

Silent Nightmare

CSC Custom Muffler



Mark Woodland (ME), Adam Sedgwick (ME), MJ Arteaga (ME), Aaron Eliason (ME)

Sponsor/Client: University of Idaho CSC team
Grad Students: Jake Gilles & Dillon Savage
Faculty Advisor: Dr. Cordon

Overview

- Problem/ Customer Specifications
- Background Research
- Testing Equipment
- SolidWorks Modeling
- Muffler Acoustic Results
- Final Design Choice
- Muffler Manufacturing
- Muffler Validation
- Final Muffler Results
- Forensics
- Questions



Background

- 2016 sound output: 73 dBa
- NPS standard: 67 dBa $\pm$ 2

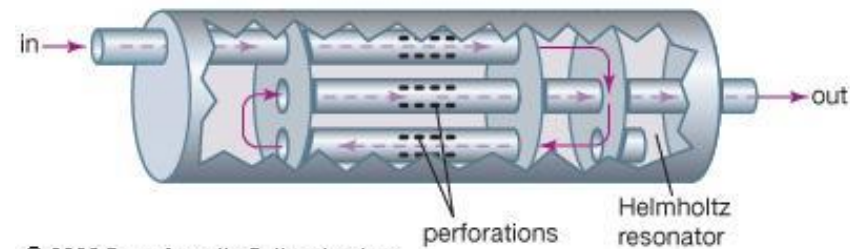
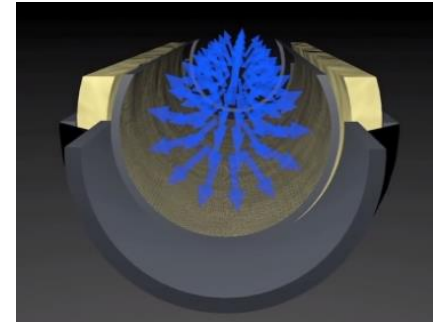


Customer Specifications

	Goal	Acceptable
dBa Loss	4	2
Power	120 hp	110 hp
Weight	20 lbs	25 lbs
Flow Rate	3.5 CFS	3.3 CFS
Back Pressure	0.63 psi	0.73
Cost to Manufacture	\$300	\$500
MSRP	\$650 (Stock)	\$200 More
Size	16"x5.5"x13"	Has to fit
Robustness	1800 F / withstand winter conditions	1800 F / withstand winter conditions

Background Research

- Muffler Components
 - Absorption Technology
 - Reflection Technology
 - Backpressure
 - Testing Procedures



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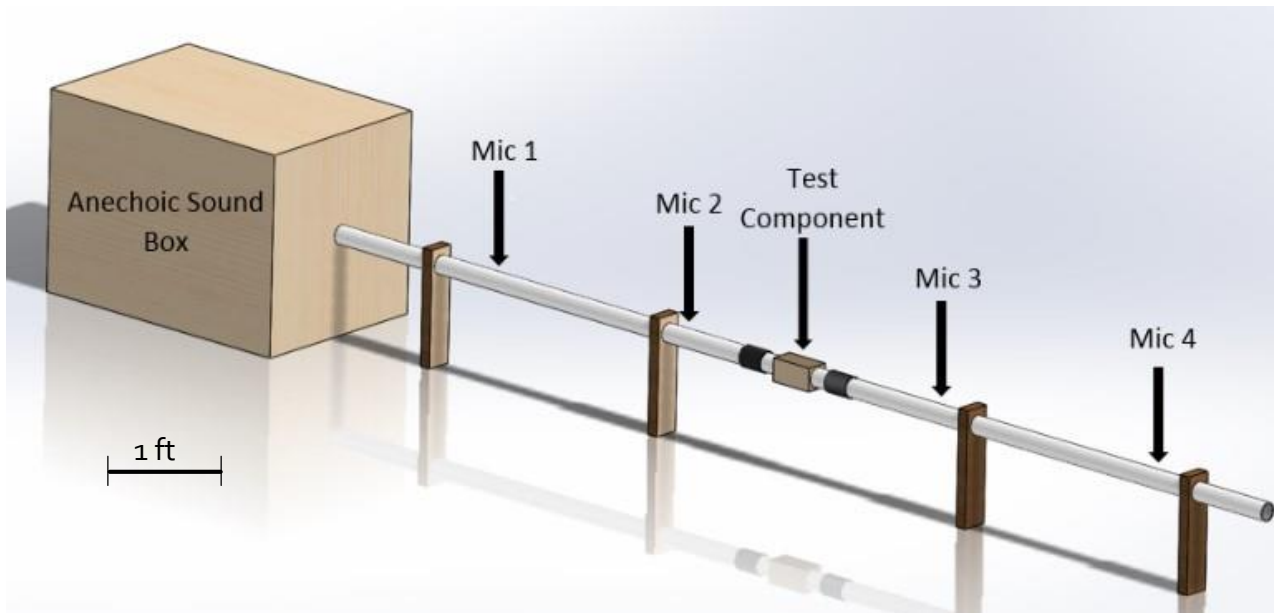


Testing: Anechoic Sound Box

- Objectively compare various acoustic components and materials
- Testing range of 80-4000 Hz

