Brake Mean Effective Pressure

We have presented the topics of **Thermal Efficiency** and **Volumetric Efficiency** as methods for estimating the potential output of a given engine configuration.

Brake Mean Effective Pressure (BMEP) is another very effective yardstick for comparing the performance of an engine of a given type to another of the same type, and for evaluating the reasonableness of performance claims or requirements.

The definition of BMEP is: *the average (mean) pressure which, if imposed on the pistons uniformly from the top to the bottom of each power stroke, would produce the measured (brake) power output.*

Note that BMEP is **purely theoretical** and **has nothing to do with actual cylinder pressures**. It is simply a tool to evaluate the efficiency of a given engine at producing torque from a given displacement.

A torque output of 1.0 lb-ft per cubic inch of displacement in a 4-stroke engine equals a BMEP of 150.8 psi. In a 2-stroke engine, that same 1.0 lb-ft of torque per cubic inch is a BMEP of 75.4 psi. *(The derivation of that relationship is given at the borttom of this page.)*

By looking at equations 8-a and 8-b below, you can easily see that BMEP is simply the torque per cubic inch of displacement, multiplied by a constant. In fact, many talented people in the engine design and developmeny business currently use torque-per-cubic inch ***("torque ratio")*** instead of BMEP, thereby avoiding that tedious multiplication process.

(The discussion on the remainder of this page is with respect to *four-stroke engines*, but it applies equally to two stroke engines if you simply substitute 75.4 everywhere you see 150.8)

If you know the torque and displacement of an engine, a very practical way to calculate BMEP is:

BMEP (psi) = 150.8 x TORQUE (lb-ft) / DISPLACEMENT (ci)

(Equation 8-a, 4-Stroke Engine)

BMEP (psi) = 75.4 x TORQUE (lb-ft) / DISPLACEMENT (ci)

(Equation 8-b, 2-Stroke Engine)

(IF you prefer pressure readings in Bar rather than PSI, simply divide PSI by 14.5)

(IF you are interested in the derivation of those relationships, it is explained at the bottom of this page.)

This tool is extremely handy to evaluate the performance which is claimed for any particular engine. For example, the 200 HP IO-360 (360 CID) and 300 HP IO-540 (540 CID) Lycomings make their rated power at 2700 RPM. At that RPM, the rated power requires 389 lb-ft and 584 lb-ft of torque respectively. (If you don't understand that calculation, **CLICK HERE**)

From those torque values, it is easy to see (from Equation 8-a above) that both engines operate at a BMEP of about 163 PSI (12.25 bar, or a ***"torque ratio"*** of 1.08 lb-ft per cubic inch) at peak power. The BMEP at peak torque is slightly greater.

For a long-life, naturally-aspirated, SI (spark ignition) gasoline-fueled, two-valve-per-cylinder, pushrod engine, a BMEP over 211 PSI (14.55 bar, torque ratio of 1.40) is difficult to achieve and requires a serious development program and very specialized components.

It is worthwhile to note that a contemporary, normally-aspirated CI (compression-ignition) engine can easily make 15 bar of BMEP, and several turbocharged CI street engines routinely exceed 20.5 bar. It is helpful to remember that BMEP is a useful tool for comparing and evaluating similar types of engines.

For comparison purposes, let's look at what is commonly believed to be the very pinnacle of engine performance: Formula-1 (Grand Prix).

An F1 engine is purpose-built and essentially unrestricted. For 2006, the rules required a 90° V8 engine of 2.4 liters displacement (146.4 CID) with a maximum bore of 98mm (3.858) and a required bore spacing of 106.5 mm (4.193). The resulting stroke to achieve 2.4 liters is 39.75 mm (1.565) and is implemented with a 180° crankshaft. The typical rod length is approximately 4.016 (102 mm), for a Rod / Stroke ratio of about 2.57. These engines are typically a 4-valve-per cylinder layout with two overhead cams per bank, and pneumatic valvesprings. In addition to the few restrictions stated above, there are the following additional restrictions: (a) no beryllium compounds, (b) no MMC pistons, (c) no variable-length intake pipes, (d) one injector per cylinder, and (e) the requirement that one engine last for two race weekends.

