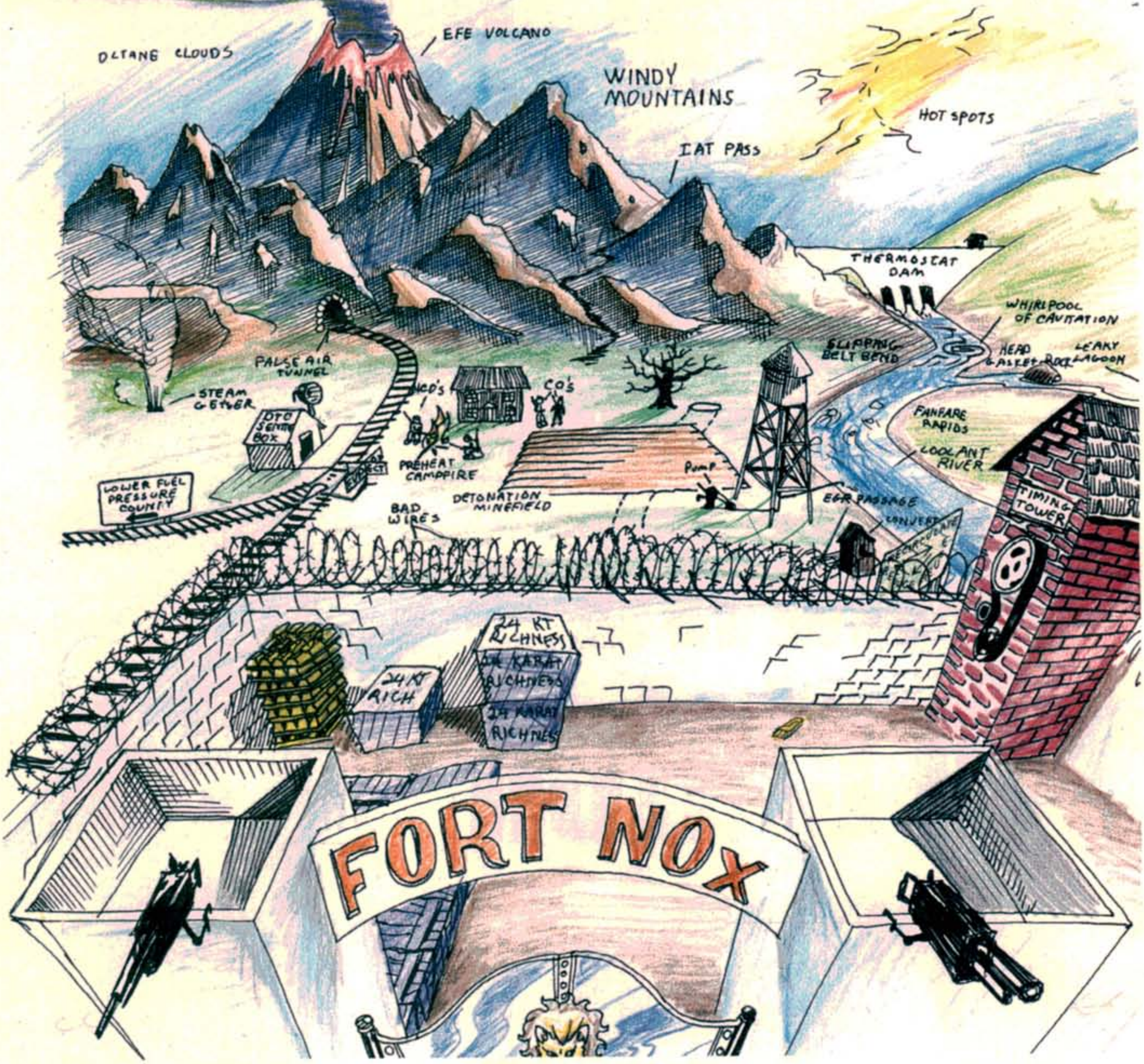



Illustration by Ken Johnson

$NO_x$ control has become a very hot topic as many many areas of the country opt for I/M 240-style enhanced emissions testing. Our illustration emphasizes the strategic value of Fort $NO_x$ and may help you understand why it has become such an important target for emissions and driveability specialists. In the pages that follow, we'll take you through the underlying theory of $NO_x$ formation and control.

We'll also back up the theory with a recent driveability problem that was recirculated from shop to shop before being resolved. Look for two more $NO_x$ related articles in the coming months as well. By the time we've finished, you'll be able to find the gold in "Fort $NO_x$" while you learn to disarm the booby traps and minefields that surround the area.

