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Measurement

(written by Jere Stahl on June 15, 1988)

The following has been generalized. The statements do not apply to all engines in all types of race cars under all racing environments.

What is this thing?

What is a flow bench? Why use a dyno? From our perspective, they are measuring devices. Tools that serve the same purpose as a micrometer, dial indicator, feeler gauge, burette, tape measure etc. Would you use a 12" ruler to measure a bore size? A feeler gauge to fit pistons? What would you do with a micrometer that measured a crank journal at 1.9955 one time and 1.9555 the next time (2% repeatability). With .040 variation I suspect you'd either get it fixed or junk it. How about a dial indicator that measures .410 cam lift one time and .402 the next time. Trash pile lookout, here comes a dial indicator! The flow bench can only tell how much air is being flowed under the test circumstances. The more work done on cylinder heads that improves air flow at the important valve lifts, the more power the engine will produce. A dyno only tells how a particular combination is working. It does not make the engine run any better. An operator can hurt an engine on the dyno by failing to pay attention to certain values such as exhaust gas temps. I tuliped an intake valve and relaxed a top ring on a 9 to 1 engine by permitting the exhaust gas temps to exceed 1600 degrees F. Normal full throttle time of an engine in a 1/2 mile race car is 4 to 5-1/2 seconds (other than some sprint cars). Running an engine on a dyno forces the builder to belly up to the truth every time. Most dynos (does not mean dyno facilities or operators) are capable of producing numeric values that are similar to measuring a bore size with a ruler marked in increments of 1/32". This is accurate enough to compare engines. The numeric values will reflect the basic power of an engine within a range of + or - 2%. These values are close enough unless you are trying to do development work and compare pieces. I know of 3 engine builders who really like to fool themselves. (How about 50-100 hp exaggeration?)

What parts really affect power?

Horsepower increases in race engines primarily result from cylinder head air movement ability. For example, consider an engine producing 1.35 hp/cu inch for whatever specific application. Presume it to be equipped with a RELATIVE camshaft, manifold, carburetor and headers. The path to 2 hp/cu inch lies primarily through increasing air movement through the cylinder heads. We must not permit any components such as the intake manifold to become a restriction. The following basic categories are presumed not to be part of power development: water pump cavitation, ring seal, valve seal, carbs that never run out of fuel, fuel injection systems that have a reasonable fuel curve and provide the engine within 5% of the fuel it wants to make max power, and ignition systems that fire spark plugs. Horsepower may result from correcting one of the above items that is not functioning properly. However these are essentially fundamental items that are common knowledge available by reading publications printed over the past 10 years to provide the information. For example, if the compression ratio is lowered from 13.75 to 13.25 and a methanol engine runs better, it is probable the fuel and ignition requirements have changed to match the supply. Fix the fuel/spark supply and then the compression ratio could stay at 13.75. Over the past 15 years at least 150 horsepower has come from cylinder head improvements on 355 cu inch oval track engines. During the same time span 467 cu inch oval track big blocks have increased 200 hp. Intake manifolds had to improve along with cylinder heads so they did not become the restriction. In the same time span there have been no more than 3% power gains in each of the following: cams, headers, carburetors. In other words you can take a cam of a relative size available in 1973 and a similar size current day cam and you will not see more than 3 % power increase. Most of the time there is a power gain by working out the camshaft - rocker arm - header - intake manifold combination for a particular engine. Power improvement from each individual item is typically only 1/2% to 2%. All four will not total more than 8% unless one item is terribly wrong. For example, headers that vary 17" in primary length with an average length of 20" will lose 40 to 50 hp. Thus, to do engine development work a dyno facility and operator must be

