



SWANSEA METROPOLITAN UNIVERSITY

PRIFYSGOL FETROPOLITAN ABERTAWE

Advanced Engine Technology

Lecture 8: Detailed Exhaust Design

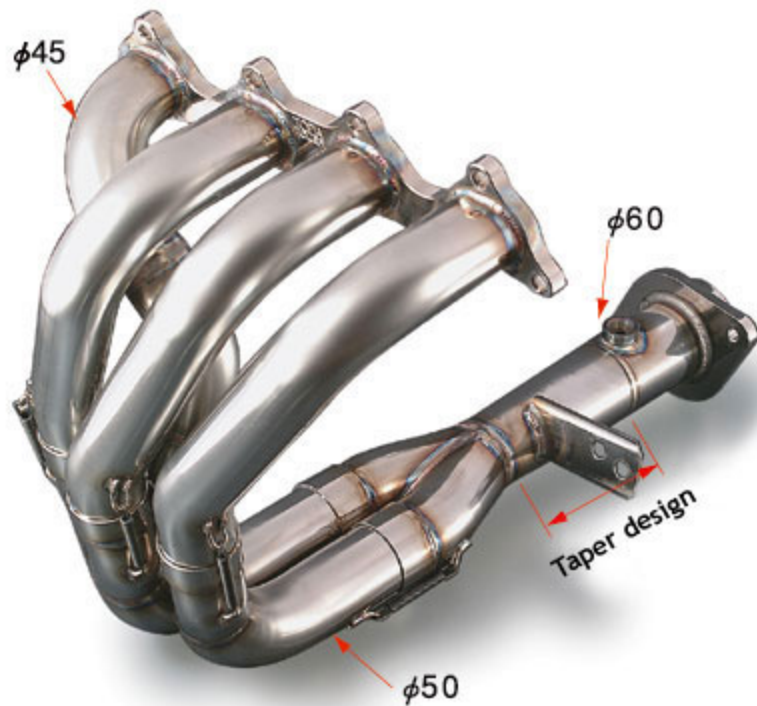
Advanced Engine Technology

Contents

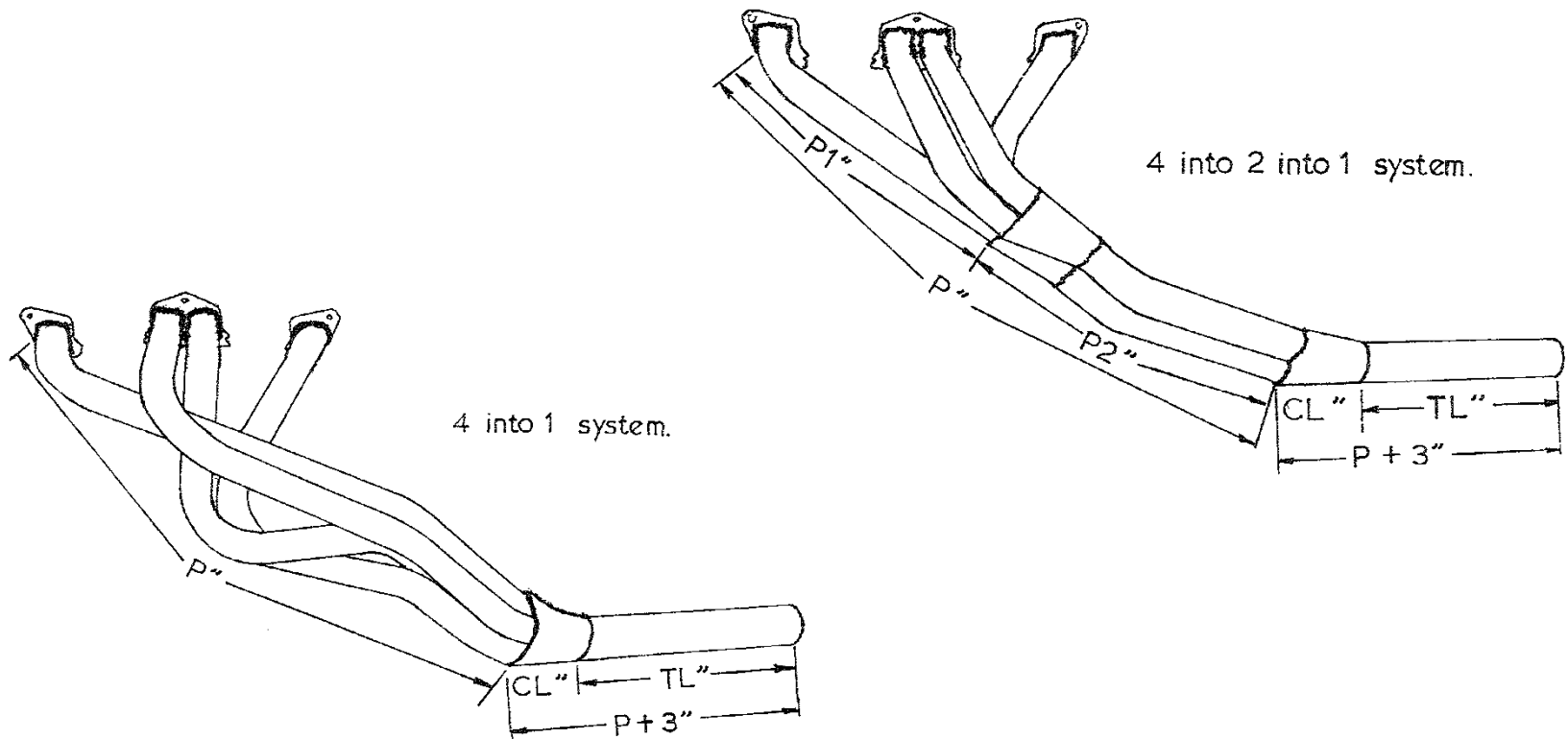
- Recap
- Header Dimensions
- Practical Header Tuning
- Unequal Length Headers
- Stepped Headers
- Collectors
- Tailpipe
- Header Finish and Fabrication

