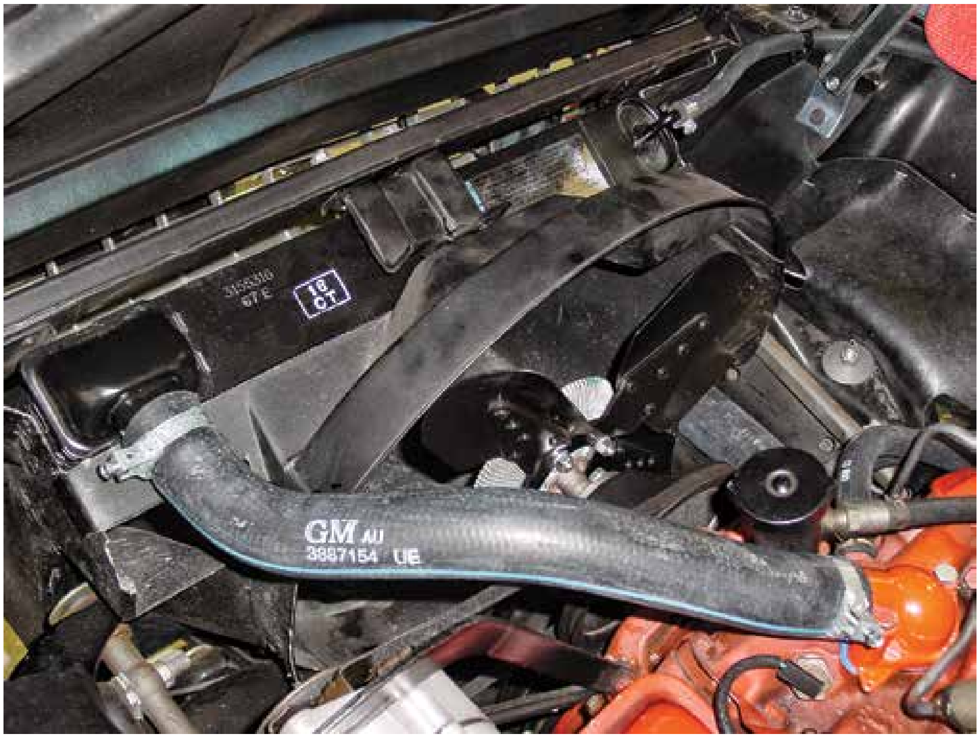
BEATIN' THE HEAT

by John Hinckley

Each year as the weather starts to warm up, the forums start to fill 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.



An overview of the complete cooling system on Corvettes

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 how each of the components work, and discuss diagnosis 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 and absorbs heat from the roof of the combustion chamber and from the exhaust port walls and 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. The tubes have fins soldered or brazed to their outer surfaces, and air passing over the 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 30-40 degrees lower than when it entered and flows into the water pump inlet, ready for another trip through the engine.

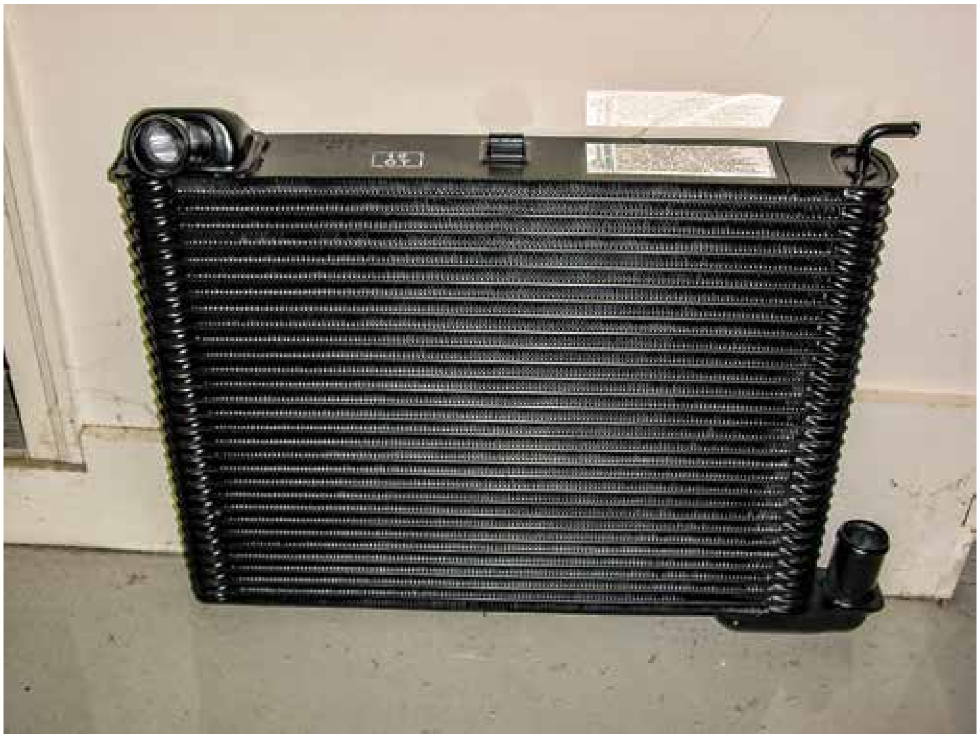
The cooling system is a closed system; the coolant expands as it absorbs engine heat, and the radiator cap maintains pressure in the system (which raises the boiling point of the coolant). If system pressure exceeds the rating of the cap, an internal valve opens and vents pressure (and possibly some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

