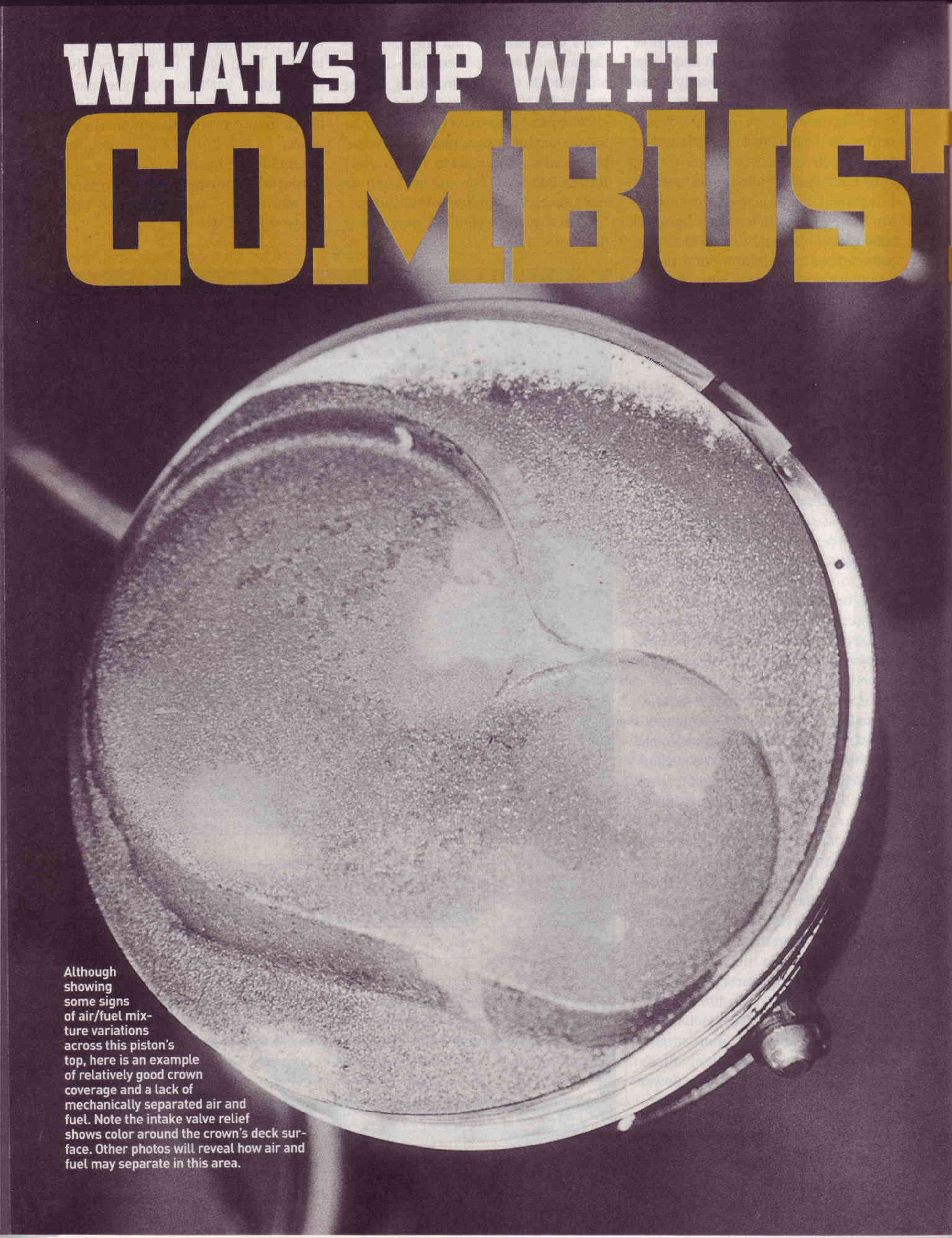
WHAT'S UP WITH COMBUST



Although showing some signs of air/fuel mixture variations across this piston's top, here is an example of relatively good crown coverage and a lack of mechanically separated air and fuel. Note the intake valve relief shows color around the crown's deck surface. Other photos will reveal how air and fuel may separate in this area.

