combustion, 32 grams (1 gram-molecule) of oxygen, or 22.4 litres of oxygen at N. T. P. Since the ratio of nitrogen to oxygen in the air, by weight, is as 77:23, or as 3.35:1, it follows that for every 32 grams of oxygen there must be 107.2 grams of nitrogen. The weight of air required for the complete combustion of 12 grams of carbon is, therefore, 139.2 grams. Moreover, since the ratio of nitrogen to oxygen, by volume, is as 79:21, or as 3.76:1, the volume of air, at N. T. P., required for the complete combustion of 12 grams of carbon, will be 22.4+84.2=106.6 litres.

If one employs, as is usually done in technecal practice, the pound as unit of weight and the cubic foot as unit of volume, the appropriate calculation shows that 12 lbs. of carbon require, for complete combustion, 378.3 cubic feet of oxygen, or 378.3+1422=1800.3 cubic feet of air, at 60 degrees F., and under a pressure of 30 inches of mercury.

For the combustion of hydrogen, we have the equation:

$$2H_2 + 0_2 = 2H_20 + 2 \text{ X } 68{,}3000 \text{ cals.}$$

That is to say, when 2 grams of hydrogen are burned in air or in oxygen so as to form 18 grams (1 gram-molecule) of water, and when the water vapour formed is condensed to the liquid state, 68,300 cals. are evolved. This is the heat of combustion of hydrogen.

If the water vapour is not condensed to the liquid state, the heat of combustion will be less than 68,300 cals. by 9700 cals., which is the latent heat given out by 18 grams of steam on condensing to water.

As in the case of carbon, one can calculate the weight and volume of oxygen or of air required for the combustion of a given amount of hydrogen, and one finds for the combustion of 2 grams of hydrogen (occupying a volume of 22.4 litres at N. T. P.), there are required 16 grams of oxygen, or 11.2 litres of oxygen at N. T. P. When burned in air, 2 grams of hydrogen will require 69.6 grams of air, or 53.3 litres of air at N. T. P.

Further, 2 lbs. of hydrogen (occupying a volume of 378.3 cubic feet at 60 degrees F. and under a pressure of 30 inches of mercury) will require for combustion, 189.2 cubic feet of oxygen, or 900.2 cubic feet of air at 60 degrees F. and under a pressure of 30 inches of mercury.

Carbon Monoxide. – When carbon is burned in a deficient supply of air, there is formed not carbon dioxide but a very different gas known as carbon monoxide, the combustion taking place in accordance with the equation:

$$2C + 0_2 = 2C0 + 2/29{,}000 \text{ cals.}$$

That is to say, for every 12 grams of carbon burned, only 29,000 cals. of heat are liberated in place of the 96,700 cals. obtained when the carbon burns in an abundant supply of air.

VELOCITY of REACTIONS & CATALYSIS

The velocity of chemical change, however, it also very greatly influenced by the temperature. Although the speed of different reactions is affected in a different degree by temperature, it may be taken as a convenient approximation that the speed of reaction is doubled by raising the temperature 10 degrees C. A simple calculation will show what the magnitude of this effect may be.

Suppose that a reaction requires one second for its completion at O degrees C. At 100 degrees C., the boiling point of water, the same change would take place in about one-thousandth of a second and if the temperature be raised but a little, say to 200 degrees C., the time required for a change will now be only about one-millionth of a second.

On the other hand, a change which would require one second to take place at 200 degrees C. would need, at O degrees C., a period of a million seconds, that is, about eleven and a half days.

This influence of temperature is of the greatest importance, and on its recognition may depend the success of a truly effective and economical engine. Pressure creates Temperature – 1 pound of pressure equals 2 degrees temperature F.

When hydrogen and oxygen, the two gaseous substances by whose combination water is formed, are heated together, they combine, and if the temperature is sufficiently high, say about 600 degrees C. (1,083 degrees F.), the combination takes place with explosive violence. But, this occurs only when a trace of moisture is present in the gases. If the last traces of moisture are removed from the gases by prolonged contact with phosphorus pentoxide – a substance which, as has been pointed out, combines with the greatest avidity with water – the mixture of hydrogen and oxygen can then be heated even to a temperature of nearly 1,000 degrees C. (1,800 degrees F.), without explosion occuring. Not only in the case of hydrogen and oxygen, but in the case also of many other gases (e.g. carbon monoxide and oxygen), combination is found to depend on the presence of moisture, of which, however, the merest trace suffices.

Carbon (coke) at a high temperature, decomposes water vapour; but as the oxide of carbon is gaseous, a mixture of carbon monoxide and hydrogen (water gas) is obtained – a dry mixture.

THE OXIDATION of NITROGEN

It is important to note one respect in which the combustion of nitrogen, or the combination of nitrogen with oxygen, differs from the combustion, say, of hydrogen. When hydrogen burns, a large amount of heat is given out and, consequently, when a mixture of hydrogen and oxygen is ignited at any point, the temperature of the surrounding gas is raised to the ignition point and the flame spreads throughout the whole mixture. In the case of nitrogen and oxygen, however, combination takes place with absorption of heat — the reaction is an endothermic one — and heat must therefore by continually added to the mixture in order to allow the process of combustion or combination to proceed. Indeed, if it were not so, a flash of lightning would set the whole atmosphere ablaze, and "deluge the world in a sea of nitric and nitrous acids!"

Further, the reaction between nitrogen and oxygen whereby the compound nitric oxide is formed, is a reversible reaction represented by the expression:

$$N_2 + O_2 = 2NO$$

and at a given temperature, therefore, only a partial combination of the gases takes place. It is, however, a general rule (theorem of Le Chatelier) that, in such a case, the reaction which takes place with absorption of heat is favored by raising the temperature; and it is, therefore, to be expected that as the temperature is raised, the proportion of nitric oxide produced will become greater and greater. This prediction from theory was confirmed by experiment.

In 1903, the Norwegian physicist, Kristian Birkeland (1867-1917), Professor of Physics in the University of Christiania (Oslo), and the engineer, Dr. Samuel Eyde, developed an economically successful process for the production of nitric acid from the nitrogen and oxygen of the air. Air was passed into a special furnace in which an electric arc was formed, and at the high temperature of obtained (about 3000 degrees C.), the nitrogen and oxygen combined to form nitric oxide (NO).

A FEW THINGS TO THINK ABOUT

Many lives could be saved if only the Demons of the Drafting Board, the so-called engine and car designers, would spend one twentieth part of their time on re-designing todays engines and cars for the customers comfort and safety, not for the benefit of the repair department and to give the customer a feeling of grandeur and superiority. Just buckling on the seat belt transforms so many lovely people into veritable Frankensteins.

With all the automatic this, power that, etc., if the whole truth were known, a good portion of deaths in cars are directly caused because of dependence on these devices and the drivers ignorance of the limitations and idiosyncrasies of these devices.

First of all, let us return to a safe and rugged front end, easy to repair and replace. With wheels cupped to bring the center of the tire in line with the king pin, and no power steering will be needed. Tie rods should be in front of the axel to hold alignment of the wheels at high speed. Let us have a frame worthy of the name, to securely maintain the various parts in correct relationship to other components, not, as now, an engine could suddenly be found hiding in your hip pocket, or lovingly lying in your lap.

Brakes, power and hydraulic, are wonderful when they work, but what a sick feeling when they fail — if you live through an experience — your emergency brake will be a poor comfort. A stick shift is a God-Send at a time like this if you are alert enough to use it. Most of us are stupified in such an emergency.

There was a time when some automobile manufacturers were interested in keeping their customers alive and supplied cars with mechanical brakes to take effect should the hydraulics fail which they did, and do to this day from various causes. Because of hydraulic brakes with power added we, the drivers, expect our cars to halt in an instant and so do not attempt to decelerate or test the brake with our toe until there is no time gap left to do anything but crash, hit the ditch or over the cliff. The obituaries read "Driver lost control".

Now do not get the idea that I blame the Auto Industries for all the causes of accidents that plague us, and bring so many each year to a sudden and screeching end. A goodly percentage of our accidents are caused by the self-appointed Nut-at-the-Wheel who, from various causes, creates situations that are lethal to himself and others. One of the worst is "chimpanzee driving" with its many variations, i.e., one hand in vague contact with some portion of the steering wheel, the other hand hanging over back of seat, wrapped around head, tweaking an ear, ratting the hair, holding down top, grasping wing or rear view mirror as though fearful of being thrown out, and in so doing, confuses drivers nearby as to what maneuver is contemplated.

It is not only the garden variety driver who is guilty of the "chimpanzee driving". I have seen it practiced by drivers of every type of official vehicle.

There used to be a law, and perhaps still is, making one handed driving illegal, and I am certain should that be widely publicized and a real crack down on offenders pressed, the traffic accident pattern would take on a much healthier look.

Transportation safty standards, have been progressed past themselves!

Now that the "Nut-at-the-Wheel" has been thoroughly examined let's get back to the rest of the vehicle. First, the frame and running gear should return to first principles as in trucks and many racing cars. Let's have a transmission that will permit towing and towing to start if the battery is dead. Second, the power plant should return to its intended function – an economical power plant to move our vehicles within the legal speed limit in a reasonable manner, and not, as now, "Bonneville Bombs and Dragging Demons", which, with their wild cams and tuned pipes, become sowers of smog and stench. These wild engine modifications should only be allowed to travel on the speedways and drag strips.

Automatic transmissions should be replaced by the stick shift to permit of a high idle rpm which is free of carbon monoxide. Remove all accelerator wells and pump devices in the carburetors which are fuel hogs and smog generators and only incite the "squirrelers to squirrel".

A slow idle is deadly to the populace because the fuel to air mixture is about 6 to 1, being deficient in Oxygen and more than half of the fuel must be ejected as carbon monoxide. As the throttle is closed at idle the cylinder does not fill with air but pumps a vacuum that draws oil out of the crankcase, further contaminating the charge and adding to the emission of foulness. As very little air has been drawn into the combustion chamber only a very few pounds of compression occurs on the compression stroke, resulting in a power stroke that is only a foul, smelly, slow burn, which is costly in fuel wasted and creates a health hazard.

The return to a valve timing that served us well for seventy five years (exhaust closes at top dead center, intake opens at top dead center) will provide us with an engine that is adequate to perform within the prescribed legal limits at a measurable saving in fuel with no raw fuel emission from the exhaust at high speeds.

The present timing with an overlap of the valves creates a ram tube effect that sucks a quantity of raw fuel from the carburetor out the exhaust pipe during the time interval that both valves are open.

From the Petaluma Argus, Sept. 29, 1965, a statement from a research chemist, Ulric B. Bray, a consultant for the

Air Pollution Control District as follows: "Los Angeles motorists use eight million gallons of gasoline a day, more than is used in all of France. Eight per cent of the gasoline escapes into the air unburned". Eight percent of eight million would amount to 600,000 gallons of raw fuel escaping into the Los Angeles area at that time.

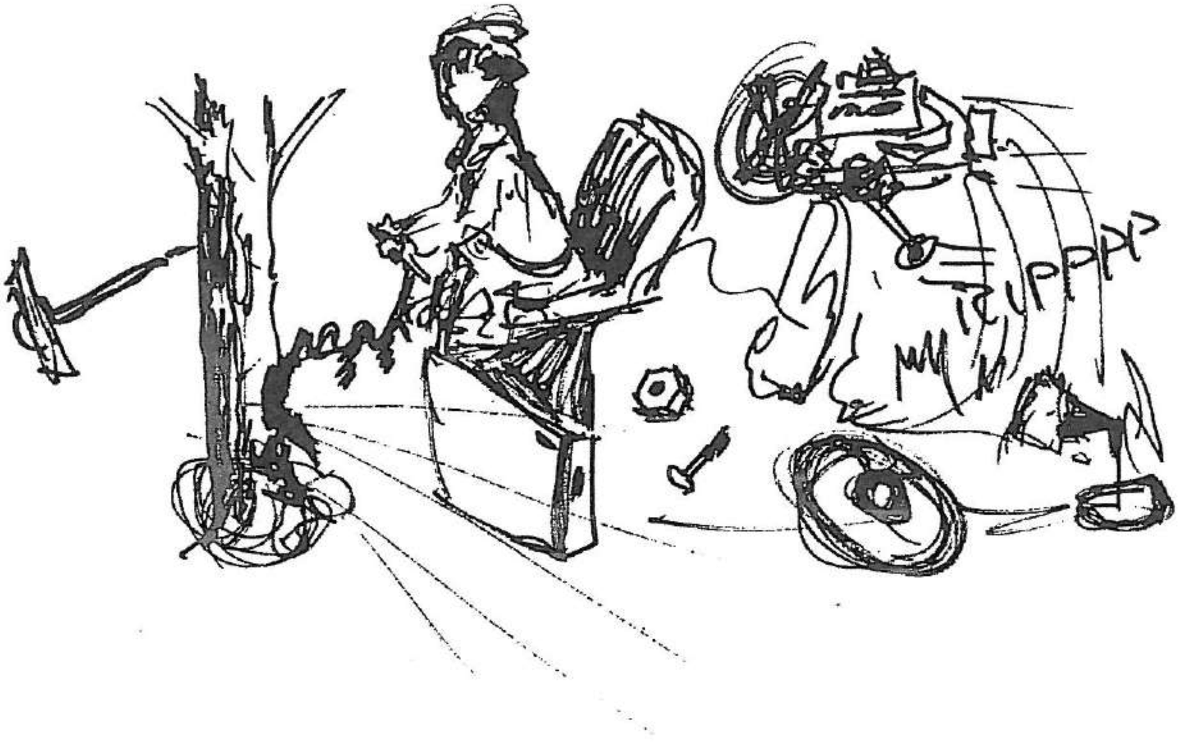
Accelerator pumps and accelerator wells should be eliminated. They are most wasteful of fuel and only incite drivers to show off, burn rubber, etc.

If engines of tomorrow are not to create smog and be more economical they will have to idle faster or else have an induced load at low speed to allow the cylinder to partially fill with air, enough to completely consume the fuel being inducted; that to be done by setting the throttle stop set screw to the point where the exhaust fumes are clean.

A water pump driven by the fan belt that will return the water to the radiator through a restriction during the low rpm range will assure a low idle and no carbon monoxide.

I do not know whether our designers of engines today are doing all the things they are doing wrong, just to please the customer or because they do not know any better. In any event, some corrections better be made or not enough customers will be alive in the 1980's to need any more discussion.

There have been absolutely no engine improvements in automobiles since I did my first major overhaul in 1905. There have been, however, two priceless accessories added, and perhaps not one person in a million would offhand elect to the place of honor that is rightfully theirs – the air cleaner and the oil filter. If properly serviced, they have



OOPS HERE COMES THAT ENGINE

done more to extend the life of automobile engines than anyone can imagine.

If the manufacturer had the customer in mind, a means would be provided to clean the oil pump screen through an inspection plate or it would unbolt from the side of the oil pan. If the screen were cleaned at least every 50,000 miles the life of the engine would be extended materially.

Prior to the advent of the above accessories five to ten thousand miles was all that one could expect before a major overhaul, which meant to bore the cylinders, oversize the pistons and rings, take up or replace bearings, etc. Compare that to my present car that has 84,000 miles on the speedometer. I knew any day at 70,000 miles the carbon in the pump screen could plug the oil line and a new engine would be needed. The pan was dropped and the screen appeared completely plugged. It was cleaned and replaced and judging from the sound of the engine and absence of oil pumping I can expect another 50,000 miles. Dropping the oil pan is a costly chore on some cars; mine is one of them.

Many engines develope blown head gaskets and the customer finds that it has a warped head. He has it ground and in the process the compression ratios will be at variance. Soon he will be back for a repeat of the same – blown gasket – grind the head and so on.

If the customer was suffering with sore feet from rocks in his shoes he would not have the cobbler put in new strings and polish his shoes as a cure. He would remove the rocks.

The same treatment is indicated for warped cylinder heads which blow gaskets. Remove cylinder studs, and draw file the stud holes. You will find the threads have lifted and the cylinder head cannot seat, result – gasket is not squeezed and a blown gasket is the result.

After the raised metal around the offending stud holes has been leveled off by draw filing, take a counter sink and remove the top thread to prevent it from lifting to cause more trouble.

Prepare gasket in prescribed manner and torque down head. After it is hot, retorque to specifications. As metal has memory, it will have returned to its original shape and no more blown gaskets.

If you would avoid burning a hole in a piston head, which occurs shortly after a valve and ring job, remove about 30 thousandths from the top land, as the top land because of heat and millions of explosions grows to be too big for the cylinder and when the valve and ring job is complete the extra heat generated will expand that portion and the piston will seize.

A bent or twisted rod can also cause a piston to scuff or burn, so have your rods and pistons checked and save a costly rework job.

A hole cannot burn in a piston that is correctly fitted, regardless of what your service man says about the mixture having been too lean. A close examination of the piston will show the top land polished or scuffed, proving it was too tight. It should never show any signs of contact, and the other lands, if any, only on the sides at right angles to the wrist pin.

POWER THIEVES

One of the stupid traits of our conventional engines is that they will consume more fuel descending a hill in any given gear at a given road speed than they will consume in climbing the same hill in the same gear at the same road speed.

Did it ever occur to you that the engine in your car will consume almost the same amount of fuel in one hour standing in your driveway in neutral as it would cruising down a level highway without other traffic at the same rpm?

You will say that is not so, but there is a very valid reason for such a contradictory phenomenon.

It is a well known fact that a conventional engine working below its design H.P. output will consume more fuel per H.P. hour by twice than if it were allowed to work as designed, and the answer is so simple I feel ridiculous in even mentioning it. At anything below its design rpm and H.P. output, the pistons are acting as vacuum pumps which consume a tremendous amount of power and the cylinder, instead of filling with air and compressing it to 90 pounds or 100 PSI, will compress to less than 1/2 that pressure producing an air explosion under half the intensity it is capable of for the fuel involved, which output is about the amount needed to make it operate as a vacuum pump. The same condition that slows you down on a curve or retards you on a hill is draining your fuel tank. See Fig. 1. Point A.

I am certain no one would recommend driving with the brakes on, but we are doing just that because our engineers are still designing engines that have too many built-in power thieves due to the erroneous theories taught and not, as many people insist, the reason is built-in obsolescence. It would be far less depressing if the latter were so.

If the throttle stop set screw was adjusted to let the engine idle at 1,000 rpms, the major source of carbon monoxide would be eliminated and greater fuel economy would result. No smog devices would be needed.

One of the most ridiculous rumors, to my knowledge, that has been making the rounds for over 50 years is the Canadian carburetor that was so fabulous it gave "umpity" miles per gallon and was bought by the oil companies and suppressed. That has as much validity as the statement "the moon is made of green cheese".

Now, if the published virtues of this engine or that engine is correct, where the manufacturer claims the Thermal Efficiency is in the 90 plus range, where would the extra performance came from, as there is only 100 percent

Let us examine a turning moment diagram for a single cylinder engine. The diagram is for an engine with a 3½ inch bore, a 5 inch stroke and a 10 inch connecting rod. Reciprocating weight of the parts for each square inch of piston head area is .45 pounds. Indicated compression pressure is about 70 pounds per square inch. The explosion pressure is 300 pounds per square inch. The engine is turning 1800 rpm.

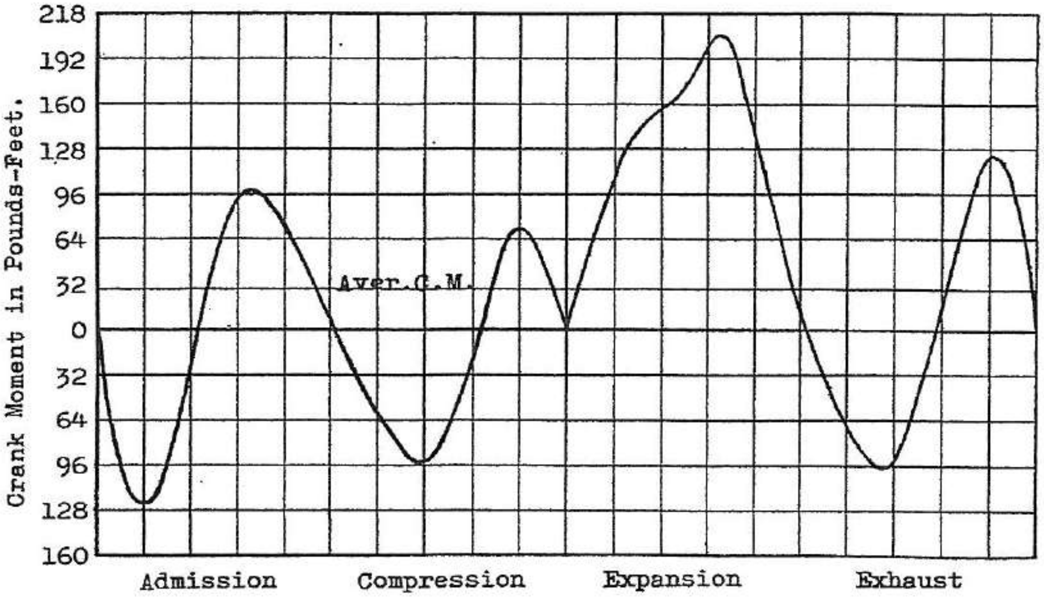


Fig. 2. Turning Moment Diagram for Single Cylinder Engine.

Fig. . is the cylinder wall side loading diagram for the same engine used for developing the turning moment diagram in Fig. . The engine is again turning at 1800 rpm. This is total side thrust.

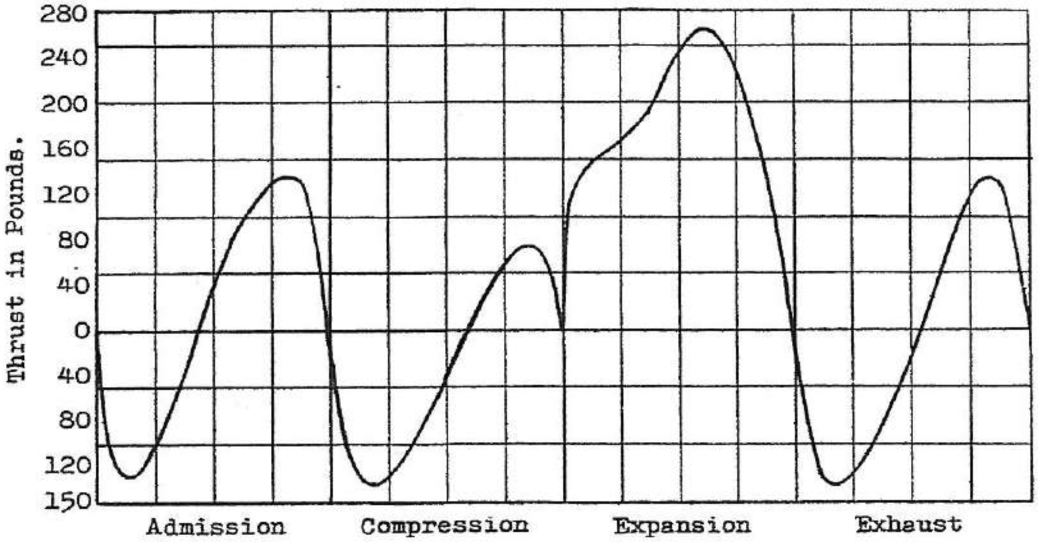


Fig. 3. Side Thrust on Cylinder Wall.

BTU's in the fuel. Which raises a question. What relationship is there between the Thermal Efficiency (or why mention it at the same time) with Mechanical Efficiency? Rather confusing it would appear to me, and I believe is intended so.

With the gap between Thermal Efficiency and Mechanical Efficiency so great, it would seem like carrying honesty too far to admit the product is so wastefull.

FALLACIES WE LIVE BY

The following are a few stumbling blocks, we the public, and those who should know better, just love to press fondly to our bosoms as gospel and immutable laws. In so doing we are blinded by the simple truths that could, if only recognized, free us from some of the chains that impede us in our climb to attain greater perfection in the field of Internal Combustion practice, mainly more H.P. per pound of fuel and lower maintenance per H.P. hour.

1. The braking effect of the engine is referred to as "under compression" and is diametrically opposed to the facts. The braking effect is produced when the throttle is closed and the pistons are pulled down by the crank-shaft to the bottom of the stroke under severe vacuum,* creating an absence of air in the cylinder which tends to draw oil from the crankcase and cannot cause more than a pound or two of compression on the compression stroke, and as the power stroke also pulls a vacuum before the exhaust valve opens an additional braking effect is induced.

A Diesel engine produces no braking effect, for it is under constant compression. Therefore, the belief or statement "braking by compression" is entirely erroneous, for if a gas is compressed by the force of the crankshaft and piston, the trapped gas being elastic, will return about the same force through the piston and rod to the crank.

2. Another fallacious belief is that a hole burned in the head of a piston is caused by too lean a mixture or the wrong heat range plugs. That is rarely so. If the piston clearances were factory correct when installed and a few thousand miles were covered, a close examination of the top land of the piston will disclose it is polished, indicating it had "grown" and was too large for the cylinder therefore creating friction that prevented the heat of combustion from being radiated through the skirt of the piston to the cylinder wall. Most piston alloys lose their strength at about 500 degrees F. and melt at 1100 degrees F. The term, "growth" in this regard is not to be confused with "expansion". It is a progressive enlarging of the piston head attributed to the successive explosions over a period of time. All pistons should be measured against the factory specifications and the top lands returned to specs when the engine is overhauled, as the increased compression resulting when new valves and rings are installed will show this growth up.

