PERFORMANCE FACTORS PART V

COMPROMISE

Designers Balance Economy, Engine Power and Acceleration

BY ROGER HUNTINGTON

IN THE PAST few months *Car Life* has presented studies of the factors in automobile performance. There has been a lot of theory propounded with a good deal of slide-rule slipping. But now I want to end this series with a discussion of some of the everyday problems design engineers face when planning a certain performance level for a car. This takes more than theory. It takes a certain insight to determine what will sell to the public and how far to compromise in any direction.

One of the first problems that faces the "performance designer" is that engine power and fuel economy on the road will be much different than when the engine was developed on the dynamometer. Engineers must consider the extra drag of accessories and fan restriction of the car's muffler and exhaust system, necessary compromises in the mechanical spark advance curve, the effect of high air temperatures under the car's hood (which reduce intake air density) and many other factors which can reduce the engine's power and torque output by 25–30%, as compared with the "corrected" output on the dyno.

A point that requires discussion is the rapid trend toward installation of air conditioning on American cars in all price classes. It is estimated that over half of all our cars will be air conditioned in 2–3 years! Current air conditioning systems rob more engine power and fuel economy than one can readily believe. Not only does it require up to 12 bhp to drive the compressor, the heat rejected from the condenser core ahead of the radiator raises air temperature in the engine compartment by 40–50° F above normal. The compartment already is 40–60° above outside air temperature. Underhood temperatures approaching 200° F have been measured on air conditioned cars on warm days.

This reduced underhood air density does terrible things to the power output. According to the SAE temperature correction factor, an increase in the engine intake air temperature from the standard 60° F to 190° would cut the power output by 10.6%. When the 10 bhp or so devoured by the compressor also is subtracted problems develop quickly. A loss of 1–2 sec. in 0–60 mph time is common when the air conditioning is turned on full. Of course, there's a loss in fuel economy. The hot underhood temperature does no harm here (in fact it may help a little); but the compressor loss is a direct drag on the engine. The loss is 3–4 mpg with air conditioning in full operation. It takes just about as much power to drive the compressor as it takes to drive the whole car at 20 mph! The designer must consider these factors in performance evaluation.

Another sobering factor here is the gradual loss of engine power as miles pile up on the car. And it's not just plain wear. A modern American passenger car engine still will show decent compression and low oil consumption (less than 800 mpq) with 50,000 miles. But what damages road performance worse than internal wear is the deterioration of spark plugs and points, and gradual build-up of carbon in the cylinders (Fig. I). An occasional full-throttle blast for a few seconds will help keep the heavy carbon out of the cylinders. But plugs and points should be replaced every 12,000 to 15,000 miles for optimum performance. Not many car owners do either of these things. And 20,000 miles on plugs and points, a heavy carbon build-up, and maybe 2° slip in the spark timing and the loss is 10 to 15% of power.

Of course, the big compromise in this whole business is the one between performance and fuel economy. Any Detroit performance engineer will state flatly that the public expects miracles. Owners want around-town fuel economy over 15 mpg with 0–60 times under 10 seconds. It isn't in the cards. In the final analysis an engine's fuel consumption depends primarily on the horsepower-hour factor. The more power used, and the more often it is used, the more fuel is burned. There is no way around it. Conversely, fuel can be saved by not using available power. Theoretically a 300-bhp car would use the same amount of gasoline as a 100-bhp car of equal weight, if both were driven the same way—as they both would be theoretically absorbing the same horsepower-hour output. And yet the 300-bhp car would have much better acceleration on top when the driver wanted it. In addition, because American road traffic tends to move in a fairly even, stable pattern at moderate speeds and acceleration rates, unlike many foreign countries, the high-horsepower car shouldn't cost much extra in fuel consumption because the extra power wouldn't be used often.

This idea has been intriguing Detroit engineers for 15 years. It was the reasoning behind the horsepower race of the 1950s. In other words, extra engine power can be carried for emergencies, with very little extra fuel consumption in normal driving at lower power levels.

