Balloon Deployment System

Spring Final Review

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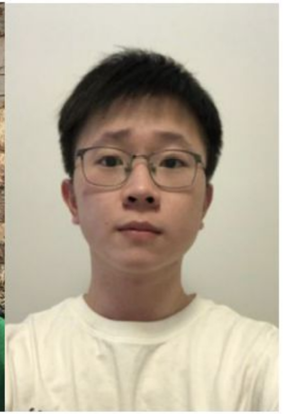


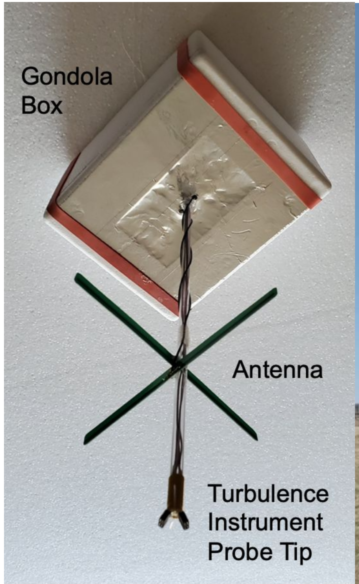
Chenshuo Yang
Structural Designer

Project Purpose and Objectives

Program Introduction

- 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:

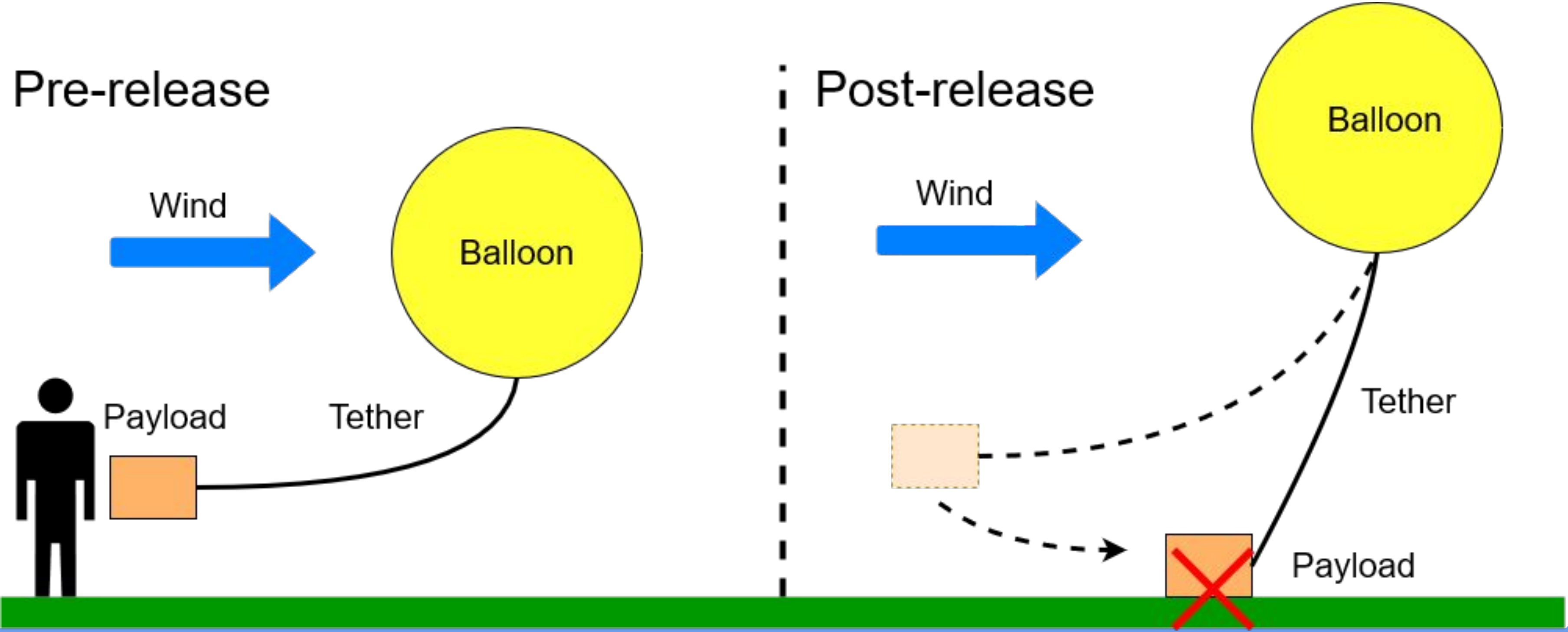


Balloon:

Project Purpose and Objectives

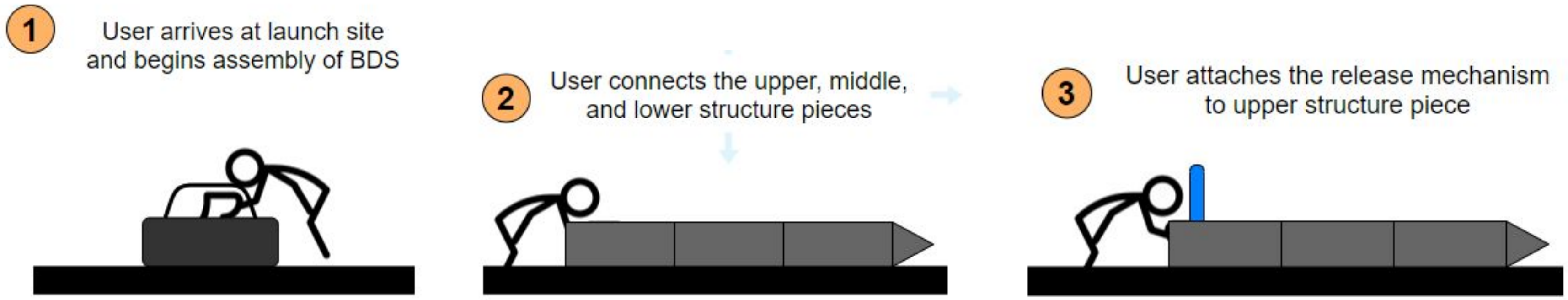
Current Problem

- Instrument payload hits ground



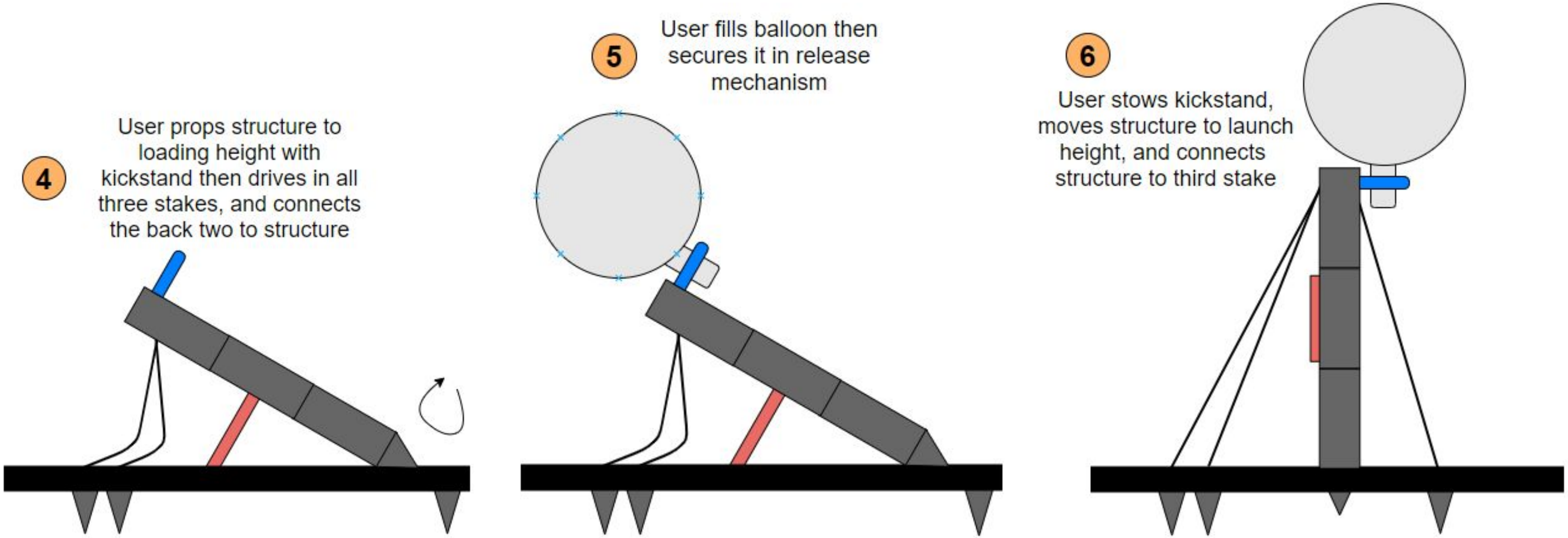
Project Purpose and Objectives

CONOPS



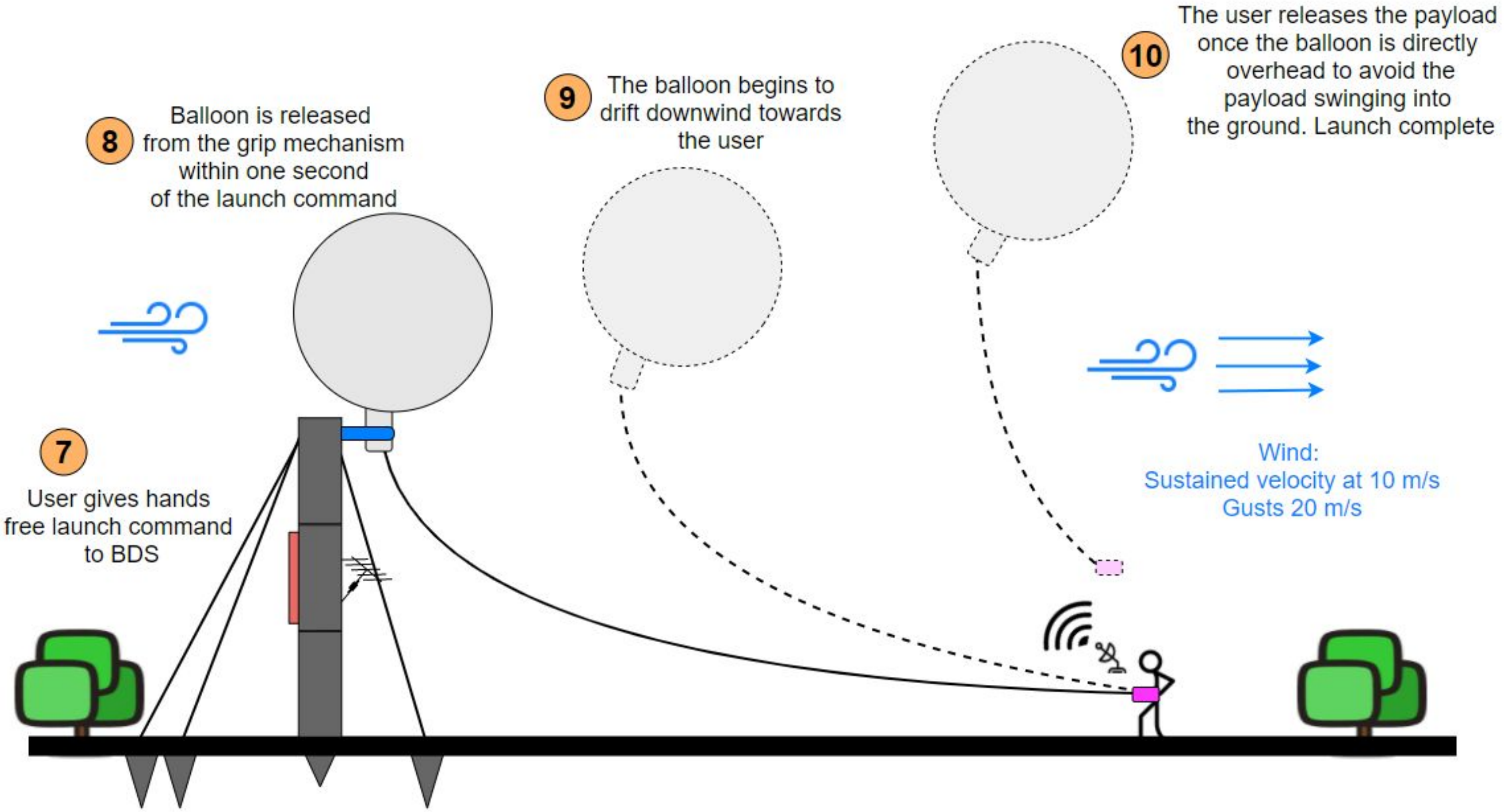
Project Purpose and Objectives

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

Levels of Success

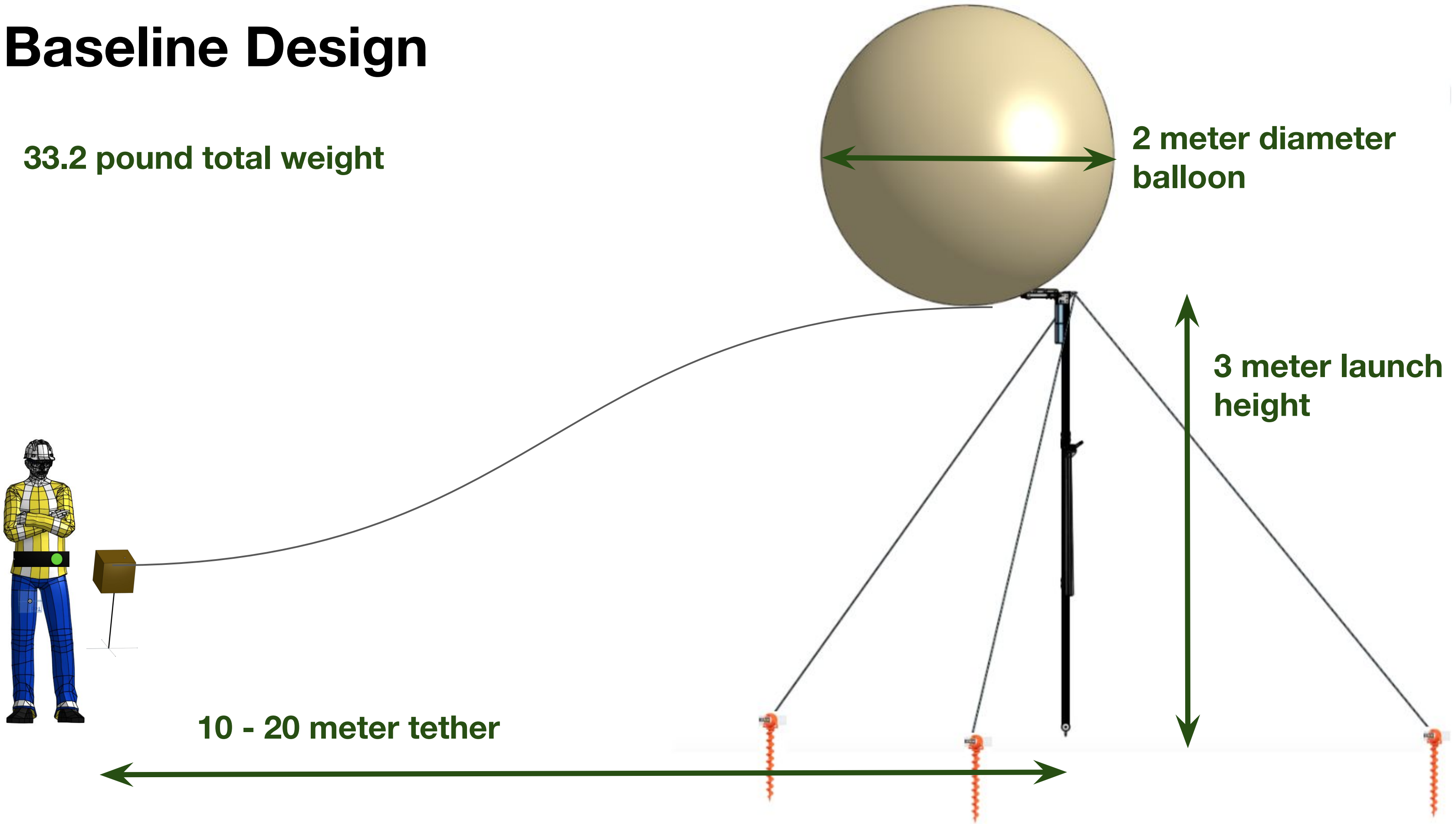
Level of Success	Portability	Launch Capabilities	Balloon Security	Cost
Level III	• Assembly Time <5 mins • Weight < 50 lbs • Tools: None • Travel Config.: 1m x 0.25m cylindrical bag	• Launches 1 or 2 balloons • Control Comm: Wireless • Release Command Remote: On user • Reliability: 30 test launches in 10 m/s sustained winds	• Sustained Wind Speed: 10m/s • Gust Wind Speed: 20m/s	• Unit Price: <$1000 • Materials: 100% off-the-shelf components
Level II	• Assembly Time <15 mins • Weight < 50 lbs • Tools: None • Travel Config.: 1m x 0.25m cylinder bag	• Launches 1 balloon • Control Comm: Wireless • Release Command Remote: Off user • Reliability: 20 test launches in 8 m/s sustained winds	• Sustained Wind Speed: 8 m/s • Gust Wind Speed: 15 m/s	• Unit Price <$1000 • Materials: 75% off-the-shelf components
Level I	• Assembly Time <15 mins • Weight < 50 lbs • Tools: multitool stored in case • Travel Config.: Fits in compact car trunk	• Launches 1 balloon • Control Comm: Wired • Release Command Remote: Off user • Reliability: 10 test launches in 1-2m/s winds	• Sustained Wind Speed: ~1 m/s • Gust Wind Speed: ~2 m/s	• Unit Price <$1500 • Materials: 50% off-the-shelf components

Design Solution

Design Solution

Baseline Design

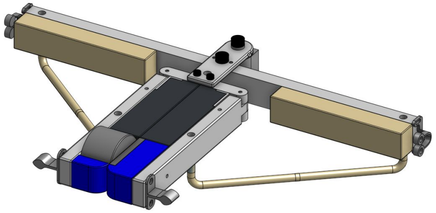
33.2 pound total weight

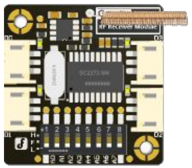


Baseline Design

BDS Subsystems

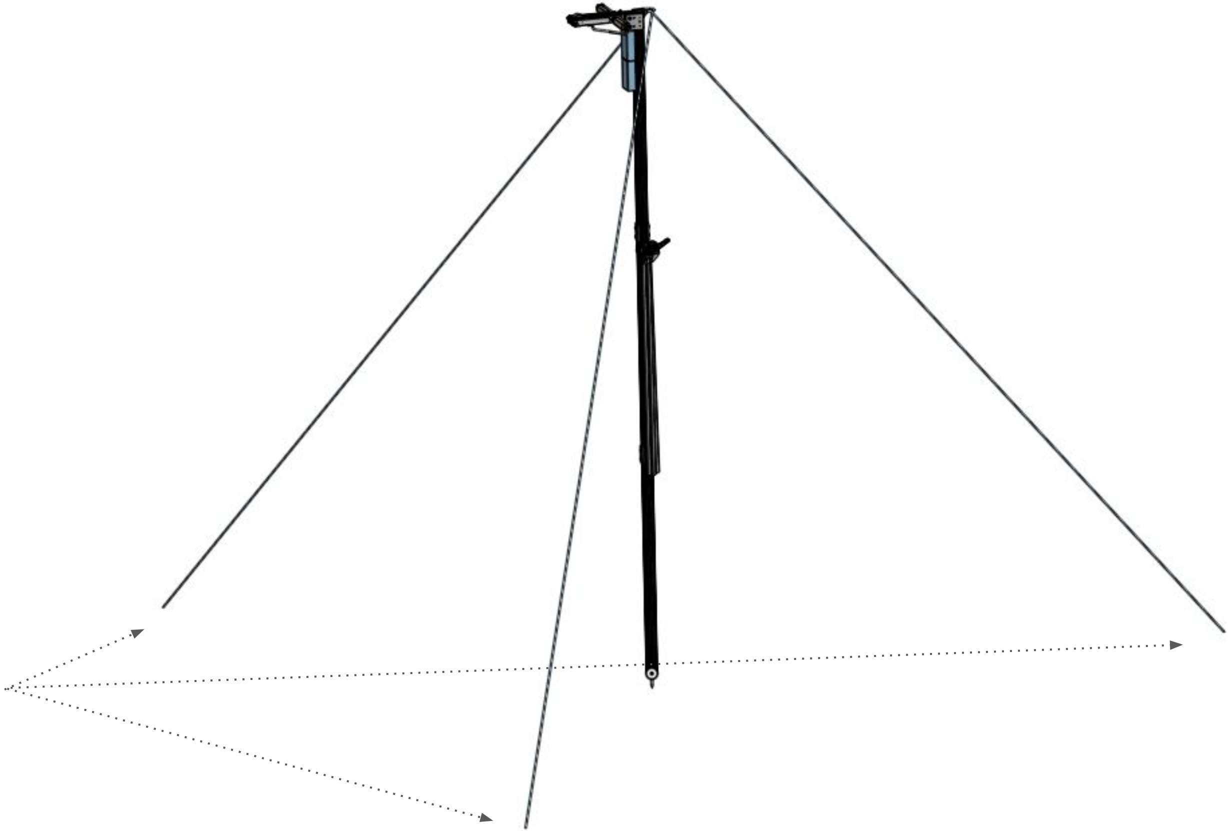
- Balloon Deployment System
  - Support Structure
    - Base
    - Extension
  - Release Mechanism
  - Command & Control
    - Transmitter
    - Receiver





Design Solution

Support Structure



Design Solution

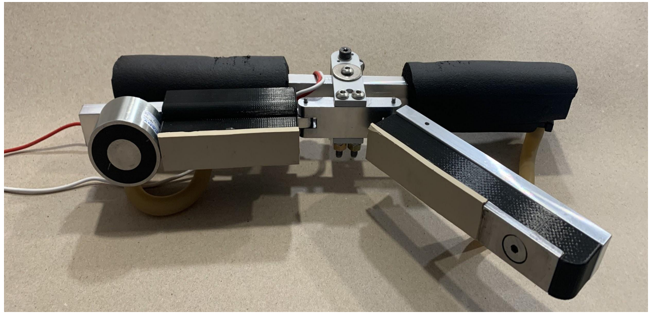
Updates

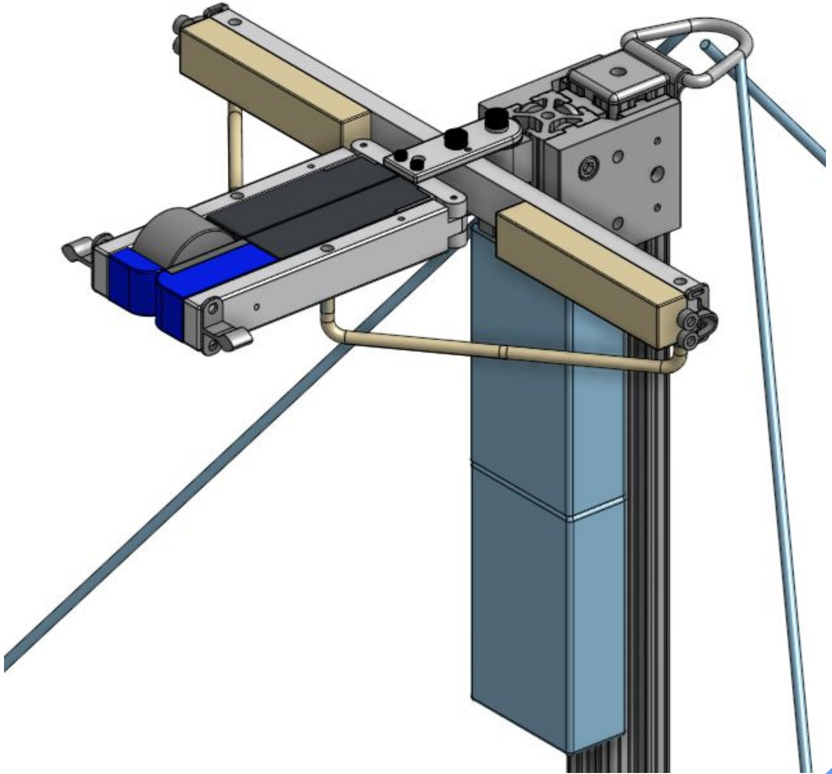
Color coordinating mating points/connections for faster assembly