- Recap
- Header Dimensions
- Practical Header Tuning
- Unequal Length Headers
- Stepped Headers
- Collectors
- Tailpipe
- Header Finish and Fabrication

- Long branches – preventing pressurisation between adjacent cylinders



- Two common designs for 4 cylinder engines



Advanced Engine Technology

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
- Here we will cover the design of a racing exhaust system in terms of pipe lengths and diameters.
- Based on the principles in Bell's "Four Stroke Performance Tuning"

Advanced Engine Technology

Pressure Wave Tuning



SWANSEA METROPOLITAN UNIVERSITY
PRIFYSGOL FETROPOLITAN ABERTAWE

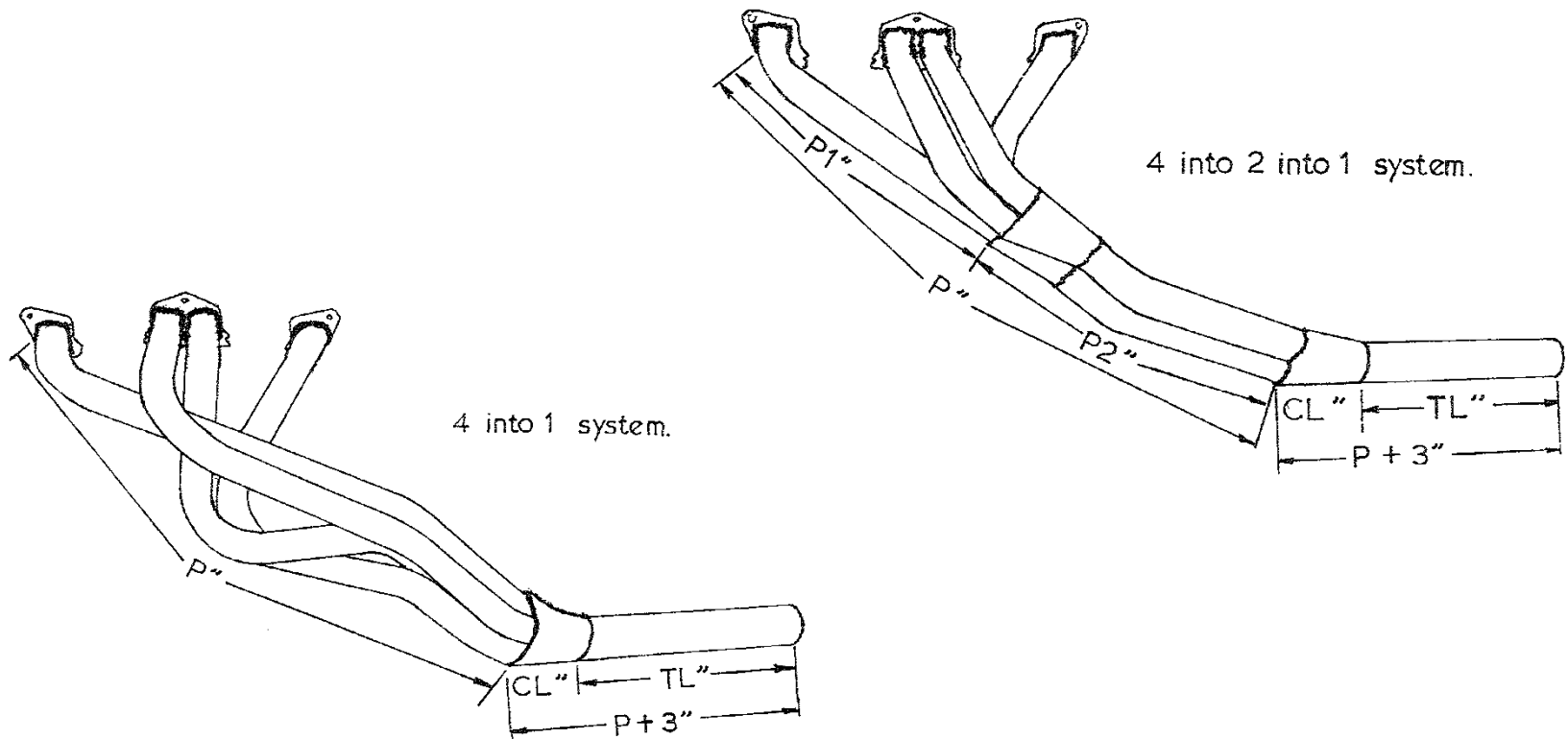


Advanced Engine Technology

Contents

- Recap
- Header Dimensions
- Practical Header Tuning
- Unequal Length Headers
- Stepped Headers
- Collectors
- Tailpipe
- Header Finish and Fabrication

- Determining P_1 , P etc.....



- Based on same principles as single pipe resonant length calculation considered in Lecture 6 (i.e. Pressure wave tuning) together with some inertia tuning effects
- Formula for primary pipe length (in mm)

