Camshafts, Aurelia's
& classic thoughts !

Er zijn vele puristen die prijzenswaardig streven naar uitsluitend de originele toestand van een classic car. Soms wil iemand origineler dan de fabriek zijn. Op deze site zijn we gewoon nieuwsgierig naar achtergronden van de originaliteit. Over alle Classic Cars kan dit item gaan en tja, wat kan hieronder nog aan toegevoegd worden ... die *"Someone"*, waarmee het verhaal begint, zouden wij allemaal geweest kunnen zijn ! laatst bijgewerkt februari 09

door Francosporto

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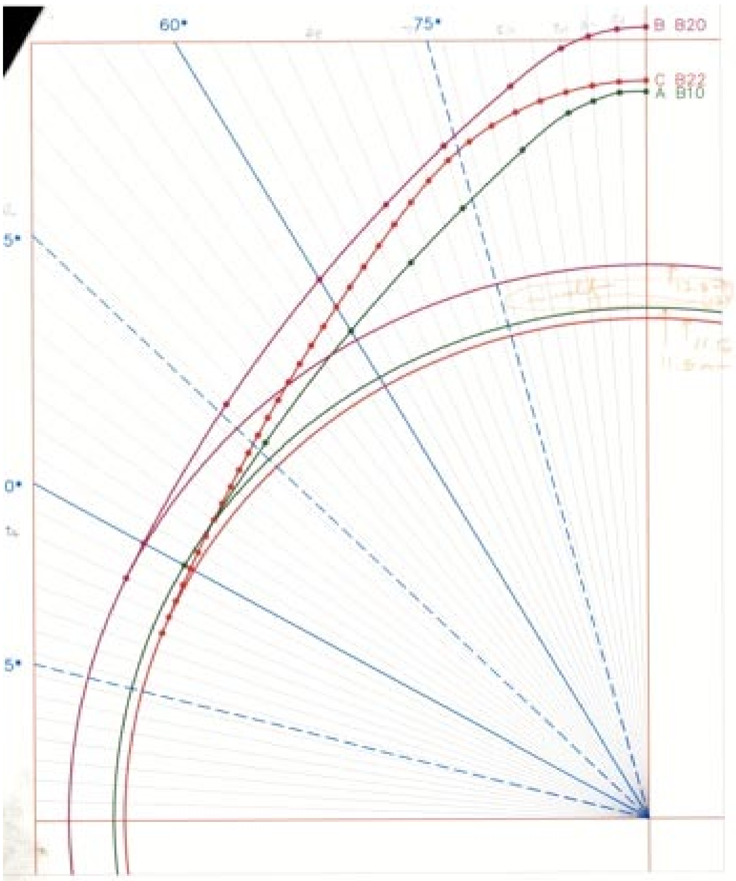
Hieronder dus voor de zekerheid voor jullie van 't internet geplukt (voor 't geval dat eea later niet meer "*online*" zou zijn) :
check it out baby to be shure on :
http://web.mac.com/geoffreyg/Cars/Home.html
Zo hoor je nog eens wat een ander er van denkt en wat komt dat ons allemaal bekend voor !
Kortom, very interesting classic thinking of mr. Geoffrey Goldberg, thanks a lot ......



a graph of the different cam lobes used in Aurelia cams from article on line
http://web.mac.com/geoffreyg/iWeb/Aurelia%20Tips%20/What%20cam%20to%20use.html

So what Cam to use ?

"Someone" once asked me (=Geoffrey Goldberg) "What cam should I use in my Lancia Aurelia?".

Here are some of his criteria and recommendations:

1. start by using the factory cam – the cars are remarkably well tuned and engineered to run with the factory cam. Setting them back to the way they were designed is the correct thing to do.

2. if you want more performance, identify why. Then the correct enhancements can be selected.

To start with, the engine should be made fresh and good. Many engines are not - they have low compression and while smooth, are not up to factory standards. Getting performance out of a tired engine, even if it seems good, is not an effective path. For example, some parts of the valve train wear significantly and effect performance. Getting all this truly back to factory standards is the first course of business.

Secondly, the carburettors and ignition should be carefully set up to factory or as new standards. Many carburettors of that period by now suffer from wear, especially around the spindle shaft. This causes them to leak air, thus making it difficult to have accurate tuning and setup. So too, jets may not be accurate to their standards, having been modified over time.

