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

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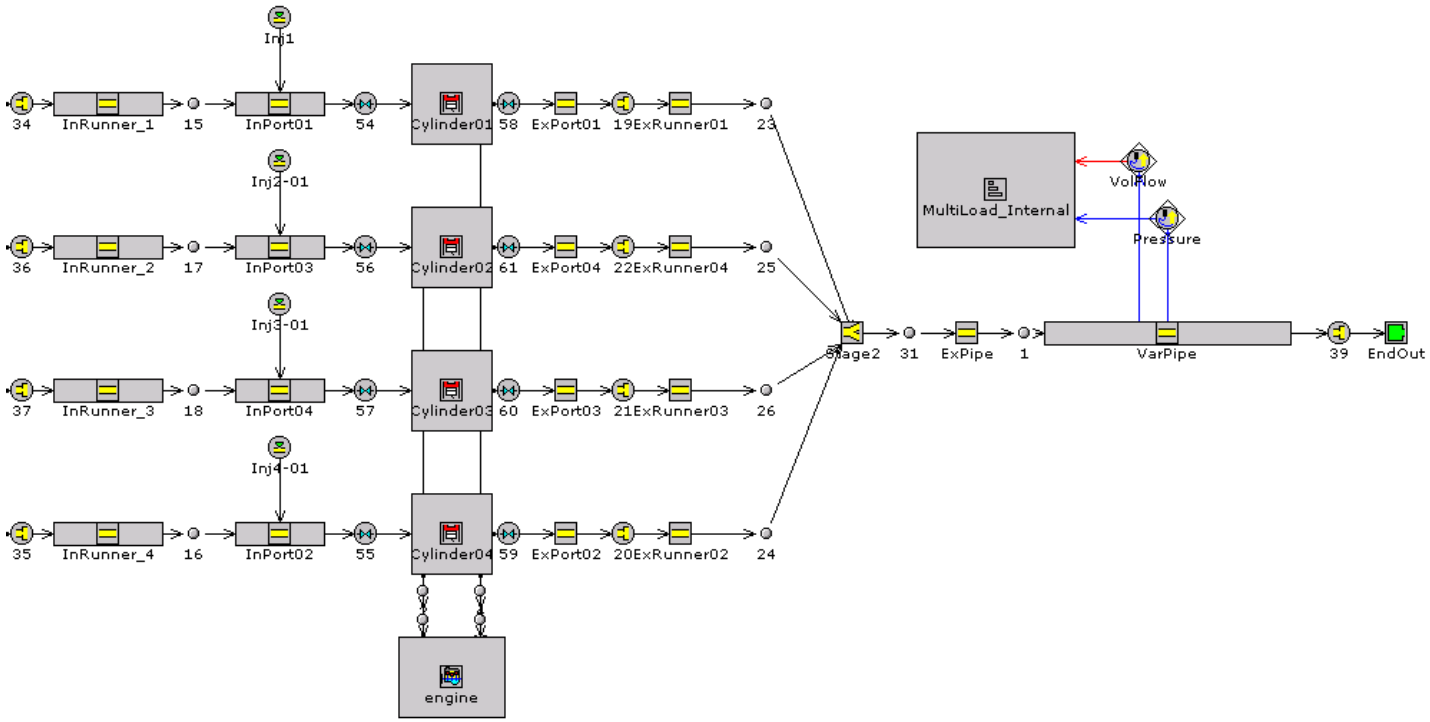
Emcon Technologies

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



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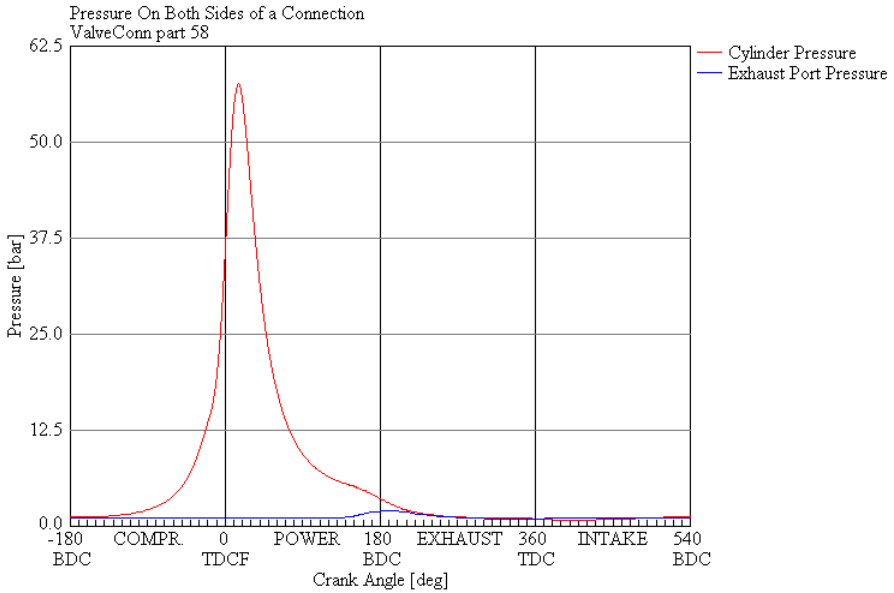
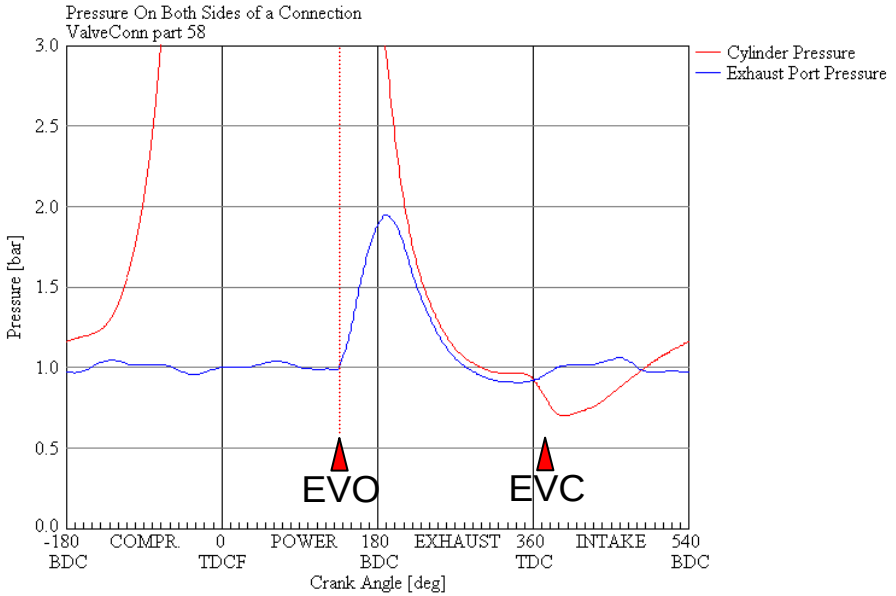
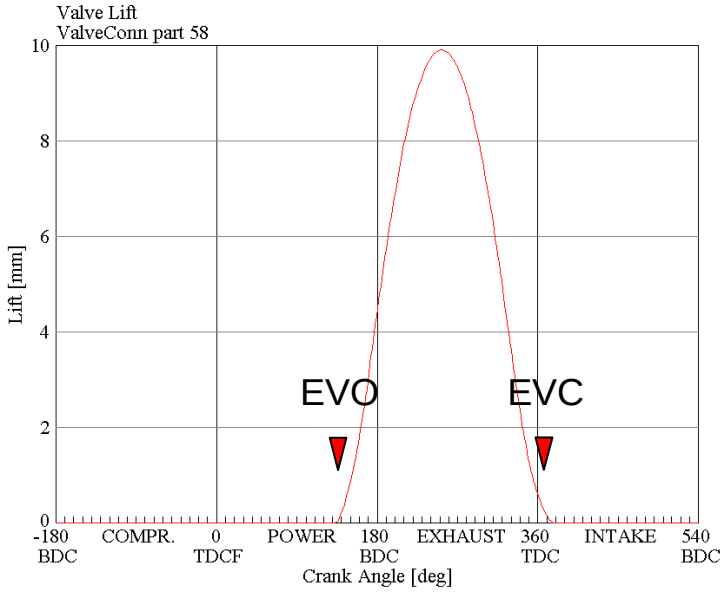
Why is there noise in the Exhaust?

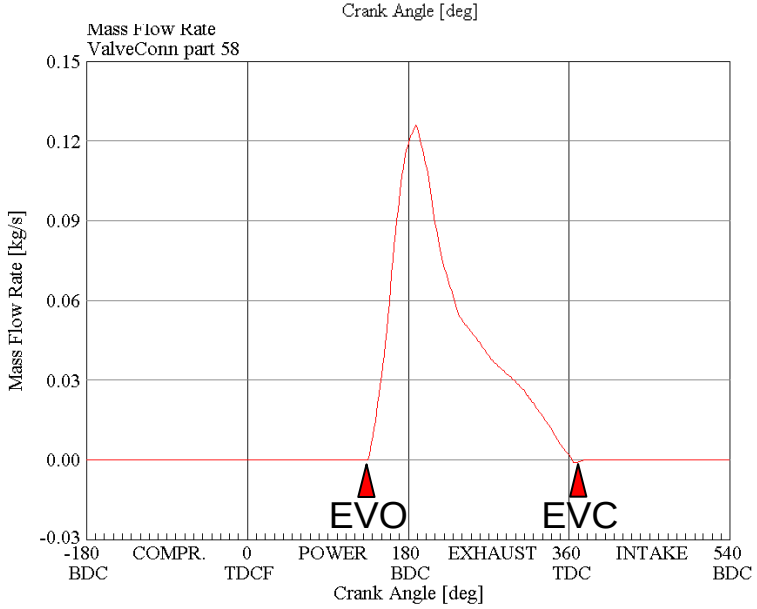
•The noise is caused by the unsteady mass flow rate from the engine. This leads to oscillations in the exhaust pipe which are emitted at the outlet as tail pipe noise.

•If the flow from the engine was a steady (non oscillating) flow there would be no order noise.

