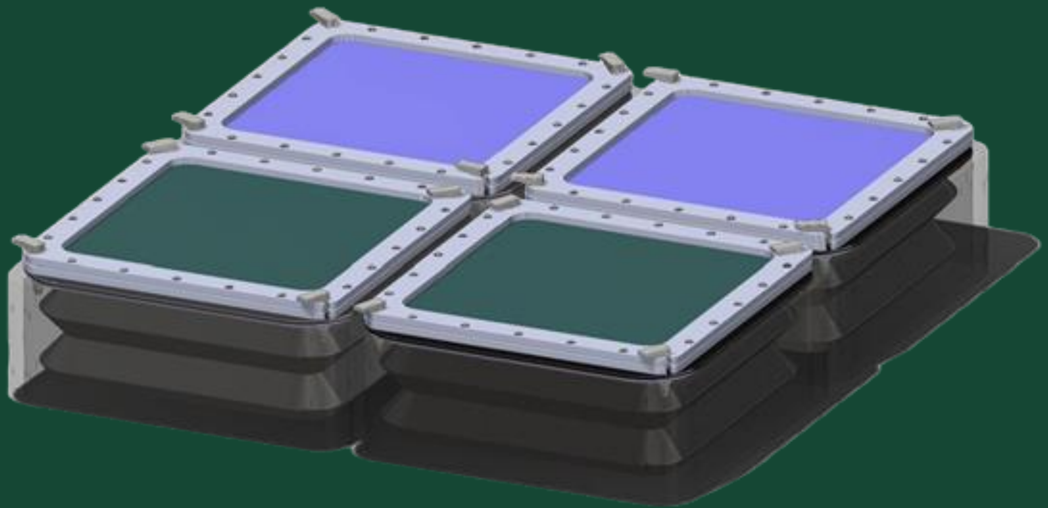
MASS

Modular **A**coustic **S**uppression **S**ystem



Student Team: Julia Megargle, Gabriel Choi, Jonathan Corvera, Lucas Kaemmerer, Michael Milner, Emmi Cayer

Advisors: Dr. John Chen, Rick Lasko

LEARN BY DOING

NASA

HuLC HUMAN LANDER CHALLENGE

Problem Statement

Current acoustic environments (ISS) can exceed noise limits and create risk to the crew

The Challenge

Acoustic standards exist to:
- Prevent hearing loss
- Maintain communications
- Support crew performance [1]

ISS Monitoring Results

ISS acoustic monitoring has identified locations and operating conditions that exceed NASA noise requirements. [2]

Crew Exposure

41% of crew dosimetry measurements have exceeded NASA noise exposure limits since 2008. [3]

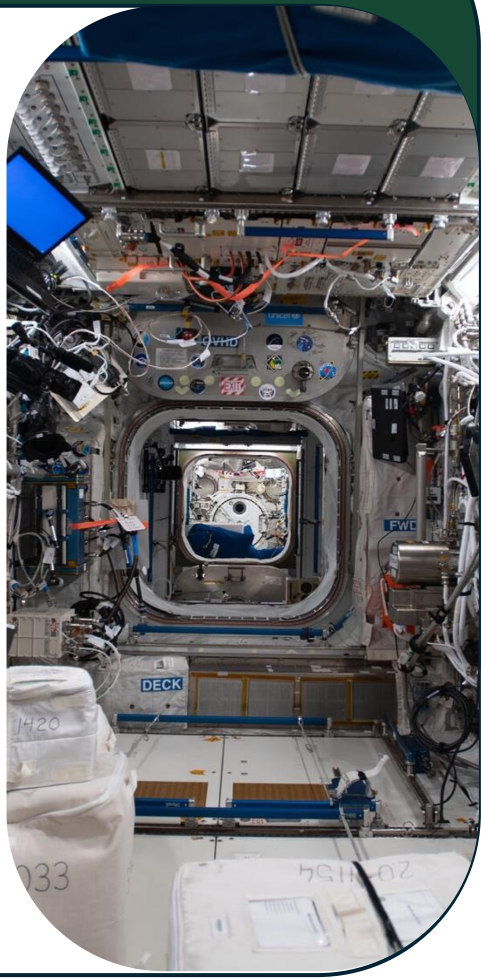
Impacts on Crew

Communication
- Degraded vocal communication
- Reduced ability to hear critical audio cues

Performance
- Reduced concentration
- Reduced productivity

Habitability
- Sleep disruption
- Reduced crew comfort

Health
- Temporary or permanent hearing loss [1]
- Irritation and headaches [6]



Objectives

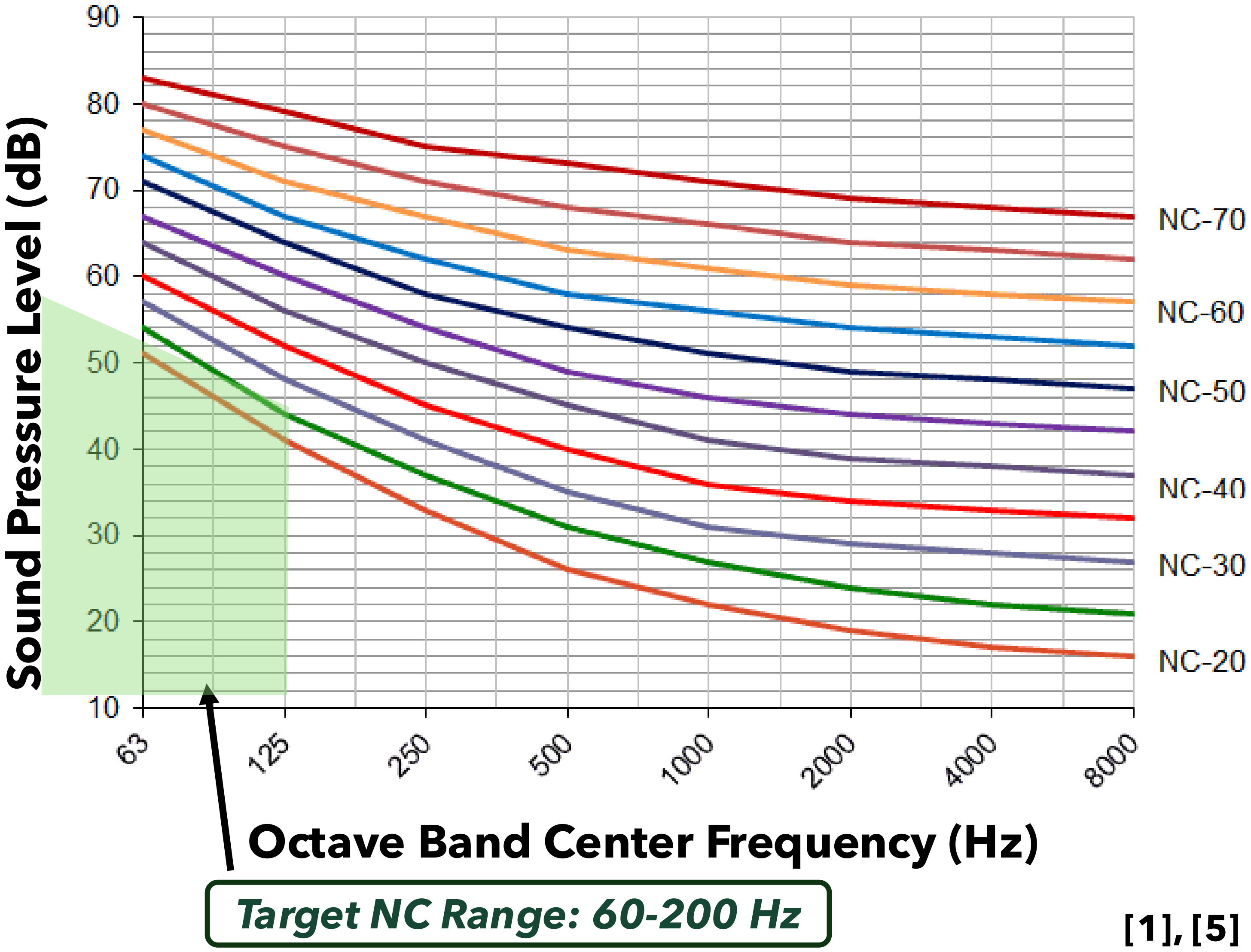
Meet NC-40
Meet NASA NC-40 acoustic requirements

Suppress Dominant ECLSS Frequencies
Range of 60-200 Hz

Maintain Low Power
Maintain power consumption below 1.5 kW

Minimize Mass & Volume
Remain below 100 lb system mass and fit within limited cabin volume

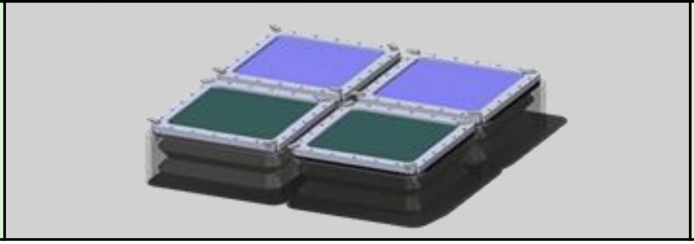
Noise Criteria (NC)



[1], [5]

Existing Solutions

Current acoustic treatments are generally passive, bulky, and not optimized for adaptive low-frequency suppression.

