ENGINE PERFORMANCE TESTING

The theoretical predictions from the previous section do not take into account effects that occur in real engines. In particular, real engines encounter mechanical friction between their moving parts and experience heat loss as a consequence of engine cooling. Engine performance testing indicates the difference between theory and practice.

Engines are tested in order to answer questions like :-

(1) How does TORQUE output vary with speed (RPM)?

NB - From full or part-throttle performance we can also derive Power/ Speed curves.
This data is needed for load matching.

(2) Is it's mechanical integrity good?
Wear, Failure, Performance loss with time , Systems O.K.?

(3) Is it's noise and vibration levels acceptable ?

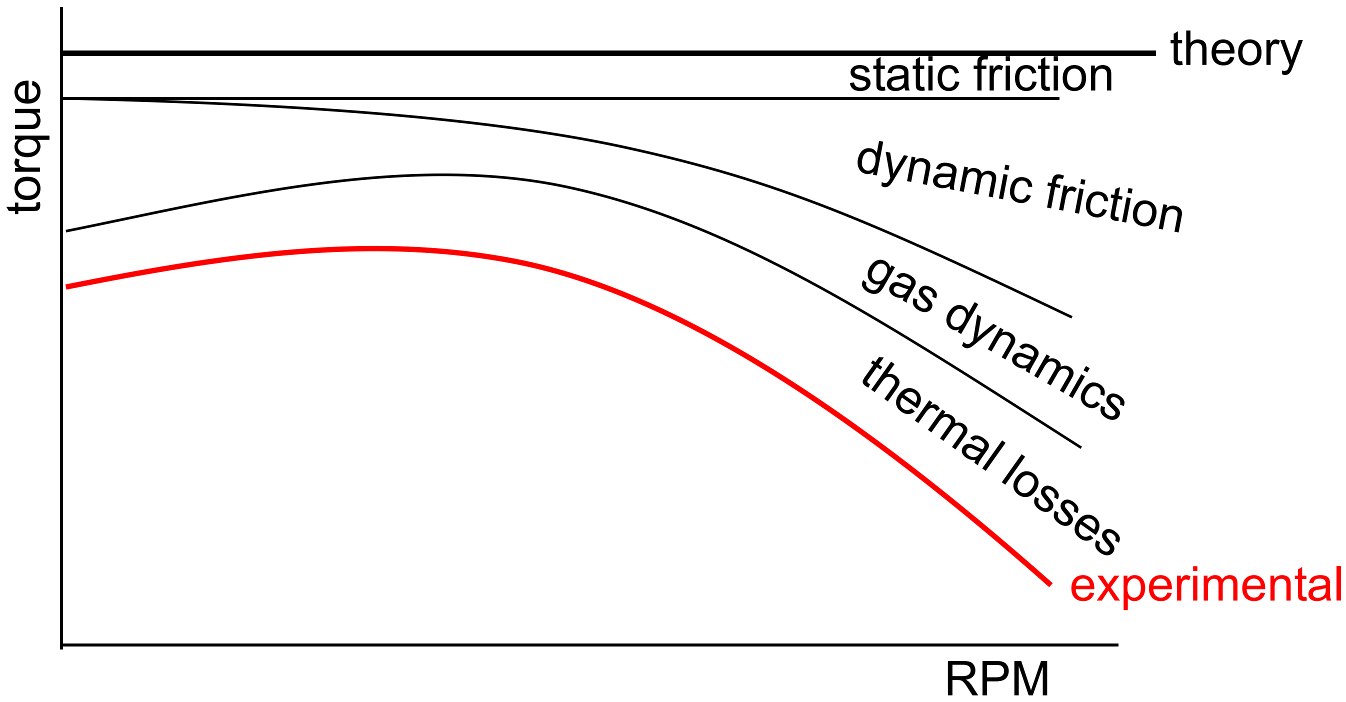
(4) How efficient is it ?

(5) What is the nature of it's exhaust emissions ?

(6) How stable and controllable is it ?