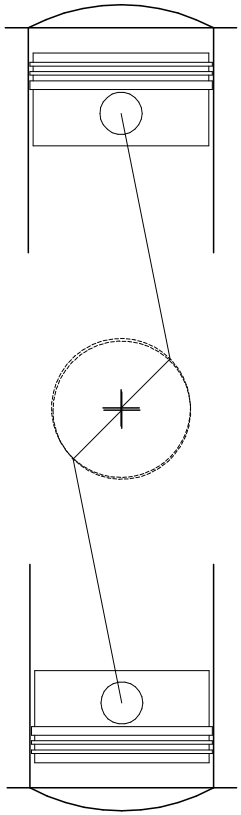


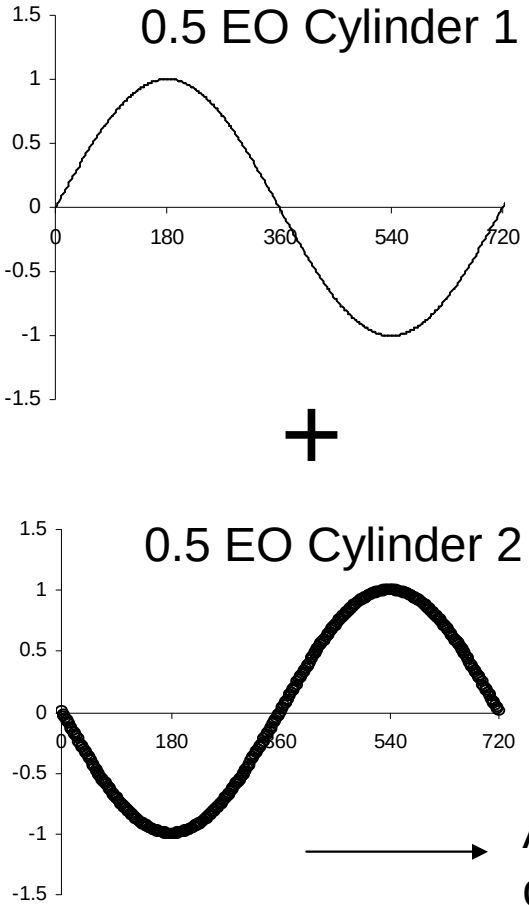




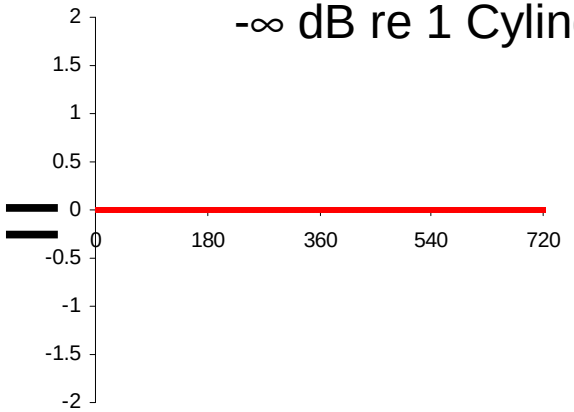


Why is 0.5 OE suppressed in a 2 cylinder engine ?



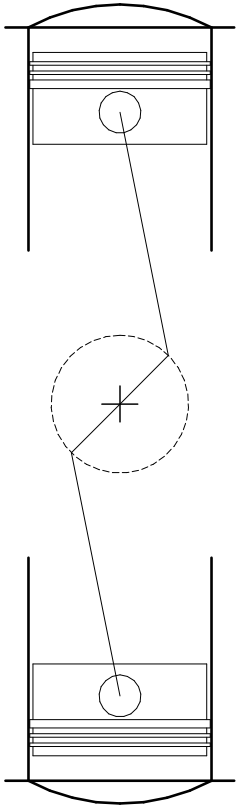


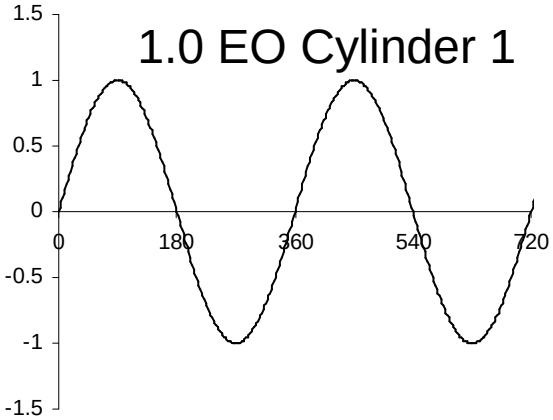
0.5 EO Summation
Total Cancellation
-∞ dB re 1 Cylinder

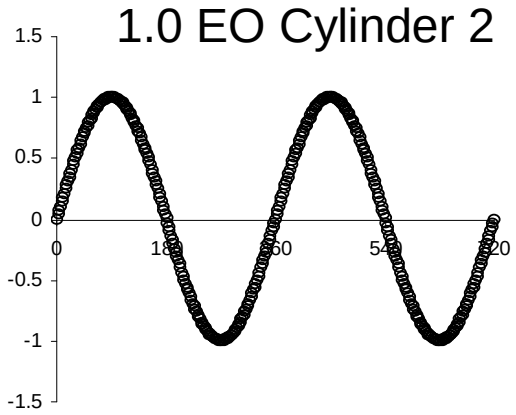


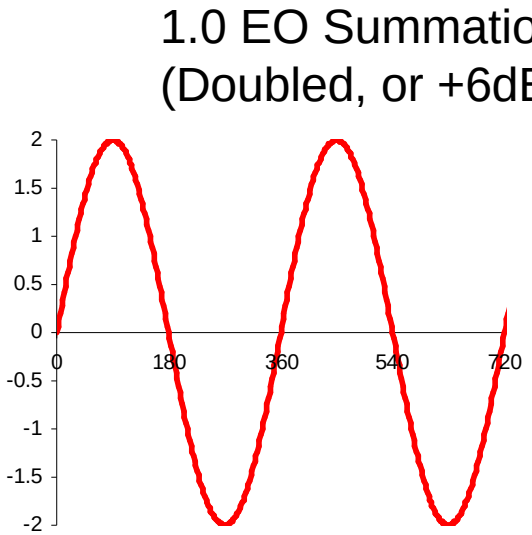
All orders are ‘shifted’ 360°CA for the second cylinder since it fires 1 revolution later.

Why is 1 EO not suppressed in a 2 cylinder engine ?

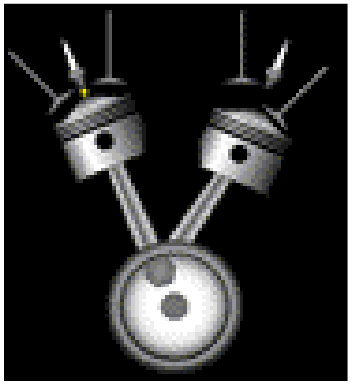


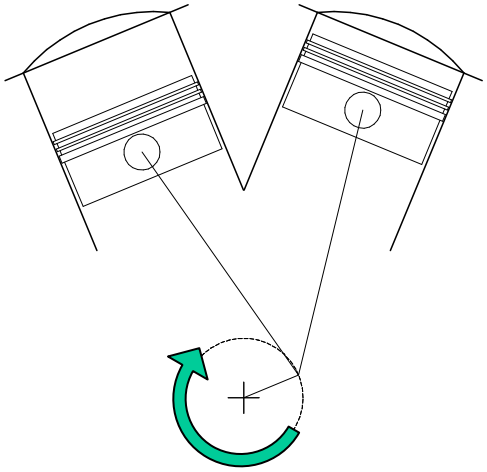


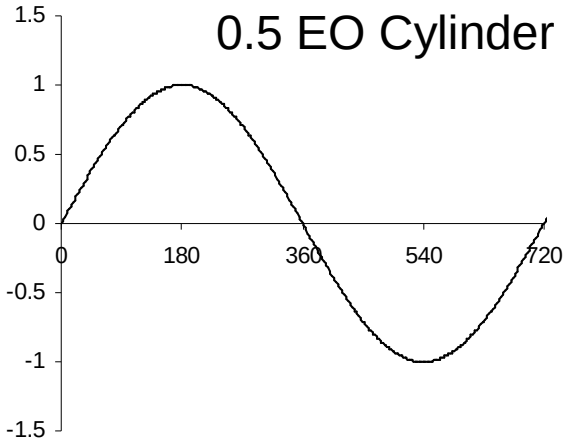


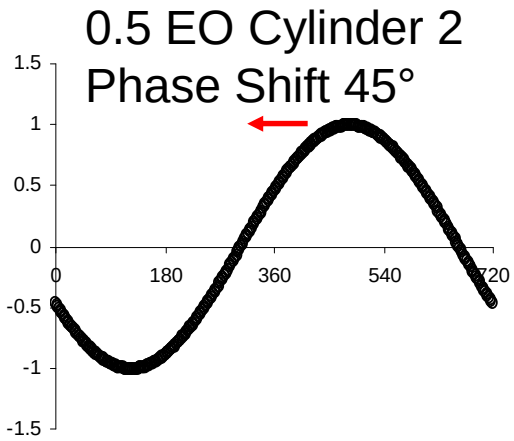


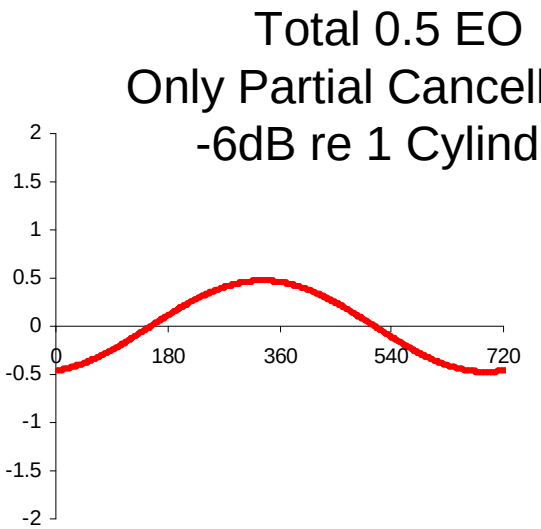
What if firing is not 360° separated for a twin cylinder ?



