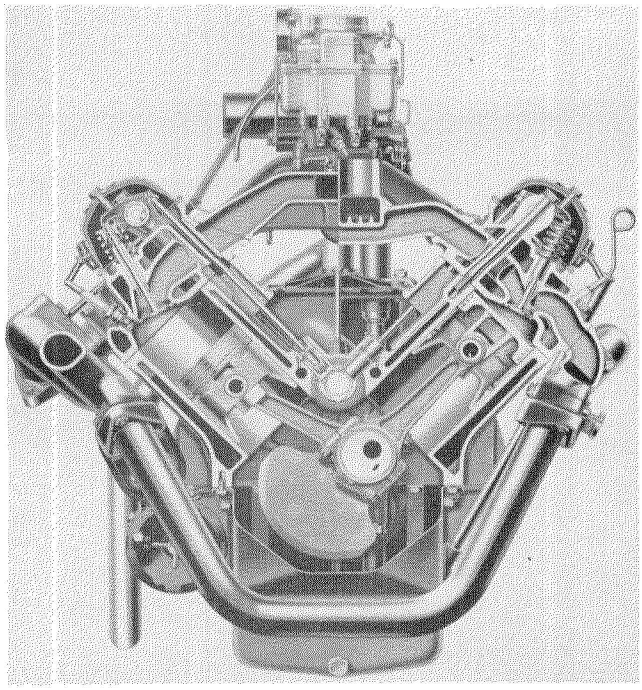
HIGH COMPRESSION ENGINES

By PETER KYROPOULOS



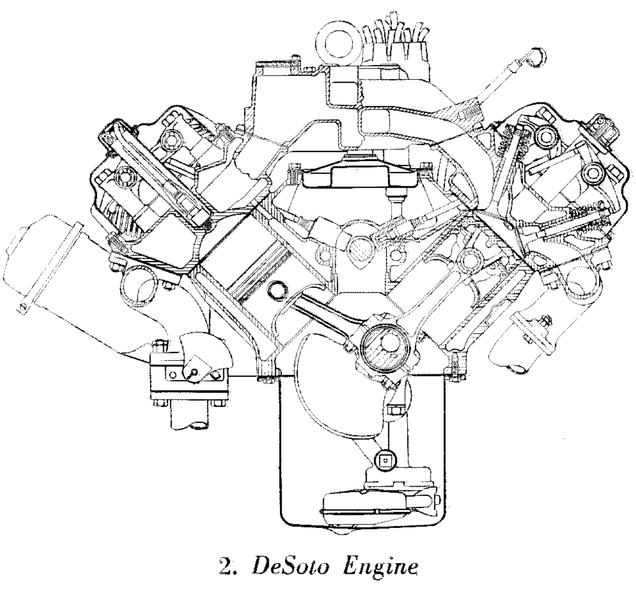
1. *General Motors Research Engine (Rocket Engine)*

They're providing real gains in power as well as in specific fuel consumption—but there's still a joker in this game

THE HORSEPOWER of automotive engines has been increasing steadily during the past years. Ronald Colman in the radio show, "The Halls of Ivy," expressed this, somewhat qualitatively, when he said, "Never has so much horsepower been given to so many jackasses." This is neatly put, but the subject is open to a more quantitative and detailed analysis.

Ample statistics on the change in engine data are available (Ref. 1). It is sufficient and less tedious to examine a summary of such data, which is presented in Table I, and shows the percent change in the most important design and performance parameters.

Table II shows some of the data for engines of recent design, at which we shall take a closer look.

