Nerdletter 6

Pandora's Box

I'm currently refreshing a drag-race engine (big-block Chevy) for a customer that have caused two thoughts to jump into my mind. The first is, I probably don't assemble engines "by the book." And second, I'm sick and tired of having to preach about the cooling system. It is this latter issue (cooling systems) which dictates the former - the way I assemble engines. I'll explain.

But, before I do, I have a confession to make - I'm building an engine that uses an electric water pump. It pains me to even use the phrase "electric water pump." These disgusting contraptions have no place on a race engine but, none-the-less, they are the pride of many drag racers. I have such disdain - even contempt - for these devices that when I see them being used on engines in magazine articles for dyno tests, I don't bother to read the article. If these dynos had water flow turbines I don't think these people would be using electric water pumps (just like if they had oil flow turbines they wouldn't be using some of the high viscosity oils). I think they use them to save a little bit of work when changing camshafts on the dyno but they do seem to be in vogue these days on hot rods. *"A product that does not perform well may still sell well and be deemed a success by the marketplace"* from The Romance of Engines.

The last time I rebuilt this engine I shipped it with a belt driven conventional water pump, but somehow during one of the race seasons someone convinced my customer (lets call him Reid because that's his name) that he needed this water pump to cool his engine down between rounds.

It is a good idea and works well for cooling the engine down when it's not running. But, as I've tried to tell him, that shouldn't take precedence over the well being of the engine when it's producing power. He argues that the water pump is doing its job because the water temperature is fine. However, I have evidence to the contrary. When I took the engine apart the first smoking gun was the ole familiar vanilla milkshake in the valley. Not much, only about two table-spoons full - but, this is classic evidence of steam pocket formation.

Second smoking gun was the rings. The top rings were trashed. Severely worn at the face. In this situation I attribute that to a lot of heat. I also noticed that, as I have many times in the past, they get worse from front to back. The coolant gets hotter as it progresses to the rear of the case and if there isn't enough pressure, i.e. flow to remove the heat, metal temperatures are going to rise. Nucleate boiling can't be controlled and that leads to steam pockets and on and on. You may have read my diatribes on this stuff before.

When I presented this evidence to Reid he said that the temperature gauge never indicated hot. I

told him that's because his temperature sensor is at the front of the intake manifold and the trouble is at the back of the heads. Years ago we did some tests where we equipped an engine on the dyno with many thermocouples and in a borderline cooling situation saw temperatures over 900 degrees at the back of cylinder heads while the water flowing out of the intake manifold looked normal. That's when we were using a cooling tower instead of pressurized cooling (on the dyno). I wrote about this once in another paper. The point is, temperature sensors should be placed where the temperatures are going to be the highest and not where the sensor is easiest to mount (at the front of the intake manifold).

I, therefore told Reid, that I was going to drill and tap the back of his heads in case there is room between the head and firewall to fit some kind of a small temperature sending unit. He was agreeable to this.

Since the observances of heat related distress near the rear of many race engines I have taken, perhaps, almost subconsciously, to bias some clearances for that condition. For instance, not all pistons are exactly the same size. Instead of matching the big cylinders with the big pistons and small cylinders with the small pistons to even the clearances, I have often put the small pistons at the rear to increase cylinder-to-wall-clearance at the rear of the engine. Especially, if I suspect the engine could go into an environment with a less than an ideal cooling system. Certainly, an electric water pump fits that description.

The other clearance is with ring end-gaps. When I file end-gaps I usually shoot for a .002" range, say for instance .018 to .020." Some of them end up right at .018 and some will be at .020 and maybe I'll slip up and get one or two at .021 or .022. I don't have a lot patience when it comes to operating my ring grinder. I do the same thing, I put the larger gaps at the rear and the tighter ones at the front.

While we're on the subject of rings, don't forget to line up the end-gaps on the top two rings before you poke them in the cylinder. Of course, that's no fun unless someone is watching you do it. I don't understand the purpose of staggering the end-gaps since the same leakage path will still exist. (I can sense that I'm going off on a tangent, can't you?). Since the rings rotate what difference is it going to make if they're lined up when they're installed. I'm sure people don't think the engine won't start if the rings are lined up. I've read that as a rule of thumb the upper ring will rotate one RPM for each one thousand engine RPM. But, as far as the leakdown percentage is concerned this isn't going to make a difference because unlike combustion the cylinder pressure during a leakdown test is long and constant and there will be plenty of time for the air to find it way past the gaps to the crankcase.

