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MODULAR EXHAUST DESIGN AND MANUFACTURING PROCESS FOR LOW COST LOW VOLUME RAPID BUILD TO ORDER SYSTEMS

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Background

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- Engine noise causes two primary issues
 - Detection range issues
 - Human factors issues
 - Communications interference
 - Hearing damage / hearing protection requirement
- Specific vehicle platform may or may not have an acoustic detection range requirement.
 - If it does, budget for noise control may permit optimized exhaust silencer.
 - If it does not, no cost or weight for exhaust silencer

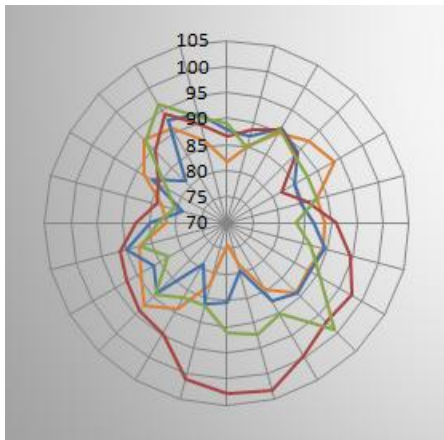
Acoustic Signature Management

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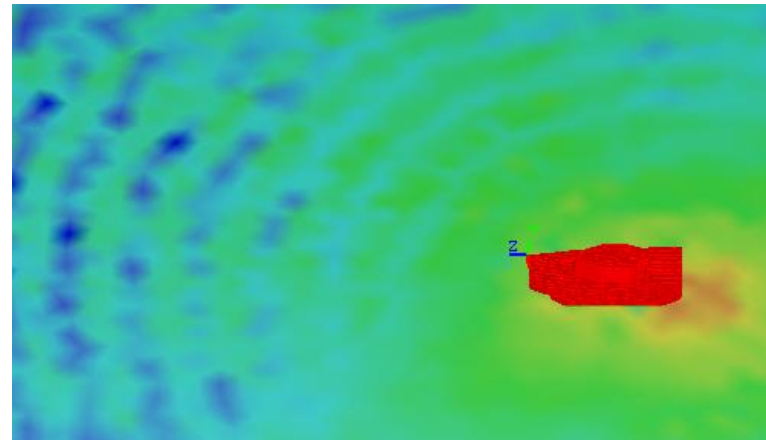
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- Characteristics of engine exhaust make it a priority when attempting to reduce overall vehicle noise signatures
 - Low-frequency combustion tones travel efficiently through the atmosphere negatively affecting detection range
- Exhaust systems can greatly reduce noise levels in and around the vehicle while improving detection range



Low
Frequency
Problem !



Human Factors Noise Issues

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- Exhaust noise is nearly always a significant contributor to vehicle noise inside and outside the vehicle.
- It impacts:
 - Soldier hearing damage
 - Crew Fatigue
 - Crew communications inside vehicle
 - Crew communications outside vehicle

Low, mid, high
Frequency
Problem !



High Performance Exhaust Systems

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- **High performance exhaust in combat vehicles have different goals than automotive, off-highway, and power sports**
 - Emphasis on low frequency attenuation (detection range)
 - Thermal management
 - Structural integrity and durability
 - Harsh climates, Mil Std 810 Shock and Vibration, etc
- **Passive mufflers require large space claims and/or exhaust flow restriction to attenuate low frequency noise**
 - Trade offs in packaging and engine power must be considered
 - Solution usually requires narrow band elements (tuners, resonators) to address low frequency noise
 - To work effectively, reasonably sized silencers targeting low frequency noise must be customized for the application!

Current State of the Art

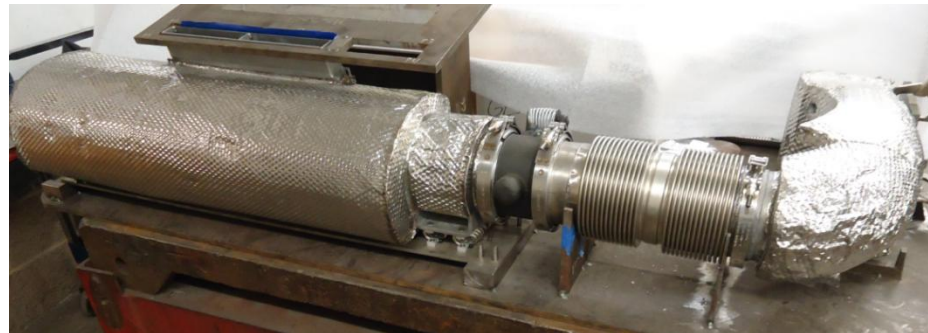
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- Currently, new high performance exhaust systems for ground vehicles lack production volumes that would effectively amortize upfront development costs
 - Much time spent running acoustic and flow analyses on design iterations
 - Depending on requirements this could lead to a complex design
 - Manufacturing process and technical data package (TDP)
 - Complex design drives up engineering time to generate TDP
 - Some features may be altered/omitted to simplify manufacturing
 - Custom tooling and fixtures
 - Hand assembled and welded in a custom fixture