If a piston is correctly fitted to a cylinder and correctly lubed and cooled, it is impossible to melt the head out.

Stand an alloy piston in about 1 inch of water in a pan and with a cutting torch try to put a hole in it. It can not be done. A bent rod producing a bind in a cylinder will also cause a hole to blow.

1. See Fig. 1. Point A.

MISLEADING STATEMENTS

Engineers and salemen confuse and mislead the public by stating the crankshafts are statically and dynamically balanced, which is a statement intended to convey a virtue that is only partially true. A crankshaft that is statically balanced serves no purpose and produces nothing functionalwise; it is at rest and cannot create vibration, power, or any thing else. It is purely negative.

The dynamic-balance part of the statement is only partially true and the partially true part occurs at only a small range of the rpms.

SMOG DEVICES A JOKE: The smog control devices now in use where the fumes from crankcase are returned to combustion chamber and the one where extra air is pumped into exhaust pipe are not effective. The first condition results because the carbureted mixture is inadequate in oxygen, which forms the pollutent in the first place. Reintroducing it into a new charge does not cause it to ignite because no additional oxygen has been added; it is induced into the same over-rich-in-fuel mixture that is polluting the atmosphere and without addition of more clean atmosphere containing no fuel, the only result that can occur is to gum up an already over-rich fueled engine.

The method where extra air is pumped into the exhaust pipe only dilutes the fumes in the pipe by contaminating the air being pumped in, but does not eliminate or reduce the pollutants in that area, merely scatters them.

High speed, 4-stroke cycle engine valve-overlap is producing a tremendous amount of raw, unburned fuel to the atmosphere by the vacuum created in the exhaust. While both the valves are open, a stream of fuel is drawn through the cylinder head that aids in cooling the valves, but pollutes the atmosphere, exactly as does a 2-stroke cycle engine.

Some of the most ridiculous things we do ——

Take a stock engine, make a few modifications, mount it on a Dyno at quite an expense, take progressive readings until it scatters and note the rpms and H.P. on the graph of its final breath and then brag about the Horses that were squeezed out. Just for your information, a 5-cent stamp, an envelope and a sheet of paper would have provided you the exact information if sent to the manufacturer of the engine you used. Quite a saving in time and money.

We put Ram Tubes on the carburetor air horn and up set the basic function of the carburetor for a carburetor is designed to inject a jet of fuel into the air stream by inducing a minus pressure at the jet and an atmospheric pressure on the surface of fuel in float chamber, so when a Ram Tube is installed, the minus pressure on the jet is progressively changed as the rpms rise, upsetting the fuel mixture and causing the carburetor to flood, thereby creating a reverse condition, not the one we are seeking.

Another error on the 2-stroke cycle is to increase the exhaust pipes ability to super scavenge. Some restrictiveness in the exhaust pipes (muffling) will boost the H.P. and rpms of a 2-stroke cycle engine.

Another misconception is the belief that the water drippings from the exhaust pipe on a cool morning when we start the engine is the hydrogen and oxygen in the fuel combining, which is postively not true. Analyze the exhaust and it will be very high in carbon monoxide because the choke is on, and no free oxygen is present for forming water. It is the heavy moisture of the atmosphere heated to above 212 degrees F. in the cylinder and recondensed to water in the exhaust pipe. A temperature of 1,800 degrees F. is necessary to cause the hydrogen in the fuel to combine with the atmospheric oxygen in the carbureted charge. Under the circumstances, this is impossible for the carbureted charge, upon starting on a cold morning, is an enriched charge, induced by the choke and does not contain enough heat or oxygen to create water, only more carbon monoxide.

AUTOMOBILE INSURANCE

One thing about our automobile coverage, that appears to me as somewhat out of line, is the rate we pay. I can understand when I drive my car off the showroom floor the coverage is predicated on the sale price of the vehicle covered. Now I have paid for one year of protection based on the purchase price. If eleven months later the car is totaled out do I get compensated for a car based upon the premium paid or on the then value as listed in the Blue Book?

It somehow appears to me that the insurance company who issued me such a coverage would scream like a crushed cat if it had to cover the loss as it would seem to the customer was promised when the salesman made out and collected for the policy.

I was made cognizant of what I would consider less than ethical – the practice of billing a customer the same price on his collision insurance on his fifth renewal as he paid on the first! Unless the insurance company was insistant on returning the car to practically new conditions, which the records fail to prove to be true, and understandably so, for the same year and style model which has never been crushed is available on used car lots for much less cost than a repair job would be. So you are then offered a used car or the Blue Book price as a cash settlement.

This practice may or may not be ethical, that is not the reason for this letter, but it caused me to do some research, it was found a growing number of motorists are cancelling the collision coverage after the second year because it is not what they feel they have been paying for.

To put it another way – they would be paying a higher rate for a lesser value protected.

THERE SHOULD BE A LAW

There should be a law to outlaw down draft carburetors. Why? Because they are a traffic hazard in this day and age of high speed traffic. They are so located that they boil the fuel on a hot day – vapor lock in interrupted traffic and the engine will go dead in the middle of an intersection or railroad crossing. Or, if the float valve sticks or a fuel line breaks a first class fire can result.

It was a stupid assumption of some designer that, because of gravity, the fuel would feed better to the engine, so the engines that knew no vapor lock were discarded. Now I carry two gallons of water to pour on the intake manifold, after removing the air cleaner.

There also should be a law against automatic transmissions for you are absolutely helpless should the engine die. You cannot be pushed or towed with the drive wheels on the ground without ruining the transmission and you cannot be pushed or towed to start should the battery be low.

Many lives could be saved (mine was) if the engine dies on a railroad crossing by placing the transmission in low or reverse and hitting the starter button and slipping the clutch if the battery is low. The same technique can be used to pull off to the shoulder out of traffic. It can be a nerve saver if the engine fails on a busy freeway.

Now, the above condition can tie up traffic for miles creating frustration in the minds of other motorists to where they will attempt to pull out into the other lanes, whereby accidents are almost certain to result.

It is nerve-racking enough to be part of normal freeway traffic without being delayed by a stalled car, be it yours or some other characters.

So please let us get back to an automobile that has some built-in "insurance" instead of a "basket case". Supply the automatics to the handicapped only.

The cost of repairing an automatic transmission in a car 5 or 6 years old could cost more than the car would Blue Book for if it were in top shape.

If it were a stick shift you could, for a few dollars, get one of your local kids down the street to fix it for you, if you were not capable of doing it yourself.

To me it seems nothing short of stupid to ask the motor manufacturers to build in safety features that are all predicated on the results that occur because of speed and collision or mechanical failure. Why not automatically hold all vehicle speeds to 60 or 70 miles per hour by a little centrifugal switch, operated by the speedometer cable which will allow the engine to operate efficiently under all conditions, but when road speed reaches the set maximum ignition is cut off and will not function until the vehicle returns to the speed for which it is set. Official vehicles to be excepted.

THERMO-NUCLEAR ENGINE

Use the Electrolysis of water as described in "The New Physics of Everyday Life", page 432, to generate Hydrogen to be used directly as a fuel in a Bourke engine using injectors. Hydrogen and Oxygen are to be separated in the generator and fed to the injector by separate tubes, to be there mixed in the injector and additional atmospheric air supplied for correct balance (just oxygen and hydrogen would be too violent).

A sponge platinum plug could be used, or conventional spark ignition if a very flexible engine is desired.

A constant rpm, high speed engine burning such a violent fuel is to be preferred to allow expansion to occur correctly and to reduce the length of time the combustion chamber is exposed to the intense heat thereby reducing the danger and damage to piston and cylinder head that would occur in a low speed engine.

Another possibility is to pass water through incandescent coils to an engine with a compression that will produce about 2000 degrees F. using sponge platinum for ignition and inducing atmospheric air as a dilutent, for a cylinder full of oxygen and hydrogen could be a pure bomb. No cylinder could contain the violent reaction of so much explosive energy in one single charge. The cylinder must first fill with atmospheric air and then the hydrogen and oxygen separately injected simultaneously.

Helium, being an insulator of Uranium, a sealed system using the Bourke cycle as the prime mover is feasable by placing an atomic pile in the spark plug hole and expanding helium in the cylinder like a steam engine, then circulate the exhausted helium gas through a condenser and return it to the cylinder, and repeat the cycle.

OBSERVATIONS ON WATER CONSERVATION

One of the most colossally stupid things we do is to allow our rainfall to wildly wend its way to the sea, and keep sinking our wells deeper each year, draining our underground basins of water which can never be replenished from the surface by normal percolation.

The water was left there eons ago. Time and the elements have covered the underground water basins with gravel, clay, soil, lave cap, sand stone and hard pan in varied sequences over the passage of time, sealing this water hermetically. Man then drills through these barriers and lifts this water out without providing an easy access for a refill. That necessitates sinking the wells deeper each year (where irrigation is heavy) until they become salty and are capped and abandoned.

Such abandoned wells would serve to funnel the flood waters back into the underground basins by placing a filter box over the top of the wells in the lowest area, thus relieving the flooding of the low farm lands that they may be productive every year.

Eventually these vast underground reservoirs would fill, providing water for future needs.

Every land holder having a well could contribute to the curing of this frightening situation at no expenses to the state if, during the rainy months, a vent tube were provided in the well casing to inject air into the funneling water to aid in the purifying process. The water to pass through a gravel-filled filter bed or box to remove foreign material before being returned to replace the untold billions of gallons so wantonly removed without any thought of the future.

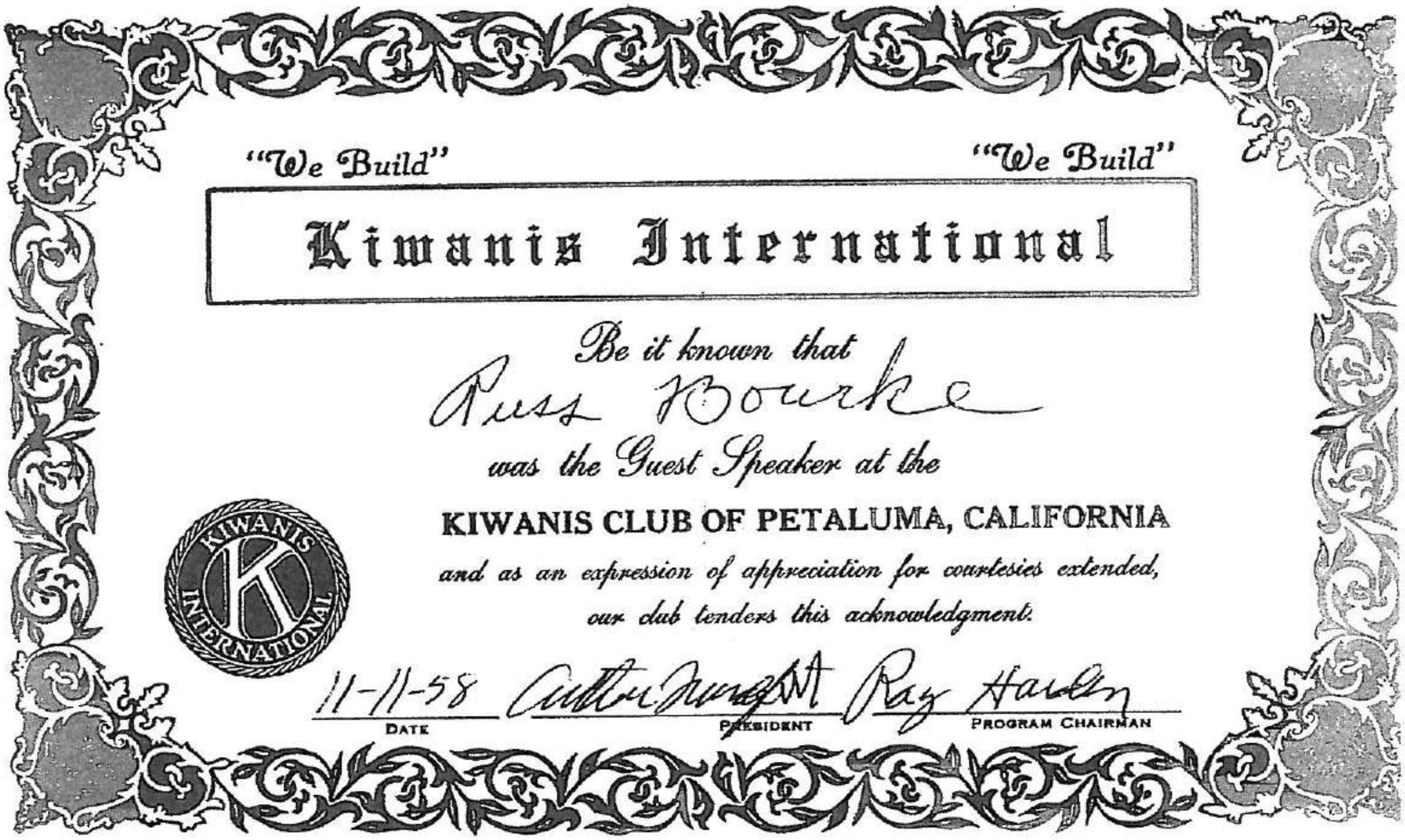
Do not get the idea I am naive and do not know that much thought (and money too) is being expended to alleviate this condition. But would it not be refreshing to see some things done in a simple, direct and inexpensive manner for a change! Perhaps that is too fundamental!

We allow countless mountain streams and canyons to pour water down the mountains into the valley, spreading destruction, while we have in many sections ready-made means to soften the savagery and, at the same time, store this water for future use with natural pipe lines to transport this water to replenish the depleting valley basins.

Throughout the United States are countless abandoned mines in the mountain areas which could be converted to water storage basins, a priceless heritage for generations unborn. Stratas are the natural means of transferring this water to other areas, for in the digging of shafts and tunnels, gravel stratas are exposed. Faults are encountered which may extend hundreds of miles as does the San Andreas fault, which, if intersected, would provide quite a pipeline to a distant point where a water shortage exhisted.

Next time you drive where a highway has been cut through a hilly country, not the varied formations exposed. Much is sedimentary, sand and gravel that can form a perfect path for water from a higher elevation.

BOURKE DISCUSSES HIS ENGINE



"We Build" "We Build"

Kiwanis International

Be it known that

Russ Bourke

was the Guest Speaker at the

KIWANIS CLUB OF PETALUMA, CALIFORNIA

and as an expression of appreciation for courtesies extended, our club tenders this acknowledgment.

11-11-58 Ray Harley

DATE PRESIDENT PROGRAM CHAIRMAN

(The following is taken from tape recorded notes prepared by Russell for discussion when he was invited to be guest speaker before the members of the Kiwanis, Rotary, Jr. Chamber of Commerce, E.A.A., Lions, Elks and other Clubs.)

A few years ago, "Atlantic Monthly" magazine published an article by automotive writer, Ken W. Purdy, who stated:

"The standard internal combustion reciprocating engine is basically so unsuited to its task that its universal acceptance and success are a source of wonderment...the true nature of the animal reveals itself when it is operating at optimum design efficiency, as in a racing automobile, in the howling gears, roar of exhaust, wild clatterings and bone-jarring vibrations. A reciprocating engine seems always to be trying to destroy itself. And so it is.

The word "reciprocating" is the key. A reciprocating engine is, in effect, a multi-barreled cannon, with the fuel charge the gunpowder, the piston the projectile, the spark plug the primer or trigger. The charge explodes: The piston, driving its connecting rod, starts to fly out the barrel, but after only two or three inches of flight it must stop, reverse itself, and come flying back toward the breech. It is this repeated reversal of movement, taking place thousands of times a minute, that is at the root of the savagery."

This was not news to me. I became fully aware of these facts some forty years previously, and my whole life has revolved around them and their implications. In 1918, I was an instructor of internal combustion engine theory and maintenance at the Air Service Mechanics School, Kelly Field, Texas. From daily discussions with the students and fellow instructors, I came to realize that the four-stroke cycle engines were basically inefficient with three dead strokes and had too many moving parts. And, the fact that many of my flying friends were lost when their plane crashed, and spilled gasoline caught fire, made a deep impression on me. I was determined to find a way to make internal combustion engines simpler, more efficient, and safer.

At that time, our engines were really only a few years out of the inventors' laboratories and we were closer to the ideas and writings of men who had conceived the internal combustion engine. Today, the textbooks young designers study are much more sophisticated – and also farther removed from fundamentals. My reading soon took me deep into the works of the 19th century pioneers – and please do not sneer at that "old hat stuff". Remember, gravity had been operating forever and nobody noticed it. Today, the law of gravity seems so obvious, but Sir Isaac Newton won eternal fame for merely noticing the obvious and describing it concisely. Once he had done that, the laws of gravity and other physical forces, as expounded by Newton, became basic tools of science and technology.

I read Sir Humphry Davy, Sir Dugald Clerk, Sir Frederic Abel, R. W. Bunsen, and other greats who had laid down the principles which sparked 20th century scientific advances. I also studied the works of lesser-known but equally capable and original investigators into hydrocarbon chemistry such as Mallard and Le Chatelier, Barthelot and Vielle, Andrews, Favre and Silberman, Beau de Rochas and Dr. Otto. To my mind, they are without peer. I wish young technicians would build better foundations for their careers by becoming more familiar with them. It is not enough to read of them. One must read them!

Here, I must comment on theory. Modern engineering courses concentrate on giving students a firm grounding in theory; knowing that they will obtain practical experience when they graduate into some profitable specialty. Webster defines theory as "a more or less plausible or scientifically acceptable general principle offered to explain phenomena" ...which sounds alarmingly like "speculation" to me! Funk and Wagnalls says the word means "a proposed explanation designed to account for any phenomenon". Russ Bourke, however, calls it a crutch to support a lame idea!

I do not mean to sound hypercritical, but wish only to stress that todays engines have been designed by blindly following the wording of somebody's theory, rather than by considering the nuances of the principle it attempts to state. This path has led designers to the point where they feel they can go no farther with piston engines. They have become involved with awful noises, smells, temperatures, fuel appetites, and rotational speeds of turbine engines. I tried to show the world another path thirty long years ago – but fate decreed that engineers should refuse to listen to my logic. They knew their theory, and upon that pillar they were determined to stand firm. Pistons, cylinders, and rods are not at fault, just the arrangement and cycle.

Almost a century ago, in 1862, the Frenchman Beau de Rochas considered the possibility of constructing internal combustion engines to extract energy from burning fuel. He states that to develope power in that manner, it would be necessary to build four functions into an apparatus – intake, compression, power, and exhaust. It is worth noting that he also said that a good internal combustion engine should have these attributes:

1) The greatest possible cylinder volume with the least possible cooling surface.

2) The greatest possible rapidity of expansion of the burning fuel.

3) The greatest possible amount of expansion of the fuel.

4) The greatest possible pressure at the commencement of expansion.

5) A minimum of moving parts.

In 1872, Germany's Dr. Otto based his Otto four-stroke cycle engine on de Rochas' theory. He interpreted de Rochas' list of four functions to mean that the piston must make four strokes to complete one cycle. His engine was a success not because it was theoretically brilliant, but because it was tractable, versatile, and readily constructed of available materials. Its compactness enabled it to compete with steam and suited it to vehicular use. Otto knew it had shortcomings when evaluated against de Rochas' list of four desirable attributes, but it did a job. Others seized upon it eagerly and it got completely away from him. Entire industries have since been built up around four stroke cycle engines.

Dr. Otto's first 4-stroke cycle packed an 8-1 compression, ratio, strictly following Beau de Rochas formula for high compression, but the engine exploded when he leaned the mixture. So until the early 1900's all engines were low compression until the advent of tetraethyl lead fuels.

The first successful Otto had a three to one ratio, to suit available fuel. The power-exhaust-intake-compression cycle resulted in three waste strokes for each productive one. Valve mechanism added cost and complication. Much fuel heat went out the exhaust ports and more went to waste in the cooling system via the flame-bathed cylinder walls. There was bad noise and vibration. Since that time, vast effort has gone into developing fuel that won't knock – by deliberately "doping" it against hydrogen-oxygen reaction – increasing valve and bearing durability, more elaborate vibration control, better output through higher revolutions and shorter strokes, better lubrication and ignition to stand higher speeds and so on.

Engineers are wrong in trying to stop detonation. The path of progress should be along the line of using it as a means of extracting more energy from each pound of fuel you have purchased.

Long ago, I freed my mind of the shackle of thinking that gasoline was the right fuel. I wanted to get away from it for aviation safety's sake – it has no place in aircraft. It is, after all, but one of many derivatives of crude oil. It thought of fuel as being a hydrocarbon, found in fluid form deep in the earth, and delved deeply into the subject of hydrocarbons and how best to squeeze maximum power from each pound of hydrocarbon fuel.

The burning of fuel is a chemical process for which precise chemical equations can be written. Given a hydrocarbon fuel and the air which surrounds us, one has only hydrogen, carbon, and oxygen to work with in devising combustion equations. Books of early basic researchers state clearly that one pound of carbon burned with oxygen will heat 8,000 pounds of water one degree centigrade, but one pound of hydrogen similarly burned will heat 34,170 pounds of water a like amount. Also, the rate of expansion of burning hydrogen-oxygen is far greater than that of carbon-oxygen. One authority wrote "Hydrogen expands at the rate of 5,000 feet per second as against carbon-oxygen's rate of 25 to 75 feet per second, but this is of no interest to the design engineer for no known engine is capable of utilizing such a violent force." (Quote of Sir Dugald Clerk).

Our teachers sometimes unwittingly erect barricades to imaginative thought.

In conventional internal combustion engines, fuel does not really explode – it burns progressively. Touch a match to some gun cotton standing in open air and it will burn harmlessly in progressive manner. But, ignite it with a percussive primer, as in a rifle cartridge, and a violent explosion results. Far more energy is released. A shock wave passing through a fuel makes it burn differently, more powerfully. Ask any atomic bomb scientist! But no, for generations now, power plant engineers have been schooled to regard detonation as bad, and their work revolves around avoiding it. To convert a conventional engine to a Hydrogen cycle would be like trying to carry water in a paper bag.

False reasoning was used in trying to make conventional engines more suitable for aviation use. All the effort has gone into reducing engine weight. Listen to the boasting about low weight per H.P. of a particular engine! The magic figure of one pound per H.P. is worshipped, which may be all right for some applications and would be commendable for aviation IF the fuel consumption curve fell off instead of soaring out the top of the graph.

Take, for example, an airplane engine weighing one pound per horse power. If 200 H.P. output is wanted, the engine will weigh 200 pounds. Standard figuring calls for fuel consumption of half pound of fuel per H.P. hour, or 100 pounds of fuel per hour. In ten hours, such an engine will burn 1,000 pounds of fuel. Takeoff weight for power producing systems is thus 1,200 pounds. If fuel consumption were halved, weight reduction could be spectacular. If engineers had neglected the engines weight in favor of better fuel utilization and had been able only to produce an engine weighing two pounds per H.P., this 200 H.P. power plant would weigh 400 pounds. But, if it burned its fuel more efficiently and consumed only ¼ pound of fuel per H.P. hour, it would burn 50 pounds per hour or 500 pounds in 10 hours flight. Takeoff weight of the power producing system would then be 900 pounds, or a saving of 300 pounds! Translate that into carrying capacity or lighter airframe, or any combination of the two, and the savings are obvious!

Once an engine has been selected to power an airplane, it represents a fixed weight. Surely, airplane designers ought to give priority, therefore, to means of substantially reducing fuel consumption! The most obvious way I can think of is through use of leaner fuel to air mixture. Todays gasoline engines run on a mixture of about 15 parts of air to 1 part of fuel. The common diesel shows us clearly that increasing the compression ratio allow the use of leaner mixtures. All diesels run leaner than gasoline engines and in some when idling, the mixture may be as lean as 1,000 parts of air to one of fuel. In the past, diesel engines have blown up from the explosive power that resulted from momentary leaning out the mixture when tapering off the fuel to stop. For that reason, some of them are today fitted with kill devices which eliminate that brief period of danger.

Lean mixtures can develop vastly more power for a simple reason. The leaner the mixture, the more oxygen there is in the combustion chamber in relation to the amount of carbon and hydrogen. The richness of a conventional gasoline engine's mixture automatically limits the combustion process to a carbon-oxygen reaction. There is not enough oxygen for a hydrogen-oxygen flame is not hot enough to initiate hydrogen-oxygen reaction. Doping of fuel with tetraethyl lead plus careful tailoring of temperatures and pressure prevents unwanted detonation that takes place in gasoline engines when limits are exceeded. In diesels, fuel is injected and burns as the piston moves away from top dead center, increasing cylinder volume and keeps heat and pressure within limits.

A gas has two specific heats, depending on whether it is kept at constant volume or constant pressure. During a power stroke in any conventional engine, combustion space volume steadily increases and the burning of fuel does not build up the pressure required to burn a very lean mixture.

If combustion took place in a closed vessel so that volume did not increase, only pressure can increase and that can raise the temperature high enough to cause a hydrogen-oxygen reaction in a lean mixture.

