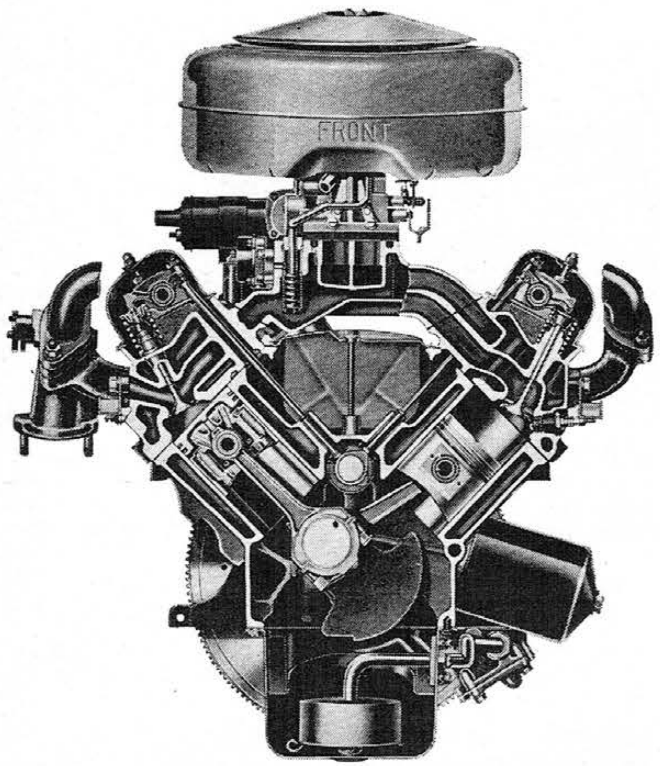
TOMORROW'S FIGHT FOR ENGINE POWER MAY NOT CENTER AROUND THE GAS PUMP. THE ANSWER COULD BE BURIED IN YOUR ENGINE!

Engineers have long been aware of the facts: combustion chambers—not expensive fuels—may hold the key to power. Here's the latest report on their search for the answers.

THE BIG *SQUEEZE* FOR POWER!

BY ROGER HUNTINGTON



WE "Detroit iron jockeys" are about to witness a battle of combustion chambers that will make the horsepower race in this country look like kids' play.

For about thirty-five years now engineers have been aware that *combustion chambers*—and not necessarily expensive fuels—were the key to tomorrow's super-efficient, super-compression piston engine. They've dreamed up a thousand gimmicks since that were supposed to do the trick. Some tried to ditch the troublesome exhaust valve hot spot by using one valve for both intake and exhaust; some tried rotary valves; others felt we could live with more conventional valve layouts if we *shaped* the combustion chamber right . . . some even ignored all the theories about shape and hot spots and concentrated on cramming their chamber full of valves.

99% of ideas have proved, for one reason or another, to be poor compromises for automotive engines.

And as far as that goes, all you have to do is look at blueprints of the latest crop of Detroit engines to realize that we're a long way from the final answer yet. Chrysler Corp. uses a radical hemispherical combustion chamber with inclined valves and central spark plug on their new mills. Cadillac, Olds, Studebaker, and the Ford Motor Co. all use a basic "wedge"-type chamber with more or less vertical valves and a plug set in one corner. Buick falls somewhere between the two extremes. Meanwhile, the manufacturers still sticking with "old" tooling and designs (before 1949) struggle to keep up with the trend to higher compression ratios by chipping away a little at the chamber contour and hoping for the best!

They can't all be right. And as Shakespeare would say, "thereon hangs a tale of sound and fury . . ."

HOW IT ALL STARTED

In the very early days of the automobile a combustion chamber was nothing more than a place you squeezed fuel into before you fired it; compression ratios were about 3½:1, pump gasoline (it acted about like *kerosene*) rated 50 octane, and you were too concerned about whether your engine would even *run* to worry about combustion chambers.

