Safe Send
Final Design Review

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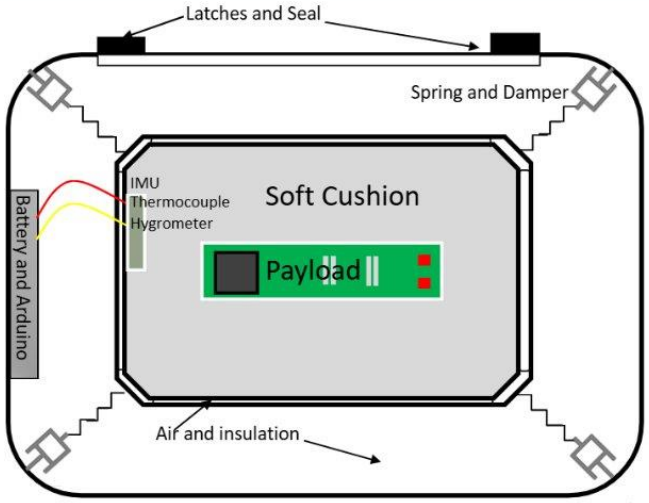
PURDUE UNIVERSITY | School of Mechanical Engineering

Problem Overview

- Shipping solution for precision assemblies and components
- Key stakeholders include precision engineering and shipping companies
  - Optics Companies
  - Microelectronics
  - Biomedical

- Tracking provides engineering companies information about shipping status

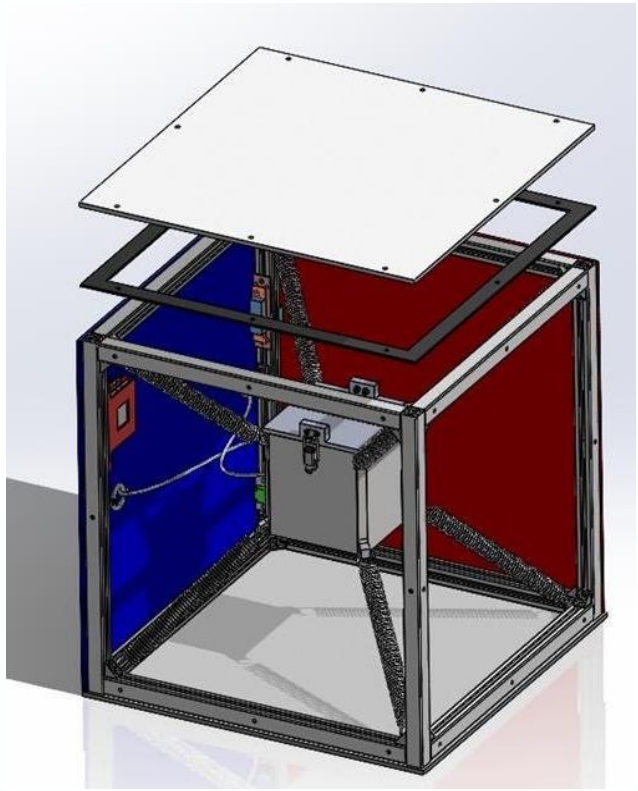
- Key Requirements
  - Minimize acceleration on payload to below 15 g from a 1-meter drop
  - Protect payload from heat and moisture
  - Track acceleration, temp, humidity

