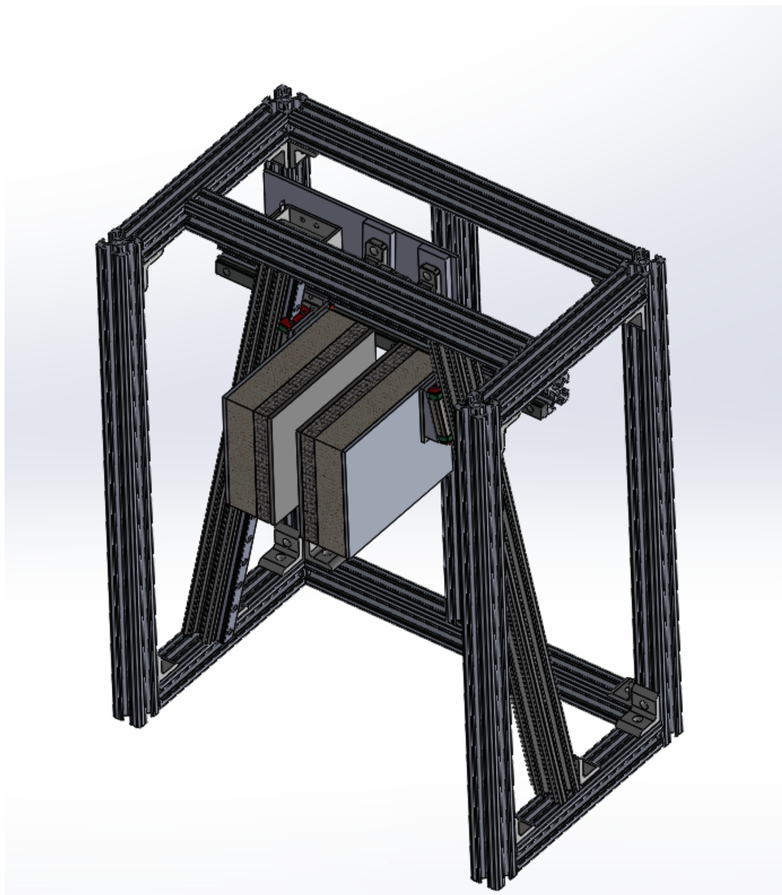
Drop Test Release Mechanism

Critical Design Review

February 23rd, 2022



Team Members

Sophie Getty
getty@calpoly.edu – Fourth Year Mechanical Engineering

Nash Levy
nwlevy@calpoly.edu – Fourth Year Mechanical Engineering

Connor Dilloughery
cdilloug@calpoly.edu – Fourth Year Mechanical Engineering

Matthew Tichenor
matichen@calpoly.edu – Fourth Year Mechanical Engineering

Faculty Advisor: Peter Schuster pschuste@calpoly.edu (805) 756-2976

Abstract

Many boxes for shipping require undergoing drop tests by the manufacturer to ensure their durability. Certain constraints are necessary to successfully carry out these tests such as not damaging the box prior to the drop and maintaining consistency throughout every drop.

Our team has designed a Drop Test Release Mechanism that addresses these constraints. It can provide repetitive drops for different objects that vary in shape and size. It is meant to address drop testing needs for more items than shipping boxes, it can also be utilized for small electronics or parts. This device utilizes a soft-clamping mechanism that can release an object with minimal force applied onto it prior to drop. A frame made of 80/20 was designed to provide rigidity to the soft-clamping mechanism. The soft clamping mechanism supports the object between it by utilizing foam and a friction pad to induce a high friction force. The clamp can be adjusted for multiple sized objects by use of sliding rails that allow it to widen or tighten. Our design focuses on just the release of the test object. A test stand to introduce varying heights must be designed for a fully functional drop test measurement process.

Contents

1 Introduction

NASA needs a team to design an autonomous flight vehicle that can deploy from a scientific balloon at 120,000 ft to safely transport a data vault to the ground. The balloon collects a large amount of telemetry data where wireless transmission is ineffective, so a physical drop is necessary.

Our previous design included four main sections: The deployment system, node protection, parafoil system, and electronic configuration. After our class Preliminary Design Review, we refined the design of each of these systems and created manufacturing plans for each. Then we submitted a CDR to NASA in which we received feedback that we were not selected to move on past the second round. Given this outcome, we have decided to focus the rest of our senior project on developing a modified version of the deployment system.

We have changed the scope of our project to develop a drop test stand. This design was inspired by the concepts previously developed in our deployment drop system that we designed for NASA. Our new project will be able to repeatably drop an item to gather impact data. A repeatable drop test is a test conducted by dropping an object from a predetermined height multiple times under controlled conditions to evaluate its performance and durability. The purpose of repeating the test is to ensure consistency in the test results and to assess the ability of the object to withstand impact and survive repeated drops. This type of test is commonly used in the design and manufacturing of products such as electronic devices, packaging materials, and safety equipment.

This report will go into detail on the design, justification, and manufacturing of our product. The design will clamp the object with sliders mounted on rails that angle inward. The sliders are held together in a system we will refer to as the carriage. Clamping metal sheets with foam between them are attached to the carriage to hold the object that will be dropped. A solenoid with a pin holds the carriage steady until a signal is sent to the solenoid which retracts and allows the object to drop. The frame will be assembled with 80/20 for an easy-to-prototype design. The design was verified with FEA, physics, and engineering standards. The report will also go over the manufacturing process of the parts that are not stock items.

2 System Design

The purpose of this system is to serve as a test platform for conducting repeatable drop tests on objects of various sizes. The system comprises a frame that accommodates two A-framing guide rails, with a carriage that moves along them during the drop test. As the guide rails widen during the fall, the carriage opens. The carriage is made up of two clamping plates that hold onto the A-framing rails. The system uses a solenoid pin mechanism to release the carriage by retracting out of linear bearings. The solenoid pin system can move vertically along two 80/20 bars, allowing for vertical adjustments which provide the ability to fit different sized objects into the carriage.

The test stand holds objects of different sizes by adjusting the height of the solenoid pin. This allows the set drop position of the object to be changeable. Since the guide rails angle inward, small objects are held up higher while larger ones are held lower. This can be seen in Figure 1.

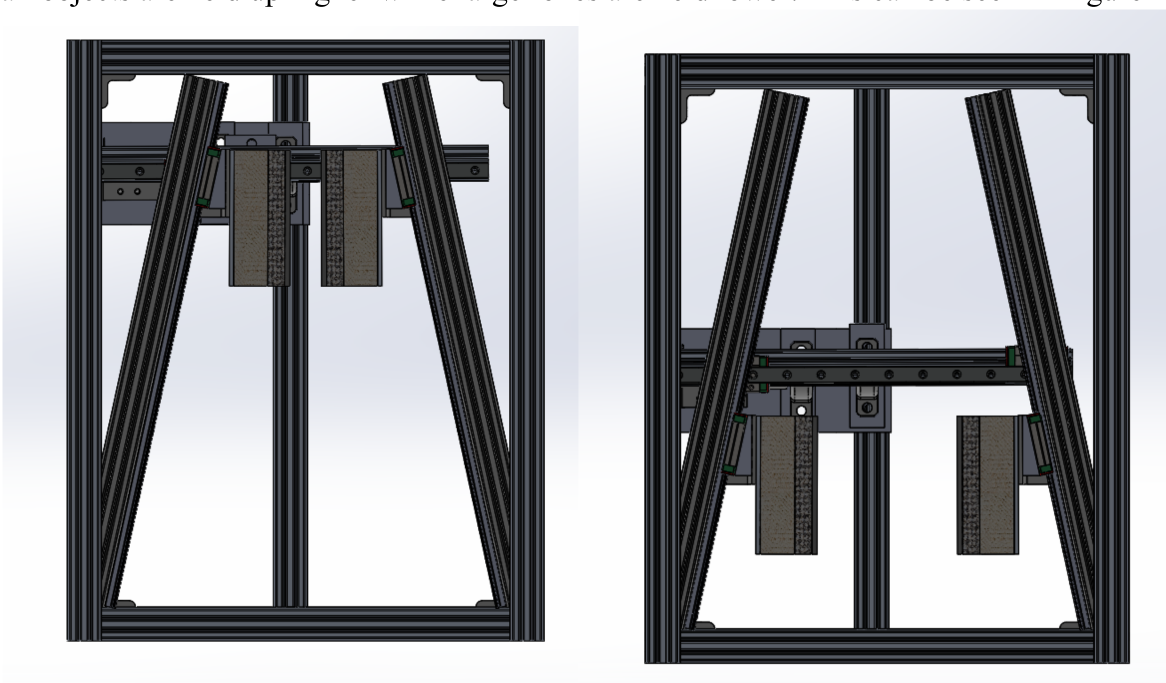


Figure 1. Varying Sized Objects Visual

2.1 Frame

The frame of our test stand will be made entirely out of 80/20 T slotted framing seen in Figure 2. The frame will be supported using corner brackets that are made specifically for 80/20. We elected to use 80/20 rather than 1/8'' aluminum plating for the following reasons:

- 80/20's Ability to change the lengths easily as our design evolves
- High strength and rigidity make it structural
- Ideal for constructing frames, supports, and other load-bearing structures
- T-slot design that allows for easy assembly and adjustment of components
- No need for specialized tools or fasteners.
- Easily cut, drilled, and machined to fit specific requirements

- lightweight and corrosion-resistant, making it ideal for use in both indoor and outdoor environments.