Foam cover on top of structure for balloon protection

Design Solution

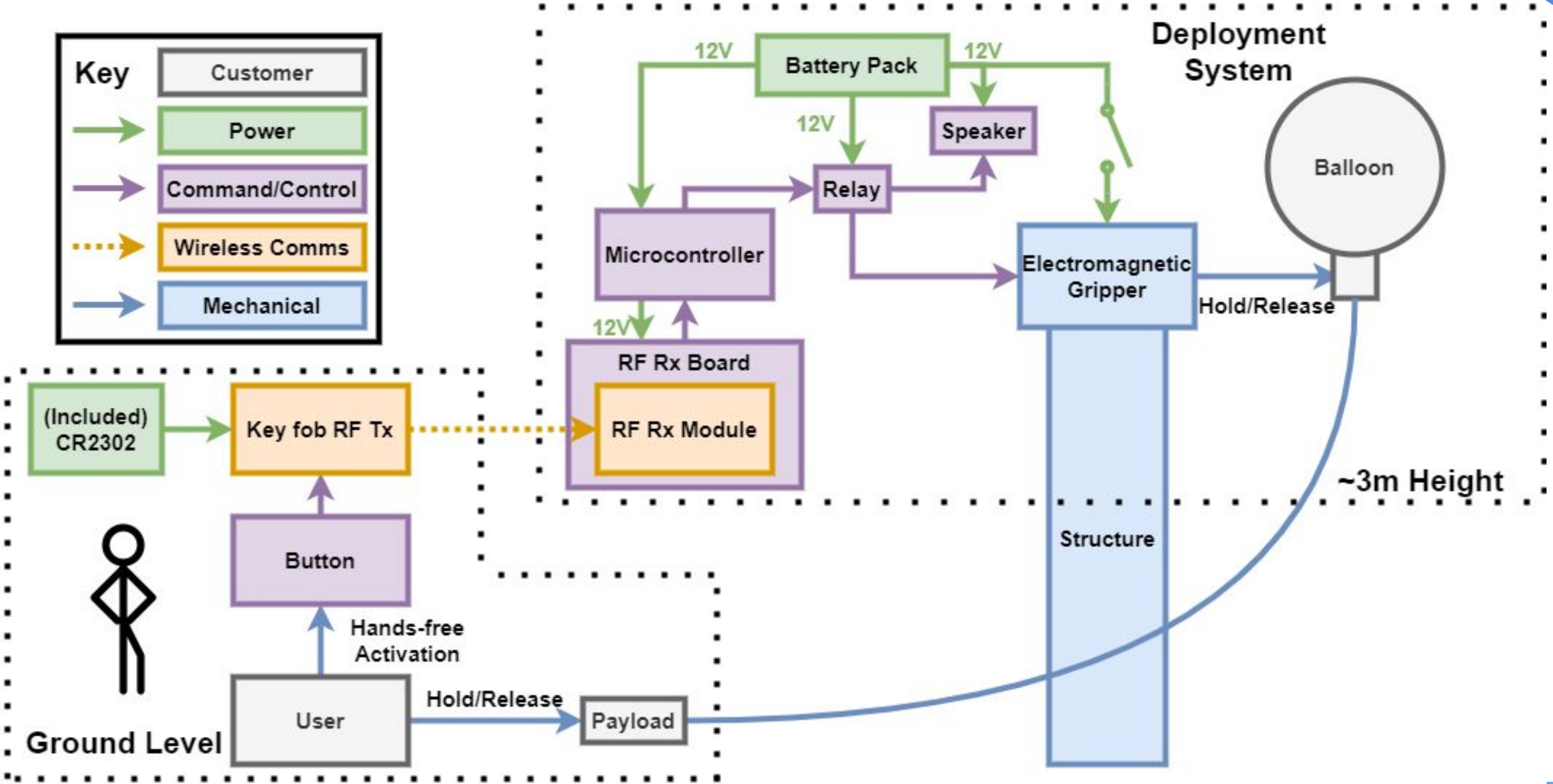
Release Mechanism





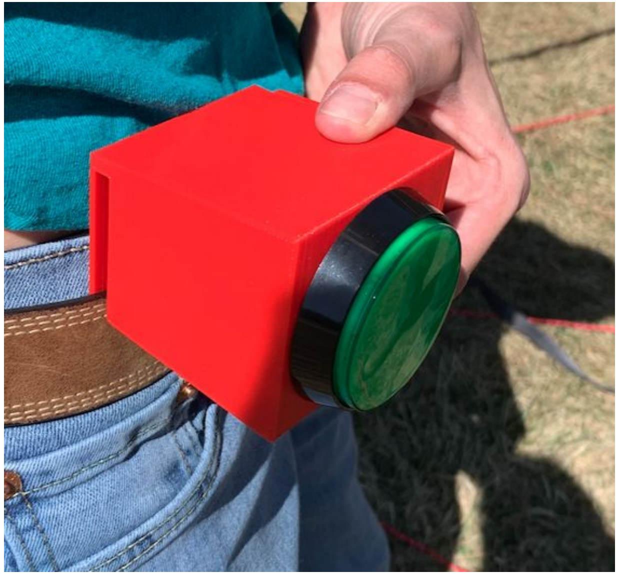
Design Solution

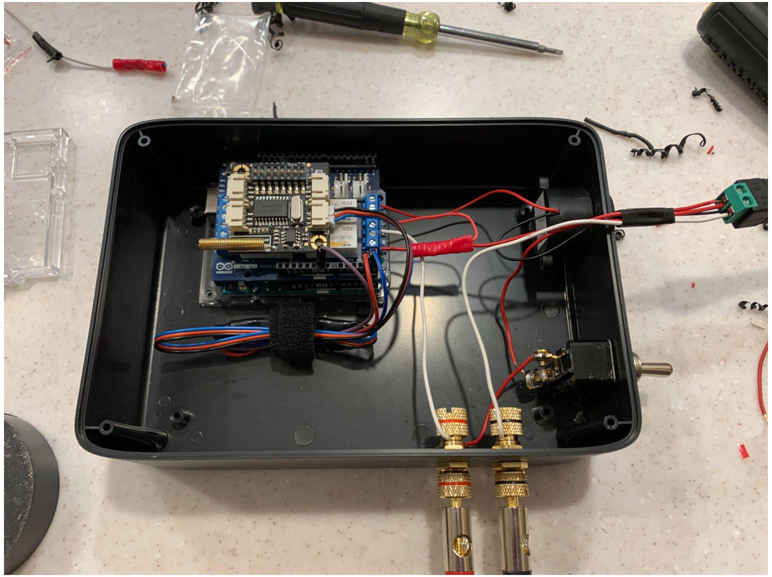
Functional Block Diagram



Design Solution

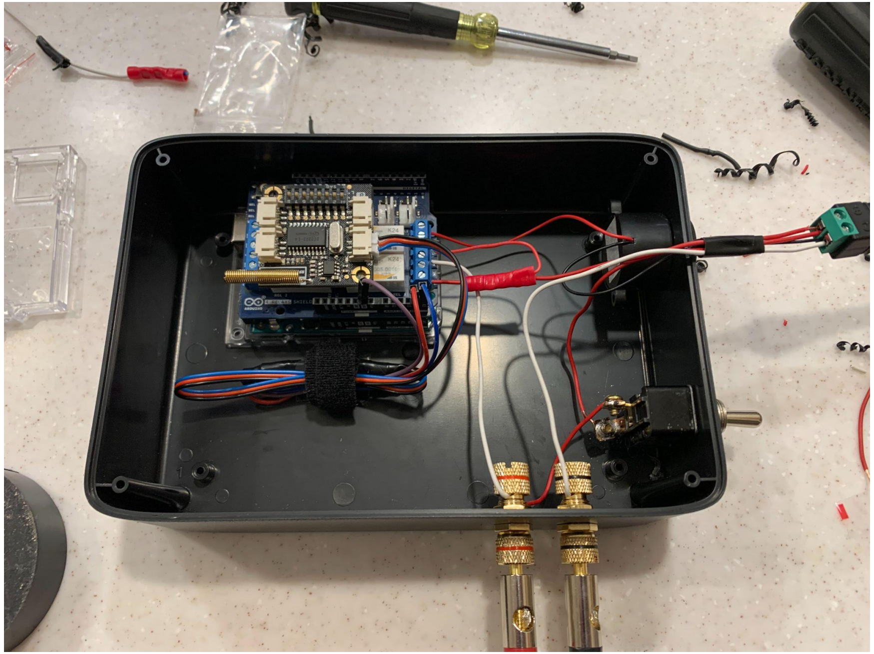
Command and Control

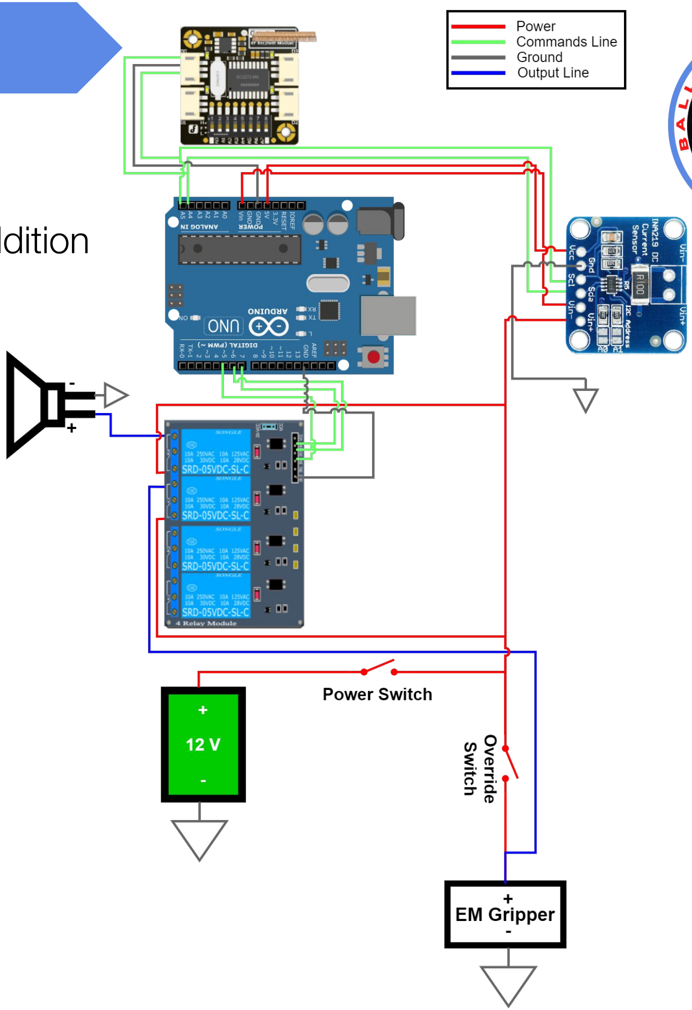




Updates

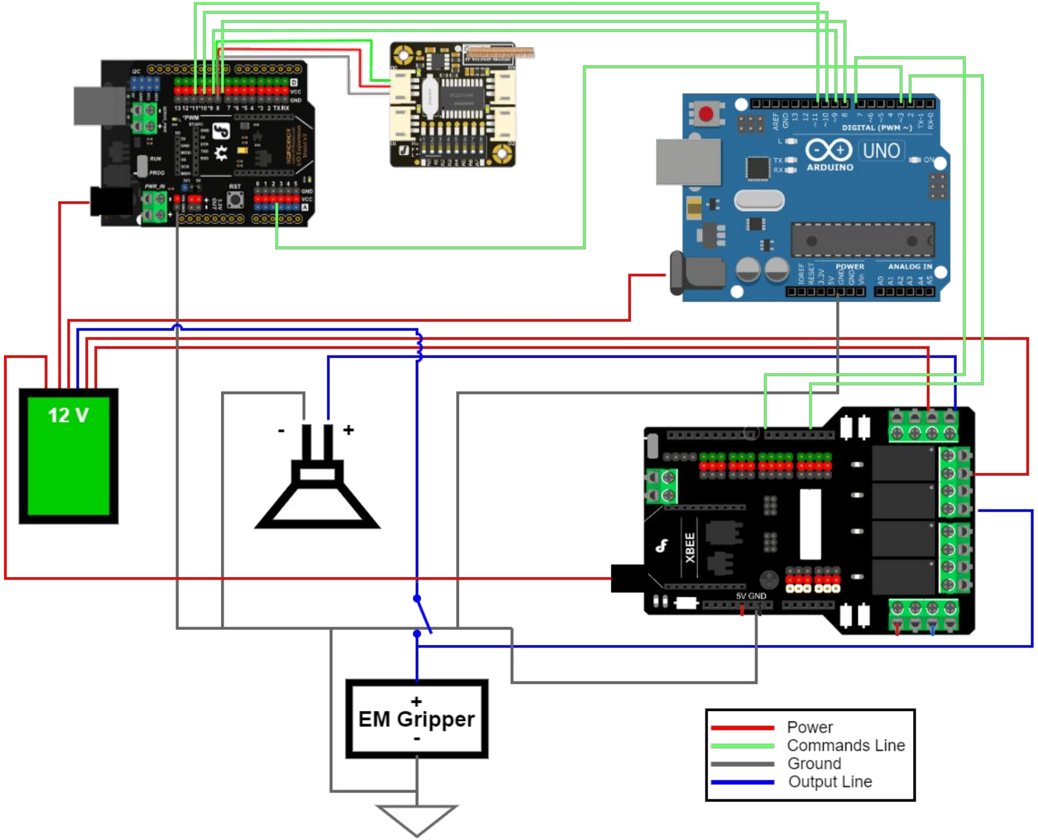
Wiring system: RF Shield removal, current sensor (INA219) addition





Design Solution

Wiring Schematic



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

Critical Project Elements

CPE	Why it is Critical
Ease of setup/transport	Launch from multiple sites per HYFLITS need
Stakes and support lines	Allow for launches in high wind condition
Internal structure strength	Survive high wind launch forces
Release mechanism	Prevent balloon neck's damage and hold the balloon at the launching height
Override switch	No premature release of balloon
Electronics	Ensure there is enough power for the duration of the entire mission
Software	Hands free release command, allow user to focus on payload safety and launch.

Critical Project Elements

CPE	Design Element	Why it is Critical
Ease of setup/transport	Collapsible structure, lightweight, padded carrying case	Launch from multiple sites per HYFLITS need
Stability in wind	Stakes and support lines	Allow for launches in high wind condition
Internal structure strength	Structure and release mech sub components all rated above max expected loads	Survive high wind launch forces
No balloon damage	Smooth and soft release mechanism/balloon interface, smooth nylon tie down supports, no sharp edges on structure	Prevent balloon neck's damage and hold the balloon at the launching height
No premature release of balloon	Permanent Electromagnet	Avoid losing balloon or balloon being damaged
Hands free release command	Electronics and software design	Allow user to focus on payload safety and smooth launch remotely. Ensure there is enough power for the duration of the entire mission

Test Overview

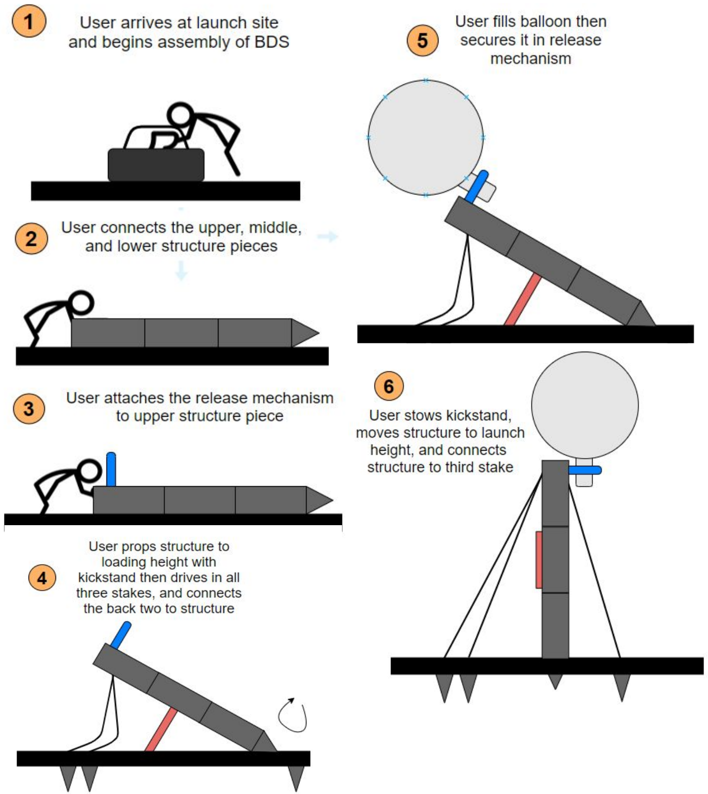
Critical Project Elements

- Tests to verify each critical project element:
  - Ease of set up/transport
  - Stability in wind
