satisfaction

C&C - Magnet Trade-Offs (Permanent Electromagnet)

- Always on except when a 12v current is applied
- Concern on user’s safety (might trigger the gripper to close during loading)
- More efficient and effective application compared



Design Requirements/ Satisfaction

C&C - Magnet Trade-Offs (Permanent Electromagnet)

	(Old) Electromagnet	(New) Permanent Electromagnet
Power Usage	High	Low
Risk	Unintended Deployment	Pinch Hazard
Likelihood	High	Low
Prevention	More Batteries	Procedures, Increased Caution

Project Risks

Project Risks

Risk Analysis

Likelihood/ Severity	Minimal (5)	Minor (4)	Major (3)	Hazardous (2)	Catastrophic (1)
Frequent (A)					
Probable (B)	Balloon bouncing off the structure				Pandemic restricts or delays project
Remote (C)		Balloon coming out when loading			
Extremely Remote (D)	Venting valve catching	Tether gets tangled		Cables/stakes come out	
Extremely Improbable (E)	Deploy signal not received			Finger pinched in release mech	80/20 connections breaking Balloon Damage

Unacceptable Risk
Acceptable Risk with Mitigation
Acceptable Risk

Verification and Validation

Verification and Validation

- Stability in wind
  - Allow for launches in high wind conditions
- Internal structure strength
  - Survive high wind launch forces
- Ease of set up/transport
  - Launch from multiple sites per HYFLITS need
- No balloon damage
- No premature release of balloon
- Hands free release command
  - Allow user to focus on payload safety and launch

Verification and Validation

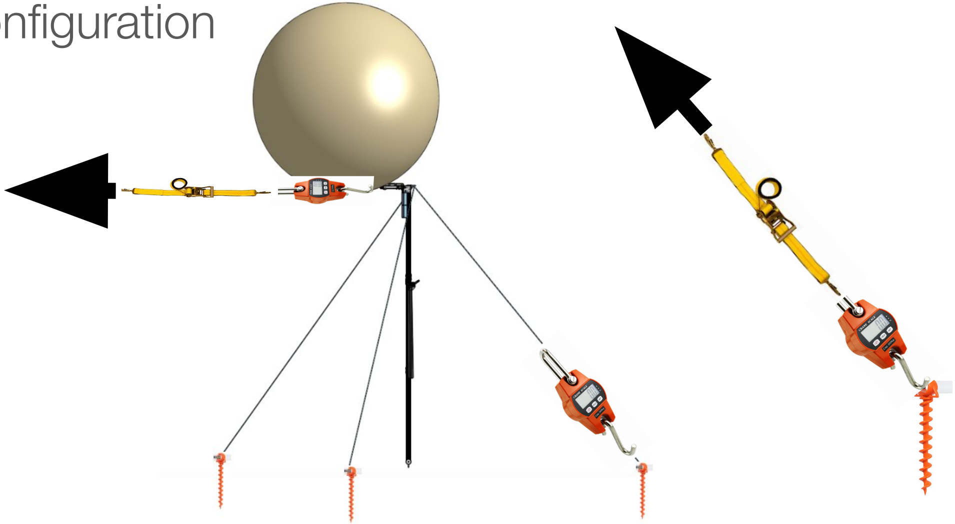
Verification Testing

Test	What is Addressed	FR/DR Motivation	Test Location
Stake	Validate pull out force	• Withstand forces/ moments	CU Aerospace Courtyard
Structural	Validate and verify full structure strength & stability	• Address stability in 20 m/s wind at 3m high • Ability to load the balloon by an avg height user	CU Aerospace Courtyard/ Testing site provided by customer
System	Verify release mechanism and software	• Wireless link and battery powered release mechanism • Hands-free operation	CU Aerospace Courtyard/ Testing site provided by customer

Verification and Validation

Staking Test

- Force exerted on the anchors does not exceed the hold force in the ground.
- We would then apply a load that is equivalent to that experienced by the balloon by using a spring scale to verify 537 N at the weakest configuration
- Use ratchet strap to simulate



Staking Test

Objectives	• Validate pull out force • Verify the functionality of stakes
Equipment Needed	• Stakes • 2 spring scale • Ratchet strap • Cables • Payload equivalent to that experienced by the ballon by pull force
Measurements Made	• Reaction force on the stake exerted by the cable
Verified Against	• Reaction forces analysis/ calculations • Reaction moments analysis/ calculations

Structural Test

Objectives	• Validate full structure strength • Verify inner joints and linear bearing strength • Verify cables attachment stability
Equipments Needed	• Stake • Teather/payload • Balloon • Bearing • Cables
Measurements Made	• Drag force • Tension force
Verified Against	• Factor of safety of structural components • Wind gust factor • Wind condition/direction may vary

System Test

Objective	• Verify software • Verify release mechanism • Validate design integration
Equipment Needed	• Payload • Arcade button • Belt/Belt attachment • Integrated system
Measurements Made	• Signal deliverable - time and distance • Electromagnet gripper position • Balloon neck condition • Cable tension • Audio feedback
Verified Against	• Analytical Predictions • Functional Logic

Project Planning

Project Planning

Organizational Chart

- **CEO / PM** — Jake McGrath
  - **CFO** — Jack Soltys
  - **Assistant To The REgional Project Manager** — Grant Norman
    - **Systems Engineer** — Kyler Stirewalt
      - **Head Command & Control Engineer** — Grant Norman
        - **Software Engineer Lead** — Aufa Amirullah
      - **Head Structural Engineer** — Peter Hurst
        - **Structures Team** — Sebastian Urrunaga
          - **Structural Designer** — Chenshuo Yang
      - **Head Release Dev. Engineer** — Austin Konnath
        - **Release Mechanism Team** — Pat Paluszek
  - **Head Test Engineer** — Sebastian Urrunaga
  - **Red Team Lead** — Pat Paluszek

Project Planning

Deliverable Breakdown Structure

- Balloon Deployment System
  - Support Structure
    - Stabilization
      - Vertical Structure
  - Release Mechanism
    - Balloon Interface
  - Command & Control
    - User Command
      - Communication System

Project Planning

Deliverable Breakdown Structure

- Balloon Deployment System
  - Support Structure
    - Stabilization
    - Vertical Structure
    - Release Mechanism Interface
  - Release Mechanism
    - Balloon Interface
    - Support Structure Interface
    - Command & Control Interface
  - Command & Control
    - User Command
    - Communication System
    - Release Mechanism Interface

Phase Work Breakdown Structure

- Balloon Deployment System
  - 1. Design
    - 1.1 PDD
    - 1.2 CDD
    - 1.3 PDR
    - 1.4 CDR
  - 2. Approval
    - 2.1 Customer & PAB Approval
    - 2.2 Material Procurement
  - 3. Material Testing
    - 3.1 Material Onboarding
    - 3.2 Specification Verification
    - 3.3 Individual Component Test
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    - 4.1 Dry Assembly
    - 4.2 Permanent Assembly
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    - 5.1 Structure Stability Test
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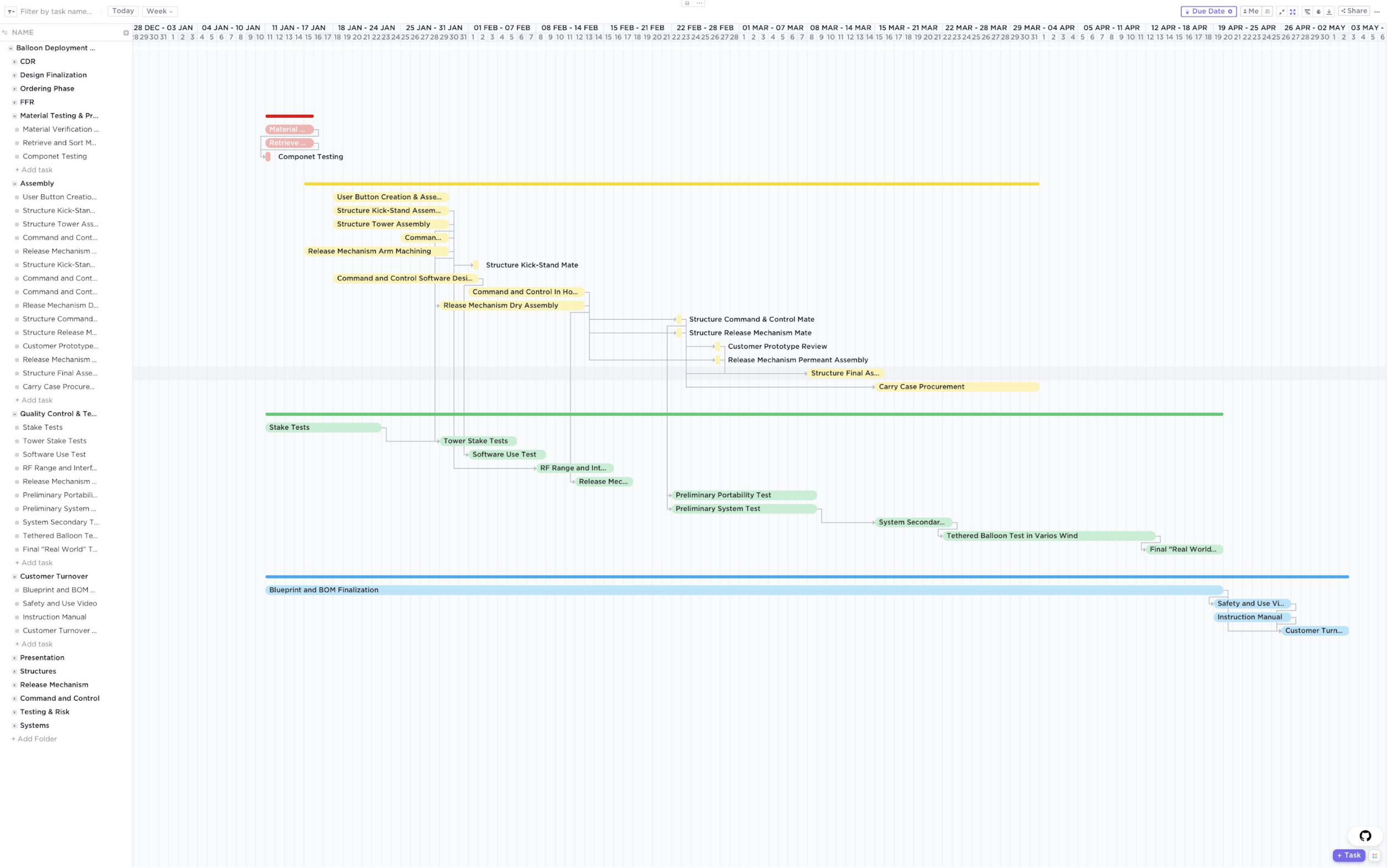
    - 6.1 Final Product Demonstration
    - 6.2 Product & Design Turnover
    - 6.3 Final Evaluation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Today
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Due Date
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NAME
28 DEC - 03 JAN
04 JAN - 10 JAN
11 JAN - 17 JAN
18 JAN - 24 JAN
25 JAN - 31 JAN
01 FEB - 07 FEB
08 FEB - 14 FEB
15 FEB - 21 FEB
22 FEB - 28 FEB
01 MAR - 07 MAR
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15 MAR - 21 MAR
22 MAR - 28 MAR
29 MAR - 04 APR
05 APR - 11 APR
12 APR - 18 APR
19 APR - 25 APR
26 APR - 02 MAY
03 MAY -
Balloon Deployment ...
CDR
Design Finalization
Ordering Phase
FFR
Material Testing & Pr...
Material Verification ...
Retrieve and Sort M...
Componet Testing
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Structure Kick-Stan...
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Command and Cont...
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RF Range and Interf...
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Preliminary Portabili...
Preliminary System ...
System Secondary T...
Tethered Balloon Te...
Final "Real World" T...
+ Add task
Customer Turnover
Blueprint and BOM ...
Safety and Use Video
Instruction Manual
Customer Turnover ...
+ Add task
Presentation
Structures
Release Mechanism
Command and Control
Testing & Risk
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Tower Stake Tests
Software Use Test
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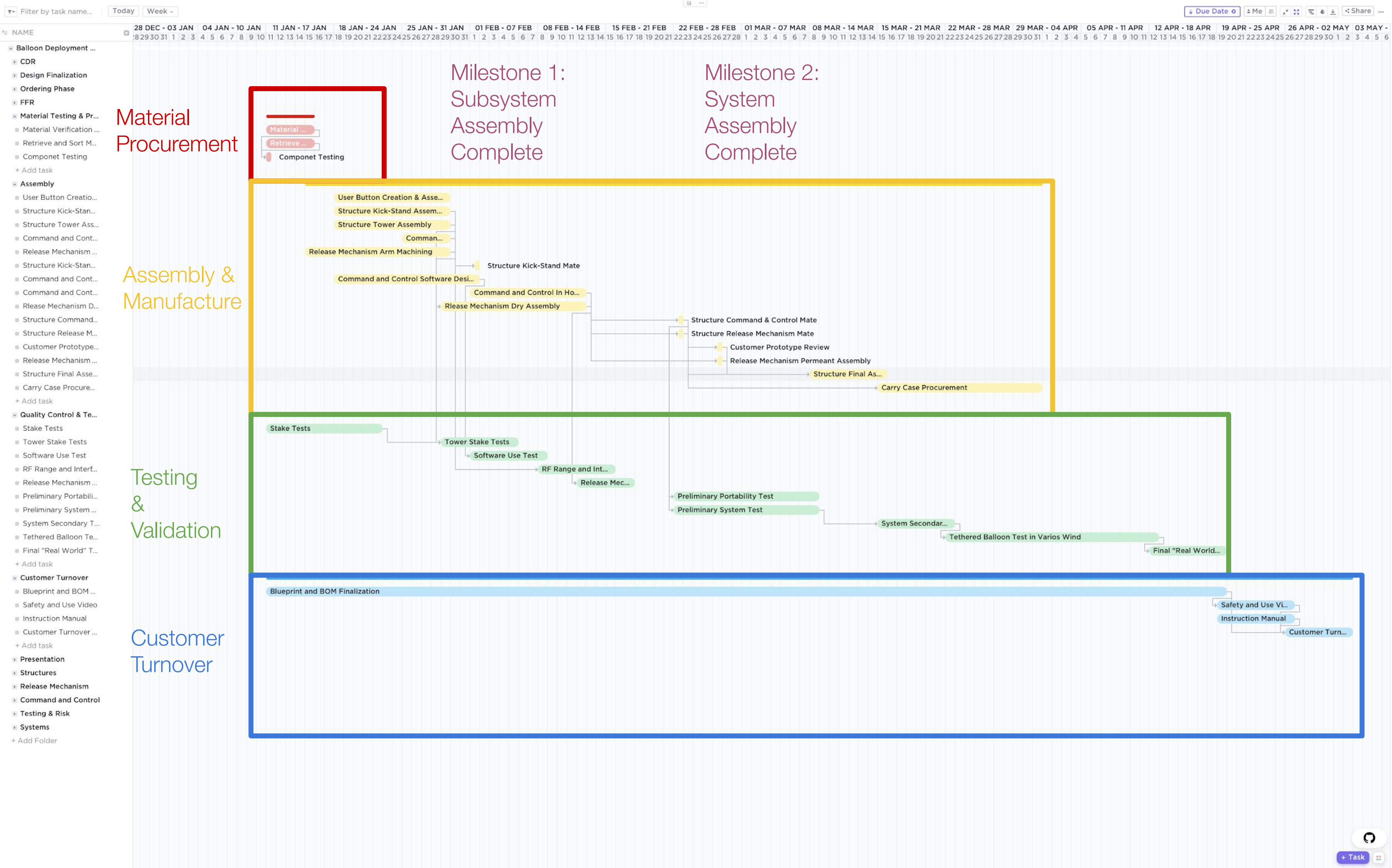
+ Task


