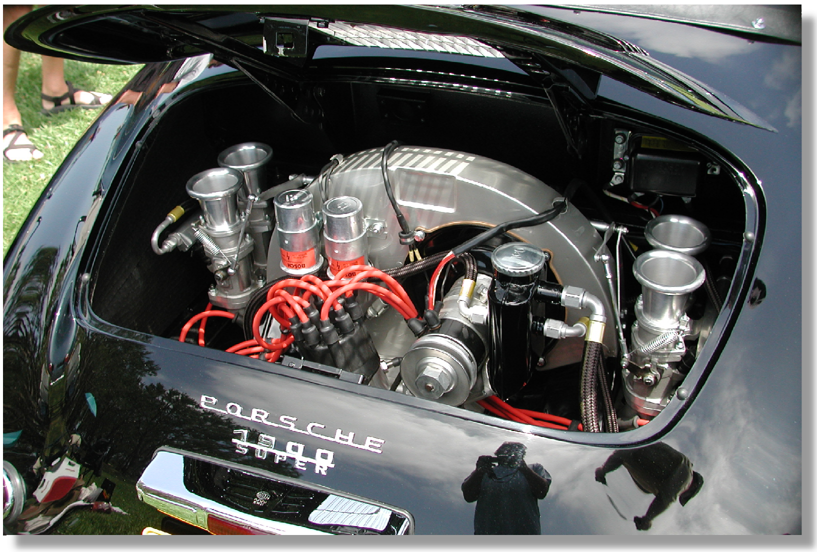


DEVELOPMENT OF THE 1925TR and 2002TR Twin Plug ENGINES

The WR 1925TR, and the new 2002TR twin-plug 356 engines are the result of many hours of computer simulation and dyno testing. This article will outline the various engine configurations, the dyno tests, and the actual driving results in 356s that have lead up to the currently available engines.

The "120HP" Baseline

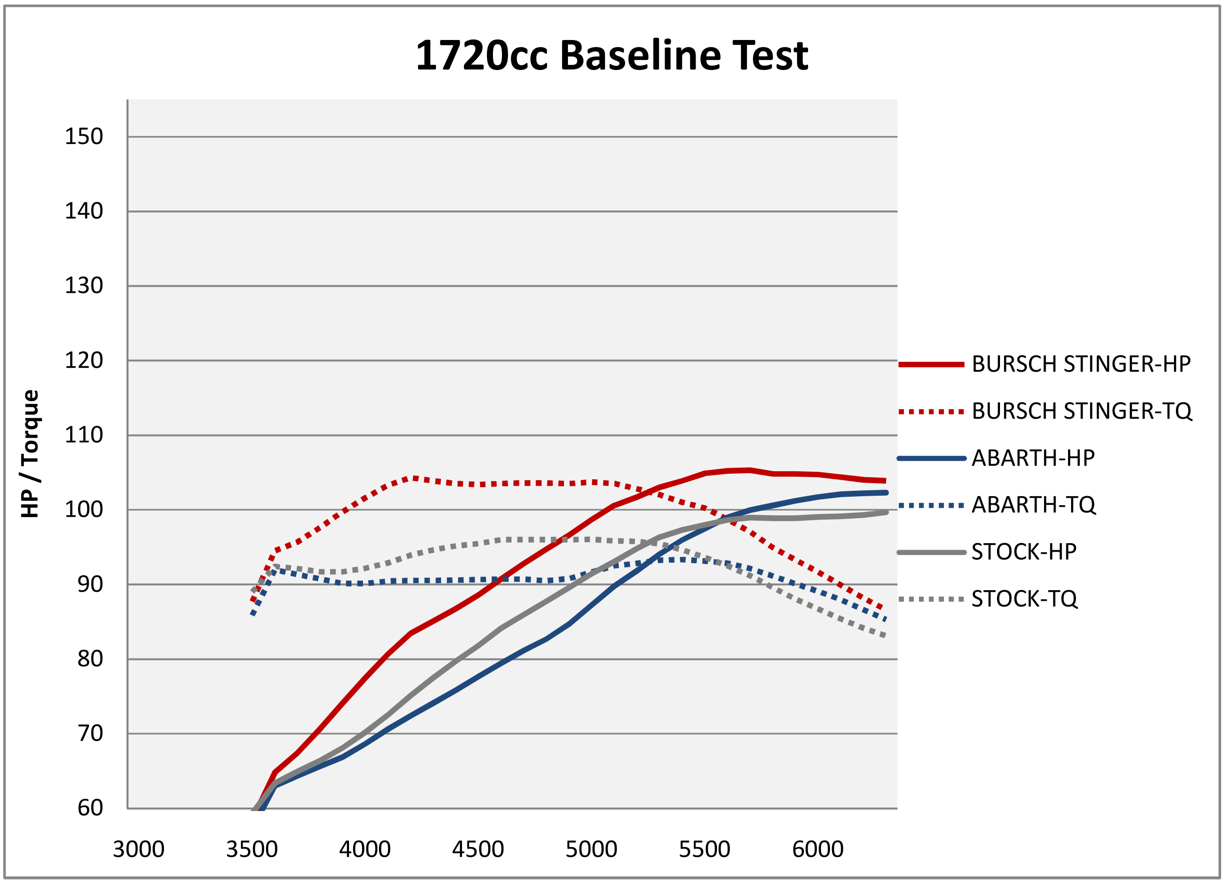
People have been building "tuned" or "hotrodded" 356 engines for years and the common approach has been to install an 86mm big bore kit, add a hotter cam, Solex 40P11 carbs, and a Bursch exhaust. This approach was said to yield 120hp, but at higher rpm with some loss of low end power. I've built many such engines, but have never subjected them to testing or evaluation, just seat-of-the-paints comparisons, and they were definitely faster.

Of course there are other ways to make a 356 fast. Modifications to install 911 engines and components can provide extreme increases in performance, but in my opinion modify the character of the 356 to a point where it is no longer a 356 but a Porsche hybrid of sorts. Going non-Porsche, VW Type 1 and 4 engines are "potential" transplant doners, but the "Porsche with a VW engine" concept has never been appealing, and there's the stigma of low cost ;-). Even Subaru and Chevy engines have been done, but please… No, I wanted to build a performance engine that I could offer my customers that would still maintain the design parameters of the 356 engine but provide the maximum increase in streetable performance.

As a start, I contacted my friend Tate Casey at Carobu Engineering in Costa Mesa, CA. Tate had plenty of experience in engine development and I figured he could help with a proper scientific approach to optimizing the hp and torque of a 356 engine. The first step was to develop a baseline test with a commonly built engine. Carobu had a new DTS engine dyno that could be used for the testing. The DTS provides computer controlled readouts at 100rpm intervals, and the unit at Carobu was a state-of-the-art system in a closed room that provided consistent air flow necessary for the air cooled 356 engine. We could test exhaust mixture on every cylinder, as well as oil temp, oil pressure, crankcase pressure, and fuel pressure. Providing all these readouts, especially the fuel mixture, at 100rpm intervals would be necessary to properly tune carburetors and select the correct emulsion tubes and jets. The DTS also had an EFI mapping program which was a great feature if I decided to use EFI at some time.

The baseline test engine was a 64SC that had stock cast iron cylinders bored to 86mm. It used JE forged pistons with a 9:1 compression ratio, a Norris 356S camshaft, and stock C/SC/912 cylinder heads. The owner of the engine had been using it in a hot street car, and had been using the factory air horns for the Solex 40P11s with no air cleaners and an old Abarth 4-pipe muffler. While on the dyno, we were going to optimize the jetting for the **Abarth with factory mesh air cleaners**, a **Bursch racing header with stinger without air cleaners (using the factory air horns)**, and a **stock Dansk muffler with the factory air cleaners** (we also tested the Abarth and Dansk with the air horns to get an idea of the affect they had on the performance…a graph of that test follows the article).The stock Dansk muffler with air cleaners would be used as my baseline on future tests. The Bursch racing header was a 1.5" with straight stinger (no muffler). Since the owner was thinking of running the car on the track at some time in the future, we decided to optimize the jetting for this application too, and I thought it would be good for comparison purposes.

I wasn't sure what to expect, but I was surprised at the results. The various dyno tests are shown below:

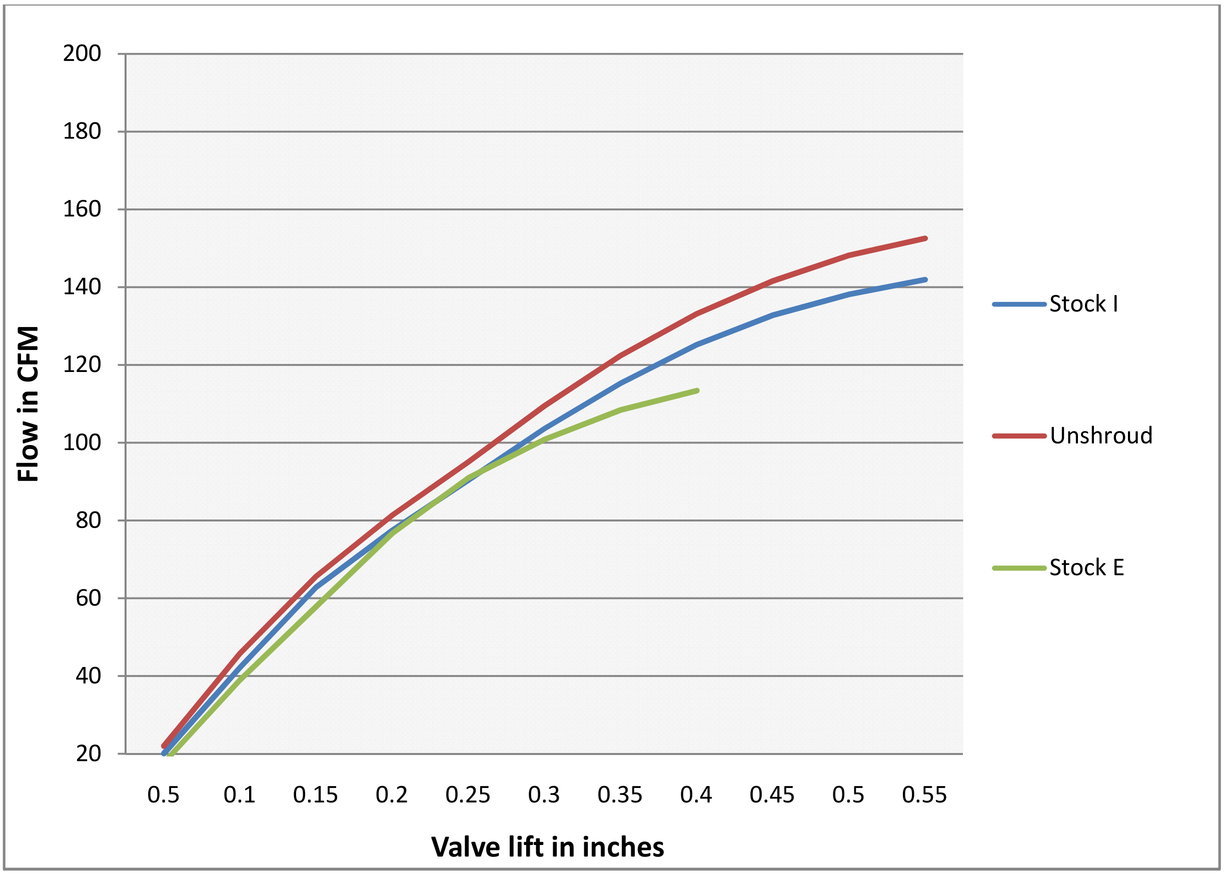


Bigger Is Always Better

As you can see the performance was somewhat less than I had hoped for, but the guys at Carobu were not surprised and said that “this happens all the time.” Well, at least we had a baseline, and I knew how much the “120hp” engine made on the DTS dyno. Tate suggested that we build a virtual engine using simulation software. The software would allow us to test various head flow, cam, carb, etc. combinations and determine in advance which combination would give the desired results. It would provide a virtual dyno test, much like the test on the actual dyno but without the expense! Since I didn’t want a race engine that required high rpm to achieve performance, we chose 6,000rpm as the desired peak horsepower point, and a good torque curve between 3500 and 5500rpm (the area where most 356 driving is done). The simulation required measuring stock headflow with the intake manifold and carb attached to the intake, and a stock J-pipe attached to the exhaust. We also used a Cam-Doctor tool to plot a digital profile for just about all of the popular 356 cam grinds available so that we could plug them into the simulation program and compare the performance of each one. The simulation would also allow us to determine the correct valve springs by measuring the weight and design of all of the valvetrain components (rockers, lifters, pushrods, retainers, etc.), and show the ratio of exhaust to intake flow. The flow of the stock heads was measured on a Superflow flowbench at Carobu using a stock cylinder, Solex 40P11 carb with 32mm venturi, and a stock J pipe. *See graph below.*

The first simulation based on the specs of the engine that we tested was amazingly close to the actual dyno test **(see graph below).** After looking at the results of the simulation, and cylinder head flow tests, several potential limiting factors were obvious. The exhaust flow was 86% of the intake flow, even with the 1.3 lift ratio of the intake rockers vs. the 1.13 ratio of the exhaust rockers (in the 60s this was common with most engines, but today a ratio of 75% has been shown to be more desirable in high performance two-valve engines). In addition, the compression ratio of 9:1 was too low for the Norris 356S camshaft, and if we wanted to increase intake flow, the 40mm carbs and 32mm venturis would need to be larger.