  - Internal structure strength
  - No balloon damage
  - No premature release of balloon
  - Hands free release command

Test Overview

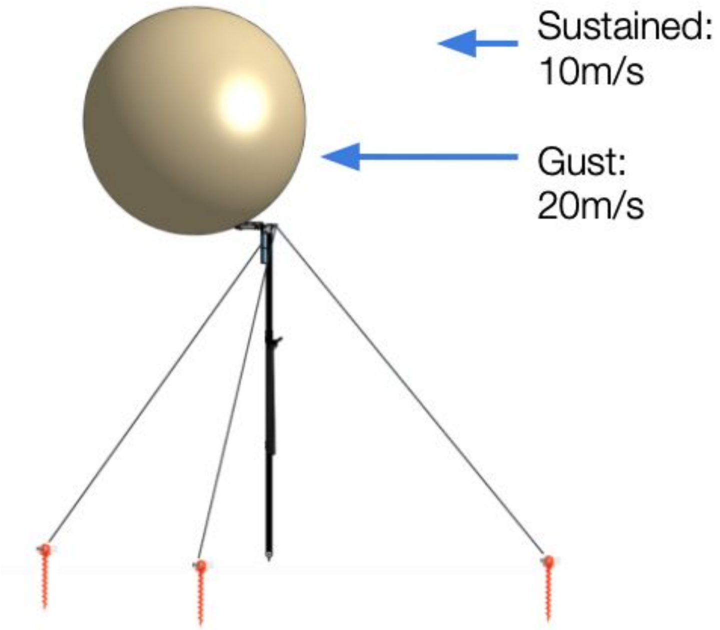
Critical Project Elements

- Ease of set up/transport
  - Final weight and dimension test
    - Dimension: 1m x .25m x .25m
    - Weight: 50 lbs max
  - Timed assembly/set-up test
    - 5 minute set up
    - No tools
  - Balloon loading test
    - Done by single user



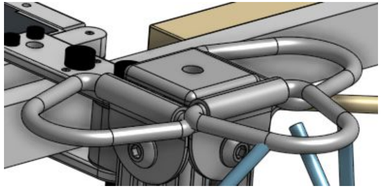
Critical Project Elements

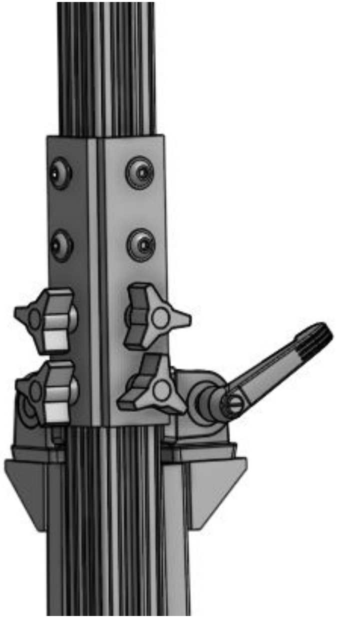
- Stability in wind
  - Stake soil test
    - Launch from multiple locations
  - Wind load test
    - Stability with balloon in 20 m/s winds



Critical Project Elements

- Internal structure strength
  - Wind load test (verifying strength):
    - Mast D-rings
    - Tie-down supports
    - Stake eyelets
    - Carabiners
    - Mast connection plates





Test Overview

Critical Project Elements

- No balloon damage
  - Balloon loading test
    - No damage during loading
  - Grip strength test
    - Hold balloon in 20m/s winds (F=365N)
  - Balloon launch test
    - Balloon flies away without hitting ground or structure
    - No entanglements
    - Balloon/payload tether doesn't snag

Test Overview

Critical Project Elements

- No premature release of balloon
  - Grip strength test
    - Hold balloon in 20m/s winds (F=365N)
  - Balloon launch test
    - Balloon is not released before commanded

Critical Project Elements

- Hands free release command
  - Current test
    - Verify system power
  - RF range test
    - Appropriate distance with tether for remote
  - Balloon launch test
    - User interface with electronics box and remote intuitive

Test Results

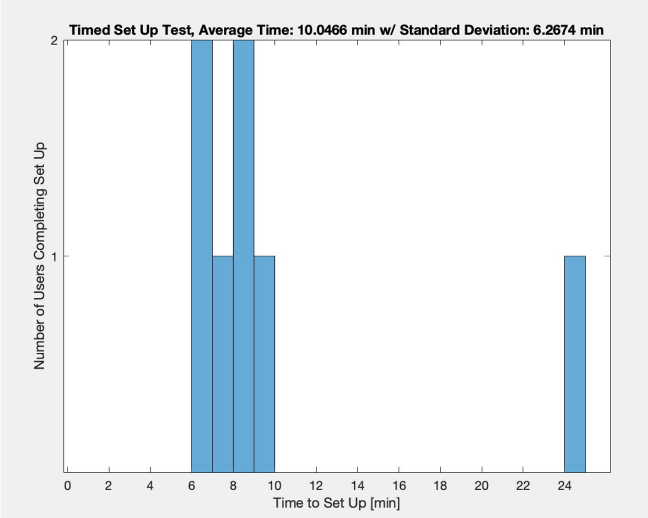
Test Results

Weight/Dimension

- Validates: Ease of set up/transport
- Procedure:
  - Measure packed system
  - Weigh packed system
- Customer requirement:
  - Dimension: 1m x .25m x .25m
  - Weight: 50 lbs max
- Results:
  - Dimension: 1.10m x .25m x .25m (10% over length)
    - Removal of mast connections and kickstand allows for exact length to be met (but longer set up)
    - Still fits in sedan trunk/backseat
  - Weight: 33.2 lbs (66% of OSHA 50 lbs limit)
  - Meets Level II Success

