2011 Yamaha Apex EXUP preproduction sled dyno evaluation

Woody (his real first name is Keith), owner of Woody's Performance Center (Yamaha Bikes and sleds) in Topsham ME is a true hotrodder. Woody came here a year or so ago and made 400+ HP with a very violent supercharged methanol fed Apex asphalt racer (dyno results posted on this website). That SC Apex really pissed off one neighbor that evening (the neighbor lives 50 yards from the dyno in an industrial zoned house) with the awful large diameter straight exhaust exiting out from under the tunnel setting a DTR decibel record, accentuated by the fact that the large concrete buildings surrounding the industrial park dyno facility act like Bose Wave speaker boxes! This poor bastard walked over to the dyno from his back porch to complain bitterly about his wife's dishes rattling off the shelf in the kitchen. But since we had just made our final dyno test and were done for the night, the neighbor was pleased.

Fast forward to 2010. Woody came back this past summer to dyno test two sleds—a wickedly powerful stroker NA Nytro (I must post those results later), and a preproduction 2011 Apex that Yamaha asked him to bring to DTR for evaluation. And since Yamaha was footing the bill for the DTR Apex test, we were obligated to wait until 9/11 for these test results to be posted.

So here they are, and assuming that Woody's preproduction 2011 Apex is typical of production, the power numbers are amazing considering the minimal changes, as offered by Yamaha's sled marketing guy Wade West:

*EXUP variable exhaust
*Exhaust header diameter increased from 35mm to 38mm
*Exhaust pipe from EXUP collector to muffler increased in diameter
*Lightweight titanium exhaust including cast titanium EXUP housing
*Muffler flow capacity increased
*Cams are identical, but timing changed to increase overlap by 5 degrees.
*Intake airbox horns increased in length from 115mm to 126mm

