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Bio: Kevin Gertgen Graduated with a BS Mechanical Engineering from University of Minnesota in 1978 specializing in internal combustion engines. Worked for Ford Motor Co from 1978 to 1992 in the Dynamometer Lab in the Engineering Center in Dearborn MI. Started Performance Trends in 1986 with release of Drag Race Analyzer, followed quickly by Engine Analyzer. These were two of the first, relatively sophisticated engine and vehicle performance simulation programs for the PC. Performance Trends has gone on to add 25 other software titles to its product line, and several engine and vehicle testing tools. These include dyno testing software and electronics, vehicle data loggers, cam test stands, valve spring testers, flow bench electronics and options, and much more.

Compute This…

Personal computers are now common place in most engine building shops. They are used for CNC machining, Cad/Cam work, crank balancing, bookkeeping, etc. When your computer goes down or you are learning new software, nothing can be as frustrating. However, used for the proper application with the proper training, they are huge time savers, and let you do things previously thought impossible.

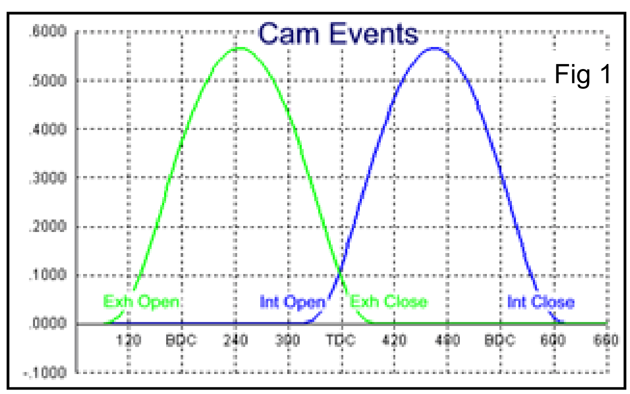
One application which has been around a while is the engine simulation program. You've probably seen the smaller ones for under $100. These are useful to give you an idea of the performance ***potential*** of some simple inputs like bore, stroke, head flow and cam specs. At the other end of the spectrum are programs you can lease for $50,000 per year. These can be so complex that it may actually be easier to build and dyno the actual engine then figure out all the info they require.

Performance Trends' Engine Analyzer Pro is a good compromise between these two extremes. It has relatively simple inputs, and lots of example engines and components preloaded, so you can build and modify an engine quickly. But the calculations going on behind the scenes are about the same as in the $50K program.

The most common use of an engine simulation is to pick a good cam for a particular engine combo. If you have a dyno, you may want to find 2 or 3 good cams on the computer, and then dyno each to pick the best. That is a whole lot easier than dyno testing 10-20 different cams.

Picking the correct cam is one of the most complex and critical aspects to building a competitive motor. You first have to worry about it making the best performance for a particular RPM range. Then you have: Does it make enough idle vacuum for the street? Are the ramps so radical it will bust up the valve train? Will I have piston-to-valve clearance problems?

When it comes to performance, each cam event is a tradeoff. For example, open the exhaust valve too early and you waste the cylinder pressure which is pushing on the piston making power. However, keep the exhaust valve closed too long, and the engine can't get rid of all the exhaust to make room for the fresh intake charge so you loose power.



Valve overlap is the time that both valves are open at TDC. If you look at the cam events which affect overlap (exhaust closing and intake opening), they are even more complex. That's because what happens during overlap is strongly affected by the tuning pulses in the intake and exhaust runners. If you have good tuning pulses, the flow continues from the intake into the chamber and out the exhaust. If there is too much overlap and these pulses are very strong, you can actually have a lot of fresh air and fuel going right out the exhaust. This is called "short circuiting", which wastes fuel and can really raise exhaust temps. If you have bad tuning pulses, you can get "reversion", where the exhaust blows back up the intake port.

But the most critical cam even is intake closing. All intake systems set up some type of "ram tuning" effect, where the piston pulls in the intake charge during the intake stroke. At BDC, the piston starts moving the other direction, but the inertia of the intake charge wants to keep filling the cylinder. These 2 opposing actions causes pressure to rise at the intake valve for a short period of time, typically 20 to 60 degrees of crank rotation some time after BDC.

The strength of this "inertia tuning" pressure pulse depends on RPM, and the length and diameter of the intake runner, flow restrictions, plenum size, and other ducts entering the plenum (like a carburetor or EFI throttle body with zip tube). These pulses can be 5-10 psi for short periods of time. If you don't keep the intake valve open long enough after BDC, you will not take advantage of this free supercharging effect. If you keep the valve open too long, the pulse will be gone (or worse, and even a vacuum pulse present) when the intake valve is closing.

