FLOW-ER-POWER

Some heady thoughts on easing the mixture's path to combustion • Text and photos by Jim McFarland

By one definition, an internal combustion engine is a form of air pump. Piston movement and combustion processes create negative and positive pressures in a given cylinder, and the manner in which corresponding inlet and exhaust gases pass through an engine forms the basis for horsepower developed. Cylinder filling can be measured on the basis of mixture volumes (by weight) which would fill an operating cylinder and one left open to atmospheric pressure. This comparison of mixture amounts is termed volumetric efficiency, with a maximum rating of 100% being used for unblown (normally aspirated) engines. Any way in which volumetric efficiency can be improved (valve timing, piston speed relative to pin offset or rod length, intake/exhaust runner tubing, carburetion changes, and a host of related departments) generally boosts total engine output, and when atmospheric pressure can be cheated to the extent that a mild supercharge (ram or scavenge) *effect* is created by additional cylinder packing, substantial power increases result.

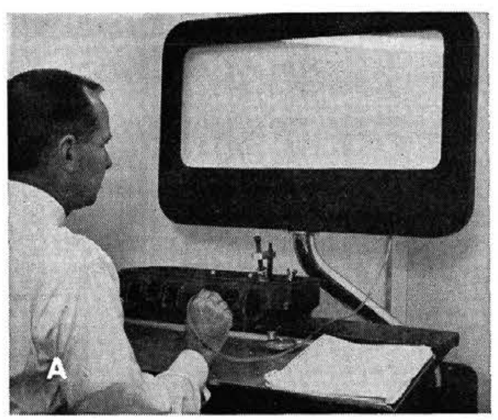
The flathead Ford V8 responded to the early-day grind operations dubbed porting and polishing, milling and filling. By today's standards, this was a "nuthin' to it" operation consisting of a general enlarging and relieving of port/block mixture passage areas. Bigger ports and smoother finishes were the basis of change, and little, if any thought was devoted to specific and scientific processes for the determination of material removal location and amounts trimmed away (or built up).

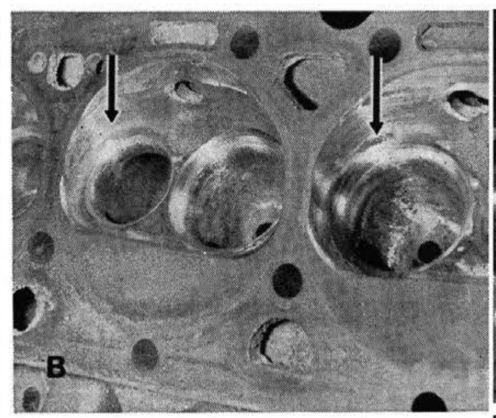
Enter the "flow bench." The device is structured to pass air (in various quantities) through a passage: intake or exhaust, port runner, across a piston-filled combustion chamber, around a valve head at some amount of valve lift, etc. Direct readings indicate flow quantities and corresponding changes relative to any alterations in flow path, such as back-cutting valve heads, unshrouding valve pockets, trimming piston tops, reaiming a port runner, and similar alterations. Then, enter an assortment of head modification service companies, a variety of product claims, and an equally spotted array of results. Some were good, some

