Balloon Deployment System

Test Readiness Review

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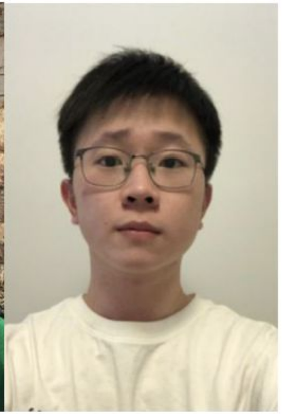
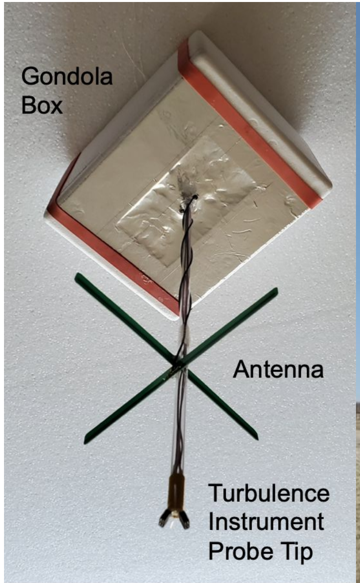

Chenshuo Yang
Structural Designer

Project Purpose and Objectives

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:

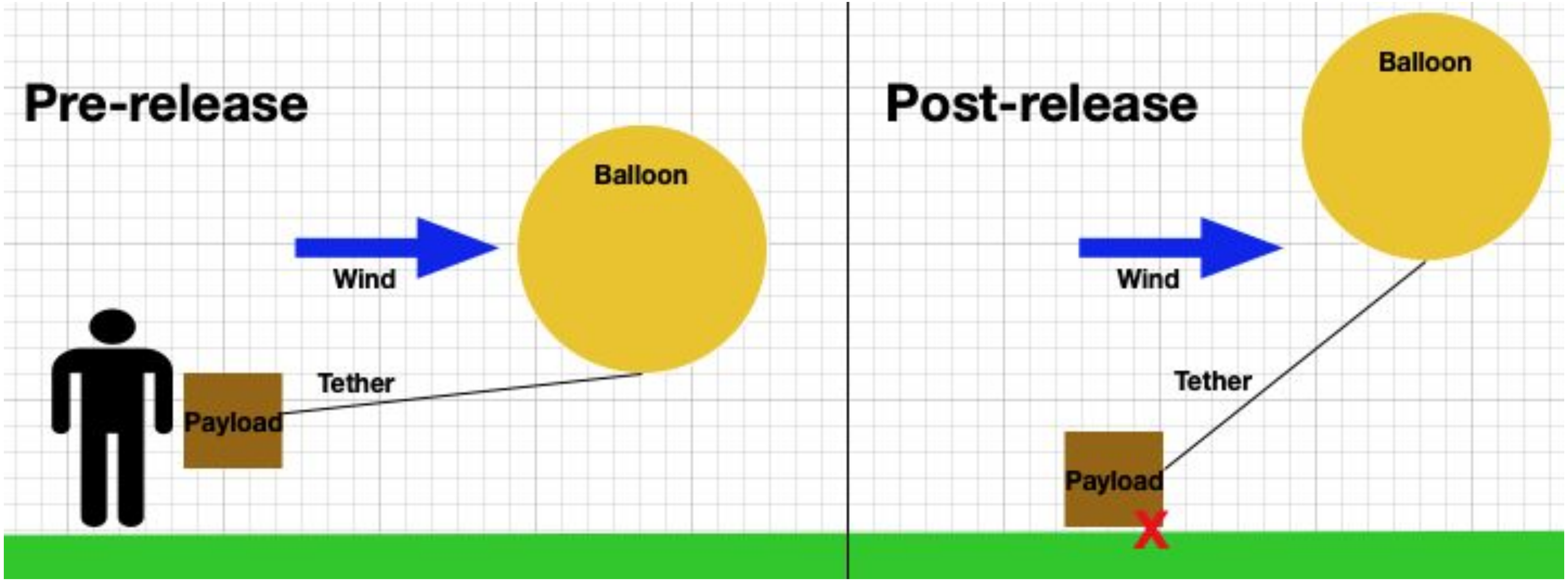


Balloon:

Project Purpose and Objectives

Current Problem

- Instrument payload hits ground

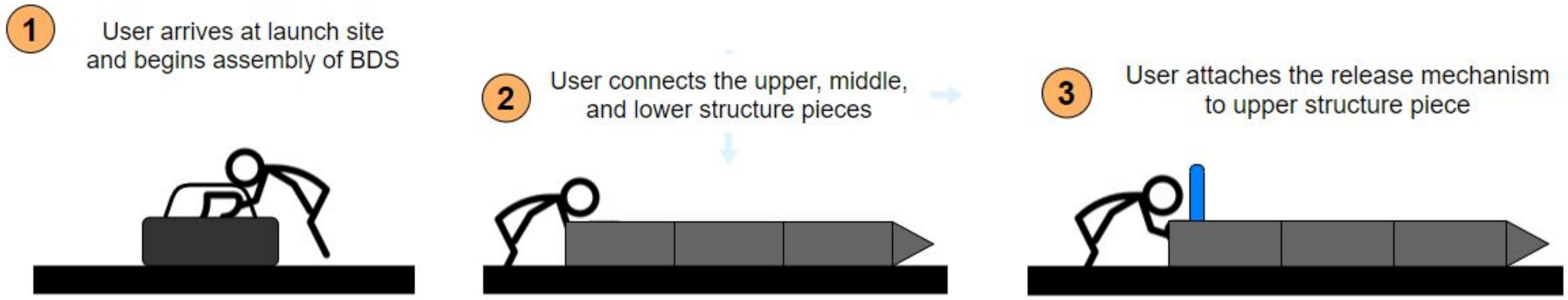


Project Purpose and Objectives
Customer’s Requirements

- 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

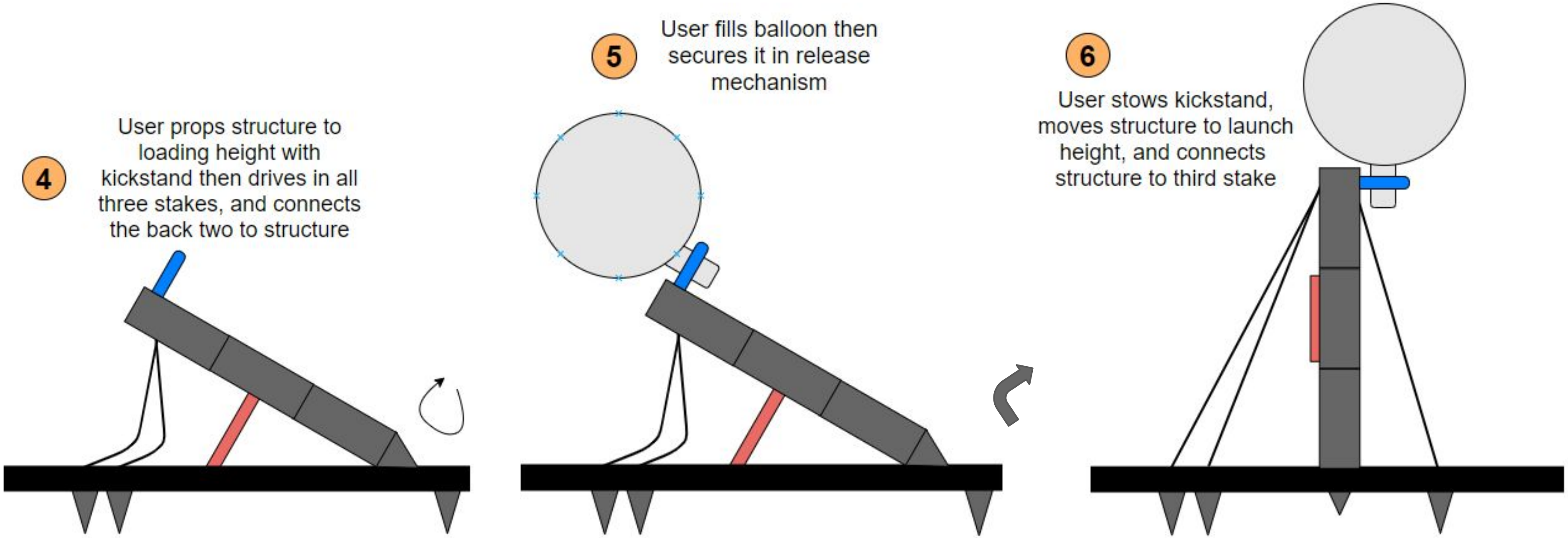
Project Purpose and Objectives

CONOPS



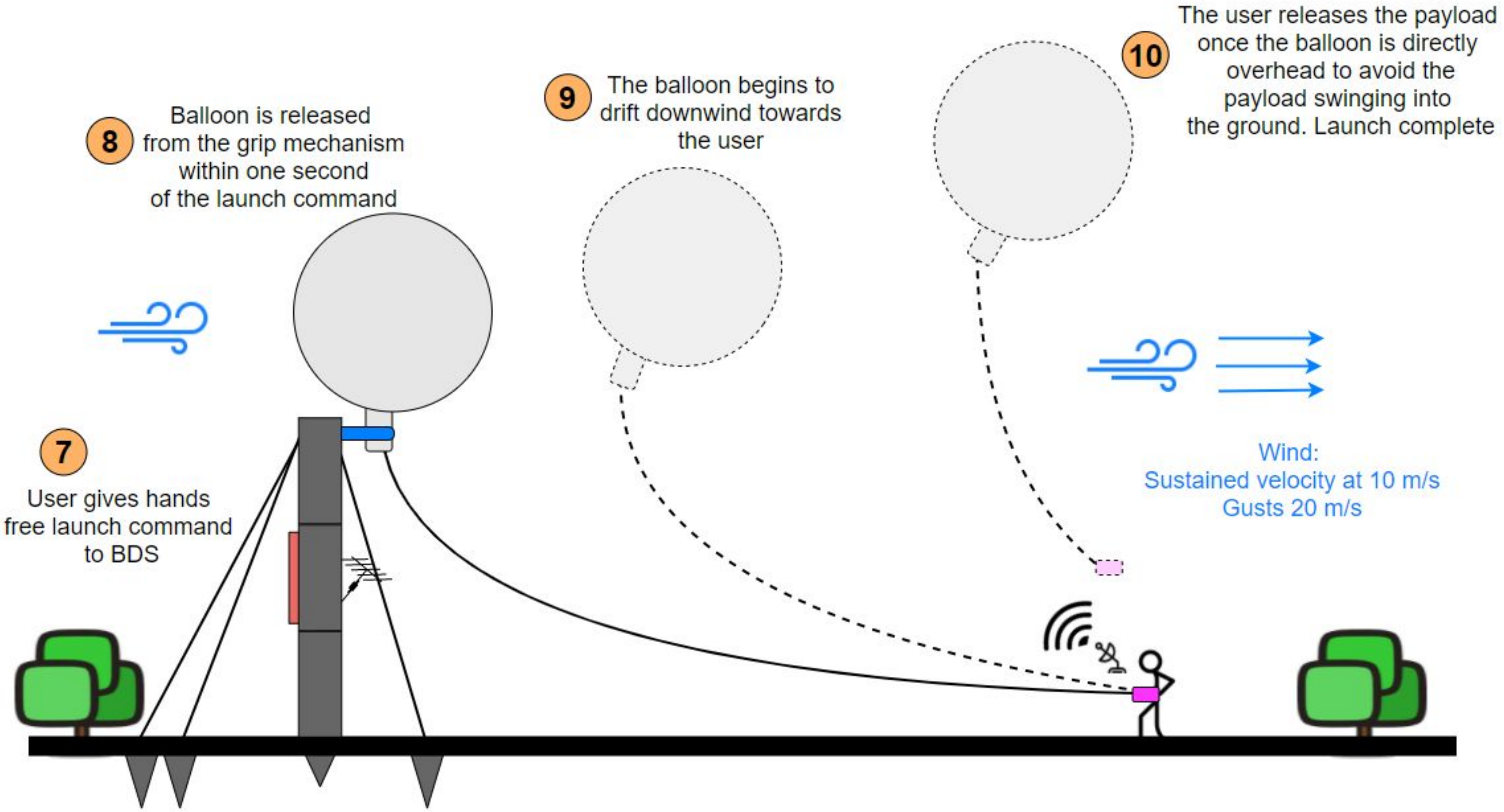
Project Purpose and Objectives

CONOPS



Project Purpose and Objectives

CONOPS



Project Purpose and Objectives

CONOPS

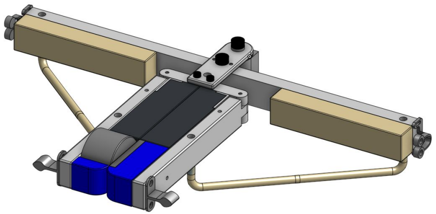
11 After confirmation of a successful launch, the user disassembles BDS and stores the system in the carrying case for departure