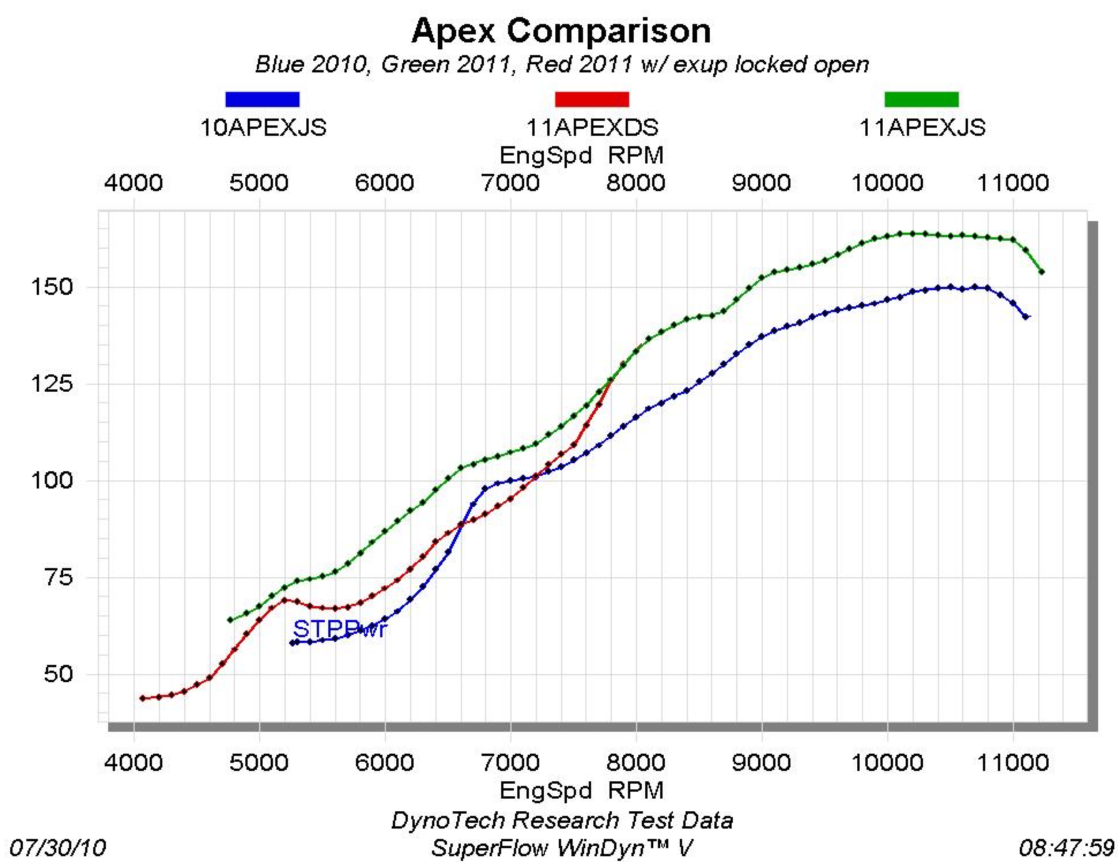
2011 preproduction Yamaha Apex

EngSpd	STPTrq	STPPwr	BSFC A	Fuel A	LM1w/b	AirTmp	LM1air	BMEP
RPM	Clb-ft	CHp	lb/hph	Lb/hr	A/F	degF	SCFM	Psi
4800	70.3	63.8	0.43	25.8	14.69	73	88.4	174.3
4900	70.3	65.6	0.42	25.8	14.67	73	88.3	174.3
5000	70.8	67.4	0.41	25.9	14.63	73	88.4	175.3
5100	72.1	70.0	0.41	26.8	14.48	74	90.7	178.7
5200	73.1	72.3	0.41	27.7	14.30	74	92.5	181.0
5300	73.3	74.0	0.41	28.7	14.04	74	94.1	181.6
5400	72.5	74.5	0.41	28.9	13.89	74	93.8	179.5
5500	71.7	75.1	0.41	29.1	13.77	74	93.6	177.7
5600	71.5	76.3	0.40	29.1	13.67	74	92.9	177.2
5700	72.3	78.5	0.40	29.3	13.58	75	93.2	179.2
5800	73.5	81.2	0.39	30.1	13.51	75	95.2	182.1
5900	74.8	84.0	0.39	31.1	13.46	75	98.0	185.3
6000	76.1	86.9	0.40	32.5	13.46	75	102.4	188.4