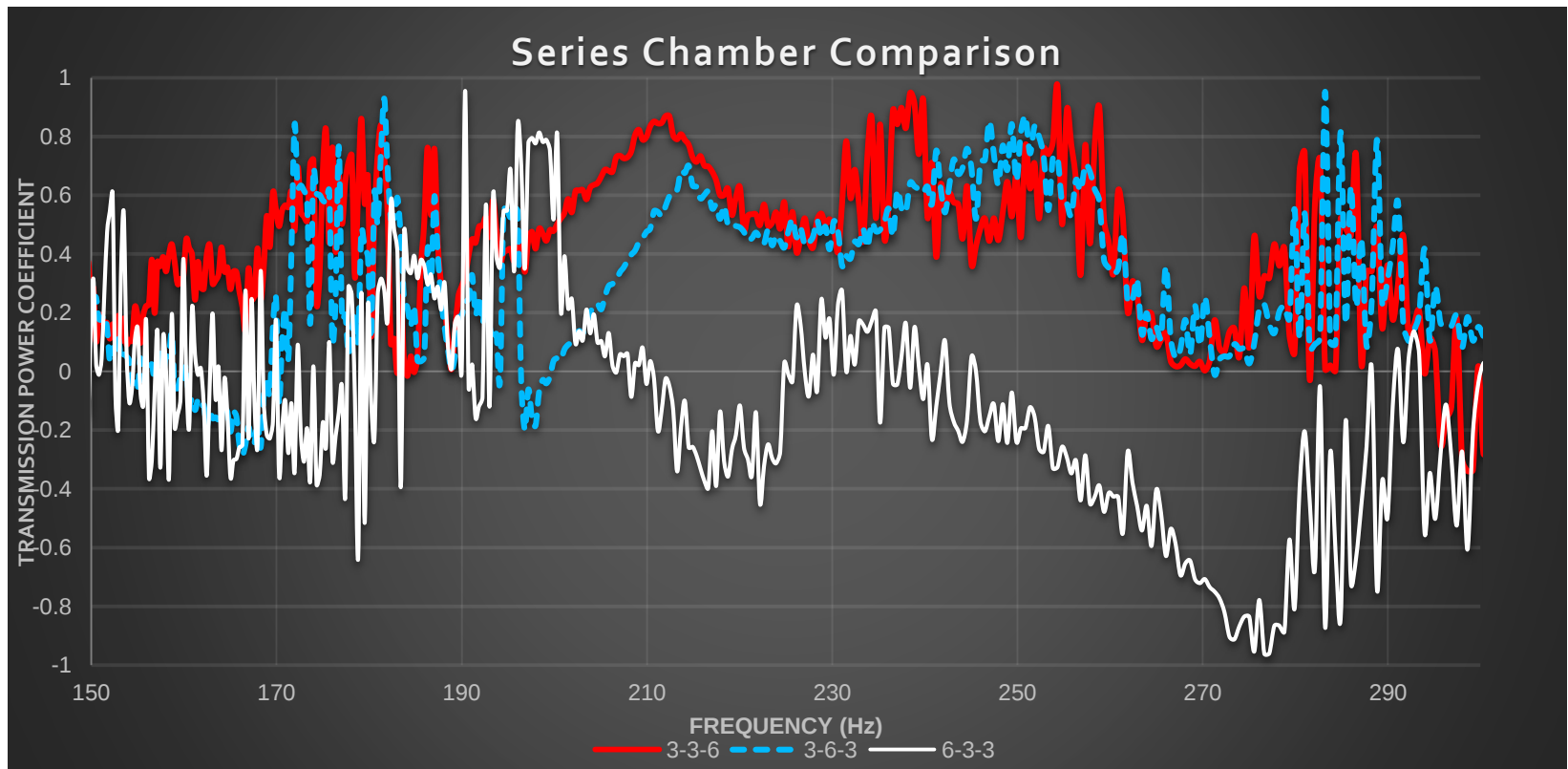
$$\lambda = \frac{c}{f} \quad [1]$$

$$\lambda > 1.71 * D \quad [2]$$



Testing Results:

Power Transmission Coefficients

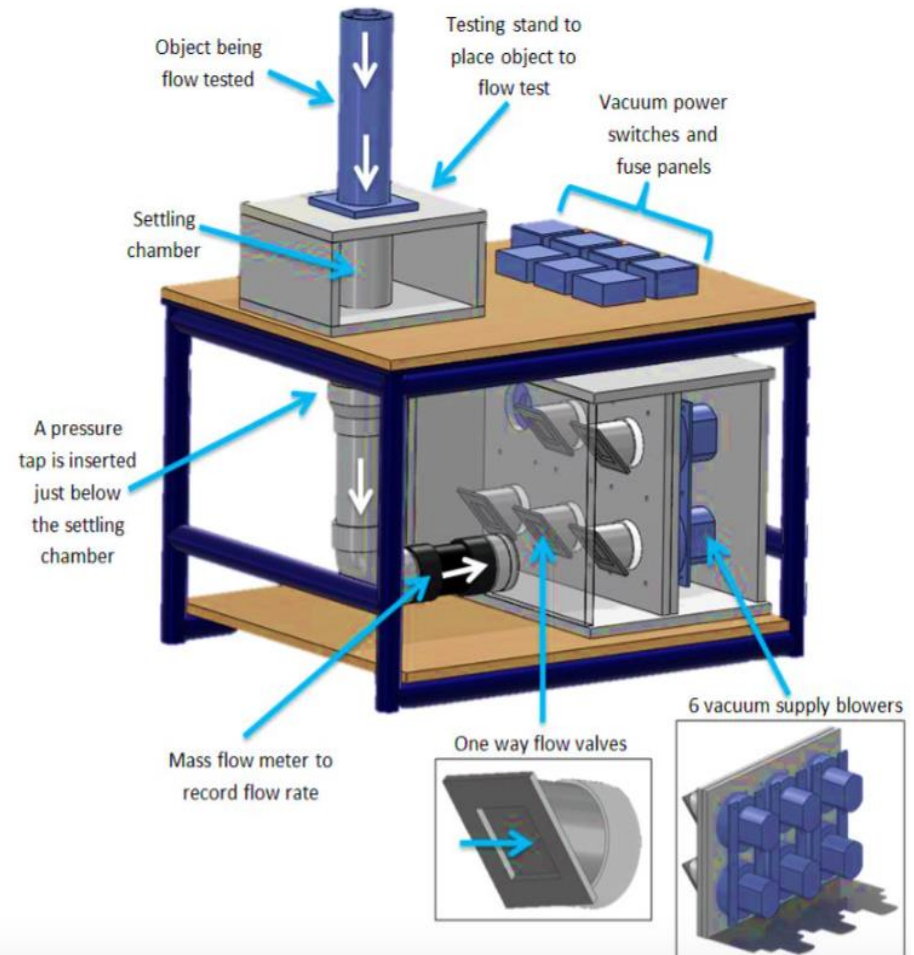


		Frequency (Hz)				
Configuration		150	500	1250	2000	Average
Series	3 then 3 then 6	0.265	0.157	0.041	-0.188	0.069
	3 then 6 then 3	0.243	-0.087	0.163	-0.469	-0.038
	6 then 3 then 3	0.133	0.206	-0.1	0.084	0.081

Testing: Flow Bench

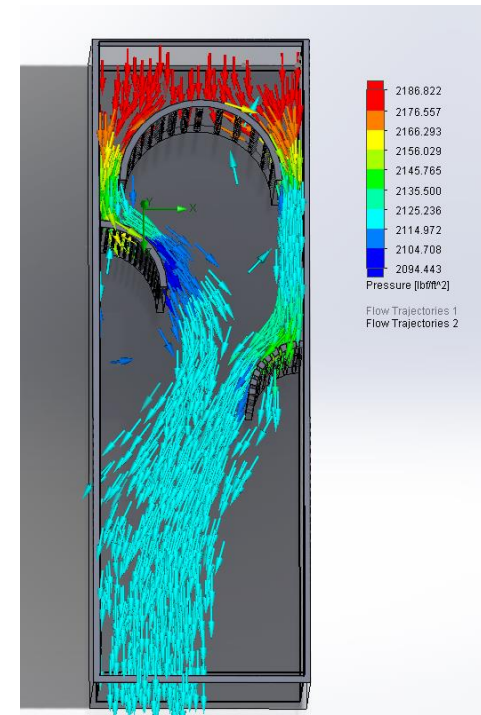
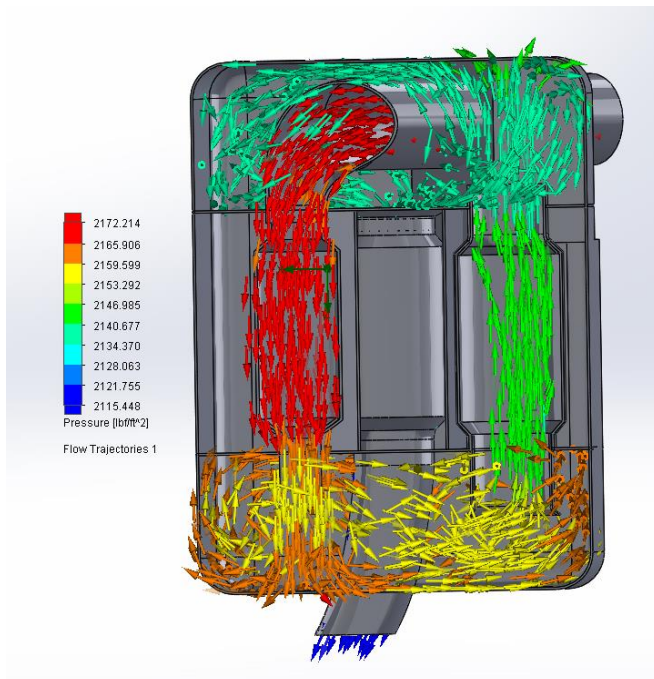
- Objectively compare back pressure on muffler's and various muffler components

Chamber Size	Back Pressure (psi)
3x3x8	0.14
4x4x4	0.19
4x4x8	0.22
4x4x12	0.3
6x6x8	0.23