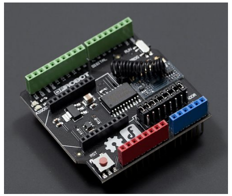
12 The user departs the launch site and is able to repeat this process for another launch when needed

Design Solution

Design Solution
BDS Subsystems

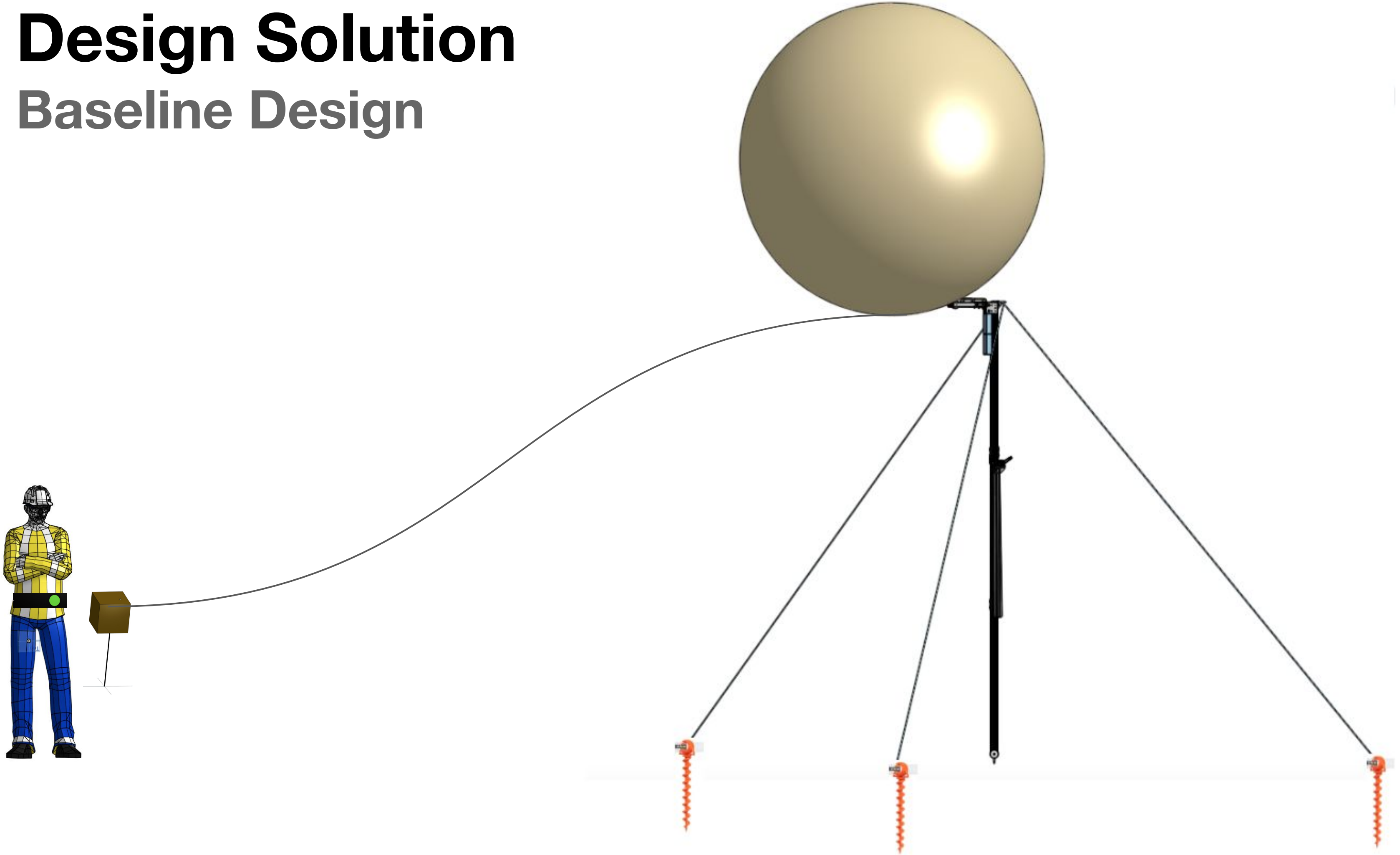
- Balloon Deployment System
  - Support Structure
    - Base
    - Extension
  - Release Mechanism
  - Command & Control
    - Transmitter
    - Receiver





Design Solution

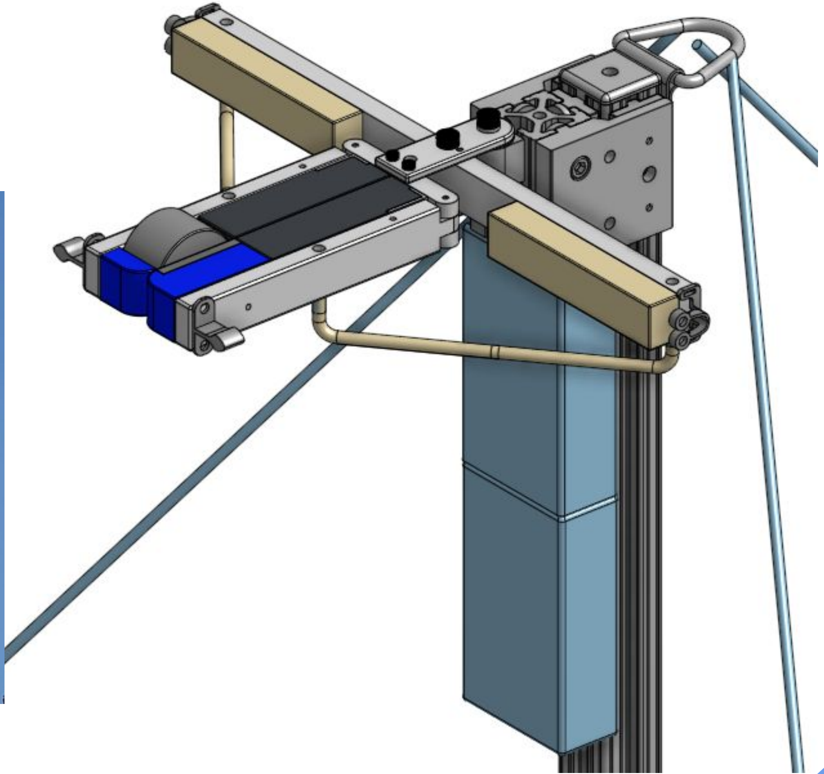
Baseline Design



Design Solution

Baseline Design

Design Solution
Release Mechanism



Design Solution

Updates

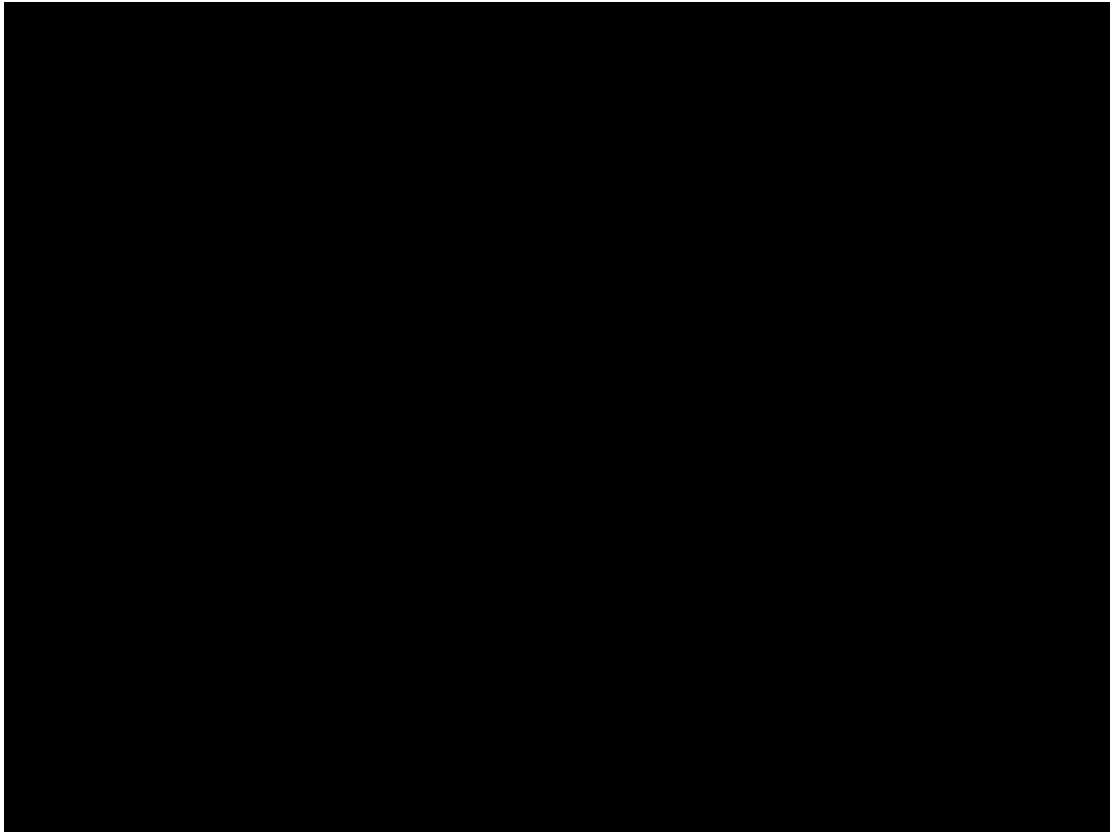
Knob Bolts: No tools req

Tie-Down Mgmt: Velcro straps to avoid tangles

Stake Safety: Turn and thread into base for storage/travel

Stake Placement: Rope/ring template for speeding up stake/tower set up (red)