6100	77.1	89.5	0.40	33.5	13.50	76	106.0	191.0
6200	78.2	92.3	0.40	34.9	13.62	75	111.2	193.7
6300	78.6	94.3	0.40	35.7	13.73	75	114.8	194.7
6400	80.0	97.5	0.40	37.2	13.90	74	120.9	198.2
6500	81.1	100.4	0.40	38.1	13.99	75	124.8	201.0
6600	82.2	103.3	0.40	39.4	14.04	75	129.5	203.7
6700	81.7	104.2	0.41	40.1	14.01	74	131.2	202.4
6800	81.4	105.4	0.41	40.6	13.92	74	132.1	201.7
6900	80.9	106.3	0.41	40.7	13.79	74	131.1	200.4
7000	80.4	107.2	0.40	40.9	13.65	75	130.7	199.3
7100	80.1	108.3	0.41	41.5	13.55	75	131.6	198.5
7200	79.8	109.4	0.41	42.1	13.48	75	132.8	197.8
7300	80.5	111.8	0.41	42.9	13.43	75	134.9	199.4
7400	80.9	114.0	0.40	43.4	13.41	75	136.3	200.4
7500	81.7	116.7	0.40	43.9	13.40	75	137.6	202.5
7600	82.5	119.4	0.40	44.9	13.40	75	140.8	204.4
7700	83.9	122.9	0.40	46.7	13.41	75	146.6	207.8
7800	84.8	126.0	0.41	48.5	13.43	74	152.2	210.2
7900	86.3	129.8	0.42	50.9	13.45	74	159.9	213.8
8000	87.6	133.4	0.42	53.1	13.46	75	167.3	216.9
8100	88.5	136.5	0.43	55.3	13.48	75	174.5	219.3
8200	88.6	138.4	0.43	56.6	13.48	75	178.6	219.6
8300	88.6	140.1	0.44	57.6	13.51	74	181.9	219.6
8400	88.6	141.6	0.44	58.2	13.55	74	184.2	219.4
8500	87.9	142.3	0.43	58.0	13.63	74	184.7	217.8
8600	87.1	142.6	0.43	57.6	13.75	74	185.1	215.8
8700	86.8	143.7	0.43	57.7	13.89	75	187.6	215.0
8800	87.5	146.6	0.44	60.1	13.99	75	196.8	216.8
8900	88.3	149.6	0.45	63.8	13.96	75	208.4	218.7
9000	88.9	152.3	0.47	67.6	13.79	75	218.1	220.3
9100	88.7	153.7	0.48	69.4	13.50	75	219.3	219.8
9200	88.2	154.5	0.48	69.9	13.24	74	216.3	218.5
9300	87.6	155.1	0.48	70.3	13.04	73	213.8	217.0
9400	87.1	155.8	0.48	70.7	12.90	73	212.7	215.7
9500	86.7	156.7	0.48	71.0	12.80	73	211.9	214.7
9600	86.5	158.2	0.48	71.5	12.72	74	212.4	214.4
9700	86.6	159.9	0.48	72.1	12.68	75	214.0	214.4
9800	86.4	161.1	0.48	72.9	12.65	75	215.8	213.9
9900	86.2	162.4	0.48	73.4	12.63	75	217.0	213.4
10000	85.6	163.1	0.49	74.4	12.61	75	219.7	212.2
10100	85.1	163.7	0.49	74.9	12.60	75	220.9	210.9
10200	84.3	163.7	0.49	75.7	12.58	75	222.9	208.8
10300	83.5	163.7	0.49	76.1	12.58	75	224.1	206.8
10400	82.5	163.4	0.50	77.1	12.58	75	227.0	204.5
10500	81.6	163.1	0.51	77.5	12.58	75	228.2	202.1
10600	81.0	163.4	0.51	78.3	12.61	76	231.6	200.6
10700	80.0	163.0	0.52	78.9	12.63	76	233.7	198.3
10800	79.1	162.6	0.52	79.6	12.65	76	236.1	195.9
10900	78.3	162.4	0.53	80.0	12.61	76	236.7	193.9
11000	77.3	162.0	0.53	80.8	12.55	75	237.3	191.6
11100	75.5	159.5	0.54	81.2	12.48	75	237.2	187.0
11200	71.9	153.8	0.57	81.4	12.41	75	236.5	178.1

So compared to the 150 HP earlier Apex we have an 8% increase in peak HP with very minimal changes in tuning/ components. Adding 10% to “velocity stack” length, inside the stock airbox, may help peak rev tuning. Larger exhaust pipe diameter must have a positive effect on power at peak revs. Cam timing? 5 degree added overlap is helpful for top end power, as we experienced 15 years ago when Kevin Cameron used the DTR bike output shaft dyno to do a cam timing evaluation for Cycle magazine. As I recall, we added 3-4% HP to a stock GS1150 Suzuki just by Kevin methodically “rolling” stock cams (using slotted intake and exhaust cam sprockets) around to optimize HP. But that added HP may have cost low end HP, and that is where Yamaha’s EXUP comes in to help out! How about exhaust pipe diameter? Big tube headers are said to make bigger high RPM HP, but lose midrange HP. But EXUP seems to more than make up the difference.

Here is a graph of the above full power dyno run, compared to a graph with the EXUP locked open. Also a graph of last year’s Amsnow/ DTR Shootout Apex is shown for comparison. As we can see, low-midrange torque/ HP is greatly increased with the addition of this excellent technology. Without EXUP, torque at 6000 RPM is 63 lb/ft—still slightly higher than it was last year (56 lb/ft). But with EXUP controlling those exhaust waves, that 6000 RPM torque is a whopping 76 lb/ft—a 35% increase in “arm stretch” when accelerating from cruise, compared to last year’s Apex!