The Bourke engine is based on all these scientific facts. It is nothing more than an apparatus to obtain a hydrogen-oxygen reaction. It releases far more energy from each pound of hydrocarbon fuel. It is simple, light, durable, and quiet.

Otto, as has been noted, developed his four-stroke cycle from de Rochas' theory. Apparently, his mechanical thinking was influenced by steam engines of his day and caused him to adopt the connecting rod and crankshaft method of converting reciprocating motion into rotary motion. So, unwittingly, he started internal combustion engines out onto a dead-end road. Today, designers realize they have reached its end. Mentally straight-jacketed by the fixed ideas and statements of their teachers, they can think only of the wasteful turbine as a means of escaping the limitations of uncontrolled reciprocating motion. I saw that blank wall long ago!

It took 14 years of study – 1918 to 1932 – for me to develop the mechanism of my engine. Realizing that the connecting rod and crankshaft arrangement as used is stupid, I looked through volumes of mechanical movements and eventually devised a refined version of the common scotch yoke – which in its original form is useless for high speed engines.

Everything seems against the connecting rod and crankshaft. At the end of every stroke, piston movement is reversed by the rod. Tension and compression forces in the rod are transmitted through crankshaft support bearings to the engine as a whole, to strain the vehicles structure and bother occupants. Piston reciprocating vibration can't be counterbalanced out 100 percent because if crankshaft counterweights were heavy enough to neutralize the force of piston reversal, they would shake the crankcase when the piston was at midstroke and the counterweight force is a right angles to the cylinder centerline. The best that can be done is to settle for some suitable percentage of counterbalancing and then go into multiple cylinders which partly blur out the remaining reciprocating vibration. The angularity between connecting rod and cylinder bore puts a heavy side load on piston during power stroke and from the beginning, conventional engines have progressed only as oils were developed to stand higher pressures. The "ping" heard when a gasoline engine knocks is caused by a metal to metal contact when excessive pressure crushes the oil film between the piston and the cylinder wall.

Rate of piston travel, hence the period spent at TDC, is a direct and unalterable function of crankpin rotation and the designer must program his combustion process to suit. As for the gas turbine, I think it is all right for very fast airplanes where propeller blade tip velocity is a barrier to higher air speed, but quite nonessential for any subsonic vehicle. It is in the same class as burning gun cotton in open air to achieve fractional energy release.

The REFINED SCOTCH YOKE solved everything for me. Its geometry is such that the twin pistons remain at TDC longer – long enough for the extremely rapid hydrogen-oxygen combustion process to combine all fuel before the downstroke really begins. I use compression ratios up to 24 to one, which gives the high pressure necessary to cushion the piston and reverse its travel should ignition fail. When a cylinder fires, its piston acts as a projectile and the entire piston and rod assembly moves. As it moves, its kinetic energy is transmitted to the crankshaft. Initial combustion temperature is higher than poppet valves could stand; but as the piston moves on its downstroke, cylinder volume increases. All the fuel has burned, however, and cylinder walls are not seared with flame. Instead, the expanding gases act just as scientific laws say they should – as a refrigerant. The pressure of still burning fuel is not suddenly valved out to the atmosphere to make a loud noise. There is no exhaust flame throwing heat energy to waste – the exhaust of my engine is so cool that a man can hold his hand close to the ports without harm.

The straight-line motion of the pistons eliminates piston slap, there is no valve clatter or gear whine, the exhaust is muted. The hydrogen-oxygen combustion does not produce carbon monoxide – if my engine were in general use we would never hear of monoxide deaths or smog caused by these engines. As the pistons are interconnected, the crankshaft never feels their reciprocating forces and counterbalancing is not needed. The action of the yoke is such that 100 percent balance is possible for the crankshaft – it spins as smoothly as a flywheel. You might guess that the engine would shake from piston action, but it does not because the twin piston assembly is free and cannot transmit its reciprocating forces to the body of the engine. It absorbs these forces within itself. It is simply thrown back and forth, explosion forces acting against momentum forces so that things are cancelled out, as in a free piston engine – which it is.

The engine burns straight fuel like any four-stroke cycle machine. The crankcase is separated from the cylinders. Piston blowby does not go into the crankcase but is recirculated via incoming charges. Oil in the crankcase is not contaminated and lasts indefinitely. The cylinders and pistons are lubricated by small oil holes which leave a metered amount of oil between the piston and cylinder wall. There is no poor idling or spark plug fouling such as is experienced when oil is mixed with two-stroke cycle fuel. Each piston produces a power stroke on every revolution; and as twin pistons are the foundation of the idea, there are two power impulses for every revolution. Any number of twin-piston power units can be bolted to a variety of bases to give power clusters of any desired output.

There is a reason for each and every detail. The engine can stand detonation pressures because there is no connecting rod angularity or crankpin bearings to suffer intolerable shock loads. Pistons have turbulating fins on them to impart tornado action to incoming charges – this makes unburned charges rush past open exhaust ports without going out through them. Piston skirts are split and preloaded against the cylinder walls so there is heat transfer when the engine first starts. If pistons were a loose fit, their heads would overheat from detonation before the rest of the metal expanded enough to dissipate any heat into the cylinder walls and crankcase oil. This, along with the coolness of incoming charges under the pistons, keeps the National Leather seals from scorching. Slipper type bearings in the yoke have large area and are made of shock-resistant alloy so they withstand detonation easily.

I have run my engines up to 2,000 hours without noticeable wear. They respond to the throttle without faltering. I had had them reach speeds of over 20,000 rpm without harm and the only apparent speed limitation is in the ability of an ignition system to produce sparks that fast. They will run on cheap fuels such as brown distillate; and as for economy, my little 38 pound, 30 cubic inch job gave 76 H.P. at 10,000 rpm and at an easy 6,500 rpm burned only one gallon per hour.

The Bourke cycle engines come closer than anything else that I am aware of to completely fulfilling the five desirable attributes for an efficient internal combustion engine laid down by the unfettered mind of Beau de Rochas a century ago.

Based upon de Rochas description and many years during which I did much studying, I eventually developed my theory of using detonation as a means of extracting more power from Hydrocarbon fuels.

By 1932, my efforts resulted in the building and testing of the first Bourke cycle engine. It not only worked, it worked so well that the basic design never had to be modified!

This engine was a four-cylinder radial for aviation use; it was really a pair of opposed twin-cylinder units running on one crankpin. Radials were the style of that time and I adopted that layout so my new engine might fit into existing airplanes easily. It was just a small engine as it was built purely as an experiment; it weighed only 45 pounds and had about twenty cubic inches displacement. There were only three moving parts – the two piston assemblies and the crankshaft. But, despite its size, extracted the total amount of energy contained in the fuel. There was no exhaust flame, and no carbon monoxide. The fuel economy was startling.

In 1933, I mounted this engine on a pickup truck and went out to stir up interest. But, I very soon discovered that internal combustion engineers of that period were unalterably opposed to ported-cylinder engines – whether they be of the common two-stroke cycle variety or something quite revolutionary! I drove to the University of California at Berkeley and showed a set of blueprints to the professor in charge of the Engineering Department. When he had finished looking at them, I announced there was an actual engine, built from those prints, ready to be demonstrated on the truck outside.

"There is no use wasting your time and mine, Mr. Bourke -- this engine cannot possibly run. Good day", was his curt response.

So, I went to the Hall-Scott Engine Company – where I received the same unbelievable treatment! Their chief engineer refused to step outside the front door where the truck was parked, proclaiming that no ported-cylinder engine was any good and none ever would be. Later on, incidentally, I had the Hall-Scott factory make some parts for me and dynamically balance the crankshaft for my next engine, a 140 cubic inch aircraft design, and also the one for my 60 cubic inch outboard motor. When these engines were completed, I obtained the use of their dynamometer for testing. The heads of most of the departments were very enthusiastic when they saw my engines in operation – but not one individual from the Engineering Department entered the laboratory while my test were being run!

I have asked engineers through the years why they were so averse to my power plant, and their replies always amounted to this: "We will spend a million dollars to prove you wrong, but not a dime to prove you right!" Rather a poor attitude for progress!

By 1934, my first little engine had been run for thousands of hours, thus proving the principle of the design and the soundness of its construction. I then built a 140 cubic inch engine which could be used in actual commercial aircraft. Patterns and jigs were made and the engine built of dural – it weighed only 95 pounds. It ran for hundreds of hours without need for changes or repair, but then I discovered that before engines could be used in licensed airplanes, they had to have an Approved Type Certificate as granted by the old Bureau of Air Commerce. Government requirements were that engines had to run for 1,000 hours on a suitable test bed while under official observation. That kind of testing cost $75 an hour and was simply beyond my means. And, with all the factory engineers against me, there was small chance of finding anyone willing to provide financial backing. All I could do was to display my engine and run it for anyone who seemed interested. I also started the slow process of taking out patents.

In 1937, the War Department heard of my engine and became interested in its possibilities. It was so quiet, that it would be ideal for a scouting plane. There are no mechanical noises, just the porpeller sound and that of the air intake if no intake silencer is fitted. The exhaust can be muffled easily to a low hiss and, actually, muffling a Bourke engine increases its power and decreased fuel consumption by maintaining sea level head pressures to any altitude within reason. Two Air Corps majors visited me in September, 1937. One of them had been in charge of the engine test section at Wright Field for ten years and knew his business. As soon as preliminary tests had been made on the 140, he recommended that it be taken to Wright at once for thorough testing. Since patents had not been issued, we agreed the engine would go to Wright under the classification of a military secret.

But red tape intervened, and my engine never went to Wright Field. Tired of official inaction and kept out of the air by the Bureau of Air Commerce, I decided that an easier way to introduce my engine might be through an outboard motor version. No regulations could stop me from selling an outboard motor to anyone who wanted to buy from me! So, in 1938 I built a four-cylinder, 60 cubic inch radial which was water cooled for the obvious reason that an ample supply of that coolant is readily available to any outboard. It burned brown distillate, at that time selling for seven cents a gallon.

This engine proved to be too powerful for existing outboard lower units — I could shear the propeller drive pin at will merely by opening the throttle a little to fast. No sturdier outboard lower units were available at the time, so two cylinders were removed and the engine operated as a twin. Bourke cycle engine produce about four times the power of other engines of the same displacement, therefore, must be fitted with proportionally larger shafts and drive gears. The outboard logged over two thousand hours and could push a light hull up to 50 miles an hour.

But alas, when the tests were completed, I found that the outboard industry was flat on its back as a result of the depression. Only two firms were still in the business and they competed for a shrunken market...a business so small they had no desire to become involved with the problems of designing, testing, and merchandising a radically different and generally unknown type of power plant.

In 1938 and 1939, I was cheered somewhat by the issuance of patents. I looked forward to better fortunes. Was had started in Europe and again I saw the possibilities my engine held for reconnaissance planes. Popular types of light planes were just then being adopted for artillery spotting and communications work, so I designed a suitable engine, named the Model H. It consisted of two 30 cubic inch twin-cylinder units set beneath, and geared to, a propeller shaft. This arrangement gave good forward visibility and a low center of gravity. It weighed 95 pounds dry and now has run 1,100 hours without any trouble.

On December 2, 1941, Government engineers completed test runs and stated it was the most fantastic thing they had ever seen. They said Government funds would be made available in about three weeks to put the engine into production for the lend-lease program of aid to the European democracies. But five days later, the Japanese bombed Pearl Harbor, we were at war, and industrial freeze orders stopped all progress on projects such as mine. I spent the war years as an optical and instrument machinist at the Mare Island Navy Yard and afterward moved to Oregon for my wife's health.

Late in 1951, we moved to Portland, Oregon. If one could qualify for priorities, materials could be obtained for engine manufacture so I decided to try it again. The 30 cubic inch model was put on the market by having all parts made to my specifications by various suppliers — I was unable to finance a shop of my own. This mehtod proved to be too costly and each engine represented a heavy financial loss, so I discontinued production.

A basic truth of engine manufacturing is that it costs surprisingly little more to build a somewhat larger version of an engine. Take, for sake of illustration, a typical six-cylinder, 90 H.P. automotive engine. A 140 H.P. version of the same thing is built in a factory having the same overhead, by machines also used to build the smaller engine. No more engineering time goes into a 3½ inch diameter piston than goes into a 3 inch one. It takes a workman no longer to drive a dozen connecting rod cap nuts into place. A six-throw crankshaft thirty-six inches long is the product of the same number of forging, machining, balancing, and installation operations as one thirty inches long. The ignition system of a 90 H.P. engine will fit a 140 H.P. engine easily. In the end, the larger engine represents only several more pounds of metal and this, in terms of raw materials cost, has a somewhat modest effect on manufacturing cost. But, the bigger engine can be sold for quite a lot more than the smaller one! The only real difference between an 18 H.P outboard motor and a 25 H.P. one is several pounds of metal. So, I decided to produce a big Bourke engine for trucks and tugboats, whose owners would willingly pay a respectable, original price for the sake of my engines long-term fuel savings and short overhaul time.

The 30 cubic inch design was enlarged to 400 cubic inch, all things being identical except for size. I had a shop set up and the work was well along, when I suffered a thyroid collapse which halted all progress. Many who had seen the smaller engine perform had been watching with interest the progress on the 400 cubic inch; and when that misfortune befell me, some of them proposed to form a corporation to develop the new engine. Being almost out of funds and unable to work, I had no alternative but to sign the papers of incorporation as they were submitted to me.

The 400 was designed to run at moderate speed, developing 200 H.P. at an easy 2,000 rpm at which horse power output it burned about eight gallons of fuel per hour. For truck and tugboat use, light weight was not vital and it was desirable for reasons of gearbox availability and water propeller efficiency to keep the rotational speed within a range comparable to that of other power plants. Bourke engines can run much faster without harm due to the absence of dead strokes and connecting rod side loads. For aviation use, I think it is best to use high crankshaft rpm as the torque curve is like that of a turbine, and gear it down for propeller efficiency. This gives high output per pound of weight.

My engines prefer low grade petroleum fuels and these, in spite of their lower volatility, go through the carburetor effectively for a simple reason — there is a strong partial vacuum under the pistons as they move on the up-stroke, and when the cylinder wall ports open, this draws air-fuel mixture in with considerable velocity; then the 50 pounds transfer pressure and the turbulence do the rest to assure thorough carburetion. If the design and installation are correct, there is no carburetor icing. I have used both carburetors and fuel injectors, the latter being a simple 50 cent item actuated by induced vacuum on the base side of the piston — these showed no sign of flutter at 15,000 rpm.

The corporation was formed and the engine completed late in 1957. Testing went ahead and things were looking up at last, especially after a visit in early 1958 by a high ranking officer in the Army's Ordnance Department. He considered the engine to have an enormous potential for military use because through the grouping of standard twin-cylinder units on any kind of base, the severe supply problems of previous wars could be eliminated. My engines will operate when mounted in any position, and also in either rotational direction, and can be attached to any conceivable shape of base in the number required to produce the total power needed. One unit could power a light truck, two on a double base could power medium trucks, or three could drive heavy trucks and tanks. When a bullet or shrapnel punctures a conventional engine block, the whole engine must usually be pulled out and replaced. But, if one or two cylinders of a Bourke cluster were damaged, a new twin-cylinder unit can be installed on the base quickly, or the good ones taken from a damaged engine for rapid field repair of other vehicles. The low fuel consumption would have immense logistic value for armies far from home, and the safety of low-grade petrole fuel in wartime is obvious. And, I must add, the combination of low weight and modest fuel requirement for any given range would make Bourke engines highly attractive to helicopter designers.

Then, in April of 1958, things went completely to pieces. Through legal maneuvering based on the wording of the incorporation papers, all authority was wrested from me by other corporation members. The engine and shop equipment was moved to an unknown location and I have since been unable to trace it or obtain information about the project. One corporation member did tell me, recently, that the engine was dismantled and gathering dust and those in power will not allow the others to proceed with the enterprise.

So, after spending forty years developing an engine for which the world was crying, I gave up hope of ever making a commercial success out of it and retired to Penngrove, California. To receive such treatment from those I trusted was a bitter experience and only my wife's understanding kept me from cracking up completely. I rather feel that my partners thought what they did would put me out of the picture entirely.

My patents have now expired and anyone can use my invention. Today, in the peaceful hills of California, I have gotten away from the world's strife and have made up my mind to take things as they are and enjoy what we have – which includes many wonderful friends and neighbors.

Of course, I love to discuss engines with people who come to visit. And, not long ago, I was discussing my engines with a lifelong friend who rode with me in the days of the Bourke outboard motor and is now with one of the nation's largest engine manufacturers. He remarked that he suspected no engine manufacturer would want to become involved with my disign because the real profit in engine manufacture lies not in the first sale, but in the parts replacement and maintenance activities which keep vast dealer and distributor networks humming busily. This is a major industry today and it just would not do for a big manufacturer to disrupt it completely by introducing Bourke engines, and the smaller companies probably don't have the resources needed to introduce something so unusual on a profitable scale. You see, after a few thousand hours of running, a mechanic with one five-sixteenths inch Allen wrench can top overhaul a Bourke 400 in only two hours!

The engine has no gaskets to replace, and as the piston rings serve only as pressure seals and not to locate a loose-fitting piston quickly enough during the warm-up period, they don't get much beating or burning and don't gum up quickly. Go into any small-town automotive supply shop and see how many firms manufacture common replacement parts – then multiply it by the nation's thousands of parts stores and you will see what the Bourke engine might do to an important industry. Planned obsolescence is the keystone of much of today's manufacturing and promotional operations, and it may be that I have made an engine that is too durable for its own good!

Yet, the low fuel consumption of about one-quarter pound per horse power hour surely should interest somebody. While we were developing the Bourke 400, one of the largest trucking concerns sent a man to look at it. He said they would buy fifty engines a month if I could guarantee to produce an increase of one-tenth of a mile per gallon in fuel consumption over that now obtainable. That may sound small, yet it is enough to attract such a buyer! Multiply it by the millions of miles traveled by the nation's truck fleet and the total saving turns out to be enormous. But since 1900, engineers have not been able to improve the fuel-to-horse power output of conventional engines by as little as one percent.

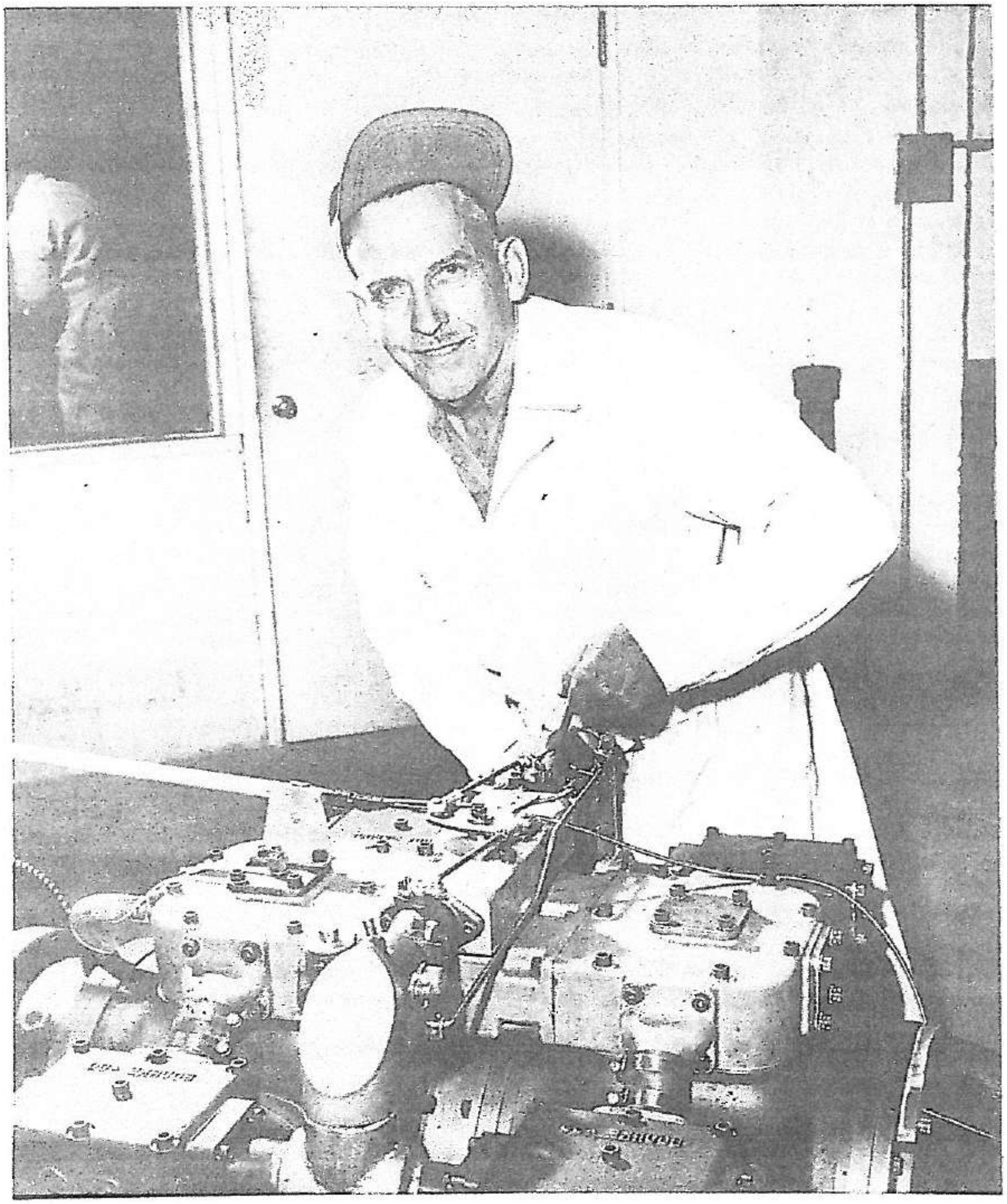
An interesting fact about my engine is that the curve of fuel consumption is like that of an electric motor's. The current consumption is like that of an electric motor's. The current consumption follows the load applied and not the curve of revolutions per minute. I said it before...now I say it again...reducing the fuel consumption of an aircraft engine can reduce takeoff weight appreciably, thereby opening new horizons in performance, range, and operating cost.

In recent years, a number of firms and individuals have built experimental Bourke engines of their own, but with poor results. They have thus spread the story that my engine has flaws. It hasn't! Their trouble stems from the fact that they made changes to suit themselves or to eliminate imagined faults, and in so doing upset the balance I have worked into it. This engine is like a mathematical formula in that when one small thing is altered, it is like changing the decimal point in a formula...the equation is rendered wholly erroneous.

For example, the exhaust ports in the cylinder walls look too small to people who have worked with other ported engines – but they are the correct size for the characteristics of the Bourke engine. They would indeed be too small if flaming gas were passing through them. But, check your chemistry! The exhaust products of a Bourke engine at time of exhaust are only two parts after the explosion in place of the three parts at the time of induction, whereas in a conventional engine, the exhaust area must be larger because the flaming gas has many times the volume it had when taken in. To get high rpms, engine men make exhaust valves larger. But you just have to shake off your preconceived notions when working with Bourke engines!

Another example is that the slipper bearings on the crankpin would give one a difficult time if he did not know that I found a highly shock-resistent alloy, 18-22 Ampco. It is the most suitable metal for that part of the engine.

Well, Gentlemen, that's about the size of it. Anyone is free to use my ideas. And, while I know I'll never make any money from all my efforts, it would please me immensely to see someone build and use a Bourke engine – and prove to the world in a conclusive way that it bypassed a most promising idea when it chose to pay no heed to what I said over the years!



THE BOURKE 400 CAN BE TOP OVERHAULED IN TWO HOURS
USING ONLY A FIVE - SIXTEENTH ALLEN WRENCH

EXCERPTS FROM "THE GAS AND OIL ENGINE" BY SIR DUGALD CLERK, 1909 EDITION

All hot-air engines are, therefore, very large and very heavy for the power they are capable of exerting.

The friction of the parts is so great that although the theoretical efficiency of the working fluid is higher than in the best steam engines, the practical efficiency or result per horse available for external work is not nearly so great. The best result ever claimed for Stirling's engine is 2·7 lbs. of coal per bk. horse-power per hour, probably under the truth, but even allowing it, a first class steam engine of to-day will do much better. According to Prof. Norton, the engines of the 'Ericsson' used 1·87 lbs. of anthracite per indicated horse-power per hour; but the friction must have been enormous. Compared with the steam engine, the practical disadvantages of the hot-air engine are much greater than its advantage of theory. Owing to the great inferiority of air to boiling water as a medium for the convection of heat, the efficiency of the furnace is much lower; owing to the high maximum and low available pressure, the friction is much greater—which disadvantages in practice more than extinguish the higher theoretical efficiency.

The gas engine method of heating by combustion or explosion at once disposes of those troubles; it not only widens the limits of the temperatures at command almost indefinitely, but the causes of failure with the old method become the very causes of success with the new method.

The difficulty of heating even the greatest masses of air is quite abolished. The rapidly moving flash of chemical action makes it easy to heat any mass, however great, in a minute fraction of a second; when once heated the comparatively gradual convection makes the cooling a very slow matter. The conductivity of air for heat is but slight, and both losing and receiving heat from enclosing walls are carried on by the process of convection, the larger the mass of air the smaller the cooling surface relatively. Therefore the larger the volumes of air used, the more economical the new method, the more difficult the old. The low conductivity for heat, the cause of great trouble in hot-air machines, becomes the unexpected cause of economy in gas engines. If air were a rapid carrier of heat, cold cylinder gas engines would be impossible. The loss to the sides of the enclosing cylinders would be so great that but little useful effect could be obtained. Even as it is, present loss from this cause is sufficiently heavy. In the earlier engines as much as three-fourths of the whole heat of the combustion was lost in this way; in the best modern engines so much as one-half is still lost.