Inside the outer cubic frame are two angled pieces of 80/20. They are supported by connecting to the bottom and top of the frame. They have an angled cut at the bottom so they can mount into the bottom of the cubic frame. The tops are mounted into a horizontal cross bar of 80/20 that lines up with the top of the entire frame.

Figure 2. Full 80/20 frame assembly

2.2 Carriage Design

There are a total of three linear rails and four sliders that are included in the design. Two rails and two sliders are mounted along the lengths of the angled 80/20 frame (one of each per angled piece of 80/20). These linear rails are responsible for enabling movement up and down within the frame. This movement allows objects to be clamped and released within the carriage. As the angled sliders move up the rails, less space is available between them. Then, as they slide down the rails, more space opens between them, meaning an object that was clamped will drop into free fall during descent of the carriage.

A single linear rail with two sliders will mount to each slider on each angled rail (perpendicularly to the height of the frame). This rail will be able to slide up and down with the two angled sliders. This component does not enable more movement, it instead constrains the two angled sliders to synchronize their motion. So, with this constraining rail attached, the angled sliders can only move up or down their angled rails together (at the same height and speed). Figure 3 displays the linear rails and the constraining rail design with the red arrows showing the movement.

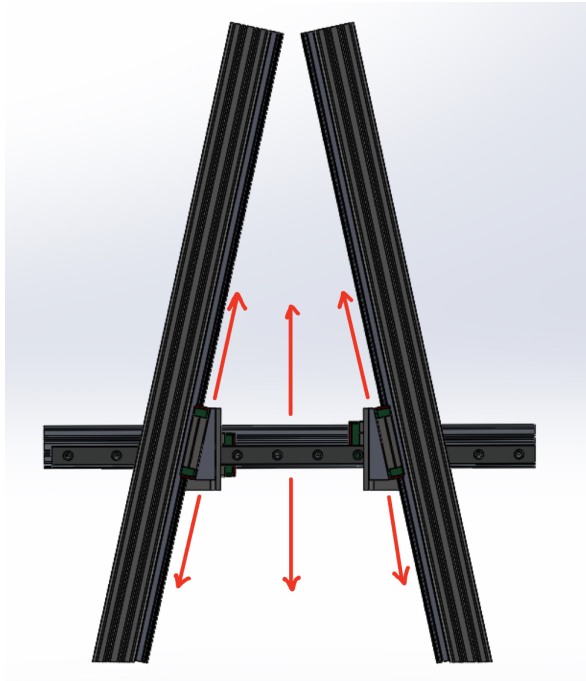


Figure 3. Rail Slider Movement

To fasten the slider on the angled rail to the slider on the horizontal constraining rail, two components are used:

1. Angled Shim: the angled shim is a custom CNC milled part that converts the angled rail to a flat surface to mount to in the vertical plane.
2. L-Bracket: An L-bracket is used to fasten the two sliders together. To secure these parts to the angled slider, the holes through the angled shim are angled, and the L-bracket is thin enough, and has enough hole clearance that it will allow the bolts to mount through it easily.

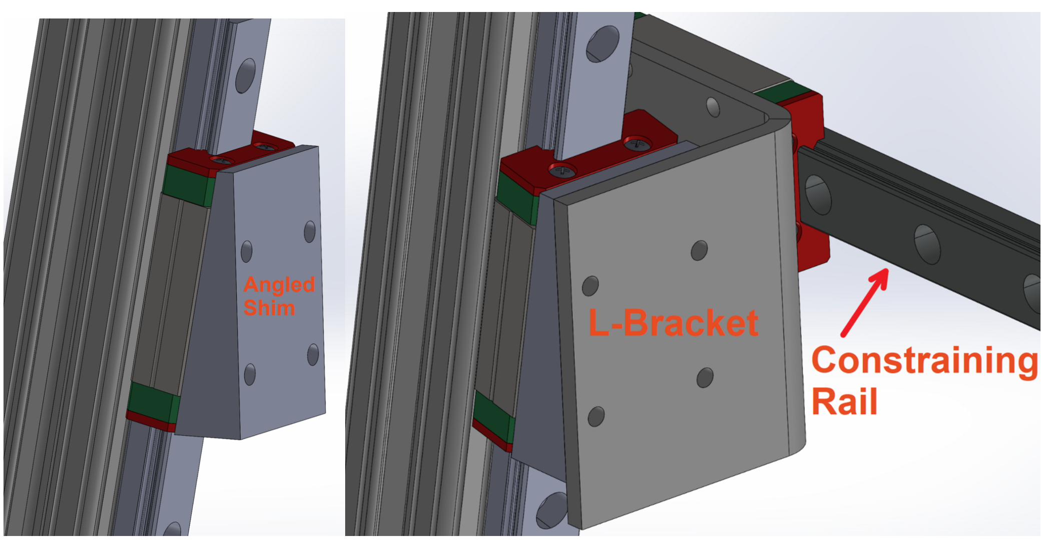


Figure 4. Angled Shim and L-Bracket

2.3 Clamp

The carriage system is what physically interacts with the object to be dropped. The carriage is essentially a clamp, that squeezes an item to support it. There are multiple elements to this clamp to form a compression plating system. These elements include:

- Clamping Plate
- Firm foam
- Soft foam
- High friction sheets

The friction pad and foam layers will be secured to each other using contact adhesive. The clamping plate will be bolted into the angled guide rails that are a part of the frame. They're specifically layered from clamping plate on the inside, to firm foam, then soft foam, and friction pad on the outside. This layering can be seen in Figure 5 below. This layering of materials works to create a dual rate spring rate similar to a progressive spring in many cars [2]. The pad area (4" X 5") allows for a strong friction force on the object being squeezed between the two plates and ensures no significant point load will be applied to the object as well.

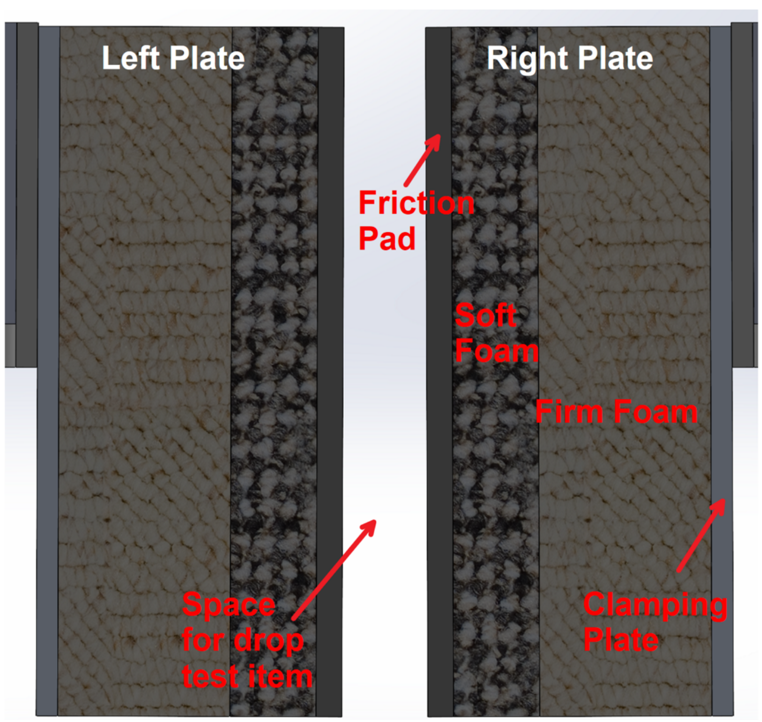


Figure 5. Clamping Plate with Foam Layers

2.4 Solenoid-Pin System

The solenoid-pin system is designed to hold the test object until being given a signal to retract its pin and drop the object. The solenoid is mounted on a custom 1/8" plate. The solenoid pin will be lengthened using another pin which will be supported by two bearings also bolted onto the plate. This allows the weight of the carriage to be supported by the bearings and not the solenoid. Then the solenoid only retracts and extends the pin through the linear bearings and has no moment applied to it.