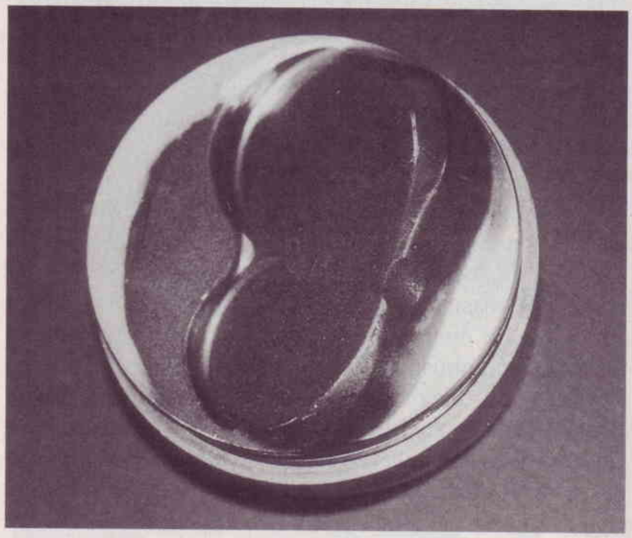
BY READING COMBUSTION SURFACES, YOU CAN LEARN MUCH ABOUT AN ENGINE'S PERFORMANCE . . . OR LACK THEREOF

TION PATTERNS?

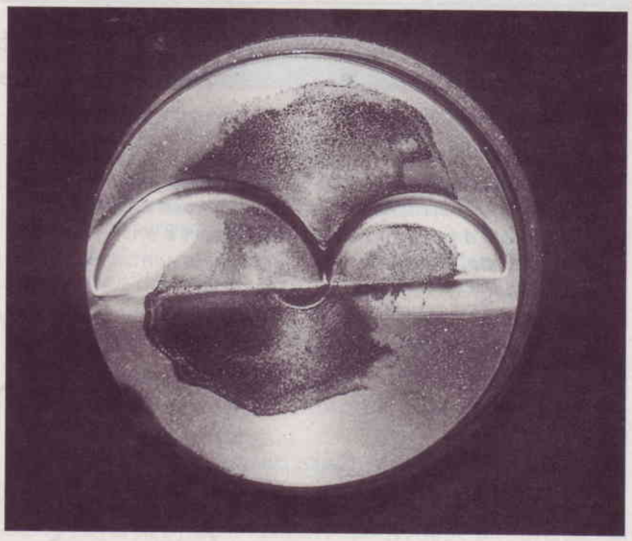
TEXT AND PHOTOS BY JIM MCFARLAND

It's likely you've looked at the combustion patterns left on piston tops and cylinder head chambers. Here's a "Saturday Nighter's" guide to understanding what you see and how these patterns can be related to steps for increasing power and parts life. Study the photos because they're the keys to finding hidden or lost engine performance.

Simply stated, we'd like air/fuel mixtures in an engine's combustion space to be uniform throughout, both prior to and during the "burn." If this were possible, the combustion process would move at a relatively uniform rate from beginning to end while avoiding detonation and optimizing power. But it's not. There are numerous and complicating factors that tend to prevent this ideal situation. However, by working to produce uniformity of air/fuel mixtures, chances are we'll boost combustion efficiency and gain power. The objective of so-called "mixture motion" (swirl, tumble, and so on) is to improve the homogeneity of fuel and air before and during combustion. The goal of this story is to provide some insight about what post-combustion "footprints" in the combustion space can reveal.



While the quench area (typically clean in higher compression engines) and crown near the spark plug are acceptably absent of color, note areas in the valve pockets where air and fuel have separated. This tends to cause overly rich conditions further in the burn area as noted across the piston dome.



Here you can see a more advanced case of air/fuel separation around the valve pockets and an amount of fuel "wash" across the plug side of the crown. Both heat and working cylinder pressure are being lost under these conditions. A disproportionate amount of fuel is usually required in an attempt to compensate for the loss in power, although this practice is largely a compromise that doesn't correct the problem.

CONDITIONS THAT RELATE TO POOR COMBUSTION EFFICIENCY

Let's say you have an engine that requires an excessive amount of ignition spark timing to run correctly. That covers numerous causes, but consider the following as it relates to combustion efficiency. If the combustion space is contaminated with residual exhaust gas, chances are additional timing is required to extend the burn time with the intention of building as much chamber heat as possible. All else being equal, heat is power. Exhaust gas contamination of fresh air/fuel charges reduces heat, and a racing engine with built-in "EGR" isn't going to fulfill its power potential.

