Flowing, Knowing and Growing

Improving engine airflow is a good start toward producing more horsepower

BY **HAROLD BETTES**

Power is a fairly powerful word in some circles. The word *power* brings to mind several images and means different things to different people. There is political *power* and there is people *power*. There is also economic *power*. Women certainly have *power* but that is way beyond the scope of this particular article. There is also *power* in the air. *Power* from the winds brought the first exploring sailors (whoever they were) to the North American continent. However, an immediate interest gets stirred up in most gearheads and engine builders when the term *horsepower* is used while only some are stirred up in discussions of *airflow*. The relationships of the two terms are very closely joined.

We humans are creatures that use the air to provide life giving oxygen and our internal combustion piston engines also use the oxygen in the air to help make power. It is a given that a piston engine is a self-driven air pump and as such the more air we can arrange to get into and out of the engine, allowing it to have the potential to make more horsepower.

The internal combustion piston engine needs three things in order to produce horsepower and shove a vehicle against the resistances of the roadway or racetrack.

There is a critical combustion triangle of fuel, spark (ignition spark at the spark plug), and air (oxygen in the air). All the components must be present at the correct time in the combustion chamber where noise and horsepower are generated.

Yes, it is basic, but consider the four stroke cycles of a four stroke engine: Intake (fresh air goes into the engine), Compression (where air and fuel are squeezed into a smaller volume), Combustion (where the air and fuel mixture is ignited by the spark plug and the mixture expands as it burns while pushing on the piston), and lastly the Exhaust (where the burned gases and residue is expelled from the engine). Yes, it is simplistic and it is basic but kindly notice that two of the events listed previously have to do with the movement of air into and out of the engine. Improving just those two cycles' efficiency will improve the potential to make more horsepower. If you can improve all the event efficiencies you can make more power but improving the airflow through the engine can easily improve horsepower. If you can capture the importance and control those events, you are well on your way to make more horsepower. It is that simple.

If we learn some particular details about the airflow characteristics of the engine and its components, it is very possible to predict with some certainty the engine's potential to make horsepower. A careful and deliberate study of the airflow of the

Figure 1. The airflow characteristics of engine components such as cylinder heads, manifolds, and throttle bodies or carburetors establish the capability of the engine to produce horsepower.

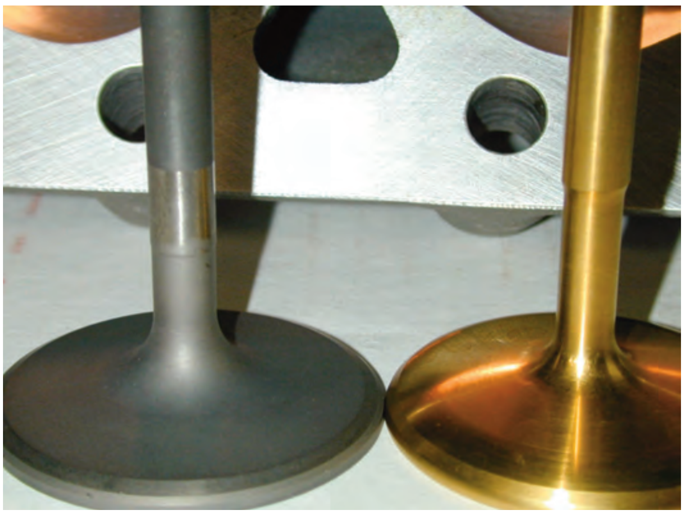

Figure 2. These intake valves are made of the same material (titanium) although shaped differently yet are the same diameters. But do they flow the same? Only testing on a flow bench can reveal the truth and the one that flows the best will help the engine to produce more horsepower.

Figure 3. A grinder is about the last thing that should be picked up when planning on improving the airflow of cylinder heads. First you have to know what needs to be done in order to be effective and random grinding may not be the correct answer. Often what looks good might not flow well.