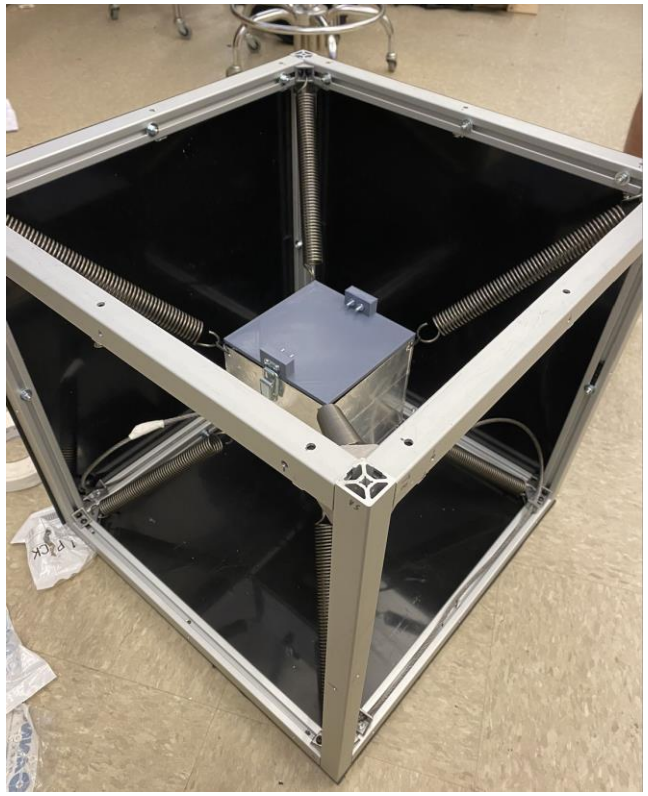


Manufacturing

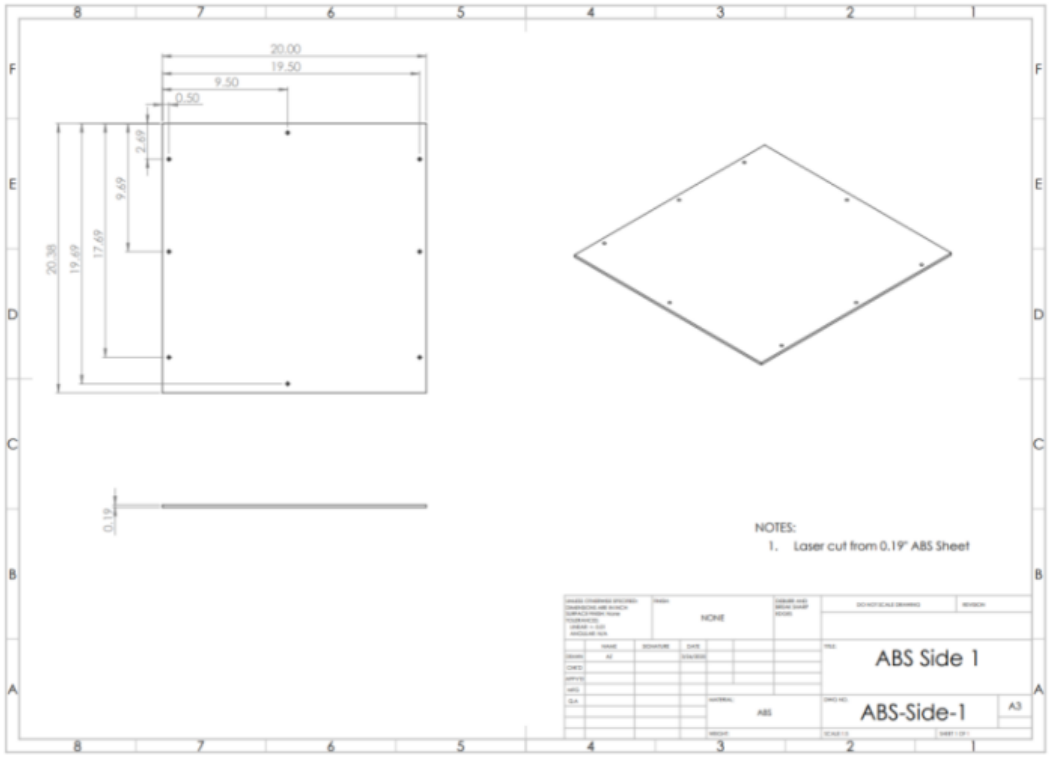
Outer Shell and Frame

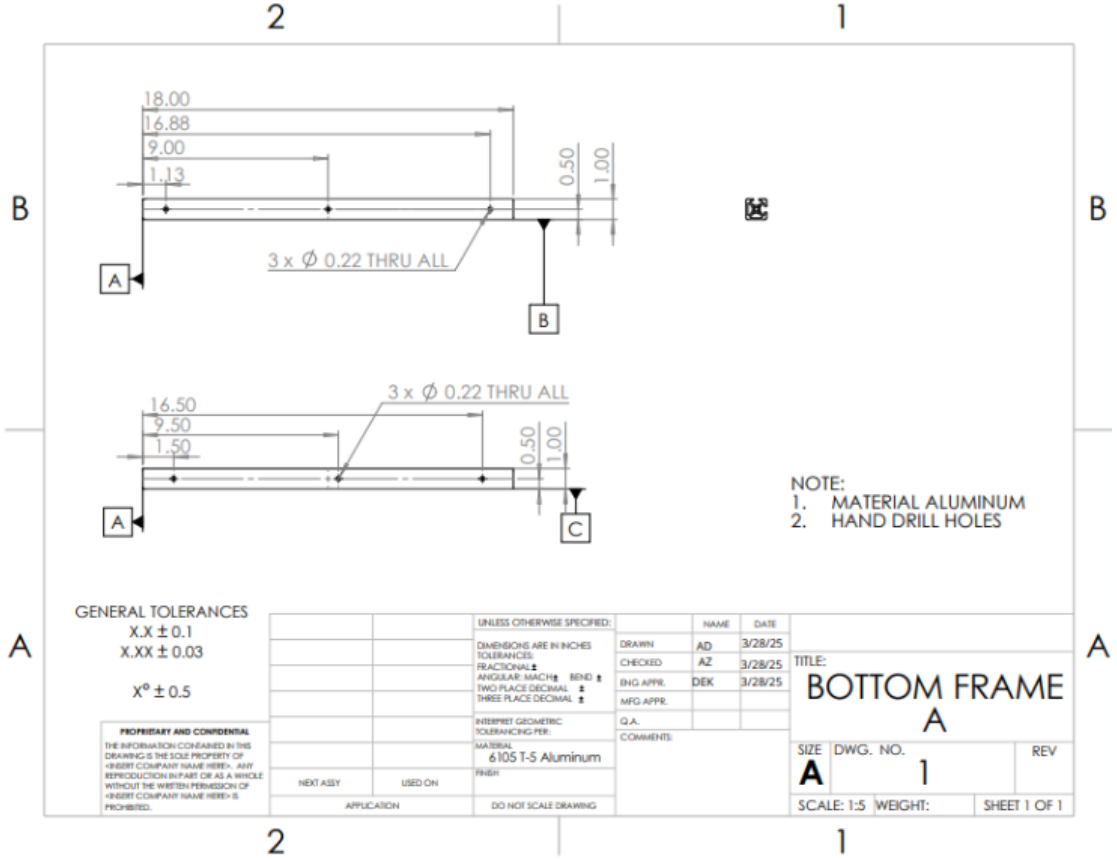
- 12 individual 80-20 extrusions make up the frame
  - Drilled
- Frame contains mounts for springs, wire rope, and electronics
- Panels attached to exterior
  - Water Jet
- 3D printed mounts and inner box



