



SWANSEA METROPOLITAN UNIVERSITY

PRIFYSGOL FETROPOLITAN ABERTAWE

Advanced Engine Technology

Exhaust System Design

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Contents

- Some final notes on cylinder heads
- Requirements of an Exhaust System
- Comparison of road and race systems
- Kinetic Energy Scavenging
- Pressure Wave (resonance) exhaust gas scavenging

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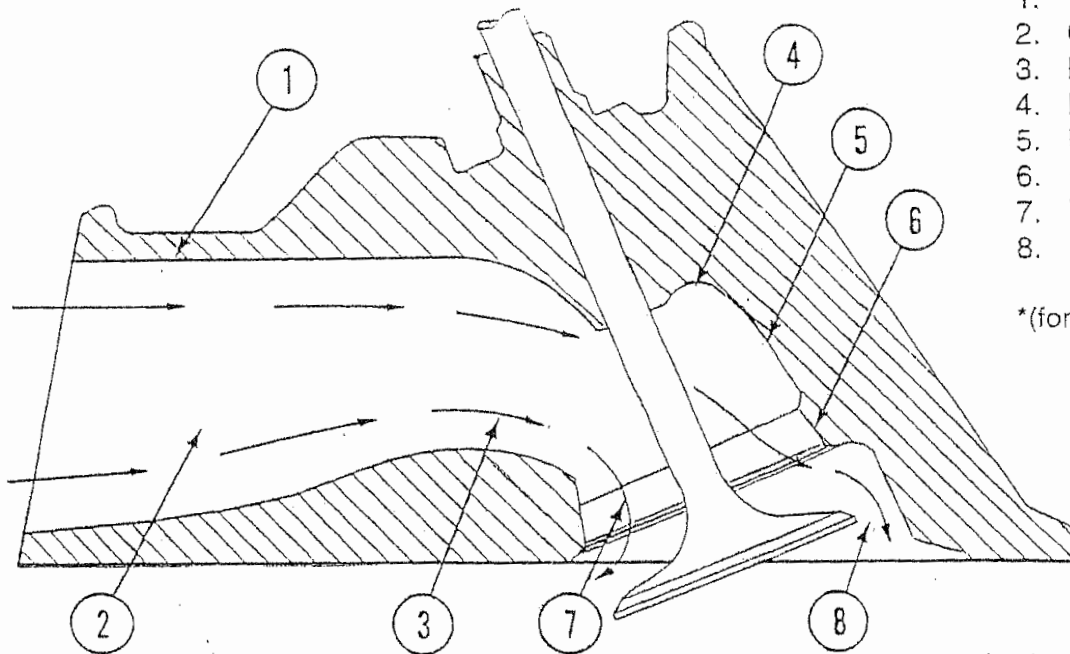
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Cylinder Head Losses

Stock Chevrolet V8 cylinder head



Source of Flow Loss

% of Loss

1. Wall Friction	4%*
2. Contraction at Push-Rod	2%
3. Bend at Valve Guide	11%
4. Expansion Behind Valve Guide	4%
5. Expansion, 25 Degrees	12%
6. Expansion, 30 Degrees	19%
7. Bend to Exit Valve	17%
8. Expansion Exiting Valve	<u>31%</u>
	100%

*(for sand cast surface; 3% for polished surface)

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Cylinder Head Losses

- It is possible to calculate flow potential for a cylinder head
- i.e. For a given pressure drop there is a maximum flow rate which can be achieved (this can be calculated per unit cross-sectional area, allowing the actual flow rate to be calculated for a particular head)
- This can then be compared to a flow bench measurement of actual cylinder head flow in order to assess the “tuning potential”

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- Remove exhaust gases from the cylinders (scavenging)
- Vent these to atmosphere at a safe position
- Meet noise limits (silencers etc)
- Emissions requirements (catalytic converters, EGR etc)
- Performance requirements
 - Actively assist cylinder emptying (improves VE)
 - “Tuned” exhausts
- Different requirements for road and race use
 - i.e. emissions, low noise etc for road
 - Power, minimal silencing, tuning etc for race systems