So, without EXUP the midrange HP would obviously be similar to last year's non-EXUP Apex. Now we might downplay midrange HP, but that is what Apex riders experience when whacking the throttle from cruise or takeoff! As we can see from the graph above, EXUP is a great way to make bikes/ sleds accelerate better. But what does EXUP really do? When Yamaha invented EXUP nearly 20 years ago, General Motors Powertrain bought a Euro-only FZ400 four cylinder bike and sent a GM engineer to DTR for EXUP evaluation. The GM engineer Steve Boehm had the then-European-only bike fully instrumented with a strip chart recorder monitoring exhaust pulses and intake pulses. The EXUP added huge midrange power to the 400cc engine compared to non-EXUP operation! Those strip-chart recordings and dyno test results were ultimately shared with Kevin Cameron, and he offers this modern day explanation that may need to be reread several times to understand the EXUP function:

YAMAHA EXUP

By Kevin Cameron, The Cellar Dweller

Yamaha's EXUP system consists of a valve, located where the exhaust header pipes join the collector, which can vary the pipe's cross-section at that point. Its purpose is to damp out exhaust pipe waves that would otherwise return to the cylinders and push exhaust gas back into them during valve overlap.

Valve overlap is that period around TDC at the end of the exhaust stroke when the intake valves have already begun to open, and the exhaust valves have not yet closed.

To understand the problem that EXUP was created to solve, consider how a properly designed exhaust pipe boosts torque.

As a cylinder's exhaust valves begin to open just before BDC, a pulse of exhaust gas is released into that cylinder's header pipe. At full throttle and high torque, gas pressure remaining in the cylinder at the moment of exhaust valve opening is roughly 100-psi, so the resulting pressure pulse is large.

The pulse travels down the header pipe at the local speed of sound, then encounters the sudden enlargement where the header joins the much larger collector pipe. The gas expands at this point, and it does so in all directions – including back up the header. This reflected wave of expansion (low pressure) travels back up the header, then into the cylinder through the still-closing exhaust valves. There, it has the effect of causing spent exhaust gas above the piston to be drawn into the pipe. The lowered pressure in the cylinder acts through the rapidly-opening intake valves to accelerate fresh charge into the cylinder. This in effect gives a head start to the intake stroke.

If cylinder volume is 250-cc and compression ratio is 12-to-one, the volume of exhaust gas in the clearance space above the piston at TDC is 22.7-cc, so from the standpoint of making torque, it is well worth our while to remove this volume of exhaust gas. A well-designed pipe, combined with enough overlap timing, can do this.

We see this on the dyno printout as the region of peak torque. Experienced tuners know that they can make this peak somewhat taller by scissoring the valve timing to make overlap longer – in effect "opening the window" to let in more of the helpful pipe wave.

Every helpful wave action in the engine also has a corresponding un-helpful action. In other words, positive and negative waves alternate continuously in the intake and exhaust pipes. At lower rpm, the exhaust waves move just as fast but the pistons move more slowly. Therefore instead of the helpful low-pressure wave arriving during overlap, it is the following wave of high pressure. This pushes exhaust gas from the pipe, back into the cylinder, and may even push it out through the intake valves into the intake pipe and the airbox beyond. When the intake stroke begins, the first gas drawn into the cylinder will be this blown-back exhaust, so the resulting charge contains a large percentage of inert gas in it. For this reason, torque falls. This is the dreaded "pipe flat-spot" that every user of four-into-one exhaust pipes has either felt or seen on dyno print-out.

It was to suppress this flat-spot that pipe builders switched some time ago from simple four-into-one designs to four-into-two-into-ones. The second enlargement in a 4-2-1 pipe can be located so that its low pressure cancels the positive pulse coming from the beginning of the collector.

Sadly, just as increased valve overlap timing can boost torque at the peak, it also pulls the flat-spot deeper. The result is that the engine has a region of steeply-climbing torque – up out of the flat-spot and onto the torque peak. While high torque is certainly desirable, that steeply-climbing torque may disqualify the engine from some uses.