The first step was to install 44IDF Weber carbs and manifolds and match the ports to the 356 heads. With the Webers I would be able to use either 32mm, 34mm, or 36mm venturis, and the jetting and parts were readily available (unlike the Solexes). With the new carbs installed with 36mm venturis and K&N air filters, the guide bosses were streamlined, the port walls were cleaned up, and the intake valves were unshrouded. We were able to achieve an increase in flow of 10cfm at .500” of lift and a consistent improvement over the entire lift cycle of the intake valve. Our ratio was now getting closer to 75% and we went back to the simulation to plug in the new data (it should be noted here that no changes were made to increase the size of the intake ports, and standard intake manifold gaskets were used)



Since we had already digitized all of the cams listed on the attached chart, it was easy to plug them into the software and see the results. I had used the Elgin 7008 camshaft many times and had been happy with the results. This was my cam of choice for any customer who wanted a “hotter” cam, but since the flow tests showed a consistent increase in flow as lift was increased, I decided to depart from the usual 356 cams and try something new. I selected a VW type 1 profile that had 240 degrees of duration at .050” (close to the Elgin 7008) but instead of .333” of lift it had .385” which would give a net of .500” vs. the 7008s net lift of .433”. Now, since the later VW cam is mounted lower in the case and doesn’t have the rod clearance problems that a 356 has, a much larger base circle can be used on the VW cam lobe which makes a short duration/high lift cam easily possible. It’s still possible on a 356 but the base circle must be ground smaller so that the rods clear the cam lobes. Grinding the base circle smaller makes the lobe smaller which increases the wear. To help with this problem, I had .020” holes EDM machined into the face of the lifters which would provide direct oiling to the cam lobes (this same modification has been used on all the future high lift cams). Special higher rate dual valve springs were used to accommodate the higher lift with lightweight aluminum retainers. The new cam was ground and then digitized and plugged into the program. The results were just what I wanted, better overall torque and hp with no change in the rpm at which the torque and hp were made.

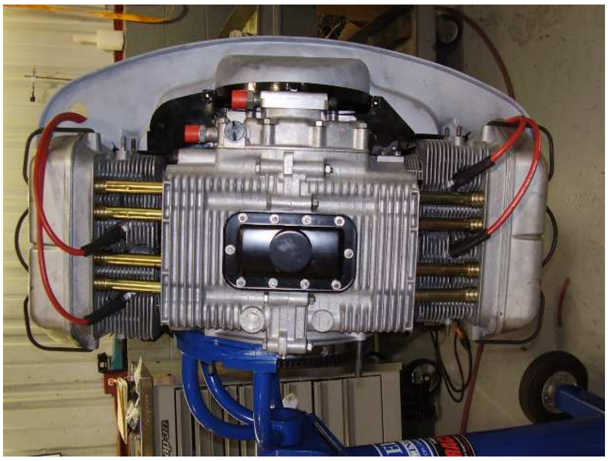
At this point Tate and I had a serious discussion about other options. Maximum torque between 3500 and 5500rpm had been the goal from the beginning, and as we installed more aggressive camshafts in the simulation, the low end torque began to drop. Maximum torque had increased, but had move up above 5000rpm which was not what I wanted. There are two ways to increase torque across the board without modifying the torque curve significantly: increase compression, and increase displacement. “Is there any way to increase the displacement? “ Tate asked. Well, 1720cc was the maximum that was traditionally available, but I remembered that an 89mm kit was available back in the early 70s, although it had a reputation for not being very reliable. “What about using a VW big bore kit?” Again, the VW 90.5mm piston and cylinder kit was an interesting size, but the spigot holes were not the same, the length and outer dimensions were way off, and they weren’t typically very consistent in their bore dimensions (made in Brazil). In addition, the pistons were a flat top design with a different wrist pin location. “What about modifying them to fit the 356?” This was an interesting thought. I could easily have JE make forged pistons to fit the 356 application, and boring the cast iron cylinders to 91mm would clean up the inconsistencies in their dimensions. If I could figure out how to modify the outer dimensions, 91mm with the standard 74mm stroke would give approximately 1925cc. “Now we’re talking,” the larger size would definitely give me the increased torque I was looking for. After modifying the first set of cylinders to fit the 356 head studs and sheet metal, I found that by boring the case and heads to fit, the cylinder walls we’re about .5mm thicker than the 86mm big bore kit. I designed a matching set of pistons and sent the specs to JE for production.

Two Are Better Than One

At this point, I figured if I was going to go for the larger size, why not increase the compression ratio too. It was well known that the 911 engines can run close to a full point higher compression with a twin plug setup. The two flame fronts in the chamber increase the efficiency of the combustion, and the engines typically require much less timing advance. I had seen a circa 1960 factory twin plug 356 engine that was used in an aviation application. The plug holes were drilled between the pushrod tubes, and a special front cover was installed that would accept a second distributor driven off of the same crankshaft gear. This special front cover was a casting that would cost a fortune to duplicate, so I would have to find another way to fire the second set of plugs.

Drilling the heads was not difficult. A special fixture was made to drill the 2nd plug hole on the bottom of each chamber so that the plug wire could extend between the pushrod tubes. I made special inboard-mounted exhaust J tubes, and modified a stock muffler, to allow easy access to the second set of plugs. On the first set of heads I used standard 14mm sparkplugs. On all subsequent heads I have used 10mm plugs so that a minimum of material is cut away from the cooling fins.

Most of the fuel injection ECUs are capable of firing two coil sets, and even four dual firing coils would have been possible in a crank-fire setup (eliminating the distributor completely), but if I was going to change to twin plug I wanted the look of a twin plug distributor like the older twin plug 911s. I wanted to optimize the 356 engine, but I didn’t want it to look like a modern application. Building a twin plug distributor wasn’t the problem, it was finding the cap and rotor. After hours of searching parts books, and the internet, I found a four cylinder twin plug cap and rotor that had been used to replace the Marelli cap and rotor on the old twin plug Alfas. I had an aluminum housing machined to accept the cap, along with a matching steel shaft that could use the special twin spark rotor. I borrowed the advance mechanism from a Mallory aftermarket distributor which allowed me to adjust maximum advance and interchange springs to specifically tailor the curve to the engine. To fire the coils I used a single Pertronix unit. The signal from the Pertronix is basically the same as the signal from a set of points and can be split to fire two coils. Two Pertronix units are not required. In an inductive ignition application, two standard coils could be fired as long as the resistance was enough to protect the Pertronix, but I didn’t want a standard inductive ignition. If I was going to go to twin plug I wanted an ignition that would provide the best possible energy to fire four plugs in a high compression application, and a CDI system was the answer. Porsche had used CDI to clean up the 911 plug fouling problems in the late 60s but the Bosch CDI was now antiquated and extremely expensive. After researching the most reliable units, I went with M&W ignitions that had a special single digital CDI box that could fire two sets of plugs eliminating the need for two CDI boxes and also providing a rev-limiter set at 7K (we now substitute the MSD 6AL-2 which is much less expensive and also very reliable).



All the specs were plugged into the engine simulation and the results were impressive. Of course, the only way to know for sure was an actual dyno test and subsequent test drive in a 356. After all the components were assembled, the first 1925cc engine was assembled to the following specifications:

<u>1925 TEST 1</u>

240 degree camshaft with .385" lift.
Modified VW cylinders bored to 91mm using custom JE forged pistons with 10.25:1 compression ratio.
Bored case with 911 piston squirters installed.
Lightened 912 connecting rods.
356C crankshaft.
11 lb flywheel with aluminum 200mm pressure plate.
Aluminum 5" front pulley.
Custom twin plug distributor using an M&W CDI box firing two Bosch CDI coils.
Stock C/SC/912 cylinder heads with 38mm intake and 34mm exhaust valves, drilled for twin plug, bored for the 91mm cylinders, and ported as noted above.
Weber 44IDF carbs with 34mm venturis and 2.25" airhorns w/K&N air filters.
Crankcase ventilation in the case and heads.
Chromoly pushrods.
Stock cylinder head studs.
Stock factory muffler modified as noted earlier for twin plug

CAROBU Engineering LLC
925 West 16th Street
Newport Beach, CA 92663
949-722-3917

Date : 06-29-2005 Time : 15:22:31
INF=.44 Mode : A-Sweep

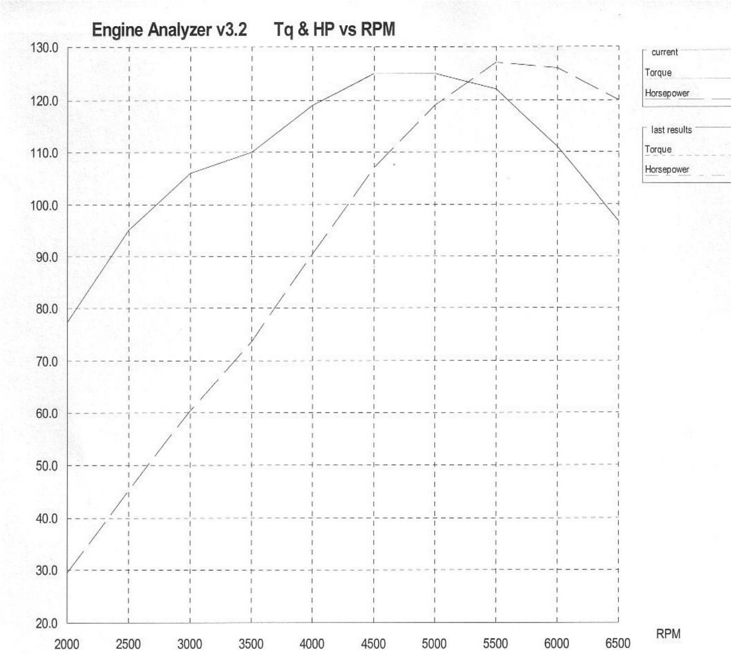
T15:22 D06-29
Carb:Weber IDF 44
Ac: 165
Chokes: 34
Exhaust: can style WAR