Just for kicks, while recently putting together a big and small-block Chevy at the same time, I performed an experiment that should lay this end-gap deal to rest. I purposely, and carefully, lined up the end-gaps on the top two rings on the odd numbered side (drivers side), and staggered the end-gaps in the conventional manner on the even numbered side, and then performed a leakdown test. I did it after each engine was completely assembled with each piston at TDC. Both engines were on the engine stand with freshly bored and honed cylinder bores. Both had been honed without a deck plate cold therefore the rather large leakage numbers are mostly attributable to bore distortation and the conservative nature (smallness) of the orifice in my leakdown tester. I had done this test before, as I had pointed out in my paper Newsletter #1 but I didn't include any numbers so here they are.

Cylinder	1	2	3	4	5	6	7	8
Leakage	8.5	12.0	6.5	8.0	12.5	7.0	13.5	9.5

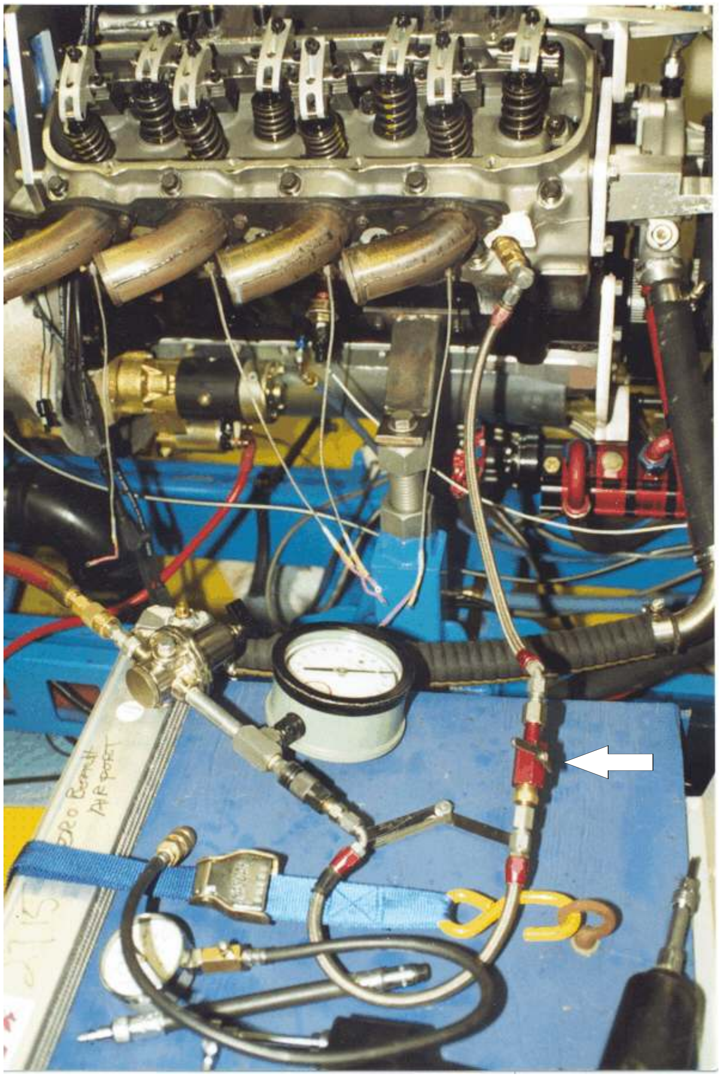
Big-block Chev (4.530 bore)

Cylinder	1	2	3	4	5	6	7	8
Leakage	7.0	8.5	5.5	11.0	12.0	9.0	10.5	8.5

Small-block Chev (4.030 bore)

Odd number cylinders have the end-gaps lined up. Even number cylinders have their end-gaps staggered in the conventional manner.