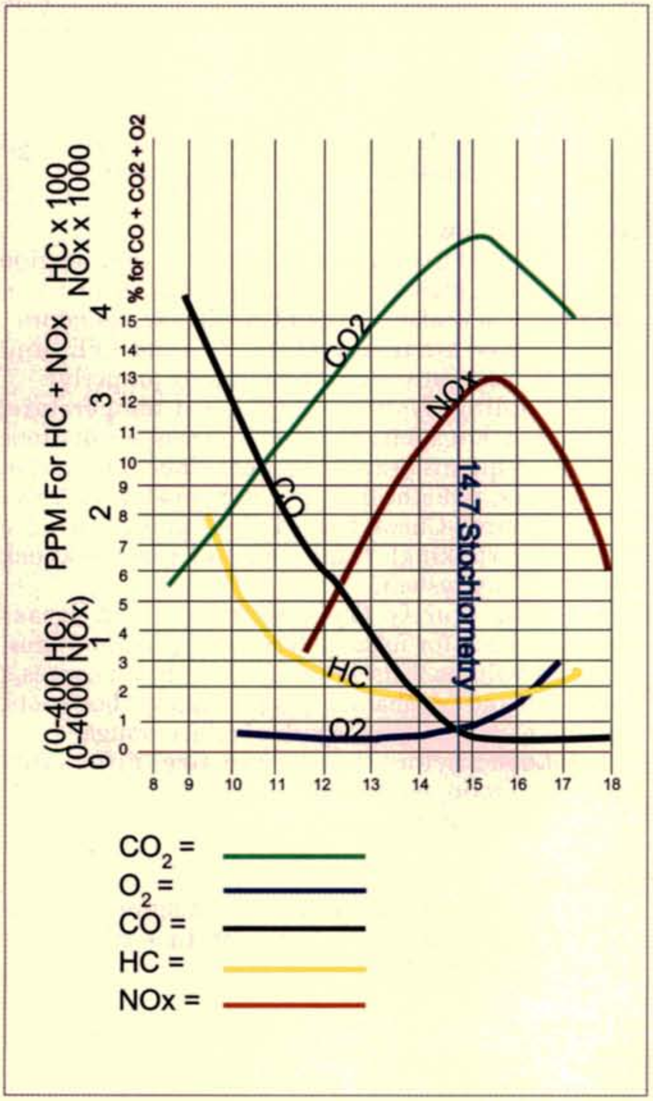
## What Is $NO_x$?

Many of us have been working with four gas analysis for several years and are already familiar with the relationships between HC, $CO_2$, CO, and $O_2$. But not that many of us have had any significant experience in working with $NO_x$. So let's start with an explanation of what $NO_x$ is, and how it is formed.

Nitrogen (the N in $NO_x$) comprises approximately 78 percent of our atmosphere. Nitrogen will not burn readily below about 1375 degrees C (2500 degrees F). It will burn above that temperature. When it does, it combines with oxygen (the O in $NO_x$) to form either NO or $NO_2$. Either of these two compounds, nitric oxide (NO) and nitrogen dioxide

($NO_2$), are present in automotive exhaust and are collectively referred to as $NO_x$. The "x" in $NO_x$ is used to represent an unknown value because we don't know if we're reading NO, $NO_2$, or maybe even a little $NO_3$ on our five-gas analyzer.

Any way you look at it, $NO_x$ is bad stuff. $NO_x$ is a class of toxic gasses that is strongly involved in the formation of ground-level ozone and photochemical smog. $NO_x$ is acidic, and when it is combined with water in the atmosphere, $NO_x$ also contributes to the formation of acid rain.




**This chart shows the relationship between each of the principal combustion byproducts in a normal spark ignition engine across a range of air-fuel ratios. As you can see, $NO_x$ production is lowest under rich (high CO) conditions and greatest under lean (high $O_2$) conditions. It is moderately high at the "ideal" 14.7:1 stoichiometric ratio and rises rapidly as the mixture becomes leaner.**

## Where Does It Come From?

As you can see in the five-gas chart in the previous column, CO, HC, and $O_2$ are at or near their lowest levels when the air/fuel ratio is at 14.7 to 1. $CO_2$ is at or near its highest level. This is the magical "stoichiometric level" we've been talking about for so many years. An engine running at this stoichiometric level produces the best compromise between fuel efficiency, performance, and emissions—except for $NO_x$. An engine running at the stoichiometric ratio will produce quite a bit of $NO_x$. At cruise, a reading of 1700 to 2500 PPM by volume upstream of the converter is normal with no $NO_x$ control. We know that's not good enough.