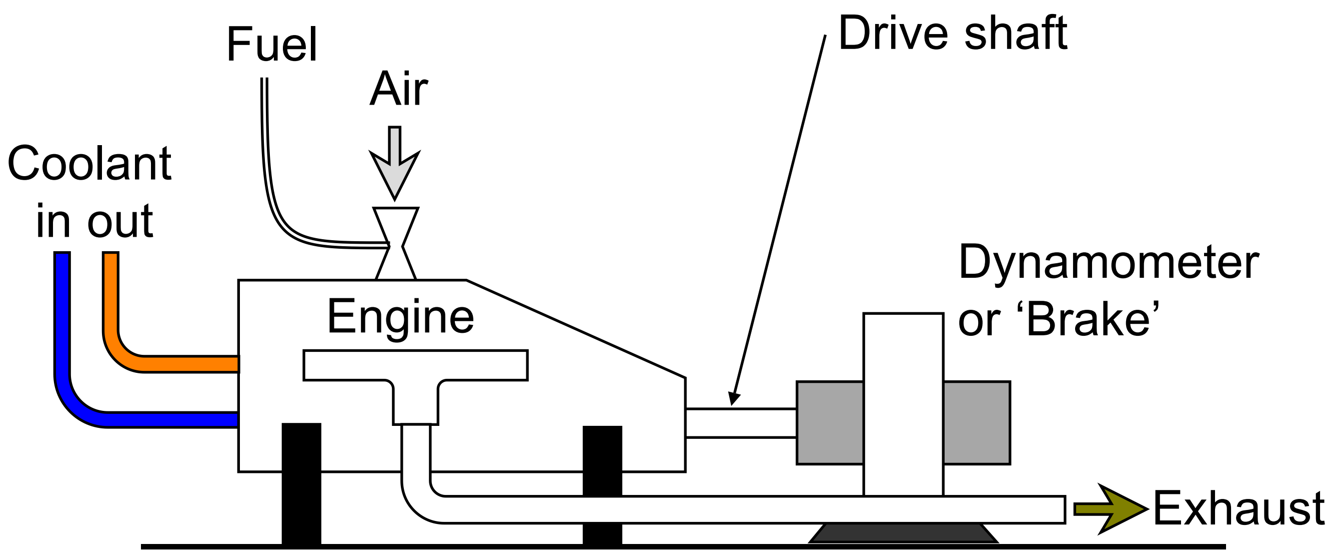
Research engines also investigate fuels, the nature of combustion process, pollutants, etc.

(1) Basic torque/speed, power/speed curves.



Power is derived directly from torque and speed
power = torque x RPM x $2\pi / 60$

Basic test rig:



(2) Mechanical Efficiency (mechanical integrity).

The mechanical efficiency of an engine is defined as :-

$$\text{Mechanical Efficiency } (\eta_{mech}) = \frac{\text{Shaft Power}}{\text{Indicated Power}}$$

Shaft Power = torque x speed (rad/s)

Indicated Power (IP) = Power produced by the expanding gases on the face of the piston.

= {Indicated Work/cycle/cylinder} x No. cylinders x No. of power strokes/sec/cyl.

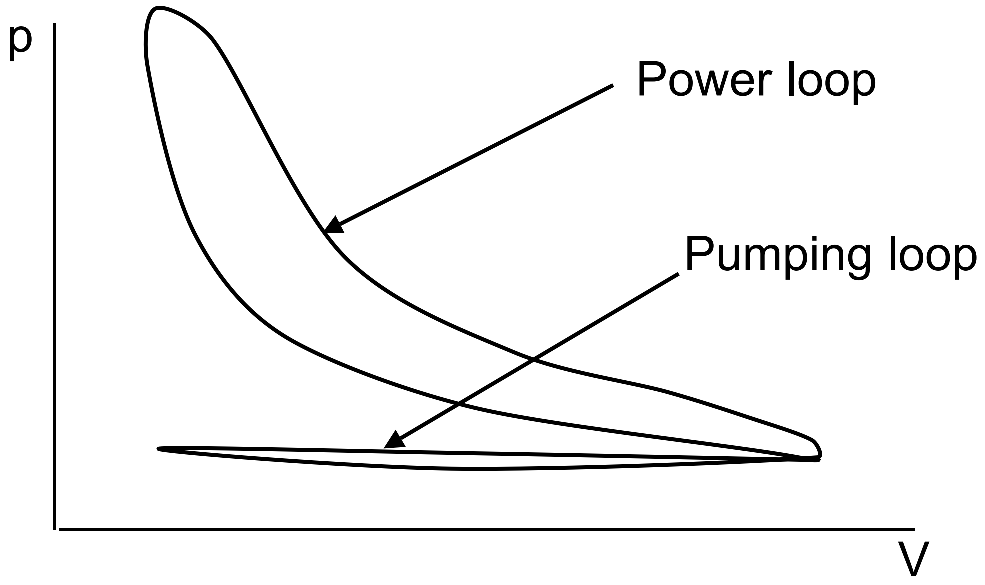
RPM/60 for a two-stroke
RPM/120 for a four-stroke !

