GT Power Simulation of the Influence of Exhaust Manifold Design on Sound Quality

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GT Power User Conference – Detroit 2009
Objective

- Study the exhaust manifold design factors that influence noise
  - Asymmetry
  - Restriction
  - Cylinder-Cylinder Interference

- Characterize the Engine Noise Source Characteristics
  - Ps and Zs from the MultiLoad Template
Why is there noise in the Exhaust?

- The noise is caused by the unsteady mass flow rate from the engine. This leads to oscillations in the exhaust pipe which are emitted at the outlet as tail pipe noise.

- If the flow from the engine was a steady (non-oscillating) flow there would be no order noise.
Why is 0.5 OE suppressed in a 2 cylinder engine?

All orders are ‘shifted’ 360°CA for the second cylinder since it fires 1 revolution later.
Why is 1 EO not suppressed in a 2 cylinder engine?
What if firing is not 360° separated for a twin cylinder?

0.5 EO Cylinder 1

0.5 EO Cylinder 2
Phase Shift 45°

Total 0.5 EO
Only Partial Cancellation
-6dB re 1 Cylinder
What else can cause incomplete 0.5 EO Cancellation?

An amplitude shift can be caused by;

- incomplete combustion in 1 cylinder
- inconsistent cylinder-to-cylinder Veff
- or imbalanced restriction in exhaust manifolds.
Singles & Twins

- Single Cylinder (4 Stroke)
- Horizontally Opposed Twin (360° Firing)
- 45°V Twin Common Crank Throw (405°-315°)
Singles & Twins: Source Level (Ps)

0.5 EO Engine Source Strength, Ps

1 EO Engine Source Strength, Ps

1.5 EO Engine Source Strength, Ps

2 EO Engine Source Strength, Ps

Ps, dB(lin) re 20µPa

100 200 300 400 500 600 rpm

Single
360° H-O Twin
45° V Twin

Single
360° H-O Twin
45° V Twin

Single
360° H-O Twin
45° V Twin

Single
360° H-O Twin
45° V Twin
4 Cylinder  (Firing 1-2-4-3)

4-2-1 with equal length primary & secondary

I4 with Log Manifold

Boxer 4

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V6
(Firing 1-4-2-5-3-6 = R-L-R-L-R-L)

6-2-1 Symmetrical

Asymmetric Log

90° V6
Firing 90° 150° 90° 150° 90° 150°

6-2-1 Manifold

Log Manifold

Odd Fire V6 6-2-1
Cylinder Interference in Twin Cylinder Engines

Cylinder 1

Cylinder 2

Mass Flow Rate [kg/s]

Crank Angle [deg]
Uneven bank-to-bank firing on a cross-plane crank V8 causes variation from cylinder to cylinder. A 8-1 manifold can overcome this (as can a flat plane crank).
V8 (Firing 1-3-7-2-6-5-4-8)

Dual V8 – No Bank-to-Bank mixing.

H-Pipe V8 with equal length primary

X-Pipe V8 with equal length primary

8 to 2 Manifold

H-Pipe

X-Pipe
V8 (Firing 1-3-7-2-6-5-4-8)

- Y-Pipe V8 with equal length primary
- Y-Pipe V8 with equal primary, Unequal Secondary
- 8-into-1 V8 with equal length primary

Graphs showing pressure levels at different rpm for 8-2-1 Y Manifold, Asymmetric Y-Pipe, and 8 to 1 Manifold for 2.5 EO, 1.5 EO, 2 EO, and 4 EO conditions.
H-Pipe ‘Tuning’ on a V8 Application

Varying the **H-pipe** diameter can have a large affect on half order levels. This is used as another tuning parameter to achieve the best sound quality.
modeFrontier Optimization V6→V8: Work Flow

Latin Hypercube

MOGA
source Pressure Level (dB) at 2000 rpm

- 6-2-1 Baseline
- V8 with H-pipe

Frequency (Hz)

Ps at 2000 rpm
mode Frontier Optimization V6 → V8: Results

Baseline

V6 (6-2-1)
Conclusions

Multi-Cylinder Engines have the potential to significantly suppress half orders.

But there are many design features which can re-introduce half order content;

**Engine Factors**
- Odd-Fire Engine
- Even Fire engine with Odd-Fire on each bank

**Manifold Factors**
- Length Differences - introduces phase errors
- Restriction Differences - introduces amplitude errors
- Inadequate Bank-to-Bank Mixing