Some of the cars suffer from excessive wear on the cam - the early (up through S. 4) lifters were not of a good design and they promoted excessive wear of the cam lobe. So inspection of the lobe is important, as is changing the lifters to the later type.

Ignition is an area where technology can help. Electronic ignition is recommended. Once, a good running Aurelia engine, that ran very well, was put on a chassis dyno and performance started to die off quickly at 5000 rpm. This showed a previously unknown problem with ignition, as the points just weren't working well. Whether it was this car, or perhaps points in general - electronic ignition seems to enhance performance at both the low and upper ranges, promotes cleaner burning and more accurate sparking.

These changes to the car can be installed almost invisible and are easily reversible. A single small wire out of the distributor to a setup under the dash is all that you see. More power, better running, easier starting, enhanced durability.... Hard to resist.

3. carb sizing, Nardi, and cams

There are many variables in play here, and they are all interrelated. In many cases, whatever cam already used in the car is fine, but there is a limit to the air flow through the stock carburettors. This (I believe) is more common in the early cars – Martin Cliffe told me that he put an early Nardi setup on an engine with the stock B10 cam, and that the performance was enhanced significantly. His conclusion was that there was plenty of life in that stock cam, and thus changing the cam wasn't required.

So too, Tim Burrett has used a different approach - making a larger carburettor with larger venturis from a stock body. He gets good airflow, and has the simplicity of a single carb. He puts the big one on his race car for the races, and a smaller one for road driving, with good success.

People's perceptions of the performance enhancement with the Nardi 2 carb setup vary. As it is a difficult job to do, because you have to pull one head to get to all the manifold fasteners, so it is not often done on a stock car without other work being done at the same time. The Nardi setup certainly sounds great and makes good noise (intake air). Some don't care for it, meaning that it doesn't do much if everything else is left the way it was. More carburettors only helps if more air is flowing – and up to about 4000, it probably doesn't do a lot. There is additional gas on the accelerator pumps and that helps, but there is something to be said for the simplicity of the stock setup.

On the other hand, if the cam is a bit improved, and the Nardi setup is well done, aligned carefully and jetted right, it can be very satisfying.

4. What cams to choose from?

The best of the stock factory cams is the 3/4th series B20 cam, or even the B22 cam. These have a good profile and pretty good lift. Of course, this cam can't be used in the 5th/6th series cars, as those have a bigger base circle. But cams with these profiles have been made for the later cars, so that issue has been addressed.

Of the aftermarket cams, the original Nardi cam is far too radical. Its exhaust timing is extreme, and while it revs very freely, it is not a good street cam.

There is a cam made in Italy for Cavalito that is between a stock cam and the Nardi. I have not used this cam, but have data on it. On paper, it seems too extreme for the street, but Cavalito says not. Walt Spak has put it in one engine I know of.

Of the US aftermarket cams, most have come from a company in California called Megacycle who have made aftermarket cams for

Aurelia's since the 1980's. They have a lot of experience and they make a good one for the street - their # 90199 profile is a fine cam. I have had an engine with that cam as have Tony Nicosia and Ed Godshalk. This cam works well with a single carb also.

So too, Dema at Elgin Cams in California made a cam for me, which I have enjoyed as well. They are easy to deal with, fast, and very competent. Also, they are a bit more up to date with their profiling. I have their cam in a B24 engine which performs very well. More on that below.

5. What engine to have?

Which cam to use depends on what engine you want to have and how you want to use it. Each car has different needs, and the engine should be designed to address those.

I had a B20 4th series for many years, with a Nardi setup. It appeared to have a stock compression ratio, but this was never confirmed. It had the Megacycle 90199 cam, a nice cam that raises the performance modestly. In general, I was very happy with this car, it would pull to 5300 in 3rd gear up long Colorado hills forever.
It may have pulled higher, but I didn't try. It also passed my "Chicago" test – able to pull from a stop in 2nd gear. Its performance was balanced nicely between revving and pulling down low – I'd guess it was breathing better than the stock cam, but still oriented to lower end power.

The B24 Convertible is a different story. When restored, its engine had a new cam from Italy, a remake of the 4th series standard cam). The rest of the engine was stock. It ran well, but I found it a bit stodgy, even a bit sluggish. While I was not looking for a boy racer, this car just seemed a bit too tame. I used to yawn when driving it. I concluded that the car was struggling with extra weight – it was 2780 lbs on the road. While this was equal to the B20 4th series (2720 lbs), the B20 had seemed so much more alive – thus the decision to enhance the engine on the B24.