Engine Type:Porsche 356
Mains: 120
Tubes: F7
Timing: 25

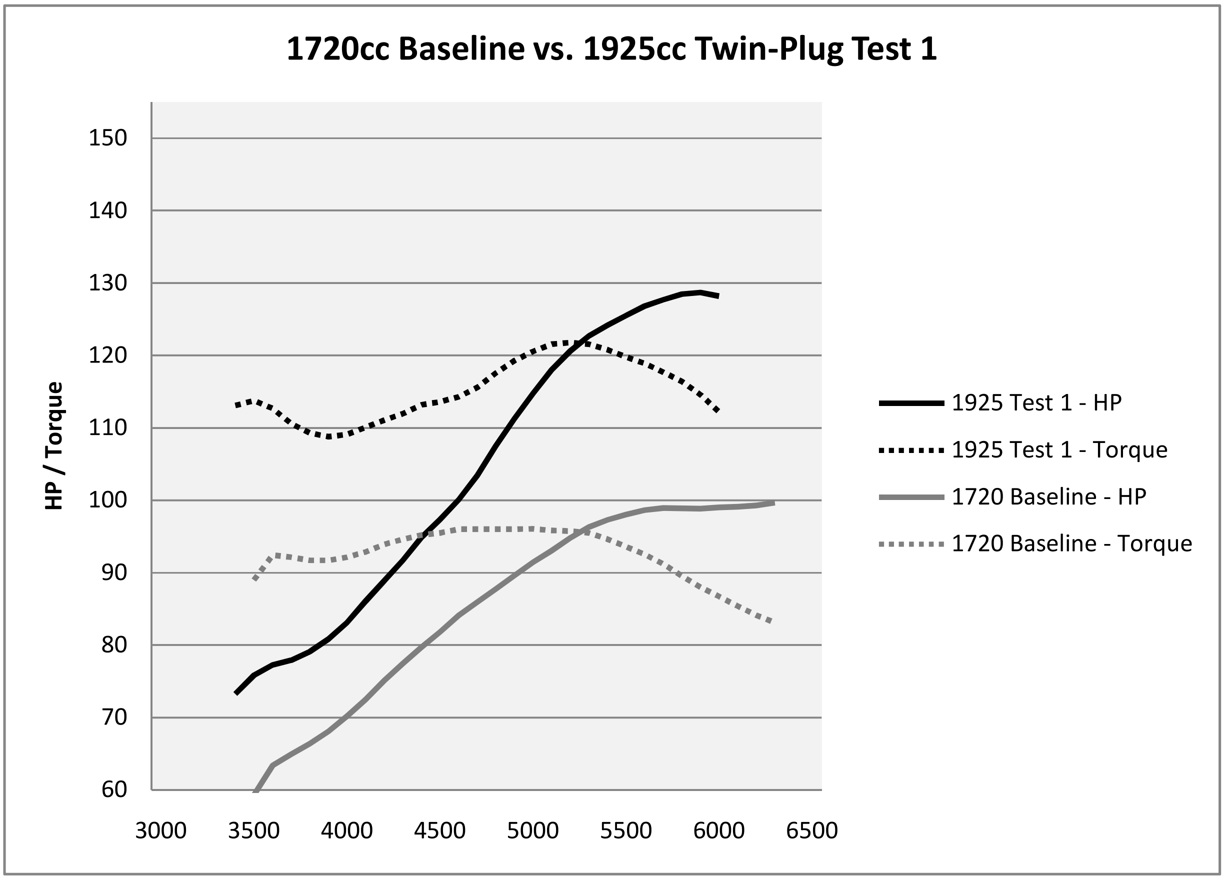
FileName : 356MARK.D07

Speed rpm	CPower C_HP	C_TQ lbft	Oil psi	Oil° °F	A/F Right	A/F Left	Fuel_P psi	ManP "Hg
3400	73.26	113.1	53.8	189	12.25	12.19	5.2	0
3500	75.84	113.8	54.3	189	11.89	12.11	5.2	0
3600	77.25	112.7	54.7	189	11.57	11.88	5.2	0
*3700	77.92	110.6	55	189	11.05	11.56	5.2	0
*3800	79.13	109.3	55.2	189	10.95	11.19	5.1	0
*3900	80.82	108.8	55.7	189	10.96	11.26	5.1	0
*4000	83.09	109.1	56	189	11.14	11.4	5.1	0
*4100	86.06	110.2	56.2	189	11.27	11.47	5.1	0
*4200	88.9	111.1	56.5	189	11.52	11.73	5.1	0
*4300	91.7	112	56.8	189	11.72	11.91	5.1	0
*4400	94.83	113.2	56.9	189	11.85	12.19	5.1	0
*4500	97.34	113.6	57	189	12.04	12.22	5.1	0
*4600	100.1	114.3	57.2	189	12.15	12.28	5.1	0
*4700	103.4	115.6	57.4	189	12.22	12.52	5.1	0
*4800	107.5	117.6	57.6	191	12.5	12.74	5.1	0
*4900	111.3	119.3	57.9	191	12.63	12.81	5.1	0
*5000	114.8	120.6	58	191	13.02	13.1	5.1	0
5100	118	121.6	57.8	191	13.14	13.28	5.1	0
5200	120.6	121.8	57.8	191	13.44	13.56	5.1	0
5300	122.7	121.6	57.7	191	13.56	13.86	5.1	0
5400	124.2	120.8	57.9	191	13.43	13.88	5.1	0
5500	125.5	119.8	57.7	191	13.54	13.86	5.1	0
5600	126.8	118.9	57.7	192	13.49	13.79	5.1	0
5700	127.7	117.7	57.1	193	13.3	13.62	5.1	0
5800	128.5	116.4	57.1	193	13.19	13.4	5.1	0
5900	128.7	114.6	57	193	13.04	13.22	5.1	0
6000	128.2	112.2	56.8	193	12.99	13.1	5.1	0
Average data in * band								
4350	94.09	113.27	56.67	189.43	11.79	12.03	5.11	0

Sample of dyno print out.



Sample of simulation of Test 1.



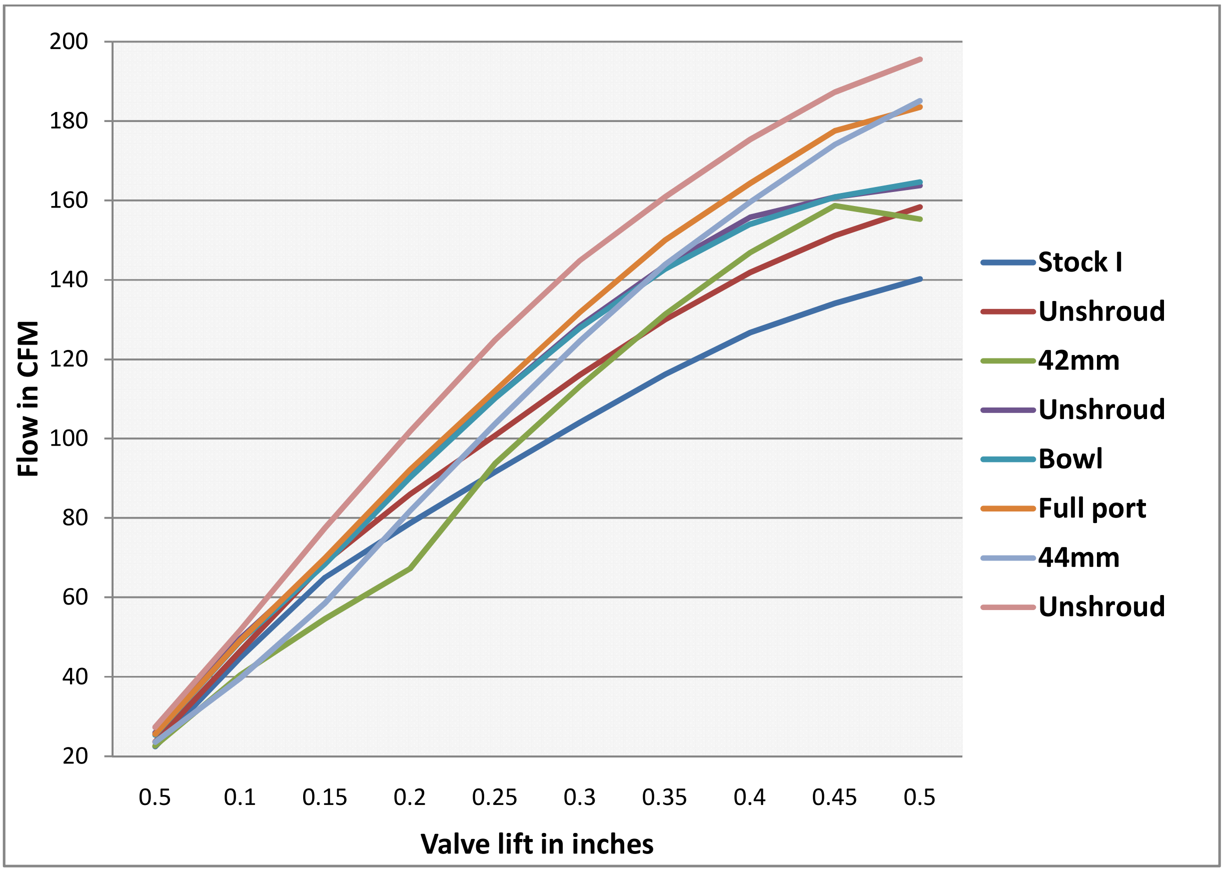
The dyno test session proved that the engine simulation was a big help in determining what changes needed to be made, and that adding cubic centimeters and compression was definitely the right approach when trying to increase torque. The new 1925cc twin plug engine made **129hp@5900rpm** and **122ftlb@5200rpm**. Compared to the Baseline test engine's **99hp@5800rpm** and **96ftlb@5000rpm**, this was up a whopping 30hp and 26ftlbs vs. the 1720cc tuned engine! Better yet, the average HP/Torque in our desired driving range of 3500-5500rpm was **99/120**, up 18hp and 26ftlbs from the base engine's **81/94**. The best power was made at 25 degrees of ignition timing advance and standard premium pump gas was used. After installing this engine in a car the driving was just as impressive. Zero flat spots, no significant "on the cam" feel to the engine, just a progressive strong power curve. In fact, we could lug the engine down below 2000rpm in top gear and floor it with no problems. The engine ran cool, with a single front oil cooler and flow through filter. *As of this writing, the engine has logged over 12K miles of very hard driving and still runs strong, has less than 3% cylinder leak down, and shows only normal cam lobe wear.*

More Flow or More Lift?

Even though I considered the first 1925cc twin plug engine a success, I had yet to really explore the potential for increasing the head flow in the standard 356 engine. We had already increased the intake flow to achieve close to a 75% ratio, but there was definitely room to improve the flow on the intake side, and the exhaust could also be improved. I decided to test some "trick" 356 cylinder heads that a friend's shop had prepared for a local vintage race customer. He had "ported" the heads to the customer's specs. but hadn't had them flow tested. They had large square shaped ports with welded Solex 40 manifolds bored-out to accept specially modified 44mm Solexes with 36mm venturis, 40mm/8mm stemmed 914 intake valves , and were claimed to be the ultimate 356 racing heads. We mounted the entire combination to the flow bench and tested the heads against our ported stock heads used on the first 1925cc twin plug. Much to our surprise, these "super-duper" race heads didn't flow any better than our mildly ported heads with stock valves, and the hogged out ports would definitely not help our low end torque. At this point I figured that starting from scratch was the best idea.

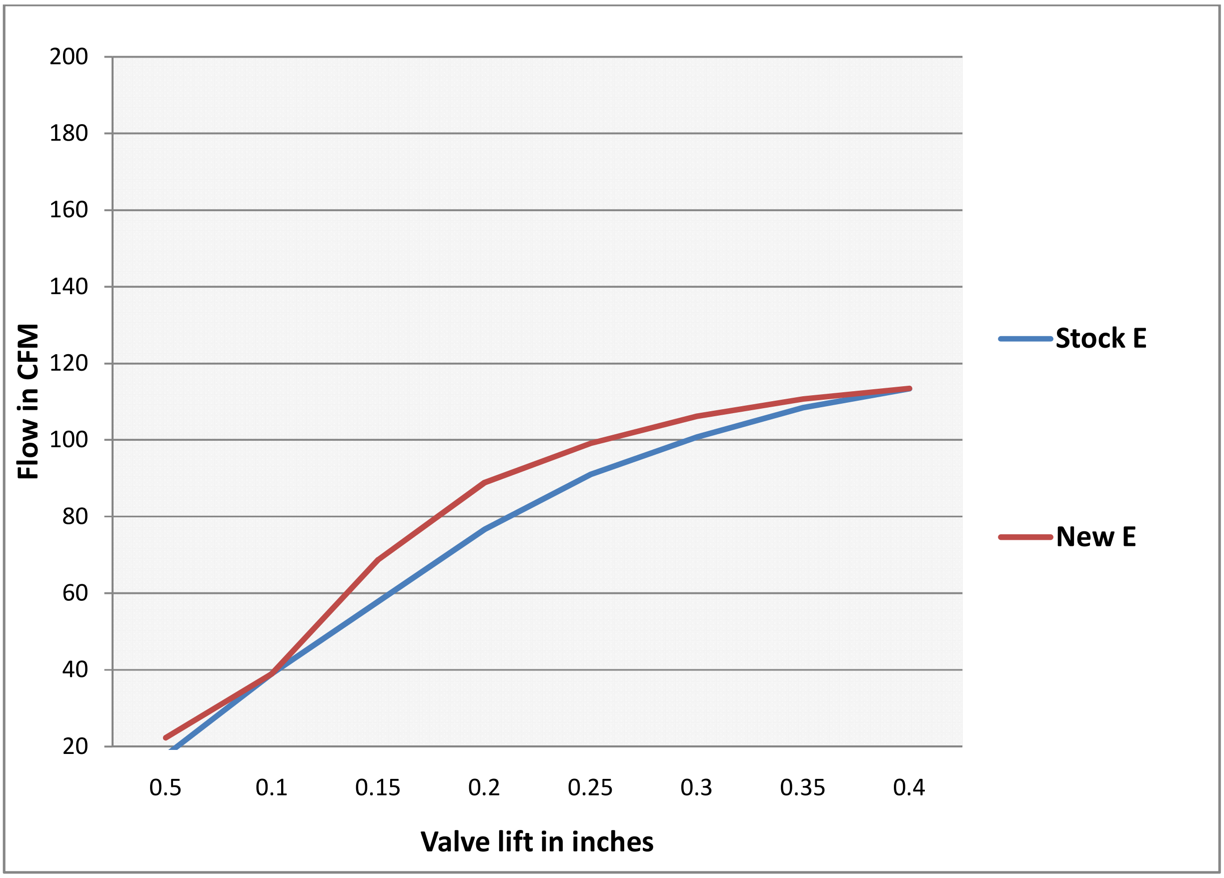
I dug a seriously cracked 912 head out of the junk pile and took it to Carobu for some step by step testing. I'm not a porting expert, and I wanted someone to approach it from a fresh perspective, so we called Tate's resident cylinder head guru Steve. Steve's recommendation after looking at the heads (the first set of 356 heads he'd seen) was that the intake port was probably large enough for a much larger valve, and since we weren't going to make special manifolds or go any bigger than 44mm carbs, we should start by flowing the heads as they were stock and then improving the port and installing bigger valves. I knew that 42mm valves were available from the 914 with 8mm stems, and that they would clear the exhaust valve on overlap,, even with a big cam, so I ordered a 914 42mm steel intake valve and a 44mm stainless aftermarket valve (just in case). We would flow heads with a 44mm intake manifold only (no carbs) since we were only testing improvements on the head. 44mm was the smallest size carb we would run and the venturi size (the biggest restriction) would be determined on the dyno.

The steps taken and the results of the tests are shown in the graph below:

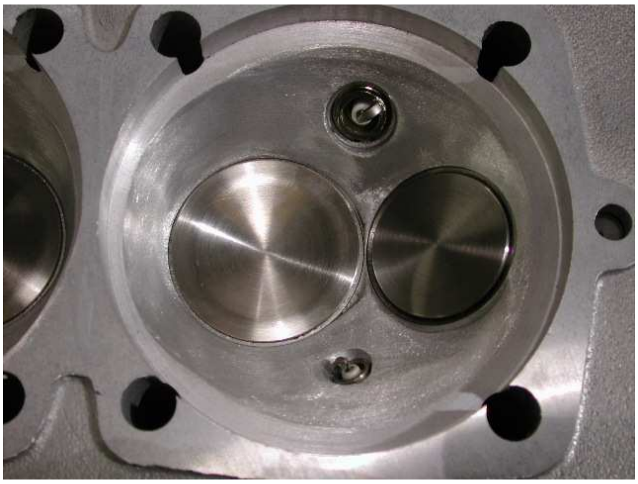


The 44mm valves were definitely the winner for max flow at 195cfm at .500" lift (the maximum lift we would run on the intake), and the flow was up over the entire lift range from that of the 42mm valve. The interesting thing was that the port size where the manifold meets the head was never enlarged in any of our tests. The stock size (at the gasket) was large enough to flow 195cfm for the big 44mm valve, and keeping it stock would definitely increase the velocity of the air, which is what I wanted for good throttle response and good low/mid range torque. The real improvement came in the unshrouding of the valve in the chamber, and the improvements made to the port just before the valve. If you examine the graph, when the 42mm and 44mm valves were installed and then after they were unshrouded, you can see the difference the unshrouding made in the flow. The only question remaining was whether the 44mm valve would clear the exhaust valve on overlap. After several mock-ups were done, I found that the valves had enough clearance as long as the valve overlap was held to a minimum. Since I wasn't going to push the peak power much past 6000rpm, a big overlap cam wasn't going to be an issue.

