Note 96

Effects of Pressure-Charging on the Power equation

When a piston engine is Pressure-Charged (PC) it affects the factors of the basic Power equation, as set out in Note 10, in a variety of ways (in the following '1' refers to the state at the air intake, '2' to cylinder inlet and '3' to cylinder exhaust. Temperatures (T) are absolute, i.e. degrees Kelvin so that Standard ambient temperature of 15 Celsius is 288 Kelvin. Pressures (P) are also absolute, i.e. P1 = Standard ambient pressure = 1 Atmosphere Absolute (ATA) = 14.7psi and 'Pressure at the Inlet Valve' (IVP) = P2 is in ATA) :-

Manifold Density Ratio (MDR) is increased by: IVP x (T1/T2);
and T2 depends upon:- IVP; the efficiency of compression;
and the cooling before cylinder inlet (2) from fuel evaporation and any interposed heat-exchanger (intercooler).

Volumetric Efficiency (EV) is raised in 2 ways:-

- By reducing the heat convected into the charge post-cylinder-entry, mainly from the hot inlet valve, because T2 is higher than T1; empirically the effect is close to
$$\left(\frac{EV(PC)}{EV(NA)}\right) = \sqrt{(T2/T1)}$$
Ref. (594,Fig.141).
- By reducing the volume of residual exhaust gas in the combustion chamber because P2 is higher than P3; the effect is
$$\left(\frac{EV(PC)}{EV(NA)}\right) = \left(\frac{R - (P3/P2)}{R - 1}\right)$$
Ref. (121).
where R = Compression Ratio.
When the engine is Mechanically-Supercharged (MSC) P3 can be taken as P1, so that
$$\left(\frac{EV(MSC)}{EV(NA)}\right) = \left(\frac{R - 1/IVP}{R - 1}\right);$$
If the engine is Turbo-Charged (TC), P3 is greater than P1 by the back-pressure needed to drive the turbine and the full expression can then be reformed as
$$\left(\frac{EV(TC)}{EV(NA)}\right) = \left(\frac{R - RT/IVP}{R - 1}\right)$$
where RT = expansion ratio across the turbine.

Mechanical Efficiency (EM) may be reduced or increased:-

- With MSC EM is **reduced** by the power extracted from the crank to drive the compressor ***less*** the pneumatic recovery of power in the cylinder on the inlet stroke because P2 is greater than P1. This recovery is much less than the supercharger driving power because of the inefficiency of the compressor and other factors described below, hence the net reduced EM.
  The in-cylinder recovery is in itself a very complex situation since:-
  (i) there is a drop of total pressure (static pressure plus kinetic energy)across the inlet valve;
  (ii) with the inlet valve opening *before* Top Dead Centre (a timing universal after 1914, to take advantage of exhaust exit momentum) and always closing after Bottom Dead Centre (to take advantage of inlet charge momentum) the P2 effect is initially and finally *resisting* a rising piston;
  (iii) if there are tuned individual inlet tracts – not known with MSC in this review - there will be resonance effects to enhance P2.
  (Of course, effects (i) and (iii) are common to NA as well as MSC).

- With Turbo-Charging (TC) EM is **increased** for the following reason:-
  the back pressure in the cylinder has to rise to P3 so that the pressure drop (P3 – P1) can drive the turbine which in turn drives the compressor to produce the inlet pressure rise (P2 – P1). This increase in P3 subtracts power pneumatically from the crank on the exhaust stroke with a rising piston (subject to similar complex effects as listed above for inlet power recovery). However, because the exhaust temperature is around 1,000C thermodynamics means that (P3 – P1) is less than (P2 – P1) (depending on overall machine efficiency). Therefore P2 is greater than P3 and puts more power pneumatically into the crank on the inlet stroke than is deducted by P3 on the exhaust stroke. As there is no mechanical power subtraction for TC the value of EM is increased.