

## Early Corvette Cooling

BEATIN' THE HEAT

BY JOHN HINCKLEY

**It's May again, the weather is starting to warm up, and it's the time of year when the forums start to fill up with posts about "overheating problems." If we understand how the C1/C2/C3 Corvette cooling systems are designed, how they work, and the solutions to common cooling problems, we can dispel some of the myths, hype, and misinformation out there and enjoy warm-weather cruising.**

Your engine creates a LOT of heat as the air/fuel mixture burns in the combustion chamber, but less than half of it performs useful work (pushing the pistons down). The rest of that heat is wasted, and goes directly through the block and head castings into the cooling system. Let's follow the coolant through the components and see how the system works, then we'll cover each of the components and discuss diagnoses and

real-world solutions to problems.

**THE COOLING SYSTEM:** Starting at the water pump, coolant enters from the radiator outlet and is pumped into both sides of the front of the block. It travels through the water jackets around the cylinder walls and absorbs heat from that area. It then moves upward through holes in the block deck into the cylinder heads, absorbs heat from the roof of

the combustion chamber and from the exhaust port walls, and then flows forward to the crossover passage at the front of the intake manifold.

As coolant exits the front of the heads and flows into the crossover passage from both sides, it encounters the thermostat. If the engine hasn't warmed up yet, the closed thermostat stops coolant flow until the coolant has absorbed enough heat to open the thermostat. If the engine has already warmed up and the coolant is hot, it flows through the calibrated opening in the thermostat and proceeds into the upper radiator hose.

The coolant, now at 180°-190°F, enters the radiator and flows through the tubes which have fins soldered or brazed to their outer surfaces. Air passing over the



1

**1** The extremely efficient Harrison stacked-plate aluminum radiator. This basic design was used from 1960-1972, and all versions are reproduced by DeWitts.



2

**2** A typical "look-alike" copper/brass replacement radiator; note the rounded/stamped end tanks. These have about 30% less cooling capacity than the original Harrison aluminum radiator.



3

**3** The Harrison aluminum expansion tank, with the inlet and overflow at the top, and the outlet at the bottom. Only fill it ½-full when cold or it may "puke" coolant out the overflow during hot-soak.

surface of the fins and outside of the tubes carries off the heat from the coolant that's transferred through the walls of the tubes. At the exit of the radiator, the coolant temperature is about 30 to 40 degrees lower than when it entered, and flows into the water pump inlet, ready for another trip through the engine.

The cooling system is a "closed system"—the coolant expands as it absorbs engine heat, and the radiator cap maintains pressure in the system (which raises the boiling point of the coolant). If system pressure exceeds the rating of the cap, an internal valve opens and vents pressure (and possibly some coolant) through the overflow hose until system pressure drops below the cap's rating.

There are three basics involved in the cooling system: the fluid (coolant) that circulates to carry heat from the engine to the radiator, the heat exchanger (radiator), whose job it is to transfer that heat from the coolant to the air, and the air flowing through the radiator core that picks up the heat and carries it off. The two most critical elements here are the heat transfer capability of the radiator and the volume of airflow through it—90 percent of cooling problems involve either one or both of them. Let's take a look at the individual components of the cooling system and see what they do (and what they don't do).

**COOLANT:** Your Corvette was designed to use a 50-50 mix of ethylene glycol-based coolant/antifreeze (the "green stuff"). The antifreeze component doesn't wear out over time, but the additive package (primarily anticorrosion elements) does—it gets weaker as it does its job. If it isn't renewed regularly,

scale and corrosion will begin to build up in the radiator tubes, which will drastically reduce the radiator's heat transfer efficiency. The buildup of scale and corrosion acts as an insulator inside the tubes, reducing the rate of heat transfer from the coolant to the air. It's a good idea to drain, flush, and replace your coolant mix every two or three years to maintain the effectiveness of the anticorrosion inhibitor package. The 50-50 mix of coolant also provides boil-over protection, as that mix, with a 15# radiator cap, raises the coolant's boiling point to 265 degrees to prevent "puking" coolant out of the overflow hose during "heat-soak" after shutdown when the water pump is no longer circulating coolant through the radiator.