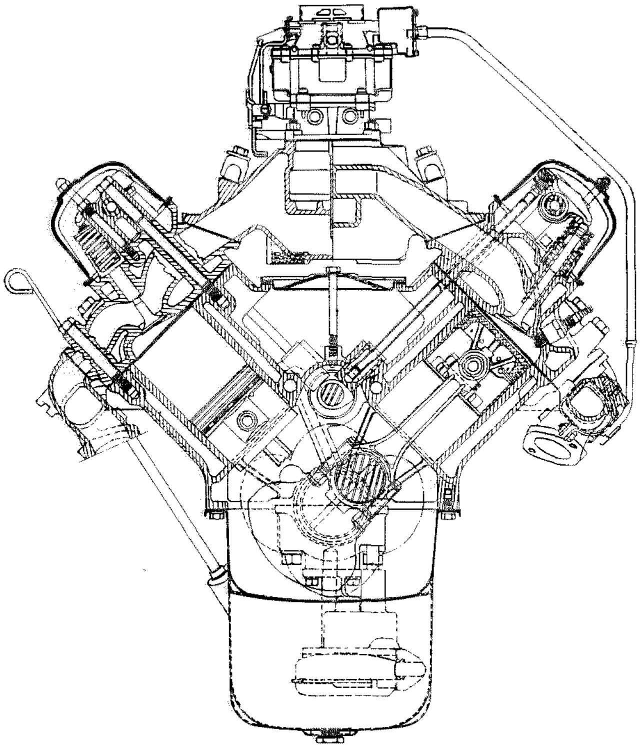


2. *DeSoto Engine*

TABLE I

Engine Design Trends 1940 - 1951
(Changes in percent)

HP/cu. in.	+37.5
Compression ratio	+36.0
Brake horsepower	+33.0
Brake Mean effective pressure	+ 3
Bore	+ 3
Stroke	— 9
Displacement	— 3.2
Displacement per cylinder	— 1
Piston speed	+ 5
Rpm	+13



3. *Studebaker Engine*

Structure of the high compression engine

Before considering performance, let us examine the engine structure. Figures 1, 2 and 3 show, respectively, typical representatives of current V-8 engines (Cadillac, DeSoto, Studebaker).

All three engines, as well as others (Oldsmobile, Chrysler, Lincoln) are 90° V-8 engines with overhead valves. All of these engines are nearly "square," meaning bore and stroke are nearly the same (see Table II). There are simple and valid reasons for this:

All these engines are designed for compression ratios of about 12:1, even though they are not now sold with ratios higher than at most 8:1. The high compression ratios require extreme rigidity of crankcase and crankshaft; otherwise the engine will display "roughness," a term used to denote combined bending and torsional vibration. This is not caused by knock but merely by high compression-end and peak pressures.* The V-8 is easily balanced and made stiff, both in crankcase and crankshaft and hence is the logical configuration, next to the in-line six. The V-6, although stiff structurally, is not easily balanced and offers little advantage over a V-8.

Overhead valves are dictated by the geometry of the cylinder and head for high compression ratios. The clearance volume becomes so small that an L-head does not have sufficient space for valve opening. Good valve opening, and hence good breathing, is just as important as high compression ratios, even though it is not nearly as much publicized and advertised.

Bore-stroke ratios of one and less, although common in reciprocating aircraft engines, are new to the automotive production engine. They have resulted in a material decrease in piston-friction and hence friction horsepower, which is a direct gain in brake-horsepower. At the same time, shortening the stroke permits increased engine speed without increasing the mean piston speed. The mean piston speed is a measure of the flow losses in the intake valves; if, therefore, this speed remains con-

* This is also the reason why, in "souped-up" stock engines, the higher the compression ratio, the more they behave like rock crushers.

TABLE II

1952 Automobile Engine Design Data

Make	Type	Bore	Stroke	Bore/stroke	Displacement cu. in.	Compression Ratio	Maximum BHP	RPM at max. BHP	BHP/cu. in.
Cadillac	V-8	3.813	3.625	1.05	331	7.5	190	4000	.574
Oldsmobile	V-8	3.75	3.438	1.09	303.7	7.5	160	3600	.526
Chrysler	V-8	3.813	3.625	1.05	331.1	7.5	180	4000	.544
DeSoto	V-8	3.625	3.344	1.08	276	7.1	160	4400	.579
Studebaker	V-8	3.375	3.125	1.07	232.6	7.0	120	4000	.516
Lincoln	V-8	3.8	3.5	1.09	317.5	7.5	160	3900	.504
Ford 6	OHV-6	3.56	3.6	.99	215.3	7.0	101	3500	.468
Willys	F-head 6	3.125	3.5	.89	161	7.6	90	4000	.559
Buick 70	in-line 8	3.438	4.313	.80	320.2	7.5	170	3800	.530
Chevrolet	OHV-6	3.50	3.75	.935	216.5	6.6	92	3400	.425
Plymouth	L-head 6	3.25	4.375	.74	217	7.0	97	3600	.448
Ford V-8	L-head	3.19	3.75	.85	239.4	7.2	110	3800	.470
Mercury	L-head V-8	3.19	4.0	.80	255.4	7.2	125	3700	.489

