Why Dyno Software Should Calculate and Plot Torque ÷ MAP

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Introduction

In this document I present the reasoning and an example of why chassis and engine dynamometers should have the capability to calculate and plot Torque ÷ MAP as an aide to tuning turbocharged motors that have less than perfect boost control.

BMEP

Brake mean effective pressure or BMEP is a good indicator of a motor's volumetric and combustion efficiency. It is the pressure applied to the piston halfway down the power stroke which would produce the same torque at the crankshaft:

*BMEP * piston_area * stroke/2 = torque*

This comes from the equations:

*pressure * area = Force*
*Force*moment_arm = torque*
Piston_area = $\pi * (bore/2)^2$

Put another way, it is the pressure applied over the 180° of crankshaft rotation that would produce the same work (Joules). Another set of equations:

*BMEP * displacement * frequency = Power*
(Note that in a 4-stroke motor the frequency of the power stroke is once every 2 revolutions)

In a naturally aspirated motor it is proportional to torque divided by displacement. At peak torque the BMEP of a highly optimized naturally aspirated F1 and NASCAR motor are both around 15 bar (about 225 psi). F1 motors make more power per L because they maintain this BMEP (and torque) to higher RPMs.

15 BMEP bar yields about 90 ft-lbs per liter.

For forced induction motors, BMEP (and thus torque), are proportional to MAP (manifold absolute pressure). So a naturally aspirated motor making 15 bar BMEP will make 30 bar (double) at 15 psi of manifold gauge pressure.

So here is a new metric I present,

"Specific BMEP" or BMEP / MAP (dimensionless)

This value will be relatively constant regardless of boost pressure. For a highly optimized gasoline engine the maximum value will be close to 15.3.

Units of ft-lbs per liter per bar of pressure can also be used (1 bar is very close to atmospheric pressure at sea level). I call this "specific torque"

Torque / MAP in bar / liter = "specific torque"

The equivalent of the 15.3 number above is the same as the naturally aspirated figure for highly optimized F1 and NASCAR motors:

90 ft-lbs/liter/bar

DYNO TUNING

When dyno tuning WOT (wide open throttle) operation, a tuner will run an RPM sweep. That is, the driver will floor the gas pedal at some low RPM, the dyno will allow RPM to rise towards rev-limit and produce a torque vs. RPM plot:

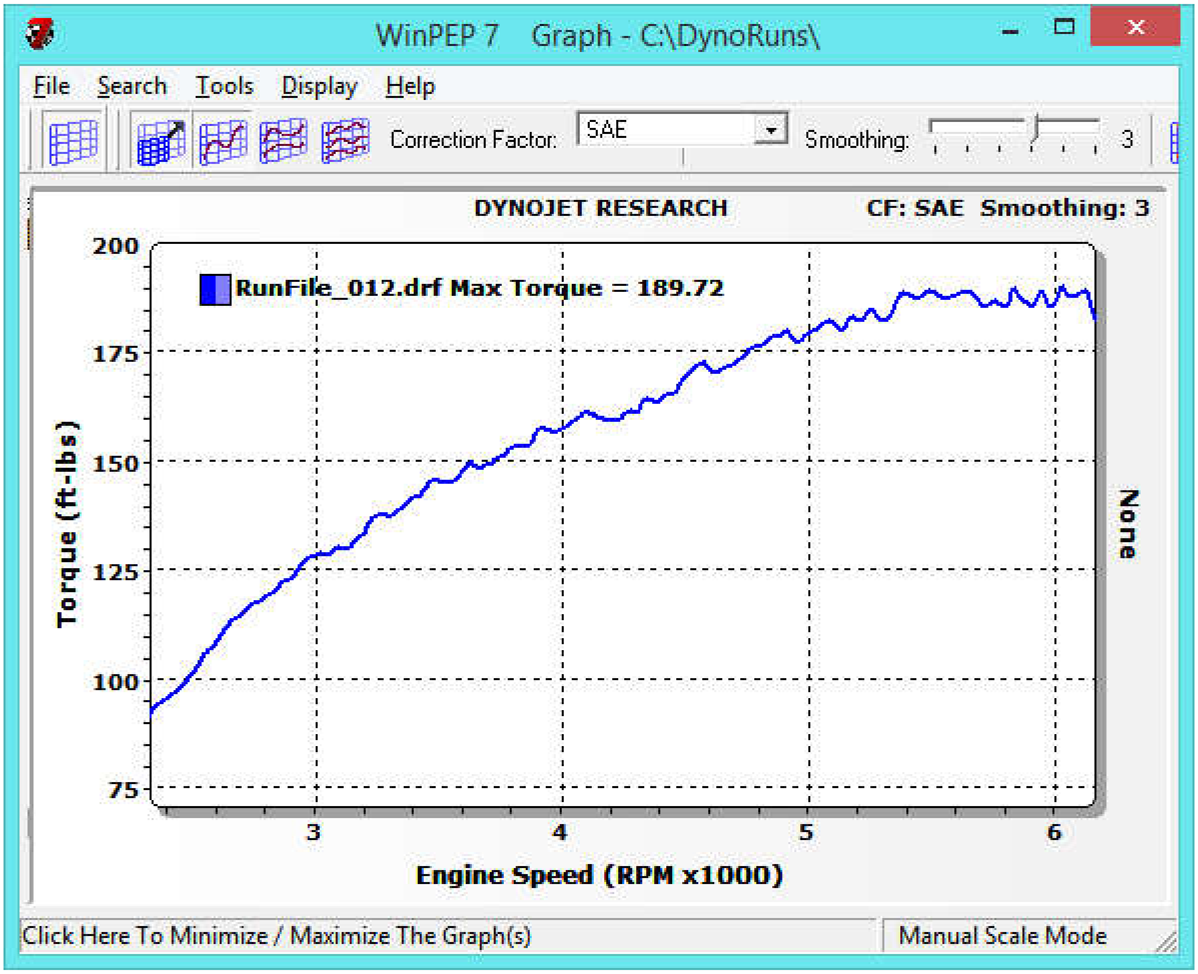


Figure 1: typical WOT RPM sweep on dyno

When tuning WOT ignition timing, the tuner will make a change, such as to add 2° of timing at all RPMs, do another sweep, and overlay the plots to look for changes in torque output. In this example, torque increased at all RPMs:

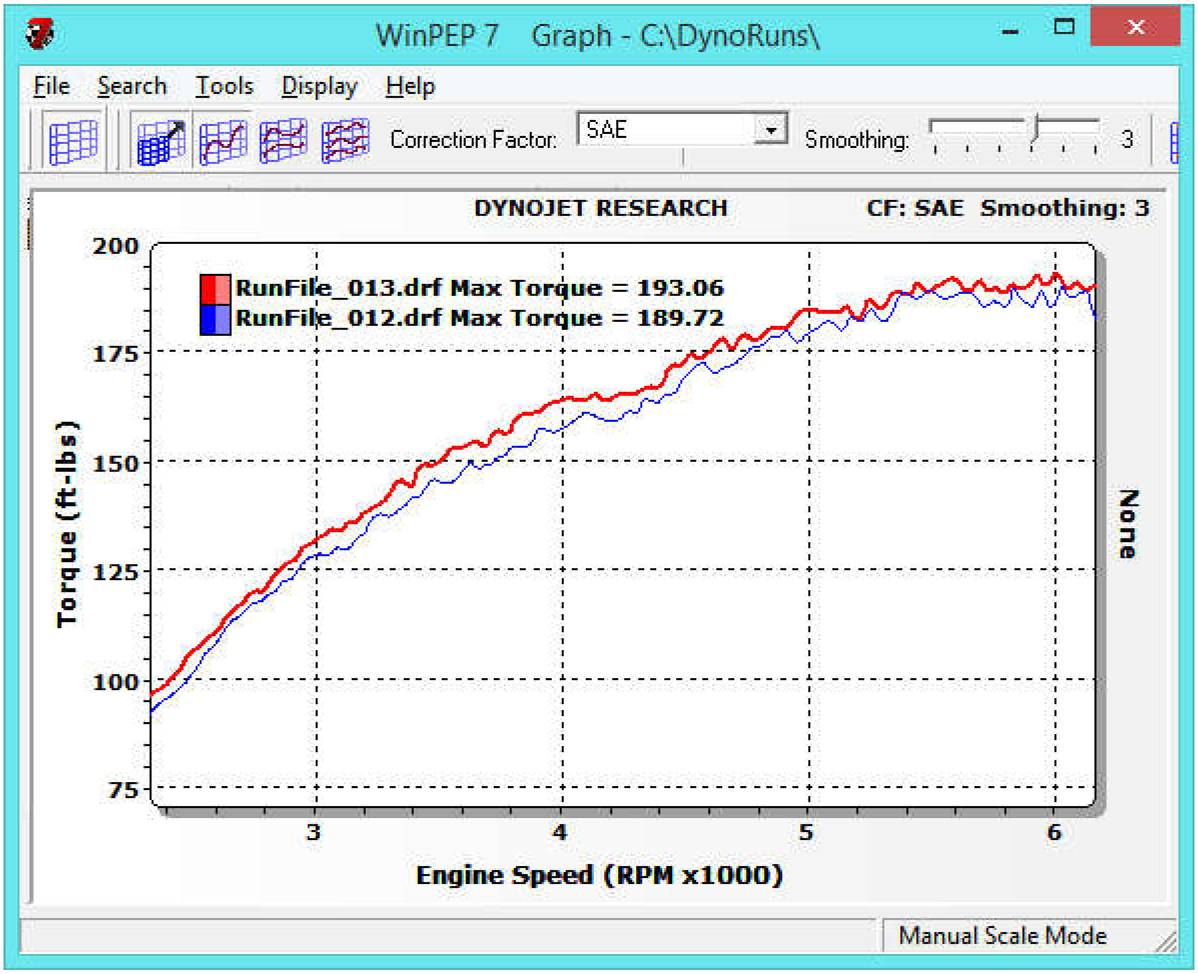


Figure 2: Red trace, run13, is improved with additional 2° of ignition advance vs. blue trace, run 12.

If the motor doesn't gain torque at certain RPMs, then the timing at those RPMs is very close to "MBT" (optimal) at those RPMs. If it loses torque at certain RPMs then the timing is over-advanced.

The process is repeated until MBT is found at all RPMs.

When a turbo motor is being tuned, there is the added complication of variable boost pressure. Without good mechanical or electronic boost control, the boost pressure can vary from run to run. More boost tends to increase torque. The problem is that if boost changes, torque will change accordingly. If the tuner is looking for small changes in torque then it's not clear if it was due to tuning changes or changes in boost pressure. What especially complicates matters is that with poor boost control, increasing ignition timing will reduce exhaust energy and thus reduce boost pressure. If timing is below MBT increasing timing will increase torque, but the resulting reduction in boost pressure may decrease torque by more than the increase from timing alone. This makes tuning difficult.

Dyno Tuning Example of a Turbocharged Motor

Here is an example. It is a 1.6L motor with a turbo and an internal wastegate driven by an actuator can plumbed to the turbo output. No additional electronic or mechanical boost controller. The owner wanted to dyno tune the car "using just the wastegate can". The can had a nominal 10 psi rating.