This makes a good theory on paper, but it has taken some sharp engineering over the past 15 years to make it come even close to working in practice. There are several marks against the theory. For one, bigger cylinders have bigger friction losses. And because engine friction is nearly independent of load, these losses don't drop much at small throttle openings and lower power levels.

ANOTHER FACTOR, the big valves and ports used for free breathing harm mixture distribution between cylinders at small throttle openings—so carburetors are jetted for richer mixtures to keep some cylinders from running too lean. An engine with smaller valves and ports can run with leaner carburetor jetting and use less gasoline.

By the same token, a good deal of carburetor venturi area for free breathing harms fuel atomization and mixture distribution at low speeds and small throttle openings. This is being solved with air-flow controlled 4-barrel carburetors such as the new Rochester Quadrajet, but it took a good bit of engineering to get this far. Another problem is valve timing. The long-duration, high-overlap cams used for maximum top-end bhp waste gasoline at low speeds by letting some of it go right out the exhaust without being burned. There's no way around this with fixed valve timing.

And there are compromises in the chassis area. Fluid-drive automatic transmissions cost gasoline in slip losses and in payment for the convenience of two-pedal driving. Soft, low-pressure tires provide a good ride, but offer a higher rolling resistance. Car weight itself is one of the toughest enemies of fuel economy. Yet, luxurious cars can't be built when weight savings are sought. And there's the axle gear ratio. A numerically high ratio which helps acceleration simply uses more gasoline by inducing a higher piston speed and friction losses at a given road speed. ▶

COMPROMISE

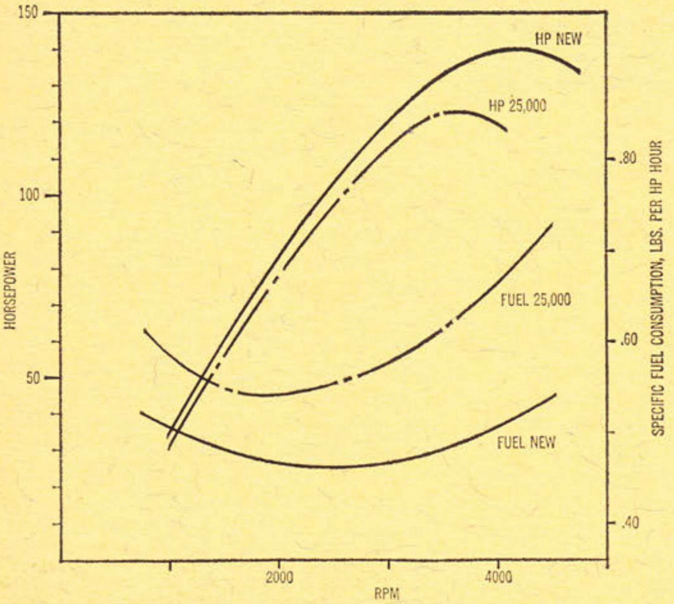

FIG. I—As carbon builds up, and plugs and points deteriorate, fuel consumption rises, bhp dwindles.

VALUES AT 60 MPH

	300 cu. in. 3.6:1 axle	400 cu. in. 2.7:1 axle
Engine rpm	2700	2000
Bhp required to drive car	30	30
Engine friction bhp loss	21	15
Pumping (breathing) bhp loss	7	7
Total indicated bhp output	58	52
Percent of full load (indicated)	33%	27%
Ind. specific fuel consumption	.43 lb./bhp-hr.	.46 lb./bhp-hr.
Miles per gallon	14.5	15.0

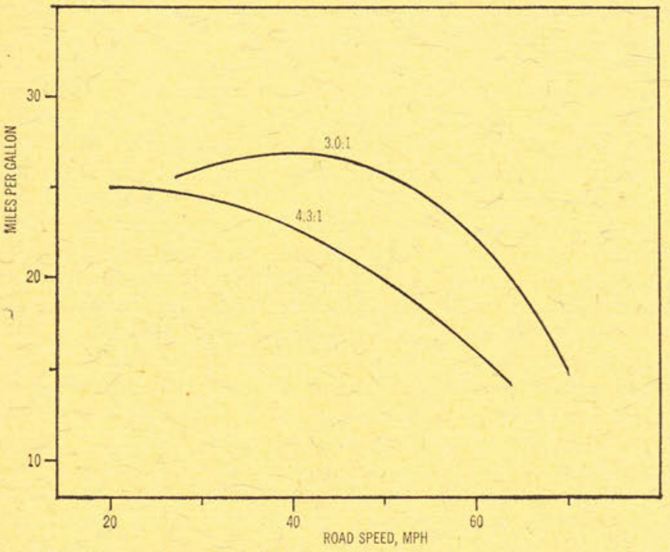

FIG. II—Curves show the 3.0:1 axle ratio best for fuel economy and all-around road performance.