Milestone 1: Subsystem Assembly Complete
Milestone 2: System Assembly Complete
Material Procurement
Assembly & Manufacture
Testing & Validation
Customer Turnover
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Balloon Deployment ...
CDR
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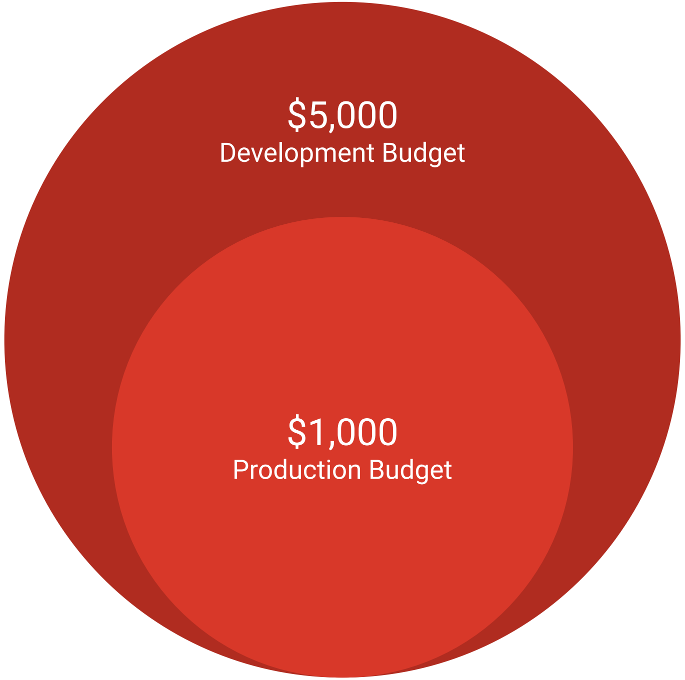
Final "Real World...
Customer Turnover
Blueprint and BOM Finalization
Safety and Use Vi...
Instruction Manual
Customer Turn...
Presentation
Structures
Release Mechanism
Command and Control
Testing & Risk
Systems
+ Add Folder

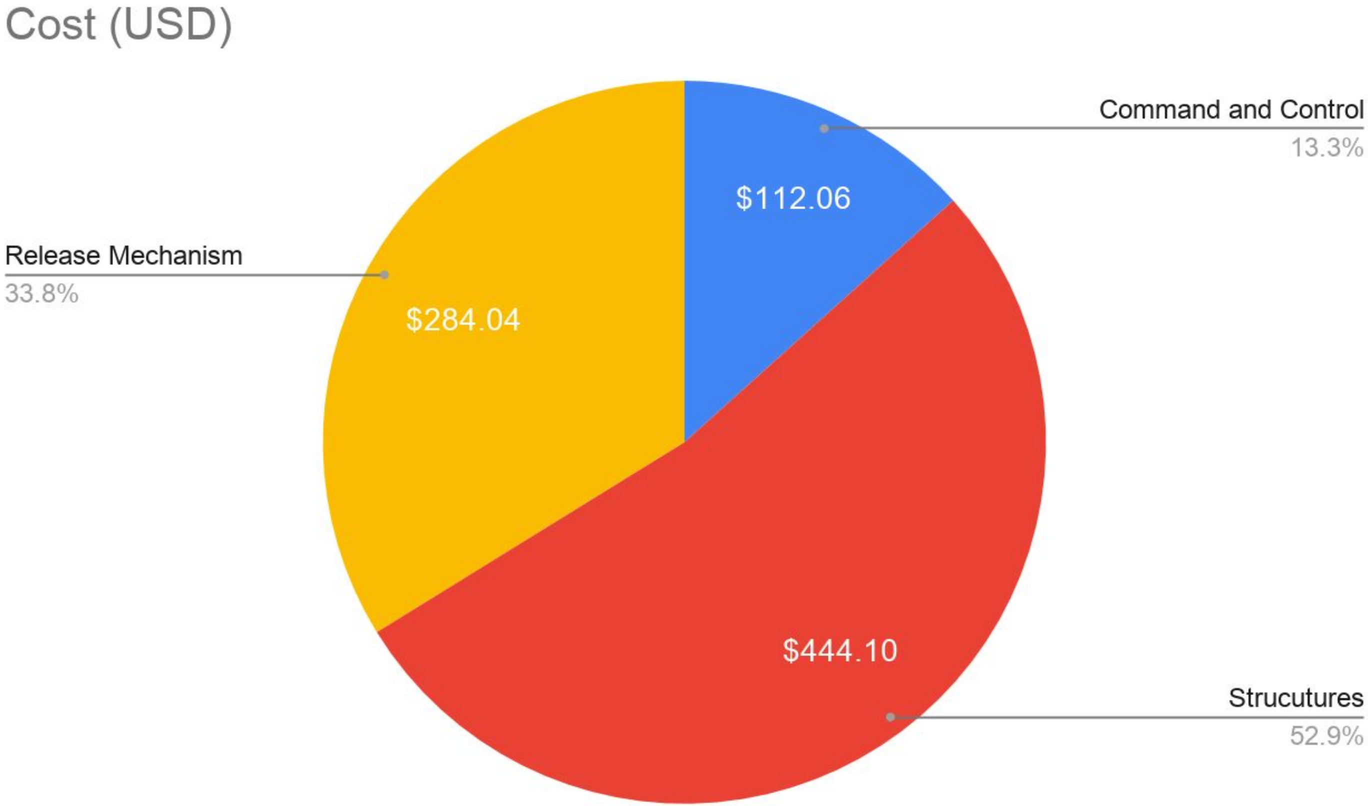
Project Planning

Cost Plan



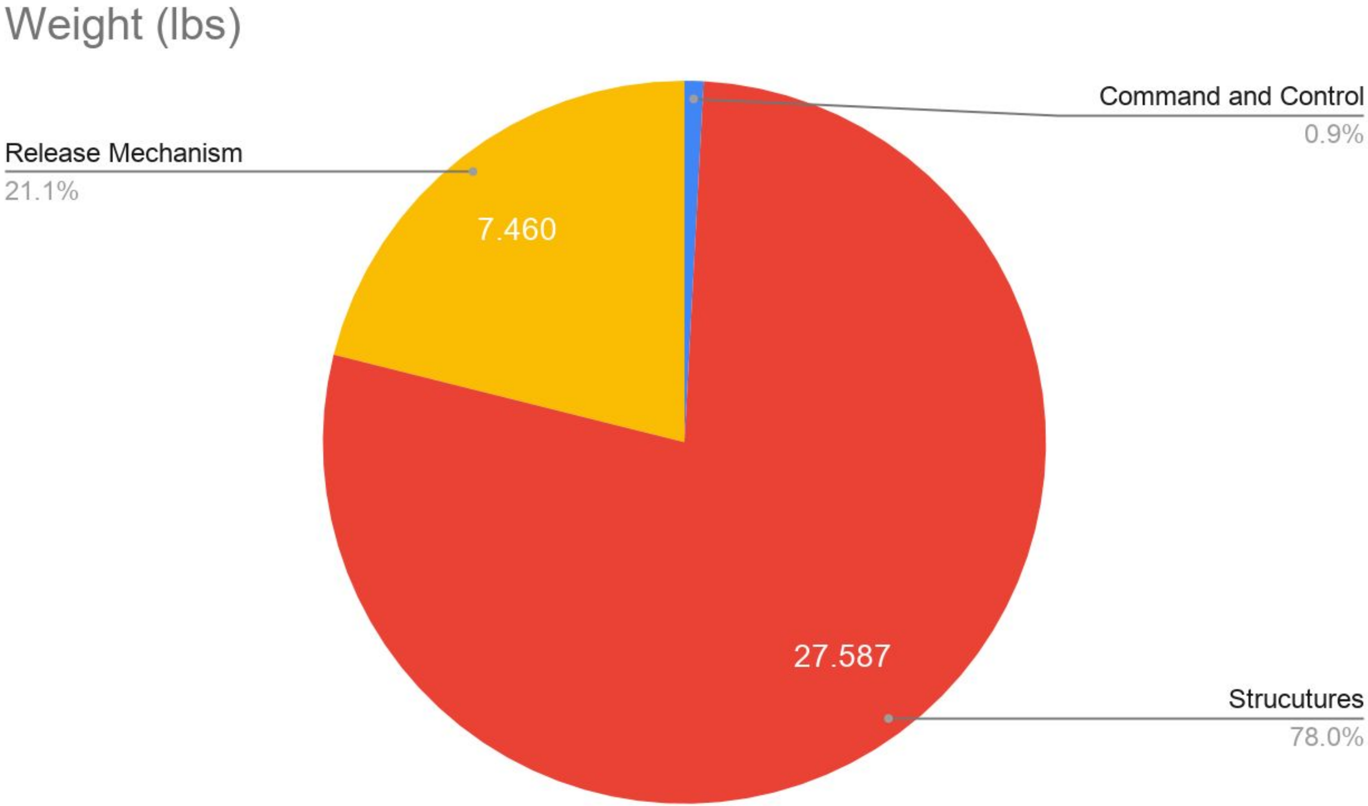
Project Planning

Cost Plan & Uncertainty



Project Planning

Weight Plan & Uncertainty



Project Planning

Test Plan

Step 1

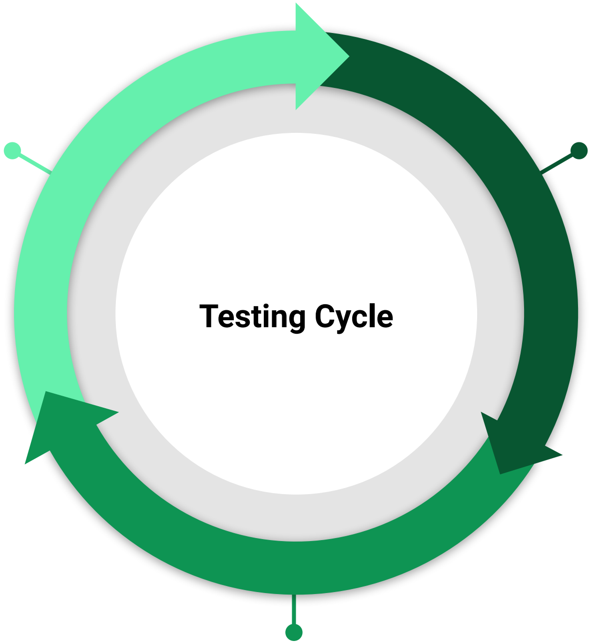
Perform Desired Test at The Beginning of Test Schedule

Step 2

Gather Data From Tests and Revise Models

Step 3

Revise Models Based on Test Data



Project Planning
Test Plan

Quality Control & Testing + NEW TASK ✓ SHOW CLOSED

TO DO 10 TASKS

Task	ASSIGNEE	DUE DATE	PRIORITY
Release Mechanism Weighted Test		2/17/21	
Stake Tests		1/22/21	
Tower Stake Tests		2/5/21	
Software Use Test		2/8/21	
Preliminary System Test		3/8/21	
Preliminary Portability Test		3/8/21	
RF Range and Interface Test		2/15/21	
System Secondary Test		3/22/21	
Tethered Balloon Test in Varios Wind		4/12/21	
Final "Real World" Test		4/19/21	

