Nitinol SMA Hold-Down Release Mechanism

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TEAM STELLARHOLD:

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Problem Definition & Requirements

Introduction- What is an HDRM?

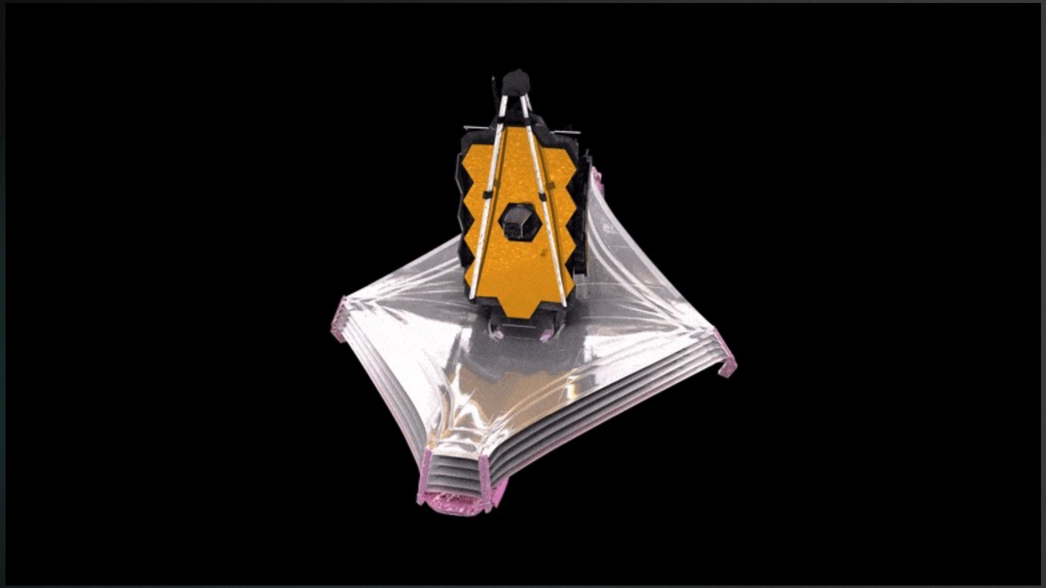


Figure 1: JWST Unfolding Example

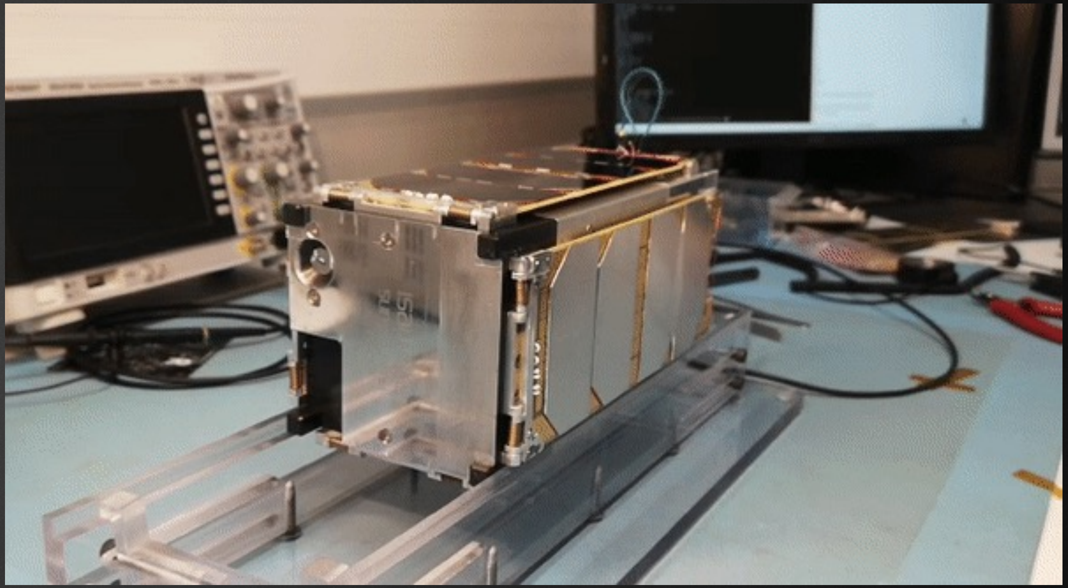


Figure 2: CubeSat Unfolding Example

Why Design a New One?

1) Most designs are not resettable
   - Cost per use = Cost per unit for non-resettable
   - **Why reset?**
2) Explore different actuation techniques
3) Original client, General Atomics – EMS, wanted an in-house design.

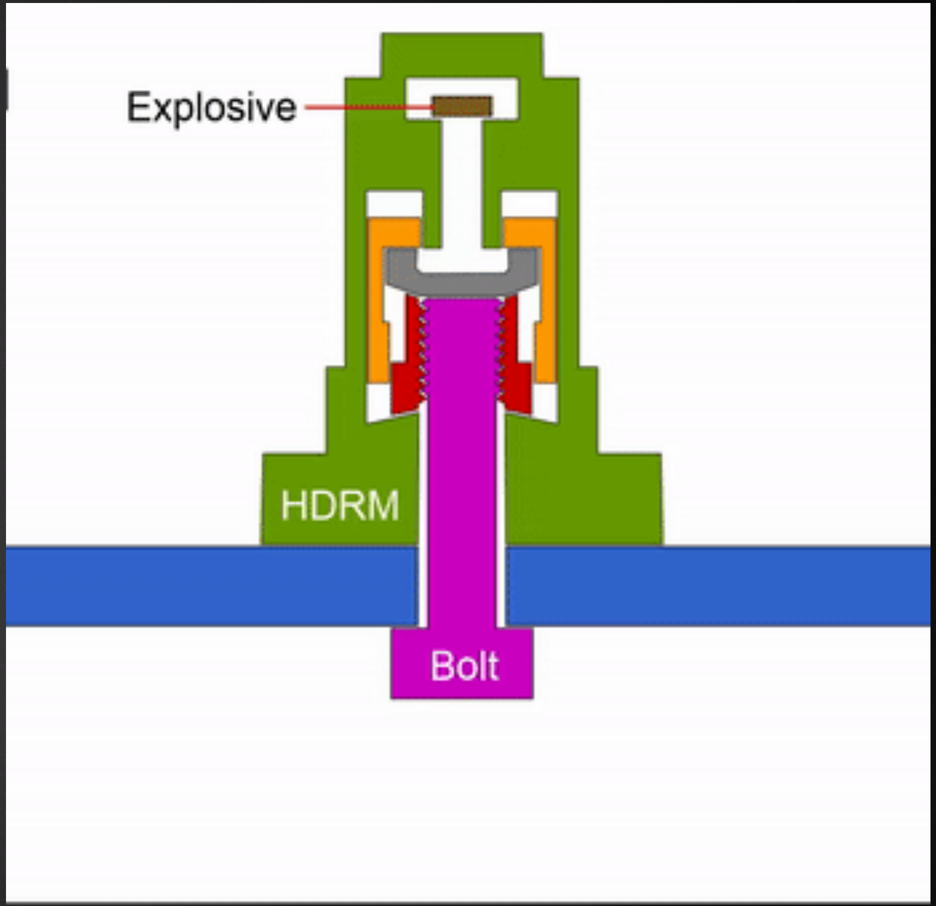


Figure 3: Single-use HDRM

Requirements

Table 1: Customer needs and Engineering Requirements Table

#	CR	ER
1	No Space Debris	No breakaway parts
2	Low Outgassing	Low outgassing materials
3	No Combustion	No combustion
4	20x30 cm Deploy Solar Panels	Minimize volume
5	Minimize Protruding Material	Minimize protruding material
6	Maximize Deployment Load/ Simultaneously	Maximize deployment force
7	Easily Resettable	No deformation
8	Retain Stowed Configuration prior to deployment	Maximize retention reliability
9	Receive Input Command	Receive input command
10	Minimize Weight	Minimize weight
11	Minimize Reset Time	Minimize actuation time
12		Maximize Nitinol life

Design Process & Solution

Decision Process - QFD

Customer Needs	Customer Weights	No Breakaway parts	Low outgassing materials	no combustion	minimize volume	minimize external hardware	maximize deployment force	no deformation	maximize retention reliability	must receive input	minimize weight	minimize reset time
		Technical/Engineering Requirement										
No Space Debris	5	1		1		1			1			1
low outgassing	3		1					1	1			
No pyrotechnics	5	1	1	1				1	1		1	1
must deploy solar panels 20x30cm	3				1							
cannot protrude more than 1cm from bottom	4				1	1			-1		1	-1
Must deploy panels on all sides simultaneously	3					-1	1		1			
Must be able to easily reset	5	1		1	-1			1				1
Must be able to retained stowed config prior to launch	5					1	1		1			
must release on command	3									1		
must have rotational abilities	2								1			
Technical Requirement Units		#	%	n/a	CU IN	cm	N	%	%	n/a	g	s
Technical Requirement Targets		0.00	0.10		1.00	1	25	2	98.5		200	<60
Absolute Technical Importance		15.0	8.0	15.0	2.0	11.0	8.0	13.0	19.0	3.0	9.0	11.0
Relative Technical Importance		3	2	3	1	2	2	3	5	1	2	2

Figure 4: Annotated QFD

Design Solution

- Pin-puller
- Manual reset
- Nitinol shape memory alloy (SMA) based movement
- Locking design (ball bearing)
- External power source