After much research, a second engine was built up for this car, with the following:

- Pistons – 9:1 compression
- Carbs – Nardi setup, redone
- Ignition – electronic
- Cam – new one reground by Dema in California.
- Exhaust – stock
- Flywheel – lightened to 15 1/2 lbs

The parameters for the cam were that it have low end power as well as some enhanced top end breathing. I had seen a hot Aurelia in California (10.5:1 compression) and didn't want anything that hot. The

Megacycle cam seemed like a nice cam, and something like that would have been fine, but they are difficult to get cams from.

Elgin Cams is run by Dema, a man who has spent many hours on cam design and engine theory. He focused on increasing lift (6 mm) and a better "ramp up" design in order to get power. The cam is not a race cam, but one for the street. Elgin Cams reground my cam and sent it back in a few weeks. They developed a profile around the standard lobe angle (112°), so it wasn't radical. Barry Sales (PHP) fiddled with the cam timing with the engine on the dyno to get the cam timing to give the best low-end torque we could get. At the end, we got about 140 ft.lbs. of torque, and 140 hp at 6000 RPM, and the engine was still pulling up, with no sign of quitting.

The B24 (as do all the later Aurelia's) suffers from too much weight. The light responsiveness of the earlier cars gives way to a bit of sluggishness, a bit of softness on the turn ins, a bit of middle age punch. As shedding weight was out of the question, adding power was the only other fix.

When the engine was first installed, several things were noticed:

- the engine pulled very well from 4000 on up, and would bury the tach (over 6000) in 3rd without a problem. It kept making power high up.
- it smoothed out down low once the jetting was changed (after about 5,000 miles in the car). We dropped the main jets to 130 from the 140 used in the dyno run. Starting from a stop in second is possible.
- it's a lot of fun to drive. Cruising at 2500 is fine, but at about 3700 noticeable power arrives. That's a bit over 75 mph, not suitable for slower expressways.
- the lighter flywheel and cam makes gear shifts much smoother. The gears just "snick" into place, and that older 6th series "lag" is gone.

The goal was to get some performance back – along the lines what I imagined Francesco de Virgilio would have done for the 1955 cars. While not up to the work they were doing with SOHC Aurelia engines, the result is very close to a Flaminia 3C 2.5 engine, a worthy goal. While its breathing may be a source of some of the improvements, careful assembly, better pistons and 9:1 CR, electronic ignition and a superior cam profile are probably what gets this engine to that level.

We have all seen the engine upgrades which are too radical and no longer maintain the Lancia character we all love. This is not one of those. This is a modest upgrade, one where that feeling of the Aurelia engine running out of breath at 5000 RPM is gone – this cam pulls and pulls, without ever losing a step.

Certainly the Megacycle cam is a good one too. It keeps the Lancia character and opens up breathing a reasonable amount. Steve Snyder and Ed Godshalk have had that cam in their engines also, and they tell of pulling past 5000 RPM without any problems. Perhaps with electronic ignition it would perform better.

The Elgin cam (and the rest of the work done on this engine) takes the car up one more step – more in the sporting side of GT, but not a hot car. It is still keeping the Lancia character and perhaps even fulfils it more. There is a difference from the Megacycle and stock cam – the car loses a bit of its "toodling" character, and picks up a whole other dimension. It's a bit like an Alfa engine now, with a very linear and full power curve. It is a lot of fun to drive. It makes more power and torque than the standard engine over 2,000 RPM, so its not that anything is lost along the way. It's just that it's a lot of fun to wind it on out…. For more mundane driving, I wouldn't go that way. For tight twisty roads, it's a hard call: it's so much fun to rev up this engine that you can lose your concentration on the road. On the other hand, the engine is so much more responsive that it is just the right tool to have at hand.

It would be interesting to see what it is like with a single carb, or even in the lighter Spider. On paper, it doesn't seem necessary at all – but when you drive it, you never look back at the other engines. A single carb, yes, but the enhanced performance is pretty seductive.
GG 12.16.06

For this next piece of general camshaft information, have the light alloy Lancia Aurelia V6 block in mind and you can do a lot of classic thinking. Follow this "*all round*" **Camshaft-Gurruh** as your performance guide.

Many thanks from Francosporto to mr. Elgin who is learning us a lot. See his interesting website www.elgincams.com while it is still online !