+ New task

Acknowledgements

Dr. Dale Lawrence
Customer

Matt Rhode
Advisor

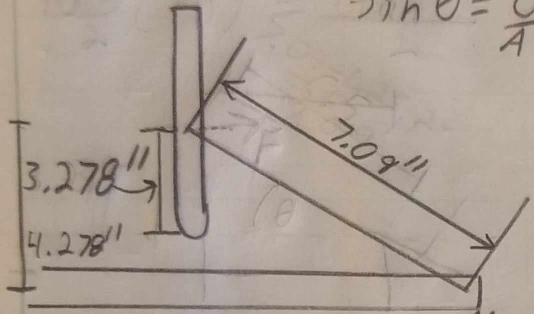
Dr. Jelliffe Jackson
Instructor

Appendix

Verification and Validation

Testing

- Structural Loading - stability and internal component testing
  - Testing of stake - Spring scale
  - Structural test - Pulley system & lift
  - System test when integrated to structure
- Ease of set up/transport
  - Opening of the Release Mechanism
  - Assembly & Setup
  - Radius of the Command and Control



$$\sin\theta = \frac{O}{A} = \frac{4.278}{7.09} \qquad \theta = \sin^{-1}\left(\frac{4.278}{7.09}\right) = 37.1^\circ$$

$$F_I = Kx\cos\theta$$

$$= (5.5)(4)\cos(37.1^\circ)$$

$$= 17.54 \simeq 17.5\ [lbf]$$

$$M = rF = (3.278)(17.5) \simeq 57.5\ [lbf \cdot in]$$

$$\alpha = \frac{\Sigma M}{I} = \frac{57.5}{7.21} = 7.976\left[\frac{rad}{s^2}\right] \simeq 8\left[\frac{rad}{s^2}\right]$$

$$t = \sqrt{\frac{2\Delta\theta}{\alpha}} = \sqrt{\frac{2\left(\frac{16\pi}{180}\right)}{8}} = 0.264 \simeq 0.26[s]$$

$$F = ma \qquad a_y = \frac{\Sigma F}{m} = \frac{20}{3}\frac{N}{kg} = 6.\bar{6}\ \frac{m}{s^2}$$

$$\Delta y = \frac{1}{2}at^2 \qquad \Delta y = 12 - 2.54 = 9.46[in] \simeq 0.24[m]$$

$$0.24 = \frac{1}{2}(6.66)t^2 \qquad t = 0.268 \simeq 0.27[s]$$

$$0.27[s] > 0.26[s]$$

Phase Work Breakdown Structure

- Balloon Deployment System
  - 1. Design
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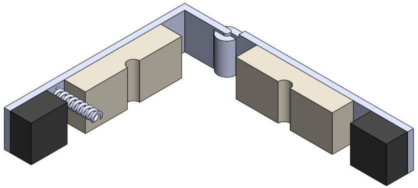
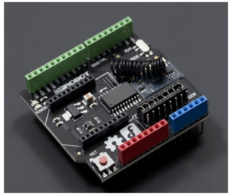
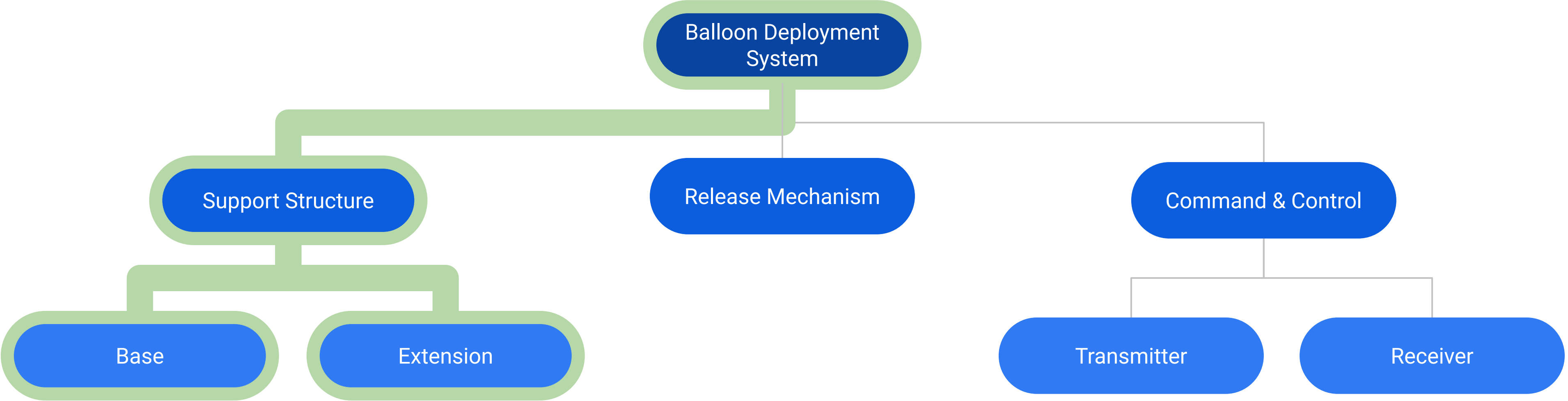
Design Solution: BDS Subsystems

- Balloon Deployment System
  - Support Structure
    - Base
    - Extension
  - Release Mechanism
  - Command & Control
    - Transmitter
    - Receiver





Design Solution: BDS Subsystems

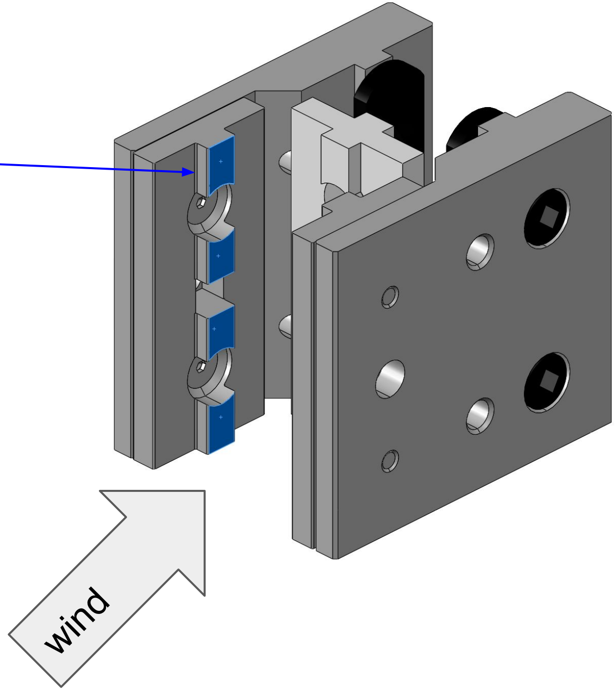


Critical Project Elements

Critical Project Elements	Requirements	Feasible
Structure	• Stable in 20 m/s winds @ 3m high • Withstand forces/moments • Balloon loaded by an avg. height user • User safety	
Release Mechanism	• Thick rubber neck with a grasp that will not damage the neck • Secure Grip of balloon in 20 m/s wind	
Command and Control System	• Hands-free operation • Wireless link and battery powered release mechanism	

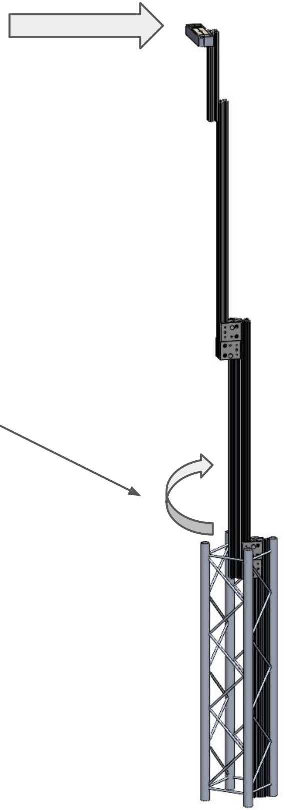
Evidence of Baseline Feasibility: Structure

- Shear (V) in linear bearing:
  - UHMW material
  - Weakest configuration w/ wind as indicated
  - Area subject to shear (blue)
  - τ=.55 MPa < τ_{max}=20 MPa

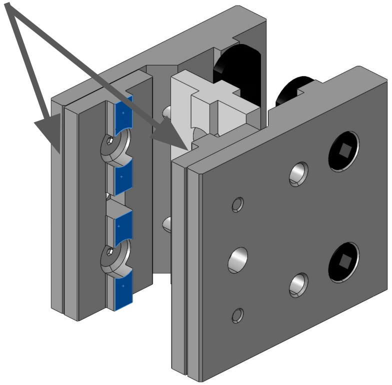


Evidence of Baseline Feasibility: Structure

- Structure Strength:
  - Bending Stress: 61.5 kPa ~ 8.91 Psi
  - Bending Moment: ~ 620 Nm

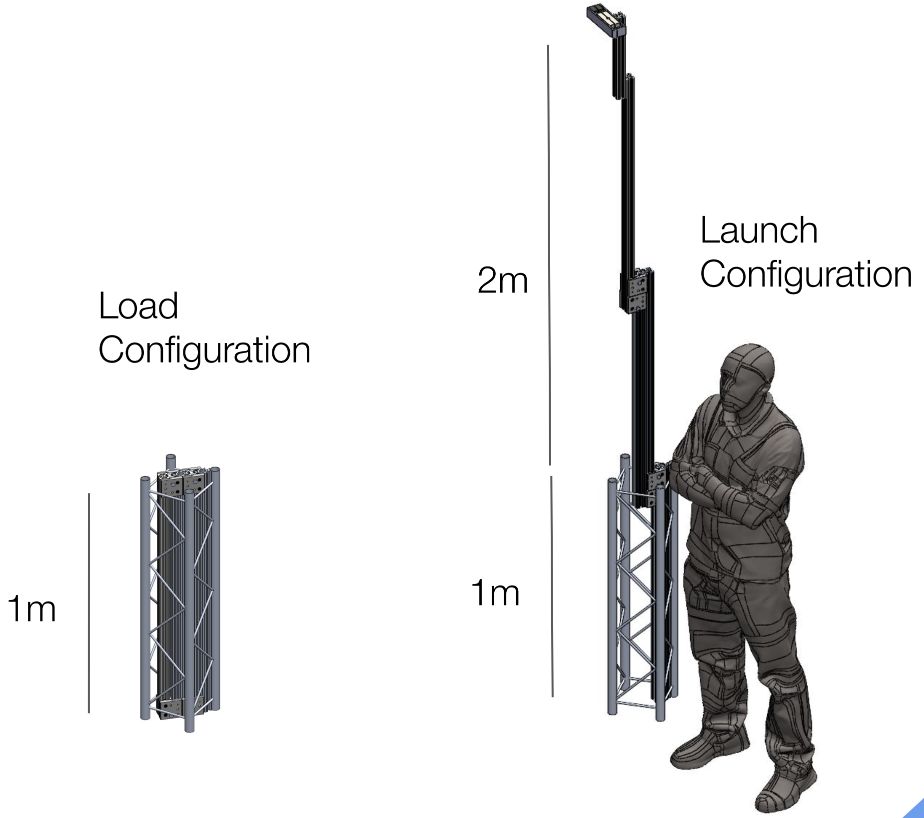


- Structure Strength:
  - Bending Stress: 190 kPa ~27.6psi
  - Bending Moment: ~620 Nm



Evidence of Baseline Feasibility: Structure

- Launch height from 3m
  - Average user height: 1.6 m (~62 in)



Critical Project Elements

Critical Project Elements	Requirements	Feasible
Structure	● Stable in 20 m/s winds @ 3m high ● Withstand forces/moments ● Balloon loaded by an avg. height user ● User safety	
Release Mechanism	● Thick rubber neck with a grasp that will not damage the neck ● Secure Grip of balloon in 20 m/s wind	
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Critical Project Elements

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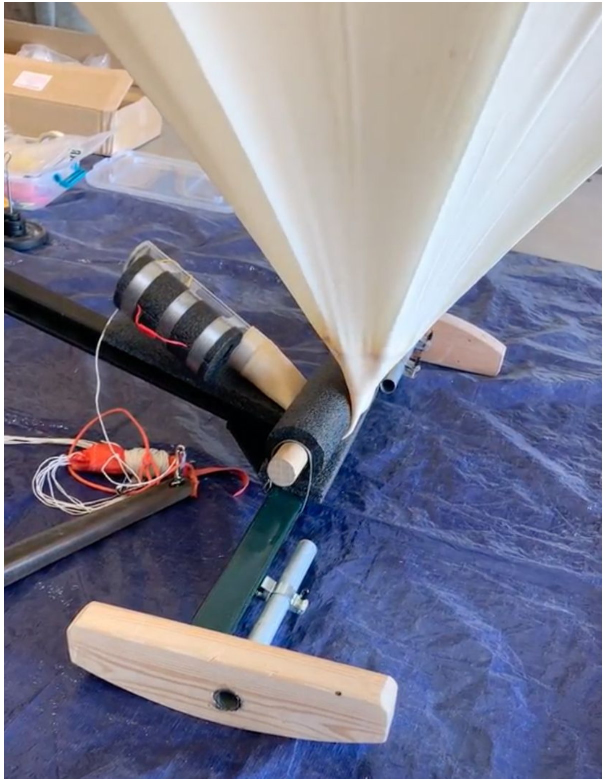
BDS Subsystems

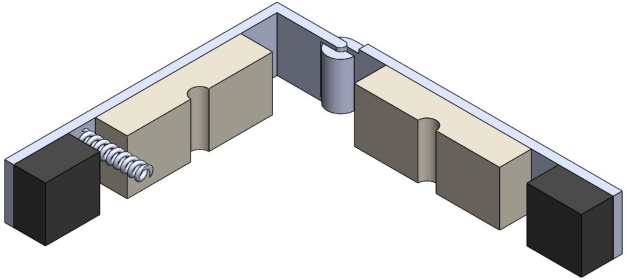
- Balloon Deployment System
  - Support Structure
    - Base
    - Extension
  - Release Mechanism
  - Command & Control
    - Transmitter
    - Receiver

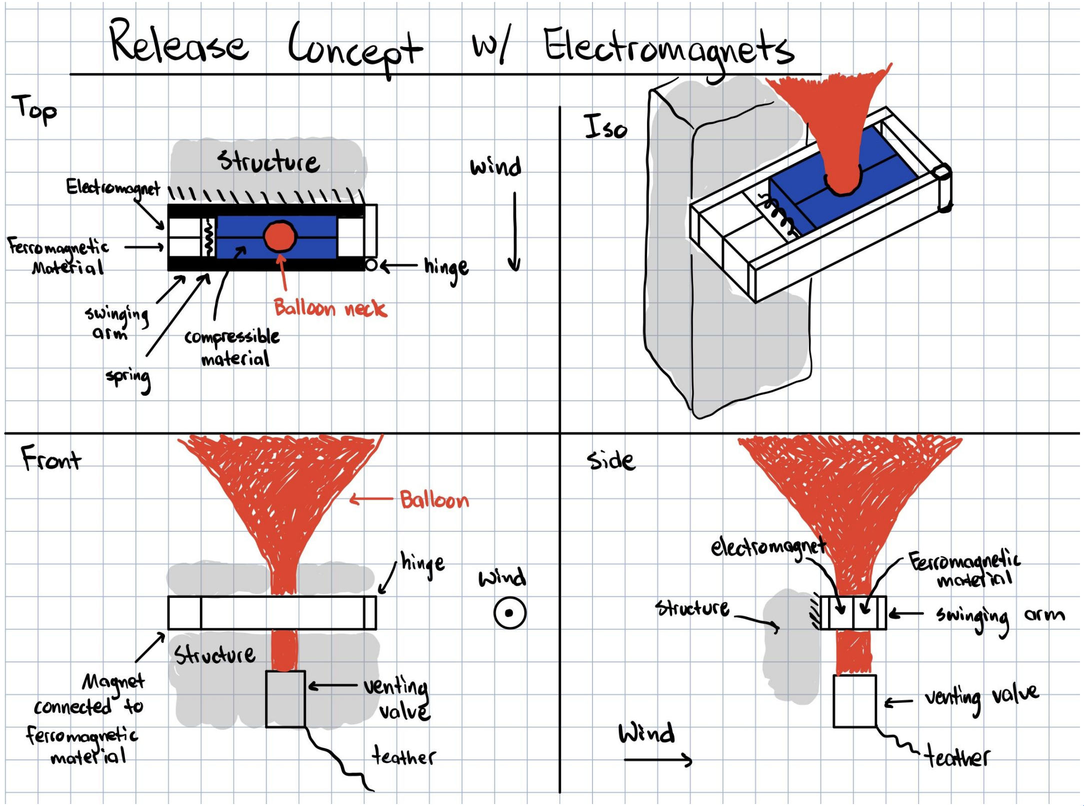
Evidence of Baseline Feasibility: Release