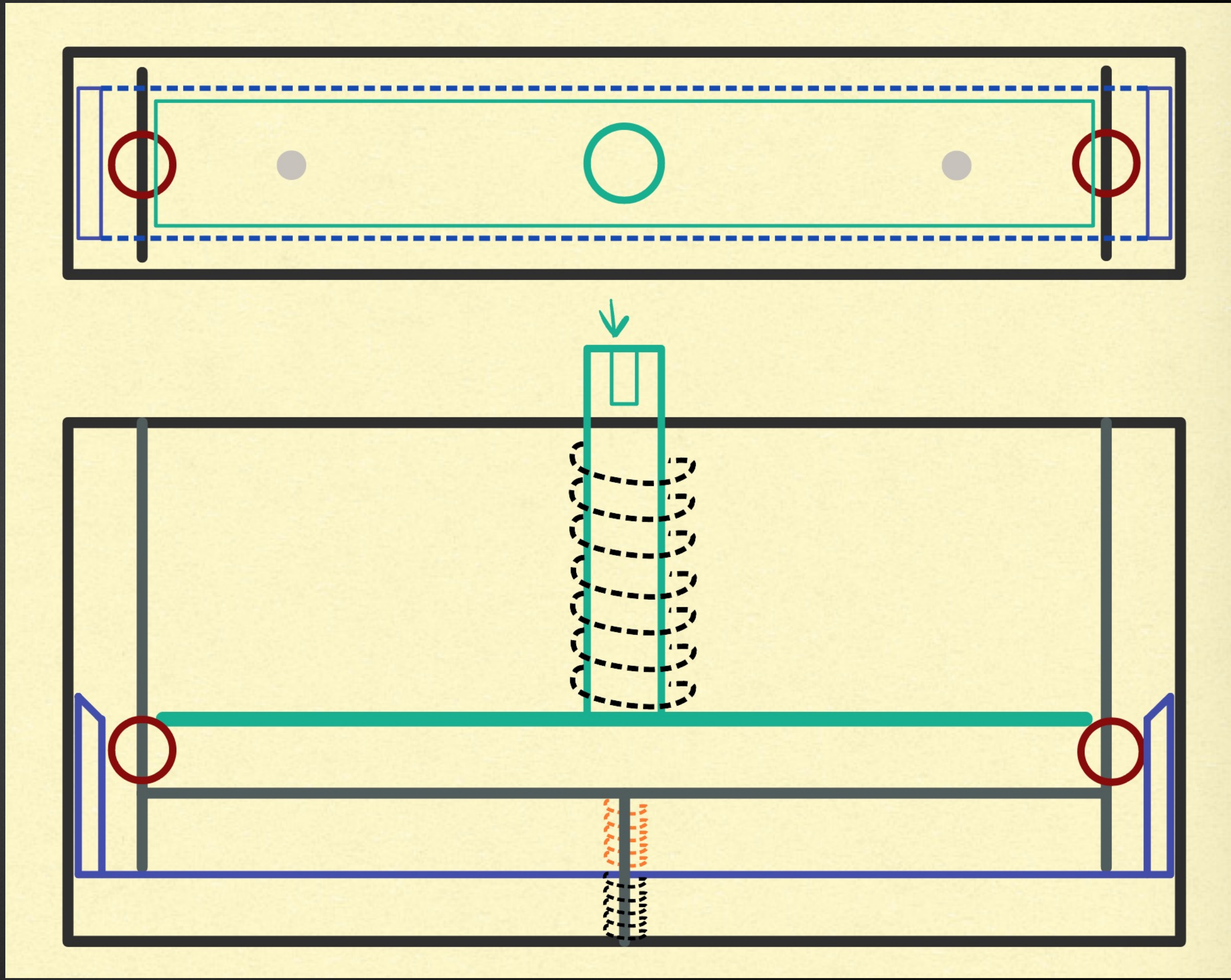


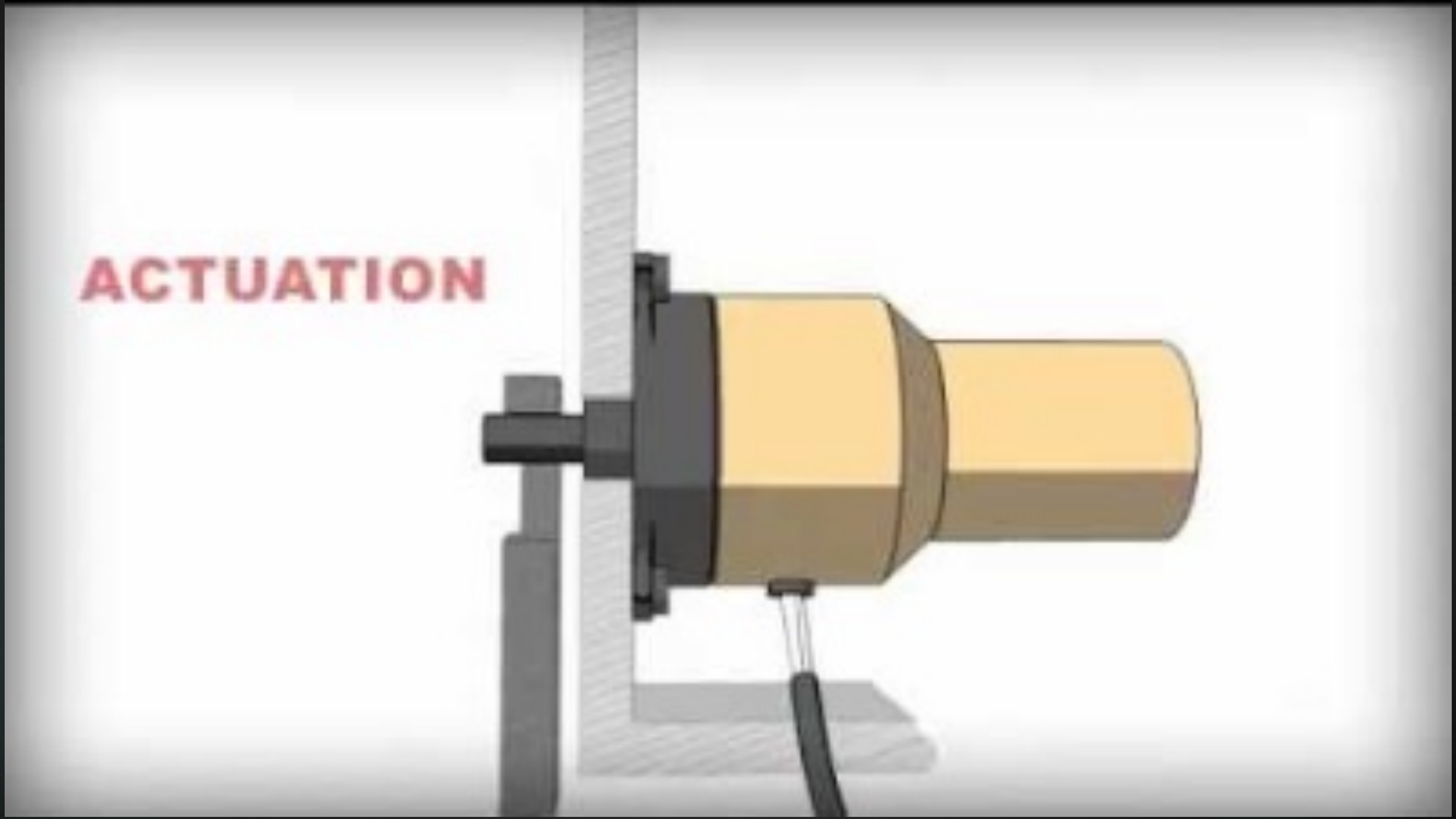
Figure 5: Sketch of Design Solution

Nitinol – What is It?

- Nickel and Titanium based
- “Shape Memory” Alloy

Nitinol SMA Example Video

What Does a Pin Puller Do?



How a Pin-Puller Works [1]