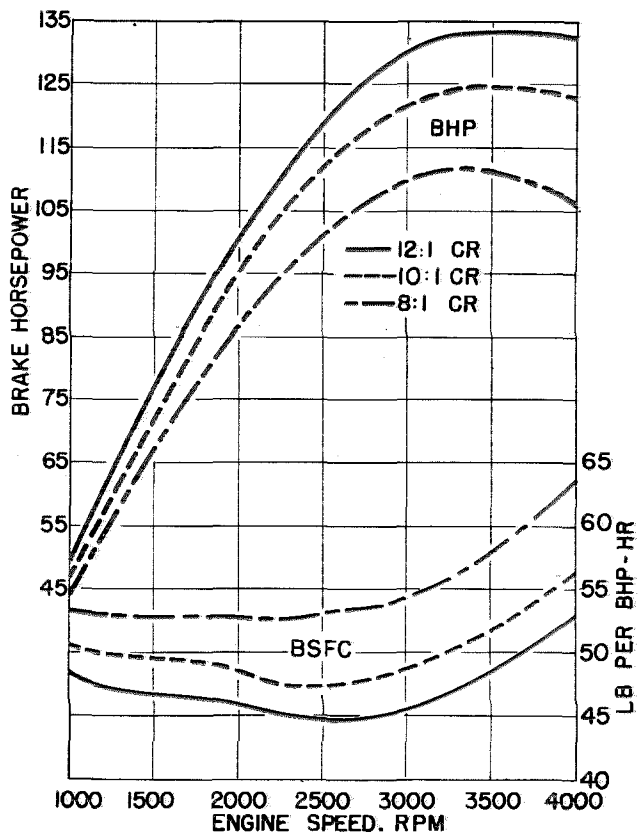
stant, the breathing capacity of the engine is unchanged.

The engines discussed so far appear rather similar, which they are, indeed, with the exception of the valve arrangement of the Chrysler "Fire-Dome" engines. The cylinder head is hemispherical and the valves form a V rather than being in a plane. This arrangement is well known and practically universally used in motorcycle and aircraft engines. The central location of the spark plug results in a shorter flame travel than in other head configurations. Other things being equal, the combustion chamber with the shortest flame travel has the least tendency to knock (Ref. 2). The spherical head and rocker arm assembly is more expensive to produce than any other head. This fact, rather than ignorance, has prevented manufacturers of production engines from adopting this cylinder head. (Let us keep in mind here that we are concerned with engines produced and producible by the million. European manufacturers with production of 25⅜ cars per year are in a position to do a lot of things which are not feasible in our production.)

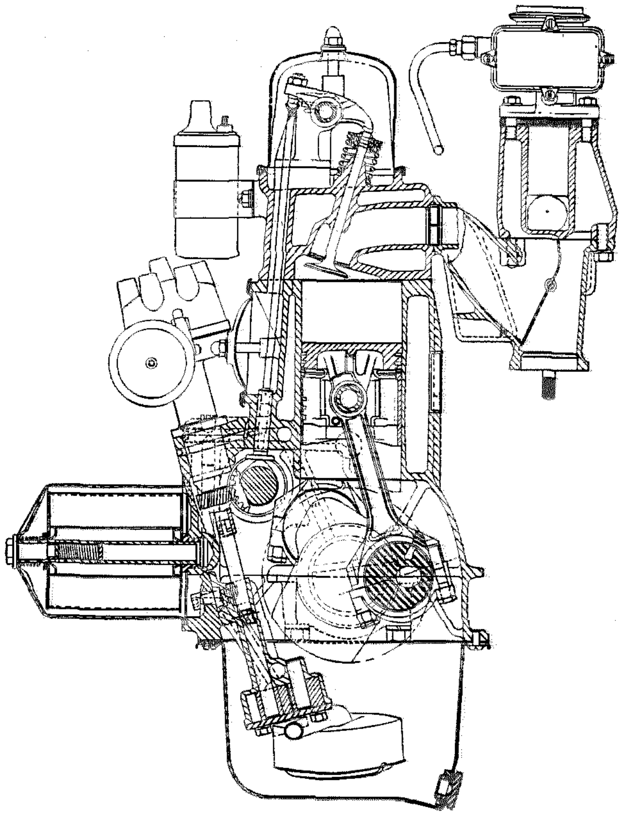
Last, but not least, we have the Ford 6 (Fig. 4) as a typical representative of a new family of six-cylinder engines designed along much the same lines as the new V-8's: high compression ratio, great rigidity, short stroke, good breathing.