Solution	Visual Example	Adaptive Response	Compact	Addresses Low Frequency
Acoustic Blankets		✗		✗
Acoustic Panels		✗	✗	✗
Vibration Isolators				✗
MASS		✓	✓	✓

[1], [4]

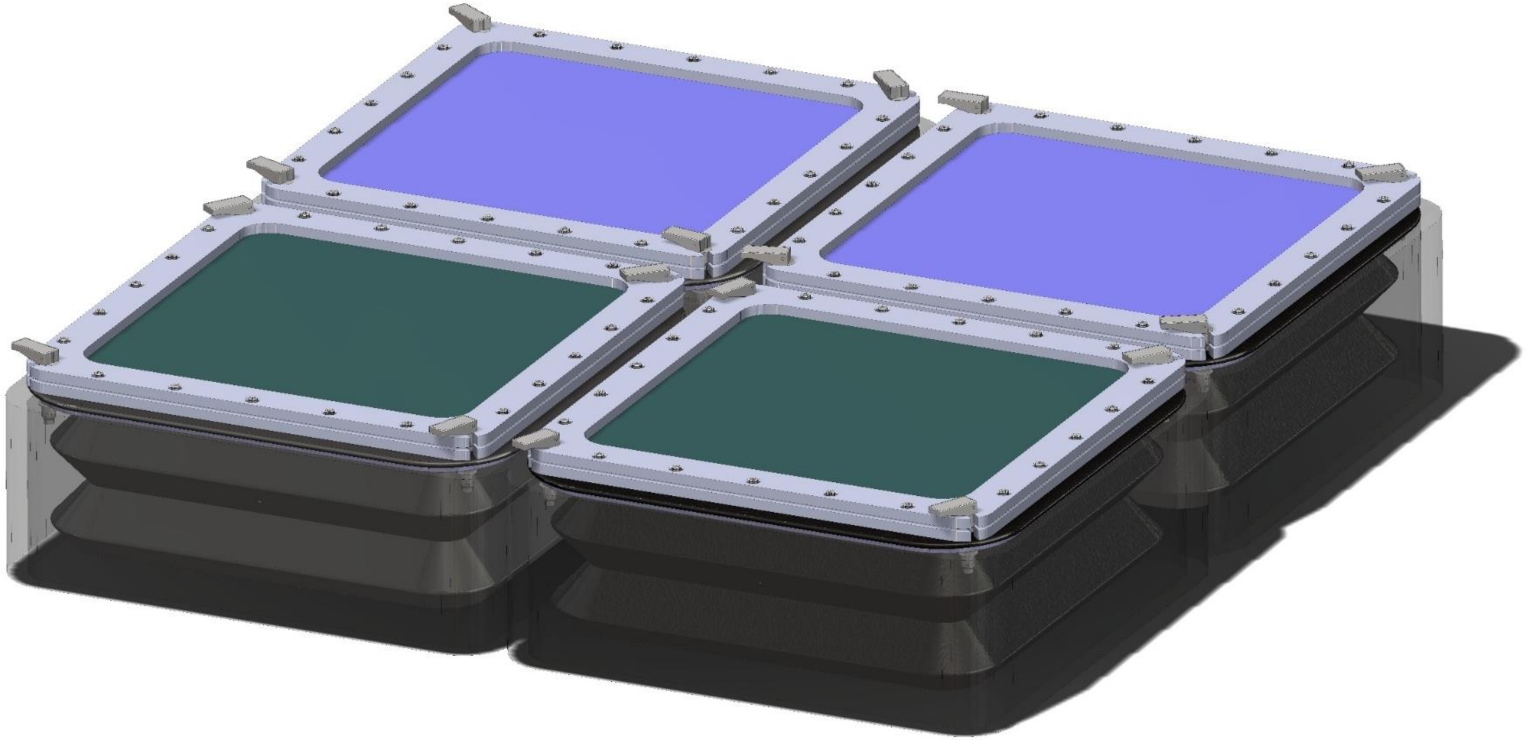
MASS Overview

Adaptive tuned membrane absorber for low-frequency ECLSS noise

60-200 Hz
Targets the dominant ECLSS noise band

Adaptive
Automatically retunes to changing frequencies

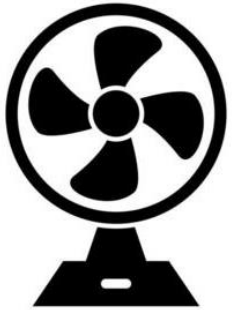
Modular
Scalable panel architecture for flexible integration



[4]

How MASS Works

1 Noise Source



ECLSS equipment produces acoustic noise within the cabin

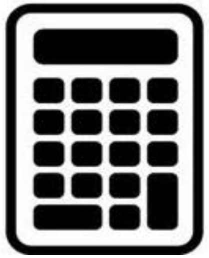
2 Microphone

Microphone sensors detect acoustic noise

3 Frequency Detection

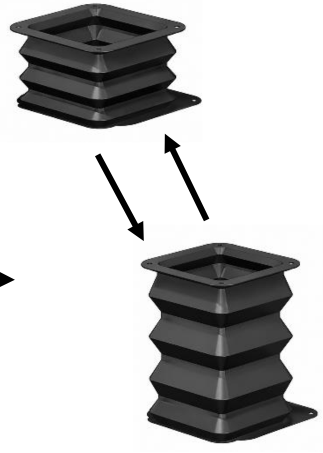
Signal processing identifies dominant frequencies

4 Depth Calculation



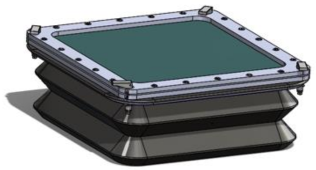
Controller calculates required cavity depth

5 Actuator Motion



Actuators move the mounting plate to required cavity depth

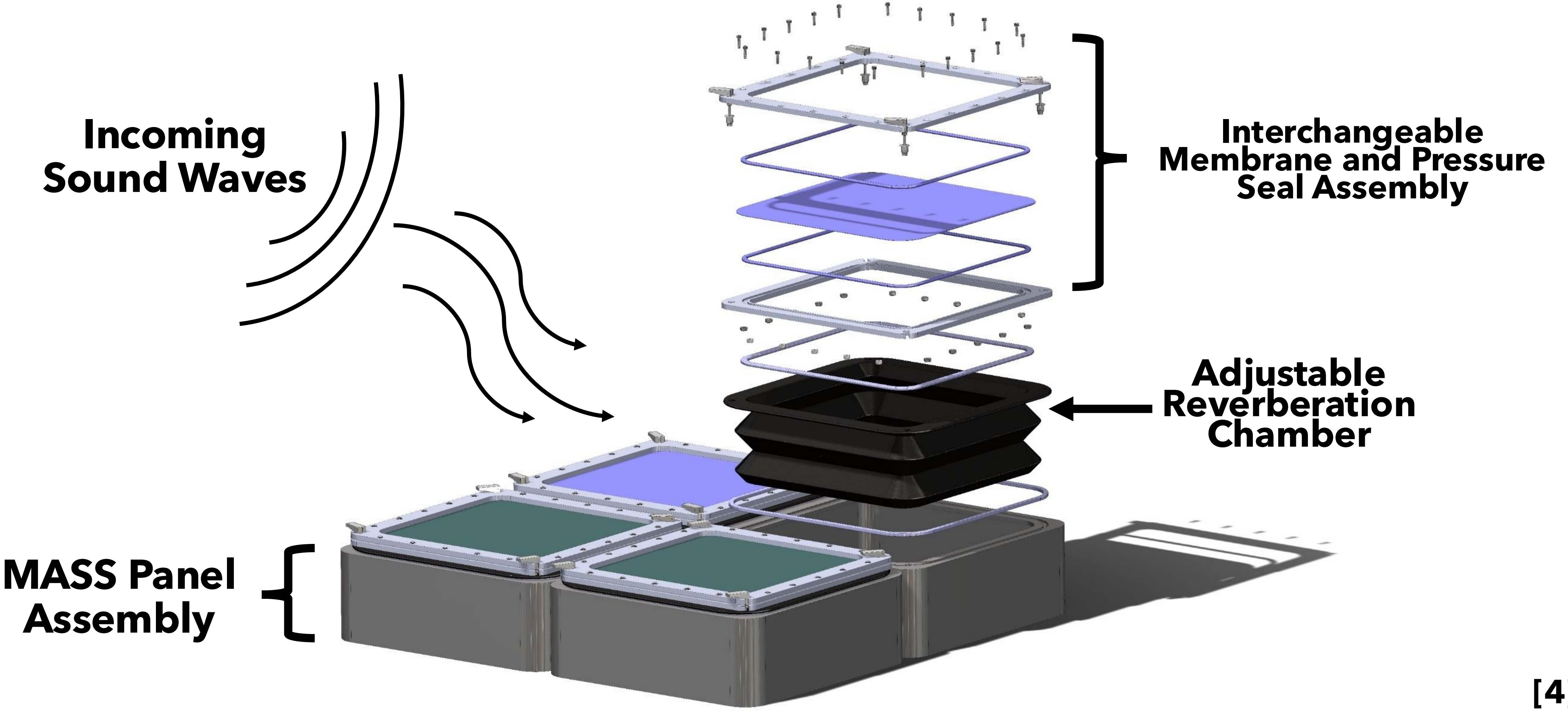
6 Noise Suppression



Coupled membrane-cavity system resonates, dissipating acoustic energy

[4]

MASS System - Components



[4], [7]

Membrane Absorber Model

Mass behaves like a spring-mass system where cavity depth controls the tuned frequency.