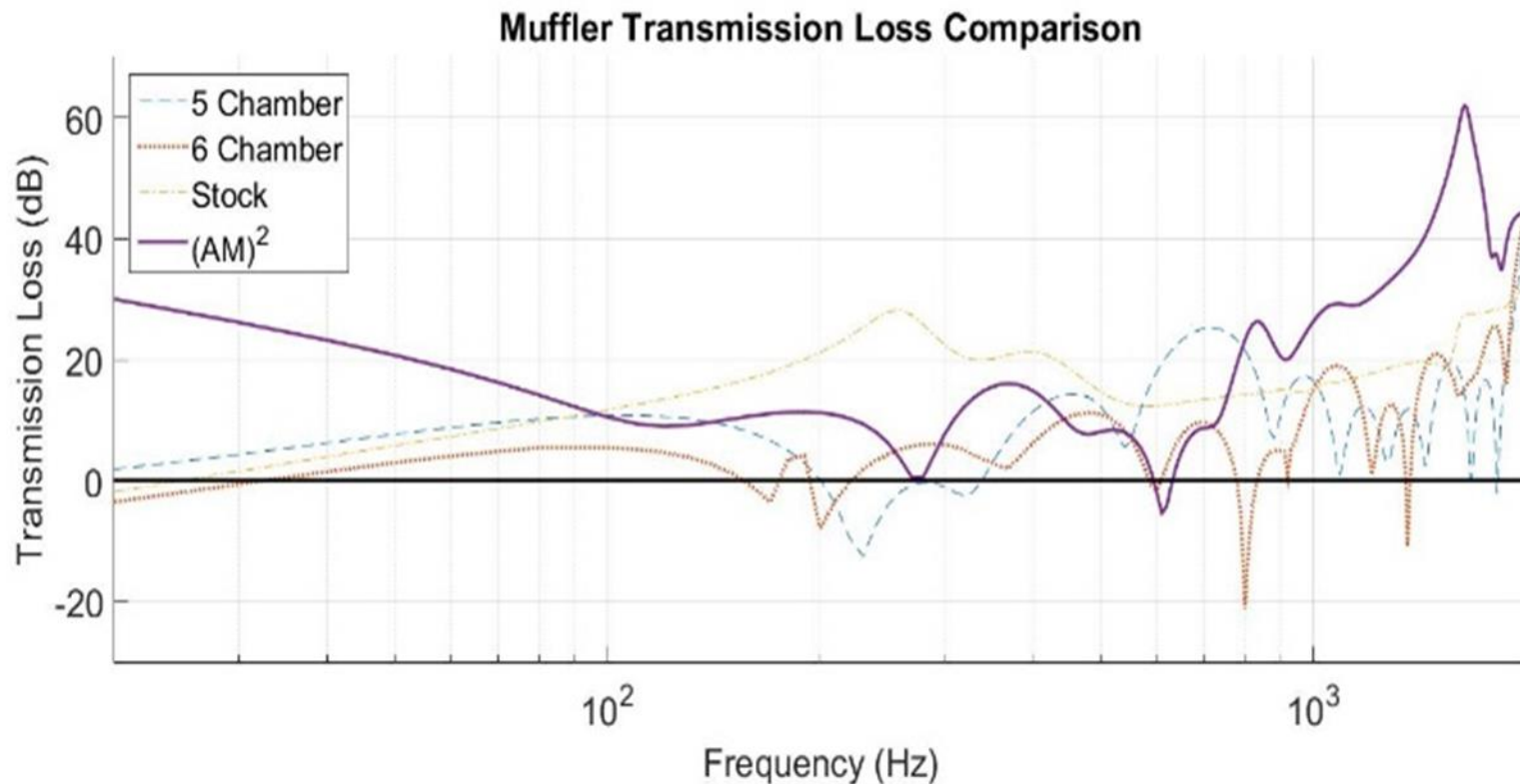
Solidworks Modeling: Simulations

- Flow tests and muffler modeling in SolidWorks
- Muffler designs compared to stock muffler
 - Back pressure target: 0.39 psi



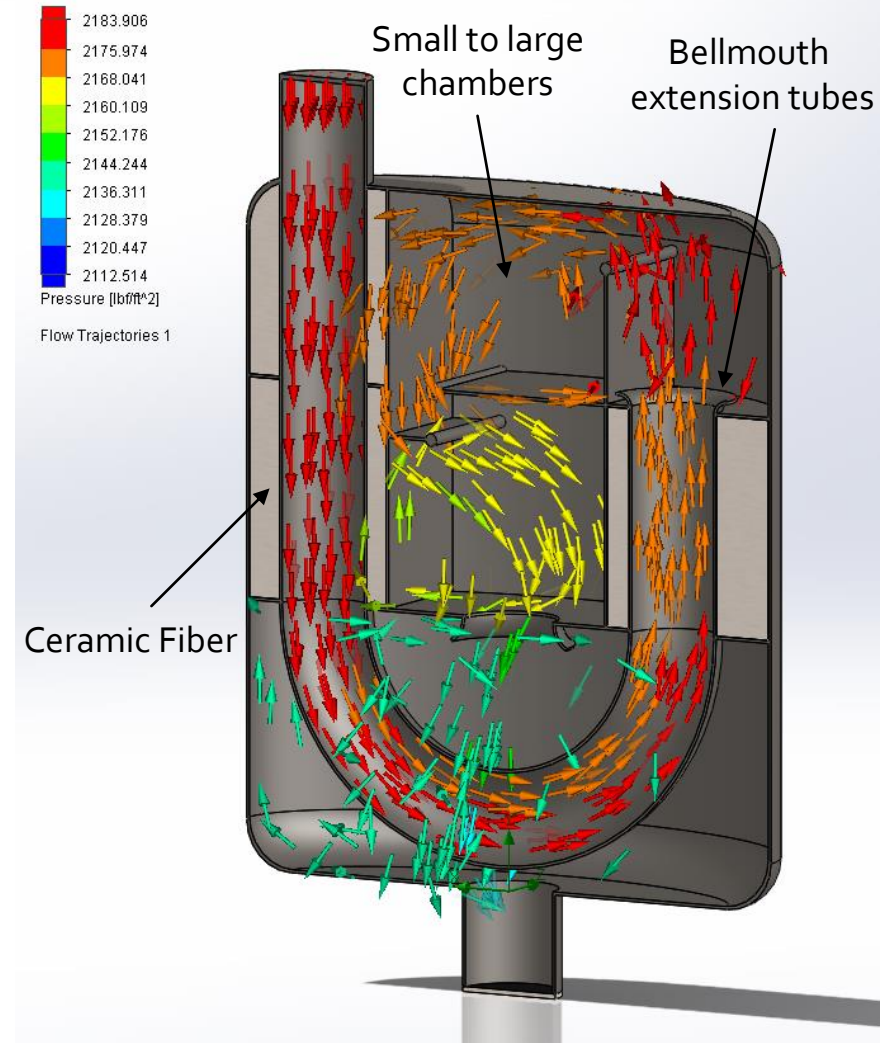
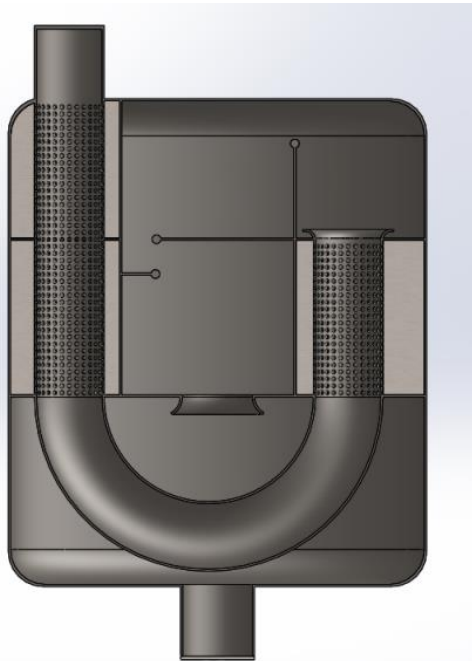
Muffler Acoustic Results