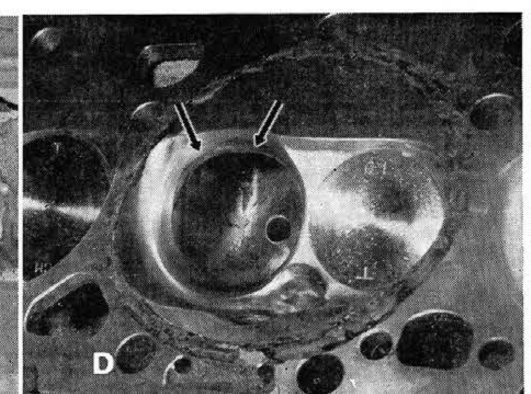
Finally enter a Van Nuys, California, firm called Air Flow Research Company that has in intensive testing attempted to discover how to improve flow significantly Admittedly this is a new organization, and only one of several; but its product effectiveness was recently bolstered by a big-block Chevy/MG that walked away with Eliminator titles at each of the '69 NHRA/AHRA winter meets. Heads on the engine were from AFR. And by "intensive testing" we *mean* thorough; more than 11,000 individual tests have been conducted, ranging from head and port dissection, cross-sectioning, polishing, and roughening-up to valve seat and shape tests. Their procedures and results are quite revealing. We think they'll be of interest and perhaps point out some of the better ways to spend your engine-modification dollars. Of course AFR is one of several head-modification organizations "in captivity," but their approach to design changes does open a new door for the enthusiast who once thought that port centerline vs. valve seat relationships were the only route to power boosts. Not necessarily.

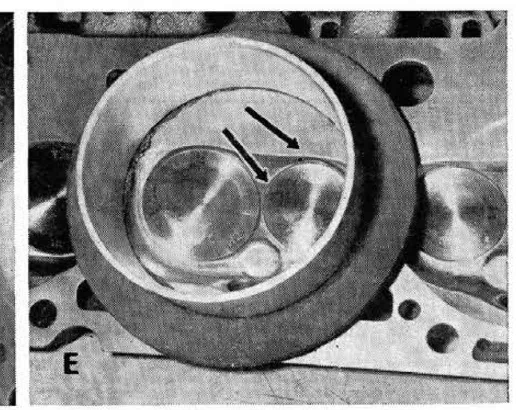
Air Flow Research designed and constructed a high-velocity high-volume test bench to determine the behavior of air at high velocity Oddly enough, a "budget" approach bounded the entire initial plunge. (Incidentally these flow machines will soon be available from Air Flow Research at a cost of less than $3000! This puts it entirely within the financial reach of hundreds of valve job/engine building automotive shops and almost assures immediate improvements in finished engine results.) AFR did not agree with the idea that data obtained with a low-velocity machine just needed to be multiplied by some conversion factor to find high-velocity results. In fact, they found that a port which may appear to be functioning through the full range of valve lift as indicated on a low-velocity machine does not actually do so. The same head placed on a high-velocity machine would cause the same readings (as the low-velocity machine) up to half the net valve lift; then it would show a failure to increase in flow as the valve lift was increased. Air turns abruptly at low speeds (while more massive fuel particles do not) but does not at high speeds; consequently, air flow will not increase at high velocity. It may even *decrease*.

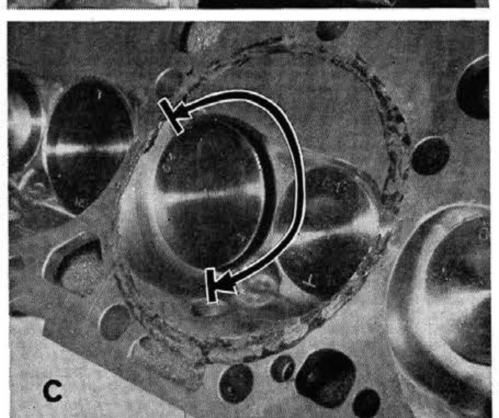
The point here is that *any* head/port modification needs to compensate for air mass vs. fuel mass characteristics during high air/fuel velocity Since fuel particles are of greater mass than "air" particles, abrupt changes in velocity (positive *or* negative) or alterations to flow direction can cause air/fuel separation. Perhaps the most common observation of this is "read" on combustion chamber walls where bright spots (variations in chamber color) often lead head modifiers to believe that mixture activity at these points requires removal of more head material. Warren Brownfield (AFR engineer) also followed this line of thought but now believes it to be erroneous. The real trick now seems to be a determination of *air* path (not fuel/air path), since the two can differ at points along an intake or exhaust runner. Colored tracers (dyes, etc.) can be used to locate partial flow directions, but if you really plan to perform a class A job, route the air correctly, and the fuel will largely take care of itself. Although not specifically proven at this time, it appears that boundary layer conditions along the interior of port runners and chambers aid in sticking mixture flow to the surface, providing an element of flow control and enabling corners or direction changes to be made with more precision and predictability. Call it what you will, this air-flow business can be made to work if you use your head.