In summary we can say that engine designers are improving performance:

(1) By raising the compression ratio. This increases power output and decreases fuel consumption.



5. *Brake Horsepower as a Function of Engine Speed and Compression Ratio (GM Research Engine)*



4. *Ford Engine*

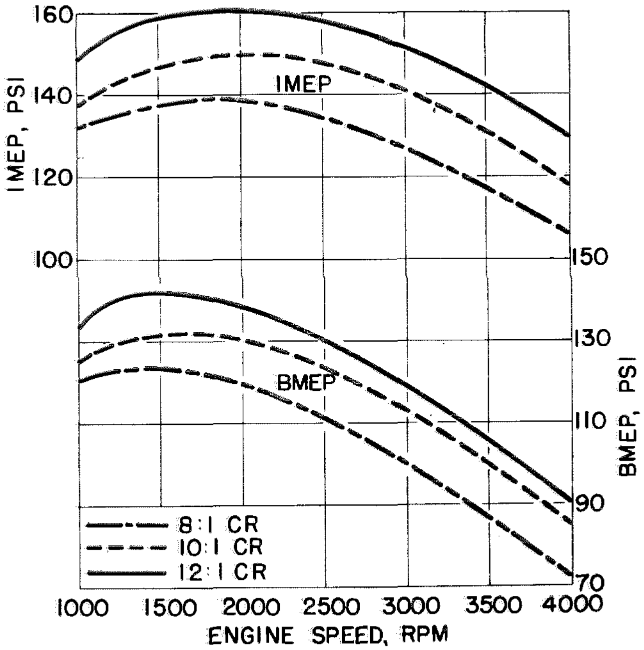
(2) By reducing engine friction. This increases the output per cubic inch displacement and improves the specific fuel consumption (lbs-fuel/bhp-hr).

(3) By improving the breathing capacity of the engine. This raises the output per cubic inch displacement and permits higher engine speeds, which, by itself, increases the output.

We shall now examine the effectiveness of these three measures separately.

Why high compression ratios?

We have, so far, compared structural details of engines. The implication has been that it is intuitively obvious why high compression ratios are desirable. The question is now: just what happens to the performance of a full-scale engine if the compression ratio is increased? This has been investigated (Ref. 3) using a General Motors engine, essentially an Oldsmobile Rocket in which *only* the compression ratio was changed. Fig. 5 shows brake horsepower plotted against engine speed for three compression ratios. Peak bhp increases by about 20 percent while the specific fuel consumption decreases by the same amount as the compression ratio is increased from 8 to 12. Similarly, the brake mean effective pressure (Fig. 6) increases numerically, but the shape of the curve remains the same. Since bmep and torque curve are identical, it is seen that torque-speed relations are not changed by increased compression ratios, a fact which is not appreciated by many hot-rod hopefuls.



6. *Brake and Indicated Mean Effective Pressure as a Function of Engine Speed (GM Research Engine)*

Friction horsepower *increases* with compression ratio (Fig. 7). This is due to increased bearing pressures as well as increased gas pressure on the piston rings.