Cooling Basics

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, and 90% 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/anti-freeze (the green stuff). The anti-freeze component doesn't wear out over time, but the additive package (primarily anti-corrosion elements) does. It gets weaker as it does its job, and 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 coolant mix every two or three years to maintain the effectiveness of the anti-corrosion 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 the overflow hose during heat-soak after shutdown when the water pump is no longer circulating coolant through the radiator.



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

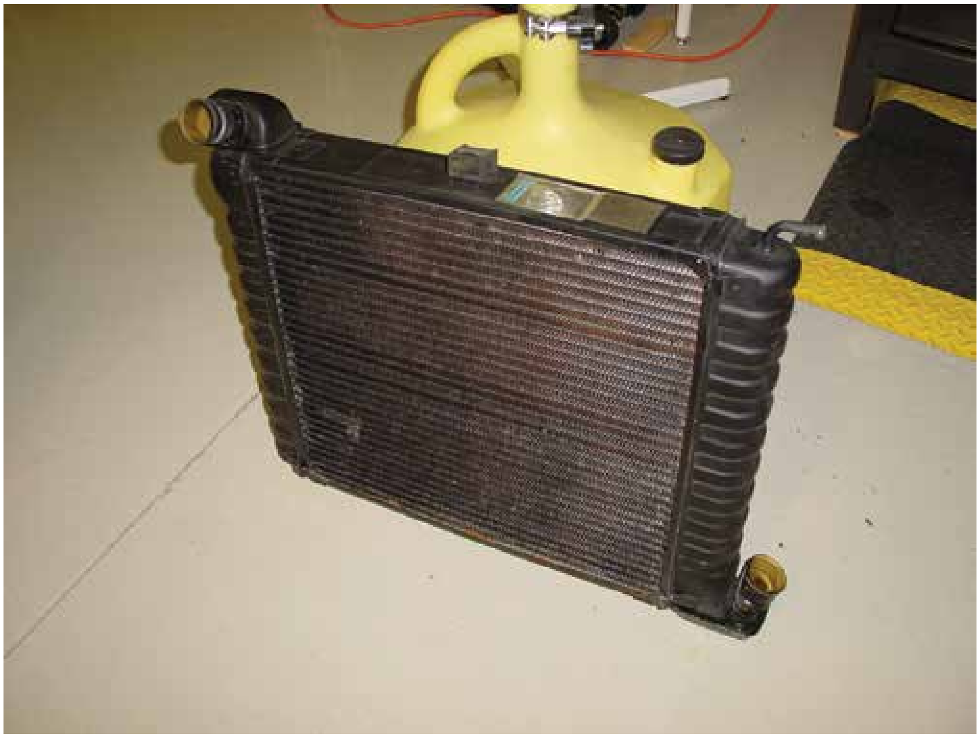
Using just water as a coolant is a bad idea, even if you live in the Deep South; you lose the anti-corrosion protection as well as some of the boil-over protection. Cures for cooling problems don't come in bottles either; they may help the symptoms temporarily, but they don't address the real root causes–radiator 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 anti-freeze 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 radiators 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.

A radiator's biggest enemy is internal corrosion. Internal scale formation and corrosion caused by the reaction of dissimilar metals in the cooling system and by worn-out anti-corrosion inhibitors in the coolant 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; nobody ever expected them to last more than ten years to begin with, and 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 a 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.