1000's or 10,000's
 \$\$ \$\$\$



State of the Art Alternative

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OVERVIEW

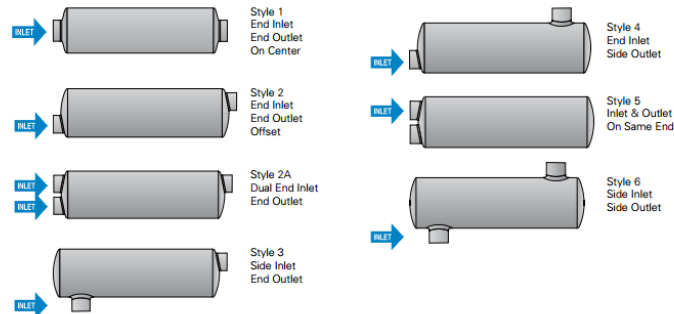
Exhaust Product Materials

A number of different materials are found in exhaust systems. Often different options are available for use in a single application. Since materials vary in strength, corrosion resistance and price, a particular material may be preferred in certain applications. Some of the most common materials, their qualities and their typical uses are listed in the table on the right.

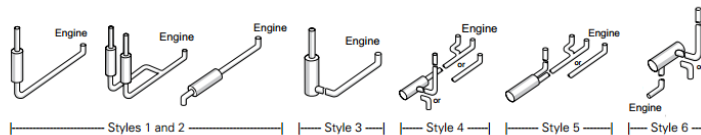
Materials*	Used in	Qualities
Aluminized Mild Steel	Mufflers	Good Corrosion Resistance
	Exhaust Components	
Stainless Steel (with and without aluminized coating)	Flexible Tubing	Stronger Excellent Corrosion Resistance
	Mufflers	
	Exhaust Components	
	Emissions Products	
Chrome	Accessories	Bright Mirror Finish
Galvanized	Flexible Tubing	Low Material Cost Temperature Limit 600°F
Cold Rolled	Accessories	Poor Corrosion Resistance Low Cost

100's or 1000's
\$ \$\$

Muffler Styles



Exhaust System Configurations



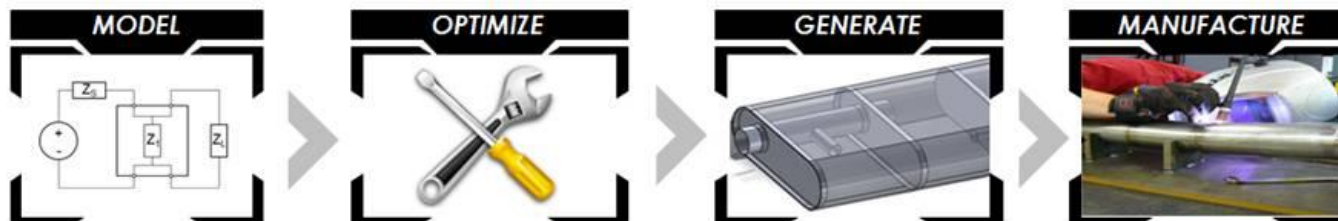
Modular Exhaust Overview

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- Modular exhaust software guides an innovative process for design, optimization and manufacturing of custom exhaust systems
 - New exhaust silencers can be quickly optimized to meet customer requirements for;
 - Desired sound attenuation (IL, TL, SPL)
 - Space claim
 - Backpressure
 - Modular design will accommodate streamlined manufacturing
 - Low cost, low volume, rapid build to order systems