A linear bearing is fastened to the back of the carriage, on the constraining rail, with a plate. The solenoid-pin mechanism extends and retracts the pin into and out of this bearing to facilitate the drop. The system can be seen in Figure 6.

The solenoid-pin mechanism that is mounted on the 1/8" plate is then fastened to the back frame onto 80/20. This plate will have set screws that hold it in place. The set screws can be loosened, and the height can be adjusted for varying object sizes.

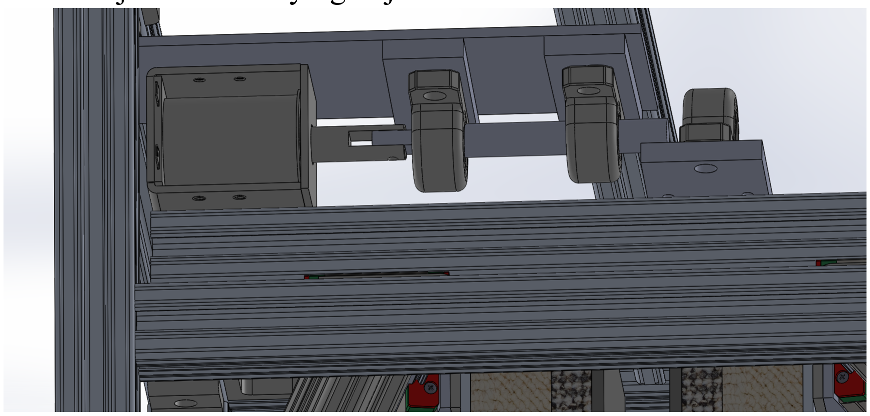


Figure 6. Solenoid-Pin Mechanism

Figure 7 shows the solenoid pin-system engaged on the left and then disengaged on the right.

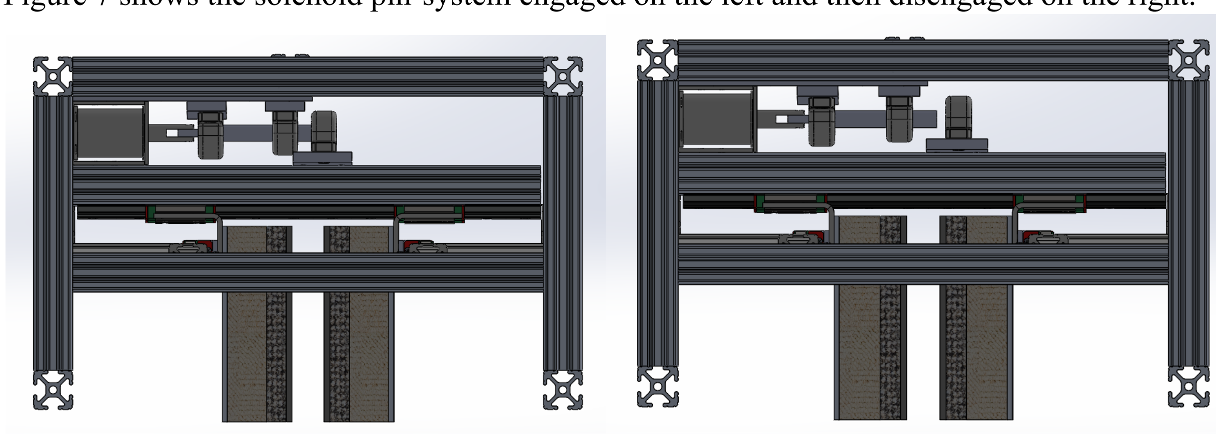


Figure 7. System Engaged Vs. Disengaged Respectfully

2.5 Damper

To avoid hard stops at the end of the carriage descent, a rubber damper is used. Two cylindrical rubber bumpers ¾" in diameter will be bolted to the bottom of the angled linear guide rails. When the carriage is dropped the sliders will hit the bumpers and compress the rubber for a controlled stop.

2.6 Electronics

The design will feature an Arduino Uno as our microcomputer for the simplicity in creating code. The Arduino must be capable of receiving a request for the solenoid to be activated. In this case, we will be using the button on the Arduino board. When the button is pressed, the Arduino will send a pulse to the solenoid, causing the pin to retract. In order to send the necessary voltage to the solenoid, the design will include a 12V power input which can be plugged into the wall. The code will also have pin assignments for the solenoid. The schematic is shown in Figure 8.

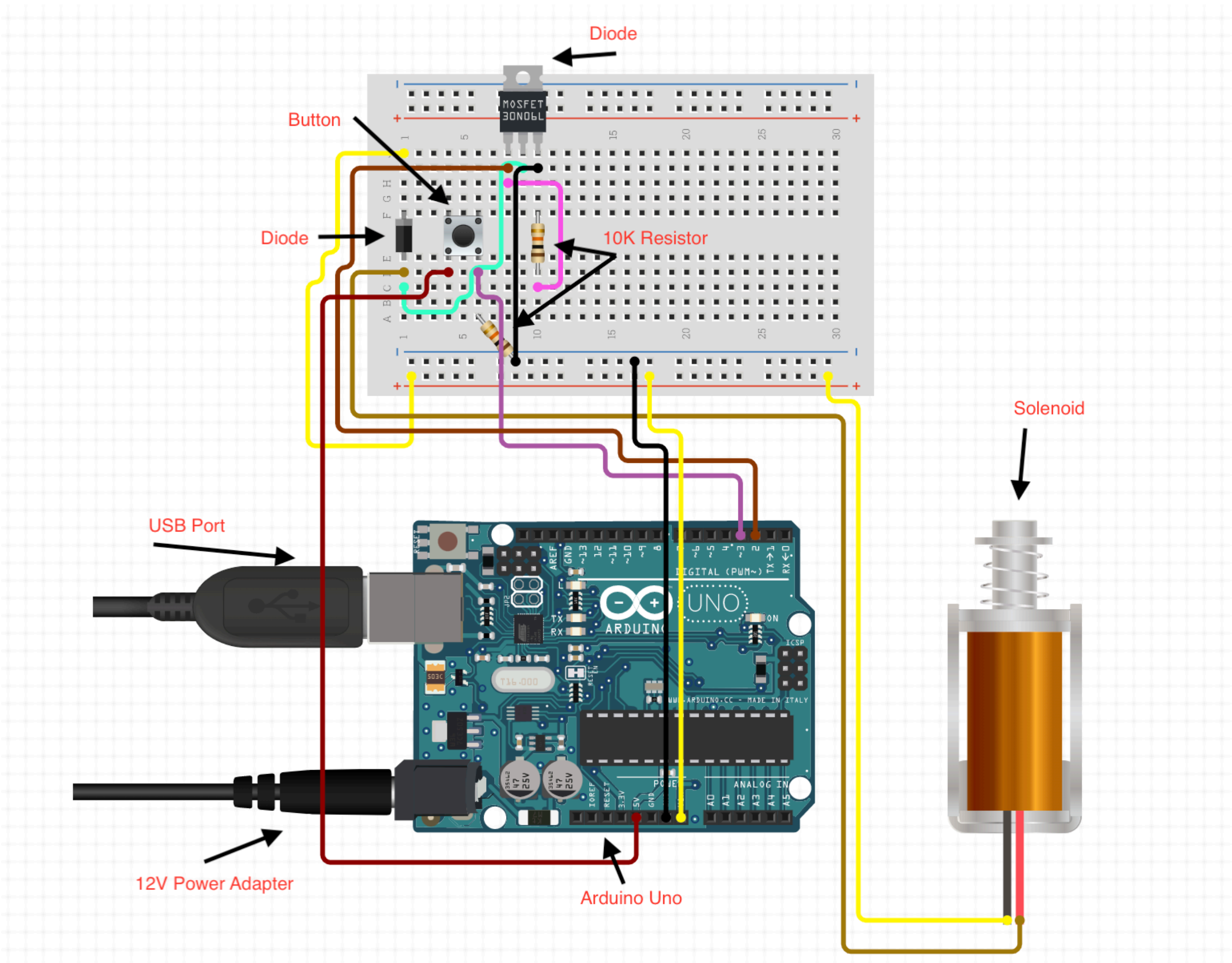


Figure 8. Electronic Schematic

2.7 Design Function

This drop test release mechanism is designed to be easy-to-use. Below is a brief description of the steps to use the mechanism.

1. Ensure that the test stand is mounted or attached to a stand. This can be done by mounting it to a table or bolting the back of the frame to a taller stand. The test stand height determines the object drop height.
2. Set the solenoid to the vertical position needed for the size of the object. The solenoid runs on 80/20 bar along the back frame and the height can be adjusted by unscrewing the set screw slider combination and moving it to different height. The solenoid must be tightly screwed down before any testing. The desired height of the solenoid can be decided by placing the test subject into the grip plates and setting it to the maximum compression wanted.
3. Place the test subject into the compressive plates
4. Engage solenoid-pin system
5. Press button on Arduino to release carriage

2.8 Cost Estimate

Below is a cost estimate for our project. Table 1 is a summary of the Project Budget given in the appendix.