- Sidlab Results: Mufflers vs. Stock



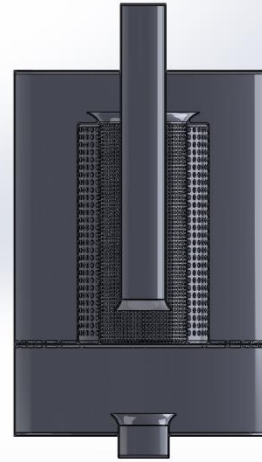
Final Design Choice: Red Dawn (AM)²

- Acoustic ability – Sidlab
- Back pressure comparison
- Cost/Manufacturability



Muffler Manufacturing

- Concentric muffler being built through facilities
- Build final design muffler
Red Dawn (AM)² here in shop



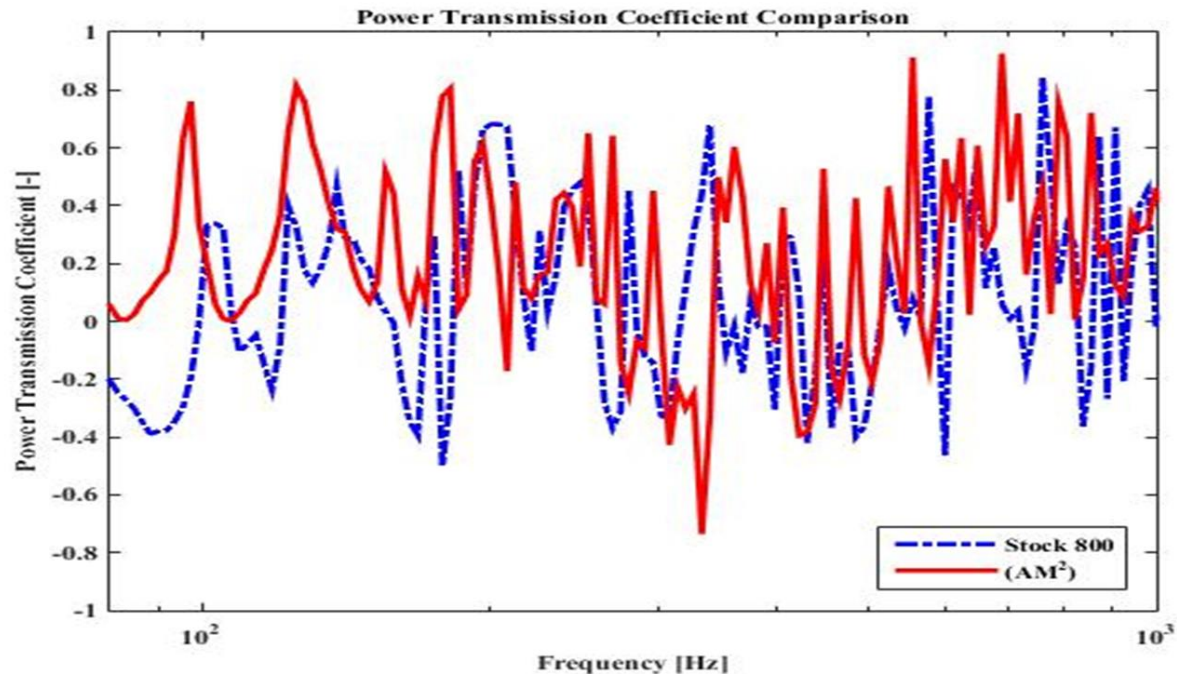
Muffler Validation

Back Pressure Vs. Stock

Configuration	Back Pressure	Change from Stock
Stock	.043 bar (.63 psi)	0%
2016 Configuration	.050 bar (.73 psi)	16%
(AM) ²	.052 bar (.76 psi)	21%
(AM) ² With Catalyst	.066 bar (.96 psi)	52%

Flow bench Vs. SolidWorks

Test Component	Solidworks	Flow Bench
Simple Expansion	.006 bar (.09 psi)	.02 bar (.23 psi)
Stock	.03 bar (.39 psi)	.04 bar (.63 psi)
Red Dawn (AM) ²	.04 bar (.51 psi)	.05 bar (.76 psi)