These tradeoffs change as the engine goes through the RPM range, as the intake and exhaust tuning pulses change because of particular runner lengths, port volumes, the particular combo of engine bore, stroke and head flow change, etc. You can see with so many tradeoffs for each cam event, picking the best cam on a dyno is lots of "cut and try", even for the experienced engine builder. If done with a computer, you really need an accurate and thorough computer simulation which take all these effects into consideration.

Table 1: 420 SB Chevy "Test Mule" Baseline Specs	**Intake**	**Exhaust**
Flow at 28", CFM	276	198
Duration at .050	256	256
Tappet Lift	.366	.366
Rocker Ratio	1.6	1.6
Centerline	108	108
Open @ .050	20	56
Close @ .050	56	20

So, what does all this theory actually look like. Lets try a simple test with the Engine Analyzer Pro simulation. Our test "mule" will be a 420 cid small block Chevy, with the specs in the table. Lets make a change just to the intake closing event to keep things simple. We'll make a big change so we can easily illustrate what is going on, reducing and increasing the event by 24 degrees.

Figure 2 shows the torque for these 3 tests, Figure 3 shows the horsepower. If you know your engines, you see what you would expect. The bigger the cam (the later the intake closing), the less the low end torque but the more the higher end torque. Torque at high RPM means horsepower, and the HP graphs from these 3 test proves this out. The cam with 80 degrees for intake closing is so late that it doesn't show any improvement until 6500 RPM.

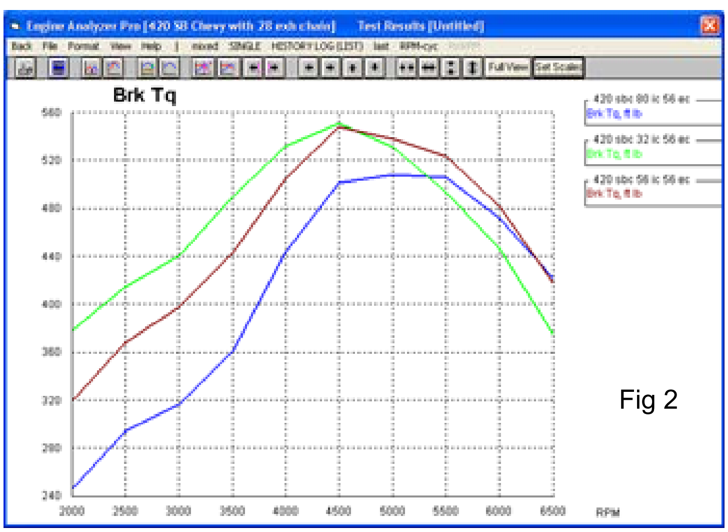


Fig 2

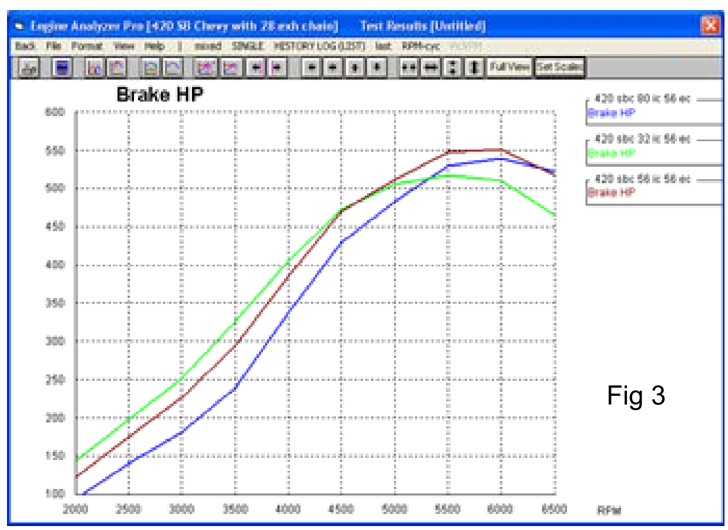


Fig 3

The Engine Analyzer Pro lets you see inside the engine, but graphing many of the internal workings of the 4 stroke processes of compression, expansion, exhaust and intake. Figure 4 shows 3 graphs of these internal workings, namely Valve Lift, Intake Port Pressure, and Intake Port Velocity at 6000 RPM.