- Current method for transport
- Similar to BDS method
- Will not damage balloon



Evidence of Baseline Feasibility: Release





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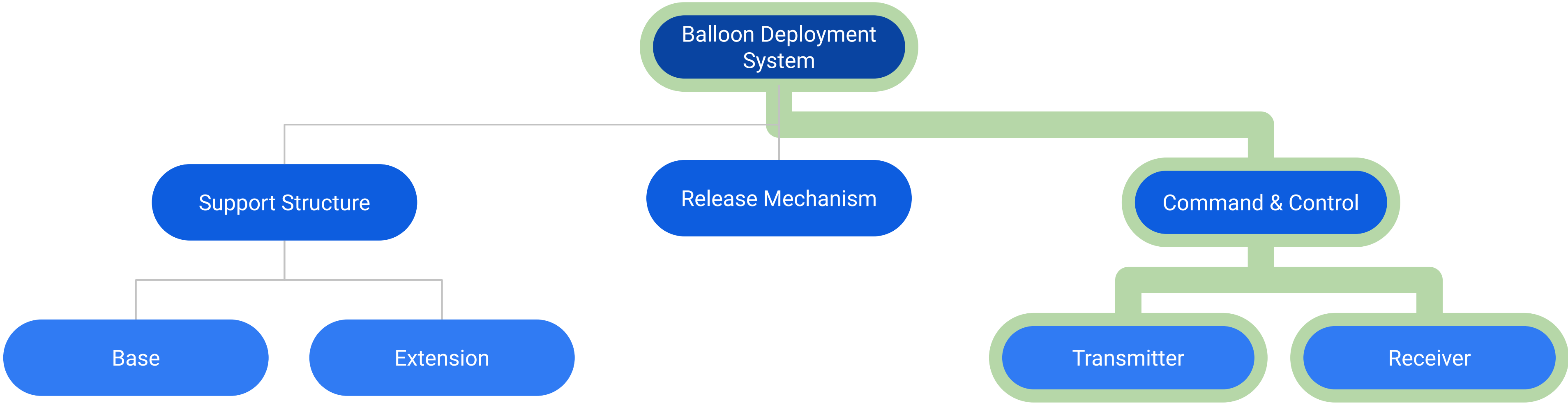
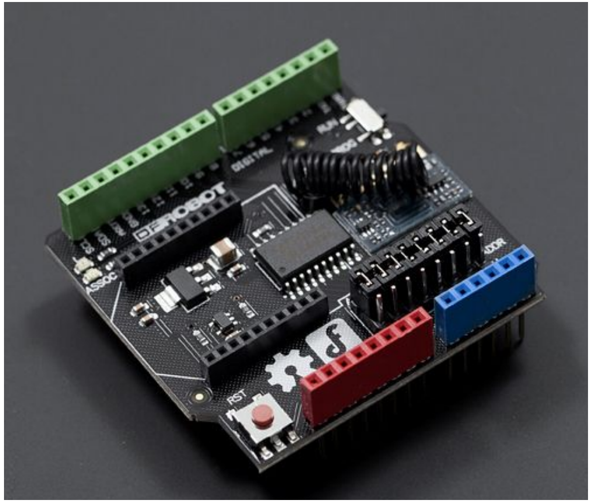
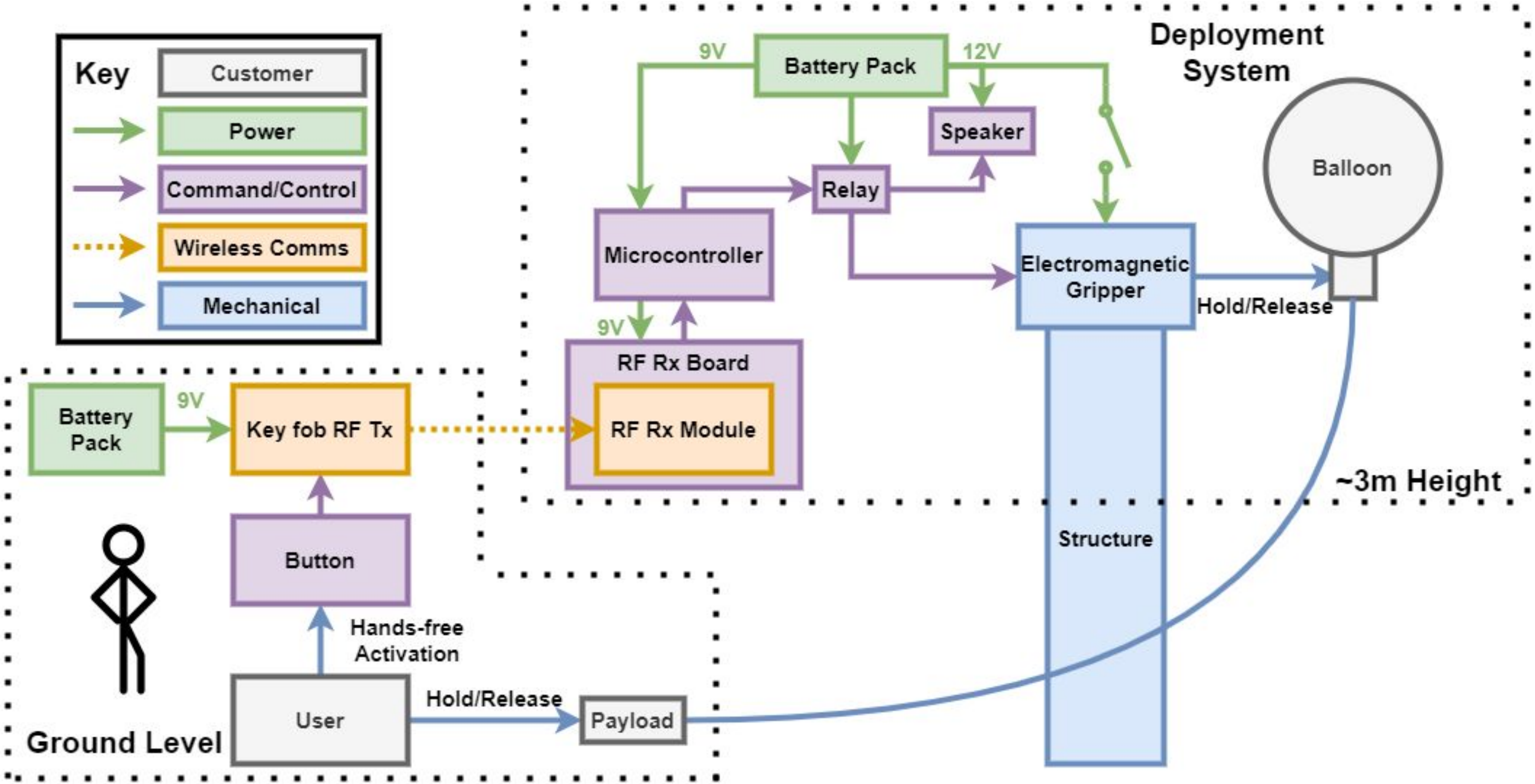
BDS Subsystems



Evidence of Baseline Feasibility: Command/Control



Evidence of Baseline Feasibility: Command/Control

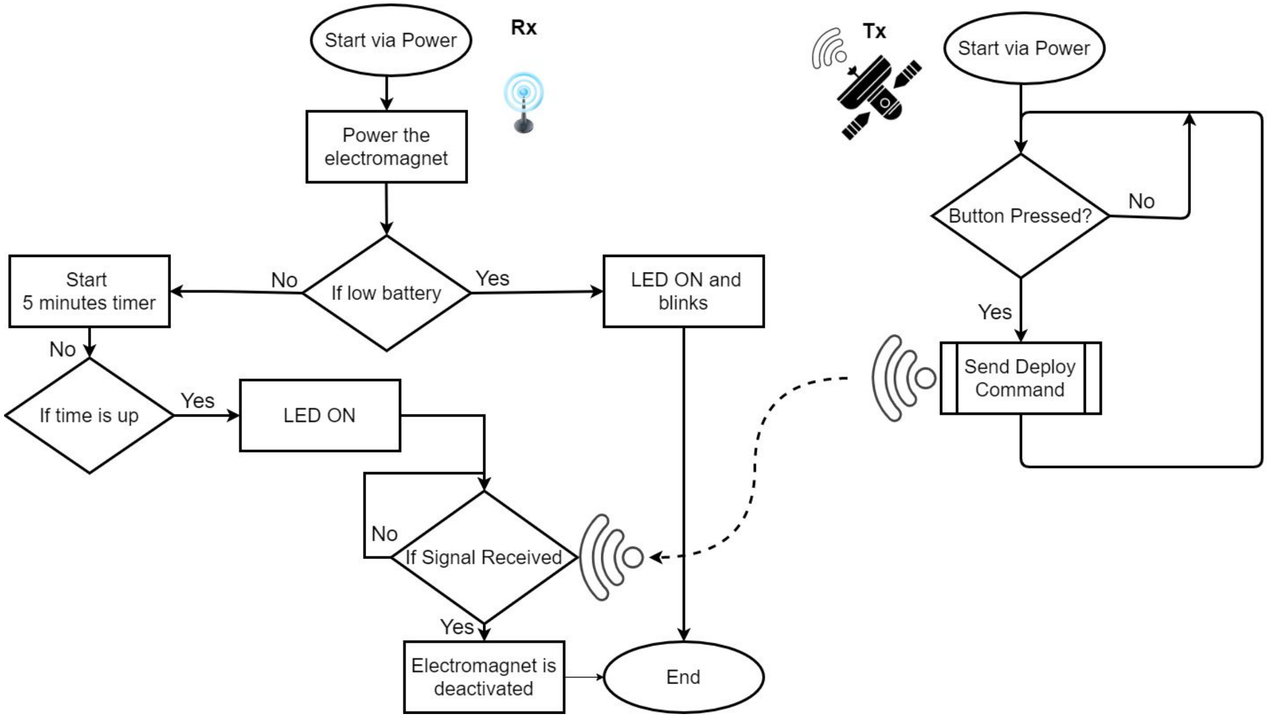


Evidence of Baseline Feasibility: Command/Control

Component	Voltage (V)	Current (A)	Power (Watts)	Time On (Minutes)	Charge (A-Hr)	Number of Launches
Receiver:						
Arduino Uno	12	0.2	2.4	5	0.017	
Electromagnet Gripper	12	3.25	39	0.01666	0.001	
RF Board	5	0.01	0.05	5	0.001	
RF Rx	5	0.01	0.05	5	0.001	
1 Speaker with 12V Battery	12	0.01	0.12	0.5	0.000	
4 Channel Relay Shield for Arduino	12	5	90	5	0.417	
Rx Total					0.436	19.037
User:						
Remote Wireless Key Fob	3	0.04	0.12	0.5	0.000	630.000
Power:						
Rechargeable Battery Pack	12	6			8.300	19.037
CR2302 (Tx)	3	0.2			0.210	630.000

Evidence of Baseline Feasibility: Command/Control

1. Power the electromagnet
2. Start the timer to prevent accidental launch during set-up
3. Send Deploy Command
4. When signal is received (and the time is up), electromagnet is deactivated
5. Balloon is launched



Critical Project Elements

Critical Project Elements	Requirements	Feasible
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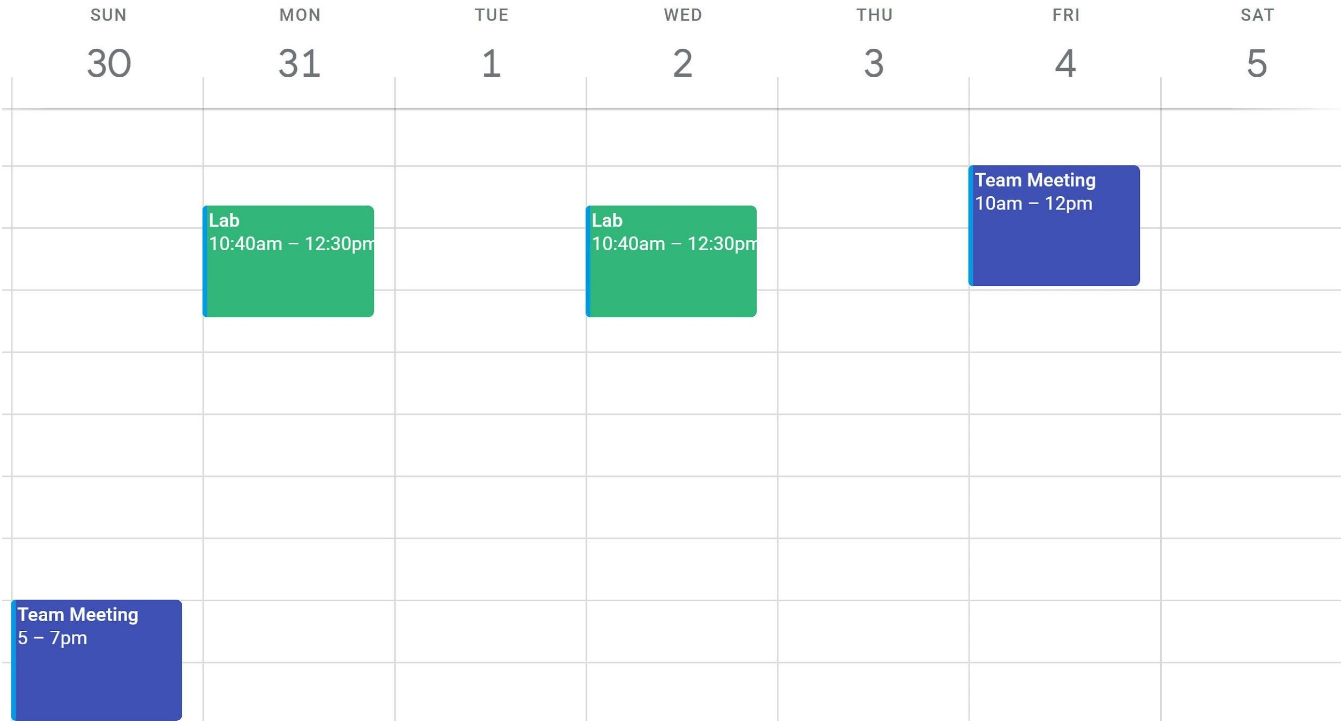
Release Mechanism	• Thick rubber neck with a grasp that will not damage the neck • Secure Grip of balloon in 20 m/s wind	✓
Command and Control System	• Hands-free operation • Wireless link and battery powered release mechanism	✓