Timelapse



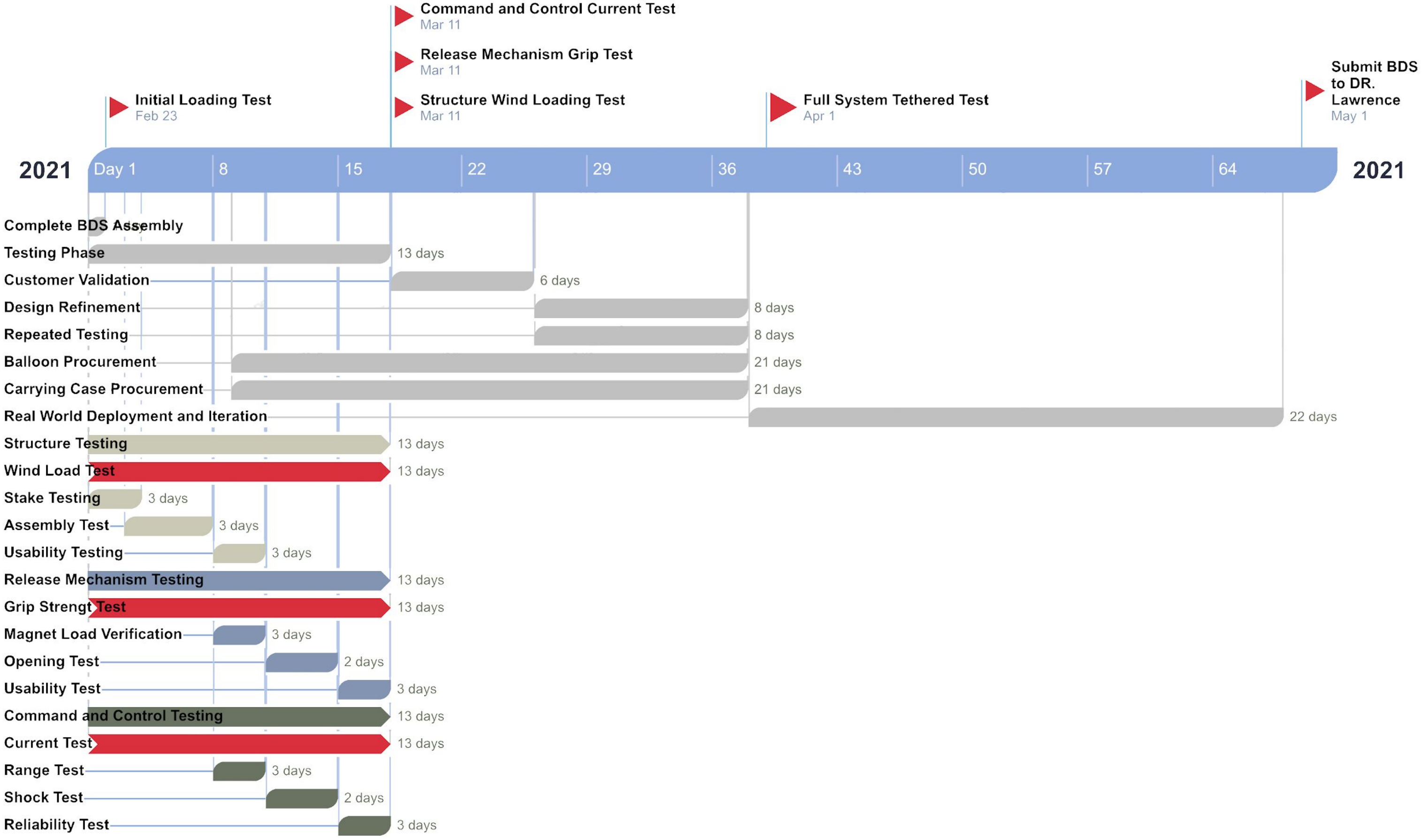
Critical Project Elements

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

Testing Schedule

BDS Spring Schedule

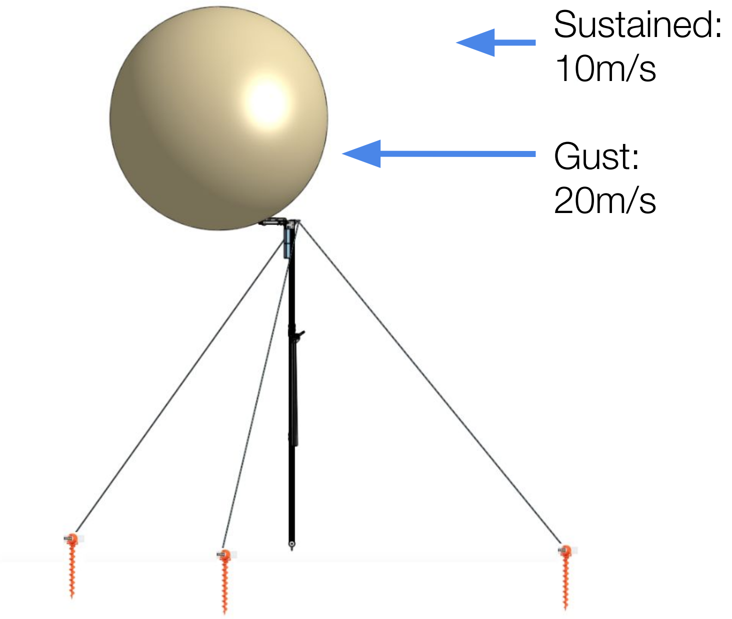


*Schedule Beginning At Test Phase

Test Readiness

Wind Load Model - Max Forces
Support Structure

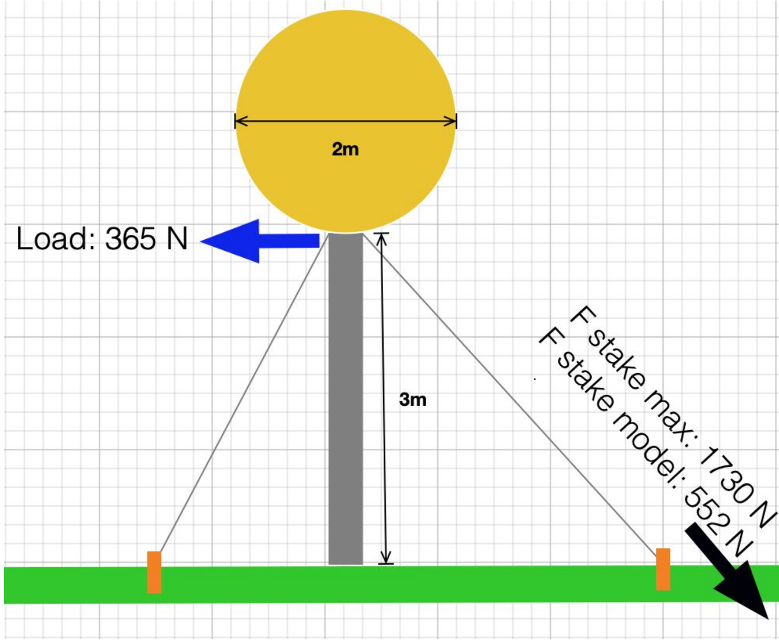
- Test to Confirm Stability in Wind
  - Test forces in supports to ensure:
    - Structure does not fall
    - Below mfg max
    - Enough support for stability
  - Highest forces expected for modeling:
    - Max Wind Sustained: 20 m/s
      - Model balloon as sphere
      - mass=3.689 kg (latex+helium)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



Wind Load Model - Moments

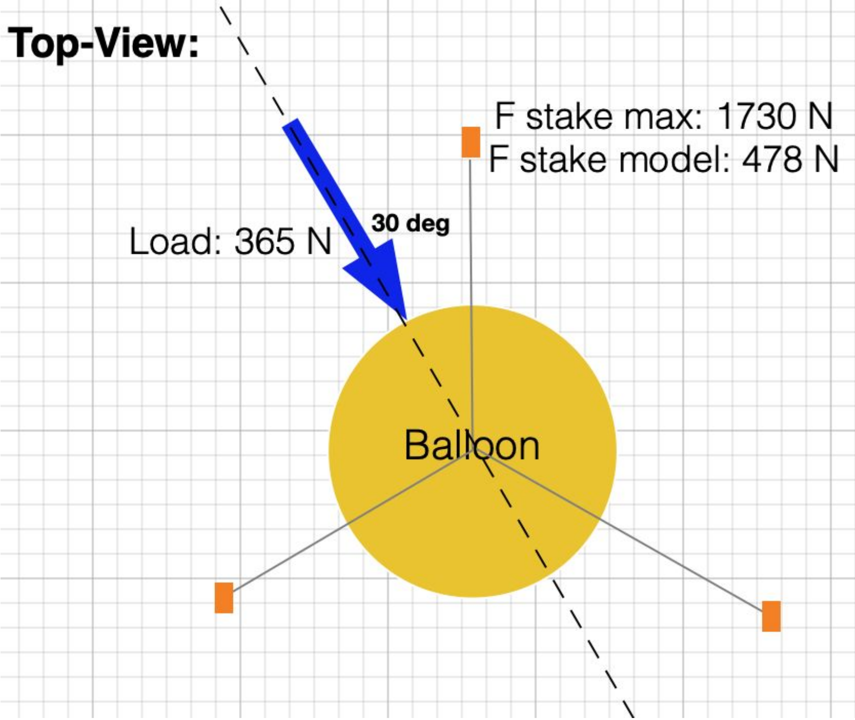
Support Structure

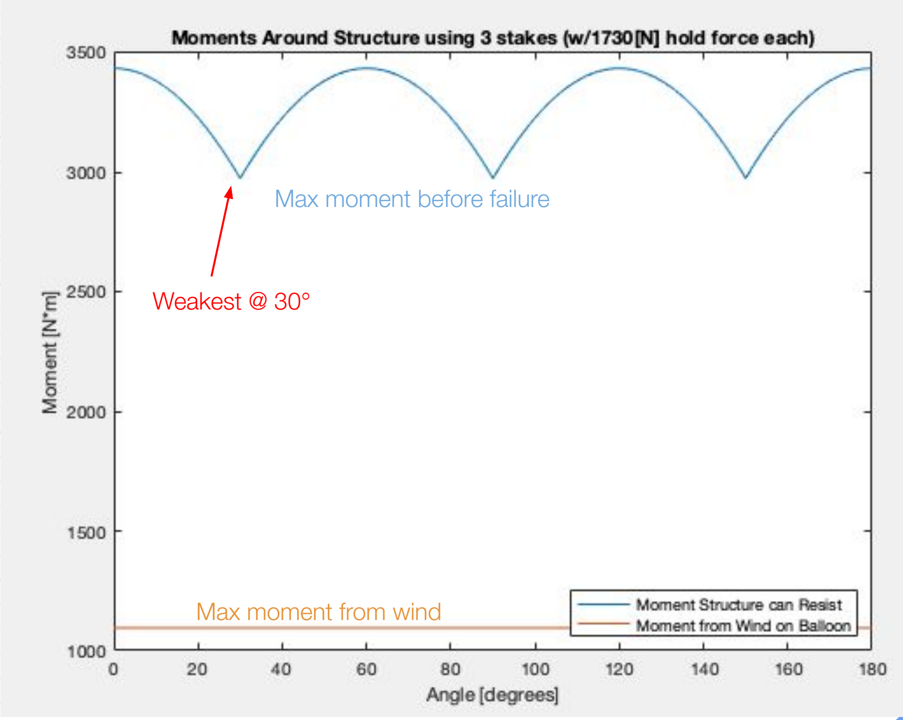
- Stability in Wind
  - Large moment to resist:
    - Wind Load: 365 N
    - Height: 3m
    - Moment_{wind}=1095 N*m
  - Ensure force at stake not above rating:
    - $F_{tie\text{-}down}$=2225N
    - $F_{stake\ @45}$=1730N
    - $F_{support}$=552N (wind coming directly on support)
    - FOS=1730N/552N=3.1



Wind Load Model - Wind Direction

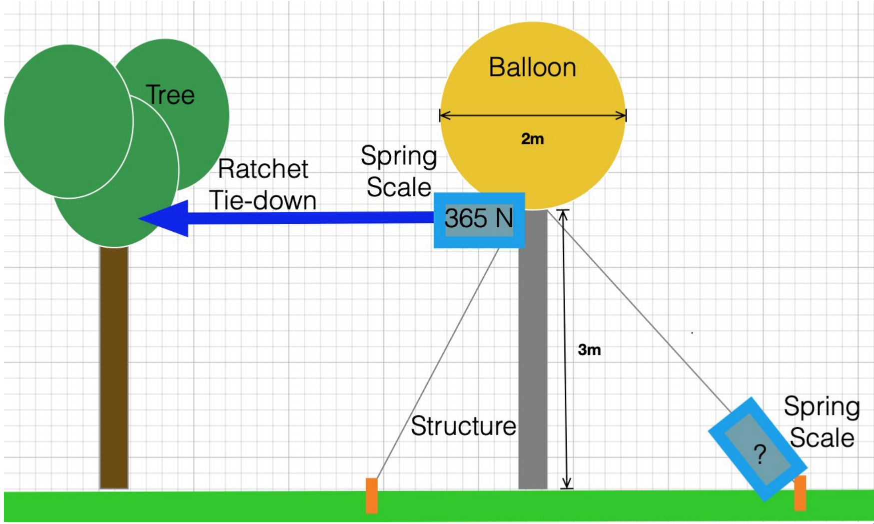
Support Structure





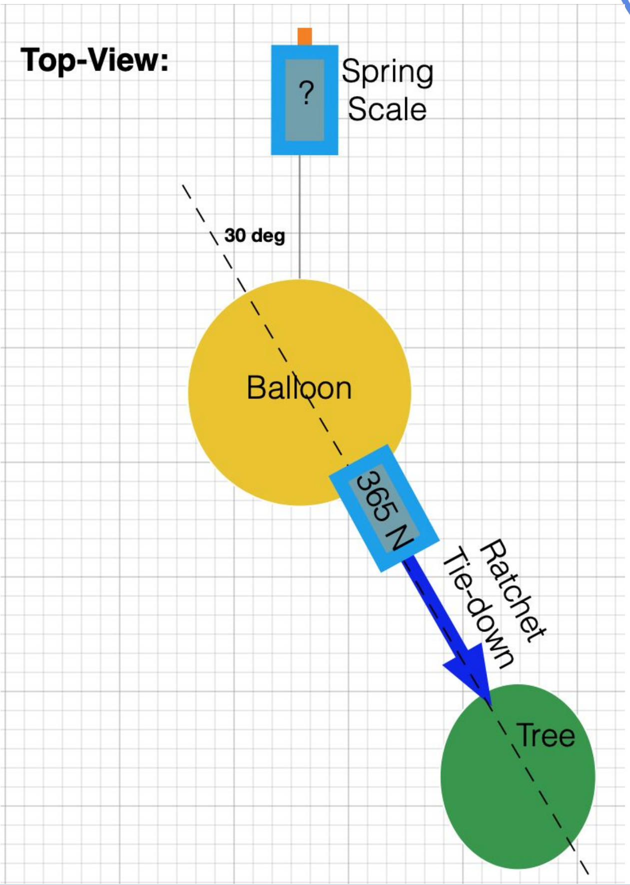
Wind Load Test

- *Rationale:* Simulate wind load acting upon structure. Verify modeled values and ensure stability
- *Equipment and Facilities*
  - Wooden dummy structure w/d-ring
  - 3 tie downs
  - 2 spring scales
  - 1 ratchet tie down (loading)
  - 1 solid tree
- *Procedure Overview*
  - Set up structure with stake @ 0 and 30 deg opposite tree, scale at stake
  - Ratchet tie down with scale between tree and top of structure
  - Simulate max load via ratchet, record value



Wind Load Test

- *Risk Reduction*
  - Confirm stake/tie-down/hardware strength
  - Confirm structure stability
- *Expected Results*
  - Structure will remain upright
  - Stakes/tie down will remain grounded/secured
- *Models to be Validated:*
  - Stake load at 0 degrees (Strongest)
  - Stake load at 30 degrees (Weakest)