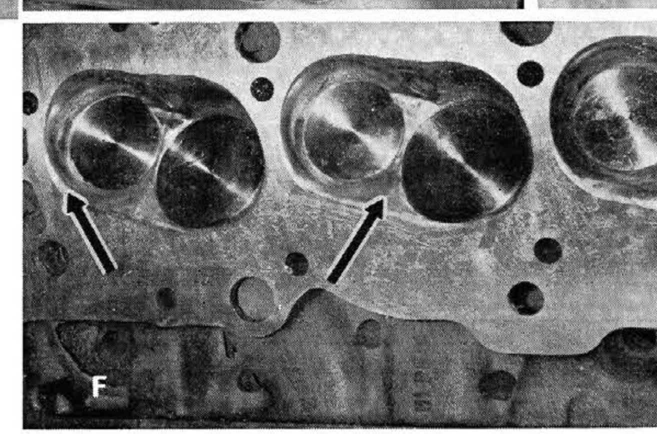








A. Direct-reading flow bench is somewhat akin to engine dyno: Comparative evaluation is key to successful testing Quantitative valves have little significance but positive or negative change can be meaningful. B Very little "shroud material" is removed from AFR heads. Basic premise is that air/fuel mix does not necessarily move in a straight line. C. Major air-passage area.



D. Fuel/air mutual separation is evident at "short side" of port runner entrance to combustion chamber. Removal of material here generates "egg-shaped" underseat section. E. Contrary to many design approaches, exhaust gas passage is said (by AFR) to be toward chamber centerline side of valve head. (Thus, short-side port alteration.) F Chamber filling.

With high-velocity equipment, results show that normally aspirated engines will reach approximately the same combustion-chamber vacuum (atmospheric/cylinder pressure differential) at maximum power output. From this rpm point upward, the engine requires more horsepower to pull the vacuum than it gains from incoming air. In making a test, you should normally try to duplicate actual cylinder conditions. For example, you could begin by placing a three-inch sleeve (or one of the same i.d. as the bore of the engine being tested) on the base of the cylinder head. Valves should be installed with low-pressure valve springs, and an adjustment (lift varying) fixture positioned on the stem. The head is then placed over the opening of a flow bench and the valve adjusted to an initial 0.100-inch lift by the fixture (opened later at 0.050-inch intervals). Flow calibrations are then recorded on a chart at each lift interval, yielding a clear picture of the flow characteristics of the port at each reading.

Two basic principles affect an engine's operation: (1) pressure differential (cylinder vs. atmospheric) and (2) temperature change. Maximum horsepower is developed at a certain combustion-chamber temperature in a given engine, and because of this, the intake-to-exhaust relationship is of utmost importance. Actually, this relationship will vary with different types of engines. For example, an air-cooled engine with a cast iron head will usually generate greater combustion-chamber temperatures than a water-cooled engine with an aluminum head, both types having the same size valves. Passenger car engines are designed to reach greatest thermal efficiency at lower rpm, and since this heat range is not suitable for higher-rpm engines, exhaust valve efficiency has to be increased to alleviate the condition.