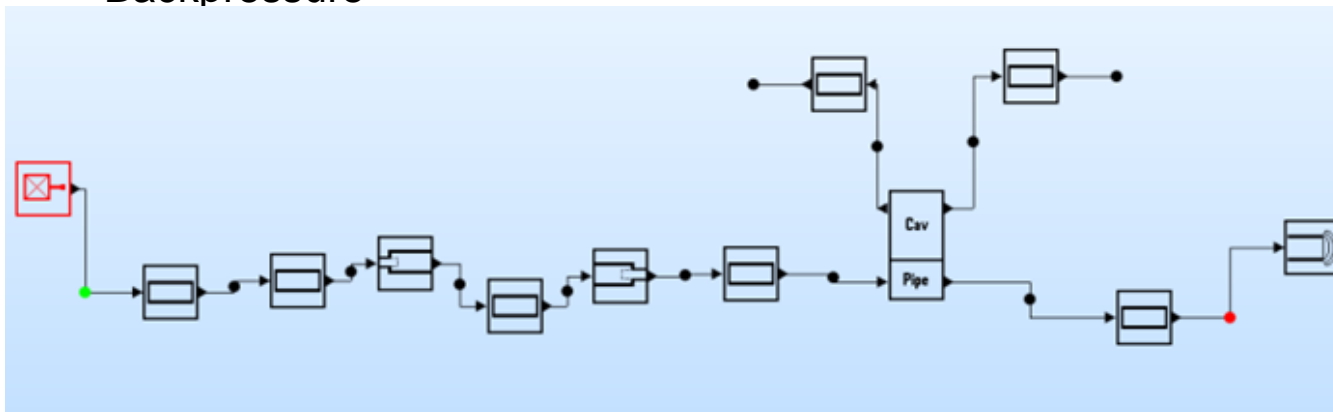
1-D Modeling

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- SIDLAB – 1-D modeling software
 - Design and optimize chains of acoustic elements
 - System of equations can be simplified with a transfer matrix
 - Transfer matrix represents a linear transformation across a string of muffler elements
 - Calculated performance results include;
 - Transmission loss (TL)
 - Insertion loss (IL)
 - Noise reduction
 - Backpressure



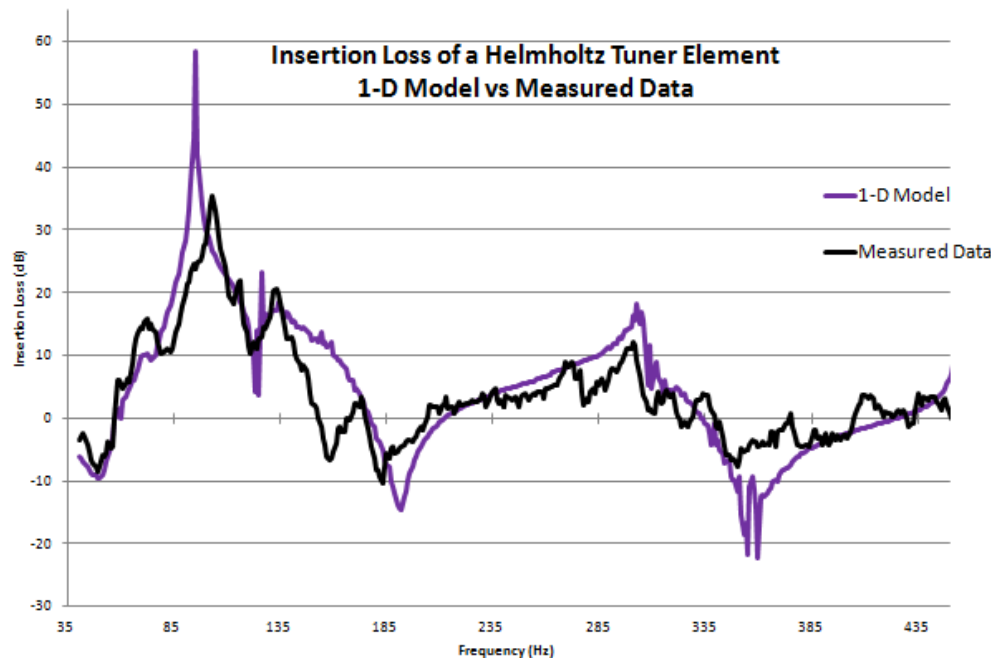
1-D Modeling

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- Acoustic elements can be configured, reconfigured or altered and new performance results can be realized very quickly
- Excellent correlation between 1-D models and actual measurements in low to mid-frequency range



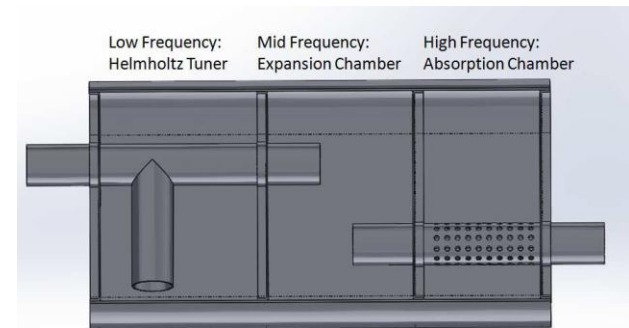
Muffler Optimization

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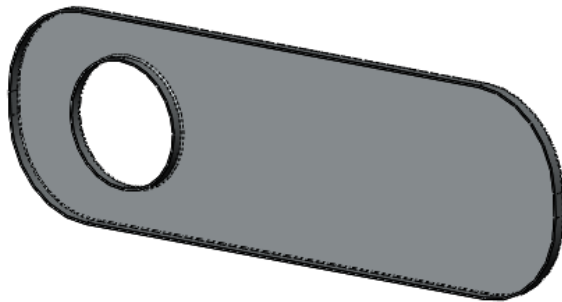