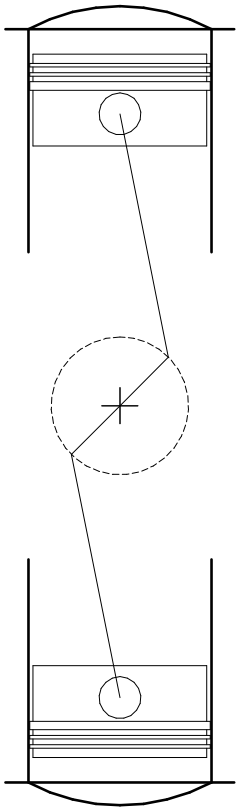


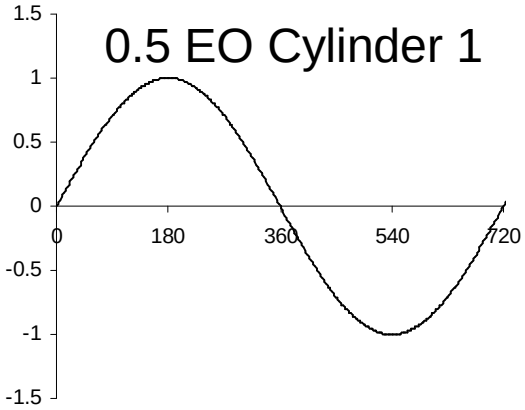


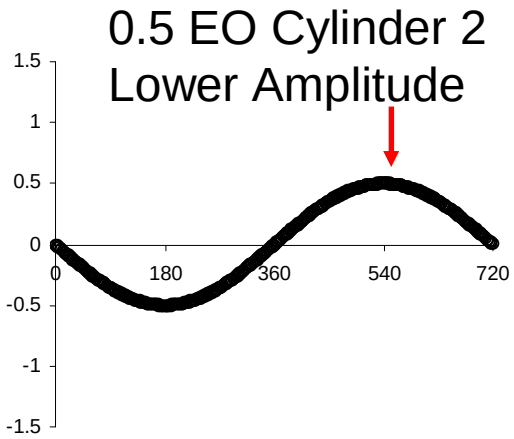


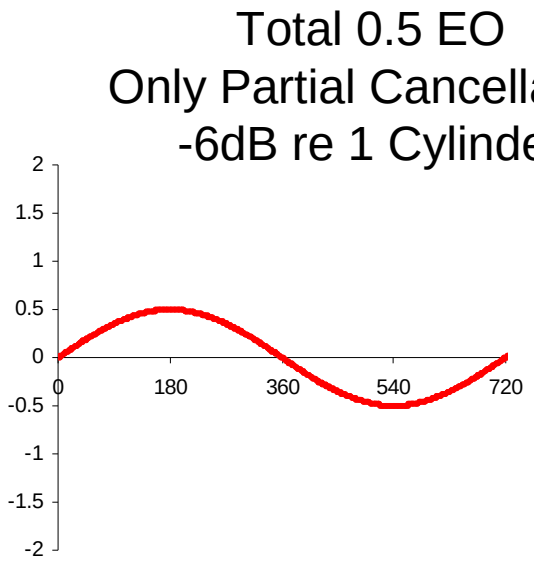


What else can cause incomplete 0.5 EO Cancellation ?





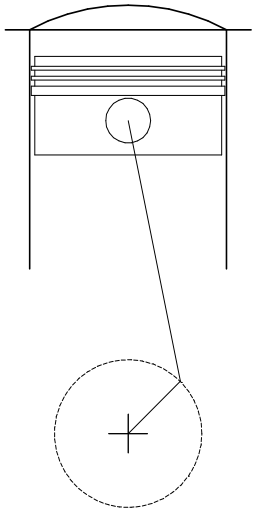




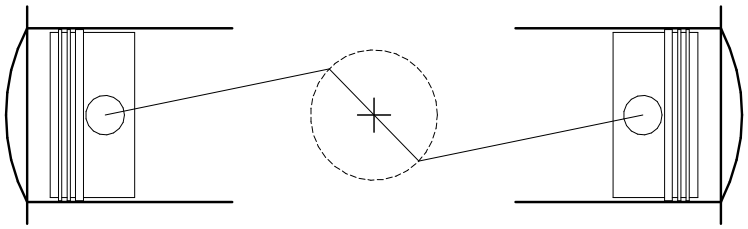
An amplitude shift can be caused by;

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

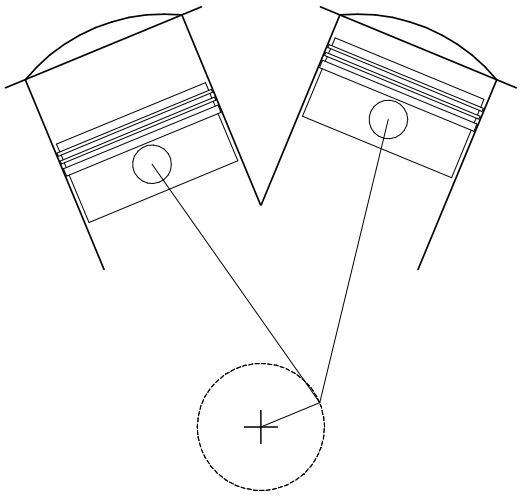
Singles & Twins



Single Cylinder
(4 Stroke)



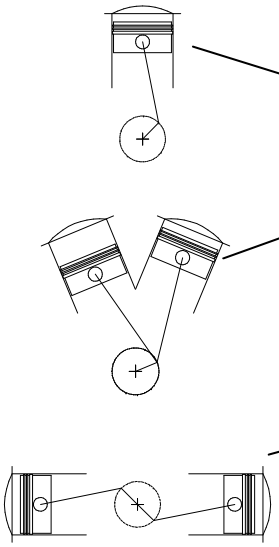
Horizontally
Opposed Twin
(360° Firing)

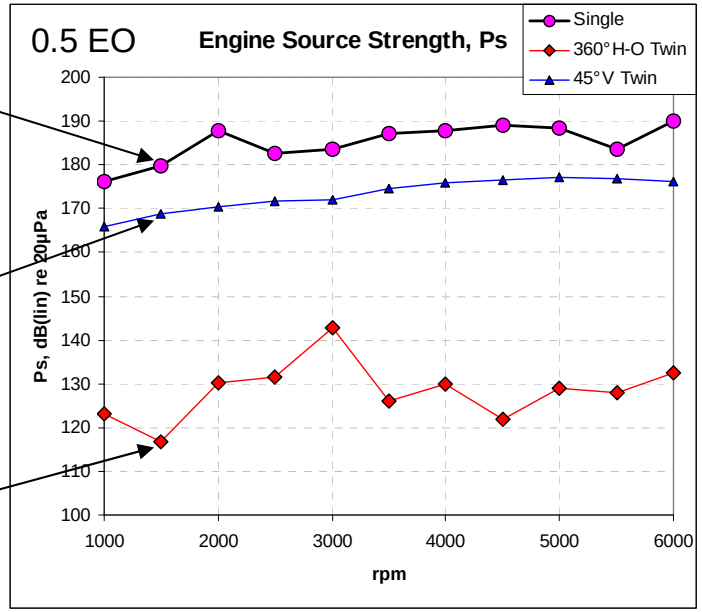


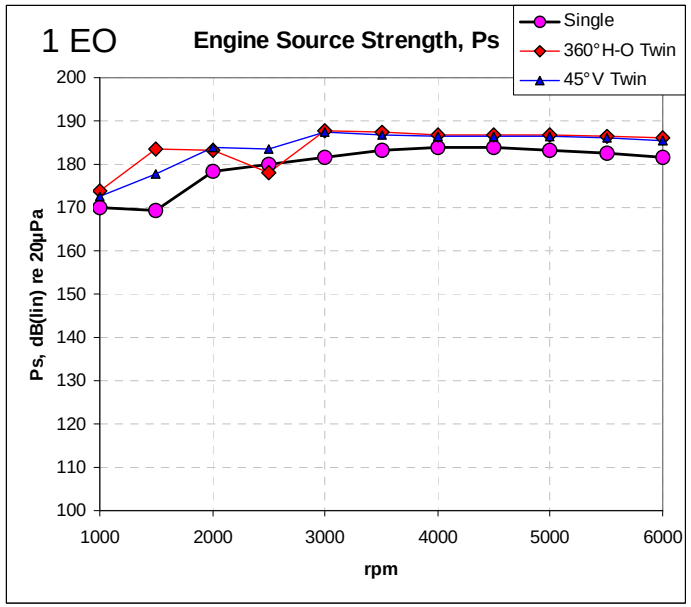
45° V Twin
Common
Crank Throw

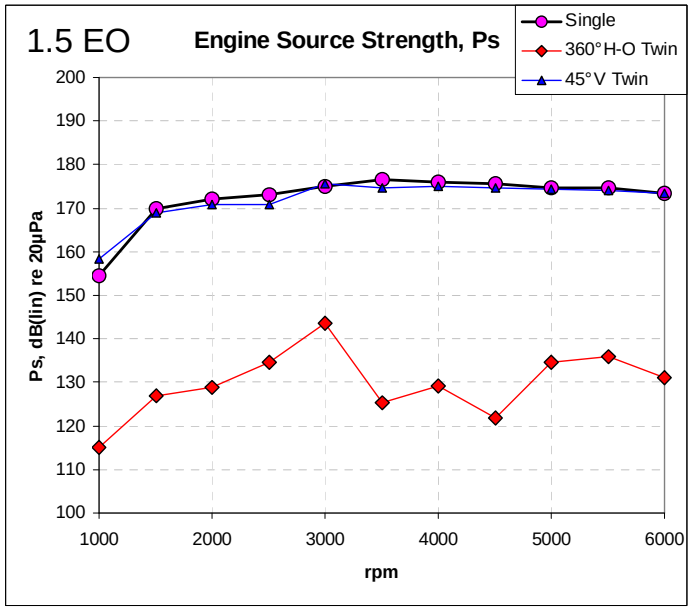
(405°-315°)

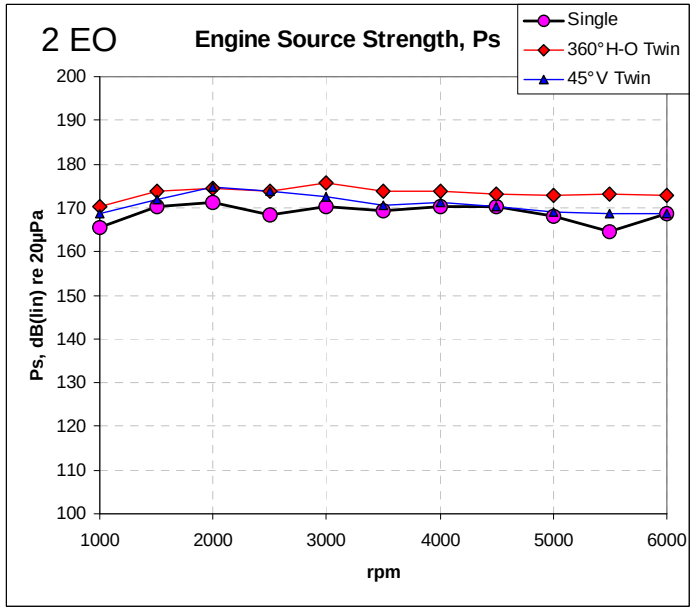
Singles & Twins: Source Level (Ps)



