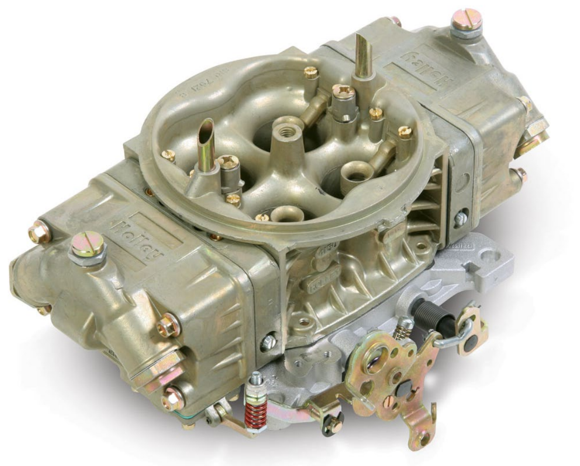
Second Strike

The Newsletter for the Superformance Owners Group

January 17, 2008 / September 5, 2011 Volume 8, Number 1

SECOND STRIKE CARBURETOR CALCULATOR

The Carburetor



As with everything in the engine, airflow is power. Carburetors are a key to airflow. As with any component, the key to best all around performance is to pick parts that match your performance goal and each other – carburetor, intake, heads, exhaust, cam, displacement, rpm range, and bottom end.

A good carburetor must do many things.

(1) Control the airflow with the throttle to control horsepower output.
(2) Meter fuel to maintain the correct fuel/air ratio across the entire rpm and throttle setting range.
(3) Mix the fuel and air to provide good fuel distribution to each cylinder.
(4) Provide high flow velocity. High flow velocity is critical to good metering and good mixing.
(5) Minimize pressure loss because a 1% pressure loss creates a 1% horsepower loss.

Second Strike Volume 8 Number 1
The Newsletter for the Superformance Owners Group
January 17, 2008

Second Strike is a publication of Second Strike LLC

Mike and Pat Stenhouse www.SecondStrike.com
400 Avinger Lane Villa 902 704-655-1902
Davidson, NC 28036-6708 Mike@SecondStrike.com

Controlling the airflow introduces the throttle plate assembly. Metering the fuel requires measuring the airflow and measuring the airflow introduces the venturi. Metering the fuel flow introduces boosters. The high flow velocity requirement constrains the size of the air passages. These obstructions cause a pressure drop, a necessary consequence of proper carburetor function.

Carburetors are sized by airflow, airflow at 5% pressure drop for four-barrels, 10% for two-barrels. This means that the price for a properly sized four-barrel is a 5% pressure loss and a corresponding 5% horsepower loss. The important thing to remember is that carburetors are sized to provide balanced performance across the entire driving range, not just peak horsepower. When designing low and mid range metering, the carburetor engineers assume airflow conditions for a properly sized carburetor - one sized for 5% loss at the power peak.

Selecting a larger carburetor than recommended will reduce pressure losses at high rpm and *may* help top end horsepower, but will have lower flow velocity at low rpm and poor metering and mixing with a loss in low and mid range power and drivability. A smaller carburetor can actually give better overall performance because the gains in mid range power can more than compensate for the slight loss in top end power.

The Carburetor Calculator

The **Second Strike Carburetor Calculator** and this accompanying document are designed to assist the car and engine builder/modifier looking for balanced performance – a car that is both enjoyable to drive on the street and competitive on the track.

The **Calculator** allows you to evaluate different sized carburetors and will tell you how well each performs on your engine by calculating the pressure drop and horsepower loss over a range of engine speeds. You can then determine if this is the right size for your engine.

The calculations are based on equations and data supplied by Holley. Simplifying assumptions have been made to reduce the amount of input and make the **Calculator** easy to use. The mathematical basis for the calculations is contained in the **Technical** section for those who are interested.

The **Calculator** is designed for normally aspirated engines with one or more carburetors drawing through a common plenum, or fuel injection with a single common throttle body. It is not designed for blowers, turbos, or nitrous or for individual runner systems such as Weber carburetors or multi-stack fuel injection.

The **Carburetor Calculator** is on www.SecondStrike.com under the Technical menu item.

Home | Technical

Second Strike Carburetor Calculator

Updated 9/5/2011 See last page of help for details

Help

Help for documentation. Requires Adobe Reader. (Second Strike V8 N1)

Specify Engine

550 Peak Horsepower

6000 at rpm

427 Cubic Inch Displacement

High Performance Street/Track Engine Type

Specify Carburetor

750 CFM Rating of Carburetor

4 Carburetor type: 4 = 4-barrel, 2 = 2-barrel

1 Number of Carburetors (1 to 6)

Results

Calculate

Estimated Airflow at Peak Horsepower

630 CFM - Recommended carburetor size

Maximum rpm

6,500 Maximum rpm used in analysis

Minimum rpm

1,270 Minimum rpm for full throttle for specified CFM Rating

for 4-barrel with mechanical secondaries (double pumper).

Pressure and Power Loss at RPM

RPM	Airflow CFM	Volumetric Efficiency VE	Pressure Loss (percent)	Horsepower Loss
4,000	434	0.88	1.7 %	6.7
4,500	499	0.90	2.2 %	10.6
5,000	555	0.90	2.7 %	14.7
5,500	600	0.88	3.2 %	18.0
6,000	630	0.85	3.5 %	19.4
6,500	642	0.80	3.7 %	18.0

Input

Specify Engine

Peak Horsepower at rpm

Specify the peak horsepower and the rpm that the peak horsepower occurs. This should be the gross horsepower - dyno horsepower at the flywheel without installation losses (without air cleaner and accessories, with open headers).

If you have net installed horsepower (with air cleaner, accessories and road exhaust system installed), increase the net installed horsepower by 15% to get gross horsepower.

If you have rear wheel horsepower, increase the rear wheel horsepower by 25%. This does not have to be exact. The horsepower is only used to calculate the horsepower loss.

Cubic Inch Displacement

Specify the actual cubic inch displacement of the engine.

Engine Type

The engine type is used to approximate the volumetric efficiency (VE) curve. The choices are:

Street
Stock street engines.

High Performance Street
Modified engine suitable for street driving. Upgraded heads, header, cam, intake, and carburetor. For 1970's vintage performance parts.

High Performance Street/Track
Modified engine suitable for street and track driving. Upgraded heads, header, cam, intake, and carburetor. For modern performance parts.

Race
Modified engine not suitable for street driving.

Ram Tuned Race
Modified engine with intake and exhaust runner lengths ram tuned for peak power rpm.

See **Volumetric Efficiency** in the **Technical** section for details.

Specify Carburetor

CFM Rating of Carburetor

Carburetors are rated in airflow capacity stated in cubic feet per minute (CFM). If you have multiple carburetors, input the CFM rating of the individual carburetor.