Timed Assembly

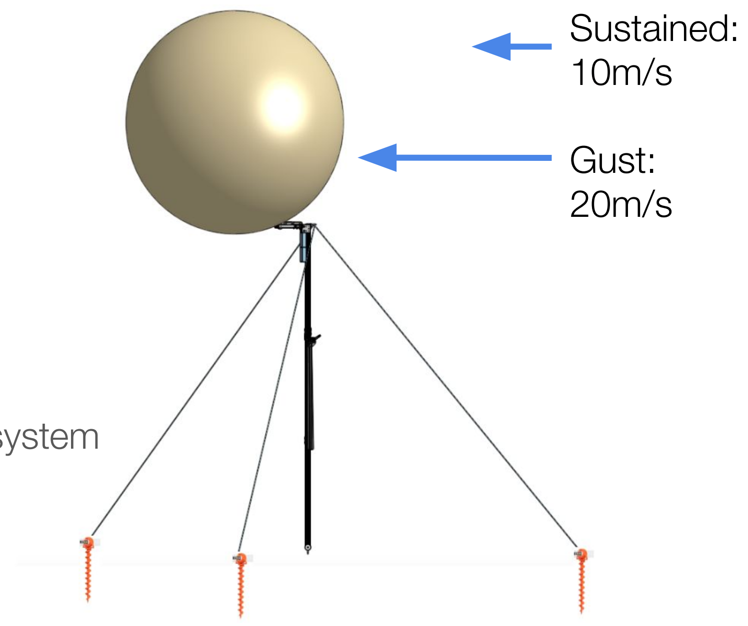
- Validates: Ease of set up/transport
- Procedure:
  - Time 1 person: Unpack, assemble mast, stake, raise structure
- Customer requirement:
  - 5 min set up (Level III), 15 min set up (Level II)
  - No tools
- Results:
  - Avg Time (7 trials): 10:03 min
  - 10 min time is representative in that end HYFLITS user will also have time to review instructions and practice (like test participants on BDS)
  - Meets Level II Success



Test Results

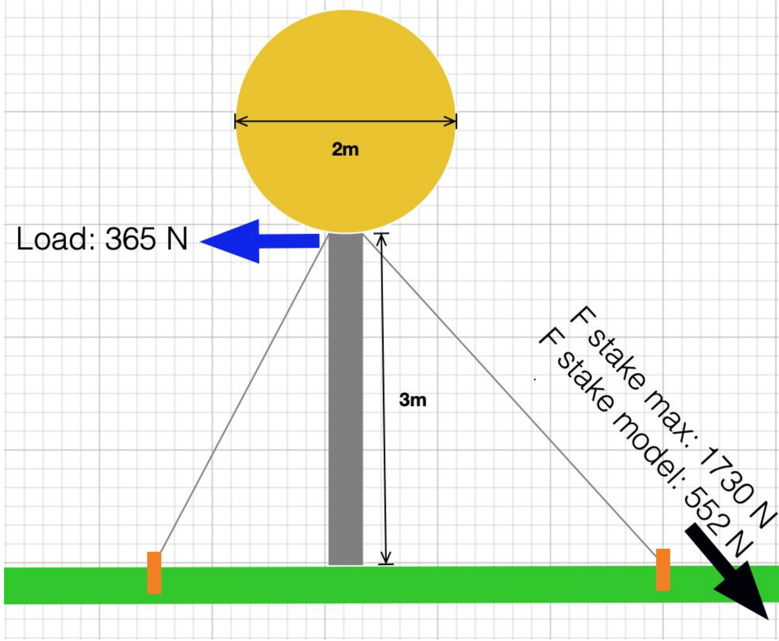
Wind Load Test - Model

- Test to Confirm Stability in Wind
    - Test forces in supports to ensure:
        - Structure does not fall
        - Below mfg max
        - Enough support for stability
    - Highest forces expected for modeling:
        - Max Wind Sustained: 20 m/s
            - Model balloon as sphere for drag
            - mass=3.689 kg (latex+helium)
            - Modeled dynamically as spring-mass system
            - Wind $Load_{MAX}$=365N

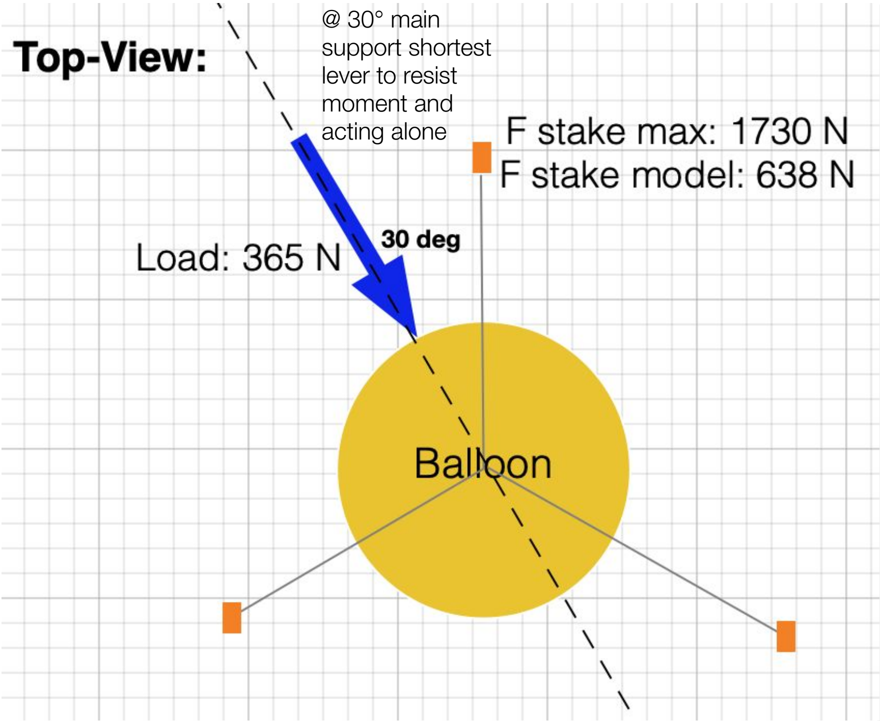


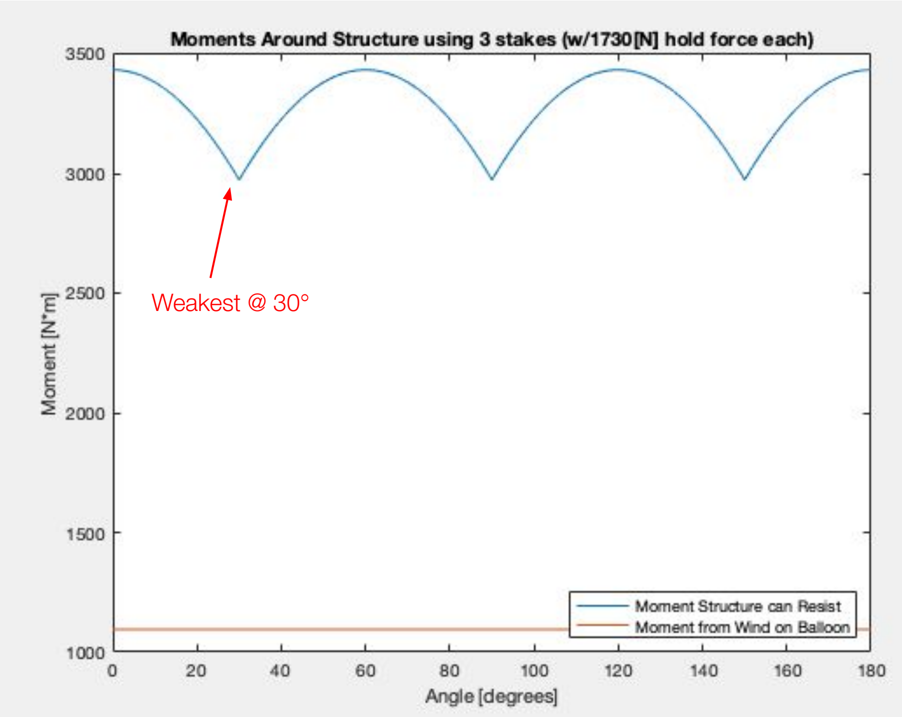
Wind Load Test - Model

- Stability in Wind
  - Large moment to resist:
    - Wind Load: 365 N
    - Height: 3m
    - $\text{Moment}_{\text{wind}}$=1095 N*m
  - Ensure force at supports not above rating:
    - $F_{\text{tie-down}}$=2225N (not failure mode)
    - $F_{\text{stake @45}}$=1730N (weakest point of system)
  - Max model load w/ wind coming directly on support:
    - F_{support}=552N
    - FOS=1730N/552N=3.1



Wind Load Test - Model



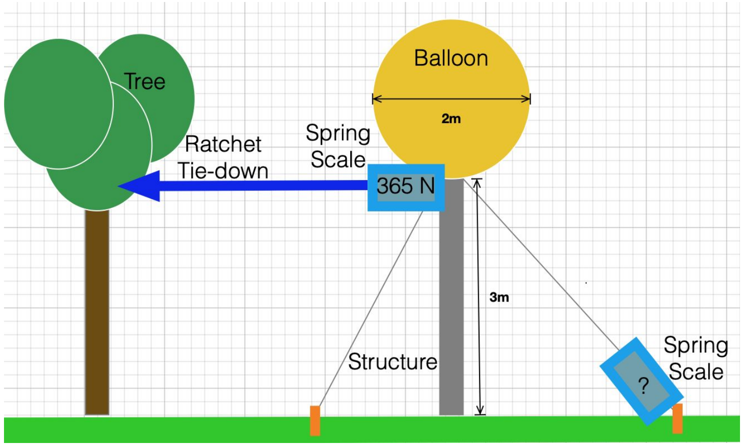


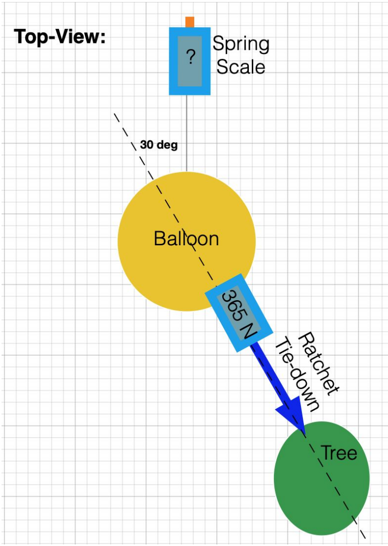
Test Results

Wind Load Test

- Validates:
  - Know stake most likely point of failure (pull out)
  - Confirm loads seen at stake to
    - Verify model
    - Ensure structure stability in wind
    - Confirm internal structure strength
- Procedure:
  - Connect top of assembled structure to tree via ratcheting tie-down to simulate wind load
  - 0 degree (strong) and 30 degree (weak) configurations for wind changing direction
  - Measure load at stakes with spring scales, ensure not above mfg rating
- Customer requirement:
  - Stability with balloon in 20 m/s winds