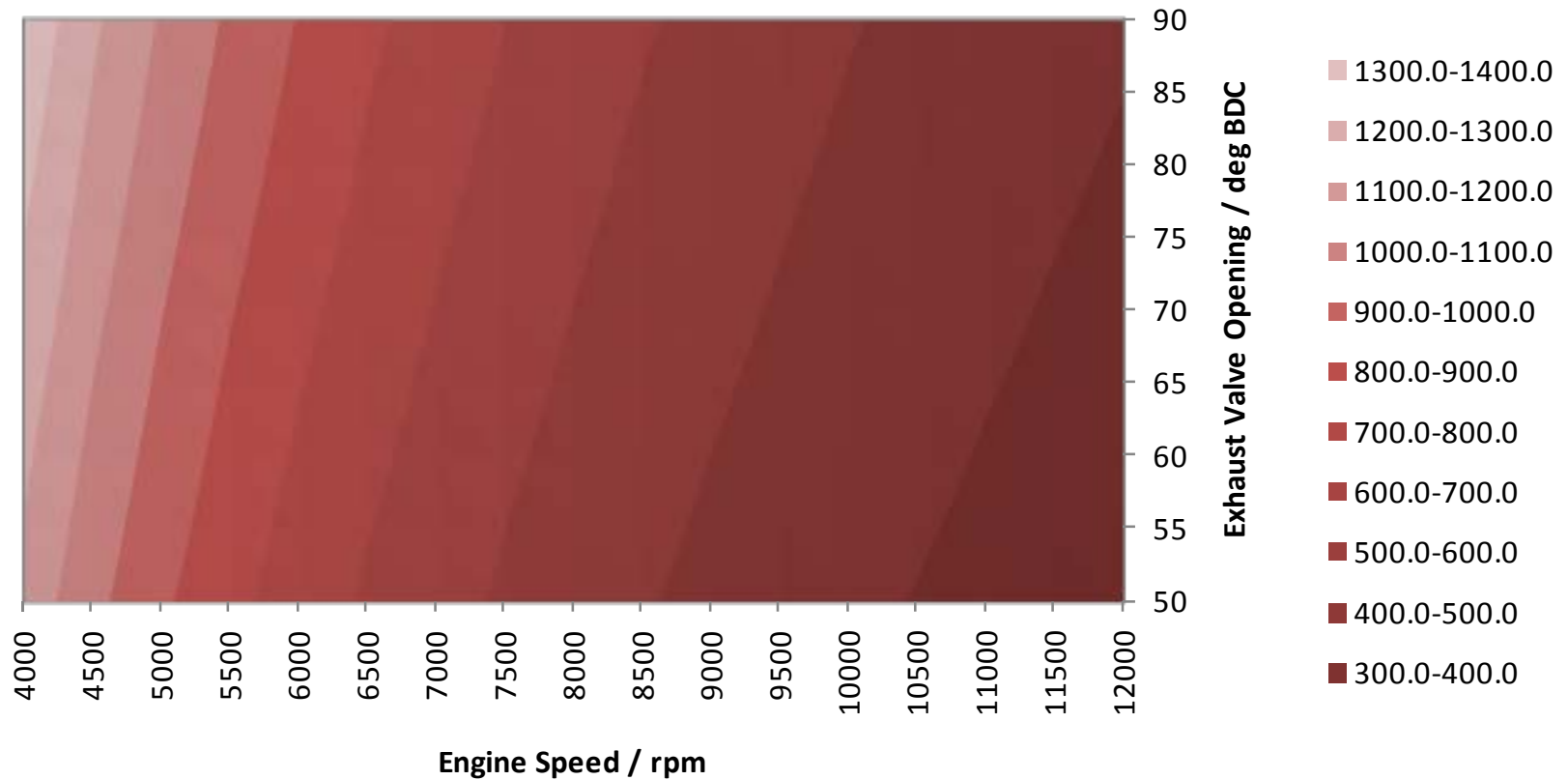
$$P = \frac{21590ED}{N} - 76.2$$

- ED = 180 + exhaust valve opening in degrees before BDC
- N = tuned engine speed / rpm

Advanced Engine Technology

Header Dimensions

Primary Length in mm, for a range of tuned engine speeds and EVO



- For a 4 into 1 system, the formula gives the total header length (P)
- For a 4 into 2 into 1 system this must be split into a primary length (P1) and a secondary length (P2)
- Adding length to the primaries tends to favour top end power
- Adding length to the secondaries tends to help mid range power

- Header diameter can be calculated in order to keep exhaust gas speeds at around 76 m/s
- This speed has been found to be optimum for maximum torque
- Thus, a bigger diameter pipe will cause this speed to occur higher up the engine's rev range
- Pipe inside diameter (ID) in mm:

$$ID = 53.34 \sqrt{\frac{v}{P + 76.2}}$$

- Where v is cylinder volume (cc) and P is header length (mm)

- These must be matched to commercially available tube sizes for fabrication of headers