Final Muffler Results

	Goal	Acceptable	Actual
dBA Loss	4	2	5
Power	120 hp	110 hp	100 hp
Weight	20 lbs	25 lbs	19.2 lbs
Flow Rate	3.5 CFS	3.3 CFS	3.5 CFS
Back Pressure	0.63 psi	0.73 psi	0.76 psi
Cost To Manufacture	\$300	\$500	\$325
MSRP	\$650 (Stock)	\$850	\$412.50
Size	16"x5.5"x13"	Has to fit	Fits
Robustness	1800 F / withstand winter conditions	1800 F / withstand winter conditions	2000 F / withstand winter conditions
CSC Competition	Meet NPS Standards, Quietest Snowmobile	Meet NPS Standards	Met NPS Standards (5 dBA lower than control snowmobile), 3 rd Quietest

Post-Competition Analysis



Questions



Heraeus



Dr. Anderson
Bill Magnie
Dr. Beyerlein

Testing Results:

Power Transmission Coefficients

		Frequency (Hz)				
Configuration		150	500	1250	2000	Average
Expansion Chamber Size (in x in x in)	3x3x8	0.008	0.828	0.491	-0.194	0.283
	4x4x4	0.296	-0.179	0.518	0.01	0.161
	4x4x12	0.287	0.522	-0.037	-0.372	0.100
	6x6x8	0.211	-0.31	0.055	0.381	0.084
Sound Material with Weight	F.G. Blanket (25 g)	0.062	-0.014	0.135	-0.565	-0.096
	F.G. Blanket (50 g)	0.627	0.765	0.073	-0.177	0.322
	Ceramic Blanket (25 g)	0.382	0.234	0.114	-0.343	0.097
	Ceramic Blanket (50 g)	0.367	0.236	0.121	-0.165	0.140
Perforated Hole Density	1/4 in 22%	0.256	0.299	0.227	-0.157	0.156
	1/4 in 40%	0.247	0.119	0.014	-0.13	0.063
	1/4 in 58%	0.2885	0.358	0.682	-0.207	0.280
Deflectors	Round Middle Same	0.316	0.238	0.332	0.026	0.228
	V Middle Same	0.48	0.113	0.339	-0.0003	0.233
	Round Desc. Size	0.319	0.161	0.191	-0.081	0.148
Series	3 then 3 then 6	0.265	0.157	0.041	-0.188	0.069
	3 then 6 then 3	0.243	-0.087	0.163	-0.469	-0.038
	6 then 3 then 3	0.133	0.206	-0.1	0.084	0.081

Sound Box Design

- Components used in sound box final configuration

Speakers [11]	15.88 cm (6.25 in)
Tweeters [11]	4.60 cm (1.81 in)
UI Sound Box	.23 m ³ (8.00 ft ³)
Waveguide Diameter	5.08 cm (2.00 in)
Waveguide Length	4.06 m (13.33 ft)
Studio-foam [12]	10.16 cm (4 .00in)
Audio Amplifier [13]	1100 W
Microphone Locations [14]	45.72 cm (18 .00 in), 137.16 cm (54.00 in), 289.56 cm (114.00 in), 381.00 cm (150.00 in)

Muffler Designs

Categories	Mark's Muffler	Aaron's Muffler	MJ's Muffler	Adam's Muffler 1	Adam's Muffler 2
Manufacturability	3	2	1	0	2
Small to Big Chambers	3	3	3	2	1
Deflector Plates	1	3	3	3	2
Perf Tube/Sound Material	2	1	1	3	2
Number of Chambers	2	3	2	1	2
Exhaust Length	3	2	2	2	1
Cost	1	3	2	1	0
TOTAL	15	17	14	12	10

0- Not Included (Worst)