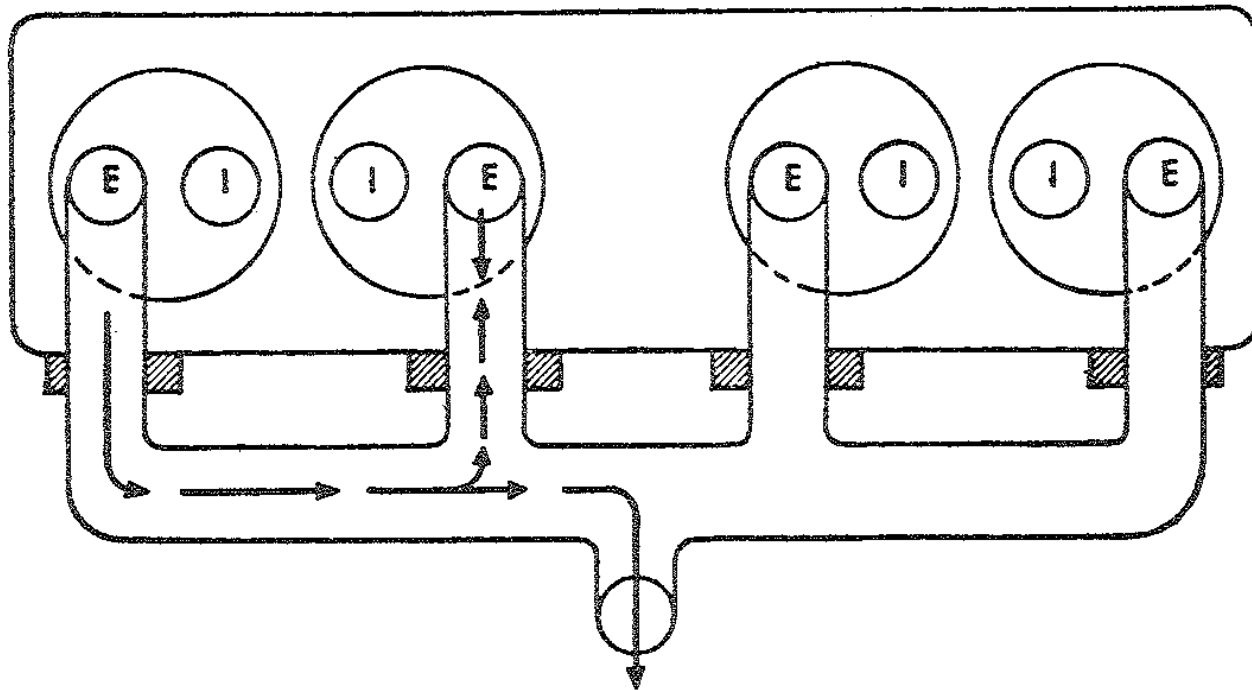
- Road car systems also have other requirements
- Rapid, low cost manufacture
- Use over a range of vehicles where possible
- Easy and rapid assembly onto vehicle
- Low under-bonnet temperature
- Durability
- Good balance between good scavenging a low and medium engine speeds and minimal power loss at higher speeds

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- Aside from the presence of a CAT and one or more significant silencers, the main difference is in the manifold
- OEM manifolds are often cast, with short branches from each exhaust port linking to a common manifold



- These work reasonably well, and are durable and reliable in road car applications.
- However, they suffer from flow interference between the short branches