Engineers have tried various compromises to avoid these problems. The latest method is a new relationship between engine piston displacement and axle gear ratio. Here's the idea: In years past, engineers have concentrated on top-end horsepower, but now realize the average driver seldom uses maximum power. Automatic transmissions up-shift at approximately 4000 rpm, below the peak of the power curve, and most drivers are annoyed by the roar and vibration of the engine winding up tight, hence they avoid this situation. So engineers now pay more attention to mid-range torque as a more meaningful criterion for engine performance. Of course the major factor in mid-range torque is cubic inches. This accounts for the recent trend toward larger and larger displacements in all price classes.

Big cylinders have high friction losses. If left to their own devices they'll use a lot more gas. Here's where the gear ratio comes in. Because engine friction increases roughly as the square of rpm, it pays to keep engine speed as low as possible. The answer is simple: Use a big-inch engine with a numerically low gear ratio to reduce rpm and friction at cruising speeds.

Another compromise ingredient is the transmission. Theoretically a 300-cu. in. engine with a 3.6:1 gear ratio will provide the same acceleration as a 400-cu. in. engine with 2.7 ratio. Forward thrust is proportional to torque times gear ratio. The big engine with the lower ratio would use less gas, because friction increases as the square of rpm, but only as the first power of cylinder dimensions (refer to table, left). But the big engine would not show outstanding high-gear acceleration with the 2.7 axle ratio. This is where the transmission comes in. By using an automatic transmission with a "kickdown" ratio of 1.5:1, the driver can instantly jump to an effective 4:1 ratio with a flick of his toe for a quick burst of acceleration to pass another car.

The transmission is the key. It has to be automatic. The driver can't shift gears manually as often as he would need to with 2.7 axle gears. For optimum flexibility, the kickdown ratio should be near 1.5:1. In other words, a 3-speed automatic is required. The 1.5 ratio gives ample punch for passing with a big engine and a low axle ratio, yet it will run out to 75 or 80 mph before up-shifting to high. The 2-speed automatics with kickdown ratios of 1.8:1 up-shift at approximately 60 mph, squarely in the middle of the passing range.

The formula for the best compromise between fuel economy and all-around road performance is an engine of 400 cu. in. or more, an axle ratio of 2.5:1 or 3.0:1, and a good 3-speed torque converter (Fig. II). This combination assures good breakaway acceleration, pep and flexibility in traffic, good fuel economy at cruising speeds—and smooth, quiet cruising at lower engine revolutions.

There's no telling how far this trend will go. Pontiac uses standard-equipment axle ratios as low as 2.41 with a 389-cu. in. engine, with excellent results. The day of 2.7:1 ratios, possibly with engines of over 500 cu. in. displacement and even more exotic high-multiplication automatic transmissions can be foreseen.

At the other end of the acceleration range—that is, "breakaway" acceleration from a standing start—other problems arise. Here the barrier of tire traction arises. This is not a serious limitation to breakaway acceleration with now standard axle ratios, but could conceivably be a problem in the future. There is a special condition that might someday limit breakaway acceleration with advanced high-torque-multiplication transmissions. This is engine rotational inertia, or "flywheel effect." It requires a certain amount of torque to accelerate the crank train, flywheel and fluid coupling mass in rotation and this torque is subtracted from the new output of the engine. The effect is equivalent to adding dead weight to the car's mass. But here's the stickler: The rotational inertia effect increases as the square of the overall speed ratio between engine and rear wheels.