Figure 4. Super Stock cylinder heads have specific rules to follow and ports can be reshaped but they must maintain mandated sizes. All exhaust testing should use a pipe to get correct flow numbers. This 1000cfm flow bench provides accurate numbers for developing components and keeps quality control on the heads at a high level. (Photo courtesy of Stu Zylstra.)

engine and components are very beneficial and provide a platform for improving the horsepower of the engine. The study of fluids in motion (air is a fluid) and is known by a descriptive engineering term called fluid dynamics.

The most common term used to describe airflow through the engine and components is CFM (cubic feet per minute) and is a volume measurement reference sometimes referred to as volumetric flow rate. A mass flow (weight per time) reference would be something such as pounds of air per unit time in seconds, minutes, or hours. The mass flow of the running engine is dependent upon atmospheric conditions or the location of the testing being done. The engine's horsepower output is sensitive to mass flow while the individual components such as cylinder heads, manifolds, carburetors, or throttle bodies are not. The assembled and running engine responds to atmospheric changes even when the components bolted together remain the same. The atmospheric effects and component comparison is being tested every day on dynamometers and racetracks. Therefore, the most common reference in CFM can be an easy way to compare measurement data no matter where the testing is being done.

Measuring the resistance to flow air is essentially what most flow benches do so the operator can quantify and compare components. The effective airflow development of the cylinder heads and manifolds and even carburetors can be evaluated on a flow bench and is a critical process in the improvement of the horsepower of an engine.

When commercial flow benches came on the performance scene in the United States back in the 1970s, many small shops became more competitive with larger and more well funded operations by having a way to not only check their cylinder head modifications but a new way to improve their work. Those that learned faster grew in specialty applications and became the "go to guys" in many areas of the country. This was the time when it was apparent all cylinder head work and valve jobs were not created equally. Any small shop can fill the need and expand customer bases by improving quality by using a flow bench as a pathway to greater success.

Engine Airflow Establishes the Engine's Potential for Horsepower

If we can learn some specific characteristics and data about cylinder heads, it can be predicted how much horsepower and at what RPM it will occur. A flow bench is the necessary and correct machine to use in order to accurately measure the airflow of the cylinder heads and other engine components that are in the airflow tract.

Of course there is also an initial assumption that the engine seals properly (no bent valves) or seized parts and the details of timing and a correct amount and type of fuel is used and all those little basics have not been neglected.

As an example, if you have an engine that is an 8 cylinder of 389 cubic inches displacement and you have some testing done on the cylinder heads and they flow 320CFM at 28" H2O test pressure at .600" valve lift. What can be predicted from that data? It obviously has 8 cylinders that displace 48.625 cubic inches each. From the airflow data it can be predicted that the engine has the potential to produce 83.2Hp per cylinder or 665.6Hp based on cylinder head airflow. However the engine needs to have an intake manifold and carburetor or throttle body attached and each of those items will typically reduce the airflow available. For the sake of this example, let's guesstimate the manifold and carburetor would reduce the cylinder head's airflow by something around 13% or 41.6CFM. So, our new calculation of predicted horsepower would be based on airflow of 278.4CFM at a test pressure of 28"H2O. Now it would have been better to have actually measured the airflow of the cylinder head with the intake manifold and the carburetor attached, but not many folks actually do the detailed work that way although they should if they want accurate numbers. Yeah, so what is the new predicted number for horsepower with the changes listed previously? The answer is 72.38Hp per cylinder or 579Hp for the entire engine working properly. And that would happen at somewhere around 6850 RPM or so. At least it has that kind of potential based on the airflow numbers given in the example.

Although the numbers listed above apply to naturally aspirated gasoline fueled applications, supercharged engines or engines using different fuels can also be improved using airflow technology techniques gained from flow bench measurements.

There are many problems in not measuring intake manifolds and carburetors attached to the cylinder heads.

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So, one has to be very wary of published flow numbers for cylinder heads and not plan on manifolds reducing the head flow numbers. It makes a difference and the only way to really know the airflow numbers is to measure them on an accurate flow bench.

Using a flow bench is not very difficult to learn. It is a bit more problematic to learn how to use the data and how to apply the simple arithmetic. As with any process, practice makes things work more smoothly and more experience in the application of the test data is another effective tool in your toolbox of knowledge.