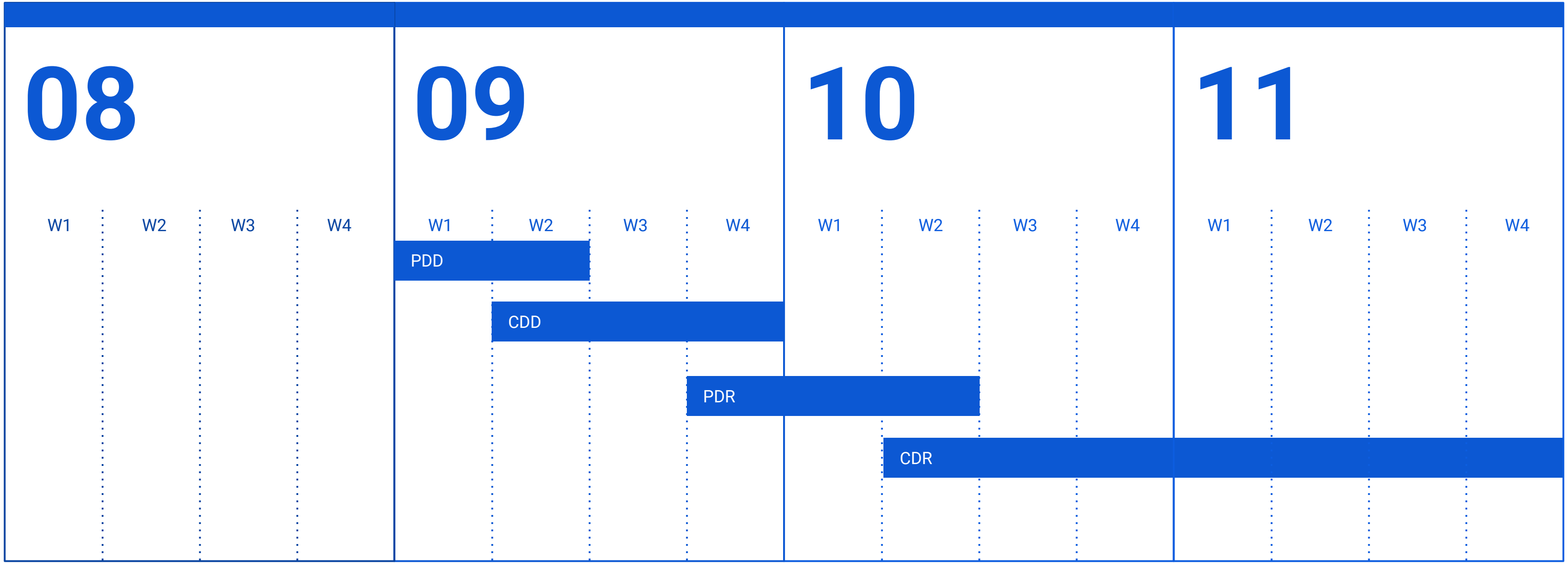
Prices

Item	Quantity	Price per Unit (USD)	Shipping Cost (USD)	Total Cost
Arduino Uno	1	$23.00	$1.63	$24.63
RF Board	2	$23.10	$0.00	$46.20
RF Rx	2	$6.80	$0.00	$13.60
Remote Wireless Key Fob	1	$5.20	$0.00	$5.20
6V Battery (Rx)	4	$15.00	$0.00	$60.00
CR2302 (Tx)	1	$2.85	$0.00	$2.85
Electromagnet	1	$95.00	$0.00	$95.00
F24 Truss	1	$231.00	$0.00	$231.00
1515 80/20	1	$22.82	$0.00	$22.82
1530 80/20	2	$39.06	$0.00	$78.12
L-Brake	4	$12.10	$0.00	$48.40
80/20 Linear Bearings	4	$48.50	$0.00	$194.00
Pulley Wire	1	$2.79	$0.00	$2.79
			Total Cost	$824.61

Current Status and Remaining Studies



Current Status and Remaining Studies



Approximate Build & Test Schedule

December

Complete CDR & Order Materials

Order materials shortly after CDR so we can use winter break as shipping time.

January

Collecting Materials & Dry Assembly

Checking on remaining orders and organizing what we have into our assembly. No machining or custom parts are required.

February

Assembly & Preliminary Tests

Testing for our requirements will begin and simulated launches will be conducted.

March

Design Revisions & Final Tests

BDS will be tested against adverse effects to see the operating range of our device.

April

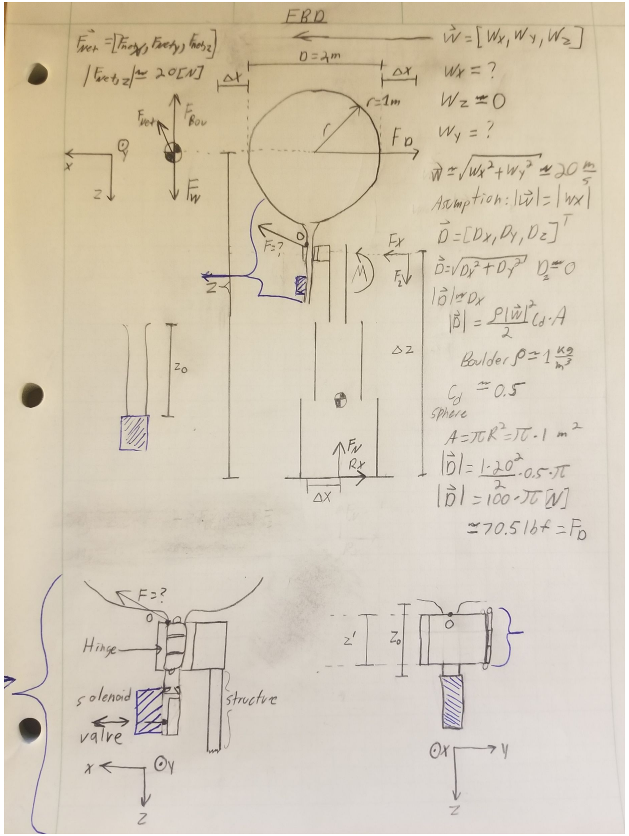
Final Deliverable & Demonstration

Delivering final product to Dr. Lawrence and demonstration levels of success by end of semester.

Current Status and Remaining Studies

- In depth analysis on wind/drag modeling on the balloon
  - Lower project cost
  - More portable
  - Higher factor of safety

Appendix - Pat Drag Work



Changing the assumption $\Delta t = 0.2$ for linear impulse

$\Sigma F_{avg} = m\frac{\Delta V}{\Delta t} = \frac{3(20)}{0.2} = 300 N \simeq 68[lbf]$

$D = qC_dA = \frac{1(20)^2}{2}(0.5)\pi = 314 N = 71[lbf]$

Cd huh $\quad Re = \frac{\rho V L^*}{\mu} \quad 17.64(10)^{-6} \lesssim \mu_{air} \lesssim 18.71(10)^{-6} \frac{Ns}{m^2}$

$\rho \simeq 1 \frac{kg}{m^3}$ $\quad T = 50°F \quad T = 90°F$

$V = 20 \frac{m}{s}$

$L^* = r = 1m \quad Re = 1 \cdot 20 \cdot 1/(18.4(10)^{-6}) \simeq 1(10)^6$

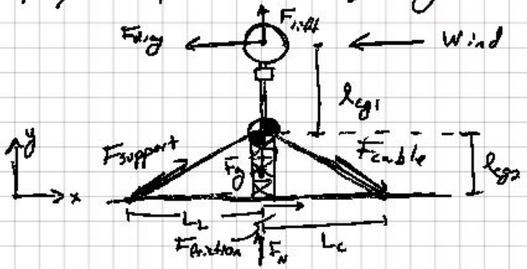
$C_D \simeq 0.2$ for smooth spheres experiencing 10^6 Re

$D = \frac{20^2}{2}(0.2)\pi = 125.66[N] \simeq 30 lbf$

Appendix - Grant Moment Work

10/5/2020

Purpose: Review Full Stability FBD



$$\Sigma F_x = \underbrace{F_{cable,x} + F_{support,x} + F_{friction}}_{\text{Call this all "}F_{resistance}\text{" which acts parallel to the ground, antiparallel to drag.}} - F_{drag} = 0$$

$$\xrightarrow{+} \Sigma F_x = F_{resistance} - F_{drag} = 0, \longrightarrow F_{resistance} = F_{drag}$$

$$\uparrow + \Sigma F_y = F_N + F_{lift} - F_g = 0, \quad F_N = F_g - F_{lift}$$

$$+\circlearrowleft \Sigma M_{Ground} = (F_{drag}) \cdot (l_{cg1} + l_{cg2}) + (F_{resistance})(0) - (F_{support,y}) \cdot (L_L) - (F_{cable,y}) \cdot (L_c) = 0$$

$$\boxed{(F_{drag}) \cdot (l_{cg1} + l_{cg2}) - (F_{support,y}) \cdot (L_L) - (F_{cable,y})(L_c) = 0}$$

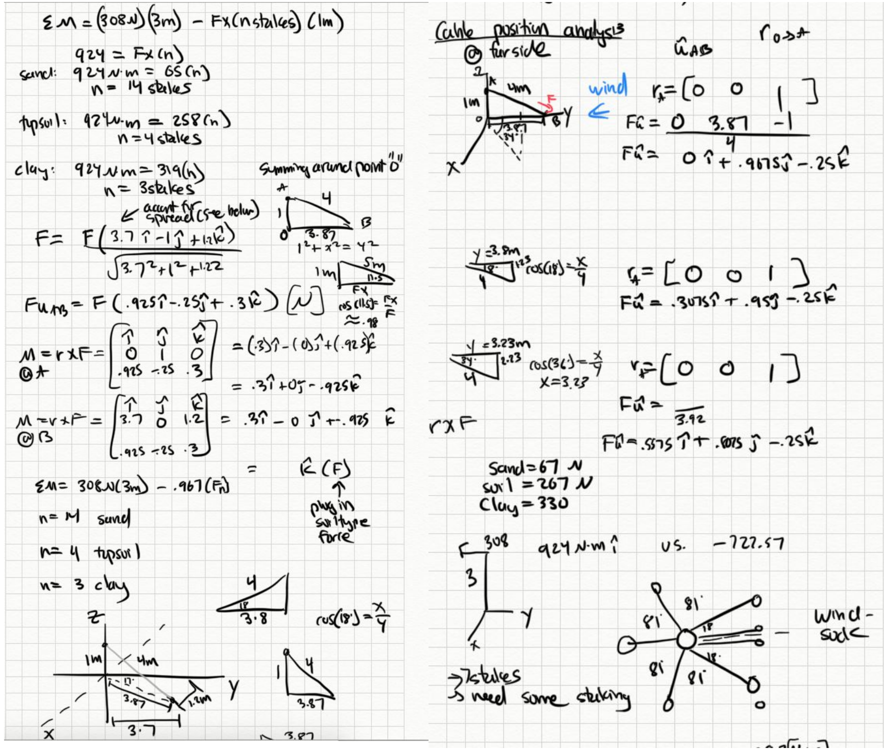
$$+\circlearrowleft \Sigma M_{CG} = (F_{drag}) \cdot (l_{cg1}) + (F_{resistance}) \cdot (l_{cg2}) - (F_{support,y}) \cdot (L_L) - (F_{cable,y}) \cdot (L_c) = 0$$

B/c $F_{resistance} = F_{drag}$:

$$(F_{drag}) \cdot (l_{cg1}) + (F_{resistance}) \cdot (l_{cg2}) = (F_{drag}) \cdot (l_{cg1} + l_{cg2}) + (F_{resistance})(0)$$

And we arrive at the same expression.