Wind Load Test

- *Test Status:* In Progress
  - Structure stayed upright at max load
  - No pull out or failures
  - Tested load well below mfg max rating
  - At weak 30 deg config, sufficient support
  - FOS_{actual}=3.6=1730 N/480 N

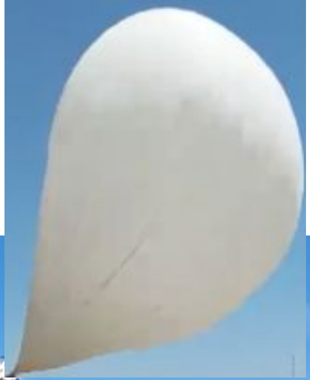
	0 degree	30 degree
Wind Load (actual)	374 N	350 N
Expected Stake Load	565 N	458 N
Mfg Rated Stake Load	1730 N	1730 N
Tested Stake Load	450 N	480 N

Wind Load Test

- *Test Status:* In Progress
  - Testing Discrepancy Improvements:
    - More precise angle measurement
    - Use actual structure (not dummy)
    - Pre-stretch tie-downs
    - Drive stakes further into the ground (less bending)
    - Measure slack in tie-downs and stake bending
      - Incorporate into updated models

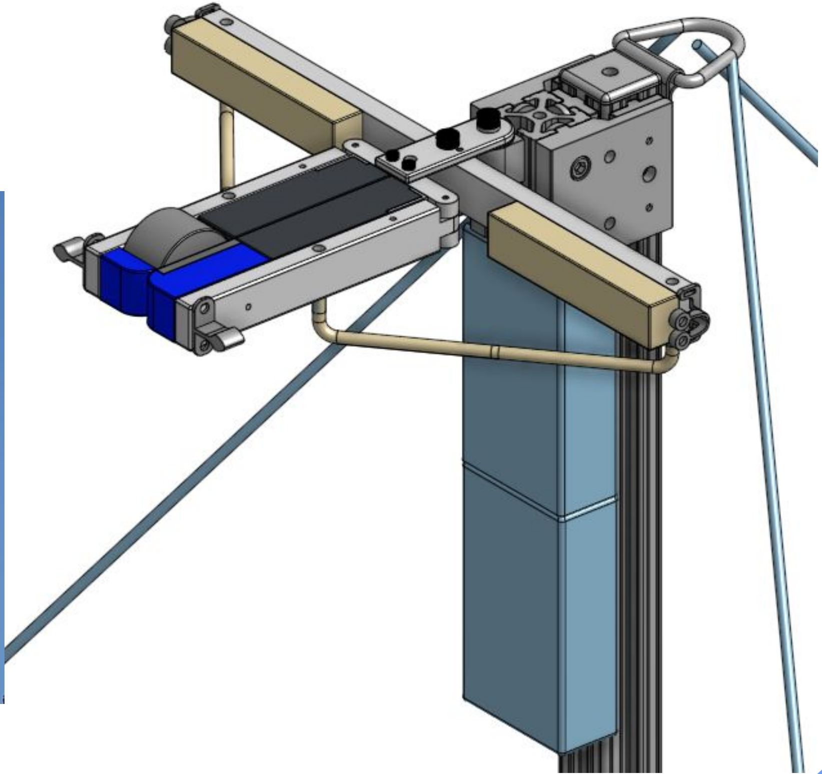
Design Solution

Baseline Design



Design Solution

Release Mechanism



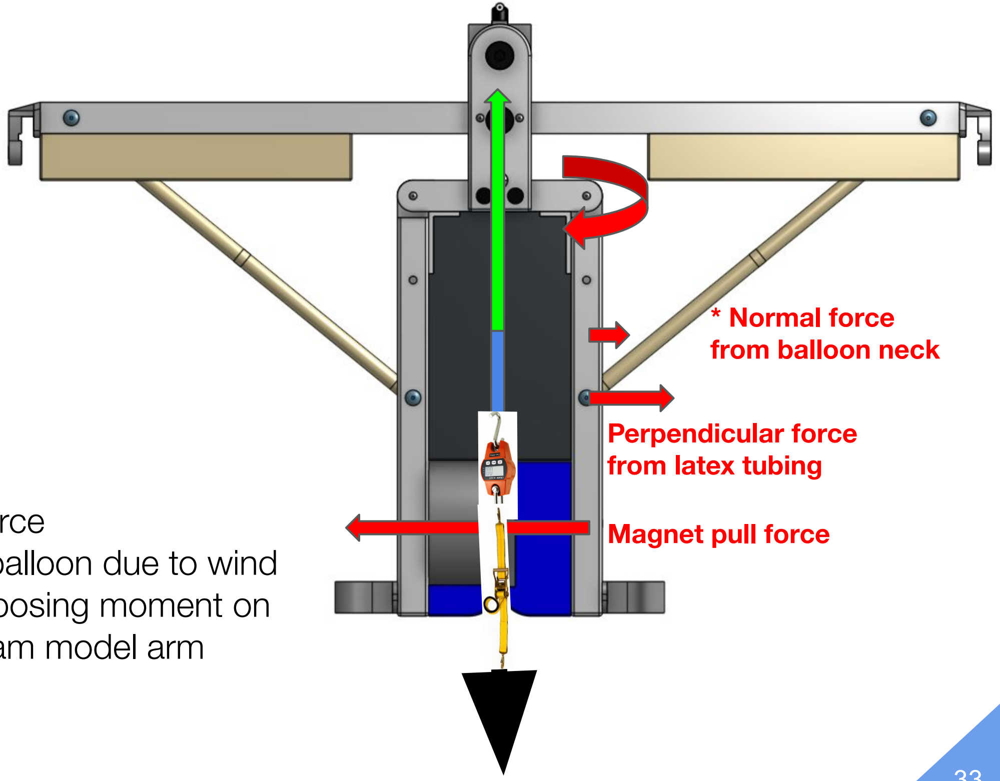
Release Mechanism - Grip Strength Model

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

$\therefore$ Total Force Friction = $2F_N \cdot \mu_s$

where F_N = magnet weight rating

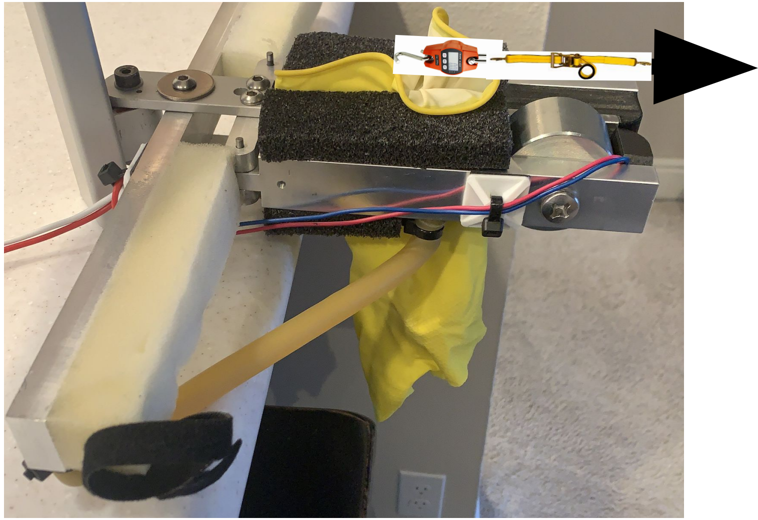
- Total Grip Strength of 1,188 N
- Required Grip Strength 365 N
- Factor of Safety = 3.1



- Friction Force (green)
- Force on balloon due to wind (blue)
- Forces imposing moment on simple beam model arm (red)

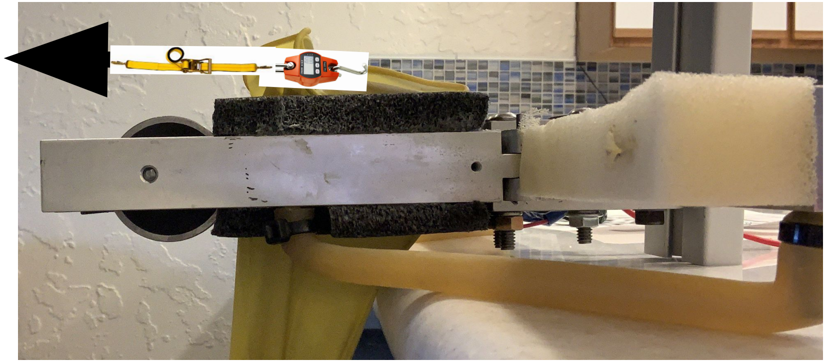
Release Mechanism - Grip Strength Test

- *Rationale*
  - Provide quantitative factor of safety of the holding force
  - To ensure no premature release of balloon
- *Equipment and Facilities*
  - Release Mechanism
  - Dish washing glove (Latex rubber)
  - Ratchet straps
  - 8020 Bar
  - Vise and Clamp
  - Spring Scale
  - Safety Glasses



Release Mechanism - Grip Strength Test

- *Procedure Overview*
  - Secure release mechanism to 8020 Bar in vise grip
  - Insert glove into the release mechanism
  - Engage the magnet
  - Attach spring scale to glove
  - Attach to ratchet strap to the spring scale
  - Clamp ratchet strap
  - Increase load with ratchet strap



- *Test Status*
  - Preliminary tests with the R.M. subsystem have exhibited that the friction force can hold the glove in place when a horizontal load is placed
  - Release mechanism is awaiting rigorous testing of grip strength capabilities

Command & Control - Current Test

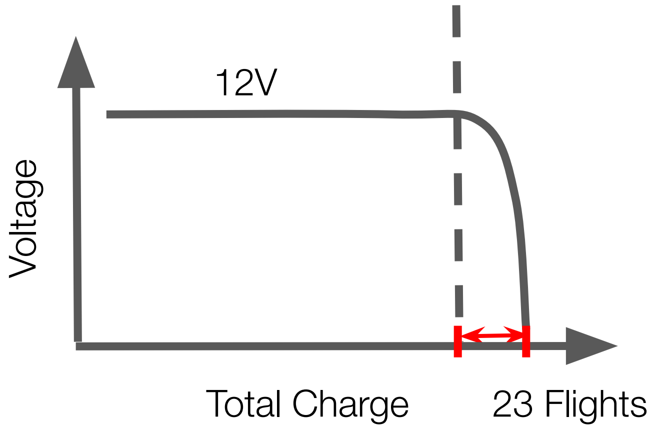
Component	Voltage (V)	Current (A)	Power (Watts)	Time On (Minutes)	Charge (A-Hr)	Number of Launches
Arduino Uno	12	0.2	2.4	5	0.017	
Electromagnet Gripper	12	3.25	39	5	0.271	
RF Board	5	0.01	0.05	5	0.001	
RF Rx	5	0.01	0.05	5	0.001	
1 Speaker with 12V Battery	12	0.01	0.12	0.5	0.000	
4 Channel Relay Shield for Arduino	12	0.01	90	5	0.001	
Rx Total					0.290	23.442
Rechargeable Battery Pack	12	6.8			6.800	23.442

Command & Control - Current Test

- *Rationale:* Verify Current Draw on Power Budget
- *Equipment and Facilities*
  - Multimeter
  - Completed Command and Control System
- *Procedure Overview*
  - *Connect Amp Probe in series with battery*
  - *Monitor Battery Voltage*
  - *Measure the current and duration of current draw for each button press, and for a launch cycle*
  - *Repeat and plot results*

Command & Control - Current Test

- *Risk Reduction*
    - *Reduce risk of unexpected battery failure*
- *Expected Results*
    - *Battery discharge profile*
    - *Audio feedback when power is low*
- *Models to be Validated*
    - *Predicted 12V Battery pack discharge profile*
    - *Power Budget*
- *Test Status*
    - *Incomplete*