Using just water as a coolant is a bad idea, even if you live in the deep south. You lose the anticorrosion protection as well as some of the boil-over protection. Cures for cooling problems don't come in bottles either; they may help the symptoms temporarily, but they don't address the real root causes—radiator heat transfer capability and airflow management. The red and purple "miracles in a bottle" are simply surfactants that minimize formation of steam bubbles at the hot casting surfaces contacted by the coolant, and are intended only for use with water, not with antifreeze coolant.

Since the OEMs no longer use the traditional green stuff and have switched to more modern coolants, the green stuff is getting harder to find. The modern Zerex GO-5 HOAT coolant, or equivalent, will work fine in our older Corvettes. Avoid using the "Dexcool" formulation—there are issues with that

formulation leaching the lead out of soldered joints, which can weaken our soldered heater cores and copper/brass radiators.

**RADIATOR:** There are two types in Corvettes: the stacked-plate aluminum Harrison design with a separate expansion tank, and the conventional copper/brass type with no expansion tank. The Harrison stacked-plate aluminum design is by far the most efficient, as it has the most fin-to-tube contact area, which is how the heat is transferred to the air. Copper/brass conventional radiators need larger cores, as they have less fin-to-tube contact area due to having narrower tubes, and they're heavier. Another key difference is that aluminum radiators can't be repaired, and they're expensive to replace; copper/brass radiators can be repaired or re-cored using the original side tanks, and they're less expensive to replace.

Your radiator's biggest enemy is internal corrosion. Internal scale formation and corrosion is caused by the reaction of dissimilar metals in the cooling system and "worn-out" anticorrosion inhibitors in the coolant. It causes both structural failure (leaks) and drastic reduction of heat transfer capability due to the "insulation" formed by the built-up deposits inside the tubes. Radiators don't age well and nobody ever expected them to last more than ten years. Without regular coolant changes, it doesn't take long for scale to build up and reduce their efficiency. Regular cooling system maintenance is the best recipe to keep your radiator working, but once scale and corrosion has built up, there isn't much you can do to remove it. Eventually, it's new radiator time.

A typical 10-year-old radiator that

## TECHNICAL EARLY CORVETTE COOLING



4 The stock Corvette water pump, designed and developed to meet the needs of the cooling system; you don't need a "race" water pump.



5 A conventional thermostat on the left, and a balanced-flow type on the right; the balanced-flow type is more accurately calibrated.



6 The radiator cap, which maintains system pressure, vents overflow, and admits air on cooldown. Most auto parts stores can verify its seal and pressure calibration.

hasn't seen regular coolant changes has lost anywhere from 20 to 40 percent of its heat transfer capability, although it may look good. Don't be fooled by a "flow test" at a radiator shop—all that tells you is that the radiator isn't plugged or severely restricted. It can't measure the radiator's heat transfer capability, which is what really counts. When the time finally comes to replace your radiator, don't be tempted to buy on price. Buy a quality radiator that at least matches the

cooling capability of the original.

**EXPANSION TANK:** Conventional copper/brass radiators with fill openings have side tanks that serve as reservoirs to accommodate coolant expansion. That's why the "Full Cold" mark is several inches below the filler neck—to allow for expansion of hot coolant. The Harrison stacked-plate aluminum radiator has no side tanks; it's all core, from end to end, so it needs an external reservoir to

provide a fill point and to accommodate coolant expansion. The companion Harrison aluminum tank has the cap/fill point, an inlet from the top of the radiator to provide a path to the tank for expanded coolant, and an overflow hose from the filler neck. The bottom of the tank has a fitting connected with a tee to the return hose from the heater core to the water pump inlet fitting, so the tank is connected to the coolant circulation system and functions as a reservoir. They



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7

7 Original lower radiator hoses had this coiled steel wire reinforcement to prevent collapse; modern hoses are made from better materials and generally don't need it.