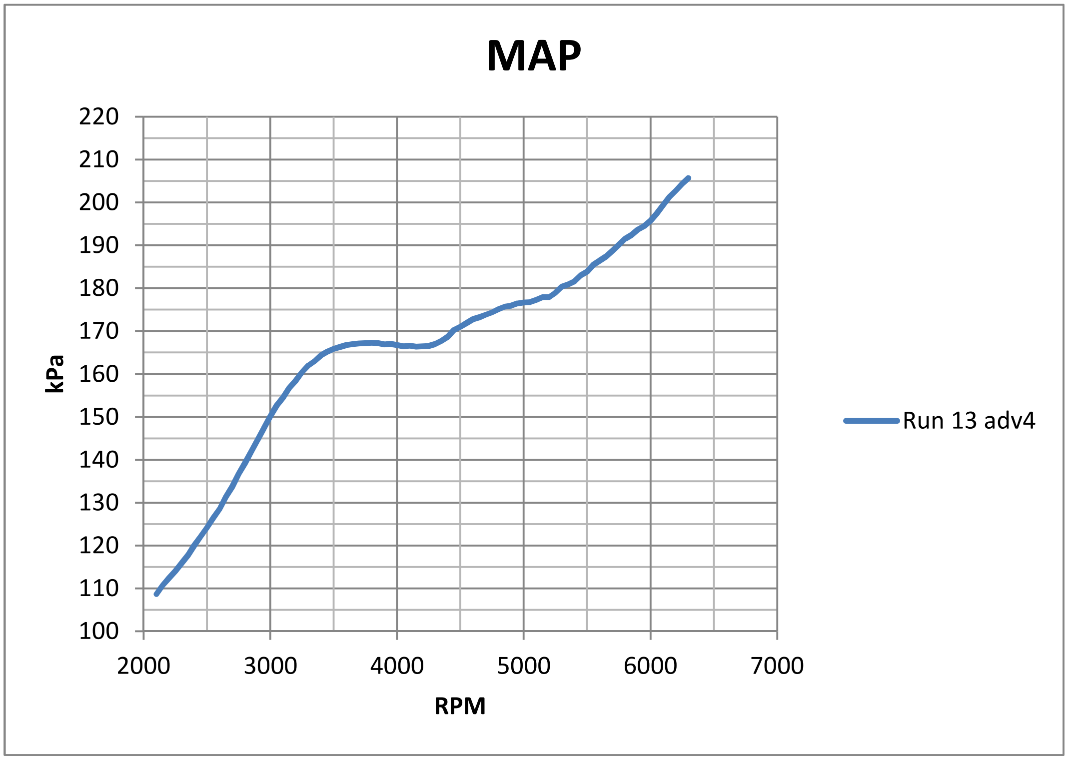


Figure 3: Manifold Absolute Pressure of turbochaged 1.6L motor with just "wastegate can" pressure. Can is rated for 10 psi cracking pressure (~ 166 kPa). Note boost creep (boost rises with RPM).

The wastegate "cracks open" at ~165 kPa which happens at around 3500 RPM. It has massive boost creep to >200 kPa at 6200 RPM. This is typical of an internal wastegate actuated by an actuator with an internal spring that has a large spring rate and a small pre-load. In control system parlance it has "low gain".

Such a low gain ("lots of creep") system will typically show significant boost pressure changes with timing changes, making tuning difficult.

Here is a closeup for ~3500-4000 RPM. Ignition timing was increased by 2° from run 13 to run 14. This would suggest that the motor is over-advanced.