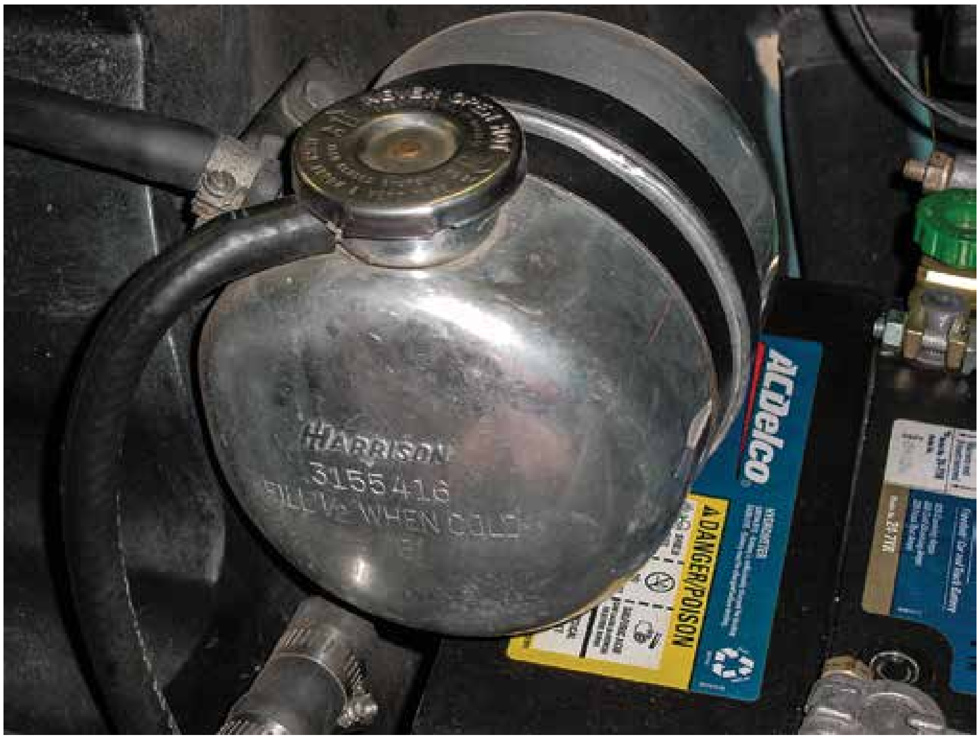


A typical look-alike copper/brass replacement radiator; note the rounded/stamped end tanks. These have about 30% less cooling capacity than the original Harrison aluminum radiator.

A typical 10-year-old radiator that hasn't seen regular coolant changes has lost anywhere from 20% to 40% 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 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, an overflow hose from the filler neck, and 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. These 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).

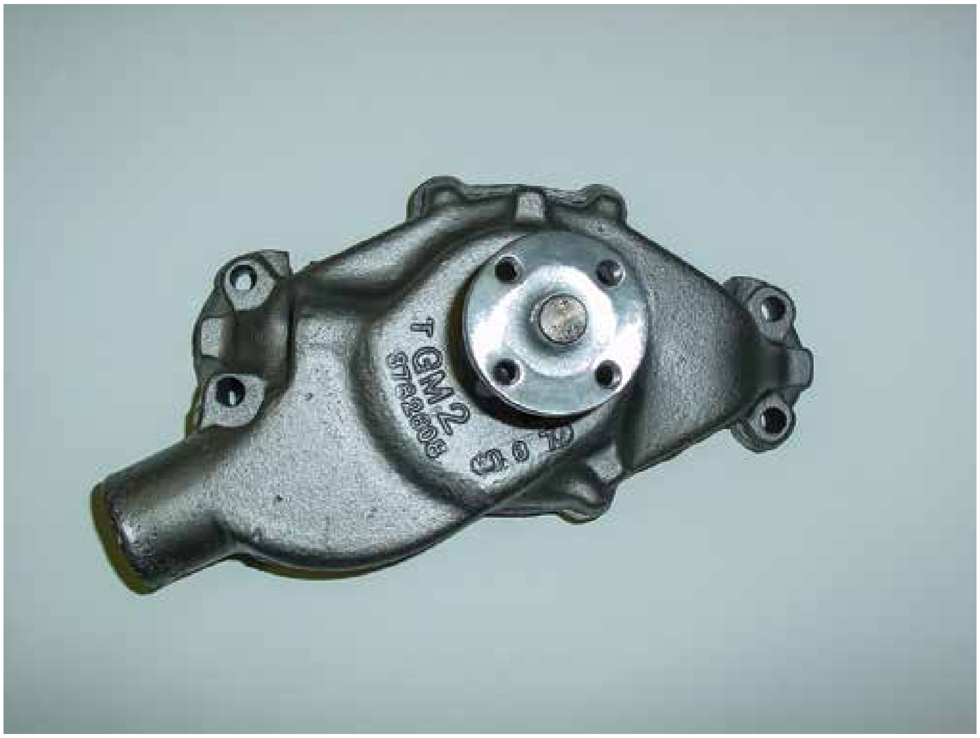


The Harrison aluminum expansion tank with the inlet and overflow at the top and the outlet at the bottom. Only fill half full when cold or it may puke coolant out the overflow during hot-soak.

Note that the expansion tank is stamped **Fill ½ 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.

