Conceptual Design Document (CDD)

University of Colorado
Department of Aerospace Engineering Sciences
Senior Projects – ASEN 4018

Balloon Deployment System (BDS)
Conceptual Design Document

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1.0 Information

1.1 Project Customers

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2.0 Project Description

2.1. Purpose

This project shall aim to create a system to aid in high wind launches of altitude balloons for gathering data from the stratosphere. The knowledge of turbulent patterns present in the stratosphere is still limited as the existing methods of turbulence measurement are costly and ineffective. Last year, the Air Force Office of Scientific Research (AFOSR) funded a project named Hypersonic Flight in the Turbulent Stratosphere (HYFLITS) to collect turbulence data in this particular part of the atmosphere. Data collected will be used to develop a high altitude aircraft that operates in the stratosphere. In order to measure and collect the turbulence data, HYFLITS utilizes a weather balloon in the 20-40 km altitude range of interest.

Currently, the process of deploying these balloons requires more than one individual and poses a risk of damaging the payload and balloon in windy conditions. With unpredictable weather conditions it is imperative to set up and deploy the balloon in a streamlined manner and avoid damage to the delicate data acquisition payload. The current deployment procedure is heavily limited by human reaction time and negatively impacts the safety and reliability of launch.

The primary goal of Balloon Deployment System (BDS) is to support the HYFLITS project by simplifying the process of balloon deployment and making the launch more efficient. This balloon launcher would help lower the risk of damaging the payload and balloon. BDS will be able to be carried and operated by a single person, utilizing a semi-automated mechanical system for balloon release. The balloon launcher is designed to launch up to 2 balloons at the same time with a structural design that can easily be assembled and disassembled once the mission is completed.

2.2. Project Objectives

To achieve the minimum requirements of success for the BDS project, the launch system must be able to safely and reliably launch a balloon from 3m high in strong winds via user commands while being easy to assemble and transport by a single person. The structure of the balloon launcher should be light and small enough to be transported in a 1m x 0.25 m cylindrical bag and easy and intuitive to assemble and disassemble. Once set up the launcher must be able to hold the balloon in up to 20 m/s gusts and 10 m/s sustained winds without falling over or damaging the balloon. The launchers must convey their state (arm/launch) to the operator wirelessly and using battery power. Moreover, the balloon launcher must have a system that can support 10-20m long tethers to the gondola, as well as shorter tethers with in-flight unwinders. The launcher's design should be easily manufactured and reproduced. The total cost of production of the launcher must be less than $1000. The following table shows each level of success for each category that has to be accomplished in this project.

Level of Success	Portability	Launch Capabilities	Balloon Security	Cost

Level III	• Assembly of this device can be performed by one person without the use of any tools • Device weight is no factor for a healthy adult • Deployment procedure is so obvious that the device can be assembled in 5-10 minutes • The device fits into a cylindrical case 25cm in diameter and 1m long.	• Launches 1 balloon with 1 payload or 2 balloons both connected to 1 payload • Control Comm: Wireless • Release Command Remote: On user • Reliability: 20 simulated test launches in 10 m/s sustained winds	• The BDS structure shall be stable and balloon launch without damage or entanglements in abnormal conditions for a typical colorado day in and around the mountains at about 20 m/s.	• The BDS shall be built within a proper facility using only bought components from the local hardware/electronics store for less than $1000 for a unit design.
Level II	• Can be assembled by a single person using nothing more than an allen key included and tethered to the device. • Device weighs less than 50 lbs and is reasonable to carry for most adults • Deployment procedure is simple and can be learned from an instructional card • The device fits into a single carrying case that can fit into the back of a sedan (55in X 36in) [11]	• Launches 1 balloon • Control Comm: Wireless • Release Command Remote: Off user • Reliability: 20 simulated test launches in 8 m/s sustained winds	• The BDS structure shall be stable and balloon launch without damage or entanglements in a typical colorado day in and around the mountains at about 8 m/s.	• The BDS shall be built within a proper facility using mostly bought components from the local hardware/electronics store. • Approximately half of the components will need to be outsourced and pre- ordered • All of which is under $1000 for a unit design.
Level I	• Can be assembled and deployed by a single user with the use of common tools like screwdrivers, standard wrenches, and pliers. • Device weighs no more than 50 lbs • Time to deploy is highly depended on user competency • The user can fit device into the average sedan, but does not fit into the desired carrying size	• Launches 1 balloon • Control Comm: Wired • Release Command Remote: Off user • Reliability: 10 simulated test launches in 1m/s winds	• The BDS structure shall be stable and balloon launch without damage or entanglements in a calm Colorado day in and around the mountains at about 1 m/s.	• The BDS shall be built within a proper facility using bought components from the local hardware/electronics store. • Approximately half of the components will need to be outsourced and pre- ordered • All of which is under $1500 for a unit design.

Table 1. Level of Success of BDS

Level I requirements are those that generally would lead to a successful balloon launch without meeting all the customer requests. These include assembly and deployment by a single user with basic tools, weight around 50 lbs and a kit that would fit in a car. Launches could only handle 1 balloon with wired command communication hardware via an off user remote control and could launch 10 times reliably in 1-2 m/s winds. The structure would be stable and cause no hard to the balloon with wind speeds less than this limit, which is approximately the 25th (hourly) percentile wind speed during the non-winter months of the year [1]. Custom parts may make up half of the total parts number and manufactured cost could be as high at $1500.

Level II requirements build off Level I and get closer to meeting all the customers requests. Tools are reduced to just an allen key, assembly can be quickly learned from an instructional card. Wireless command communications are used instead of wired and reliability is verified in higher winds at 8m/s over 20 trials. Structure stability and balloon safety shall occur in higher winds at 8m/s, the average 90th percentile of hourly wind speed on the windiest day of each year, in Boulder, CO [1]. Finally manufacturing costs shall be within the $1000 customer limit for a prototype.

Level III requirements meet close to all the customer's needs and requests. At this level no tools are required for assembly and weight is a non issue for the average adult being far less than 50 lbs. No instructions are required to build and assembly time takes 5-10 minutes. The full kit fits into a .25x1m carrying case. This system shall have the ability to launch a 2 balloon rigged payload using remote control on the user. Reliability shall be tested in 20 tests in 10 m/s winds. Structure stability and balloon safety must be verified in 20 m/s wind gusts. All parts for this level will be off the shelf.

2.3 Concept of Operations

Figure 1 shows BDS's Concept of Operations (CONOPS) diagram. After receiving the BDS in it's travel case the user goes to the launch site via car or foot. Once at the site the user assembles the BDS taking approximately 5-10 minutes to complete. Once the BDS has been assembled, the user will load the balloon and attach the payload while the BDS is in loading configuration. Next, the user will proceed to put the BDS in launch configuration; the 'arm' and 'launch' commands will then be given while the user stands downwind of the BDS with payload in hand. Once the balloon is overhead, the user will release the payload. Once the balloon is away the user will disassemble the kit, return the contents to the travel case and vacate the site.

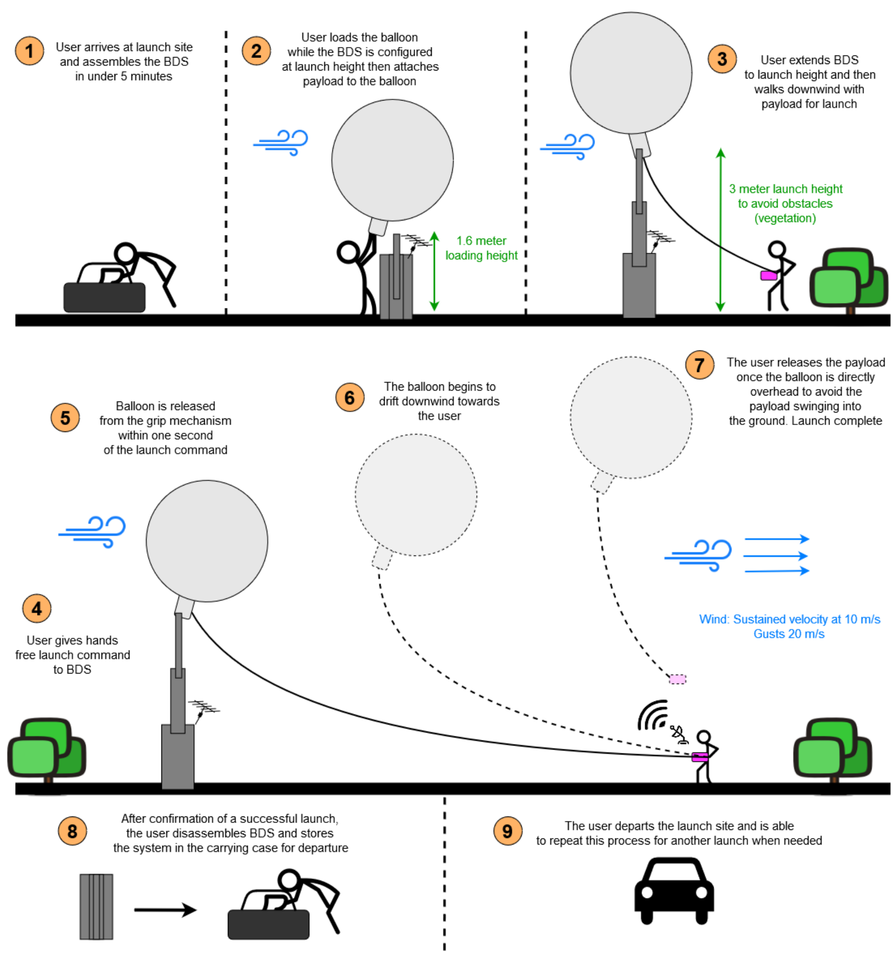


Figure 1. BDS CONOPS

2.4 Functional Requirements

The BDS system has 10 functional requirements and every functional requirement is derived from the project objectives. The functional requirements are the critical elements to follow that will be used as the foundation of the trade study and design process. The following table outlines every functional requirement that needs to be achieved in this project.

	Functional Requirements	Rationale/Explanation
FR 1.0	One person shall be able to set up with no tools required for assembly/disassembly.	Ease of use and self contained kit for the user to bring to site.
FR 2.0	The setup shall take less than 5 minutes to set up/disassemble.	Quick deployment of the balloon.
FR 3.0	The launcher (for each balloon) shall collapse into a cylindrical storage/carrying bag of 1 m length and 25 cm diameter.	Ease of transport.
FR 4.0	Balloons shall be held 3m or more above the ground and 6m apart in the case of a 2 balloon launch.	Avoid balloon ground damage or balloons becoming entangled.
FR 5.0	Payload shall not hit the ground during setup and deployment.	Avoid damage to payload instruments.
FR 6.0	The balloon deployment system shall hold 1 or 2 balloons and be launched within 1 s of each other.	Allow multiple deployments if required for data gathering.
FR 7.0	No heating of the launcher or sharp edges on the launcher. Launcher shall hold the rubber balloon neck (not tether).	Avoid potential damage to balloon
FR 8.0	The launching system shall function in 10 m/s sustained wind, with up to 20 m/s gusts.	Allow launches in a wide range of wind conditions.
FR 9.0	The system shall be hands-free (hands will hold payload) communication of commands/launcher status between user and launch device.	Allow single person launch with hands-free for payload release as balloon rises.
FR 10.0	Battery powered launcher/release mechanism.	Remote area launch capability.

Table 2. Functional Requirements of BDS

2.5 Free Body Diagram

The balloon shall exhibit a drag force that will cause forces on the gripping mechanism and the base of the structure contacting the ground. These forces in turn create moments on the structure. The two centers of gravities were drawn for the balloon and structure separately. The c.g. of the balloon was offset to draw the forces associated with the balloon more clearly. The net upward force is approximately 20 N. The mass of the heaviest balloon is 3 kg and a payload of about ½ kg according to our customer and expect a maximum drag force of approximately 100∗ **π** N ≅ 70.5 lbf.