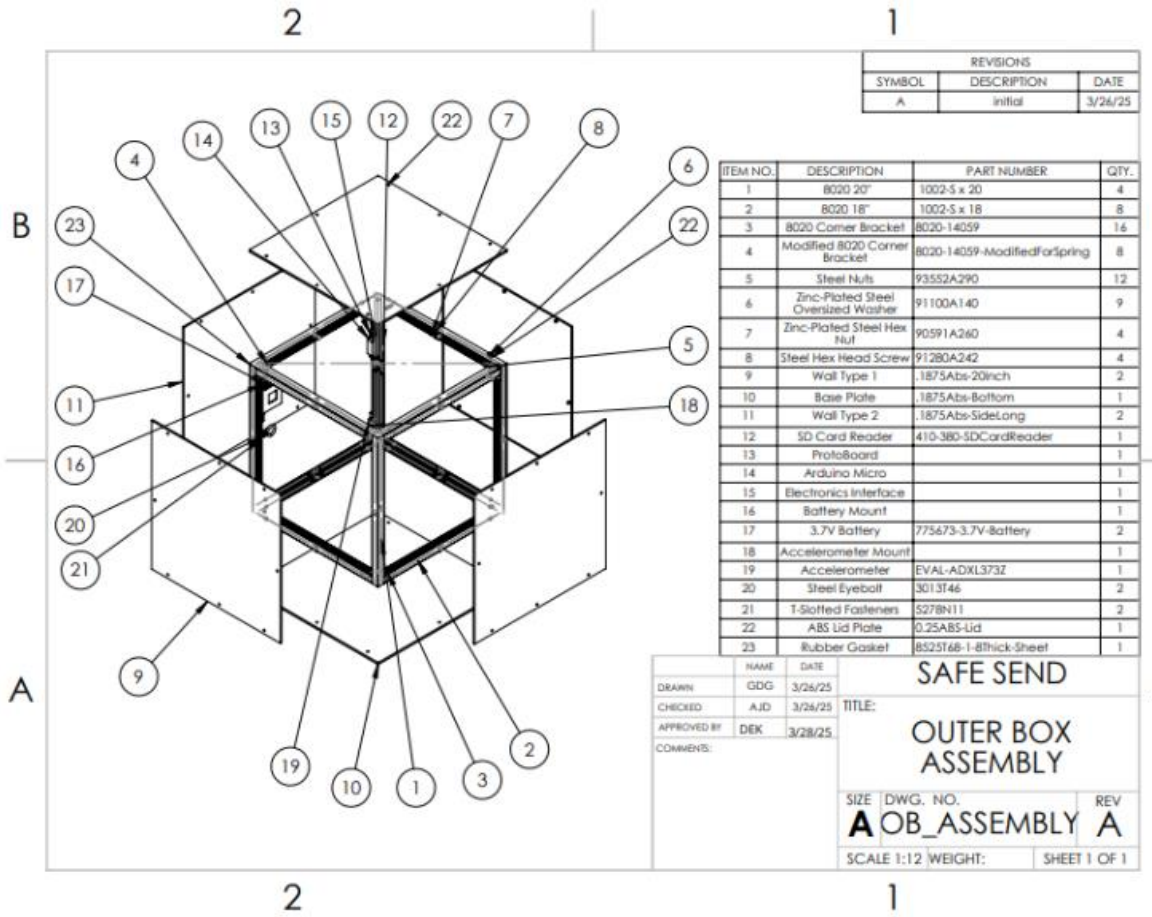


Manufacturing Drawings





Assembly - Drawings



REVISIONS		
SYMBOL	DESCRIPTION	DATE
A	initial	3/26/25

ITEM NO.	DESCRIPTION	PART NUMBER	QTY.
1	8020 20"	1002-S x 20	4
2	8020 18"	1002-S x 18	8
3	8020 Corner Bracket	8020-14059	16
4	Modified 8020 Corner Bracket	8020-14059-ModifiedForSpring	8
5	Steel Nuts	93552A290	12
6	Zinc-Plated Steel Oversized Washer	91100A140	9
7	Zinc-Plated Steel Hex Nut	90591A260	4
8	Steel Hex Head Screw	91280A242	4
9	Wall Type 1	.1875Abs-20Inch	2
10	Base Plate	.1875Abs-Bottom	1
11	Wall Type 2	.1875Abs-SideLong	2
12	SD Card Reader	410-380-SDCardReader	1
13	ProtoBoard		1
14	Arduino Micro		1
15	Electronics Interface		1
16	Battery Mount		1
17	3.7V Battery	775673-3.7V-Battery	2
18	Accelerometer Mount		1
19	Accelerometer	EVAL-ADXL373Z	1
20	Steel Eyebolt	3013T46	2
21	T-Slotted Fasteners	5278N11	2
22	ABS Lid Plate	0.25ABS-Lid	1
23	Rubber Gasket	8525T68-1-8thick-Sheet	1

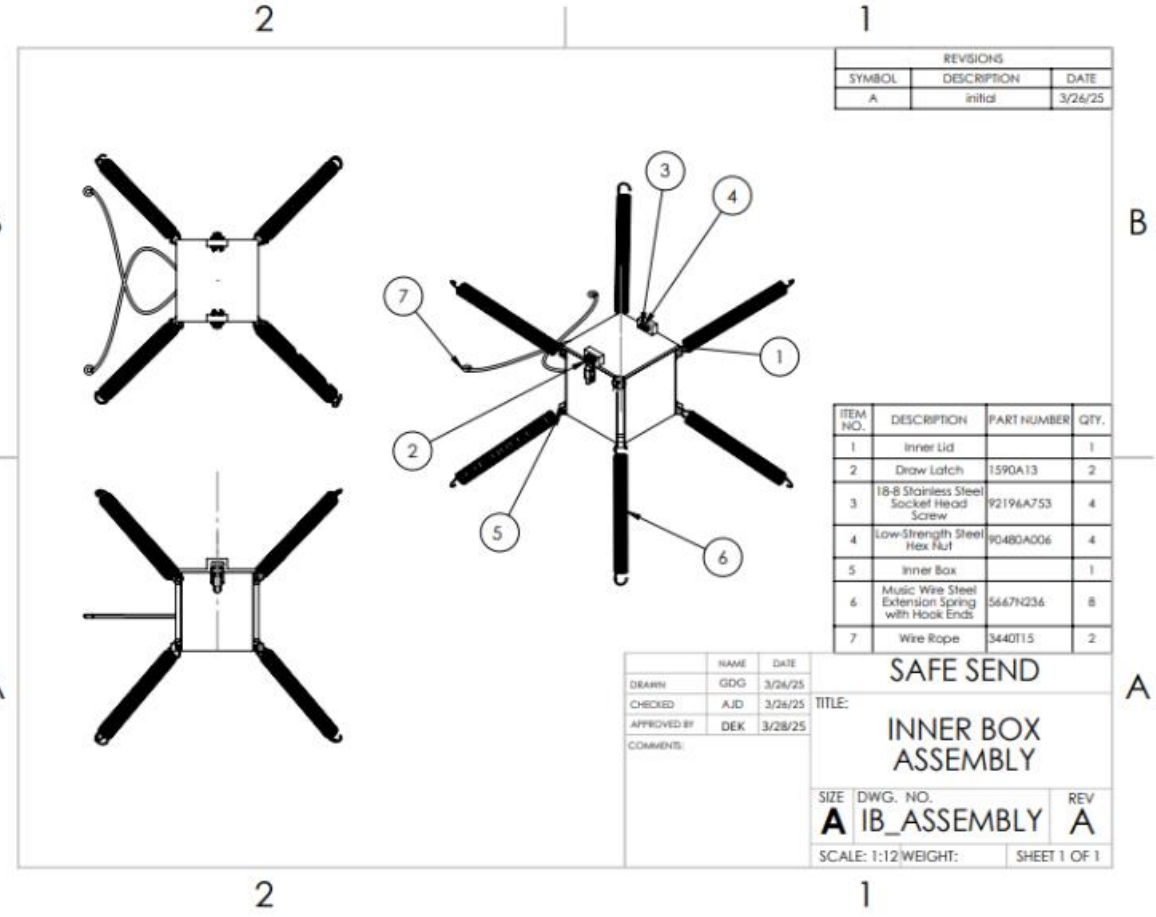
	NAME	DATE
DRAWN	GDG	3/26/25
CHECKED	AJD	3/26/25
APPROVED BY	DEK	3/28/25
COMMENTS:		