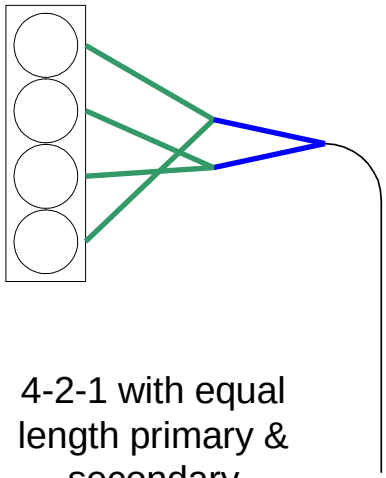




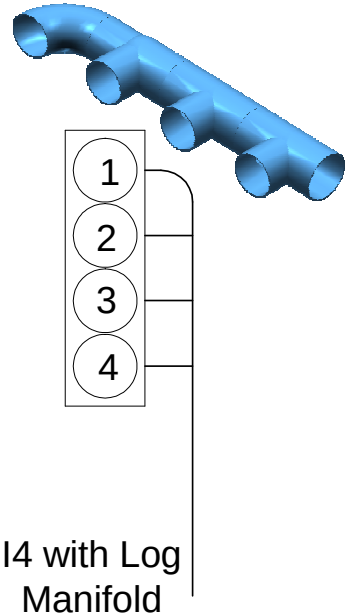




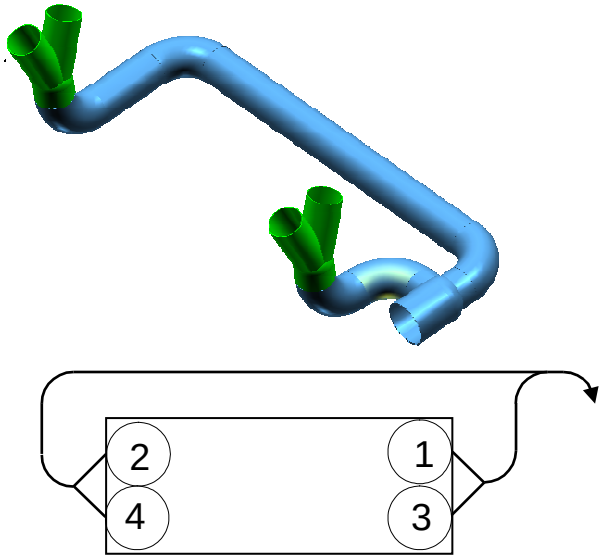
4 Cylinder (Firing 1-2-4-3)



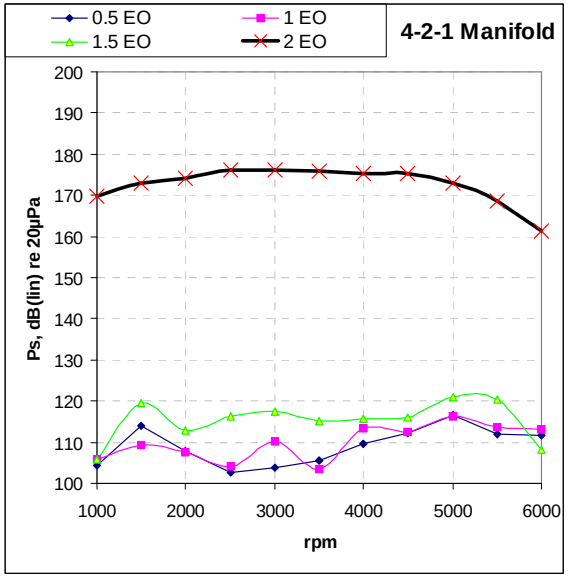
4-2-1 with equal length primary & secondary

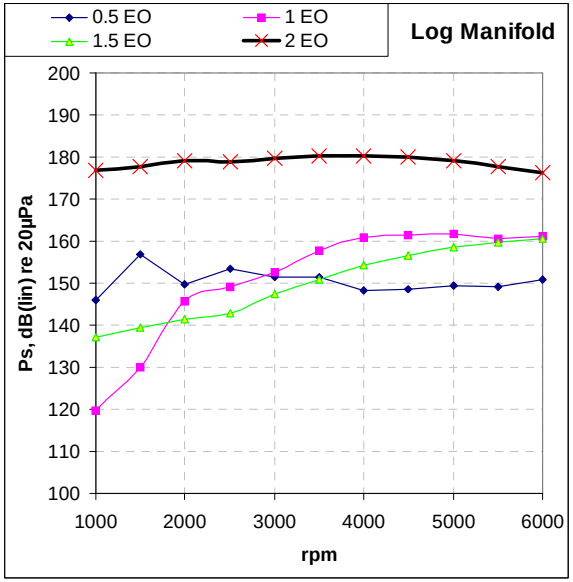


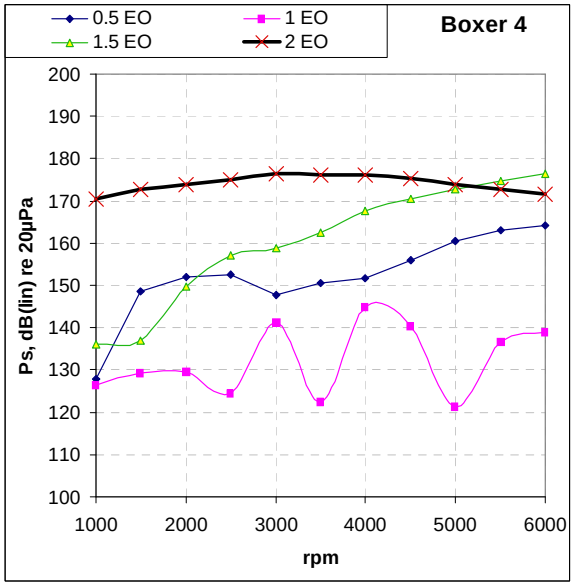
I4 with Log Manifold



Boxer 4



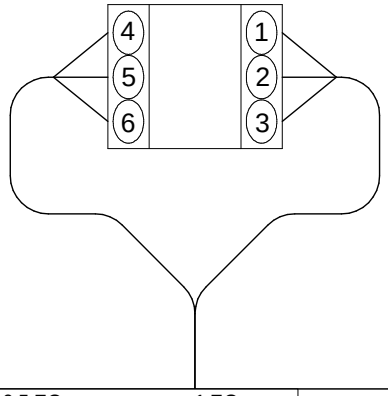


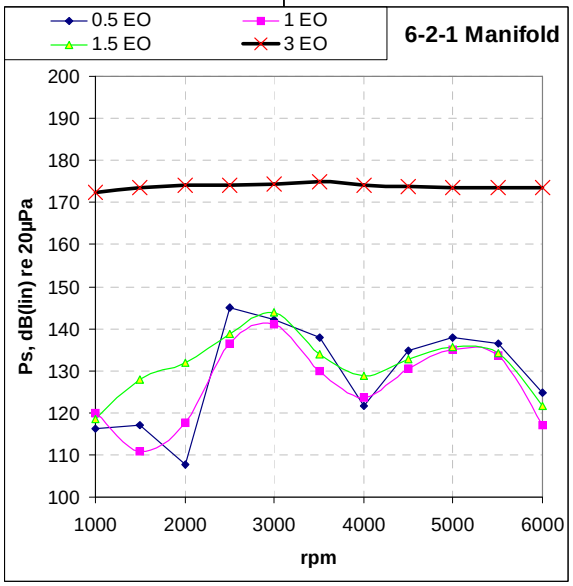


V6

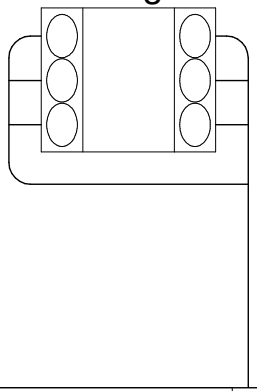
(Firing 1-4-2-5-3-6 = R-L-R-L-R-L)