Carburetor type

Enter 4 for a four-barrel carburetor or 2 for a two-barrel carburetor. The difference is in the rated pressure drop. See **Carburetor Ratings** in the **Technical** section for details.

Number of Carburetors

The number of carburetors can range from a single carburetor to as many as six. For example, enter 1 for a single four-barrel. Enter 2 for two four-barrels. Enter 3 for three two-barrels. Enter 6 for six two-barrels on a log manifold.

Results

Click on the calculate button to calculate the results for your input.

Estimated Airflow at Peak Horsepower

The airflow is calculated according to the formula provided by Holley and includes **volumetric efficiency**. See the **Carburetor Ratings** section for details. The **Estimated Airflow at Maximum rpm** is your engine's maximum airflow requirement and is a good starting point for sizing your carburetor.

Ignoring volumetric efficiency in the Holley sizing equation can and often does result is selecting a carburetor that is one or two sizes too big.

Maximum rpm

The maximum rpm used in the analysis is the peak horsepower rpm plus 500.

Minimum rpm

The **minimum rpm** for full throttle for four-barrel carburetors with mechanical secondaries (double pumpers). Full throttle operation below this rpm will result in an excessively lean condition resulting in stumbling, backfiring, and possible engine damage. The minimum rpm is also a good relative measure of low end performance and drivability, the lower the better. See **Minimum rpm** in the **Technical** section for more information and the calculation. The **minimum rpm** should not be interpreted as the minimum cruise rpm.

The minimum rpm is not applicable (N/A) for two-barrel carburetors.

Pressure Loss and Power Loss at RPM

The table shows airflow, volumetric efficiency, pressure loss and horsepower loss as a function of rpm. The math for the calculation is in the **Technical** section.

The **rpm** spans 2500 rpm up to the specified maximum rpm in 500 rpm increments.

The **airflow** is the actual airflow based on displacement, rpm, and volumetric efficiency.

The **volumetric efficiency** is calculated based on the specified engine type.

The **pressure loss** is expressed as a percentage of atmospheric pressure. A one percent loss in pressure translates into a one percent loss in airflow, which translates into a one percent horsepower loss.

The **horsepower loss** is based on the horsepower at the stated rpm and the calculated pressure loss. The power curve is approximated from the stated peak horsepower and rpm.

Examples

The following examples illustrate how to use the **Calculator** to select a proper sized carburetor.

Example 1: High Performance Street 427

Peak Horsepower:........ 550
At rpm........ 6000
Cubic Inch Displacement........ 427
Engine Type........ High Performance Street/Track
CFM rating of carburetor........ 650
Carburetor type........ 4
Number of Carburetors........ 1

The estimated airflow is 630 cfm at the specified horsepower peak of 6000 rpm. A 650 cfm carburetor is a good base point for further evaluation.

To evaluate other sizes, the **Calculator** was run for a series of available sizes from 650 cfm to 1050 cfm. The **Pressure Loss** and **Horsepower Loss** at 6000 rpm are shown in the following chart. The **Relative Horsepower Gain** shows the horsepower gain from changing size from the 650 cfm base point.

Increasing the size from a 650 to a 750 gains only 6 horsepower. For the street and even street/track, the 650 should be a better choice because of better low speed operation.

Size CFM	Pressure Loss	HP Loss	Relative HP Gain	Minimum Rpm
650	4.7%	25.8	**Base**	1025
750	3.5%	19.4	6.4	1270
850	2.7%	15.1	10.7	1532
1050	1.8%	9.9	15.9	2104
2x650	1.2%	6.5	19.3	2898

It is important to note that significant increases in carburetor capacity have a relatively small effect on power. The 60% larger 1050 Dominator gains only 16 horsepower over the properly sized 650. However, the minimum rpm goes from

1025 to 2104, indicating a significant loss in low end and mid range performance and drivability.

Two 650's (2x650) offers a 19 horsepower gain with the potential for no loss in drivability since low speed operation only uses the primary side of the primary carburetor. But there are complexity considerations. And if the carburetors have mechanical secondaries, you cannot stand on it to nearly 3000 rpm. However, it looks awesome and that is worth a lot.

For a high performance street machine, there is a little to gain in high-end horsepower by going over the Holley recommended size, but a good bit to lose in low end metering and drivability. Perhaps the Holley engineers know what they are doing in this case.

Example 2: Trans Am 302

Consider another example where the Holley engineers didn't follow their own advice.

When the Holley Dominator was introduced, Holley wanted to showcase it in the 1969 Trans Am series. They convinced Ford to put two 1050 cfm Dominators on the Boss 302 Trans Am engine. The dual 1050's would not begin to run cleanly until near the 8000 rpm redline. It was a disaster for road racing because accelerating hard out of the corners was impossible.

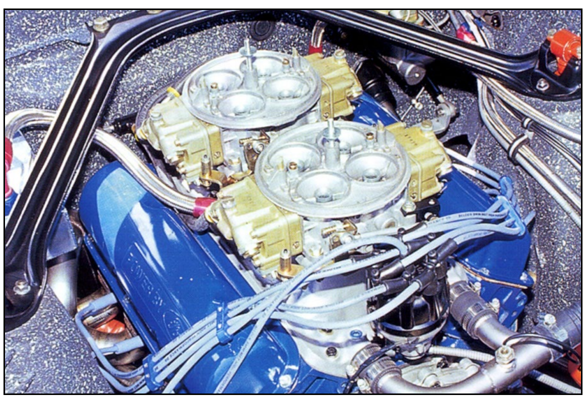


Figure 1: No end to excess. 1969 Trans-Am Boss 302 sporting 2 (!) 1050 cfm Holley Dominators.

The Bud Moore Trans Am 302 produced 460 horsepower at 7500 rpm. If we plug this into the **Calculator** for 2x1050 cfm Dominators and a more reasonable (for track use) single 850 cfm carburetor, we get the following results at 7500 rpm:

Size CFM	Pressure Loss	HP Loss	Relative HP Loss	Minimum rpm
2x1050	0.4%	1.8	**Base**	8413
850	2.4%	11.1	9.3	2166

Note that the calculated minimum rpm for full throttle for the double 1050's is 8400 rpm, which is above the 8000 rpm maximum rpm. No wonder it ran so badly. With an 850, the minimum rpm is 2200, much better. If the Holley engineers had used their own math, they could have seen this one coming.

The drivers were more than willing to give up the additional ponies of the dual Dominators at the top end to get an engine that would actually pull in the mid range. The dual Dominators were ditched and they went back to a single 850 four-barrel.

This is one case where too much really was too much.