Design Approach – Flow Model

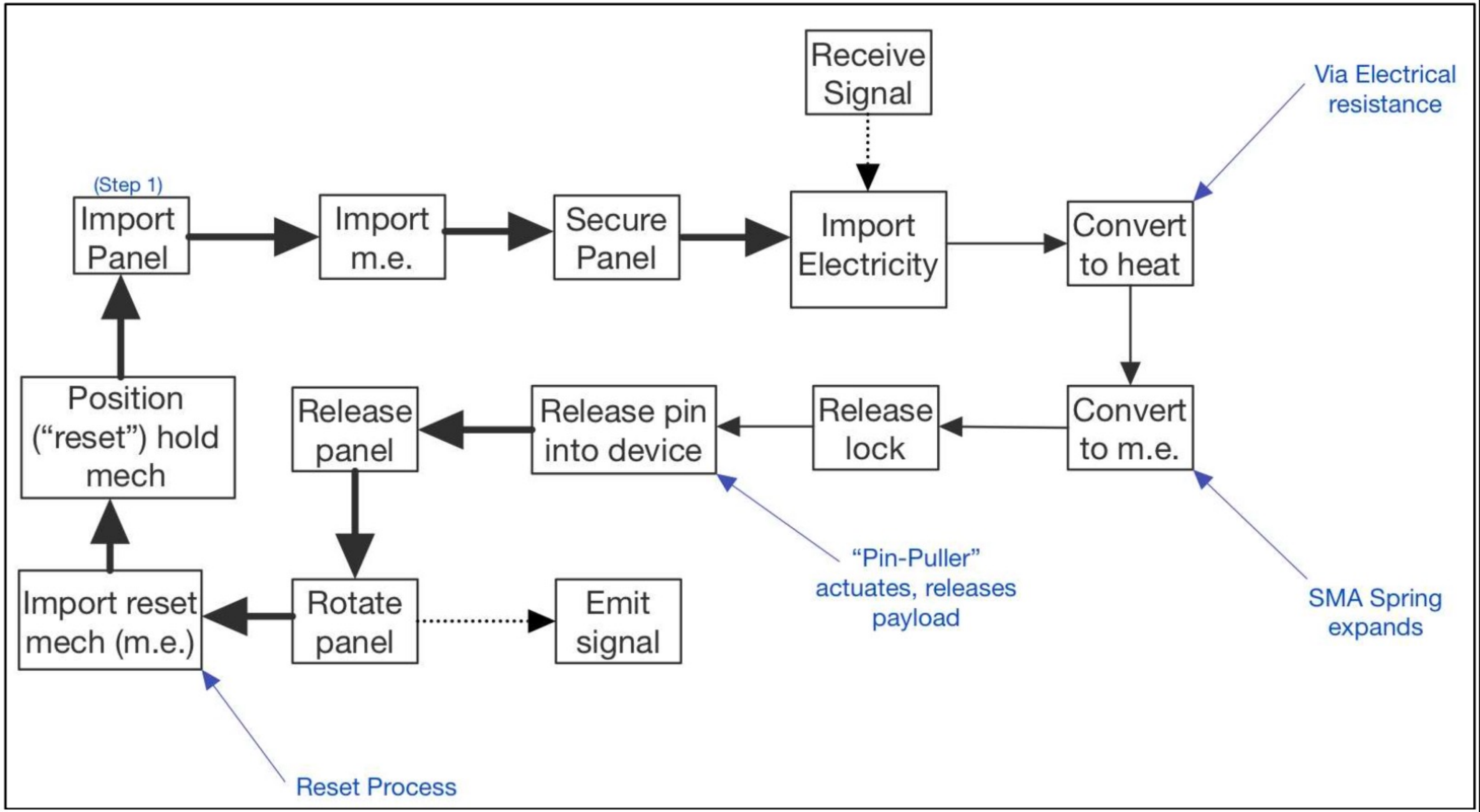


Figure 6: Process Flow Model

Electrical Components

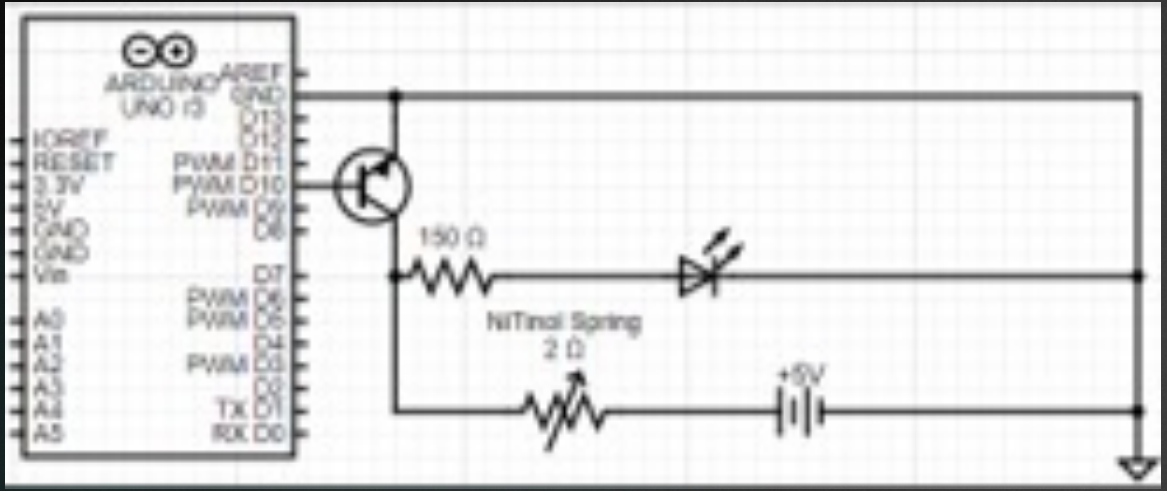


Figure 7: Pulse Width Modulated Circuit Schematic

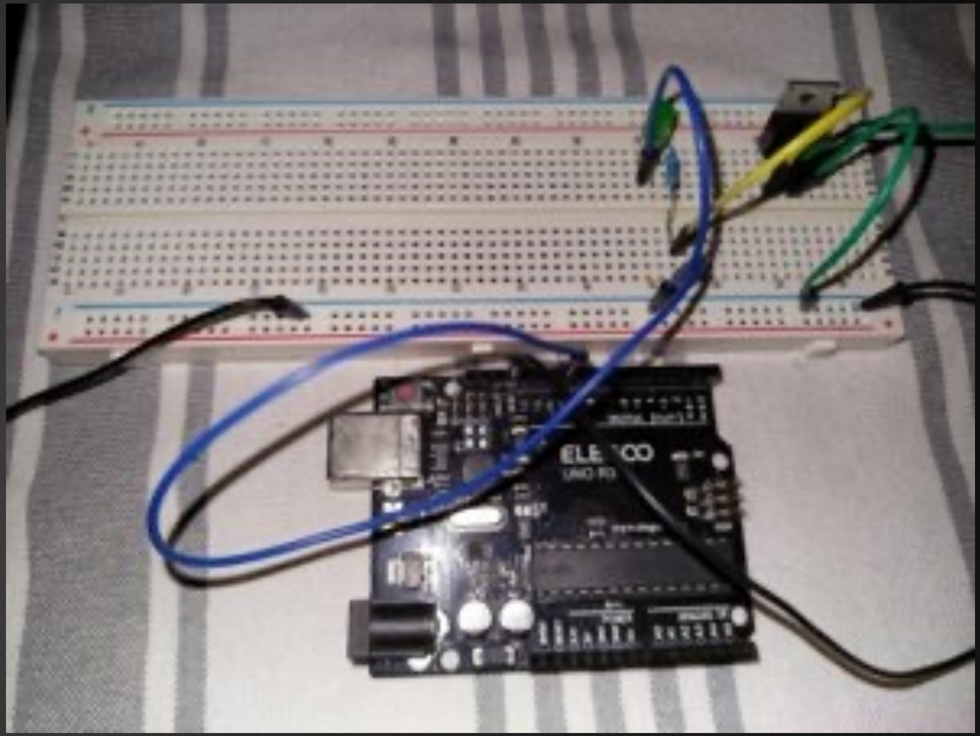


Figure 8: Final Circuit Build

Prototyping & Final Designs

Design Approach – Prototyping

Figure 9: 1st Prototype

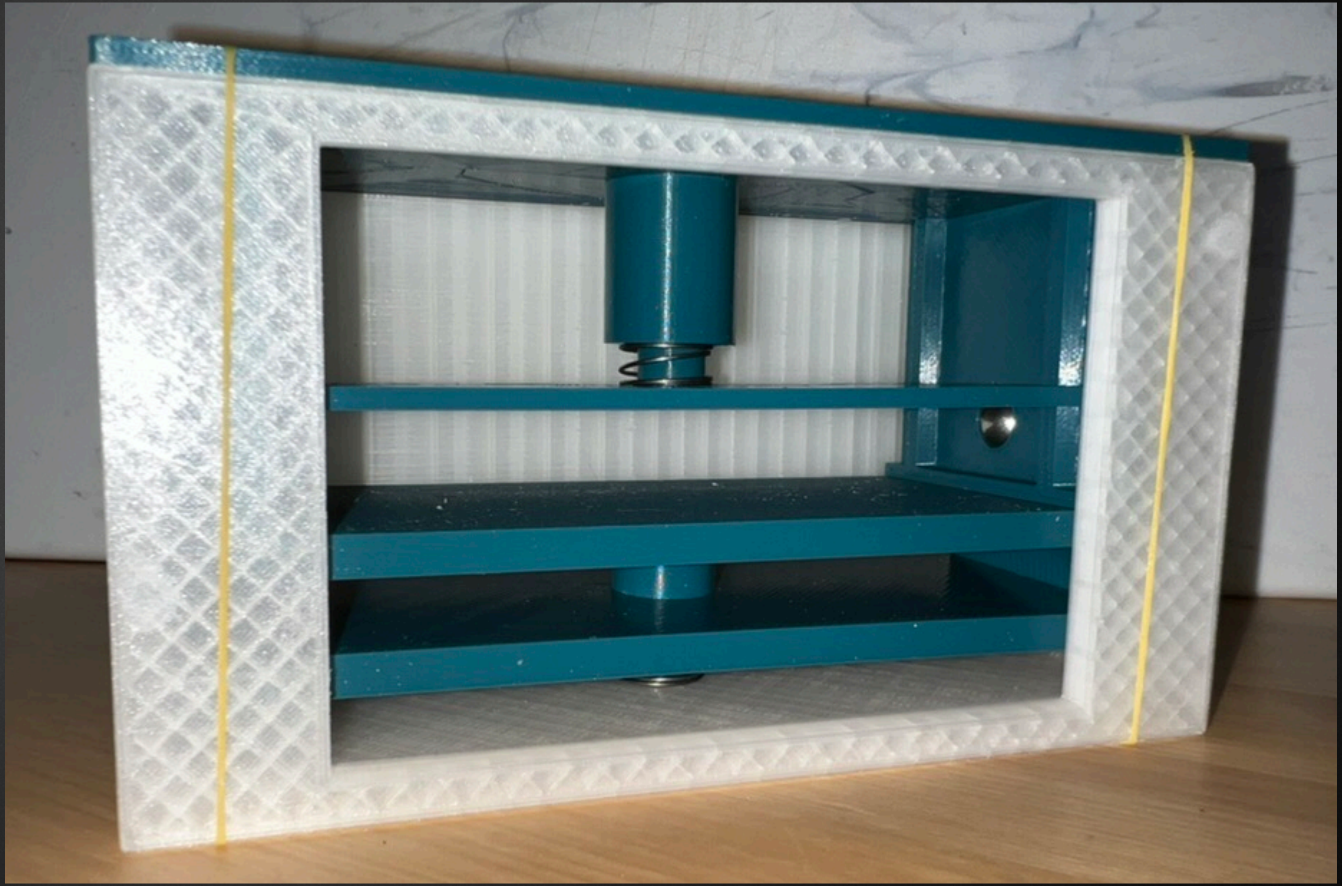