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{\gamma P_0}{m_s d}}$$

Key parameters:
m_s - membrane surface density
d - cavity depth

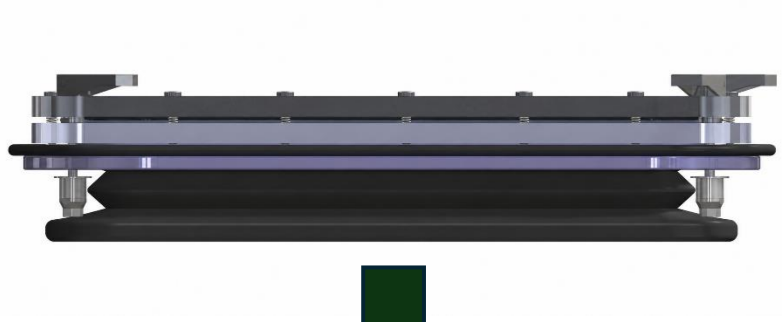
LARGER CAVITY DEPTH

Greater Depth

LOWER FREQUENCY

60 Hz

SMALLER CAVITY DEPTH



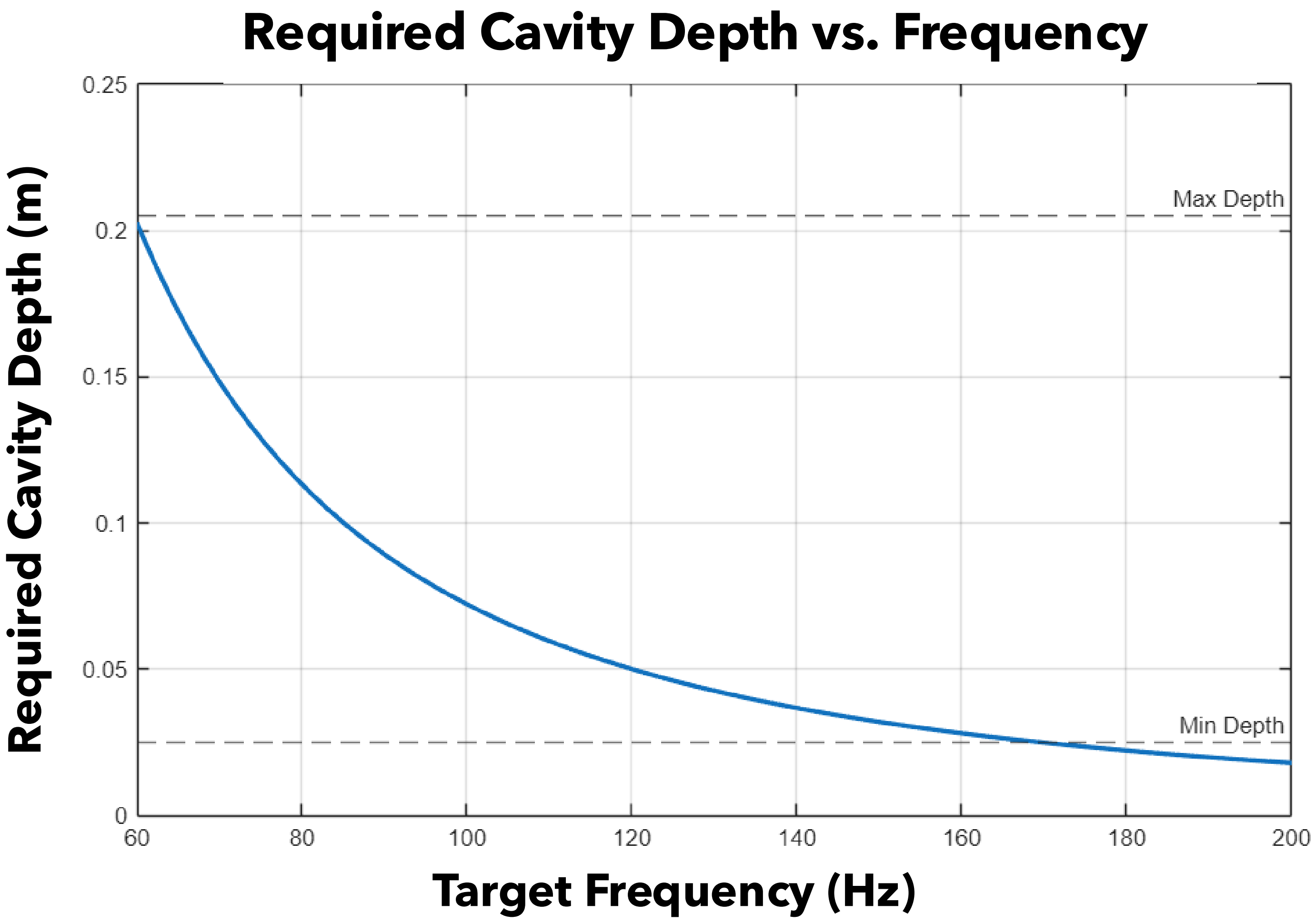
Less Depth

HIGHER FREQUENCY

200 Hz

[4]

Validation – Theoretical Analysis



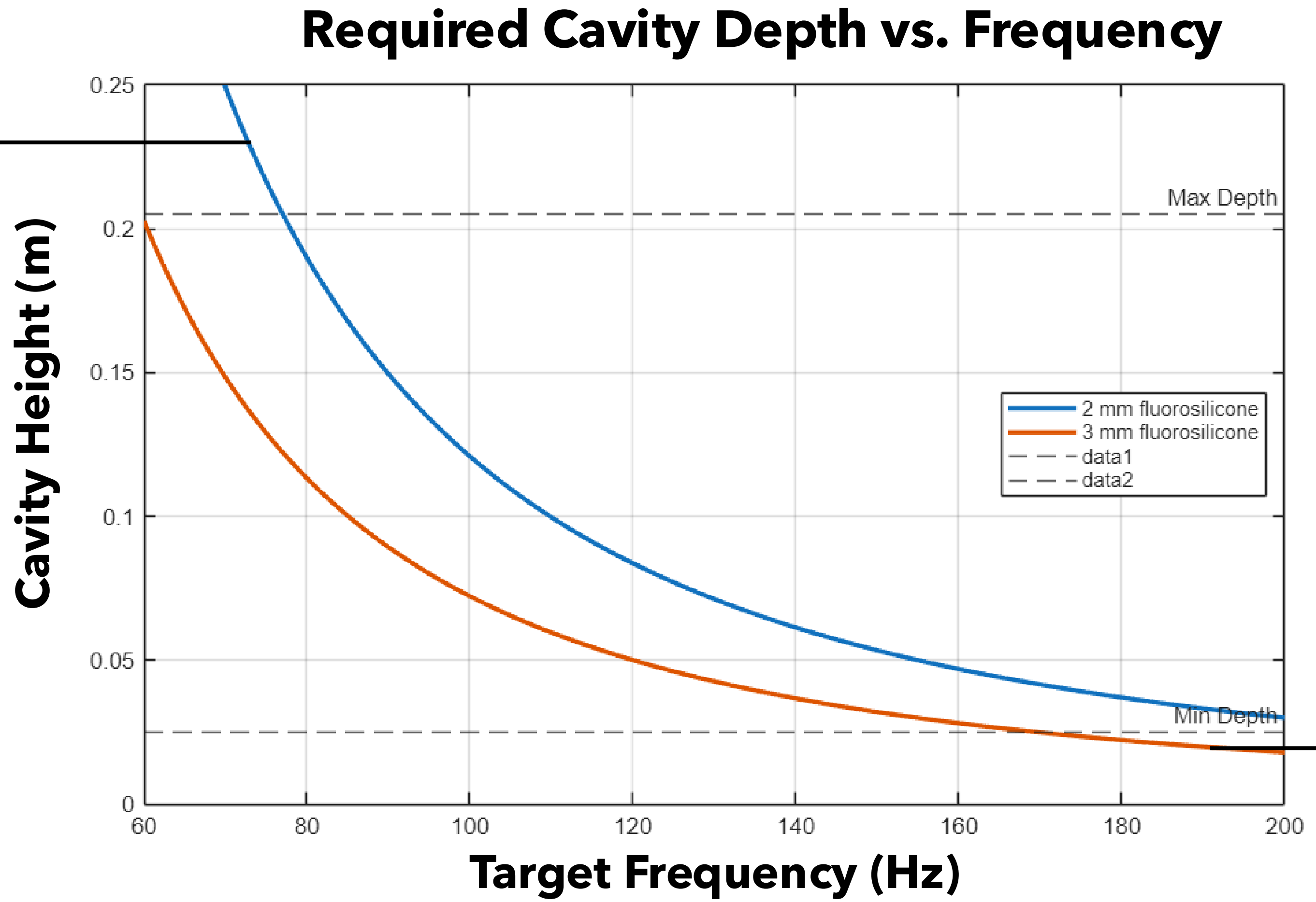
3 mm fluorosilicone suppresses 60–170 Hz.

[4]

Validation – Full Frequency Coverage

2 mm membrane

→ 76–200 Hz



3 mm membrane

→ 60–170 Hz

Together: Covers entire target range of 63-200 Hz

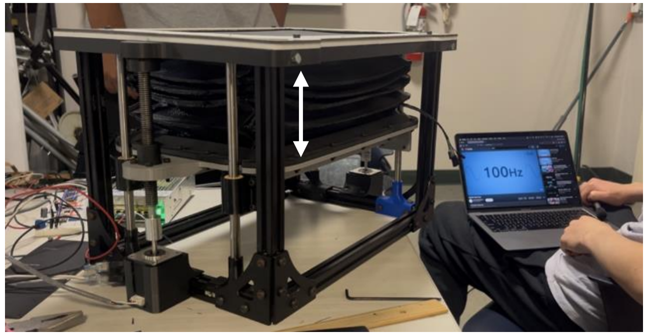
[4]

Validation – Feasibility Prototype

Prototype testing verified core functionality, pressure equalization, and structural feasibility of MASS

1. AUTOMATIC TUNING

Actuators tuned cavity depth to target frequencies

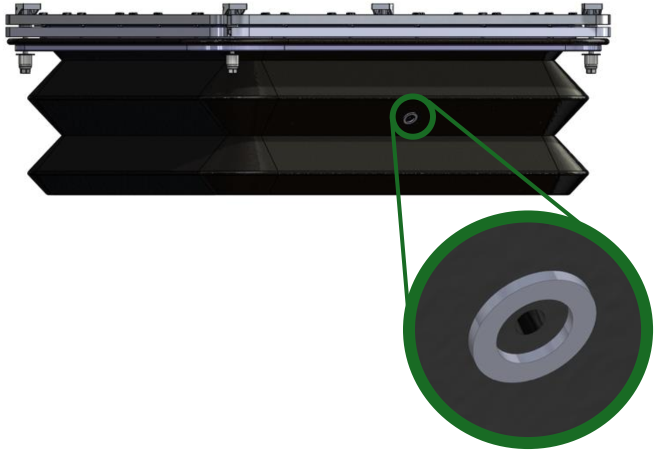


60-250 Hz

Automatic tuning verified

2. PRESSURE EQUALIZATION

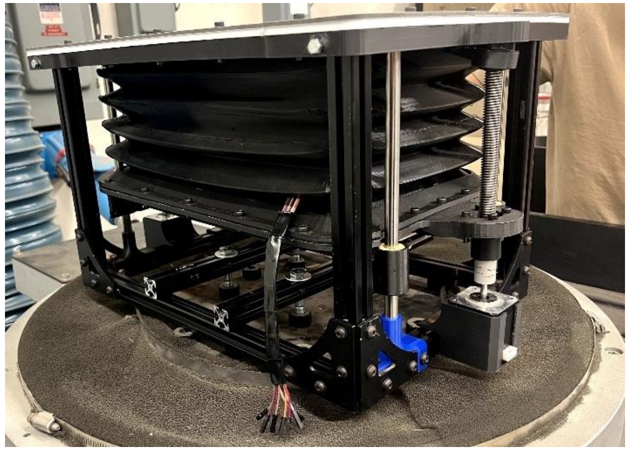
Internal pressure equalized through 13mm aperture