Example 3: 392 with 3 Two-Barrels

The engine is a 392 with three two-barrel carburetors. The question is - what size? The input specifications are:

Peak Horsepower:.. 475
At rpm.. 5600
Cubic Inch Displacement... 392
Engine Type............................ High Performance Street/Track
CFM rating of carburetor.............................. To be determined
Carburetor type... 2
Number of Carburetors.. 3

The first step is to run the **Calculator** as see that the airflow requirement at the horsepower peak is 540 cfm. Holley offers two-barrels in 350 and 500 cfm sizes. Since this is a progressive setup, it is reasonable to look at the airflow in four-barrel rating terms. See **Carburetor Ratings.**

Size	Primary Airflow At 10%	Total Airflow At 10%	Primary Airflow At 5%	Total Airflow At 5%
350	350	1050	247	742
500	500	1500	354	1061

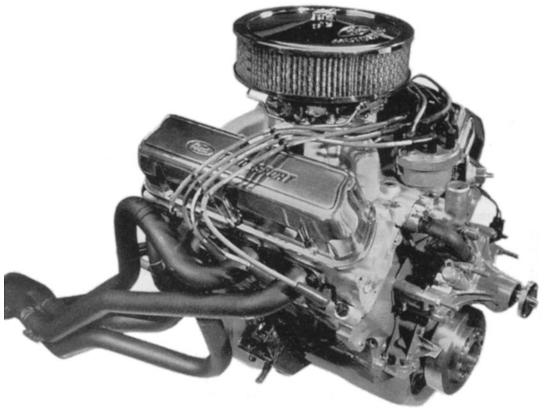
The 3x2 set up cruises on the primary carburetor. For the 350, it is like cruising on the primaries of a 500 cfm four barrel, which is great. The total airflow for the 350 setup exceeds the requirement by 200 cfm, which is not so great. For the 500, it is like cruising on 700 cfm four-barrel, which is too big.

Now run the **Calculator** for both the 350 and 500. Both setups are too big at full throttle. The smaller 350 cfm two-barrel setup gives a better match for low speed operation and is a better choice for balanced performance.

Size CFM	Pressure Loss	Horsepower Loss
3x350	2.6%	12.6
3x500	1.3%	6.2

Three two-barrels are a challenge to set up and tune. A single 600 cfm four-barrel would work fine and be a lot easier. But when you raise the hood, those three deuces really look fine.

Example 4: A351 SVO Crate Engine



The input specifications for this engine are:

Peak Horsepower: 385
At rpm 5800
Cubic Inch Displacement 352
Engine Type .... High Performance Street
CFM rating of carburetor 780
Carburetor type 4
Number of Carburetors 1

The A351 was the first SVO crate engine and a very popular one for Cobra replicas early on. The A351 features a single plane manifold and a fairly stout A351 cam. The Ford Motorsports catalog specifies a 780 cfm Holley carburetor.

Most of these engines were fitted with the Holley 4160 3310, 750 cfm with vacuum secondaries. Is the 750 too much for this engine? Yes. Drivability is an issue with this engine. And testing with this engine showed that the vacuum secondaries never fully opened, even with the lightest secondary spring. The 750 did not work well on either end.

A first pass with the Calculator indicates that the airflow at peak horsepower is 473 cfm. A 750 is three sizes too big for this engine and brings into question the practice of installing an oversized carburetor with vacuum secondaries and letting the vacuum secondaries sort it out.

If the carburetor is three sizes too big, the primaries are three sizes too big. Low end and mid range performance suffers accordingly. If the carburetor is so big that the secondaries never open, then the secondaries are not functioning as designed. The top end suffers accordingly. It is reasonable to assume that this engine would have performed better all across the rpm range with a much smaller carburetor.

Discounting the 750 and starting over, the airflow requirement for this engine is 473 cfm. The two closest fits are:

- Holley 4150HP 390 double pumper
- Holley Street Avenger 570 with vacuum secondaries.

Size CFM	Pressure Loss	HP Loss	Minimum rpm
473	5.0%	19.2	772
390	7.3%	28.3	578
570	3.4%	13.2	1021

Compared to the target size of 473 cfm, the smaller 390 has an additional 9 horsepower loss. The larger 570 gains 15 horsepower over the 390.

The better choice would lie with mid range performance. When faced with a choice like this, Holley recommends going down a size rather than going up a size. The 390 HP would most likely offer superior mid range and be the better choice. The low end and mid range gain with a smaller carburetor is real. Dyno tests with a 4150HP 390 and a 4150HP 750 on a 427 CID engine showed that the 390 made more low and mid range power than the 750.

It is highly likely that replacing the 750 with a 390 would have resolved the drivability issues with this engine.

Two important lessons learned here.

- An oversized carburetor is not the right answer even with vacuum secondaries.
- When the requirement lies between two sizes, Holley recommends the smaller size.

Recommendations

When using the **Calculator** for to size your carburetor, you should shoot for a pressure loss in the 5% range at the peak power rpm. A carburetor 100 cfm bigger is oversized. A carburetor 100 cfm smaller is undersized. When the requirement is between two sizes, pick the smaller size.

Technical

Carburetor Basics

In an internal combustion engine, power comes from fuel and air mixed together and burned. Gasoline engines require a more or less constant air/fuel ratio. Power is controlled by controlling airflow with a throttle.

The function of a carburetor is to meter fuel into the intake air stream in direct proportion to the airflow. The metering is done by creating a pressure drop, which sucks fuel from the float bowl into the air stream. The higher the speed of the airflow, the stronger the metering signal, and the more precise the fuel metering.

A carburetor has to meter properly over a very wide range of airflow. For a 650 cfm carburetor it could be from 3 cfm at idle to 650 cfm at full power maximum rpm.

To complicate matters a bit, the fuel air ratio does vary a bit as shown in Figure 2. At idle, the air/fuel ratio is rich (around 11.0:1) to provide a smooth idle. At cruise, it is leaned out for maximum economy (around 16.5:1). At maximum power, it gets rich again for maximum power (around 12.7:1). See Figure 2.

This is all too much for a simple carburetor; so modern four-barrel carburetors have three metering circuits.

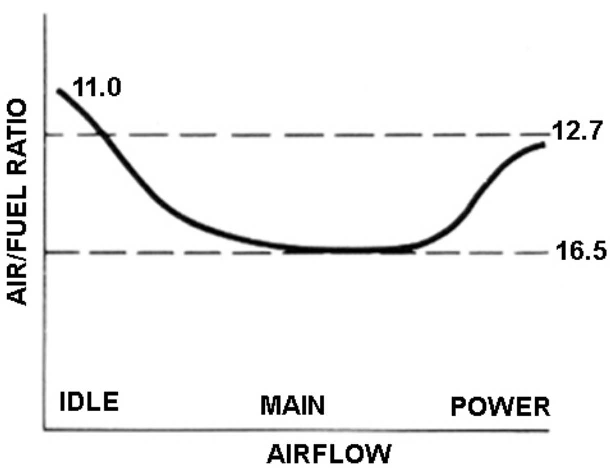


Figure 2: Air/Fuel Ratio

Idle / Low Speed Circuit

For idle and low speed operation (including cruising in high powered cars), there is not enough airflow to activate the main jets. Fuel is metered through **idle ports** just below the **throttle plate** at idle. The vacuum below the nearly closed throttle plate sucks the fuel into the air stream. As the throttle is opened **a transfer slot** spanning the throttle plate is exposed to the vacuum allowing more fuel to match the increasing airflow. See **Carburetor Tips** for a photo.