At the end of the 2006 season, most of these F1 engines ran up to 20,000 RPM in a race, and made in the vicinity of 750 HP. One engine for which I have the figures made 755 BHP at an astonishing 19,250 RPM. At a peak power of 755 HP, the torque is 206 lb-ft and peak-power BMEP would be 212 psi. (14.63 bar). Peak torque of 214 lb-ft occurred at 17,000 RPM for a BMEP of 220 psi (15.18 bar). There can be no argument that 212 psi at 19,250 RPM is truly amazing.

However, let's look at some astounding **domestic** technology.
The NASCAR CUP race engine is a severely-restricted powerplant, allegedly being derived from "production" components, although as of 2010, all 4 engines competing at that level (Chevy, Dodge, Ford, Totota) are purpose-built race engines designed specifically to NASCAR's rule book.
By regulation, CUP engines have a maximum displacement of 358 CI (5.87 L). They must use a cast-iron 90° V8 block with a 4.500 inch bore spacing and a 90° steel crankshaft. A typical configuration has a 4.185" bore with a 3.25" stroke and a 6.20" conrod (R/S = 1.91). Cylinder heads are similarly purpose-designed and highly-developed, but limited to two valves per cylinder, specific valve angles, specific port floor heights, etc.. The valves are operated by a single, block-mounted, flat-tappet camshaft *(that's right, still no rollers as of 2012)* and a pushrod / rocker-arm / coil-spring valvetrain. It is further hobbled by the requirement for a single four-barrel carburetor (until 2011) and now (2012 on), by a 4-barrel-carburetor-like throttle body and individial runner EFI. Electronically-controlled ignition is allowed (as of 2012), and there are minimum weight requirements for the conrods and pistons.

How does it perform? In early 2010, the engines were producing in the neighborhood of 860 HP at 9000 RPM, and they operate at a max race rpm in the vicinity of 9400 rpm. That max rpm is controlled by a NASCAR rule that specifies the final drive ratio at each track (the "gear rule"). If it were not for the gear rule, these engines would be operating at well over 10,000 rpm at the race track..

Consider the fact that, to produce 860 HP at 9000 RPM, requires 501 lb-ft of torque, for a peak-power BMEP of nearly 211 PSI (14.55 bar). Peak torque (2010) was typically about 535 lb-ft at 7800 RPM, for a peak BMEP of over 226 psi (15.6 bar, torque ratio of 1.50).

THAT is truly astonishing. **Compare** the F1 engine figures to the CUP engine figures for a better grip on just how clever these CUP engine guys are. In addition, consider the fact that (a) a single engine must be used for each race meeting, which includes at least two practice sessions, a qualifying session, and the race, which can be as long as 600 miles, and (b) the Penske-Dodge engines that won the 2012 championship did not suffer a single engine failure throughout the 2012 38-race season.

That being said, recent winners in the annual Engine Masters competition are achieving over 16.9 bar BMEP (245 psi, torque ratio of 1.63 !) with normally-aspirated, petrol-fueled, SI, 2-valve pushrod engines, although the builders freely admit that, due to the very aggressive cam profiles, rocker ratios, gross valve lift numbers, and other compromises aimed at maximizing BMEP, these engines have relatively short life expectancies.

To appreciate the value of this comparison tool, suppose someone offers to sell you a 2.8 liter (171 cubic inch) Ford V6 which allegedly makes 230 HP at 5000 RPM, and is equipped with the standard OEM iron heads and an aftermarket intake manifold and camshaft. You could evaluate the reasonableness of this claim by calculating (a) that 230 HP at 5000 RPM requires 242 lb-ft of torque (230 x 5252 ÷ 5000), and (b) that 242 lb-ft. of torque from 171 cubic inches requires a BMEP of 213 PSI (150.8 x 242 ÷ 171).

You would then dismiss the claim as preposterous because you know that if a guy could do the magic required to make that kind of performance with the stock heads and intake design, he would be renowned as one of the pre-eminent engine gurus in the world. (You would later discover that the engine rating of "230" is actually "*Blantonpower*", not Horsepower.)

As a matter of fact, in order to get a BMEP value of 214 PSI from our **GEN-1 aircraft V8**, we had to use extremely well developed, high-flowing, high velocity heads, a specially-developed tuned intake and fuel injection system, very well developed roller-cam profiles and valve train components, and a host of very specialized components which we designed and manufactured.

DERIVATION OF THE BMEP EQUATIONS

The definition of BMEP (Brake Mean Effective Pressure), as previously stated at the top of this page, is: *" the mean (average) pressure which, if imposed on the pistons* ***uniformly*** *from the top to the bottom of each power stroke, would produce the measured (brake) power output".* AGAIN, NOTE that BMEP is **purely theoretical** and **has nothing to do with actual cylinder pressures**.