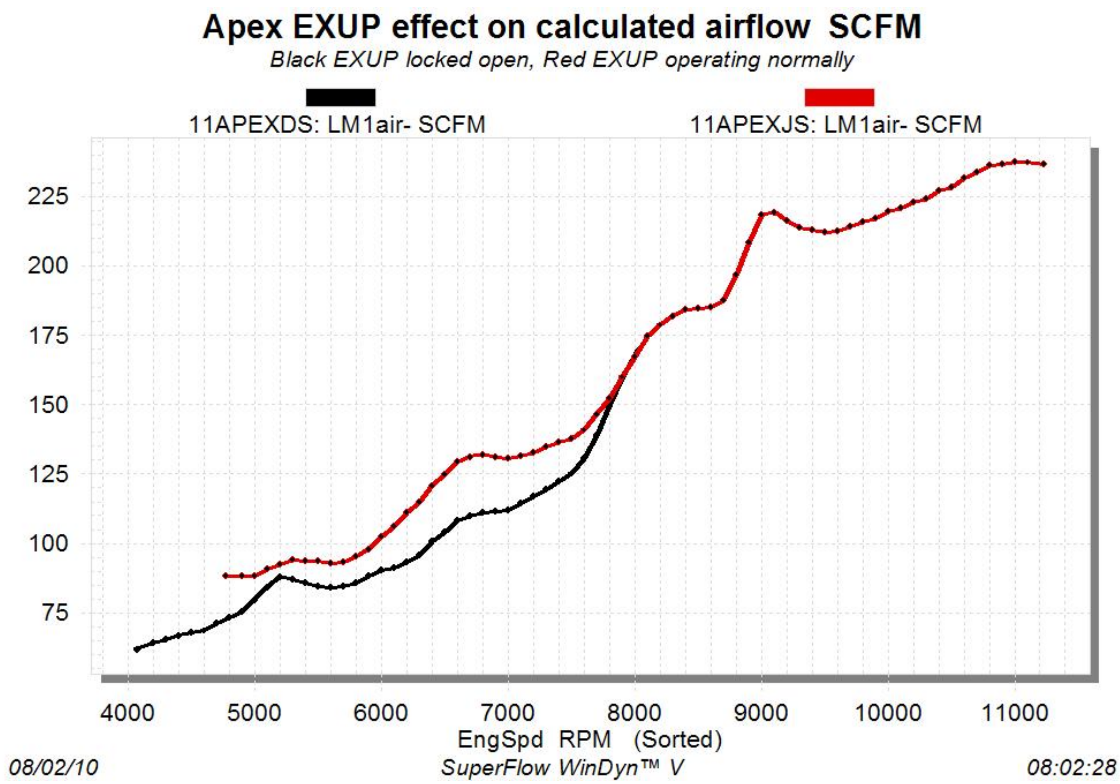
If the engine is carbureted rather than fuel injected, the result is even worse, as carburetors don't care which way air passes through them – they add fuel either way. This makes the flat-spot even worse by seriously enriching the mixture.

Now we get to EXUP. Just as the barely-open valves of a narrow overlap timing act to damp out waves that pass through them, so the EXUP valve can damp out pipe waves by being partly or nearly closed at appropriate times. This, by killing the positive pipe wave that would otherwise stuff the cylinder with exhaust gas, the nearly-closed EXUP valve increases torque at the flat-spot rpm. It is simply programmed into the valve controller to close down the valve to a small aperture at the rpm at which a flat-spot would normally appear.