Suppose you've discovered an inordinate amount of fuel is required to optimize power. The possibility exists that excessive mechanical separation of air and fuel is the cause, requiring additional fuel to compensate for unburned and separated fuel passing directly out of the exhaust ports. Such cases often require additional spark timing, too—both conditions are undesirable. Remember, the later you can initiate spark, the less "negative" torque

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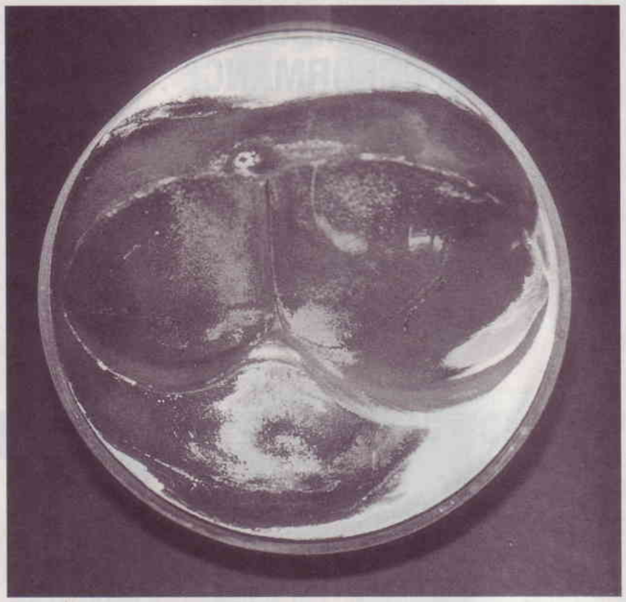
will be produced on the crankshaft. Even though increased spark can improve power, it's at the expense of work being done against the crank's normal direction of rotation. Poor mixture quality, including air/fuel separation, can lead to excessive spark timing requirements.

Improper matching of piston crowns and combustion chambers can also lead to mechanical separation of air and fuel. Unless good levels of mixing (homogeneity) are achieved, portions of induced mixtures will be disrupted (separated from the air) and reduce net power. Increased mechanical compression ratio achieved by allowing incorrectly shaped piston crowns to invade combustion chambers is a common cause for such problems. What you may gain by increasing the mechanical compression ratio can be partially lost by reduced mixture quality and decreased combustion efficiency.

If there's a rule of thumb embedded in this discussion, it points to the need for staying focused on the combustion space as you look for ways to make power or the reason a given engine package isn't living up to expectations. This area may become a window to an engine's ability to efficiently convert fuel and air into heat or power. Developing the skill to read combustion patterns is time well spent, especially if you intend to assemble parts packages that make good power.

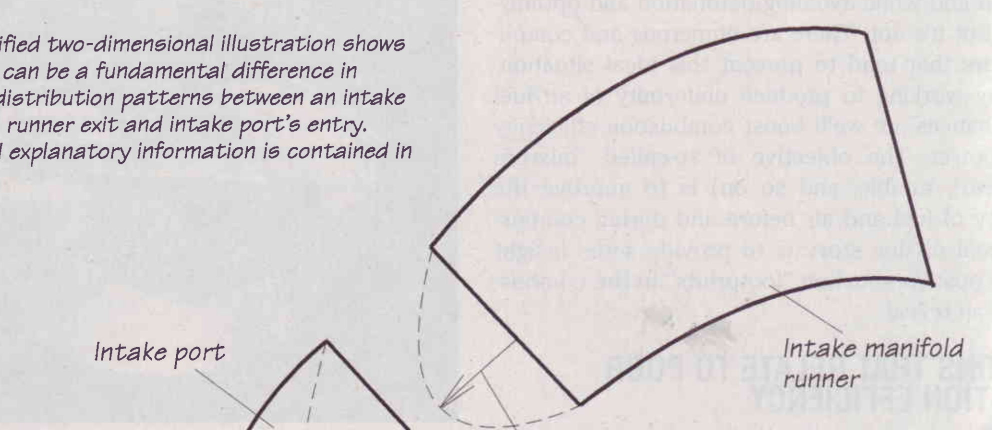


In this photo, primary mixture motion was counterclockwise. The pattern indicates separation of air and fuel in the intake pocket and rich conditions against the combustion chamber's backside wall on both the intake and exhaust sides. Note how rich the burn becomes at about "3 o'clock" and how it turns leaner as it progresses onto the crown's deck. Not bad, but another case of mixture variation throughout the combustion space.