Since I now had plenty of intake flow we looked at the exhaust side of the heads. With the 44mm intakes, the 34mm exhaust valve is the maximum size possible, and even if I could increase the exhaust valve size, the port size is very limited without welding the head. A good cleanup of the ports, streamlining of the guide boss, and a change to specially made 34mm stainless valves with 8mm stems provided some additional exhaust flow in the middle section of the lift cycle (see graph).



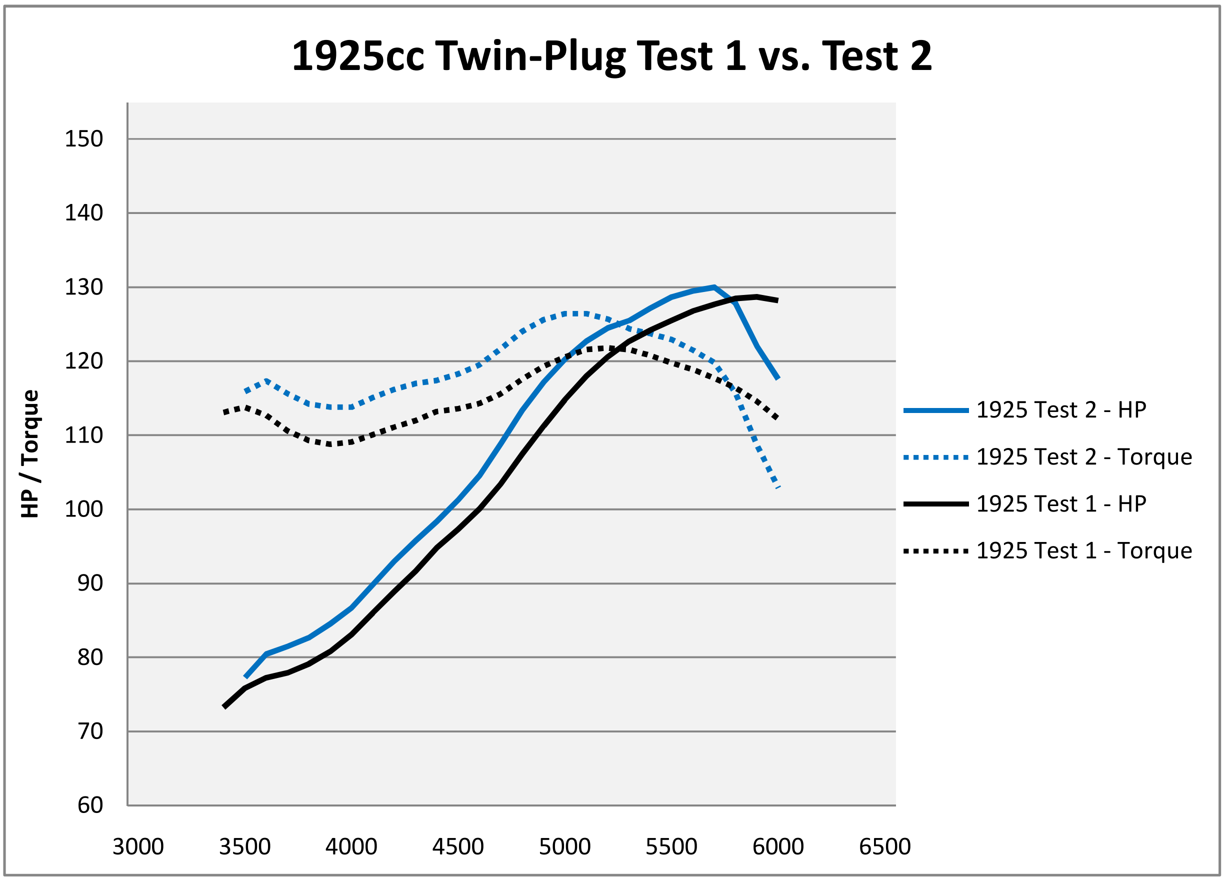
We went back to the engine simulation with the new flow numbers and found that with the added flow we were at about 70% on the intake to exhaust flow ratio. Generally speaking the exhaust should be about 75%, but the result of a lower exhaust ratio is to move the power curve down, giving up some top end for additional low end torque. Since I wasn't looking for maximum horsepower but rather maximum torque, and since I didn't want to extremely modify the 356 heads, this was not a problem. In the simulation the torque was definitely up, and since the head flow was significantly increased, I thought I'd try a cam with close to stock lift.

I assembled the next engine with the following changes:

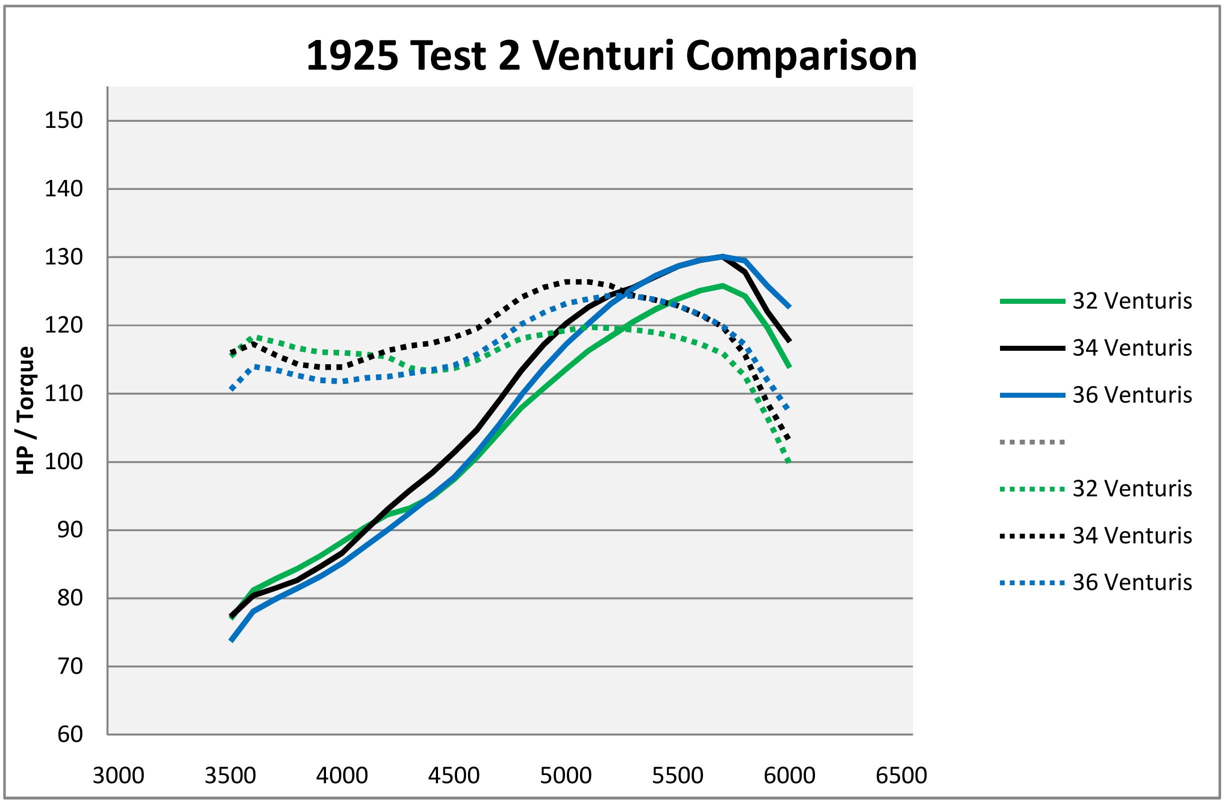
1925 Test 2

Elgin 7008 camshaft, 241 degrees with .333" lift.
Scat lightweight crankshaft and Carrillo rods (per customer's request).
Stock weight flywheel and Centerforce clutch kit (per customer's request).
Heads modified with 44I/34E stainless valves, dual valve springs, and chromoly retainers.
Stock C/912 pushrods.
Raceware cylinder head stud kit.



The head work definitely paid off. The results of the dyno test showed **130hp@5700rpm** and **126ftlbs@5000rpm**. The average hp/torque in our desired driving range was **103/120**. It is interesting that almost the same average HP and Torque were achieved with the new cylinder heads, but with a much milder camshaft with .050" less lift! We compared 32, 34, and 36mm venturis on the dyno and ended up choosing the 34s for this engine (see graph). It was even more impressive in the car than the first 1925cc twin plug. The low end torque and mid range was incredible for a 356, and the engine would easily pull to 6500rpm in 1st and 2nd gear, even though the dyno tests showed it falling off after 5700rpm. The car had a front oil cooler system, a GT torque biasing limited slip differential, and an extra tall "G" 4th gear. The differential really helped prevent tire spin on quick take offs, a (sometimes fun) problem that we encountered with the first engine.

Below is the venturi comparison chart:

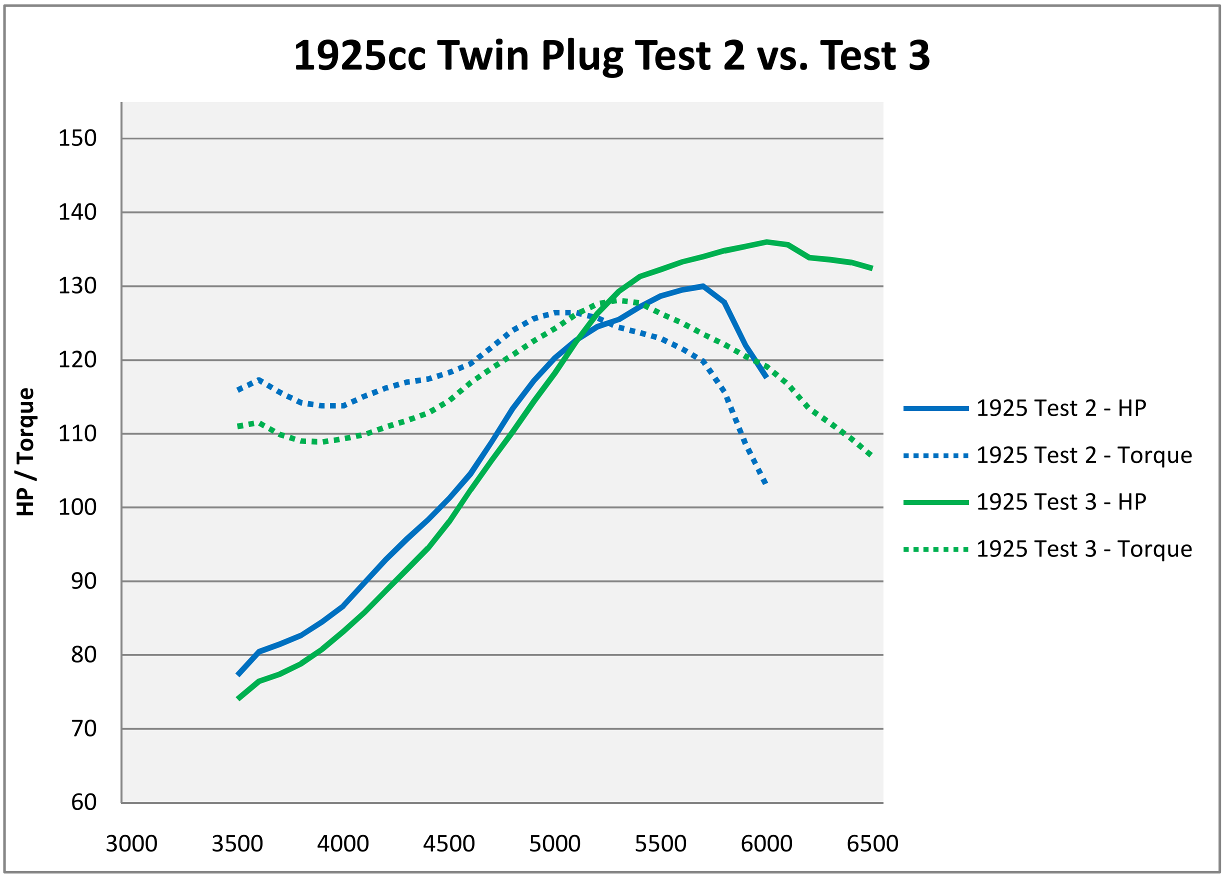


More Duration = More RPM = More HP

With the next engine, the customer wanted us to try and push the powerband up a little so we used another VW grind, modified for 356 use, that had 242 degrees of duration and .365" of lift. The engine was assembled with the following changes from Test 2:

<u>1925 Test 3</u>

242 degree camshaft with .365" lift.
Stock SC/912 crankshaft and rods.
Chromoly pushrods.
Lightweight flywheel and aluminum pressure plate.



This was the most interesting test, and it showed the potential for higher rpm power with the bigger valves, bigger cam, and 36mm venturis. Peak horsepower was **136@6000rpm** and torque was up to **128ftlbs@5300rpm**. While the average hp/torque in our target driving range of 3500-5500rpm was actually down at **102/116**, maximum horsepower was up due to the higher rpm. The engine now made peak power at 6000rpm and had an almost flat power curve all the way up to 6500. Above 5000rpm this engine really found its sweet-spot, but was still very happy at low rpm. It had no low speed issues and would putt around town just like the other two engines. Even though the horsepower and torque were down below 5000rpm, it wasn't really noticeable to any of us at the shop, and it still made better low end torque than the Test 1 engine.