Table 1. Cost Estimate

System:	Product:	Quantity	Cost
All Components	M3 Fasteners	N/A	$50.00
	1/8" x 8" x 8" Aluminum Sheet	1	$20.23
Frame	80/20 T-slotted Framing 2' Length	2	$24.34
	80/20 T-slotted Framing 3' Length	4	$66.60
	"Silver" Corner Brackets 1"x1"	20	$158.40
	Oil-Embedded Mounted Sleeve Bearing	2	$30.32
Carriage	L-Bracket Support	2	$14.36
	Unthreaded Bumper	2	$4.62
	1/2" x 1-1/8" x 6" Aluminum Bar	1	$5.64
	Linear Guide Rails and Sliders	3	$77.97
Solenoid	Solenoid	1	$43.40
	7/16" diameter 6061 Round Bar 1/2" Length	1	$4.31
Compression Plating	High Friction Sheets	1	$17.90
	Soft Foam	1	$9.88
	Firm Foam	1	$39.99
Electronics	Arduino Uno	1	$28.50
	12V Wall Mount Adapter	1	$10.99
	10K Resistor	2	$0.28
	Breadboard	1	$6.99
	Jumper Wires Bundle	1	$4.70
	TIP120 Transistor	1	$1.00
	1n4004 Diode	1	$0.10
Total			$719.54

3 Design Justification

3.1 Clamping Plates FEA

To size the clamping plates, we tested the deflection using FEA in SolidWorks for a ¼" and 1/8" sheet metal plate as seen in Figure 9. The 1/8" metal plate deflects 0.017" and is therefore suitable for our test stand.

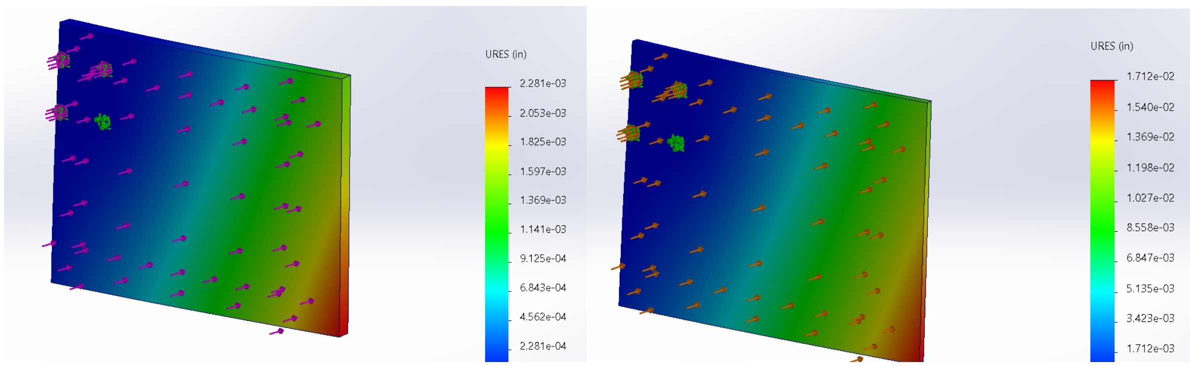


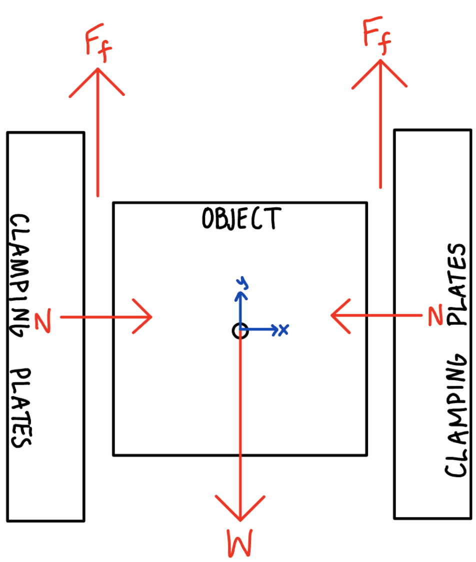
Figure 9. FEA justification for thickness of clamping plates ¼'' and 1/8'' left to right

3.2 Angled Track

Since we want our design to work with a variety of box sizes, the apparatus will use an angled track. Small boxes are held near the top of the track and larger boxes are held further down.

3.3 Force and Weight Calculation:

To determine the maximum object, weight our device can grip, we created a free body diagram as seen in Figure 10. We then used the coefficient of friction mu given for our friction sheets. To determine our max normal force, we researched the maximum force a standard shipping box can withstand before buckling damage is done to the cardboard [1]. The equation is shown in Figure 10.



$$\sum F_y = 0$$

$$2F_f - W = 0$$

$$W = 2\mu N$$

$$W = 2 * 0.6 * 20lb$$

$$W = 24lb$$

Figure 10. Max Weight Calculation

3.4 Pads

It's necessary to use two different foams to hold the box up. By combining soft foam with firm foam, we can hold light objects with the soft foam compressing and heavier, stronger objects with the compression of the firm foam. Then, a high friction sheet is used to maximize the friction to hold up the box.

3.5 Bearings

Since we want to minimize the number of vertical forces acting on the pin of the solenoid, we used bearings to support the loads. After creating a Free Body Diagram and using MATLAB to solve for the forces, we found that it would be best to use two different bearings to mount the solenoid extension pin. We will also use a linear bearing at the end of the extension pin, where the pin slides out of. We felt that using linear bearings to mount the extension pin was a favorable option because it minimized the amount of friction forces counteracting the pull force from the solenoid. As a result, we could use a smaller solenoid to pull the extension pin.

3.6 Solenoid

Since we do not need to stop the pin at discrete locations, a solenoid can be used in place of a linear actuator. Solenoids are a cheaper and lighter way to have an automated pin retraction system. After studying the forces acting on the apparatus, we felt that it was necessary to use a 12V linear solenoid to pull the extension. Our calculations required that we use a solenoid capable of producing a force of around 23 oz. However, we felt it was necessary to use a 12V solenoid capable of a 52 oz force to increase the reliability of the motor.

3.7 Frame

To test the rigidity of the frame to make sure it can safely support all the subsystems, an ABAQUS FEA study will be performed. To determine the worst-case scenario, a 24lb force will be modeled for the object being dropped. The weight of the guide rails along with the solenoid weights were also modeled since they are fully supported by the frames. For the boundary conditions in the study, the entire bottom face of the frame was constrained in all directions. This is to model the mounting that the test stand will need before testing. This will be Sophie's final project in her FEA class and will be completed by the end of the quarter before building the frame.

3.8 Safety, Maintenance, & Repair

One of the main concerns is the maintenance of the linear guide rails. The linear guide rails provide the track that guides the orientation and the drop of our test subject. Due to the budget of the project, we have elected to use cheaper guide rails. Because of this, we will have to ensure that the guide rails are properly cleaned and lubricated to prevent binding. For lubrication we plan to use a part solvent that will remove dust and particulates from the rails.

Another safety hazard in a repeatable drop test could be any potential danger to the people involved in conducting the test or to those who may be present in the testing area. Some examples of safety hazards in a repeatable drop test include:

- Pinching hazards between the guide rails and the sliders.
- Sharp edges on frame.

- Falling debris that could injure individuals nearby.
- Electrical hazards: from the use of a solenoid and power source.
- Insufficient protective gear such as helmets, gloves, or safety glasses.

Because of these hazards, proper safety measures and protocols should be followed to mitigate any risks and prevent accidents or injuries during drop testing. There will be pinch warning stickers, and sharp edges will be sanded.

3.9 Remaining Concerns

We need to ensure that the weight of the carriage will not create problems with the carriage stem. This area is our biggest concern because we need to ensure the horizontal guide rail does not experience any deformation that might cause it to create a nonlinear guide path. We added a horizontal piece of 80/20 for the guide rail to rest against to minimize this problem. This part of the design will need to be tested thoroughly to make sure this problem is not critical.

Another issue that we might experience is the guide rails binding. The design must use tight tolerances to ensure no binding takes place. If binding occurs, the path of the horizontal guide rail might become nonlinear and mess up the drop.

4 Manufacturing Plan

4.1 Procurement

We have a $1000 budget granted to us for our senior project. Since we do not have a sponsor anymore, our team is responsible for every purchase in this manufacturing process. We plan to place an online order with the vendor McMaster-Carr for the 80/20 T slotted framing, T slotted framing brackets, linear bearings, and our solenoid. We will place an online order with Amazon for the linear guide rails, carriages, and Arduino Uno system.