Valve Lift is somewhat familiar to most engine builders. It is cam tappet lift times rocker arm ratio, then subtract off valve lash. You can see for the 3 conditions tested, only the Intake Closing event is changed, which shortens up the closing ramp.

Intake Port Pressure is what was talked about earlier, the inertia tuning "ram" effect. During the intake stroke, port pressure is low, well below atmospheric pressure of 14.7 PSI. Then at BDC, when the piston has stopped and starts coming back up in the cylinder, the pressure starts to rise as the column of air has to slow down. The graph shows the pressures go 7 to 8 psi above atmospheric pressure. The graph also shows the duration of the ram tuning lasts about 120 degrees, peaking at about 60 degrees after BDC.

Intake Flow Velocity is the speed ***and direction*** of the intake charge going through the intake port right before the valve. A high velocity means a lot of intake charge is entering the cylinder, which is great for making HP. A negative velocity means that flow which was already in the cylinder is being pushed back out into the intake port (sometimes called flow reversion) which means lost HP.

The Intake Flow Velocity shows the reason for the different torque and HP results for the 3 cam timings at 6000 RPM. The green graph (32 deg intake closing) is being cut short, falling more quickly than the other 2, labeled “Lost Flow Potential”, and that is why it only makes 511 HP at 6000 RPM. The blue line (80 deg intake closing) shows reversion which is why it only makes 539 HP. The dark red line shows the best shape, of good flow velocity through the closing process, but nearly no reversion, which is why it produces the best 551 HP.

Figure 5 shows the same 3 sets of graphs, but for 3000 RPM. The Intake Port Pressure shows a much lower ram tuning pulse at intake closing, of only a couple of PSI. The Intake Flow Velocity shows that all 3 cam timings produce reversion at intake closing. The 32 deg intake closing shows the least reversion and why it produces the most HP at 3000 RPM of 251 HP. The 56 and 80 degree intake closing events product only 227 and 181 HP respectively. For better HP at 3000 RPM, you would want an even earlier intake closing event, but I guarantee you it would not produce any HP up at 6000 RPM.

If we wanted to delve further into the effects of how adjusting the intake closing effects HP, we could look at pumping work (the work the engine must exert to ingest and expel the air charge), residual fraction (how much burnt exhaust remains in the chamber from the previous cycle), how the residual fraction affects the requires spark advance, etc. Or, we can do what is done by most Engine Analyzer Pro users, and most dyno operators. You look at the resulting torque and HP curves and pick the cam that produces the best overall performance you are looking for.

Luckily, that is very easy to do with the Engine Analyzer Pro. It has a feature called “Chain Calculations”, where you set up the program to try hundreds of combinations of specs, and have the program sort out which produces the best peak or average torque or HP over a particular RPM range. You can also have the program disregard combos which do not produce a certain amount of idle vacuum. This helps ensure the results you keep will work on the street, or in certain race classes which require a certain minimum vacuum.