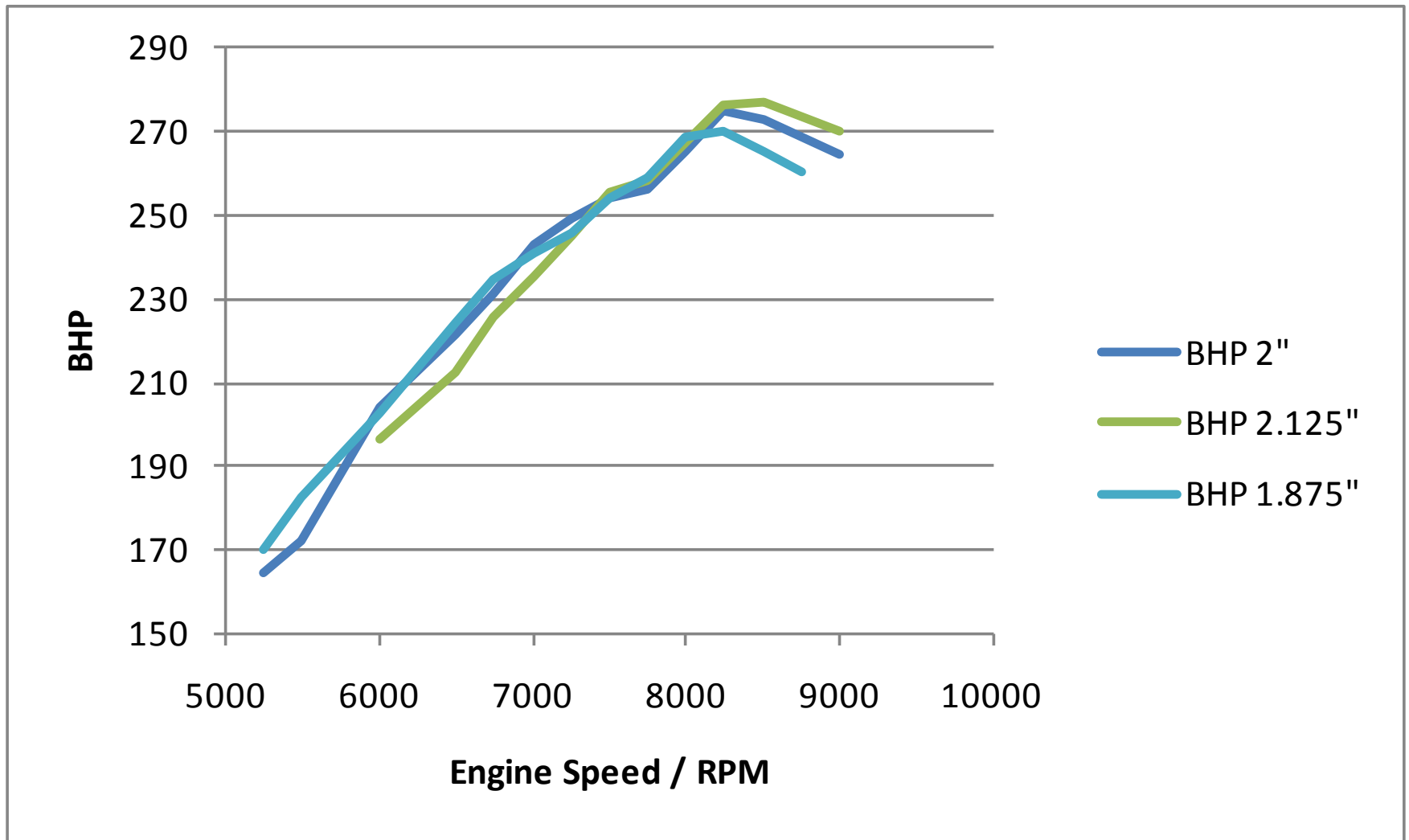
For a 500cc cylinder (i.e 4 cyl 2litre)									
	EVO / degrees BTDC								
Speed	50	55	60	65	70	75	80	85	90
4000	34	33	33	33	32	32	32	32	31
4500	36	36	35	35	34	34	34	33	33
5000	38	37	37	37	36	36	36	35	35
5500	40	39	39	38	38	38	37	37	37
6000	41	41	41	40	40	39	39	39	38
6500	43	43	42	42	41	41	41	40	40
7000	45	44	44	43	43	43	42	42	41
7500	46	46	45	45	44	44	44	43	43
8000	48	47	47	46	46	45	45	45	44
8500	49	49	48	48	47	47	46	46	46
9000	51	50	50	49	49	48	48	47	47
9500	52	52	51	51	50	50	49	49	48
10000	54	53	52	52	51	51	50	50	49
10500	55	54	54	53	53	52	52	51	51
11000	56	56	55	54	54	53	53	52	52
11500	57	57	56	56	55	55	54	53	53
12000	59	58	57	57	56	56	55	55	54

- Recap
- Header Dimensions
- Practical Header Tuning
- Unequal Length Headers
- Stepped Headers
- Collectors
- Tailpipe
- Header Finish and Fabrication

- Due to variations in cams, inlet manifolds, cylinder head porting etc, these calculations are a guide only!
- The calculations presented so far are relatively simple
- They can provide a basis for “fine tuning” of a design on the dyno
- Experimentation with dimensions can yield interesting results
- 2-litre Opel XE engine with 3 configurations, all 4 into 1 pipes of fixed primary length and tailpipe length and diameter
 - 2 in headers
 - 2.125” headers
 - 1.875” headers