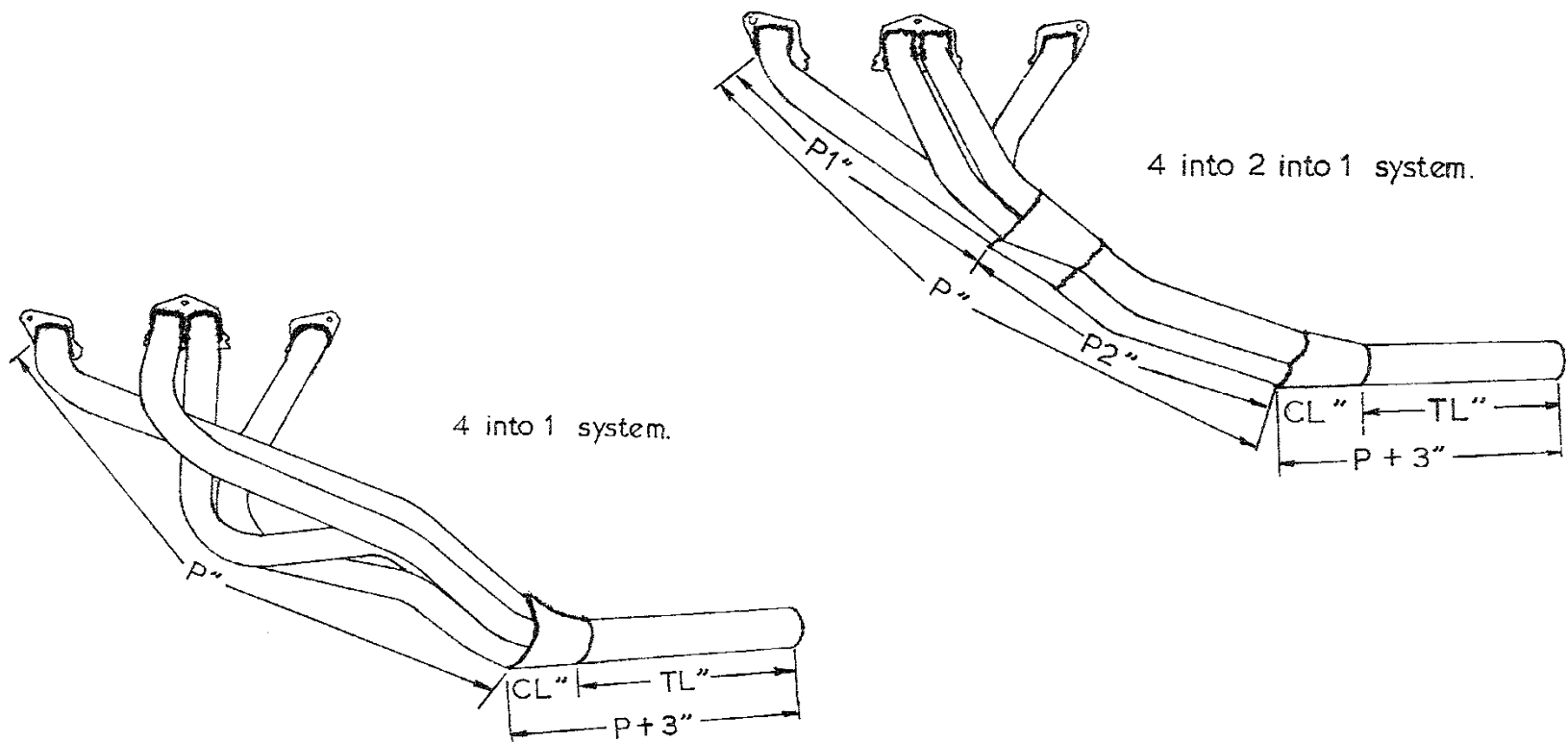


- Left hand cylinder is just after bottom dead centre, exhaust valve has recently opened and there is a strong, high pressure flow of gas from the cylinder
- Adjacent cylinder is at the end of its exhaust period, around TDC, where the remaining exhaust gas is being removed from the cylinder
- The residual gases are at lower pressure than the gases flowing in the manifold from the left hand cylinder
- This pressure imbalance will restrict the flow of residual gases from the cylinder, and can even lead to extra exhaust gas from the left hand cylinder flowing into the adjacent one!

- Long branches – preventing pressurisation between adjacent cylinders



- Two common designs for 4 cylinder engines

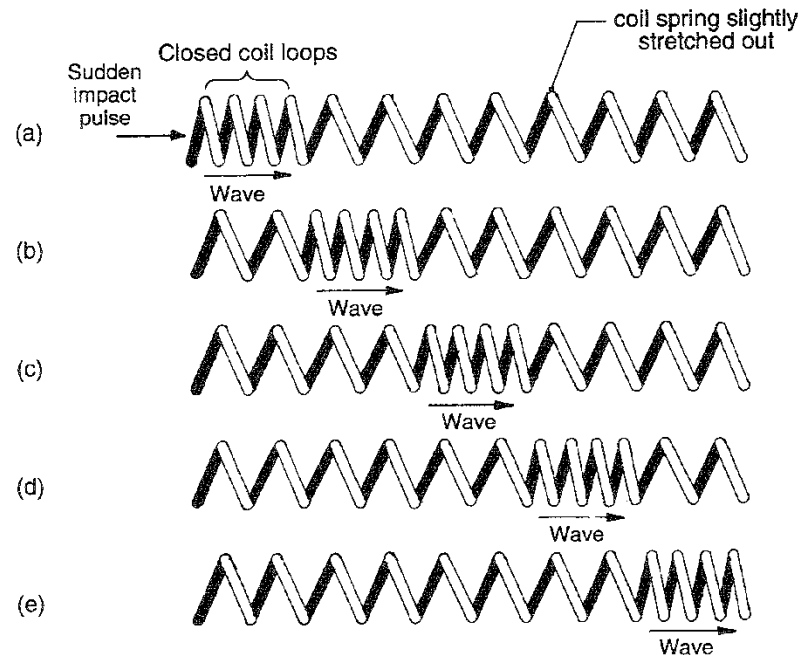


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Kinetic Energy Tuning

- Also known as Inertia Tuning
- Exhaust gases are compressible – they can compress and expand
- Think of travelling waves in “slinky springs”