Figure 10: 2nd Prototype

Design Approach – Last Prototype

Figure 11: 3rd Prototype

Design Iteration: Alternative Design

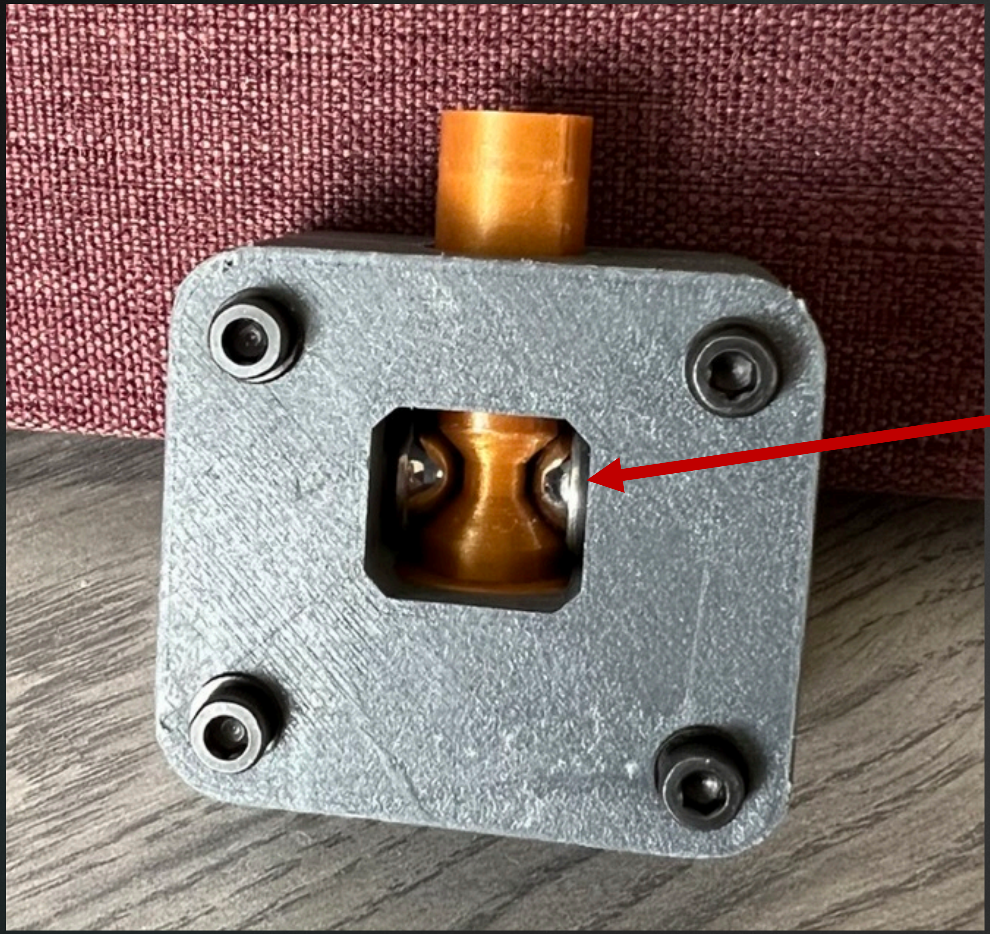


Figure 12: Alternate Design: Proof of Concept

Figure 13: Ball Plunger

Final Design

- **Designed for Manufacturing**
- Off-the-shelf U-channels and rods
- Most operations achievable on the manual mill and lathe
- Other parts manufactured using 3-d printing and CNC machining