4.49 sec

Average equalization time

3. STRUCTURAL VERIFICATION



10.3 g RMS

Random vibration profile survived

NASA Integration Requirements

FREQUENCY RANGE	POWER CONSUMPTION	SYSTEM MASS	MAXIMUM DEPTH
Target 60-200 Hz	**Target** < 1.5 kW	**Target** <100 lb	**Target** Minimize cabin intrusion
MASS Value 60-200 Hz	**MASS Value** 1.36kW	**MASS Value** ~83.5 lb	**MASS Value** ~8 in
MET	**MET**	**MET**	**MET**

Mass meets all primary constrains for adoption on the Artemis Human Lander.

[5], [6]

Top Risks & Mitigations

Risk	Consequence	Mitigation
High Pressure Differential	**Incorrect Tuning Frequency**	• 13 mm pressure equalization aperture • Validated sealing behavior during chamber adjustment
Electrical System Failure	**Loss of Adaptive Capability**	• Space-rated wiring and components • Fail-safe mode holds chamber at default ECLSS frequency
Actuator Position Error	**Incorrect Cavity Depth**	• Position feedback from actuators • Calibration checks Software travel limits

Key risks have been identified, and mitigation strategies have been incorporated into the MASS design

[4]

Budget and Cost Estimate

$5.63M

Total Development Cost

3- year Development Program

30% Contingency Margin Included

Major Cost Driver	Cost
Personnel	$3.78M
Testing & Facilities	$0.25M
Hardware & Fabrication	$0.30M
Cost Margin	$1.30M
Total	**$5.63M**

Key Assumptions

- 10- person engineering team
- 3-year development schedule
- One flight-ready MASS unit
- 30% contingency margin

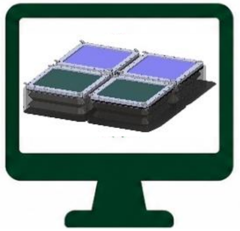
Cost estimate developed using a NASA-style lifecycle approach from prototype development through flight implementation.

[5]

Path to Flight

A phased approach to design, validate, and implement the MASS for Artemis Missions

2026



Design Refinement

- Material Selection
- CAD refinement
- Prototype updates

TRL 3-5

2027

Testing & Validation

- Anechoic chamber insertion-loss testing
- Lander environment validation
- Design iteration

TRL 6-7

2028

Fabrication

- Final manufacturing
- System Integration

TRL 8

2029

Implementation

- Multi-panel MASS deployment
- Artemis ECLSS integration

TRL 9

[5]

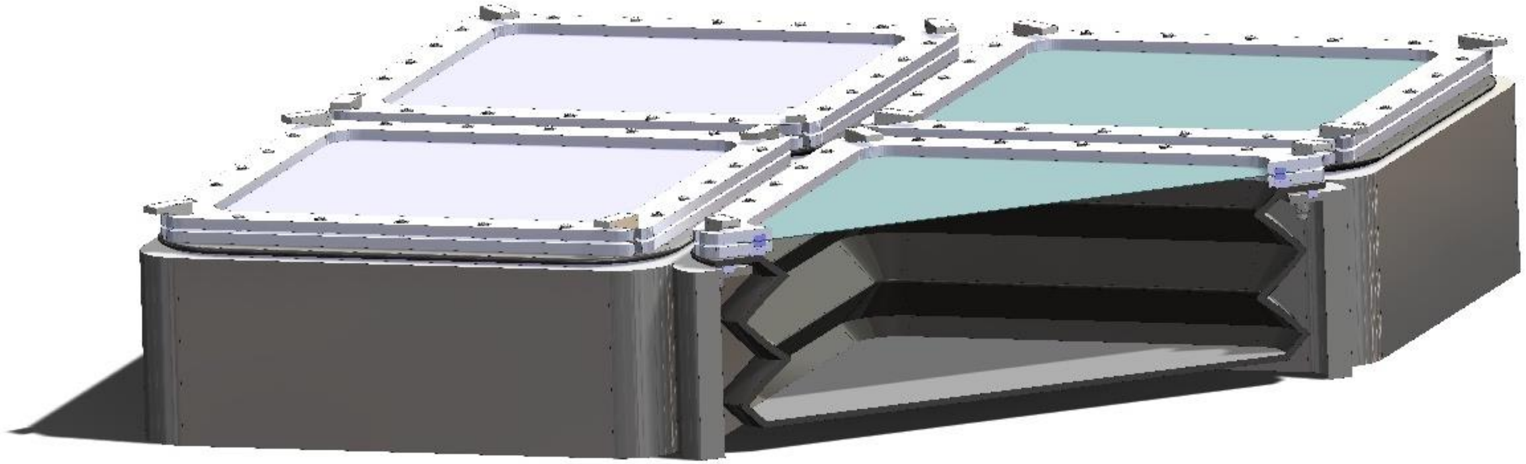
Why MASS Matters

PROBLEM

Current acoustic treatments are passive and struggle with adaptive low-frequency suppression.

SOLUTION

MASS is an adaptive tuned membrane absorber that automatically adjusts cavity depth to target dominant ECLSS frequencies.



VALUE TO NASA

✓ Improves crew habitability and communication
✓ Reduces disruptive low-frequency ECLSS noise
✓ Meets NASA mass, power, and volume constraints
✓ Prototype feasibility demonstrated
✓ Supports long-duration Artemis missions

References

[1] NASA Office of the Chief Health and Medical Officer (OCHMO), Technical Brief TB-035: Acoustics, 2023.

[2] Limero et al., Internal Acoustics of the International Space Station and Other Spacecraft, NASA, 2017.

[3] Limardo et al., Status — International Space Station (ISS) Crewmembers' Noise Exposures, NASA, 2021.

[4] Zhao et al., Theoretical Model of Membrane Acoustic Absorber with Compact Magnet, JASA, 2021.

[5] NASA Human Lander Challenge Competition Flyer, 2026.

[6] NASA-STD-3001 Volume 2, Human Factors, Habitability, and Environmental Health, 2025.

[7] Fluorosilicone in Aerospace: High Performance Sealing, RD Rubber Technology Corp., 2025.

[8] J. R. Goodman and F. W. Grosveld, NASA/SP-2015-624: Acoustics and Noise Control in Space Crew Compartments, 2015.

[5], [6]

Appendices

Appendix A. Full Membrane Absorber Derivation

When incident sound waves excite the membrane, the membrane behaves like an oscillating mass. The sealed air cavity behind the membrane provides a restoring force due to compression of the trapped air.

Pressure change in the cavity:

$$\Delta P = -\gamma P_0 \frac{\Delta V}{V}$$

where:

γ= ratio of specific heats for air (~1.4)
P_0= ambient pressure
V= cavity volume
ΔV= change in cavity volume

For membrane displacement x over area A:

$$\Delta V = Ax$$

Since cavity volume is:

$$V = Ad$$

where $d$is cavity depth,
substituting gives:

$$\Delta P = -\gamma P_0 \frac{Ax}{Ad}$$

$$\Delta P = -\gamma P_0 \frac{x}{d}$$

This produces an effective acoustic spring constant per unit area:

$$k' = \frac{\gamma P_0}{d}$$

Appendix A. Full Membrane Absorber Derivation Cont.

The membrane surface mass density m_s acts as the oscillating mass per unit area.

The membrane-cavity system therefore behaves as a simple harmonic oscillator:

$$\omega_0 = \sqrt{\frac{k'}{m_s}}$$

Substituting for k':

$$\omega_0 = \sqrt{\frac{\gamma P_0}{m_s d}}$$

Converting angular frequency to frequency in Hz:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{\gamma P_0}{m_s d}}$$

This equation defines the resonance frequency of the membrane absorber.

Rearranging to solve for cavity depth:

$$d = \frac{\gamma P_0}{(2\pi f_0)^2 m_s}$$

This relationship is used by MASS to determine the required cavity depth needed to suppress a measured dominant frequency.

Appendix A. Full Membrane Absorber Derivation Cont.