For the idle circuit, the air/fuel ratio is rich (around 11:1) to provide a smooth idle. The air/fuel ratio is adjusted with the idle mixture screws.

Main Circuit

About the time that the throttle plate passes the top of the transfer slot, the carburetor transitions to the main circuit. The **venturi** and **boost venturi** accelerate the airflow and create a pressure drop that sucks fuel up from the **float bowls** and into the air stream. The fuel air ratio is controlled by the both the **main jets** and the **air bleeds**.

Larger main jets increase the fuel flow and make the mixture richer. Larger air bleeds decrease fuel flow and make the mixture leaner. Making adjustment to the mixture is done by changing the main jets. Changing the air bleeds is not recommended.

For the main circuit, the air/fuel ratio is typically around 16.5:1 for best cruise economy.

Power Circuit

At full power, maximum power is required. The mixture needs to be enriched from maximum economy (16.5:1) to maximum power (12.7:1). When engine vacuum drops at wide open throttle, the **power valve** opens to supplement the fuel metered by the main jets.

The amount of additional fuel and the resulting air/fuel ratio is controlled by the **power valve channel restriction** in the **metering block**.

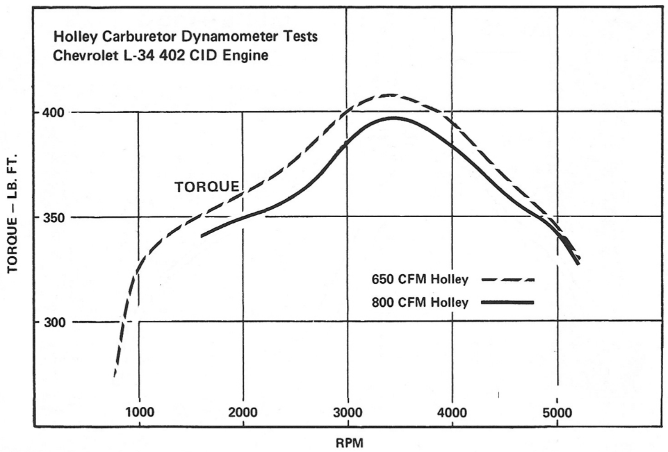
The Trade Offs

Doubling the size of a blower, turbo, or nitrous system can double the horsepower gain. These power adders are adding more oxygen and fuel to the air stream. Carburetors are not power adders. A carburetor actually costs horsepower by creating the pressure drop necessary for fuel metering. Doubling the size of the carburetor only decreases the relatively small pressure drop so the gain is relatively small.

The trade off is a simple one. Small carburetors work better in the low end and mid range. Larger carburetors up to a point work better at the top end.

Larger carburetors have lower airflow speed and a lower pressure drop, which reduce the pressure drop and horsepower loss at the top end.

Smaller carburetors have higher airflow speed. The higher airflow speed provides a better metering signal and better fuel atomization. When the fuel is better atomized it provides a more uniform mixture to each cylinder, which in turn makes more power because each cylinder is running at the correct mixture. The more precise metering and better atomization result in better low speed drivability and full throttle mid range power.



The engine in this Holley dyno test is a 402 CID Chevrolet L34 producing 325 horsepower at 5000 rpm. The airflow at peak horsepower is 407 cfm. The somewhat oversized 650 produced significantly more torque than the considerably oversized 800 all the way to the 5000 rpm power peak. Nowhere did the oversized 800 out pull the smaller 650.

Bigger is always bigger, but not always better.

Carburetor Ratings

Carburetors are rated by airflow expressed in cubic feet per minute at a specified pressure drop. After evaluating the performance considerations over the entire airflow range, the carburetor sizing standards have been established to provide a balance of performance across the entire engine operating range.

Two-barrels and four-barrels are rated differently. The difference is that two-barrels only have primaries and four-barrels are progressive, running on the primaries at low speed and the primaries and secondaries at high speed.

- Two-barrel carburetors are typically rated in cfm at a 10% pressure drop.
- Four-barrel carburetors are rated in cfm at a 5% pressure drop.

A two-barrel cfm rating can be converted to the equivalent four-barrel rating by multiplying it by 0.707.

The rated airflow is not a hard limit. As shown in Figure 3 for a 650, 750, and 850, a carburetor will pass more airflow at a higher pressure drop and less at a lower pressure drop. At a given airflow, the carburetor with the higher rating will have a lower pressure drop. For example, at 650 cfm, a 650 will have a pressure drop of 5%. A 750 will have 3.8% and an 850 will have 2.9%.