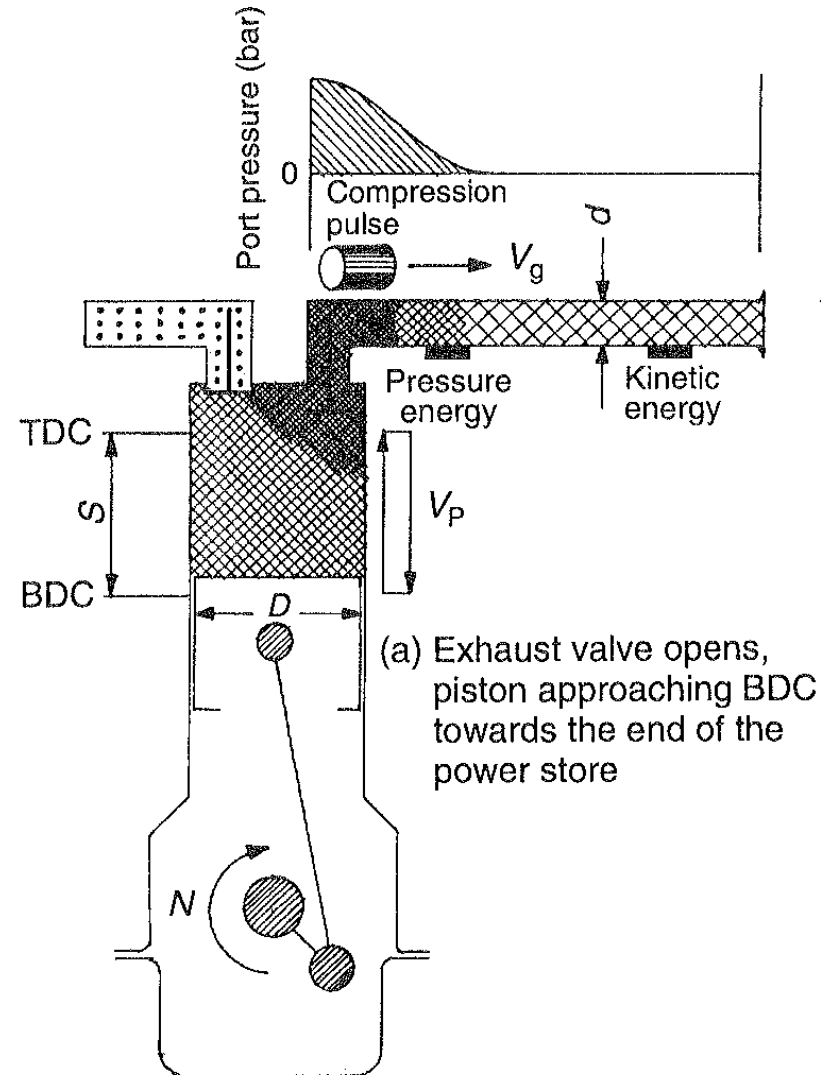
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Kinetic Energy Tuning