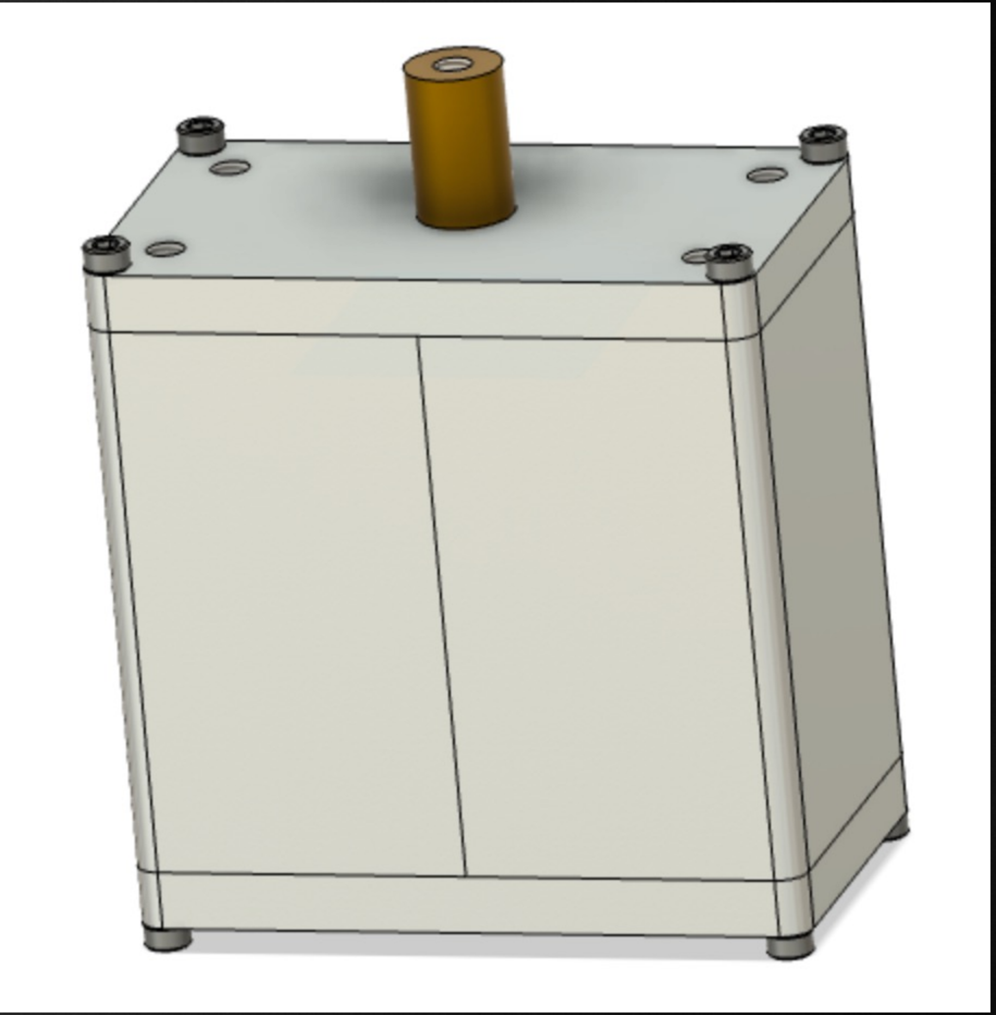


Figure 14: Assembled View of Final Design CAD

CAD Explosion

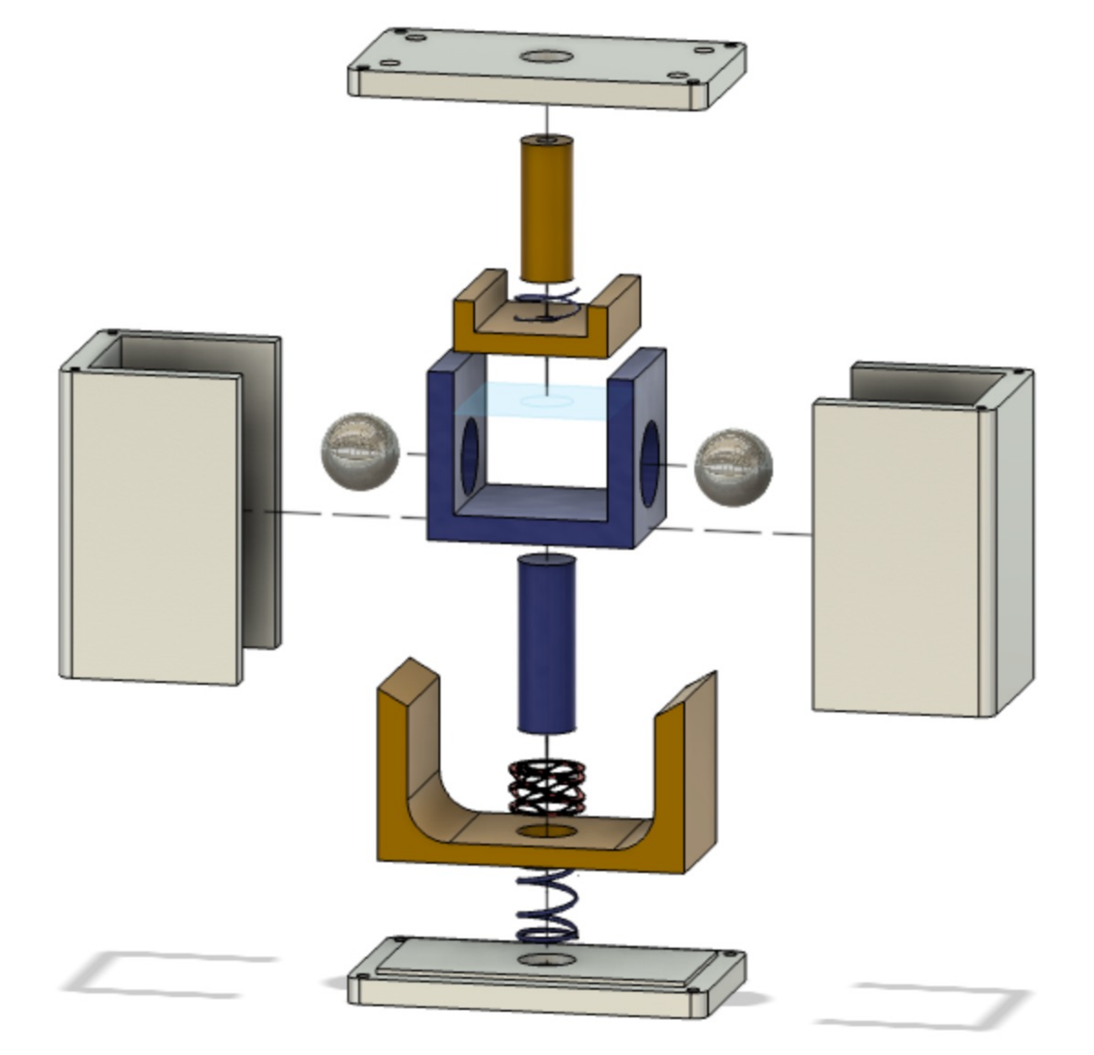


Figure 15: Exploded View of Assembly

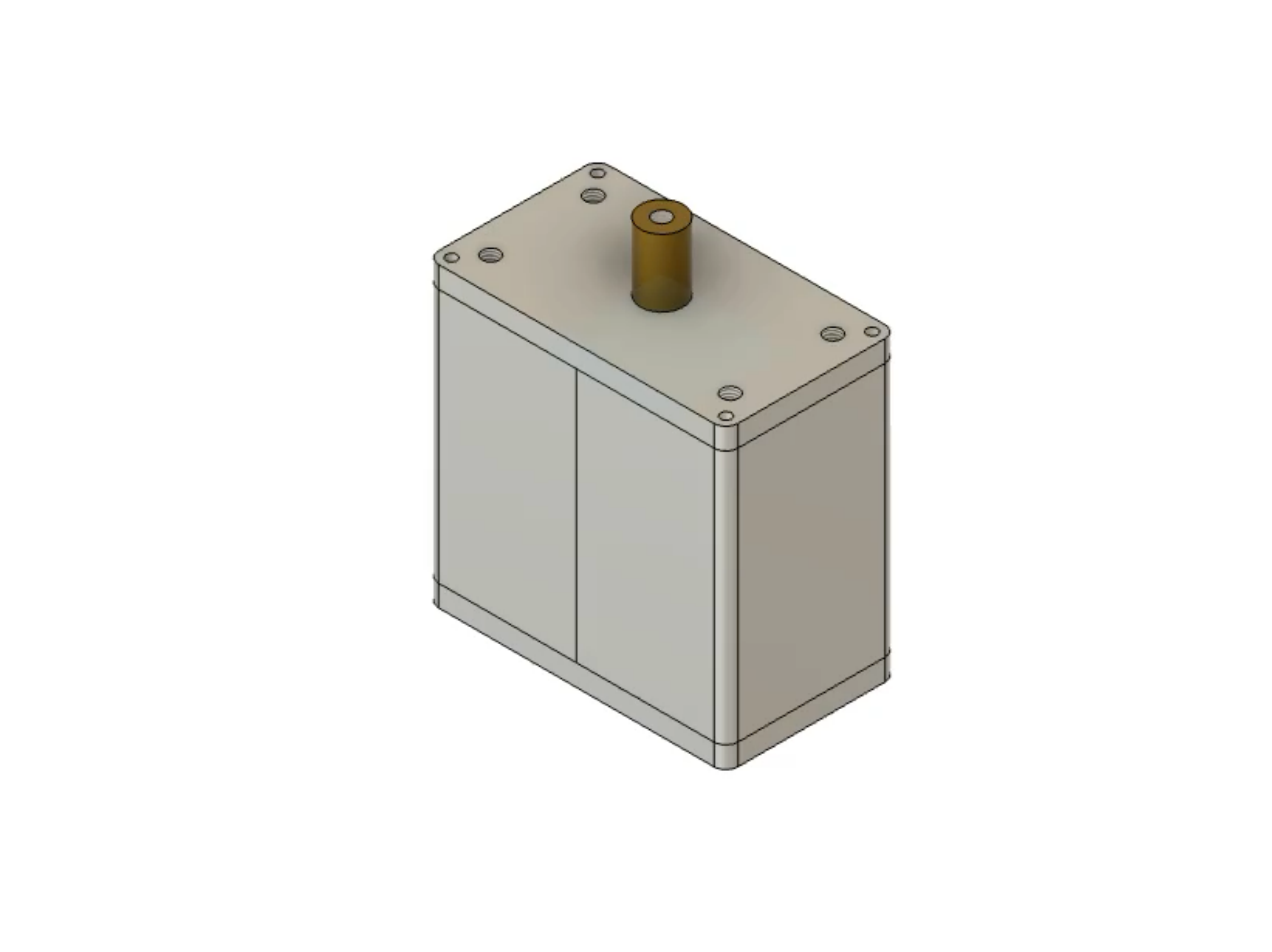


Figure 16: Exploded Animation of Assembly

Final Design

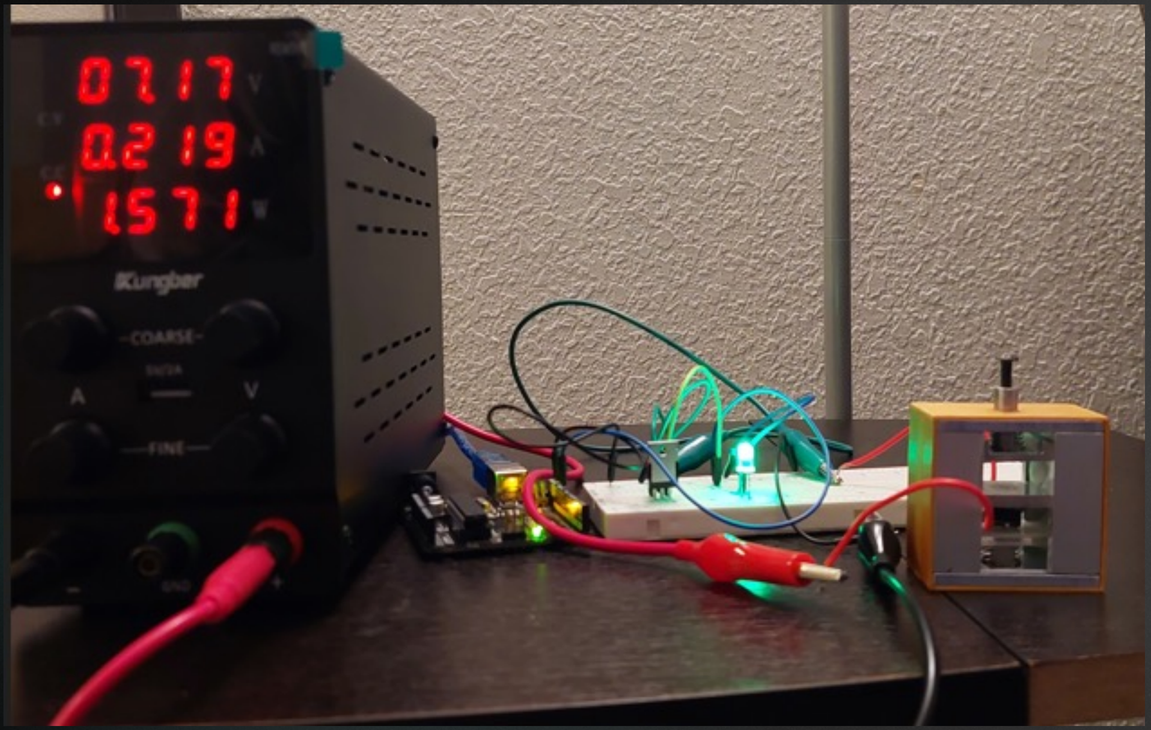


Figure 17: Fully Assembled Device (Front View)