A little consideration of what is occurring in the gas engine cylinder at each explosion will show that this is not surprising. Platinum, the most infusible of metals, melts at about 1700° C.; the ordinary temperature of cast iron flowing from a cupola is about 1200° C.; a temperature very usual in a gas engine cylinder is 1600° C., a dazzling white-heat. The whole of the gases filling the cylinder are at this high temperature. If one could see the interior it would appear to be filled with a blinding glare of light. This experiment the writer has tried by means of a small aperture covered with a heavy glass plate, carefully protected from the heat of the explosion by a long cold tube. On looking through this window while the engine is at work, a continuous glare of white light is observed. A look into the interior of a boiler furnace gives a good notion of the flame filling the cylinder of a gas engine.

At first sight it seems strange that such temperature can be used with impunity in a working cylinder; here the convenience of the method becomes evident. The heating being quite independent of the temperature of the walls of the cylinder, by the use of a water-jacket they can be kept at any desired temperature. The same property of rapid convection of heat, so useful for generating steam from water, is essential in the gas engine to keep the rubbing surfaces at a reasonable working temperature. In this there is no difficulty, and notwithstanding the high temperature of the gases, the metal itself never exceeds the boiling point of water.

So good a result cannot of course be obtained without careful proportioning of the cooling surfaces for the amount of heat to be carried away; in all modern engines this is carefully attended to, with the gratifying result that the cylinders take and retain a polished surface for years of work just as in a good steam engine.

The gas engine method gives the advantage of higher temperature of working fluid than is attainable in any other heat engine, at the same time the working cylinder metal may be kept as cool as in the steam engine. It also allows of any desired rate of heating the working fluid in any required volumes.

In consequence of high temperatures the available pressures are high, and therefore the bulk of the engine is small for the power obtained.

It realises all the thermodynamic advantages claimed for the hot-air engine without sacrificing the high available pressures and rapid rate of the generation of power which is the characteristic of the steam engine.

For rapid convection of heat existing in the steam boiler is substituted the still more rapid heating by explosion or combustion, a rapidity so superior that the power is generated for each stroke separately as required, there being no necessity to collect a great magazine of energy.

The only item to the debtor side of the gas engine account is the flow of heat through the cylinder walls, which disadvantage is far more than paid for by the advantages.

CHAPTER V.

COMBUSTION AND EXPLOSION.

In the preceding chapters the gas engine has been considered simply as a heat engine using air as its working fluid ; it has been assumed that in the different cycles, the engineer is able to give the supply of heat either instantaneously, or slowly, at will ; and also that he can command temperatures so high as 1000° C. or 1600° C. It is now necessary to study the properties of gaseous explosive mixtures in order to understand how far these assumptions are true.

ON TRUE EXPLOSIVE MIXTURES.

When an inflammable gas is mixed with oxygen gas in certain proportions, the mixture is found to be explosive ; a flame approached to even a small volume contained in a vessel open to the air will produce a sharp detonation. Variation of the proportions will cause change in the sharpness of the explosion. There is a point where the mixture is most explosive ; at that point the inflammable gas and the oxygen are present in the quantities requisite for complete combination. After explosion the vessel will contain the product or products of combustion only, no inflammable gas remaining unconsumed, or oxygen uncombined, both having quite disappeared in forming new chemical compounds.

That mixture may be called the true explosive mixture.

Definition.—When an inflammable gas is mixed with oxygen in the proportion required for the complete combination of both gases, the mixture formed is the true explosive mixture.

If the chemical formula of an inflammable gas is known, the volume of oxygen necessary for the true explosive mixture can be at once calculated. Elementary substances combine chemically with each other in certain weights known as the atomic or combining weights: chemical symbols are always taken as representing those weights of the elements indicated. In dealing with inflammable gases used in the gas engine it is convenient to remember the following symbols and weights:

Element	Symbol	Combining weight
Oxygen	O	16
Hydrogen	H	1
Nitrogen	N	14
Carbon	C	12
Sulphur	S	32

In entering or leaving any compound the elements invariably enter or leave in weights proportional to those numbers or multiples of them. Thus hydrogen and oxygen combine with each other, forming water; the formula of the compound is H_2O, meaning that 18 parts by weight contain 16 parts of O and 2 parts of H. Similarly when carbon combines with oxygen two compounds may be formed, according to the conditions, carbonic oxide or carbonic acid, formulæ CO and CO_2, the former containing in 28 parts by weight, 12 parts of carbon and 16 parts of oxygen; the latter in 44 parts by weight containing 12 parts of carbon and 32 parts of oxygen.

The formula of a compound therefore not only indicates its nature qualitatively, but it also indicates its quantitative composition.

H_2O not only tells the nature of water, but it represents 18 parts by weight; CO means 28 parts by weight of carbonic oxide: CO_2 means 44 parts by weight of carbonic acid. The numbers 18, 28 and 44 are know as the molecular weights of the three compounds in question.

When dealing with gases it is more convenient to think in volumes than in weights. It is easier, for instance, to measure the proportions of explosive mixtures by volume and to say this mixture contains one cubic inch, one cubic foot or one volume of inflammable gas to so many cubic inches, feet or volumes of oxygen.

Fortunately there exists a simple relationship between the volumes of elementary gases and their combining weights, and also between the volumes of compounds and their molecular weights.

If equal volumes of the elementary gases are weighed, under similar conditions of temperature and pressure, it is found that their weights are proportional to the combining weights. Taking the weight of the hydrogen as 1, then the weights of equal volumes of nitrogen and oxygen are 14 and 16 respectively. If then it is wished to make a mixture of hydrogen and oxygen gases in the proportion of 2 parts by weight of the former to 16 parts by weight of the latter, it is only necessary to take 2 vols. H and 1 vol. O. The law may be stated in two ways, as follows:

Taking hydrogen as unity, the specific gravity of the elementary gases is the same as their combining weights; or

The combining volumes of the elementary gases are equal.

Instead of troubling to weigh out portions of the gases it is at once known that one volume of nitrogen weighs 14 parts, the same volume of hydrogen weighing one part, oxygen 16 parts, and so on through all the gaseous elements, under the same temperatures and pressures.

Knowing that water is the compound formed by the combustion of hydrogen and oxygen, and that its formula is H_2O, it is at once apparent that the true explosive mixture of these gases is 2 vols. H and 1 vol. O. By experiment it is found that the volume of the water produced is less (of course in the gaseous state) than the volume of the mixed gases before combination.

The measurement requires to be made at a temperature high enough to keep the steam formed in the gaseous state. Measure 2 vols. H and 1 vol. O into a strong glass vessel heated to 130° C.; the total is 3 vols.; fire by the electric spark over mercury. It will be found that the steam formed when it has cooled to 130° C. after the explosion, measures 2 vols. It has been found to be true for all gaseous compounds, that however many volumes of elementary gases combine to form them the product is always two volumes. In elementary gases, one volume always contains the combining weight; in compound gases, two volumes always contain the molecular weight. Compared with hydrogen, therefore, the specific gravity of a gaseous compound is always one-half of the molecular weight.

As before, the law may be stated in two ways :

Taking hydrogen as unity, the specific gravity of a compound gas is half its molecular weight; or

The combining volume of a compound gas is always equal to double that of an elementary gas.

These laws are known as Gay-Lussac's laws, and form part of the very basis of modern chemistry.

Using them, the true explosive mixtures by volume and the volumes of the products of the combination can be found for any gas or mixture of gases, whether elementary or compound.

The inflammable compound gases, used in the gas engine, forming some of the constituents of coal gas are :

Inflammable gas	Formula	Molecular weight	Molecular vol.
Marsh gas	CH_4	16	2
Ethylene	C_2H_4	28	2
Carbonic oxide . . .	CO	28	2

Applying Gay-Lussac's laws, the oxygen required for true explosive mixtures and the volumes of the products of combustion are as follows for all the inflammable gases used in the gas engine :

	H_2O Steam.	CO_2 Carbonic acid.
2 vols. hydrogen (H) require 1 vol. oxygen (O) forming . .	2 vols.	—
2 vols. marsh gas (CH_4) require 4 vols. oxygen (O) forming .	4 vols.	2 vols.
2 vols. ethylene (C_2H_4) require 6 vols. oxygen (O) forming .	4 vols.	4 vols.
2 vols. carbonic oxide (CO) require 1 vol. oxygen (O) forming	—	2 vols.
2 vols. tetrylene (C_4H_8) require 12 vols. oxygen (O) forming .	8 vols.	8 vols.

With hydrogen and oxygen 3 volumes before combination become 2 volumes after combination. WITH CH_4 and O, also WITH C_2H_4 and O, the volumes of the products of combustion, are equal to the volumes of mixture. With carbonic oxide and oxygen 3 volumes before become 2 volumes after combination.

ON INFLAMMABILITY.

Previous to 1817, Sir Humphry Davy made the admirable researches which led him to the invention of the safety lamp. He then made experiments upon different explosive mixtures, and found that under certain conditions they lost the capability of ignition by the electric spark. True explosive mixtures, he observed, may lose inflammability in two ways ; by the addition of excess of either of the gases or of any inert gas such as nitrogen, and by rarefaction. The hydrogen explosive mixture, if reduced to one-eighteenth of ordinary atmospheric pressure, cannot be inflamed by the spark. Heated to dull redness at this pressure it will recover its inflammability and the spark will cause combination.

One volume of the mixture to which has been added nine volumes of oxygen is uninflammable, but if the density is increased or the temperature raised, it recovers its inflammability.

Eight volumes of hydrogen added, produces the same effect as the nine volumes of oxygen, but only one volume of marsh gas or half a volume of ethylene is required. The excess which destroys inflammability varies with the temperature, increasing with increase of temperature. Heating the mixture widens the range, both of dilution with excess or inert gas and reduction of pressure.

The point where inflammability ceases by diluting is very abrupt and sharply defined. The author has found that a coal gas which will inflame by the spark in a mixture of 1 gas and 14 air will not inflame with 15 of air. If the experiment be repeated on a warmer day it may inflame with 15 of air, but will not with 16 air. As the proportion is fixed for any given temperature it will be convenient to call that proportion for any mixture the 'critical proportion.' Any mixture in the critical proportion becomes inflammable by a very small increase of temperature or pressure. The exact limits of dilution temperature and pressure have yet to be discovered.

Passing from any true explosive mixture by dilution to the mixture in the critical proportion, the inflammability slowly diminishes, the explosion becoming less and less violent, till at last no report whatever is produced, and the progress of the flame (if a glass tube is used) is easily followed by the eye.

In his great work on gas analysis, Professor Bunsen confirms Davy's observations in every particular, proving loss of inflammability by dilution and reduction of pressure as well as its restoration by heating, increase of pressure and slight addition of the inflammable gas. His work, however, was not published till 1857.

ON THE RATE OF FLAME-PROPAGATION.

The sharp explosion of a true explosive mixture is due to the very rapid rate at which a flame, initiated at one point, travels through the entire mass and thereby causes the maximum pressure to be rapidly attained. With a diluted mixture the flame travels more slowly. Dilution therefore diminishes explosiveness in two ways—by increasing the time of getting the highest pressure and also by diminishing the highest pressure which can be got. Professor Bunsen's experiments are the earliest attempts to measure the velocity of flame movement in explosive mixtures. His method is as follows:

The explosive mixture is allowed to burn from a fine orifice of known diameter, and the rate of the current of the issuing gas carefully regulated by diminishing the pressure to the point at which the flame passes back through the orifice and inflames the explosive mixture below it. This passing back of the flame occurs when the velocity with which the gaseous mixtures issue from the orifice is inappreciably less than the velocity with which the inflammation of the upper layers of burning gas is propagated to the lower and unignited layers. Knowing then the volume of mixture passing through the orifice and its diameter, the rate of flow at the moment of back ignition is known. It is identical with the rate of flame propagation through the mixture.

Bunsen made determinations for the true explosive mixtures of hydrogen and carbonic oxide.

VELOCITY OF FLAME IN TRUE EXPLOSIVE MIXTURES. (*Bunsen.*)

Hydrogen mixture (2 vols. H and 1 vol. O). .	34 metres per sec.
Carbonic oxide mixture (1 vol. CO and 1 vol. O) .	1 metre per sec. nearly.

The method is a singularly simple and beautiful one and answered thoroughly for Professor Bunsen's purpose at the time he devised it. Several objections, however, may be brought against it. The mixture in issuing from the jet into the air as flame, becomes mixed to some extent with the air and so cools down; the metal plate also, pierced with the orifice, exercises a great cooling effect. If the hole were made small enough the flame could not pass back at all, however much the flow is reduced, because the heat would be conducted away so rapidly as to extinguish the flame. This had been shown by Davy in 1817; indeed it is the principle of the safety lamp. These causes probably make Bunsen's velocities too low. MM. Mallard and Le Chatelier have made velocity determinations by a method designed to obviate those sources of error.

The explosive mixture is contained in a long tube of considerable diameter, closed at one end, open to the atmosphere at the other. At each end a short rubber tube terminates in a cylindrical space closed by a flexible diaphragm. A light style is fixed upon the diaphragms. A drum revolves close to each style, both drums upon the same shaft. A tuning fork, vibrating while the experiment is being made, traces a sinuous line upon the drum and so the rate of revolution is known. The mixture is ignited at the open end, and the flame in passing the lateral opening leading to the first diaphragm ignites the mixture there, and so moves the style and marks the drum; the arrival of the flame is signalled at the other end in the same way. The drums revolving together, the distance between the two style markings measured by the vibration marks of the tuning fork gives the time taken by the flame to move between the two points. The numbers got in this way are the rates of the communication of the flame through the mixture, back into the tube, while the flame can freely expand to the air; when both ends are closed the velocity is much greater. Then, not only does the flame spread from particle to particle of the explosive mixture at the rate due to contact of the inflamed particles with the uninflamed ones, but the expansion produced by the inflammation projects the flame mechanically into the other part and so produces an ignition, which does not travel at a uniform rate, but at a continually accelerating one. In the same way, using the open tube but firing at the closed end, the expansion of the first portion adds to the apparent velocity of propagation, and projects the last portion of the mixture into the atmosphere. The true velocity of the propagation is the rate at which the flame proceeds from particle of inflamed mixture to uninflamed particle by simple contact; the true velocity depends upon inflammability alone, the rate under other conditions depends also upon heat evolved, and therefore movement due to expansion, mechanical disturbance of the unignited by the projection of the ignited portion into its midst. These conditions may vary much ; the inflammability remains constant.

Mallard and Le Chatelier's results for the true velocity of propagations are :

VELOCITY OF FLAME IN TRUE EXPLOSIVE MIXTURES.
(*Mallard and Le Chatelier.*)

	per sec.
Hydrogen mixture (2 vols. H and 1 vol. O) . . .	20 metres.
Carbonic oxide (2 vols. CO and 1 vol. O) . . .	2·2 ..

Bunsen's rate for hydrogen mixture seems to have been too great, and for carbonic oxide mixture too little. The rate for a true and very explosive mixture such as hydrogen is liable to be inaccurately determined, as temperature variation makes a great change, and it is difficult even with Mallard and Le Chatelier's method to obtain concordant experiments. With less inflammable mixtures the difficulty disappears. As true explosive mixtures are never used in the gas engine, their properties concern the engineer only as a preliminary to the study of diluted mixtures. The most explosive mixture which can be made with air contains a large volume of nitrogen inevitably present as diluent.

The following are some of their results with diluted mixtures, which are stated to be correct within 10 per cent. error of experiment :

VELOCITY OF FLAME IN DILUTED MIXTURES. (*Mallard and Le Chatelier.*)

			per sec.
1 vol. hydrogen	mixture	+ ½ vol. oxygen . . .	17·3 metres.
..	..	+ 1 vol. oxygen . . .	10 ..
..	..	+ ½ vol. hydrogen . . .	18 ..
..	..	+ 1 vol. hydrogen . . .	11·9 ..
..	..	+ 2 vols. hydrogen . . .	8·1 ..

These rates show that the true explosive mixture of hydrogen and oxygen when diluted with its own volume of oxygen falls from 20 metres per second to 10 metres, that is, it becomes one-half as inflammable ; when its own volume of hydrogen is the diluent, the velocity only falls to 11·9 metres per second. Hydrogen therefore has less effect in diminishing inflammability than oxygen.

Remembering the fact that the atmosphere contains one-fifth of its volume of oxygen, the remaining four-fifths being nearly all nitrogen, it is easy to get the proportions for the strongest explosive mixture possible with air. Two volumes hydrogen require 1 volume oxygen, and therefore 5 volumes air. The strongest possible mixture with air is two-sevenths hydrogen, five-sevenths air. The following experiments are for hydrogen and air in different proportions :

VELOCITY OF FLAME IN DILUTED MIXTURES. (*Mallard and Le Chatelier.*)

			per sec
Mixture,	1 vol.	H and 4 vols. air	2 metres.
..	1 ..	H and 3 vols. air	2·8 ..
..	1 ..	H and 2½ vols. air	3·4 ..
..	1 ..	H and 1⅘ vols. air	4·1 ..
..	1 ..	H and 1½ vols. air	4·4 ..
..	1 ..	H and 1 vol. air	3·8 ..
..	1 ..	H and ½ vol. air	2·3 ..

Very strangely the velocity is greatest when there is an excess of hydrogen present. To get just enough of oxygen for complete burning, 1 volume H requires 2½ volumes air, which would be naturally supposed to be the most inflammable mixture, as it gives out the greatest heat, but for some reason it is not. When the hydrogen is increased beyond 1 volume H to 1½ volumes air the velocity again falls off. A determination for coal gas and air gave 1 volume gas, 5 volumes air a velocity of 1·01 metres per second, and 1 volume gas, 6 volumes air 0·285 metres per second. With coal gas also the maximum velocity is got with the gas slightly in excess.

So far, these rates of ignition or inflammation are measures of inflammability, and are the rates for constant pressure; the rates for constant volume are very different, and the problem is a more complex one. Inflaming at the closed end of the tube, they found that even very dilute mixtures gave a sharp explosion, and in the case of hydrogen true explosive mixture, the velocity became 1000 metres per second instead of 20. With hydrogen and air 300 metres per second were obtained.

MM. Berthelot and Vieille have proved that under certain conditions even greater velocities than these are possible. The conditions, however, are abnormal, and the generation of M. Berthelot's explosive wave is exceedingly undesirable in a gas engine. It is generated by inflaming a considerable portion of the mixture at once, and so causing the transmission of a shock from molecule to molecule of the uninflamed mixture: this shock causes an ignition velocity nearly as rapid as the actual mean velocity of movement of the gaseous molecules at the high temperatures of combustion. The difference between this almost instantaneous detonation and the ordinary flame propagation may be compared to similar differences in the explosion of gun cotton discovered by Sir Frederic Abel. Gun cotton lying loosely, and open to the air, will burn harmlessly if ignited by a flame; indeed, a considerable portion may be laid upon the open hand and ignited by a flame without the smallest danger. The same quantity in the same position, if fired by a percussive detonator, will occasion the most violent explosion, the nature of the shock given to the gun cotton by the detonator causing a transmission of the kind of vibration necessary to cause its almost instantaneous resolution into its component gases.

The explosive wave in gases seems to originate in like conditions. Its velocity for the true explosive mixture of hydrogen and oxygen is 2841 metres per second, and for carbonic oxide mixture, 1089 metres per second. The velocity is independent of pressure between half an atmosphere and one and a half atmosphere. It is independent, too, of the diameter of the tube used, within considerable limits, or of the material of the tube, rubber and lead tubes giving similar results. Diluting the mixtures diminishes[17], and heating increases it. The experiments are very interesting and important, from a physicist's standpoint, but, fortunately for the inventor dealing with gas engines, the explosive wave is not easily generated in a gas engine cylinder; if it were, it would be impossible to run the engines without shock and hammering.

The velocity which really concerns the engineer is that due to inflammability, and expansion produced by inflaming—the velocity, in fact, with which the inflammation spreads through a closed vessel. As it cannot be discussed without considering other matters—heat evolved by combustion, and temperatures and pressures produced—it will be advisable first to give the heat evolved by combustion, and then devote a complete chapter to explosion in a closed vessel.

HEAT EVOLVED BY COMBUSTION.

Careful experiments upon the heat evolved by the combustion of gases in oxygen have been made by Favre and Silberman, and

also by Professor Andrews. The physicists first named burned the gases at constant pressure in a specially devised calorimeter. Professor Andrews mixed the gases in a thin spherical copper vessel, closed it, and exploded by the spark: the vessel being surrounded by water gave up its heat to the water, the weight of which being known, the rise of temperature gave the heat evolved.

Quantities of heat are measured by taking water as the unit. In this work, a heat unit always means the amount of heat necessary to raise unit weight of water through 1° C.

Taking an average of Favre and Silberman and Andrews's results, the inflammable gases used in gas engines evolve upon complete combustion the following amounts of heat:

	Heat units.
Unit weight of hydrogen completely burned to H_2O evolves . .	34,170
Unit weight of carbon completely burned to CO_2 evolves . . .	8,000
Unit weight of carbonic oxide completely burned to CO_2 evolves .	2,400
Unit weight of marsh gas completely burned to CO_2 and H_2O evolves	13,080
Unit weight of ethylene completely burned to CO_2 and H_2O evolves	11,900

That is, one pound weight of hydrogen burned completely to water will evolve as much heat as would raise 34,170 lbs. of water through 1° C., or the converse. One pound of carbon in burning to carbonic acid evolves as much heat as would raise 8,000 lbs. of water through 1° C. These numbers give the amount or quantity of heat evolved. The intensity or temperature of the combustion may be calculated on the assumption that the whole heat is evolved under such conditions that no heat is lost, or is applied to anything else but the products of combustion. To make the calculation it is necessary to know the specific heat of the products.

The amount of heat required to heat unit weight of water through one degree is 1 heat unit, the specific heat of any other body is the number of heat units required to heat unit weight of the body through one degree. Gases have two different specific heats depending upon whether heat is applied while the gas is kept at constant volume, or at constant pressure; both are required in dealing with gas engine problems. The specific heat at constant volume is sometimes known as the true specific heat; in taking the specific heat at constant pressure the gas necessarily expands, and so does work on the external air; this specific heat is therefore greater than the former by the amount of work done. For the gases used in the gas engine the two values are as follows. The ratio between the two is also given, as it is frequently required in efficiency calculations. The experimental numbers are Regnault's, the calculated specific heat at constant volume, Clausius.

SPECIFIC HEATS OF GASES.

(*For equal weights. Water* = 1.)

Name of gas	Sp. heat at constant pressure	Sp. heat at constant volume	$\frac{\text{Sp. heat con. pres.}}{\text{Sp. heat con. vol.}}$
Air	0·237	0·168	1·413
Oxygen . . .	0·217	0·155	1·403
Nitrogen . . .	0·244	0·173	1·409
Hydrogen . . .	3·409	2·406	1·417
Marsh gas . . .	0·593	0·467	—
Ethylene . . .	0·404	0·332	1·144
Carbonic oxide . .	0·245	0·173	1·416
Steam	0·480	0·369	1·302
Carbonic acid . .	0·216	0·171	1·165

It is convenient to remember that the specific heats of combining or atomic weights of the elements are equal—Dulong and Petit's law. To this law there are few exceptions, and the permanent elementary gases, oxygen, nitrogen, and hydrogen, obey it almost absolutely. As equal volumes of these gases represent the combining weights, it follows that equal volumes of these gases have the same specific heat. Taking the specific heat of air as the unit, the specific heat of hydrogen and oxygen gases is also unity. The compound gases do not obey the law so closely. The calculation of temperature of combustion can now be made. The amount of heat evolved from unit weight of a combustible is usually said to measure its calorific power, that amount divided by the specific heat of the products of the combustion is said to be the measure of its calorific intensity. The calorific intensity is indeed the theoretical temperature of the combustion: taking hydrogen first, unit weight evolves 34,170 heat units. But the water formed weighs 9 units (from formula H_2O), and if its specific heat in the gaseous state were unity, the supposed maximum temperature of combustion would be $\frac{34170}{9} = 3796{\cdot}6$. But the specific heat is less than unity; therefore the theoretical maximum will be greater. It is $\frac{34170}{9 \times 0{\cdot}480} = 7909{\cdot}7$. For certain reasons to be considered later, no such enormous temperatures are ever attained by combustion. In the above calculation the latent heat of steam should first have been deducted, as it is included in the total heat evolved as measured by the calorimeter: it is 537 heat units. 34,170 − 537 gives the total heat available for increasing the temperature, the amended calculation is $\frac{34170 - 537}{9 \times 0{\cdot}480} = 7785{\cdot}4$, still an exceedingly high temperature.

Calculating the heat evolved by burning carbon in the same way, but omitting any deduction for the latent heat of carbonic acid (it does not affect the calorimeter, as it does not condense), the theoretical temperature produced by burning in oxygen is still higher, being 10,174° C. Burning in air the theoretical temperatures are lower as the nitrogen present acts as a diluent, and must necessarily be heated to the same temperature as the products of the combustion. They are given as follows in 'Watts' Dictionary.'