Heat dissipation is essentially unchanged by increased compression ratio (Fig. 8). It is well to recall the energy balance in an engine, as shown in Fig. 9. Approximately 1/3 of the energy supplied by the fuel is transformed into brake work, delivered for our use. One third of the energy leaves through the exhaust, and the last third represents cooling losses to water and oil. If we look at it this way, the radiator which we are tempted to consider as an inferior piece of hardware, takes on more importance.

Engine performance—car performance

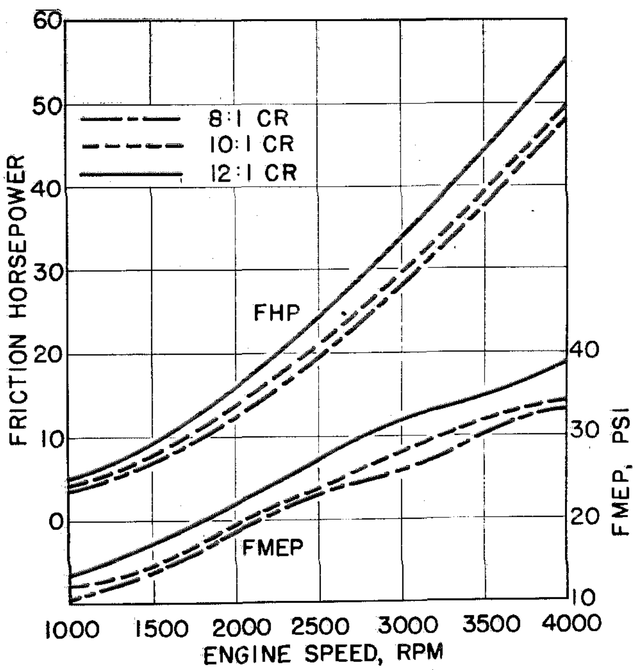
Finally we have Fig. 10 which translates the engine performance into car performance, assuming the power required of a typical passenger car. The effect of axle ratio is shown in this diagram, in order to emphasize the importance of this parameter. Comparing cars with identical axle ratios, the improvement in mileage is about 17 percent. If we specify that the car shall have the same acceleration with 8 and 12 compression ratio, we can afford to reduce the axle ratio from 3.6 to 3.1 with an additional gain of about 10 percent in mileage.

How about engine friction?

The increase in friction with compression ratio was shown in Fig. 7. Comparing, however, the newer (square) engines with their older, long stroke, counterparts, a definite gain is noted, due to reduced stroke and careful attention to design details. Comparing the Cadillac V-8 side-valve engine (1948) with the 1949 OHV (Over Head Valve), friction horsepower has been reduced from 45 to 37 horsepower at 3200 rpm. For the same engines, fan and waterpump horsepower have been reduced from 6.3 to 3.3 at 3200 rpm, i.e., by about 50 percent. Although the total amounts of power absorbed by friction are not very large, worthwhile gains are being made by constant efforts to improve detail design.

Breathing capacity

The output of any thermodynamic power producing machine is proportional to the mass flow of working medium passing through the engine. In the spark ignition (automobile) engine the fuel air ratio varies only within narrow limits throughout the operating range. The power output is, therefore, proportional to the air flow through the engine. Anything that restricts the flow of air through the engine reduces power. We use this effect when we close the throttle. Valve size, valve opening, intake and exhaust manifolding and carburetor design have decisive effects on air flow (breathing) in the engine, and engine designers are constantly at work on these items. It is difficult to find data which isolate this effect, but we have one which illustrates the point well. Fig. 11 shows brake horsepower vs. rpm for a stock Chevrolet (216.5 cu. in.) engine with stock head and with a special head which has larger intake valves and an auxiliary intake manifold. No other changes were made. The improved breathing resulted in an increase of about 20 percent in maximum power at full throttle. A warning to the all-too-eager beaver is in order. The gain in full throttle maximum power is no measure of the improvement in part throttle cruising mileage, which will be small for the existing special head, unless the manifold-carburetor combination is drastically improved.