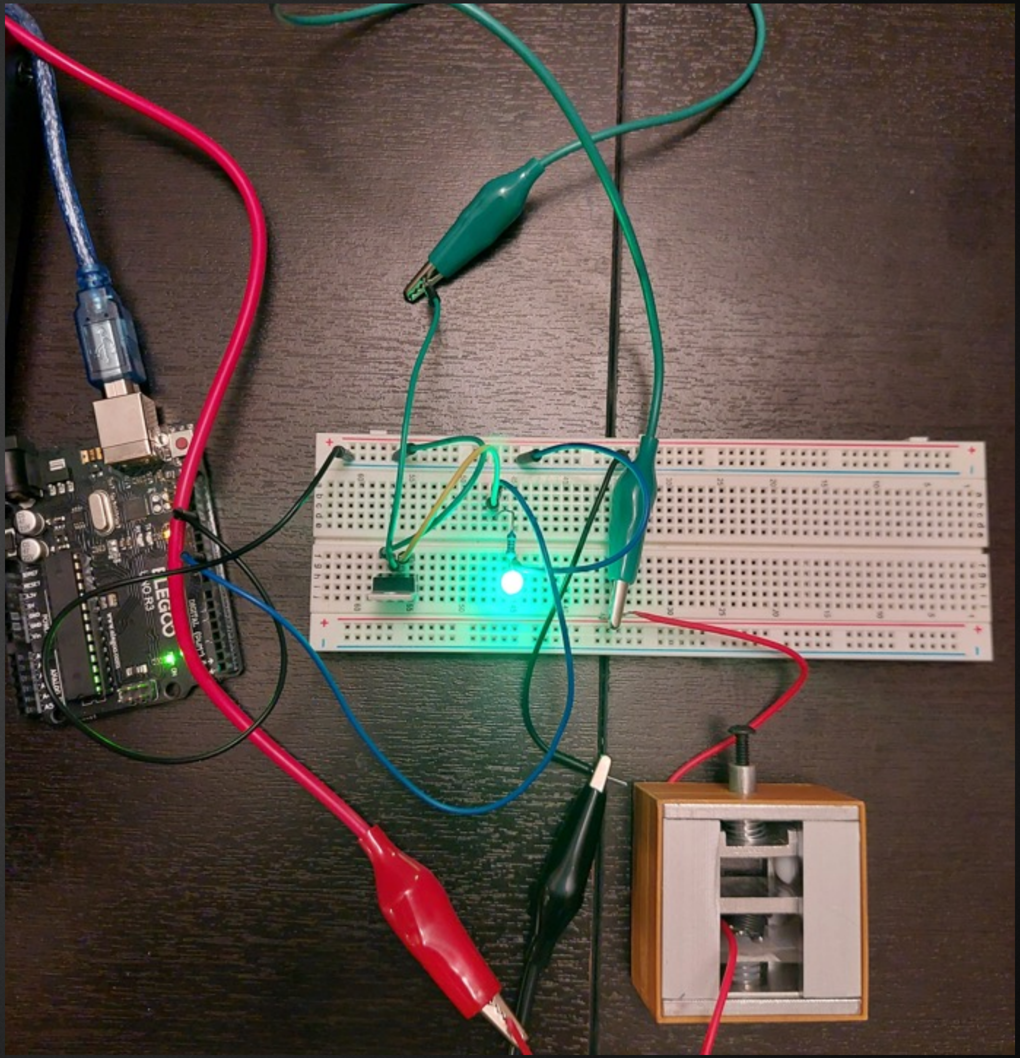
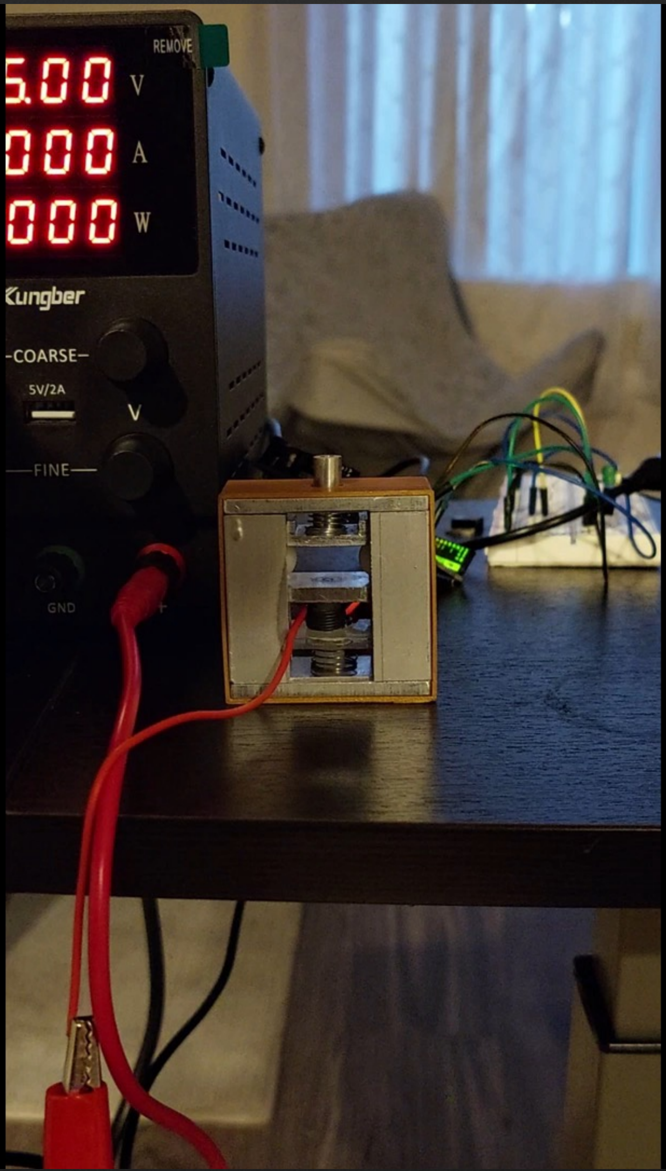


Figure 18: Fully Assembled Device (Top View)