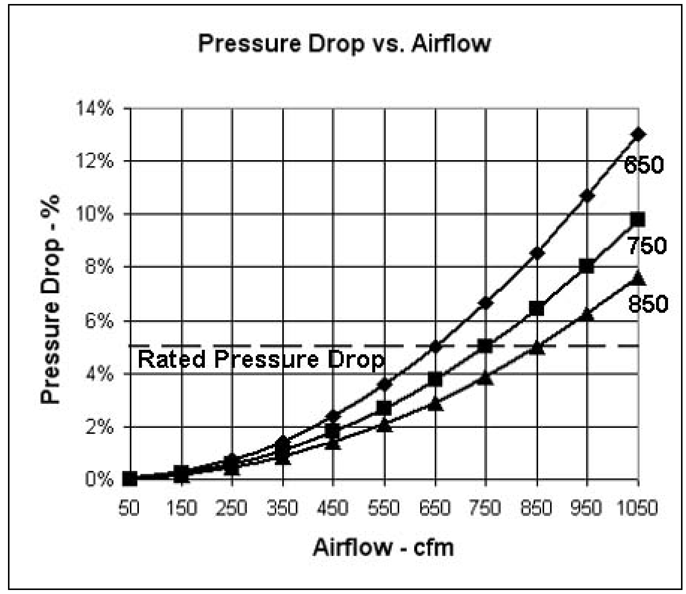


Figure 3: Pressure Drop

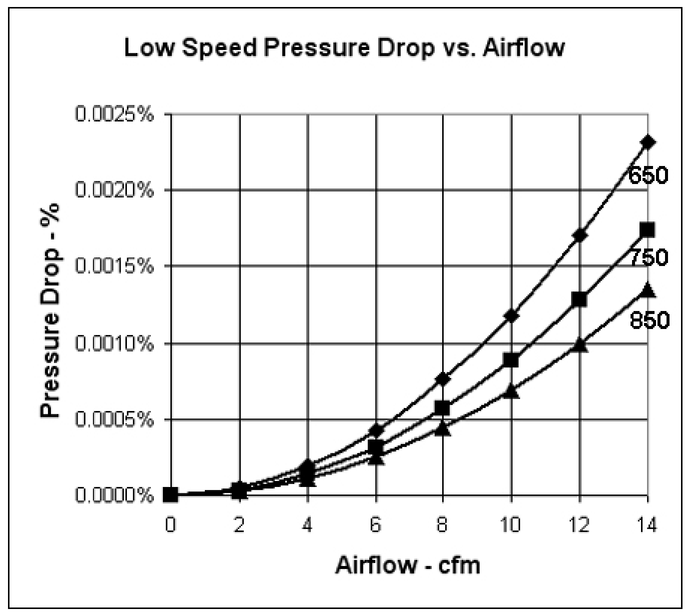


Figure 4: Low Speed Pressure Drop

Low speed operation is also a consideration. In Figure 4, consider a "small car with a large engine" that needs about 12 cfm of airflow to cruise at 50 mph in fifth gear. A 650 has a pressure drop of 0.0017% at that speed. At 12 cfm a 750 has a pressure drop of 0.0013%, a 25% loss in flow velocity and a 41 % drop in metering signal. An 850 has a pressure drop of 0.0010%, a 40% loss in flow velocity and a 65% drop in metering signal.

Looking at it another way, if the 650 cruises comfortably at 1575 rpm, the 750 would have to cruise 1850 rpm to get the same metering signal and the 850 at 2100 rpm. And that is a big difference.

Carburetor Sizing

Holley recommends the following equation for sizing a four-barrel carburetor on a four-stroke engine.

$$CFM = \frac{CID \times RPM \times VE}{3456}$$

where
CID is the engine displacement
RPM is the maximum engine rpm (redline)
VE is the volumetric efficiency

For our Example 1 550 horsepower 427, engine, the math is:

$$CFM = \frac{427 \times 6000 \times 0.85}{3456} = 630$$

A single carburetor of the calculated size will have the rated pressure drop for the engine and rpm used. For example, a 427 with a 630 cfm four-barrel and a volumetric efficiency of 0.85 will have a 5% pressure drop at 6000 rpm. A 630 cfm two-barrel would have a 10% pressure drop.

Volumetric Efficiency

The sizing equation includes the volumetric efficiency.

Volumetric efficiency is defined as:

$$\text{Volumetric Efficiency (VE)} = \frac{\text{Actual airflow}}{\text{Theoretical airflow}}$$

The theoretical airflow is defined as:

$$CFM = \frac{CID \times RPM}{3456}$$

The volumetric efficiency is reduced by pressure losses in each component of the intake system including ducting to the air cleaner (if any), air cleaner, carburetor, intake manifold port, cylinder head port, intake valve and finally discharge into the cylinder. For a high performance street/track engine these losses are typically around 15% at maximum rpm. Since the recommended pressure drop in the carburetor is 5%, the carburetor can account for about a third of the intake system losses.

Ram tuning, based on strong flow velocity and resonance in the intake "pipe", increase the volumetric efficiency. Ram tuning harnesses the pressure waves in the pulsating intake and exhaust airstreams to improve cylinder filling and scavenging, improving the volumetric efficiency at the design rpm of the ram tuning system.

Various Holley carburetor manuals suggest the volumetric efficiencies for various engine types shown in Figure 5.

Engine Type	VE at Peak Torque	VE at Peak HP
Street Stock street engines.	0.75	0.70
High Performance Street Modified engine suitable for street driving. Upgraded heads, header, cam, intake, and carburetor. For 1970's vintage performance parts.	0.85	0.80
High Performance Street/Track Modified engine suitable for street and track driving. Upgraded heads, header, cam, intake, and carburetor. For modern performance parts.	0.90	0.85
Race Modified engine not suitable for street driving.	0.95	0.90
Ram Tuned Race Modified engine with intake and exhaust runner lengths ram tuned for peak power rpm.	1.00	0.95

Figure 5: Assumed Volumetric Efficiency VE

The original Holley engine types and associated volumetric efficiencies were defined in the 1970's for 1970's level performance parts. The **High Performance Street/Track** engine type has been added for the **Calculator** to provide for the significantly better performance parts currently available, particularly cylinder heads.

The **Calculator** assumes that the volumetric efficiency curve vs. rpm is a second order polynomial through the specified points with the peak at the torque peak. The torque peak rpm is assumed to occur at 80% of the power peak rpm.

For our Example 1 engine:
Peak Power rpm = 6000
VE = 0.90
Peak torque rpm = .8 * 6000 = 4800
VE = 0.85

The corresponding volumetric efficiency curve is shown in Figure 6 and is included the **Calculator** output table following.

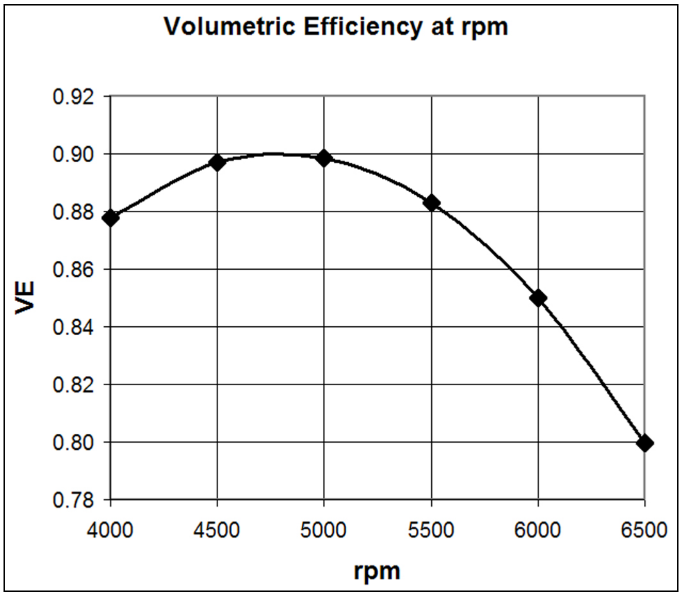


Figure 6: Example 1 Volumetric Efficiency Curve

At 100% volumetric efficiency, airflow is linear with rpm. However, the variation in volumetric efficiency causes the airflow to be non-linear with rpm. See Figure 7. The actual airflow is included in the **Calculator** output table.