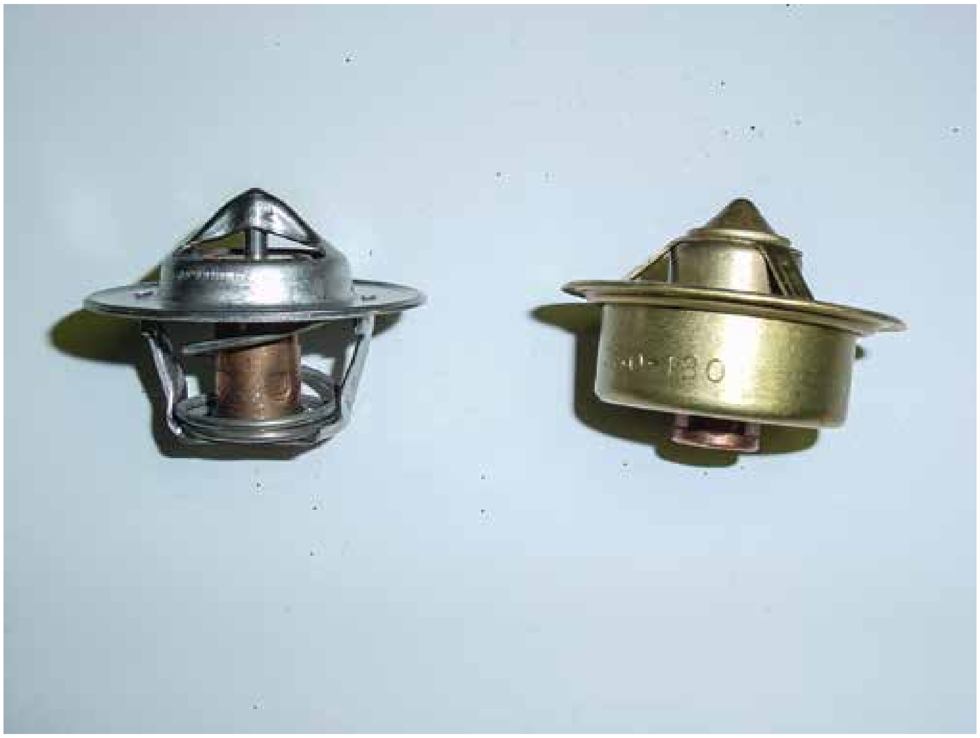
Water Pump

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; 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. That becomes obvious when you see coolant dripping from the weep hole in the bottom of the snout portion of the casting.



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

Stock water pumps work just fine; there's no need for high-flow or race 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 from constant wide-open throttle from an 800-hp 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 the 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.

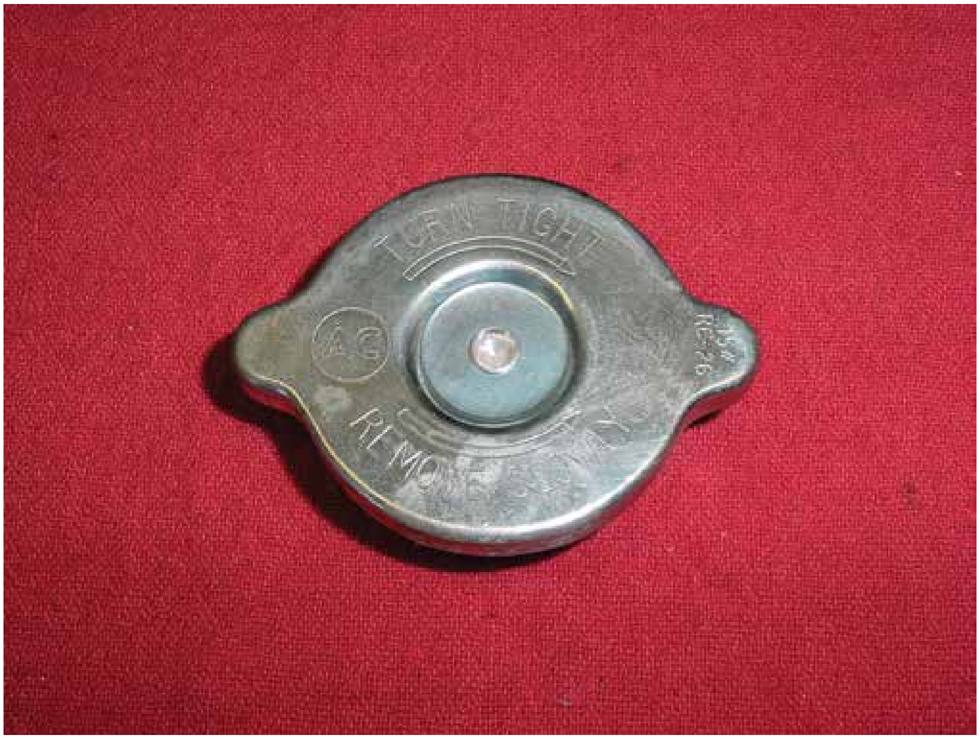


A conventional thermostat on the left and a balanced-flow type on the right; the balanced-flow type is more accurately calibrated.

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** one 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.

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.



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

If you have a 180° thermostat and the engine operates at 220°, changing to a 160° thermostat won't change the 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 the engine needs (runs at 180° with a 180° thermostat), changing to a 160° thermostat may result in reducing the operating temperature to 160°, but this is rare except in cold weather. Furthermore, 160° is too cold; OEM testing has proven that the rate of cylinder bore and piston ring wear at 160° is **double** the wear rate at 180°. And a coolant temperature of 160° 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. 160° thermostats were specified in the 1930s for the old alcohol-based anti-freezes, which would boil off and evaporate at 185°; there's no other reason for them.