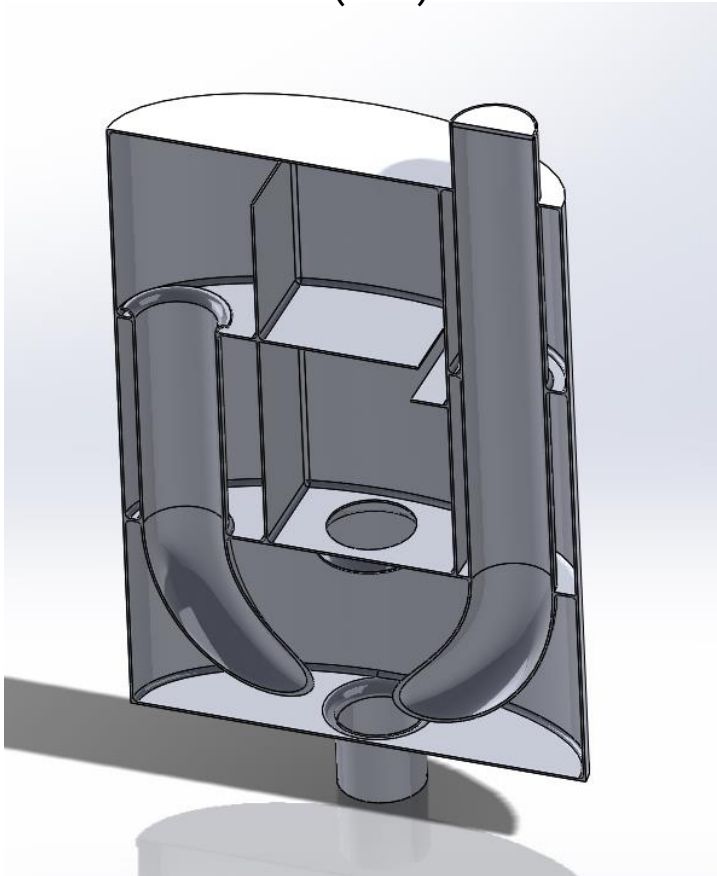
1- One

2- Two-Three

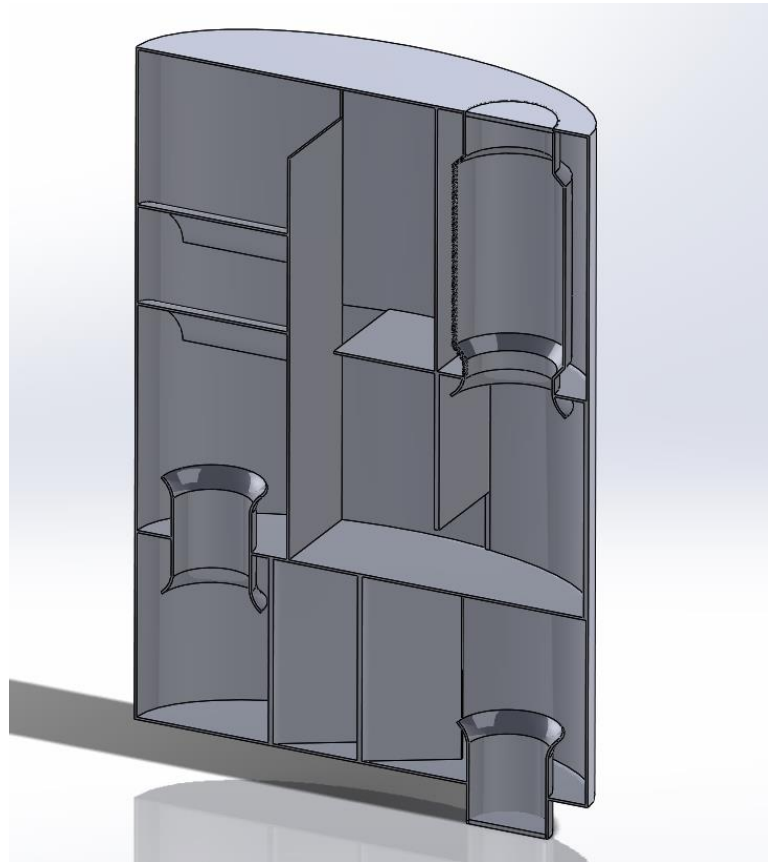
3- Over Three (Best)