World War I changed all that. Intensive development of the internal-combustion spark-ignition engine in the aviation, truck, and auto fields during this period brought up a terrific new headache—*detonation.* As "breathing" was improved and compression ratios boosted over 4:1, the fuel-air mixture in the cylinder no longer wanted to *burn* evenly; instead, a portion of the combustible mixture would *explode* violently, setting up destructive pressure waves in the cylinder. This detonation, or "knock" as some call it, was pounding heavy-duty engines to pieces in 1920.

There have been many theories about exactly what knock is and what causes it. We're still not sure today. However, here is the consensus of the latest theories: Detonation is nothing more than *self-ignition* of the *last portion* of the fuel-air charge ahead of the normal flame front. Experiments have proved that normal combustion in an engine cylinder spreads out evenly from the spark plug in approximately a *spherical* (circular) flame front at a more or less constant speed, this flame speed depending mostly on the *turbulence* of the mixture. Obviously the pressure rise caused by the combustion in the flame front will compress the unburned mixture ahead of it (in a sort of pressure wave just like the bow of a ship); this compression raises the temperature of the charge. Add to this the heat picked up from combustion chamber surfaces—and you quickly reach the self-ignition temperature of the unburned portion of the mixture. The result is—POOF!!

A brilliant British scientist, Harry Ricardo, doped this all out on paper in 1919! He figured the way to control knock was to bring the combustion chamber surface farthest from the spark plug right down within 1/16" of the piston to form a "quench area" that would literally *chill* the last portion of

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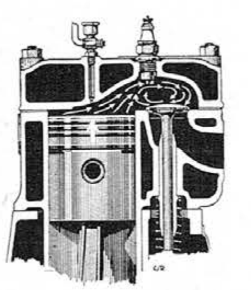
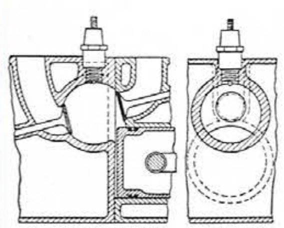
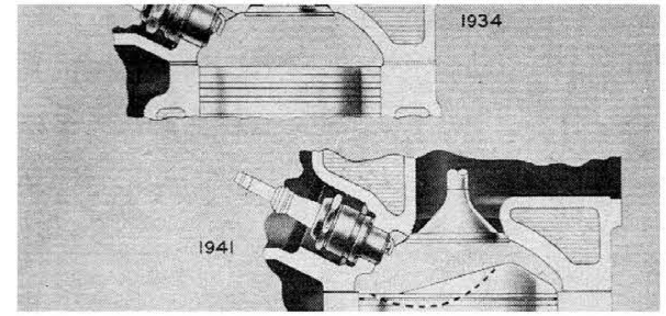


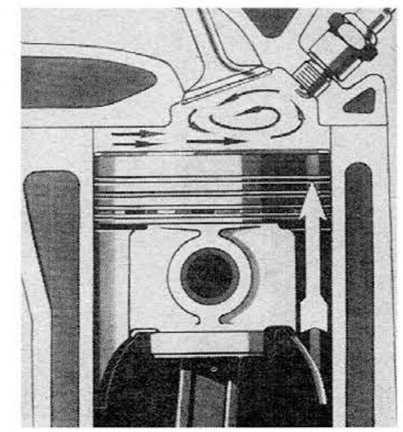
Developed in early '20s by British scientist Harry Ricardo, this style was first attempt at combustion design. Knock control was created by a "quench" area which would chill last of charge to prevent self-ignition then common