8

8 The fan, clutch, radiator, and shroud are an engineered "system"; keep them as originally configured to maintain your Corvette's cooling airflow management.

are trouble-free unless the relatively thin aluminum has been attacked by corrosion (which is why they use a unique 307 or RC-26 filler cap with no plain steel exposed to the coolant).

Note that the expansion tank is stamped "Fill 1/2 When Cold" on the inboard end. If you fill it all the way or "top it off" when cold, there's no room for expansion of hot coolant, and coolant will puke out through the overflow hose until enough air space is created in the system to accommodate expansion.

**WATER PUMP:** The water pump just circulates the coolant. Its speed relative to the crankshaft and its impeller design were carefully arrived at by the engineers who developed it to move the correct volume of coolant at the proper velocity through the calibrated restriction of the thermostat to serve the needs of the cooling system under all operating conditions. Its shaft rides in sealed bearings and there hasn't been any need for "water pump lubricant" for decades. When the bearings deteriorate, you can feel both radial and axial slop in the shaft, and that will start to tear up the seals. Wear becomes obvious when you see coolant dripping from the "weep hole" in the bottom of the snout portion of the casting.

Stock water pumps work just fine. There's no need for "high-flow" or "race" water pumps, unless you like their appearance. NASCAR "race" pumps are uniquely designed so they won't cavitate at 9,000 rpm while moving coolant that has to absorb the heat at a constant wide-open throttle from an 800hp engine. You don't need that on the street, and "race" pump impellers are much less efficient at normal street operating rpm than the impeller in a stock factory pump. If your pump leaks, either have it rebuilt or replace it. Water pumps are hardly ever the cause of a cooling problem, unless

they're really ancient and the impeller blades have corroded away.

**THERMOSTAT:** This is probably the most misunderstood component in the cooling system. Thermostats have absolutely nothing to do with controlling maximum engine operating temperature. Period. What does it do? At cold start, it blocks the flow of coolant out of the engine until the trapped coolant reaches the thermostat's rated temperature, at which point it opens and permits coolant to begin circulating. This aids rapid warm-up, which reduces cylinder bore and piston ring wear by bringing the engine up to operating temperature relatively quickly. Once it's open, it modulates the flow of coolant through its calibrated restriction so coolant temperature never drops below its rated opening point, assuming the cooling system is efficient enough to cool the engine down to that level. During the winter, the thermostat modulates flow to ensure that the coolant stays at or above its rating point for optimal heater/defroster operation. In most cars, it's essentially wide open all the time, and only the heat transfer efficiency of the radiator, and the airflow through the radiator, determine the engine's maximum operating temperature.

If you have a 180-degree thermostat and your engine operates at 220 degrees, changing to a 160-degree thermostat won't change your operating temperature one bit. You need more radiator, more airflow, or both, to reduce operating temperature. If you have an extremely efficient cooling system with more heat rejection capability than your engine needs (runs at 180 degrees with a 180-degree thermostat), changing to a 160-degree thermostat may result in reducing your operating temperature to 160 degrees, but this is rare except in cold weather. Furthermore, 160 degrees is too



**9** The thermo-modulated Corvette fan clutch – key to idle and low-speed airflow, and far more efficient than any “flex-fan”.

cold; OEM testing has proven that the rate of cylinder bore and piston ring wear at 160 degrees is double the wear rate at 180 degrees, and a coolant temperature of 160 degrees won't let the oil in the pan get hot enough to boil off condensed moisture and blow-by contaminants, which then remain in suspension and accelerate the formation of acidic sludge. In the 1930s, 160-degree thermostats were specified for the old alcohol-based antifreezes, which would boil off and evaporate at 185 degrees. There's no other reason for them.

Balanced-Flow thermostats like Robertshaw makes (also sold by Mr. Gasket with their name on them) are calibrated much more accurately than conventional parts-store thermostats, and will maintain a constant coolant temperature with little or no detectable cycling. Although most thermostats are very reliable, they fail closed, which can cause a lot of engine damage in a big hurry if you don't spot the sudden temperature rise.