SAFE SEND

TITLE: OUTER BOX ASSEMBLY

SIZE	DWG. NO.	REV
A	OB_ASSEMBLY	A

SCALE 1:12 WEIGHT: SHEET 1 OF 1



REVISIONS		
SYMBOL	DESCRIPTION	DATE
A	initial	3/26/25

ITEM NO.	DESCRIPTION	PART NUMBER	QTY.
1	Inner Lid		1
2	Draw Latch	1590A13	2
3	18-8 Stainless Steel Socket Head Screw	92196A753	4
4	Low-Strength Steel Hex Nut	90480A006	4
5	Inner Box		1
6	Music Wire Steel Extension Spring with Hook Ends	5667N236	8
7	Wire Rope	3440T15	2

	NAME	DATE
DRAWN	GDG	3/26/25
CHECKED	AJD	3/26/25
APPROVED BY	DEK	3/28/25
COMMENTS:		

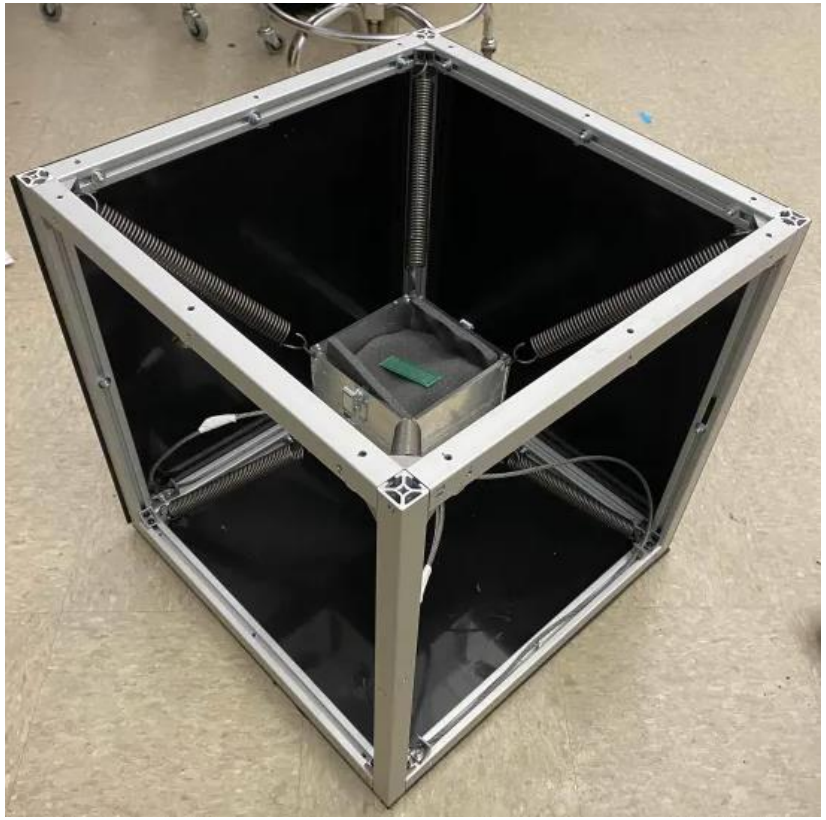
SAFE SEND

TITLE: INNER BOX ASSEMBLY

SIZE	DWG. NO.	REV
A	IB_ASSEMBLY	A

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

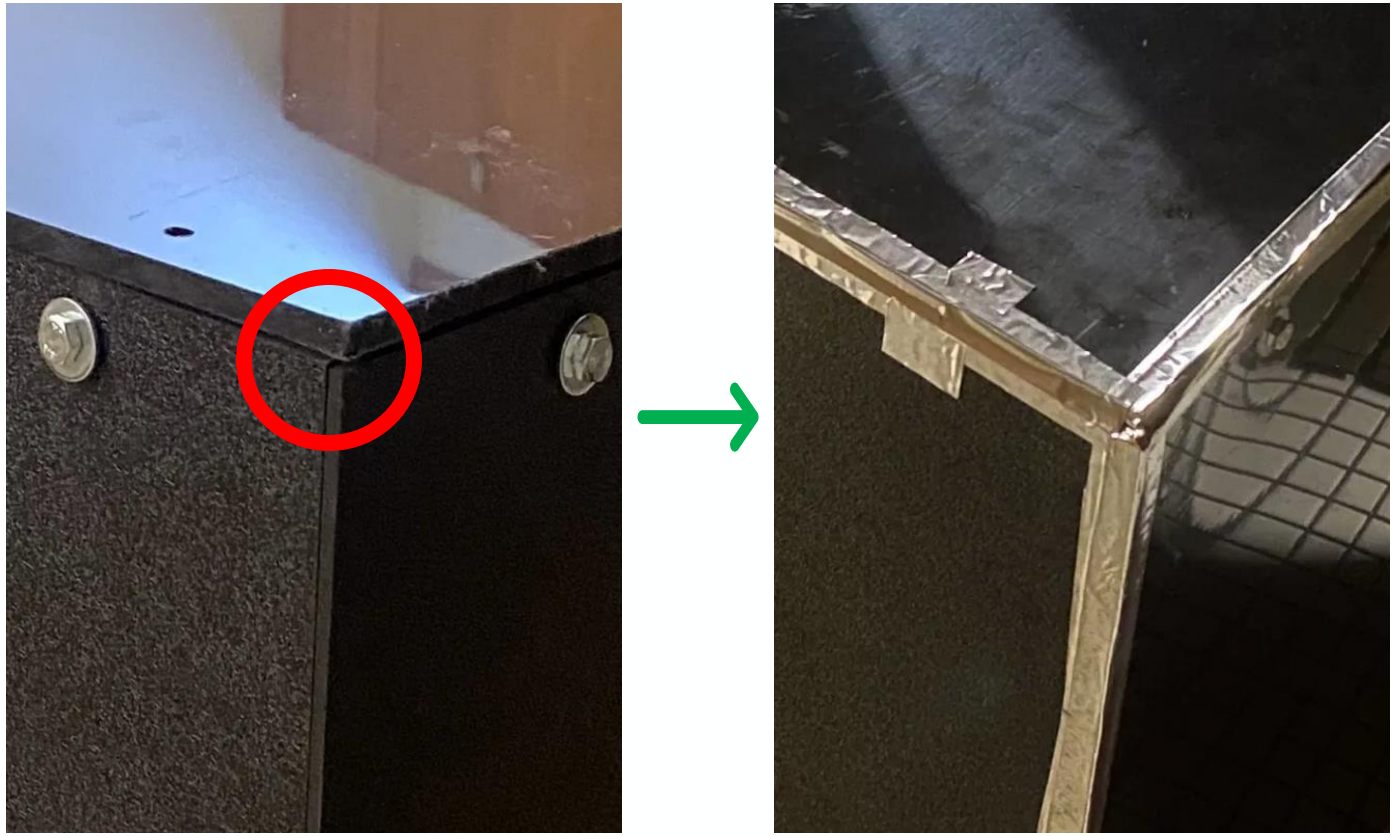
Assembly - Results



Assembly - Changes

Differences from CDR

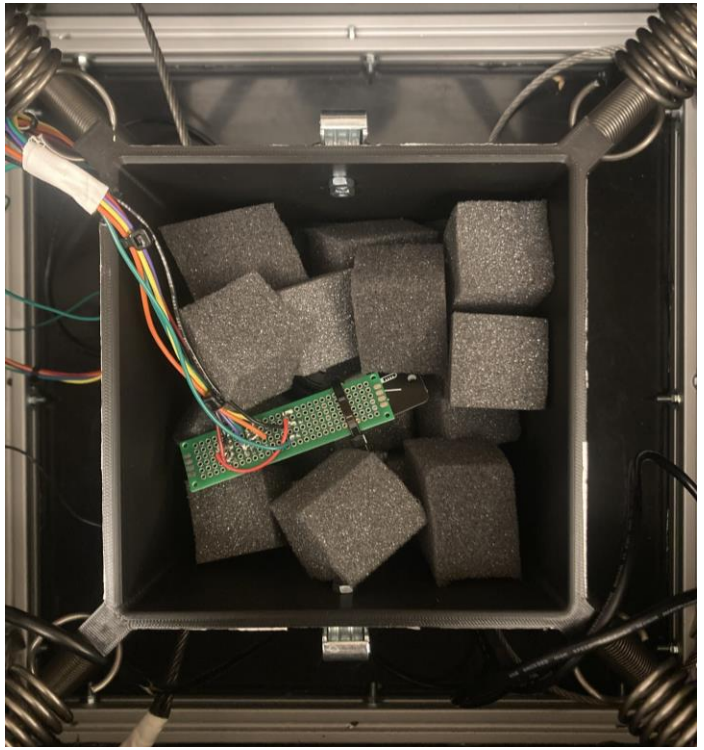
- Panel gaps observed during assembly
  - Epoxy didn’t fully seal
- Edges taped with adhesive foil
  - Air barrier & water proofing
- Wire Rope Orientation