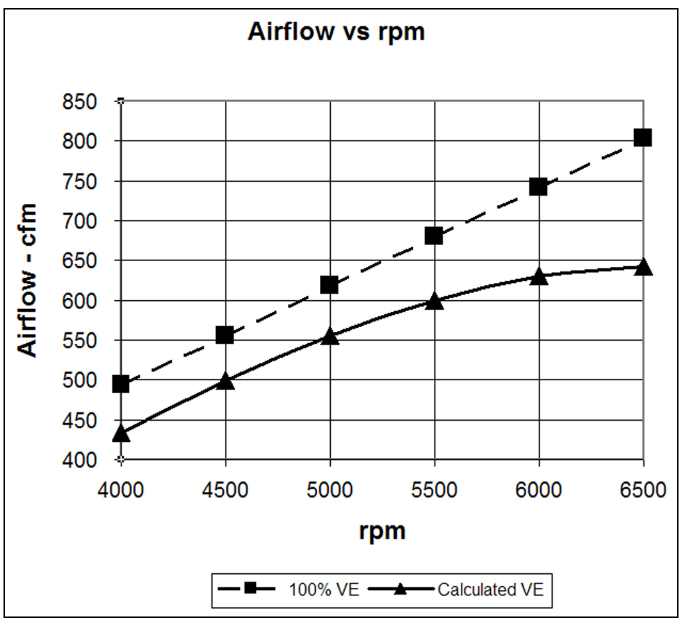


Figure 7: Airflow vs. rpm

Note that the airflow at 6000 rpm is 741 cfm at 100% VE and 630 at the calculated 85% VE. Ignoring VE would bump one carburetor size.

Ignoring VE in the Holley sizing equation can and often does result is selecting a carburetor that is one or two sizes too big.

Also note that the calculated pressure drop in the carburetor goes up with airflow squared. At 100% VE, the pressure drop would go up with rpm squared. However, because VE is falling off with rpm squared, the pressure drop tends to be more linear with rpm.

Horsepower Curve

The horsepower curve is calculated as follows.

The peak horsepower and rpm are input.

The peak torque rpm is assumed to occur at 80% of the peak horsepower rpm. The peak torque is assumed to be 1/85% or 1.176 times the torque at peak horsepower. From this the horsepower at the torque peak is calculated.

The assumed horsepower curve is a second order polynomial through the horsepower peak and horsepower at peak torque rpm with the peak at the horsepower peak.

For our Example 1 engine:

Peak power = 550
Peak power rpm = 6000
Torque at peak power = 5250 * 550 / 6000 = 481
Peak torque rpm = .8 * 6000 = 4800
Peak torque = 481 / .85 = 566
Power at peak torque = 566 * 4800 / 5250 = 517

The horsepower peak and horsepower at peak torque are shown in bold. The assumed horsepower curve through these points is shown in Figure 8:

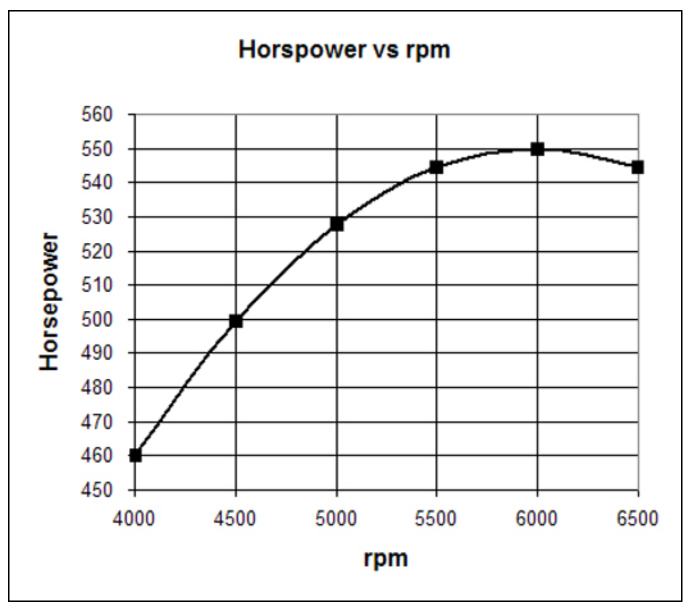


Figure 8: Assumed Horsepower Curve

Minimum rpm for Full Throttle

Holley has a complex 3-dimensional graph for determining the minimum rpm for full throttle for mechanical secondary (double pumper) carburetors. See reference 2, page 53. The formula for this graph was determined by non-linear quadrature (fiddling with the math) to be:

$$Minimum\_rpm = 26.5 \times \frac{CFM\_rating^{1.5}}{CID}$$

where

Minimum_rpm is the minimum full throttle rpm
CFM_rating is the CFM rating of the carburetor
CID is the engine displacement

In addition to telling you when to keep your foot out of it, the minimum rpm is a good measure of the rpm at which the carburetor will meter properly. Hence it is a good relative measure of the drivability of a carburetor. The lower the minimum rpm, the better the drivability. The **minimum rpm** should not be interpreted as the minimum cruise rpm.

Carburetor Tips

In General

Years of experience with many owners have shown that the owners with engines tuned for street use drive their cars more, enjoy them more, and keep them longer. Owners who go wild wind up leaving their cars in the garage and loosing interest. So my advice tends toward street drivability over all-out performance.

If you are tuning a carburetor for racing only, I assume that you know what you are doing. Have at it. If you drive on the street, even with a high performance engine, then I suggest staying away from racing inspired carburetor tuning. Racing tuning tricks are intended to increase high-end performance at the expense of low end drivability, a reasonable trade off for the track. However they usually make the engine hard to live with on the street.

Holley four-barrels, even the Holley HP, are designed as dual-purpose carburetors for street and track. Significant deviations from out of the box settings will likely make them hard to drive.

Selecting the Carburetor Model

My experience is with Holleys, so my suggestions apply to Holleys. I have a Holley HP 750, which is one size too big for the 427 Windsor in SP 218. I never said I was immune to “bigger is better”. I had a 650 double pumper on my 302 powered autocross Mustang that was two sizes too big. The Holley HP 390 would have been perfect.

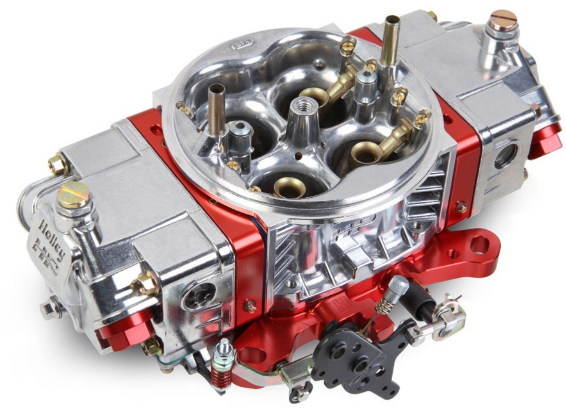


Figure 9: Holley 4150HP Ultra 750

The 750 size is very popular with Superformance owners in spite of being oversized for most engines. Holley makes three models in the 750 range.