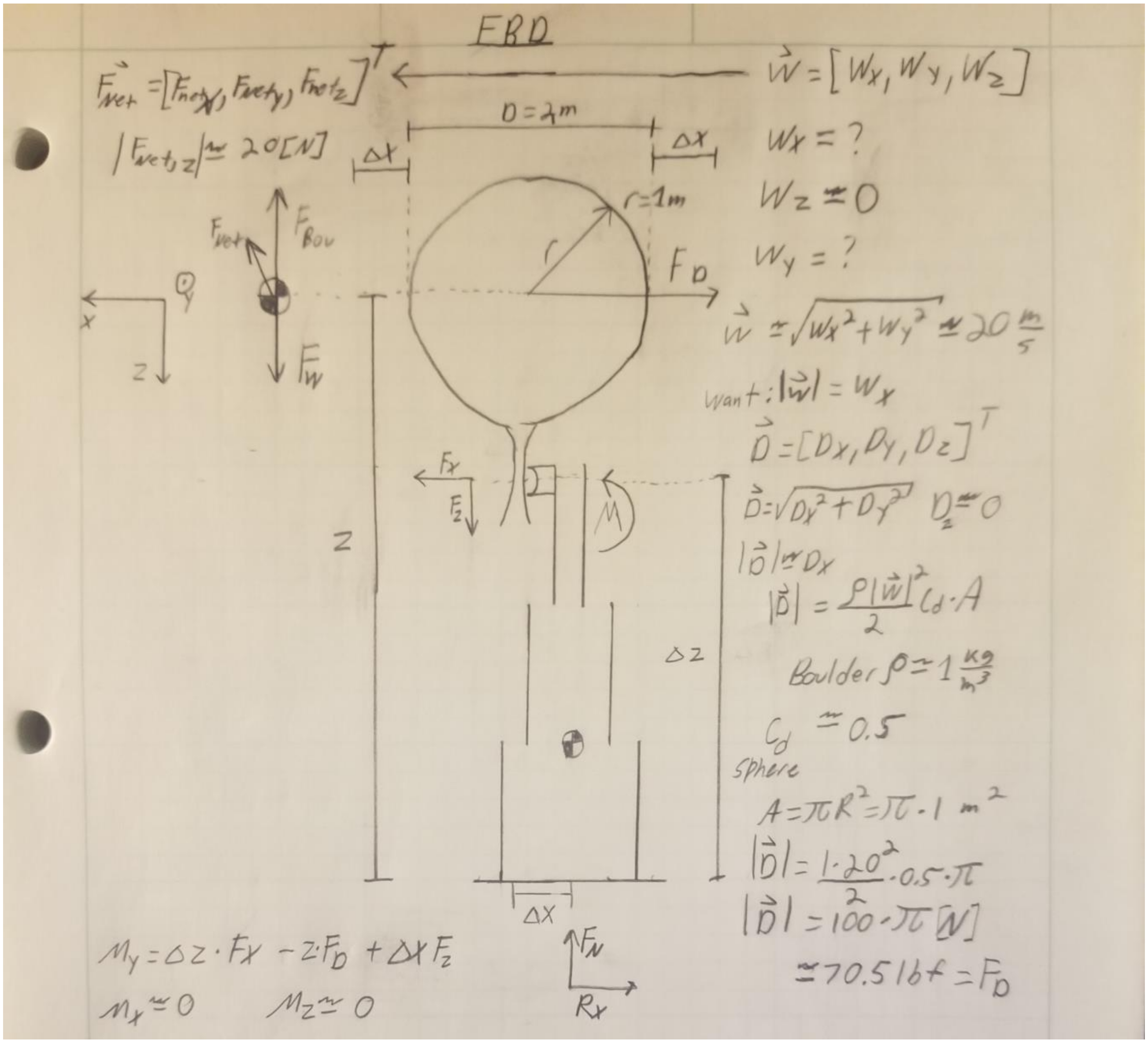


Figure 2: Free Body Diagram

2.6 Functional Block Diagram

The functional block diagram is displayed below in figure 3. As shown, the grasping mechanism will be attached to the structure, where the receiver is attached to the grasping mechanism. Through RF signals sent by the user will determine the release time.

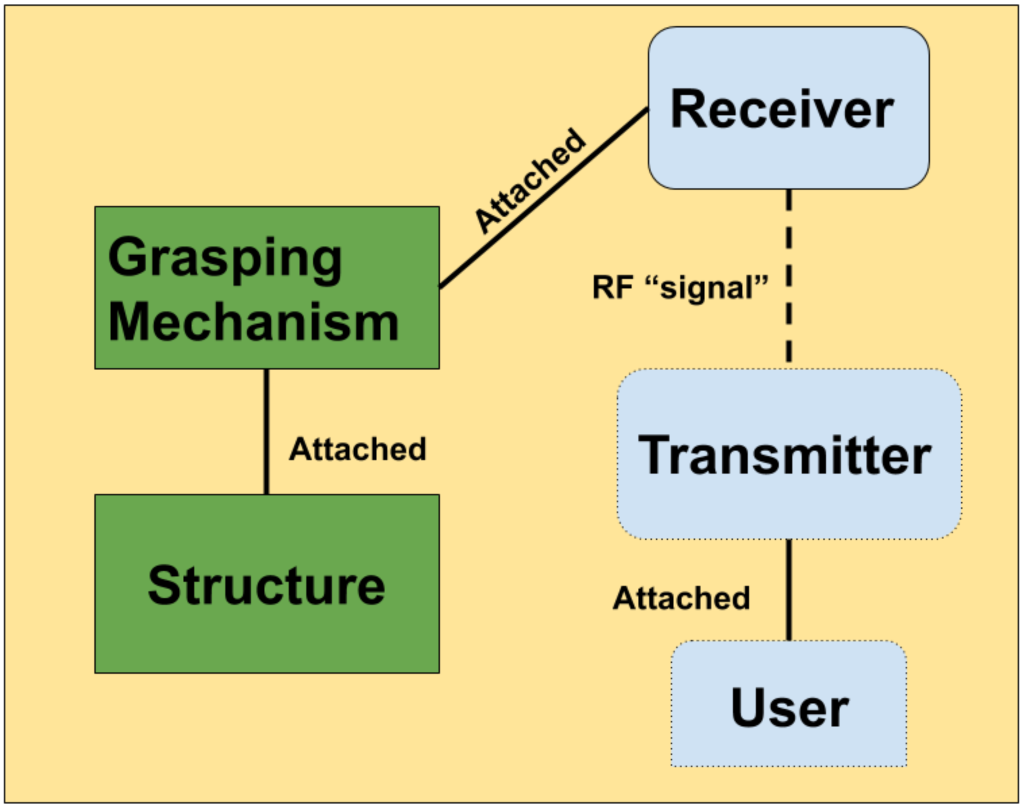


Figure 3: Functional Block Diagram

3.0 Design Requirements

FR 1.0: One person shall be able to set up with no tools required for assembly/disassembly.

Motivation: According to the customer, in order to reduce the number of items required for launch, no tools should be required to assemble the balloon deployment system.

Verification: Assembly tests performed by the team and users outside of the team will determine if assembly is feasible by a healthy adult without the use of tools.

- **DR 1.1:** Individual components should not weigh more than 25lbs.
  - **Motivation:** According to OSHA regulation, a weight greater than 25 lbs. should not be held at arm's length any number of times. Assembly of a structure could require the user hold components in place, so each component should be able to be maneuvered by hand without the use of additional support structure.
  - **Verification:** The weights of individual components will be tracked.
- **DR 1.2:** All mechanisms meant to lock in place should be secured by the use of thumbscrews or spring mechanisms. Sufficient locking capability should be able to be accomplished without the use of torque increasing devices (i.e screwdrivers, wrenches, pliers).
  - **Motivation:** The absence of fasteners that require specific tools or designs that require tools in order to achieve sufficiently secure connections; Require the customer to remember to bring more material to each launch. Removal of such devices from the design allows for a more streamlined launch process.
  - **Verification:** We will monitor the use of fasteners very closely in the design of the BDS. Any connection will be *designed* to be secured without the use of tools rather than modified after the fact.
- **DR 1.3:** Assembly of the BDS should require no more than two hands.
  - **Motivation:** The customer requests that launches should be performed entirely by a single person. Therefore, any additional people or support structures like a wall, chair or rope, should not be required for the assembly of the BDS.
  - **Verification:** Test assembly procedures will be performed in simulated launch conditions like in a windy grass field, similar to where the customer's balloons are launched.

FR 2.0 The setup shall take less than 5 minutes to set up/disassemble.

Motivation: As requested by the customer, to provide quick and consistent launch capabilities.

Verification: Assembly tests by the team and users outside of the team will determine if assembly time is feasible for a healthy, trained adult. Assembly time is defined as the duration when the bag is opened until when the device is ready to accept the balloon.

- **DR 2.1:** The BDS system shall have an intuitive, user-friendly assembly. See **DR 1.1**, **DR 1.2**, and **DR 1.3** above. The simplicity of the assembly is also motivated by this requirement. Thus, satisfying **DR 1.1**, **DR 1.2**, and **DR 1.3** supports the fulfillment of this functional requirement.
  - **Motivation:** Heavy components, the required usage of tools, and required assistance all correspond to the assembly / disassembly task taking more time. Clearly, we aim to quickly set up / disassemble the mechanism.
  - **Verification:** The system shall conform to **DR 1.1**, **DR 1.2**, and **DR 1.3**, as defined by their respective verification criteria.

FR 3.0 The launcher (for each balloon) shall collapse into a cylindrical storage/carrying bag of 1 m length and 25 cm diameter.

Motivation: According to the user, this size carrying bag is desirable for a single user to load the launcher into

a personal vehicle. This again supports the mission as a single-user operation. Furthermore, the grouping of equipment prevents damage and lost parts.
Verification: The stowed configuration in the bag shall be measured along each dimension. The diameter is defined as the maximum distance in the direction perpendicular to the measurement of the length dimension.

- **DR 3.1:** No single component shall be more than one meter in its stowed state, along it's largest dimension. Note that this dimension corresponds to *length*.
  Motivation: This ensures that no single component will prevent the system from collapsing to the required size.
  Verification: Stowed components shall be measured to be less than one meter in length.

- **DR 3.2:** In the plane perpendicular to the length dimension, each component shall be less than 0.25 meters, in *width*, measured along each axis.
  Motivation: This ensures that no single component will prevent the system from collapsing to the required size.
  Verification: Stowed components shall be measured to be less than 0.25 meters in width.

FR 4.0 Balloons shall be held 3m or more above the ground and 6m apart in the case of a 2 balloon launch.
Motivation: The customer requests this requirement so that the balloons are less likely to collide/tangle or to come into contact with environmental hazards, such as vegetation. After deployment, the balloon may follow a parabolic trajectory due to wind and payload weight interactions.
Verification: The balloons will vary between launches, but generally, the customer agrees that a one meter diameter balloon is a good design driver. We also assume that the balloon is a sphere, resting on top of the gripper mechanism. Under these simplifications, we may define the measurements of interest. The distance from the center of the gripping mechanism to the ground shall be measured as the *height*. The distance between the centers of two gripping mechanisms on separate structures, plus one meter, gives the *distance between balloons*.

- **DR 4.1:** The supporting structure shall interface with the gripper at a height that allows the balloon to be at least 3 meters.
  Motivation: This criteria is necessary to meet the *height* portion of the functional requirement.
  Verification: The distance shall be measured, and if there is reason to believe that this distance varies, then a mean shall be used.

- **DR 4.2:** Components acting over some distance, such as controls and commands, shall be able to interface with two gripper mechanisms located 7 meters apart from one another.
  Motivation: This criteria is necessary to meet the *distance* portion of the functional requirement.
  Verification: This feature shall be functionally demonstrated on two mechanisms spaced 7 meters apart, with visual verification.

FR 5.0 Payload shall not hit the ground during setup and deployment.
Motivation: To Avoid damage of the payload and payload instruments for data collection.
Verification: Mock assemblies shall be performed to ensure that the payload is safely supported while the structure gets assembled and loaded.

- **DR 5.1:** Shelf/hook on structure shall hold payload to avoid damage during balloon loading.

Motivation: Allows the user to avoid placing the payload on the ground.
Verification: Structure has shelf/hook that shall safely hold the payload during loading tests.

- **DR 5.2:** Launcher holds the balloon upwind from user 3m above ground to balloon's bottom.
  Motivation: Height and wind directions allow the balloon to launch with sufficient height and direction so the user can release the payload with minimal chance of ground contact once the balloon is overhead.
  Verification: Measure height of release mechanism to stand 3m off the ground.

FR 6.0 The balloon deployment system shall hold 1 or 2 balloons and shall be launched within 1 second of each other.
Motivation: Some launches require two balloons to be attached to a single payload. The balloons shall be launched synchronously (release time is defined as when the gripping mechanism completes actuation) such that the balloons launch and act as though they are a single unit.
Verification: Visual and timed checks shall be conducted during test launches.

- **DR 6.1:** Dual BDS units shall be used simultaneously, therefore each unit shall be responsible for a single balloon.
  Motivation: Simplifies the design and operation for dual balloon launches by reusing familiar equipment.
  Verification: Test launches shall be conducted in dual launch configurations.

- **DR 6.2:** Each unit shall be able to receive commands from the same controller.
  Motivation: Reduces the hardware the user requires for a dual balloon launch.
  Verification: Launches shall be tested in dual deployment configurations such that double balloon launch is successful for a heavier payload.

FR 7.0 No heating of the launcher or sharp edges on the launcher. Launcher shall hold the rubber balloon neck (not tether).
Motivation: Avoid any potential sources of damage to the balloon material prior to launch.
Verification: The release mechanism will not have any sharp edges. All protrusions will be covered to avoid the
balloon being punctured by a gust of wind. Any metal parts of the release mechanism that may come into contact with the balloon material will be thermally insulated to avoid a hot metal surface damaging the balloon. The balloon will be gripped by the neck only.

- **DR 7.1:** The gripper part of the release mechanism must be manufactured to fit the diameter of the balloon neck.
  Motivation: The gripper must securely hold the balloon to avoid a premature launch from a strong gust of wind.
  Verification: The diameter of the balloon neck shall be measured.

- **DR 7.2:** The neck shall remain functional and undamaged after launch.
  Motivation: The balloon will not be able to operate as intended if an impediment has occurred within the neck structure (venting valve).
  Verification: The gripper shall be designed such that there will be no destructive forces on the neck.

FR 8.0 The launching system shall function in 10 m/s sustained wind, with up to 20 m/s gusts.
Motivation: Since the balloons are being launched near the foothills, random gusts of wind are common. To

ensure that the balloon does not launch prematurely, the launch structure must be able to grip the balloon through these guests up to 20 m/s winds. The structure itself also must not topple/break in these winds.
Verification: The strength of the launching system will be thoroughly tested. A 20 m/s gust exerts approximately 70 lbs of force, so it shall be tested accordingly. The system will also be staked/secured to the ground.

- **DR 8.1:** The truss/main load bearing structure must be secured to the ground or be heavy enough that it will not topple from an external force of 70 lbs.
  Motivation: The launching system must remain upright in fast winds.
  Verification: An external load of 70 lbs will be applied to the system to ensure it is stable.

- **DR 8.2:** The release mechanism must hold the balloon in place during high winds.
  Motivation: The balloon must not launch prematurely.
  Verification: The gripping strength of the release mechanism shall be verified using a test balloon in a high wind environment. Also see **DR 7.1**.

