Elements of Combustion Engineering

For seventy-five plus years aftermarket suppliers have been marketing various products designed to improve "street performance." Invariably they tout improved HP (sell the "Sizzle") as their main marketing tool. Let's look at this to see if there is any rational for pushing HP. Does it pass the "Smell Test" to be the "Gold Standard" for improving street performance, or is it just an ill-conceived, enduring marketing methodology sending the unwary down the wrong path, chasing the wrong target in pursuit of improved "street performance?" First let's define a few terms.

Performance: Are we talking about HP (Horsepower) or Torque? Knowing why is important to understand how! Don't get seduced into chasing HP with an OEM designed 54 HP NA (Naturally Aspirated) XPAG with vintage engine architecture designed to provide reasonable engine service life, using OEM (**not upgraded**) parts, and maybe 30-45k miles between rebuilds. Many of today's modern engines offer 100k mile warranties and service life 300k-400+ miles. With period vintage engines, **HP is not the Holy Grail for greater vintage engine street performance**. It is only useful in a macho dyno contest to see who can spend the most $$$ in order to determine who is willing to rev their engine the highest before it grenades! With modern and vintage engines, useable street performance increases are related to the **rate of acceleration from point A to point B. Torque is the Gold Standard, not peak HP.**

RPM: (Revolutions Per Minute) which are related to HP (put your engine on a Dyno and it becomes obvious that HP is directly related to and a function of RPM.) RPM higher than stock Redline will reduce the **service life** of the engine due to the potential for increased loads, wear and rpm **necessary** to add **HP**. These can overwhelm the ability of the period engine architecture to cope with the increased stresses, as greater **HP** is directly related to higher **RPM**. Higher RPM over OEM design **Red Line** will overstress all engine components, especially valve train dynamics, unless expensive engine upgrades are made to accommodate the additional mechanical, thermal, frictional and harmonic stresses encountered. This can be a very tricky "can of worms" as when the size of the **combustion event** increases, excess heat will also be generated in the cylinder/combustion chamber that must be mitigated with costly "fixes." **Examples are:** ceramic thermal barriers on piston crowns, exhaust ports, exhaust manifolds, combustion chamber and thermal resistant Inconel, Nimonic, et.al. exhaust valves (**NOTE:** the material selected is dependent on thermal environment that the exhaust valves are exposed to). Anti-wear and Anti-friction such as Ion Nitriding, DLC coatings, and heat sinks such as bronze valve guides, copper matrix coated piston rings are desirable too. Also powdered metal, copper matrix alloy valve seats to enhance thermal transfer from the combustion chamber to the water-cooled engine head. See: https://www.dura-bondbearing.com/products/powder-metal-valve-seats/ for extended service life. Friction generates heat, so the trend, even in daily drivers, is to migrate to 1mm top and second rings and 2mm oil rings. Narrower rings = less friction = less heat =less wear.

HP: is basically a function of the **amount "work" (torque) done over time (RPM),** i.e. the number of power strokes used in a specific time to get to Redline, a **derived rate of work done. HP is only useful at sustained max RPM**, such as offshore boat racing and other racing primarily done at a high percentage of Wide-Open Throttle. As max HP is only available at a high, very narrow RPM range, a 6-8+ speed tranny will be required to keep RPM in the very narrow max power range. One can maximize HP via either greater torque or greater RPM. The downside of the latter is that greater RPM impacts the service life of the engine, w/o spending cubic (lots of) money on engine upgrades. For max torque, tell your engine builder or cam supplier that you want maximum available BMEP (Brake Mean Effective Pressure)/Torque **(see definitions below)** throughout the mean specified, operational RPM range**. Select a cam with the optimum valve timing that maximizes the available number of units of air per intake cycle to which additional units of fuel can be added, in order to maximize the size of the combustion event and resultant torque.** Hopefully your engine builder or cam engineer may also suggest going to FI (Forced Induction) by adding a blower, turbo, or using nitrous oxide (a strong oxidizer) and/or adding cubic inches. Any of these will increase or accommodate more a/f (air/fuel, i.e. O_2) **mass** into the combustion event to maximize BMEP and torque, without introducing undesirable excess RPM beyond the abilities of the period engine architecture design to cope with.

Torque: Basically, the **measured** twisting force ("work") imposed on an object (crankshaft journal) to be rotated by "X" rate/size of combustion event expansion pressure force. (BMEP = size of combustion event pressure) thrusting the piston down.