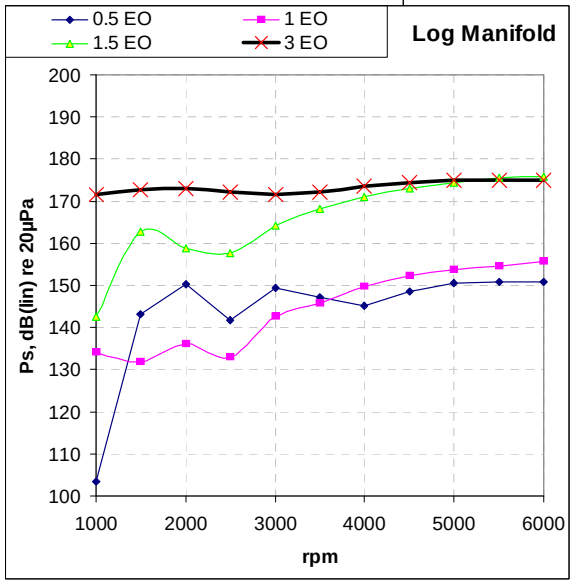
6-2-1 Symmetrical





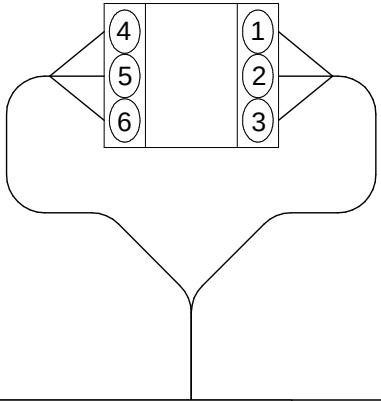
Asymmetric Log

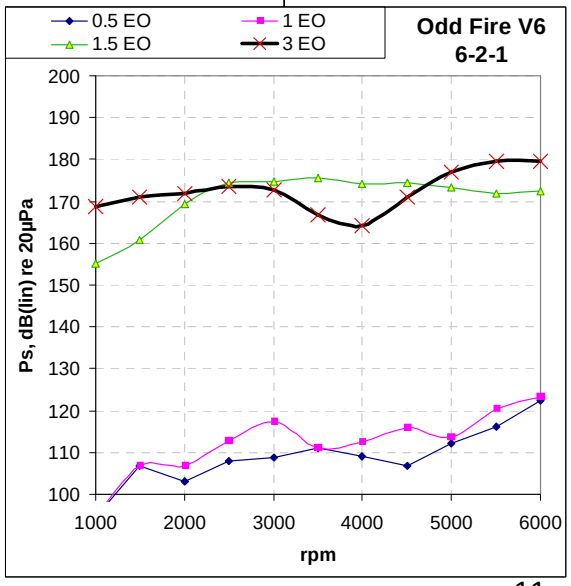




90°V6

Firing 90°-150°-90°-150°-90°-150°





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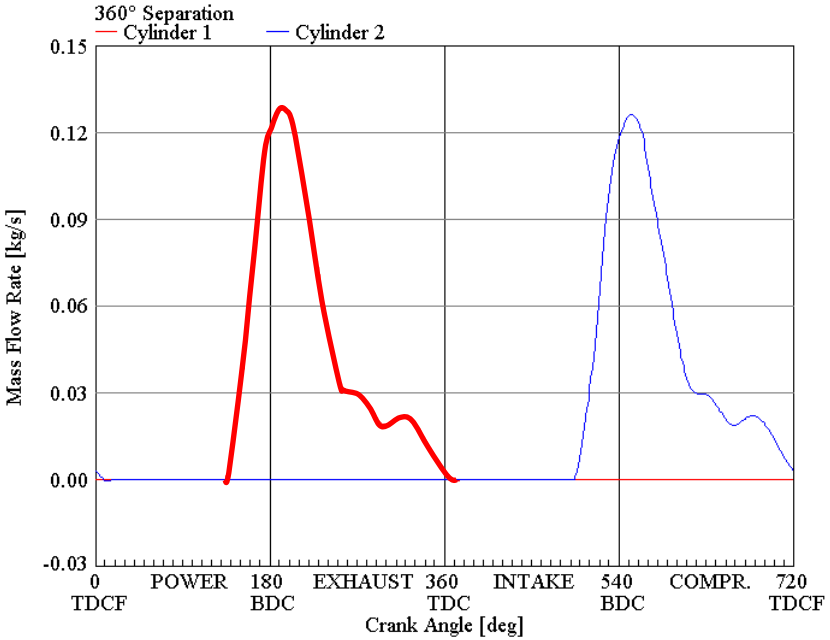
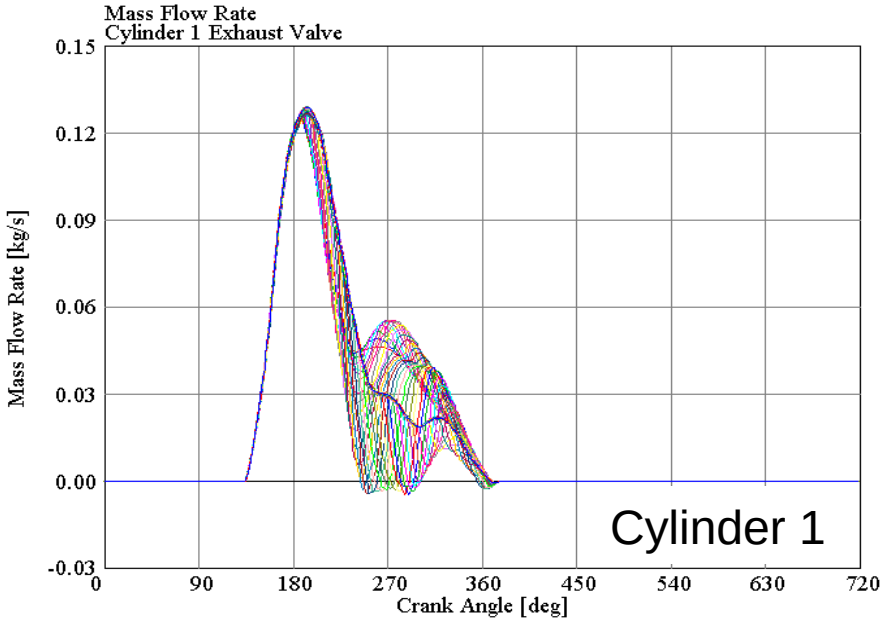
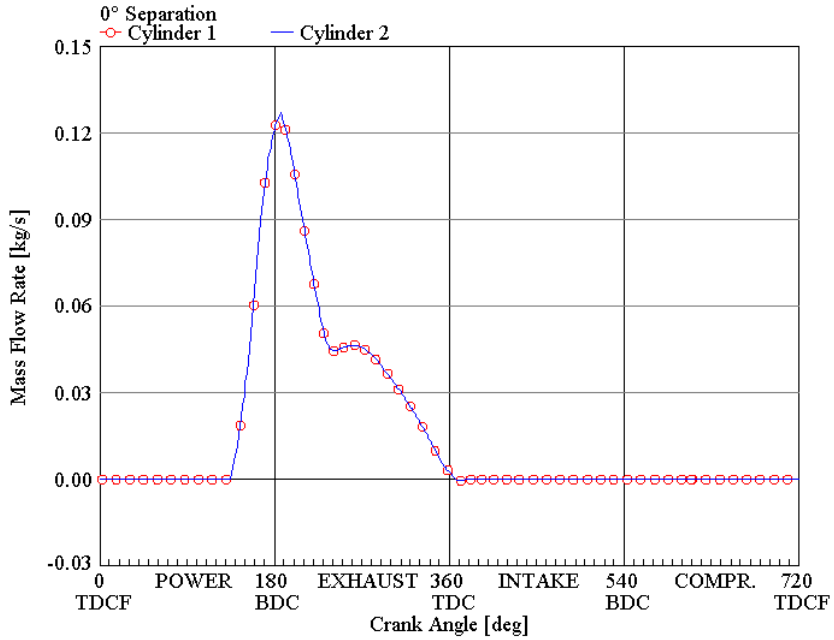
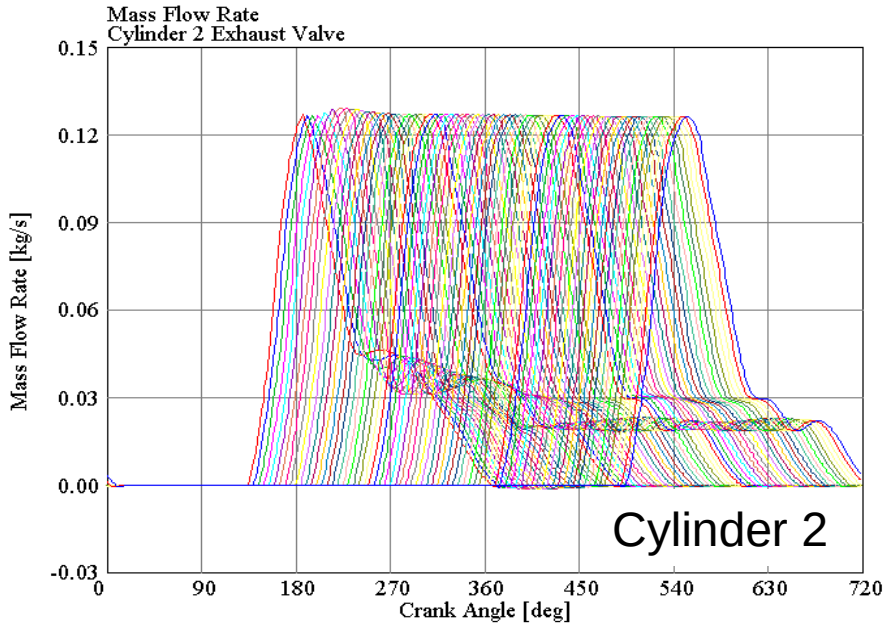
Cylinder Interference in Twin Cylinder Engines









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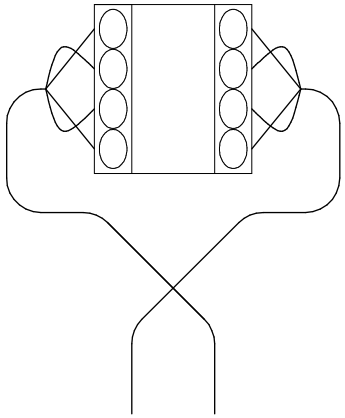
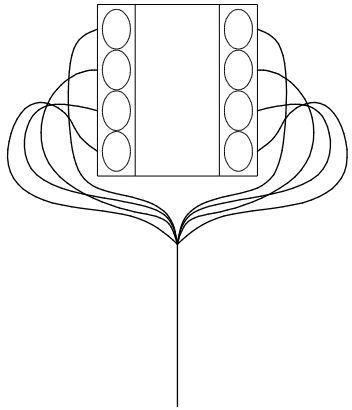
Cross Plane V8

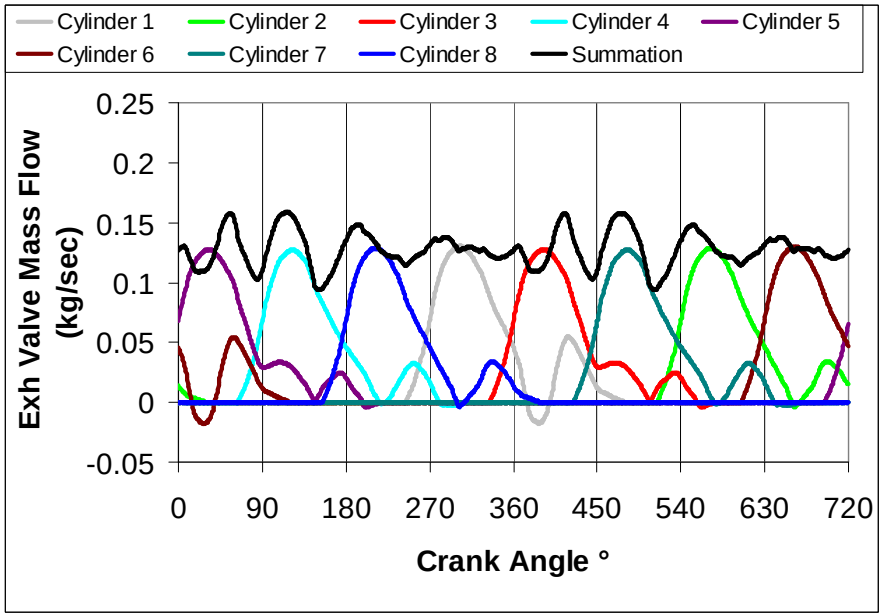
(Firing 1-3-7-2-6-5-4-8 = R-R-L-R-L-L-R-L)