FR 9.0 The system shall contain hands-free communication of commands/launcher status between user and launch device.
Motivation: Since the launch system must be able to be assembled by only one person, the command communication system must be operable without the use of hands since the user will be holding the payload while the balloon is launching.
Verification: The command communication system shall be operated hands-free. Also see **DR 1.3**.

- **DR 9.1:** The system that communicates the launch command from the user to the release mechanism must be a remote system (RF is looking like best option as of now).
  Motivation: The user can hold the payload while the balloon is launching to keep the payload from swinging into the ground and being damaged.
  Verification: The command communication system shall be designed for remote operation.

FR 10.0 Mobile power source for launcher/release mechanism.
Motivation: Since the launch site is near the foothills, any power sources must be mobile.
Verification: Any electric systems will be powered by a battery. Also see **DR 2.1**.

- **DR 10.1:** All systems (release mechanism, command, etc.) that require power must be battery compatible.
  Motivation: The launching system will be set up away from any power outlets so any systems that require electricity must be battery powered.
  Verification: All electric systems shall be designed to accommodate a mobile power source.

4.0 Key Design Options Considered

The balloon deployment system is broken down into three core components: the support structure, the release mechanism, and the command and control system.

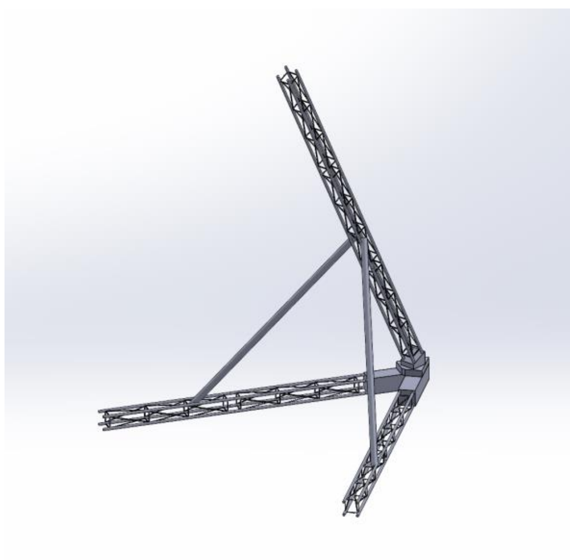
4.1 Support Structure

The support structure is the component of the design responsible for achieving a stable configuration in the expected environmental conditions at the required height for the launch. Additionally, the structure acts to support the other components of the BDS system. The support structure will be the largest component in the system (in both mass and volume), therefore it is critical to consider designs that are low weight and easily collapsible in order to satisfy portability requirements. The support structure has been further broken down into the following subcomponents: the truss or main load bearing structure, the anchoring, extension mechanism, release mechanism interface, and payload support subcomponents. Each subcomponent will be discussed and include a sketch, description, pros/cons list, as well as its compatibility with other design choices.

4.1.1 Trusses/structure

4.1.1.1 Tilting Truss

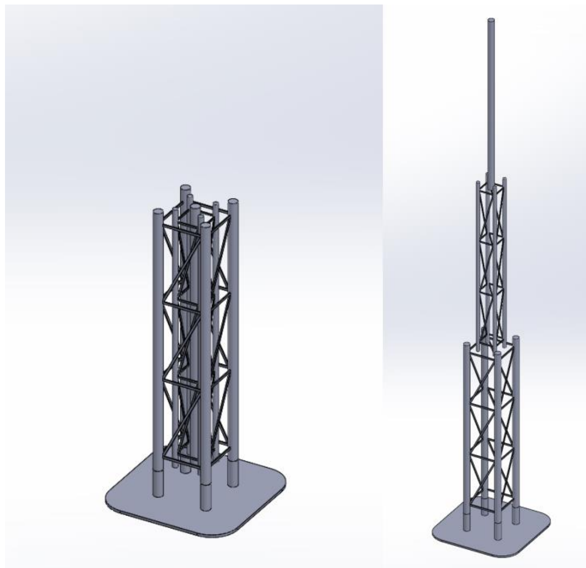
- **Description**: This design is composed of one main tower that is connected to a base plate by a hinge. The baseplate has "V" shaped legs that offer support to the main tower via support bars. These support bars also are connected to rails on the legs that allows the main tower to be raised and lowered for loading and launching.
- **Sketch:**



- **Pro:**
  - High stability
  - Simple extension mechanism
  - Off the shelf components
- **Con:**
  - Much larger footprint
  - Many truss sections required
  - Structure must be aligned with the wind
- **Compatibility**:

- Anchoring: inherent to design. Legs and support beams will be able to keep the entire structure stable
- Extension: inherent to the design
- Release mechanism: integrated at the top of the main tower. Will have to be aligned with the main tower for a straight launch
- Payload support: support shelf/claw can be included on the base platform to hold the payload while the gripper is being loaded.

4.1.1.2 Telescoping Truss

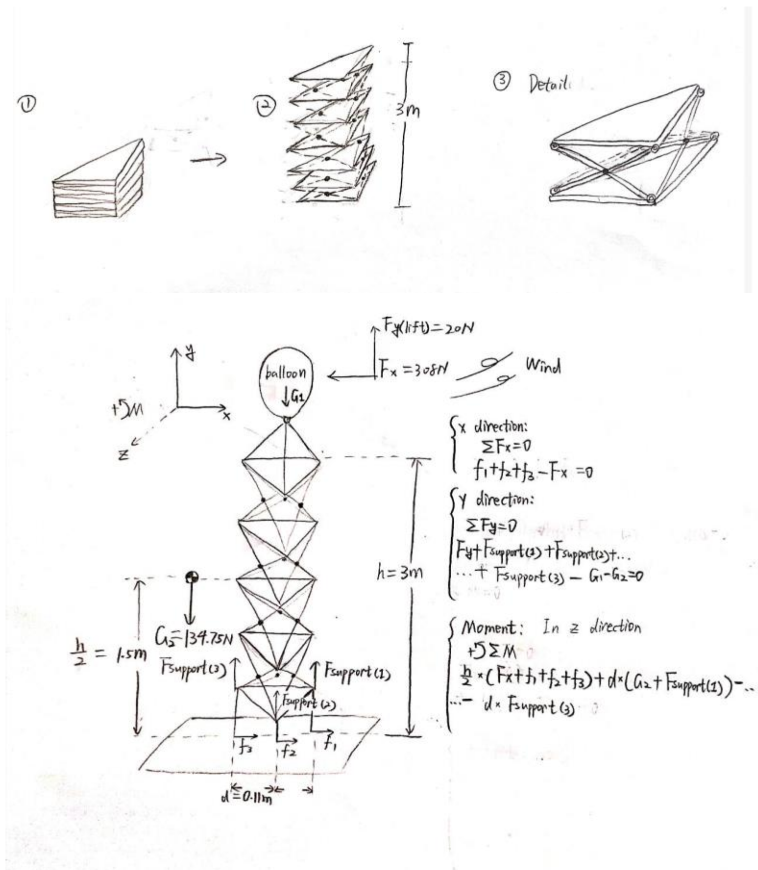


- **Description:** This design features three nesting truss sections one meter in length each. Each truss section is connected via locking telescoping rails to the inner section. Each section can be independently extended and stowed for ease of setup. The user would first extend the inner section and attach the gripping mechanism. The next section will then be raised in order to load the balloon. Once the balloon is loaded, the final section will be extended to the final launch height.
- **Pro:**
  - Off the shelf trusses may be used
  - Multiple loading heights can be included in the design for varying user heights
  - Self contained unit
  - Various configurations can be made for differing truss sizes
- **Con:**
  - Single bulky unit
  - Telescoping rails will have to be custom designed and manufactured
  - Telescoping rails will have to be attached to the trusses during manufacturing process
- **Compatibility:**
  - Anchoring: can use either tension cables attached to the middle section or support bars. Additionally, the base can use legs as a way to stabilize the structure
  - Extension: inherent to the telescoping mechanism
  - Release Mechanism: will be attached to the top section. custom integration plate/connector will have to be designed

  - Payload support: can be included anywhere on the largest unit. Claw and shelf support designs are the most compatible. A boom can be included in the design to support the payload by hanging.

4.1.1.3 Folding Triangular Base Truss

- **Description:** This design would utilize a triangular footprint for the truss and have the ability to fold flat. The structure would be composed of sections that would stack to the desired height of 3m. The user should attach the anchoring parts to the bottom base, and connect the releasing mechanism to the top base. Then once the balloon is loaded by the gripper, the user can adjust the height up to 3m by extending the truss.
- **Sketch:**

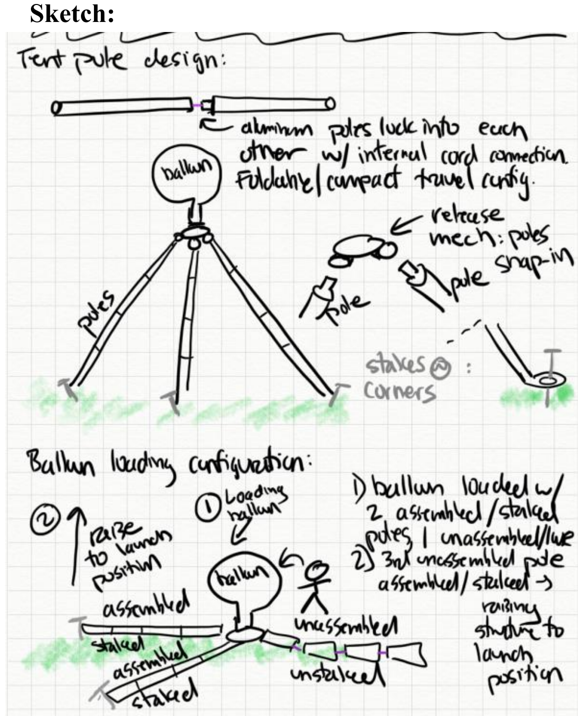


- **Pro:**
  - Preassembled sections
  - Can be folded to a smaller volume
  - Easily portable
  - Simpler than the collapsible square truss
  - Can adjust the maximum height simply by adding more bases
  - More space to support the load
- **Con:**
  - limited prefabricated options
  - additional assembly time needed to lock the folding mechanism
  - additional assembly time needed to unfold up to 3m
  - heavy
- **Compatibility:**

- Anchoring: Can use either the tension cables or support bar to connect the bottom base to the ground and enhance the stability.
- Extension: Inherent to the design.
- Release Mechanism: Will be attached to the top base section. Customized integration plates/connectors will have to be designed.
- Payload support: Inherent to the design. The payload can be put on the bottom base since the triangular base has enough space, also the anchoring mechanism will ensure the security and supporting stability.

4.1.1.4 Foldable Tent Pole Large Tripod

- **Description:** This is a large tripod design that would utilize aluminum, steel or carbon folding tent poles that snap together with cord inside. Each pole would meet at the release mechanism/balloon attachment point and lock in. The bottom of each pole would have a loop for stake attachment in order to anchor the structure to the ground. 2 poles would be assembled and staked before the balloon was attached. Once attached the final stake would be assembled and then raised and staked, bringing the structure to launch height in the process. Cost estimated at $160 at high end and weight at 20 lbs at the high end.
- **Sketch:**



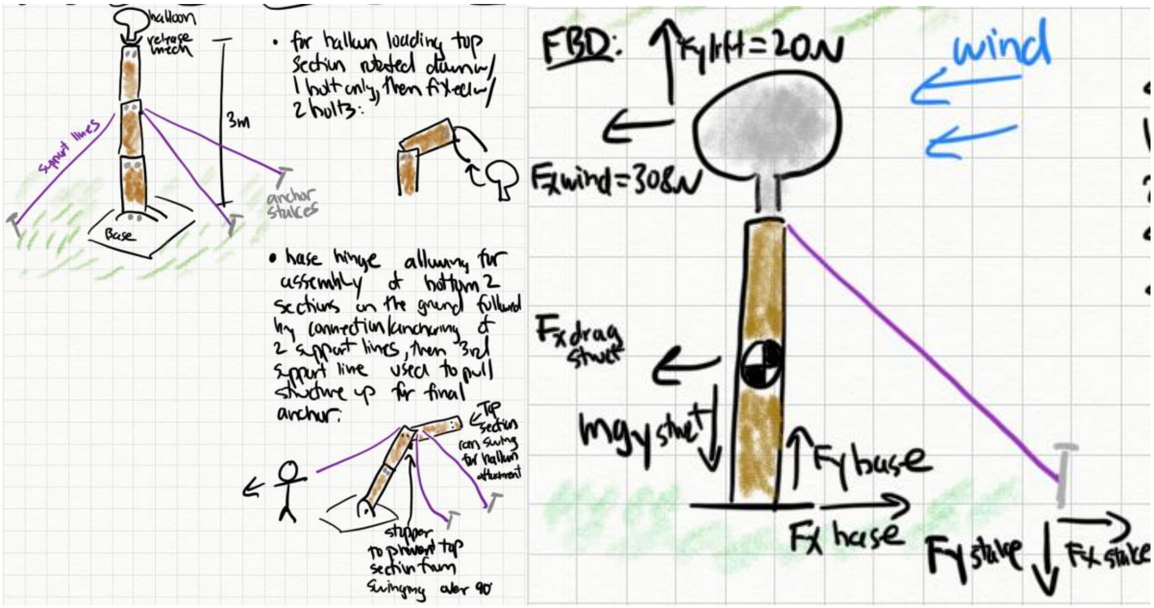
- **Pro**:
  - Lightweight
  - Inherently stable
  - Low cost
  - Simple and intuitive set up
  - Compact for travel
  - Off the shelf poles

- Unlikely to injure user during setup
- **Con:**
    - Off-the-shelf connectors may be hard to find
    - Machining required for top release mechanism joint
    - Lack of strength
    - Requires very lightweight release mechanism
    - Lack of rigidity
    - Durability concerns
- **Compatibility:**
    - Anchoring: built in at bottom of poles for stakes
    - Extension: inherent with long poles and set up with 2 poles being anchored and third being extended and assembled to get balloon to launch height
    - Release mech: Top where poles meet could be designed for any release mechanism
    - Payload support: None, would need solution and poles likely not strong enough to hold securely

4.1.1.5 Sectional 2x4 Wooden or Truss Beam

- **Description:** This design would utilize 3 1m sections held together with 2 bolts and anchored to a base.. Further launch support would be provided by 3 support lines staked into the ground. The first 2 sections would be attached together with 2 bolts and therefore locked in line with each other. This section would then be attached to the base with another 2 bolts holding it upright. At this point the support lines would be attached and anchored at the top of the 2nd section. The third and final 1m section would then be attached with 1 bolt allowing it to swing to 90 degrees for balloon loading on the release mechanism at a height of 2m. This would then be rotated up and locked with the second bolt for launch configuration. Cost would be ~$20 for wood, fasteners and rope, weighing around 25 lbs for those items as well.