  - Loop shape to X formation
- Electronics Wiring
  - SPI Daisy Chain -> Iterate using code
  - Logic stepper



Electronics & Sensing

Wiring and Improvements

- Two sets of accelerometers and temp/humidity sensors write data to SD card
- 3 Protoboards soldered for tracking
  - Main housing had Arduino Micro, SD Card, and Logic Stepper
  - Each measurement apparatus held a DHT22 temperature and humidity sensor and a ADXL373 accelerometer using SPI communication
- Soldered connections improved data acquisition
- Improved wire quality which enhanced reliability

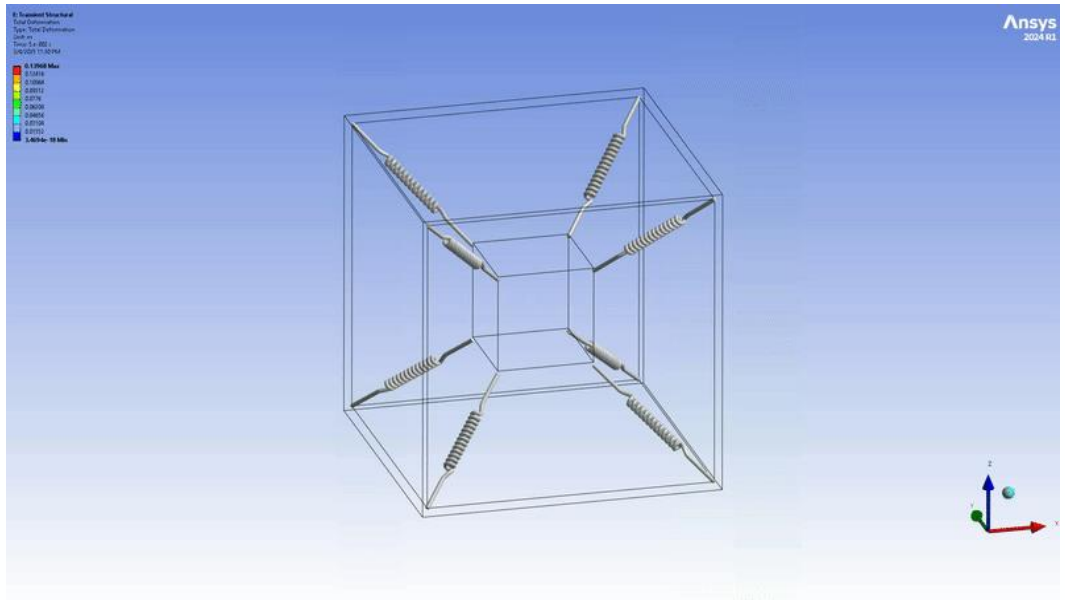


Electronics Potential Improvements

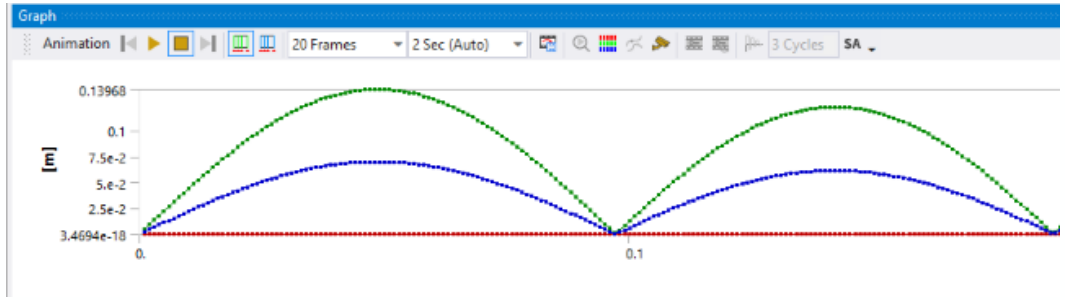
- Address acceleration data noise
  - PCB to ensure high-quality connections
- Improve data storage capacity
  - Test and implement accelerometer "wake up" mode to save data storage space
  - Increase storage size
- Improve ease of recharging for batteries
  - Charging from wall outlet