Note: Shaft Power may also be referred to as ‘Brake Power’ because the shaft power output is measured by a ‘brake’ or ‘dynamometer’.

The Mechanical Efficiency of an engine is an indicator of the amount of power lost to friction, or used to drive auxiliary devices (oil pump, valves, alternator, water pump) within the engine.

Indicated work/cycle

If we can measure the pressure volume relationship within the cylinder we can measure the indicated work/cycle.



Indicated work = Area of p-V loop , hence we can find the IP.

Indicated Mean Effective Pressure (IMEP or p_m)

Because the cylinder pressure continuously varies we define a mean pressure which, if it acted over the whole stroke, would do the same work as the varying pressure.

Ind.Work/cycle = p_m x stroke x cyl. face area

= p_m x L x A

Indicated work/cycle has to be measured using high speed pressure transducers and fast transient data recorders. Otherwise we must resort to 'dodges' such as the MORSE test.

It follows that the Indicated Power of an engine is given by:
p_m x L x A x N or IP = PLAN
where N = total number of power strokes /second

Morse test

If we are testing a multi-cylinder engine an alternative method for estimating the Indicated Work/cycle (and hence the Mechanical Efficiency) consists of cutting out each cylinder in turn & measuring the shaft power, keeping the engine speed the same.

It is based on the assumption that:-

Output power = Indicated power - Friction power

All cyls. $W = I_1 + I_2 + I_3 + I_4 - W_f$

or $W = IP - W_f$ (i)

Cyl.1 cut out $W_{-1} = I_2 + I_3 + I_4 - W_f$

Cyl.2 cut out $W_{-2} = I_1 + I_3 + I_4 - W_f$

Cyl.3 cut out $W_{-3} = I_1 + I_2 + I_4 - W_f$

Cyl.4 cut out $W_{-4} = I_1 + I_2 + I_3 - W_f$

Adding the above 4 eqns gives:-

$$\sum W_{(-)} = 3 \sum I_{1-4} - 4 W_f = 3\, IP - 4 W_f \quad \text{(ii)}$$

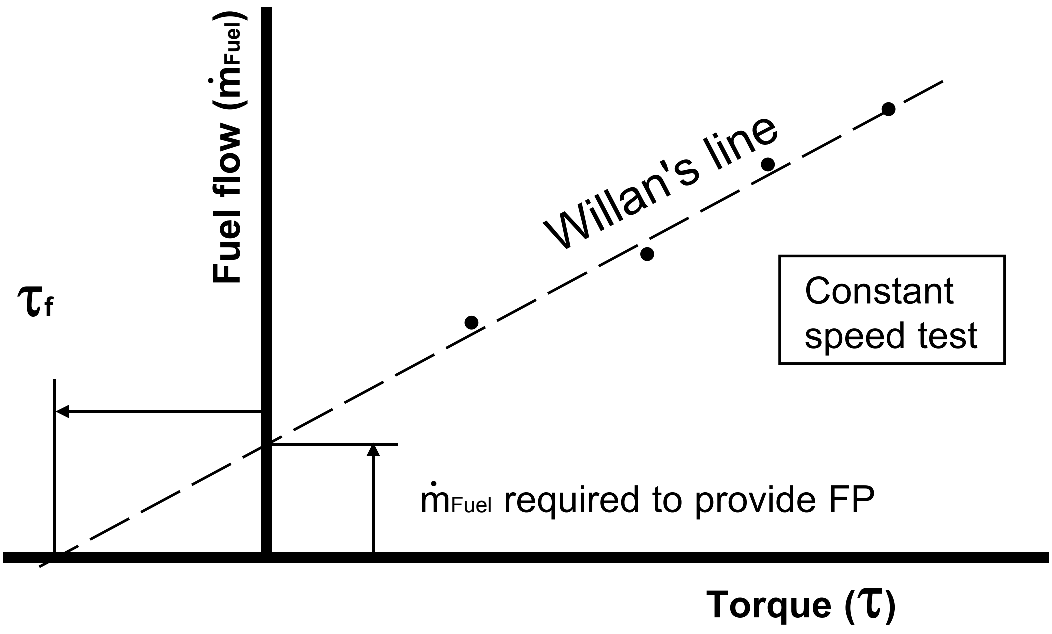
Eliminating W_f from eqns (i) and (ii) gives:-