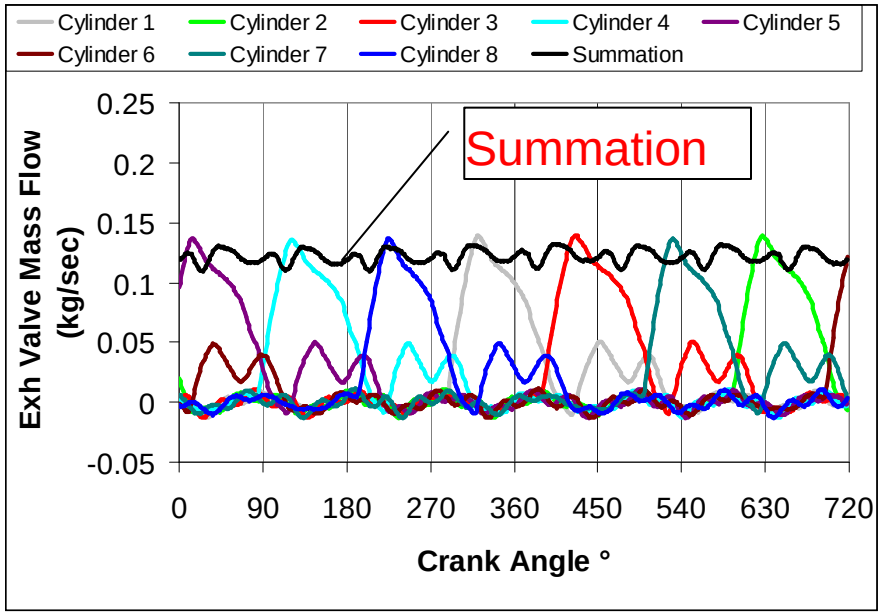
8-2-X-2



Symmetrical
8-1 Manifold







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).

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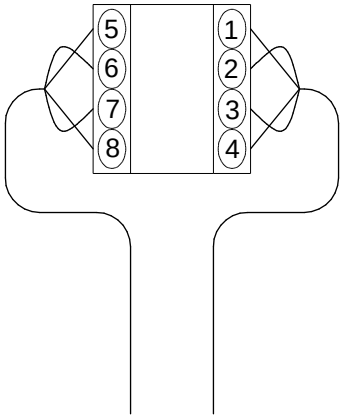
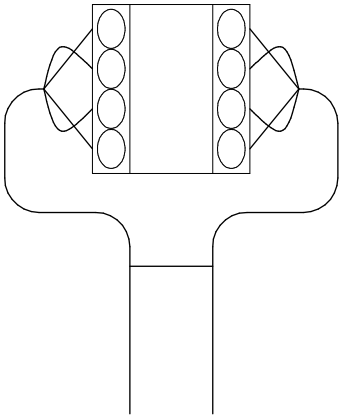
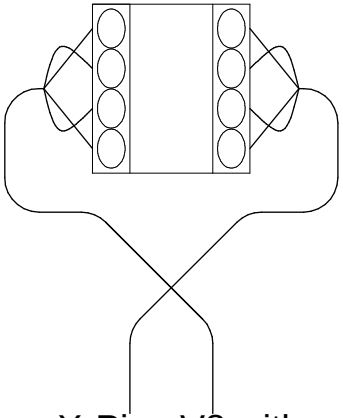
V8 (Firing 1-3-7-2-6-5-4-8)



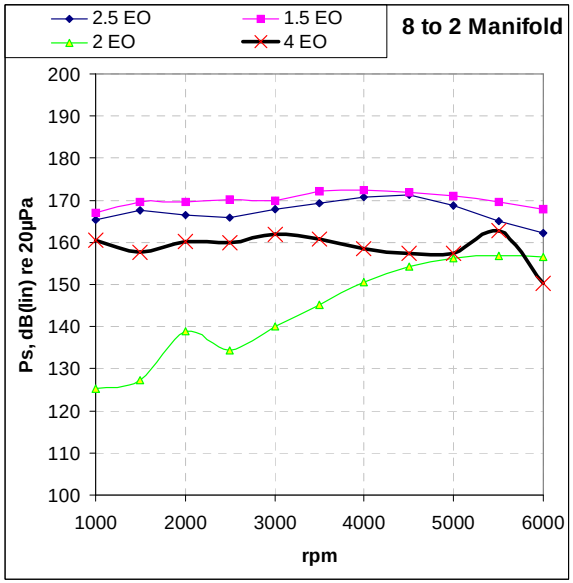
Dual V8 – No Bank-to-Bank mixing.

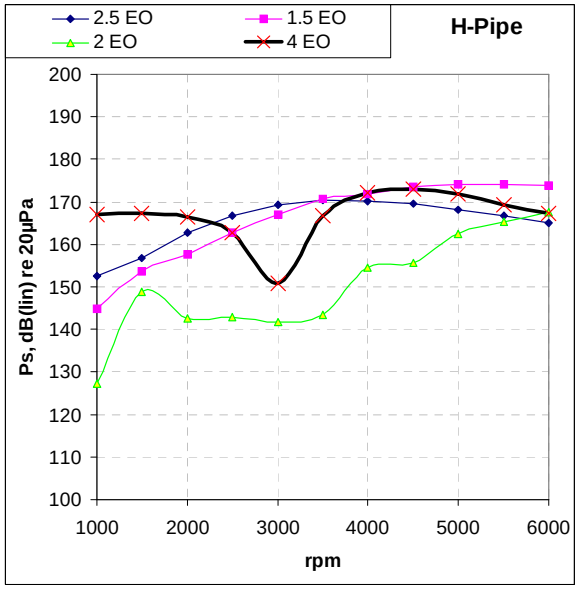


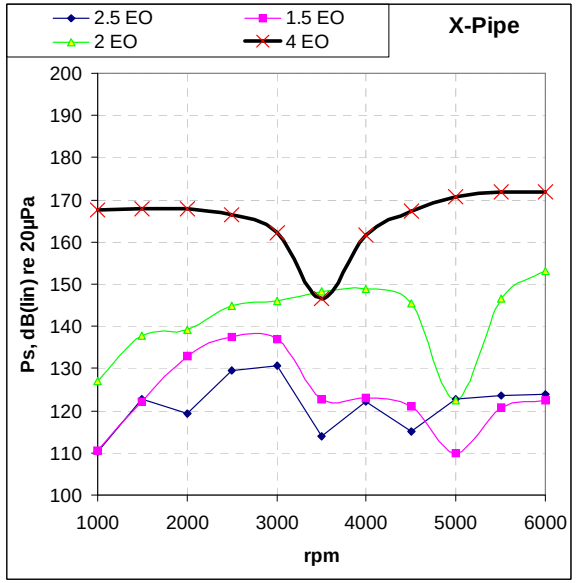
H-Pipe V8 with equal length primary



X-Pipe V8 with equal length primary







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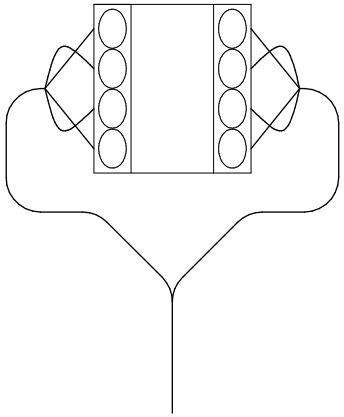
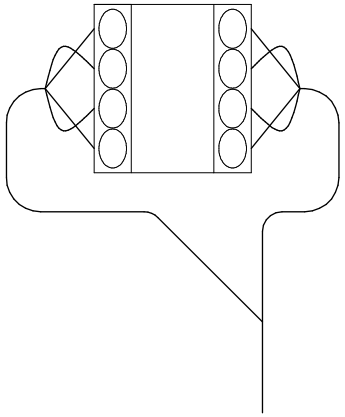
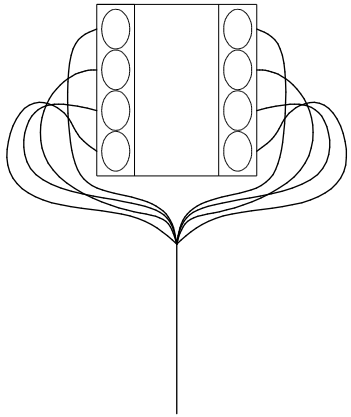
V8 (Firing 1-3-7-2-6-5-4-8)



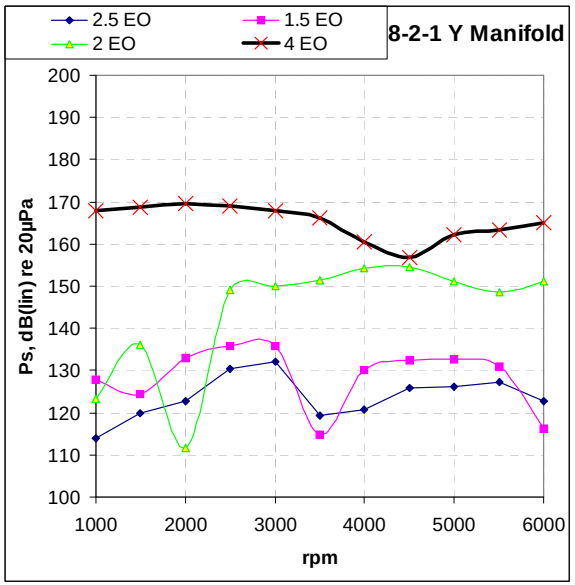
Y-Pipe V8 with equal length primary

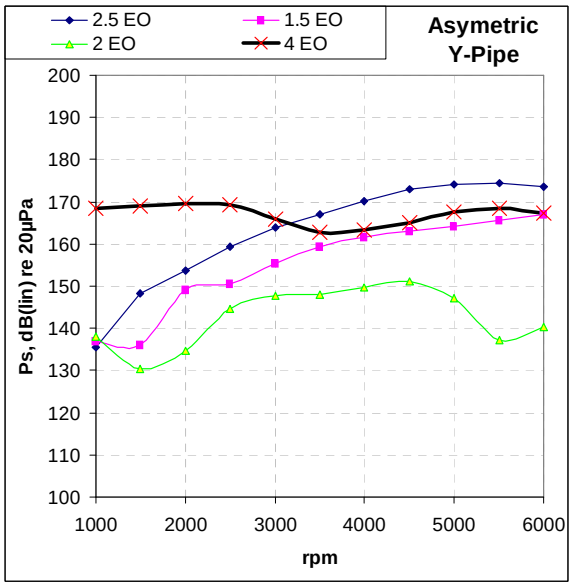


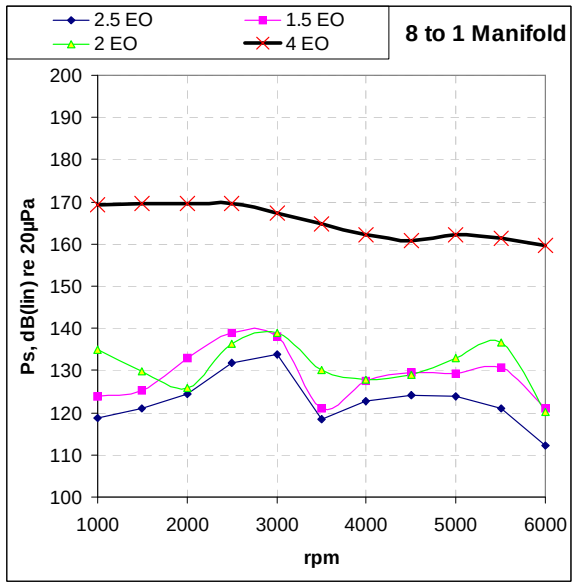
Y-Pipe V8 with equal primary, Unequal Secondary