Shock Analysis

- ANSYS Transient Structural
- Simulates conditions of worst case 1 m drop
  - Input 4.43 m/s velocity
- Max displacement = 5.5 inches
- Meets max acceleration requirement (15 g)



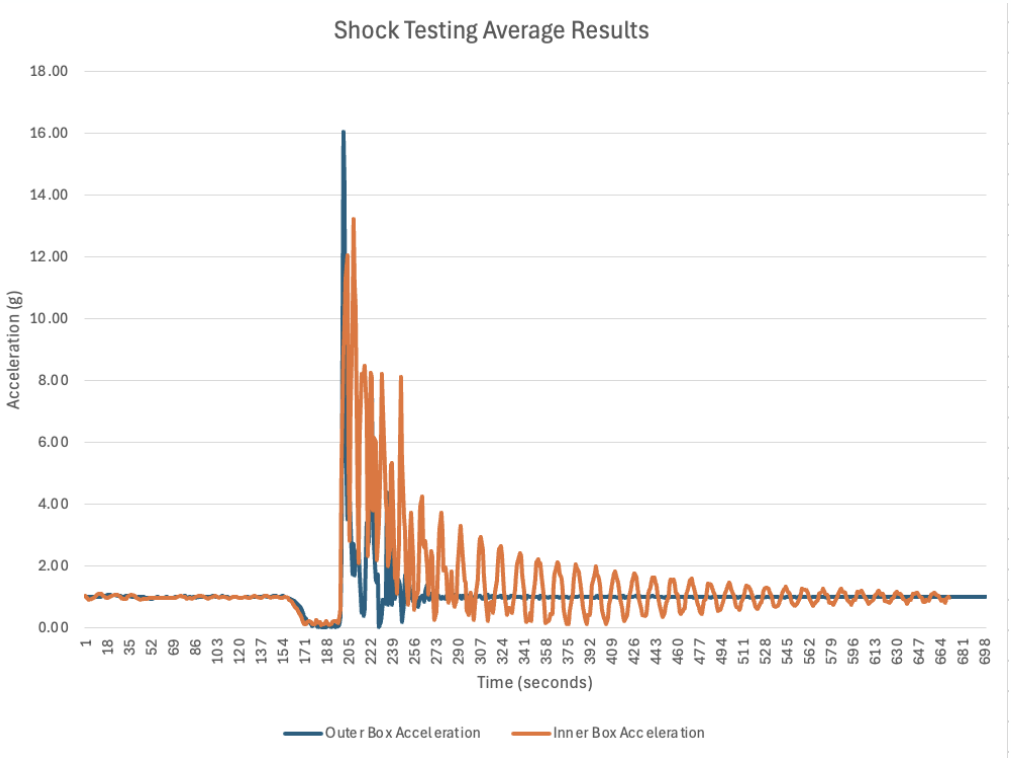
- Used this result to drive spring selection
  - Minimum 500 N/m Spring
  - Dampers needed to stop vibration
    - Wire Rope



Validation Testing

Shock Testing

- Conducted 5 trials of 1 meter drop test
- Maximum acceleration of the outer box is 16.2 g
- Maximum acceleration of the inner box is 13.1 g
- Nearly a 97.38% decrease in loading based on calculated g-force
- **Meets requirement** of reducing shock to below 15 g



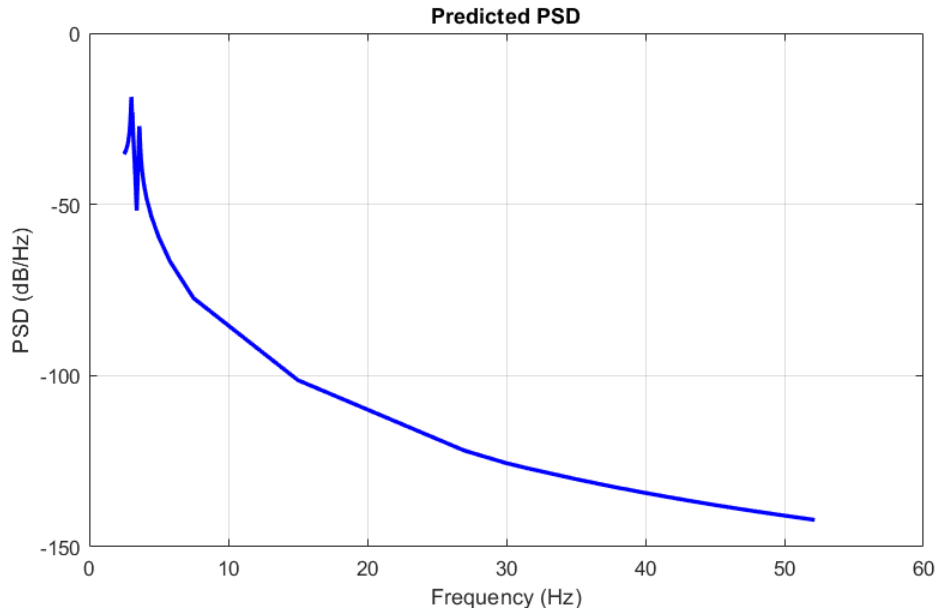
$$a = \frac{v^2}{2s} = \frac{(4.43)^2}{2 \times 0.002} = \frac{19.6}{0.004} = 4,900\,\mathrm{m/s^2}$$