Simplified Illustration of Pressure Distribution Relationships in an Inlet Flow Path

{Side-view of typical intake port and manifold runner}

This simplified two-dimensional illustration shows how there can be a fundamental difference in pressure distribution patterns between an intake manifold's runner exit and intake port's entry. Additional explanatory information is contained in the story.



Pressure distribution patterns can be determined by the use of airflow bench velocity probes or as evaluated in PC-based software packages of the type offered by Performance Trends' "Port Flow Analysis 3.0" {www.performancetrends.com}.

NOTE: Visualize the effects of placing a "dog-leg" in a flow duct and how this can affect overall flow characteristics, compared to a duct not containing such a change in flow direction. This is analogous to mis-matching pressure distribution patters in an inlet flow path...and the possibility of disrupted combustion.

CLEAN AREAS IN THE COMBUSTION SPACE

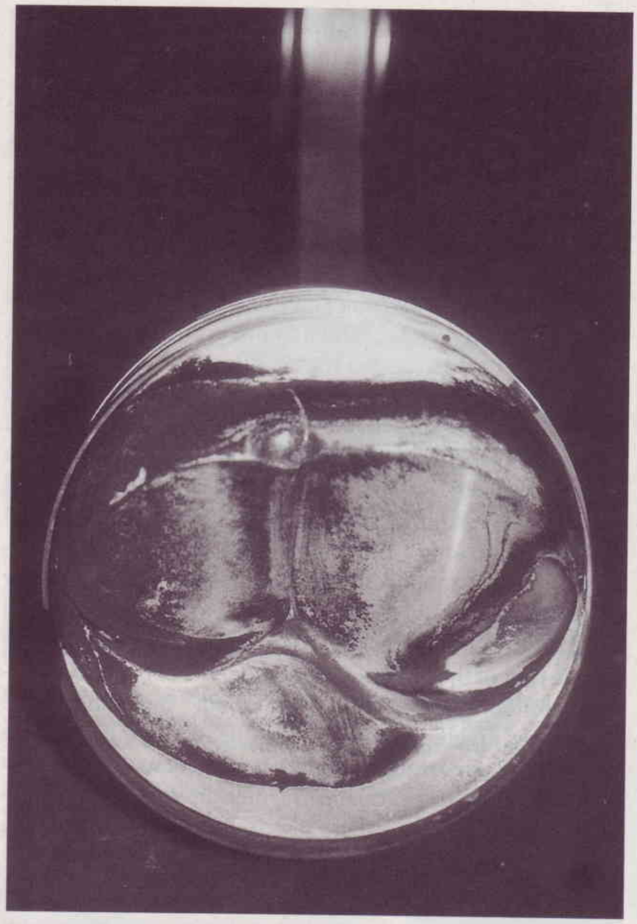
Are these acceptable? Not necessarily. Areas not exhibiting combustion residue frequently suggest fuel "wash" or the possibility of separated air and fuel passing over and causing the clean surface. For example, with its intake valve removed, look down an intake port toward the combustion chamber.

A line-of-sight path often indicates the path of fuel flow, which is not always the same path as air. The relative incompressibility of fuel (compared to air) and the greater-than-air level of kinetic energy it develops moving in excess of 300 feet/second during a typical intake cycle (around peak torque and above) can lead to air/fuel separation during changes in flow path direction. At higher rpm, flow rate increases accordingly. Therefore, as you peer into the port, the back side of the combustion chamber may exhibit a clean area of fuel wash. Such areas are candidates for the so-called "dimpling" process, a method in which air conditioning is used to improve fuel conditioning.

In a similar fashion, clean areas on piston crowns can be further indications of separated air and fuel. That's the worst case. In the best case, these conditions suggest abrupt changes in air/fuel ratios caused by interruptions in the movement of homogenized air and fuel moving through the combustion space. (By examining the accompanying photos, you'll see visual examples of descriptions being provided in the text.) Ideally, the smaller the combustion chamber and the flatter the piston crown, the higher the probability of reducing mechanical separation of air and fuel as mixtures pass through the combustion space, at least as far as piston-crown intrusion is concerned. What follows is an opportunity to increase flame rate, thereby reducing initial spark timing requirements and minimizing negative torque on the crank. Combustion processes, disrupted by wide ranges in air/fuel ratio caused from poor mixture quality, are at the heart of optimizing engine power. Remember, the combustion spaces can be a window to increasing engine output. Don't read 'em and weep. Read 'em and do something about what you see.