Performance Camshafts

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The goal in rebuilding an engine is to return its performance and reliability to what it once was. The goal in "building" an engine is to increase its power within the capabilities of that engine without unduly ruining its other performance factors — drivability, mileage, reliability, and perhaps smog-law compliance.

Building a performance engine is not just a matter of tossing "speed parts" like a big cam into it, nor is building high performance or racing engines anywhere near as simple as some people imagine. Change *one thing* and that's a different engine. Change *many* things and you have entered another profession, as an *engine developer*.

The package of professional skills you acquired as a rebuilder still apply to building high performance engines, whether for yourself or for customers. But a few advanced skills must also be acquired (or rented). So must further, up-to-date insights, for making effective decisions long before the first cutting edge touches metal. Then knowledge is power.

The topic of engine performance is enormous, and enormously complicated. So one article can lead only so far. We try the possible. The May 2004 issue of Shoptalk carried my article entitled "Camshafts" that covered the basics of how engines operate across six working cycles, how cam designs affect those cycles, and some recommendations. This article looks for a moderate but real increase in power to a production engine that must run well at reasonable rpm on pump gas.

Find the Balanced Package

Before *changing* anything on an engine, closely examine it in detail. See how each aspect of the engine balances against the others. Maximum usable rpms are limited by resistance to gas flow through the engine, and maximum piston speed is limited by stresses from the inertia of moving parts. Bring the weaker features of the engine up to the performance level of its strong points.

Focus your attention close to the action, in the combustion chamber and ports. The better the burn and freer the flow through those, the more power develops. The better the balance *among features* in the combustion chamber and ports, and the better the cam(s) choreograph the activity there, the more power develops. But the further away you wander from the action, the less improvement comes from your efforts. Chroming the cat-back exhaust system looks pretty but accomplishes nothing.

In the big 2-valve iron V8s, most of us are familiar with, the short block is generally a pretty strong assembly, usually capable of handing quite a bit more power than it now puts out in a regular passenger car. With the exception of its pistons and static compression ratio, build much the same short block as you would for 100,000-mile service life. Power potential lies upstairs, in the heads, the intake and exhaust systems, and especially in the right performance cam to direct the action.

Coming in the other door are many modern, perhaps unfamiliar, alloy 4-valve engines. Most of their heads already flow air extremely well. Slightly different camshafts can release further potential from these heads and make more power than the production lower end can handle in one piece. So here your first task becomes structural. Replace aluminum threads with steel. Fit a permanent "girdle" around free-standing tops of cylinder bores to encourage them to sit still for the honing head, and later for faster-moving pistons. *Then* fine-tune the top end.

Figure out what the engine want to do. Give it the cam(s) that make that happen.

Rod Ratio

Somewhat surprisingly, the connecting rod affects intake flow. More specifically, the ratio of the center-to-center length of the connecting rod to the stroke of the engine — termed the rod/stroke ratio or just rod ratio — has a significant effect on Volumetric Efficiency. More surprise: the effect of rod ratio differs for 2-valve *vs*. 4-valve engines.

Airflow in a normally-aspirated engine is driven into the cylinder only by the ΔV between the 14.7 psi of the atmosphere and whatever *less* pressure is inside the cylinder at that instant. The greatest difference in pressure occurs shortly after the piston is moving downward at its fastest. Piston velocity peaks when the rod and the crank throw are at right angles to each other.

The exact number of degrees ATDC for maximum piston velocity can be found in any trigonometry table. The Tangent of the angle ATDC is twice the rod ratio for that engine. Then add 2-3° for time for that news to reach the intake valve at the speed of sound and affect airflow there. The sum should come between 70° and 80° ATDC. The shorter the rod ratio, the earlier that piston velocity peaks.

Airflow in 2-valve heads begins slowly. So airflow through these heads responds to a long rod ratio, close to 2:1, for maximum draw after 75° ATDC.

By comparison, a 4-valve engine flows a lot more air at the lower and mid lifts through its smaller valves and ports. This allows its rod ratio to be smaller without hurting power, more like 1.55:1. Check the rod ratio in a Honda. Airflow demand in the 4-valve engine occurs closer to 70° ATDC.

Another flow difference between 2-valve and 4-valve heads is the ratio of exhaust flow to intake flow. Exhaust valves and ports are always made smaller than the intakes, because exhaust flow gets pushed first by high cylinder pressure, then by the piston on the way up. In 2-valve engines the exhaust port flows between 60% and 80% of the intake. Exhaust flow in 4-valve engines is very high, somewhere in the 80% to 90% region. Later we'll see how these factors affect cam selection.