Speaking of leakdown testers. In that paper I described the one I built using an expensive calibration gauge but I failed to mention that the critical part of the leakdown tester is the orifice. I called it MIL/SPEC because I got the orifice specification out of an aircraft engine book. It called for a .040" hole (#60 drill) with a 45 degree chamfer at the entry and exit (as I recall - since that was over 30 years ago). I made sure my orifice length was at least ten diameters long although the book didn’t call for that. Knowing that carburetor jets are broached and not drilled to keep them consistent and how sensitive they are to nicks and burrs, it’s easy to understand why leakdown testers can vary in their readings. In fact a carburetor jet or air bleed might be a good place to start (then all you would have to do would be to add the chamfers) when building your own leakdown tester.



Leak-down tester. Arrow shows the ball valve

I like the idea of building your own because they’re so simple. And, you don’t need two gauges. You only see two gauges on them because that makes them look more complicated and adds to the cost. The same gauge that measures the leakage can also measure the line pressure. If you set the line pressure above 100 psi and the regulator at 100 and can subtract the gauge reading from 100 then the money you’ve saved can go toward buying a higher quality regulator (that doesn’t drift as much - go to a place that sells paint equipment) and a bigger more accurate gauge. Putting a small ball-valve after the gauge and orifice will make it easy to quickly (by shutting the valve) check regulator output pressure. Nuff said.

The other reason racers use electric water pumps is because it saves horsepower. We only performed one test of one of these pumps compared to a belt-driven pump and if memory serves, we could barely see the difference in power. It was not a good test however because we didn't go back and repeat it. The reason for that was we didn't want to take a chance on hurting the engine because of the three gpm this so-called "high-flow" electric pump was producing. Most decent belt-driven pumps will provide eight to ten gpm per 1000 engine rpm (when geared normally).

I surmise that when they quote flow figures for these electric water pumps it's free flow numbers that's being presented and not the flow the pump produces when working in the system. Especially when people put in flow restrictors. That's why fuel pump flows are generally compared at a reference pressure.

Even if it took ten or more horsepower to pump the water - I'd rather have at least 50 gpm through the engine at peak power, (and a minimum of 30 psi) than create steam pockets which could lead to some degree of detonation. But hey, I'm obviously in the minority here.

All of that having been said, it is now eight months later - December 07 and I want now tell you the rest of the story about Reid's engine and his 2007 racing season because a noteworthy thing happened.

What I didn't mention was that after I began to refreshen his engine in 07 he decided he wanted me to see if I could give him some more power. This is a 516 cu. in big-block Chevy in a El Camino that he bracket races and he had room to grow in the bracket. Since the heads had only been pocket ported by Dart I saw where I could make some gains in both the intake and exhaust ports. I went whole hog and fully ported them. According to my calculations the increase in airflow from the intake side alone should have been good for 35 horsepower and I made enough gain on the exhaust side to keep the flow ratio about the same.

He originally purchased this engine from us. It had started life as a 502 but somewhere along the line we upgraded the crank to a 4340 and the rods were changed to Carrillos. It was used one season for white-water endurance boat racing. The pistons were flat-tops so it was still at an 11 to one compression ratio. Very low for a drag-race engine. After we had honed the cylinders the piston-to-wall clearance had crept to the ragged edge of being too much so the decision to increase the compression was easy. I had JE put a maximum dome on them which meant I had to hand fit each piston to each combustion chamber. I used thin strips of clay to insure adequate clearance and this was very time consuming. The static compression ratio came out to be 14.85 to one. I forgot to mention that the heads were the Pontiac Big-Chief 18 degree.

Cometic Gaskets built me a head gasket with a bore opening only .005" larger than the cylinder size and a little over .030" thick since the piston was only down the bore a couple thousandths. This resulted in a smacking clearance (piston deck to head deck) of around .035." Because the ring package was as high as possible on the piston I felt we had as minimum a crevice volume big-block as reasonably possible.

Reid had felt that the power was flattening out before he reached the finish line and was wanting to change the cam anyway. But now, with the airflow gain that seemed necessary. Dema Elgin ground us a new cam with considerably more lift (.840" net intake & .790 net exhaust). This meant changing to a different valvespring, (PSI DR1224 from CV products) retainer, keeper,

Flowing Big-Chief head

springcup and shim size.