BMEP: (Brake Mean Effective Pressure)

Essentially the mean size of the downward expansion pressure from the Combustion Event, exerting thrust atop piston and inputting a turning force into the crankshaft journal producing a "work output" (torque).

HP = torque x RPM/5250 ("work" times the # of power strokes, or rate of "work" done).
Torque = HP x 5250/RPM (a rotating force producing an amount "work" done over time.)
BMEP = 150.8 x torque/displacement in cubic inches, or torque output per cubic inch.

Let's stick to basic combustion engineering elements: BMEP-Torque-HP

- Increasing torque is a function of increased BMEP; (BMEP is also useful as a **measure of engine efficiency** in producing and **comparing** different engine's torque per cubic inch).
- **BMEP & thus torque for "X" size engine can only be increased by increasing the size of the CE (Combustion Event)** and its downward mean rate of expanding pressure thrust across top of piston, throughout the power stroke.
- The most basic way to increase the size of the combustion event and the resultant BMEP/torque in a NA (naturally aspirated) engine of "X" size is **via cam timing to increase the number of units of air, (really the units of O_2 component of air), inhaled per intake cycle at one atmosphere ~ (or more or less) 14.7 PSI,** and **increasing compression ratio.** The more units of air made available means that more units of fuel can be introduced into Combustion Event **for a bigger "bang".**
- **The EASY PART of adjusting the a/f (air/fuel) mix in a NA engine is adding units of fuel to units of air in correct Stochiometric a/f proportions. (See definition below.)**
- **The HARD PART in a "NA" engine is adding units of O_2 laden air to balance the equation** in order to increase the size of Combustion Event as measured by greater BMEP output number for greater torque. Any air intake at over 100% Volumetric efficiency is "money in the bank" providing a supercharging effect. As far back as the early 1960's, MZ

motorcycle's engineer (Walter Kaaden) was able to ultimately achieve 140% volumetric efficiency out of MZ's two cycle "NA" GP engines, for a then unheard of 200 HP per liter. Utilizing his *Wave Form Pulse Theory*, (an extension of his research and work on WWII pulsed "buzz bomb" technology), Kaaden was functionally able to increase the size of the BMEP at Combustion Event and subsequent torque by adding 40% more air input to mix with additional fuel, at twice as many power strokes per revolution as available to competitors four cycle "NA" GP engines. This was the result of much greater BMEP available by using Kaaden's advanced evolution of two stroke technology than was available from four stroke "NA" engines of the same displacement. Essentially MZ put **four cycle** Moto GP out of business for a time. MZ may have won the battle, but they lost the war when Honda & other four-cycle Moto GP entrants succeeded in having 2 cycle engines banned on environmental emissions grounds. Today's two cycle race bikes are making ~ (about) 400 HP/liter and meeting emission standards by using Direct Injection to resolve the emissions issues. For more on "Back Story" see: Mat Oxley's *Stealing Speed*, and or Jan Leek's *MZ The Racers, the birth of the modern two-stroke.* Alas, the latter is a rarely available collector's item, long out of print.

- The more **mass** of air that can be introduced into the cylinder volume, meaning that more of the O_2 component of air will be taken in on each intake cycle. This means even more units **of** fuel can be added to a/f equation resulting in an even **bigger "bang"** at the Combustion Event, starting at and throughout the power stroke. As the **contained combustion explosive event detonates, the combustion gasses expand** thrusting the piston down with a force that is dependent on the size of the BMEP number, generating torque. The rate of fast or slow burn expansion also defines the amount ignition advance required to ignite a/f mix. Slow burning a/f mixes require large amounts of advance to complete combustion by ~ (about) 20° ATDC on power stroke.
- **High Velocity Porting:** Maximizing the volume of a/f (air/fuel) mix to be transited into the combustion chamber is also a function of maximizing mean **laminar**, (non-turbulent**)** **air/fuel velocity** through ports. **See Lovell Factor below.** Detached, non-laminar, churning, turbulent flow of a/f mix loses both momentum and important velocity attempting to transit even minor port direction changes. (Think turning vanes in AC ducting to address undesirable generation of turbulent air flow from direction changes influencing both flow velocity and momentum.) The object is to maximize and maintain "attached" laminar, non-turbulent flow at optimum a/f velocity throughout mean operational rpm range. **Also see: Reynolds Number**, **Boyles Law** and **Bernoulli's Law,** all elements of **Fluid Dynamics.** The fuel component of a/f mix tends to cling to port walls ("Wet-Out") negatively affecting "attached" laminar flow, creating additional drag and turbulence, further restricting target flow velocity. This is a reason for today's trend to Direct Fuel Injection into combustion chamber, **bypassing both manifold and port injection**. **High Reynolds Numbers** means that detached viscous a/f flow through ports is generating, chaotic, vortices, turbulent a/f eddies and detached a/f flow through ports. Best resolved by bypassing disrupting effects of Reynolds Numbers involvement, via direct fuel injection into cylinder. **Insight:** At some point it can be foreseen that the next step would be metered air injection directly into cylinder. Should that come about, one could do away with Blowers, Turbos, just let CPU add a/f mix for BMEP/torque on demand. It would be nice to eliminate the intake side of the valve train It would be a step beyond CPU controlled Camless valve actuation such as being introduced by Koenigsegg, et al.