4.2 Manufacturing

To manufacture the frame, a metal saw will be used to cut the T- slotted framing on the saw. Once all 80/20 pieces are cut, ensure that the cuts are clean and free on loose scraps. It is important that the cuts are clean so the attachments between pieces are strong.

Frame

Metal Saw

1. Using a metal saw cut the single T- slotted framing on the Saw to the following cut list:

Length (inches)	Quantity
16	2
17.64	4
12	3
7	4

2. Using the metal saw, cut the 16’’ pieces to have an 12° angled cut on one bottom edge each (see drawing package)
    a. To get the 12° cut rotate the circular saw to 12° then cut the bottom
3. Using a metal saw cut the double T- slotted framing on to 16’’

1/8” Clamping Plate:

Water Jet

1. Cut out two 4” x 5” x 1/8” Aluminum sheet metal

Drill Press or Mill

2. Drill 4X holes completely through metal plate with 3mm drill bit and dimensions from clamping plate drawing

Solenoid Plate:

Water Jet

1. Cut out 3” x 5” x 1/8” Aluminum sheet metal
    a. **NOTE this part can be water jetted out of the same piece of aluminum sheet metal as and at the same time as the clamping plate

Drill Press or Mill

2. Drill 2X holes completely through metal plate with 5/16’’ drill bit and dimensions from the solenoid plate drawing
3. Drill 4X holes completely through metal plate with 7/64’’ drill bit and dimensions from the solenoid plate drawing

Solenoid Bearing Spacer:
Table Saw
1. Use the table saw to cut the solenoid bearing spacer out of wood

Drill Press or Mill

2. Use the drill press to drill through holes through the spacer following the dimensions

Solenoid Pin:
Mill
1. Use the mill to machine the aluminum bar stock to the correct dimensions per the pin drawing

Angle Shim:
Mill
1. Load aluminum stock into vice
2. Place 12° block underneath aluminum stock
3. Mill triangular angle shim following the dimensions provided by the drawing
4. Mill 4X holes completely through aluminum triangle with 3mm drill bit and dimensions from drawing

Foam:
Scissors
1. Cut firm foam to 4" x 5"
2. Cut soft foam to 4" x 5"
3. Cut friction sheet to 4" x 5"

4.3 Assembly
1. Using the "Silver" Corner Brackets and the fasteners provided, anchor all the frame pieces together per the exploded assembly drawing
2. Bolt long M3 bolts to side slider going through clamping plate, L-bracket, and angle shim. Then repeat on the other side.
3. Glue firm foams to clamping plates
4. Glue soft foams on top of firm foams
5. Stick the friction sheets to the soft foams
6. Attach the carriages to the guide rails
7. Bolt the guide rails to the 80/20 angled back support using M3 T-nut screws
8. Attach the angled 80/20 and guide rail subassembly to the frame following the exploded drawing using the fasteners provided
9. Attach the bearing to the solenoid plate per the drawing
   a. Mount the bearing spacer underneath the bearing in between it and the solenoid plate
   b. Secure the bearing using 3/8-16 screws secured by washers
10. Attach the solenoid to the solenoid plate using 4 #8-32 screws secured by washers
11. Attach the solenoid plate to the double 80/20 back bar using set screws and sliders
    a. Make sure the sliders are in the 80/20 track before securing the entire frame.

Refer to Appendix F for further details on manufacturing plan

5 Design Verification Plan

The most important aspects of our drop test stand are repeatability, structural stability, and orientation. We plan to preform to following tests to verify our design plan for our drop test release mechanism:

5.1 Drop Test Impact Repeatability

We will place an accelerometer inside or on top of a test subject. We will then drop this item 20 times at three different heights and record the impact on each test. We will then analyze this data. This can be used to show that the impact at the same heights on the same objects will be consistent. If our data is not consistent, this means that our design does not create repeatable impact tests.

5.2 Compression Plate Weight Testing

We will test a series of different weights in our compression plates. We will use a deflection gauge to test the deflection and strain on critical points within our structure with a variety of weights. We will test weights of size: 1lb, 5lbs, 10lbs, 15lbs, and 20lbs. For this test to be considered successful, the structure must have minimal deflections under all load cases. We will start with smaller weights to ensure that we do not break the compression plates during testing. We will work up to the larger weights.

5.3 Frame Weight Testing

We will test a series of different weights on critical points of our frame shown by FEA produced by Sophie in the future. We will use a deflection gauge to test the deflection and strain on critical points within our structure with a variety of weights. This test will be very similar to the compression weight testing in that we will work up in weights and will consider the test successful if there are minimal deflections.

5.4 Track Timing Testing

We will need to test that the left and right sliders fall at the same speed throughout the drop. To do this we will drop just the carriages at different heights and visually record the position and timing of the sliders with a slow-motion camera. After recording the test, we will use frames from the video to determine the exact instance when each guide rail reaches the bottom. The goal is that left and right carriage need to reach the bottom within 0.05s of each other. This is to make sure that the object will fall at the correct orientation.

5.5 Object Orientation at Release

At the moment the object is released from the carriage guide rail system, it should be in the desired orientation. Our goal is for our test stand to give repeatable data so therefore we will test 5 different objects. We will drop each of these objects 5 times and compare the orientations. We will use a slow-motion camera for this test and will use the frames from the video of the drop to determine the angle of the object at the time of release. We will need to establish a predetermined datum on the object before dropping to measure the angle from. We will consider this test successful if the same objects have repeatable data and have the same orientations within 5° of each other. Also, we can overlay the drop orientation photos of the test on top of each other and show their precision.

6 Conclusions

A repeatable drop test is a test that involves dropping an object multiple times from a predetermined height under controlled conditions to assess its strength and durability. This type of test is important to ensure the object's ability to withstand impact and survive repeated drops. It is commonly used in the design and manufacturing of various products, including electronic devices, packaging materials, and safety equipment.

Our team has developed a Drop Test Release Mechanism that facilitates repetitive drops for objects of different sizes and shapes. Our device features a soft-clamping mechanism that will not damage the object before dropping. To enhance rigidity and prototype easily, we use an 80/20 frame, while foam and a friction pad provide high friction force to support the object. The clamp can be adjusted to accommodate various object sizes through A-framing linear rails. A solenoid-pin system releases the carriage, and object, using a pin that retracts out of linear bearings. Our design focuses solely on the release of the test object, and a separate test stand must be developed for measuring drop test results at different heights.

The deflection of the clamping plates was justified using FEA, and the rest of the frame deflection will be justified before the end of the quarter using an ABAQUS FEA study. The weight of our object was justified using a free body diagram and force equations, with the importance of not crushing the box during clamping in mind. The solenoid was chosen through force calculations of the max weight object. Our mechanism will be manufactured using a water jet for plates, drill press for holes, and mill for the angled shim.

Ordering parts and manufacturing the prototype is our next milestone. Once manufactured, we plan to test our prototype and make any corrections necessary so that our final design can successfully address our goals. Any other recommendations to improve the final product, such as cost reductions, will also be assessed throughout this next phase of our project.

References

[1] "Corrugated Box Strength: Packaging Supplies in MD & PA." *PSI*, 28 Sept. 2022, https://psimd.com/box-strength/.

[2] Kyle. "Linear vs. Progressive Springs: Which Is Better for Your Car?" *COBB Tuning*, 5 July 2022, https://www.cobbtuning.com/linear-vs-progressive-springs-better-car/.

Appendices

Appendix A – Indented Bill of Materials (iBOM)

Drop Test Stand
Indented Bill of Material (iBOM)