Contemporary testing now indicates that port *size* is not as important as port *shape* in achieving maximum flow rate. In fact, it is now believed that the port should be as small as possible, yet designed to point the greatest mass of air at the cylinder centerline (with the head installed on the block). The port should be shaped to control the air completely in its most natural route; otherwise, a friction loss or turbulent blockage (two air streams flowing against each other) can result, due to obstructions and/or low pressure areas, either of which will cause a flow loss and disruption of laminar (streamlined) flow in the runner. As an example, consider an aluminum disc four inches in diameter, ¾-inch thick, with a 1½-inch hole bored through the center. The entrance to the hole of side one is radiused approximately ¼-inch to obtain the desired contour; the other side is left unradiused. The radiused side might flow-test at 5.35 inches of water, while the unradiused side, because of its improper shape, might flow only 2.38 inches of water. So the improperly shaped side decreased the effective diameter of the hole by about 33%

Of course valve seat and pocket design also affect air flow Tests have indicated that air does not pass a valve seat equally on all sides (circumferentially); therefore, the seat and pocket must be contoured (by hand), a process which consumes about one-third of the time invested in the "porting" of heads. Because air moves at its greatest speed past the valve seats, this phase of head modification is very critical. Ports, valve seats, and valve shapes (including valve backs) should be developed simultaneously Port cross-sectioning should be such that the port has at least 80% more capacity than the valve. For example, a 327 Chevy F.I. head might show a port capacity of 6.50 inches of H_2O, whereas the valve capacity of the same cylinder head at a maximum flow would measure only 3.30 inches. Porting the 327 would accomplish nothing beneficial; in fact, a performance decrease could result because of lowered air velocity. To increase the valve's flow capability a design change involving port *direction* and *elevation* would be required, rather than a change in port size. This would entail grinding the exhaust port to increase its capacity from 1.40 inches to 2.75 inches (almost 100%) to eliminate turbulent blockage caused by air flow down the shrouded side of the combustion chamber, past the valve and valve seat at a velocity too great to allow air flow turn (direction change), shutting off the port, and limiting flow to approximately 1.90 inches of H_2O. Incidentally, tests on the 327 Chevy exhaust port area have pointed up the fact that conventionally ported heads generally flow 1.90 inches of H_2O, regardless of the shape of the exhaust port exit!

The polishing of port surfaces can also be considered a "mind bender." Since, for example, the 327 Chevy ports have been determined to have about 80% greater flow capacity than the valves on large-displacement engines, there is little point in polishing these ports to a larger diameter. Also, vapor travel tests have shown that because heavier-than-air particles have a greater momentum and particle mass (back to our previous comment) than air, they tend to leave the air stream when flow direction is altered abruptly Their tendency is to strike the outer passage wall or surface on the outside of the direction of turn. If the wall is slick (polished), the particle droplets tend to slide down the wall; whereas, if

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the wall is rough (such as in a standard casting), the droplets tend to ride up on the casting peaks and reenter the air stream. So don't be too anxious to create mirror finishes in those port runners.

Extensive combustion chamber investigations have also been "flogged" by the head workers. It is a popular notion among "flow experts" that chamber shrouds should be ground and relieved next to the spark plug hole. Large gains have apparently been attributed to this practice, but recent tests indicate that flow can be reduced by as much as 10% after such modifications are performed. The fact that chamber wall areas near the spark plug often lack carbon deposits (while the rest of the chamber has such unwanted deposits) may have led to the assumption that high-velocity air causes a washing action. However, the major portion of air (about 80%) has now been found to turn from *underneath* the valve and into the cylinder *toward* the cylinder bore centerline before reaching the shrouded side of the chamber. When the air changes directions abruptly, it is now thought that suspended gases leave their state of suspension, taking a straight route and hitting the chamber wall, thereby causing the washing condition. Bluing sprayed into the intake passages during flow checks and under full vacuum has shown that heavy color concentrations are deposited along the shrouded side of the intake valve and the combustion chamber next to the spark plug location, verifying the separation of fuel and air theory.