- As the a/f velocity through the ports in "NA" engines is a function of, and related to RPM, it is bad practice to hog out ports oversize as air/fuel mix velocity will slow, **(Boyles Law)** affecting the volume of a/f mix available to enter cylinder in the "X" limited intake time available as RPM increases. FI (Forced induction) engines, being pressurized beyond one atmosphere, are a different story.
- **Lovell Factor**

1. https://www.rbracing-rsr.com/lovellgascalc.html
2. https://mechanics.stackexchange.com/questions/22408/what-is-the-lovell-factor#:~:text=The%20Lovell%20factor%20refers%20to%20the%20average%20%28mean%29,of%20the%20air-fuel%20mixture%20at%20the%20intake%20valves.
3. https://www.highpowermedia.com/Archive/the-effect-of-valve-size

Achieving greater a/f flow velocity increases the a/f mass available to fill cylinder in the ever-decreasing amounts of time available during which intake valves are open, as RPM increases. It is also a function of the intake valve "**Curtain Area**" (which is the volume of an imaginary cylinder described by the i.d. of the valve seat times the height of the valve at full lift). The faster the valve opens (acceleration rate) and the longer it stays open (duration) the more the mass of air/fuel mix can enter the cylinder, resulting in maximizing the size of the combustion event and the expansive pressure (BMEP) force slamming the piston down, thus generating more torque. The bigger the BMEP pressure output, the greater amount of thrust input into the crank journal which creates greater torque and when combined with greater RPM results in greater HP. **Note**: most bespoke high-performance competition engines and even some daily driver engines use four valve heads. Pre and post WWII, five and even six valve race heads were not uncommon, as they likely provided greater combined "Curtain Area" and less weight per valve than two valve heads. However, these heads introduced very complex valve train dynamics until introduction of pneumatic actuation of valves. Ducati, being "old school," still opts to stick to their evolution of the Mercedes mid '50's Desmodromic springless valve train in their race bike engines to resolve discordant valve train spring harmonic resonances.

As an aside, Hyundai has "one-upped" Honda's V-Tech valve train innovation with a CVVD "Continuously Variable Valve Duration" valve train.
See: https://www.hyundainews.com/en-us/releases/2808 Audi is introducing daily driver E-Turbo engines using an electric motor to keep turbo spooled up to eliminate turbo lag.

Stochiometric: For gasoline this is an a/f ratio of 14.7:1. This is the a/f ratio necessary for 100% complete a/f **combustion, leaving zero elements of un-combusted energy on the table not contributing to increasing the size of BMEP/torque.** Running a rich non-Stochiometric a/f mix is "**a fix**" done to address unresolved thermal issues in the combustion chamber when the compression ratio is **deliberately** pushed to limits of octane for fuel used. Increasing the compression ratio is the simplest way to increase performance, until the onset of detonation. The excessive, heat induced, detonation can be postponed, to an extent, by running a higher-octane fuel and or a richer cooling a/f mix, at expense of poor emissions and poor fuel milage. As the excess unburned fuel evaporates, it cools piston, valves and combustion chamber temperatures and blows still yet un-combusted and sometimes still combusting air/fuel mix out the exhaust. It also dilutes sump oil! The various tapered SU needles offered are a means to keep the air/fuel mix at or near Stochiometric throughout the RPM range for whatever fuel cocktail is used, As the RPM increases and more air mass is introduced to fill cylinder volume, the reduced diameter of the tapered needle lifts out of the jet allowing more fuel to be added, in order to keep air/fuel ratio as near as possible to ideal Stochiometric of 14.7:1 for gasoline throughout RPM range. **Note:** Stochiometric for E-85 fuel is on order of 9.7:1, or 34% richer than gasoline, E-15 @ 13.8 = 6% richer and E-10 @ 14.1 = 4% richer. (**Note**: Running a 14.7:1 a/f ratio for gasoline will be very lean unless a richer needle is fit when switching to suit E-fuels. Especially E-85 for its cooling effect, to resolve detonation from too high a compression ratio). Today's lean burn, fuel restricted, daily driver engines run ECU controlled +/- 20:1 a/f mix when not under load and 14.7:1 Stochiometric when under full load. Some serious race engines, such as used in F1, are so “Fuel Rule” constrained they have to run +/- 40:1 a/f ratios when not under load and Stochiometric for their fuel “cocktail” when under full load. This makes them so ultra-lean burn and fuel starved, that they will not start without something akin to a piezo igniter in a rich pre-ignition chamber in place of a spark plug to initiate combustion in the cylinder. **Win win**, as the engineers deemed that the spark plug took up too much space in the cylinder head combustion chamber, better used by bigger or more intake valves to increase “Curtain Area” a/f intake potential.”