Airflow numbers without test pressure references makes the flow numbers meaningless but many still fall for the flow numbers if they are big numbers.

Getting air into the engine has been most of the focus thus far, but the exhaust side can and should be measured also. In fact all cylinder head testing on the exhaust side should also include the use of a pipe on the exhaust port. While not as critically important as the intake side of the engine, exhaust improvements can enhance the performance of a cylinder head by complimenting the intake flow particularly during the overlap event.

Camshafts and Airflow

There is no way a camshaft selection can make up for inadequate airflow for an engine. Simply put, camshafts cannot create airflow. The valve timing events can help to enhance the benefits of whatever airflow is available, but they cannot create airflow. That is the kind of statements that stirs hate and discontent among some. There are many myths that support camshafts as a cure all for engines that have all sorts of other issues to overcome. Inadequate airflow of cylinder heads and intake manifolds is way up on the hit parade of problems to be solved when building for maximum performance.

And the only way to check out what restrictions you have in the airflow path of the engine is to measure each item on a flow bench. Way too many folks believe in magical methodology in choosing camshafts while many others simply choose the last part number on the catalog page. With airflow based data driven decisions, the choice of a camshaft need not be a roll of the dice or the flip of a coin.

CNC Versus Hand Porting

Most CNC programs first started as a hand ported port and then the port is "digitized" in order to copy the shape. The uses of CNC equipment has increased in many ways in the aftermarket industry. The porting of cylinder heads by using CNC machines is quite popular, but is it better than hand porting? It depends. It depends on how well the hand developed port was digitally measured and thus copied by the CNC operations. Many considerations used by CNC programmers and operators might not exactly duplicate the original hand ported configuration of a good flowing port. The CNC machined ports can be done faster

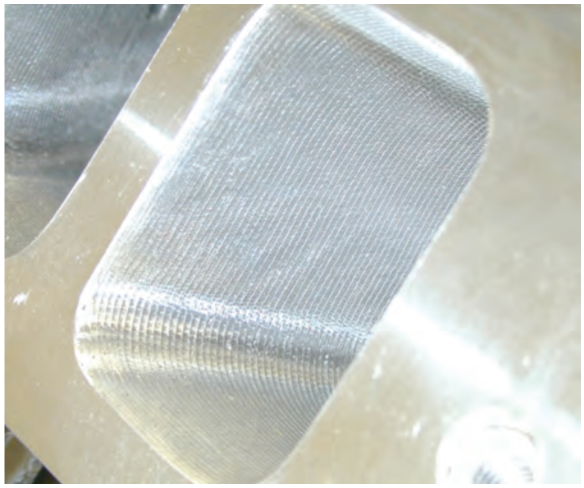


Figure 5. This shows the rows and rows of cutting tool paths of a CNC machined intake port. How can you know if the port flow is any better or worse than a hand developed port? The CNC programmer might or might not have an interest in airflow but the CNC machined heads can be produced much faster than doing the job by hand.

than hand porting and everything from the coarseness (how rough) of tooling cuts and how hard the cutting tool is forced or “crowded” causing tool deflection or wear can cause problems with the finished CNC port. However it is by far faster than hand porting. The CNC operations allow comparatively rapid turnaround times from raw casting to a finished product. However when all is done the finished piece still needs to be measured on a flow bench as a quality control checking item. Many CNC ports can be refined further by hand tweaking the port shape and measured often on a flow bench so the progress can be tracked carefully. Not everyone or every organization does their product development in the same way (there is more than a subtle hint in there somewhere).

Using a Flow Bench to Improve Quality and Performance

The use of a flow bench can certainly improve the quality of work any shop or individual produces. Proper application of the data collected can also improve performance and increase the power potential of the tested parts. Simple flow testing cannot by itself provide any performance gain, but can provide data in order to improve the parts tested. If nothing else, flow testing parts can help to select the parts or modifications that provide better flow characteristics. It is very rare that better flowing parts don’t provide reliable potential for increased horsepower. The flow bench can help to find the parts that can make building more horsepower much more likely. A flow bench is much less expensive than a dynamometer and takes much less floor space and support, so it becomes an easy choice as a piece of equipment that can pay for itself over a sensible period of time.