Does the color of combustion residue mean anything? It can. The type of fuel being used has a measure of influence. Alcohol tends to burn cleaner and leave lighter-colored residue, compared to gasoline. In either case, you'd like to avoid a wide spread in color, light to dark. Darker areas suggest the combustion of rich air/fuel mixtures while lighter ones point to lean ratios. Flame rate also slows as mixtures become increasingly fuel rich, again suggesting the need for earlier spark timing (to be avoided where possible).

If you spot areas much darker than other locations, particularly on piston crowns, it's reasonable to assume excessive fuel may have puddled and been lost before combustion was complete. This is evidence of rich, slow-burning mixtures. In such cases, look for very light-colored areas nearby. These may be indications of very lean mixture conditions and suggests detonation or near-detonation conditions. If you suspect this problem exists, even short of



Here you can see the evidence of a fairly wide range of a/f ratios in the combustion space. Note mixture richness along the back side of the dome (around the spark plug area) and a worse condition as the burn progresses to the exhaust side. This photo suggests excessively rich mixtures trailing around the piston's perimeter, resulting in an inefficient burn and lost power.

mechanical damage to piston rings or ring lands, inspect the rod/crank bearings for further evidence. An engine can run for a period of time in threshold detonation, lose power, and not damage piston assemblies, which can be detected by reading piston-crown combustion patterns and inspecting "hammered" bearings.

Especially in engines using flat or near-flat piston crowns, you can expect most of these areas to be pretty much covered by combustion residue, hopefully in a shade of gray without significant variation in color contrast. Such engines can have either low mechanical compression ratio or have relatively small combustion chamber volumes and higher compression. In either case, if the pistons are notched for valve clearance, watch for clean crown surface areas immediately past sharp edges accompanying the notches. To help prevent mechanical separation of air and fuel in these areas, a gentle blending of the edges tends to help. Increased burn efficiency and power often replace what you may lose in compression ratio.

Can conditions upstream of the combustion space affect the burn? Certainly. In particular, the distribution of pressure between an intake manifold's runner exits and cylinder head intake ports can be especially influential. To improve an understanding of how this works, take a moment to study the included illustration showing a two-dimensional relationship between a runner's exit flow pattern and an intake port's inlet flow pattern. You will see two different pressure distribution patterns in the illustration. Because of these differences, there can be an exchange of energy at the junction between manifold and head, causing a disturbance in the incoming air. While not always detrimental to mixture quality, it's possible this condition can cause downstream mixture motion, which is disruptive to an efficient burn. The goal is to match the profiles.