Radiator Cap

The radiator cap simply seals the cooling system, and 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 it is a 1973 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 a 15# cap with a 22# cap, the operating temperature won't change one bit. What **will** change is the temperature at which the coolant will boil (and puke out through the overflow hose), as the coolant's boiling point increases with increased system pressure. There's another coolant lesson here–a 50-50 antifreeze/water mix at 15 psi boils at 265°, while a water-only coolant at 15 psi boils at about 250°. The 50-50 mix provides another 15 degrees of boilover protection.

If you're not sure the 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.

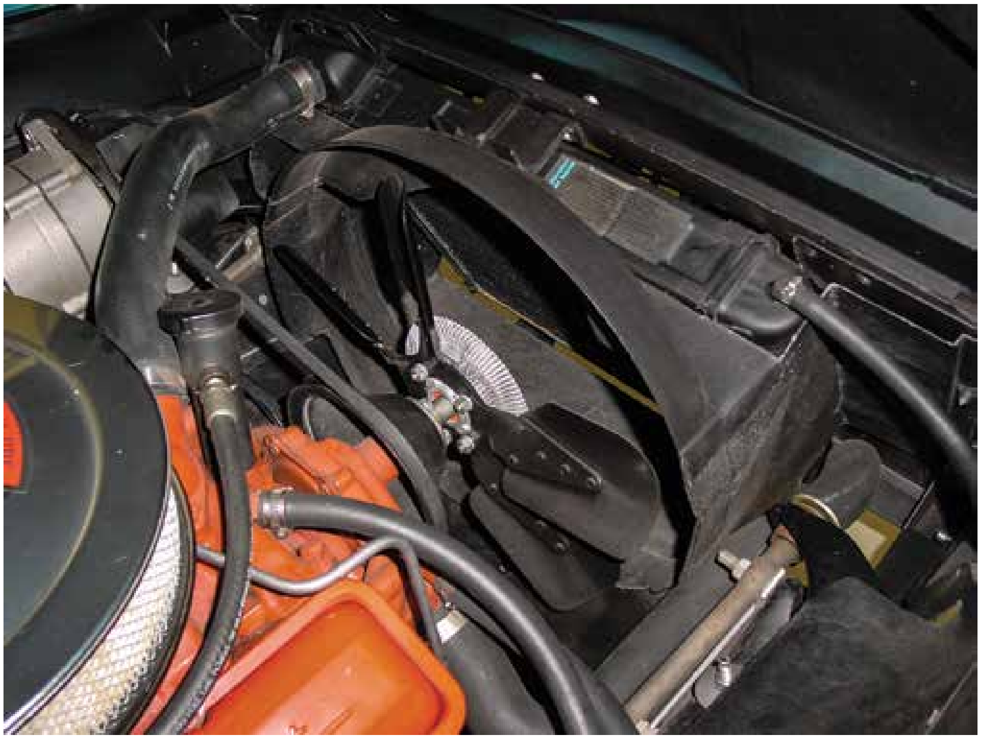

Original lower radiator hoses had this coiled steel wire reinforcement to prevent collapse. Modern hoses are made from better materials and generally don't need it.

Fan Shroud and Seals

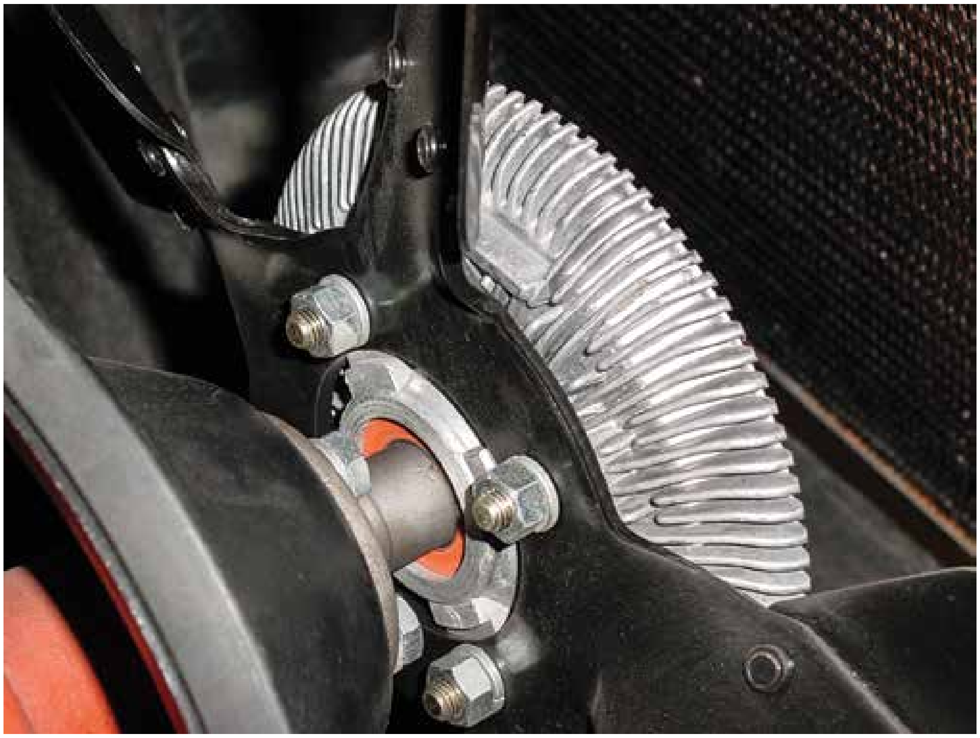
Managing airflow through and across the entire surface of the radiator core is the fan shroud's job, especially at idle and at low speed in traffic (in combination with the fan). The shroud must be the correct part to fit the radiator configuration, and the gaps between the two should be sealed with 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 eliminates 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 underhood air is drawn over the top of the radiator support and gets recirculated through the radiator again. You only want cooler outside air flowing through the radiator, not hotter underhood 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 fan, clutch, radiator, and shroud are an engineered system; keep them as originally configured to maintain your Corvette's cooling airflow management.