Key Result:

$$f_0 \propto \frac{1}{\sqrt{d}}$$

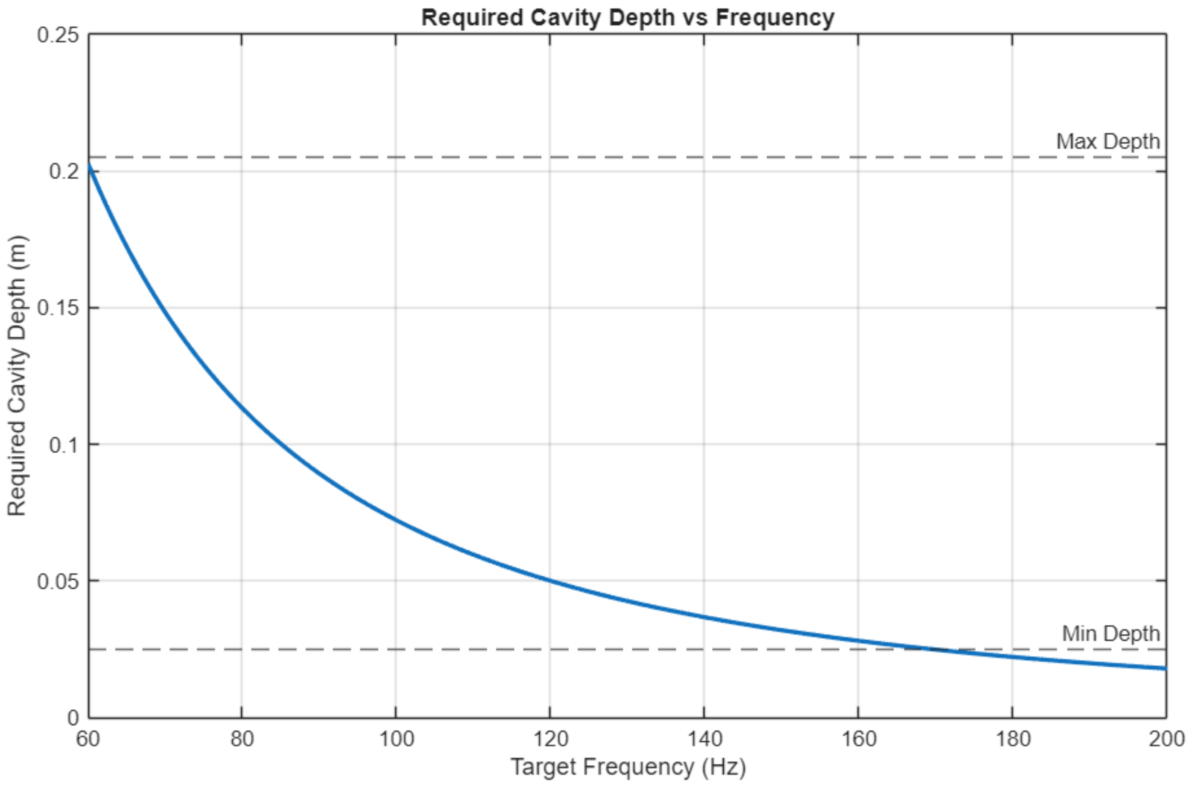
Larger cavity depth → lower frequency suppression

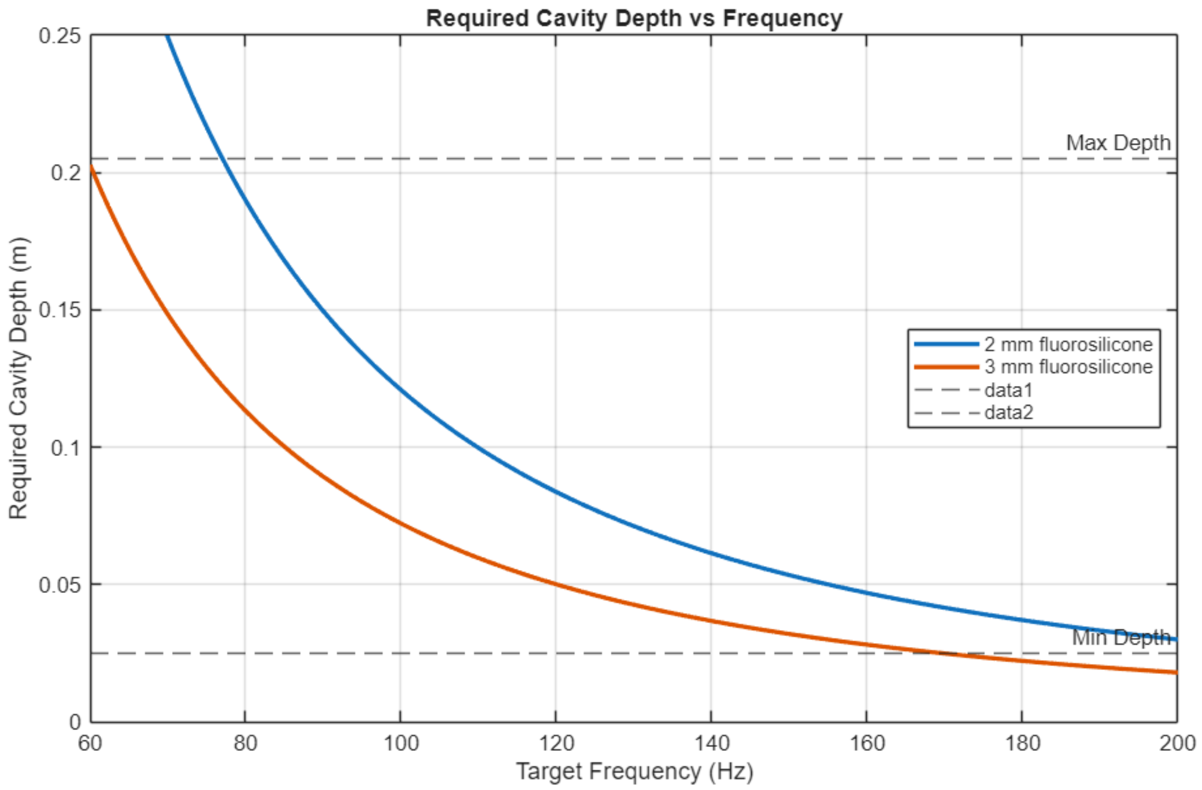
Smaller cavity depth → higher frequency suppression

Therefore, adjusting cavity depth allows MASS to tune its resonance frequency and suppress noise across the target 60–200 Hz range.

$$\boxed{d = \frac{\gamma P_0}{\left(2\pi f_0\right)^2 m_s}}$$

Appendix B. Full Frequency-Depth Plots





Appendix C. Full Pressure Equalization Calculations

To size the pressure equalization aperture, use the orifice flow equation:

$$Q = C_d A \sqrt{\frac{2\Delta P}{\rho}}$$

where:

- Q= volumetric flow rate (m^3/s)
- C_d =discharge coefficient
- A= hole area (m^2)
- ΔP= pressure difference (Pa)
- ρ =air density (kg/m^3)

For a circular hole:

$$A = \frac{\pi d^2}{4}$$

Substitute area into the orifice equation:

$$Q = C_d \left(\frac{\pi d^2}{4}\right) \sqrt{\frac{2\Delta P}{\rho}}$$

Solve for hole diameter:

$$d = \sqrt{\frac{4Q}{\pi C_d \sqrt{2\Delta P/\rho}}}$$

Using the report assumptions:

$$Q = 0.001\, m^3/s$$
$$C_d = 0.6$$
$$\Delta P = 100\, Pa$$
$$\rho = 1.2\, kg/m^3$$

Final result:

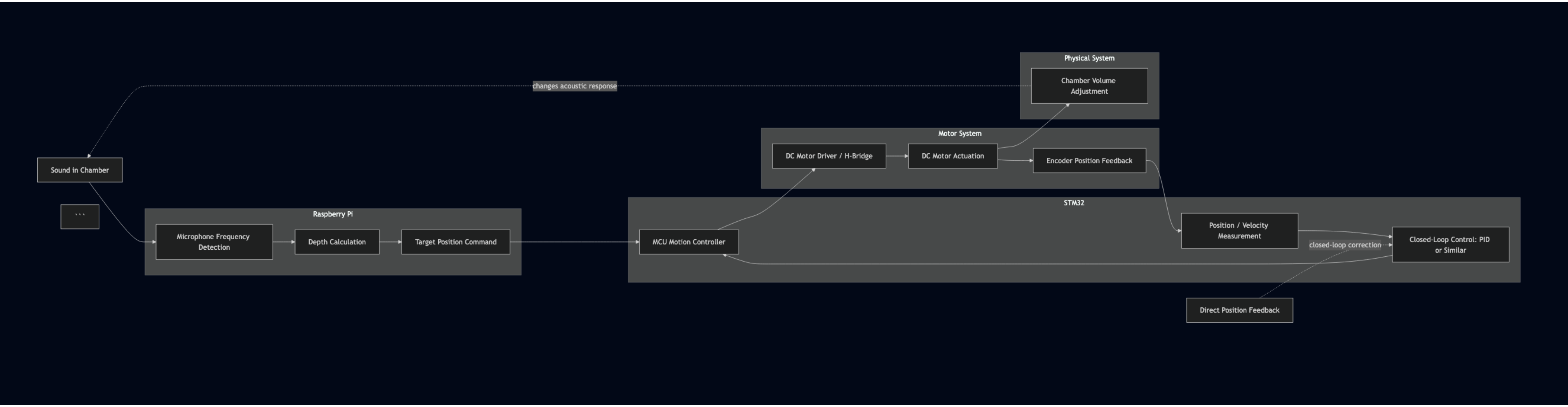
$$d \approx 13\, mm$$

Conclusion: A **13 mm aperture** is sufficient for pressure equalization during chamber adjustment.