Things only get worse if we try to lean the mixture further. Lean mixtures burn hotter than rich mixtures, so it follows that $NO_x$ formation will increase as the mixture gets leaner (our five-gas chart backs this up). As combustion chamber temperature climbs over 2500 degrees F, $NO_x$ production will also increase. If all we were looking for was lower $NO_x$ emissions. the easiest strategy would be to feed the engine a rich mixture. Unfortunately, a "24-karat" rich mixture is tactically inferior when it comes to the control of the other exhaust pollutants.

## $NO_x$ Conspirators

We know that a lean fuel mixture will raise combustion temperatures, but there are several other related factors that can also affect combustion chamber temperatures and $NO_x$ formation:

- The temperature of the incoming air charge (the IAT Pass in the Windy Mountains in our lead page illustration) can raise or lower combustion chamber temperatures significantly. If the engine is forced to breath hot, preheated air, it's already well on its way to higher combustion chamber temperatures. Higher combustion chamber temperatures mean more $NO_x$ formation.
- Higher than normal compression reduces combustion chamber volume and creates extra heat in the combustion chamber. Excessive compression may be the result of carbon buildup in the combustion chamber (possibly caused by a previous rich-running condition).
- An over-advanced ignition timing system (the Timing Tower in our illustration) causes abnormal combustion (ping or detonation) and will also raise combustion temperatures and increase $NO_x$ formation.
- Cooling system inefficiencies (our Coolant River), whether they are caused by scale or rust in the block, an obstructed radiator, a bad thermostat, a faulty water pump or fan, a loose belt, or a leaking hose, can all cause higher than normal combustion chamber temperatures and higher $NO_x$ production.

• Low octane fuel can cause $NO_x$ formation. Low octane fuel burns faster than high octane fuel. In a high-compression engine, low octane fuel may explode rather than burning evenly in a controlled burn. The exploding fuel increases combustion chamber heat and encourages the formation of $NO_x$.

Take a closer look at our "battlefield area map" of Fort $NO_x$ to see some of the other pitfalls that can send $NO_x$ levels soaring.

## On The Defensive

It's not hard to see why our first line of defense for Fort $NO_x$ must be strict control over combustion chamber temperatures. It's a good thing that most cars provide us with a secret weapon: the EGR system. The EGR system recirculates exhaust gasses into the combustion chamber by adding a small amount of exhaust to the incoming air/fuel charge. Introducing exhaust into the combustion chamber has the same effect as throwing ashes onto a fire: Since the recirculated exhaust gasses have already been burned once, they can't be burned again. The exhaust gasses absorb some of the heat in the combustion chamber and keep the fire from becoming too hot.

An EGR system keeps the combustion chamber temperature down and lowers $NO_x$ formation. If the EGR system is functioning properly, the 1700-2500 PPM readings that we saw at the stoichiometric level should drop to between 500 and 1000 PPM during cruise conditions. Tailpipe readings should stay that low, except for transient spikes on acceleration and during deceleration. The EGR system is represented in our drawing by an underground tunnel which allows us to safely bypass the "Detonation Minefield."

## EGR Testing

Even if you don't have access to a portable $NO_x$ analyzer, testing EGR operation is relatively straightforward on most cars:

• Tee into the EGR vacuum control line, then install a vacuum gauge near the EGR valve. Make sure the hose is long enough to allow you to position the gauge where it will be visible during a road test.

• Take the car for a road test. Look for a reading of 4 to 10 in Hg on the vacuum gauge under cruise conditions. This indicates that the emission control system is at least trying to open the EGR valve.

• Back in the shop, remove your vacuum gauge before fully opening the EGR valve at 2000 RPM. This should cause the engine to run quite rough. If the EGR valve is working right, the engine will have a hard time swallowing all those exhaust gasses.

• Don't rely on the old "stall-at-idle" test. Even an EGR system whose passages are clogged to pin-head size may still be capable of stalling the vehicle at idle. A severely clogged EGR system won't be capable of passing the volume of exhaust gasses that are needed to really cool those blazing fires under higher RPM and load conditions.

## $NO_x$ Checklist

All right, that's enough theory for now. Let's look at a recent problem on the $NO_x$ front. We've created a checklist that can be used to track down the cause of $NO_x$ failures. It starts with a visual inspection and a quick check for diagnostic trouble codes flashed by the malfunction indicator lamp (MIL). We've checked the boxes that apply to our vehicle.

**Preliminary Checks**

____ Fluid levels (especially oil and coolant).

____ Possible DTCs at MIL lamp: EVP, low $O_2S$ volts, lean exhaust, ECT or IAT out of range.

**$NO_x$ Prevention**

_X_ EGR: stalls engine if added at idle, engine runs rough if EGR added at 2000 RPM, check vacuum supply at cruise. Check EGR valve temperature.