able to recognize small power changes in the 1/2 to 1 % range. Eventually there will be 25 to 75 hp lost if these small changes are not measured and realized. The romance related to connecting rod length generally will make no more than 2% power difference. Most data appears to indicate that torque is shifted up or down so long as the rod to stroke ratio stays between 1.6 and 1.85 for push rod engines. A rod length change will make the most difference at one end or the other of the RPM range. Oval track engines that must operate below 5000 appear to be able to use rod length to crutch lazy intake ports. Certainly there are driveability considerations. We are not discussing rule changes such as the 9 to 1 compression ratio and 390 carbs that took away 75 to 125 hp. However, in oval track racing HORSE POWER DOES NOT NECESSARILY WIN RACES. I don't want to touch the situation of too much power here. DRIVEABILITY WINS MORE RACES THAN HORSE POWER. Many drivers are forced to compromise their line/position on the track due to the way the engine runs. This restricts their freedom to use driving skills and chassis/setup. Ford SVO type cyl heads are probably more difficult to make driveable, fuel efficient and torque competitive. I suspect this is due to the tremendous variation in velocity distribution that exists in the intake port and the length of the exhaust port. It appears the SVO head will transfer a great deal of heat back into the cyl head from the exhaust port.

Who needs more headaches?

We get letters from people who tell us they have built engines that have won races for years. None of these engines were ever run on a dyno. If you don't have a dyno or are dissatisfied with your present facility consider the following. There are only two reasons to get into the dyno mess: (1) you feel the need to understand more about engines or (2) your customers are demanding you have the capability. A dyno can drive you nuts. It's expensive to build, costly to operate, makes noise and reduces employee productivity. Further, it upsets neighbors, creates more work, adds more confusion, and as much anxiety and stress as a second girl friend or wife. (I know a guy who had two (2) wives and a girl friend at the same time but he didn't have a dyno or race car.) It will only tell you if all that effort you just put into whatever paid off (which usually doesn't). So instead of making you feel good, it makes you feel bad. When you run an engine on the dyno, you have to face the truth (or some approximation of the truth). Sometimes I wonder if I'm some sort of masochist. Dyno testing seldom makes me feel smart. Too often when testing is completed and we are trying to figure out what happened, I see where I screwed up by missing some obvious things. Now its too late to try them. Then, I start feeling dumb and lose more of the all too little self esteem. Compile this with lack of repeatability and it's more confusing than driver/owner feedback which is always so subjective and filled with so many ifs, buts, and maybes but is usually easier to take. In fact, I'm finding that 7 out of 10 dyno operators are not aware they have repeatability problems. They never tried to repeat a test three (3) times and fold the data sheets in a fashion that lets them see the numbers along side each other. If I had never thought about dynos or looked at a zillion dyno data sheets, I'm sure I'd have less gray hair, fewer wrinkles and certainly more money. We have talked with people who had a dyno and sold it because the numbers did not make sense. They were not getting repeatability which resulted in more confusion than it resolved. A dyno is too expensive to use for finding oil leaks and to make sure an engine isn't going to blow up in the first 5 minutes. In fact, there have been occasions when engine builders found customers declining to spend the money to have an engine run on the dyno. Several geographic areas refuse to support the additional expense of dyno testing. We believe dynos and flow benches are like race cars, a bottomless pit that can suck up all the time and/or money that can be thrown at them.

What does it take?

We hear comments that some dyno users say it doesn't make any difference what the oil or water temperatures are when they test. From the sample dyno data, phone conversations and significant differences between the way engines run on the race track I suggest it's time to recognize some realities. What do you want to accomplish? Are you satisfied with your present reputation and position relative to your competitors? If you are, fine. There's nothing wrong with being satisfied. In fact, it's an enviable position and state of mind. If a person has built no more than 20% of the engines at a particular race track and yet wins at least 80% of the time, there certainly is little motivation to change. It is not possible to stop technological progress. Look at the F1

and Cart race cars and rule changes. Every year more rules are written to slow the cars down and yet they keep going faster and getting more expensive. Presently a F1 car cost is valued at $1,000,000 and a Cart car at $325,000. This doesn't count the facility, manpower, spare parts, spare cars etc. The rules being created by many oval tracks that are requiring cast iron cyl heads, flat tappet cams etc. are, in reality, going to raise costs due to the time it takes to develop an advantage. It's a real can of worms to acid port cyl heads. Perhaps its time to evaluate whether to get in deeper or back off and find something else to do. It requires a great deal of discipline, persistence and dogged determination to become a good dyno operator. An operator must insist that testing (data recording) only be done when the oil and water temps meet certain standards. It takes persistence to keep changing a cell ventilation system and dyno muffler system until you can walk in the cell and never smell exhaust. The carb air supply system must not allow the air temp to vary more than 2 degrees F over a series of tests.