If Reid had learned anything from us, it was the importance of the dyno, so he took it to the same place that tested it the previous year (since I was no longer in business). He called me and left a sarcastic sounding message indicating that they had completed the first dyno test and wanted to know what had happened to the 50 horsepower I had promised him. I knew we had 35 from the porting alone and that by being very conservative there was at least another 20 from the compression increase. So, I was worried and started to organize my excuses but the only ones could be was that there was something wrong with their dyno calibration and that, “sorry I did the best I could.” Two days later, when we finally did get to talk, he again started out by saying “so much for that 50 horsepower gain you promised me” - and I started to open my mouth and he then said - “it wasn’t fifty it was one hundred and five! What a relief. He made 895 horsepower - which ain’t bad for 516 cu. in. big-block with a single four-barrel carburetor.

So, how did his season go - not so good. He couldn’t get the car to hook up because of the power increase. Things were too different so he didn’t win the championship. At the end of the season he pulled the engine and had me do an inspection of it to see how it weathered the racing season. I did the typical valve-lash check and leakdown, which were fine. The main bearings looked good. But, the rod bearings were a different story. Interestingly, it was a pattern I had seen before - from engines with low coolant flow. The cylinders at the back had bad rod bearings (metal-to-metal contact) and the ones at the front looked good.

That’s the noteworthy observation I wanted to pass along. What are we to make of all this? He’s still using that electric water pump. Notice earlier I said, “some degree of detonation.” It’s obvious that some detonation is going on in those back four cylinders. It could be full blown detonation but it’s just starting near the end of his pass. Or, it could be light-knock, going on for somewhat longer - who knows. What we do know is that those four bearings probably wouldn’t have lasted another season because they had lost their spread and sometime soon down the road were going to grab the crank. We did not change the front four rod bearings - that’s how good they looked. Nothing could be seen on the sparkplugs and I no longer have a boroscope (to observe piston tops), but regardless of what they would have showed the bearings were the smoking gun that indicates all is not well in Reid’s engine. He never mentioned going back to the belt driven water pump which is still sitting right there on the shelf next to his car.

The moral of my story - I think people who use these so called “high-flow” electric water pumps are blissfully unaware of what’s going on in the rear water passages of their cylinder heads. When engines with these pumps are called upon to make high power levels, inadequate cooling velocity can cause detonation. This can open a Pandora’s box of engine distress, problems and failures. The first signs of which, are usually, latte style water in the oil normally seen in the valley. If the engine builder/tuner isn’t experienced enough to realize the true source of this engine distress then the engine is doomed to a troubled history. Ironically, this is job security for the engine builder. I would encourage anyone who uses one of these insidious devices to install an additional temperature gauge in the rear of one of their cylinder heads and keep an eye on it when the engine is making a lot of power. You may be in for a shock.

Exhaust Noise

The word combustion sounds like it should have noise associated with it. But, combustion and explosion are two quite different kettles of fish.

Sometimes, during a leak-down test leaky valves are encountered. This is especially the case if you’re leaking down an engine that hasn’t been run for awhile and the valves and/or valve seats have had time to form a bit of corrosion on them. The result of this is a larger than normal amount of air escaping past the intake or exhaust valve. There is usually an easy fix for this. Just take a rubber-faced (preferably a dead-blow) hammer and give the rocker-arm a wack or two above the valve. The 100 psi air pressure in the cylinder will blow the surfaces clean after a few cycles with the hammer. After each hit you can usually watch the pressure gauge climb higher (leak-down number getting lower).

The first time I did this to a valve was quite startling. I wasn’t prepared for the loud bang I got because I hit an exhaust valve and the headers were not on the engine. It was at that instant that the light came on and I realized what I already knew but had never thought about. Exhaust noise doesn’t come from combustion - at least not directly.

The reason we hear an explosion, whether it be a firecracker, gunshot, or dynamite, is that the sound-barrier is being broken. We know that the speed of sound is 1087 ft/sec at 32 degrees F and increases in velocity about 1.1 ft/sec per degree Fahrenheit increase in temperature. For example, when TNT explodes it produces a shock wave that travels over 22,000 ft/second - well in excess of the sound barrier.

Combustion on the other hand is supposed to be a controlled **burn**. In a typical engine running at moderate speed the mean flame speed is around 300 ft/second - far from the speed of sound. That only leaves the source of engine noise to the sound barrier being broken by the escape of cylinder pressure past the exhaust valve at the time it leaves the seat - the beginning of the blowdown period - as evidenced by my sudden release of cylinder pressure with the hammer. This means initial gas speeds of over 2000 ft/second - you do the math.