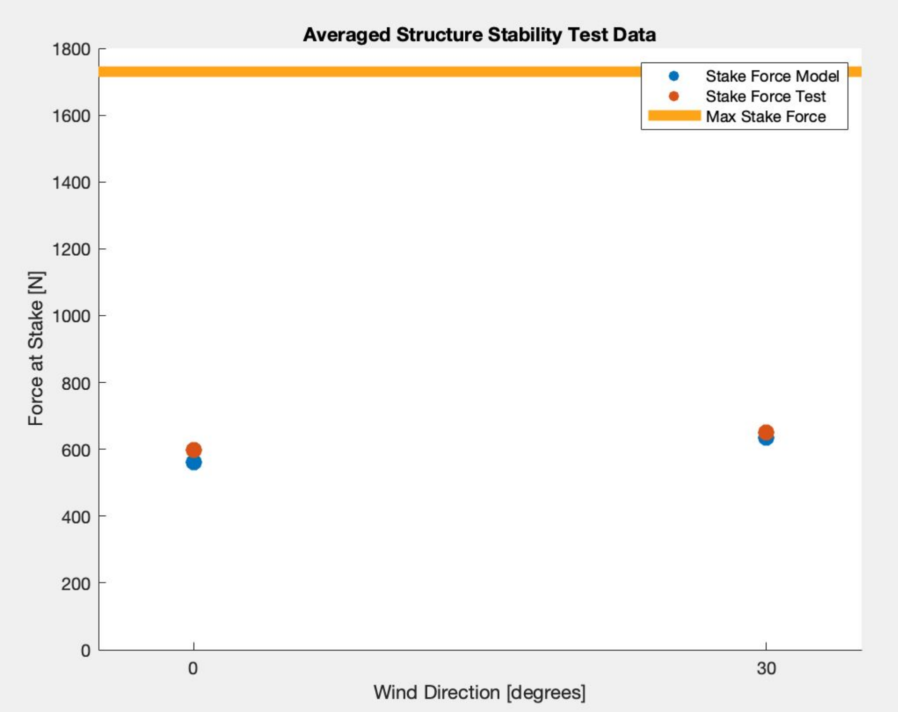
Test set-up:





Wind Load Test

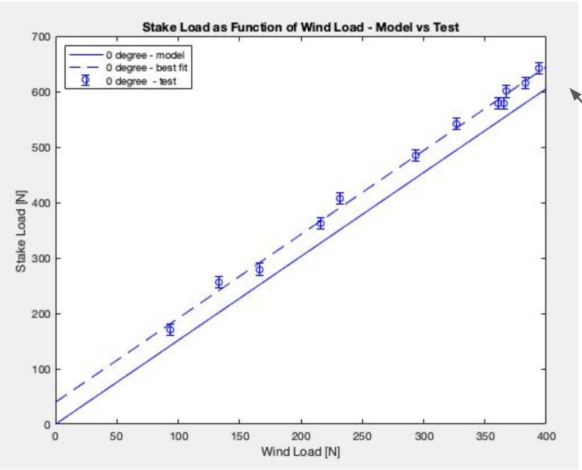
- Overall Results @ Max Wind Load Expected:
  - 3 trials at 0 deg and 3 trials at 30 deg:
    - Model matches test - see plot
    - Structure stayed upright
    - No component failures/bending
    - Max load at stake well below stake max rating
    - min FOS at 2.6
    - Meets Level III Success

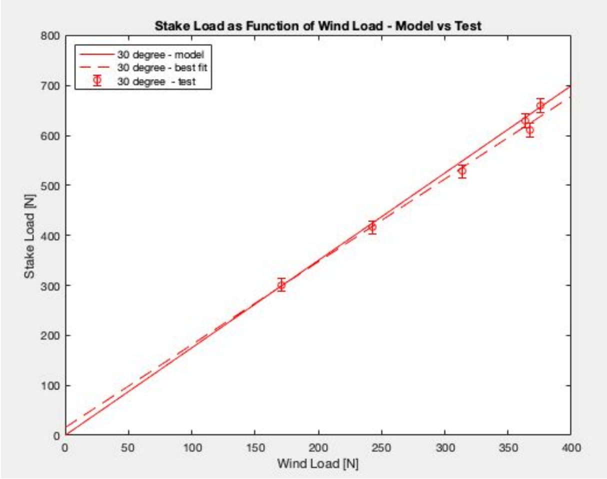


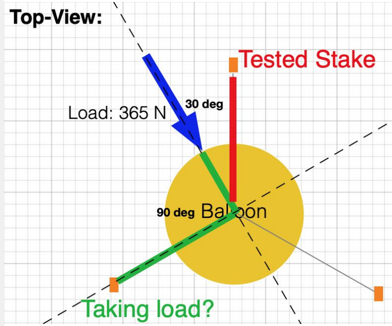
Test Results

Wind Load Test

- Results @ Range of Wind Loads:
  - Test data points shown alongside model line and best fit line
    - 0 deg standard deviation = 10.5N
    - 30 deg standard deviation = 13.5N
  - Model matches test data fairly well, 0 deg model low overall by ~40N
    - 40N is high end of tension in support before wind loading
    - Model assumed mast balancing with min tension in supports until load applied
  - Model very close in 30 deg model, but why isn't pre-tension showing up?
    - If not measured accurately (above 30 deg), another support line could be taking some load?
    - More testing to confirm-use single support to isolate w/ better angle finding

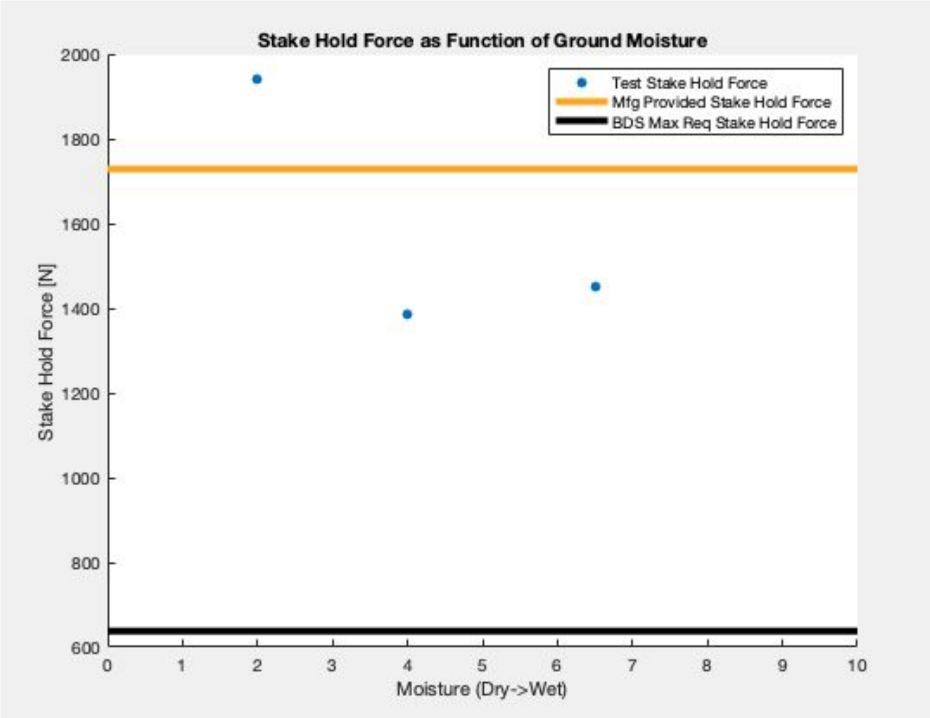






Stake Soil Test

- Validates: Stability in Wind
- Procedure:
  - Screw stake into soil (small anchors, large provided)
    - Same soil type w/ different amounts of moisture
  - Attach spring scale to screw eyelet
  - Attach opposite end of spring scale to ratchet tie down
  - Attach tie down to tree or truck hitch
  - Note load at pull-out
- Customer requirement:
  - Launch from multiple locations based on HYFLITS needs
- Results (ongoing):
  - Grass covered, dry soil:
    - Exceeded mfg load rating in dry conditions
    - Sufficient hold force in wetter conditions
  - Sand ~150N hold force, not feasible for launch
  - Small anchors tested. Large anchors are provided with system as well with 1.6x the hold force



Test Results

Balloon Loading Test

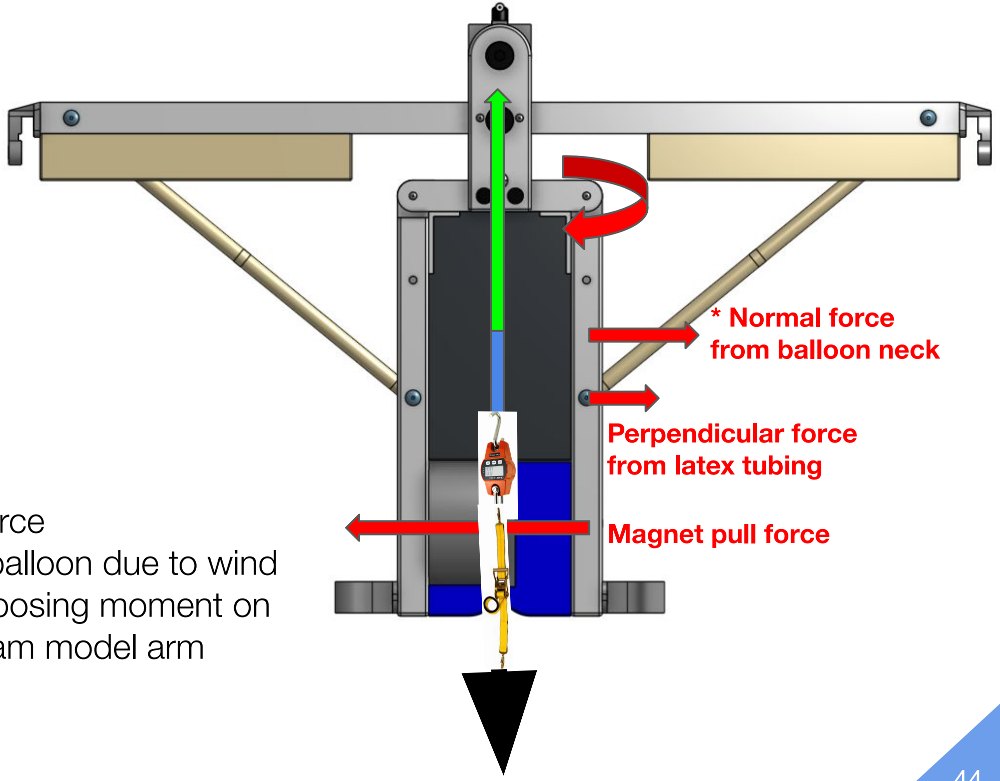
- Validates:
  - Ease of set up
  - No balloon damage
- Procedure:
  - Open release mechanism with one hand
  - Load and lock balloon in place
- Customer requirement:
  - Done by single user
  - No balloon damage
- Results:
  - Based on 10 trials on April 1, 2021:
    - Balloon loaded successfully each time by single user
    - Team, customer and bystander user trials conducted
    - No balloon damage
    - Learned importance of instructing user that venting valve must be facing away from mast
    - No need to remove surgical tubing on one side for loading
    - Level III success

Grip Strength Model

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

$$\therefore \boxed{\begin{array}{l}\text{Total Force Friction} = 2F_N \cdot \mu_s \\ \quad \text{where } F_N = \text{magnet weight rating}\end{array}}$$

- Total Grip Strength of 1,156 N
- Required Max Grip Strength 365 N
- Factor of Safety = 3.1