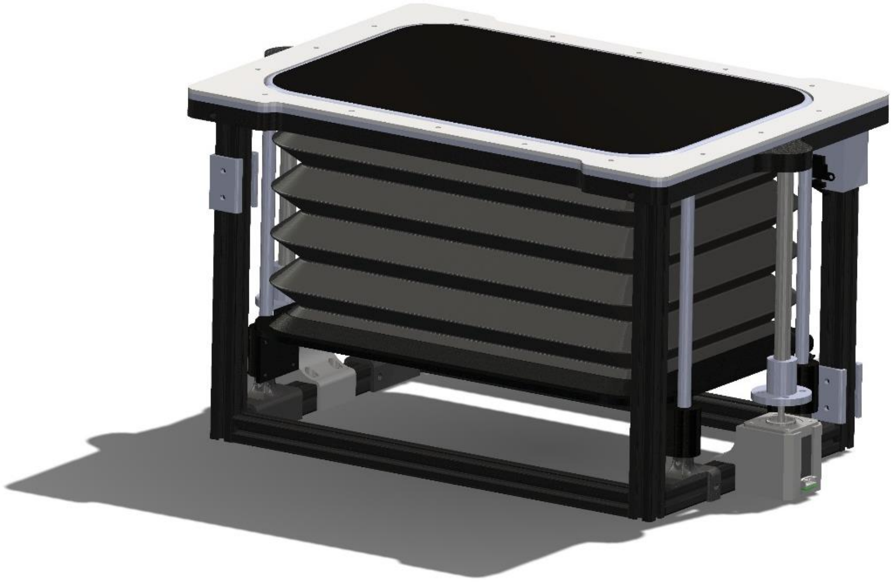
Appendix D. Chamber Pressure Equalization

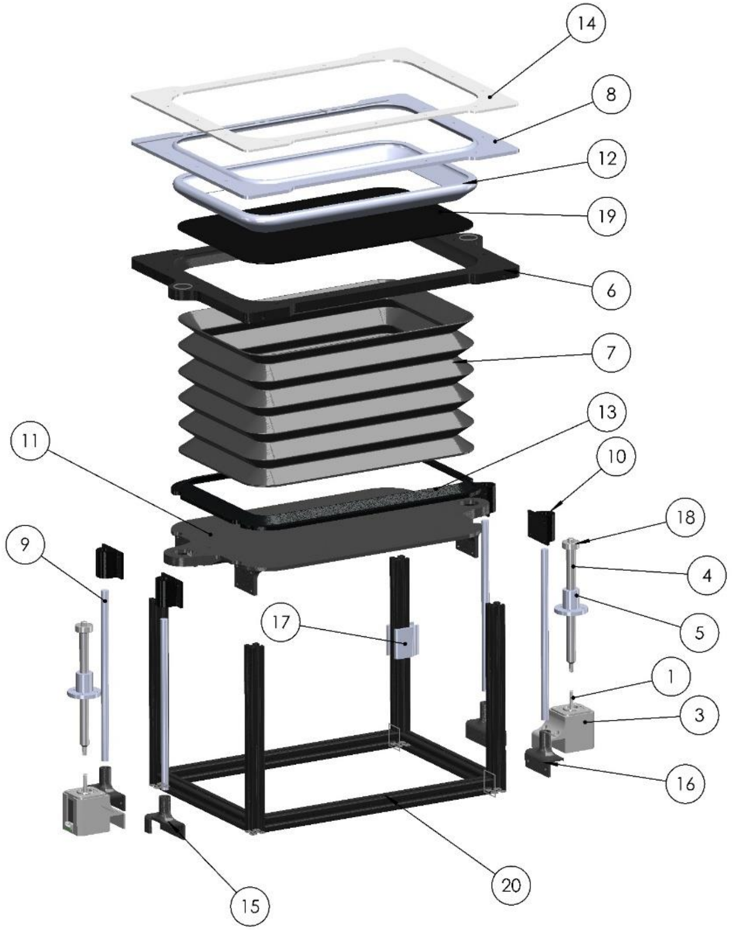
Actuation Distance [in]	Initial Pressure Difference [kPa]	Time To Equalize [seconds]
3	1.1	3.89
3	1	4.86
3	1.2	4.68
3	1.3	5.34
3	1	3.66

Appendix E. Actuation Controls



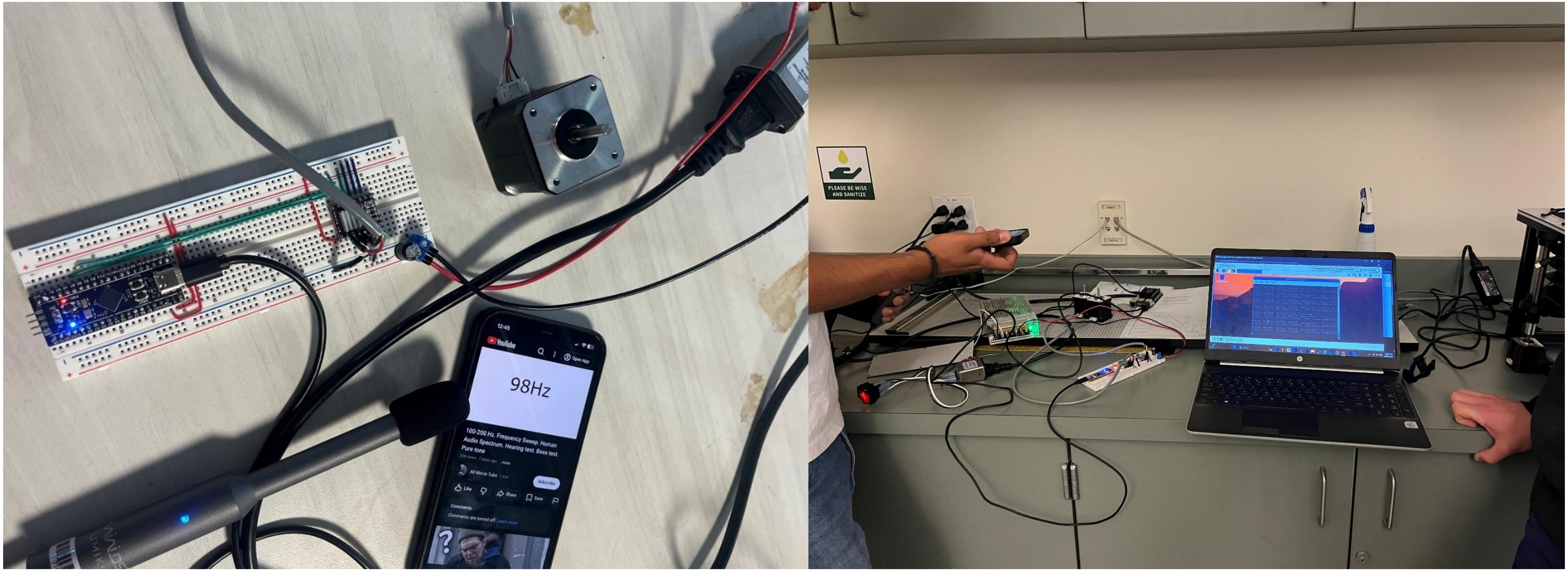
Appendix F. Physical Verification Prototype CAD





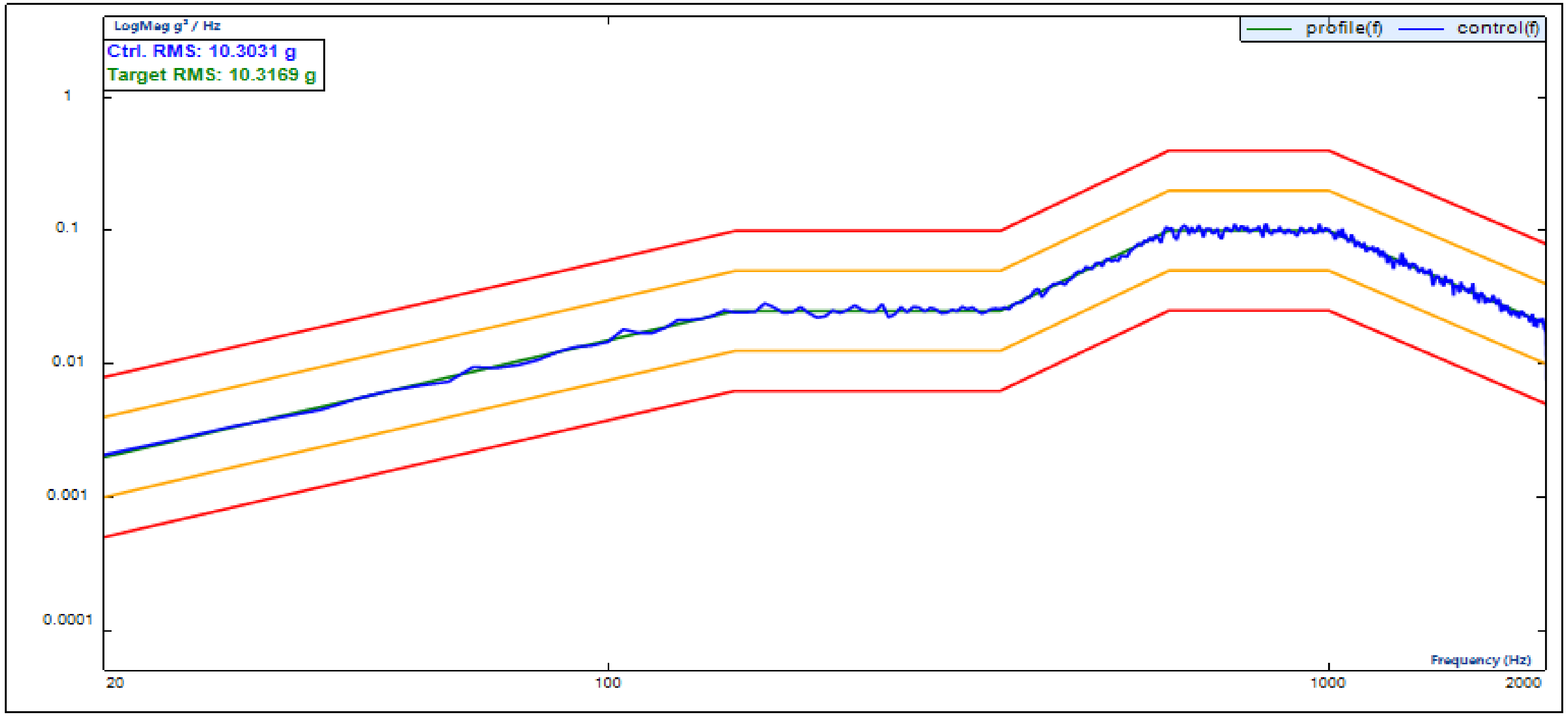
ITEM NO.	PART NUMBER	QTY.
1	STEPPER MOTOR	2
2	ALUMINUM EXTRUSION	6
3	MOTOR MOUNT	2
4	LEAD SCREW	2
5	LEAD SCREW THREADED NUT	2
6	TOP MOUNT PLATE	1
7	ACCORDIAN STRUCTURE	1
8	THIN MOUNTING PLATE	1
9	LINEAR RAIL	4
10	LINEAR RAIL SLIDER	4
11	BOTTOM PLATE	1
12	TPU SEAL	1
13	BOTTOM ACCORDIAN MOUNTING PIECE	1
14	ALUMINUM MOUNTING PLATE	1
15	RIGHT RAIL MOUNT	2
16	LEFT RAIL MOUNT	2
17	MIC MOUNT	1
18	STEEL BALL BEARING	2
19	MEMBRANE	1