$$\boxed{IP = 4W - \sum W_{(-)}}$$

Willan's Line Test (Diesel Engines only)

In testing diesel engines (at a constant speed) it is found that the torque output increases linearly with fuel consumption over a reasonable power range

This characteristic can be used to estimate its mechanical efficiency by effectively finding the internal frictional torque by plotting torque output against fuel flow.



At a given torque output :

$$\eta_{mech} = \frac{\tau \times \omega}{\left(\tau + \tau_f\right) \times \omega} = \frac{\tau}{\tau + \tau_f}$$

(3) Noise / Vibration

Noise :- measured directly - subject to noise regulations.

Vibration :-

- can be detrimental, leading to failure of major and auxiliary engine parts;
- engine must be dynamically balanced
- anti - vibration mounts prevent vibration transmission ;
- field of study in it's own right

(4) Engine Efficiencies

Mechanical efficiency (as above)

Volumetric efficiency (a measure of how well the engine 'breathes')

$$\text{Vol. eff. } (\eta_{vol}) = \frac{\text{Induced air volume flow rate } (m^3/\text{min})}{\text{Engine capacity} \times \begin{cases} \text{RPM} & \text{2-stroke} \\ \text{RPM}/2 & \text{4-stroke} \end{cases}}$$

Thermal efficiency $(\eta_{th}) = \dfrac{\dot{W}}{\dot{m} \times LCV_{fuel}}$

In **practical** terms an engine's fuel efficiency is measured by it's Specific Fuel Consumption (SFC), also called BRAKE Specific Fuel Consumption (BSFC), recognising that the engine’s power output is measured using a 'brake'.

$$\text{BSFC} = \frac{\text{Fuel flow (kg/h)}}{\text{Brake Power (kW)}} \quad \text{[kg/kWh]}$$

NB: Engine capacity = total swept volume of the engine = L x A x n (n = number of cylinders)

(5) Exhaust Emissions

The nature of the exhaust emissions is dependent upon the fuel used, the quality of the combustion process, and the presence of ‘contaminant’ substances such as sulphur or oil additives.

Most IC engine fuel molecules consist of approximately equal numbers of Carbon and Hydrogen atoms - and can be represented by the chemical formula C_6H_6

The combustion process consists of these fuel molecules breaking down and combining with the oxygen of the air to give energy (in the form of the heat of combustion) and the products of combustion.

If the combustion process were ***ideal or complete*** all of the carbon would oxidise to CO_2, and all of the hydrogen would oxidise to give water (in the form of steam) H_2O.
As a chemical equation we would write:

$$C_6H_6 + y\,(\underline{0.21O_2 + 0.79N_2}) > a\,CO_2 + b\,H_2O + c\,O_2 + d\,N_2$$

C_6H_6: molecule of fuel

y: air/fuel ratio (molecular)

$(0.21O_2 + 0.79N_2)$: ‘molecule’ of air

$c\,O_2$: excess oxygen

The value of ‘y’ is critical to the combustion process.
The chemically ‘correct’ value which results in complete combustion and <u>no</u> excess oxygen is known as the stoichiometric air/fuel ratio (AFR).
Above this value the peak combustion temperature reduces; below this value partially oxidised products are formed - in particular pure carbon (soot) and carbon monoxide CO.

(6) Stability / Controlability

Usually has to be evaluated in conjunction with the load it is driving

Engine / Load Matching