It is the shape of the air flowing duct (port) that is much more important than size (volume), so just making a huge port is not the best answer. How does one find the balance of shape and size? Straight answer is: With flow bench testing experience and accumulation of shaping experience. Try to get started accumulating

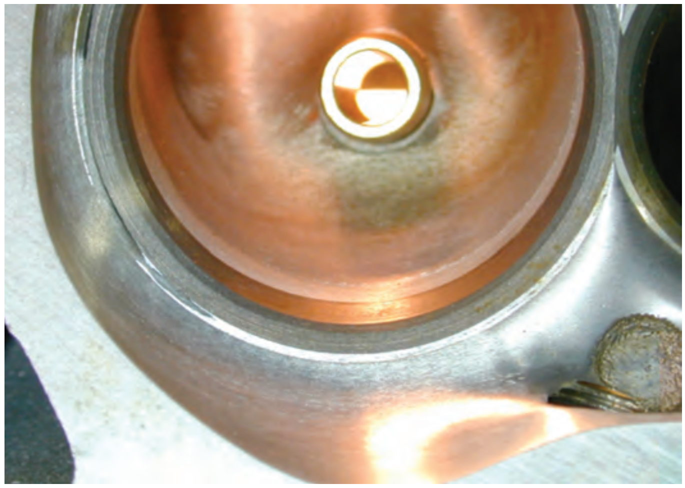


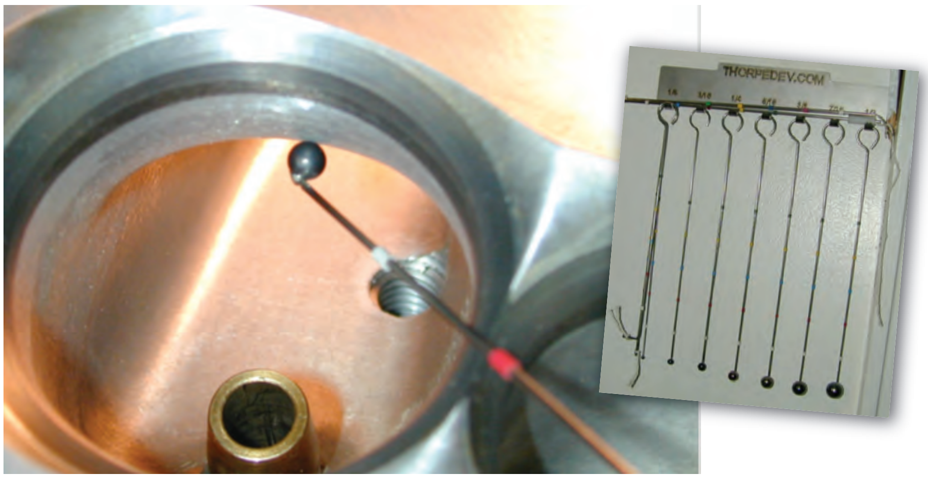
Figure 6 & 7. The combustion chamber on the intake side is of a laid back design that probably enhances the airflow path from decreasing the shrouding of the intake valve. The only way to be sure is to measure the results on a flow bench.

both as soon as possible. The goal should be to create a shape that flows well without being too big and that is sometimes a tough balance to control.

How does a combustion chamber's shape affect airflow? It can be tested on the flow bench. Have you ever taken a look at the combustion chamber shape that has a "laid back" wall directly opposite the intake flow path? Perhaps it was developed on after a flow test showed it improved the intake airflow. One cannot guess so it must be tested.