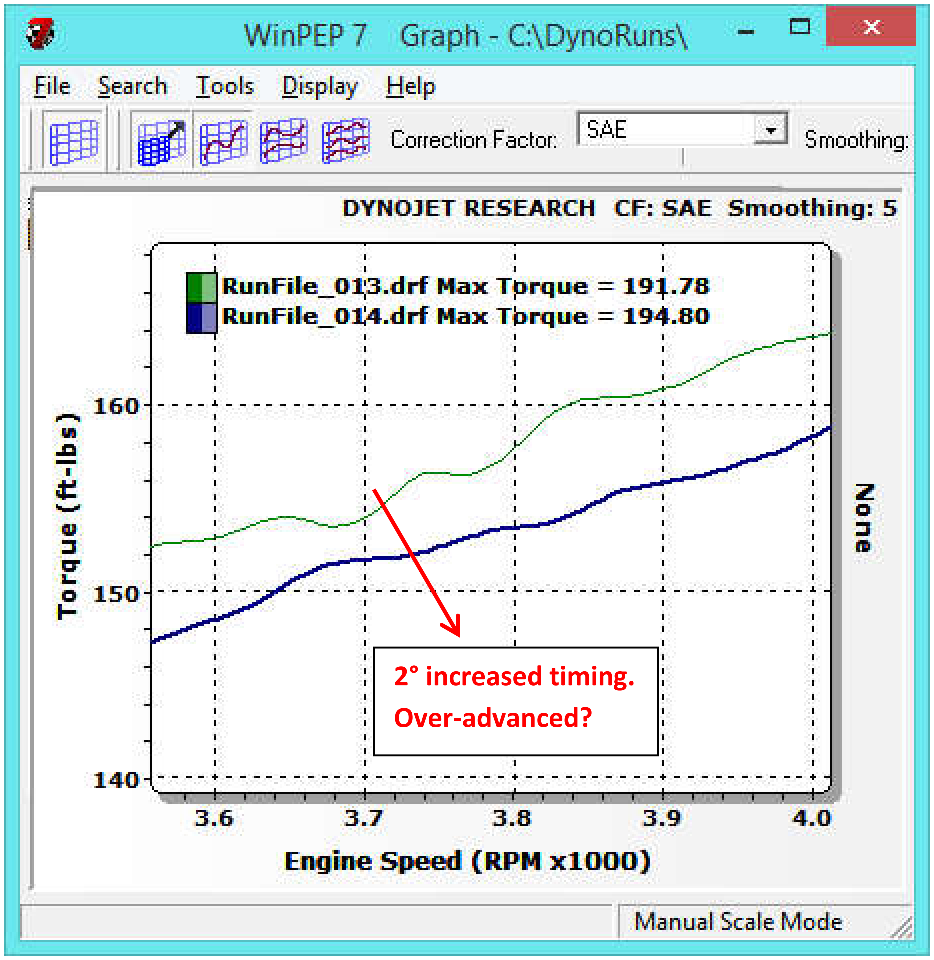
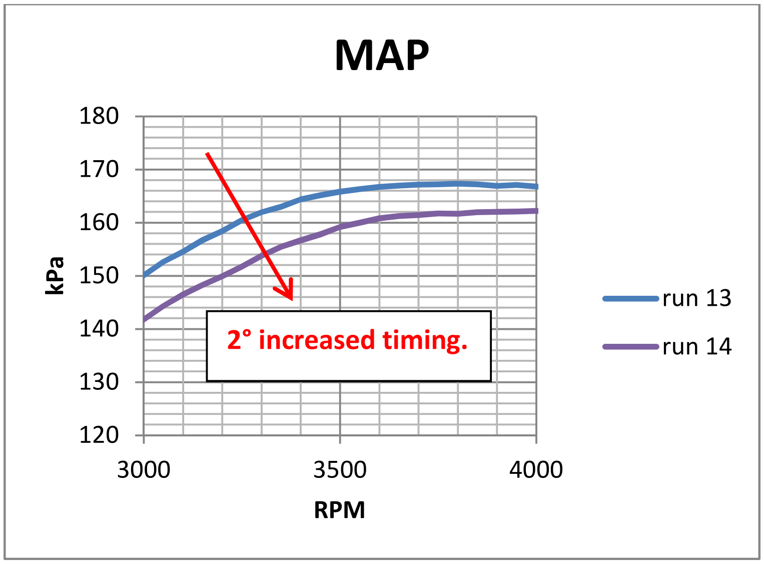
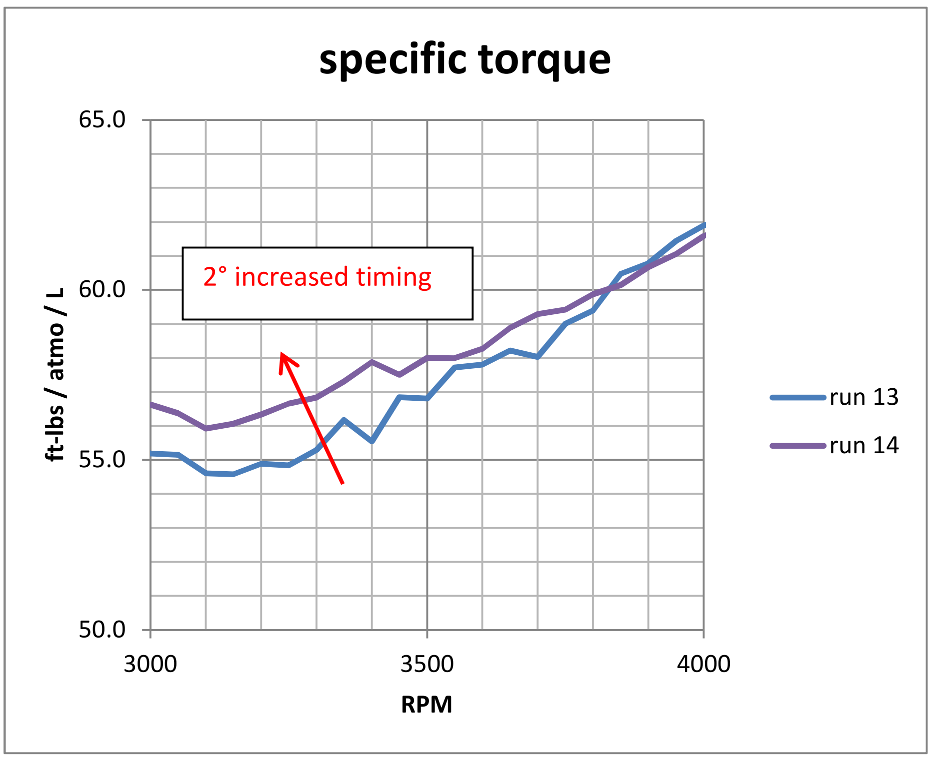


Figure 4: Closeup of dyno plots of runs 13 & 14. Run 14 has 2° additional advance over run 13 but has lost torque, initially suggesting run 14 is over-advanced.