What is Repeatability?

The terms data and repeatability are used frequently. For purposes of identification we need to define the terms. Data refers to the values derived from measurement while using a flow bench or dyno. Flow bench numbers relate to air flow through whatever component on a flow bench. Dyno numbers such as torque, RPM, fuel flow, oil / water temperatures, and exhaust gas temperatures are collected while the engine is running under load. These numeric values are normally recorded on paper and must be perceived to be factual information because they are to be used for analysis and reasoning. Repeatability is defined as the similarity of the numeric values of the data when we repeat or duplicate the test. For example, observe the following data resulting from running the same test (3) times at 300 RPM's per /sec on a computer controlled dyno. The oil and carb temperatures (not shown here) indicated good test procedures were followed and that cell ventilation was acceptable.

CAUTION - CAUTION - CAUTION
DO NOT REPEAT TESTS UNLESS YOU ARE PREPARED FOR MORE CONFUSION.

	Test #1	Test #2	Test #3
RPM	CHP	CHP	CHP
4000	354.3	345.6X	351.9
4250	391.5	390.8	382.3X
4500	429.7	431.8	421.8X
4750	466.1	458.9X	465.1
5000	493.4	495.6	491.6X
5250	520.4x	515.2	514.1
5500	537.5	534.3	529.0X
5750	554.0	551.7	543.9X
6000	564.6	562.5	556.7X
6250	568.6	565.1	567.5
6500	570.6	574.8X	570.8
6750	564.3	566.0	561.8X
7000	554.6	553.2	557.2X

Business Sense.

It's very difficult to put together a dyno facility for less than $15,000. There certainly are a number of people who cannot afford to have a dyno and that's ok too. In fact, if you think a dyno will make you any money, guess again. Probably every other piece of equipment you buy will produce more ROI (return on investment). Prepare your customers to pay an additional $500 to $650 per engine when you start running all engines. Consider the time it takes to put an engine on the dyno, run in, re-torque heads, and re-lash valves. Make a few power runs, get it off

the dyno and clean up and you've spent an average of 5 or 6 man hours. If your shop rate is $25.00 p/hr, that's $150 for labor. Add $350 per engine for ROI and you're at $500. Plus the expense for fuel, oil, filters, plus an allowance for items that wear out. If you've invested $45,000.00 and are satisfied to get a 5-year payback you're looking at $450.00 per engine plus labor, expense items and maintenance. Many people believe a piece of equipment must pay for itself in 3 years. With this kind of investment some insist on running every engine including all the street and tow vehicle engines. They say it helps pay for the equipment and stops comebacks. Dyno testing is MEASUREMENT. MEASUREMENT TAKES TIME. Who is going to pay for the time? It seems many of the more successful engine builders take time in Nov, Dec, and Jan to do testing. Testing done at their own expense. They add up what it cost including labor at shop rate. Next, project how many engines will be built over the next season and amortize the testing cost over each engine. Spending 120 hours testing/changing at a shop rate of $30.00 per hour creates a labor recovery alone of $3600. If you're going to amortize it over 15 engines that's $240 for the labor per engine plus the cost of the parts, etc.

What's your outlook?
Several engine builders have bragged to me that they never use any valve train girdles. (and when you've got a cam that's border line on dynamics it may break fewer parts without a girdle.) Other people tell me they've done the same valve job for 20 years. People have told me they can inspect block core-shift by the casting uniformity around the cam bearings and that checking core-shift with an ultrasonic tester is unnecessary. There are engines assembled using plasti-gage to check bearing clear-ances. Numerous cylinder heads have had one chamber cc'd one time and have never been near a flow bench, and so on. Races are won every week by engines that had this sort of detail go into their building. Everything in life is relative. Relative to the surroundings, relative to the competition. Measurement takes TIME, TIME costs money. Most of the power improvements over the past 25 years can be summed up in one word: MEASUREMENT