Compression Ratios

It is important to realize that the engine sees three different compression ratios. One is the static ratio which we are all familiar with: clearance volume + swept volume, divided by the clearance volume. A number like 9:1 is a common static compression ratio.

The second is the effective compression ratio, which the engine sees when the intake valve closes against the valve seat. A number like 7:1 is common. This is determined by the interactions of the static compression ratio, the rod ratio, and cam timing for closing the intake valve. (Wrist-pin offset has an additional but minor effect.)

Third is the dynamic compression ratio which is when the engine is in the peak power range and the volumetric efficiency is above 100%, then the cylinder pressure-compression, when the intake valve closes, is at its highest, example above 8:1.

Building an engine for more performance often means raising the *static* compression ratio close to 10:1, but keeping the *effective* compression ratio not much over 7:1. Anything lower gives up power. Anything much higher will not run at low speed with WOT on pump gas without detonating and destroying itself.

Head Examination

Before selecting a cam, long before *changing anything*, take benchmarks to determine what a production head already provides, feature by feature. Trust no published specifications. *Measure everything*. What diameter and width are the valve seats? What angle? How did the factory finish the top and throat cuts? Is there a good radius behind the seat to direct airflow through the open valve curtain? Does the backside radius of the valve complement that?

Which way does the port aim mixture into the cylinder? 2-valve heads direct flow around the circumference of the cylinder in a motion termed *swirl*. 4-valve heads send flow in head-over-heels *tumble* down the bore. Too little *or too much* of either motion stalls flow. Is the mixture aimed dead into the cylinder, around its circumference in a swirl, or splat up against a cylinder wall? Hello BBC.

Is airflow shrouded after it passes the valve by running into a side of the combustion chamber? Was the chamber cast with some *intentional* shrouding? Check a SBC Vortec chamber. GM did something clever there for guiding flow *past* the valves. Is the spark plug well out of the way of the incoming air/fuel charge, or does it look as if it will be soaked silly before it *attempts* to fire? Will that affect how plugs should later be indexed?

Look deeper down the ports. Do the machined cuts blend smoothly into "as cast" surfaces? Do lumps or ridges protrude where casting cores once *almost* aligned? *Feel* inside. How sharp is the turn to the critical short-side radius? Did casting cores leave a sharp edge there to turbulate and stall flow?

What is the overall shape of the port, both lengthwise and in cross-section? Does the port narrow gradually along its length to accelerate airflow, or change size suddenly? Does it address the port from a high angle and turn smoothly into the bowl area, or does it send airflow along a long flat trip across the head then demand a sharp drop at the valve? (Hi there, Jaguar XK.)

Is the cross-section square with dead corners of zero flow, or perfectly round so flow spins this way and that but not in? Is the exhaust port just a big hole in the head? (Hey, Mopar B. Meet Ford Cleveland.) Where does the cross-sectional area of the port become smallest, and how small is that? A new skill at casting with latex can bring that shape outside for more direct and insightful analysis.

What does the finish of the chamber look like? It does not have to be polished (although doing that does not hurt), but surfaces should be reasonably smooth with no sharp edges. More power makes more heat. Heat seeks peaks. Gently bevel sharp edges, or the engine will pre-ignite off its own internal glow plugs.

Go with the Flow Bench

So far we have examined heads much as any avid gearhead would on his garage workbench. We now know what they *look like*. But how do they *flow*? Take them to a flow bench.

A flow bench is the measurement tool to analyze airflow through the ports. A bench can now be used in three modes. First, to measure the airflow rate through each port as a function of valve lift. Then to probe inside ports to analyze the details of airflow. Finally – and this is *very* new – attach a wet-flow adapter to the bench and actually *see* the dyed flow leaving the port and entering the cylinder. All three procedures add up to help you decide how to address these heads.

Air flows through intake ports into an "adapter" exactly the same diameter as the cylinder and two bore lengths long. Air flows from the chamber through exhaust ports into a stub stack the same diameter as the header pipe and at least eight inches long. Part of the fun of operating a flow bench is getting to fabricate and inventory an interesting assortment of adapters.

Take airflow measurements in cubic feet per minute across *the entire* range of valve lift, at every increment of 1,27 mm. Continually adjust the flow bench so it keeps working at the same "depression", the working pressure difference through the port, to keep your measurements meaningful. For later comparison with other heads or your modifications to these, always work with the same depression.