Assy Level	Part Number	Descriptive Part Name	Qty	Part Cost	Source	URL	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4					
0	1000	Drop Test Stand			------		
1	1100	Frame			------		
2	1110	Angled Cut Pieces 16"	2		Cut from 80/20 stock		
2	1120	Cut Piece 17.64"	4				
2	1130	Cut Piece 12"	3				
2	1140	Cut Piece 7"	4				
2	1150	Cut Piece 15.65"	1				
2	1160	Silver Corner Bracket, 1" Long for 1" High Rail T-Slotted Framing	20	$7.32	McMaster	https://www.mcmaster.com/47065T236/	item 47065T236
1	1200	Guided Drop Assembly					
2	1210	Linear Guide Rails		$26	Amazon		
2	1220	Stainless Steel Carriage Blocks	3		Amazon	.8ca997d7-1ea0-4c8f-9e14-a6d756b83e30	2X 400mm with 2 carriages + 1X 300mm
3	1221	L - bracket Support	2	$7.18	McMaster	machine safety barriers | McMaster-Carr	1 -3/4 x 1 - 3/4 x 2 inch , machine holes as specified in drawing
3	1222		1	$ 5.64	custom	https://www.mcmaster.com/products/ba	0.5 X 1.125 X 6 inches aluminum bar stock
2	1230	Compression Plating					
3	1231	Clamping Plate			custom		machined aluminum
3	1232	High Friction Sheets	1	$17.90	Lee Valley	https://www.leevalley.com/en-us/shop/tc	12" x 36"
3	1233	Soft Foam	1	$10	Home Depot	https://www.homedepot.com/p/FUTURE-	N/A
3	1234	Firm Foam	1	$39.99	Amazon	https://www.amazon.com/Prosource-Inte	item 735-2436
3	1235	Fastners		$ 50.00			
2	1240	Extension Pin Bearing System					
3	1241	Oil-Embedded Mount Sleeve Bearing	1	$15.41	McMaster	https://www.mcmaster.com/5912K4/	Will support the weight acting on the extension pin
3	1242	Bearing Spacer	2	$15.00	McMaster	https://www.mcmaster.com/aluminum-sh	Positions the bearing to make concentric with pin
2	1250	Carriage Stem Bearing System					
3	1251	Oil-Embedded Mount Sleeve Bearing	2	$15.41	McMaster	https://www.mcmaster.com/5912K4/	Will attach to the extension pin
3	1252	Carriage Stem Block	1	$15.00	McMaster	https://www.mcmaster.com/aluminum-sh	Holds up the carriage
1	1300	Solenoid Parts					
2	1310	Solenoid	1	$43.10	McMaster	https://www.mcmaster.com/solenoids/lin	Pull Motor - 12 V
2	1320	Solenoid Extension Pin	1	$4.31	McMaster	https://www.mcmaster.com/aluminum-b	Will be cut to length
1	1400	Electronics					
2	1410	Arduino Uno	1	$28.50	Amazon	https://www.amazon.com/Arduino-A000	Will be coded
2	1410	12V Wall Mount Adaptere	1	$10.99	Amazon	https://www.amazon.com/ABLEGRID-12-V	Used to provide more power to solenoid
2	1430	10K Resistor	1	$0.00	Self-sustained	N/A	Connor has some
2	1440	TIP120 transistor	1	$0.83	Digi-Key	https://www.digikey.com/en/products/de	N/A
2	1450	Breadboard	1	$ 6.00	Amazon	https://www.amazon.com/Qunqi-point-E	N/A
2	1460	Jumper Wires	6	$ -	Self-sustained	N/A	Connor has some
2	1470	1n4004 Diode	1	$ 0.50	Digi-Key	https://www.digikey.com/en/products/de	N/A
1							
	Total Parts		**63**				

Item Description	Vendor	Part #	Quantity	Cost	Shipping and Tax	Total Cost	How Purchased	Account Used	Date Purchased	Location
80/20 T-slotted Framing 2' length	Mcmaster	47065T101	2	$24.34			Order	ME Purchase		Mcmaster
80/20 T-slotted Framing 3' length	Mcmaster	47065T101	4	$66.60			Order	ME Purchase		Mcmaster
Silver Corner Bracket, 1" Long for 1" High										
Rail T-slotted Framing	Mcmaster	47065T236	20	$158.40			Order	ME Purchase		Mcmaster
Oil-Embedded Mounted Sleeve Bearing	Mcmaster	5912K4	2	$30.82			Order	ME Purchase		Mcmaster
Solenoid	Mcmaster	70155K511	1	$43.40	$58.20	$425.28	Order	ME Purchase		Mcmaster
7/16" 6061 Round Bar 1/2' length	Mcmaster	8974K26	1	$4.31			Order	ME Purchase		Mcmaster
1/8" thick x 8" width x 8" length Aluminum Sheet	Mcmaster	89015K239	1	$20.23			Order	ME Purchase		Mcmaster
L-bracket Support	Mcmaster	2313N39	2	$14.36			Order	ME Purchase	2/21/2023	Mcmaster
Unthreaded Bumper	Mcmaster	9540K77	2	$4.62			Order	ME Purchase	2/21/2023	Mcmaster
Angle Shim	Mcmaster	9246K491	1	$5.64			Order	ME Purchase		Mcmaster
High Friction Sheets	Lee Valley	88K509	1	$17.90	$9.82	$27.72	Order	Guest		Lee Valley
Soft Foam	Future Foam	117-2013	1	$9.88	$0.99	$10.87	Pick-up	N/A		Home Depot
Linear Guide Rails/Carriage Blocks	Iverntech	B0762MKQFD	3	$77.97					2/21/2023	Home Depot
Firm Foam	ProsourceFit	ps-2296-hdpm-grey	1	$39.99	$14.56	$172.01	Order	Connor's		Amazon
Arduino Uno	Arduino	A000066	1	$28.50						Amazon
12V Wall Mount Adapter	Albegrid	B009ZZKUPG	1	$10.99						Amazon
10k Resistor	DigiKey	CFR100JR-52-10K	2	$0.28						Digikey
TIP120 Transistor	Digikey	497-2539-5-ND	1	$1.00	$20.59	$33.66	Order	Connor's		Digikey
Breadboard	DigiKey	DKS-BBOARD3.3	1	$6.99						Digikey
Jumper Wires Bundle	DigiKey	1738-1374-ND	1	$4.70						Digikey
1n4004 Diode	DigiKey	2368-1N4004-ND	1	$0.10						
Fasteners M3	Home Depot	N/A	N/A	$50.00	$0.00	$50.00				

