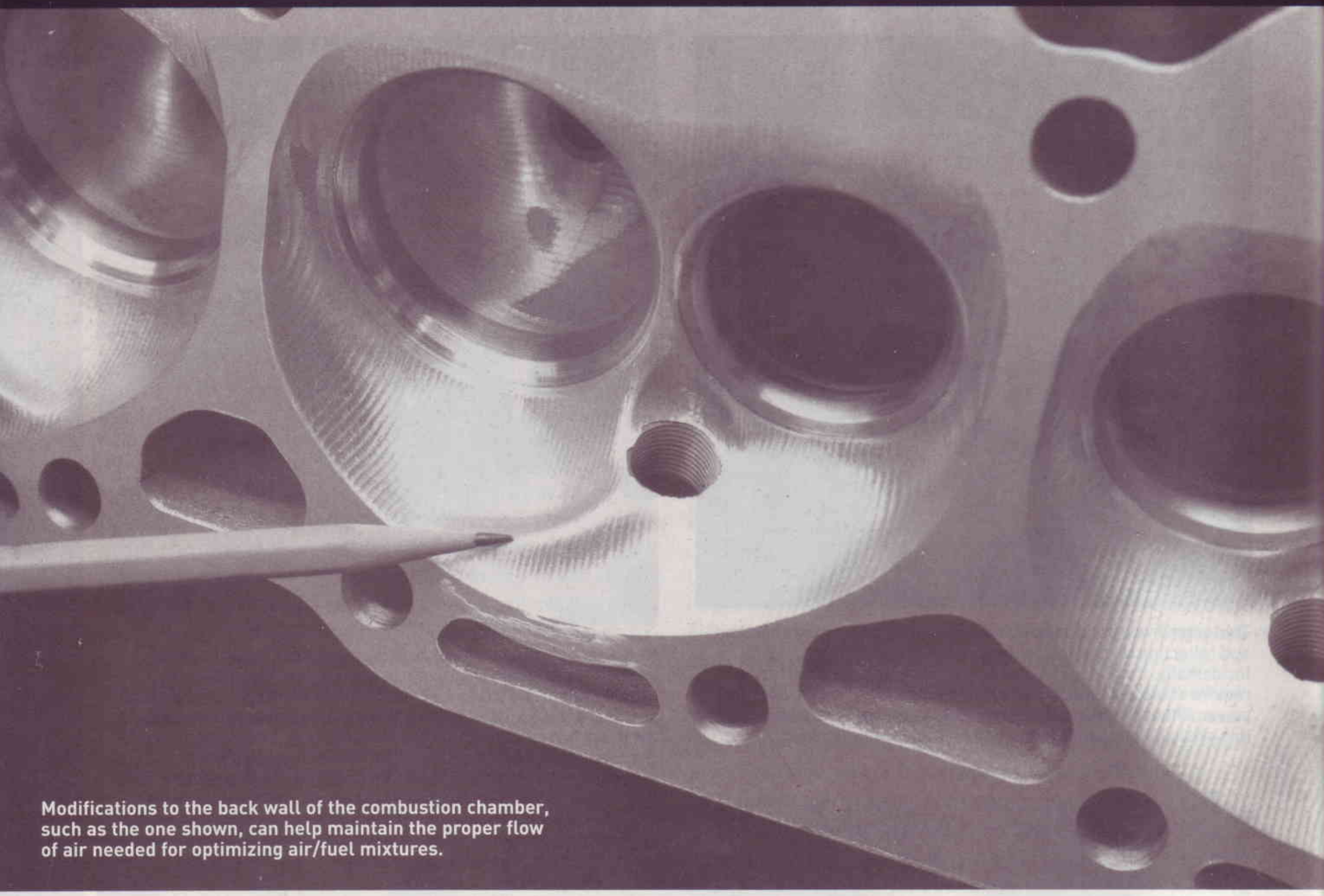


Modifications to the back wall of the combustion chamber, such as the one shown, can help maintain the proper flow of air needed for optimizing air/fuel mixtures.

ENGINE AIRFLOW: MORE THAN JUST NUMBERS

AIRFLOW QUALITY CAN YIELD COST-EFFECTIVE PERFORMANCE GAINS

BY JIM MCFARLAND

A prominent engine builder was asked, "What's the most frequent question you get when discussing cylinder heads with a customer?" His answer? "How much air will they flow, or how many cubic centimeters are the ports?"