____ Intake air temperature. Are the EFE and intake air preheat systems functioning properly?

____ Cooling System: Check head temperature, circulation, hot spots, plugged passages, air pockets, antifreeze quantity and concentration, thermostat, belts, hoses, radiator flow, cooling fan and controls.

____ Timing: Check base timing, timing advance (check for sticking), timing control system, knock sensor, TCSA system.

____ EGO: verify $O_2$ sensor function (cross counts), check for false air/vacuum leaks, fuel pressure and volume tests, other lean condition causes.

____ Engine Mechanical: valve timing, hot spots, excessive compression, spark plug heat range.

____ Load Factors: Proper tire size, differential final drive ratio, payload exceeded?

____ Fuel: Correct octane level?

**Treatment**

____ Check catalytic converter reduction bed efficiency, measure exernal temperature difference before and after catalytic converter.

**Symptoms:**

____ Ping

____ Dieseling

____ Lean exhaust

____ Backfires through exhaust

____ I/M 240 failure

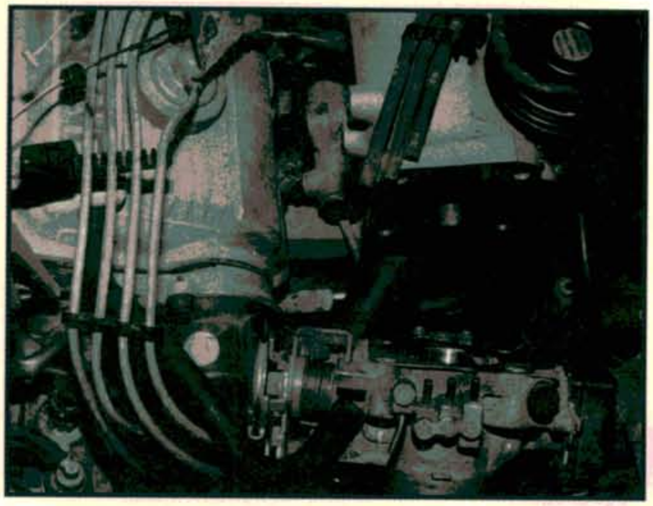
____ Low EGR temperature

_X_ Stalling, rough idle, high HC, low $CO_2$, possibly high $O_2$ and CO, high EGR temperature

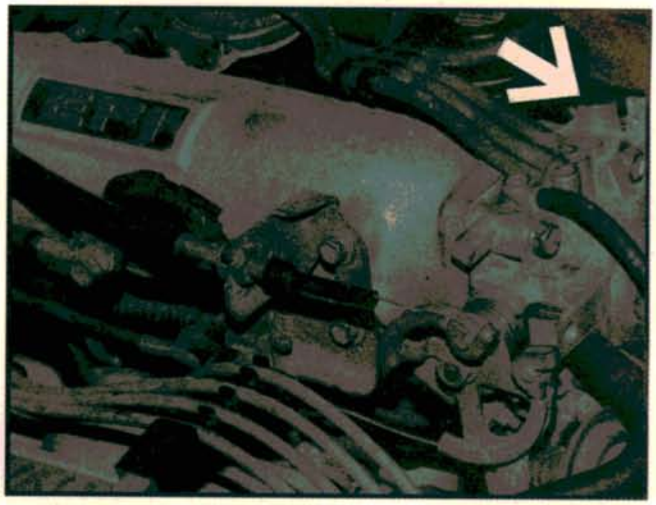
—By Sam Bell

Our first vehicle (a 1990 Celica with 2.2 liter 5-S FE motor and automatic transmission) came to us because it was stalling intermittently and had an occasional miss. After 44,000 miles of mostly trouble-free driving, it was finally time to start thinking about vehicle maintenance. A new set of plugs to replace the originals seemed like a good place to start. The number 4 plug had a slightly glazed look in its eye, but wasn't bad enough to indicate any serious internal engine problems.