	Calorific power	Temperature produced	
		In oxygen	In air
Carbon	8080	10174° C.	2710° C.
Hydrogen	34462	6930° C.	2741° C.

These are the supposed temperatures burning in the open atmosphere, and therefore at constant pressure, the gases expanding doing work upon the air. At constant volume, that is, burning in a closed vessel so that the volume cannot increase but only the pressure, the temperature should be greater as the specific heat at constant volume is less. Allowing for that, the numbers become

THEORETICAL TEMPS. OF COMBUSTION AT CONSTANT VOLUME.

	Temperature produced	
	In oxygen	In air
Carbon	12820	—
Hydrogen	9010	4119

Such temperatures have never been produced by combustion, for many reasons, of which all save the most potent have been discussed by the earlier writers on heat. This is Dissociation.

DISSOCIATION.

Most chemical combinations, while in the act of formation from their constituent elements, evolve heat, and as a general rule, the greater the heat evolved the more stable is the compound formed. The compound after formation may generally be decomposed by heating to a high enough temperature, heat being one of the most powerful splitting up agencies known to the chemist. The nature of the decomposition varies with the compound. In many cases the process is irreversible, that is, although heating up will cause decomposition, cooling down again, however slowly, will not cause recombination. In some compounds, however, under certain conditions the process is reversible, and recombination occurs on slow cooling.

Definition.—Dissociation may be defined as a chemical decomposition by the agency of heat, occurring under such conditions that upon lowering the temperature the constituents recombine.

Groves found long ago that water begins to split up into oxygen and hydrogen gases at temperatures low compared to that produced by combustion. Deville made a careful study of the phenomena, and found that decomposition commences at 960° to 1000° C. and proceeds to a limited extent: raising the temperature to 1200° C. increases it, but a limit is reached. The amount of decomposition depending upon the temperature, for each temperature there is a certain proportion between the amount of steam and the amount of free oxygen and hydrogen gases present. If the temperature is increased, the proportion of free gases also increases: if temperature is diminished, the proportion of free gases diminishes. If the temperature be raised beyond a certain intensity, the water is completely decomposed: if lowered beyond a certain temperature, complete combination results. The same thing happens with carbonic acid, the temperature of decomposition is lower.

It is quite evident, then, that at the highest temperatures produced by combustion, the product cannot exist in the state of complete combination. It will be mixed to a certain extent with the free constituents which cannot combine further until the temperature falls; as the temperature falls, combustion will continue till all the free gases are combined. The subject, from its nature, is a difficult one in experiment, and accordingly different observers do not quite agree upon temperatures and percentages of dissociation, but all are agreed that dissociation places a rigid barrier in the way of combustion at high temperatures, and prevents the attainment of temperatures, by combustion, which are otherwise quite possible. With no dissociation, hydrogen burning in oxygen should be able under favourable circumstances to give a temperature of over 6000° C., as has been shown. Deville's experiments upon the temperature of the oxyhydrogen flame, at constant pressure of the atmosphere, gave under 2500° C. The estimate was made by melting platinum in a lime crucible, with the oxyhydrogen flame playing upon the platinum, the crucible being well protected against loss of heat by lime blocks, so that the platinum could really attain the temperature of the flame; when at the highest temperature, the molten platinum was rapidly poured into a weighed calorimeter, and the rise in temperature noted. From this was calculated the temperature of the platinum. The experiment was dangerous and inaccurate, but it is the only serious attempt which has been made to determine the temperature of the oxyhydrogen flame at constant pressure.

The highest temperature produced by hydrogen burning in oxygen has been determined by Bunsen, and also Mallard and Le Chatelier, for combustion at constant volume, that is, explosion.

As the theoretic calculation shows, with no dissociation a temperature of 9000° C. is possible. The highest maximum it is possible to assume from Bunsen's experiments is 3800° C.; from Mallard and Le Chatelier's, 3500° C. The two sets of experiments are concordant. It is true the latter physicists do not attribute the difference wholly to dissociation, but they agree that part is due to this cause; and that there is an enormous difference between heat temperature actually got and that which should be possible if no limit existed, all are agreed. With air, Bunsen's figures show a maximum of about 2000° C., Mallard and Le Chatelier say 1830° C.; the present writer has also made experiments with hydrogen in air, and finds the highest possible temperature to be 1900° C. The calculated maximum is 4119° C. The difference is not so great as with the true explosive mixture, which is to be expected, but all experiments agree in proving that there is a considerable difference.

CHAPTER VI.

EXPLOSION IN A CLOSED VESSEL.

THE value of any inflammable gas for the production of power by explosion, can be determined apart altogether from theoretical considerations by direct experiment. It is evident that the gas which for a given volume causes the greatest increase in pressure, will give the greatest power for every cubic foot used, provided that the pressure does not fall so suddenly that it is gone before it can be utilised by the piston.

Two qualities will be possessed by the best explosive mixture: (1) greatest pressure per unit volume of gas: (2) longest time of maximum pressure when exposed to cooling.

In the gas engine itself the conditions are so complex that the problem is best studied in the first instance under simplified conditions. The author has made a set of experiments upon many samples of coal gas mixed with air in varying proportions, to find the pressures produced, and the duration of those pressures; igniting mixtures at atmospheric pressures and temperature, and also at higher temperature and initial pressures. He has made some experiments upon pure hydrogen and air mixtures in the same apparatus for comparison.

The experimental apparatus is shown at fig. 19. It consists of a closed cylindrical vessel 7 inches diameter and 8¼ inches long, internal measurement, and therefore of 317 cubic inches capacity. It is truly bored, and the end covers turned so that the internal surface is similar to that of an engine cylinder; the covers are bolted strongly so as to withstand high pressures. Upon the upper cover is placed a Richards indicator, in which the reciprocating drum has been replaced by a revolving one; the rate of revolution is adjusted by a small fan, a weight and gear giving the power.

The cylinder is filled with the explosive mixture to be tested; the drum is set revolving, the pencil of the indicator pressed gently against it, and the electric spark is passed between the points placed at the bottom of the space. The drum is enamelled and the pencil is a black-lead one. The pressure of the explosion acts upon the indicator piston, and a line is traced upon the drum, which shows the rise and fall of pressure. The rising line traces the progress of the explosion: the falling line the progress of the loss of pressure by cooling. The rate of the revolution of the drum being known, the interval of time elapsing between any two points of the explosion or cooling curve is also known. That is, the curve shows the maximum pressure attained, the time of attaining it, and the time of cooling. Line *b* on fig. 20 is a facsimile of the curve produced by the explosion of a mixture containing 1 vol. hydrogen and 4 vols. air. Each revolution of the drum was accomplished in 0·33 sec., so that each tenth of a revolution takes 0·033 sec. The vertical divisions give time; the horizontal, pressures. In this experiment the maximum pressure produced by the explosion is 68 lbs. per square inch above atmosphere, and it is attained in 0·026 second. Compared with the rate of increase the subsequent fall is very slow. The rise occurs in 0·026 second; the fall to atmosphere again takes 1·5 second, or nearly sixty times the other. It is in fact an indicator diagram from an explosion where the volume is constant, the motor piston being absent, and the only cause of loss of pressure is cooling by the enclosing walls. The exact composition of the mixture, its uniform admixture, the temperature and pressure before ignition, are all accurately known. After studying explosions under these known conditions, it becomes easier to understand what occurs under more complex conditions, where the moving piston makes the cooling surface change, and where the expansion doing work also requires consideration. As the rapidity of the increase of pressure measures the explosiveness of a mixture, the time occupied from the commencement of increase to maximum pressure will be called the ***time of explosion.*** The explosion is complete when maximum pressure is attained. It does not follow from

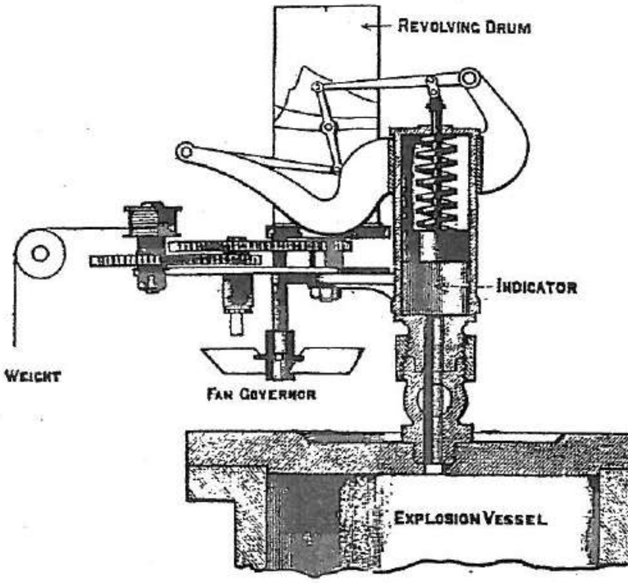
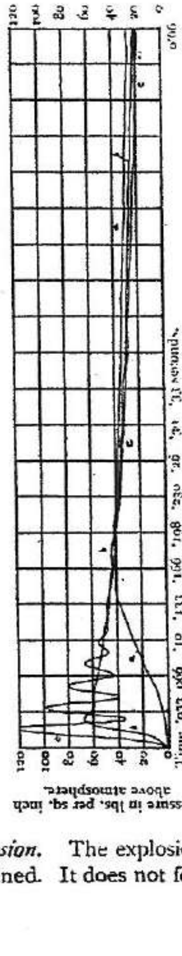
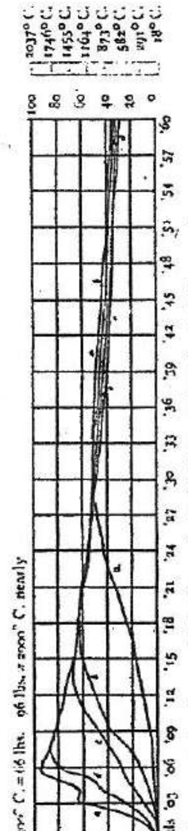


FIG. 19.—Clerk Explosion Apparatus.

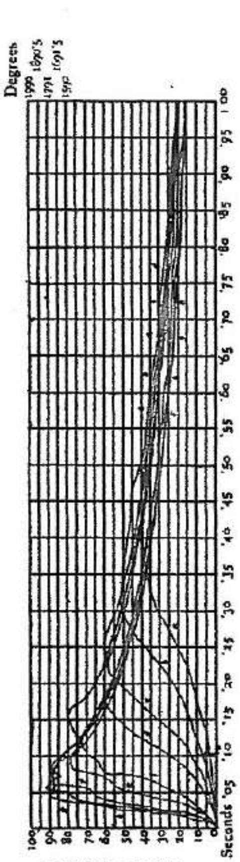


Vessel used 7 ins. diam. and 8½ ins. long. Scale of indicator spring 1 lb. = $\frac{1}{64}$ inch.
Mixtures used pure hydrogen and air. Experiment *a*, 1 vol. hydrogen to 6 vols. air; *b*, 1 to 4; *c*, 1 to 5.
Temperature of gases before ignition 16° C.; pressure (atmospheric) 14·7 lbs.

FIG. 20.—Explosion of Gaseous Mixtures. Experiments in a closed vessel.



Vessel used 7 ins. diam. and 8½ ins. long. Scale of indicator spring 1 lb. = 1/32 inch. Mixtures used Glasgow coal-gas and air. Experiment *a*, 1 vol. gas to 13 vols. air; *b*, 1 to 11; *c*, 1 to 9; *d*, 1 to 7; *e*, 1 to 5.
Temperature of gases before ignition, 18° C.; pressure atmospheric.



Vessel used 7 ins. diam. and 8½ ins. long. Scale of indicator spring 1 lb. = 1/32 inch. Mixtures used Oldham coal-gas and air. Experiment *a*, 1 vol. gas to 14 vols. air, temp. (of explosion and measuring vessels) 18° C.; *b*, 1 to 13, 16·7°; *c*, 1 to 12, 16°; *d*, 1 to 11, 16·1°; *e*, 1 to 9, 16·7°; *f*, 1 to 7, 16·7°; *g*, 1 to 6, 16°; *h*, 1 to 5, 16°; *i*, 1 to 4, 19°.
Centigrade temperatures, assuming no loss of volume, owing to combination of mixtures. Atmospheric pressure, 14·7 lbs., and mean temperature before ignition, 17° C.

FIG. 21.—Explosion of Gaseous Mixtures. Experiments in a closed vessel.

this that the combustion is complete; that is another matter. The explosion arises from the rapid spreading of the flame throughout the whole mass of the mixture, which may be called the inflammation of the mixture. More or less rapid inflammation means more or less explosive effect, but not complete combustion. The complete burning of the gases present does not occur till long after complete inflammation.

The terms *combustion*, *explosion*, and *inflammation* will be used in this sense alone:

Combustion, burning: complete combustion, the complete burning of the carbon of the combustible gas to carbonic acid, and the hydrogen to water. So long as any portion of the combustible remains uncombined with oxygen the combustion is incomplete.

Complete explosion, the attainment of maximum pressure.

Time of explosion; the time elapsing between beginning of increase and maximum pressure.

Complete inflammation, the complete spreading of the flame throughout the mass of the mixture.

Confusion has arisen through the indifferent use of these terms, which are really distinct and are not synonymous.

With mixtures made with Glasgow coal gas the author has obtained the following maximum pressures and times of explosion.

EXPLOSION IN A CLOSED VESSEL. (*Clerk.*)

Mixtures of air and Glasgow coal gas.

Temp. before explosion . . . . 18° C.
Pressure before explosion . . . . atmospheric.

Mixture		Max. press. above atmos. in pounds per sq. in.	Time of explosion
Gas.	Air.		
1 vol.	13 vols.	52	0·28 sec.
1 vol.	11 vols.	63	0·18 sec.
1 vol.	9 vols.	69	0·13 sec.
1 vol.	7 vols.	89	0·07 sec.
1 vol.	5 vols.	90	0·05 sec.

The highest pressure which any mixture of coal gas and air is capable of producing without compression is only 96 lbs. per sq. in. above atmosphere and the most rapid increase is not more rapid than always occurs in a steam cylinder at admission. Many

H 2

are still prejudiced against gas, compared with steam, because of the so-called explosive effect, and the fear that gas explosions may occasion pressures quite beyond control, like solid explosives. The fear is quite unfounded: the pressure produced by the strongest possible mixture of coal gas and air is strictly limited by the pressure before ignition, and can always be accurately known; and so provided for by a proper margin of safety in the cylinders and other parts subject to it.

The most dilute mixture of air and Glasgow gas which can be ignited at atmospheric pressure and temperature contains $\frac{1}{14}$ of its volume of gas, and the pressure produced is 52 lbs. above atmosphere. The time of explosion is 0·28 second; so slow is the rise that it cannot with justice be termed an explosion. It is too slow to be of any use in an engine running at any reasonable speed; the stroke would be almost complete before the pressure had risen. The mixture containing $\frac{1}{6}$ of its volume of gas is that with just enough oxygen to burn the gas. It is anomalous that the highest pressure is given with excess of coal gas. The rate of ignition also is greatest with that mixture. This agrees with the results obtained by Mallard and Le Chatelier, excess of hydrogen giving the highest rate of inflammation.

Similar experiments were made with air and Oldham coal gas.

EXPLOSION IN A CLOSED VESSEL. (*Clerk.*)

Mixtures of air and Oldham coal gas.

Temp. before explosion . . . . . . 17° C.
Pressure before explosion . . . . . . atmospheric.

Mixture		Max. press. above atmos. in pounds per sq. in.	Time of explosion
Gas.	Air.		
1 vol.	14 vols.	40	0·45 sec.
1 vol.	13 vols.	51·5	0·31 sec.
1 vol.	12 vols.	60	0·24 sec.
1 vol.	11 vols.	61	0·17 sec.
1 vol.	9 vols.	78	0·08 sec.
1 vol.	7 vols.	87	0·06 sec.
1 vol.	6 vols.	90	0·04 sec.
1 vol.	5 vols.	91	0·055 sec.
1 vol.	4 vols.	80	0·16 sec.

The highest pressure in this case is 91 lbs. per square inch above atmosphere, but the most rapid explosion is 0·04 second and 90 lbs. pressure, a little less pressure than is given by Glasgow gas but a slightly more rapid ignition. The mixtures are evidently more inflammable, as the critical mixture is $\frac{1}{15}$ volume of gas instead of $\frac{1}{14}$ as with Glasgow gas. Although repeatedly tried, a mixture of 1 volume gas 15 volumes air failed to inflame with the spark.

Hydrogen and air mixtures were also tested as follows:

EXPLOSION IN A CLOSED VESSEL. (*Clerk.*)

Mixtures of air and hydrogen.

Temp. before explosion . . . . . . 16° C.
Pressure before explosion . . . . . . atmospheric.

Mixture		Max. press. above atmos. in pounds per sq. in.	Time of explosion
Hyd.	Air.		
1 vol.	6 vols.	41	0·15 sec.
1 vol.	4 vols.	68	0·026 sec.
2 vols.	5 vols.	80	0·01 sec.

The inferiority of hydrogen to coal gas, volume for volume, is very evident; the highest pressure is only 80 lbs. above atmosphere, and the mixture requires $\frac{2}{7}$ of its volume of hydrogen to give it, while coal gas gives the same pressure with about $\frac{1}{10}$ volume. The hydrogen mixture, too, ignites so rapidly that it would occasion shock in practice, the strongest mixture having an explosion time of one-hundredth of a second. With gas the most rapid is four-hundredths of a second.

THE BEST MIXTURE FOR USE IN NON-COMPRESSION ENGINES.

From these tables can be ascertained the best gas and the best mixture for use in non-compression engines with cylinders kept cold. Take first Glasgow gas, and determine which mixture gives the best result.

(1) Power of producing pressure.

Suppose one cubic inch of Glasgow coal gas to be used in each of the five mixtures, whose maximum pressures and times of explosion are given in the table on p. 99, the mixtures would measure respectively 14, 12, 10, 8, and 6 cubic inches. Let them be placed in cylinders of 14, 12, 10, 8 and 6 square inches piston area; the piston will in each case be raised one inch from the bottom of its cylinder. If the pressures upon the piston were the same, equal movements of piston would give equal power; if therefore the mixtures gave equally good results the maximum pressure multiplied by the piston area will in all cases be the same.

Multiplying 14, 12, 10, 8 and 6 by their corresponding pressures 52, 63, 69, 89, and 96 respectively, the products are 728, 756, 690, 712, and 576. These numbers are the pressures in pounds which each mixture is capable of producing with one cubic inch of Glasgow coal gas, cylinders of such area being used that the depth of mixture is in every case one inch.

Proportion of Glasgow gas in mixture	$\frac{1}{14}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{6}$
Pressure produced upon pistons by one cubic inch	728	756	690	712	576 pounds.

The best mixture is seen at a glance; it is that containing one-twelfth of gas. The pressure produced by one cubic inch of gas is at its highest value 756 pounds, in a cylinder of 12 inches piston area, and containing 12 cubic inches of mixture.

In modern gas engines the time taken by the piston to make the working part of its stroke is generally about one-fifth of a second. If the pressure in one mixture has fallen more, proportionally in that time, then although it may give the highest maximum, it may lose too rapidly to give the highest mean pressure. To find this cooling effect, find the pressure to which each mixture falls at the end of 0·2 second after maximum pressure; it is in the different cases:

Mixture containing gas	$\frac{1}{14}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{6}$
Time after beginning explosion (0·2 sec. after max. pressure)	0·48	0·38	0·33	0·27	0·25 sec.
Pressure in lbs. per sq. in.	43	48	47	55	57
Press. respectively by 14, 12, 10, 8, and 6	602	576	470	440	342

The lower row expresses the relative pressures still remaining after allowing each explosion to cool for one-fifth of a second from complete explosion; they express the resistance to cooling possessed by the mixtures. It is evident at once that the strongest mixtures cool most rapidly; a higher temperature being produced, more of the heat of the explosion is lost in a given time.

(2) Power of producing pressure and resisting cooling.

To find the best mixture for producing pressure and resisting cooling, those numbers are to be added to the corresponding ones for maximum pressure:

Proportion of Glasgow gas in mixture	$\frac{1}{14}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{6}$
Pressure produced upon pistons by one cubic inch gas	728	756	690	712	576
Pressure remaining upon pistons 0·2 sec. after complete explosion	602	576	470	440	342
Mean pressure	665	666	580	576	459

The mean of the two sets gives numbers expressing the relative values of the mixture for producing pressure, and at the same time resisting cooling. The two weakest mixtures are best in both respects, the low result given by the strongest mixture is due to the fact that excess of gas is present and it remains unburned, it proves how easily the consumption of an engine may be increased by even a slight excess of gas in the mixture.

The two best mixtures ignite too slowly, but in the actual engine that is easily controlled, as will be explained later. The best mixtures are 1 vol. gas 13 volumes air, and 1 vol. gas 11 volumes air. With more gas the economy will rapidly diminish.

The experiments with Oldham gas treated in the same way give the following results:

Proportion of Oldham gas in mixture	$\frac{1}{15}$	$\frac{1}{14}$	$\frac{1}{13}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{7}$	$\frac{1}{6}$	$\frac{1}{5}$
Pressure produced upon pistons by one cubic inch gas	600	721	780	732	780	696	630	546	400
Pressure remaining upon pistons 0·2 sec. after complete explosion per sq. inch	31	40	42	44	44	47	52	50	46
Pressure per piston	465	560	546	528	440	376	364	300	230
Mean pressure upon piston	532	640	663	630	610	536	497	423	315

Here, too, the best mixture lies between one-twelfth and one-fourteenth of gas; with less and more gas the result becomes worse and worse. Glasgow and Oldham gases seem to be very nearly equal in value per cubic foot for the production of power, as the pressure produced from one cubic inch in the best mixture of each is very similar. The average pressures during 0·2 second from complete explosion are exceedingly close, Glasgow gas mixture containing one-twelfth gas giving 666 lbs. pressure per cubic inch of gas, and Oldham gas for the same mixture and the same quantity giving 630 lbs.: Glasgow gas one-fourteenth mixture 665 lbs. pressure, Oldham gas 640 lbs. The hydrogen experiments give as follows:

Proportion of hydrogen gas in mixture .	$\frac{1}{4}$.	$\frac{1}{5}$.	$\frac{2}{7}$.
Pressure produced upon pistons by one cubic inch hydrogen	287.	340.	280.
Pressure remaining upon pistons 0·2 sec. after complete explosion per sq. inch.	35.	39.	40.
Pressure per piston . .	245.	195.	140.
Mean pressure upon piston . . .	256,	267,	210.

The best mixture with 1 cubic inch of hydrogen only gives a pressure of 267 lbs. available for 0·2 second, so that its capacity for producing power, compared with Glasgow and Oldham gas, is as 267 is to 665 and 640 respectively. To produce equal power with Glasgow gas nearly two-and-a-half times its volume of hydrogen is required. The idea is very prevalent among inventors that if pure hydrogen and air could be used, greater power and economy would be obtained; these experiments prove the fallacy of the notion. Hydrogen is the very worst gas which could be used in the cylinder of a gas engine, it is useful in conferring inflammability upon dilute mixtures of other gases, but when present in large quantity in coal gas it diminishes its value per cubic foot for power.

PRESSURES PRODUCED IF NO LOSS OR SUPPRESSION OF HEAT EXISTED.

From the fact already mentioned in the last chapter, that the theoretical temperatures of combustion are never attained in reality, it will naturally be expected that the pressures produced by explosions in closed vessels will also fall short of theory. This is found to be the case. It has been observed by every experimenter upon the subject, beginning with Hirn in 1861, who determined the pressures produced by the explosion of coal

gas and air, and hydrogen and air. He used two explosion vessels of 3 and 36 litres capacity; they were copper cylinders with diameters equal to their length. He used a Bourdon spring manometer to register the pressure. He states that:

(1) With 10 per cent. hydrogen introduced the results were: according to experiment, 3·25 atmospheres; according to calculation, 5·8 atmospheres.

(2) With 20 per cent. of hydrogen, the results were: according to experiment, 7 atmospheres, which is very much below the calculation.

(3) With 10 per cent. of lighting gas introduced the results were: according to experiment, 5 atmospheres, *i.e.* much more than with the introduction of an equal volume of pure hydrogen.

He notices especially the low pressure produced by hydrogen as compared with lighting gases, but observes truly that this should not excite surprise—although the heat value of hydrogen is great, yet it is so when compared with equal weights of other substances—and that coal gas being four or five times as heavy as hydrogen, quantity is balanced against quality; therefore volume for volume it gives out more heat.

He considers that there is no difficulty in explaining the very considerable difference found between calculation and experiment, as the metal sides are at so low a temperature compared with the explosion, that the heat is rapidly conducted away, and the attainment of the highest temperature is impossible. Bunsen, in his experiments, observed the same difference, and so later did Mallard and Le Chatelier. The author's experiments fully confirm the accuracy of those observers. In no case, whether with weak or strong mixtures of coal gas and air, or hydrogen and air, is the pressure produced which should follow the complete evolution of heat.

