University of Maine FSAE Engine Team

Preliminary Exhaust Design

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Purpose:
To discuss the design parameters to focus on when designing a v twin Formula SAE exhaust system.
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Summary:
Formula SAE rules restrict the decibel output level of the car’s exhaust system to be less than 110 db. The Engine Control’s team is required to design, and fabricate and exhaust system which will meet FSAE’s rules, while maintaining the engine’s performance and efficiency.

Background:
As a first year Formula SAE team with no prior exhaust design experience it is expected that the new design will improve over the past design using modern exhaust design principles. The current exhaust system underwent limited design with many weaknesses. One of the biggest downfalls of the current exhaust is the unequal length headers with lack of intermediate piping. Currently the exhaust gasses from each cylinder merge inside the muffler at different points inside the muffler body rather than merging at a certain point. A proper merge pipe should help to increase exhaust efficiency throughout the 6500 to 9500 RPM range where the engine will be spending most of its time. The current design is restrictive compared to many other teams’ designs which target for close to the noise level limit; the current muffler is close to 10 db under the current competition limit.

Problem Definition:
To design a Formula SAE compliant exhaust system for an Aprilia RXV 550 that optimizes engine performance and efficiency while meeting the noise criteria outlined by Formula SAE rules.

Design Parameters:
Sound Level:
The formula SAE rules state that the engines sound level must not surpass 110 db during any part of the competition. If the judges suspect excess exhaust noise after initial testing, a car may be retested at any point during the competition. The stock Aprilia RXV 550 exhaust produces 94 db, while most aftermarket exhaust systems produce close to 100 db. When testing the current exhaust system values of about 101 db were consistent using the same measurement distances required during completion. This leaves a large amount of room for exhaust options as the noise level can be raised nearly 10 db over what it currently is. Most aftermarket exhaust systems produce great power gains with just a 4 db increase in noise output. Below are the official 2012 Formula SAE noise measuring procedures [1].

B10.2 Noise Measuring Procedure

B10.2.1 The sound level will be measured during a static test. Measurements will be made with a free-field microphone placed free from obstructions at the exhaust outlet.
level, 0.5 m (19.68 inches) from the end of the exhaust outlet, at an angle of forty-five degrees (45°) with the outlet in the horizontal plane. The test will be run with the gearbox in neutral at the engine speed defined below. Where more than one exhaust outlet is present, the test will be repeated for each exhaust and the highest reading will be used.

B10.2.4 Test Speeds
The test speed for a given engine will be the engine speed that corresponds to an average piston speed of 914.4 m/min (3,000 ft/min) for automotive or motorcycle engines, and 731.5 m/min (2,400 ft/min) for “industrial engines”. The calculated speed will be rounded to the nearest 500 rpm. The test speeds for typical engines will be published by the organizers.

B10.3 Maximum Sound Level
The maximum permitted sound level is 110 dBA, fast weighting.

B10.4 Noise Level Re-testing
At the option of the officials, noise can be measured at any time during the competition. If a car fails the noise test, it will be withheld from the competition until it has been modified and re-passes the noise test.

Manifold Design:
When designing the exhaust manifold for the FSAE car, a few crucial things are to be considered. The length of the pipe from where it exits the exhaust port to where both of the cylinder’s flows meet is known as the runner length. This runner length allows the horsepower/torque curves to be changed by varying them. A shorter runner will produce more peak HP, while the longer runner will shift the torque curve lower in the rpm band. With the Aprilia’s 11000 RPM redline, and current gearing options it estimated that the majority of competition will be run in the 6500 to 9500 RPM range. This is helpful to know, as the runner length can be tuned to perform best within the specified range. Figure 1 below displays a common aftermarket exhaust system for the Aprilia 550 utilizing equal length runners which the current exhaust does not offer.

Figure 1; Equal length runner Aprilia exhaust system. Source: http://www.maxmoto.co.uk/images/aprilia_ev06_exhaust_8797232.jpg
**Muffler Design:**
The main focus of muffler design is to meet the maximum sound requirements while maintaining engine performance and efficiency. The car’s system will be designed to utilize a sound absorption (straight through) type muffler rather than a sound canceling (baffled) muffler for the sole reason of increased flow from the absorption over the sound canceling muffler. The basics of this design revolve around the exhaust running through a perforated tube with filler material packed around it rather than running through chambers which muffle the sound. The filler material allows some of the sound to be absorbed into itself while maintaining good flow characteristics. The nature of this sound absorption muffler allows the noise level to be tuned with based on different filler materials inserted inside the case.

![Sound absorption muffler cut-away view](http://www.autoexcellenceonline.com/muffler-exhaust-system.html)

**Flow Characteristics:**
Many performance 4 stroke motor bike exhausts in the recent years have developed expansion chambers designs to aid exhaust flow. When comparing the exhaust setups of these bikes to other 4 stroke vehicle they chassis layout allows for rather long exhaust runners. To optimize both exhaust flow and power output many performance exhausts have gone to a design that incorporates some sort of expansion chamber located close to the engine. Figure 3-5 show various types of these expansion chambers. Manufactures claim as much as a 8 percent increase in horsepower with the use of these header designs. The chamber creates a larger place for the expansions and contraction of exhaust gases much like a merge pipe in a modern 4-10 cylinder engine would. This merge pipe allows proper cylinder scavenging to occur where in an ordinary constant diameter pipe would not allow for this. Many of these expansion chambers lower the exhaust close to 1.5db which is also a benefit as a less restrictive muffler can then be used.
Figure 3; FMF’s exhaust expansion chamber design.  Source: http://img234.imageshack.us/img234/4462/fmf0fg.jpg

Figure 4; Doma’s Aprilia exhaust system.  Source: http://images.24mx.se/products/xlarge/132750-domahelsystem.jpg
**Results:**
A redesign of the current Formula SAE Aprilia 550 exhaust design should increase efficiency while maintaining the SAE noise criteria. When comparing the current exhaust noise to our limit, significant flow improvements can be made with the help of both an expansion chambers and a tunable noise absorbing muffler. The switch from our current unequal length headers to equal lengths should allow both cylinders to operate at equal efficiency. These designs can be validated during dynamometer testing where small changes can be made and results easily viewed.

**Sources:**