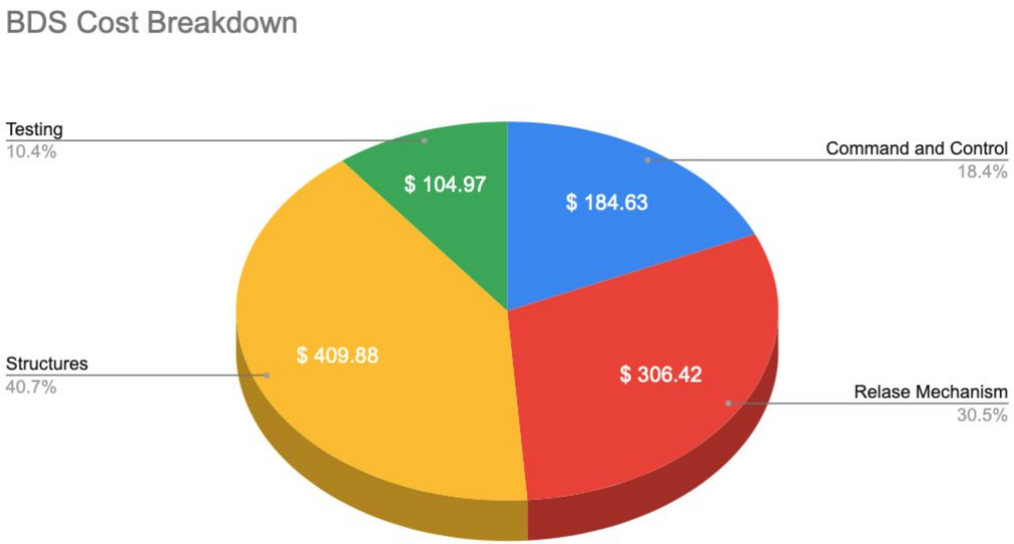
Budget Status

Previous Budget Status

- Purchased 100% of prototype materials
- $941.59 of $5,000 or 18.8%

Current Budget Status

- Purchased 100% of prototype materials
- $1005.90 of $5,000 or 20.1%



Acknowledgements

Dr. Dale Lawrence
Customer

Matt Rhode
Advisor

Dr. Jelliffe Jackson
Instructor

Appendix

Screw-in Stake Test

- *Rationale:* Verify hold force of ground stakes
- *Equipment and Facilities:*
  - Strong tree w/soil and sand nearby
  - Tape measure
  - Spring scale
  - Ratchet tie down
- *Procedure Overview:*
  - Wrap tie down @ 75 in from ground on tree
  - Screw in ground stake @ 66 in from tree base
  - Hook tie down from tree to spring scale
  - Hook scale to stake
  - Ratchet tie down until 537N reached on spring scale

Screw-in Stake Test

- *Risk Reduction:*
  - reduce chance of pull-out/collapse
- *Expected Results:*
  - Stake rated @ 1730N @ 45°
  - No pull out @ 640N (max load)
- *Models to be Validated:*
  - Manufacturer stated stake hold force
  - Stake ability to hold at max wind load
- *Test Status:* Completed
  - Complete
    - Required: 640 N
    - Soil Tested: 726 N
    - Sand Tested: Fail

Structure Assembly Test

- *Rationale*
  - Determine the feasibility of assembly w/single user
- *Equipment and Facilities*
  - 3 tower bars w/connections
  - Allen key
  - 3 meter height space
- *Procedure Overview*
  - Lay all three 1 m 8020 bars
  - Slide bar into junction bracket
  - Tighten bolts
  - Open kickstand
  - Place structure in load configuration

Structure Assembly Test

- *Risk Reduction*
  - Analyzes steps needed to assemble
  - Determine efficiency of assembly
- *Expected Results*
  - Assembly by one person
  - Time: Under 5 minutes
- *Models to be Validated?*
  - CONOPs assembly of tower
- *Test Status: Completed*
  - Difficult to align both bolts when sliding tower together
    - One piece bolt on order, will stay aligned
  - Remove allen key requirement
    - knob bolts on order
  - Kickstand L-brakes need adjusting once upright

Tower Raising Test

- *Rationale*
  - Test single user structure staking and raising
- *Equipment and Facilities*
  - Dummy structure (before machining done)
  - Tie downs
  - Stakes
  - Grass/soil covered ground
- *Procedure Overview*
  - Measure tie-downs, adjust to length
  - Measure location of base of structure/stakes
  - Screw stakes into ground
  - Attach 2 tie-downs to structure and stakes
  - Raise tower and attach last tie down

Tower Raising Test

- *Risk Reduction*
    - Ensure structure can be raised by one person
- *Expected Results*
    - User can raise structure single handedly
    - Structure secure once erect
- *Models to be Validated*
    - CONOPs of structure staking and assembly
- *Test Status:* In progress
    - User raised structure without balloon (complete)
    - Structure secure without wind
    - Need: actual structure with release mech + dummy balloon

Release Mechanism - Magnet Strength Test

- *Did the manufacturer give us a faulty magnet*

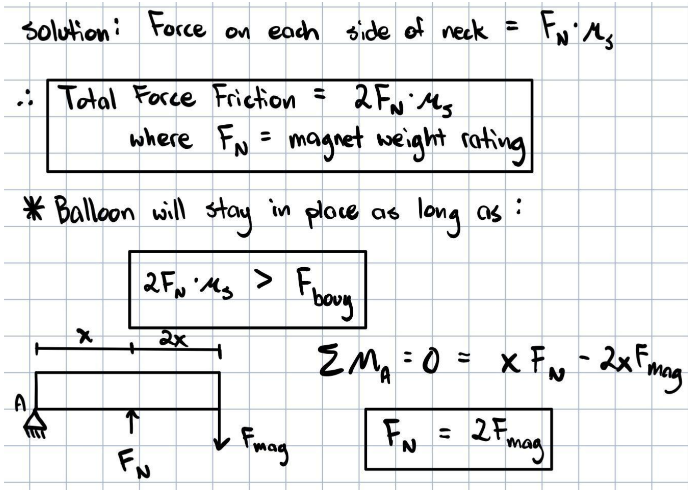
Release Mechanism - Grip Strength Model

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

$\therefore$ Total Force Friction = $2F_N \cdot \mu_s$

where F_N = magnet weight rating

Release Mechanism - Grip Strength Model



High Level Functional Tests

Release Mechanism - Loading Test

- *Rationale*
  - Single person launch requirement
- *Equipment and Facilities*
  - Release mechanism, balloon, and structure (top piece)
- *Procedure Overview*
  - The balloon shall be placed into the release mechanism and locked in place

Release Mechanism - Loading Test

- *Risk Reduction*
  - Loading procedure is simple enough to be performed by one person
  - Ensuring fingers won't be pinched
- *Expected Results*
  - The balloon can easily be loaded with no harm
- *Models to be Validated*
  - No models, test is primarily for ease of use
- *Test Status*
  - Dry assemble of release mechanism has shown a single person can load a balloon successfully
  - Easy of use requirement still needs to be tested with the full assembly

Release Mechanism - Opening Test

- *Rationale*
    - Ensure release mechanism arms clear venting valve
- *Equipment and Facilities*
    - Release mechanism
    - Slow motion recording
    - 8020 secured in vise
- *Procedure Overview*
    - Arm release mechanism
    - Power magnet to release swinging arms
    - Record process from above and side in slow motion using an iPhone™

Release Mechanism - Opening Test

- *Risk Reduction*
  - Ensure venting valve will not become damaged during launch
  - Ensure arms will latch upon opening
- *Expected Results*
  - Arms should open 16° in 0.26 seconds
- *Models to be Validated*
  - Rotational kinematics model using simple mass moments of inertia
- *Test Status*
  - Awaiting assembly of release mechanism

Command & Control - Timing Test

- *Rationale*
  - *Optimize arm and disarm user-interfaces*
- *Equipment and Facilities*
  - *Command and Control Equipment + Electromagnet*
- *Procedure Overview*
  - *Walk through the launch procedure with various user-interface timing/feedback schemes*
  - *Determine the preferred user-interface scheme for launching*

Command & Control - Timing Test

- *Risk Reduction*
  - *Reduces risk of user error*
- *Expected Results*
  - *Selected parameters*
- *Models to be Validated*
  - *Software and hardware logic*
- *Test Status*
  - *In progress*

Command & Control - RF Range Test

- *Rationale*
  - *Verify that the RF range exceeds 20 meters*
- *Equipment and Facilities*
  - *Open area, RF housing, electronics housing*
- *Procedure Overview*
  - *Iteratively test 10 button presses at a variety of distances*

Command & Control - RF Range Test

- *Risk Reduction*
  - *Understand and quantify risk of false negatives.*
- *Expected Results*
  - *Likelihood estimate for false negative of RF system*
- *Models to be Validated*
  - *10m-20m launch range requirement, user-interface with false negatives*
- *Test Status*
  - *Completed on 02/18/2021*

Command & Control - Shock Test

- *Rationale*
  - Drop test that makes sure the release mechanism and electronics box work if accidentally dropped
- *Equipment and Facilities*
  - Release Mechanism
  - Electronics
  - Patch of Land/soil
- *Procedure Overview*
  - Travel to a field
  - Drop release mechanism & electronics box
  - Inspect any damage & test functionality
  - Repeat on dirt or gravel

Command & Control - Shock Test

- *Risk Reduction*
  - Reduces the uncertainty of failure if accidently dropped
- *Expected Results*
  - All systems working with little to no damage
- *Models to be Validated*
  - Automated system and Operation
  - Release Mechanism Rotational kinematics
- *Test Status: Incomplete*

Command & Control - Command System Test

- *Rationale*
    - *Verify hardwares can receive command from the software to control the output of the RF signal*
- *Equipment and Facilities*
    - *Electronic box contains with command and control electronic system + arcade button*
    - *The release mechanism*
- *Procedure Overview*
    - *Configure the electronic system with the Arduino and turns on the override switch*
    - *Turn off the switch, stands about 15 meters from the electronic box with the arcade button is placed on user's waist.*
    - *Press the button for the first time, the user will hear audio feedback for 5 seconds.*
    - *Press the button for the second time, the user will hear audio feedback for 10 seconds and gripper will automatically deactivate.*
    - *After 10s from gripper being opened, gripper is magnetized again and ready to repeat*
    - *Test edge cases for logic*

Command & Control - Command System Test

- *Risk Reduction*
  - *Reduce risk of command and control system failures*
- *Expected Results*
  - *Receive the RF signal from user to the receiver within 1s*
  - *Output of audio feedback when RF signal is received within 1 s and output the sound for 3s for the first time and 5s for the second time of user pressing the arcade button*
  - *Demagnetized gripper after RF signal is received within 3s*
  - *Output audio feedback when battery is below 5V*
  - *Logic Test Cases*
- *Models to be Validated*
  - *Automated system and operation, state logical diagram*
    - *Gripper: (Battery, Safety, Override, RF Signal)* $\in \{0,1\} \rightarrow \{0,1\}$
- *Test Status*
  - *Incomplete*

Full Loading Test

- Rationale
  - Ensure the release mechanism, structure, and C&C integrate perfectly
  - Single person set up
- Equipment and Facilities
  - Release mechanism, structure, electronics, balloon
- Procedure Overview
  - Refer to CONOPS steps 1-6

Full Loading Test

- *Risk Reduction*
  - *BDS is safe and simple to launch a balloon solo*
- *Expected Results*
  - *The loading procedure is easily completed by one person*
- *Models to be Validated*
  - *Few models, this test is more systematic*
- *Test Status*
  - *Incomplete*

End to End System Test

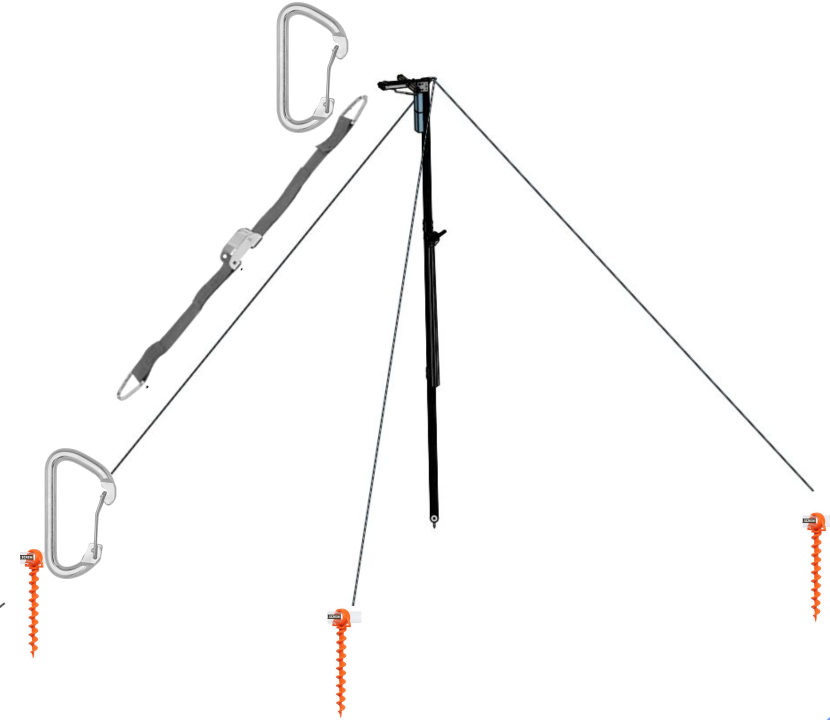
- *Rationale*
  - Test the entire structure, release mechanism, and systems test
  - Test the assembly and release of a tethered balloon
- *Equipment and Facilities*
  - Structure
  - Release Mechanism
  - Electronics box
  - Tethered balloon
  - Patch of soil/land
- *Procedure Overview*
  -

End to End System Test

- *Risk Reduction*
  - Validate the completion of the project
- *Expected Results*
  - All systems work
  - Able to do it as one person
- *Models to be Validated*
  -
- *Test Status:* Incomplete