The SAE recommends a depression of 71,5 cm of water (about 1 psi). Some experienced engine developers use less, maybe 40,5 cm. A few use more. Careful. Depressions of much more than 101,5 cm produce falsely optimistic flow numbers. Truly bad ports can be *made* to flow *great* numbers at unreasonably high vacuum. But later they'll die on the engine, and that customer will be very unhappy about your services. As with a dyno, never rig the system just to make big numbers. It's pointless. Accuracy is an operator skill, painstakingly acquired. And findings vary from bench to bench, even among the same model, by as much as 10%. Conversion factors for readings at different depressions are not reliable. So don't bother "racing" somebody else's flow numbers. Believe what *you* see.

Measure *every* port. If one port flows less than the rest, that cylinder will need different spark timing from the others, and total spark advance will be compromised for the weak cylinder rather that set for best power from the good ones. Low to mid lift is very important on the exhaust valve. Mid to high lift is more important to the intake. But measurements of intake flow at lift as low as 1,27 mm is also important. That gets flow going and also accepts the final pulse of mixture arriving by inertia before the valve closes at high rpm.

Findings should be tabulated for later reference, but for analysis *graph* all the flow numbers as a function of lift. Trends jump out at you from graphs. At what lift does the rise in flow level out on the intake and exhaust sides?

What is the ratio between intake and exhaust flows? The ratio should remain quite steady across the range of lift. If not, there is an opportunity to find power. I prefer to port most heads to achieve exhaust flow 75-80% of the intake. Exhaust flow above 90% may make power at the drags, but a lot of intake charge goes sideways out the exhaust valve. Fuel economy suffers and so does torque.

Experiment. Go a bit beyond your expected maximum lift, to find out what happens there. Try a valve with a different shape to its backside radius. See how much a clean back-cut improves flow. If you have a surplus (say, cracked) head to play with, try different seat angles, widths, and multiple top and throat cuts. Notice how a 30° seat flows great at low lift but dies at high lift. Radius the top edge of the exhaust valve margin, and compare flow numbers with a square margin. If the customer demands bigger valves, try *just one* first to see where this program is headed.

What the bare head tells you is a baseline. Now attach the intake manifold and carburetor (or FI intake and throttle body). Everything changes. I have seen a loss of 10-60 CFM after the intake system was installed, on cylinder heads properly ported with valve job completed. After the intake was installed I have also seen great variations between flow numbers among different intake ports, as much as 20 CFM. Most CFM numbers quoted are *without* the intake manifold installed. This is mistaking the mission. It is flow through *the entire* system that the engine sees. Corrections here pay off big.

Next, probe the flow with a Pitot wand. Find pressure differences, flow velocities, dead spaces, and intriguing mysteries. Does the smallest cross-sectional area of the port restrict the air flow, creating turbulence, or is the port *so* large there that very little velocity develops down the port? Is the intake port efficient all over its area, or is the floor and one corner dead? When you find a dead space, fill that with clay and see what happens next. If it's good, epoxy the solution in permanently. Check along the floor of the port on the short-side radius. Does flow follow the curve, or is it breaking off?

The very latest bench equipment can now view *wet flow*, dynamically and in detail. This is an extremely promising process. Airflow is one thing, but a running engine flows air "wet", mixed with gasoline in a ratio around 14:1. Wet flow more closely approximates what happens inside engines. And for the first time you can *watch* dyed mixture flow into the cylinder – or better – videotape and freeze-frame it across the range of valve lift.

Wet flow is a powerful tool for analyzing mixture motion into cylinders. Testing has shown that the flow through each intake tract must be individually matched as a partner to its port so that each cylinder receives the same amount of mixture and close to the same degree of mixture motion.

If some cylinders are weak from poor motion, spark timing among cylinders could vary as much as 6°. Timing the engine for the poor cylinder loses power. Timing set for the better cylinders burns the piston in the weak cylinder.

Wet benches map the flow vortexes inside the chamber. Even the big boys are learning from this. Chrysler's new head for Pro Stock couldn't win. A wet bench discovered a huge vortex soaking the plug. Chrysler reshaped the chamber. Dart, the respected maker of aftermarket high-performance heads, now wet-flows their designs.