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 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 one-half-inch 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. The original system is tough to improve on, assuming that all the components of the cooling system are functioning properly and haven't been butchered, altered, removed, substituted, or backyard-catalog-engineered to improve them. 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 thermo-modulated Corvette fan clutch is key to idle and low-speed airflow and far more efficient than any flex-fan.

The job of the thermo-modulated fan clutch is to move as much air as possible at high coolant temperatures and to relax at high rpm and 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.

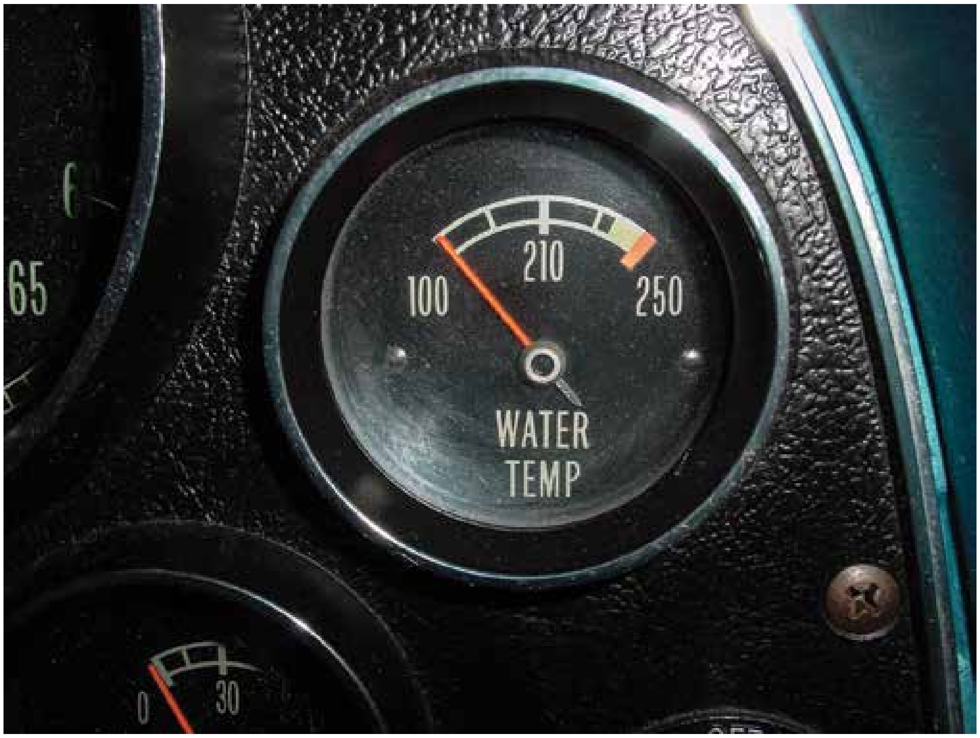
Most of them essentially disengage over 3500 rpm, and in the C2/early C3 days they were calibrated to tighten up and engage fully at about 190 degrees and at around 210 degrees in later C3s. Remember that when you buy a current Eaton or Schwitzer replacement, most have the later calibration and won't be quite as effective as the original clutch when it was new. Several people in the hobby can rebuild an 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; GM 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 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% of the face of the radiator core gets no airflow at all, but 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. 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 ram airflow through the radiator. Keep an eye on them and ensure they're in place and securely attached so they can do their job at freeway speeds.