- Optimization consists of choosing appropriate muffler configuration and elements and tweaking the parameters that control performance
- Some example parameters include;
 - Muffler shape, width and height
 - Chamber length
 - Pipe diameter and length
- Reduces disparity between target attenuation curves (TL or IL) and analysis results
- Currently the optimization is performed manually
 - Future enhancements will include an optimization algorithm that'll automatically tune the parameters to reduce error between results and target





- Modular design software will limit the complexity of the muffler
 - No special tooling required
 - Modular, scalable parts will increase commonality across designs
 - Muffler shape and configuration limitations will ensure a simple, streamlined manufacturing process can be utilized



Technical Data Package

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- Manufacturing model created by design software facilitates automatic creation of the Technical Data Package (TDP)
- Minimal engineering time required to finalize TDP for prototype and production
- TDP contains manufacturing specifications for the exhaust system
 - Part drawings
 - Assembly drawings
 - 2-D layouts for CNC cutting

Manufacturing Techniques

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- Manufacturing must support low volume production and short lead times
 - Ground vehicle exhaust market is not large enough to support fully automated production lines
 - Mixture of CNC automation and simple forming techniques work well for low volume production of custom mufflers
 - No special tooling
 - Quick changeover and setup between different parts
- Manufacturing process includes;
 - CNC waterjet cutting
 - Digital roll forming
 - Stamping with modular die sets
 - Hydraulic tube bending, flaring, swaging
 - Resistance roll welding



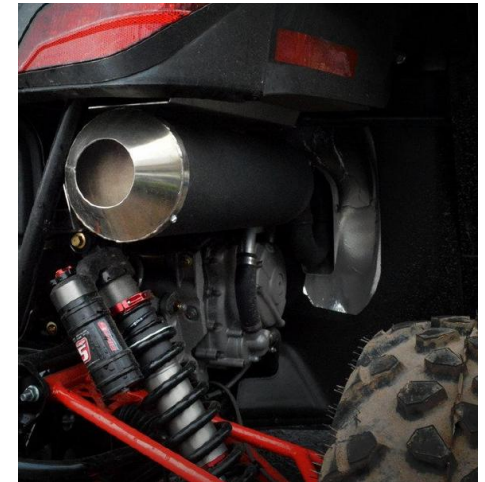
Modular Exhaust Applications

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- Modular process can be applied to most markets requiring low to mid volume production of fully customized, high performing mufflers
- Recently used to develop high performing, aftermarket mufflers for the power sports industry
 - EzRyde launched a new line of UTV mufflers in June 2015
 - Initial design, prototype build and performance testing accomplished within two weeks
 - Seven muffler variations (makes and models)
 - Lead time of 1-2 days for current production
 - Up to 12% increase in horsepower over stock
 - Minimal increase in sound level and weight



Modular Exhaust Applications

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- Ground vehicle programs without stringent acoustic requirements and minimal resources allocated for exhaust system development
 - Provides a solution for programs that may consider new exhaust system development too expensive and/or time consuming
 - Optimization geared towards size, weight, durability and total cost instead of detection range requirements
 - Cost effective alternative to buying a catalog muffler
- SBIR investment in capability development offers something between fully optimized and catalog selection, at a nominal cost increase over the catalog.
- Supports lean concepts and just in time manufacturing.

Modular Exhaust Applications

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- Commercial equipment – Optimized for industry noise standards
 - Industrial
 - Agricultural
 - Construction
 - Gen sets
 - Forestry/Timber harvesting

Cost Benefits

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- Modular exhaust process removes the labor intensive iterations of design and optimization normally employed to develop high performing exhaust systems
- Manufacturing of modular mufflers shows up to 75% reduction in cost-to-build when compared to conventional, low-volume manufacturing of fully customized mufflers.
- Build-to-order mufflers negate large inventories by supporting just-in-time manufacturing
 - Modular exhaust design and production can be up and running in a very short time

Conclusions

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- Advanced acoustic analysis, 3-D CAD modeling and manufacturing technology have been integrated to form a new state of the art process for exhaust system development
- Fills need to greatly reduce cost and logistical footprint of customized exhaust procurement for ground vehicles
 - Without sacrificing engine power or performance