Therefore, the first priority is to maximize BMEP for torque. Only chase **venerated** HP via greater RPM, **if** a short service life rebuild budget available, as service life of components will drop dramatically, without spending serious dollars to upgrade much of the period engine architecture, especially RPM related unstable valvetrain and other engine parts interactive harmonic dissonances.

- FI (Forced Induction i.e. Turbos or Blowers), generate gobs of torque because they push multiple psi of boost (air/O_2) **over** one atmosphere 14.5 psi or ~ (about) one Bar available to NA engines, at a higher a/f velocity**, allowing greater cylinder “fill rate” in the ever-decreasing amounts of time available to fill cylinder as RPM increases. This is assuming** air inflow intake mass is not restricted by undersize (restrictor plate) carb inlets impeding volumetric efficiency. Back in the mid ‘80’s F1 Turbo Era, BMW selected **used,** i.e. “well-seasoned” (100k+ miles), stress relieved M12/13, **80 HP 4-cylinder daily driver blocks** as the foundation for their **I-4 (inline 4) 1.5L-2L** F1 turbo engines. With as much **turbo boost** and **RPM over Red Line** as engineers calculated or dared, the engines eventually achieved an (estimated) 1400 HP+/- at 5.5+/- bar boost in Qualifying Mode. This was dialed back +/- 20% in Race Mode. BMEP, torque and were only estimated. This was estimated because they exceeded the dyno’s capacity to read torque. See: https://www.racefans.net/2020/04/14/f1-most-powerful-car-brabham-bmw-turbo-1400-bho/t/2020/04/14/f1-most-powerful-car-brabham-bmw-turbo-1400-bho/

- A 50% increase in HP at daily driver speeds will hardly be noticed, whereas a 50 % increase in torque will immediately be useful to increase **rate** accelerate to Redline from A to B distance over time. Of course, if acceleration uphill, on a Freeway entrance ramp, or passing is important, keep the stock 5.125:1 rear end ratio. If engine is torque modified, and fuel economy or keeping up with Freeway traffic is important, use a higher 4.87:1 or higher rear ratio or an overdrive tranny.

In summary:

HP is a **derived** number, a function of **torque** at “X” **rpm** dyno readings. One can maximize HP via either greater torque or greater RPM. The downside of the latter is that maximizing RPM impacts the service life of the engine w/o spending vast amounts of dollars to improve engine architecture.
For greater performance, chase torque via greater mass of air/fuel mix input to increase size of the combustion event, or add blower, turbo, cubic inches, or nitrous oxide (speed in a bottle). All of these will generate improved **rate of** A to B acceleration performance without need for excessive RPM, by providing additional O_2 component of air, thus allowing introduction of additional fuel to a/f mix. Note that Nitrous requires different Stochiometric and timing, dependent fuel cocktail used.
Most (non- racers) spend nil time at Redline, so RPM becomes less important than useful torque when seeking more street performance for better A to B **rate of acceleration** in modern traffic. That takes torque.

50 lb-ft of Tq. X 5000 RPM = 47.6 HP, whereas
100 lb-ft of Tq. X 5000 RPM = 95 HP.
Chase torque, not RPM!!

For more technical information see:
http://www.profblairandassociates.com/pdfs/Back_to_basics.pdf

TVO (**T**he **V**intage **O**ne)
TC 4926
Oct. 2020