Model 3310: The basic 750 carburetor. Model 4160 with center hung float bowls, vacuum secondaries, and manual choke. About $250.

Street Avenger: Model 4150. 770 cfm, center hung float bowls, quick change vacuum secondaries, and electric choke. About $360.

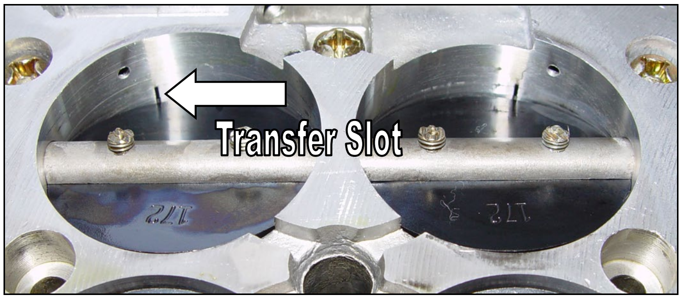
HP 750: Model 4150. Center hung float bowls, vacuum or progressive mechanical secondaries, no choke, and four corners idle system. About $670, $720 for the HP Ultra.

The Model 4160s have a non-adjustable secondary metering plate. The Model 4150s have a secondary metering block with replaceable jets and provision for a power valve. A conversion kit from 4160 to 4150 is available from Holley if you have a 4160 and want to tune the secondaries.

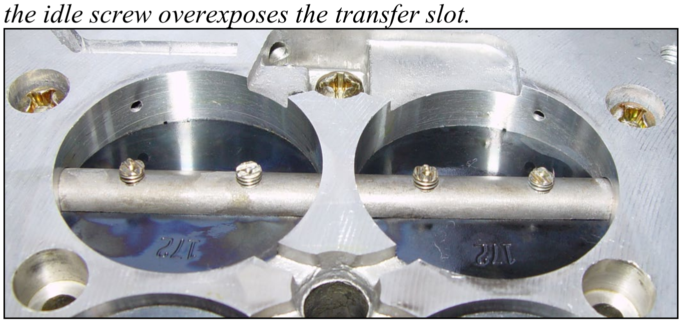
The Holley HP 750 cfm was dyno tested against the Holley 3310 750 cfm and Street avenger 770 cfm on a 427 CID engine. The superior metering ability of the Holley HP produced an additional 10 horsepower over the 3310 and Street Avenger.

You get what you pay for and a few dollars more for the Holley HP or new HP Ultra is well worth it. The chokeless race design and superior metering are worth a few ponies on the top end. The four corners idle system with idle speed adjustment and idle mixture adjustment on both primaries and secondaries really helps low end drivability.

Making a Hot Cam Idle Properly



Big cams take big air at idle. Opening the throttle too far with the idle screw overexposes the transfer slot.



When the idle screw is set correctly, the transfer slot will be just barely exposed. (Photos of underside of carburetor)

Figure 10: Idle speed adjustment

Engines with hot cams and low idle speed vacuum require larger idle throttle openings to get the necessary idle airflow. The larger throttle opening overexposes the transfer slot and interferes with the transition from idle to low speed, which make the engine run poorly at low speed. It also makes it hard to set the idle mixture and causes the engine to run on when you shut it off.

Before working on the carburetor, modify the distributor advance curve to improve idle vacuum. See **Modified Advance Curve** following.

To fix the carburetor, first get the engine to idle, even if badly. Remove the carburetor, turn it over, and look at the transfer slot. If the transfer slot is exposed (top photo), you have too much idle throttle setting.

If your carburetor does not have idle airflow adjustment on the secondaries, Holley recommends drilling a 3/32 or 1/8 inch in each primary throttle plate on the same side as the idle circuit. Airflow will pass through these holes and allow you to close the throttle plate to the correct position (lower photo).

If you have a Holley Street Avenger or 4150HP, first try to fix the problem by increasing the idle speed setting on the secondaries. Check for transfer slot exposure on the secondaries as well. If this isn't enough, then drill the holes in the primary throttle plates.

The Holley 4150HP Ultra has an integrated idle bypass system for idle control with radical camshafts. There are four air bleed holes around the center post (see photo previous page). The throttle plates are set to give proper transfer slot coverage. The idle speed is set with the idle bypass system adjustment.

Modified Advance Curve

The typical initial timing for a mechanical advance is 12 degrees before top dead center. Experimentation has shown 20 degrees of initial advance significantly improves engine efficiency, increases idle vacuum, and reduces the low speed drivability issues. For most high performance engines, the volumetric efficiency and hence the effective compression ratio is so low at low engine speeds that detonation under load is not a problem. The MSD Billet and Pro-Billet distributors provide the ability to tailor the advance curve to achieve high initial advance and normal full advance.

Vacuum Advance (Not!)

Vacuum advance is used to advance the timing under high vacuum (light load) to improved engine efficiency under cruise conditions. Engines with rough idle do not tolerate vacuum advance. The fluctuating vacuum at low engine speeds causes the advance to fluctuate and hence the power to fluctuate, resulting in lurching and bucking at low engine speeds. The use of vacuum advance is not recommended.

Increasing Cruise Fuel Economy

For small cars with large engines, most cruising is done on the idle circuit. Leaning out the idle circuit can have a significant positive effect on cruise fuel economy. For example, if your idle mixture setting is 1.5 turns, try 1.0 turns. You can pick up 2 mpg.

Blocking Power Valve (Not!)

Blocking off the power valve and using larger main jets cause the engine to run rich at cruise conditions. This is not recommended for engines driven on the street. The excess fuel can wash the oil off the cylinder wall, leading to premature wear.

Blocking Carburetor Heat (Not!)

Most dual plane manifolds have an exhaust crossover passage under the carburetor. The passage allows the exhaust gases to heat the bottom of the plenum and vaporizes the fuel at low speed, improving low speed fuel atomization and distribution and thereby improving low speed operation.

I blocked this off on my 302 autocross engine to gain a few high-end ponies, and then spent two years trying to solve the low speed tip in stumble. I changed everything and screwed up the carburetor in the process. I unblocked the passage, reset the carburetor to stock, and voila, it worked beautifully.

Vacuum Secondary Springs

Dyno testing has shown that replacing the vacuum secondary spring with the lightest spring available (the white spring) adds about 40 lb-ft of torque in the mid range with no adverse affects. This is one of the tuning tricks that actually works for a high performance street engine.

Vacuum vs. Mechanical Secondaries

Once you have figured out that rapid opening of the secondaries is good, why not get a mechanical secondary double pumper and control it yourself.