- **Sketch:**



- **Pro:**
  - Inexpensive
  - Off the shelf materials
  - Easy of manufacture
  - Easy set up
  - Compact for travel
  - Sturdy materials
- **Con:**
  - Not inherently stable
  - Design lacks inherent stiffness
  - Set up time and complexity
  - Risk to user if structure collapses
  - Weight
  -
- **Compatibility:**
  - Anchoring: designed for base plate and support lines, can be customized for any base plate deemed best for system
  - Extension: extension built into modular design
  - Release Mech: not designed yet, easy to make work with any release mech design
  - Payload Support: easy with truss design, may need additional support if wood material chosen.

4.1.1.6 Windsock Base Telescope

- **Description:** "260cm Heavy Duty Aluminum Alloy Photography Photo Studio Light Stands Kit" [2]. Standard light stands for photography with a tripod base and boom that is adjustable for height. Extends to over 2.6m in height and fits in .96m x.12m carrying case. Cost is $68 and weighs 4.7 lbs.

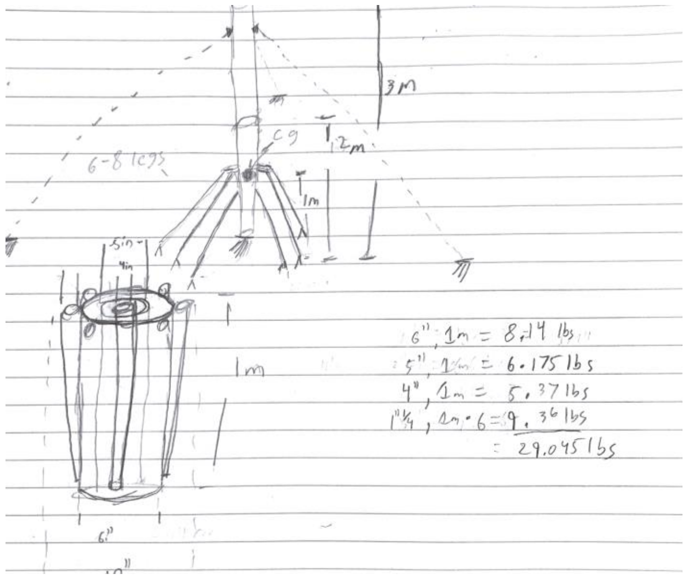
- **Sketch:**

- **Pro:**
    - Inexpensive
    - Off the shelf
    - Stable/freestanding
    - Easy and intuitive set up
    - Fits in required carrying case
    - Lightweight
    - Standard threaded attachment at top for release mech
    - Extendable boom for loading balloon
- **Con:**
    - Requires additional height of .4m
    - Potential modification of tripod legs for base interface
    - Boom may lack sufficient strength and stiffness in high winds
    - No control over manufacturer standards/tolerances
- **Compatibility:** Uses photography standard threaded ends for release mech attachment, would need modification for base and support line attachment.
    - Anchoring: anchoring achieved via tripod legs which would need customization for use with connected base plate or support lines from midway up the boom
    - Extension: Designed with extension built in but will need further height added at the top of the boom or at the base to meet 3m requirement
    - Release Mech: Threaded top connection is standard for photography and could be used for release mech.
    - Payload Support: Requires customization for support.

4.1.1.7 Windsock Base truss

- **Description:** 3m in height beam broken down into 3 sections, each of smaller diameter, via locking telescoping rails. 6 legs of .75 m length attached to the center of gravity of the structure that fold down from its 1 m length case. If need be, there will tethers at the 2.5 m length to attach to the ground.

- **Sketch**

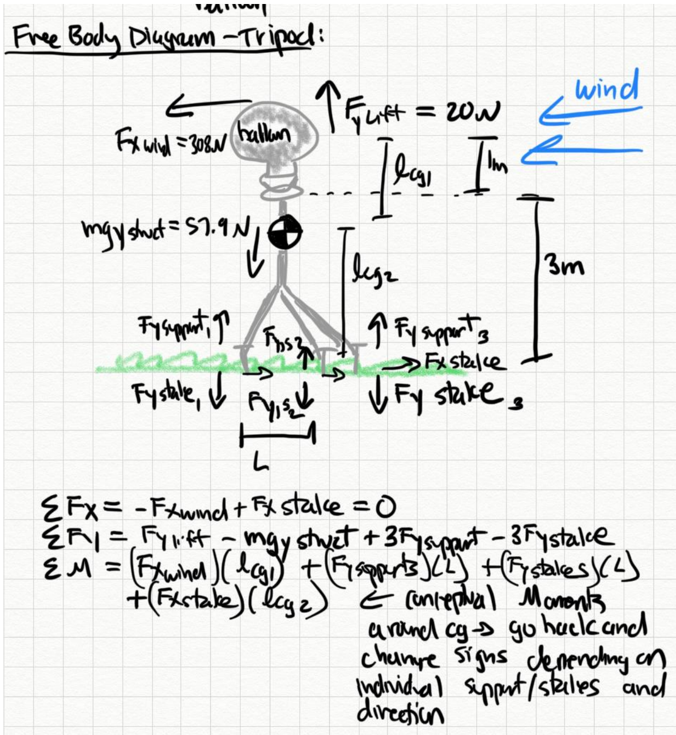


- **Pro:**
  - Comes in a cylinder casing
  - Moderate cost
  - Easily transportable
  - inherently stable
  - multiple back ups for support
  - Off the shelf products
- **Con:**
  - Heavy
  - Will need customization
  - Telescoping rails will be needed to
- **Compatibility:**
  - Anchoring: anchoring through base legs, no need for a base plate.
  - Extensions: needed to be customized to meet height requirements
  - Release Mech: release mechanism should be attached to the top of the structure.
  - Payload support: May need support at the top half with using tethers attached to the ground.

4.1.1.8 Tripod Style with Threaded Extension

- **Description:** 3m in height tall off the shelf tripod. Extending tripod legs with threaded beam extension on top of tripod. Tripod legs and extending beam allow for balloon loading and then extension of the system for launch. Cost is $300, weight is 13lbs.

- **Sketch:**



- **Pro:**
  - Easy and intuitive set up
  - Inherently stable
  - Lightweight
  - Moderate cost
  - Sturdy
  - Proven design
  - Reaches required height
  - Adjustable for balloon loading
  - Known cost
- **Con:**
  - High cost
  - Will need customization for base plate or support line integration
  - No control over manufacturer standards/tolerances
  - Will need to determine specifications of structure for modeling
- **Compatibility:**
  - Anchoring: anchoring achieved via tripod legs which would need customization for use with connected base plate or support lines from midway up the boom
  - Extension: Designed with extension built in
  - Release Mech: Threaded top connection is standard for photography and could be used for release mech.
  - Payload Support: Requires customization for support.

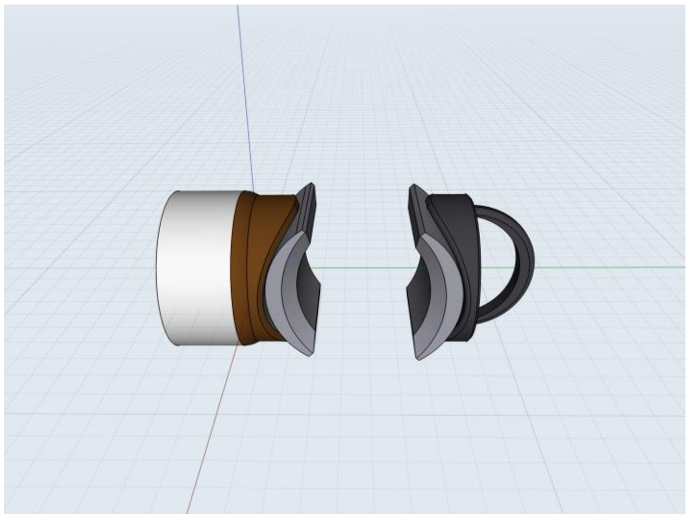
4.2 **Release Mechanism**

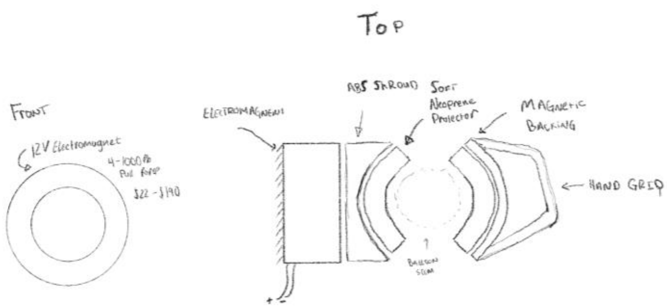
Providing a reliable and effective way to secure the neck in a holding/releasing configuration.

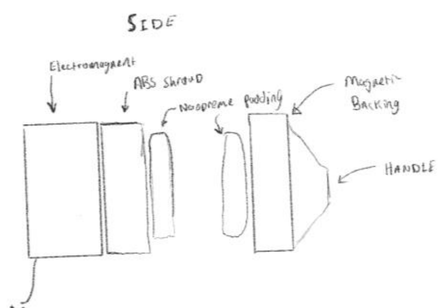
4.2.1 Magnetic Gripper

4.1.2.1 Electromagnetic Clamp

- **Description:** An electromagnet is permanently fixed to the launch stand. The outer face of the electromagnet is counted with soft neoprene rubber to protect the balloon. A complementary magnetic backing face is also coated with the neoprene rubber. When on, the electromagnet attracts the magnetic back plate, firmly securing the balloon neck. On release command, the electromagnet is shut off and the backplate falls, releasing the balloon.
- **Sketches:**



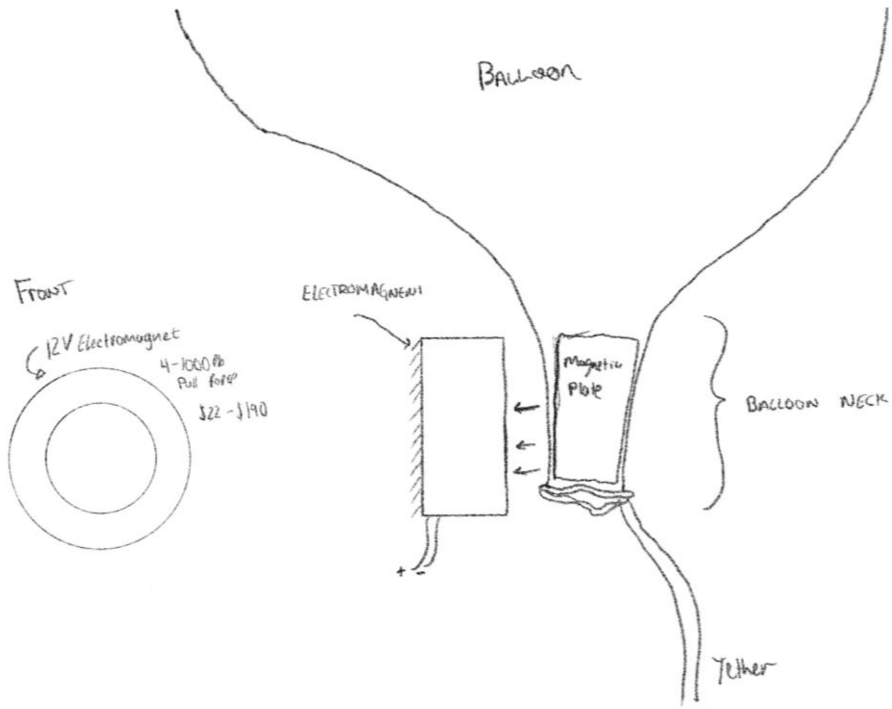




- **Pro:**
  - Relatively easy to manufacture
  - No expensive construction materials
  - Wide variety of electromagnets allows for upgrades
  - Few moving parts (the hand grip falls to the ground)
  - Metal does not contact the balloon
- **Con:**
  - Requires an always on voltage source