The same thing happens when the intake valve is struck. If the intake manifold is not attached it sounds just like the exhaust but when it is, the sound is somewhat dampened or deadened by the plenum. Check it out.

Anyway, I just thought that this should be pointed out because I imagine a lot of folks figure engine exhaust noise comes from what they wrongly believe are a series of all those little explosions. I have a lot of fun with this now when I demonstrate a leak-down test for my engine class. With everyone standing around the engine (on the engine stand) and no one talking - to maximize the drama - cylinder at a hundred psi, I wack the exhaust valve with the hammer - and kapow - there’s always a few that really jump.

Eating Humble Pie

When I was doing my time in boot camp at The Naval Training Center in San Diego (1963) I used to drool longingly at a new 63 Corvette coupe that was often parked below the barracks window in the evenings. I thought that was the neatest car I had ever seen an vowed to myself that I would save my nickels and dimes and buy one of those when I got of the Navy. And, I did just that.

I started autocrossing it in 1967 but I soon needed to go faster and joined the ICSCC (International Conference of Sports Car Clubs) in 1969 and got my novice road-racing license that year. After the novice program I needed to go faster than the small-block was taking me and with the help of a friend took the body off the frame, lightened, stiffened and changed everything. Another friend and I had designed big wide beautiful rear fender wells that accommodated a fourteen inch wide wheel with a tires that left a fourteen inch wide footprint. I had a new 460 cu. in. big-block. I didn't make it back to the track until 1972.

One of the early races that year or maybe the first - I can’t remember - was at the Westwood racetrack near Vancouver BC. My car was fast - one of the fastest in Conference. As I recall after the Saturday morning practice session someone commented that my times were close to the track record and that really got my attention. So, when the next session came around I really went all out. I knew I was faster and a few laps later, sure enough, I came over deers leap and reached the hairpin at the bottom of the hill I could see people clapping. I didn’t think I could go any faster

1976

and figured they must have announced that I had set a new track record so I came into the pits and as I did people in the bleachers stood up and were applauding. Needless to say I was thrilled and grinning from ear to ear I’m sure. I put my hand out the window and waved at the people (that was before window nets were required). Then I saw crew and my wife, she was also very excited and came running up to my door and exclaimed; “they’ve just landed on the moon!”

That was Apollo 16 and I didn’t even come close to a track record. I ate humble pie but nonetheless, still treasure the memory.

The Hidden Sponsor

What is the test of a good race fuel - it's resistance from detonation (octane), its energy value, stoichiometry of the air-fuel mixture, how fast it burns, the most mass for the volume, its

I was the A/SR class champion in 1976 and the Lola here was second.

distillation curve, how much it weighs? I think it would largely depend on the kind of racing involved. Certainly, the fuel requirements for Pro-Stock drag car or a SCCA GT-1 car are going to be wholly different than the fuel requirements for a F1 car. Back in the F1 fuel heyday, in the mid 80's, when fuel was not as closely policed, they reportedly ran 90% toluene and who knows what all. The contents of these magic elixirs were the most closely guarded secrets in F1. It was also touted as costing over $1000 per gallon.

If the main requirement is it's resistance from detonation - I guess we should call that its octane rating- then once again I'm going to climb onto the av-gas soapbox. Not because it's a superior product, but because I hate to see racers being taken to the cleaners for a product (race gas) that doesn't have to cost what it does even though I know they could come up with many reasons why race fuel costs what it does. It could do no better than to start life as the same base stock as av-gas - only that it (race gas) doesn't come from Aruba. The only reason it's not starting life as av-gas is because to be av-gas it first has to designated as such.

I have made BMEP's (brake mean effective pressure) of 320 psi with 100LL av-gas with a turbocharged engine (BMEP = HP x 13,000/ L x RPM where L = engine capacity in liters). Average engines produce 130 - 145 psi, good engines 160 - 180 psi, modified engines 175 - 195 psi, racing engines 185 - 210 psi, exceptional engines 220 psi (these are all normally aspirated of course). If you extrapolate that a Nextel Cup engine will produce peak torque at 7000 rpm and make 700 horsepower there, that would equate to 227 psi. If you want to use torque for BMEP it then = 150.8 x Torque (lb-ft)/Engine Disp (cubic inches).