Appendix - Pete Moment Work



$\Sigma M = (308N)(3m) - F_x(n \text{ stakes})(1m)$

$924 = F_x(n)$

sand: $924\ N\cdot m = 65(n)$

$n = 14$ stakes

topsoil: $924\ N\cdot m = 258(n)$

$n = 4$ stakes

clay: $924\ N\,m = 319(n)$

$n = 3$ stakes

Summing around point "O"

account for spread (see below)

$F = \dfrac{F(3.7\hat{i} - 1\hat{j} + 1.2\hat{k})}{\sqrt{3.7^2 + 1^2 + 1.2^2}}$

$1^2 + x^2 = 4^2$

$\cos(11.5) = \dfrac{F_x}{F} \approx .98$

$F_{uAB} = F(.925\hat{i} - .25\hat{j} + .3\hat{k})\ [N]$

$M = r \times F = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0 & 1 & 0 \\ .925 & -.25 & .3 \end{vmatrix} = (.3)\hat{i} - (0)\hat{j} + (-.925)\hat{k}$ @A

$= .3\hat{i} + 0\hat{j} - .925\hat{k}$

$M = r \times F = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 3.7 & 0 & 1.2 \\ .925 & -.25 & .3 \end{vmatrix} = .3\hat{i} - 0\hat{j} + -.925\hat{k}$ @B

$= \hat{k}(F)$

plug in soil type force

$\Sigma M = 308N(3m) - .967(F_n)$

$n = 14$ sand

$n = 4$ topsoil

$n = 3$ clay

$\cos(18°) = \dfrac{x}{4}$

Cable position analysis @ far side

$\hat{u}_{AB}$ $r_{O \to A}$

wind

$r_A = [0\ 0\ 1]$

$F_{\hat{u}} = \dfrac{0\ \ 3.87\ \ -1}{4}$

$F_{\hat{u}} = 0\hat{i} + .9675\hat{j} - .25\hat{k}$

$y = 3.8m$, $\cos(18) = \dfrac{x}{4}$

$r_A = [0\ 0\ 1]$

$F_{\hat{u}} = .3075\hat{i} + .95\hat{j} - .25\hat{k}$

$y = 3.23m$, $\cos(36°) = \dfrac{x}{4}$, $x = 3.23$

$r_A = [0\ 0\ 1]$

$F_{\hat{u}} = \dfrac{\quad}{3.92}$

$F_{\hat{u}} = .5575\hat{i} + .8075\hat{j} - .25\hat{k}$

$r \times F$

Sand = 67 N

soil = 267 N

Clay = 330

308, 3

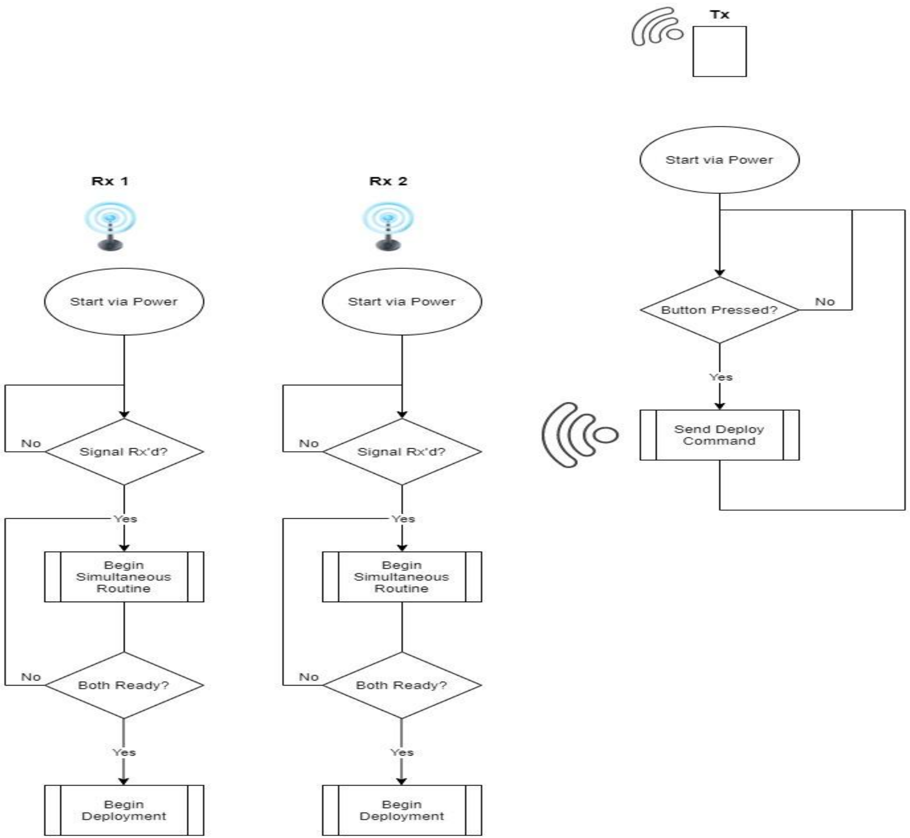
$924\ N\cdot m\ \hat{i}$ vs. -727.57

→ 7 stakes

→ need some staking

wind-sock

Appendix- Secure two system deployment



Appendix: Evidence of Baseline Feasibility - Structure

- Material properties:

	Description	Material	Area	Tensile Strength	Shear Strength	
Extending Bar	8020 bar 1.5 in x1.5 in	6105-T5 Aluminum	744.16 m^2	280 MPa	170 MPa	
Base Truss	Global Square Truss F24	6082-T6 Aluminum	1.068e-4 m^2	250 MPa	210 MPa	
Support Cables	Steel wire rope ¼ inch	Steel	3.166e-5 m^2	200 MPa	NA	
Support Legs						

Appendix:Evidence of Baseline Feasibility - Structure

Fasteners/Junctions stress

The bolt will be used for connecting rail and the top bar. Two bolts stabilize the connection point.

- Assumption:

  - Wind force is acting on the connection part in the y direction.

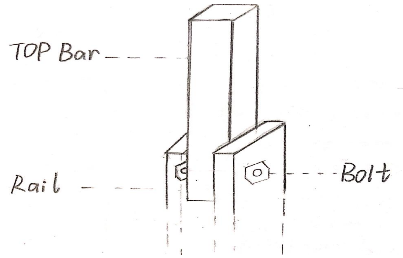
  - Two bolts are identical, the reaction force from each bolt is the same.

- Purpose:

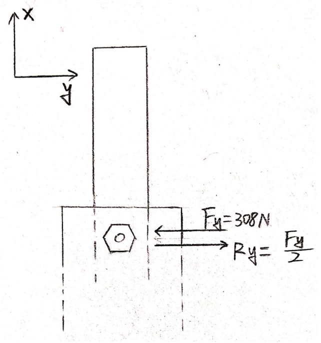
  - Determine the maximum shear stress on each bolt.

  - Minimum diameter of the bolt.

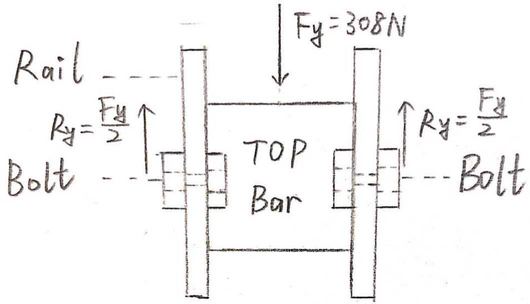
Connection between rail and top bar :



Front view :



Top view :



Appendix:Evidence of Baseline Feasibility - Structur

- Fasteners/Junction Stress:
  - Minimum diameter required for Grade 5 anchor bolts is 1/2 inch (12.7 mm)
  - Minimum required area for the bolt:

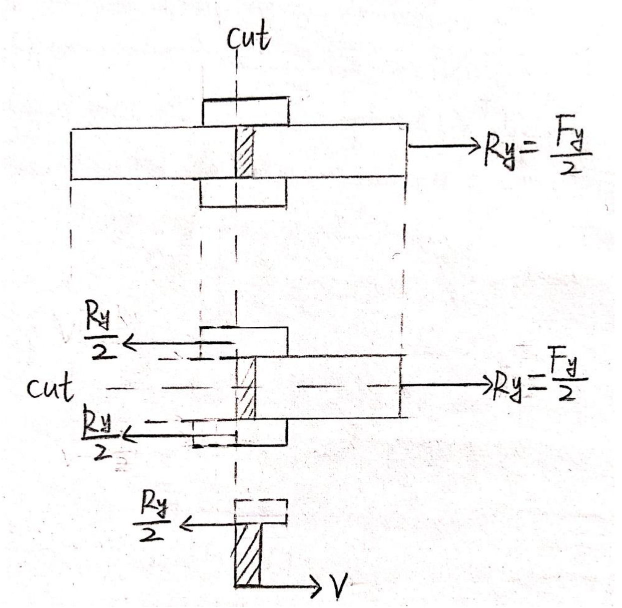
$$A_{min} = \frac{\pi \cdot d_{min}^2}{4} = \frac{\pi \cdot 0.0127^2}{4} \qquad \therefore A_{min} = 1.2668 \cdot 10^{-4}(m^2)$$

  - Shear stress of the bolt:

$$V = \frac{R_y}{2} = \frac{154N}{2} = 77N$$

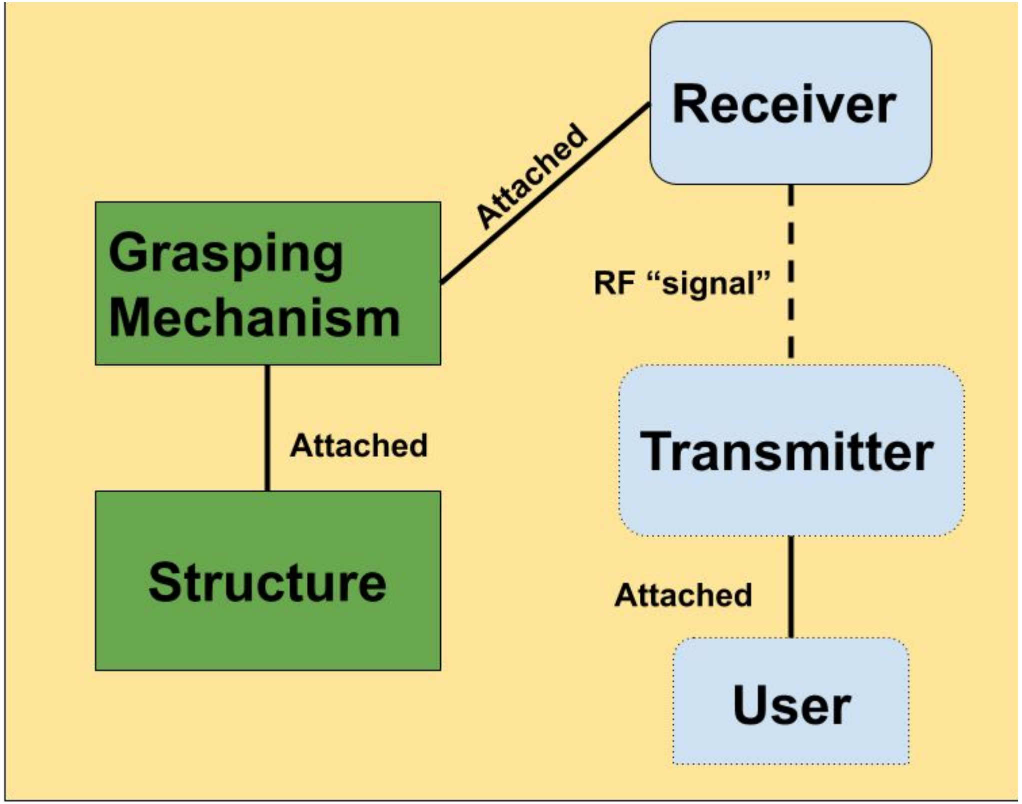
$$\tau = \frac{V}{A} \qquad \tau_{max} = \frac{V}{A_{min}} = \frac{77N}{1.2668 \cdot 10^{-4} m^2}$$

$$\therefore \tau_{max} = 607.830kPa \approx 88.158psi$$



Tip:For a commonly used Grade 5 hex cap anchor bolt,its tensile strength of **120,000 psi,** and the shear strength is nearly **70000 psi**.

Appendix - Project Description - Functional Block Diagram



Appendix:Evidence of Baseline Feasibility - Structure

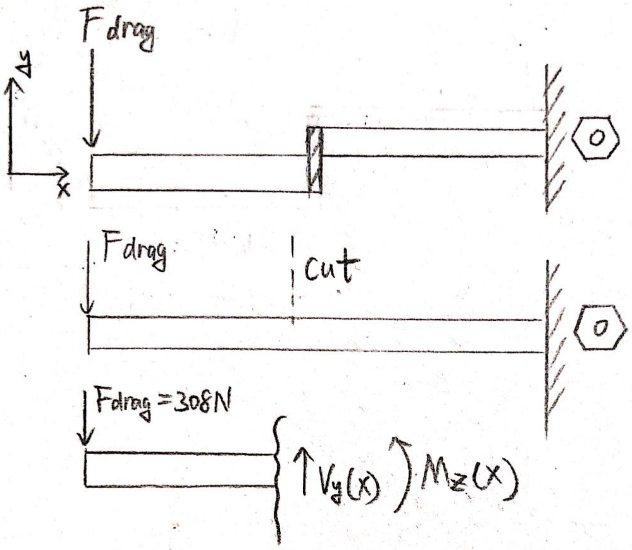
- Structure strength:
  - Moment and deflection of the bolt section:

$$M_z(x) = -311.376x$$

$$EI_{zz}v''(x) = \frac{-311.38}{2}x^2 + C_1$$

$$EI_{zz}v'(x) = \frac{-311.38}{6}x^3 + C_1x + C_2$$

$$v(x) = \frac{-51.896}{EI_{zz}}(L-x)^2(2L+x)$$

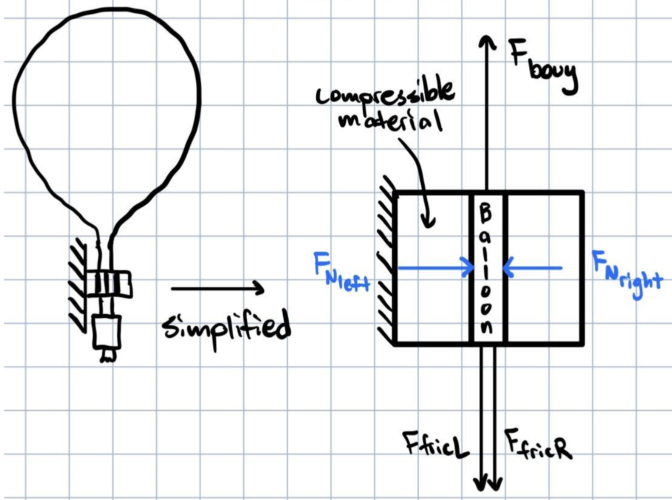


Appendix: Evidence of Baseline Feasibility - Release Mechanism

Governing equation: $F_{fric} = F_N \mu$

Governing principle: Friction independent of surface area

assume: thickness of balloon neck negligible, no wind condition

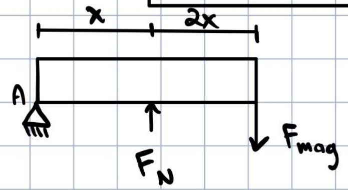


Solution: Force on each side of neck = $F_N \cdot \mu_s$

∴ $\boxed{\text{Total Force Friction} = 2F_N \cdot \mu_s \quad \text{where } F_N = \text{magnet weight rating}}$

✱ Balloon will stay in place as long as:

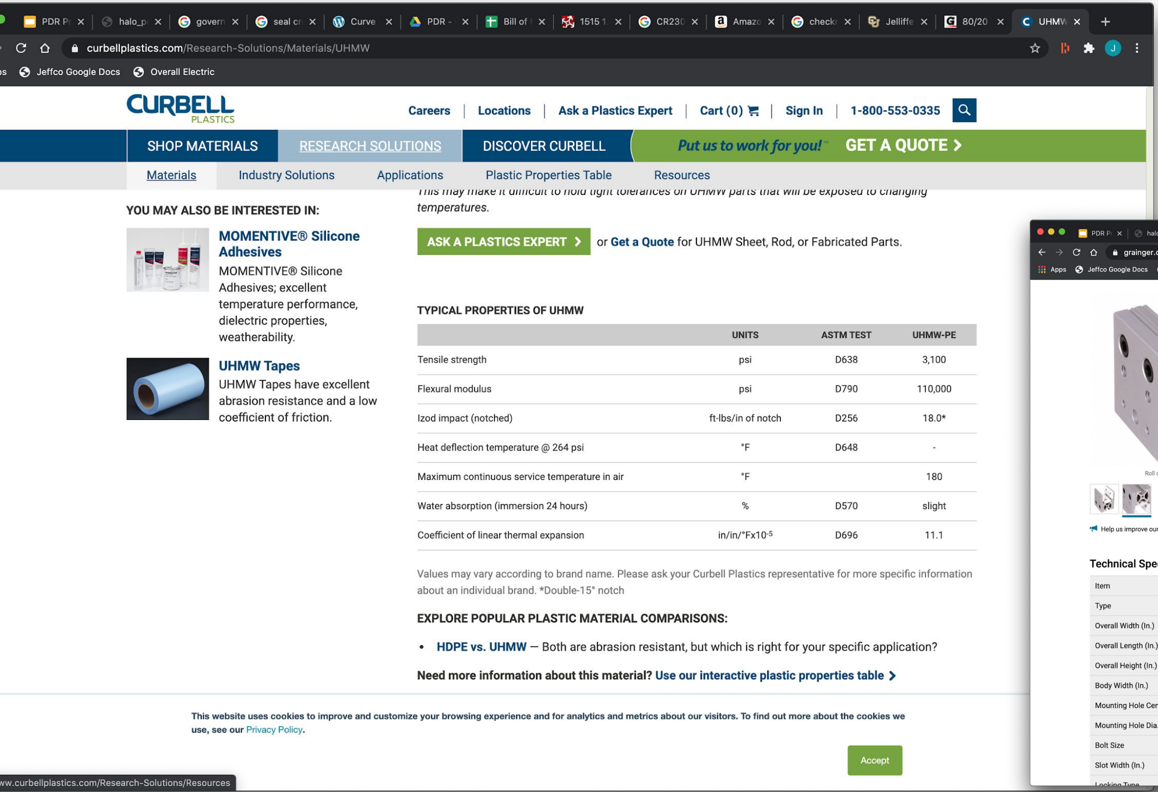
$$\boxed{2F_N \cdot \mu_s > F_{bouy}}$$

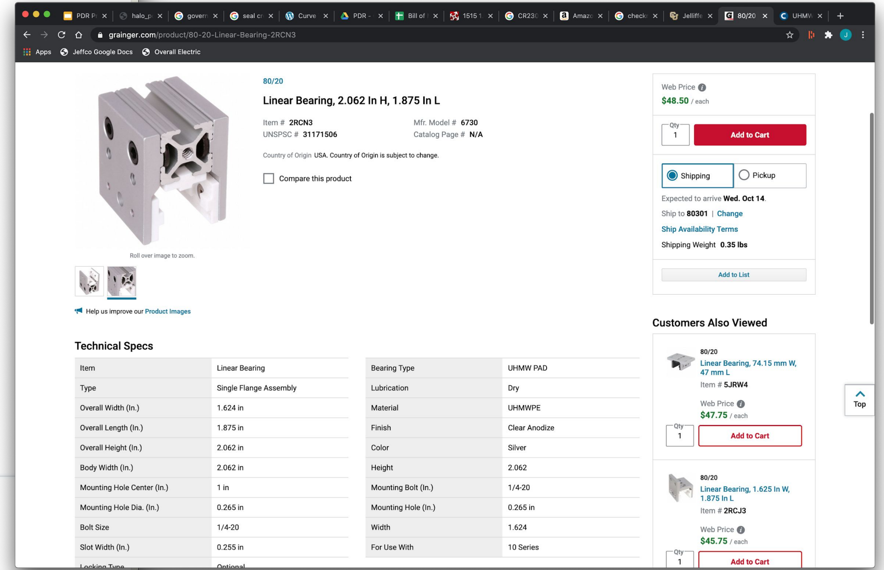


$$\Sigma M_A = 0 = x F_N - 2x F_{mag}$$

$$\boxed{F_N = 2F_{mag}}$$

gs



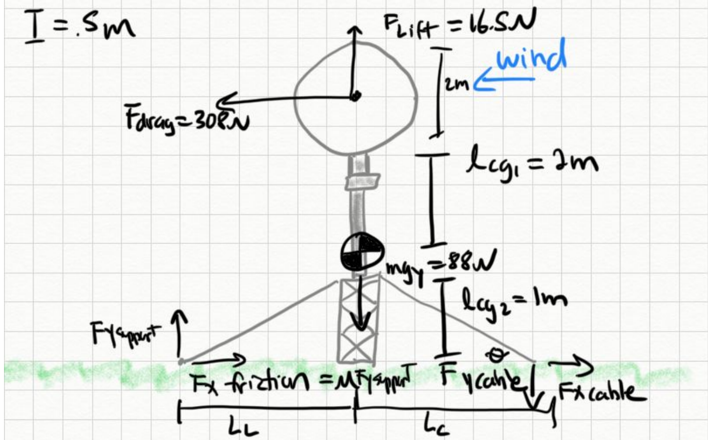


Previous slide shows max shear stress of ~88 PSI; UHMW has a tensile strength of 3100 PSI; FOS ~35

Appendix - Evidence of Baseline Feasibility - Structure

- Stability in 20 m/s winds
  - Max x-dir force on balloon: 308 N or 70lbs @ 3m high
    - Drag of a sphere:
      - $D_{sphere}=q_{\infty}*S*C_d$
      - $q_{\infty}=(½)\rho_{\infty}V_{\infty}^2$
      - $S=(\pi/4)d^2$
  - Anchor pull out force/Support line tension:
    - Tent Stakes: 66N vert pull, 133 N angle pull
    - Screw Style: 1165 N vert pull, 1730 N angle pull
    - 1/4 in. Upwind Steel Wire Rope: 6227.5 N in tension
  - X-dir length of upwind cables/downwind support legs:
    - No anchoring: 9.5 m (unfeasible)
    - Tent stake anchoring: 5.7 m
    - Screw anchors: 1.55 m

$$D = q_{\infty} S C_d \qquad q_{\infty} = \frac{1}{2}\rho_{\infty} V_{\infty}^2 \qquad S = \frac{\pi}{4} d^2$$



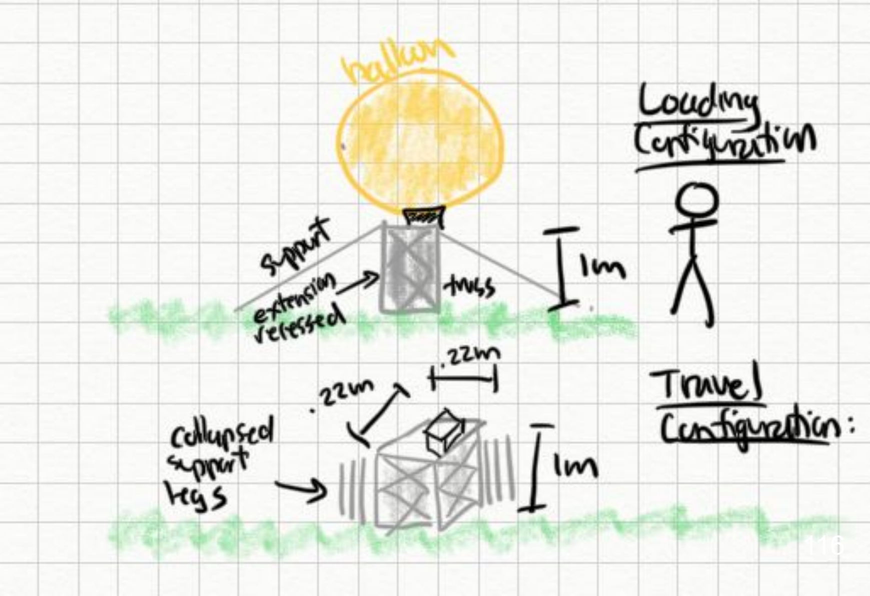
$\Sigma F_x = -F_{drag} + F_{x friction} + F_{x cable}$

$\Sigma F_y = F_{Lift} - mg_y + F_{y support} - F_{y cable}$

$\Sigma M_{cg} = F_{drag} \cdot l_{cg1} - F_{y support} \cdot L_L + F_{friction} \cdot l_{cg2} - F_{y cable} \cdot L_c + F_{x cable} \cdot l_{cg2}$

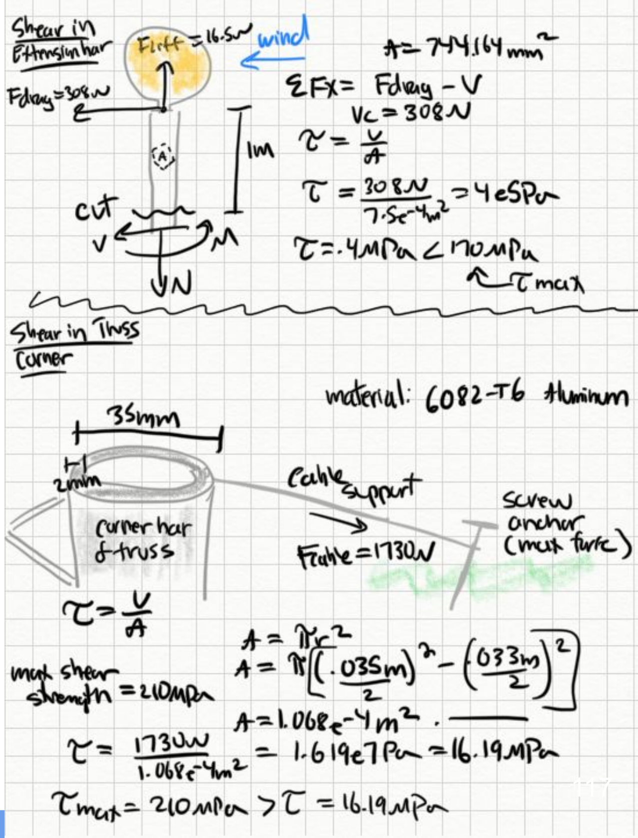
Appendix - Evidence of Baseline Feasibility - Structure

- Loaded by Single User
  - Truss section staked to ground
  - Balloon loaded at 1 m (3.3 ft)
    - Within reach of user
  - Extension bar raised/locked for launch at 3m height
- Collapsible
  - 1 m truss section, 2x 1 m bar extension
  - Support legs assembled in 1 m max length sections
  - Cross section of truss: .22m x.22m
  - Wing nut/bolt on support legs
  - Carabiner clip on upwind cable anchors
  - No tools required besides hammer for staking



Appendix - Evidence of Baseline Feasibility - Structure

- Structure strength:
  - Shear (V) in extending bar:
    - 8020 Aluminum
    - τ_{max}=170 MPa
    - A=744 mm^2
    - τ=V/A=.4 MPa < τ_{max}
  - Shear in extension bearing:
  - Shear (V) in truss corner bar:
    - 6082-T6 Aluminum
    - τ_{max}=210 MPa
    - A=106.8 mm^2
    - τ=V/A=16.2 MPa < τ_{max}
  - Truss support leg/cable junction
    - Load/ft: 604 N load/foot
    - Max center load: 3962 N



Appendix - Evidence of Baseline Feasibility - Structure

- Structure Strength:
  - Shear Stress = 0.4 MPa
  - Axial Stress = 2.79 KPa
  - Bending Stress = 102 MPa
  - Maximum bending moment= 616N·m
  - Maximum moment acting on linear bearing: 308N·m
  - Maximum deflection= 2.369e-9 m(~0m)

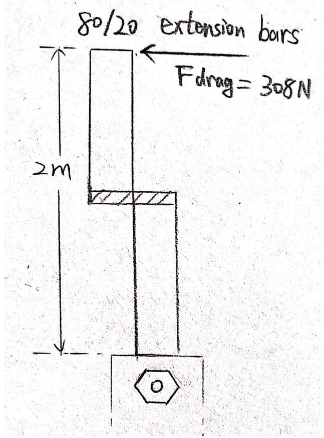
$$\sigma_b = \frac{My}{I}$$

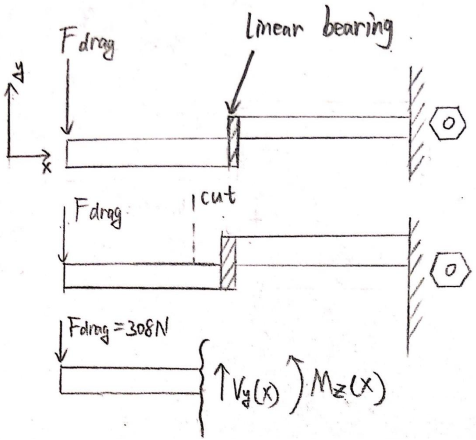
σ_b – Bending stress

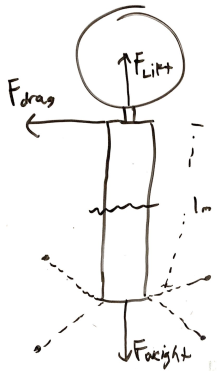
M – Calculated bending moment

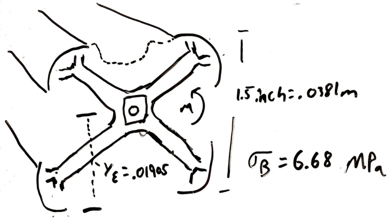
y – Vertical distance away from the neutral axis