Going High-Tech

At this point a good customer approached me with the idea of building a fuel injected version of the 1925cc twin plug engine. I'd never done EFI before but was open to trying it. Since EFI doesn't depend specifically on manifold vacuum for a signal (like carburetors), a more aggressive camshaft would be possible, though I would still have to keep the overlap to a minimum to prevent the large 44mm intakes from contacting the exhaust valves on overlap.

Before continuing, I should say that electronic fuel injection is a subject that alone would require several pages of text, so at this point I will just stick to the basic installation and testing of the engine. Generally, the 356 is not well suited to EFI because of the necessary modifications, but it can be done. A constant fuel pressure is required, and a looping fuel system needs to be fabricated with a return line to the tank. Also, to prevent fuel starvation on hard cornering, acceleration, or braking, a baffle needs to be built into the tank. A 12V alternator has to be used in place of the generator because the EFI electronics require a constant voltage (even at idle), not to mention the amperage required by the high pressure fuel pump, the CDI box, and any accessories or lights you might also want to run. Finally, the most important part of the EFI system next to the ECU, the wiring loom, needs to be fabricated by a company that has the necessary experience and skill required to build a military spec harness to eliminate interference problems. On a more positive note, even though the installation of a complete and correct EFI system is a big undertaking, the parts are readily available.

For this engine, I chose an Elgin 7208 high lift camshaft. It was the hottest street cam that Elgin recommended and had a duration of 248 and a lift of .370”. Another mock up and check showed that the big valves had enough clearance on overlap, but this would probably be the most aggressive cam possible with my current head design. The simulation software showed the best sized throttle bodies would be the 45s offered by TMW. They fit the Weber manifolds, had a built in throttle position sensor, matching fuel rail and fuel pressure regulator, injector holes, and needed only slight machining to work with the 356 throttle linkage. Since I wanted to keep the look of a twin plug distributor and plug wires, I modified the shaft of the distributor to trigger two Hall sensors, one with the *sync* sensor (to fire each cylinder), and the other with a *reference* sensor (to tell the ECU which cylinder was number 1). Ignition advance would be handled by the ECU. The injectors and fuel pump were Bosch units, and I used lightweight Aeroquip fuel hose and fittings.

The heart of an EFI system is the ECU, and there are plenty of them on the market. The most well known aftermarket unit for serious racing is Motec, and this is the unit that I chose. They have excellent support, and set the standard for dependability and flexibility in installation. Even though the engine was a twin plug, I was only going to need one ignition output to the CDI, so I was able to use the least expensive model, the M4. I used a 911 Bosch head temp sensor to provide a signal for warm up. After all the EFI components were assembled with the finished engine, measurements were taken and I had Sakata Motorsport Electronics design and fabricate a military spec harness to fit the car and engine.

We were finally ready to dyno test the first 1925cc twin plug engine with EFI and it had the following changes compared to the Test 3 engine:

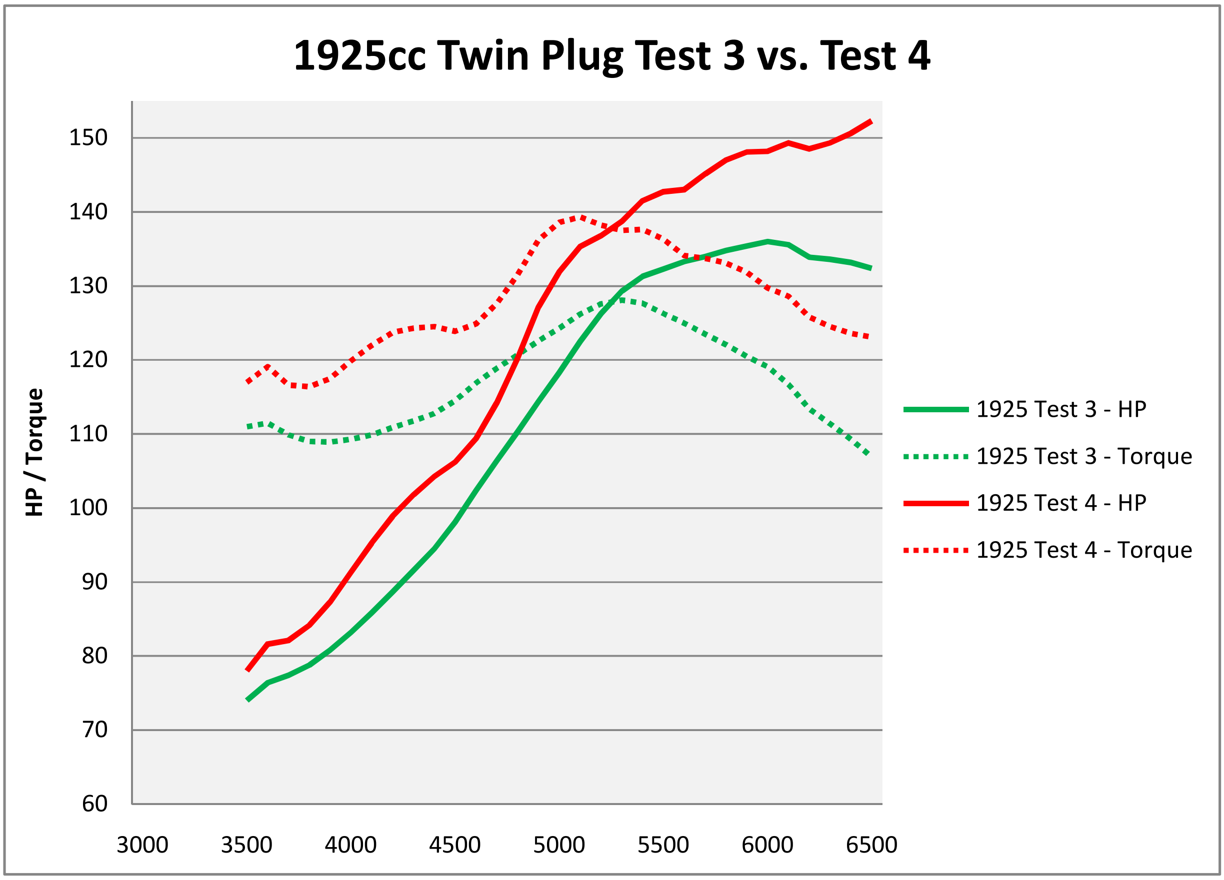
1925TRI Test 4

Elgin 7208 camshaft, 248 degrees with .370” lift.
45mm TWM throttle bodies with TWM airhorns (no air cleaners per customer request).
Scat lightweight crankshaft with Carrillo rods.
Special twin plug distributor for EFI.
Special 12V alternator.
JE forged pistons, 10.5:1.
One cylinder head modified for head temp sensor.

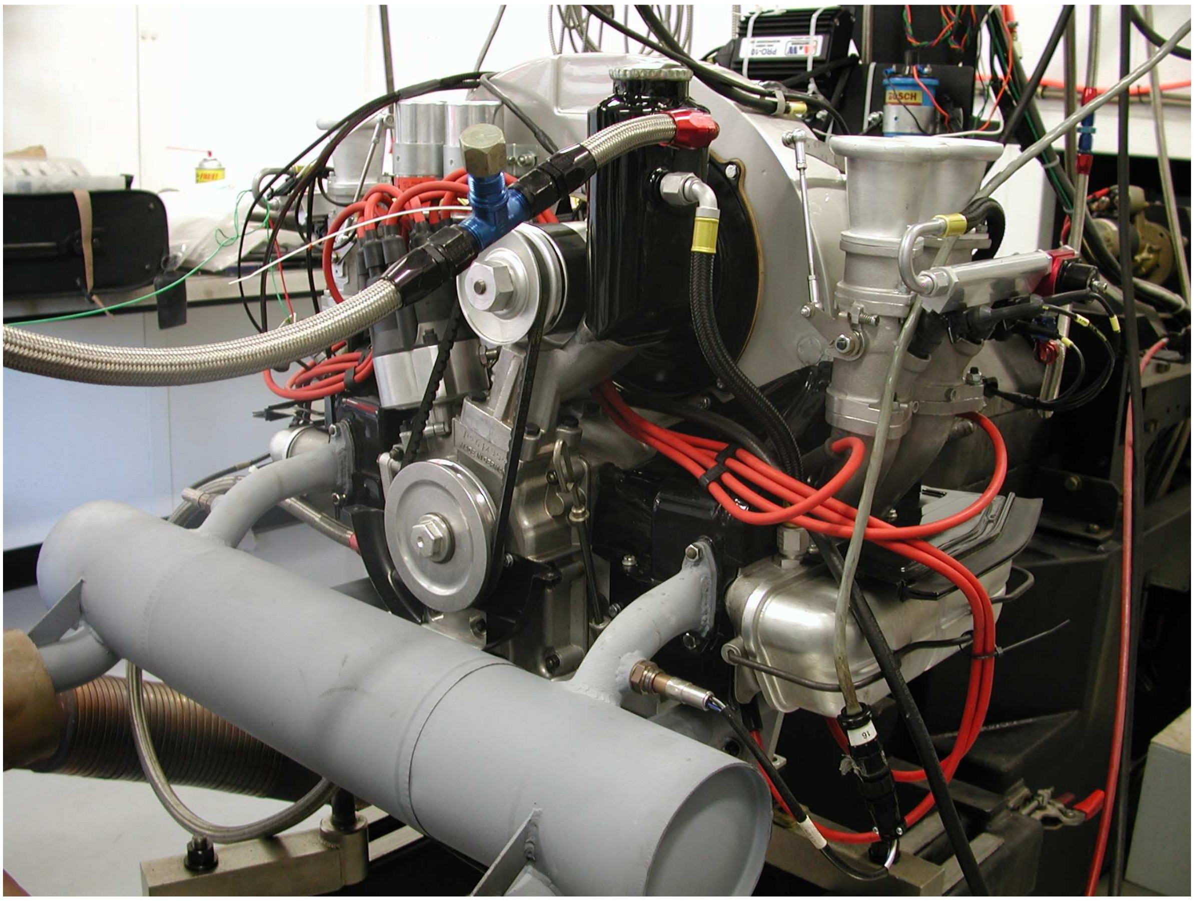
The engine was delivered, with the completed wiring loom, to Carobu for dyno testing. The engine was initially run with a base program installed (this is something for a Motec technician…not a do-it-yourselfer). Once the break-in period was completed, the mapping stage was started. On the DTS dyno the mapping is performed as follows: The engine is started and run at 10% throttle. The dyno is set to mapping mode at 3000rpm. The fuel mixture is corrected if necessary, and the throttle position is increased to 20%. At this point the mapping mode of the DTS dyno kicks in and the computer automatically increases the load on the engine to hold the rpms at 3000. The mixture is again corrected and the throttle position is increased to 30%, 40%, and so on up to 100% throttle with the mapping mode continually increasing the load. Once the 3000rpm mapping is done the engine is revved to 3500rpm and the same process is repeated. The dyno can do this mapping process at any rpm level, but for the 356 3000 to 5500 at 500rpm intervals is plenty. The Motec ECU can fill in the blanks for the 100rpm intervals up to redline, and for infinite throttle positions. Full throttle runs are also done to optimize and test peak performance, and various timing adjustments can also be tested. After dyno testing, the ECU has suggested settings for warm up, acceleration, etc. and these can be easily adjusted in the car with a laptop computer.

I have to admit that the entire mapping and subsequent in-car adjustments were very easy. Most of this was due to the expertise of the late George Clarke, the main technician at Motec, who was in charge of the mapping at Carobu. The complete dyno process took 10 hours, and the in-car adjustments were completed at my shop in about 3 hours. The engine has run flawlessly for three years and the EFI has required no maintenance or adjustments.

The 1925TRi engine (as we call it at the shop…the carb version is the 1925TR) performs amazingly! The engine has incredible power with excellent throttle response, from idle to the 7000rpm redline. The starting and warm-up are better than carburetors, and the reliability of the system has been perfect. The bigger cam and throttle bodies definitely improved the performance, as you can see in the graph. Power output on the dyno was up to **152hp@6500rpm** and **139ftlbs@5100rpm**. The average hp/torque between 3500 and 5500rpm was now up to **110/127.**



The engine was installed in a lightweight Speedster with trick suspension, a CBAA close ratio gearbox and short shifter, and 60mm GT front brakes. It has the same power to weight ratio as a 1973 2.7 RS…but it seems faster. We clocked the 0-60mph time from a standing start at 6.2 sec.