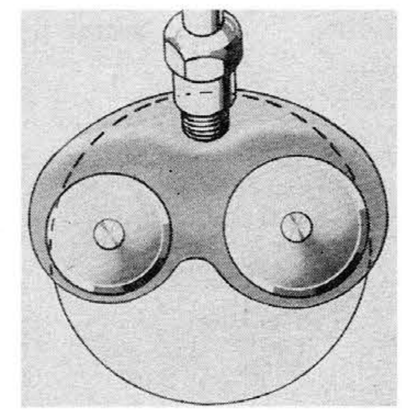
Often called one of the early "weirdies," the Bonnefoy-Cudraz design of 1926 was based on belief that violent swirl in the fuel-air mixture was the whole answer. Anti-knock gasoline, using tetra-ethyl lead was on market. It caused boost in compression



Buick began work on OHV combustion chamber designs early in '30s. The '34 design was rough and knocked badly. As possible solution turbulator piston was tried in 1938

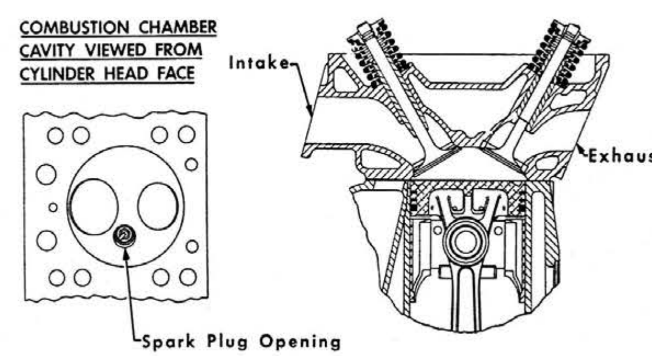


The critical period for turbulence during combustion cycle is period just before spark fires. Here, quench area becomes very powerful "squish area." The gas trapped between piston and head is squirted into main combustion chamber at high velocities. This hastens burning and greatly reduces the octane requirements



Drawing shows the layout of Ford's newest wedge-type combustion chamber design. The light area over piston is squish area, while the darker area is the open combustion chamber. This is typical of newer designs which could create 12:1 ratios. Today, they'd be rough running but approach is what Kettering calls "Mechanical Octanes"

Three of the best-known attempts to get detonation control with smoothness are shown here. They represent theories still in use. Ricardo design, left, fathered dome chamber. Janeway, right, triggered much development during '30s



Chrysler's popular hemispherical combustion chamber features a wide angle around the plug. Many engineers consider this bad from standpoints of roughness and detonation, but design can house big valves for plenty of Brake Horse Power

THE SQUEEZE FOR POWER

(Continued from page 29)

the charge and prevent self-ignition. He also rounded out the dome of the chamber to give a swirling motion to the charge (to speed up burning) and put the spark plug above the exhaust valve, so the first part of combustion would be at the hottest point in the chamber. Fig. 1 shows an early example of the now-famous Ricardo head.

And it worked. Chrysler was the first to adopt the idea in this country on their highly-advanced 1924 6-cylinder model—and virtually *every L-head design in the world* since then has used the basic principle. Harry Ricardo was the father of the science of combustion chamber design.

Just about this same time, however, an entirely new approach to the problem of detonation appeared. Thomas Midgley and Charles Kettering, of General Motors Research, were assigned to try to build *knock resistance* into gasoline. I don't suppose this is a proper part of the subject of combustion chambers, but certainly the results of their work have had a vital influence on practically every phase of engine design in the last thirty years. As you know, they were the boys who discovered that small amounts of tetraethyl-lead fluid added to gasoline would delay combustion reactions in the unburned mixture and eliminate knock under quite severe conditions. A mere three cc's per gallon would boost the octane rating of straight-run gas of the early '20s to about 70, and it was claimed that it would permit up to 6½:1 compression ratio (though none of the manufacturers approached this figure until Chrysler went to 6:1 on their famous Red Head engine of 1927). Incidentally, "Ethyl" was put on the market in 1924.

So, as of the mid-'20s, engineers really had *two* powerful weapons with which to fight for higher compression ratios—scientific combustion chamber design and 70-octane premium pump gas.