Stop right here and take note. Nothing was said about port shape, surface finish, airflow quality, cross section versus torque range, combustion chamber shape, or any other characteristic of potential impact on optimizing power—only the amount of airflow and the size of the ports. What's implied is that more flow must mean more power and/or the bigger the better when, in fact, both expectations can be misleading, if not incorrect.

ROLE OF THE FLOW BENCH

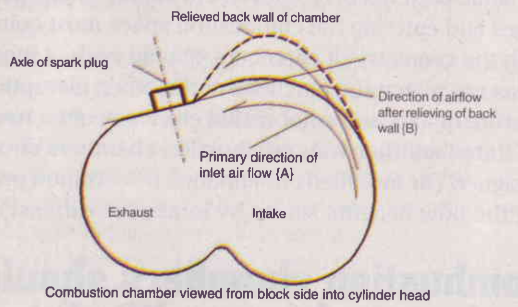
This is not a magical piece of equipment; its limitations need to be recognized. In particular, simply increasing airflow volume (based on flow bench readings) does not always result in power gains—it can, but not conclusively. This will be discussed more in length later.

What it can do is provide a benchmark for determining the "potential" for increased horsepower. Rather than theorize on how this can be done, here's a quote from Harold Bettes, a reliable and knowledgeable technical source at SuperFlow . . . and longtime gearhead:

First of all, flow benches can be used to quantify information you've heard or been told about. Knowing airflow values is useful in order to make proper selection of parts that support airflow, such as camshafts and intake manifolds. In fact, even rear-gear ratio choices can be tied to intake airflow because peak power tends to occur at peak airflow, and this can be computed.

Here's how that works: Let's assume you've obtained intake port (or port/runner) flow data at 10 inches of water. Based on optimum spark timing, air/fuel ratio, volumetric efficiency, and burn efficiency, we can estimate a conservative level of power. Simply multiply the flow reading by 0.43 to obtain a value for

Airflow Changes from Modification to Combustion Chamber Back Wall



Combustion chamber viewed from block side into cylinder head

NOTE: While modifications of this type may lead to net increases in inlet airflow, subsequent disruption of mixture quality can have a negative effect on combustion efficiency, the result of separated air and fuel. Evidence of this problem can be found by "spray pattern" tests using an airflow bench and valve set at about 70 percent of net lift.

power per cylinder. For example, based on a flow reading of 200 cubic feet per minute and an eight-cylinder engine:

200 cfm x 0.43 = 86 x 8 cylinders = 688 hp @ peak power rpm

If the flow data had been collected at 25 inches of water, the multiplier would be 0.27 instead of 0.43, resulting in 432 hp at peak power rpm. To determine the rpm at which these estimated values of peak horsepower would occur, a similar approach can be taken. That equation is as follows:

Peak power rpm = 2,000/displacement of one cylinder x [intake flow in cfm at 10 inches of water bench depression]

If we assume some typical values for cylinder volume and intake flow, the equation is:

Peak power rpm = 2,000/43.75 x 156 cfm = 7,131 rpm

Bettes emphasizes that this approach (as outlined in SuperFlow's instructional materials) assumes airflow data is obtained from a "full intake system" (carburetor, manifold, and cylinder head) and is for engines that are well sealed and of a mechanical compression ratio greater than 9:1. You should note that none of the foregoing information makes a single mention of port volume, only flow quantity.

THE IMPORTANCE OF AIRFLOW QUALITY

Aside from pure, steady-state, one-directional airflow numbers, air benches can be used to identify airflow "quality" conditions. A distinction should be made between flow quantity and quality, especially for carbureted engines. These rely upon the transfer of air and fuel from carburetor to combustion space, often plagued with problems that reduce how well the mixture is maintained [its homogeneity]. By proper study on a flow bench, the cause of these problems can be identified and often removed. Once again, here's how that works.