Contemporary head modifiers are serious individuals. For example, AFR assumes the following procedure: Each head is researched completely before a grinder's services are called upon. Porting consumes about one-third of the time spent in modification; roughing-in, blending, and polishing valve seats to achieve the desired contours and flats are a part of an AFR "head job." Following completion of the valve job, the cylinder head is placed on the flow machine with the reworked valves in place, and the flow is checked to ascertain that maximum flow has been obtained. *Each* port is checked, for as much as an 8-10% variation in flow has been found from port to port. Each step is coordinated to make sure the finished product does indeed provide maximum air flow. The old flathead "Henry" is fast fading.

Results? You may be of the thought that "talk is cheap, but where's the action?" Well, one bona fide test was conducted at Fiasco Automotive in North Hollywood, California. A 396 Chevy-engined Chevelle of Richard Johnson and Al White was used. It was equipped with a single three-barrel carb, headers, an L-88 cam, and a stock three-speed automatic trans. After a year of strip competition, the Chevelle was posting 11.80 e.t.'s at a consistent 117 mph. On the "wheel," the car dyno'd at 400 hp (peak) at 5600 rpm. The AFRC heads were installed, and minor adjustments made to carb jetting, plug heat range, timing, etc. However, because the dyno's maximum hp reading was 400, it was not possible to register any increases in horsepower; but the dyno did reach maximum capacity at 4800 rpm rather than 5600, and it held at the 400 figure to 6400 rpm. Extrapolation of the horsepower curve indicated that about 470 hp was reaching the ground (590 hp at the flywheel).

Tests at the drag strip were just as interesting. The 20-run figures averaged 124.14 mph and 11.40 e.t.'s consistently (with one low of 11.38). Tire pressure was altered to handle the increased torque. the driver was quite impressed, and both the owner and driver indicated that the engine was more sensitive to tuning changes than it was without the "new" heads. The loud and crisp exhaust note was also noticeable (caused by the shape and efficiency of the exhaust ports), and one could recognize the car by sound alone.

Wrap-up? Volumetric efficiency is the label on the horsepower jug. More air, more pressure, more go. But considering the freshest flow data at our disposal, it now appears that mixture movement control toward and around the "short side" of the port runner/valve seat combination is the plan. Wide valve seats interrupt total flow, and the most critical zone of modification appears to be located just below the valve seat. "Aiming" the mixture flow may not really be the method pursuant to super horsepower extraction. But increasing the per-cycle volume of mixture (fresh *and* spent) is and the "head scientists" can be the key to this part of the plan. And if you're a super thinker, don't forget to include the cam grinders, exhaust system builders, and crank/rod/piston guys. They may not know it yet, but with the results achieved thus far, we're willing to wager that AFR-type groups will soon be subjected to a flow of customers not just trying to avoid any port in the storm.. of controversy? ■■

327 CHEVY F. I. HEADS
Air-flow chart

VALVE LIFT	STOCK 327 F. I. HEAD	A. F. R. "VELOCITER HEAD"	COMPETITION HEAD	"LARGE PORT" HEAD (Full-radius ports)
2.020 INTAKE VALVE — RAW FLOW DATA				
100	.300	.450	.380	.250
.150	.600	.900	.750	.500
.200	1.000	1.440	1.180	.820
.250	1.420	1.940	1.720	1.300
.300	1.900	2.510	2.250	1.750
.350	2.210	3.000	2.750	2.150
.400	2.430	3.220	2.880	2.420
.450	2.500	3.340	2.980	2.500
.500	2.620	3.400	2.930	2.500
.550	2.600			
1.600 EXHAUST VALVE — RAW FLOW DATA				
100	.200	.320	.210	.250
150	.420	.650	.320	.550
.200	.700	1.030	.620	.820
.250	.920	1.450	1.000	1.100
.300	1.050	1.950	1.310	1.350
.350	1.200	2.330	1.600	1.600
.400	1.300	2.520	1.820	1.780
.450	1.400	2.680	1.880	1.900
.500	1.430	2.720	2.030	
.550