I – Moment of inertia around the neutral axis





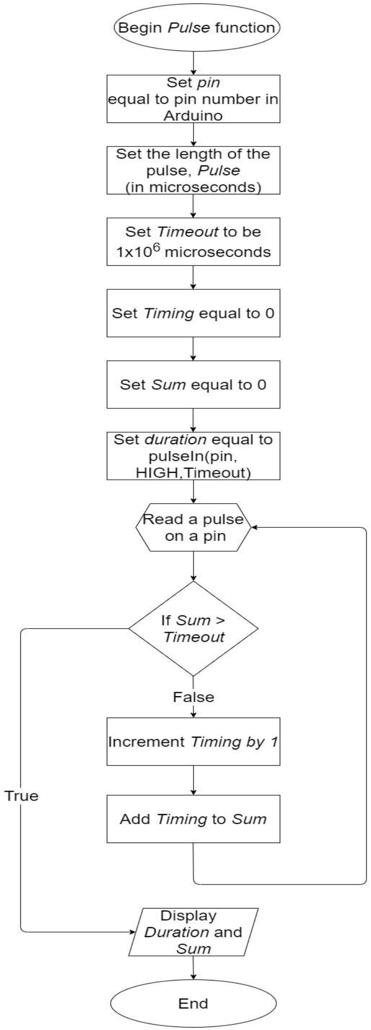




Appendix - Evidence of Baseline Feasibility: Command/Control

sketch_oct08a §

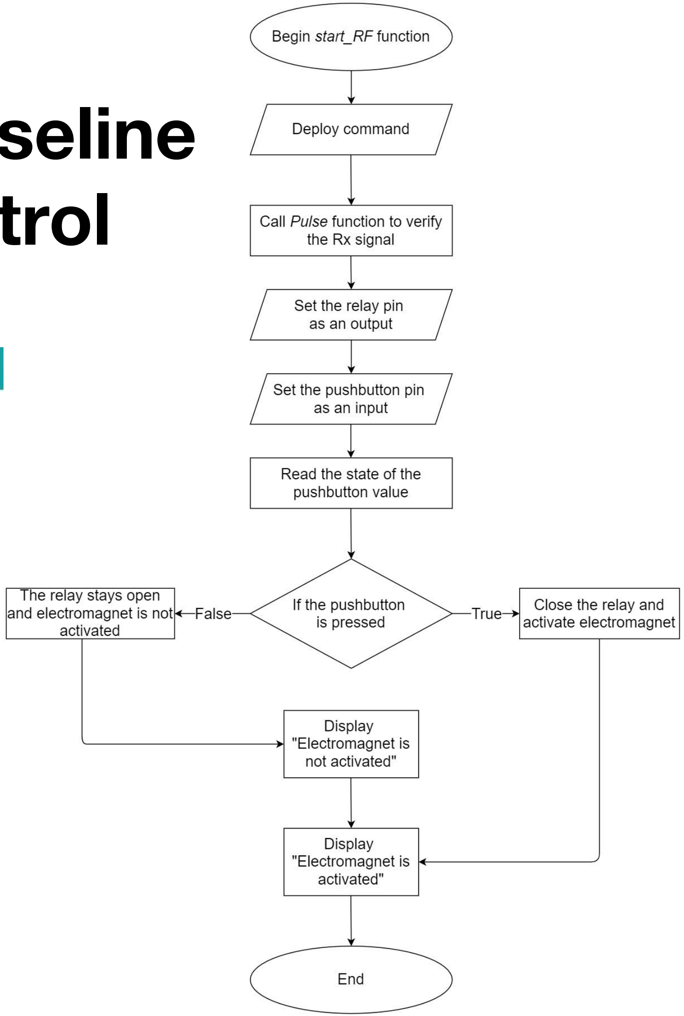
```
int pin = 7;
unsigned long duration;

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  pinMode(pin,INPUT);
}

void loop() {
  // put your main code here, to run repeatedly:
  time = pulseIn(pin,HIGH);
  Serial.println(time);
}
```



Appendix - Evidence of Baseline Feasibility: Command/Control

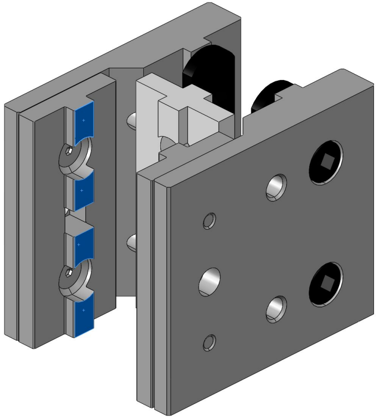
start_RF

```
// constants won't change. They're used here to set pin numbers:
const int pushbuttonPin = 2;     // the number of the pushbutton pin
const int relayPin =  13;       // the number of the LED pin

// variables will change:
int buttonState = 0;          // variable for reading the pushbutton status

void setup() {
  // initialize the relay pin as an output:
  pinMode(relayPin, OUTPUT);
  // initialize the pushbutton pin as an input:
  pinMode(pushbuttonPin, INPUT);
}

void loop() {
  // read the state of the pushbutton value:
  buttonState = digitalRead(pushbuttonPin);

  // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
  if (buttonState == HIGH) {
    // relay close:
    digitalWrite(relayPin, HIGH);
  } else {
    // relay open:
    digitalWrite(relayPin, LOW);
  }
}
```



Appendix - Evidence of Baseline Feasibility: Structure

- Shear (V) in linear bearing:
  - UHMW material
  - Area subject to shear
  - τ=.55 MPa <τ_{max}=20 MPa



Roll over image to zoom.

Help us improve our Product Images

80/20

Linear Bearing, 2.062 In H, 1.875 In L

Item # **2RCN3** Mfr. Model # **6730**
UNSPSC # **31171506** Catalog Page # **N/A**

Country of Origin USA. Country of Origin is subject to change.

☐ Compare this product

Technical Specs

Item	Linear Bearing	Bearing Type	UHMW PAD
Type	Single Flange Assembly	Lubrication	Dry
Overall Width (In.)	1.624 in	Material	UHMWPE
Overall Length (In.)	1.875 in	Finish	Clear Anodize
Overall Height (In.)	2.062 in	Color	Silver
Body Width (In.)	2.062 in	Height	2.062
Mounting Hole Center (In.)	1 in	Mounting Bolt (In.)	1/4-20
Mounting Hole Dia. (In.)	0.265 in	Mounting Hole (In.)	0.265 in
Bolt Size	1/4-20	Width	1.624
Slot Width (In.)	0.255 in	For Use With	10 Series

Max shear stress of ~80 PSI; UHMW has a tensile strength of 3000 PSI; FOS ~37.5

Appendix: Design Requirements/Satisfaction

- Stability in Wind

Dynamic Modeling Explanation

① $V_{\infty 1} = 0$ m/s

② $V_{\infty 2} = 20$ m/s

Assume Balloon Accelerates with windspeed (No Drag)

Wind Force / Structure Force

① t ② $t+\Delta t$ ③ $t+2\Delta t$

$V_1 = 0$ m/s $V_2 = 20$ m/s $V_3 = 0$ m/s

The balloon goes from 0 m/s to 20 m/s over Δt

Using average acceleration: $a_{avg} = \frac{V_2 - V_1}{\Delta t}$

① ② ③

Worst case

At 3, we need $V_3 = 0$

So by symmetry, we can calculate the average force Required to decelerate from 20 m/s to 0 m/s as

$F_{avg} = m\,a_{avg} = 20$ lbf By Design

So now, rearranging, we find

$\Delta t = 0.2$ s

So if the 0 → 20 m/s gust happens FASTER than $\Delta t = 0.2$ s, we'll exceed 20 lbf to slow the balloon down.

Now we want to show that the gust to 20 m/s must be longer than 0.2 s

Def: Gust Factor: $G = \frac{V_{gust}}{V_{sustained}}$

For 20 m/s Gust case, we have 10 m/s sustained. So $G = 2$

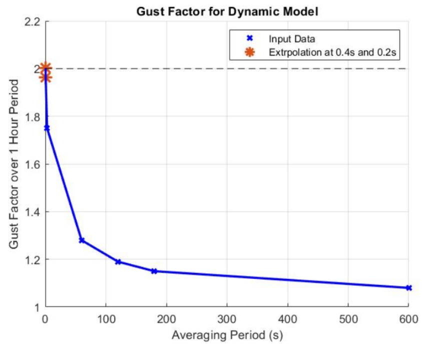
Gust Factor Depends on Duration of gust (as V_{gust} ↑ as t ↓).

Looking at Gust Factors, we extrapolate

$G = 2.0027$ for $\Delta t = 0.2$ s

This suggests that V may double over 0.2 s, so our 0.2 s arrest time is reasonable.

↳ $V_{avg\,0.2s} = 2 \cdot V_{avg}$



https://www.wmo.int/pages/prog/www/tcp/Meetings/HC31/documents/Doc.3.part2.pdf

Appendix Design Requirements/Satisfaction

<u>Stability in wind Calculation:</u>

- Sustained wind:

$V_\infty = 20\,m/s$
$r = 1\,m$
$c_d = .4$
$\rho = 1.225\,kg/m^3$

$D = \frac{1}{2}\rho V_\infty^2 (\pi r^2)\cdot c_d$

$\boxed{D = 307.87\,N}$

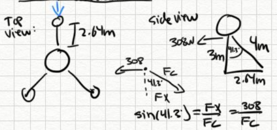
- Gusts → assume accelerating mass (ignore drag)

$\Delta t = .2s$ (Gust factor research model)
$m = 3.689\,kg$ (latex + helium)
$a = \frac{\Delta V}{\Delta t}$

$\Delta V = 20\,m/s - 10\,m/s$

$F = (3.689\,kg)\left(\frac{10\,m/s}{.2s}\right) = \boxed{184.45\,N}$

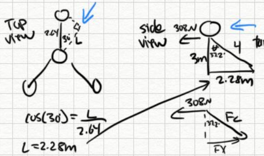
- <u>Moment calculations:</u>



$\sin(41.3°) = \frac{F_x}{F_c} = \frac{308}{F_c}$

$\Sigma F_x = -308N + F_c \sin(41.3°) = 0$

$\boxed{F_c = 466.67\,N}$ → strongest



$\tan^{-1}\left(\frac{2.28}{3}\right) = 37.2°$

$\cos(30°) = \frac{L}{2.64}$

$L = 2.28m$

$\sin(37.2) = \frac{308N}{F_c}$

$\Sigma F_x = -308N + F_c \sin(37.2°) = 0$

$\boxed{F_c = 509.43\,N}$

<u>Stake hold:</u>

@45° = 1730N
@vert = 1165.4N

→ $FOS = \frac{1165.4N}{509.43N} = 2.28$

$\boxed{FOS_{anchor} = 2.28}$

Moments around structure:

$\frac{\text{min moment resist}}{\text{max moment wind}} = \frac{2002\,Nm}{924\,Nm} = 2.16$

$\boxed{FOS = 2.16}$

<u>Internal Structure Strength:</u>

- <u>Cable/Tower attachment:</u>

$FOS_{Dring} = \frac{\text{max Dring Force (tension)}}{\text{max Force cable (tension)}} = \frac{2224N}{537} = 4.14$

$\boxed{FOS_{Dring} = 4.14}$

$FOS_{Dring-bolt} = \frac{\text{max tensile stress bolt}}{\text{max tension stress}}$

$\tau = \frac{V}{A}$

I 5/16" = .00794m
steel

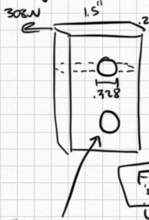
$A = \pi r^2 = \pi\left(\frac{.00794m}{2}\right)^2 = 4.95e\text{-}5\,m^2$

$\tau_{bolt} = \frac{509N}{4.95e\text{-}5\,m^2} = 1.027e7\,Pa$

$\tau_{max\,steel} = 3.8e8\,Pa = 55,000\,psi$ (matweb) = .75 of max tensile stress (wikipedia)

$\boxed{FOS_{bolt\,shear} = \frac{3.8e8\,Pa}{1.027e7\,Pa} = 37}$

- Bar joints



$A = (.25)(1.5) - (.25)(.328) =$

$A = .293\,in^2 = .000189\,m^2$

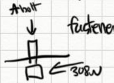
$\tau = \frac{V}{A} = \frac{308N}{1.89e^{-4}\,m^2} = 1.63e6\,Pa$

$\tau_{max\,Aluminum} = 207\,MPa$

$\boxed{FOS_{joints} = \frac{207\,MPa}{1.63\,MPa} = 127}$

↳ actually higher as this assumes 1 plate takes entire load

fasteners:



$A = \pi r^2 = \pi\left(\frac{3}{16}\cdot\frac{1}{2}\right)^2 = .0276\,in^2 = 1.78e\text{-}5\,m^2$

$\tau = \frac{V}{A} = \frac{308N}{2(1.78e\text{-}5\,m^2)} = 8.65e6\,Pa$

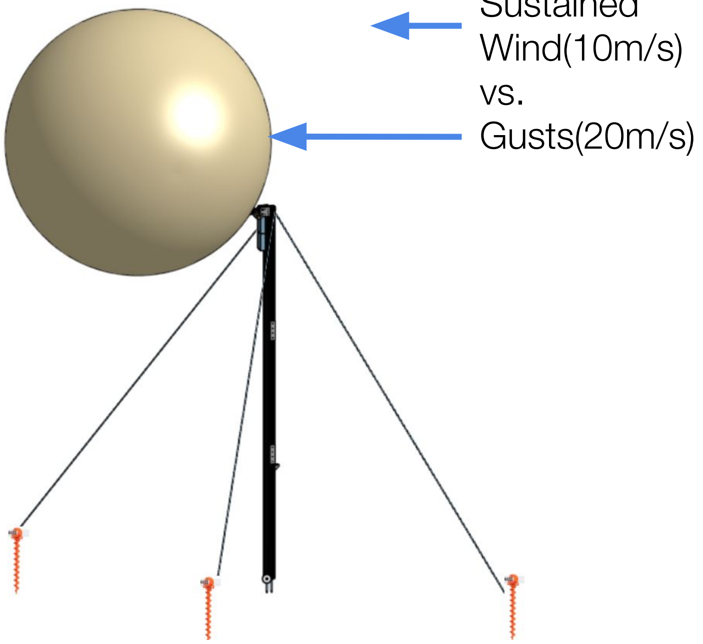
2 bolts per joint

$\tau_{max\,steel} = 3.8e8\,Pa$

$\boxed{FOS_{bolts} = \frac{3.8e8\,Pa}{8.65e6\,Pa} = 44}$

Appendix: Design Requirements/Satisfaction

- Stability in Wind
  - Highest forces expected for subsequent modeling:
    - Max Wind Sustained
      - Max potential wind: 20m/s
      - Model balloon as sphere
      - mass=3.689 kg (latex+helium)
      - Drag: 308N (upper bound)
    - Max Wind Gust (Balloon tug/bounce):
      - V=10m/s -> 20 m/s
      - Gust Factor = $V_{Gust} / V_{Sustained} = 2$
      - Δt=0.2s (V=10m/s to V=20m/s)
      - $a = \Delta V / \Delta t = 50\ m/s^2$
      - Force=ma=184.5N



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