Consider air to behave like a compressible fluid. It has viscosity, effectively increasing with flow rate (speed). But it also tends to adhere to the inner surfaces of the inlet path (see illustration). Although there are exceptions to creating and maintaining stable airflow with minimum turbulence, it is usually sensible to take this approach for the majority of engine applications. But even if there are deliberate steps taken to create specific air or mixture motion (either controlled or random), air remains the "working fluid" by which fuel is communicated to the combustion space. It is therefore worthwhile to understand the effects and benefits of controlling or affecting airflow quality.

How can a flow bench be used to study airflow quality? Well, some veteran bench operators rely on the "sound" of port or passage performance. If it's "quiet," then it's stable or exhibits minimum turbulence. By the use of pressure probes, it's possible to do a more accurate job of locating and quantifying trouble spots along a flow path.

Two such examples of probes are provided in accompanying illustrations. While "velocity" probes are suitable for mapping pressure distribution patterns and identifying areas of high and low dynamic pressure in a passage, "J" probes help determine where boundary layer disturbances lie and the potential for fuel to separate from the air stream. Both of these methods are useful tools when evaluating flow passages for airflow quality. They are also of benefit when studying airflow characteristics during flow directional changes, particularly in inlet paths where fuel and air tend to separate due to the compressibility and mass (weight by volume) differences between fuel and air.

To illustrate how this weight difference can affect mixture homogeneity, consider this example: A train comprised of loaded cattle cars is moving down its tracks at a constant speed. In this example, the train is analogous to air and the cattle to fuel. At this point, the combination is well "mixed." Now, visualize what happens if the train suddenly changes in speed or direction, or accelerates or decelerates. It doesn't require much imagination to realize how the quality of this "mixture" will be affected, accordingly. Such is the case between air and fuel in an inlet path during changes in air direction or speed. The greater the difference in fuel particle size (atomization efficiency), the greater the problem of air/fuel separation, and the worse the quality of mixture delivered to the combustion space. It follows that impaired mixture quality translates into reduced power.

Surface texture is another factor that can influence flow quality, particularly on the inlet side where attempts to keep fuel suspended are made.

Roughness is especially effective in areas of low flow activity where fuel and air tend to become separated. Smooth intake ports may tend to increase raw airflow, but you can expect them to be less effective in maintaining fuel suspension than rougher surfaces.

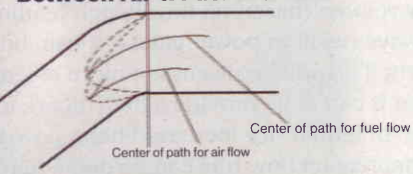
Exhaust ports, on the other hand, respond well to polished surfaces since mixture quality is not an issue. But what is most important to remember is that flow quality cannot be overlooked in deference to quantity.

Before we leave the subject of mixture quality, it might be worthwhile to mention that in some cases it's of value to create vigorous mixture or airflow motion if the results lead to increased fuel atomization. For example, let's consider the limitations placed on "restricted" engines: those for which limited airflow and/or mechanical compression ratio is required. In these instances, it's important to burn every possible "drop" of induced fuel. So if an inlet path can be created (given the fact total flow is limited) that creates very aggressive "agitation" of the air, the possibility exists for reducing net fuel droplet size at the time of combustion, trading off flow loss to improved combustion efficiency. The more fuel that's burned, the higher the net cylinder pressure and output, giving an engine the impression its compression ratio is higher than it actually is. Little wonder some current restrictor engines are using "spiral" inlet passages.

THE INFLUENCE OF COMBUSTION CHAMBER SHAPE

It is one thing to work toward port configurations that produce sufficient flow capability, but how flow is directed into the combustion space is quite another. Taken at face value, combustion chambers are intended to work in conjunction with flow patterns created by intake and exhaust. Particularly on the intake side,

Flow Path Differences Between Air & Fuel in a Turn

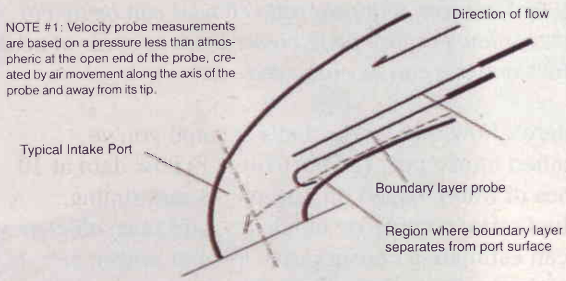


NOTE: Unless accompanied by proper design of passage cross section, air and fuel tend to separate during flow direction changes. By the combined use of "velocity" and "boundary layer" probes, passages can be mapped to determine the severity of this condition and when it has been corrected. In particular, along the short side of paths changing direction, the boundary layer probe will identify areas of layer separation and potential locations where separated fuel tends to migrate. The use of so-called "D" or "trapezoid" cross sections can help bring the two centers of flow {air and fuel} more into coincidence.