Design Solution
Structure

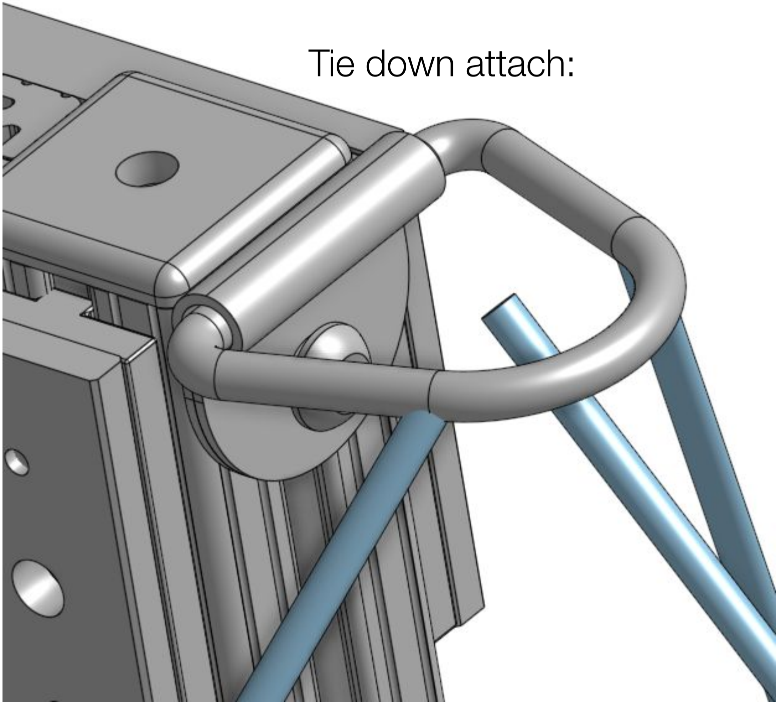
- 3 sections of T-frame Al bars form tower
    - Al brackets bolt together
- Tower staked with 3 ground anchors
    - Screw in anchors
    - Adjustable tie down strap support lines
- Dimension:
    - Tower: 3m x 3.8cm x 3.8cm
    - Footprint: 3 stakes 2.64m from tower @ 120°
- Weight: 29 lbs



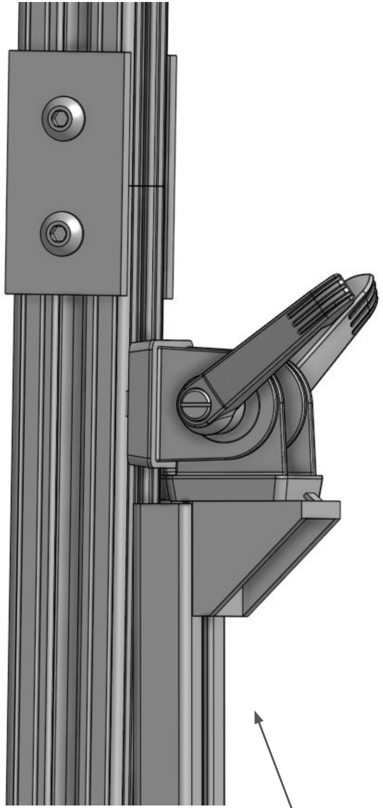
Design Solution

Structure

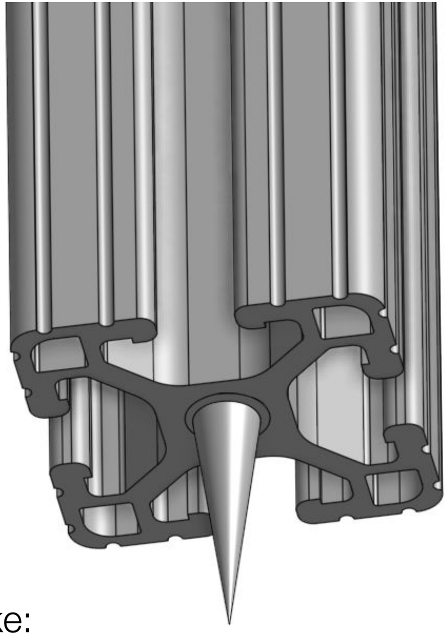
Tie down attach:



Bar joint:



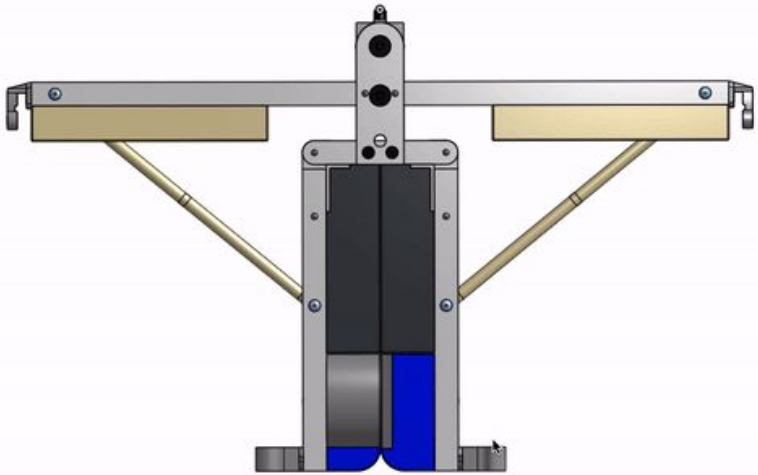
Folding kick-stand:

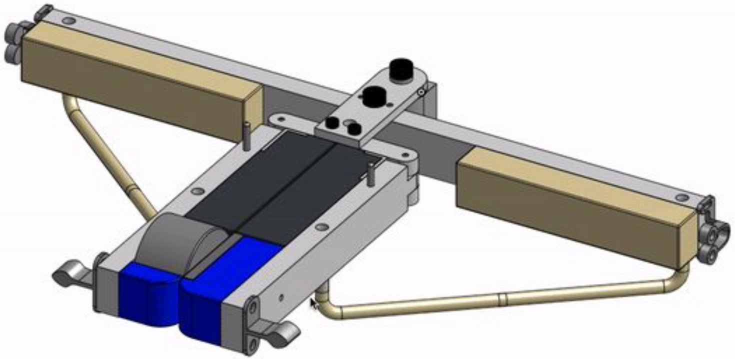


Stake:

Design Solution

Release Mechanism - DOF



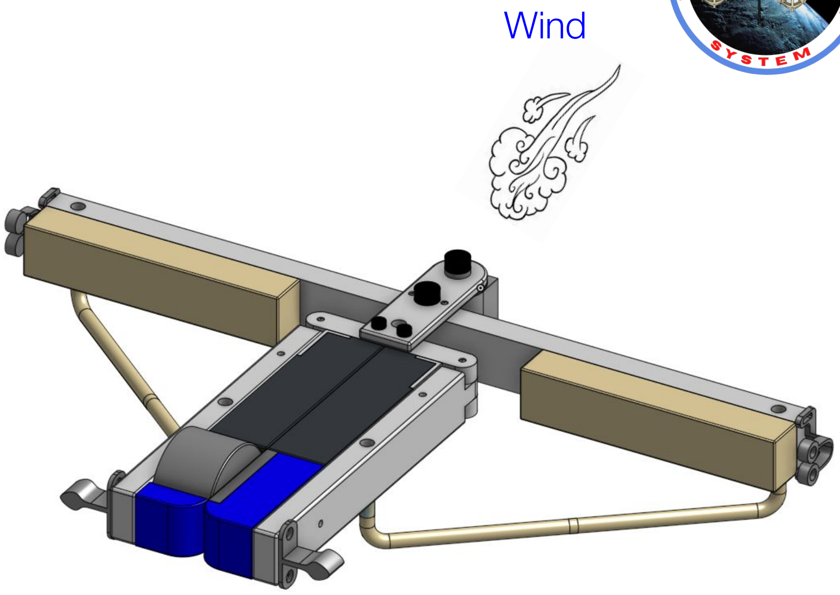


Note: This motion is stopped by locking pin until structure is risen and secure

Design Solution

Release Mechanism - Armed

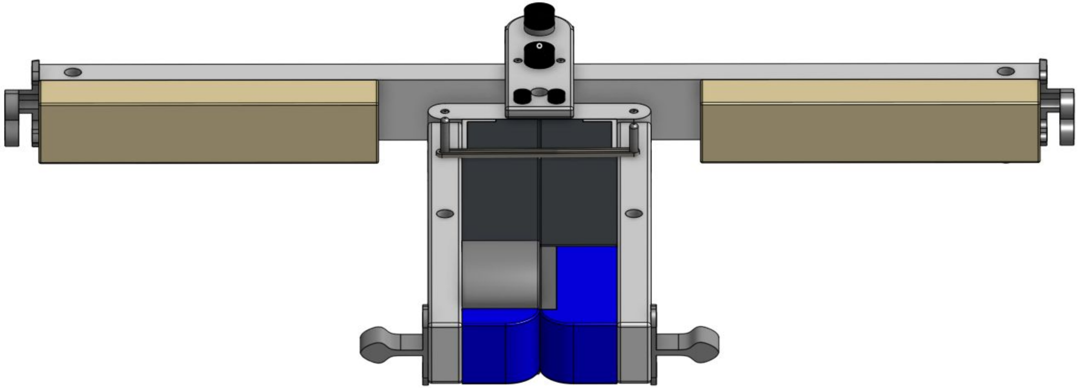
- Permanent Electromagnet latches with ferromagnetic steel
- Surgical tubing mounted to pins
  - Slip fit to swinging arms
  - Friction fit to back-plate
- Polyethylene foam gripping balloon
  - Adhesive spray to secure
- Polyurethane foam backstop coupled with 7lb pull-force cabinet latches



Design Solution

Release Mechanism - Loading

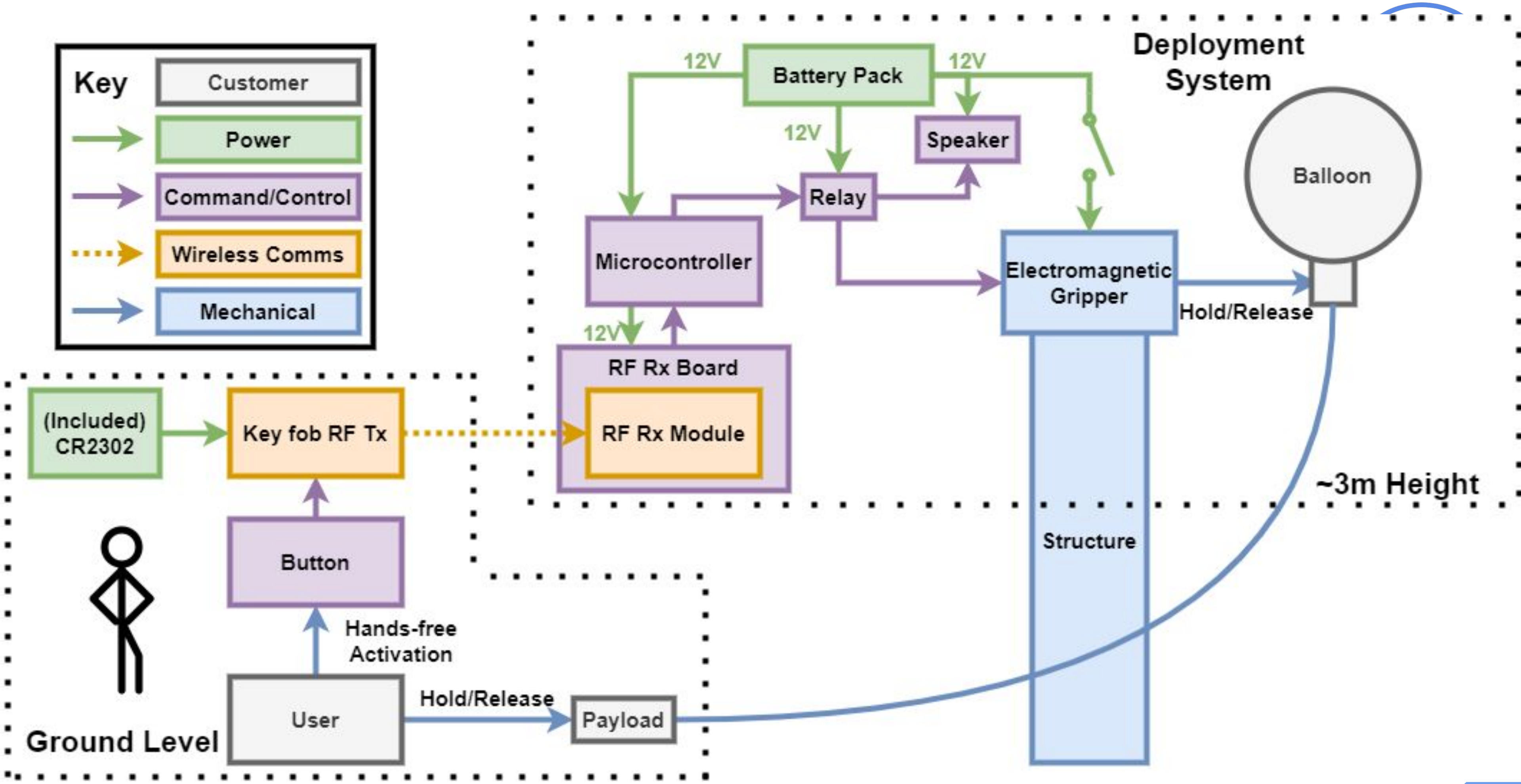
- 5 in. rubber band for loading resistance
  - Removable slip-fit pins
- 108° freedom in mounting swivel
  - Removable locking pin
- Rounded PLA inserts around electromagnet and steel
- Dimensions
  - Swinging Arms: 7 in.
  - Backstop: 14.75 in.
  - Arm-to-arm parallel distance: 3.3 in
- Weight: 7.5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