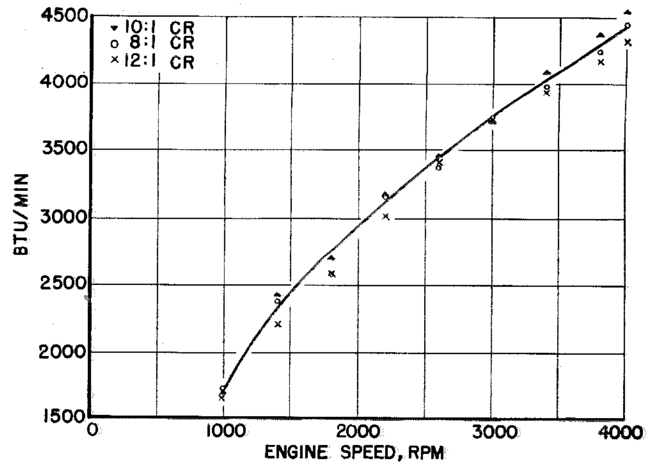
7. *Friction HP and Friction Mean Effective Pressure as a Function of Engine Speed (GM Research Engine)*

Another example of gains from improved breathing without complete redesign is represented by the Willys F-head, shown in Fig. 12. The basic L-head engine remains unchanged. The L-head is replaced by a head with one intake valve, actuated by rocker arm and pushrod. This permits a very large intake valve diameter as well as lift, and results in materially reduced intake losses which, in turn, increase full throttle output. This measure remains a makeshift solution. The fact that Rolls Royce uses the F-head design does not persuade the writer of this discussion that it has heretofore undisclosed merits.

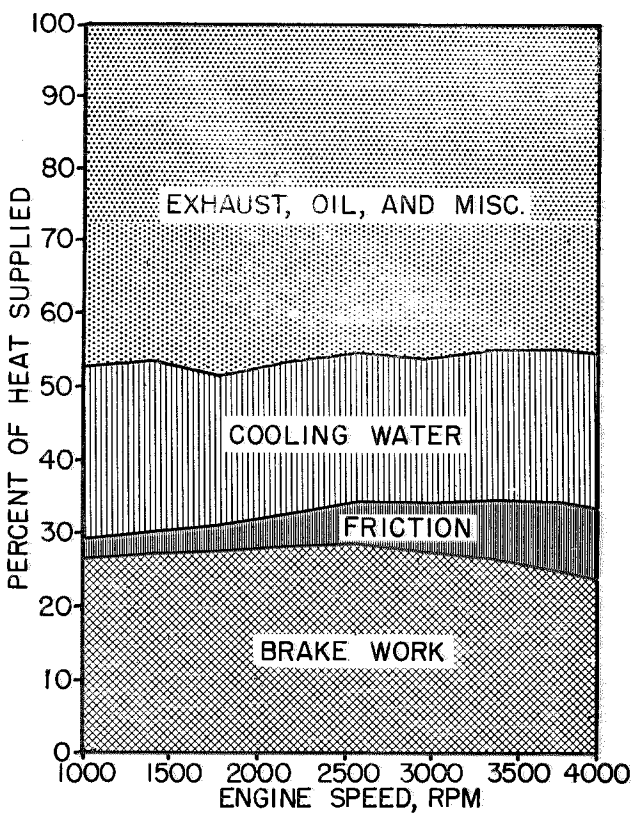
Fuel and maintenance requirements

It was pointed out that the new engines are designed for compression ratios around 12:1 but are now sold with about 7.5:1. This corresponds to an octane requirement of about 82 which is met by present premium fuels. At 12:1 compression ratio the octane requirement is of the order of 100.