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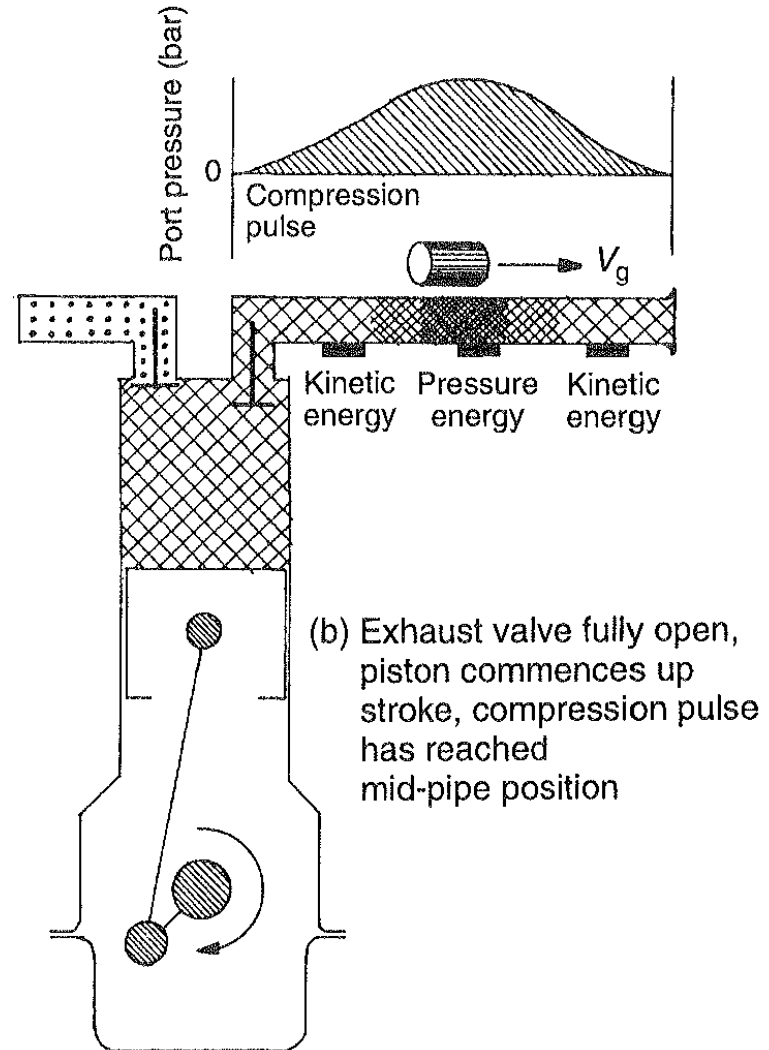
- Exhaust valve opens
- High pressure combustion products released to the exhaust system
- Pressure pulse causes high flow velocity in exhaust tract
- i.e. pressure energy is transferred into kinetic energy



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Kinetic Energy Tuning

- Pressure wave travels outwards along pipe
- Leading (compression) side raises the pressure in the pipe
- Trailing side reduces pressure in the pipe
- Remember our spring analogy



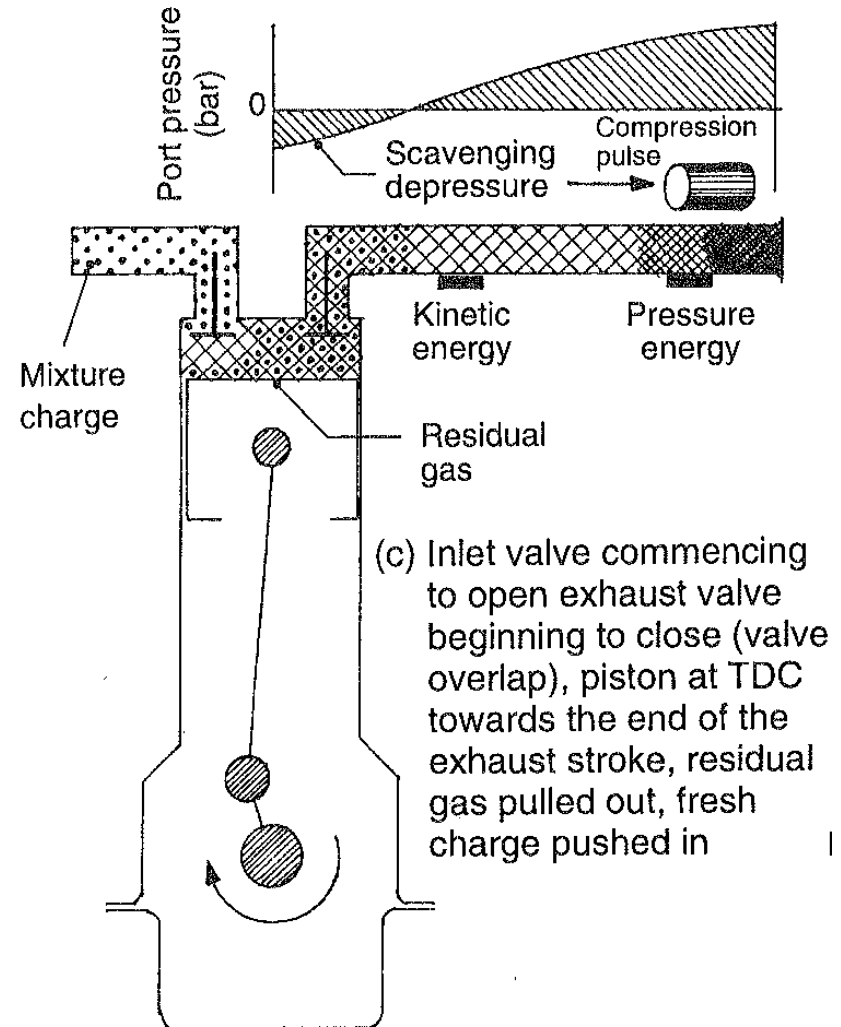
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Kinetic Energy Tuning