If we put the definition into mathematical form, we get:,

HP = BMEP x piston area x (stroke / 12) x RPM x power-pulses-per-revolution / 33000

Working through that equation in terms of a single cylinder engine, **BMEP** (in PSI) multiplied by **piston area**(square inches) gives the **mean** force applied to the piston during the power stroke. Multiplying that force by the**stroke** (inches divided by 12, which changes the units to feet) gives the net **WORK** (in foot-pounds) produced by the piston moving from TDC to BDC with the BMEP exerted on it throughout that motion. (Clearly this is not an attempt to represent the reality in the combustion chamber. As previously stated, BMEP is simply a convenient tool for comparing and evaluating engine performance.)

Next, **power** is defined as work-per-unit time. Therefore, multiplying the WORK (ft-lbs) by the **RPM**, then multiplying by power-pulses-per-revolution (**PPR**) gives the net (brake) power (foot-pounds per minute in this example) produced by one cylinder. (In a single-cylinder engine, **PPR** is either **1** for a 2-stroke engine or **1/2** for a 4-stroke engine.
Since one **HORSEPOWER** is defined as 33,000 foot-pounds-of-work-per-minute, dividing the WORK (ft-lbs) by**33,000** changes the units from foot-pounds-per-minute to HP.

Since it is clear that **piston area x stroke** is the displacement of one cylinder (in cubic inches), then the equation can be simplified to:

HP = BMEP x (displacement / 12) x RPM x power-pulses-per-revolution / 33000

Horsepower is also defined as:

HP = Torque x RPM / 5252

Substituting that equation into the preceding one gives:

Torque x RPM / 5252 = BMEP x displacement / 12 x RPM x PPR / 33000

Reducing that equation gives:

BMEP = (Torque x 12 x 33,000 / 5252) / (Displacement x PPR)

Evaluating the constants, 12 x 33,000 / 5252 = 75.39985, which can safely be approximated by 75.4. Simplifying the equation again gives:

BMEP = (Torque x 75.4) / (Displacement x PPR)

It is also clear that because the equation includes PPR, it applies to engines with any number of cylinders by using the total displacement, total brake torque, and correct PPR.
Suppose, for example, that you measured 14.45 lb-ft of torque from a 125 cc (7.625 CID) single-cylinder **2-stroke**engine at 12,950 RPM, you would have 35.63 HP (285 HP per liter, quite impressive indeed). The BMEP would be:

BMEP = (14.45 x 75.4) / (7.625 x 1) = 142.9 psi (9.85 bar)

That BMEP (9.85 bar) is an impressive number for a piston-ported 2-stroke engine.
However, suppose someone claimed to be making that same torque from a single cylinder **4-stroke** 125 cc engine at 12,950 RPM. The power would be the same (35.63 HP, or 285 HP per liter). The power density would not **necessarily** set off alarms, (the 2008 2.4 liter F1 V8 engines approached 315 HP per liter), but the BMEP would cause that claim to be declared highly questionable:

BMEP = (14.45 x 75.4) / (7.625 x 1/2) = 285.8 psi (19.7 bar)

That BMEP (19.7 bar) is clearly absurd for a normally-aspirated engine. Professor Gordon Blair stated that exceeding 15 bar of BMEP in a N/A engine is virtually impossible, but that was a few years ago. NASCAR Cup engines are now approaching 15.6 bar

Clearly, the difference between 2- and 4-stroke engines is simply a factor of 2, because of the fact that a 2-stroke cylinder fires once per revoultion whereas a 4-stroke engine fires only once per two revolutions. The equations can be simplified further by incorporating that PPR factor in the constant 75.4 and eliminating PPR from the equation, therefore making the constant for a 4-stroke engine 2 x 75.4 = 150.8. That produces the equations shown at the top of this article, which use the full engine displacement and measured torque.

BMEP = 150.8 x TORQUE (lb-ft) / DISPLACEMENT (ci)

(Equation 8-a, 4-Stroke Engine)

BMEP = 75.4 x TORQUE (lb-ft) / DISPLACEMENT (ci)

(Equation 8-b, 2-Stroke Engine)

Source:

http://www.epi-eng.com/piston_engine_technology/bmep_performance_yardstick.htm