Advanced Engine Technology

Practical Tuning

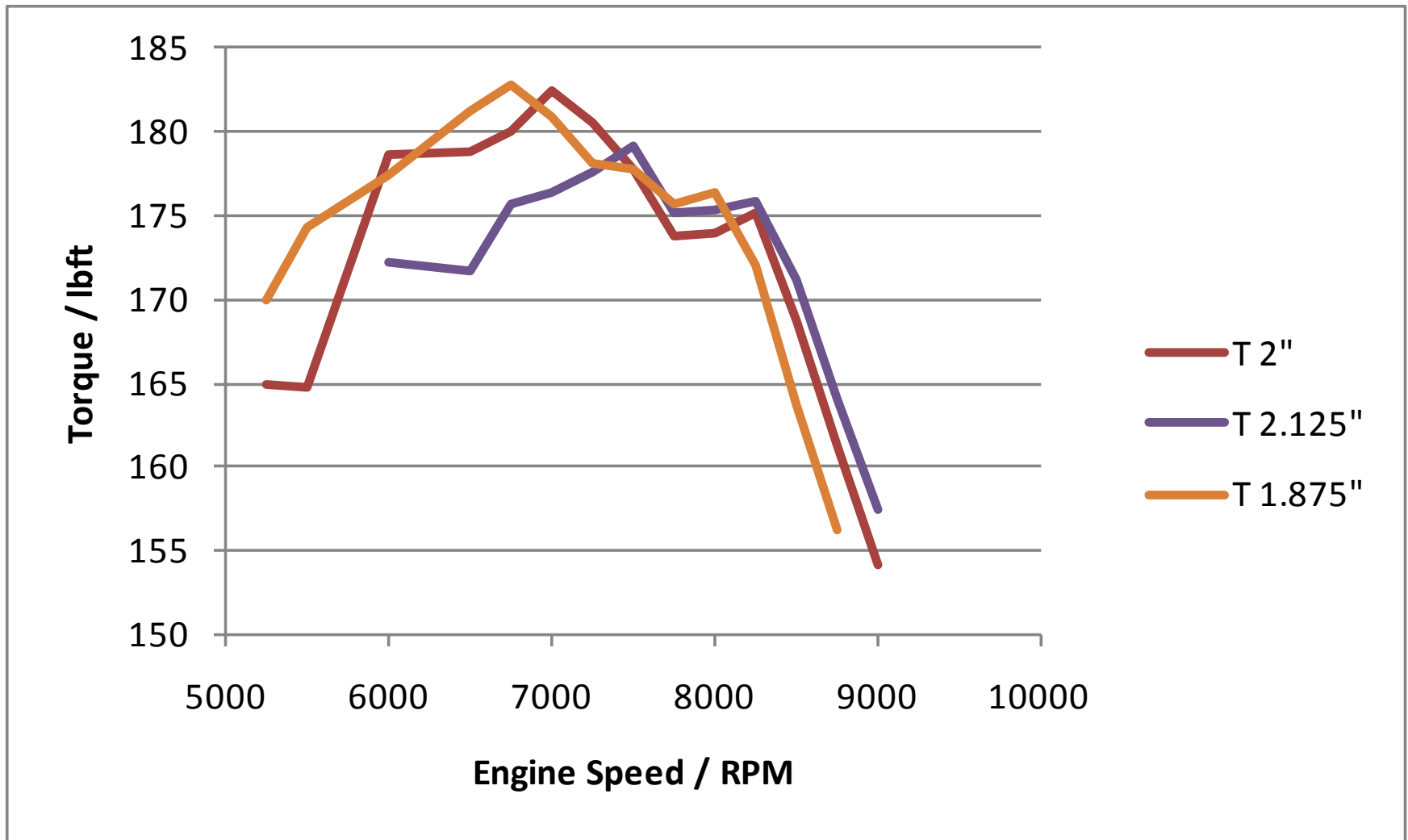


Advanced Engine Technology

Practical Tuning



SWANSEA METROPOLITAN UNIVERSITY
PRIFYSGOL FETROPOLITAN ABERTAWE



Advanced Engine Technology

Contents

- Recap
- Header Dimensions
- Practical Header Tuning
- Unequal Length Headers
- Stepped Headers
- Collectors
- Tailpipe
- Header Finish and Fabrication

Advanced Engine Technology

Unequal length headers

- Tune the torque peak in each cylinder to a slightly different rpm
- Flattens and smooths the torque curve
- More drivable engine – tunes out the sudden rush of power
- Aim to adjust primaries by no more than 100mm from the nominal tuned length selected using the formula
- Can often also help with packaging!!