Lets get classified.
What is being measured: cylinder head flow, core shift, (honing plates - Matthews/ Stahl) resulted from discovering bore distortion (Jenkins), ring side and back clearance (Jenkins), blow by, more careful attention to deck height, dome cc, chamber / piston shape, chamber volume, fuel distribution, valve job effect on air flow and power. Also measured are effects of 500/1000 miles on the valve job as affects airflow and power. (Bingham) Very few engine builders inspect valve and seat face condition on rebuilds. The heads should be flowed before and after rebuild to see how the shape changes affect airflow which is power. Camshafts that beat up the valve faces and valve seats create unnecessary power losses. They can cause more power loss due to air flow changes than the difference in similar cams from six cam manufacturers. One of the main decisions in a finish valve job configuration must be the long term power effects. If the engine loses 20 hp over 1000 laps due to valve seal surface shape changes, then I suggest a need to change cams. A initial 10 hp loss due to a cam change would leave the engine in a overall better condition. Oval track racing is very competitive. Factors such as the way a chassis handles due to the sharpness and throttle response of a engine may be overlooked. These factors are more important than all out power in winning races. Very seldom do we hear road race people mention driveability, but then there are fewer of them compared to oval track racers. A properly configured engine will be as sharp the day it's pulled out for rebuild as the day it went in and it should be at least 1000 laps (500 miles) later. Do you know the effects on air flow and power from carbon buildup in exhaust ports. Manufacturers of intake manifolds spend many hours of flow bench and dyno development. A carburetor can screw up fuel distribution beyond belief. It is my opinion that the power differences in seemingly similar carburetors are due to fuel curve and booster position (fuel distribution) than differences in air flow.

What do you get out of it?
Can you find 3-5 hp difference in carburetors? Have you checked fuel distribution on all the engines you've built this year? How much variation in exhaust gas temps (EGT's) is acceptable before power is affected? The people who build the most powerful engines have closed the loop from the grinding bench to the flow bench to

the dyno to the race track. They observe the effects at each stage. They can find 3 or 4 hp in a minor chamber shape change, or valve job, or exhaust port shape on carbon buildup. I believe the engine builders involved in the more competitive forms of racing are spending 3 to 4 times as long building engines today than 15 years ago. Where is this time going? Into MEASUREMENT. I suspect most people are quite careful and thorough with bearing clearances, piston to wall clearance, piston to valve clearance, etc. Why? Because if it isn't pretty close, the engine will break, a reputation can go to hell in a hurry when engines break even if the builder is not at fault. A few can find the 5 to 10 hp difference among similar cams from different manufacturers or the 5-10 hp between some minor header combinations. They have been able to stack as much as 50 hp over competitors. At some race tracks and certain times over the past 5 years these engines have dominated. Fortunately for some engine builders POWER DOES NOT WIN MANY SHORT OVAL TRACK RACES except WINGED CARS. The chassis setup and driver can offset 75 to 100 hp. In fact, DRIVEABILITY of the engine CONTRIBUTES more to FINISH POSITION than POWER in most types of SHORT OVAL TRACK RACING. Drag racing is the only area where the development of power is paramount. Different types of cars are more critical of driveability than others.

Do you really want to dance?