**RADIATOR CAP:** The radiator cap simply seals the cooling system; it has a two-way pressure-vacuum valve to maintain a given pressure in the system (typically 15 psi) after the system warms up and the coolant expands (which vents through the overflow hose nipple in the filler neck when that pressure is exceeded). The vacuum side of the valve allows air (or coolant, if you have a '73 or later with a coolant recovery bottle) to flow back into the radiator as a vacuum is created when the system cools down.

The radiator cap, like the thermostat, has absolutely nothing to do with maximum operating temperature. Period. If you have a cooling problem and replace your 15# cap with a 22# cap, your operating temperature won't change one bit. What will change is the temperature

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**10** The gauge you hate to look at if your cooling system isn't up to snuff; verify its accuracy with an I.R. gun so you know what it's really telling you.



**11** The original AC temp sending unit on the left, and a Wells TU-5 replacement on the right; calibration of replacements is always suspect — check the gauge reading against an I.R. gun "shot" of the upper radiator hose.

at which the coolant will boil and puke out through the overflow hose. There's another coolant lesson here—a 50-50 antifreeze/water mix at 15 psi boils at 265 degrees, while a water-only coolant at 15 psi boils at about 250 degrees. The 50-50 mix provides another 15 degrees of boil-over protection. If you're not sure your cap is sealing properly or venting at the proper pressure, most auto parts stores have a cap tester to verify its operation.

**LOWER RADIATOR HOSE:** The upper radiator hose is always under pressure, but the lower hose lives at the intake (suction) side of the water pump, and under some operating conditions (acceleration, sustained high rpm) is under a partial vacuum. That's why the original lower radiator hoses had an internal coiled steel wire reinforcement to keep the hose from collapsing and restricting flow back into the water pump. Over time, this coil corrodes and, sometimes, disappears completely. It won't be obvious visually with the engine idling, as pump inlet suction is minimal at idle. Squeeze the hose with your hand, if it collapses, the reinforcement is history and the hose should be replaced. This is frequently a contributor to abnormally elevated highway-speed operating temperature. Current OEM and reproduction lower hoses are made from improved materials, and generally don't have (or need) the internal wire reinforcement.

**FAN SHROUD AND SEALS:** Managing airflow through and across the entire surface of the radiator core is the fan shroud's job, especially at idle and at low speed in traffic, in combination with the fan. The shroud must be the correct part to fit the radiator configuration, and the gaps between the two should be sealed with foam strips or rubber flaps so the fan

forces all incoming airflow through the radiator core, not around it. The radiator itself should also be sealed to the radiator support for the same reason, and most original A/C installations included these seals. Many configurations also have a rubber flap or foam seal between the top of the radiator support and the hood inner panel. This closes that gap when the hood is closed, and does two things. It closes off another path for outside airflow to go over (instead of through) the radiator, and it stops the phenomenon where hot under-hood air is drawn over the top of the radiator support and gets re-circulated through the radiator again. You only want cooler, outside air flowing through the radiator, not hotter under-hood air.

**FANS AND CLUTCHES:** The fan's job is to pull as much air as possible through the radiator core at idle and in low-speed traffic, and to present minimum airflow restriction to ram-air through the radiator at highway speeds. Factory fans are very carefully designed for maximum efficiency and minimum noise (which is why the blade positions are staggered), and are designed to provide maximum efficiency when the tips of the blades are half-in/half-out of the rear edge of the shroud, with approximately 1/2" clearance from the blade tips to the shroud. The radiator/shroud/fan combination on each Corvette is the result of a lot of tedious hot-weather development work by the engineers who designed it, and the original system is tough to improve on, assuming that all the components of the cooling system are functioning properly. These cars didn't overheat under normal conditions when they were new, and they shouldn't now, if the system is still composed of the correctly-configured components.

The job of the thermo-modulated fan clutch is to move as much air as possible



12

**12** The Raytek MT-4 infra-red temperature gun – the best cooling system diagnostic tool you can buy for verifying coolant and component temperatures.