Thus, with hydrogen mixtures (*Clerk's experiments*):

	Per sq. in.		
1 vol. H 6 vols. air gives by experiment . .	41	lbs.	above atmosphere.
The calculated pressure is	88·3	,,	,,
1 vol. H 4 vols. air experiment gives . . .	68	,,	,,
Calculated pressure is	124	,,	,,
2 vols. H 5 vols. air experiment gives . .	80	,,	,,
Calculated pressure is	176	,,	,,

Without exception the actual pressure falls far short of the calculated pressure; in some manner the heat is suppressed or lost. That the difference cannot altogether be accounted for by loss of heat is easily proved; the fall of pressure is so slow from the maximum that it is impossible that any considerable proportion of heat can be lost in the short time of explosion. If so large a proportion were lost on the rising curve, it could not fail to show upon the falling curve; it would fall in fact as quickly as it rose. Again, the increase of pressure would be less in a small than in a large vessel, as the small vessel exposes the larger surface proportionally to the gas present. It is found that this is not so. Bunsen used a vessel of a few cubic centimetres capacity, and got with carbonic oxide and oxygen true explosive mixture 10·2 atmospheres maximum pressure; Berthelot with a vessel 4000 cb. c. capacity got 10·1 atmospheres; with hydrogen true explosive mixture Bunsen 9·5 atmospheres, Berthelot, 9·9 atmospheres. All the difference, therefore, cannot be accounted for by loss before complete explosion.

Mixtures of air and coal gas give similar results.

The following are the observed and calculated pressures for Oldham coal gas. (*Clerk's experiments.*)

	Per sq. in.		
1 vol. gas 14 vols. air, experiment gives . .	40	lbs.	above atmosphere
Calculated pressure is	89·5	..	..
1 vol. gas 13 vols. air, experiment gives .	51·5	..	..
Calculated pressure is	96	..	..
1 vol. gas 12 vols. air, experiment gives . .	60	..	..
Calculated pressure is	103	..	..
1 vol. gas 11 vols. air, experiment gives . .	61	..	..
Calculated pressure is	112	..	..
1 vol. gas 9 vols. air, experiment gives . .	78	..	..
Calculated pressure is	134	..	..
1 vol. gas 7 vols. air, experiment gives . .	87	..	..
Calculated pressure is	168	..	..
1 vol. gas 6 vols. air, experiment gives . .	90	..	..
Calculated pressure is	192	..	..

The results with Glasgow gas are so similar that it is unnecessary to give a table; in no case does the maximum pressure account for much more than one-half of the total heat present. As all of the deficit cannot have disappeared previous to complete explosion, it follows that the gases are still burning on the falling curve, that is, the falling curve does not truly represent the rate of cooling of air heated to the maximum temperature, because heat is being continually added by the continued combustion of the mixture. This will be fully proved by a study of the curves.

It may, however, be taken as completely proved by the complete accord of all physicists who have experimented on the subject, that for some reason nearly one-half of the heat present as inflammable gas in any explosive mixture, true or dilute, is kept back and prevented from causing the increase of pressure to be expected from it. Although differences of opinion exist on the cause, all are agreed on the fact; they also agree in considering that inflammation is complete when the highest pressure is attained.

TEMPERATURES OF EXPLOSION.

With a mass of any perfect gas confined in a closed vessel the absolute temperatures and pressures are always proportional: double temperature means double pressure. Temperatures T, t (absolute), pressures corresponding P, p: then $\frac{T}{t} = \frac{P}{p}$ (Charles's law). If explosive mixtures behaved as perfect gases, the pressure before explosion and temperature being known, the pressure of explosion at once gives the corresponding temperature. It has been shown at page 82 that explosive mixtures do not fulfil this condition, but change in volume from chemical causes quite apart from physical ones. It follows, therefore, that these changes must be known before the temperature of the explosion can be calculated from the pressure. In the cases of hydrogen and carbonic oxide true explosive mixtures with oxygen, a contraction of volume is the result of combination. It comes to the same thing as if a portion of the perfect gas in the closed vessel was lost during heating; the temperature then could not be known at the higher pressure unless the volume lost is also known.

Suppose one-third of the volume to disappear, upon cooling to the original temperature, the pressure would be reduced to two-thirds of the original pressure, and this fraction of the original pressure must be taken as $p_1=10$. As both steam and carbonic acid at temperatures high enough to make them perfectly gaseous occupy two-thirds of the volume of their free constituents, it follows that p_1 must be taken as $\frac{2}{3}\,p$, wherever the temperatures are such that combination is complete. But here another difficulty occurs. Bunsen found that hydrogen and oxygen in true explosive mixtures gave an explosion pressure of 9·5 atmospheres. The calculated pressure for complete combustion, and allowing for chemical contraction is 21·3 atmospheres. It is evident enough that complete combustion has not occurred, but it is difficult to say what fraction remains uncombined. Yet unless the fraction in combination be known the contraction cannot be known, and therefore the temperature corresponding to the pressure cannot be known.

Berthelot has pointed out that in a case of this kind the true temperature cannot be calculated, but it may be shown to lie between two extreme assumptions, both of which are erroneous.

(1) Temperature calculated on assumption of no contraction.

(2) Temperature calculated on assumption of the complete contraction.

Let the two temperatures be (1) T^1 and (2) T.

	T^1	T
2 vols. H, 1 vol. O, explosion pressure (absolute) 9·9 atmospheres . .	2449° C.	3809° C.
2 vols. CO, 1 vol. O, explosion pressure (absolute) 10·8 atmospheres . .	2612° C.	4140° C.

The lower temperature could only be true if no combination whatever had occurred, which is impossible, as then no heat at all could be evolved; the higher temperature could only be true if complete combination, and therefore complete contraction, occurred. The truth is somewhere between these numbers.

When the explosive mixture is dilute, the limits of possible error are narrower, because the possible proportion of contraction is less; with hydrogen and air mixture in proportion for complete combination, 2 volumes of hydrogen require 5 volumes of air. The greatest possible contraction of the 7 volumes is therefore 1 volume. If all the hydrogen burned to steam, the 7 volumes contract to 6 volumes. With more dilute mixtures the proportion diminishes.

With a mixture containing $\frac{1}{5}$ of its volume hydrogen, 10

volumes can only suffer contraction to 9 volumes. With $\frac{1}{7}$ volume hydrogen, 14 volumes can contract to 13 volumes.

The limits of maximum temperatures for those mixtures are as follows (*Clerk*):

	T^1	T
1 vol. H, 6 vols. air, explosion pressure (absolute), 55·7 lbs. per sq. in. . .	826° C.	909° C.
1 vol. H, 4 vols. air, explosion pressure (absolute), 82·7 lbs. per sq. in. . .	1358° C.	1539° C.
2 vols. H, 5 vols. air, explosion pressure (absolute), 94·7 lbs. per sq. in. . .	1615° C.	1929° C.

The possible error is here much less than with true explosive mixtures; coal gas is of such a composition that some of its constituents expand upon decomposition previous to burning, and so to some extent balance the contraction produced by the burning of the others. The possible error is therefore still further reduced. The composition of Manchester coal gas as determined by Bunsen and Roscoe is as below. The oxygen required for the complete combustion of each constituent is also given, and the volumes of products formed.

ANALYSIS OF MANCHESTER COAL GAS. (*Bunsen and Roscoe.*)

		Amount required for complete combustion	Products
	vols.	vols. O	vols.
Hydrogen, H . . .	45·58	22·79	45·58, H_2O
Marsh gas, CH_4 . . .	34·9	69·8	104·7, CO_2 & H_2O
Carbonic oxide, CO . . .	6·64	3·32	6·64, CO_2
Ethylene, C_2H_4 . . .	4·08	12·24	16·32, CO_2 & H_2O
Tetrylene, C_4H_8 . . .	2·38	14·28	19·04, CO_2 & H_2O
Sulphuretted hydrogen, H_2S	0·29	0·43	0·58, H_2O & SO_2
Nitrogen, N . . .	2·46	—	2·46
Carbonic acid, CO_2 . .	3·67	—	3·07
Total	100·00	122·86 O	198·99, CO_2 H_2O & SO_2

When burned in oxygen 100 volumes of this sample of gas require 122·86 volumes of oxygen, total mixture 222·86 volumes; the products of the combustion measure 198·99 volumes. Calculating to percentage, 100 volumes of the mixture will contract to 89·4 volumes of the products. As 100 volumes of the mixture will contain 55·1 volumes of oxygen, it follows that if air be used, four times that volume of nitrogen will be associated with it, that is, 55·1 × 4 = 220·4. The strongest possible explosive mixture of this coal gas with air containing 100 volumes of the true explosive mixture will be 320·4 volumes, and it will contract upon complete combustion to 309·8 volumes.

One volume of this gas requires 6·14 volumes air for complete combustion, and 100 volumes of the mixture contract to 96·6 volumes of products and diluent. A contraction of 3·4 per cent. Dilution still further diminishes the change; thus a mixture, 1 volume gas 13·28 volumes air, will have only half that contraction, or 1·7 per cent.

From these figures it is evident that the limits of possible error in calculating temperature from pressure of explosion does not exceed, in the worst case, with coal gas and air 3·4 per cent., and in weaker mixtures half that number. The fact that the whole heat is not evolved at the explosion pressure, and that therefore the whole contraction does not occur then, further reduces the error. It is then nearly correct to calculate temperature from pressure without deduction for contraction. This has been done for Glasgow gas and for the Oldham gas experiments by the author.

EXPLOSION IN A CLOSED VESSEL. (*Clerk.*)

Mixtures of air and Glasgow coal gas.

Temp. before explosion . . . . . . 18° C.
Pressure before explosion . . . . . . atmos. 14·7 lbs.

Mixture		Max. press. above atmos. in pounds per sq. in.	Temp. of explosion calculated from observed pressure
Gas.	Air.		
1 vol.	13 vols.	52	1047° C.
1 vol.	11 vols.	63	1265° C.
1 vol.	9 vols.	69	1384° C.
1 vol.	7 vols.	89	1780° C.
1 vol.	5 vols.	96	1918 C.

Mixtures of air and Oldham coal gas.

Temp. before explosion . . . . . . 17° C.

Mixture		Max. press. above atmos. in pounds per sq. in.	Temp. of explosion calculated from observed pressure	Theoretical temp. of explosion if all heat were evolved
Gas.	Air.			
1 vol.	14 vols.	40	806° C.	1786° C.
1 vol.	13 vols.	51·5	1033° C.	1912° C.
1 vol.	12 vols.	60	1202° C.	2058° C.
1 vol.	11 vols.	61	1220° C.	2228° C.
1 vol.	9 vols.	78	1557° C.	2670° C.
1 vol.	7 vols.	87	1733 C.	3334° C.
1 vol.	6 vols.	90	1792° C.	3808° C.
1 vol.	5 vols.	91	1812° C.	
1 vol.	4 vols.	80	1595° C.	

Those temperatures calculated from maximum pressure, although not quite true are very nearly so, whatever be the theory adopted to explain the great deficit of pressure. It does not follow, however, that they are the highest temperatures existing at the moment of explosion; they are merely averages. The existence of such an intensely heated mass of gas in a cold cylinder causes intense currents, so that the portion in close contact with the cold walls will be colder than that existing at the centre. There will be a hot nucleus of considerably higher temperature than that outside, but whatever that temperature may be, the increase of pressure gives a true average. It may be taken, then, that coal gas mixtures with air give upon explosion temperatures ranging from 800° C. to nearly 2000° C., depending on the dilution of the mixture. The more dilute the mixture the lower the maximum temperature; increase of gas increases maximum temperature at the same time as it increases inflammability.

The author has made explosion experiments in the same vessel with mixtures previously compressed, and finds that the pressures produced with any given mixture are proportional to the pressure before ignition, that is, with a mixture of constant composition, double the pressure before explosion, keeping temperature constant at 18° C., doubles the pressure of explosion. The experiments are laborious, and they are not yet complete for publication, but the general principles already developed are true for compressed mixtures also.

EFFICIENCY OF GAS IN EXPLOSIVE MIXTURES.

Rankine defines available heat as follows :

'The available heat of combustion of one pound of a given sort of fuel is that part of the total heat of combustion which is communicated to the body to heat which the fuel is ~~burned~~; and the efficiency of a given furnace, for a given sort of fuel, is the proportion which the available heat bears to the total heat.'

The gas engine contains furnace and motor cylinder in one ; nevertheless the efficiency of the working fluid is quite as distinct from the furnace efficiency as in the steam engine. Rankine's definition is quite true for the gas engine.

The fuel being gas, the working fluid consists of air and its fuel and their combinations ; the available heat is that part of the heat of combustion which serves to raise the temperature of the working fluid ; the part which flows into it to make up for loss to the cold cylinder walls cannot be considered available. To be truly available it must either increase temperature, or keep it from falling by expansion. The heat flowing through the cylinder walls is a furnace loss, incident to the explosion method of heating.

The experiments upon explosion in a closed vessel provide data for determining the furnace efficiency as distinguished from that of the working fluid. The proportion of heat flowing from an explosion to the walls in unit time will depend upon the surface of the walls for any given volume. The smaller the cooling surface in proportion to volume of heated gases, the slower will be the rate of cooling. Therefore to be applicable to any engine, the explosion vessel in which the experiments are made should have the same capacity and surface as the explosion space of the engine.

The author's experiments are therefore only strictly applicable to engines with cylinders similar to his explosion vessel. Within certain limits, however, the error introduced by applying them to other engines is inconsiderable.

Assuming the stroke of a gas engine (after explosion) to take 0·2 second, this may be taken as the time during which the pressure of explosion must last if it is to be utilised by the engine. In a closed vessel the pressure falls considerably in 0·2 second, the average pressure may be taken as nearly indicating the available pressure during that time. The heat necessary to produce that pressure is the available heat ; and its proportion to the total heat which the gas present in the mixture can evolve is the efficiency of the gas in that explosive mixture.

With Oldham gas the best mixture is (table, p. 103) 1 volume gas 12 volumes air ; the average pressure during the first fifth of a second is 51 lbs. per square inch above atmosphere. If all the heat present heated the air, the pressure should be 103 lbs. effective, so that the efficiency of the heating method is $\frac{51}{103} =$ 0·49.

The strongest mixture which still contains oxygen in excess is 1 volume gas 7 volumes air, the average available pressure is 67 lbs. per square inch (all heat evolved would give 168 lbs.), the efficiency is $\frac{67}{168} =$ 0·40 nearly.

Calculated in this way the efficiency values for Oldham gas mixtures are :

Prop. of Oldham gas in mixture .	$\frac{1}{15}$.	$\frac{1}{14}$.	$\frac{1}{13}$.	$\frac{1}{12}$.	$\frac{1}{10}$.	$\frac{1}{8}$.	$\frac{1}{7}$.
Heating efficiency	0·40,	0·48,	0·50,	0·43,	0·46,	0·40,	0·37.

The furnace efficiency plainly diminishes with increased richness of the mixture in gas.

TIME OF EXPLOSION IN CLOSED VESSELS.

The rates of the propagation of flame in explosive mixtures given in tables, pages 86 and 87, are true only where the inflamed portion is free to expand without projecting itself into the unignited portion. They are the rates proper for constant pressure.

Where the volume is constant, in a closed vessel, the part first inflamed instantly expands and so projects the flame surface into the mass, compressing what remains into smaller space.

To the rate of inflammation at constant pressure are added the projection of the flame into the mass by its expansion and also the increased rate of propagation in the unignited portion by the heating due to its compression by portion first inflamed.

It follows that the rate continually increases, as the inflammation proceeds until it fills the vessel.

This is evident from all the explosion curves. The pressure rises slowly at first, then with ever increasing rate till the explosion is complete; thus the explosion curve for hydrogen mixture with air $\left(\frac{2}{7}\text{ H}\right)$, shows an increase of 17 pounds in the first 0·005 second, the maximum pressure of 80 pounds being attained in the next 0·005 second. With the weaker mixtures the same thing occurs, rise of pressure, slow at first, then more rapid, and in some cases becoming slow again before maximum pressure. The time taken to get maximum pressure varies much with the circumstances attending the beginning of the ignition. If a considerable mass be ignited at once, by a long and powerful spark, or by a large flame, the ignition of the weakest mixture may be made almost indefinitely rapid. Something very like Berthelot's explosive wave may result. This is due to the great mechanical disturbance caused by the rapid expansion of the portion first ignited; the smaller that portion is the more gently does the flame spread. A small separate chamber connected with the main vessel, if filled with explosive mixture and ignited, will project a rush of flame into the main vessel and cause almost instantaneous ignition. The shape of the vessel, too, has a great effect upon the rate. Where it is cylindrical and large in diameter proportional to its axial length, ignition is extremely rapid, the flame is confined at starting, and is rapidly deflected by the cylinder ends, and so shoots through the whole mass.

By so arranging the explosion space of a gas engine that some mechanical disturbance is permitted, it is easy to get any required rate of ignition even with the weakest mixtures.

The maximum pressure is not increased by rapid ignition.

Starting the ignition from a small spark, the time taken to ignite increases with the volume of the vessel.

Berthelot has experimented upon this point with explosion vessels of three capacities, 300 cubic centimetres, 1500 cubic centimetres, and 4000 cubic centimetres. He finds time of explosion (he also takes maximum pressure to indicate complete

explosion) of mixture 2 vols. H, 1 vol. O, and 2 vols. N. in 300 cubic centimetre vessel, 0·0026 second; and in 4000 cubic centimetre vessel, 0·0068 second.

With mixture of carbonic oxide and oxygen, 2 vols. CO, 1 vol. O, smaller vessel, 0·0128 second; larger vessel, 0·0155 second. Mixtures with air were much slower. The conclusion then is obvious, that in large engines the time of explosion will be longer than in small ones.

'MAYOR' OF PENNGROVE

Bourke Shows His Engine

Story and Picture
By BOB LIPMAN

HIS HONOR, THE MAYOR—In his Penngrove home, Russell Bourke stands before an engine that could have ranked him with the top inventors in history. Although never marketed, the Bourke engine is considered a remarkable advance in the engineering field, yet it never yielded Bourke any financial rewards.

"Let them worry about my engine. I'm just concentrating on having a good time," Russell Bourke said in his Penngrove home.

The famous inventor of the Bourke engine, which has never been marketed to its full capability, has assumed the title of honorary mayor of Penngrove and he and his wife Lois are taking life easy — no longer worrying about losing rights to an engine he said could have given him untold wealth.

Now it's running engines for youngsters, fixing mechanical items for friends and tinkering with radio and phonographic equipment, while Lois adds to her collection of more than 9,000 record selections.

A national magazine has asked Bourke to bring it up to date on his engine, but he said there is nothing to write about.

"I had an idea for many years and saw it develop into the ideal engine. It was perfect, but circumstances played too strong a part against it," he exclaimed.

ONE-STROKE

The Bourke one-stroke engine has cooperative pistons which are connected to one rigid connecting rod that shuttles through an oil filled sealed crankcase. There are only two moving parts in the engine — the piston connecting rod and the crankshaft. All other parts found in the conventional engine have been discarded.

In 1918, while teaching engine maintenance in the Air Force Service Mechanics School at Kelly Field, Tex. he became impressed with the idea that the four cycles used in engines was all wrong.

After the war, the depression forced him to delay his plans until 1932 when he made his first working model. The engine passed the Air Corps tests, was recommended to the engineering department in Washington D.C., but got lost in red tape.

As it was coming before capital bureaucrats, the Japanese bombed Pearl Harbor and a freeze order came out to produce only things already in production.

For the remainder of the war, Bourke worked at Mare Island.

His wife developed a crippling arthritis which also delayed the way of the engine. Hearing of an Oregon doctor who could help Lois, the couple moved to Wheeler where they stayed seven years. Russell went into land development and soon decided to retire.

They returned to this area in 1961 and he was induced to build a large engine. A group of investors entered the scene and by the time a few years had passed. Bourke had lost rights to the engine.

The patents ran out in 1957. The machinery is still sitting in a factory, unused, Bourke stated. Anyone can manufacture it now.

Why hasn't it been developed? "That's simple. It will run on any fuel with a hydro-carbon base, needs no repair and the oil in it is good for life," Bourke said.

He indicated this would be a blow to the repair, parts and gasoline industries.

His motors would run everything from a motorboat to an airplane. Bourke still has the original engine he first built and has a host of parts and machinery in a garage.

"There's no smell, smoke, noise or vibration when my motor is in operation."

PORCHE INTERESTED

Bourke said a representative from Porche in Germany visited him recently and made sketches of the engine, showing that some people are still interested.

Another achievement, little known, was Bourke's development of a slipper bearing. He said the reasons that many jets blew up in the early days was the bearing was shot and resulted in the rest of the engine exploding.

He developed a bearing which would not break, one used in his engine, but it was copied by a major company, although he never received any compensation, and again his project gave him little monetary benefit.

"I've had to reevaluate things. I find it's not so important to worry about the fame and glory I could have obtained. I have everything I want and the rest of my life will be devoted to my wife and having an enjoyable life."

RUSSELL BOURKE INVENTS NOVEL LIGHT-WEIGHT MOTOR

Russell Bourke, of Sonoma mountains, brother of L. A. Bourke, of the Must Hatch Incubator Company, on Tuesday demonstrated at the city corporation yards on A street an aeroplane motor of his own design and build. Many interested spectators attended the demonstration which proved the mechanical skill of the inventor.

The motor which weighs 40 pounds consists of four cylinders, has no valves or gears and fires four times to a revolution. It develops forty horse power and is capable of taking up light aircraft, although the inventor has plans for the building of a motor to care for heavier ships.

This motor reduces the weight for light planes and increases the horsepower, a feature long-sought in the airplane industry. The motor has only three moving parts, according to Bourke. He has named it the Silver Eagle and at present has applied for a patent at Washington, D. C. It is probable that Bourke will demonstrate it to army and navy officials in San Francisco and to officials of airplane manufacturing concerns after he has received the patent.

It was pointed out at the demonstration on Wednesday morning that aviators for many years have been seeking a motor of light weight but capable of developing increased horse power. In a recent test at his ranch Bourke was able to operate the motor for fifteen hours on a half gallon of gasoline. It was pointed out that with the motor invented by Bourke it will not be necessary for aviators to carry such a large supply of gasoline as at present.

Bourke's father is the inventor of the famous Must Hatch Incubator from which the present hatchery on the corner of 7th and F streets takes its name which is known throughout the world.

Meanwhile, there was talk among the owners of motor driven pleasure craft of the possible formation of a speedboat club on the river.

Russell Bourke, designer of a special twin-cylinder motor that has proved particularly successful in marine work took out the "Popeye," owned by Jerry Turney, Tuesday to try out a new fuel in his outboard. The motor, a twin cylinder outfit with a top operating RPM of 10,000. worked successfully on a 52 gravity fuel made of a distilate and stove oil mix.

Bourke is now constructing an inboard motor of the same design. This will be a twin cylinder supercharged unit developing 75 horsepower at 4,000 R PM, and is being built as a special racing job.

It appears that one Petalumaan with an inventive genius may be contributing something new in the field of engineering. Some weeks ago this writer predicted that Russell Bourke's four-cylinder two-cycle motor had possibilities of revolutionizing the field of aviation.

Soon after an account of the Bourke engine appeared in these columns, the War Department in Washington ordered a qualified engineer from Hamilton Field to make a thorough investigation of the new invention.

Airplane Motor Perfected By Russell Bourke After Nine Years; Patents Are Leased

Out on his little farm at Route 3, Box 311, Petaluma, there was born, recently, a brainchild of Russell Bourke in the form of an airplane motor, the Model H, the acme of his nine years of experimenting and building of internal combustion engines. It is a handsome bit of engineering, and a machine of which Mr. Bourke is justly proud. Built of duraluminum, it shines like silver, and its small, compact size belies its power and performance, for it weighs 95 pounds and turns out 60 horsepower at 5150 revolutions per minute.

Patented in the United States and many foreign countries, the American patent rights are leased to the Silver Eagle Motors, Ltd. Mr. Bourke has built several styles of engines, internal combustion types using a different principle of action as is commonly used in the average engine.

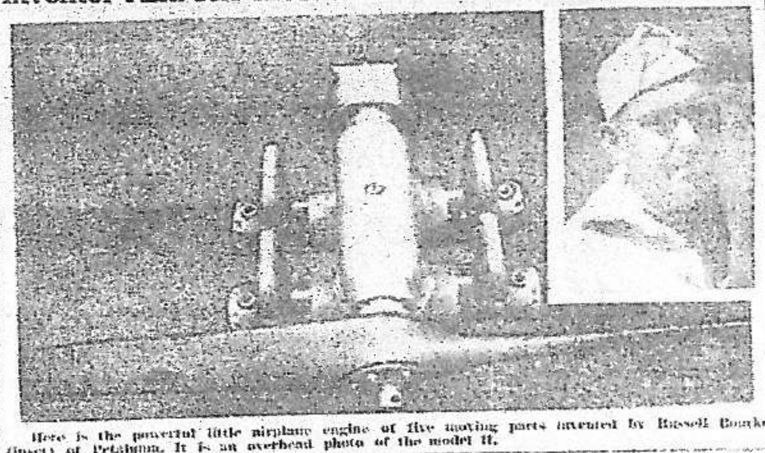
The Model H is a 4-cylinder engine of 60 cubic inches displacement, with overhead, geared drive. There are but five moving parts to the motor, which reduces to a minimum the loss of power by friction and thereby cuts down fuel consumption. The cylinders are fluid cooled, and the heads, which have small fins, are air cooled. The engine occupies a space [illegible] inches and could be suitably mounted in the wings of a plane. It runs backward as forward at will, and as smoothly as oil. Fuel oil [illegible]

[illegible]

her inventor husband. That Mr. Bourke will now be rewarded by his efforts there is no doubt, for his engine may soon be gracing planes of the nation through the company to which he has leased the patent rights.