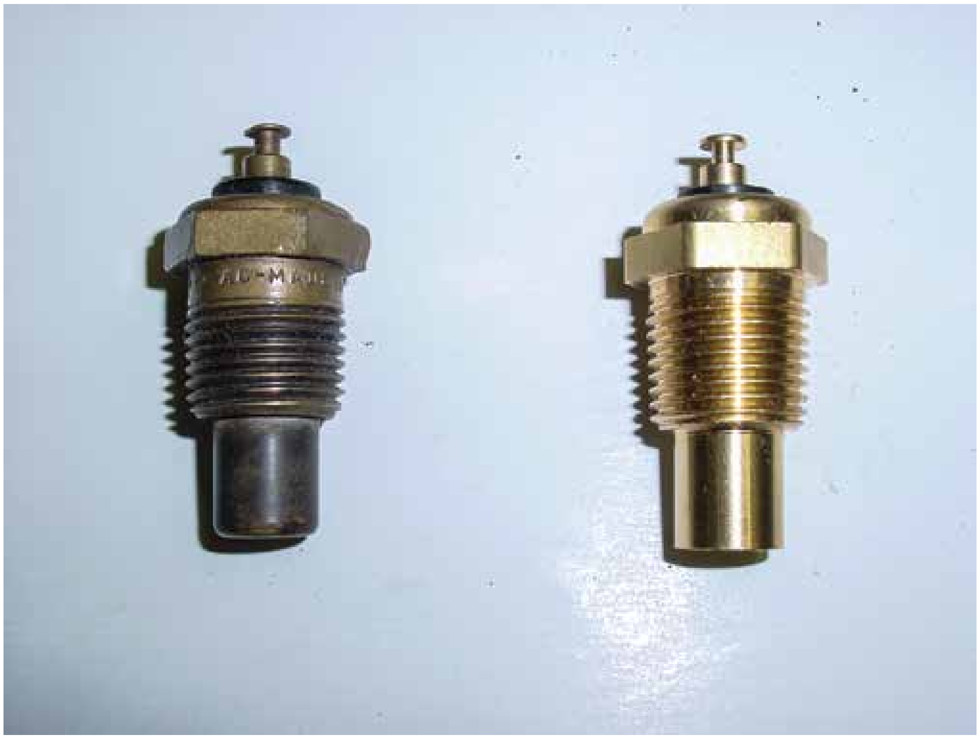


The gauge you hate to look at if your cooling system isn't up to snuff; verify its accuracy with an I.R. gun so you know what it's really telling you.

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). 12 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, but 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. Several hobby vendors now have replacement senders that are advertised as being properly calibrated.


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.

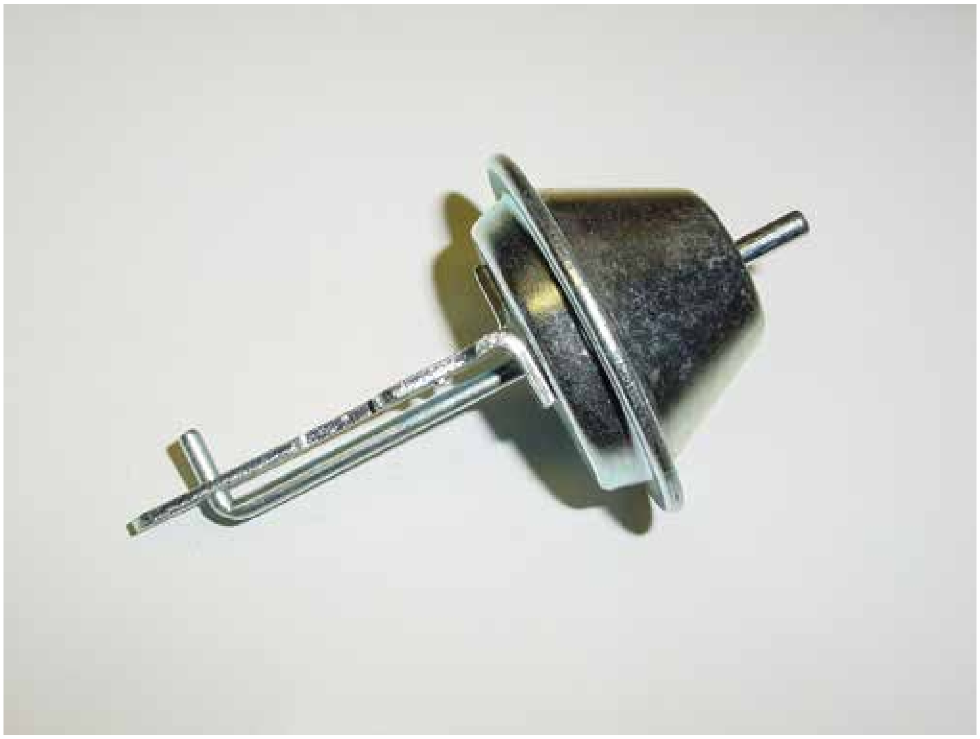
Before you dive into solving a cooling problem, make sure you really have one. **Step #1** is to either buy an infrared temperature gun (about $60) or go to a shop that has one and shoot the upper radiator hose just above the thermostat housing with the engine at full operating temperature. Compare that 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, 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 temperature, most of which was then transferred through the exhaust port walls into the coolant in the cylinder heads.