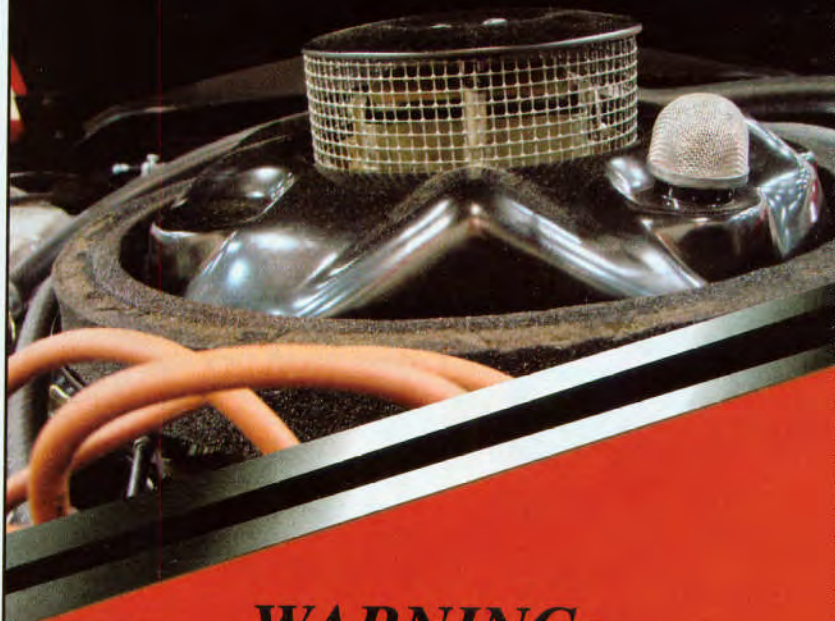
at high coolant temperatures, and to relax at high rpm and at normal operating temperatures for reduced noise levels when maximum cooling isn't required. The temperature-sensitive bi-metallic element on the front of the clutch (a coil on Eaton clutches, a plate on Schwitzer clutches) reacts to the temperature of the air exiting the radiator, and actuates an internal valve that controls the flow of the fluid that determines the degree of lockup.

Most of them essentially disengage over 3,500 rpm, and in the C2/C3 days they were calibrated to tighten up and engage fully at about 190 degrees, and at around 210 degrees in later C3s. Remember that when you buy a current Eaton or Schwitzer replacement – most have the later calibration, and won't be quite as effective as the original clutch was when it was new. Several people in the hobby can rebuild your original fan clutch to the original calibration if that's important to you.

What about "flex-fans"? GM never used them. Flex-fans aren't as efficient at moving air as the factory fans, they present more of a ram airflow restriction at highway speeds than a factory fan when the flexible blades flatten out, and some of them have a bad reputation for shedding blades due to metal fatigue at the blade-to-hub attachments. The factory fan and clutch is a much better all-around system than a flex-fan. They wouldn't have spent the money for an expensive thermo-modulated fan clutch if they thought a cheap flex-fan would do the job just as well.

What about aftermarket electric fans? Unless you get a really well-engineered dual-fan setup with a full shroud that covers the entire face of the radiator core (with pressure-relief flaps for added ram airflow at highway speed), they're a poor substitute for the factory fan setup, they

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13

**13** For optimum idle and low-speed cooling, your vacuum advance unit must be calibrated to your idle vacuum level, and connected to a full manifold vacuum source, not to "ported vacuum."



14

**14** Basic tune-up tools are essential to set dwell, set and "map" your timing and advance curve, and adjust idle mixture.

don't move anywhere near the volume of air the fan/clutch system does, and they place a major electrical current draw (30-40 amps) on the system at the worst time, when the alternator is at its lowest speed. The typical single round aftermarket fans that attach directly to the radiator core only draw air through the portion of the core that's enclosed within the diameter of the fan blades. The other 50 percent of the face of the radiator core gets no airflow at all. The factory shroud ensures that air is drawn through every square inch of the core, all the way to the corners.