4.1.2.2 Balloon Neck Modification

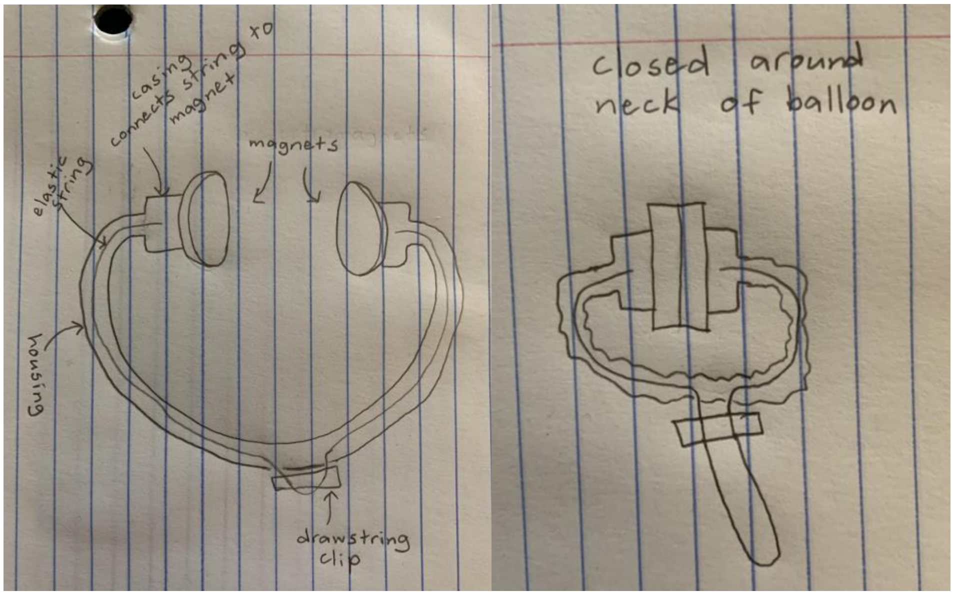
- **Description:** Permitting customer approval, the balloon neck is permanently outfitted with a light weight magnetic plate that can tether the balloon on an electromagnet. When the electromagnet is on, the washer is attached to the launch mechanism. To release the balloon, the electromagnet is shut off and the balloon is released.
- **Sketch:**



- **Pro:**
    - No moving parts
    - Simple Operation
- **Con:**
    - Heating of metal plate could damage the balloon
    - Magnetic plate could reduce payload capacity of balloon
    - Balloons would have to be modified in advance

4.1.2.3 Drawstring

- **Description:** An elastic string in a protective malleable housing. The string's length can be adjusted to fit to the balloon neck, similar to a drawstring backpack or the waistband on a pair of athletic shorts. A magnet is at either end of the string to hold the mechanism around the balloon neck. When ready to launch, the magnets are separated (by hand or could use electromagnets).
- **Sketches:**

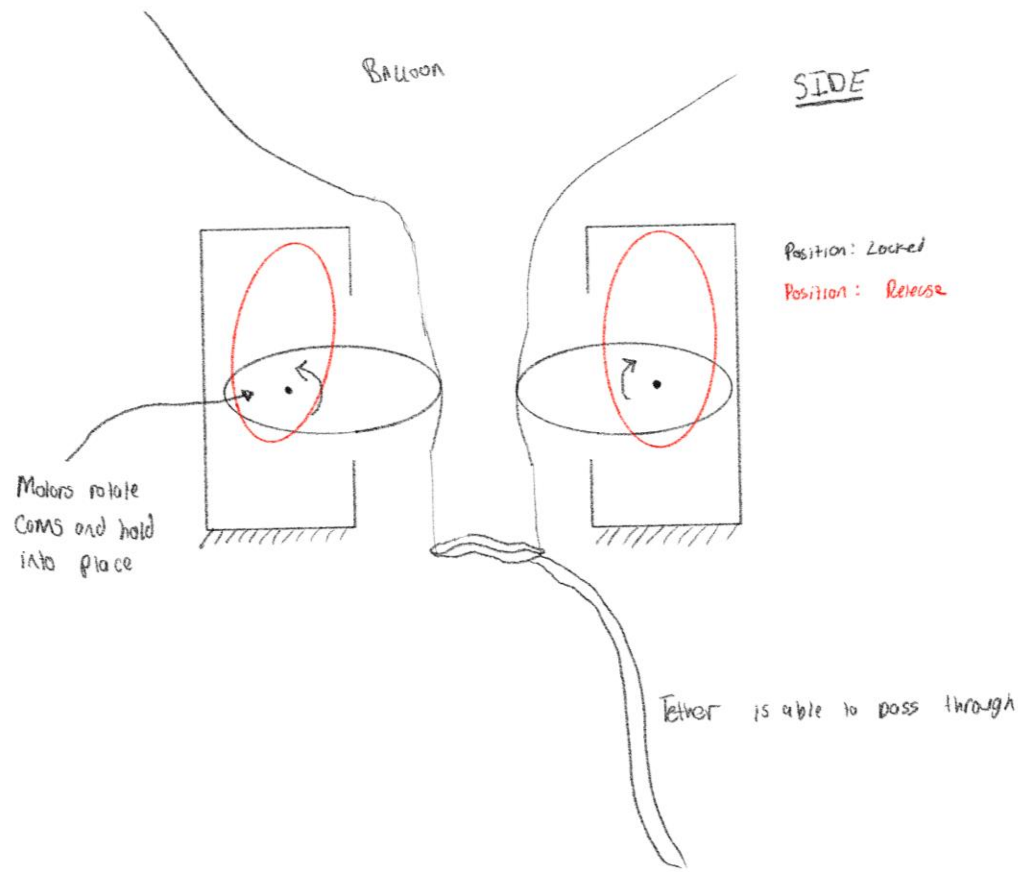


- **Pro:**
  - Easy to use, a type of mechanism people are familiar with
  - No moving parts
- **Con:**
  - Hard to integrate with truss, has no solid attachment points
  - Must ensure the magnets do not clamp over balloon material
  - Heating of magnets near balloon could cause damage

4.2.2 Friction Fit

4.2.2.1 Rubber Housing

- **Description:** Two rotating ellipses that rotate into holding and releasing positions by the power of the motor. The housing for the cams would be attached to the structure such as the electronics for the motors can get through.
- **Sketch:**



- **Pro:**
  - Rotating cams are a fixed distance apart (balloon neck deformation can be controlled)
  - Parts are simple to obtain
  - Metal does not contact the balloon
- **Con:**
  - Electric motors needs to hold back at most ~70lbfs of drag
  - Rotating parts
  - Tether needs to pass through the housing safely

4.2.3 Grasping Mechanism

4.3.2.1 Prefabricated Robotic Hand

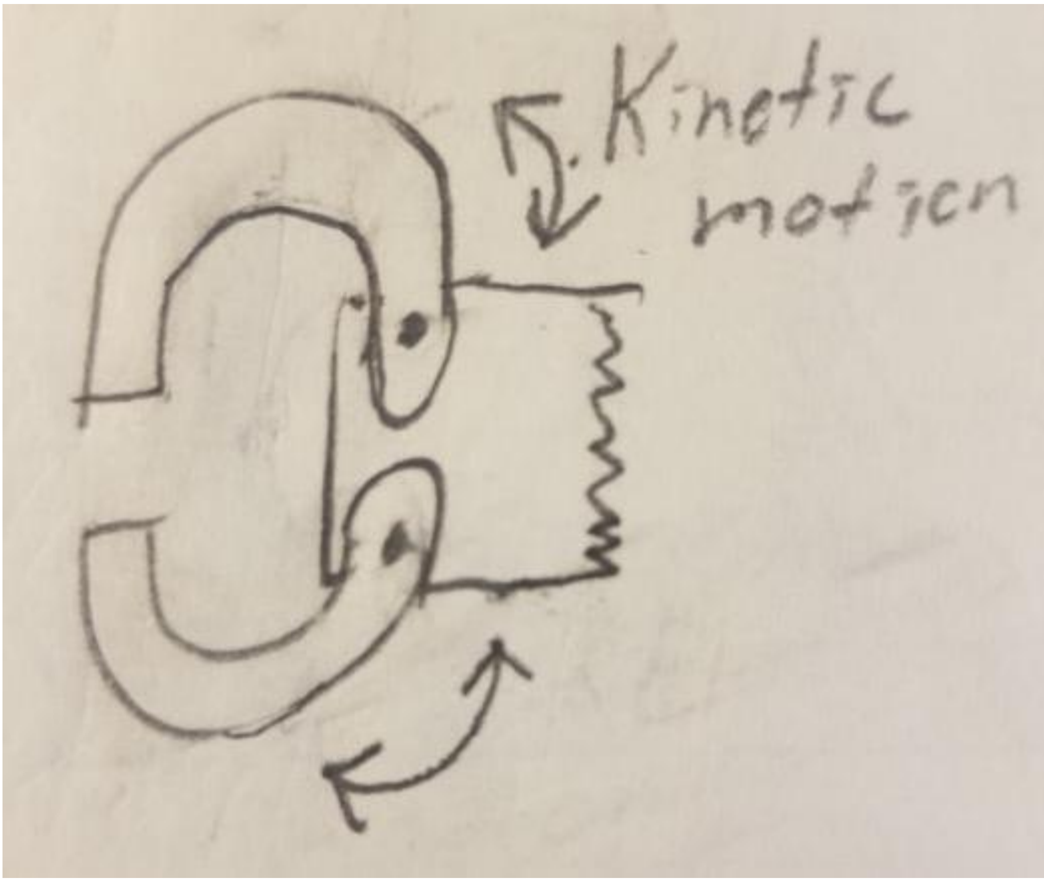
- **Description:** A pre-built robotic hand that is capable of holding the balloon and essentially providing the person launching with a third arm. The mechanism would grip the balloon and release when ordered. This mechanism would be purchased in its entirety.
- **Sketch:**

https://www.banggood.com/DIY-5DOF-Robot-Arm-Five-Fingers-Metal-Mechanical-Paw-Left-and-Right-Hand-p-1099018.html?utm_source=googleshopping&utm_medium=cpc_organic&gmcCountry=US&utm_content=minha&utm_campaign=minha-us-pc&currency=USD&createTmp=1&utm_source=googleshopping&utm_medium=cpc_bgs&utm_content=frank&utm_campaign=frank-pla-us-all-brand-0513&ad_id=435264204190&gclid=CjwKCAjw-5v7BRAmEiwAJ3DpuJHhWDYZyEBQP9o74TEksRuLDHWwzXXVCVfF2ZgegftNf31IptXdOhoCelsQAvD_BwE&ID=557354&cur_warehouse=CN

- **Pro:**
    - Reliable
    - Easy to understand and use
- **Con:**
    - Small moving parts
    - “Easy way out”
    - Expensive to replace, if one part breaks we have no repair knowledge; a new hand must be bought
    - Requires a power source

4.3.2.2 Simple Claw

- **Description:** Similar to the Prefabricated Robot Hand but more simplified. Rather than having several small moving parts, the claw has a two-part gripping mechanism that is controlled by an actuating servo. The arm would be attached to the top of the structure such as the electronics to get through.
- **Sketch:**

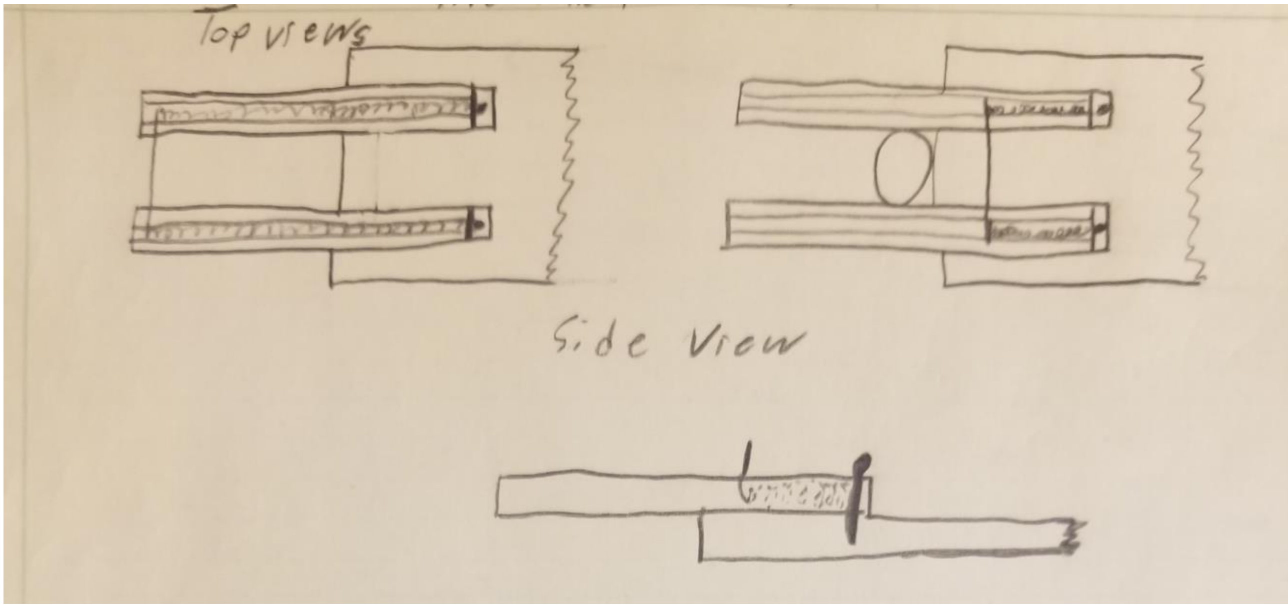


- **Pro:**
  - Minimal volume used in travel configuration
  - Low mass
  - The arm of the claw will be manufactured to the structure specifications
- **Con:**
  - Size of claws would be manufactured to fit these specific balloons to ensure a solid grip. But this means if the type of balloons used changes, the mechanism must be changed too
  - Additional electronics needed to support the servos

4.2.4 Spring Mechanism

4.4.2.1 Pusher System

- **Description:** This design uses a horizontal bar at the end of two rail enclosures to push the neck out of holding. These enclosures would house the springs while they loaded, released and used to wedge the neck into the loaded position. These rails would be attached to a mount that would be attachable to the top of the structure.
- **Sketch:**



- **Pro:**
  - No additional electronics
  - Low mass
  - Minimal volume used in travel configuration
- **Con:**
  - Neck needs to be able to deform enough and withstand the force
  - Requires a manual cock back
  - Potential to lose grip in crosswinds
  - Balloon contacts metal

4.3 Command and Control System

The command and control system connects the user to the gripping system, by allowing for commands to be transferred over the distance between these two pieces. Such commands that would be relayed may include preparing for deployment, actuating the gripper, and locking the gripper in a no-deployment state.