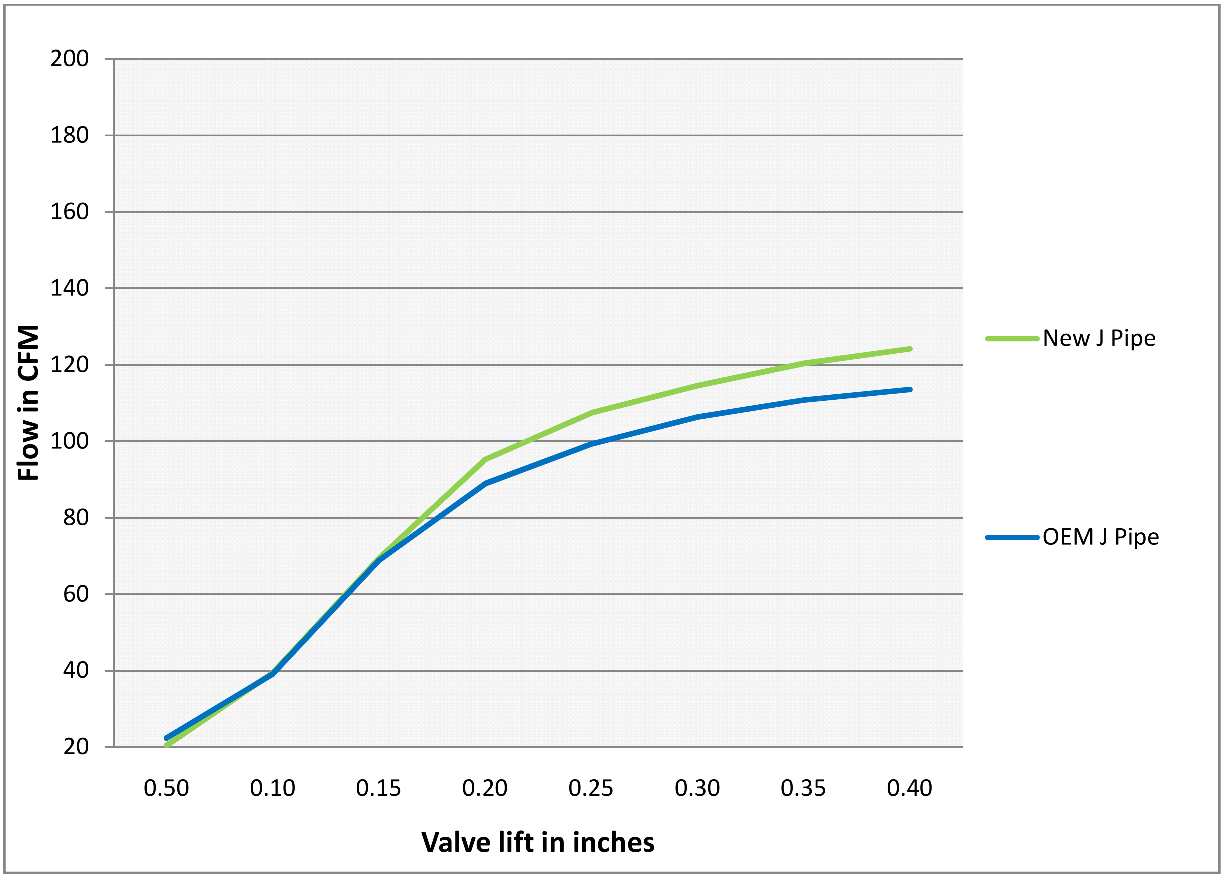


Back To Basics

At this point I thought we had gotten pretty close to the limit with the 356 engine on the street. I wasn't sure if the bigger cam was going to provide the same broad power curve with carburetors as it had with EFI, but the only way to find out was to try it.

I still hadn't explored optional exhausts, but I didn't want to use a 4:1 system because I didn't like the VW type look and sound. The stock muffler didn't have equal length header pipes, and even though we had tried different tail pipes for a sportier look and sound, the internals of the muffler were definitely not designed for 150 horsepower. I decided to start from scatch and design an exhaust that would provide *some* sound damping, look very similar to original, and provide enough flow for the new engine. The length and OD of the primary pipes definitely play a part in the tuning of the torque curve, although, not as much in a "can" type exhaust compared to a true equal length 4:1 header. Since the primary pipes for cylinders 1 and 3 have to come from the front of the engine, their length is already determined at about 33". By passing the cylinder 2 and 4 pipes over the top of the muffler can, and continuing them inside as much as possible, I was able to increase their length to about 26".

This wasn't optimum, but was better than original. Through testing on the engine simulation, we found that 1.5" primaries were the optimum size for best torque, but on the flow bench we made an interesting discovery regarding the stock J tubes. As the tube exits the exhaust port (on cylinders #1 and #3) it turns down sharply into the heater can; when I fabricated the new muffler I brought the header pipes straight out from the port for a smoother transition. When tested on the flow bench, this change realized a considerable increase in flow on the #1 and #3 cylinders.



The main can would be 5" OD, 16ga tubing with 2.125" tailpipes. Sound damping was provided by a 1.625" perforated section inserted into the tailpipe which was wrapped with ceramic cloth. The tailpipes had a 15 degree bend to further breakup the resonance. I fabricated the first exhaust system out of 304 stainless-steel and after testing built a jig so additional systems could be made later.

At this point I only had one set of my cast iron cylinders left in stock. The modification process was not easy, and because cast iron is so brittle, was very difficult to machine. I had heard of LN Engineering's machined aluminum cylinders in the 88mm and 90mm size for 356s and approached Charles Navarro about making my 91s. I sent Charles a sample of one of my cast cylinders, and after some slight dimensional adjustments, he was confident that he could make them. The aluminum cylinders would have obvious thermal advantages over cast iron, plus the nickel/silicone/carbide (Mahle-Nikasil) coating had proved itself in the 911 engine. Another advantage would be the cylinder to head seal, which has always been a problem in the 356 engine with cast iron. Charles claimed improved wear, increased sealing, cooler running, and better power, and I now had quality cylinders that could be ordered as I needed them.

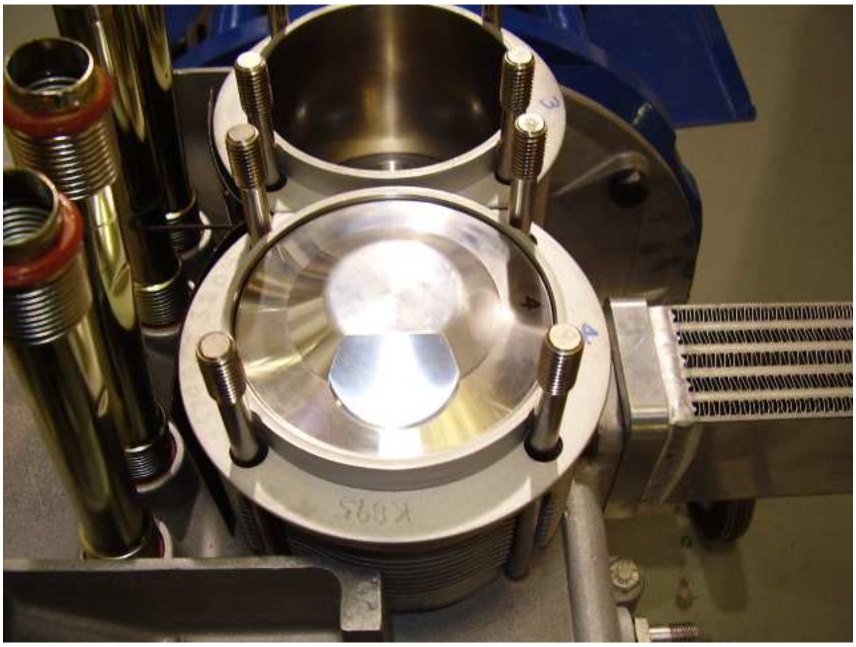
I received the first set of LN's custom 91mm cylinders just as I was preparing to build the next 1925TR. The workmanship was flawless. I ordered a set of JE pistons with 10.5:1 compression ratio and used their special Nikasil ring package. Because of the increased expansion of the aluminum cylinders, a very close machined clearance of .0013" was specified on the pistons. The ring gaps are also much closer than a cast iron cylinder for the same reason. Since I was using all aluminum cylinders, I had steel tipped 2024 aluminum pushrods made for both engines (see below for the test results).

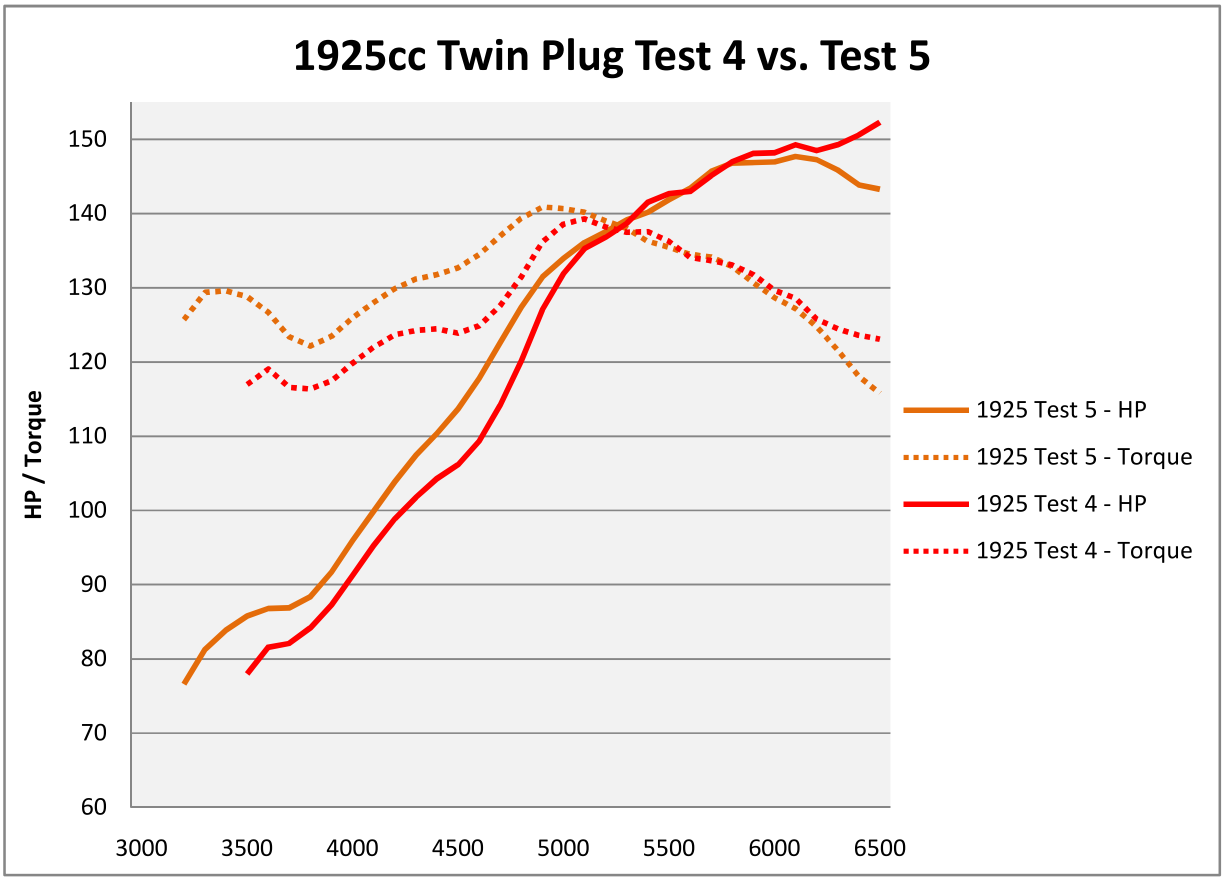
The new engine was going to run carburetors, but I still wanted to keep the 7208 high lift camshaft which had worked so well in the EFI engine. If there were drivability problems with the hotter cam, I'd have to deal with them after the dyno testing. Interestingly, I had two customers that wanted 1925TR engines as the same time, so I worked my schedule so that I could build the engines simultaneously with the identical specs, and test them back to back on the Carobu dyno.

The two new engines were assembled with the following specifications:

1925TR TEST 5 and 6

248 degree camshaft with .370" lift.
Special LN Engineering 91mm "Nickies" cylinders using custom JE forged pistons with 10.50:1 compression ratio.
Bored case with 911 piston squirters installed.
Scat lightweight crank with Carrillo rods.
WR 10.5lb Flywheel kit with aluminum 200mm pressure plate.
Aluminum 5" front pulley.
Custom twin plug distributor using a MSD CDI box firing two Bosch CDI coils.
WR High-Flow cylinder heads, 44I/34E w/dual springs and chromoly retainers.
Weber 44IDF carbs with 36mm venturis and 2.25" airhorns w/K&N air filters.
Crankcase ventilation in the case and heads.
Special aluminum pushrods.
Raceware cylinder head studs.
WR Sport Exhaust for twin plug.





I have to admit, we were all very surprised by the carbureted power vs. the fuel injection, even with the new exhaust. The dyno test showed **148hp@6100rpm** and **141ftlbs@4900rpm**. The average hp/torque from 3500-5500rpm were up to **114/134**. The LN cylinders performed very well. Leak down was just 3% after the first day of dyno testing, and there was virtually no smoking, even on the first start. The longer primaries and lower backpressure of the WR Sport Exhaust boosted the low and mid range torque, and provided a much sportier sound. The very upper rpm power was (probably) limited by the 36mm venturis vs. the throttle body's wide open 45mm diameter. The most amazing thing was that the result of the back to back testing of both engines was very similar (see graph). There was very little difference between the two engines, in both torque and HP.

But…the real question was how would these carbed engines perform in day to day driving? The results were more of a surprise than the dyno test. The street performance, from low speed around town to flat out on the interstate was as good as the EFI. Of course, all that “high-tech” does give you something. Cold starts are done without the usual popping and spitting that is common to 356s, and altitude changes (should be) no problem.

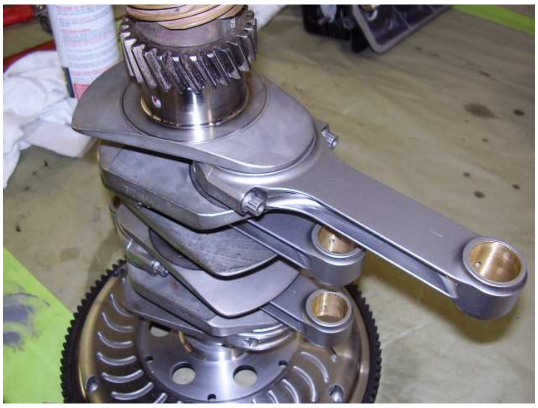
The 1925cc engine definitely likes the bigger cam, and it didn’t seem to have any negative effect on the drivability. As mentioned before, average HP in our 3500-5500RPM range was now up to 114 from 110, and the average torque was up to 134 from 127.