Two Methods for Evaluating Port Flow Quality

{Methods can be used for areas other than in intake passages, as shown}

NOTE #1: Velocity probe measurements are based on a pressure less than atmospheric at the open end of the probe, created by air movement along the axis of the probe and away from its tip.



NOTE #2: Manometric measurements of boundary layer "separation" from port surface are indicated in a manometer reading *opposite* to that of velocity pressure measurements. Boundary layer disturbances can lead to flow quality problems.

dynamic patterns of air movement exiting intake passages and entering the combustion space must coincide with the geometry of chambers. Should each of these two areas not match the functions of the other, disruption in mixture quality and combustion efficiency often result.

Stated another way, combustion chambers should be designed (or modified) to enhance or continue providing the flow benefits set up by intake (or exhaust)

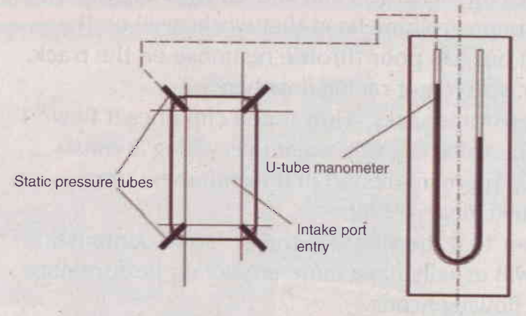
Combustion chambers should be designed (or modified) to enhance or continue providing the flow benefits set up by intake (or exhaust) ports.

ports. By way of example, take a moment to examine the accompanying illustration that shows a generic combustion chamber. Note that this chamber is laid out to help direct incoming air (or air/fuel mixture) in a counter-clockwise fashion, thereby helping maintain the energy while aiding motion in a circular or "swirling" motion. If, for reasons of improving raw airflow (as might be measured on a flow bench), the back wall of the chamber is extended beyond the original contour, it's possible to increase total flow and decrease combustion efficiency.

According to Pete Incaudo of CNC Cylinder Heads, "There's a critical relationship between back wall position and top cut on the intake valve seat. The idea is to maintain airflow directed around toward the center of the bore while laying back the wall to improve flow. You don't want to lose the 'rotation' of incoming air, with respect to the cylinder bore. Directing too much airflow toward the back wall can destroy proper mixture motion. In an extreme case, the wall can be laid back so far that any influence by the top cut to help maintain circular motion of the inlet flow is lost. When this happens, any gains in flow from laying back the wall is lost to poor combustion efficiency. Power suffers accordingly."

Here's another instance where airflow quality becomes more important than quantity. It also reflects the fact that a mere increase in flow may not provide an attending boost in power. Unless additional airflow is constructed in a fashion that supports combustion, it becomes wasted. As intake air enters the combustion space, there is a combined "venturi" effect created between the intake valve head, valve seat, and sidewall of the combustion chamber. Consequently, the dimensional relationship between these three components is important to both net inlet flow and flow direction around the perimeter of the cylinder.

Static Pressure Measurement for Distribution Pressure Profiling



NOTE: See sidebar on "Pressure Profiling" for details on this illustration. Although only one U-tube manometer is shown, a group of four such instruments can be used for simultaneous measurement of static pressure in each of an intake port's entry corners.

As further evidence of the importance of chamber back wall position and shape, note the photo showing a "rib" or flow "director" placed and configured to help direct air (air/fuel charge) back toward the spark plug. This same rib, another Incaudo creation, also tends to aid airflow tumble and mixture homogeneity just past its location. Brief atomized shots of machinist blue into a flowing intake port can produce chamber patterns leading to the positioning and shaping of such ribs, or other devices intended to aid flow quality in the combustion space.