ROUGHNESS

Up to this time, combustion chamber design was strictly a matter of controlling detonation in the last portion of the charge to burn. No particular attention was given to the combustion process *as a whole*. It was soon realized that this wasn't going to work out. As compression ratios went up, even though the engines didn't knock badly, they were getting awfully *rough*. The high rates of pressure rise during combustion in the cylinders were actually deflecting or *bending* the whole crank train and engine structure excessively; this, in turn, set up annoying vibration and drumming on the road, especially when accelerating. Since the maximum *rate* of pressure rise—usually expressed in lbs./sq.in. per degree of crank

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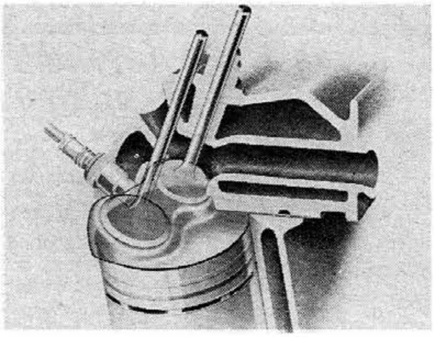
rotation—comes early in the combustion process, it was obvious that chamber design was going to have to be a lot more than providing some turbulence and a quench area over the piston.



This is a cast of the combustion chamber on the new Ford-Merc V-8; note how extremely compact the open section is

Robert Janeway, then of G.M. Research, was the major pioneer in working for smoother combustion as well as detonation control. In the late '20s this brilliant mathematician devised a complicated method whereby he could take a plaster cast of any combustion chamber and predict on paper the pressure rise rates with an error of less than 10%—and he could also predict pretty well if a given engine would run "smooth" or "rough." (The secret of the process was a special tool that would cut the plaster cast up into layers on a spherical surface, with the center at the spark plug; assuming constant flame speed, these layers represented various columns of gas burned after a certain amount of crank rotation.

According to Janeway's theory, of course, the instantaneous pressure rise in the cylinder was proportional to the relative *area* of the flame front—and, conversely, the pressure rise could be limited by shaping the combustion chamber to give gradual flame front growth just after the spark. In fact, by allowing for stiffness of the engine structure, calculating impact and deflections, this slide rule wizard figured that a maximum pressure rise of 36 psi/deg. crank travel would be quite rough . . . and, strangely enough, close to this figure seems to be the upper limit for acceptable smoothness today!

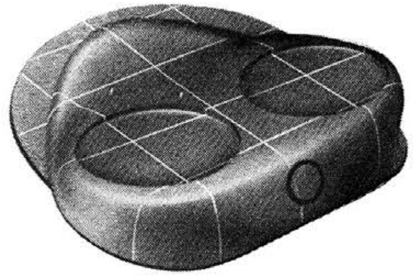
Janeway's work triggered a lot of new combustion chamber development around 1930. Fig. 3 shows the best-known designs, including Janeway's own "anti-shock" head. Ricardo got in on it, too. He agreed that pressure rise was the key to smoothness, but he felt if you had a gradual rise very early in the combustion cycle you could handle more than 50 psi/deg. in the middle without roughness. His patented "shock-absorber" head is shown in Fig. 3. Another Britisher, W. A. Whatmough, came up with a streamlined "anti-turbulent" head (Fig. 3): he put his spark plug in one extreme corner of the chamber and got the lowest maximum

(*Continued on page 50*)

pressure rise of all—only 16 psi/deg. You can see that there was little agreement between the three men; but apparently the chamber worked because you can find a modification of one of the three designs in most any side-valve engine today!

OHV PROBLEMS

One thing all the early boys seemed to agree on was that a combustion chamber for side valves could be made much smoother and more knock resistant at a given compression ratio than an overhead-valve layout, and that the open hemispherical chamber, with its rapid rise in flame front area and combustion pressure, was *absolutely out* for utility passenger cars.