Advanced Engine Technology

Unequal length headers

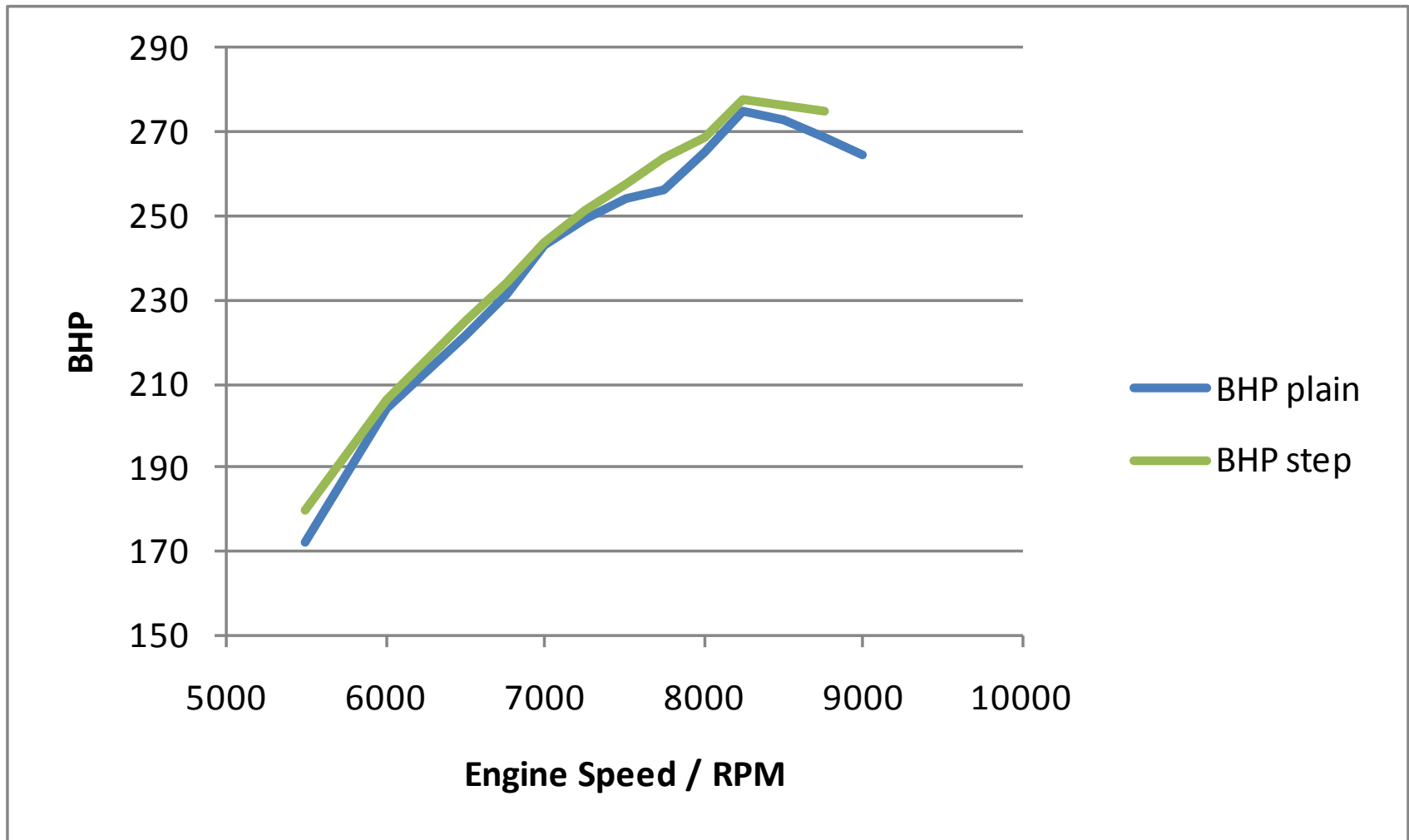


- Recap
- Header Dimensions
- Practical Header Tuning
- Unequal Length Headers
- Stepped Headers
- Collectors
- Tailpipe
- Header Finish and Fabrication

- A gently tapered conical header would, in theory, provide the best gas flow – preserving gas momentum whilst keeping restriction and turbulence to a minimum
- A stepped header is nearer to this ideal than a constant diameter header
- Typical design has one (sometimes two) steps of about 3-6 mm increase in diameter
- Step position can be experimented with on dyno or using computer simulations
- Test on 2-litre Opel XE engine comparing plain and stepped headers