Coming here when a baby with his parents, A. E. Bourke, now of San Gabriel, and the late Mrs. Helene Bourke, Russell received his education in Petaluma. His father invented the Must Hatch Incubator. Russell was for two years in the United States army air service at Kelly Field as an instructor during World War No. 1, and here is where he became interested in gas engines. He has two brothers, Alonzo, of San Francisco, Leo A. Bourke, one of the proprietors of the Sales & Bourke hatchery.

Inventor And His Invention



Here is the powerful little airplane engine of five moving parts invented by Russell Bourke (inset) of Petaluma. It is an overhead photo of the model H.

Markets At A Glance

NEW YORK, Aug. 12 (AP) — Following is a brief resume of the markets:

STOCKS — Irregular; leaders in [illegible].

BONDS — Mixed; [illegible].

FOREIGN EXCHANGE — Quiet; unchanged.

COTTON — [illegible].

SUGAR — Lower; [illegible].

METALS — [illegible] copper.

WOOL — [illegible].

Chicago:

[illegible]

SAN FRANCISCO MARKETS

SAN FRANCISCO, Aug. 12. [illegible]

MARKETS

AUGUST 12

SAN FRANCISCO, Aug. 12 — [illegible]

Poultry Products and Poultry [illegible]

[illegible] butter was [illegible].

NEW YORK MARKETS

By Associated Press

White Eggs

[illegible]

POULTRY PRODUCERS

Local Trade

San Francisco

[illegible]

PETALUMA EGG GRADES

[illegible]

PETALUMA BUTTER

Retail

[illegible]

Butter, Eggs And Poultry Market In Review

Following is the review of the San Francisco butter, egg and poultry market and the New York butter market for Monday, Aug. 11, up to 3 p.m. by the U. S. Dept. of Agriculture, Bureau of Agricultural Economics.

San Francisco Market

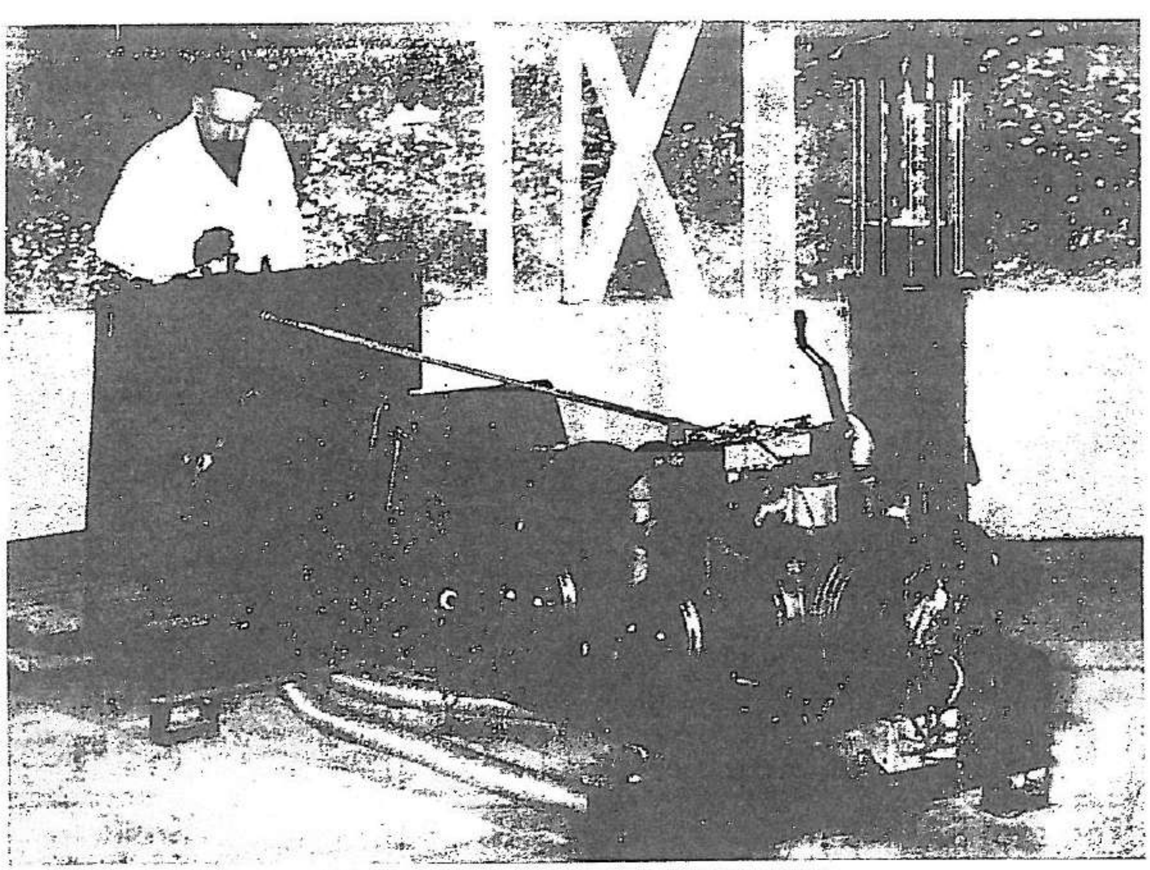
BUTTER — The [illegible]

RAF Raids Germans

(Continued From Page 1)

[illegible]

TRY IT!



RUSSELL BOURKE AND HIS NOW FAMOUS ENGINE
Family resides in Penngrove area

Bourke Engine Attracts Attention From Every Corner Of The Country

By BILL SOBERANES

A. F. Bourke arrived in Petaluma with his wife and four sons, Leo, Ivan, Alanzo and Russell in 1898, and a new and important era was started here.

The senior Bourke went on to become a prominent figure in the chicken industry; his son Ivan died shortly after returning from World War I; Leo went on to own the largest hatchery in the world; Alanzo once ran for president, and Russell became a famous inventor.

Today Russell Bourke and his wife, Lois, live in the quiet little community of Penngrove, and his story is one that would fill a book and right now he's compiling material for just such a book.

Today folks from all over the world visit the Bourke residence for two reasons — to see the famous engine he invented and never marketed and to listen to his plan to clear up the smog condition caused by our automobiles today.

Besides these two fascinating chapters in his life, Russell Bourke has had many others. In 1914 he went to Nicaragua with his father. The purpose of this trip was to teach the natives of this land all about the chicken business. Being an adventurer, Russell ran off and became a law officer at the Liberator Mine. This was a gold operation, and the man who headed it was Herbert Hoover, who later became president of the United States. The Bourkes returned to this area in 1916, and, as the ship they were sailing on came through the Golden Gate, the Tower of Jewels, which was such a prominent part of the 1915 San Francisco World's Fair, toppled. It was a spectacular sight, according to Russell.

Now, Russell decided he needed more education so he enrolled at Healds Business College, and, after graduating, he headed back to Petaluma where he went to work for the automobile firm of Sparks and Murphy.

The next step in Russell Bourke's career saw him enlisting in World War I.

After the war Russell became a homesteader in central California, and it was then that he met his wife, Lois.

Russell built what many considered the first bulldozer, he helped develop the roads into the famed Pinacles, and he came back to Petaluma in 1926. In 1931 the Bourkes took over the famed Whitney Ranch on the Petaluma side of the Sonoma Mountains and Russell became a combination beef raiser and deputy sheriff.

The story of the Bourke Engine has appeared in many national magazines, and Sports Aviation carried this story in three different issues.

Bourke said he had the idea for many years and saw it develop into the ideal engine. He said it was perfect, but time and circumstances played too strong a part against it.

The Bourke one-stroke engine has cooperative pistons which are connected to one rigid connecting rod that shuttles through an oil filled sealed crankcase. These are the only two moving parts in the engine — the piston connecting rod and the crankshaft. All other parts found in the conventional engine have been discarded.

It was in 1918 while teaching engine maintenance in the Air Force at Kelly Field, Tex., that Bourke became impressed with the idea that the four cycles used in engines were all wrong.

After the war he had plans to work on his dream engine, but the depression forced him to wait until 1932 when he made his first working model.

This engine passed the Air Force test and was highly recommended by the engineering department in Washington, D. C., but got lost in red tape.

Just when the government was again about to start manufacturing the Bourke Engine, the Japanese bombed Pearl Harbor and a freeze order come out to produce only things already in production.

Bourke then went to work at Mare Island and remained until the war was over.

In the meantime Russell Bourke's wife developed a crippling arthritis which also delayed the production of his engine. Then Russell heard of a doctor in Wheeler, Ore. who had helped many folks in Lois' condition. So he packed up his belongings, and he and his wife headed for this spot.

The Bourkes stayed in Oregon for seven years, and while there, Russell went into the land development business.

In 1961 the Bourkes returned to this area, and he started work on a bigger engine. A group of investors entered into this and within a few years lost his rights to the engine.

The patents ran out in 1957. The engine is still unused and anyone can now manufacture it, Bourke said.

Why hasn't it been developed?

The answer is simple. It will run on any fuel with a hydrocarbon base, needs no repairs and the oil in it is good for life, according to Bourke.

These motors would run everything from a motorboat to an airplane. Bourke still has the original engine and has a host of parts at his Penngrove home.

Here's another amazing point. Bourke's motor has no smell, smoke, makes no noise and does not vibrate while in operation.

Another little known Bourke achievement, his development of a slipper bearing. He said the reason that many jets blew up in the early days was because the bearing was shot and resulted in the rest of the engine exploding.

He developed a bearing which would not break, one used in his engine and one that was copied by major companies.

Today Bourke is more interested in smog control than he is in his engines. The brochure he is preparing on this subject contains many pages, and, like his engine, he doesn't figure on getting rich from this worthwhile project — in fact he's willing to give it to humanity, and he's willing to show his well developed smog control plan to anyone who is interested.

On top of all this, Russell Bourke and his wife, Lois, have an amazing collection of clocks at their Penngrove home, and they can tell you what time it is in any place in the world. Yes, they even have a clock that runs backward, after pointing this one out, Russell smiled and said — "but remember this, you can't turn the clock of life backward."

Two years ago Russell and Lois Bourke took up playing the organ and today have twin organs in their home, and both are excellent musicians.

To top things off, the Amazing Bourkes have a 12-year-old Burmese dog named Lady that is about the smartest animal this writer has ever seen. When Russell says he has a headache this dog goes to the medicine cabinet and brings him a bottle of aspirin.

When its dinner time. Lady fetches a satchel, opens it and takes out her three dishes. When she's through eating, she puts the dishes back in the satchel.

Then, as a climax, Lady lies on her back while Russell sits on the floor and hands her a baby bottle full of milk. Lady takes this bottle between her two front paws and drinks it like a human baby would under the same conditions.

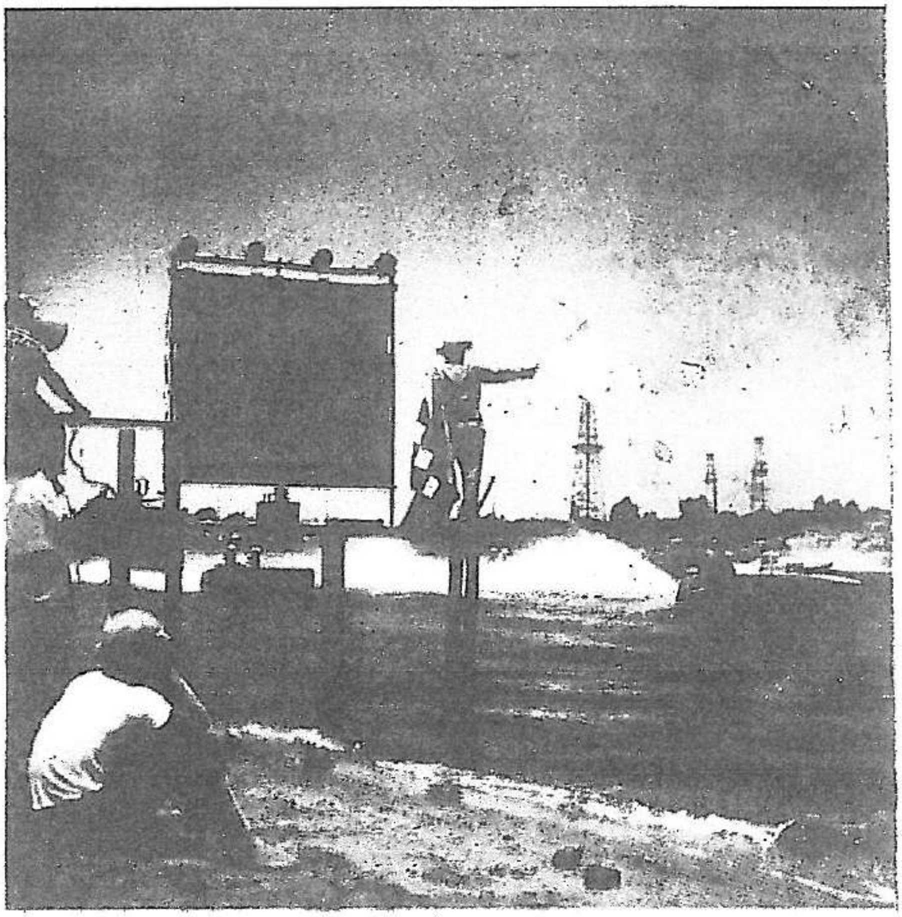
As we said before, the Russell Bourkes are amazing people, and you'll have to marvel at their wonderful philosophy for living. Despite the fact that they did not commercialize on his many great inventions, the Bourkes love life, love their friends and are completely content with what they have today.

SPEED & SPRAY

50 cents

SPEED and SPRAY

SEPTEMBER, 1953



HOW TO BUILD
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PLANS AND SPECIFICATIONS

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PAVIA TO VENEZIA
WORLD'S LONGEST BOAT RACE

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REGATTA IN TROPICAL MEXICO

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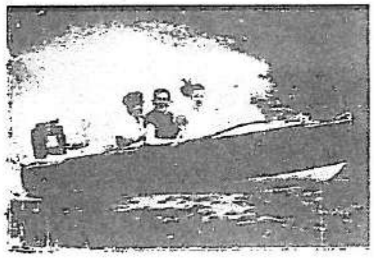
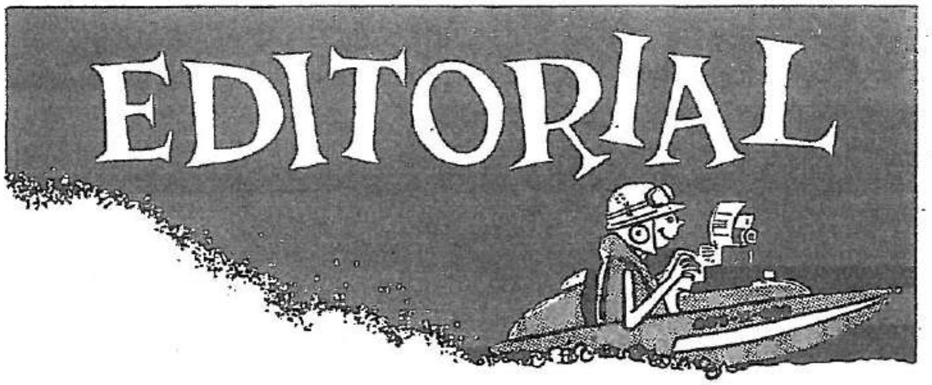
RACING AROUND THE WORLD
INBOARDS-OUTBOARDS-STOCK



INTERNATIONAL
BOAT RACING AND WATER SPORTS



ARE YOU DOING YOUR PART?

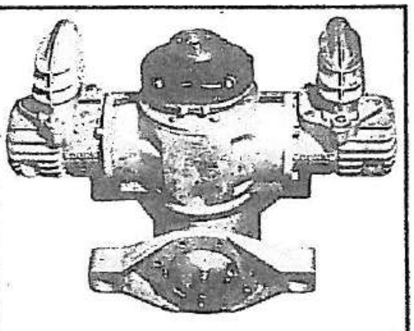
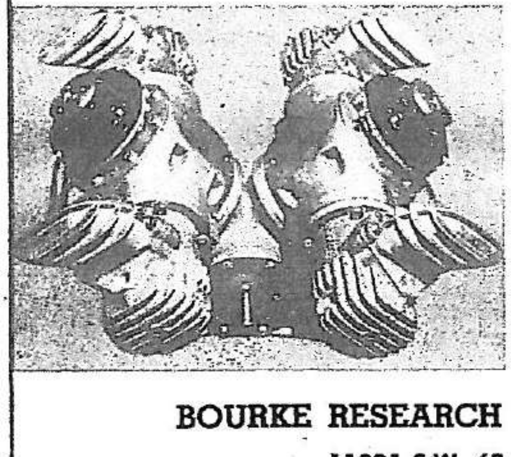
THE sport of power boating—whether it be on the racing, the water sports or the social side, is dependent for success on its elected officers and its appointed committeemen. This is true both in the local club and in the national governing organizations. Are YOU honestly carrying your share of the load?

Let us pay tribute this month to the backbone of all organized boating, the individual who accepts an elective office or an appointment, and then fulfills the obligations of the job. This is the fellow who answers his mail promptly and never passes the buck. He attends scheduled meetings and doesn't cry about the amount of work he has to do. He has the guts to make a decision and it is usually a fair one. He isn't an intolerant advocate of one particular branch of power boating and he keeps his nose out of politics.

Often this man can ill afford the expenses of his position, but he sacrifices without a murmur and never demands pay or expenses. He will often waive legitimate fees when the budget won't stand the traffic. When someone else falls down on their job, he will pitch into help. He doesn't beef about conditions or knife others in the back. He isn't a noisy windbag and is not fond of being shoved into the public eye. Whether this fellow wears three stars or is just a committeeman, he is never officious or overbearing. he doesn't "know it all" and is always willing to listen and learn.

One of the nicest things about this guy is that he honestly isn't looking for praise or glory. His reward is the satisfaction of seeing his favorite sport profit by his work. With his modesty in his own accomplishments, he is generous with his praise for the other workers. Boating means everything to this man. "As Ye Sow—So Shall Ye Reap," and truer words were never written. He puts a full measure of work and enthusiasm into the sport and realizes a keen appreciation of the results of his efforts. Every one in boat racing profits by his contribution. What a guy! God bless him. If we only had more like him.

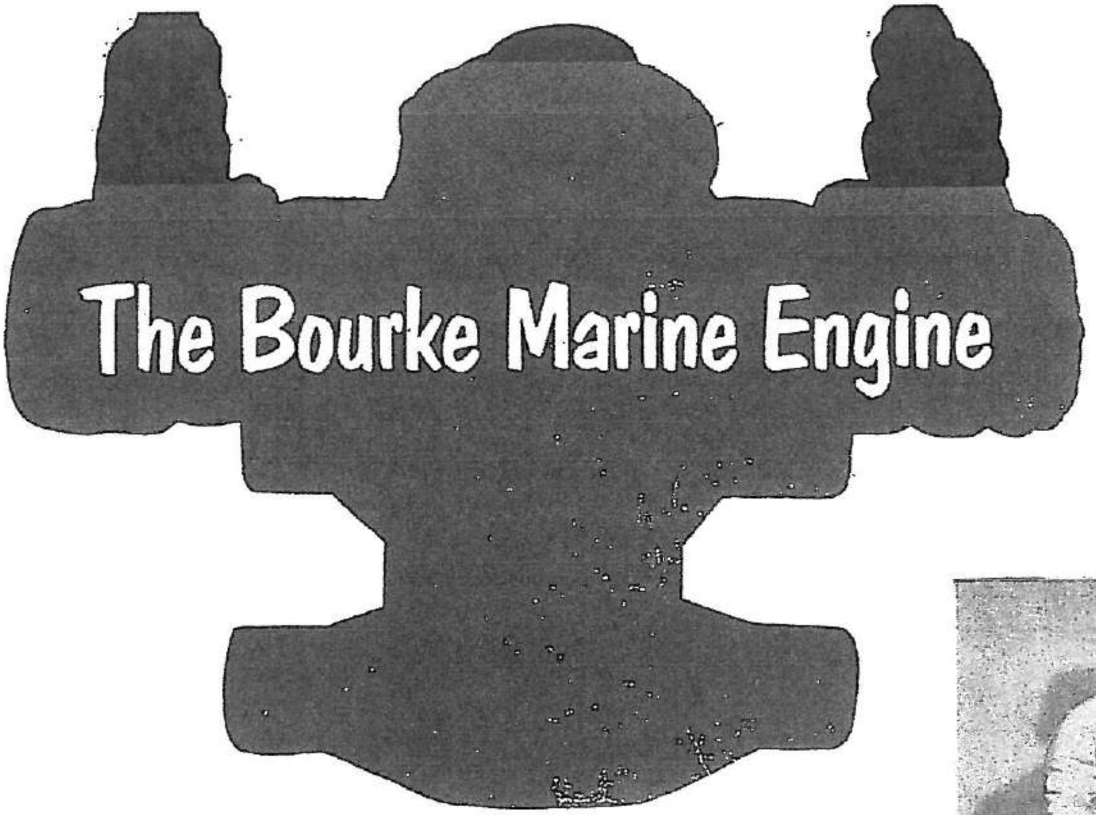
Are YOU doing your part? Or is one of these "right guys" carrying you along on his back? Next month we will discuss the other category of officers and committeemen —the leech, the do-nothing, the glory seeker, the trouble maker, the wind bag, the gutless wonder and the vultures who make a racket out of their official positions. Don't miss it! Elections are coming up and this will be a juicy one!



CUSTOM BUILT

See story on page 13.

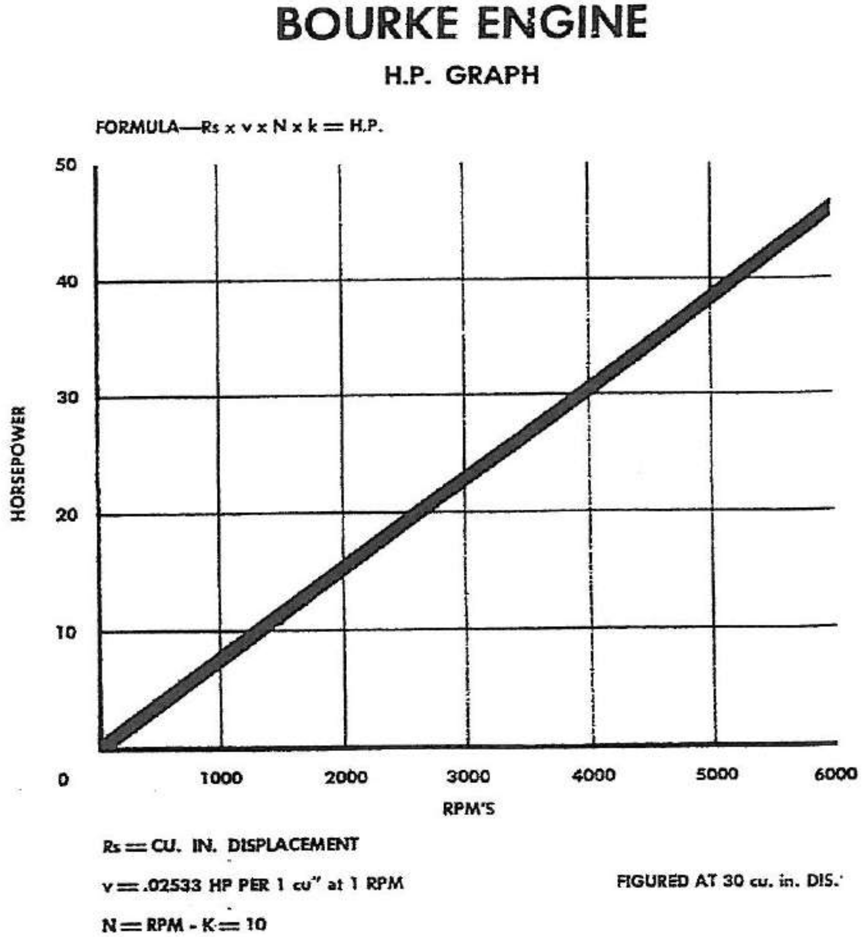
Further information
on request.

BOURKE RESEARCH LABORATORIES
11031 S.W. 63 AVENUE
PORTLAND, 19, OREGON



The Bourke Marine Engine

Mr. Bourke is shown here with one of his engines mounted on a heavy duty Evinrude lower unit. The carburetor and manifold are in use on this particular engine. The unit can, however, be equipped with a fuel injector.