How much time of your time are your customers willing to buy? Have you asked whether they want you to flow the cylinder heads before and after a rebuild? Do they want every port flowed? Since it takes time to build horsepower, how much horsepower do your customers want? How much power are they willing to pay for? Perhaps we need to improve communication: communication between manufacturers and engine builders, communication between engine builders and racers. How valid is driver feedback? How many questions do you ask the drivers after each weekend of racing? Have you made a list of those questions so the driver can think at the race track and prepare himself to answer those questions? I know a guy who has a normal auto machine shop, no race engines. When he rebuilds an engine he tells the customer to fill it with water the first time. After it's started and running and checked for leaks, they are to switch to antifreeze. You guessed it, several customers went to antifreeze right off the bat and had a leak with 340 Mopars. Did he fail to communicate? Did the customer not understand or just choose to ignore the advice? If you want to dance, you've got to have music. What kind of music quality do you want? What kind of music are you willing to pay for? Do you feel you must make $10, or $15 or whatever for every hour you put in your work? There's a difference between working for little or no pay to figure out how to do a valve job or learn to run a new machine. For example, someone just starting to port cylinder heads should be prepared to spend several hundred hours with no pay. It takes time to learn how to use the grinder to remove metal in all the necessary places. Once a person has learned how to remove metal and customers want to take advantage of this ability, they should be willing to pay for the development work of learning where to remove metal. To learn to understand and grasp engines will probably take a minimum of 2000 hrs of study, thinking and instruction and as much as 5000 hrs. A person should not expect to be paid while learning. THERE ARE NO FREE LUNCHES-- not for you and not for your customers. You may choose to believe that engine temperatures make no difference in dyno testing. Most people think it's not necessary to repeat tests to check for validity or it is a waste to build a separate air supply system for engine air. You have a freedom of choice. Please don't try to tell me there is 20 hp in changing valve lash .002 or wonder why engines from a certain engine builder will run away from those built by someone else. We have shop people with $10 radio's turned up so loud the music is 50% distortion and they are happy. Some even say its good music. There are others who feel they must use a $150 boom box to get better quality. How discriminating are you? How discriminating are your customers? Sure, you'd like to buy race headers for $49.95, and your customers would like a 650 hp 1 x 4 brl 355 for $5000.00 but now let's be realistic.

Can you dance alone or do you need a partner?

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How much advice have you received from the sources where you buy parts? Have you considered that manufacturers are, for the most part, dependant upon engine builders and racers for feedback? They rely on this feedback to determine if a problem exists and what direction to take for new products. You are the first to know when there is a problem. Unless you tell the manufacturer, how is the problem going to be fixed or improved? There is no manufacturer who has enough hard core racing business to support proper Research & Development programs. Are you concerned where your customers finish the race? Are you satisfied with an answer such as "I didn't win". As a manufacturer who's parts are subjected to frequent dyno testing, we only ask for a fair test. Show us the numbers on your dyno sheets. If you don't have any comparison tests or did not dyno the engine then tell us about the customer feedback. If the tested parts were off more than 2% on power then it is logical to not race those parts. MOST DYNO TESTS are NOT REPEATED to check for the VALIDITY of TEST RESULTS. Any time you compare different parts you MUST REPEAT THE TEST. Too many people do not want to repeat tests due to the confusion it creates (don't confuse me with facts syndrome). Until someone figures out how to measure driveability on the dyno, you owe it to yourself, the mfg and racer to try the parts on the race track. Consider informing the different mfgs of involved parts whenever you do comparison dyno tests. Regardless of the test outcome it should improve your relationship with manufacturers. There is a chance you might learn something from such an exchange of information and following discussion. Since only the racer bellies up to the truth every time out, it really won't hurt you if the manufacturer points out some error or questions what you did. IMPROVEMENT does not come easy. THERE ARE NO FREE LUNCHES. Only then are you giving the mfg an opportunity to figure out what happened and leave it up to them to change, improve, respond or whatever. Your relationship with parts mfgs can be compared to 2 people who dance together on a ball room floor. One person usually has to ask the other to dance. People who dance together frequently probably have better chemistry between them. It is not necessary for people to have good chemistry to dance well. The super chemistry is only required to dance frequently. If your present dance partners are providing you with all the advice you need then by all means stay with them. Loyalty is a rare quality in this market place. However, AS IN RACING, no manufacturer will win all the time. None of us learn as much from WINNING as by LOSING. PROGRESS comes from LOSING, not from WINNING. The more you provide a mfg with information and appear to want to develop a working relationship, the more you should benefit. You will be among the first to get the "Trick New Deal" which may or may not be desireable. Quite probably there is an advantage more often than not. Put yourself in any racing parts manufacturer's shoes and you'd feel the same way. If one of your customers were to take an engine to a dyno facility to test and compare to some other engine builder's engine, what would you ask for? "A FAIR TEST". Some manufacturers such as ourselves are willing to loan parts for testing based on getting copies of the dyno test results.