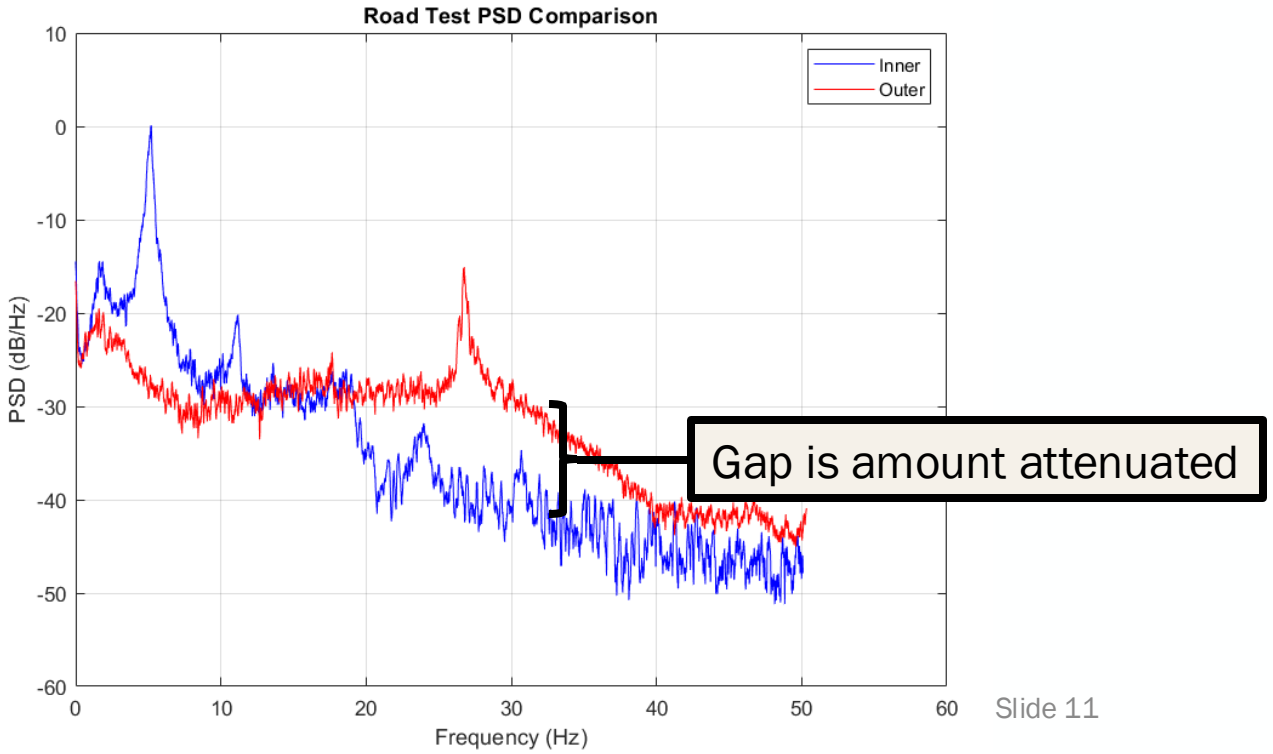
$$\text{G-force} = \frac{4,900}{9.81} \approx \boxed{500\,g}$$

Validation Testing

Vibration Testing

- 15-minute drive in car
- Shape of PSD is as predicted in the CDR
- Peak at 5 Hz instead of 3 Hz
- Attenuation starting at 10 Hz
  - 5 – 15 dB attenuation past 20 Hz
    - Meets 3 dB requirements
  - Inner box power is 3% to 31% of environment
    - Average of 10%

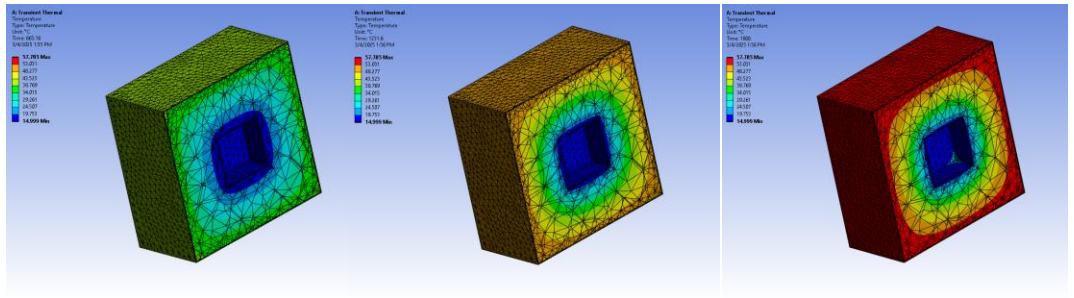


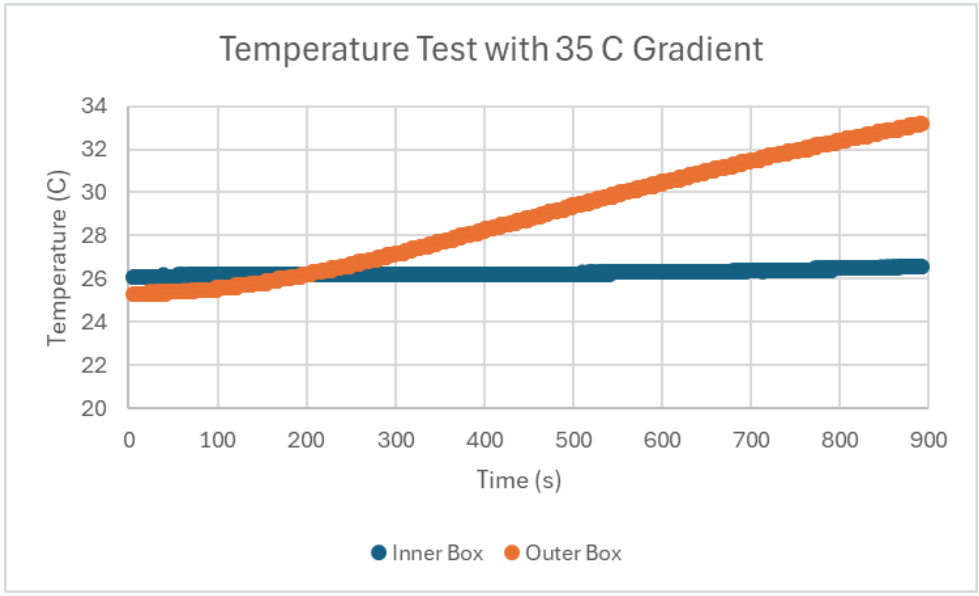


Validation Testing

Thermal Performance

- Box subjected to a 35° C temperature gradient in a sauna
- Inner box experienced 0.5° C increase from 26.1 to 26.6 in 15 minutes
  - 0.033° C/min
  - Estimated 0.042 °C/min at 45° C gradient
- Meets 0.5° C/min requirement
- Outer Box increased 7.9° C