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

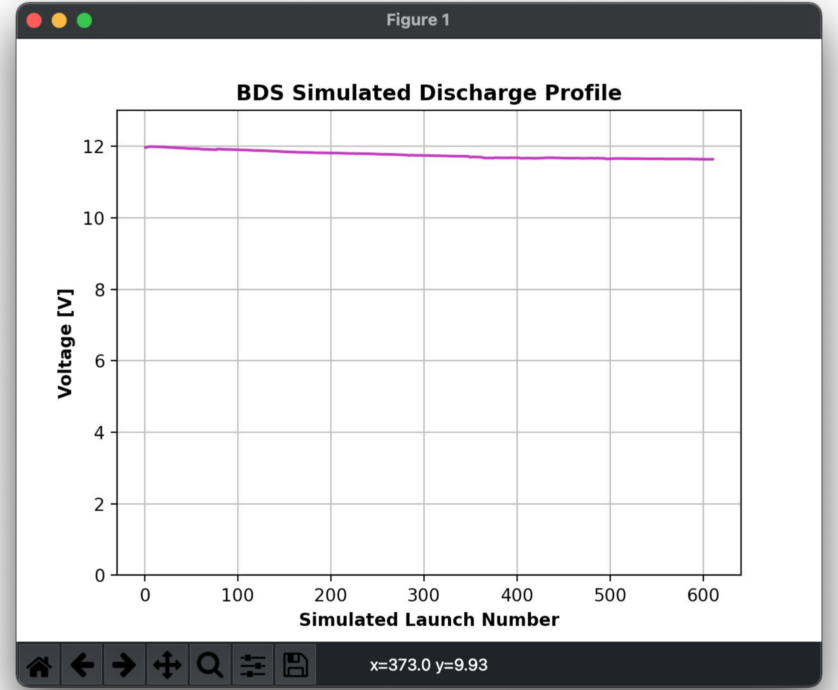
Grip Strength Test

- Validates:
  - No balloon damage
  - No premature release of balloon
- Procedure:
  - Place latex glove in release mech
  - Pull on release mech via latex glove @ 365N max wind load
  - Verify no pull out
- Customer requirement:
  - Hold balloon in 20m/s winds (F=365N)
- Results (ongoing):
  - Average F_{max}=590N
  - FOS=1.61
  - Limiting factor latex, not gripper
  - Rope wedging issue, reducing grip
  - Level III Success

Test Results

Current Test

- Validates:
  - Hands free release command
- Procedure:
  - Simulate launches while monitoring voltage
- Customer requirement:
  - Wireless system
  - Improved user experience
- Results:
  - Far surpassed requirements
  - Capable of more launches than needed



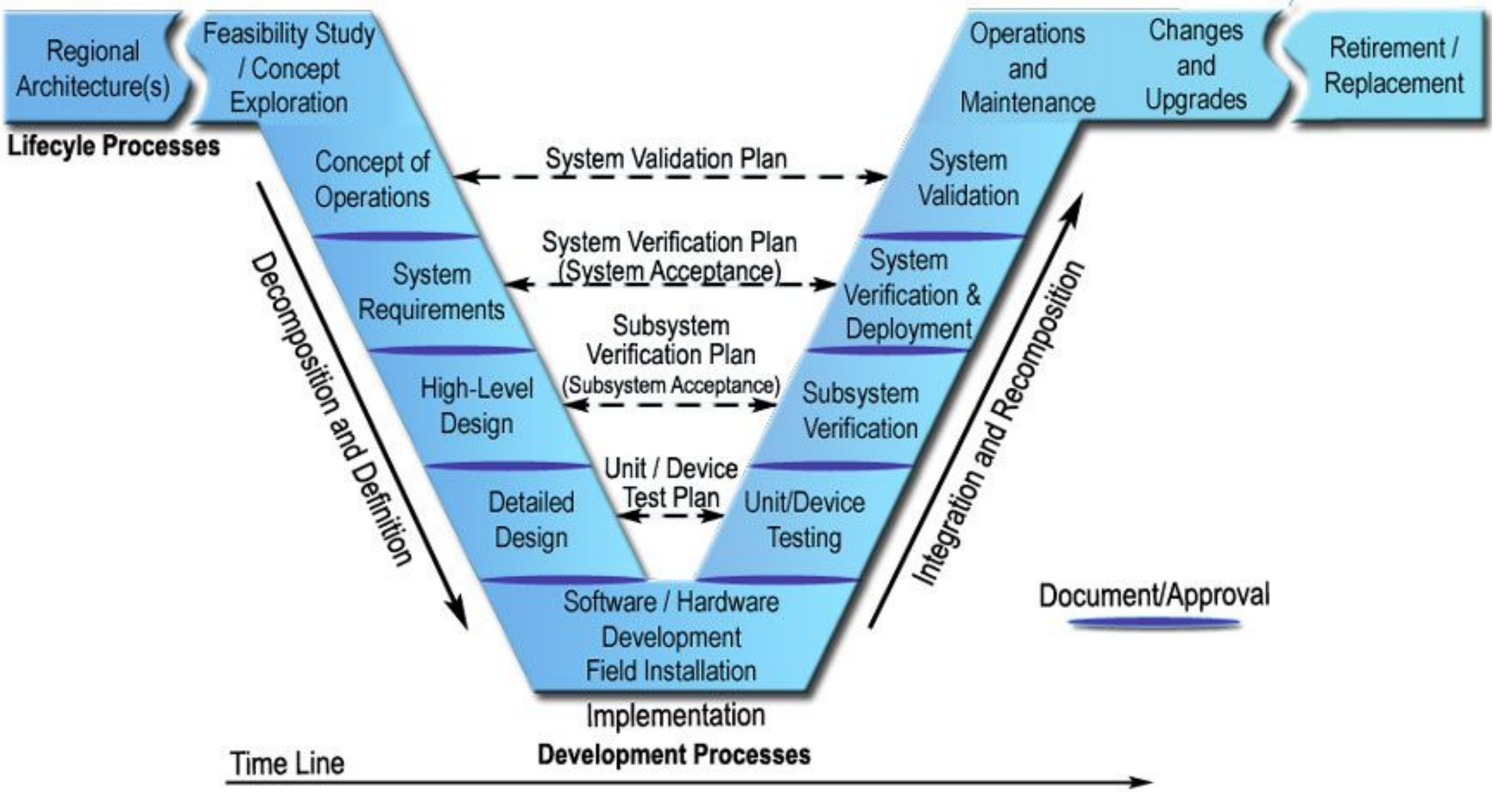
Balloon Launch Test

- Validates:
  - No balloon damage
  - No premature release of balloon
  - Hands free release command
- Procedure:
  - Load tethered balloon
  - Raise structure
  - Release tethered balloon w/remote
- Customer requirement:
  - Balloon flies away
  - No entanglements
  - Balloon/payload tether doesn't snag
- Results:
  - Based on 10 trials:
    - No balloon damage occurred
    - Balloon held securely
    - No snags or entanglements on release
    - Hands free release
    - Level III success

Systems Engineering

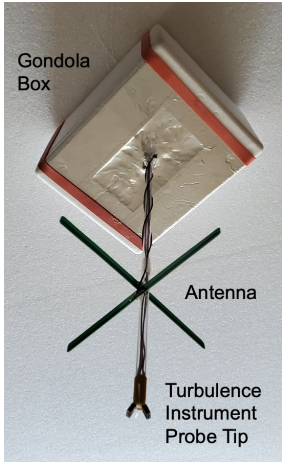
Systems Engineering

Overhead "V" Waterfall Design



Functional Objectives

- We aim to design, build, and test a high altitude balloon launcher for use in heavy winds to support 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.



Functional Requirements

FR	Description
1.0	One person shall be able to assemble/disassemble the BDS with no tools.
2.0	The assembly/disassembly shall takes less than 5 minutes to complete.
3.0	The structure shall collapse into a carrying bag of 1 m length and 25 cm diameter maximum.
4.0	The payload shall not hit the ground during setup or deployment.
5.0	If needed, capability to launch two balloons within one second of each other.
6.0	The BDS shall be made of heat resistant materials and have no sharp edges which might damage the balloon.
7.0	The BDS shall function in 10 m/s sustained wind with up to 20 m/s gusts.
8.0	Communication between the BDS and the release button shall be hands-free.
9.0	All systems shall be powered by battery.

Functional Objectives/Requirements

1) Balloon launcher for use in heavy winds, tall enough to keep payload safe, battery powered.

2) Pose no risk for balloon damage, be operable by a single user hands free and be easy to set up and transport.

FR	Description
1.0	One person shall be able to assemble/disassemble the BDS with no tools.
2.0	The assembly/disassembly shall takes less than 5 minutes to complete.
3.0	The structure shall collapse into a carrying bag of 1 m length and 25 cm diameter maximum.
4.0	The payload shall not hit the ground during setup or deployment.
5.0	If needed, capability to launch two balloons within one second of each other.
6.0	The BDS shall be made of heat resistant materials and have no sharp edges which might damage the balloon.
7.0	The BDS shall function in 10 m/s sustained wind with up to 20 m/s gusts.
8.0	Communication between the BDS and the release button shall be hands-free.
9.0	All systems shall be powered by battery.

Systems Engineering

Initial Design and Trade Studies

Release Mechanism Subsystem

Metric / Evaluation Criteria	Weight	Electromagnetic Clamp	Drawstring	Rubber Housing
Ease of set-up	0.15	9	7	10
Speed of set-up	0.05	10	8	10
Portability	0.2	7	10	4
Protection of Balloon Material	0.1	8	8	7
Grip Strength	0.25	10	4	10
Trigger Resiliancy	0.1	8	7	8
Energy Efficiency	0.05	8	7	6
Budget Availability	0.1	6	8	5
Total	1.00	8.35	7.10	7.60

Structure Subsystem

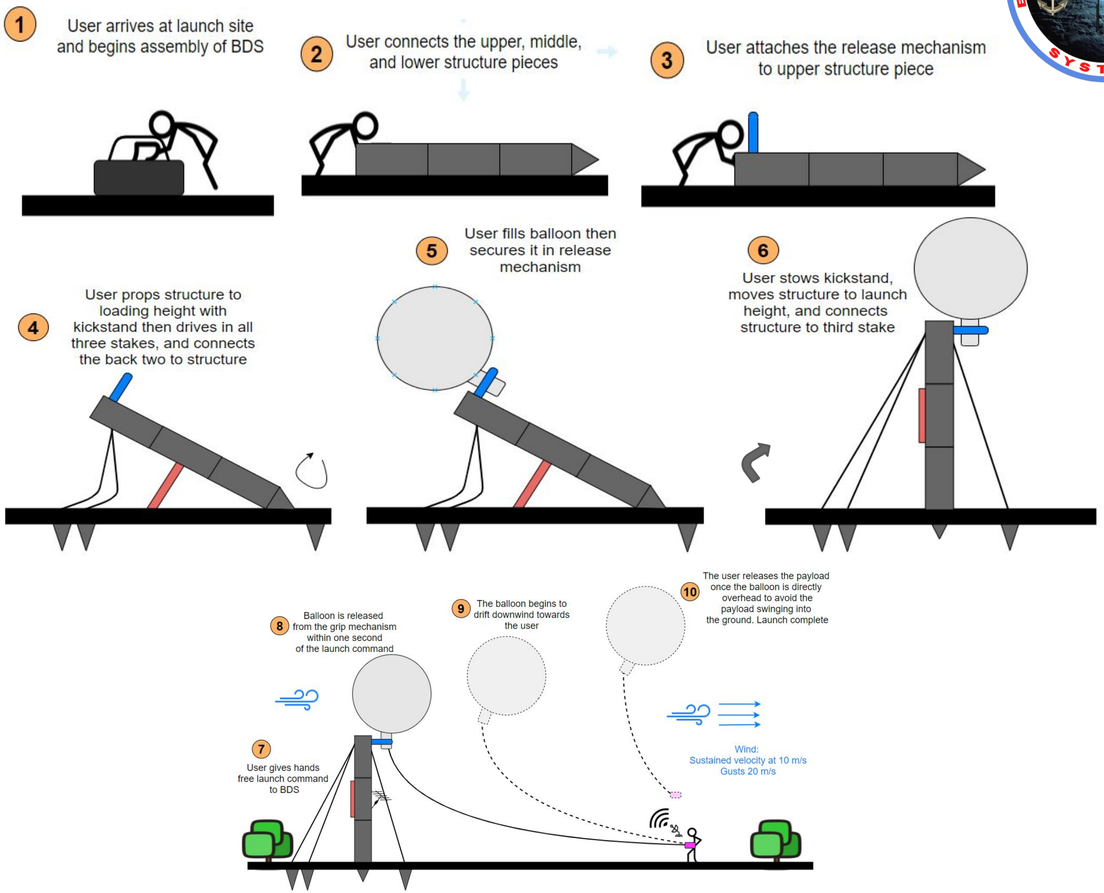
Metric / Evaluation Criteria	Weight	Telescoping Truss	Tent Pole Tripod	Tripod Style with Threaded Extension
Balloon/ Payload Safety	0.3	9	6	9
Weight	0.06	10	9	8
Ease of fit in Carrying Case	0.06	10	10	9
Inherent Stability	0.3	5	9	8
Feasibility of Build/Mfg/Off shelf	0.1	8	6	10
Ease of Setup / Configuration	0.15	10	7	10
Budget Availability	0.03	5	7	6
Total	1	7.9	7.5	8.8