A cast of the Ford wedge-type chamber

That was an era of long-stroke L-head engines. A few of the manufacturers tried vertical overhead valves for mass production (Buick, Chevrolet, etc.), but they had their troubles. Knock and roughness were continual headaches. A study of specification tables will show that compression ratios on OHV engines of the '30s were consistently lower than the L-heads. For instance, Fig. 4 shows the '34 Buick combustion chamber. Note the wide open space around the plug, no quench area, etc.; the large models had only 4.9:1 compression ratio, and even the small-bore jobs with 5.2:1 were on the ragged edge of serious knock with premium gas of that day—and rough to boot.

The OHV boys tried a number of gimmicks during these years. Designer Alex Taub got quite good results on the new Chevrolet design in 1937 by pocketing the exhaust valve in the quench area and using a very small combustion chamber around the intake. The octane requirement was higher than current L-heads, but the engine was quite smooth.

About this time the Buick engineers decided to try a new path to lick the OHV combustion chamber bug—*turbulence*. Turbulence had been a pretty hit-and-miss item up until then. Early researchers disagreed violently on its effect. Ricardo thought it helped kill knock by speeding up the flame front, but soft-pedalled it on his later designs because he was afraid it would make them rough. Whatmough ignored turbulence. Janeway laughed at any thought that a mere swirl-

(*Continued on page 52*)

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ing in the charge could have any effect on flame speed; and besides, he didn't think there was any very violent gas motion by the end of the compression stroke anyway. We know today that Ricardo was closest to being right about turbulence . . . but more on that later.

Certainly Buick was all wrong with their "Turbulator" piston in 1938! Their engineers figured that, by rounding out the piston head and building it up on the side opposite the plug, the fuel charge would be more or less rolled up in a ball right in front of the plug on the compression stroke, and this would greatly speed up combustion (see Fig. 4). It didn't work. When they went to 7:1 compression on their compound-carburetor models in 1941, the octane requirement with a carbon load sky-rocketed far beyond the best pump gas available—and you couldn't tune it out with a spark adjustment. The '41 Buicks were probably the "knockingest" cars ever put on the roads!

THE EFFECT OF TURBULENCE

New laboratory techniques developed in the last few years have finally shown us the true nature of mixture turbulence and its effect on combustion. We know now that the critical period in the cycle for turbulence is just before the spark fires, and not conditions during the intake and compression strokes as some earlier researchers thought. And the key factor here is our quench area. This actually becomes a powerful *"squish area"* as the piston nears top center, and the fuel-air mixture trapped between piston and head is squirted out into the main combustion chamber at high velocity. This hastens burning and greatly reduces the octane requirement. (See Fig. 5.)

Thus our beloved quench area serves two important functions—to control turbulence and to chill the last part of the charge to burn and control detonation. Tests have shown that you can vary the octane requirement within wide limits by merely changing the size of the quench or squish area; the larger the area, the higher the gas velocity in the chamber at the time of ignition, the faster the burning, and the lower the octane requirement. Oldsmobile enlarged the squish area on their '51 Rocket model from 16% of the piston area to 30%—and reduced octane requirement four points with one blow! One OHV chamber of 9:1 compression ratio with a large squish area showed a requirement of only 70 octane. (It should be noted here that tests prove that the clearance in the squish area between piston and head must be less than .100"—and preferably .050"—to have any appreciable effect on combustion.) This all proves how wrong Buick was with their Turbulator piston and how wrong Janeway and some others were years ago to ignore turbulence as a factor in com-

(*Continued on page 54*)

bustion. Such is progress, I guess . . .

But lest you think we've got all the problems solved with a little turbulence, hear this: When we speed up the burning by increasing turbulence, we also boost the maximum rate of pressure rise in the cylinder—and our engine gets *rough* again! It's a vicious circle. Furthermore, modern research supports Janeway in his contention that pressure rise is at least partly a function of the relative growth in area of the flame front, just as if you were to cut up a plaster cast of a modern chamber with his spherical cutter of 25 years ago. That theory still holds water

The latest knowledge on turbulence and roughness dictates that *all* our current OHV combustion chambers have to be a killing compromise between how much compression you can use without rattling like marbles in an ashcan when the engine carbons up and how much combustion roughness the customer will take before going to the next showroom.