Fig 4

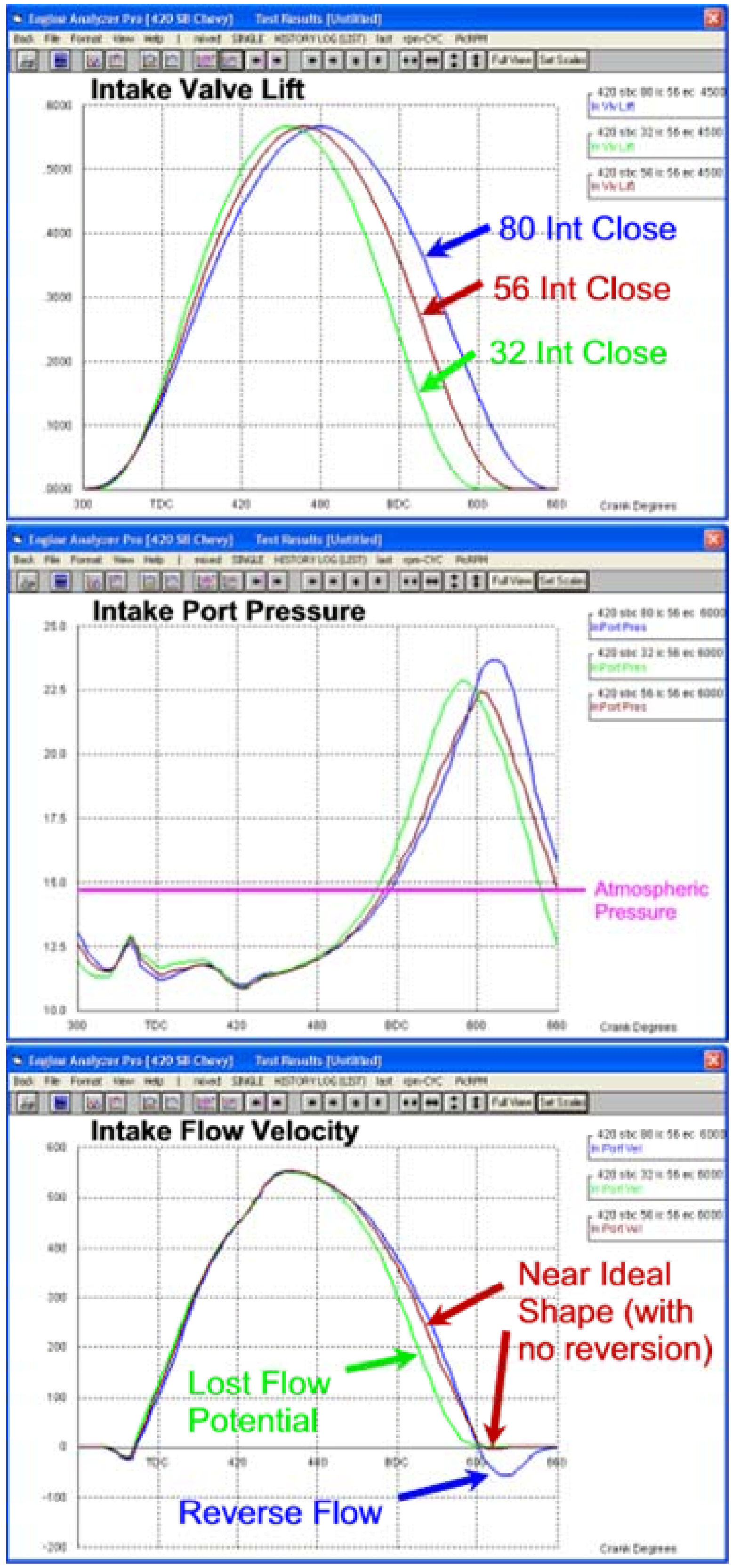
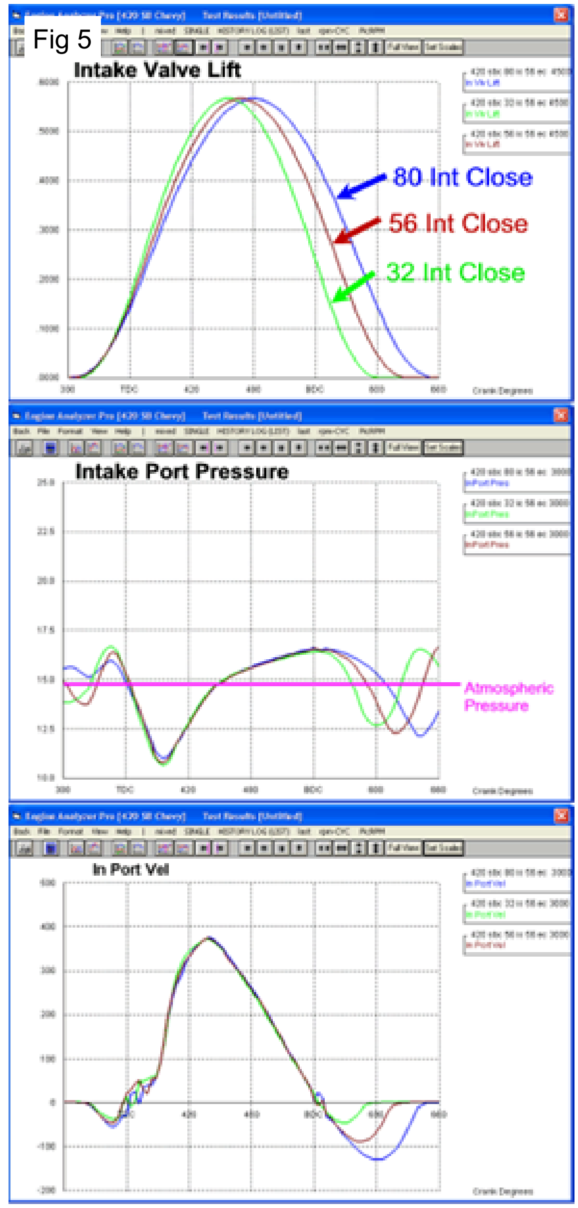


Figure 6 shows the Engine Analyzer Pro's screen for setting up these calculations. It shows 6 different settings of intake and exhaust centerlines and durations. These in effect are effectively about 1300 different combinations of intake and exhaust opening and closing events. This many calculations takes quite about of time, about 5 hours. But remember the computer is doing all the work. You can walk away and come back in 5 hours to get the 10 most promising combos. Obviously, that is a lot easier and cheaper than making 1300 dyno pulls with 1300 cam changes.