However, the boost pressure logs clearly show run 14, with more advance, has lower boost pressure:



If torque ÷MAP were plotted instead, we see this:



This tells a different story – that the increased timing from 3000-3500 RPM increased BMEP/MAP, but not at 4000 RPM. Therefore the timing was at MBT at 4000 RPM but not from 3000-3500 RPM.

The complete set of plots are below.

Run 11:	baseline
Run 12:	4000 RPM onwards increased by 2°
Run 13:	4000 RPM onwards increased by another 2°
Run 14:	3000 RPM onwards increased by another 2°

Table 1: Description of run-to-run changes

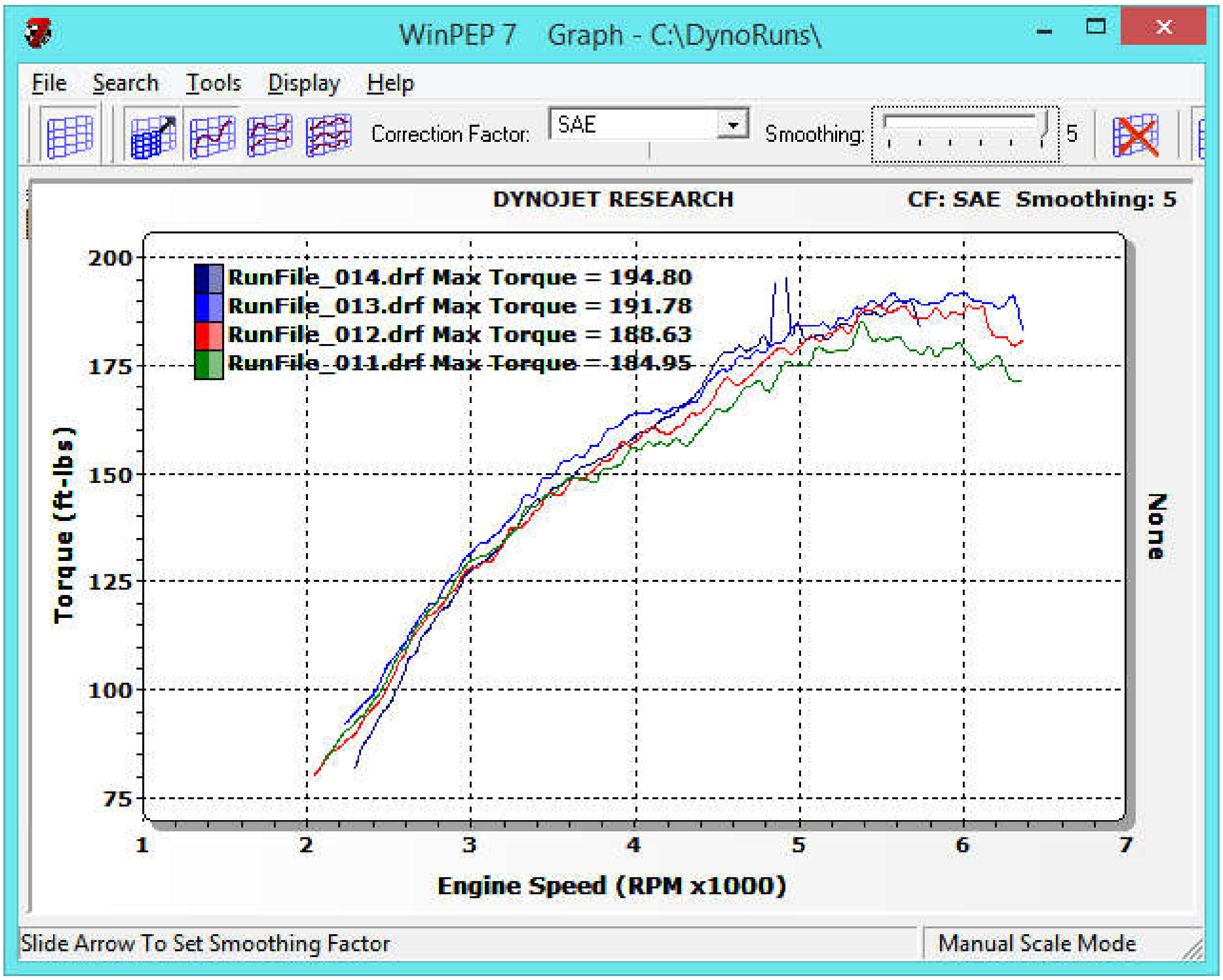


Figure 5: Family of torque curves with increasing advance as per Table 1

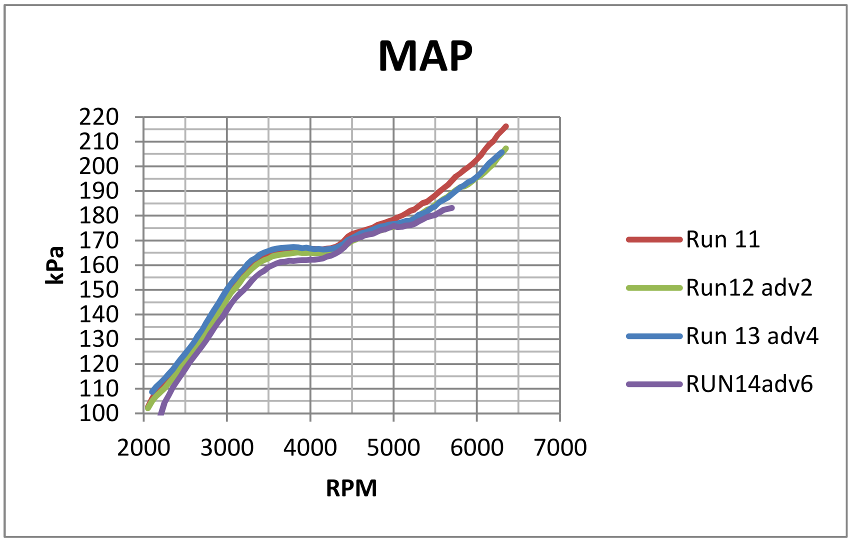


Figure 6: MAP log of the 4 runs

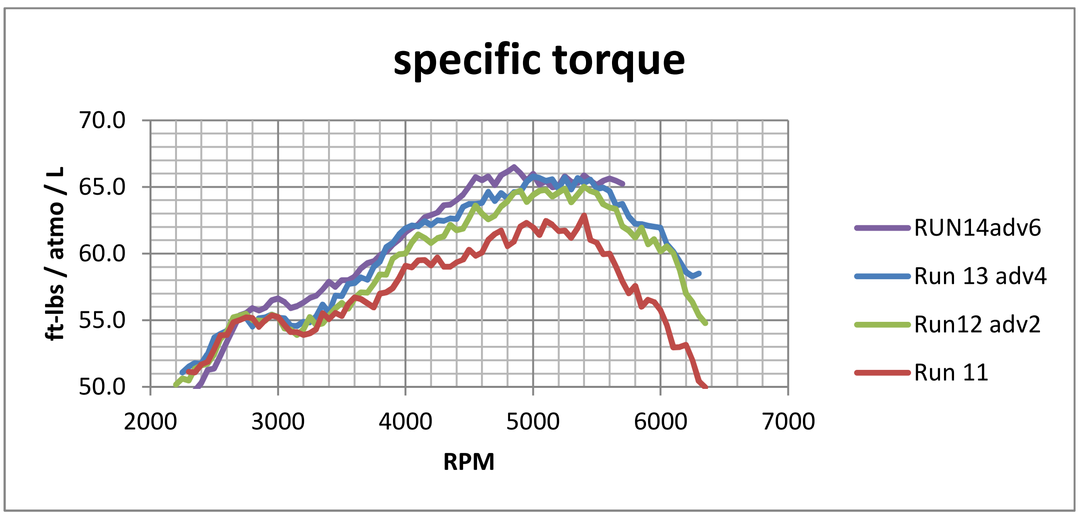


Figure 7: Specific torque of the 4 runs

Figure 7 shows the whole tale. From 3000 onwards, Run 13 is at MBT at 4000 and 5200 RPM. Put another way, run 13 has the correct timing at 4000 and 5250 RPM, but the motor needs more advance than run 13 at 3000-3250 and 4250-4750 RPM.

Conclusion

The capability of dyno software to calculate and display torque / MAP, or better yet, torque / MAP / displacement would be useful as an aide to tuning turbocharged motors. Additionally, a standard benchmark of specific torque output is useful. A range of peak values of 67 to 72 ft-lbs / L / bar appears to be a good value for many production motors on a chassis dyno with drivetrain losses included. A motor that produces less than this may have problems that should be investigated. Well optimized production motors with very good V.E. and combustion chamber design will produce upwards of 75 ft-lbs/ L / bar/