Total Cost:	$719.54

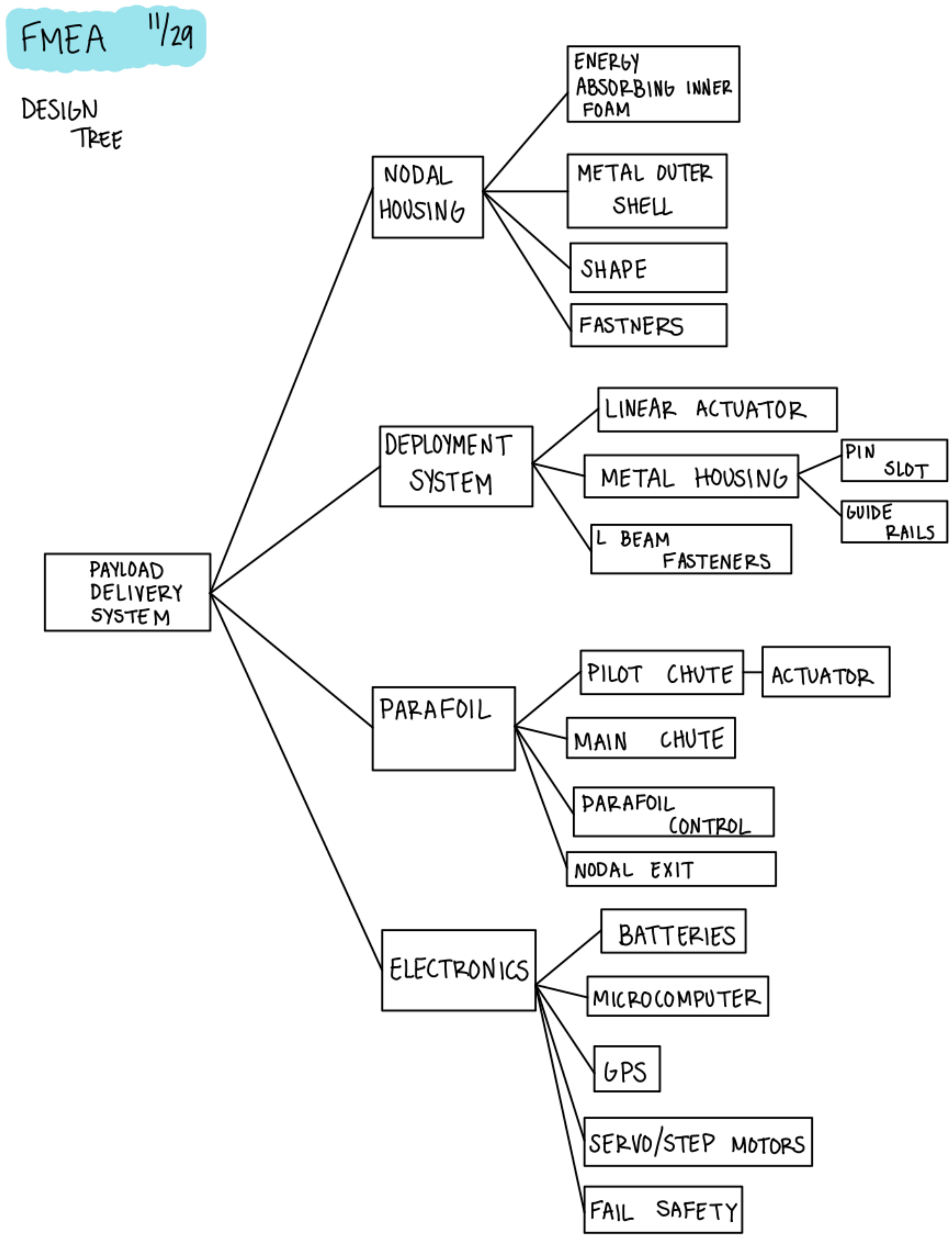
Appendix C – Supporting Evidence

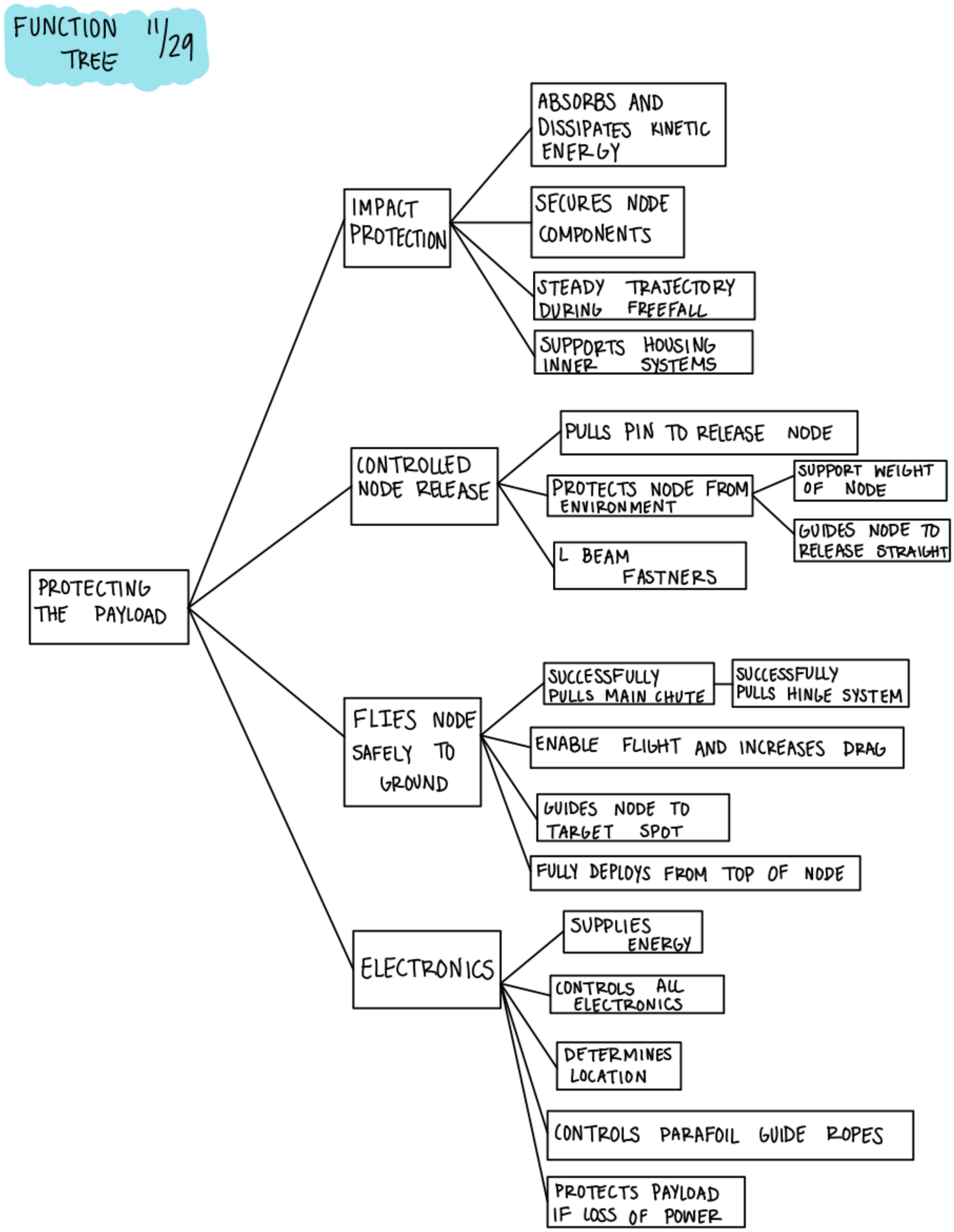
Solenoid Bearing Force Analysis Calculations

```
 % Solenoid Justification

Wb = 0.379  %lbf
Wb = 0.3790
W = 35      %lbf
W = 35
l1 = 6/12;  %ft
l2 = 1/12;  %ft
l3 = 3/12;  %ft
Mu_b = 0.02
Mu_b = 0.0200
F2 = ((-Wb - W)*l1 + (Wb*(l1+l2+l3)/2) + W*(l1+l2+l3))/(l2)
      F2 = 139.6210
F1 = Wb + W - F2
F1 = -104.2420
fb1 = F1 * Mu_b
             fb1 = -2.0848
fb2 = F2 * Mu_b
      fb2 = 2.7924
fbox = W * Mu_b
      fbox = 0.7000
Fs = fb1 + fbox + fb2
      Fs = 1.4076
Fs = Fs * 16
      Fs = 22.5213
```

Appendix D – Failure Modes & Effects Analysis (FMEA)




FUNCTION TREE 11/29
PROTECTING THE PAYLOAD
IMPACT PROTECTION
ABSORBS AND DISSIPATES KINETIC ENERGY
SECURES NODE COMPONENTS
STEADY TRAJECTORY DURING FREEFALL
SUPPORTS HOUSING INNER SYSTEMS
CONTROLLED NODE RELEASE
PULLS PIN TO RELEASE NODE
PROTECTS NODE FROM ENVIRONMENT
SUPPORT WEIGHT OF NODE
GUIDES NODE TO RELEASE STRAIGHT
L BEAM FASTNERS
FLIES NODE SAFELY TO GROUND
SUCCESSFULLY PULLS MAIN CHUTE
SUCCESSFULLY PULLS HINGE SYSTEM
ENABLE FLIGHT AND INCREASES DRAG
GUIDES NODE TO TARGET SPOT
FULLY DEPLOYS FROM TOP OF NODE
ELECTRONICS
SUPPLIES ENERGY
CONTROLS ALL ELECTRONICS
DETERMINES LOCATION
CONTROLS PARAFOIL GUIDE ROPES
PROTECTS PAYLOAD IF LOSS OF POWER

Appendix E – Design Hazard Checklist

PDR Design Hazard Checklist **F16 Drop Release Mechanism**

Y	N	
X		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	X	2. Can any part of the design undergo high accelerations/decelerations?
X		3. Will the system have any large moving masses or large forces?
X		4. Will the system produce a projectile?
X		5. Would it be possible for the system to fall under gravity creating injury?
	X	6. Will a user be exposed to overhanging weights as part of the design?
	X	7. Will the system have any sharp edges?
	X	8. Will any part of the electrical systems not be grounded?
	X	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	X	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	X	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	X	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	X	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	X	14. Can the system generate high levels of noise?
	X	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
X		16. Is it possible for the system to be used in an unsafe manner?
	X	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

PDR Design Hazard Checklist **F16 Drop Release Mechanism**

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
There are several pinch points along the linear guide rails. Since the carriage slides down the rails it is possible for someone to pinch or hurt themselves when setting up the carriage.	We will have specific warnings and instructions on how to load and unload the carriage. We will also make sure that the carriage has an appropriate clamping system, and the pin is installed correctly make sure that the carriage will not fall unless it is given the signal by the user.	3/30	
The system will produce a projectile. After the object is released from the test stand it will free fall until it hits the ground.	We will have a specific distance that the user must stand away from the test stand when they release the object. The distance will vary based on the size of the object.	4/15	
Since the test stand will have to be mounted on a higher surface to create a bigger drop height, there is a hazard of the test stand falling from the height if it is not mounted correctly.	We will either design a bracket or custom clamp to ensure that the test stand is safely mounted to the surface. Alternatively, we could use a series of vice clamps to ensure safety during testing.	4/1	
The system could be used in an unsafe manner if the user loads an object that is too heavy. This could cause the carriage to break, and parts could shear and fly off.	We will have exact specifications for the limiting weights and sizes that our drop mechanism can support.	3/15	
The system will have a large moving mass when the carriage system is sliding and holding and releasing the test subject. It is important that this mass does not drop and injure or harm anything around it. It is also important that this mass is loaded balanced.	We will have a set of safety guides for the user and specific instructions to make sure that the mass is balanced when loaded into the clamping system. We may add a back to our carriage.	4/25	