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- Pressure pulse reaches the end of the exhaust pipe
- Piston is near TDC and residual gases must be scavenged from cylinder
- The low pressure area behind the pulse helps to suck gases out of combustion chamber and draw fresh charge into it
- Heisler p273c



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Pressure Wave Tuning

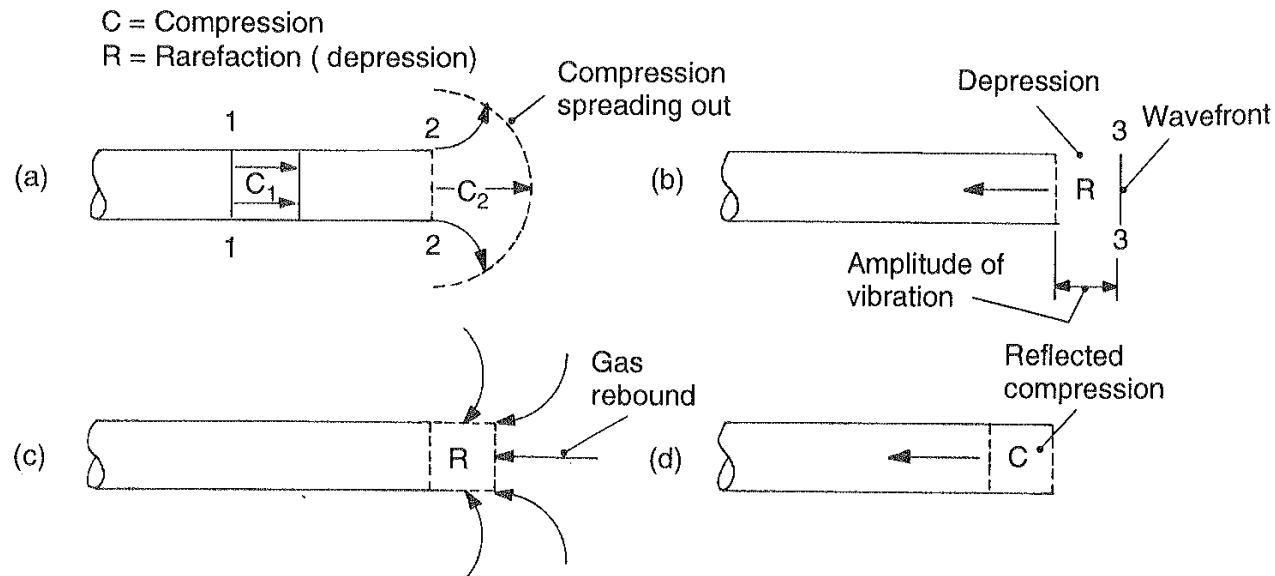


- What's this all got to do with organ pipes?
- They (and most other wind instruments) produce a note when a column of air inside the pipe *resonates*
- Changing the geometry of the pipes changes the note (i.e. trombone, flute etc)
- By making the length of an exhaust pipe such that it resonates at a frequency matched to engine speed, we can enhance the scavenging of exhaust gas from the cylinder

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Pressure Wave Tuning

- Relies on the fact that when the high pressure wave created by the exhaust valve opening reaches the end of the exhaust pipe, a low pressure wave is “reflected” back along the pipe
- Pressure waves travel at the speed of sound in gases (after all, that’s what sound is!)





- Pressure wave tuning sets the exhaust pipe length such that this negative wave reaches the exhaust valve towards the end of the exhaust stroke to assist with scavenging
- A crankshaft interval, θ_t , for this to occur of 120° has been found to be optimal
- i.e. 120° of crank rotation after the exhaust valve opens, the positive pressure pulse will have travelled along the pipe to its end, and the reflected negative pressure pulse will have travelled back along the pipe to exhaust valve



- To calculate the exhaust length, we must calculate the time it takes for the wave to travel the length of the system and back:

$$t = \frac{2L}{C}$$

- Where L is the length of the exhaust in metres
- C is the speed of sound in the exhaust gas (ms^{-1})
- Crankshaft angular displacement during the same period is:

$$\theta_t = t \times \frac{N}{60} \times 360$$

- N is the engine speed (rpm)



