Engine Cooling Primer

by David Clinton

All mechanisms which produce power create heat; that heat must be accommodated somehow. From nuclear power plants, wind generators and of course automobile engines, street or racing.

The focus of this treatise is high horse power liquid cooled engines.

Much of what I have learned started when I became an airplane owner. I have an extensive aviation background. When released from active duty in the US Navy, I accepted a position as a corporate pilot; simultaneous with that change in lifestyle I purchased my first of many airplanes, a P-51 Mustang. The 51 was powered by a Packard built Rolls Royce V-12 Merlin, liquid cooled.

The engine was 1650 ci, and produced 1400 horsepower at takeoff power which was 61hg boost or double standard atmospheric pressure which is 15psi at sea level. Boosted engines produce two kinds of heat, induction and combustion, both relate to the total heat production of the engine, BTU, which must be managed to prevent detonation/ preignition but harnessed to utilize the power produced. On the 51 the induction temperature would approach 80-90 C, really hot. The 51 had a after cooler and an intercooler, but most race car engines usually do not have such devices.

The 51 also had a very bad engine habit of overheating the aft cylinders on both banks, with consequential results of burning valves, pistons and liners. My very good friend at the time was also a 51 owner and a premier TFD hemi engine builder, Dave Zeuschel (now departed). Dave correctly analyzed the problem was not air/fuel flow but related to water flow being dammed in the rear cylinders water distribution. His solution was simple; he designed a -6 AN balance line from the rear cylinder exterior transport to the front of the cylinder bank. This simple solution effectively removed the dam and improved water flow which resulted in no more hot rear cylinders.

Now what is the relation to our current race engines, factory produced or aftermarket? Simple, the very same blockage exists in many racing engines….4,6 or 8 cylinders. How do we know that? Well, block designs are usually cast which sometimes or maybe always are not designed with water flow efficiency in mind, only the necessary flow to assure dependable heat transfer at normal operating conditions. The term Steam holes is little understood; it effectively refers to trapped water in the block that steams and must be relived; obviously steam no longer conducts heat but is the result of stagnant water super-heated to produce steam.

So, consider a LS7 in a Corvette might be rated at 700hp and advertised as such. But I guarantee that engine will not produce the rated power or even 75% constantly. Consider that an airplane engine must prove airworthy at 60-80% power output for the life cycle of the engine and they routinely are operated at that power output in normal cruise for hours at a time in all kinds of atmospheric conditions. The LS7 could never reach that output for any length of time, no criticism of the product, it was not designed to accommodate that kind of use.

So, lets cover the two central issues of the cooling cycle; tuning and the heat transfer cycle using water as the medium or some mixture of water and an anti-freeze.

Tuning is separated into 3 categories, 1 fuel/airflow and ratio 2 Cam timing and 3 the liquid cooling system.

Air/fuel flow; I am good friends with Austin Coil, the winningest crew chief in NHRA history; 16 national Funny Car championships as John Force's crew chief, a record not likely to ever be matched or exceeded. I think Austin is one of the smartest guys on the planet.

In the late 1990s Austin discovered an imbalance in the fuel/airflow delivery in the 426 supercharged Hemi used in TFD and Funny cars. The rear cylinders would go lean and burn pistons, valves and sleeves while the other 6 cylinders would run normal. These Hemi engines have multiple fuel pumps, fuel nozzles and other fuel flow control items. The current fuel flow rate is around 60gpm, so mixture and air ratio are essential to full performance potential. Over a period of time Austin deduced the problem and developed a fix; he moved the supercharger back on the manifold, a brilliant idea. He was aided in the concept by Don Jackson. This feature fixed the flow issues and after that the flow was virtually balanced to all 8 cylinders. Austin went forward to design a "Blower dyno" to perfect hie idea. For many years John Force enjoyed a substantial performance advantage enabling the team to win 16 championships. Now all NHRA nitro teams use the blower setback designed by Austin.

Controlling fuel/air flow to all cylinders in engines is a delicate balance of pressure ratios. These ratios are dictated by intake design, exhaust flow and cam timing. If we start with valve timing first the intake and the exhaust come as a second block or concept, in other words the cam timing dictates the needs of intake and exhaust design, size shape and length of intake runners or exhaust pipe dimensions and length.