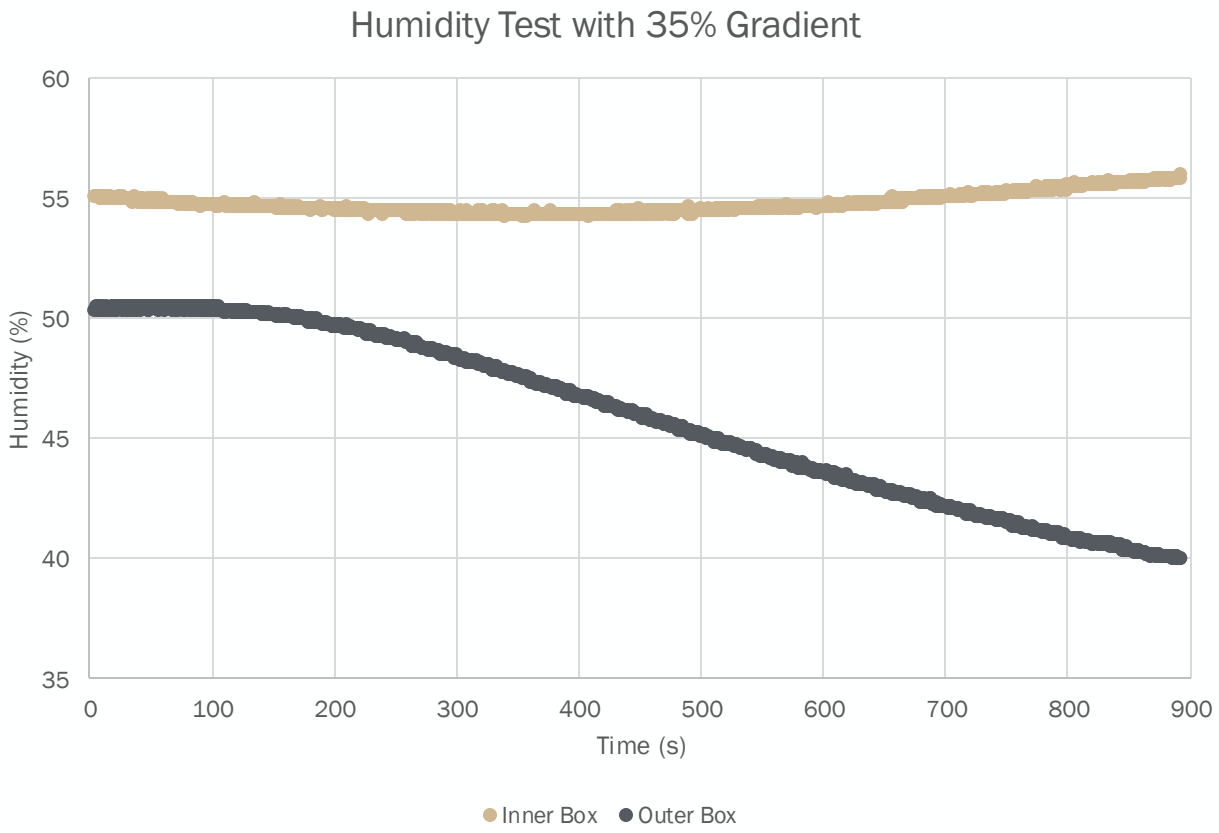




Humidity Testing

- Box subjected to a 35% humidity difference
  - Sauna less humid than ambient
- Inner box experienced extremely steady humidity
- Outer Box decreased by 10%
  - Absolute humidity stayed the same

- Unable to perform original waterproof testing due to poor alignment caused by insufficient rivet installation



Requirements & Results Recap

Shock:

Requirement: < 15 g with 1 meter drop

Result: 13.1 g ☑

Vibrations: 3 dB attenuation above 10 Hz

Result: Negligible attenuation from 10 – 20 Hz ☒

5 – 15 dB attenuation above 20 Hz ☑

Thermal:

Requirement: 0.5° C/min when subject to a 45° C temperature gradient

Result: 0.042° C/min ☑

Humidity:

Requirement: Humidity does not change when sprayed by water

Result: No change with 35% humidity gradient ☑

Business Proposition

Renting Safe Send

- Safe Send will rent units out
- Assumptions:
  - Each device used 40 times a year
    - Every 9 days
  - 4405 devices in circulation
  - $135.87 to make; $598,507 upfront cost
- Revenue:
  - Rent for $15 a day
  - $15.86 million annual revenue
- Impact:
  - Protects delicate components
  - Relaxes design requirements

Sector	Annual Shipments	0.01% precision shipments	5% Market Share
MEMS Devices	34 Billion	3,400,000	170,000
Semiconductor	1.15 Billion	115,000	5,750
Medical Device	85 Million	8,500	425

Design Improvements

Frame

- Injection molded foamed ABS frame
  - Fixes bolt alignment
  - New box is 18.5 lbs
- Handles

Vibrations

- Foam/rubber mounts for springs and dampers

Electronics

- Rechargeable battery
- Increased data storage
- Reduce data noise
- App for tracking

Thank You!

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Backup – Cost Estimate

Sample Injection Molding Cost – Main Body

Injection Molded Body:

Material Cost: 7741.92 cm3 x 1.05 g/cm3 x 0.00293 $/g = $23.81

Projected Area: 2580.64 cm2

Runner %: 5%

Shot area: 2709.67 cm2

Injection Pressure: 500 bar

8500 kN machine used

Cycle time

T = 70 s

Mold Point System:

Base cost = 50 + 0.023A*h0.4 = 150 hours

Ejection hours 2.5*A0.5 = 30 hours

Geometric complexity: 30 surface patches, 15 hours

10% increase for not critical finish, 2% for tolerance

Mold Cost = 218.4 hours = $8736

Total Cost = (Nt/n)(k1+m1F)t + C1n0.766 + NtCm

Cost = $27.70 per part

Final Cost Estimate

Component	Average Unit Cost (USD)
Microcontroller (Arduino-equivalent)	$2.00
Accelerometer (high sample rate)	$1.75
Humidity + Temp sensor	$1.25
Battery	$2.00
PCB Fabrication (2-layer)	$1.50
Assembly + Passives	$3.00
Firmware flashing + Testing	$1.50
Overhead/Buffer	$1.50
Total per unit	**$11.50**

Bought in bulk for 4500 units

Springs: $0.75 per spring = $6

Wire Rope: $4.50 for 10 feet

Rubber Gasket: $14

Fasteners: $3

Injection Molded Costs:

Body: $27.70

Lid: $7.97

Inner Box: $6.55

Assembly time: 60 minutes = $30

Total Cost (with 20% fudge factor) = $135.87 per unit

Eng requirements

Engineering Requirements	Metric	Units
Thermal Insulation		
Designed for range of outdoor temperatures	-29 to 57	Celsius
Inside shall be below a temperature change of less than 0.5 C/min given a temperature gradient of 45 C	0.5	C/min
Shock		
The package shall resist shock from 1 meter flat and corner drop test, limiting package acceleration to 15 g's.	15	g
Vibrations		
Natural frequencies of fragile components are attenuated >100 Hz	-3	dB
Natural frequencies of shock/vibration isolation system are attenuated ~10 Hz	-3	dB
Environment		
Package shall withstand water up to 0.5m for 30 minutes	0.5	m
Avoid using materials that could produce particulate	n/a	n/a
Tracking		
Product shall track any vibrational and thermal disturbances throughout the whole shipping duration	3	days
Customer Requirements		