- But we already have an equation for t in terms of pipe length
- Substituting for t gives

$$\theta_t = \frac{2L}{C} \times \frac{N}{60} \times 360 = \frac{12LN}{C}$$

- Thus, the optimum exhaust length for a given engine speed to produce resonance can be determined
- Note that this does not take into account of the effects of other branches / cylinders etc
- But speed of sound in exhaust gas varies with temperature

- At 0° C, the speed of sound in a gas, C_1 , is 330 ms⁻¹
- It varies with the square root of the absolute temperatures i.e.

$$\frac{C_2}{C_1} = \sqrt{\frac{T_2}{T_1}}$$

- So for exhaust gas at an average temperature of 400° C:

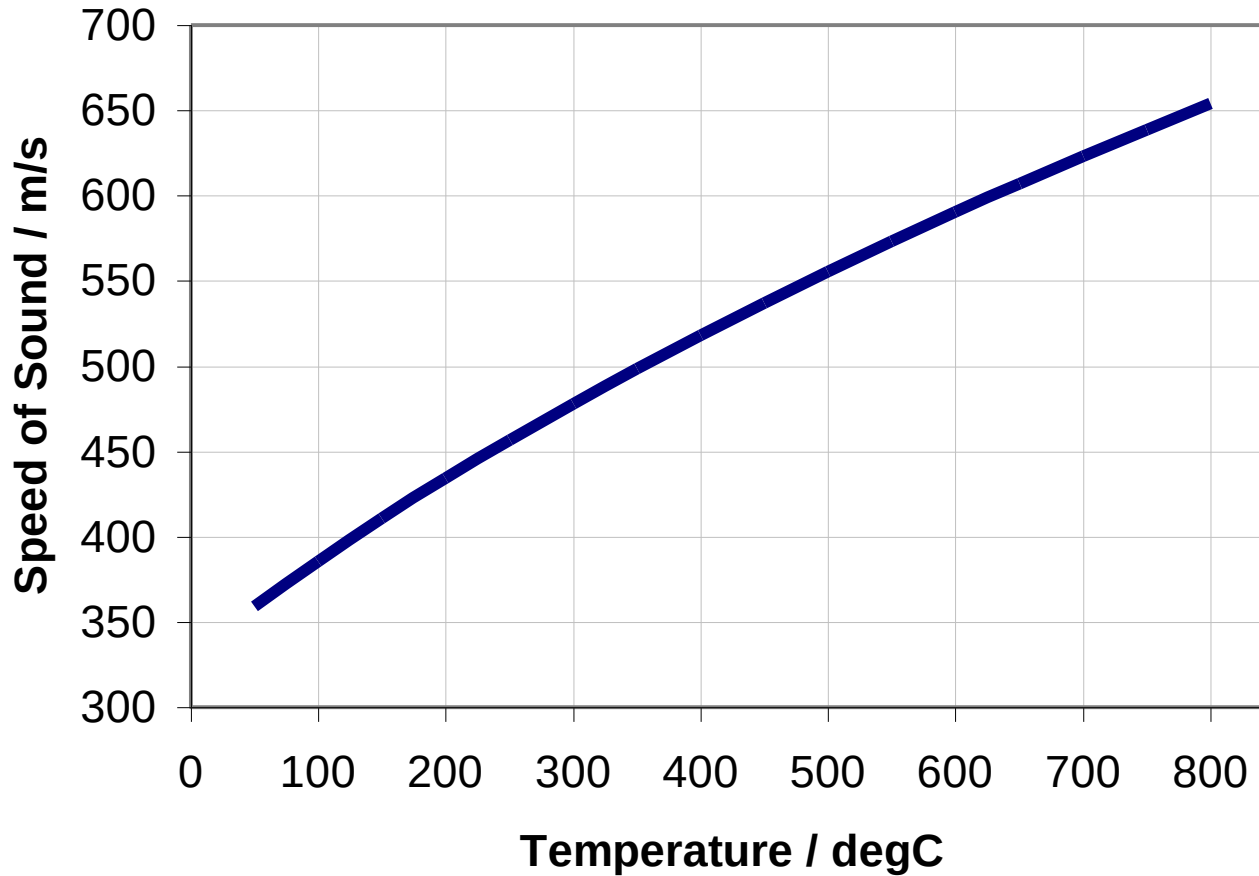
$$C_2 = 330 \times \sqrt{\frac{273 + 400}{273}} = 518 \text{ m/s}$$