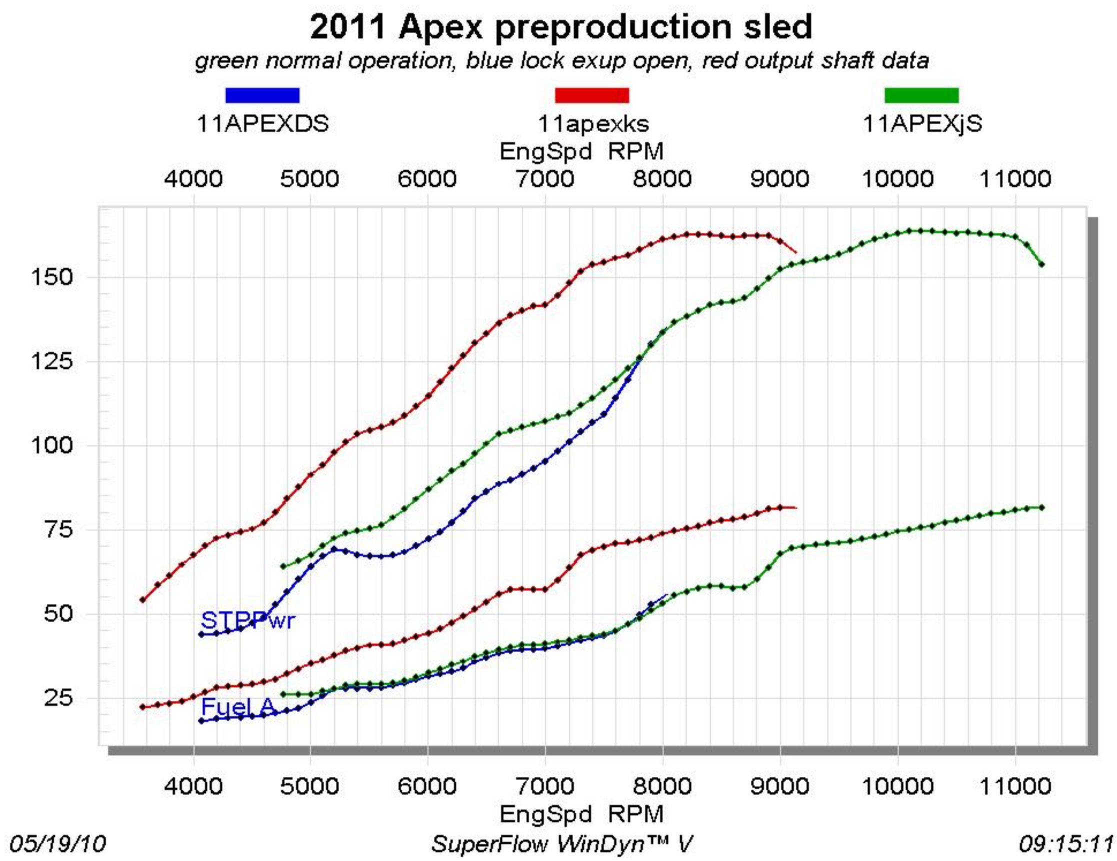
With EXUP nearly closed, a positive pipe wave cannot delay the intake process by stuffing the cylinder and intake pipe with exhaust gas, so engine airflow increases. Naturally, EXUP programming is done on the dyno, by experiment.

A recent application by Aprilia on their RSV4 Superbike racer uses the header valve as a "Jake brake" for rider Leon Camier, who likes a lot of engine braking. To generate engine braking the valve is closed with ignition and fuel injection in cut-off, and the throttles are opened just enough to create the desired effect.

Back to DynoTech Jim……
One interesting effect of EXUP is, as KC explains, that at midrange revs the closed or choked-off EXUP valves actually increase airflow! Here is a graph showing computed airflow SCFM (based upon measured fuel flow and LM1 wideband readings). As we can see here, the wide-open collector (with EXUP valve locked open), flows much less midrange air than the properly choked-down EXUP!



Finally, to allay concerns of those who worry about midrange torque compared to the similarly powerful XP800 and F and XF800, here is a graph comparing the torque and HP of the 2011 Apex crankshaft compared to that of the geared-down 2011 Apex output shaft that the clutch is attached to. As we can see, that HP curve is identical, but torque is increased by a function of the gear reduction. Here is the reduced speed output shaft torque curve, which is totally a function of gear reduction:



2011 Apex, output shaft data:

EngSpd RPM	STPTrq Clb-ft	STPPwr CHp	BSFC A lb/hph	Fuel A lb/hr	LM1w/b A/F	AirTmp degF	LM1air SCFM
3567	79.5	54.0	0.43	22.1	15.25	77	79.2
3700	82.8	58.4	0.41	22.8	14.94	77	80.1
3800	84.7	61.3	0.40	23.3	14.77	77	80.9
3900	86.9	64.5	0.39	24.0	14.60	77	82.4
4000	88.4	67.4	0.40	25.3	14.41	77	85.7
4100	89.8	70.1	0.40	26.7	14.19	77	89.1
4200	90.5	72.3	0.41	28.0	13.97	77	92.0
4300	89.6	73.4	0.41	28.3	13.82	77	91.9
4400	88.5	74.1	0.41	28.7	13.68	77	92.3
4500	87.6	75.1	0.41	29.1	13.58	77	92.9
4600	88.0	77.0	0.41	29.6	13.51	77	94.0
4700	89.4	80.0	0.40	30.5	13.46	77	96.5
4800	92.0	84.1	0.41	32.1	13.45	77	101.4
4900	93.9	87.6	0.41	33.6	13.43	77	106.1
5000	95.8	91.2	0.41	35.1	13.51	77	111.5
5100	97.0	94.1	0.41	36.2	13.67	77	116.3

5200	98.9	97.9	0.41	37.5	13.85	77	122.1
5300	100.0	100.9	0.41	38.9	13.99	77	127.9
5400	100.5	103.3	0.41	39.8	13.99	77	130.9
5500	99.8	104.5	0.41	40.5	13.92	77	132.5
5600	98.9	105.5	0.41	40.6	13.77	77	131.4
5700	98.4	106.8	0.41	41.1	13.65	77	131.9
5800	98.5	108.8	0.41	41.9	13.56	77	133.6
5900	99.4	111.6	0.41	43.2	13.50	77	137.1
6000	100.3	114.6	0.41	44.1	13.45	77	139.4
6100	102.2	118.7	0.41	45.6	13.41	77	143.8
6200	104.0	122.8	0.41	47.3	13.41	77	149.2
6300	105.5	126.6	0.41	49.1	13.45	77	155.2
6400	106.9	130.3	0.42	51.3	13.48	77	162.6
6500	107.7	133.2	0.43	53.5	13.50	77	169.8
6600	108.5	136.4	0.43	55.6	13.50	77	176.4
6700	108.6	138.5	0.44	57.1	13.56	77	182.0
6800	108.2	140.0	0.43	57.3	13.65	77	183.8
6900	107.5	141.3	0.43	57.2	13.77	77	185.1
7000	106.4	141.8	0.43	57.0	13.89	77	186.1
7100	106.8	144.4	0.44	59.8	14.01	77	196.9
7200	108.1	148.2	0.46	63.7	13.99	77	209.5
7300	109.2	151.8	0.47	67.3	13.82	77	218.7
7400	109.0	153.6	0.48	68.9	13.48	77	218.4
7500	108.0	154.3	0.48	69.9	13.19	77	216.8
7600	107.5	155.6	0.48	70.7	12.94	77	215.0
7700	106.8	156.6	0.48	71.2	12.83	77	214.9
7800	106.6	158.3	0.48	71.9	12.77	77	215.8
7900	106.2	159.7	0.48	72.6	12.75	77	217.6
8000	105.8	161.1	0.49	73.7	12.70	77	220.0
8100	105.0	162.0	0.49	74.5	12.66	77	221.8
8200	104.1	162.5	0.49	75.2	12.65	77	223.6
8300	102.9	162.7	0.50	76.0	12.65	77	226.0
8400	101.6	162.6	0.50	76.9	12.63	77	228.3
8500	100.2	162.1	0.51	77.7	12.63	77	230.7
8600	98.9	162.0	0.51	78.1	12.61	77	231.5
8700	97.9	162.1	0.52	78.7	12.60	77	233.0
8800	96.9	162.4	0.52	79.8	12.56	77	235.6
8900	95.8	162.3	0.53	81.0	12.53	77	238.5
9000	93.8	160.7	0.54	81.5	12.48	77	239.0
9100	90.6	157.6	0.55	81.4	12.41	77	237.4

Now you might notice the HP is slightly different from the crankshaft speed data, but that is mostly a function of the air temp probe coming unplugged, defaulting to 77 deg F resulting in slightly different corrected HP than with the probe connected. But this is surely good enough to compare actual clutch torque numbers to the other engines we have tested here. Torque people are sometimes obsessed with that peak torque number, but the most important issue is the shape, and broadness of the HP curve.