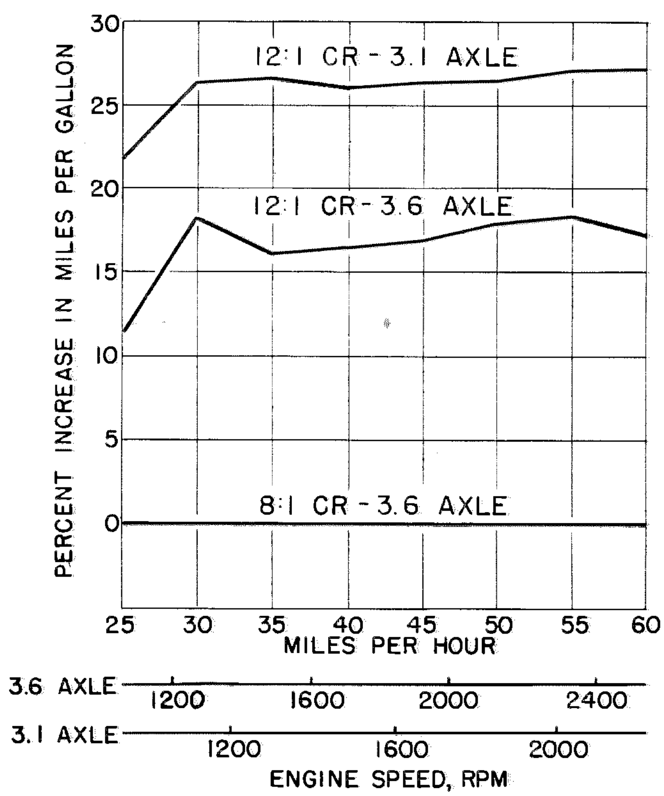
Although service experience is generally good, engines require more careful tuning and ignition and carburetor maintenance. This is to be expected. If compression ratios are to be increased in the future this will become even more important. Engine cleanliness becomes the more essential, the higher the compression ratio, since octane requirements increase rapidly as deposits build up in the combustion chamber. Perfect valve and piston ring seal is necessary if high compression ratios are to be effective. Where the compression-end pressure and peak firing pressure are, respectively, 200 and 750 psi at 7:1 compression ratio, they are 450 and 1100 psi at 12:1. The full advantage of the high compression ratio is lost if appreciable leakage occurs. Improved maintenance methods are being developed, such as the "head on carbon removal" method which employs a rice blast through the spark plug hole to remove carbon without necessitating removal of the cylinder head. Nevertheless, somewhat more frequent tuning and other maintenance operations must be expected.



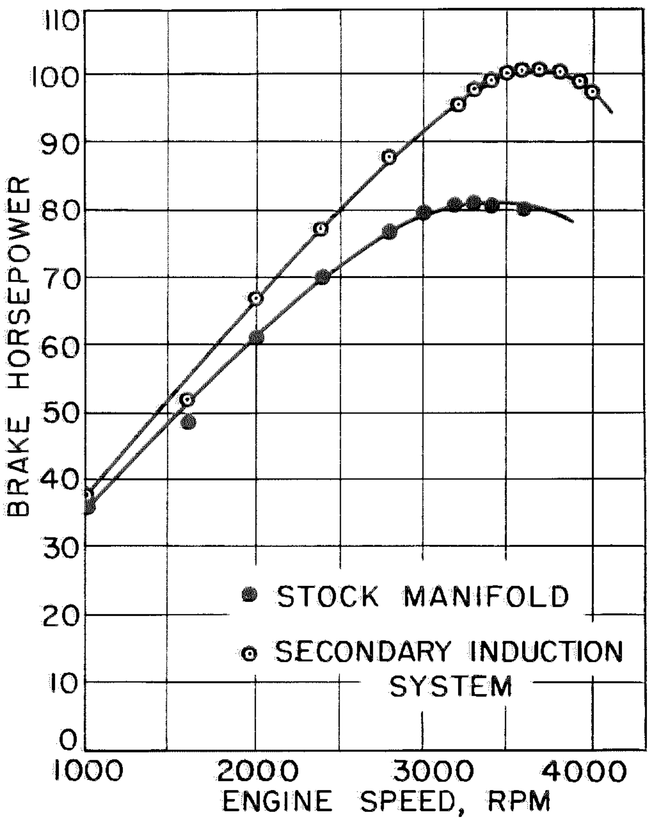
8. *Heat Rejection to Cooling Water as a Function of Engine Speed (GM Research Engine)*



9. *Breakdown of Energy Supplied by Fuel to Engine (10:1 Compression Ratio—GM Research Engine)*



10. *Effect of Compression Ratio and Rear Axle Ratio on Mileage for a Typical Car. (GM Research Engine)*



11. *Effect of Improvement in Breathing Capacity on Full Throttle Power (Chevrolet 216.5 Cu. In. Engine)*

Now that we have horsepower, —what can we do with it?