How do you pick dance partners?

Do you buy rods based on price, reliability, or the personality of the person you deal with? Does the same criteria apply to all the parts you buy? Are you concerned that the person you discuss specific information with will pass it on to the next engine builder he talks to? Why do some engine builders appear embarrassed to send a manufacturer dyno test results? Unless there is a valid concern for confidentiality (such as Winston cup), each manufacturer knows what parts you're buying from him and therefore using? Several people have stated they feel their cyl head flow data is proprietary information. I guess if you're the KING of the pile then it is proprietary. However, if you need to improve, how do you expect to accomplish the improvement? What are your priorities--feeling comfortable with your suppliers or building more reliable, powerful and driveable engines? Do you choose cams based on specs, delivery time, driveability, valve train reliability, driver feedback, dyno test results, or pricing? What criteria do you apply to buying pistons--reliability, are they in stock, delivery time, lowest price, or best machining quality?

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Can you afford to dance?
If you now have a dyno, the answer is yes. The problems vary from facility to facility. Too many dyno cells suffer from inadequate ventilation systems and poor exhaust systems. You should be able to walk into a dyno cell at any time and never smell exhaust. There are so many cases of improper engine coolant water systems (cooling tower water line sizes) and lack of pressurized cooling systems it MAKES ME WINCE to think of the BOILING WATER and what it's doing to the engine. How does it affect the engine? To correct the deficiencies may cost be a few hundred dollars or a few thousand. Most of the price you pay will be in how you do things. Are you willing to make sure the engine oil temp is exactly 190 deg F every time you pull the handle to start a test? Computer controlled dynos permit testing in rates such as 300 RPM's per second and quicker. The quicker modes do not produce useable data so far as repeatability is concerned. If the engine has such light components or high compression ratio that running at slower acceleration rates is not practical, it is necessary to repeat each test 3, 4 or 5 times and then assemble the data. Note the word, assemble, not average. If you would like a sample of this concept, repeat any test 5 times. Send me the printouts or files on disk. After I've analyzed them, they will be mailed back to you. Perhaps the methods I use to analyze the data will be of some value to you. If you agree with the logic then you may obtain more useable results from your test data.

Communication.
Communication is the key to accomplishment. There is only one thing that counts in the world--RESULTS. Results come from effort put out in an organized fashion. The most successful people are the most organized. They have goals and use specific objectives to reach those goals. They take time to think and plan. They communicate those plans and guidelines to people to help implement and carry out the objectives to reach the goals which produce the RESULTS which measure the success. To have COMMUNICATION when there are instructions being transmitted, it is essential that the listener not be left to draw any conclusions. To have effective COMMUNICATION with technical related information, the technological level of the listener must be on a technological level with the vocabulary of the speaker.

Writers Trivia.
For something that started out to be a paragraph it appears I've lost control again. Then too, I have admitted for years to having the world's first perpetual motion machine (my mouth), as some of you have telephone bills to confirm. Anyway, I'd like to make it clear, the above is my perceptions and opinions. Obviously many of you have more than a little responsibility for the state of conditions of these elements. Since you will also have a major influence on any future thoughts, I'd like to suggest that you disagree with me on any point you choose.

In order to convince me that I am in error, you may either write, call or perform a test. If a test is required to make your point, I suggest you REPEAT the test three times. I really like to be shown I am wrong. It helps put things into perspective and most of all, I learn. A few years ago we spent over 100 man hours designing and building a new concept oil pan. As a last minute early February project it got on the dyno 6 days before the Daytona 500. I was sure there would be 5 to 8 hp gain. Yes, the pan made a significant power change. Unfortunately it was in the wrong direction. When we bellied up to reality that time, we lost 15 hp over the previous best race car pan, and 30 hp over the then best dyno pan. Yes, we learned from it. We proved I didn't know how to make a good horsepower race pan, but now I know HOW NOT TO MAKE A PAN. Bobby Meeks (Edelbrock) told me many years ago that it was MORE IMPORTANT TO KNOW WHAT NOT TO DO THAN TO KNOW WHAT TO DO.

Go ahead, it's your turn.

This space is left for you!