**C3 FRONT AIR DAMS:** The primary difference between the C1/C2 and C3 cooling systems is the source of outside air for the radiator. C1/C2s have the traditional direct airflow through the grille into the radiator, and C3s were the first generation of bottom-breathers, where most of the airflow into the radiator is deflected from below through holes in the lower front bumper/fascia area with the help of plastic air dam panels. These fragile pieces are frequently on the losing end of contact with speed bumps, driveway entries and parking lot blocks. This doesn't affect cooling much at idle and in low-speed traffic, but loss of those panels will have a major effect on highway-speed cooling due to lack of adequate airflow through the radiator. Keep an eye on them and ensure they're in place, and are securely attached so they can do their job at freeway speeds.

### TEMPERATURE GAUGE AND SENDING UNIT:

Corvettes use an electric temperature gauge, driven by a sending unit in the intake manifold or cylinder head. The sending unit sensing element is directly exposed to the coolant leaving the engine, and contains a thermistor (temperature-sensitive

variable resistor). Twelve volts is supplied to the gauge, which is then connected through a wire to the terminal on the sending unit. At the sending unit, the 12 volts go through the thermistor element to ground through the threads on the sending unit. The varying resistance of the thermistor with coolant temperature causes deflection of the gauge needle to indicate the coolant temperature.

When the sender and gauge were made, they were calibrated to a standard value so they worked together to provide a reasonably accurate indication – they are not laboratory-standard precision instruments. Age, dust, dirt and moisture affect the gauge movement and its electrical components, and the sending units also deteriorate with the years. Replacement sending units are not accurately calibrated to match the gauge, and almost all of them cause the gauge to read 20-40 degrees too high, although the Wells TU-5 (\$5.00 at AutoZone) has proven to be much closer to original calibration than any of the other replacements, and several hobby vendors now have replacement senders that are advertised as being properly calibrated.

Before you dive into solving a cooling problem, make sure you really have one. Step #1 is to either buy an infra-red temperature gun (about \$60) or go to a shop that has one, and shoot the upper radiator hose just above the thermostat housing with the engine at full operating temperature and compare that reading with what the gauge shows at the same time so you know what the gauge is really telling you.

**IGNITION TIMING:** What in the world does ignition timing have to do with cooling problems? Plenty. I've gone into the detail of the murky and little-understood world of ignition timing and vacuum advance in previous articles,





15

15 Setting correct initial timing and ensuring that your vacuum advance unit is fully-deployed at idle are essential for maximum idle and low-speed cooling performance.

but suffice to say that inadequate spark advance at idle is a major contributor to idle and low-speed cooling problems, especially on engines equipped with A.I.R. (Air Injection Reactor) systems and ported vacuum for the distributor vacuum advance diaphragm. These engines (and some without A.I.R. as well) had intentionally-retarded spark at idle, which significantly increased exhaust gas temperatures, most of which was then transferred through the exhaust port walls into the coolant in the cylinder heads.

Without going into gory detail, the cure for this is to connect the distributor vacuum advance to full manifold vacuum and re-adjust idle speed and mixture screws to reduce exhaust gas temperature and stabilize the idle with the vacuum advance fully-deployed. You'll also need an advance can calibrated so it's fully-deployed with at least 2" Hg. less vacuum than your engine develops at idle (about \$10 at NAPA).

**THE BOTTOM LINE:** The coolant carries the engine's heat to the radiator, which rejects it to the air passing through it; if the radiator can't reject the heat to the air passing through it as fast as the coolant delivers it, you've got a cooling problem. 90% of the time, the problem is either the radiator or airflow management. Check each component, isolate the root cause, and repair or replace it. If you add more motor (which makes more heat), add more radiator. Most low-speed cooling problems are related to airflow management and/or ignition timing, and most highway-speed cooling problems are related to the radiator or restricted air or coolant flow. The solutions come in boxes, not bottles. Keep your Corvette cooling system in top shape, and you can watch the scenery while you're cruising instead of the temperature gauge. ■

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