The runs were made from 3500 to 6500 in 1000 RPM steps, just 4 RPMs, to save time. Otherwise 5 hours could have been 10-20 hours. It came up with various combos which produced the highest average HP over that RPM range. Table 2 shows the resulting cam specs which produced the best Average HP over the 3500-6500 RPM range, and best Peak HP in that RPM range. The cam with the best Average HP has less duration than the cam with best Peak HP, because it must make good HP over the entire RPM range, not just 6000 RPM. The cam with best Average HP also produces more idle vacuum.

Figure 7 shows the baseline cam we started with, compared with these 2 cams with best Average HP and best Peak HP. At the top end, all 3 cams are similar with relatively minor differences. At lower RPM, there is a more significant difference and the cam with best Average HP is significantly better.

This would be where you would now purchase a cam (or cams) and go to the dyno. When you buy your cam, do not disregard what the cam grinders say. They may have additional experience to warn you of things a simulation program can not see. For example, they may say a particular cam's firing order doesn't work well with a particular intake manifold, or a particular cam will produce spark scatter with certain distributors. There are just some things which can only be sorted out on the dyno. But a simulation program lets you pick the most promising parts for the performance you are looking for, to minimize the parts and dyno testing.



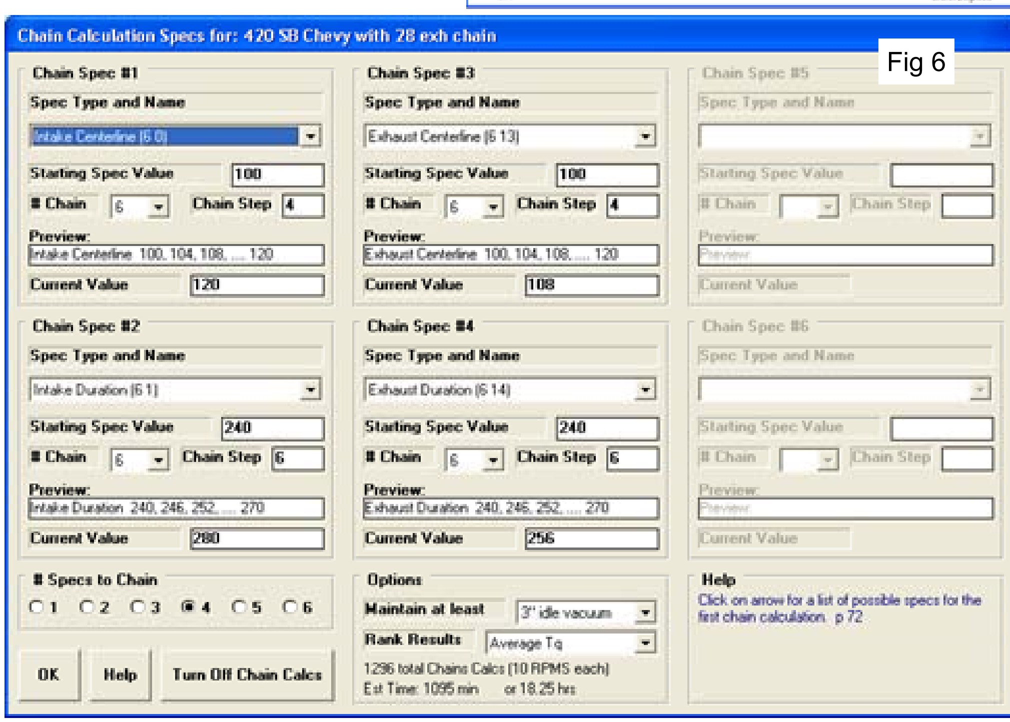


Table 2: Optimized	Intake Centerline	Intake Duration	Exhaust Centerline	Exhaust Duration	Avg HP	Peak HP	Idle Vacuum
Avg HP	112	240	104	258	385	552	12.0
Peak HP	104	264	104	270	373	557	6.9
Baseline	108	256	108	256	380	551	10.2