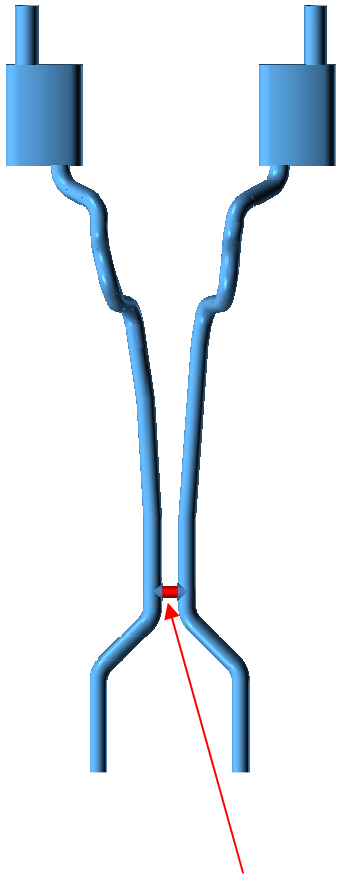
8-into-1 V8 with equal length primary

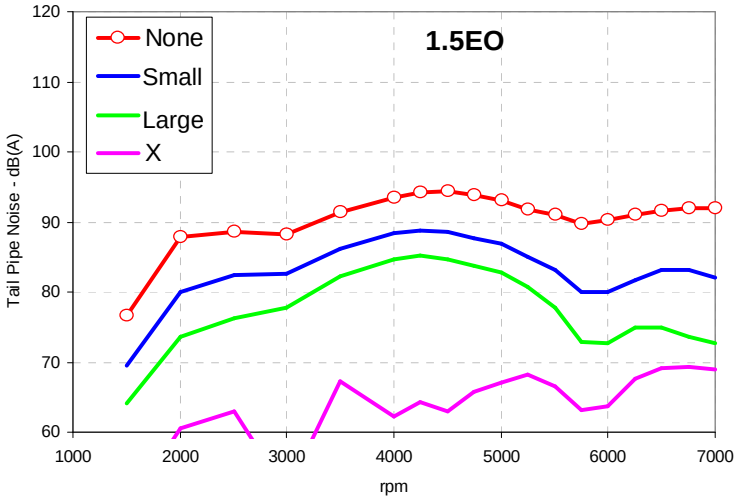


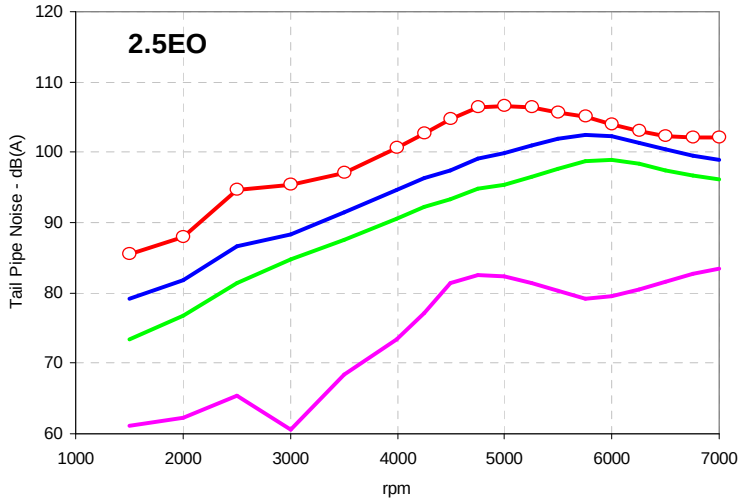


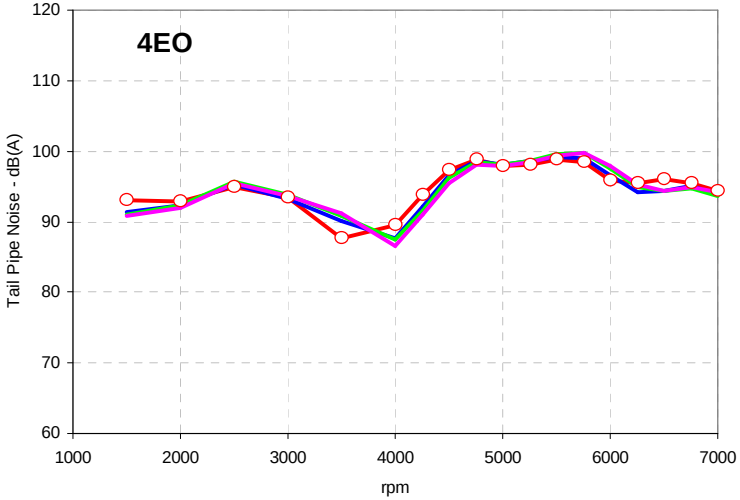


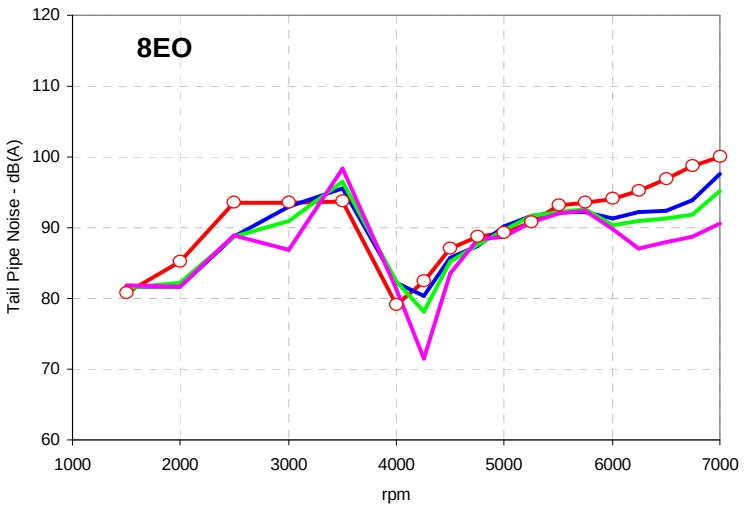
H-Pipe 'Tuning' on a V8 Application











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.