Both of these engines were completed just before the LA Lit meet in 2007. I used one of them (thanks to customer Keith Hofnagle) to do an exhaust comparison demonstration at Carobu on Saturday afternoon just before the get together at European Collectibles. The results of that test can be seen on the website. The engine actually performed better during this second dyno test, and was definitely benefiting from the added break-in time (these test numbers were used in the final hp/torque figures).

More Stroke + More Flow = More Fun

91 millimeters is the largest reasonable piston size for the 356 engine. With the 74mm crankshaft, 1925cc is then the largest engine size possible. Stroking is a possibility but the rod-to-cam clearance is the issue. At 74mm the rod-to-cam clearance with stock rods is already dangerously close (<1mm). The only way to make the crankshaft stroke longer is to either reduce the size of the connecting rod big end or the camshaft lobe. The camshaft base-circle is already somewhat small, and must be made smaller for high lift cams. That leaves the rod bearing…

The 356 rod bearing at 53mm is relatively large by today’s standards. By changing to a smaller diameter 2.0” (50mm) Clevite type bearing we are able to have special rods made that allow the extra clearance for a 77mm stroke crankshaft. In addition to being smaller in diameter, the rod bearings are now approximately 1mm wider which actually provides more oil cushion than the stock 53mm bearing. The rod length is maintained stock and the wristpin is simply pushed up into the piston an extra 1.5mm which ismade possible by the super thin rings that we now use with the Nikasil cylinders from LN Engineering.



With a 77mm stroke the engine size has been pushed to 2002cc. A longer stroke in a street engine has the advantage of increasing the torque throughout the entire rpm range. In a race engine piston speed becomes an issue at high rpm, but since we're not looking to push the limit much above 6K, piston speed is not a real concern.

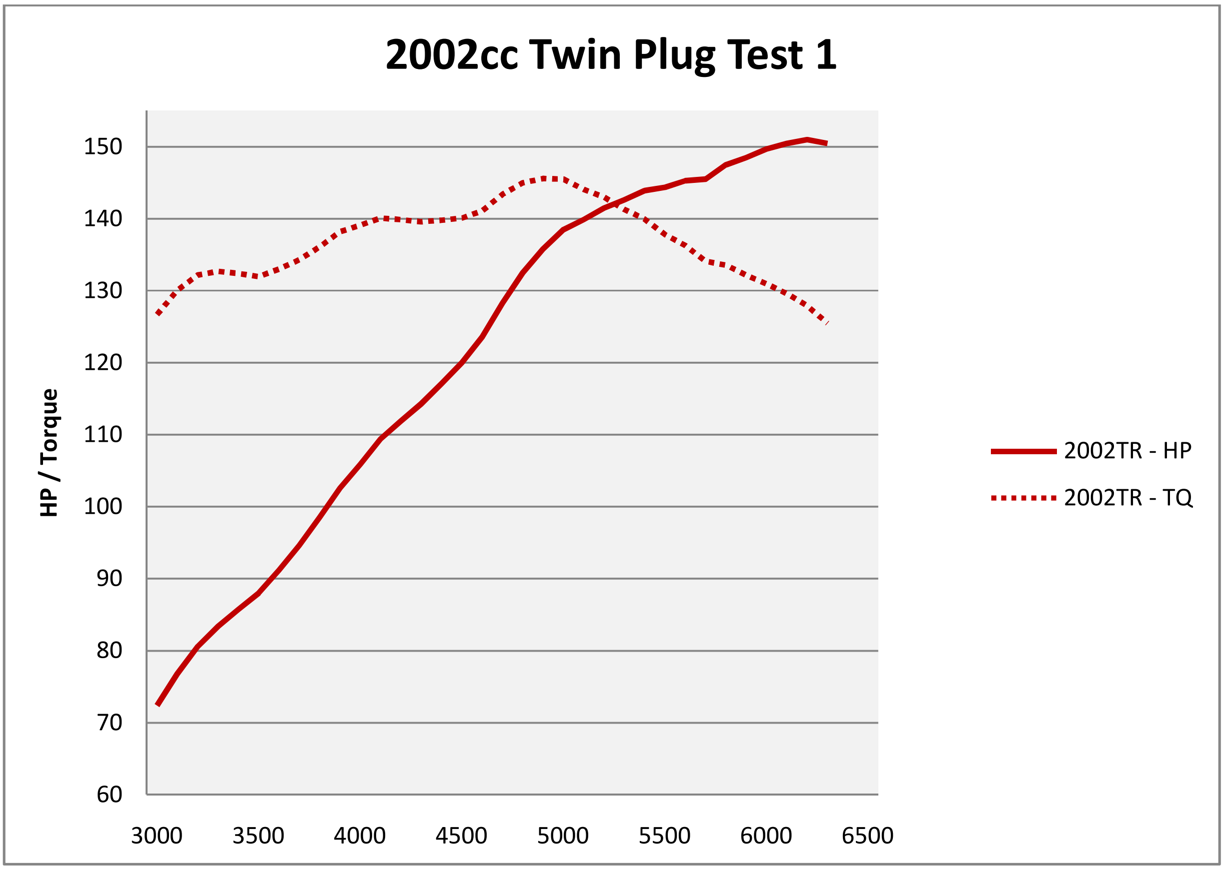
The next engine in the twin-plug configuration is the 2002TR. The first engine built to these specifications has a slightly more conservative look than the previous twin plug engines…and a different sound. At the customer's request, we painted the WR twin plug distributor black, painted the black cap to match the early brown Bosch cap, painted the Bosch CDI coils black and installed vintage decals, and used black Magnacor plug wires. This gave the engine a much more conservative and vintage look that fit with the car, a basically stock (in appearance) 1959 Sunroof Coupe. The different sound comes from the use of a stock Dansk muffler. The customer had heard about the excellent performance of the stock muffler at our test during the 2007 Literature Meet Weekend, and felt that the small sacrifice in power was worth the added comfort (and the "sleeper" nature) that he wanted for his car. We'd also be able to use the factory heater boxes after some modification. His car is also equipped with a GT torque biasing differential and a taller 4th gear for added comfort during freeway cruising, and a single front oil cooler with thermostat.

This first engine was tested at our new dyno facility, Heads Up Performance in Fullerton, CA. The owner and dyno operator, Roger Crawford, is a well know pioneer of high horsepower VW engines. His shop is equipped with the latest DTS dyno with all the goodies.

The engine specifications are listed below:

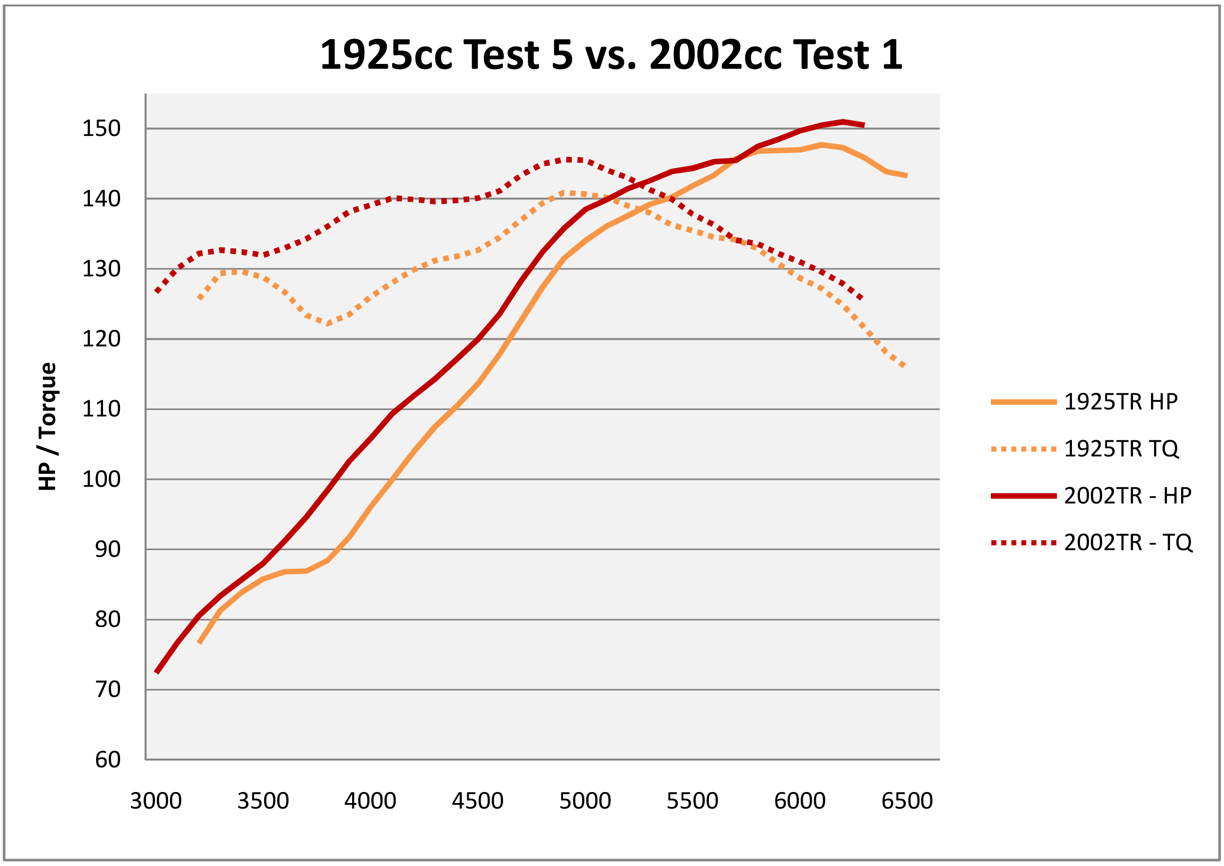
2002TR Test 1

248 degree Elgin camshaft with .370" lift (advanced 1.5 degrees).
Special LN Engineering 91mm "Nickies" cylinders using custom JE forged pistons with 10.50:1 compression ratio.
Bored case with 911 piston squirters installed.
WR 77mm Lightweight crankshaft made by Scat using special Carrillo rods.
WR 10.5lb Flywheel kit with aluminum 200mm pressure plate.
Aluminum 5" front pulley.
Custom twin plug distributor using a MSD CDI box firing two Bosch CDI coils.
Series II WR High-Flow cylinder heads, 44I/34E w/dual springs and chromoly retainers.
Weber 44IDF carbs with 36mm venturis and 2.25" airhorns w/K&N air filters.
Crankcase ventilation in the case and heads.
Special aluminum pushrods.
ARP cylinder head studs.
Stock Dansk muffler using modified heater boxes.



The results were an impressive **151hp@6200rpm** and **146ftlbs@4900rpm**. The average hp/torque from 3500-5500rpm was up to **121/140** compared to the best figures obtained with the 1925TR of 114/134. The stock sound of the exhaust is very deceiving, and while I love the sound of the WR Sport Exhaust at the 7K redline, it's nice to drive through traffic and not be noticed.

A comparison of the 1925cc Twin Plug Test #5 and the new 2002TR (with stock muffler) are shown below:



For a graph comparing the 2002TR engine to a completely stock 2L 911S please read the WR Dyno Tests article.

A Different Direction and a Big Surprise

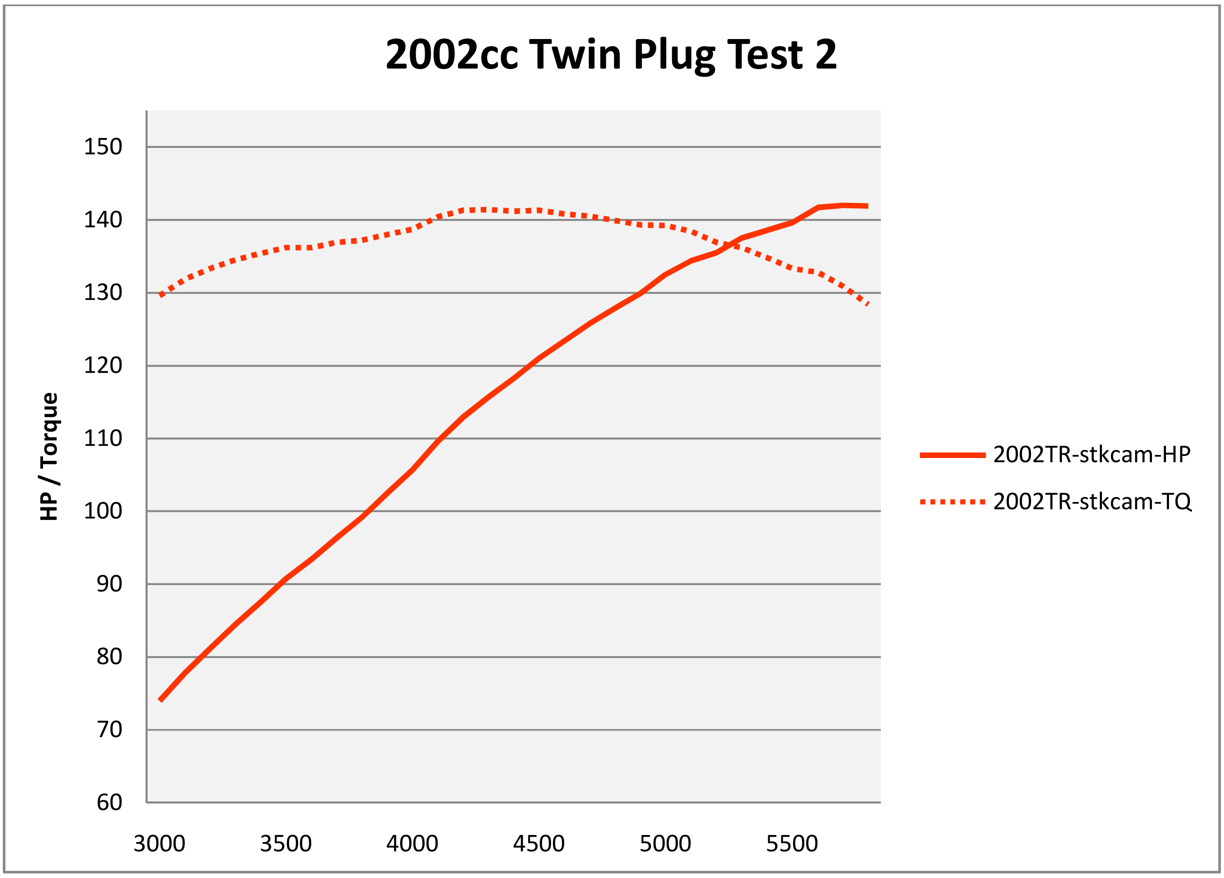
In the quest for maximum torque and power from 3500-5500rpm, I'd been playing with the engine simulation software and decided to try something that would definitely improve the idle, fuel mileage, and low speed running characteristics. We'd tried a stock muffler on the last TR engine, but up until now, I really had no sample of an engine with a **completely stock cam**. Such an engine would not only show me how much the camshaft affected the overall performance of my modified engines, but it would also be a good test of the increase gained from the other modifications alone. The carbs were optimized on the dyno and 34mm venturis replaced the 36mm.