Av-gas is going to weigh a little less (0.70 specific gravity) but not enough to require a jet change. If anything, I've noticed that it might burn a little slower but this is really hard to quantify. So you might want to advance the timing one or two degrees. It's true that you want a race fuel to burn as fast as possible because this makes for less negative work on the piston. It will also reject less heat to the coolant and exhaust leaving more to be converted to work on the piston. However, on numerous occasions, we switched between race gas and av-gas and adjusted the timing for MBT (mean best torque) and found negligible difference (with dyno repeatability of about 2 hp out of 600) and then switched back again with the same results.

Here is a poignant reminder from Sir Harry Ricardo's book <u>The Internal-Combustion Engine</u> - "it is found that all pure hydrocarbon fuels, no matter what their composition or heat value may be, give, at the same compression ratio, the same power output and the same thermal efficiency to within less than one percent so long as they are vaporized and delivered to the cylinder at the same temperature."

It is illegal to use av-gas in a road car because no tax as been paid on it. But, it is legal to use it in a boat or an engine on a dyno. So, it seems like it should be legal to use it in anything that doesn't use public roads - that's why it's legal for airplanes. With the same reasoning, it seems like it should be legal for race cars. I wonder if it would be legal at PIR (Portland International Raceway) since it is a public park. Oh well.

Av-gas usually runs 20 or 30 cents more per gallon than 92 octane pump gas. This is way less than half of what race gas cost which is going to save hundreds of dollars (for a typical SCCA road-racer for instance) over the cost of a race season. That's why I call it the hidden sponsor. All you need to do is find a **small** airport and go talk to them. Tell them it's not for a road car and don't buy less than 55 gallons at a time and you'll leave a hero.

$M=E/C^2$

And now, from the "since nobody cared to ask department." The name of my paper - Deductions from the Phenomena of the Thermal Boundary Layer - I borrowed from the name of Einstein's first paper he wrote circa 1900 titled, Deductions from the Phenomena of Capillarity. In it, he used statistical analysis to attempt to explain the forces that interact among the molecules in a liquid. He was trying to approximate the size of an atom. This was important because the very existence of molecules and atoms was still being debated by many physicists at the time.

I'm not just another pretty face you know - I have other interests outside that of engines - hobbies - like playing nine-ball for cash, and reading about history. Especially, the history of physics. I read a lot of these books written for the physics lay person. For the most part they're easy to understand and it's fascinating to learn how to days technology all came about. Starting with the ancient Greeks, to Galileo, Newton and especially, Einstein. Physics history may not have the breadth of a subject like, say, military history, but its cast of geeky characters is every bit as interesting and colorful.

I have the urge to write papers explaining some of the exciting things I have learned from these books to share with my fellow gearheads. Things far more exciting than anything that could ever come from an engine - but, I don't imagine that would be appreciated by the few who say they enjoy my engine utterings. So for now, I'll just pass on the title of what is, so far, the most interesting book I've read. It's $E=MC^2$ by David Bodanis. I first read it a couple of years ago and have re-read it several times since. This is a book about the worlds most famous equation, where it came from and how it's changed the world. The author takes each symbol of the equation separately, including the "=" sign and explains their meaning and implications. Historically, this book is superbly researched. If you're a gearhead do yourself a favor and read this. Even the notes at the end are fascinating - for instance, they explain how close Germany really came to getting radioactive weapons, why there are parts of World War I German battleships on the moon and that Maxwell didn't write Maxwell's equations. And, by the way, Einstein didn't write $E=MC^2$. In the symbols he was using at the time the equation would have come out as $L=MV^2$. If you enjoy that book let me know and I can turn you on to some others.

I've been sneaking some of this physics stuff into my engine class lectures (including special relativity) and, so far, its been very well received. My objective for this is to perhaps unlock, in my students, the awareness of the interesting and exciting "science" side of engines, and life in general.

What let the physics genie out of the bottle in me was the first time I read about wave-particle duality. That was so fascinating that I couldn't get enough of it. I think most gearheads would find this type of stuff as exciting as I do. And, if I hadn't of learned about $E=MC^2$ I would have never realized that a valve spring weighs more when it's compressed - by the amount equal to E/C^2 (where E is the energy released and C = speed of light).

Pat Usher