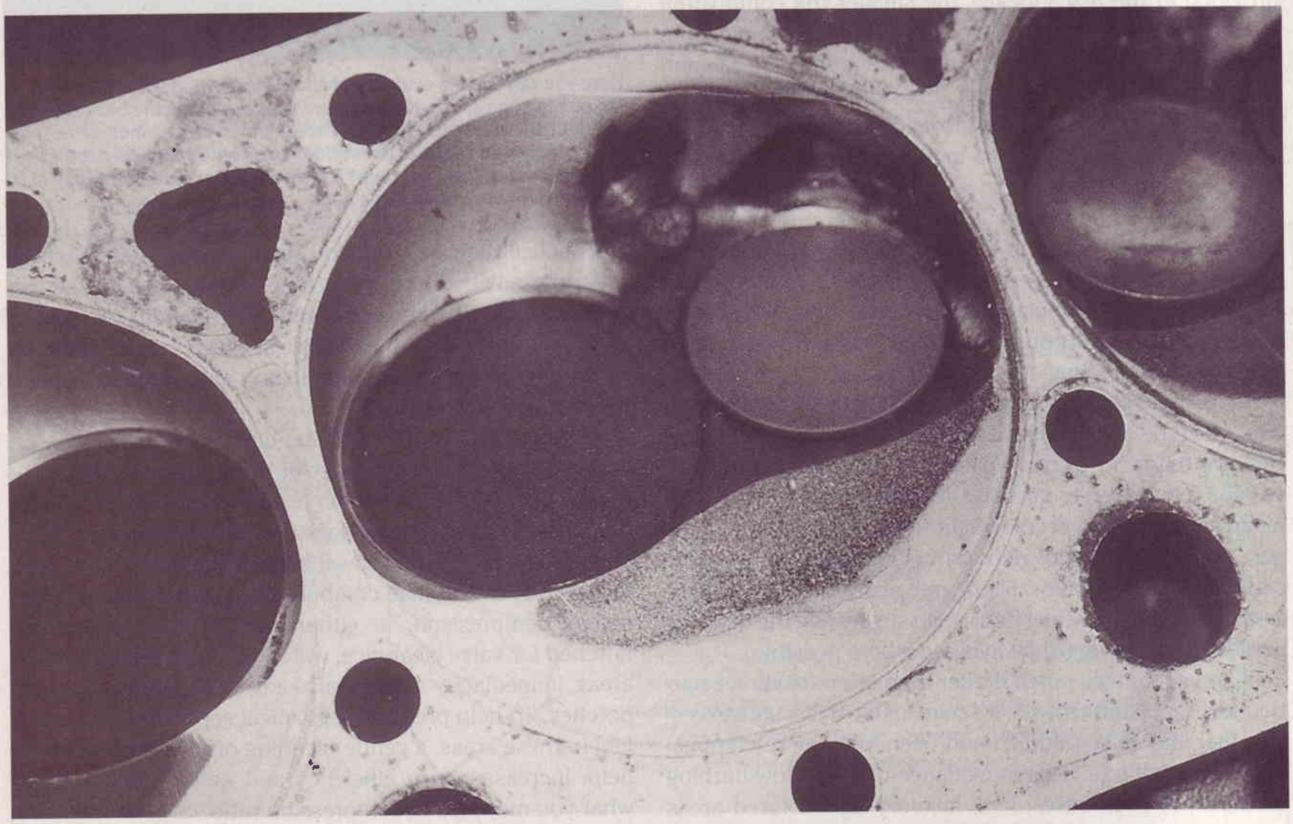
Furthermore, since air is compressible (certainly when compared to fuel), it can assume energy or directional changes more readily than the heavier fuel. If air changes direction quickly enough, a mechanical separation of it and fuel occurs, resulting in a possible alternation of air/fuel ratio downstream of the junction. Typically, there is adequate mixture motion in the combustion space as flow enters this area and is prepared for closing of the intake valve. Efforts to create desirable amounts of swirl or tumble are part of the intentional components of beneficial mixture motion. Other types of "motion," including those sometimes created at the manifold/head interface, may be harmful to supporting combustion efficiency.

To minimize this problem, the measurement and matching of manifold exit pressure distribution patterns with the intake ports is a worthwhile step to improving downstream mixture quality. This can be done on an airflow bench using velocity probes or by the use of the pressure maps capability often included in PC-based software geared to computer-aided airflow measurement. A typical example is Performance Trends' Port Flow Analyzer 3.0, which you can review on the Web at www.performancetrends.com.

It is important to understand that air is the medium by which fuel is communicated to the combustion space. Therefore, air quality must be considered in order to communicate fuel in its most combustible form. This is especially true when certain techniques are used to intentionally create specific mixture motion patterns, which can be disrupted by peripheral conditions (like the manifold/head interface issue just described).

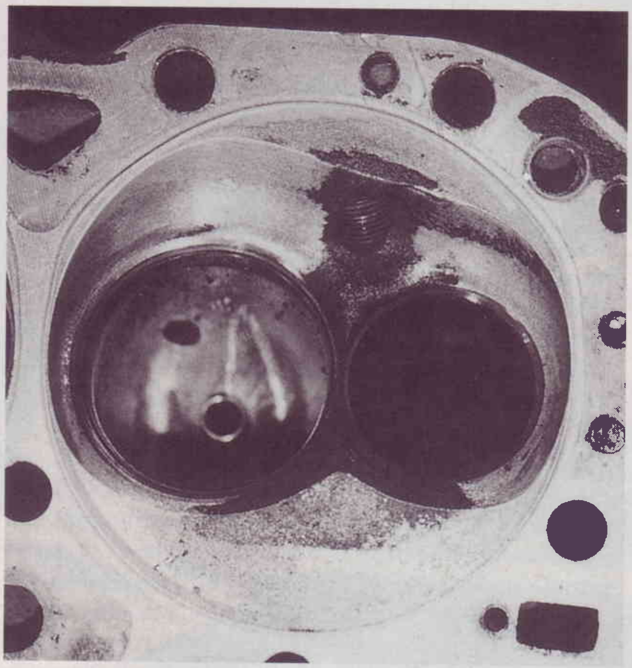
CONCLUSIONS FOR THE "SATURDAY NIGHTER"