Command and Control Subsystem

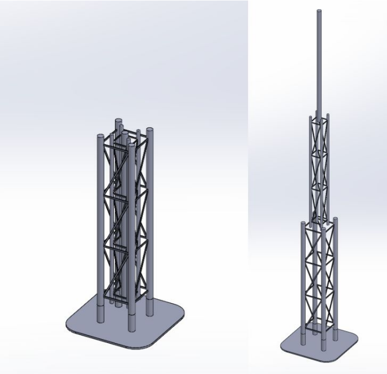
Metric / Evaluation Criteria	Weight	RF "Radio"	Bluetooth	Wired
Maneuverability and Distance	0.2	10	6	3
False Positive Resistance	0.3	10	10	10
False Negative Resistance	0.05	10	10	10
Simplicity, Current Knowledge	0.05	7	5	10
Ease of Setup / Configuration	0.25	7	5	3
Budget Availability	0.05	5	5	10
Off-the-Shelf Availability	0.1	6	3	10
Total	1	8.45	6.75	6.85

Systems Engineering

Concept of Operations



- Trade Studies Focuses
  - Ease / Speed of transport and setup
  - Stability in wind
  - Internal strength of structure
  - No premature release
  - No balloon damage
  - Hands free use



Initial Design and Trade Studies

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Risk Assessment

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

Systems Engineering

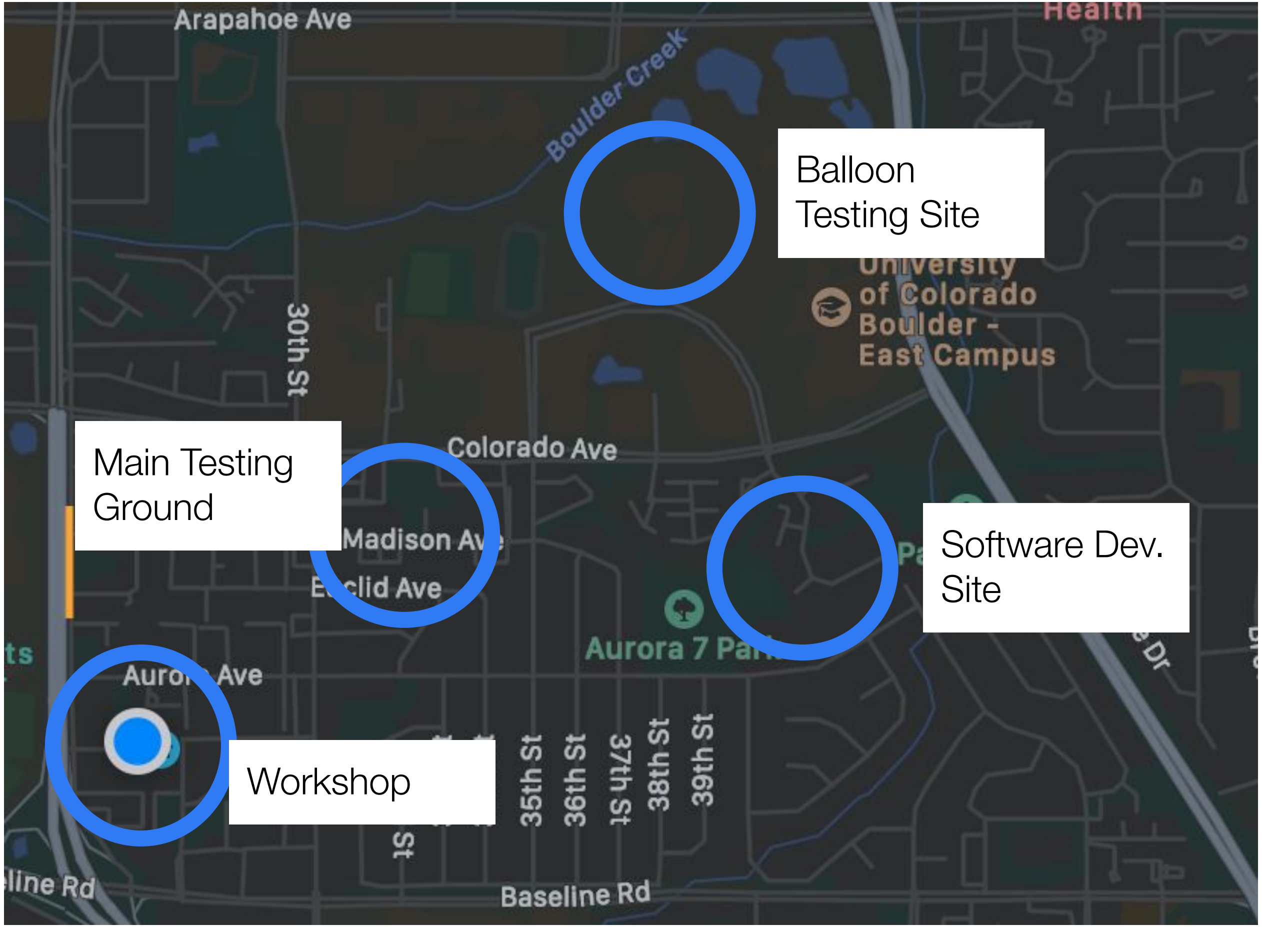
Challenges Encountered & Lessons Learned

- Challenges
  - Consistent measurements for stake placement
    - Template
  - Command & Control integration
    - Antenna hole
- Lessons Learned
  - Simple designs allow more time for iteration
  - Extensive testing can yield smooth integration
  - Communication is one of the most efficient ways to success

Project Management

Lessons Learned

Project Management



Commuters From Broomfield

Remote Students in China and New York

Lessons Learned

Aufa Amirullah
Software Engineer Lead

Peter Hurst
Head Structural Engineer

Matthew Konnath
Head Release Developmental Engineer

Jake McGrath
CEO / PM

Grant Norman
Assistant To The Project Manager

Patrick Paluszek
Red Team Lead

Jack Soltys
CFO

Kyler Stirewalt
Head Systems Engineer

Sebastian Urrunaga
Head Test Engineer

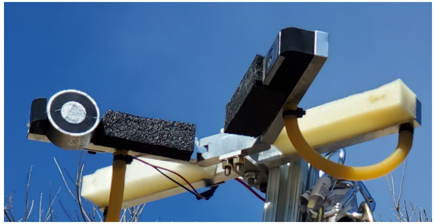
Chenshuo Yang
Structural Designer

Predicted Vs. Actual Costs

Subsystem	Predicted Cost	Actual Cost	Percent Change
System	$ 991.58	$ 950.06	-4.19%
Command and Control	$ 184.63	$ 207.52	12.40%
Release Mechanism	$ 306.42	$ 258.35	-15.69%
Structures	$ 409.88	$ 434.20	5.93%
Testing	$ 104.97	$ 1,239.39	1080.71%
Budget Total	$ 991.58	$ 2,545.31	156.69%

$740

$385



Cost to Customer

Included:

- BDS Shipped
- Carrying Case
- Research and Development
- Instruction and Use Manual
- Fabrication Manual
- Training Session

Hours Worked	Hourly Rate	Overhead	Materials	Customer Cost
1552	$ 65,000.00	200.00%	$ 1,753.63	**$ 153,135.93**
	$ 2,080.00		$ 40.00	
	$ 31.25		$ 52.19	
			$ 49.99	
			$ 24.99	
			$ 15.99	
			$ 3.62	
			$ 3.62	
			$ 28.99	
			$ 28.99	
			$ 28.99	
			$ 24.99	
			$ 489.32	
		Total:	**$ 2,545.31**	

Questions

Test Results

Back up slides:

Test Results

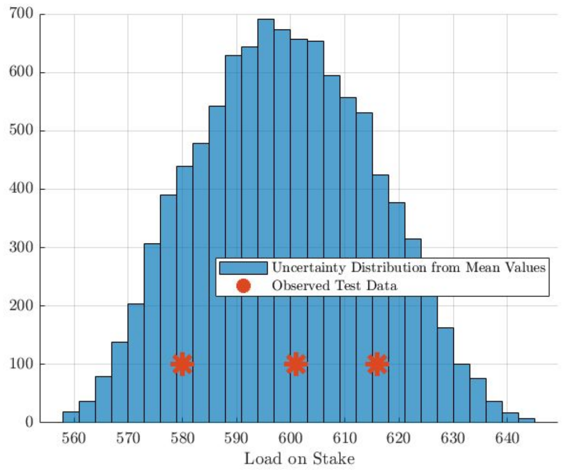
RF Range Test(more trials)

- Validates:
  - Hands free release command
- Procedure:
  - Walk away from release mech to set distances based on payload tether length
  - Test remote at each distance away
- Customer requirement:
  - Wireless System, 10-20m tether
- Results:
  - Range max per mfg: 40m
  - Remote battery not secure initially
    - Re-secured for subsequent tests
  - Range initially: 6m
    - Moved receiver antenna outside of box to increase range
  - Range currently: 19.5m

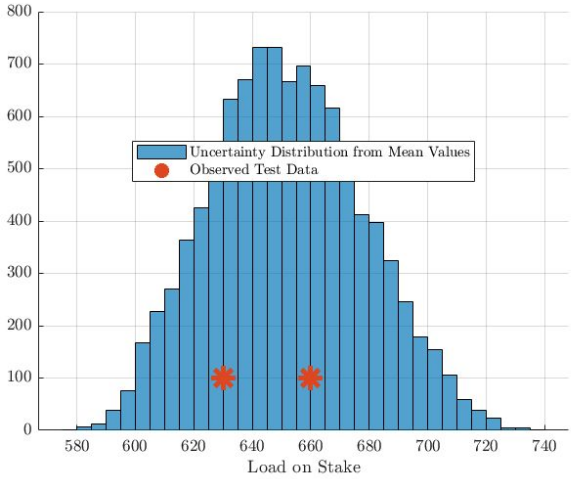
Wind Load Test

- Results against Monte Carlo Simulation:
  - Max load @ 20m/s and expected load at stake
  - Tested data points fall within Monte Carlo distribution to account for effect of random sampling of inputs based on uncertainty at both 0 and 30 degree config.

0 degree:



30 degree:



Test Results

Wind Load Test

- Other sources of error:
  - Tested forces slightly higher than modeled:
    - Letting system settle before reading stake load
      - go above required load
      - let settle back to required load
      - read stake load
    - Stretching in tie downs change geometry of model? (however should make tested load lower)
    - .88 N spring scale resolution
  - Overall:
    - model validated (w/ pre-tension in supports)
    - structure is stable

Date	3/2/2021	3/2/2021	3/2/2021	3/2/2021	3/2/2021	3/2/2021	
Angle (degrees)	0	0	0	30	30	30	
Wind Load (actual) [N]	361	383	367	346	364	376	
Expected Stake Load [N]	546	579	555	605	637	658	
Mfg Rated Stake Load [N]	1730	1730	1730	1730	1730	1730	
Tested Stake Load [N]	580	616	601	660	630	660	Avg Error:
% error	-5.88%	-5.98%	-7.66%	-8.28%	1.08%	-0.33%	-4.51%
FOS	3.0	2.8	2.9	2.6	2.7	2.6	