Advanced Engine Technology

Stepped Headers

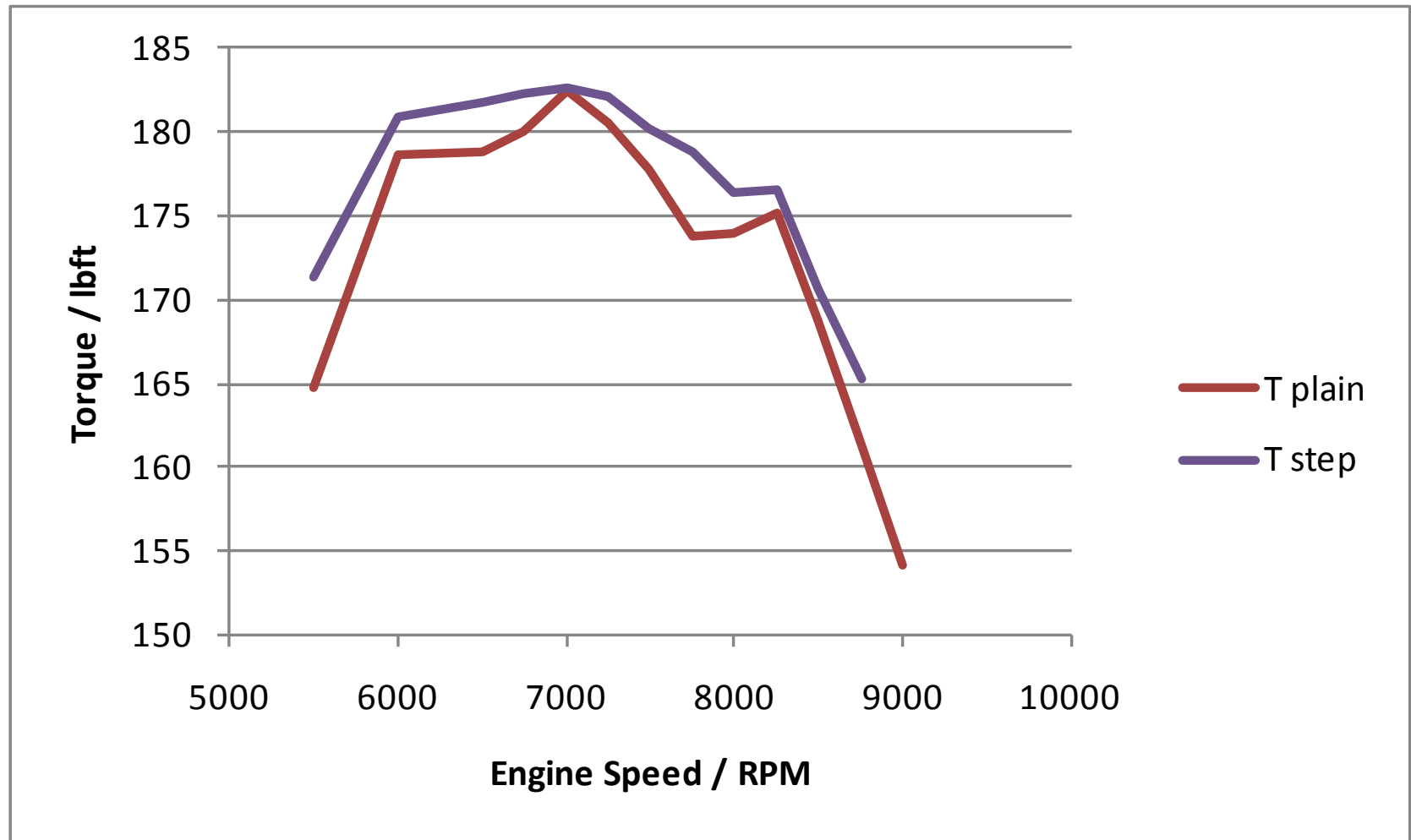


Advanced Engine Technology

Stepped Headers



SWANSEA METROPOLITAN UNIVERSITY
PRIFYSGOL FETROPOLITAN ABERTAWE



Advanced Engine Technology

Stepped Headers

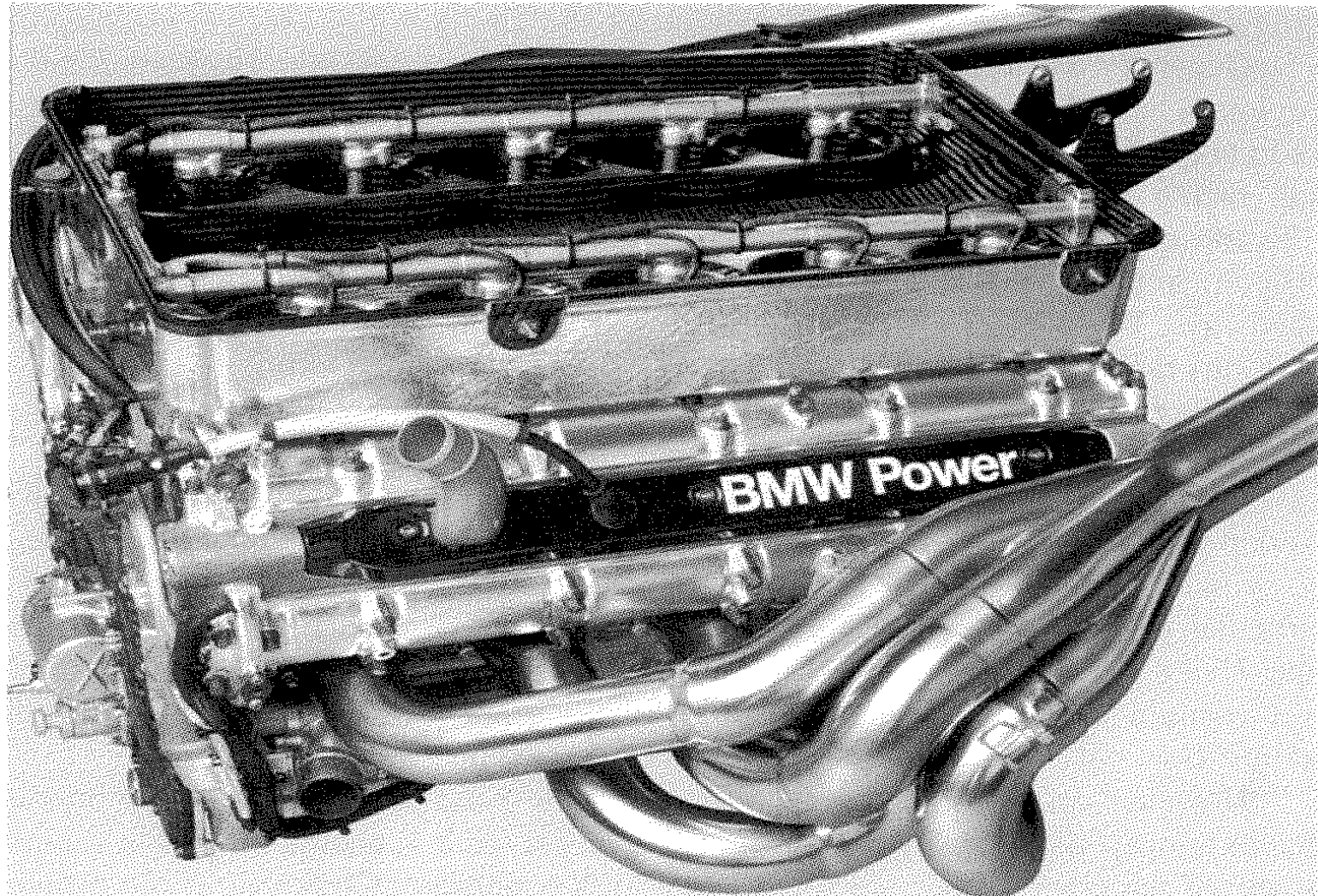


Advanced Engine Technology

Stepped Headers



SWANSEA METROPOLITAN UNIVERSITY
PRIFYSGOL FETROPOLITAN ABERTAWE



Advanced Engine Technology

Stepped Headers

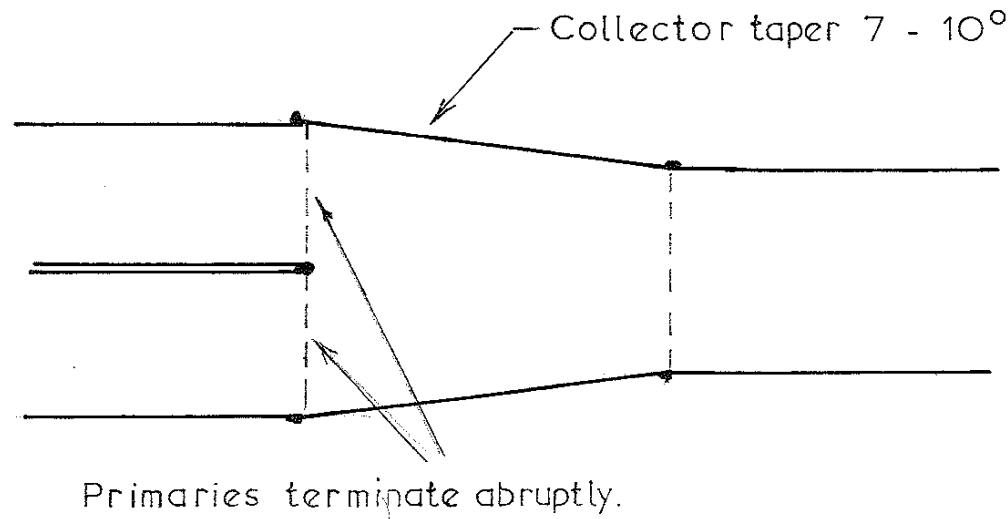


- Recap
- Header Dimensions
- Practical Header Tuning
- Unequal Length Headers
- Stepped Headers
- Collectors
- Tailpipe
- Header Finish and Fabrication