Appendix F – Manufacturing Plan

Subsystem	Component	Purchase (P) Modify (M) Build (B)	Raw Materials Needed to make/modify the part (only M & B)	Where/how procured?	Equipment and Operations anticipate using to make the component	Key limitations that this operation places on any parts made from it
Solenoid/Pin System	Solenoid	P	n/a	McMaster	n/a	n/a
	Pin	B	n/a	McMaster	n/a	n/a
	4X 8/32" Screws	P	n/a	McMaster	n/a	n/a
	2X 3/8-16 Screws	P	n/a	McMaster	n/a	n/a
	Bearings	P	n/a	McMaster	n/a	n/a
	Custom Pin	B	Aluminum bar stock	McMaster	Mill	The part dimensions must be extreemely accurate in order to fit inside the solenoid in
	Bearing Spacer	B	Wood	School	Table Saw	part must be sanded and clean
	Mounting Plate	B	Aluminum stock metal	McMaster or Home Depot	Water Jet to cut and drill/tap to create holes	Hole Placements will need to be precise
Housing	80/20	M	80/20	McMaster or Home Depot	Metal Saw to cut to length	Must be Precise especially the angled pieces
	T Slotted-Brackets X6	P	n/a	McMaster	n/a	n/a
Carriage	3X Guide Rails with Sliders	P	n/a	Amazon	n/a	n/a
	1/8" Clamping Plate	M	Aluminum Sheet Metal	McMaster	Water Jet to cut and drill/tap to create holes	Drilled holes need to be precise
	Soft Foam	P	n/a	Amazon	n/a	n/a
	Hard Foam	P	n/a	Amazon	n/a	n/a
	Glue	P	n/a	Miners Hardware	n/a	n/a
	M3 bolts	P	n/a	McMaster	n/a	n/a
	2X C-2-C Mate	M	L-beam Stock	McMaster	Cut Stock to length, drill holes to match carrriage and angle shim	n/a
	Rubber stop	M	Rubber	Amazon	Drill through rubber	rubber may tear around drilled center
	2X Angle Shim	M	Aluminum bar stock	McMaster	CNC Mill	angle face and thin to clamp
Controls	Ardunio	P	n/a	Amazon	n/a	n/a
	Wires	P	n/a	Amazon	n/a	n/a
	Battery	P	n/a	Amazon	n/a	n/a
	Diode	P	n/a	Digi-Key	n/a	n/a
	Transistor	P	n/a	Digi-key	n/a	n/a
	Breadboard	P	n/a	Amazon	n/a	n/a
	Resistor	P	n/a	Digi-key	n/a	n/a

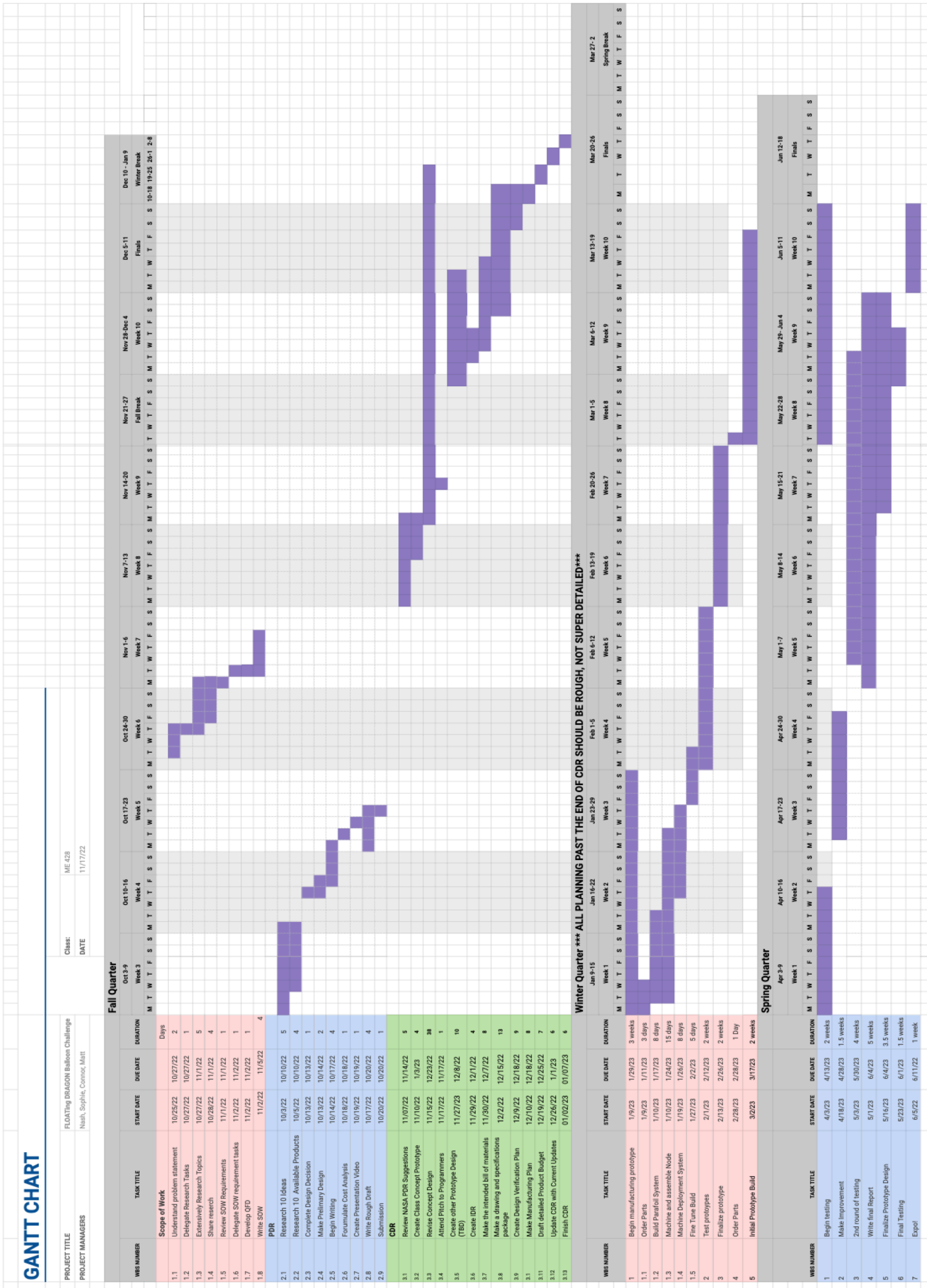
Appendix G – Design Verification Plan (DVP)

DVP&R - Design Verification Plan (& Report)

Project:	Drop Test Stand		Sponsor:							Edit Date: 2/16/23	
TEST PLAN										**TEST RESULTS**	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
1	Drop Test Impact Repeatability	We will place an acceleraometer inside or on top of a test subject. We will then drop this item 20 times at three different heights and record the impact on each test. This can be used to show that the impact at the same heights on the same objects will be consistent	Impact Testing	Needs to give consistent data for several drops	Accelerometer, box for testing	Whole Assembly	Everyone	April			
2	Structural Weight Testing	We will test a series of different weights in our compression plates. We will use a deflection gauge to test the deflection and strain on crictical points within our stucture with a variety of weights.	Deflections	Needs to give small unoticable deflections.	Deflection Gauge or possibly load cell	Whole Assembly					
3	Frame Weight Testing	We will test a series of different weights in on main points on concern on our structural protoype frame. We will use a deflection gauge to test the deflection and strain on crictical points within our stucture with a variety of weights.	Deflections	Needs to give small unoticable deflections.	Deflection Gauge or possibly load cell	Structural Prototype					
4	Track timing testing	We will need to test that when the solenoid releases the carriages that the left and right carriage fall at the same speed. To do this we will test dropping just the carriages at different heights and visually observing and timing how long each side takes to fall.	Time to reach bottom	Left and right carriage need to reach the bottom within 0.1s of each other.	Timer	Guide Rails and Frame					
5	Object Orientation after Release	We will need to test that at the moment the object is release from the carriage hguide rail system, it is in the desired orienatation. Our goal is for our test stand to give repeatable data so therfore we will test 5 different objects. We will drop each of these objects 5 times and compare the orientations. We will use a slow motion camera for this test	Orientation at release	Orientation for same object is within 5° of each other	Slow Motion Camera. Electronic protractor	Whole Assembly					

Complete these columns when you conduct the tests.

Appendix H – Gantt Chart



Appendix I – Arduino Code

```
int solenoidPin = 4; //This is the output pin on the Arduino we are using
const int buttonPin = 2; // the number of the pushbutton pin


void setup() {
pinMode(solenoidPin, OUTPUT); //Sets the pin as an output
pinMode(buttonPin, INPUT); //Sets tthe pin as an output for the button
}


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


if (buttonState == HIGH) {
digitalWrite(solenoidPin, HIGH); //Switch Solenoid ON
delay(1000); //Wait 1 Second
}
else {
digitalWrite(solenoidPin, LOW); //Switch Solenoid OFF
delay(1000); //Wait 1 Second
}
}
```