Let's have a closer look . . .

THE PICTURE TODAY

Chrysler has staked ten years and $100 million or so on brute horsepower and torque. Their hemispherical combustion chamber permits huge valve area and large, free-flow porting for super breathing. (See Fig. 7.) The other manufacturers will never be able to touch them on BHP per cubic inch with present head layouts. But the Chrysler products are definitely rougher, especially at low speed, and they'll never be able to stay with the more conventional OHV chambers on compression ratio. These are hard facts. Chrysler engineers argue that their chamber doesn't collect carbon so easily and has a smaller surface-volume ratio so there is less heat loss to the coolant, and efficiency can be maintained without going to super-high compression ratios. This is true enough—but if we ever see a real "compression ratio race" . . .

The boys who have used the more conventional wedge-shaped chamber—Cadillac, Olds, all Ford products, Studebaker—are in a different position. They can't house the big valves that Chrysler can, so will have to take a back seat on BHP, but the basic combustion chamber layout should permit considerable future development on combustion control without major changes in expensive tooling. Figs. 8 and 9 show the general layout of the Ford wedge-type chambers. Some of these types are getting by quite well right now above 8:1 compression ratio on 90-93 octane (Research), though they're definitely on the ragged edge after a couple-thousand miles of carbon buildup. At any rate, these engines now have the lowest octane requirement in relation to compression ratio of any in America.

Actually, the faithful old L-heads are not far behind. Notice that Packard is

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successfully using 8.7:1 ratio this year! The side-valve chamber can be designed to give excellent smoothness and knock control, just as Ricardo and his friends told us 25 years ago. L-heads are a dead issue today, though, simply because the chamber restricts air flow (breathing) at high compression ratios and couldn't possibly be adapted for anticipated 12:1 ratios of the next decade. All L-heads now surviving were originally designed more than 15 years ago, and it's only a matter of time before all will disappear.

Buick was in serious trouble with knock and pre-ignition last year. For '54 they've had to shrink down the chamber to make it much more compact and efficient. This has helped . . . but I have a hunch Buick enthusiasts are in for a big change in head layout one of these days.

THE FUTURE

We're going to see a lot of combustion chamber development throughout the industry in the next decade. Our beautiful new short-stroke V-8 blocks are just itching to soak up the pounding of 12:1 compression ratios. They're built for it. Super compression saves gas, so it's a deal for John Q. The petroleum industry is ready to do its part; 96-octane is already available at the pump in some sections of the country, and William Holaday of Socony-Vacuum recently said they could "tool up" for quantity production of 98-octane anytime, though at a price premium. This fuel could handle 10:1 compression in most of today's OHV engines.

Combustion chamber development—or "mechanical octanes," as Kettering likes to call it—will have to fill the gaps. We haven't scratched the surface yet on squish magic and turbulence control. We could readily build high-turbulence engines today that could carry 12:1 compression on 90-octane gas, but they'd be rough. It looks like a compromise now. But maybe some new thinking on gas flow in the cylinder will be an answer to good knock resistance without excessively fast pressure rise. Fuel injection is coming, and this will give us a terrific boost. Texaco, in fact, recently built an experimental f.i. engine in which the incoming air is given a swirling motion as it comes through the valve; this thing will burn *kerosene* at 12:1 without a whisper of knock—and it's smooth, too. One manufacturer I know of is experimenting with a *spherical* combustion chamber virtually in a hollow in the piston top, surrounded on all sides by squish area. The octane requirement is ridiculously low.

One way or the other, we're in for a very interesting period of combustion chamber development out of Detroit—literally a race for the elusive 12:1 compression ratio . . . and woe betide the engineer who trades one compression ratio point for 10 or 20 horses!!