This is the first engine tested with the new **WR harmonic damper** custom made for us by ATI. The damper and its affect on performance are outlined below.

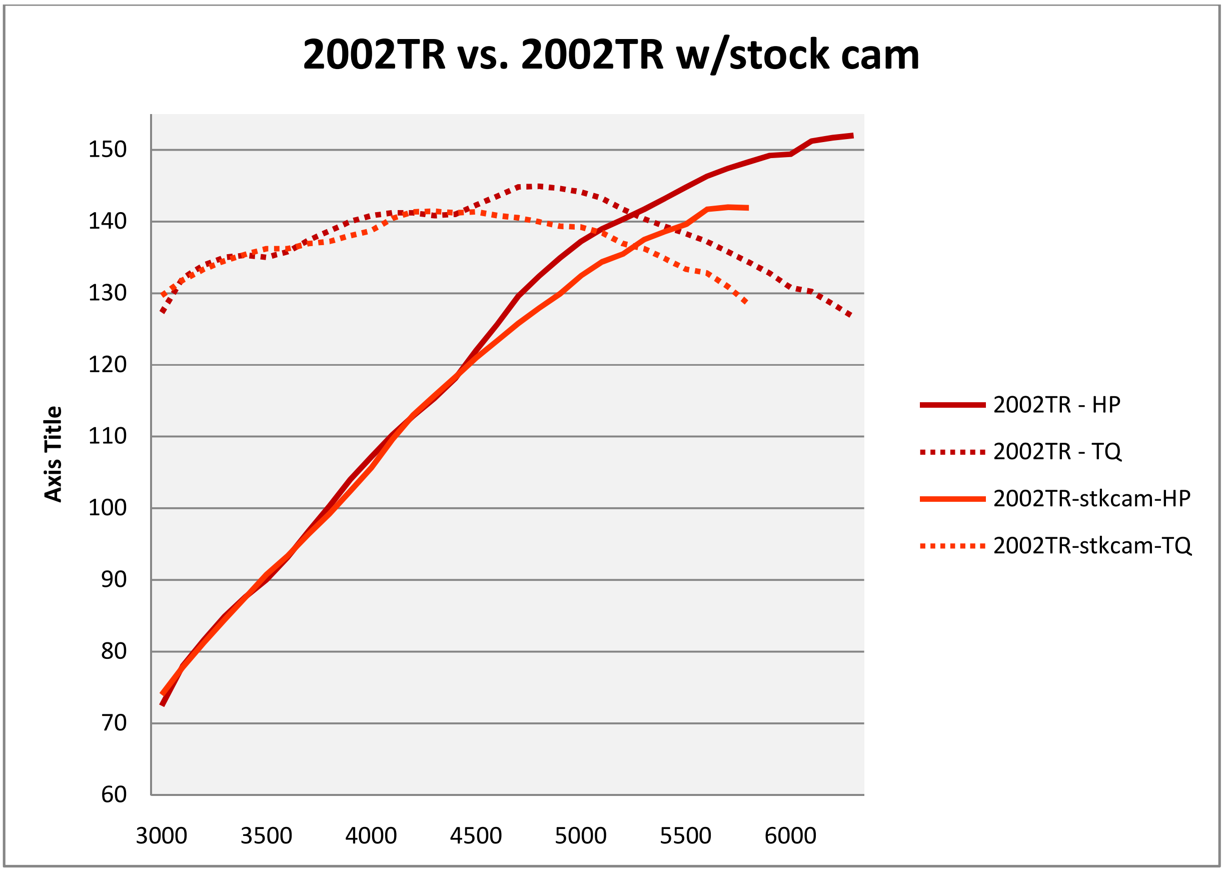
The next 2002TR engine was assembled with the following specs.

2002TR Test #2

Stock #16 Super/S90/SC/912 Camshaft, 234 degrees at .050” with .333” lift.
Special LN Engineering 91mm “Nickies” cylinders using custom JE forged pistons with 10:1 compression ratio.
Bored case with 911 piston squirters installed.
WR 77mm Lightweight crankshaft made by Scat using special Carrillo rods.
WR 10.5lb Flywheel kit with aluminum 200mm pressure plate.
Custom WR harmonic damper made by ATI with 5” pulley.
Custom twin plug distributor using a MSD CDI box firing two Bosch CDI coils.
Series III WR High-Flow cylinder heads, 42I/34E w/dual springs and chromoly retainers.
Weber 44IDF carbs with 34mm venturis and 2.25” airhorns w/K&N air filters.
Crankcase ventilation in the case and heads.
Special aluminum pushrods.
ARP cylinder head studs.
Stock Dansk muffler, no heater boxes.



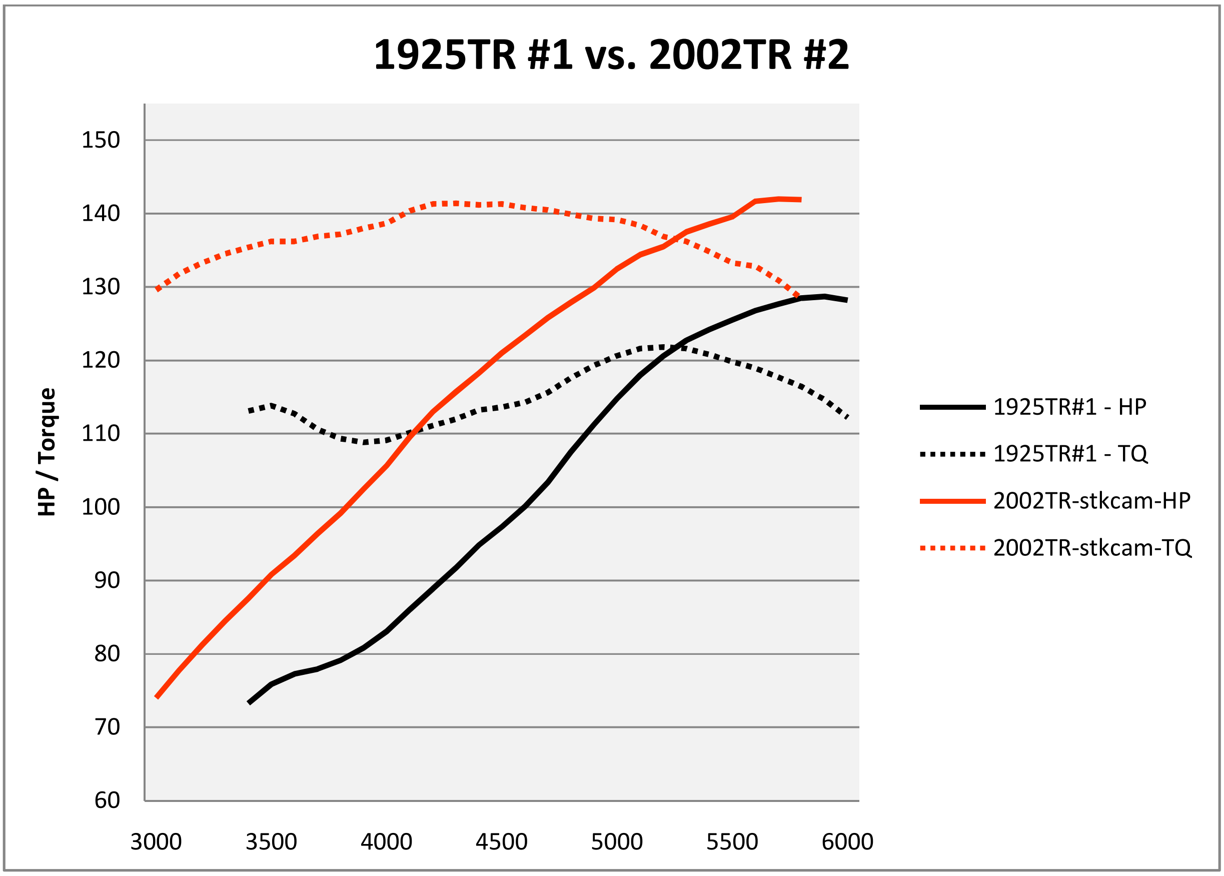
This test was a big surprise. The output with a stock cam and stock exhaust was **142hp@5600rpm** and **141ftlbs@4300rpm**. The horsepower pulled flat from 5600 to 6000 rpm so the cam and smaller venturis were probably limiting the output, but the lower end was solid and I was excited to drive the car and see if the power difference was noticeable. Average hp/torque from 3500-5500rpm was still impressive at **119/138.5**. Below is a comparison of the 2002TR with stock cam vs. sport cam.



This engine was installed in the car that tested our first twin plug, the "Orange Peeler", a 64 Coupe in GT trim with BBBD gearing and all our suspension tricks. With this engine installed, the idle is just like a stock SC. The car starts well and can be driven normally with no feeling that the revs must be kept up to match the cam. Throttle response is immediate from idle with no hesitation, and the engine can be driven without the need to downshift because of the extra torque. Comparing this engine to the 2002TR #1 is difficult. There really is no sensation that this engine with its mild cam is any less powerful, it will rev to 7K in first gear if you're not careful, and it doesn't seem to run out of power at higher RPMs. It does seem more comfortable poking along at 2K in traffic and the low speed throttle response is excellent…much like a stock SC, only with much more torque. I'd say that after driving the car I'd compare the difference of the 2002TR#1 and 2002TR#2 to that between a 911E and 911S. The S has more power, but depending on how you drive, you might never notice.

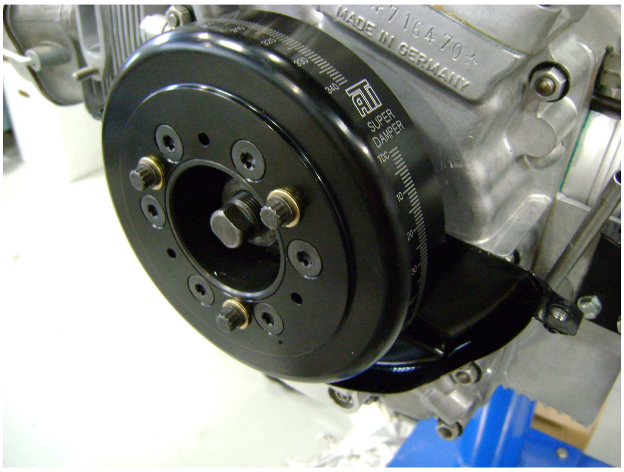
Something to consider when comparing engine performance on the dyno, is that we're comparing maximum performance at wide open throttle. There really is no way to accurately compare engine flexibility and throttle response on a regular dyno. For this we have to rely on the actual driving impression. In addition, gear ratios, flywheel weight, car weight, and wheel/tire weight can all have a dramatic affect on a car's performance.

Just for fun, below is a comparison of the first 1925cc twin plug engine that was originally installed in the "Orange Peeler" to the current 2002TR with stock camshaft and exhaust. Several years of development have produced an engine that is more powerful, more refined, and more quiet.



The WR Harmonic Damper

With the longer 77mm stroke it was determined that some form of damping on the flywheel was needed at high rpm. The purpose of a harmonic damper is to dampen the resonance created by the crankshaft as it rotates. The WR Harmonic Damper weighs 7 lbs. and is engineered to fit properly and incorporates the 5" pulley size that is correct for a high performance 356 engine with the Nickies cylinders. It dramatically smoothes the 4 cylinder 356 engine and provides protection and longer life to the bottom end. It is a true harmonic damper, and not just a heavy pulley. Details on how a true harmonic damper works are available on the ATI website.



COMING UP NEXT

We have several 2002 twin plug engines in the works. Two are being built to more radical specs which should show the high rpm potential of the 2 liter engine. These are being done with EFI but will be fully streetable, not racing engines. *For other variations of the 1925 and 2002 engines please see the Dyno Tests article.*