Design Solution
Structure

G: Gripper, 1 = open
S: Safety Switch, 1 = closed
O: Override Switch, 1 = closed
B: Battery, 1 = high
R: RF Signal, 1 = received

G = B && !S && (O || R)


Key
Customer
Power
Command/Control
Wireless Comms
Mechanical
Deployment System
Battery Pack
12V
12V
12V
Speaker
Relay
Microcontroller
12V
RF Rx Board
RF Rx Module
Electromagnetic Gripper
Balloon
Hold/Release
~3m Height
Structure
(Included) CR2302
Key fob RF Tx
Button
Hands-free Activation
User
Hold/Release
Payload
Ground Level

Software - Initialization

```
/*The following 4 pin definitions,correspond to 4 buttons on the
int D1 = 8;     //The digital output pin 1 of decoder chip(SC2272)
int D2 = 9;     //The digital output pin 2 of decoder chip(SC2272)
int D3 = 10;    //The digital output pin 3 of decoder chip(SC2272)
int D4 = A5;    //The digital output pin 4 of decoder chip(SC2272)
int power = A4; // The digital output to deactivate pin
int buzzer = 13;    //Receiving indicator

/* For the Relays*/
byte relayPin[4] = {4, 7, 8, 12}; // initialize relay pin
int gripper_relay = relayPin[2];
int buzzer_relay = relayPin[3];

/* For the Launch Arm Sequence*/
int counter = 1;
```

Software - Main Function

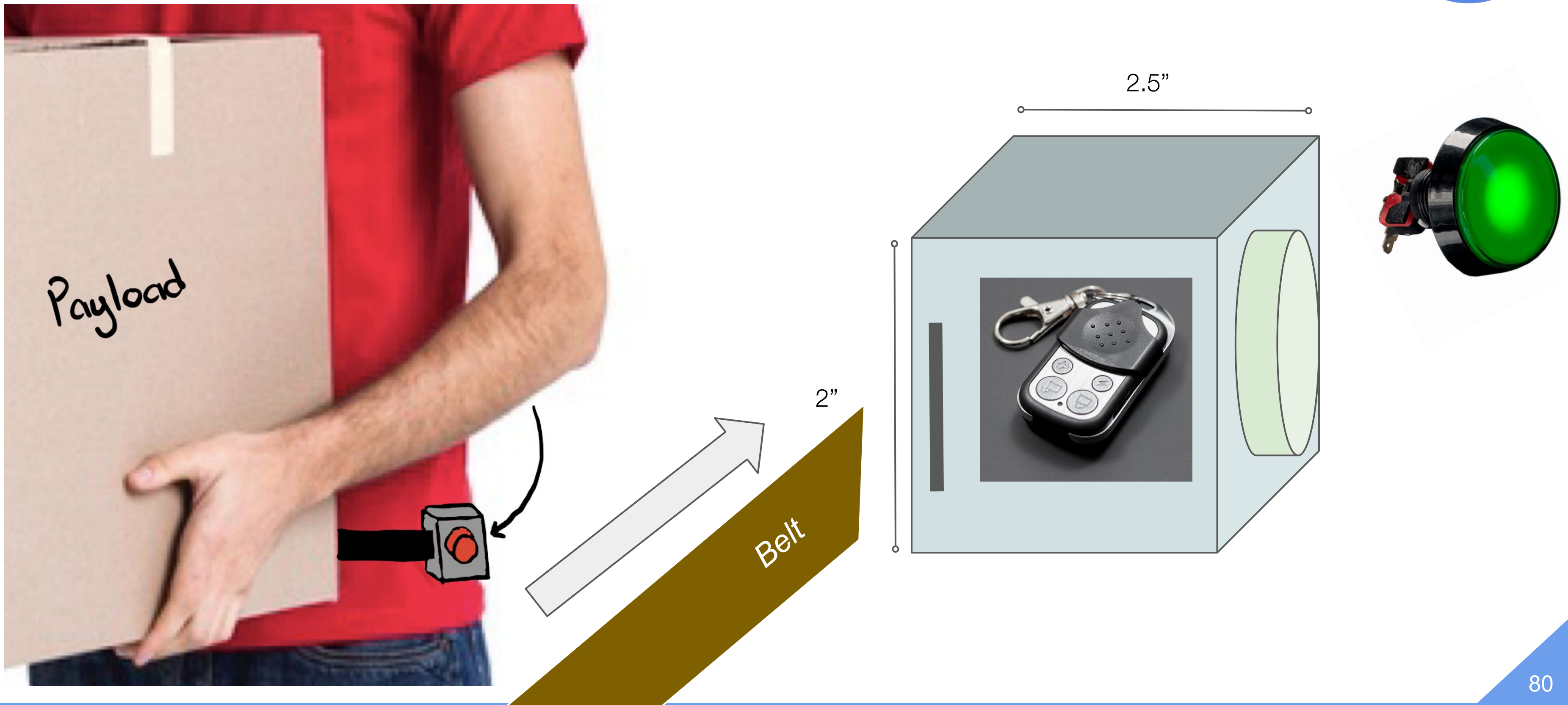
```
void setup()
{
  Serial.begin(9600);

  /*The four pins order below correspond to the 4 buttons on the remote control.*/
  pinMode(D4, INPUT);   //Initialized to input pin, in order to read the level of tl
  pinMode(D2, INPUT);
  pinMode(D1, INPUT);
  pinMode(D3, INPUT);
  pinMode(power, OUTPUT);
  pinMode(gripper_relay, OUTPUT);
  pinMode(buzzer_relay, OUTPUT);

  digitalWrite(buzzer, LOW);
  digitalWrite(power, HIGH);
}
```

Software - Built Functions

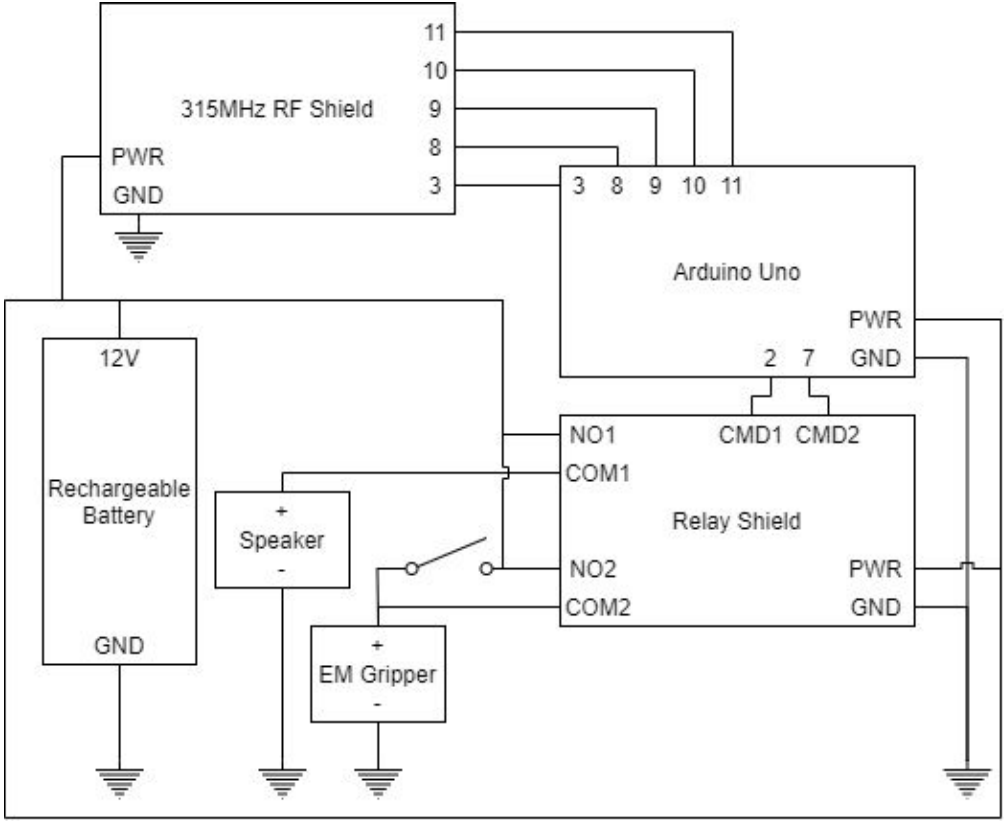
```
void deactivateFob(int duration) {
  digitalWrite(power, LOW);
  delay(duration);
  digitalWrite(power, HIGH);
}
void deactivateGripper(int duration) {
  digitalWrite(gripper_relay, HIGH);
  delay(duration);
  digitalWrite(gripper_relay, LOW);
}
void beep(int nbeeps, int del, int start_del)
{
  delay(start_del);
  for (int i = 0; i < nbeeps; i++) {
    digitalWrite(buzzer_relay, HIGH);
    delay(del);
    digitalWrite(buzzer_relay, LOW);
    delay(del);
  }
}
```