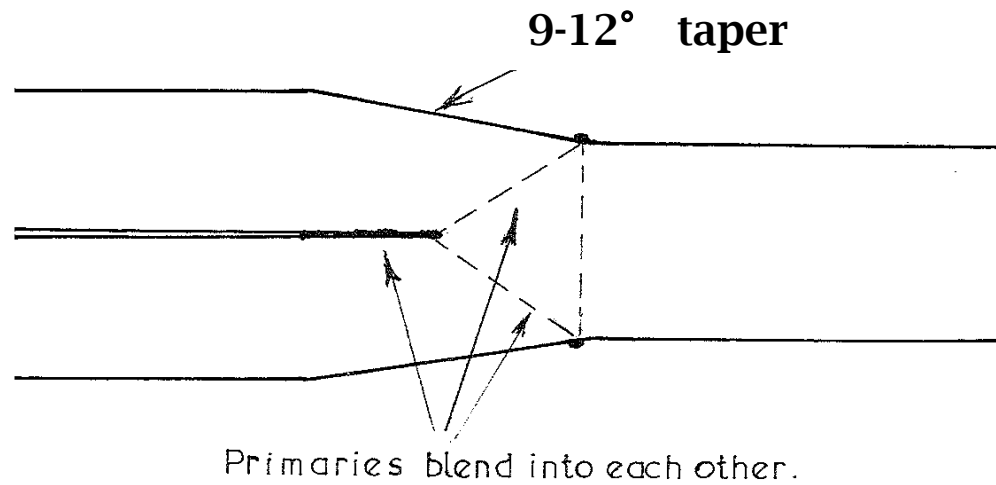
- Collector joins primary tubes together as one
- Different collector styles can tune the behaviour of the exhaust
- Collector can enhance the momentum (or inertia) tuning effect
 - When exhaust valve closes, and vacuum left in exhaust caused by rush of exhaust gas out of system will be lost
 - *Unless* it is connected to the other headers by a collector.
 - The vacuum lowers pressure in the other headers, assisting scavenging of those which have open exhaust valves

- **Baffle-type collector**

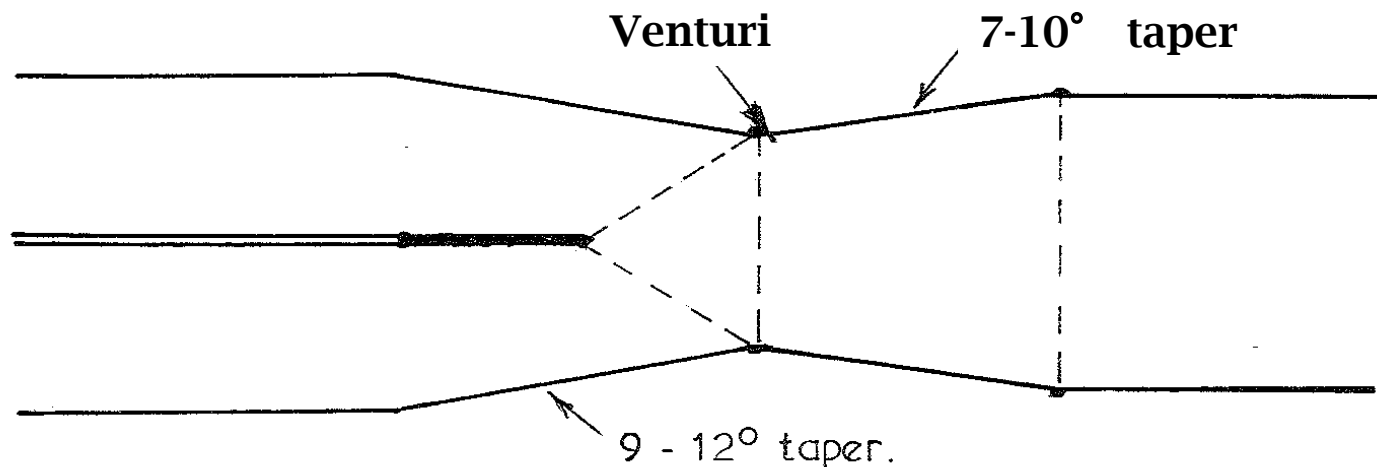
- Pipes abruptly terminate in collector
- This enhances wave tuning effect (acts like an open pipe end)
- Taper angle is important
- Too shallow a taper creates too much turbulence if expansion is too abrupt



- **Merge-type collector**
 - Headers gently blend into tailpipe
 - Reduces the pressure reflection effects (which can have a negative effect at non-tuned engine speeds)
 - Testing can determine the most effective angles



- **Venturi-merge collector**
 - Diameter necks down then expands to tailpipe
 - This “venturi” effect increases gas speed
 - Boosts inertia scavenging effects
 - Typically make diameter of venturi 12mm greater than diameter of primary tubes



Advanced Engine Technology

Contents

- Recap
- Header Dimensions
- Practical Header Tuning
- Unequal Length Headers
- Stepped Headers
- Collectors
- Tailpipe
- Header Finish and Fabrication

- For open, unsilenced exhausts, overall tailpipe and collector length is equal to the primary length plus length of exhaust ports (usually around 75mm)
- Diameter (mm) then set using:

$$ID = 50.8 \sqrt{\frac{2v}{P + 75}}$$

- where v is volume (cc) of one cylinder, P is primary length (mm)
- Further calculations necessary for silenced systems to determine tailpipe dimensions

Advanced Engine Technology

Contents

- Recap
- Header Dimensions
- Practical Header Tuning
- Unequal Length Headers
- Stepped Headers
- Collectors
- Tailpipe
- Header Finish and Fabrication

- Welds impeding into tube can restrict flow and induce turbulence – grind these smooth
- Header is extension of exhaust port
 - Avoid abrupt bends
 - Gases don't like sharp changes of direction
- Consider placement and severity of bend carefully
- Pay attention to alignment of flanges and exhaust ports

Advanced Engine Technology

Fit and Finish