I have heard two concerns about mechanical secondaries – low speed bog and poor fuel economy.

As to low speed bog, according to the Holley charts, a 427 with a 750 double pumper should not be given full throttle below 1200 rpm. In the real world, this is never going to happen. Not a problem.

As to fuel economy, the mechanical secondaries have an additional spring. The additional spring can be felt in the throttle petal so you know when you are getting into the secondaries and the second accelerator pump. When economy is the concern, staying out of the secondaries is easy. Again, not a problem unless you want it to be.

Whistles and Main Jet Extensions

On cars with serious acceleration, braking, and cornering capabilities (like ours), fuel sloshing in the float bowl is a serious problem. Fuel can slosh into the float bowl vents causing an overly rich mixture. Fuel can pull away from the main jets causing an overly lean mixture. Often the problem is severe enough to cause the engine to stall.

To keep fuel out of the bowl vent, Holley offers the Fuel Bowl Vent Baffle, also known at the Whistle.

Figure 11: Holley Fuel Bowl Vent Baffle – Part 26-40

Cheap. Install on both primary and secondary float bowls.

To keep the fuel from sloshing away from the main jets, Holley offers main jet extensions.

Main jet extensions should be considered mandatory for hard launches at the drag strip. The hard launch will pull the fuel completely off the jets in the rear float bowl and stall the engine. This has been verified by embarrassing personal experience.

The main jet extensions require a notched float. The notched float is standard on the Holley HP series.

Install main jet extensions front and rear. Cheap and effective.

Figure 12: Main Jet Extensions and Notched Float Part 116-10

Air Bleeds (Not!)

Racers like to change the air bleeds to get more punch coming out of corners. In my experience, this modification makes the car hard to drive on the street with a 500 rpm or better increase in minimum cruising rpm

The Holley HP series offers replaceable air bleeds. However the HP documentation says, "Do not change the air bleeds. Serious injury or death may result." Pretty clear. Leave them alone.

Personal Experiences

In my position within the Superformance family, I talk to many owners, engine builders, dealers and installers. The biggest disappointment that many owners have is that they have overdone it – too much engine, too much cam, too much carburetor – and the car is no fun to drive. The car sits in the garage until its premature departure to a new owner.

I am certainly not immune to the "bigger is better" syndrome. When I replace the original 357 CID 351W in SP 218, I went all out. My goal was to make the car quicker than any original Cobra including competition Cobras and even Shelby's personal twin supercharged car.

The first iteration of the engine exceeded the target horsepower, but it was a beast to drive. It would not cruise comfortably below 2000 rpm. We motored down the Blue Ridge Parkway in second gear. Not good.

Making horsepower is the easy part. Here in the heart of NASCAR country, there are any number of engine builders who can make all the power you want. Making it drivable is another story. While building the engine for SP 218, I talked to a number of aftermarket performance parts tech hot line. They all knew how to make power. No one knew the impact on drivability.

It took a lot of engineering work to reach the drivability goals while still making the performance goals. Changes were made to the cam, ignition, exhaust and carburetion to improve the situation. These changes are detailed in Second Strike Volume 7 Number 1, available on www.SecondStrike.com under Newsletters as a PDF download. Also see **Example 1**.

The results are very satisfying. The performance goals were exceeded. The 129 mph 11.2 second quarter mile (on 15" street tires) far exceeds even the supercharged Cobras (116 at 11.9 according to the Feb 1968 Road & Track road test). And from time to time I manage to lap the field at track events in the street tire run groups.

Just as important, the street drivability goals were also achieved. SP 218 has over 40,000 miles on it including over 3,000 track miles. It has been on vacations as far away as New England and Alabama and day trips through our beautiful Blue Ridge Mountains. It is well suited to brisk motoring on back roads. The goal of balanced performance was achieved.

In testing on SP 218's 427 Windsor, we ran the Holley 3310, Street Avenger and HP carburetors on the street, track, and dyno. The HP is the best and worth the extra money.

I settled on the HP 750 using charts base on 100% volumetric efficiency. If I had the **Calculator** back then, I would have picked the HP 650. The Holley HP 750 made about 10 more horsepower than the Street Avenger 770. So the HP 650 would make about the same power as the 770 Street Avenger. And it would run better at low end. Going "better" can be better than going "bigger".

I purchased my HP 750 double pumper used. The original tuner had tricked it out by blocking off the power valves, changing the air bleeds, and changing the main jets. The owner had given up on it because it was undrivable.

The first step was to put everything back to stock specifications as a starting point. I then set up the idle to get the correct transfer slot exposure. The holes were already drilled in the throttle plates and they seemed to work out.

My first trip to the drag strip was humiliating. It stalled dead off the line every time. The main jet extensions and whistles fixed that.

Dyno runs indicated that the stock main jets produced a full throttle air/fuel ratio in the 12.5 to 13 range all the way up the rpm range, so that was fine.

The engine launches hard with no hesitation and pulls strongly and cleanly to the 6500 rpm redline in every gear. On the other end, it is happy cruising along at 1500 rpm in fifth gear.

The idle mixture is a little on the lean side on purpose. I get 18 mpg cruising at 65 mph; dropping to 16 mpg at 80 mph. Overall fuel consumption is 14 mpg. Not bad for a large high performance engine in such a blunt car.

For cold starts without a choke, it runs a little roughly for about a minute and then settles in. The minimum rpm for full throttle of 1270 rpm is not a problem since I never go there. I am very pleased with the Holley HP 750 and the way it works across the full spectrum of driving.

References

1. Holley website http://www.holley.com/division/Holley.asp

2. Holley 4150 & 60 carburetor handbook, Mike Urich, HP Books, Tucson AZ, 1980

3. Holley carburetors and manifolds, Mike Urich & Bill Fischer, HP Books, Tucson AZ, 1976

4. Road & Track on Mustang 1664-1977, Mustang Trans-Am Track Test, Road & Track, Jan 1971, Brookland Books, Cobham, Surrey, England, 1986.

Updates

11/18/2007
Add estimated airflow at maximum rpm
12/22/2007
Add Example 2, additional tips
12/28/2007
Documentation upgrade
1/4/2008
Add minimum rpm
1/17/2008
Specify rather than calculate maximum rpm
Add support for two-barrel carburetors.
Add airflow and volumetric efficiency to output table.
Move the VE curve intercept from the maximum power rpm to the maximum power rpm + 500 which has the effect of increasing the airflow at maximum rpm.
Add two more examples to documentation.
9/5/2011
Add High Performance Street/Track Engine Type
VE = 0.90 at peak torque, 0.85 at peak power
Move the VE curve intercept back to maximum power rpm.
Calculate maximum rpm as peak power rpm plus 500.
Documentation upgrade.