Of the benefits derived from learning to read combustion patterns, the potential for power gains through improved combustion efficiency is principal. Clean areas just past sharp edges in the flame path typically cause air/fuel separation and wasted fuel that could otherwise be used for power. It's important to realize that modifications to combustion surfaces (pistons in particular) that cause slight decreases in mechanical compression ratio can lead to increases in power from improved burn efficiency.



Typical of both gasoline and alcohol-fueled engines, fuel wash can occur on a line-of-sight path from the intake port to the combustion chamber back wall. While this photo is of a small-block Chevrolet V-8 chamber, similar conditions can exist in other brands/designs of cylinder heads. Note the clean area adjacent to the spark plug and evidence of an excessively rich burn just past the plug where separated fuel re-collects into a rich condition. Dimpling of clean surfaces helps restore boundary layer activity and improve burn efficiency.

This engine was in trouble. Fuel was washing around the chamber and collecting toward the center portion of the chamber. Incidentally, it was too rich there. Engines in this condition often require excessive amounts of spark timing and/or fuel to optimize power. Either or both of these requirements suggest a problem like this exists before heads are pulled and surfaces examined.



Here's an advanced stage of air/fuel separation. Note the fuel-washed areas on the chamber's back wall near the intake and exhaust valves. An excessively rich condition existed in the channel beginning at the spark plug and progressing across the chamber to the quench area. Cylinder pressure conditions, under such adverse circumstances, reduce uniformity of flame travel and pressure rise, causing a net reduction in power. Mismatches between intake manifold runner exit and intake port entry velocity patterns can lead to this version of disrupted combustion efficiency. Depending upon an engine's horsepower potential, these problems can reduce power in the range of 4 to 8 percent per cylinder.

This writer has seen numerous cases where changes to piston crowns that reduced compression ratio by up to a half-point still produced 3–5 percent net gains in power with the same volume of consumed fuel and less spark timing. If it becomes necessary to create increases in compression ratio at the expense of sharp-edged disruptions in the flame path, perhaps the higher compression ratio is of little value. Remember, combustion is not an event—it's a process. Visualized in very slow motion, consider it much like setting a sheet of paper on fire. Once begun, the flame moves progressively throughout the combustion space (although much quicker), similar to the burning of the paper.

Therefore, in reading about or modifying piston crowns and combustion chambers, identify and provide for smooth flame movement. Sharp-edged valve reliefs or piston crowns can contribute to mechanical separation of air/fuel mixture and reduced combustion efficiency, as noted in the accompanying photographs. When a problem arises, it's usually characterized by very dark combustion residue (if an overly rich condition exists) or clean areas that often signal fuel wash and the loss of burn efficiency.

A significant amount of data suggests a large percentage of liquid fuel (or improperly conditioned fuel) becomes atomized in the combustion space after the intake valve closes. This is the result of heat and pressure during the compression stroke. Even though this condition appears verifiable, it's still a wise decision to work toward inlet air-flow structuring that enhances fuel atomization and suspension along the entire induction path, prior to the inlet valve closing, regardless of where fuel is introduced into the air stream. The more you can condition pre-compression stroke mixture or air quality, the less reliance is placed upon what happens after the intake valve closes.

Finally, there's another area in the combustion space that is often a source of lost power. In the interest of gaining airflow, chamber back walls are sometimes laid back to improve line-of-sight flow. This is frequently the result of cylinder head modifications made in alcohol-fuel engines where increased air is required for the reduced latent heat of combustion these fuels provide compared to gasoline. Once again, a trade-off may be required to optimize net airflow but not at the expense of poor flame travel. Observing combustion patterns is a key to solving this problem.

Reading combustion chambers and piston crowns is a "homemade" approach to gauging the results of the airflow/combustion compromise, allowing additional changes to be made in the combustion space after an engine has been run and has produced residue patterns. In these cases, the old axiom, "More flow isn't always more power," might be modified to read, "More flow isn't necessarily more power unless air quality supports good combustion efficiency." **EM**