Engine Cycles and Cam Timing

Once you have the particular performance characteristics of the heads carefully mapped, use that information to select *the one* cam that makes the engine make power like it wants to. Compare your test results against what the engine experiences while it goes through all six cycles.

Engine cycles are determined by the direction the piston is traveling and the timing of the openings and closings of the valves — collectively termed valve-timing events. Timing these events becomes complicated because a lot of compromise must be made in order to balance out all of engine operating cycles. The May 2004 article outlined the six engine cycles of a four-stroke engine. This time we'll walk through each cycle in turn, now from the viewpoint of determining how changing every valve-timing event affects other cycles, and how balance builds power.

------- *The Power Cycle: TDC to Exhaust Valve Opening*

By the time the crankshaft reaches 90° ATDC, cylinder pressure has dropped greatly and most of the power that can be recovered from it already has been. So opening the exhaust valve well before BDC loses less power from the power cycle than it later gains across the following cycles. The lower the rod ratio, the faster cylinder pressure drops.

-·------ *The Blowdown Cycle: Exhaust Valve Opening to BDC*

The blowdown cycle relieves excess (but unrecoverable) cylinder pressure and begins clearing exhaust gases off the energy of their own pressure. Otherwise the piston would have to push all the exhaust gases out of the cylinder on the next up-stroke, lowering horsepower from a pumping loss.

The timing for Exhaust Opening is the least important of the four valve events. It can be anywhere between 50° and 90° BBDC, so its timing is easily adjusted to match the performance characteristics of that engine.

With higher compression ratios the burn rate is faster, so the exhaust valve can be opened earlier, which aids in the cylinder blow-down. With lower compression ratio (static 8:1 or lower) you want to delay the exhaust opening as late as possible in order to utilize the last usable bit of pressure that is on top of the piston. But that hurts the top end horsepower, because the blow-down period is no longer as effective.

------- *The Exhaust Cycle: BDC to Intake Valve Opening*

The piston reaches maximum velocity at about the same number of degrees BTDC as it did ATDC on the way down, or a degree or so sooner with offset wrist pins. The exhaust valve must be open sufficiently by this time so that spent gases in a hurry meet little resistance against being pushed out.

How far the valve must be open is known from flow-bench data. The proper cam meets that need from a combination of timing, total lift, and its rate of lift (its "velocity").

------- *The Scavenge Cycle: Intake Valve Opening to Exhaust Valve Closed*

The scavenge *cycle* occurs during the overlap *period*, when intake and exhaust valves are both open at the same time. The intake valve is just opening. The exhaust is closing but not yet seated. Overlap is what the cam and valves are doing, dictated by the combination of total cam duration and the locations of lobe centers. Scavenging is what *the engine* is doing with that.

A good number of engine processes (and a few unsolved mysteries) are going on now simultaneously. The most important are (1) scavenging the last of the exhaust gases as much as possible from the clearance volume, where the piston cannot reach to push them out, and (2) initiating intake flow into the cylinder *without* wasting very much of it out the open exhaust valve.

Overlap duration increases as total duration increases, and it also increases as the lobe center *decreases*. Increasing the time for Overlap makes more time for scavenging at high rpms. Residual exhaust gases kill power twice over: they displace their volume in incoming charge, and later during combustion they absorb heat that should have gone into making power. At 5000 rpm an engine with a high-performance cam carrying 55 degrees of overlap must complete the entire scavenge cycle in less than two *thousandths* of a second.

In standard engines, valves are open together for only 15-30 degrees of overlap. In a race engine operating between 5000 and 7000 rpm, the overlap period is more like 60-100 degrees. The penalty for so much overlap in a street engine is very poor running at lower rpms, when a lot of the intake charge has time to sidetrack directly out the open exhaust valve. Mileage goes South. Heads overheat from fuel burning in exhaust ports. The engine runs hot. The exhaust system gets fueled like a blowtorch. The tailpipe turns white. Catalytic converters fry. The buyer blames the cam grinder.

Timing Exhaust Closing must be balanced against flow through the intake port. If the intake port flows poorly from being too small (or *too large*) then later Exhaust Closing might help to initiate intake flow. I consider this only as a last resort for kick-starting a lazy intake port. It always carries some charge out the exhaust valve, wasting fuel and all that.

Make the overlap period as short as will complete the job of scavenging. Factor in the effects from the combustion chamber size and shape (including the shape of the piston top) and shrouding near valves. Balance power goals with other requirements for the intended usage, such as idle quality, low-speed throttle response, fuel economy, and smog test compliance.