Demonstration



Manufacturing & Speedbumps

Manufacturing Process – Manual Operations

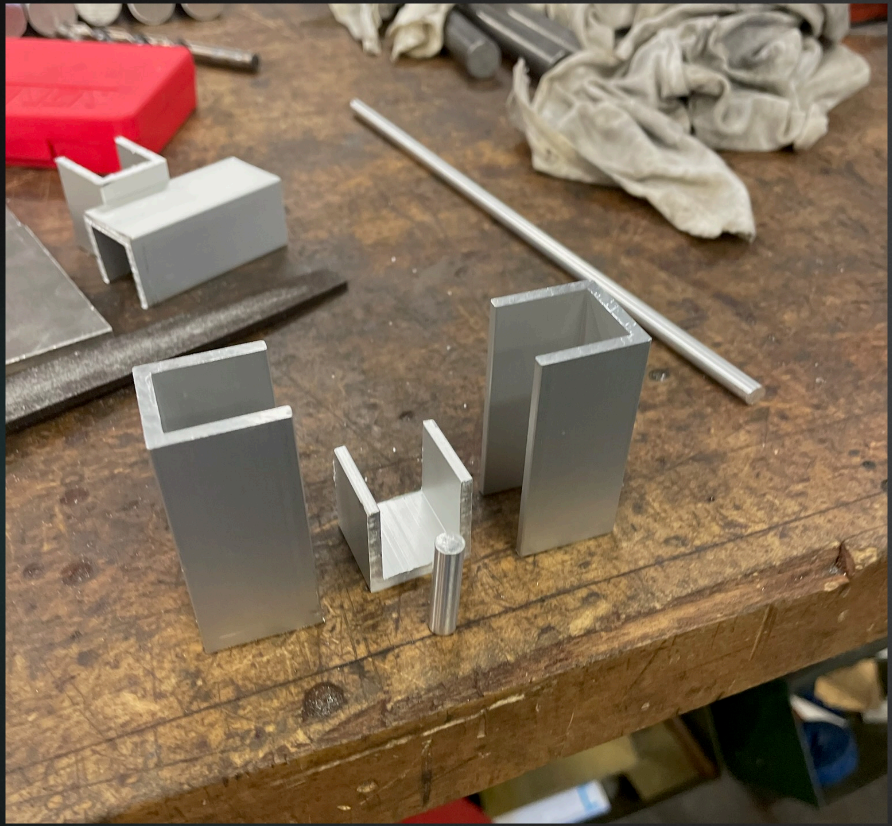


Figure 19: U-Channels to Cut Down to Size for Enclosure

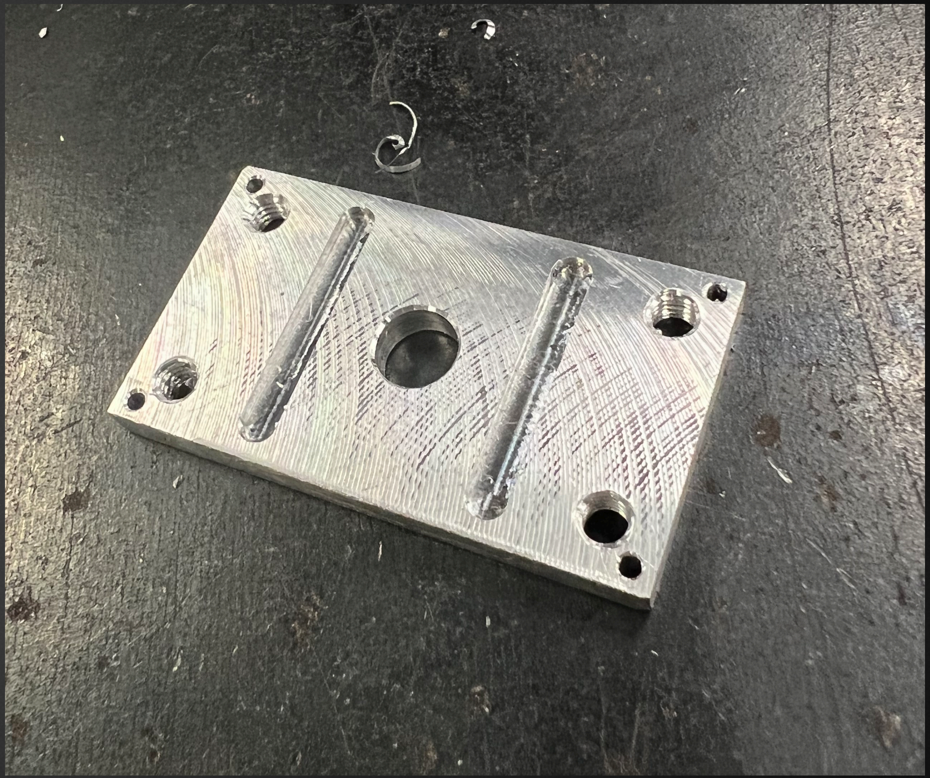


Figure 20: Top Cap Manufactured on Manual Mill

Manufacturing Process – Automated Operations

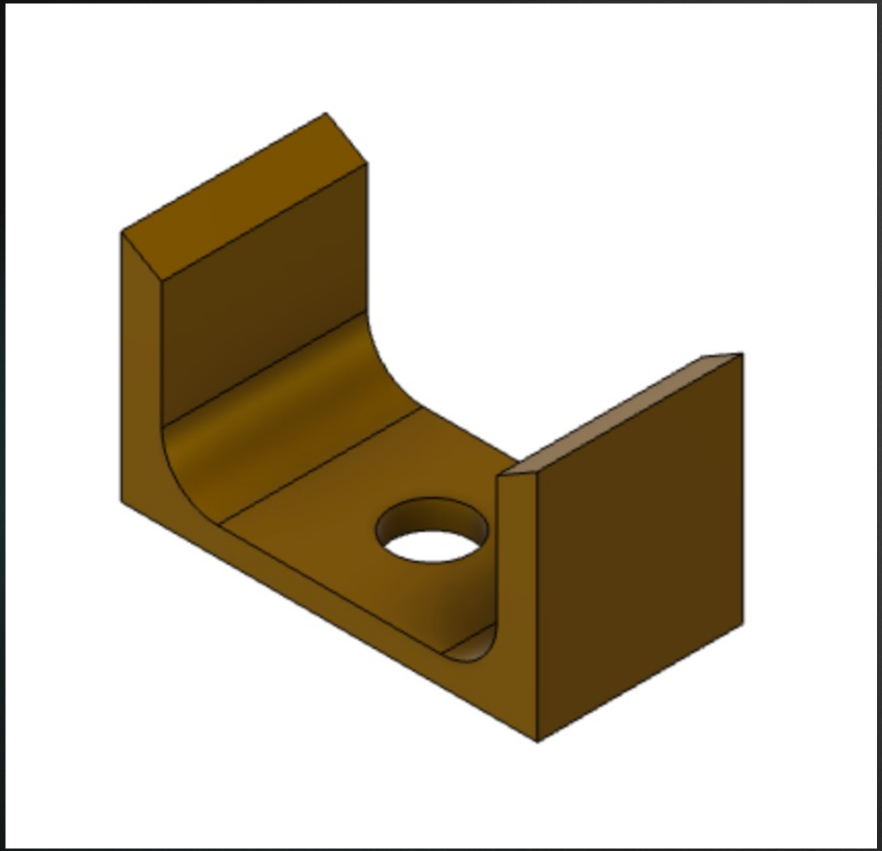


Figure 21: 3-D Printed for Low Friction

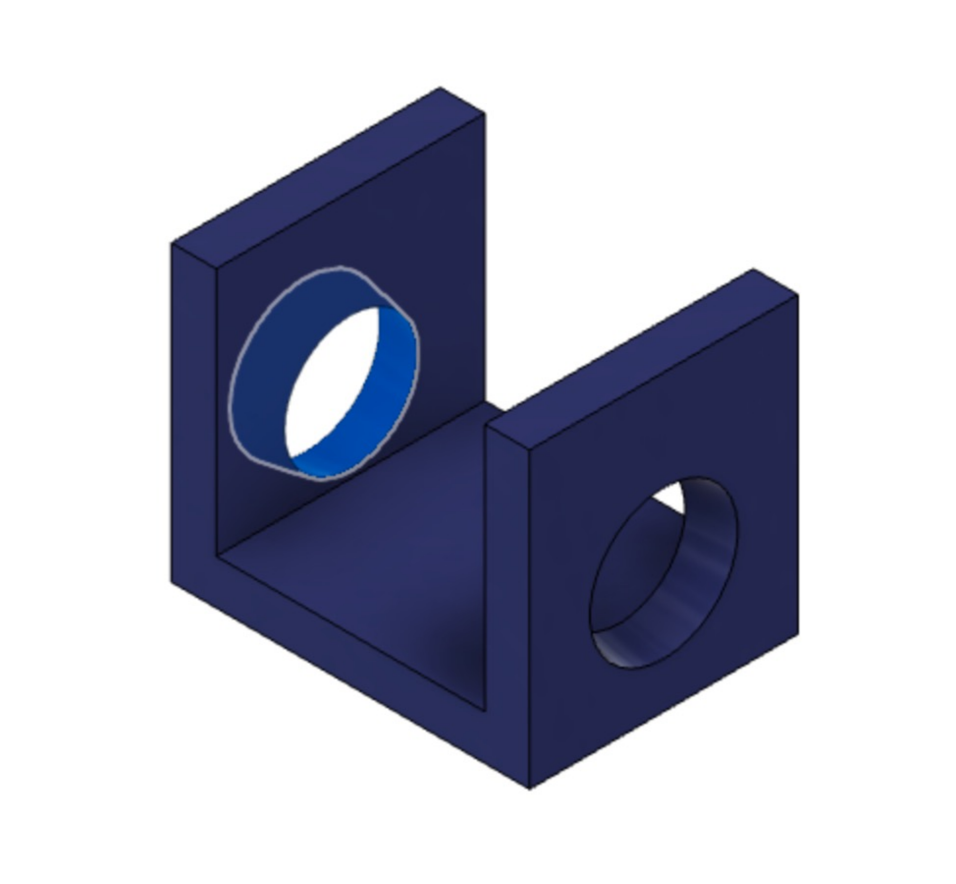


Figure 22: CNC'd Due to Complex Geometry

Obstacles & Modifications

- Current design required drilling and tapping 8x holes 1.6mm diameter.
- Broke two taps & 1 drill bit.
- Settled for sleeve and clamping for holding.

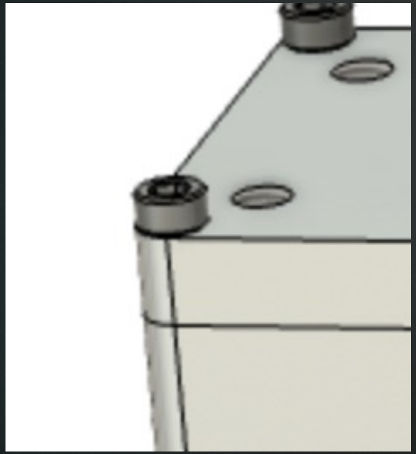


Figure 23: Original assembly method

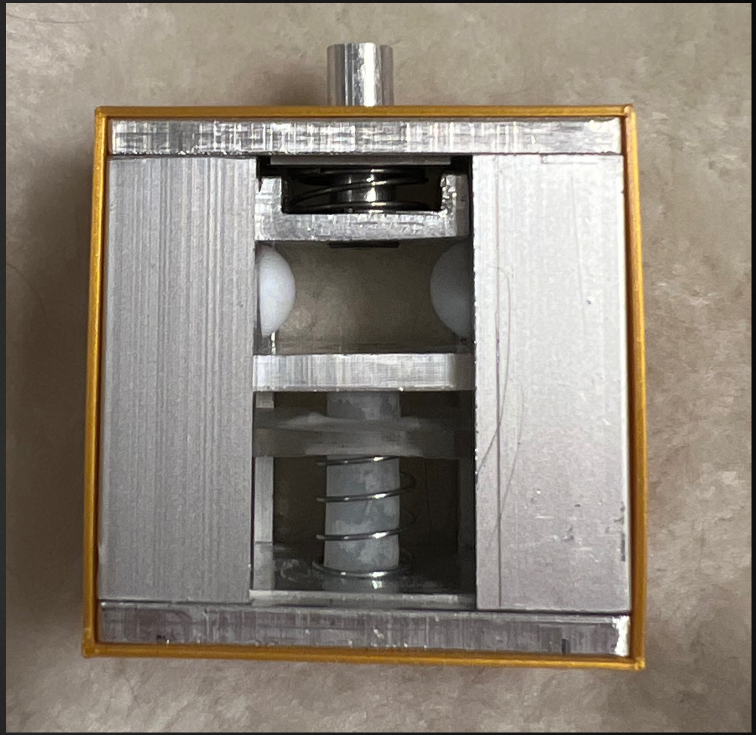


Figure 24: Manufactured Model (SMA spring missing) with Sleeve

Testing

Testing Plan

Table 2: Testing Plan Summary

Experiment #	Experiment/ Test	Relevant DRs
1	Actuation Test	ER9/CR9, ER3/CR3, CR7
2	Actuation Voltage Test	ER11/CR11
3	Spring Force	ER9
4	Shear Load Test	ER7, ER6/CR6
5	Measurement Verifications	ER5/CR5, ER4
6	Weight Verifications	ER10/CR10
7	Outgassing Verifications	ER2/CR2
8	CubeSat Deployment	CR4, ER6/CR6, CR8
9	Debris Verification	ER1/ CR1