4.3.1 Communication Hardware

4.1.3.1 The communication hardware enables communication between the user and the gripping mechanism. This is the method in which commands are transferred between the user and the device. Note: Drawings are not useful in this section, thus they were omitted.

4.1.3.2 Radio

- **Description:** The use of radio frequencies to carry modulated signals from some command to the launch device. A common example of this is the communication between two walkie talkie radios.
- **Pro:**
  - Familiarity with protocols from ASEN 3300
  - Hardware is commonly available
  - Very large spectrum available for use
  - Variable frequency
  - Omnidirectional
  - Multiple connections
- **Con:**
  - Potential interference depending on the launch site
  - Variable Frequency

4.1.3.3 Infrared

- **Description:** The use of infrared light to transmit information from the user to the launch device. A common example of this is the communication between a remote control and television set.
- **Pro:**
  - Limited chance of interference
  - Cheaply available transmitters and receivers
- **Con:**
  - Easy to interrupt or block
  - Very directional
  - Single direct connection

4.1.3.4 Bluetooth

- **Description:** The use of a bluetooth network to transmit information from the user to the launch device. A common example of this is communication between mobile phones and wireless headphones.
- **Pro:**
  - Minimal chance of interference
  - Interface directly with embedded hardware/software
  - Interface directly with off the shelf mobile devices
  - Support multiple connections
- **Con:**
  - Less experience with bluetooth communication
  - The "pairing" process

4.1.3.5 Mechanical System

- **Description:** The use of a physical connection to the device that transfers torque or force in order to activate the launch mechanism. A common example of this is the physical connection between gas pedals and carburetor in older vehicles.
- **Pro:**
  - Reliable
  - No chance of software failure or interference
- **Con:**
  - Distance Limited
  - Potential for mechanical failure
  - Weight increases with distance from launch mechanism
  - Less flexibility with many terrains and configurations

4.1.3.6 Wired

- **Description:** Connecting the command device to the launcher via a wired connection. An example of this is connecting speakers to a television set via wires to transmit audio information.
- **Pro:**
  - Small chance of interference
  - Distance is practically only limited to wire length
- **Con:**
  - Setup difficulty
  - Potential for wire to tangle
  - Weight increases with distance from launch mechanism

4.3.2 Commands

4.2.3.1 The action or actions leading to arming and deployment of the balloon, or in some cases, arming and disarming of the deployment mechanism. The phrases multiple input, multiple output (MIMO) and single input, single output (SISO) are used to describe the versatility of the command system. The *single input, multiple output* and *multiple input, single output* structures are grouped with SISO and MIMO respectively, as the focus is on the input system here.

4.2.3.2 On Person

- **Description:** The method of command is directly connected to the user is some way. The user need not find the activation method because, during launch conditions, the method will always be available on their person or by performing some human action.
- **Pro:**
  - Always available
  - Location agnostic
- **Con:**
  - Could restrict movement
  - Greater chance of damage while moving
  - Increased customization to user

4.2.3.3 Off Person

- **Description:** The method of the command is not connected to the user in any way. The user does not always have access to the communication method and cannot activate the device by performing some human action.
- **Pro:**
  - Users can be quickly switched
  - Not movement restrictive
- **Con:**
  - Higher chance of losing communication method
  - Likely tied to one location
  - Less mobility
  - Location dependent

4.2.3.4 Timed Release

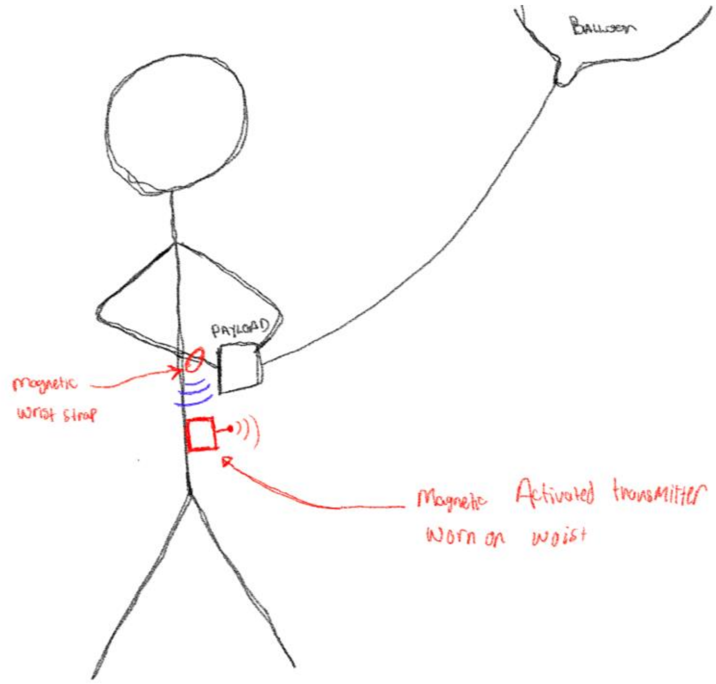
- **Description:** The user issues a command on the launch mechanism which starts a countdown timer to release.
- **Pro:**
  - Easy to use
  - Not restrictive
  - No location restrictions
- **Con:**
  - User has no control over release with wind speed
  - Difficult to abort launch sequence

4.3.3 <u>On Person Commands</u>

4.3.3.1 The user is required to have some additional device on, attached, or innate to their person in order to issue commands.

4.3.3.2 Magnetic Mechanism

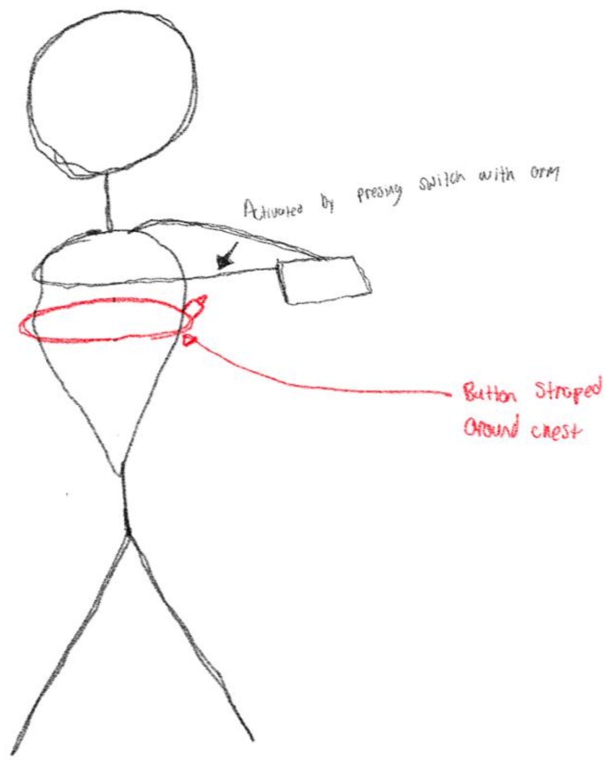
- **Description:** Without the use of hands, the user connects two magnets or uses one magnet to activate a switch on their person to trigger the command. For example, using a magnetic wrist strap to trigger reed switch work on the waist.
- **Sketch:**



- **Pro:**
  - Reliable
  - Doesn't require direct contact (close enough could activate)
- **Con:**
  - Single input single output
  - Relies on movement capability of user
  - Potentially sensitive if around metal
  - Potentially sensitive to normal movements.

4.3.3.3 Button / Switch / Etc.

- **Description:** Without the use of hands, the user manipulates their body to press a button or flick a switch. For example, using the elbow to press a switch attached to the side.
- **Sketch:**



- **Pro:**
    - Simple to operate
    - Easily repeatable action
- **Con:**
    - Relies on movement capability of user
    - Single input, single output
    - Potentially sensitive to normal movements.

4.3.3.4 3-D Gesture Recognition From a Wearable Device

- **Description:** The user wears a device that transmits spatial information about some part of the user to a central computer unit. The command is triggered when a particular orientation of the user is met. This technology would be similar to currently available VR technology.
- **Sketch:**

https://www.forbes.com/sites/helenalbert/2020/07/27/hand-movement-sensor-could-revolutionize-activity-tracking/#6e1d4a314f2e

- **Pro:**
  - Multi input, multi output operation
  - Very customizable
- **Con:**
  - Very complex
  - Larger computer processing requirement
  - User dependent
  - User could accidentally activate gesture performing normal human actions

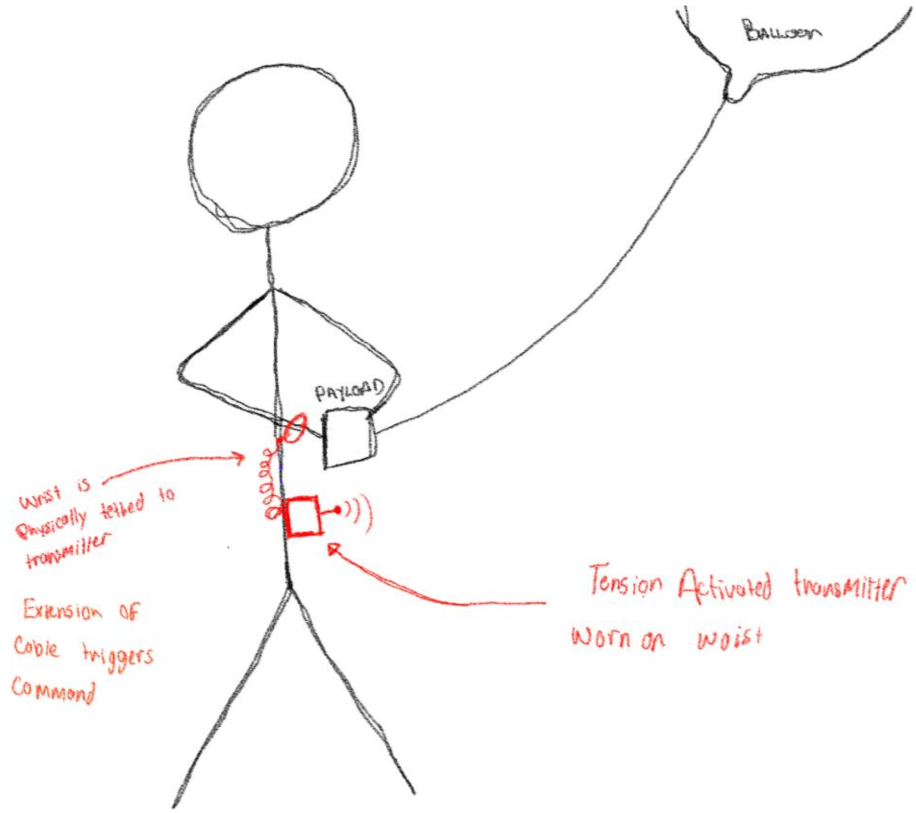
4.3.3.5 Reflective / Light Emitting Wearable

- **Description:** User wears either an emitter or reflector which sends or bounces signals (e.g light signals) to the launch mechanism. The user controls commands by either blocking transmission or pointing body parts at the launching mechanism.
- **Pro:**
  - Versatile method to activate; i.e. does not require to have specific flexibility, strength, etc
- **Con:**
  - High sensitivity to the environment
  - Either SISO or increased complexity

4.3.3.6 Mechanical Connection Mechanism

- **Description:** The user wears a bracelet, anklet, belt, etc. that is mechanically connected to the launch mechanism. The user issues the command by some physical action that moves the attachment point in a substantial way.

- **Sketch:**



- **Pro:**
  - Easier to tune to appropriate sensitivity and reliability
  - Generally transferable to many other environments and launch conditions
- **Con:**
  - SISO
  - Possible complexity introduced for issuing more than one command.

4.3.3.7 Hand Pressure Sensitivity System

- **Description:** The user wears some sort of glove or bracelet that is pressure sensitive. The pressure input may be on one finger, and may issue a command with a sequence of tapping, or the system may issue a command if the user removes pressure in some way.

- **Sketch:**

https://pressureprofile.com/body-pressure-mapping/finger-tp

- **Pro:**
  - Equipment does not impinge or inhibit user's mobility
  - MIMO
- **Con:**
  - Complex system, challenging to configure
  - Delicate and likely easy to break

4.3.3.8 Wearable Microphone

- **Description:** The user wears a microphone and uses it to issue vocal commands, which are interpreted to launch commands.
- **Pro:**
  - Equipment does not impinge or inhibit user's mobility
  - MIMO
- **Con:**
  - Sensitive to wind interference
  - Complex system, challenging to configure
  - May be difficult to adapt to different users

○

4.3.3.9 Tesla's Neurolink

- **Description:** User undergoes medical operation to become equipped with Tesla's neurolink technology. User interfaces directly with the launching mechanism via bluetooth and thinks to issue commands.
- **Pro:**
  - Simple, user customizable operation
  - Very accurate

    - Very small chance of false commands
    - Easy to arm/disarm mechanism
- **Con:**
    - Expensive
    - Potentially dangerous
    - User dependent
    -

4.3.4 Off Person Commands

4.4.3.1 The user is not required to have some additional device on, attached, or innate to their person in order to issue commands.