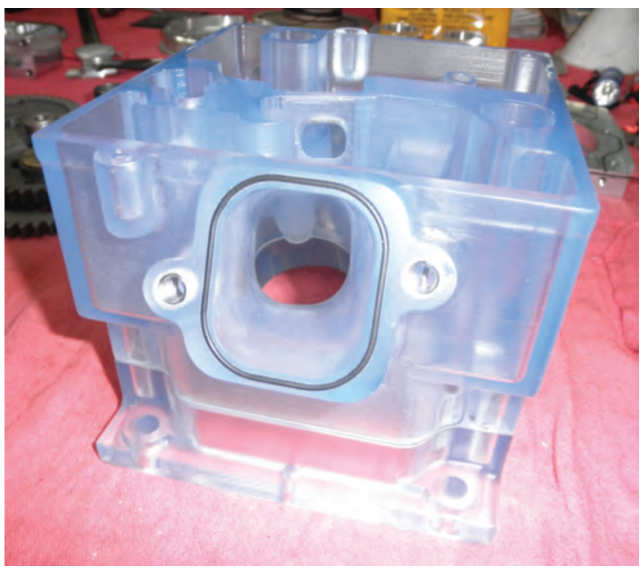
Buzzwords, Attitudes, and Knowing What You Are Talking About

The late great American physicist Richard Feynman stated, "I learned very early the difference between knowing the name of something and knowing something." So perhaps buzzwords and the like are not nearly as important as those that use them make them out to be. There are a very many buzzwords and some verbal shorthand concerning racers and racing and gearheads in general, but when it comes to airflow it sometimes gets out of hand. Sometimes the buzzword of the week gets tossed out and something else replaces it for no reason other than someone else's new comment or opinion. Or perhaps it comes from lots of opinions on the various uses of the internet. So, how do you get to understand all this stuff? There is not a real need to do anything special relative to "airflow linguistics" other than just call items as you learn about them. As an example a port does not "back up" as it has no reverse gear. The clumsy term simply means the port flow is decreasing as the



Figures 8 & 9. The very critical area over the short side radius is hard to get to but very important to shape properly so intake flow does not separate from the turn. Here the place is pointed out by using a 3/16" flow ball. An assortment of flow balls and flow flags should be within reach of any flow bench testing (inset photo). Very handy tools for airflow development projects.

Figure 10. Here is a single-cylinder rapid prototype plastic head for a new clean sheet of paper design 60 degree V-12 engine. For aviation use, airflow development data from flow bench work indicates 800+Hp at 4600RPM for the naturally aspirated version and the turbocharged model is targeted for 1600Hp at 6000RPM. (Photo courtesy of EPI, Inc.)



valve is opened. Just say something that can be understood by a twelve year old kid. How about "pinch point"? Makes you want to watch out for your fingers for sure, but it is clumsily describing the port area near the pushrod on a pushrod engine or perhaps it means the point of minimal cross section somewhere in the port if the engine is an overhead cam setup (thus no pushrod). The term "stall" means the port does not gain flow with more valve opening. The short side radius is a fairly descriptive term and is an important part of a port's configuration. Learn where it is and why it is important.

An attitude of desiring to learn and perhaps apply that learning to improving your business or perhaps even to start a business based on what you learn is worthwhile but not necessarily an easy path. The flow measurement path is the knowing path toward success.

Sometimes it is more cost effective to use a model cylinder head for airflow development and rapid prototype pieces can be generated if budget is available before a final design is settled on. A sensible approach to airflow development saves countless hours and errors. An individual or a small shop can work on broken heads or manifolds before a final product design is decided speeding up the development process. The inertia of a larger shop can be a detriment to success if innovative and results oriented personnel are not in the cylinder head department.

Try your very best to keep learning and to help others to learn. Watch out with airflow however, as it becomes quite addictive in a very good way. There is power in the air but it is up to you to not just find it but to apply it as part of your business plan or racing program. ■

Harold Bettes is author of *Engine Airflow* and co-author of *Dyno Testing and Tuning*. He has been a mechanical engineer for over 40 years and has been involved in motorsports in one fashion or another for more than half a century. Harold is a recipient of many awards for his contributions in furthering mechanical engineering in the motorsports industry and aftermarket. He is an active consultant on test facilities, equipment and racing engine configurations and designs. He is also writing a novel about experiences in Southeast Asia, Mexico, and Texas.