Design Solution

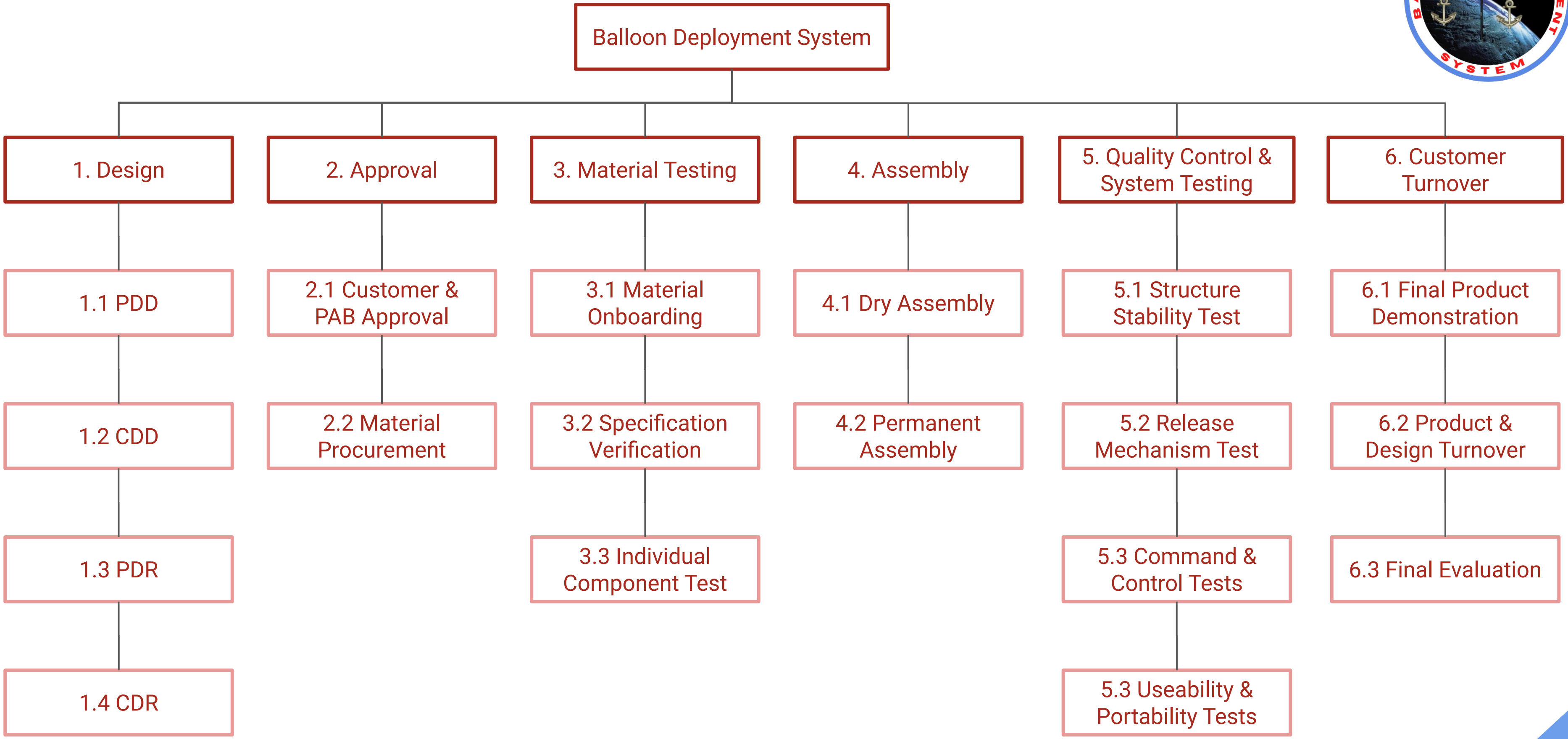
Command and Control



Wiring Diagram



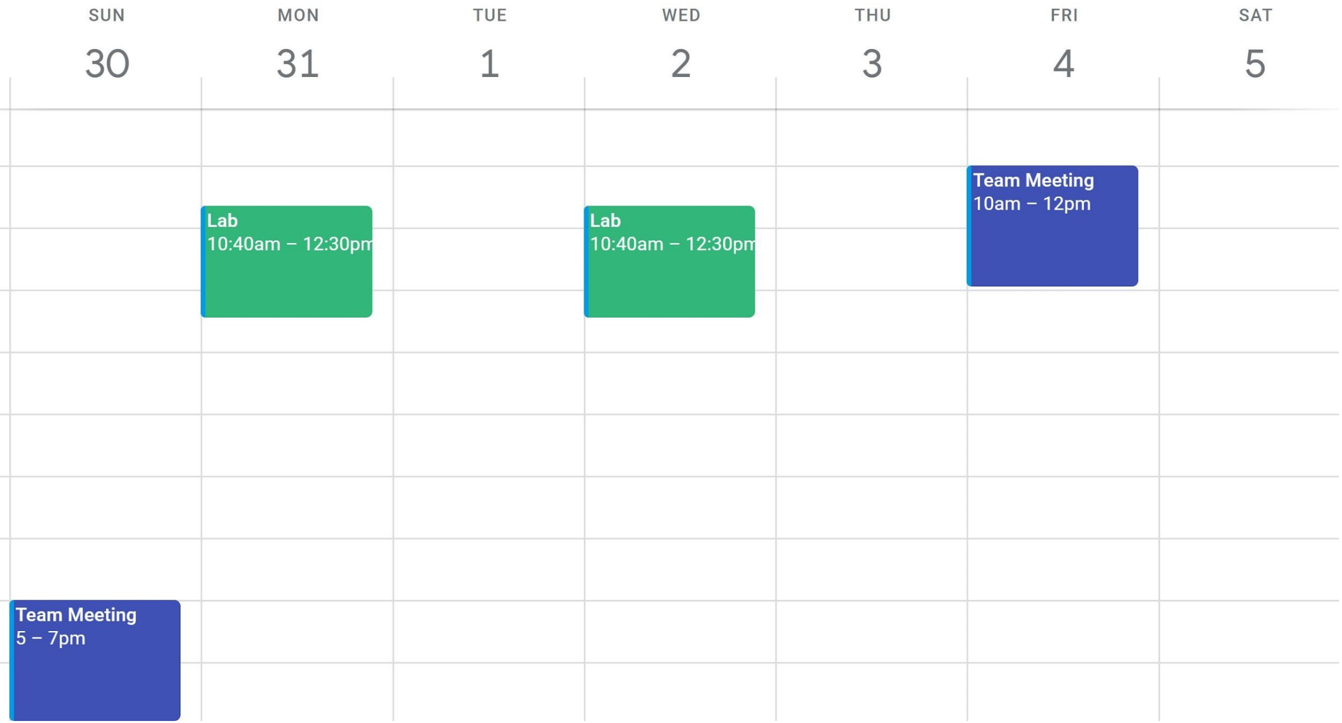
Phase Work Breakdown Structure



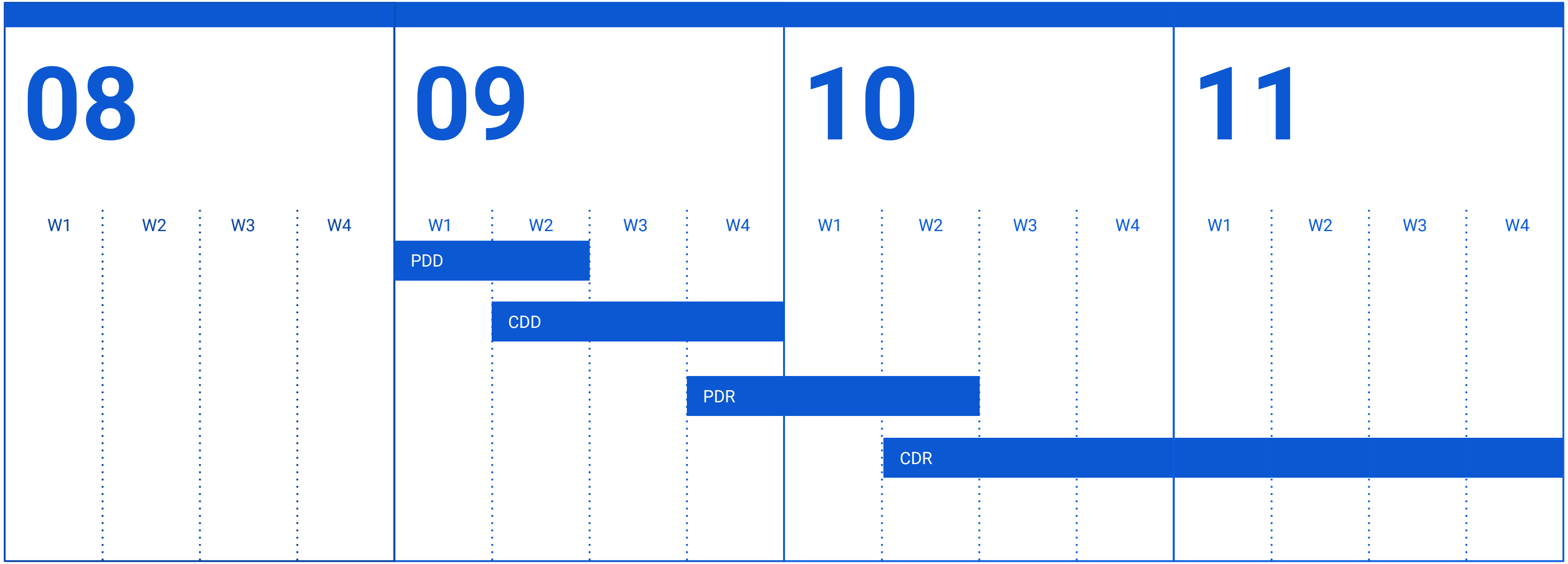
Prices

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.

References - PDR

Modulus of Elasticity: https://www.azom.com/properties.aspx?ArticleID=920

Wind direction change: https://rmets.onlinelibrary.wiley.com/doi/pdf/10.1256/wea.176.04
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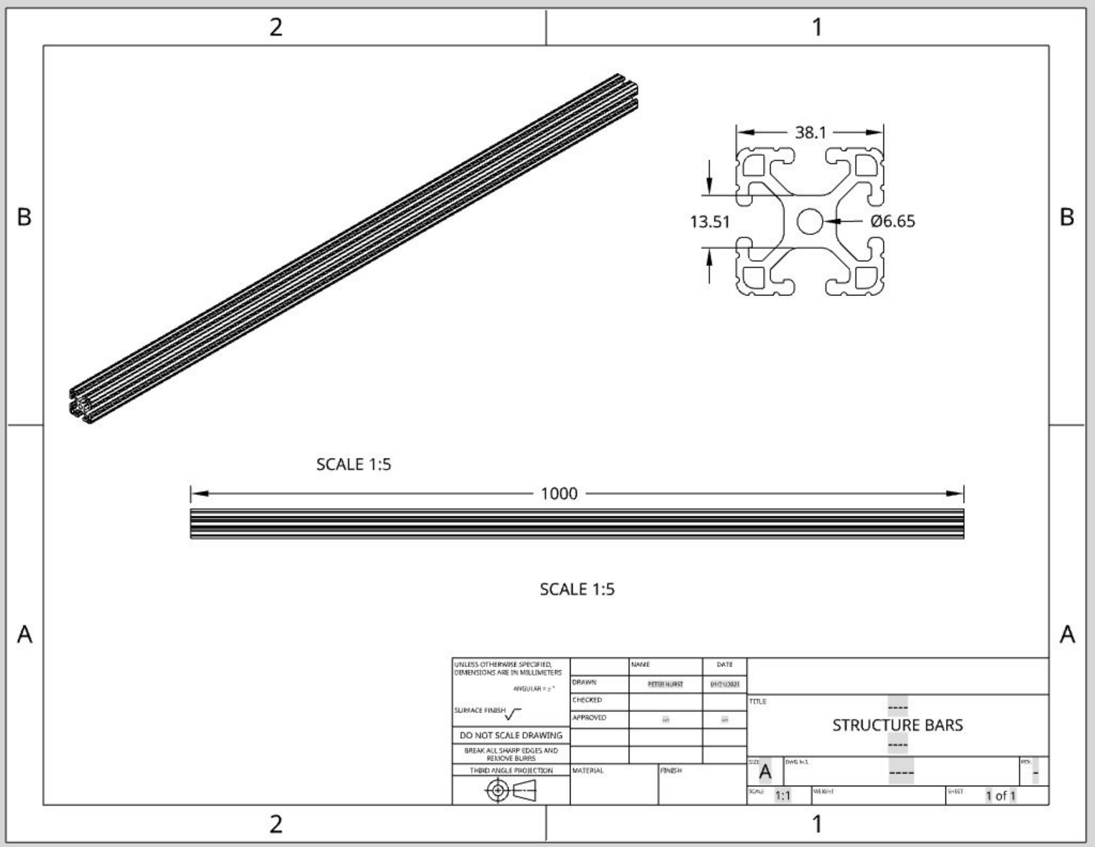
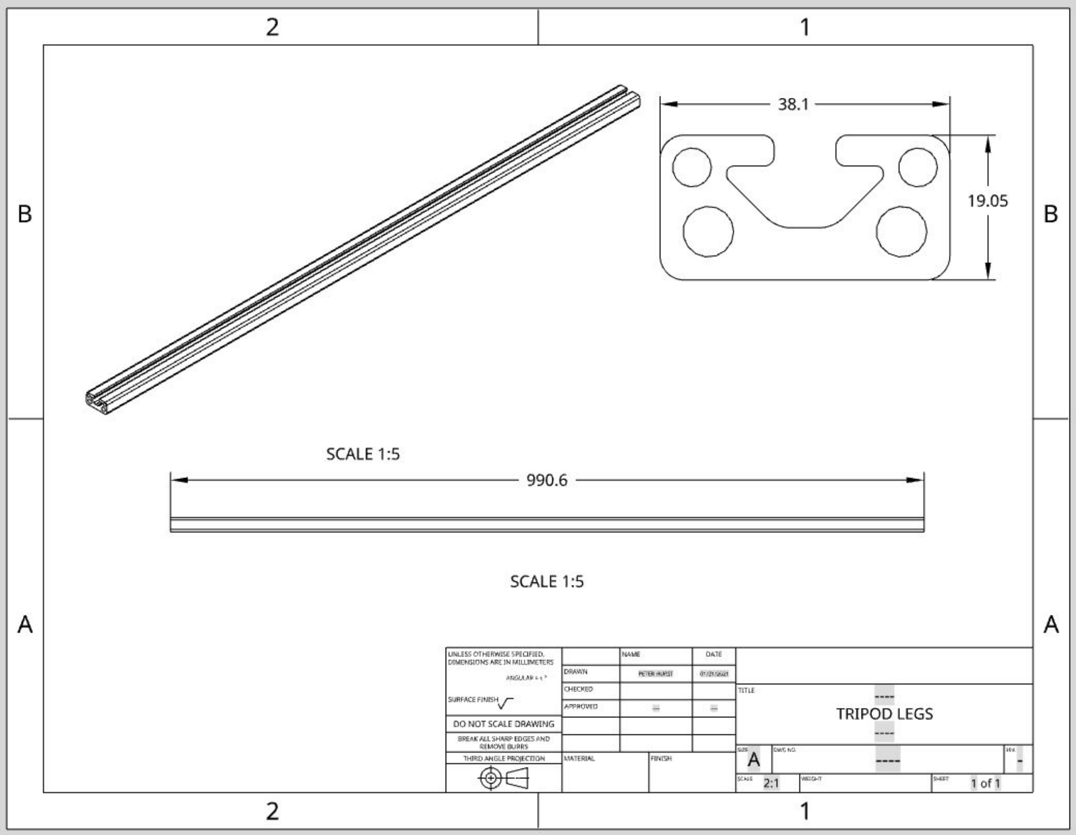
https://cdn-shop.adafruit.com/datasheets/maxell_cr2032_datasheet.pdf

Appendix - Structures full size drawings



Appendix - Structures full size drawings



Appendix - Structures full size drawings