4.4.3.2 Voice Commands

- **Description:** An external microphone is used to pick up the user's vocal commands.
- **Pro:**
    - Equipment does not impinge or inhibit user's mobility
    - MIMO
- **Con:**
    - Very sensitive to wind
    - Complex system, challenging to configure
    - May be difficult to adapt to different users

4.4.3.3 Gesture Commands

- **Description:** Moving your body in a certain way that a "Kinect" like device would detect remotely. For instance, a camera or position recognition system would detect the user moving their hands above their head to issue a certain command.
- **Pro:**
    - Equipment does not impinge or inhibit user's mobility
    - MIMO
- **Con:**
    - Requires more equipment and space to configure and use
    - May be difficult to adapt to different users

4.4.3.4 Foot Pedal

- **Description:** The user presses on a mechanical system using their foot to issue a command.
- **Pro:**
    - Extremely reliable system
- **Con:**
    - SISO
    - Increased complexity for multiple commands
    - Requires a predetermined launching location

4.4.3.5 Wind Speed Detection

- **Description:** A command is issued based on the wind speed.
- **Pro:**
    - Minimal user interface or consideration
    - User independent
    - May give better launch timing than user
- **Con:**
    - Difficult to use in a stand-alone system
    - May be difficult to use in low wind conditions

4.4.3.6 Physical Location

- **Description:** A command is issued based on the physical location of the user. Requires some wearable or supplementary equipment for determination. Phrased differently, the user walks to some physical launch position in space (i.e some pad) to arm; staying on the pad to launch.
- **Pro:**
    - Minimal user interface or consideration
    - User independent
- **Con:**
    - Takes longer duration to time release
    - Potentially inconsistent based on inaccuracies in calculated position
    - Requires additional setup for use
    - SISO

4.4.3.7 Launch Stand

- **Description:** Launch stand has a beam that the user interrupts with a body part.
- **Pro:**
    - Allows many options for user interaction
- **Con:**
    - Increased complexity
    - SISO

5.0 Trade Study Process and Results

5.1 Structures

5.1.1 For the structural design of the BDS the following trade study was conducted to best meet the design requirements based on functional requirements from the customer. The main elements the study focused on evaluating were balloon safety, structural stability in the first tier with ease of set up, weight, foldable/compact travel design and cost in the next tier down.

5.1.2

Metric / Evaluation Criteria	Score	Level Description
Balloon/Payload Safety	0	Consistent contact with the balloon/payload in any conditions
	5	Some contact with balloon/payload in high winds
	10	No contact with the balloon/payload in any conditions
Weight	0	50 lbs<
	5	25-50lbs
	10	25lbs>
Ease of fit in Carrying Case	0	Van/SUV needed
	5	Can fit in the car
	10	1m x 25cm
Inherent Stability	0	Rely heavily on anchoring
	5	Marginal stability if anchors fail
	10	No anchoring required/inherently stable
Feasibility of Build/Mfg/Off shelf	0	Custom tower structure, release mech interface and anchors
	5	Custom anchors and release mechanism interface
	10	No custom/all off the shelf
Ease of Setup / Configuration	0	Assembly is through an instructional video/ class
	5	Assembly through construction card
	10	Assembly is common sense
Budget Availability	0	over $500 mfg
	5	$400 to $500 mfg
	10	sub $400 mfg

5.1.3 [Why were this evaluation criteria chosen? (Tie to FR in some way)] These evaluation criteria are all directly related to important functional requirements that are essential for project success including keeping the balloon and payload free from damage, having a system that is stable in potentially high winds and designing a structure that can be assembled, transported and reproduced easily and under $400 for the manufactured structure budget portion.

5.1.4 [Discuss why each weight was assigned to each criteria] Score weights are based on how critical each criteria is to the success of the project within the structural space. Balloon/payload safety and the stability of the structure are the most important design aspects for the structure. If the balloon is cut, payload damaged or the structure falls the design will not be a success and will not achieve its goal of streamlining high wind launches. Ease of assembly and then ease of manufacture were weighted next as the system is unlikely to be used if it is too hard to set up or too difficult to reproduce. Weight, ease of fit in carrying case and finally budget received the lowest weights. While weight is important none of the designs seemed to be too far off the 50 lb limit and the success of the structural system was not overly dependent on being much below this. In fact one could argue that the stability of the structure could be enhanced with more weight allowing the center of gravity to move to a lower position. In a similar way none of the designs appeared to be too far off the limit of being able to fit in the 1x.25m carrying case and designs that are above this limit could still be very useful. Finally from a budget perspective the team felt that even if a design comes in over the $400 allotment for manufactured cost it would not be hard to fine tune the design to get within the limit.

5.1.5 [What are the results of your trade study? (Include Table Here)]

Note: Example trade study included below. Insert your own.

Metric / Evaluation Criteria	Requirement / Motivation	Score Weight	Tilting Truss	Telescoping Truss	Folding Triangular Base Truss	Tent Pole Tripod	Sectional 2x4 Wooden or Truss Beam	Tripod Style with Threaded Extension	Windsock Base
Balloon/ Payload Safety	FR 5.0, FR 7.0, FR 8.0	0.3	5	9	8	6	8	9	10
Weight	FR 1.0, FR 3.0	0.06	2	10	4	9	5	8	5
Ease of fit in Carrying Case	FR 3.0	0.06	0	10	10	10	7	9	9
Inherent Stability	FR 4.0, FR 8.0	0.3	10	5	7	9	5	8	5
Feasibility of Build/Mfg/Off shelf	Project Timeline	0.1	6	8	7	6	9	10	5
Ease of Setup / Configuration	FR 1.0, FR 2.0, FR 3.0	0.15	5	10	5	7	7	10	5
Budget Availability	LVL1-3: Cost	0.03	0	5	5	7	8	6	5
Total		1	6.0	7.9	6.9	7.5	6.8	8.8	6.7

5.1.6 [Discuss the final results in words and what implications this could have on the final product. What are the best results and did we expect this? Is more research needed? We are not selecting the best design here.] After reviewing the trade study, the Tripod Style with Threaded Extensions received the highest score of 8.8 with the next top scores of 7.9 and 7.5. All of the structures designs have been designed with the payload safety and stability as the main concern. In general all of the designs meet the functional requirement, but not all of them meet every level of success. The Telescoping Truss and the Tripod Style with Threaded Extension both are easily feasible and can meet almost all levels of success. The difference is that the Telescoping Truss has more room for modifications and alterations within its design, while the Tripod style would have more modeling than designing. More research would be needed for the Tripod style and was concluded to be a good back up.

5.2 Release Mechanism Trade Study

This trade study assists in the selection of a mechanism to efficiently load and launch the balloon. An effective mechanism is one that can keep the balloon gripped in the spontaneous wind gusts on the foothills. It must be lightweight and easy/quick to set up, such that one person can comfortably launch a balloon solo. This mechanism must also be protective and reliable of keeping the balloon material from being damaged in any way. It also must grip the balloon's neck in such a way that a premature launch is negated.

5.2.1 Metrics/evaluation criteria

Metric / Evaluation Criteria	Score	Level Description
Ease of set-up	0	Requires multiple tools or two people
	5	Requires minimal tools with one person
	10	Intuitive with no tools and one person
Speed of set-up	0	Takes longer than 10 minutes to attach balloon
	5	Takes less than 5 minutes to attach balloon
	10	Takes less than 1 minute to attach balloon
Portability	0	Doesn't fit inside carrying case / more than 25 lbs
	5	Fits inside carrying case with structure/less 10 lbs
	10	Easily fits inside carrying case with structure/less than 1 lbs
Protection of Balloon Material	0	Touches surface of balloon / has sharp edges / no temperature mitigation
	5	Only holds neck of balloon / may have hard edges (not necessarily sharp) / some temperature mitigation
	10	Only holds neck / soft edges / hypothermic
Grip Strength	0	Grip strength less than 20 lbs (only holds the balloon on a calm day)
	5	Grip strength equal to 70 lbs (the estimated maximum force on balloon from 20 m/s wind)
	10	Grip strength holds 70 lbs with a FOS of 1.5 (105 lbs)
Trigger Resiliency	0	No fail safety for trigger, release is prone under dynamic conditions
	10	Trigger is completely resilient to failure
Energy Efficiency	0	System can hold balloon less than 10 minutes, difficult to integrate the electronics to the structure/gripping mechanism interface
	5	System can hold balloon for 45 minutes
	10	System can hold balloon indefinitely, necessary electronics can be easily integrated with structure/gripping mechanism interface
Budget	0	Out of budget ($1,000)
	2	Responsible for more than half of the budget (<~$500)
	5	Within budget but restricts other components (<~$150)
	10	The cheapest, smallest influence on other budgets (<~$20)

5.3 These evaluation criteria were chosen with the safety of the balloon in primary consideration; half of the criteria ensure its protection. These criteria directly satisfy FR 7.0 - 10.0, ensuring that the balloon does not touch hot surfaces or protrusions, and ensuring that the balloon does not launch prematurely. The other criteria enable the single-person launch customer requirement. A release mechanism that is lightweight and intuitive to set up satisfies FR 1.0 - 3.0.

5.3.1 These weights are directly correlated to the success of the release mechanism. The grip strength was the most important metric of the BDS. Without a reliable mechanism to hold these couple hundred dollar balloons in place, the safety of the solo user and the success of the overall mission would be in jeopardy. The purpose of this project was to reduce the current endeavor it was to deploy a balloon. Current time to deploy a balloon is one hour and we were asked to assemble/disassemble the BDS within five minutes. Making the release mechanism such that it minimizes the volume and mass would allow for greater maneuverability that allows for a faster assemble/disassemble time. It would also then maximize the easy at which a user can deploy balloons and hence it is our third heaviest weight. These three critical metrics of the release mechanism are our underlying design divers. The three next heaviest weights saw equal importance and received equal weights. The last two metrics were not that important to our customer but still were linked to our functional requirement.

5.3.2 Trade study results

Metric / Evaluation Criteria	Requirement / Motivation	Weight	Electromagnetic Clamp	Balloon Neck Modification	Drawstring	Rubber Housing	Prefabricated Robot Hand	Simple Claw	Pusher System
Ease of set-up	FR 1.0	0.15	9	10	7	10	8	8	8
Speed of set-up	FR 2.0	0.05	10	10	8	10	10	10	6
Portability	FR 3.0	0.2	7	8	10	4	6	7	5
Protection of Balloon Material	FR 7.0	0.1	8	5	8	7	7	6	3
Grip Strength	FR 8.0	0.25	10	7	4	10	4	3	4
Trigger Resiliency	FR 9.0	0.1	8	7	7	8	6	6	2
Energy Efficiency	FR 10.0	0.05	8	8	7	6	7	8	9
Budget Availability		0.1	6	7	8	5	6	8	8
Total		1.00	8.35	7.65	7.10	7.60	6.15	6.25	5.25

5.3.3 From this trade study, one can see the Electromagnetic Clamp received the highest rating of 8.35 while the next three options are very closely rated between 7.65, 7.60, and 7.10 and. From an "at glance" perspective, these numbers all followed what was initially expected with the exception of the balloon neck modification. While this could be very effective as a pure release strategy, it may be an unrealistic or undesired option due to the added risk of modifying the delicate material. Aside from the Rubber Housing method, the general trend is that systems with rated magnetic, score higher than more mechanical systems. The lower ratings received by the mechanical systems were largely due to their lacking in holding the balloon safely, grip strength, and trigger resiliency. Should further investigation reveal complications with electromagnetic systems, there is relatively high confidence in the Rubber Housing mechanism as a viable alternative.

5.4 Command and Control Trade Study

There are two trade studies to consider within the command and control system. The command and control system is tasked with relaying the user's command to the gripper mechanism. Naturally, this is broken down into two tasks: the command, and the method in which the command is communicated over space to the gripper. First, we consider the hardware giving access from the user to the gripper. Second, we evaluate the options for the user issuing the command. Thus, we proceed with the discussion of the hardware trade study fully, and then continue with a similar consideration of the command trade study. Both of these subsystems may have many different feasible approaches, and both accomplish key goals within the overall mission, although with varying levels of success depending on the selected option.