As we have seen, real gains in power as well as in specific fuel consumption have been made and further improvements are readily available. There is, however, a joker in this game: the word "specific" fuel consumption, meaning the pounds of fuel per brake horsepower-hour. No matter how low a figure this may be, multiplied by a large number of horsepower it comes out to be a goodly number of pounds and hence gallons (there are about 6 pounds of gasoline to a gallon).

The power required for level road cruising is moderate. Table III shows average values for 11 cars (Ref. 4).

The difference between power-required and power-available is immediately apparent. What happens to this difference? It is used for acceleration and to ruin a potentially good mileage. Modern automatic transmissions permit high accelerations with extreme smoothness which makes the driver forget how much power he is actually using. It is rather futile to advise restraint in acceleration. If the power is there, it is going to be used. It is equally useless to ponder whether this is good or bad or whether manufacturers or customers are to be blamed for this development. Approximately 20 percent of the cars sold in 1951 belong to the so-called "overpowered" class. The resulting driving habits are presumably what prompted Mr. Colman to make his remark.

TABLE III

Average Road Horsepower: 1949 Cars

Speed (mph)	20	40	60	80	100
Road Power Required (hp)	5	15	30	65	145

REFERENCES:

(1) *Automotive Industries*, March 15, 1950

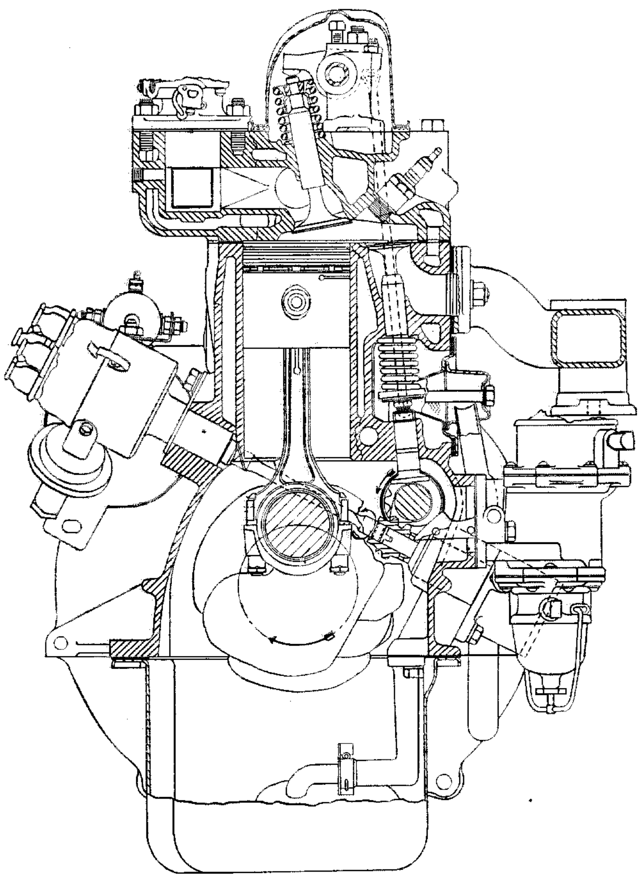
(2) Obert, E. F., *Internal Combustion Engines*, International Textbook Co., Scranton, Pa., Second Edition, 1950, Ch. 14, p. 449.

(3) Roensch, M. M., "High Compression Engine Performance," *SAE Journal*, June, 1949, p. 17.

(4) Gaines, R. W., Burton, R. W., Bruns, H.P. "Road Testing Cars—Types, Problems, Instruments," *SAE Journal*, October, 1951, p. 48.

CREDITS:

Figure 2 *Automotive Industries*, November 1, 1950
Figures 3,4 *Automotive Industries*, February 1, 1952
Figures 5-10 *SAE Journal*, June, 1949
Figure 11 *Motor Trend*, March, 1952
Figure 12 *Automotive Industries*, January 1, 1952



12. *Willys Engine (F-Head)*