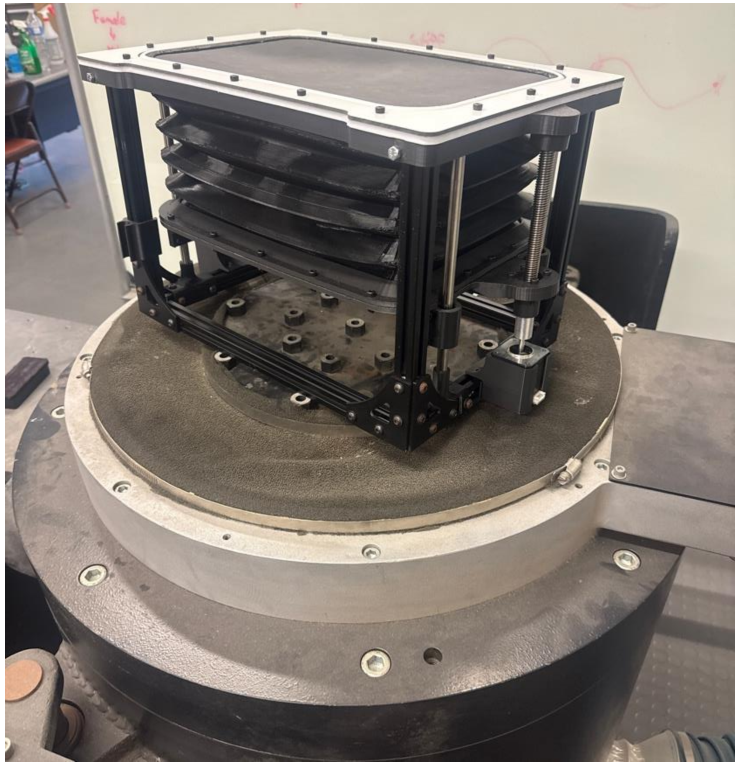
Appendix G. Prototype Testing Photos



Frequency Response Verification

Appendix G. Prototype Testing Photos Cont.





Structural Stability Verification

Appendix H. Full Risk Matrix

Probability	Consequence 1	Consequence 2	Consequence 3	Consequence 4	Consequence 5
5					
4			8	3	
3			7		2,4,5
2			9		1,6
1					

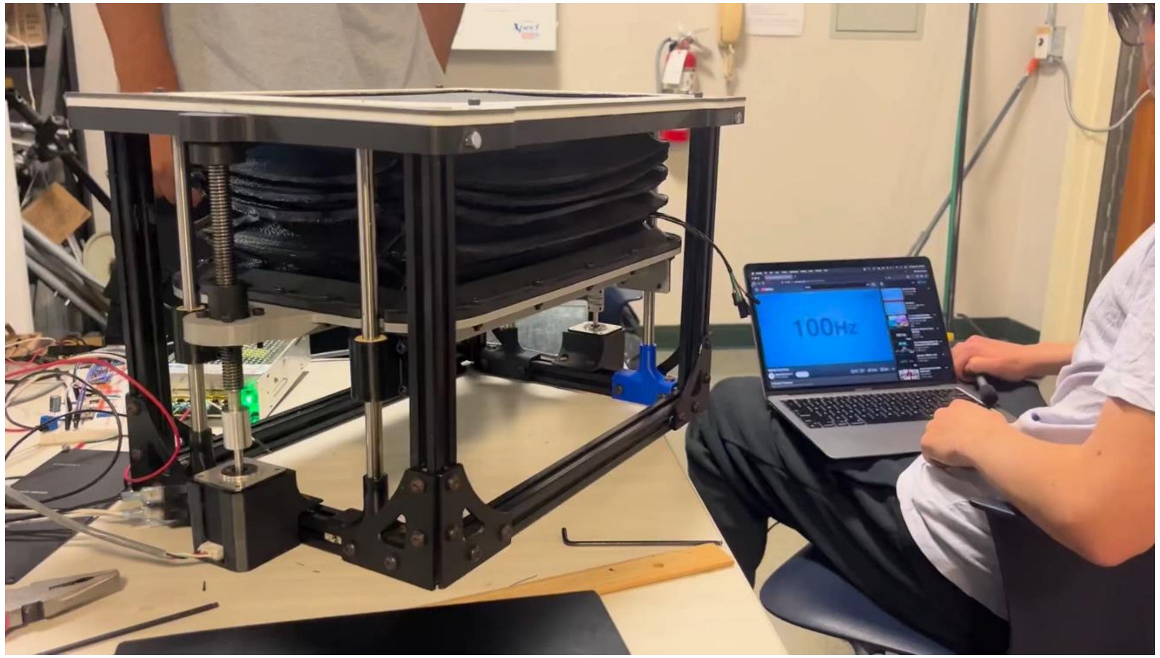
Appendix H. Full Risk Matrix Cont.

ID	Risk Name	Description	Related Systems	P	C	Plan
1	Membrane Resonation Failure	Membrane fails to resonate at target frequency	Mechanical, HLS	2	5	Complete analysis and testing of membranes before integration.
2	Electrical System Failure	Electrical components stop functioning causing linear actuators to no longer move eliminating noise dampening adjustability	Electrical, Control	3	5	Use electrical and wiring components rated for space, design fail-safe mode where MASS remains fixed at default chamber depth for dominant frequency found in lander during testing
3	High Pressure Differential	Pressure within the internal reverberation chamber is largely different from the surrounding external pressure	Mechanical, Control	4	4	Include a controlled pressure equalization aperture, validate sealing behavior during chamber adjustment, emphasize aperture inspection during maintenance
4	Actuator Positioning Error	Linear actuators move the mounting plate to the incorrect chamber depth	Mechanical, Control	3	5	Add actuator position feed back, do calibration checks, implement software limits to prevent movement outside allowable depth range
5	**Acoustic Monitoring Inaccuracy**	**Acoustic sensors inaccurately identify the dominant frequency within the lander**	**Electrical, Control**	**3**	**5**	**Implement extensive sensor calibration, frequency filtering, and acoustic measurements before actuator movement; extensive acoustic testing and programming**
6	Mounting Failure	Device detaches, loosens, or vibrates from its mounted location during launch or operation	Mechanical, HLS	2	5	Design mounting brackets for launch loads, use vibration resistant fasteners, perform structural and vibrational testing before system integration
7	Excessive Mass	Device mass exceeds critical point where it interferes with launch loads	HLS, Propulsion	3	3	Track device mass throughout design, use lightweight materials, reduce nonessential structural components
8	Excessive Volume	Device volume takes up excessive space within the HLS interfereing with astronaut living and working space	HLS	4	3	Minimize protrusion into crew space through optimization of cavity depth and material selection
9	Power Consumption	System requires excessive power for sensors, controls, and actuation	Electrical, HLS	2	3	Limit the duty cycle of the actuators, use low power sensors, ensure it is only operational when frequency retuning is required

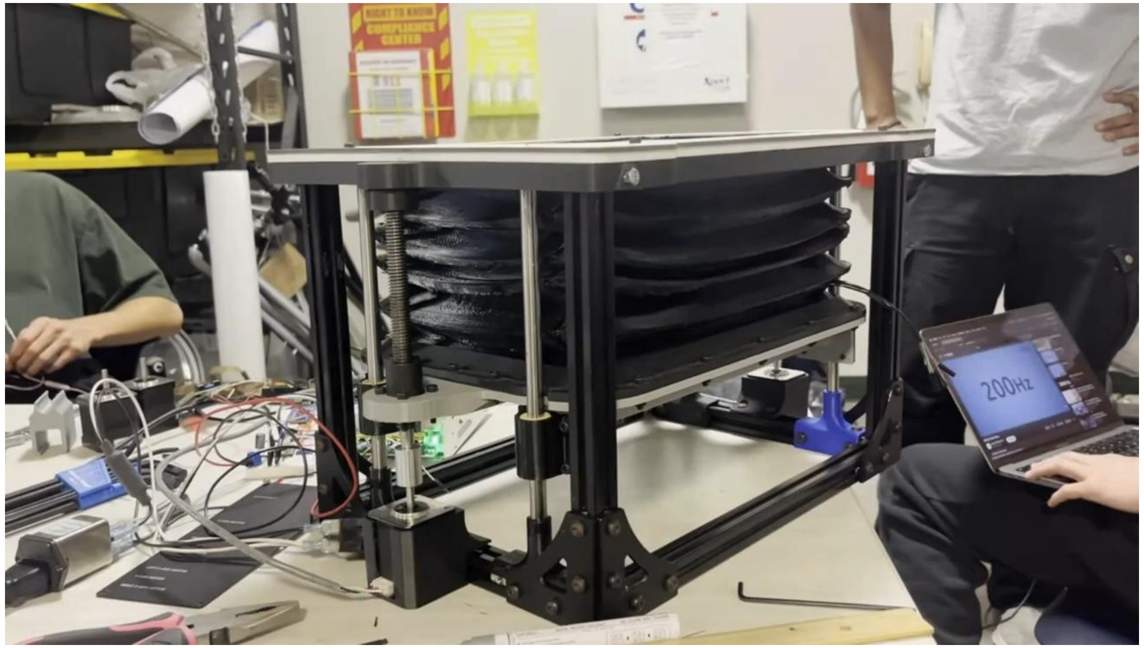
Appendix I. Full Budget Breakdown

Mission Phase	Year 1: Dev Phase (2026)	Year 2: Test Phase (2027)	Year 3: Fab & Impl. (2028)	Total ($)
PERSONNEL				
Engineering & Design	900,000	600,000	500,000	2,000,000
Fabrication & Assembly	250,000	160,000	360,000	77,0000
Testing & Inspection	110,000	500,000	400,000	1,010,000
Total Personnel(12)	1,260,000	1,260,000	1,260,000	3,780,000
DIRECT COSTS				
Prototyping Hardware	100,000	50,000	0	150,000
Testing Facilities & Equip.	0	150,000	100,000	250,000
Final Hardware (1 Unit)	0	0	150,000	150,000
Total Direct Cost	100,000	200,000	250,000	550,000
FINAL COST CALC.				
Total Projected Cost	1,360,000	1,460,000	1,510,000	4,330,000
Total Cost Margin(-30%)	408,000	438,000	453,000	1,299,000
TOTAL PROJECT COST	**1,768,000**	**1,898,000**	**1,963,000**	**5,629,000**