PRESSURE PROFILING

Intake manifold runners are extensions of cylinder head inlet ports. This is one axiom among many airflow parts designers. In order to accomplish this objective, there are several methods. Among them is the matching of intake port pressure distribution patterns to the exit flow distribution patterns of intake runners. Here's an example of how this works:

Assume there is an inlet port fitted with an entry radius, typically about 0.500 inch. Using a 0.125-inch-thick piece of plastic with an opening that matches the intake port, fitted with static pressure tubes at each corner of the opening (see illustration), a "distribution" of pressure (corner to corner) can be measured. A simple U-tube manometer can be used in lieu of something more sophisticated. Incidentally, such measurements should be made with the entry radius in place.

Remove the entry radius and bolt up the intake manifold to be used. Re-check the static pressure measurements at each corner of the inlet port. If they remain within 3 to 5 percent of their readings prior to installation of the manifold, an acceptable "pressure profile" has been determined. In some instances, a smaller percentage than this is desirable.

However, if the readings fall outside this limit, airflow quality—and often quantity—has been disrupted by installation of the manifold. In most instances, adjustment of intake manifold runner entries (either length or radius) can be modified to bring the profile into the desired range. The objective here is to prevent any "conflict" in airflow transition from intake manifold runner exit to intake port entry. As a rule, the greater the disruption (in inequality) of the pressure profile, the greater the loss in airflow quantity and quality. In particular, in carbureted engines involving wet intake flow (air and fuel), such disruptions can lead to mechanical separation of fuel from the air and unwanted changes in air/fuel ratio in the combustion space. You know the rest.

COMMON AIRFLOW BENCH OPERATOR MISTAKES

Whether you perform your own airflow tests or have the work done by a service, there are some topics and precautions worth keeping in mind. Because cylinder head and intake manifold modifications are part of his everyday activities, Dennis Wells (Wells Racing Engines) shared some of his experiences:

"If I had to list the top 10 suggestions I'd make to someone using a flow bench, here's what they'd be:

- Always check the bench's calibration before performing a test.
- Begin every flow test by checking the test piece for external leaks. On cylinder heads, this includes forgetting to install a spark plug. Just about any shop with a flow bench has been guilty of this at one time or another.
- When flowing an intake port, incorrect readings will result if the exhaust valve is pulled slightly open as a result of a weak flow spring.
- To avoid incorrect readings, make certain the flow range control is properly set.
- Intake port entry radius must match the mouth of the port exactly, or turbulence will invalidate readings.
- The fixture attaching a cylinder head to the flow

bench must be the same size as the engine's bore.

- Do not continue to enlarge ports just because flow continues to increase. You can end up with a high-flowing, large-runner-volume head that works well on the flow bench but has poor throttle response on the track. Remember, you're not racing flow benches.
- When a customer asks, 'How much cfm does it flow?' I tell them the valve doesn't remain very long at maximum lift. Be more interested in flow numbers from 0.200 to 0.600 inches of lift.
- Remember that the shape of the port and combustion chamber will usually have more impact on performance than large flowing heads.
- Spend some time learning to use velocity and boundary layer probes to study airflow quality and airflow stability. Both these topics can lead to increased power and on-track acceleration."

On the subject of where in the lift range port flow is most critical, consider the following thoughts. For both intake and exhaust valve movement, we are dealing with a continually moving valve (other than at peak lift) once it gets into its lift cycle. The idea is to determine the percentage of total intake or exhaust valve lift at which these two valves remain off their respective seats most of the time. We also need to relate these two percentages (one for the intake, one for the exhaust) to piston speed (acceleration) or crankshaft angle.

From another perspective, we're trying to figure out the valve lift at which the piston is doing the most work toward creating a low-pressure condition in the cylinder (intake stroke) and the lift at which the piston is doing the most toward ridding the cylinder of exhaust gas (exhaust stroke). Over time, it appears that these two conditions occur at about 70 percent of net intake lift and 85 percent of exhaust valve lift. In other words, other than viable concern for low lift flow (in both directions) for intakes and low lift flow (in both directions) for exhausts, these two percentages are related to intake and exhaust valve lifts for which the ports should be the most efficient. Spend a little time with these statements. They can be worth some power. **EM**

SOURCES

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