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Pressure Wave Tuning



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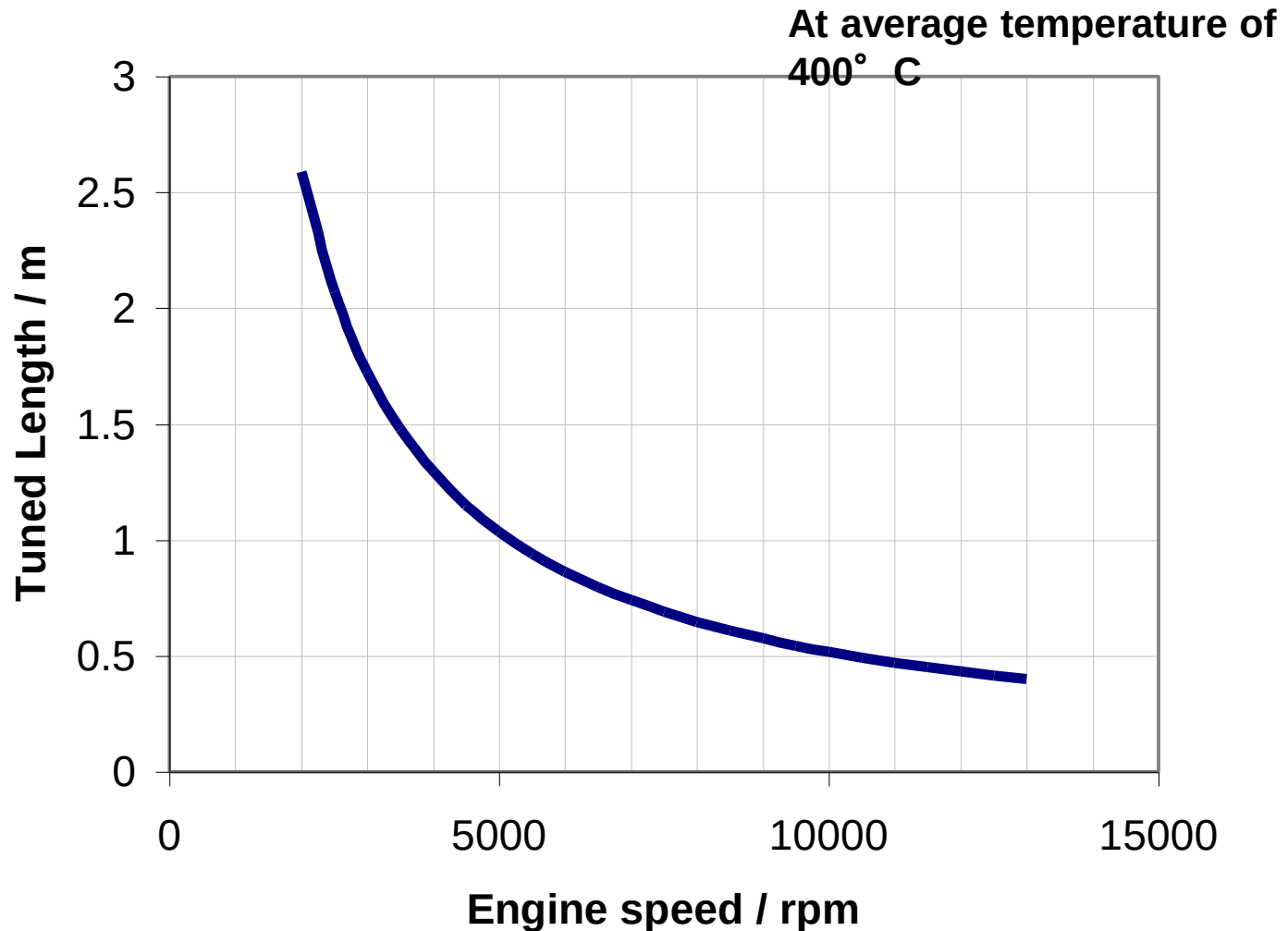


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- But
 - Speed of sound is not constant along pipe as temperature changes
 - Reflections can occur at collectors, changes of diameter etc etc
- This theory is an indication only!
- The real behaviour of exhaust systems is based on these principles but is more complex
- Interference between pipes, changes of section, unequal length headers etc will all be covered in the next few lectures
- However, remember that we have shown that a change in exhaust system length can affect the position of peak power in an engine

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Pressure Wave Tuning



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