------- *The Intake Cycle: Exhaust Valve Closed to Intake Valve Closed*

I consider Intake Valve Opening the second most important valve timing event, because that does two important jobs. (1) It initiates the Scavenge Cycle and (2) it begins lifting the intake valve out of the way of the incoming charge. The air/fuel mixture began entering the cylinder during the Scavenge Cycle, builds to a maximum, tapers off, then packs in a final gulp.

The intake valve is in a race with that pressure differential at maximum piston velocity that drives intake flow. The valve always loses this race, because max draw happens between 70° to 80° ATDC, yet the intake valve does not open fully until it reaches centerline, down around 105° to 115° ATDC.

When you can't win, do your best. Get the valve out of the way *as far as possible* by giving it a fast rate of lift, a "high velocity". Much the same *could* be accomplished by more valve lift, but then the nose of the cam gets pointy and *real stiff* springs are needed for closing the valve – a combination not favorable to very long service life.

The Intake Closed point – when the valve seals on the seat – *is the most important valve-timing event*. This event governs both the engine's rpm range and its effective compression ratio. Closing the intake valve later optimizes intake flow for high rpm and allows inertia to pack in its last gasp of air. The drawback to that is back-flow at low rpm. But closing the valve earlier shuts down rpm. Pick your operating range.

------- *The Compression Cycle*

The piston compresses the air/fuel mixture to a high enough pressure and temperature for it to be ignited efficiently by the spark. The effective compression ratio must be high enough to compress and pre-heat the air/fuel mixture for a fast, complete burn.

But *too much* heat and pressure kick off the whole charge at once in the destructive explosion of Detonation. When pistons taken from a blown engine show ring lands melted as if by a cutting torch, that was by Detonation. (If a hole has been blasted through *the center* of the piston crown, that came from a hot spot in the chamber *pre-igniting* the mixture.)

Tweaking for idiosyncrasies, nitrous, supercharging, turbocharging

I Prepare the cylinder head and fit a good, small-diameter exhaust system. To increase the rpm band, increase the compression ratio. I do not advocate extra high lift, long duration, or very high compression in a street car. I use velocity. I have never seen a normally aspirated engine make more power by lifting beyond the flow capacity of the head.

Within limits, experienced cam makers can juggle timing events to customize valve action to the special requirements of that particular engine. Careful here. Not all valve timing is equally important. Exhaust Opening may be re-timed with little impact elsewhere. But Intake Close is tied closely to the static compression ratio, and cannot be re-timed very far without upsetting the dynamic compression ratio, cylinder pressure, resistance to Detonation, burn rate, rpm range, and just about everything else that makes power. Intake Opening is slightly less important, and Exhaust Close less than that. So juggle needs of the engine against the importance of timing events.

I find it amusing to see people treat the 4-valve engine like 2-valve engines when they select cam durations and lifts. Timing and lift for the 4-valve engine must be made different, due a 4-valve's quicker air flow velocity as well as its high ratio of exhaust to intake flow. Even with only moderate total cam duration, a cylinder under a 4-valve head sees enough air flow by 75° ATDC. For example, a high-performance 2-valve engine for the street would need 270°-280° of total duration, but a 4-valve engine would require only 250°-260° total duration for equivalent performance. Any more duration closes the intake valves so late that the engine would become very peaky, hardly suitable for street driving. 280°-290° for the 4-valve engine would be the equivalent to 310°-320° on the 2-valve engine.

In a 4-valve engine the intake and exhaust cams can use the same duration until the intake cam gets into the 270°-280° duration range. In some production 4-valve engines, its good exhaust flow can *over*-scavenge cylinders. Less duration on the exhaust would help that.

Timing the Exhaust Opening event should be re-examined whenever an engine begins using a supercharger, turbocharger, or nitrous oxide. Be careful with a 2-valve supercharged engine. The extreme pressure still in the cylinder can bend the valves and pushrod if the exhaust valve tries to open too early against it. Turbocharging requires wider lobe centers to narrow the overlap period. Nitrous responds to slightly wider lobe centers and more duration so the exhaust valve opens earlier to relieve the higher cylinder pressures nitrous generates. Pick you power goal. Balance *the package* for it.

I hope that this information as well as the May 2004 Shoptalk article will help you better understand the very complex internal combustion engine. Happy tuning!

For a glossary on camshaft terminology, visit Dema's website: www.elgincams.com