Muffler Designs

Mark's Muffler: $(AM)^2$

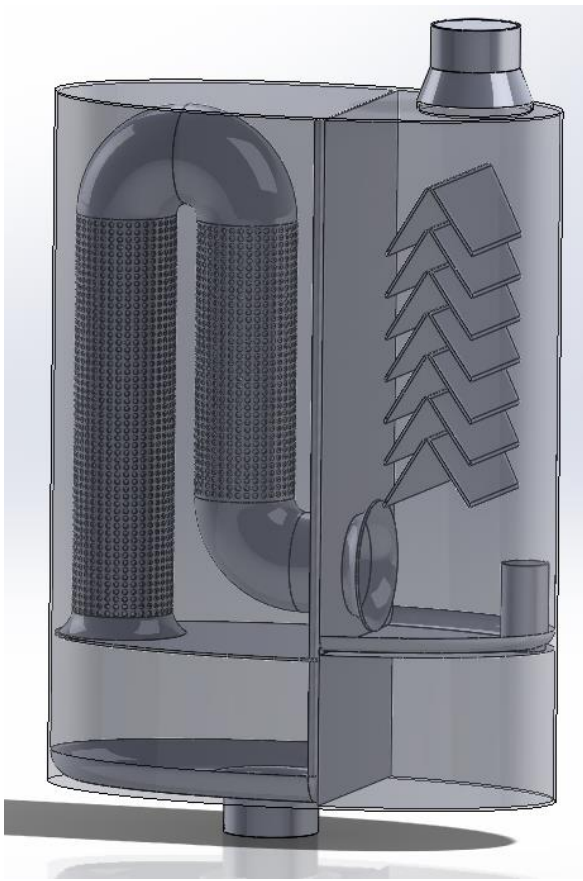


MJ's Muffler

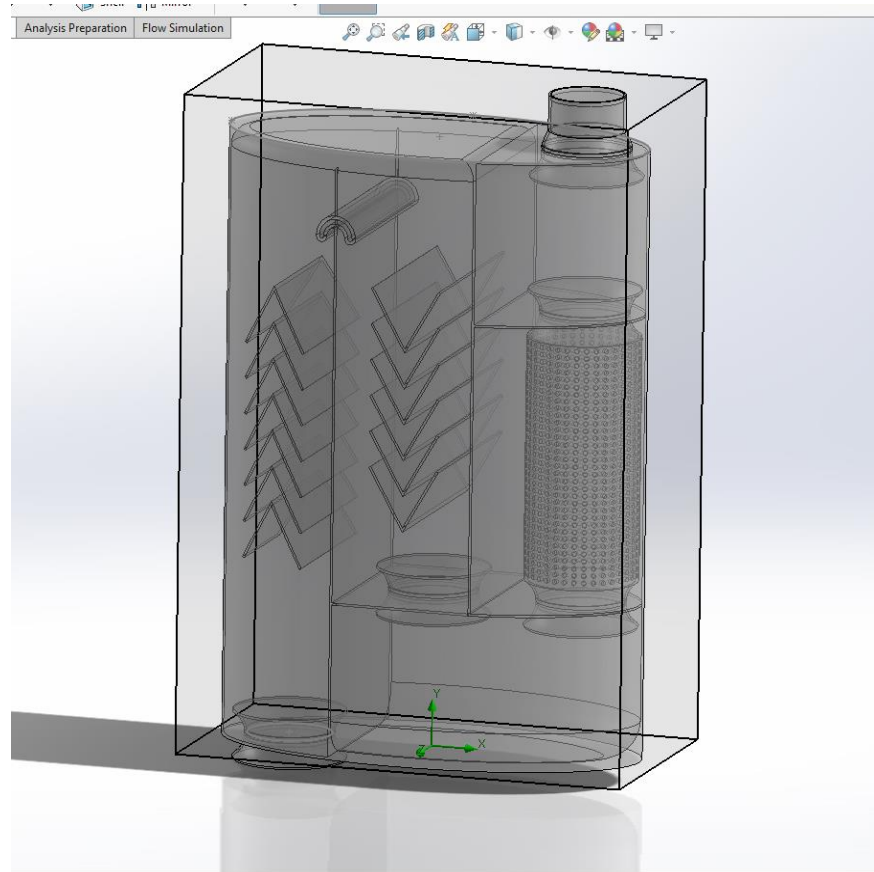


Muffler Designs

Adam's Muffler 1

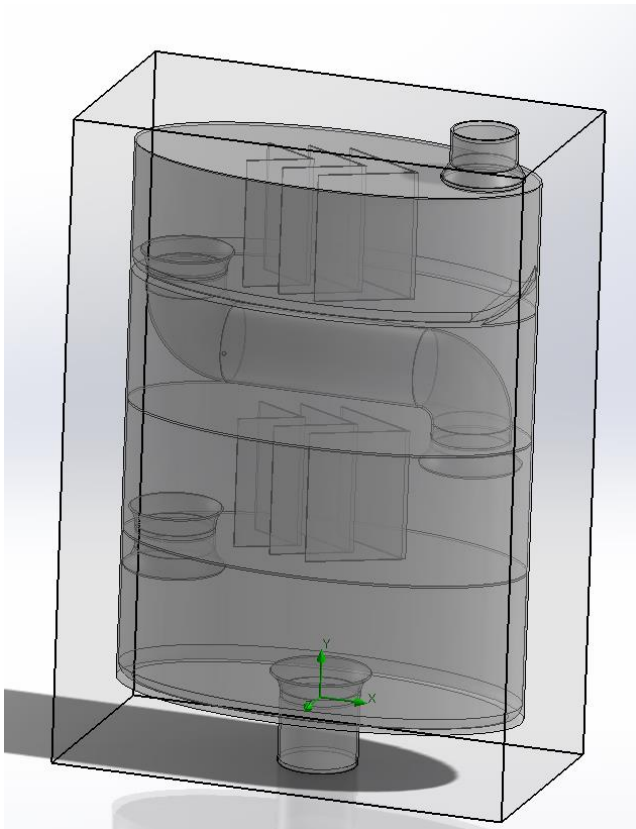


MJ's Muffler

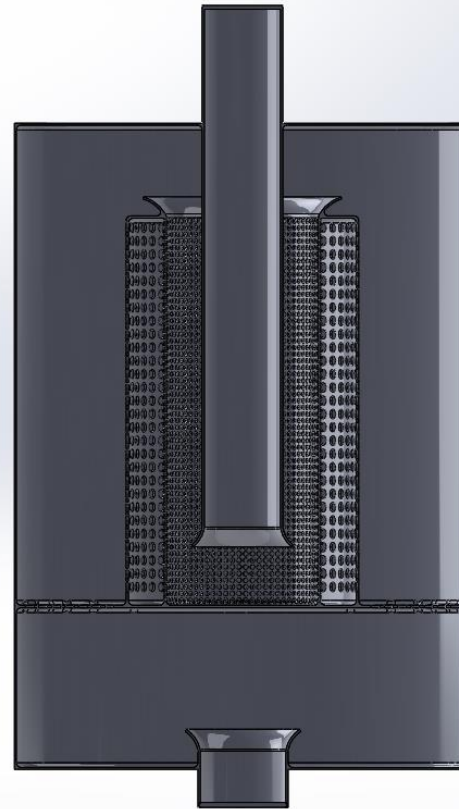


Muffler Designs

Adam's Muffler 2



Concentric Muffler



Budget Overview

Part	Cost	Payment Method
BRP Snowmobile Muffler Components	\$ 2,000.00	Donated
Sound Box	\$ (290.00)	Budget
Prototyping Materials (PVC, Wood, Adhesive)	\$ (100.00)	Budget
Manufacturing Materials (Steel, Perf Tubes)	\$ (630.66)	Budget
2" Steel Tubing	\$ (35.60)	Budget
Perforated Sheets	\$ (47.73)	Budget
2" Perforated Tubing	\$ (31.26)	Budget
Mandrel Bend	\$ (41.07)	Budget
18 Gauge Steel	\$ (100.00)	Budget
Concentric Muffler	\$ (300.00)	Budget
Welding Supplies	\$ (75.00)	Budget
3D Filament	\$ (25.00)	Budget
Expo Poster	\$ (75.00)	Budget
Total Cost for Budget	\$ (1,217.66)	
Budget Amount	\$ 1,500.00	
	\$ 282.34	

General Equations

Wavelength

$$\lambda = \frac{c}{f}$$

Speed of Sound

$$c = \sqrt{\gamma RT}$$

Firing Frequency

$$f = \frac{rpm * N_c}{60 * N_r}$$

Sound Pressure Level/ Acoustic Pressure

$$SPL = 20 \log \left(\frac{P_e}{P_{ref}} \right)$$

$$P_e = P_{ref} * 10^{SPL/20}$$

Impedance

$$r = \rho c$$

Insertion Loss

$$IL = 20 \log_{10} \left| 1 + \frac{Z_c + Z_L}{Z_b} \right|$$

Intensity Transmission Coeff.

$$T_i = \frac{4r_1 r_2}{(r_1 + r_2)^2}$$