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

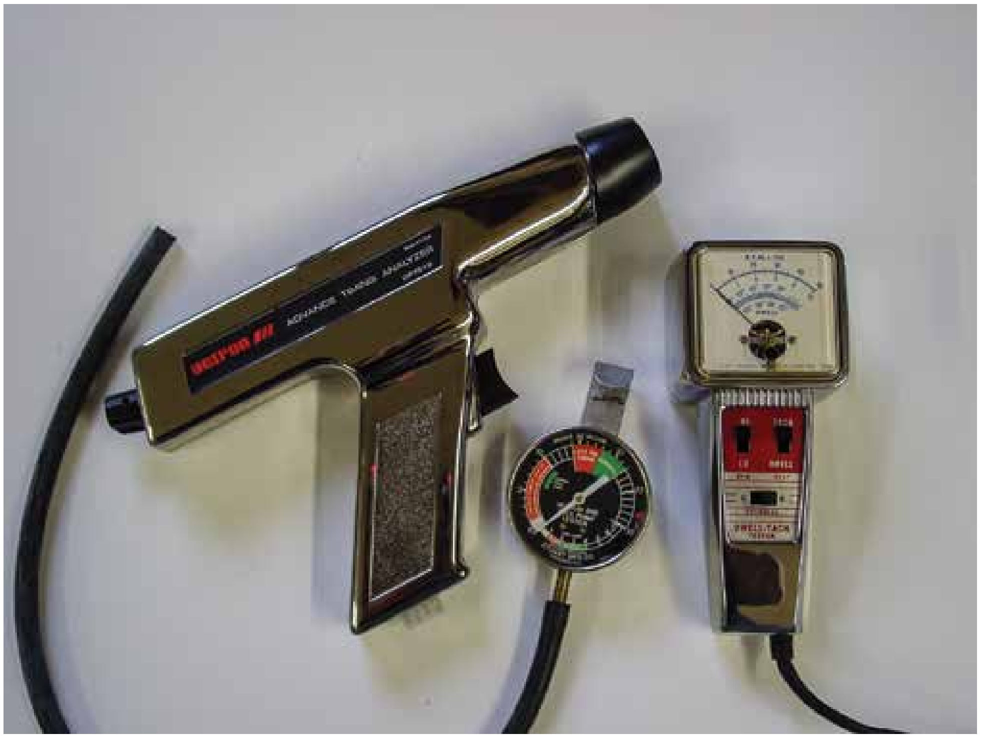
Without going into gory detail, the cure for this is to connect the distributor vacuum advance to full manifold vacuum and re-adjust idle speed and mixture screws to reduce exhaust gas temperature and stabilize the idle with the vacuum advance fully-deployed. You'll also need an advance can calibrated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

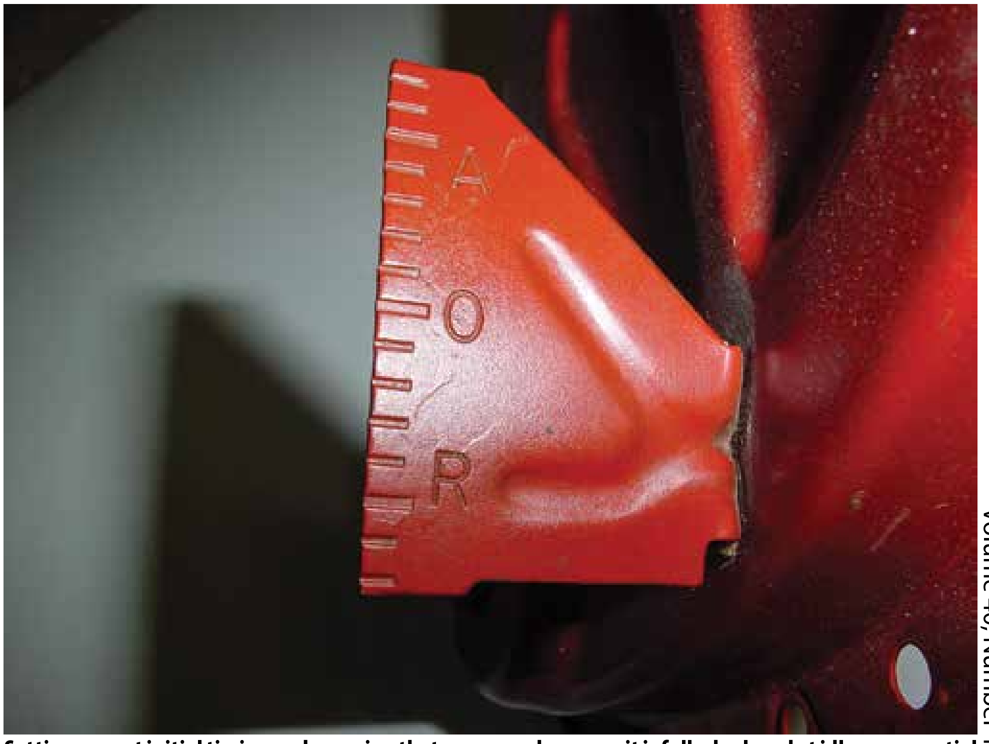

For optimum idle and low-speed cooling, a vacuum-advance unit must be calibrated to idle vacuum level and connected to a full manifold vacuum source, not to ported vacuum.

Summary

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. Ninety percent 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 cruising instead of the temperature gauge.


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



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

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