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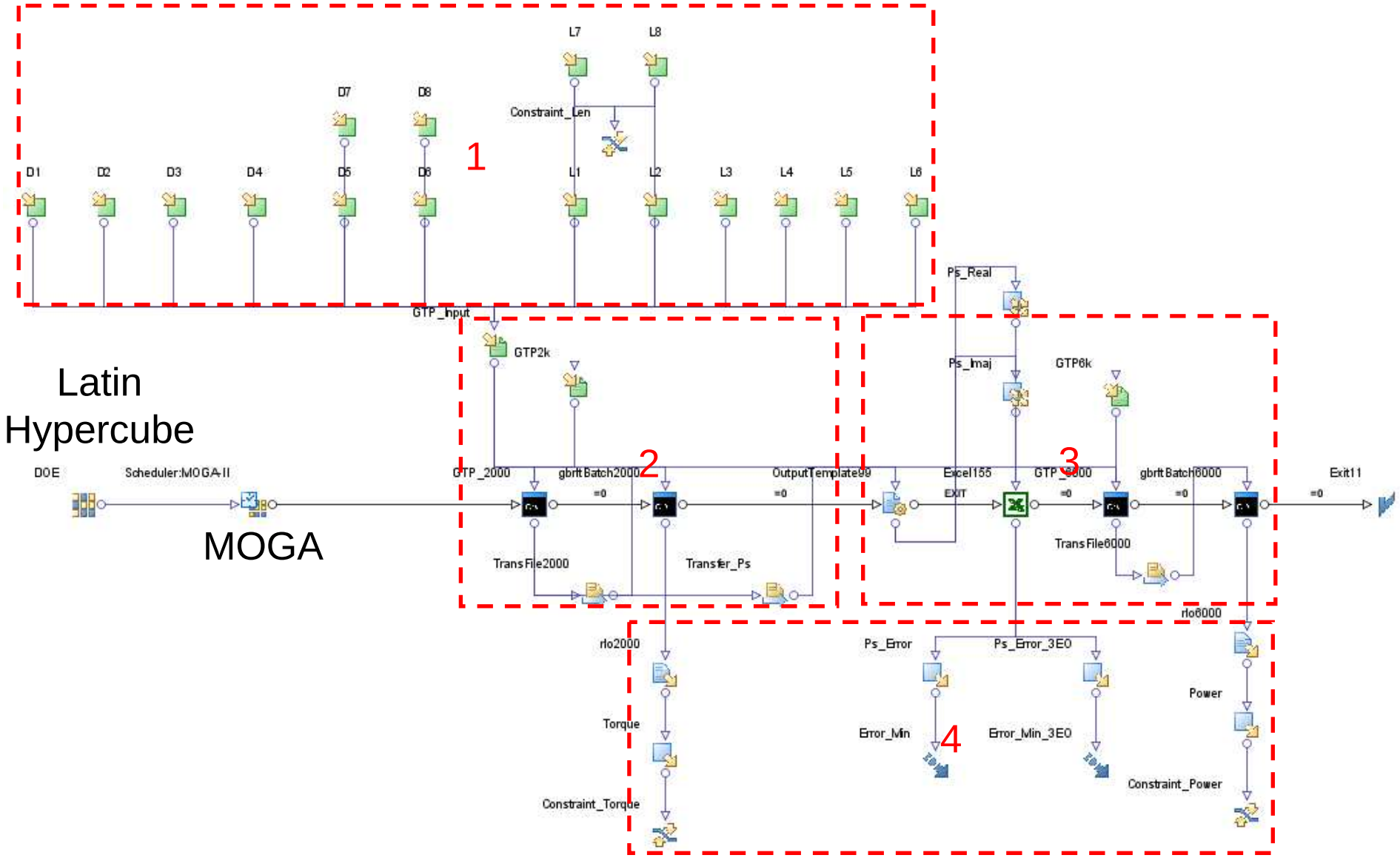
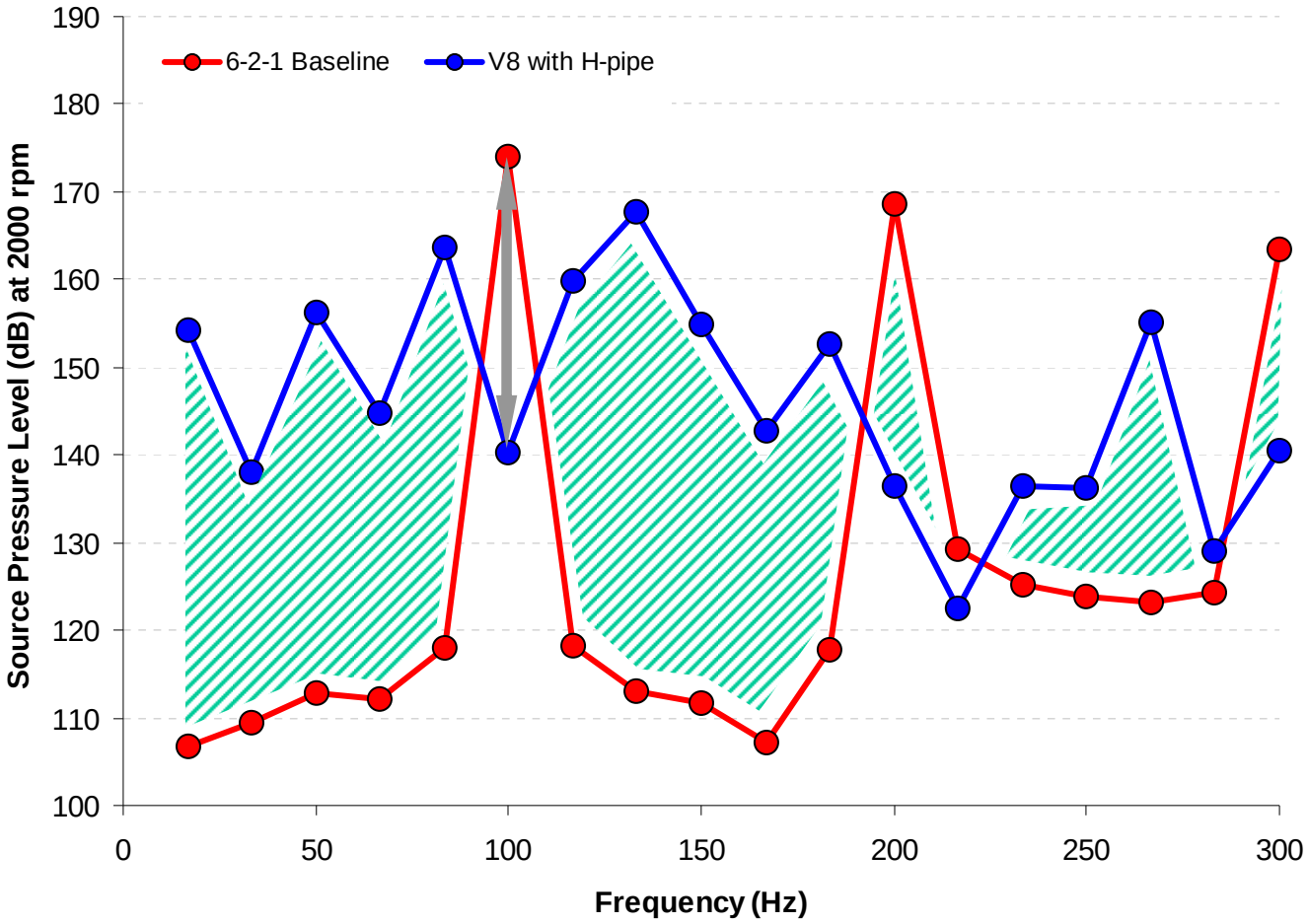
modeFrontier Optimization V6→V8 : Work Flow



modeFrontier Optimization V6→V8 : Targets

Ps at 2000 rpm



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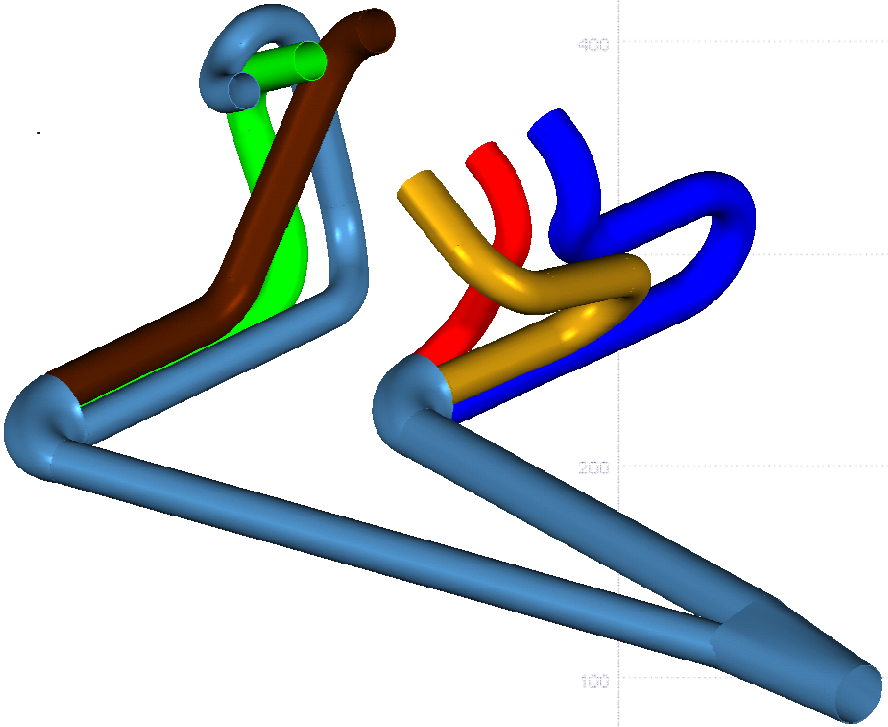
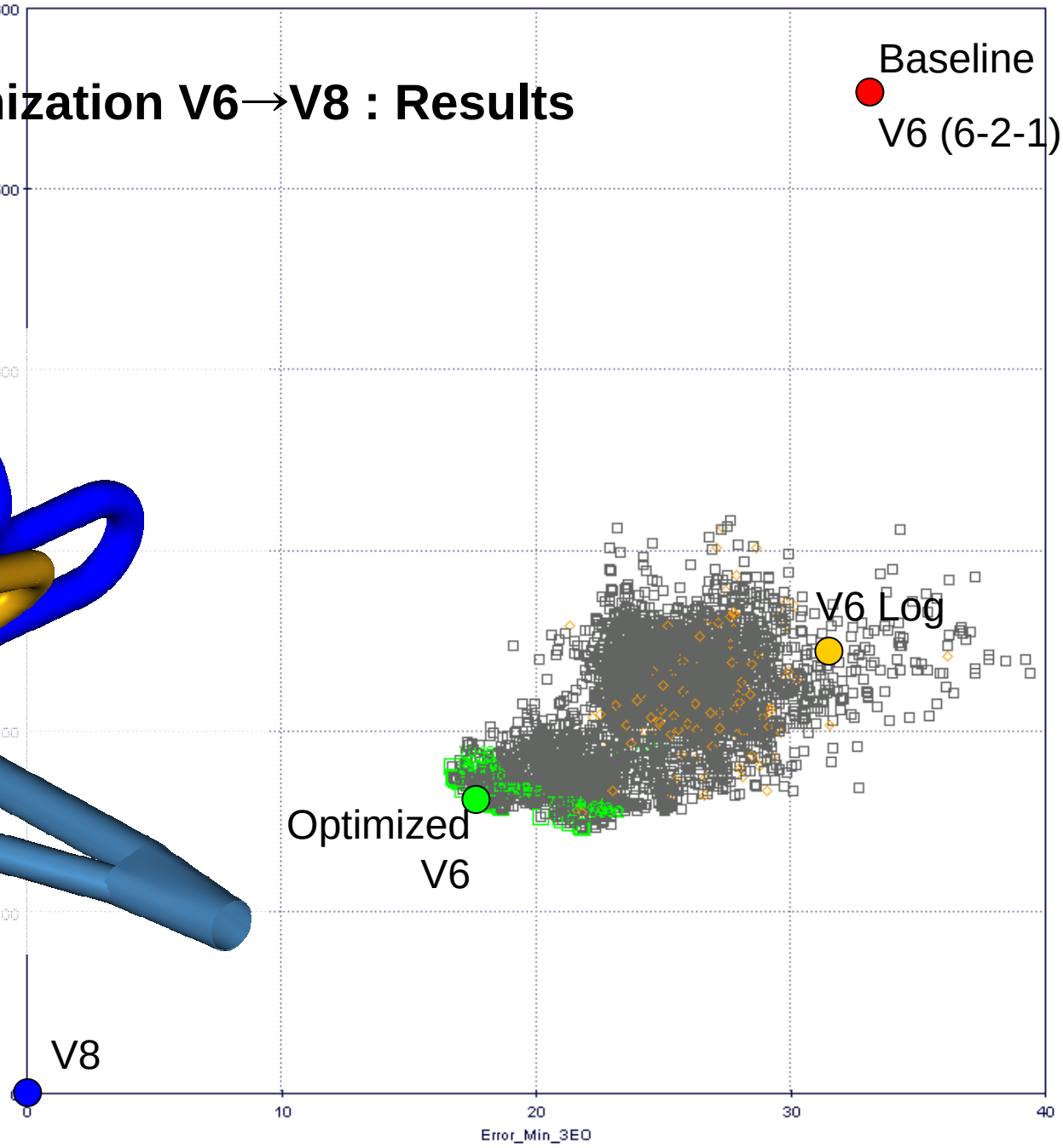
modeFrontier Optimization V6→V8 : Results





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