Appendix J. Prototype in Action



100 Hz Response



200 Hz Response

Appendix K. Technology Readiness Level Assessment

TRL 9
- Actual system "flight proven" through successful mission operations

TRL 8
- Actual system completed and "flight qualified" through test and demonstration (ground or space)

TRL 7
- System prototype demonstration in a space environment

TRL 6
- System/subsystem model or prototype demonstration in a relevant environment (ground or space)

TRL 5
- Component and/or breadboard validation in relevant environment

TRL 4
- Component and/or breadboard validation in laboratory environment

TRL 3
- Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2
- Technology concept and/or application formulated

TRL 1
- Basic principles observed and reported

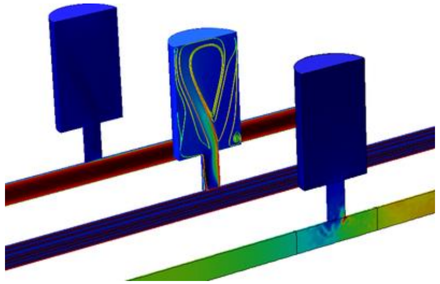
Evidence	TRL
Theory	2
Simulation	3
Functional Prototype	4
Acoustic Chamber Testing	3
Relevant Environment Testing	4

Current MASS maturity: TRL 3

Appendix L. Why Membrane Absorber Instead of Helmholtz Resonator?

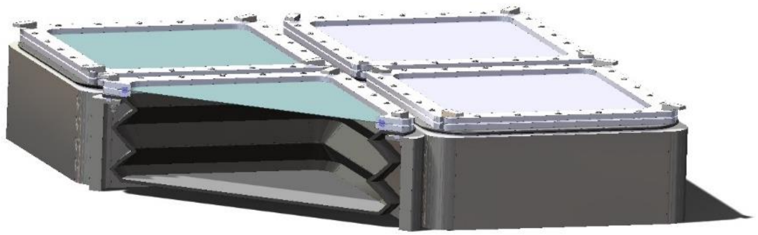
Helmholtz Resonator

- ✗ Fixed geometry
- ✗ Single tuned frequency
- ✗ Requires multiple resonators
- ✗ Less adaptable



MASS

- ✓ Adjustable geometry
- ✓ 60–200 Hz range
- ✓ One adjustable unit
- ✓ Adaptive



MASS was selected because it can adapt to changing ECLSS frequencies in real time.

Appendix M. Expected Noise Reduction

Absorption From Impedance

$$\alpha = 1 - |R|^2$$
$$R = \frac{z-1}{z+1}$$
$$z = \frac{Z_s}{Z_0}$$

α = absorption coefficient (-)
R = reflection coefficient (-)
Zs = surface impedance of MASS ($Pa \cdot s/m$)
Z0 = characteristic impedance of air ($Pa \cdot s/m$)

At resonance, MASS is designed so the reactive terms cancel, increasing absorption at the tuned frequency

Total Cabin Absorption

$$A_{total} = A_{cabin} + \alpha A_{MASS}$$

where:

$$A_{MASS} = N A_{panel}$$

So more wall coverage means larger acoustic absorption area.

Estimated SPL Reduction

$$\Delta L_p = 10 log_{10}\left(\frac{A_{after}}{A_{before}}\right)$$

or:

$$\Delta L_p = 10 log_{10}\left(\frac{A_{cabin} + \alpha A_{MASS}}{A_{cabin}}\right)$$

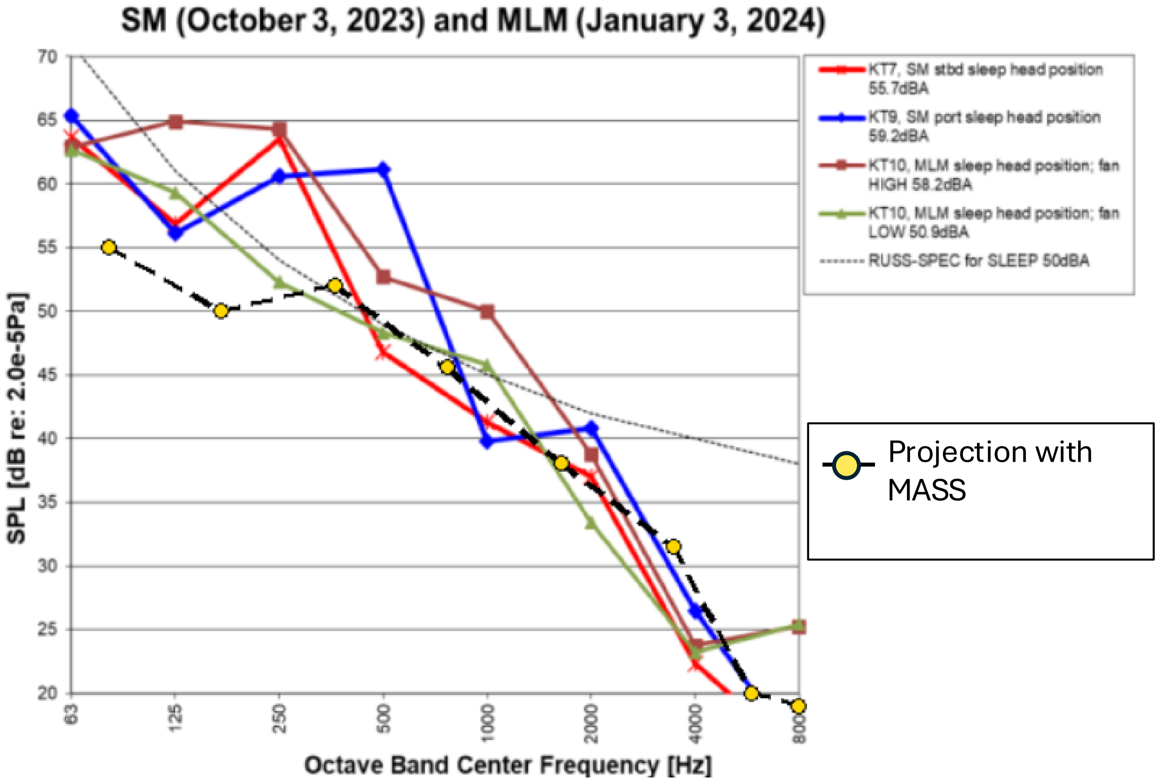
Appendix M. Expected Noise Reduction

If MASS panels significantly increase total cabin absorption, the expected reduction is:

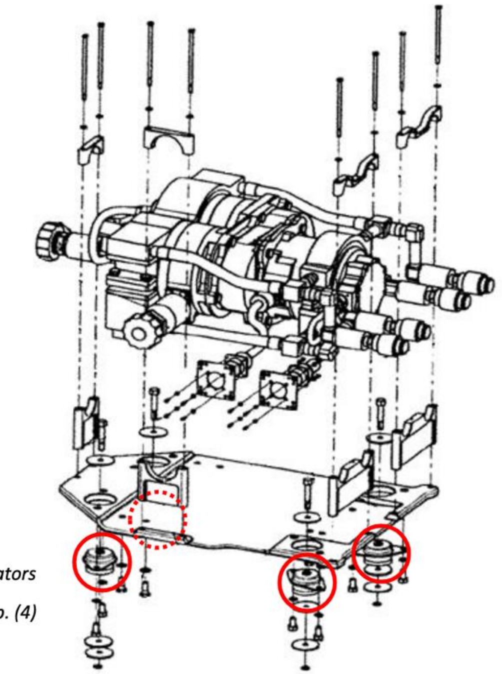
6–10 *dB overall cabin SPL*

with higher reduction near the tuned resonance frequency.

More panel area + higher absorption coefficient = greater dB reduction.
Final values require acoustic chamber insertion-loss testing.



Appendix N. Mounting



Barry Controls Isolators

Typ. (4)

Figure 35. Locations of the four commercially available isolators used to quiet the U.S. Airlock depressurization pump.

Properties

✓ Flexible

✓ Durable

✓ Appropriate density range

Enables both the membrane function and the accordion chamber function.

[8]

Appendix O. Why Fluorosilicone?

Properties

✓ Flexible (40-80 Shore A)

✓ Durable

✓ Aerospace heritage

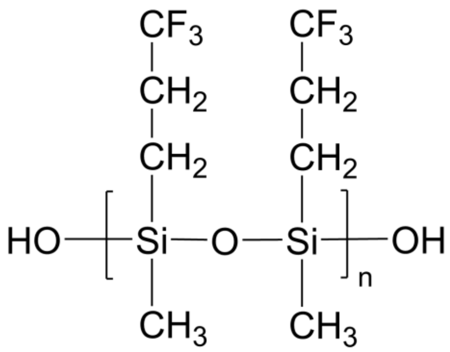
✓ Maintains pressure seal

✓ Appropriate density range

✓ Chemical resistance

✓ Temperature stability(-60°C to 204°C)

✓ Used in industry for jet fuel system



Flourosilicone O-rings

Enables both the membrane function and the accordion chamber function

Appendix P. Timeline - Quarterly

Year 1: Development Phase

Quarter 1: Design Requirements
Quarter 2: Preliminary Analysis
Quarter 3: Design Refinement
Quarter 4: Prototype Fabrication

Year 2: Design Refinement and Testing Phase

Quarter 1: Prototype Testing
Quarter 2: Design Iteration
Quarter 3: Finalize Design
Quarter 4: Final Manufacturing Plan

Year 3: Final Fabrication and Implementation Phase

Quarter 1: Final Fabrication
Quarter 2: Part Inspection
Quarter 3: Flight Certification
Quarter 4: Final Implementation