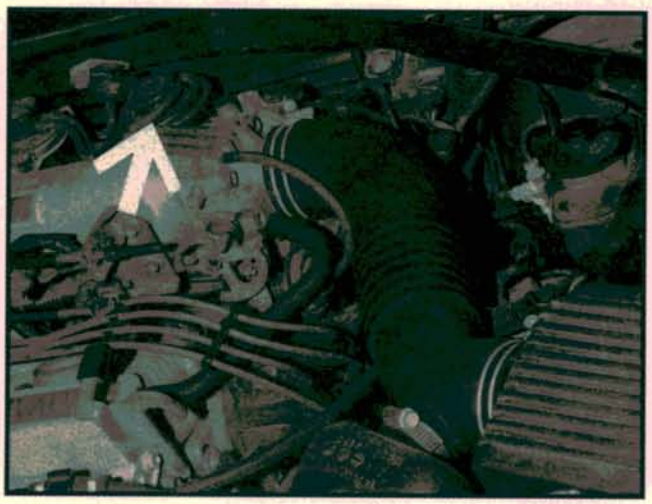
One of our favorite diagnostic tools is a plastic squirt gun filled with a mild solution of baking soda and water. After a few warm-up shots to sharpen our aim (apprentices make excellent targets), a well-placed squirt revealed the cause of the occasional miss in number 4 that had affected the condition of the spark plug. The spark plug wire was arcing at the distributor cap tower. A test drive confirmed that the new cap and wire assembly had eliminated the miss, at least for the time being.



When the intermittent stalling returned a week later, the customer's husband decided to save us all some time and grief by having the corner gas station raise the idle speed. Unfortunately, this was accomplished by adjusting the throttle stop screw, not the air bypass screw. When we made the proper idle speed adjustment at the air bypass screw, the throttle plate decided it was time for it to stick. Oh well, the throttle body needed cleaning anyway. Once again, the stalling problem had disappeared.

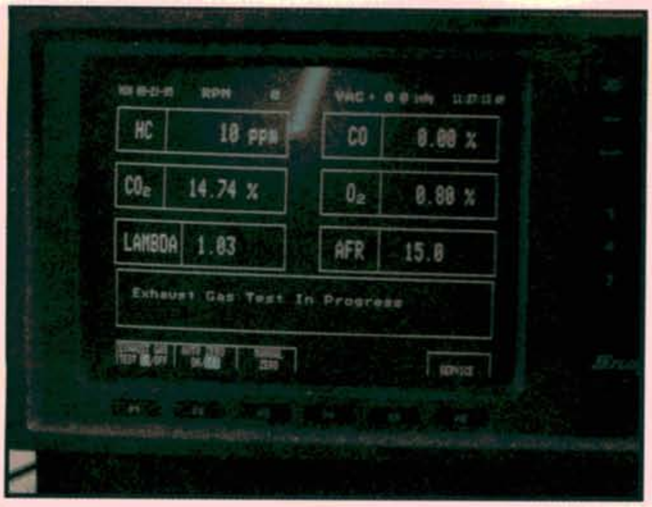


Another week passed before the customer showed up at our door in the middle of a hectic Friday afternoon (without an appointment). She complained that the Celica occasionally ran very rough on deceleration and at idle, but she could keep the engine from stalling if she kept her foot pressed lightly on the gas. Under the circumstances, raising the idle speed by turning the air bypass screw was the best we could do until we could devote more time to a thorough diagnosis.



The car returned on Monday morning. By then, the vacuum hose to the EGR valve had been disconnected and plugged by a well-intentioned soul at yet another service station. This hadn't helped, as the stalling persisted. We plugged in our gas analyzer and scope (along with an IV of fresh coffee). Before we could get out the camera, HC ranged as high as 4417 PPM, $CO_2$ as low as 12.14 percent, CO hovered near 2.84 percent, and $O_2$ climbed as high as 2.01 percent. Something was very, very wrong.

The temperature at the EGR valve was 293.9 degrees F! Even though the EGR vacuum hose had been disconnected and plugged, the EGR was still feeding a full dose of exhaust into the intake manifold at idle. We attached a piece of clean vacuum hose to the EGR valve, then gently blew into the hose. This produced a slight popping noise from the EGR diaphragm and the stalling problem promptly disappeared. The gummed-up throttle valve housing was starting to make more sense.




The EGR valve was sticking open intermittently. Blowing into the diaphragm port was enough to reseat the valve, but it would stick open again soon. We special ordered a new EGR valve from the dealer. A new part number hinted at a possible redesign. With the new EGR installed, HC was down to 10 PPM, $CO_2$ was up to 14.74 percent, CO read zero, and $O_2$ was at 0.80 percent. Meanwhile, EGR valve temperature was down to 143 degrees F, and the stalling was permanently vanquished.


The stalling problem was finally fixed, but we later learned that the car had been sold several months after its build date, and was still covered by the 5/50 emissions warranty. According to our local Toyota dealer, in order to comply with the terms of the warranty (and get a refund for the special order part), we would have to reinstall the original EGR valve. The dealer then confirmed our diagnosis and reinstalled our special-ordered EGR valve. We held up our end in the name of customer goodwill!