Cam timing is a little understood subject; it involves lift, duration and overlap. Lift is purposed to as process to accommodate engine cubic inches, cylinder head design and expected flow. Duration; the purpose of duration is to provide cylinder scavenging during the exhaust stroke. Scavenging allows both the intake and exhaust valve to be open simultaneously for a short period of time. There is a twofold effect created, 1 the in rush of a new air/fuel mixture aides in evacuating the spent gases in the combustion stroke, 2 the hot gases that are evacuated take resident heat with them, a cooling process. Overlap is the technical term used to the amount and length of duration.

Next, we have ignition timing, when the spark is introduced and for how long determine the proper burning rate, called flame propagation. The burning gases inside the cylinders determine power output and they start burning after BDC and stop before top dead center. The cylinder pressure peak is reached at TDC when the heat is greatest; this is where the greatest heat lives and must be accommodated, so we exhaust it after using the power but the heat lives in the area surrounding the cylinder. The valves and pistons are spared usually, but the heads, and cylinder walls are not. The heat resides and grows in these areas and must be eliminated or the engine material will melt.

Now we move to the actual cooling process; the physics of the subject is covered by "Newtons Law of Cooling". I am not a thermodynamics expert and I doubt anybody reading this is, however the law covers things such as forced convection, heat transfer coefficient, relative temperatures and types of heat exchangers.

So, let's move to the basics we all understand of liquid cooling; Volume, flow and velocity.

Volume is a fairly easy concept to understand, how much does our cooling system contain in a liquid measure. If you were to operate an inboard powered boat, most of this discussion would be moot, there always plenty of coolant available and it pristine, never having been heated. But in our cars, we have a defined, limited amount room; dictated by space, engine design and engine arrangement. However, there is a relationship to volume and BTU generation which must be accommodated by the heat exchanger(radiator) The volume of liquid carrying the heat from the engine must be cooled sufficiently before return to the engine; to small of a radiator or an insufficient amount of water will not fully transfer the heat. So radiator size, efficiency and airflow of a differential temperature are necessary to do the job, part of Newton's law.

Flow and velocity are symbiotic in cooling systems. Flow is obviously a must and is determined by the size of the water pump which also is valued according to a SPWF, specific water flow. The capacity of the pump is usually more than would normally be needed by the engine so in addition to constrictions in the engine, plumbing and radiator. The throttle in the system is the thermostat; it is usually made of brass with a flapper valve that opens or closes according to the predetermined temperature setting. In todays vehicles the Auto companies, driven by emissions regulations, run the engines hot, usually about 200* F.

Perhaps it's time to review an "Old Wives Tale" on occasion some believe that removing the thermostat and the attending restriction to flow will reduce operating temperature. False…. The velocity of the flow is a specific design feature of how long the cooling medium stays in contact with the heated surface to allow heat transfer to occur. An analogy would be if you passed your hand over a gas flame on a stove, you would not be burned or conduct any of the flame, but if you held your hand over the flame, well the results would be obvious.

The flow and velocity within the engine block are the final determining factors relating to efficient engine cooling. The only unfortunate portion of this equation is our ability to accurately determine what the flow is in ALL the areas in the block. The current crop of engine blocks is either open deck or the more conventional closed deck. The premise of the open deck is that the block will be full of a large volume of water, unfortunately much of the water will be static and not flow. The flow is managed by the delivery to the head through dedicated passages, which then exits at some point and is returned to the radiator; the cycle is continuous as long as the engine is running.

In the solid deck, there is less area to actually observe the flow. As a for instance, in Siamese bores, almost the norm for large displacement engines, there is usually no flow between cylinders. The theory is because if cylinders don't fire adjacently no excess heat is developed. This premise is not true.

When Darton invented the MID product, we engaged in elaborate water flow test to measure the contact area of the water on the TOTAL exterior surface in order to predict what cooling efficiency we might expect. We intentionally engineered siamesse passages for flow. The intent of the design was always to add cylinder strength but most importantly provide exceptional cooling and flow where it counts the most, at the one third top of the sleeve where most of the combustion heat is generated and needs to be removed.

On the solid deck we have no idea what the interior water flow is, only engineering models; seems to work most of the time I guess, but in our studies where we have sectioned aluminum blocks reveal many places of annealing(softening) of the material, a sure sign that area has been overheated. One of the obvious solutions is to bleed water from external passages communicating with the water jackets or other known potential hot spots. And of course, we can't ignore the effect of oil flow on cooling, but sometimes this is an inverse result; if we run the oil hotter it doesn't always result in more efficient cooling in total.

Obviously, this is a complex subject so that is why this is called a primer.