5.4.1 Hardware trade study evaluation criteria

Metric / Evaluation Criteria	Score	Level Description
Maneuverability and Distance	0	User is required to be stationed at a specific range and distance to operate
	3	User is unable to easily maneuver in order to accommodate wind direction
	6	User is limited in practical range; signal connection could be dependent on environmental factors
	10	Range and direction of user is not an issue for any reasonable application
False Positive Resistance	0	Command is *likely to occur* independent of the user. The hardware is capable of accidentally launching the balloon when there is no command
	5	Command *could occur* during regular movement/conditions. The hardware is capable of accidentally launching the balloon when there is no command during regular setup movement/conditions.
	10	Command is *extremely unlikely* during regular setup movement/conditions. The hardware is not capable of accidentally launching the balloon when there is no command during setup movement/conditions.
False Negative Resistance	0	False negative is likely to occur no matter what. The hardware is not capable of launching the balloon when there is command on the first attempt.
	5	False negative risk is highly mitigated by ideal use. The hardware is sometimes capable of launching the balloon when there is command, but there is a time when it is not able to function properly.
	10	False negative is unlikely to occur no matter what. The hardware is not capable of launching the balloon when there is no command in the first attempt
Simplicity, Current Knowledge	0	Team would have to take a class in order to apply hardware
	5	Team could easily apply hardware with some practice and research
	7	Team has members with familiarity that could lead the development effort
	10	Team has an expert on hand
Ease of Setup / Configuration	0	Software tools or physical are required to pair command to launch mechanism
	3	Software does not need to be configured, but physical connections need to be made by the user to set up device
	5	Some common pairing process is required to pair command to launch mechanism

	7	The system could be dependent on a specified frequency or channel; process does not require an expert to understand
	10	The system 'just works'; no setup process is needed
Budget Availability	0	Out of budget ($1000). The cost of production of 1 unit hardware is more than $1000 which is beyond the team's budget availability
	2	Responsible for more than half of the budget (<~$500). The cost production of 1 unit hardware is within the range of $200- $500 which takes more than half of the budget just to produce 1 unit hardware
	5	Within budget, but restricts other components (<~$150). The cost of production of 1 unit hardware is within the range of $50-$150, but this limits the opportunity to buy other components that are needed in other departments
	10	The cheapest, smallest influence on other budgets (<~$20). The cost of production of 1 unit hardware is within the range from $0-$20 which has the smallest effect on other budgets from other departments
Off-the-Shelf Availability	0	System custom designed and custom purchased out-of-house, can not replace components themselves
	3	System custom designed and custom purchased out-of-house, can replace components if needed, but requires software changes
	6	System custom designed and custom purchased out-of-house, can replace components if needed
	7	System custom designed but assembled from common components (no ICs), can replace components if needed
	10	Entire system purchased self-contained (no soldering, minimal assembly)

5.4.2 These evaluation criteria link back to the functional requirements, as illustrated below by the *Requirement / Motivation* column within the trade study matrix. In summary, these criteria stem from the overall purpose of having a versatile configuration. Weights were assigned to each criteria, based on the overall importance in achieving mission success. Each criteria was first ranked in order of importance for ensuring mission success. In other words, for each criteria we consider "if criteria x fails, how likely is it that higher level success criteria are not met". This establishes an order of importance. From here, numerical weights are assigned in decreasing magnitude, with higher likelihoods of failed success criteria corresponding with higher weighting values. Of course, these weights are then adjusted to sum to unity. Both false positive resistance and maneuverability were both weighted heavily; if the user is unable to adjust for wind or maneuver in the event of changing wind direction, the mission will either become very delayed or fail einiterly. Ease of setup and configuration isn't as crucial to mission success or failure, but is directly beholden to the customer's assembly time requirement; thus, this criteria was weighed less heavily but is still important for overall project success. While false negative resistance is important, it is still less important than false positive resistance. If the user sends a command which the system doesn't respond to, then they can simply send the command again, the mission won't fail. Finally, simplicity and current knowledge, budget availability and off-the-shelf availability are important options to keep in mind, but are inherently constrained by the project and don't impact the customer's success significantly.

5.4.3 *Hardware Trade Study Results:*

Metric / Evaluation Criteria	Requirement / Motivation	Weight	RF "Radio"	Infrared	Bluetooth	Mechanical	Wired
Maneuverability and Distance	FR1.0, FR2.0, FR3.0	0.2	10	6	6	3	3
False Positive Resistance	FR4.0, FR5.0	0.3	10	5	10	5	10
False Negative Resistance	FR2.0	0.05	10	5	10	5	10
Simplicity, Current Knowledge	Project Timeline	0.05	7	5	5	7	10

Ease of Setup / Configuration	FR1.0, FR2.0, FR3.0	0.25	7	7	5	3	3
Budget Availability		0.05	5	5	5	5	10
Off-the-Shelf Availability		0.1	6	6	3	3	10
Total		1	8.45	5.8	6.75	4	6.85

5.4.4 In the trade study, we see that the RF and wired options emerge as the preferred options. This was expected, as the infrared and bluetooth options provide basically the same functionality of RF, but with more specialization. Similarly, the mechanical option follows the same idea as the wired option, but introduces further complexity with its physical implementation. However, the RF and wired communication options each offer differing distinct advantages and disadvantages, and should be taken into further consideration. The RF option wins out due to it's versatility in setup conditions. The increased complexity is worth it, as the project revolves around the idea of a quick setup. In other words, the complexity of the RF system does not necessarily correlate to the success of the mission, but the lack of maneuverability and setup difficulties of the wired system introduce distinct obstacles in meeting success criteria.

5.4.5 Command trade study evaluation criteria

Metric / Evaluation Criteria	Score	Level Description
False Positive Resistance	0	Command is *likely to occur* independent of the user. The command system is capable of giving a command to accidentally launch the balloon when there is no input signal
	5	Command *could occur* during regular setup movement/conditions. The command system is capable of giving a command to accidentally launch the balloon when there is no input signal or during system set up
	10	Command is *extremely unlikely* during regular setup movement/conditions. The command system is not giving a command to launch the balloon when there is no input signal or during system set up
False Negative Resistance	0	False negative is likely to occur no matter what. The command system is not capable of giving a command to launch the balloon on the first attempt.
	5	False negative risk is highly mitigated by ideal use. The command system is not capable of giving a command to launch the balloon after the first attempt has been made
	10	False negative is unlikely to occur no matter what. The command system is capable of giving a command to launch the balloon on the first attempt
Flexibility of Command Structure	0	SISO and requires additional design work to have multiple inputs
	4	SISO but multiple inputs easily added
	6	SISO with multiple inputs easily added, and commands can be inverted with the same input repeated (without design work)
	10	MIMO
Simplicity/Ease to Issue Command	0	User Required to Take Course
	5	User needs to read or memorize instructions
	10	User needs no preparation
Freedom of Movement / Usability	0	User has to be at a certain place and can not move
	5	User can move within a fixed radius, but can not change launch direction without reconfiguring command device

	10	User can move anywhere in the launch area
Cost/ Budget Availability	0	Out of budget ($1000). The cost of production to build a command system is more than $1000 which is beyond the team's budget availability
	2	Responsible for more than half of the budget (<~$500). The cost of production to build a command system is within the range of $200- $500 which takes more than half of the budget just to build such system
	5	Within budget, but restricts other components (<~$150). The cost of production to build a command system is within the range of $50-$150, but this limits the opportunity to buy other components that are needed in other departments
	10	The cheapest, smallest influence on other budgets (<~$20). The cost of production to build a command system is within the range from $0-$20 which has the smallest effect on other budgets from other departments
Off-the-Shelf Availability	0	System custom designed and custom purchased out-of-house, can not replace components themselves
	3	System custom designed and custom purchased out-of-house, can replace components if needed, but requires software changes
	6	System custom designed and custom purchased out-of-house, can replace components if needed
	7	System custom designed but assembled from common components (no ICs), can replace components if needed
	10	Entire system purchased self-contained (no soldering, minimal assembly)

5.4.6 These evaluation criteria link back to the functional requirements, as illustrated below by the *Requirement / Motivation* column within the trade study matrix. In sum, these criteria stem from the overall purpose of resisting false positives; in other words, the activation of the release mechanism when the user does not intend for the mechanism to release. This is crucial to the success of the mission, thus it is weighted most heavily. Next, freedom and movement and flexibility of command structure are important, but the relative scores of these categories are not mission critical. Poor evaluations in these categories may make the mission more difficult or cumbersome, but will not affect the success of the mission. Simplicity is important from a user experience perspective; every proposed design fits within the confines of hands free communication, so all additional simplicities are niceties. The same logic follows for budget availability, off the shelf availability, and false negative resistance; all of these categories should be considered, but are negligible in terms of overall mission success.

5.4.7 *Off Person Command Trade Study Results:*

Metric / Evaluation Criteria	Requirement / Motivation	Weight	Timed Release	Voice	Gesture	Foot Pedal	Wind Detection	Launch Stand	Physical Location
False Positive Resistance	FR4.0, FR5.0, FR6.0	0.3	0	0	5	10	0	5	5
False Negative Resistance	FR2.0	0.05	10	5	5	10	10	5	5
Flexibility of Command Structure	FR4.0, FR5.0, FR6.0	0.15	0	10	10	0	0	4	4
Simplicity/Ease to Issue Command	FR1.0, FR2.0, FR3.0, FR9.0	0.2	10	10	5	10	10	10	10
Freedom of Movement / Usability	FR1.0, FR2.0, FR3.0, FR9.0	0.15	10	5	5	0	10	0	0
Budget Availability		0.05	10	10	2	5	5	5	5
Off-the-Shelf Availability		0.1	6	3	7	6	6	3	6
Total		1	5.1	5.3	5.8	6.35	4.85	4.9	5.2

5.4.8 *On Person Command Trade Study Results:*

Metric / Evaluation Criteria	Requirement / Motivation	Weight	Magnetic mech.	Button / Switch	3D Gesture	Light Emitter	Mechanical Connection	Pressure Sensitivity	Wearable Microphone	Tesla's Neurolink
False Positive Resistance	FR4.0, FR5.0, FR6.0	0.3	5	5	5	0	10	5	0	10
False Negative Resistance	FR2.0	0.05	10	10	5	0	10	5	5	10
Flexibility of Command Structure	FR4.0, FR5.0, FR6.0	0.15	6	6	10	0	0	10	10	10
Simplicity/Ease to Issue Command	FR1.0, FR2.0, FR3.0, FR9.0	0.2	10	10	5	10	10	5	10	10
Freedom of Movement / Usability	FR1.0, FR2.0, FR3.0, FR9.0	0.15	10	10	10	5	0	10	10	10
Budget Availability		0.05	5	5	5	5	5	5	5	0
Off-the-Shelf Availability		0.1	7	7	6	7	7	3	3	0
Total		1	7.35	7.35	6.6	3.7	6.45	6.3	5.8	8.5

5.4.9 In this trade study, we see that magnetic mechanism and button or switch mechanism are the preferred options. This was expected, as the 3D gesture is more prone to error when giving the command inputs. Tesla's Neurolink is the best option in terms of functionality, however in terms of budget and off-the-shelf availability, it does not seem possible and realistic to use such a system in the BDS. Although both magnetic mechanism and button system share the same score in the trade study, each option offers different advantages and disadvantages that should be taken into further consideration. The magnetic mechanism option wins out due to its reliability in setup conditions and does not require direct contact with the user, i.e. it is close enough to be activated. As one of the project objectives is a quick setup and the ability to launch a balloon by one person, this on-person command is the closest choice in meeting success criteria.

6.0 Selection of Baseline Design

The results of the trade studies were evaluated against general engineering intuition of the options' feasibility and usefulness. That is, the design options that were qualitatively perceived as superior were compared to their quantitative scores from the trade studies. Nonetheless, options ranking closely in the trade study were compared directly to one another to determine the superior option. This secondary level of comparison avoids making decisions based on arbitrary weight and point allocations, instead using a more in-depth analysis. Further, this comparison was done with the entirety of the team, providing a perspective different from that of the original trade study designers.

6.1 Structures Team Baseline Design

The results of the trade study for the structures designs reduced to the Telescoping Truss design and the Tripod with Threaded Extension design. Both of these designs were the highest scoring designs, scoring within a point of each other. The advantages and disadvantages of each design were then weighed against each other and discussed in depth. Ultimately, the Telescoping Truss design was selected to be developed further. This design option was selected over the other due to its greater freedom of design options compared to the off the shelf tripod option. This increase in design freedom allows many more solutions to be implemented in the case of future obstacles. Additionally, modeling will be much simpler since all specs will be designed as opposed to trying to find this information from the manufacturer of the tripod. However, the advantage of the inherent stability of the tripod will be incorporated into the Telescoping design moving forward. This helps address any concerns with the stability of the system in extreme weather conditions. Initial brainstorming includes modifying the base of the telescoping truss to include legs that will help increase its stability. Further designs will iterate on the best solution to increase the stability of this design.

6.2 Release Mechanism Baseline Design

Upon examination of the trade study results, the best design chosen for the release mechanism is the Electromagnetic Clamp. Other considered designs included the Balloon Neck Modification, Drawstring, and Rubber Housing. Although scoring the second highest in the trade study, the Balloon Neck Modification was ruled out due to an increased probability of damaging the balloon inherent from adding a modification to a sensitive material. This left the Drawstring and Rubber Housing as the next most viable competitors to the Electromagnetic Clamp. The drawbacks to the Drawstring method stem from slightly lower scores in ease and speed of setup and a significantly lower score in grip strength. The drawbacks to the Rubber Housing design stemmed primarily from portability. With grip strength and portability as the largest weighted factors within the trade study, it was clear to down select the best design to the Electromagnetic Clamp. This system scored highly in grip strength, ease of use, and portability, along with having little risk of damaging the balloon or accidentally releasing early.

6.2.1 Command and Control Baseline Hardware

As mentioned previously, the RF and wired communications cover the vast majority of the design space, although with fewer drawbacks than the infrared, bluetooth, and mechanical options. This is also clearly shown by the comparable scores in the trade study. However, the RF communication method is preferred over the wired method. This is due to the project's overarching focus on ease of setup and usability. Again, these metrics are shown within the trade study, where the wired system ranks poorly due to the added complexity of maneuvering physical materials. Similarly, using the RF method does not increase the difficulty or complexity too much, as RF is a very well-known and commonly used communication method. Thus, concurring with the results of the trade study, the clear communication hardware design option is to use radio frequency communication.

6.2.2 Command and Control Baseline Command Mechanism

Reiterating the results of the trade study, the on-person magnetic mechanism and button/switch are the preferred options. It is worth noting that buttons and switches themselves may involve magnetic triggering. Further these options boil down to the difference between using two pieces (magnets) and a single piece (button/switch). Thus, the button/switch will be used, as it achieves the same functionality with easier user interface.

6.3 Overall Baseline Design

Overall, the selection for the BDS's baseline design emphasised robust balloon safety, customer satisfaction, and most importantly, the importance of a flexible design space. The user will wirelessly communicate with the launch stand via a RF signal; said commands will be initiated by an on person button/switch which is activated without the use of hands. One example of this could be pressing a button on the user's waistband with either elbows or wrists. The RF signal will activate an electromagnetic release mechanism that grasps the neck of the balloon via magnetic force. Precautions will be taken to protect the neck of the balloon against potential damage that could result from gripping. Finally, the entire release mechanism will be supported by a modified telescoping truss which takes advantage of the flexibility of a custom design and the inherent stability of a tripod.

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