Table 3: Recap of Requirements

#	CR	ER
1	No Space Debris	No breakaway parts
2	Low Outgassing	Low outgassing materials
3	No Combustion	No combustion
4	20x30 cm Deploy Solar Panels	Minimize volume
5	Minimize Protruding Material	Minimize protruding material
6	Maximize Deployment Load/ Simultaneously	Maximize deployment force
7	Easily Resettable	No deformation
8	Retain Stowed Configuration prior to deployment	Maximize retention reliability
9	Receive Input Command	Receive input command
10	Minimize Weight	Minimize weight
11	Minimize Reset Time	Minimize actuation time
12		Maximize Nitinol life

Testing (cont'd)

Table 4: Specification Sheet (ERs)

Engineering Requirement	Target	Units	Tolerance	Measured/ Calculated Value	ER Met? Y/ N	Client Accept able? Y/N
No breakaway parts	0	-	0	0	Y	Y
Low outgassing materials	0	-	0	-	N	Y
No combustion	0	-	0	0	Y	Y
Minimize volume	1	cu. In	+0.5	3.4 in^3	N	Y
Minimize protruding material	1	cm	0.1	0.1 mm	Y	Y
Maximize deployment force	25	N	- 5	14.5	N	Y
No deformation	0	%	+2	0	Y	Y
Maximize retention reliability	100	%	1.5	100	Y	Y
Receive input command	-	-	-	-	Y	Y
Minimize weight	200	g	+50 -200	75	Y	Y
Minimize reset time	30	sec	+30	15	Y	Y
Maximize SMA Spring life (1N)	50	Cycles	5	20	N	Y

Table 5: Specification Sheet (CRs)

Customer Requirements	CR Met? Y/N	Client Acceptable? Y/N
No Space Debris	Y	Y
Low Outgassing	N	Y
No Combustion	Y	Y
Can deploy 20x30cm panels	N	Y
Minimize protruding material	Y	Y
max deployment load / simultaneously	N	Y
Easily resettable	Y	Y
Retain stowed config prior to deployment	Y	Y
Receive input command	Y	Y
Minimize Weight	Y	Y
minimize reset time	Y	Y

Budget & Future Work

Budget & Expenses

Table 6: Breakdown of Expenses and Purchases – photos omitted for simplicity

Part Description:	Cost:	Quantity:	Date:	Make/ Buy:	Primary Vendor:	Manufacturer:
Acrylic Sheets	21.83	2	09/06/22	Buy	Amazon	Acrylic Mega Store
Nitinol Spring (2.4 mm)	19.58	1	02/23/22	Buy	Amazon	Kellogg's Research Lab
Aluminum Block	$40.39	2	09/06/22	Buy	Amazon	VERNUOS
Generic Springs	$14.18	1	09/06/22	Buy	Amazon	Ninoge
Ball-Nose Plunger	$8.38	2	04/05/22	Buy	McMaster-Carr	McMaster-Carr
Arduino	$49.12	1	09/06/22	Buy	Amazon	Arduino
Aluminum Rod	$30.43	1	09/06/22	Buy	McMaster-Carr	McMaster-Carr
U-Channel	$29.55	2	10/5/22	Buy	McMaster-Carr	McMaster-Carr
PTFE Balls	$12.28	1	10/5/22	Buy	McMaster-Carr	McMaster-Carr
Polyethylene Rod	$5.01	1	10/5/22	Buy	McMaster-Carr	McMaster-Carr
Socket Head Screw	$19.81	1	10/5/22	Buy	McMaster-Carr	McMaster-Carr
PTFE Film	$24.45	1	10/5/22	Buy	McMaster-Carr	McMaster-Carr
Drill Bit	$6.84	1	10/5/22	Buy	McMaster-Carr	McMaster-Carr
Compression Spring	$7.24	1	10/5/22	Buy	McMaster-Carr	McMaster-Carr
Compression Spring (Short)	$29.28	1	10/5/22	Buy	McMaster-Carr	McMaster-Carr
Flat Head Screw	$9.27	1	10/5/22	Buy	McMaster-Carr	McMaster-Carr
Load Cell	$10.42	2	10/5/22	Buy	Amazon	ALAMSCN
SMA Spring	$20.93	2	10/5/22	Buy	Amazon	NexMetal
Standoff "Kit"	$21.83	1	10/5/22	Buy	Amazon	VIGRUE
MOSFET Transistor	$10.50	1	10/31/22	Buy	Amazon	Bridgold
M1 Bit/Tap	$8.50	2	10/18/22	Buy	Amazon	Drill America Store
Power Supply	$62.91	1	10/18/22	Buy	Amazon	Kungber
3D Printed Part	$20.02	1	10/10/22	Make	NAU	NAU Idea Lab
3D Printed Part	$16.04	1	10/26/22	Make	NAU	NAU Idea Lab
Part Total:	**$457.38**					
Total Budget:	**$2,000.00**					
Remaining Budget:	**$1,542.62**					

Budget & Expenses Cont'd

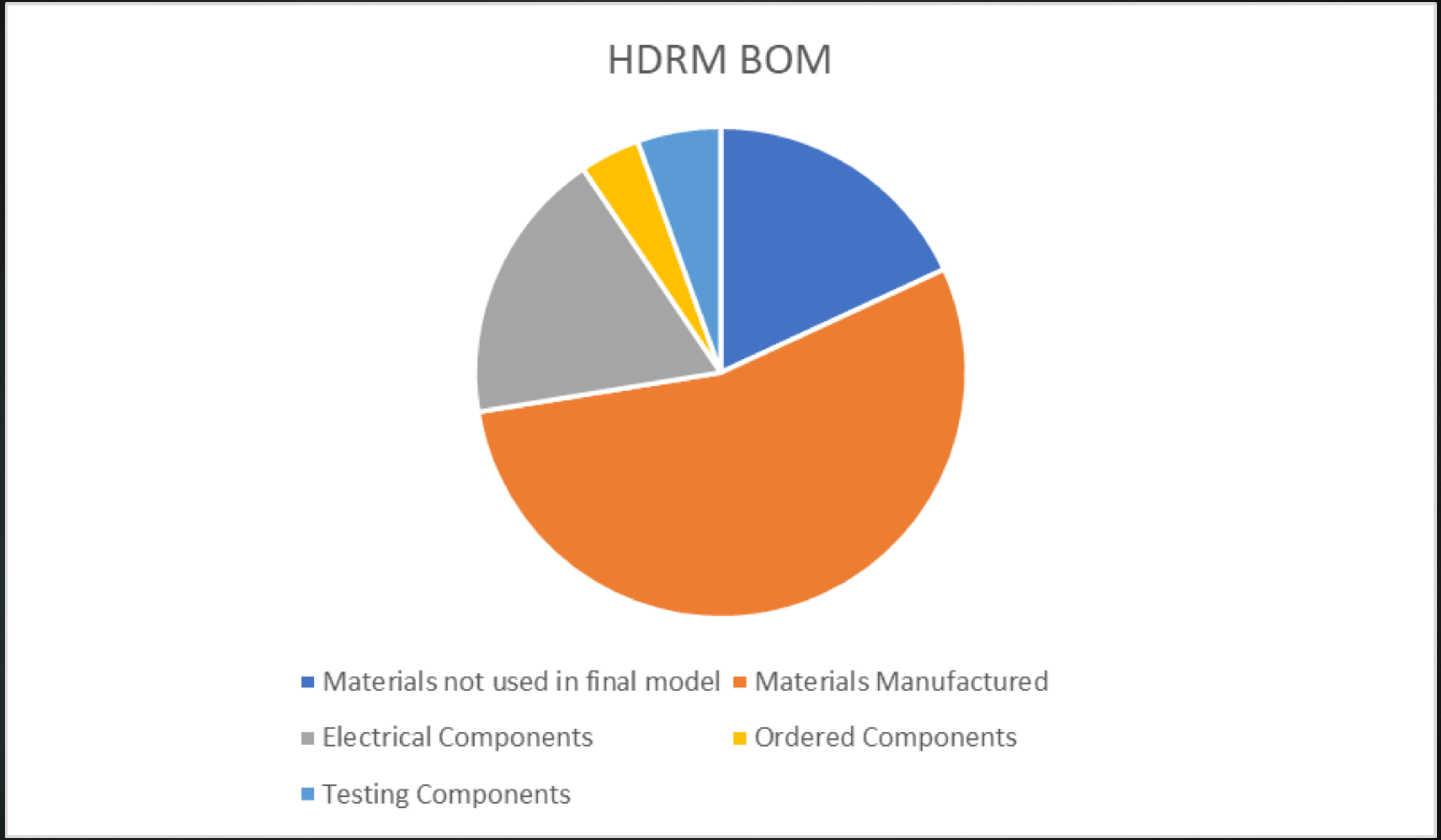


Figure 25: Expense Summary

Future Work

- Fitting the design into 1 cubic inch using more precise machinery
- Using a stronger higher-grade metal that can function under space conditions
- Customizing a stronger SMA spring to made the device more reliable and improve functionality of the bias spring
- Lower outgassing material to replace the 3D printed part
- Utilizing screws (or other method) to hold the design together
- Testing actuation under space temperature and turbulence
- Certification under NASA's standards and codes for use in space

Thank you!

- Questions?

Check out out site!

References

[1] Ben, “Tini™ Pin puller,” *Ensign-Bickford Aerospace & Defense*, 05-Jul-2022. [Online]. Available: https://www.ebad.com/tini-pin-puller/. [Accessed: 08-Dec-2022].