Obviously, as we increase this overall torque multiplication ratio, we increase the equivalent mass that's added to the car weight. Eventually a point is reached at which the equivalent mass is increasing faster with multiplication ratio than the forward thrust that accelerates this equivalent mass. At this point the maximum acceleration rate starts to fall off with increases in the overall torque ratio. A SAE paper on this subject, published several years ago, quoted an N/V ratio (rpm/mph) of approximately 180 for an average 3-speed automatic transmission and typical V-8 engine of normal rotating mass. At this point the equivalent rotating mass of the engine and flywheel would be 50–60% of total car weight. A 4000-lb. car appears to present more than 6000 lb. for rear wheel thrust to accelerate. Increasing the gear ratio to any extent actually reduces maximum breakaway acceleration in low gear.

The N/V ratio of 180, with average tire diameters, represents an overall torque multiplication ratio of approximately 14:1. Multiplication of a modern 3-speed torque converter is about a 2.1:1 stall ratio times a 2.5:1 gear ratio for a 5.25:1 overall ratio. However, the effect of the torque converter fades out at about 10 mph in this situation, so only the gear multiplication ratio of 2.5 counts here. This allows use of an axle ratio of 5.5:1 before the overall low gear multiplication reaches 14:1. This upper limit on axle ratio would drop with more exotic torque converter transmissions which spread their fluid multiplication effect over a broader range. Breakaway acceleration can't be increased indefinitely with higher and higher torque multiplication ratios, even if adequate tire traction were available. The rotating inertia effect wouldn't permit any additional acceleration. This effect is apparent on heavy, small displacement drag racing cars that don't have enough power to burn their tires loose violently. In one case a switch from 5.12 to 5.67 rear end gears actually reduced the acceleration rate in low gear. But the owner switched from his stock 30-lb. flywheel to a 12-lb. aluminum wheel and went more quickly with the 5.67 gears. He merely reduced his engine's rotating inertia.

To this point, discussion has been concentrated on the performance of utility cars. In the past few years, however, the sports-personal car has taken a prominent place in the automotive industry—the Corvette, GTO, Olds 442, Barracuda S, Mustang GT, and like cars sacrifice some fuel economy for superior performance. Buyers of this type of car expect compromise, and accept it. But, just putting a big standard engine in a little car may actually increase mpg, because of lighter total car weight. The limit here is poor handling due to nose-heavy weight distribution. So the next step is to modify the existing engine for increased performance. The usual result is that only the top-end horsepower is improved, and the driver is obliged to use the gearbox liberally to receive full potential performance. In addition, the inevitable lower effective axle ratio and hotter cam timing harm fuel economy. This situation occurs with the Formula S option for the Barracuda which uses the standard 273-cu. in. block. The example of the other school is the GTO, which uses the Pontiac 389-cu. in engine (in mild tune) in the senior compact Tempest body.

The Corvette is perhaps the best compromise. This car features a special lightweight body and chassis with the engine positioned far enough rearward so weight balance is not a critical problem. Either a light 327 engine or a heavier 427 may be installed with no great difference in handling. Very good acceleration and fuel economy are provided by the mildly-tuned engine, due to its light weight. Strong acceleration with fair economy are characteristics of the larger engine. The light weight and deep engine setback are the keys to Corvette success.

A safe prediction is that more of these high-performance cars, lighter, with special bodies and chassis, but using production chassis components and engines from other lines, will be seen in the future. The buyer will be able to choose any one of several engine options for the desired compromise between performance, fuel economy and street flexibility. And he still will own a sporty, distinctive package with above-average performance and handling. This is today's Corvette. It could be tomorrow's GTO or Barracuda.

ADMITTEDLY the recent Washington highway safety investigations have Detroit a little jumpy about performance. The fact remains, however, that performance is one of the most saleable commodities a passenger car has to offer. Washington may try to limit performance, but it is certain that Detroit always will try to offer the best possible compromise. ■

PERFECT EXAMPLE of performance compromise is Pontiac Bonneville, which uses 421-cu. in. engine to drive through long 2.71:1 rear axle.

LIGHT WEIGHT, good balance and moderately large piston displacement make the Chevrolet Corvette a good acceleration-economy compromise.