Rs = CU. IN. DISPLACEMENT

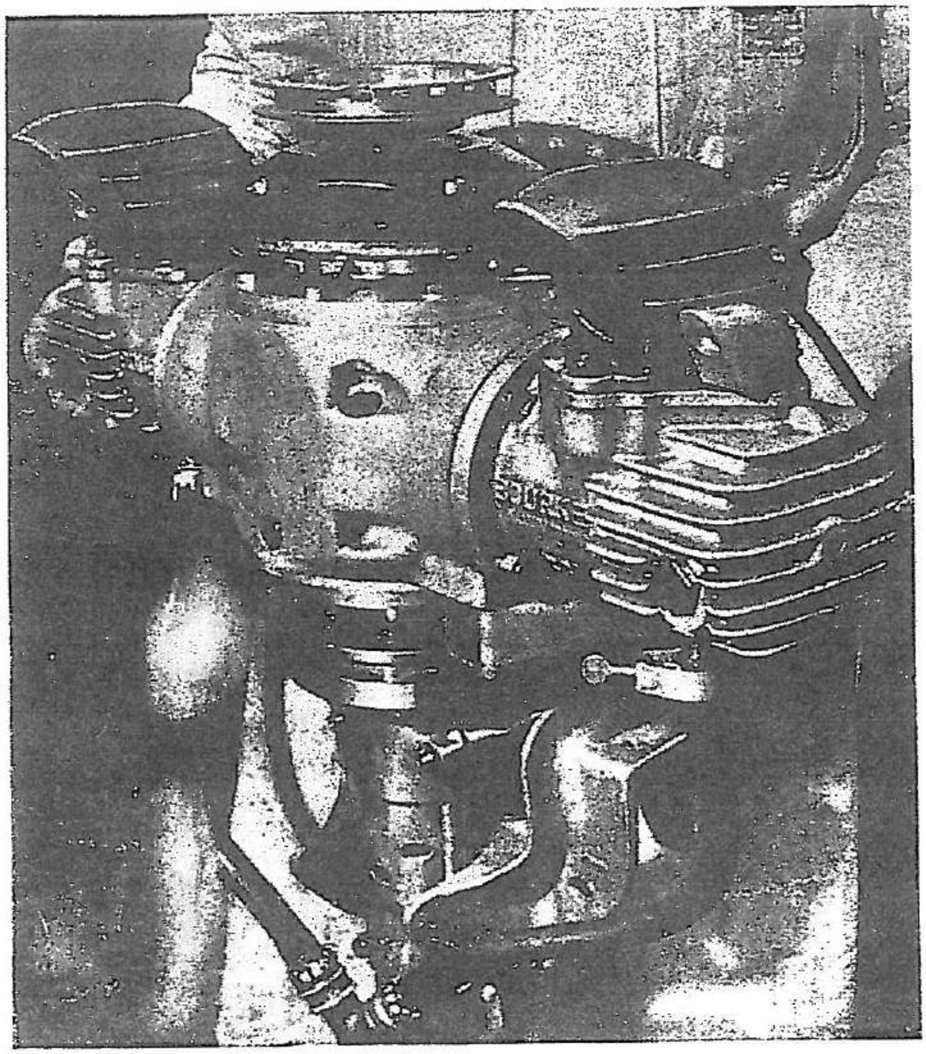
v = .02533 HP PER 1 cu" at 1 RPM

N = RPM - K = 10

FIGURED AT 30 cu. in. DIS.

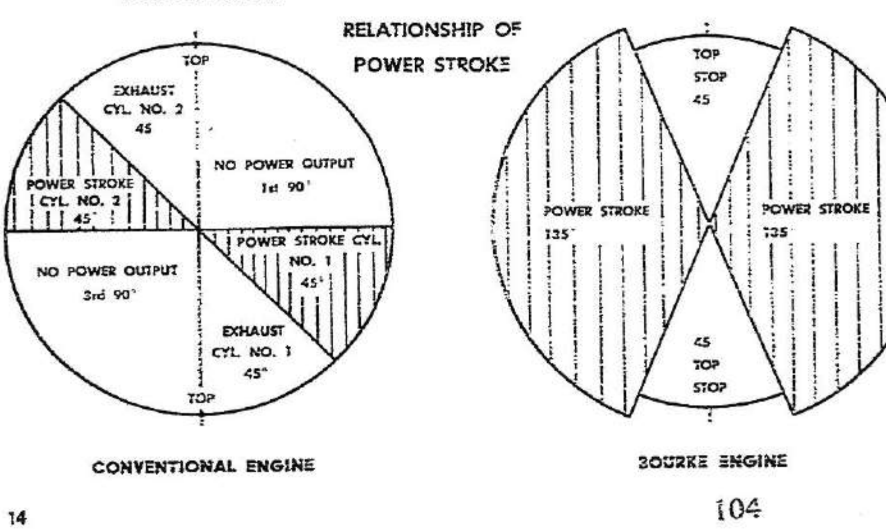
Story and Photos by PETER G. SUKALAC

BACK in 1918 a young man by the name of Russ Bourke was teaching engine maintenance at the Air Service Mechanics School on Kelly Field, Texas. In his day to day discussions on the theory of the internal combustion engine using the Otto Cycle, Russ was convinced that engineers were on the wrong track as the four cycles involved were very inefficient and engines being developed along this design were too heavy and employed far too many precision parts. He set about the task of developing his own ideas until he had what he thought would be a new principal of operation. On consulting his superiors Russ was met by a complete lack of interest, therefore, he decided to one day build his own experimental model engine.



Close-up of the engine reveals the extremely compact and clean design. The two top finned housings are the exhaust outlets. The magneto occupies the center position on the end of the crankshaft. The plug on lower right-hand side of the cylinder above the water hose is used to vary compression.

2 CYL. ENGINE



The Great War ended and Russ returned to civil life, and, due to reasons of an economic nature, past plans were shelved until in 1932 he was able to construct his first working model. The engine was a success and proved once and for all that the design was basically sound. In subsequent years the myriad technical problems that were encountered were overcome and an engine was prepared for tests for use in aircraft. The engine passed the USAAF preliminary test with ease and was recommended by their engineering staff. However, the Washington merry-go-round being what it was, nothing was ever done about putting the engine to actual use.

Russ then turned to marine development as the engine was a natural for boats. A 4 cylinder radial was built in 1938 and on the test stand developed 90 H.P. at 6500 RPM's, and proved capable of turning 15,000 RPM's. The engine did not prove successful on the water, however, because it was a case of too much torque for the existing drives.

From this design was evolved a 2 cylinder opposed type that was highly successful, logging over 2,000 hours on the water. The coming of Pearl Harbor stopped further development and very little was done until materials were again available at the war's end.

During the last five years Russ has brought the engine to a point where production is possible and the years of experiment and trial are at last over.

The production engine is of the opposed cylinder type, having cooperative pistons attached to a common rigid connecting rod which shuttles through a sealed oil-filled crankcase. The oil is never changed as there is no oil contamination, oil level being maintained by adding oil as it is used by the piston rings. No oil is mixed with the fuel.

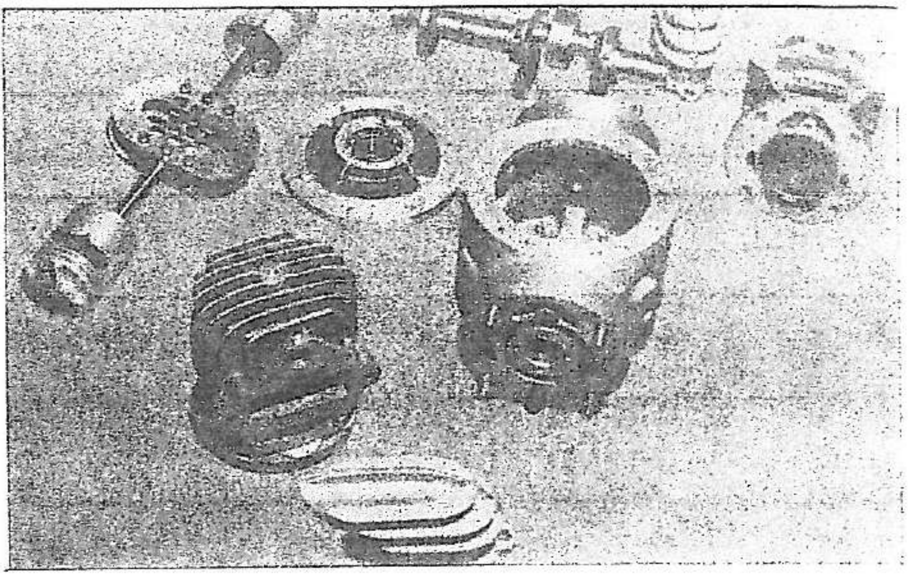
The most practical fuels for the engine are those of the lower grade, such as brown distillate. The fuel and air are fed by automotive type carburetion or by a special internal injector. (The latter was developed for racing or constant duty work.)

The engine employs no flywheel as the crankshaft is dynamically balanced at all speeds and is not connected to the connecting rods. The crankshaft is pushed around by a high speed modification of the scotch yoke. The inertia forces generated by the rod assembly are used directly to charge and compress the mixture.

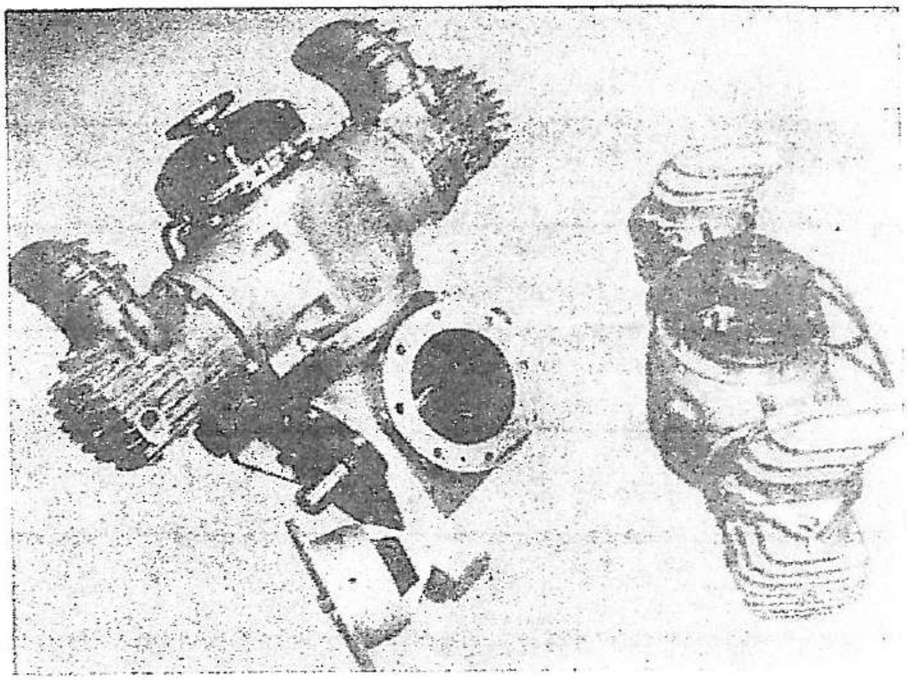
Ignition may be by battery or magneto. The spark is used as an exciter to control burning since the ignition advance is 90 BTDC. The shuttling action of the yoke allows the pistons to come to rest at the top of each stroke, thereby allowing *all* the fuel to burn and a clean, cool, odorless exhaust results. (So cool that ones fingers may be inserted into the exhaust while the engine is in operation.)

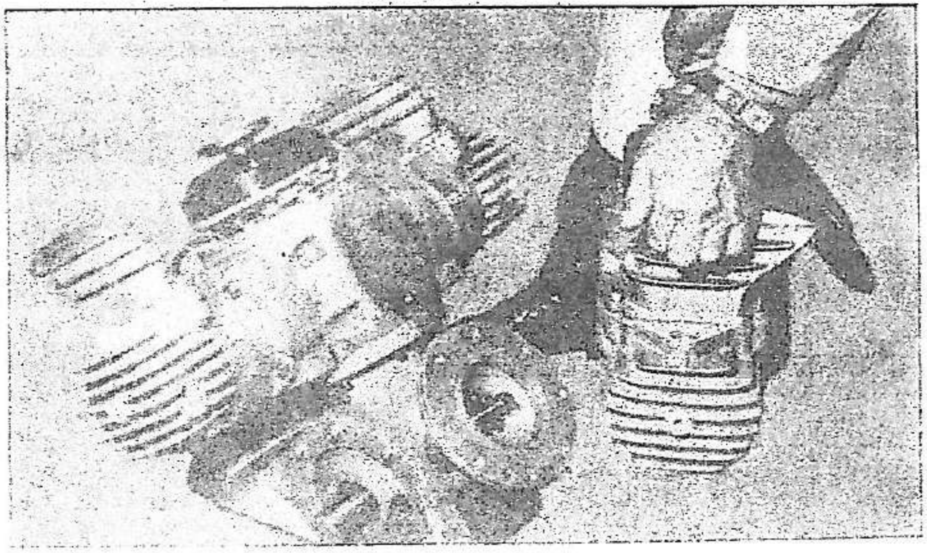
There are no mechanical noises, due to the absence of valve gear, camshaft and gears, and other conventional accessories. The absence of these particular items accounts for the light weight of 38 pounds of the 2-cylinder unit (developing 45 H.P. at 6500 RPM).

An exploded view reveals the stark simplicity of the Bourke Engine. The large casting in the center of the picture is the crankcase. Cylinders are held on by the four studs shown. Bottom left shows the exhaust outlet side of the cylinder and the outlet casting. Upper left shows the piston rod yoke assembly. The plate with the ball bearing race in the center of the photo carries the crankshaft. An identical plate on opposite side is not shown. The crankshaft shown at the top of the picture is pushed around by the yoke shown on the piston assembly. The shaft is capable of over 20,000 RPM's. The large bearing and counter weights on the crankshaft acts as a gyroscope when in operation. At top right the intake channel can be seen in one of the cylinders.



The engines may be used singly or in pairs. In this particular case the right-hand bank has been removed to disclose the pinion and shaft assembly that makes this type of mounting.





Mr. Bourke is shown mounting the right-hand bank. The engines are all interchangeable. Any unit can be used as a single or operated in pairs.

What You'll Find in Twelve '54 Cars

SCIENCE and MECHANICS

The Magazine That Shows You How

25¢
FEBRUARY

Performance Tests on 1954 Nash Rambler

Noise-Proofing Your Own Home

Fold-Up Boat Trailer You Can Build

Art Bade

Many receivers simply are not able to keep out strong, nearby signals even though they may be many megacycles away from the frequency to which the receiver is supposedly tuned. The common solution is the installation of a high-pass filter in the receiver antenna line, inside the chassis if practicable. TVI committees are experienced in determining the cause in particular cases and do so gratis. When the fault is the receiver, in many instances the manufacturer (through his service agency) will arrange for the installation of suitable remedies at nominal cost or none at all."

In the September 1953 issue of QST, the ARRL reported 292 TVI committees functioning in 281 communities. Complaints of TV interference to the FCC are referred to these TVI committees for investigation without cost. In nearly all cases where interferences and remedies are investigated in a cooperative atmosphere between amateurs and TV set owners, the interference problems are eliminated.

Racing Yellow Jacket

Enclosed are pictures of my *Yellow Jacket* which I built following your Craft Print #168 very closely. I raced 21 times this last season with the Michigan Outboard Racing Association, using a Mercury K.G4 class A, and I found this boat very good at high speed and on fast turns. With this boat I took the M.O.R.A. State Champion 1953 Class A 2nd place trophy.

5829 Dixie Hwy. **Ken Huntwork**
Saginaw, Mich.

Congratulations, Ken. As a hustler, that Yellow Jacket really has a sting to it.

Anybody Seen Bourke's Engine?

Can your readers help me to locate an engine? In 1941 I saw in Petaluma, Calif., the most amazing engine imaginable, invented by an Irishman named Bourke. I was given the opportunity to handle the controls on a 4-cylinder "H" model mounted on test stand, and to pilot a 2-cylinder outboard. The performance was so spectacular that it set my head in a whirl and to own one has been my dream.

As I recall the "H" model was two 2-cylinder 30 cubic inch power heads geared to a common driveshaft. They had battery ignition and were sure hot with a top *rmp* in excess of 10 thousand. They were so designed that one could own a six or an eight by adding more 2-cylinder units.

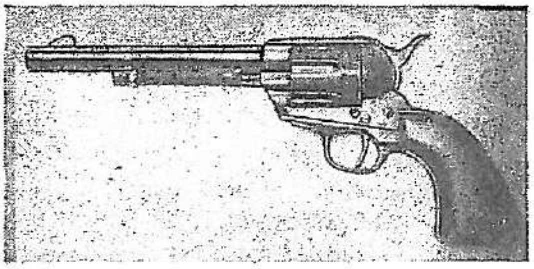
They were being readied for production, but the freeze order on all new developments came shortly after Pearl Harbor, so I assumed that is why they never hit the market. I've had many a hot argument with shipmates who claimed such an engine can't work (mono-cycle) but I know what I saw and the performance of it, and I had hoped to find the engine to vindicate myself. Does anyone know of such an engine?

U.S.S. Helena CA75 **R. F. Sullivan, IC1**
c/o FPO San Francisco, 1/c Mess
California

Stop hiding your light under a driveshaft, Bourke. Let's hear from you.

Justice to a Colt

Here's a snapshot of a wooden Colt .44 single action, which I fashioned after your Craft Print #173. The walnut grips, hammer, trigger, recoil shields and ejector tube are separate pieces, as is the cylinder. For the metallic finish, I used stove polish, rubbed when dry with powdered graphite. Hope it does your pattern justice.



2127 School St. **Henry Frahm**
Chicago 18, Ill.

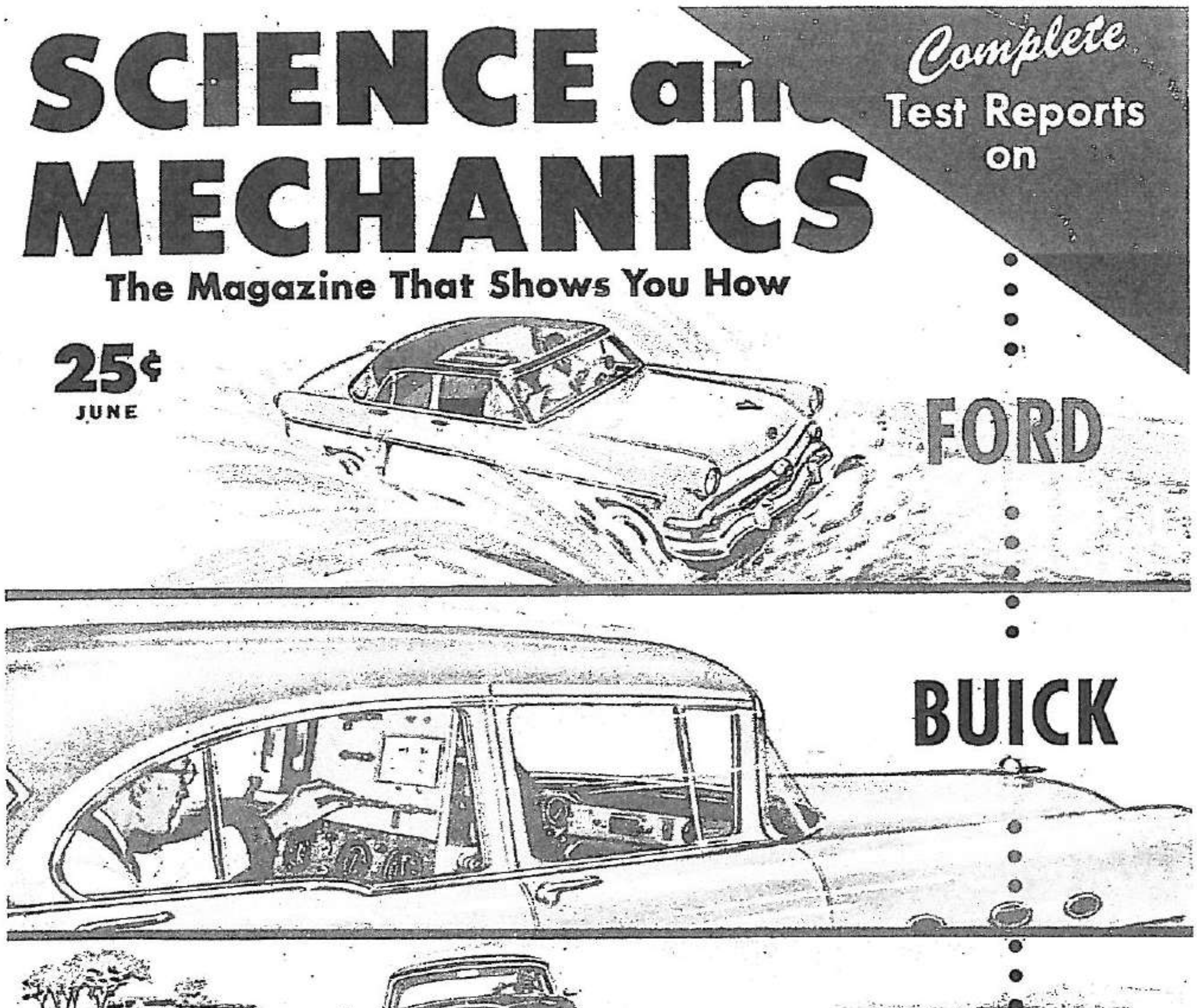
It certainly does, Henry—and then some.

Hauling Trailers

Please send your Car-Trailer Performance Chart (p. 90, Oct. '53 S&M). We note, through experience of our drive-away trucks, that the 27-ft. single axle trailer uses more fuel and takes longer on the road than a 35-ft. trailer weighing 7000 lbs., or about the same as a 40-ft. trailer weighing 7500 lbs. These larger coaches have tandem axles and 4 wheel brakes.

These drivers prefer to haul the larger models, and report that our 45-ft. model weighing 9000 lbs. pulls faster and easier than the smaller two-wheel job (27 ft. and 5000 lbs.) and that they make more money hauling it. Pickup trucks are used here of course.

The trailer you used on test is a notoriously poor puller on the road, according to these drivers, who work for the commercial haulaway companies and pull everything. There is evidently a lot of difference in body design and



SCIENCE an MECHANICS

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JUNE

Complete

Test Reports on

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PACKARD

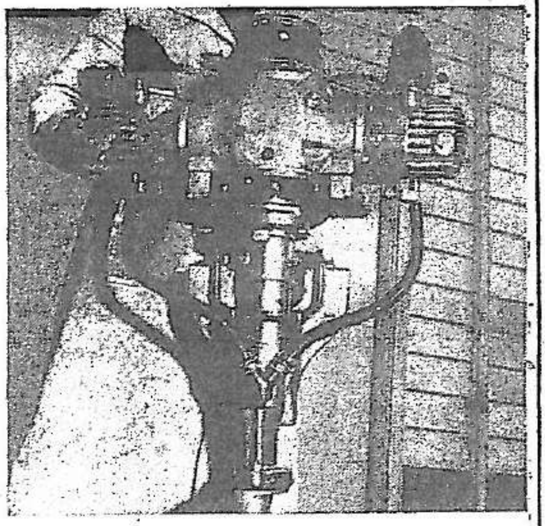
is well balanced. Where can I buy or have made concave and convex cutters of different radii? Also, where can I buy a good grade of cedar and white oak for this type boat?

Central City, Nebr. **John E. Trainor**

For the cedar and white oak, suggest you try Boat Dept., Craftsman's Wood Service, 2729 S. Mary St., Chicago, Ill. Most large hardware stores can supply standard shaper cutters or blanks you can cut to fit your needs, following directions given in Deltacraft publication #4575 (Rockwell Mfg. Co., Pittsburgh 8, Penna.)

Here's Bourke!

On page 22, Feb. '54 S&M, I find myself being chided for hiding under a driveshaft. If you ever saw or heard one of these little demons scream out from 0 to 10,000 plus *rpm's* you would realize that is the last place anyone would want to hide, for it is the weakest link in the train. They twist off like a tallow candle if one romps on the throttle with the vigor of youth, as my stock of twisted shafts will testify.



I have written Reader R. F. Sullivan and told him one of the first production models was earmarked for him. One of the largest automobile manufacturers sent a representative to acquire my patents on a royalty basis, but refused to guarantee production, as have more than a dozen other prospective producers. So I am planning on setting up a small company to produce the 30 cu. in. power head as shown in the accompanying photos. I have all the patterns, blueprints, jigs etc., for limited production, so the Hi-*Rpm* boys shall not be disappointed.

Should more *hp* be desired than the V-4, a V-T-6 can be had by coupling the two gear boxes in line. Of course if someone wanted to crack the *Blue Bird* land or *Slo-Mo-Shun* water speeds the only limit to the number of cylinders in your power plant would be your financial ability to buy and couple, because with this means of *hp* increase the top *rpm* remains the same as though it were still 30 cu. in., that is, 10,000 plus *rpm*.

One snapshot shows a Bourke 30 mounted on a Quicksilver racing lower unit (weight as shown 85 pounds) which will be tested on the river shortly. On every previous attempt the propeller shear pins sheared as fast as we could replace them and we tried every known material available. We plan this time to use the smallest propeller available. It will cut down our top speed, but if we can leave the dock using this lower unit, that will be cause for rejoicing.

This engine will idle equal to any, but I don't know of any hot iron artists who would trade Rev's for a masterpiece of low speed rhythm. Yours for higher, safer *rpm's* and engines that don't come "unglued!"

Bourke Research **Russ Bourke**
11031 S.W. Sixty-Third Ave.
Portland 19, Ore.

Thanks, Russ, for your prompt report.

Li'l Gem Was Easy

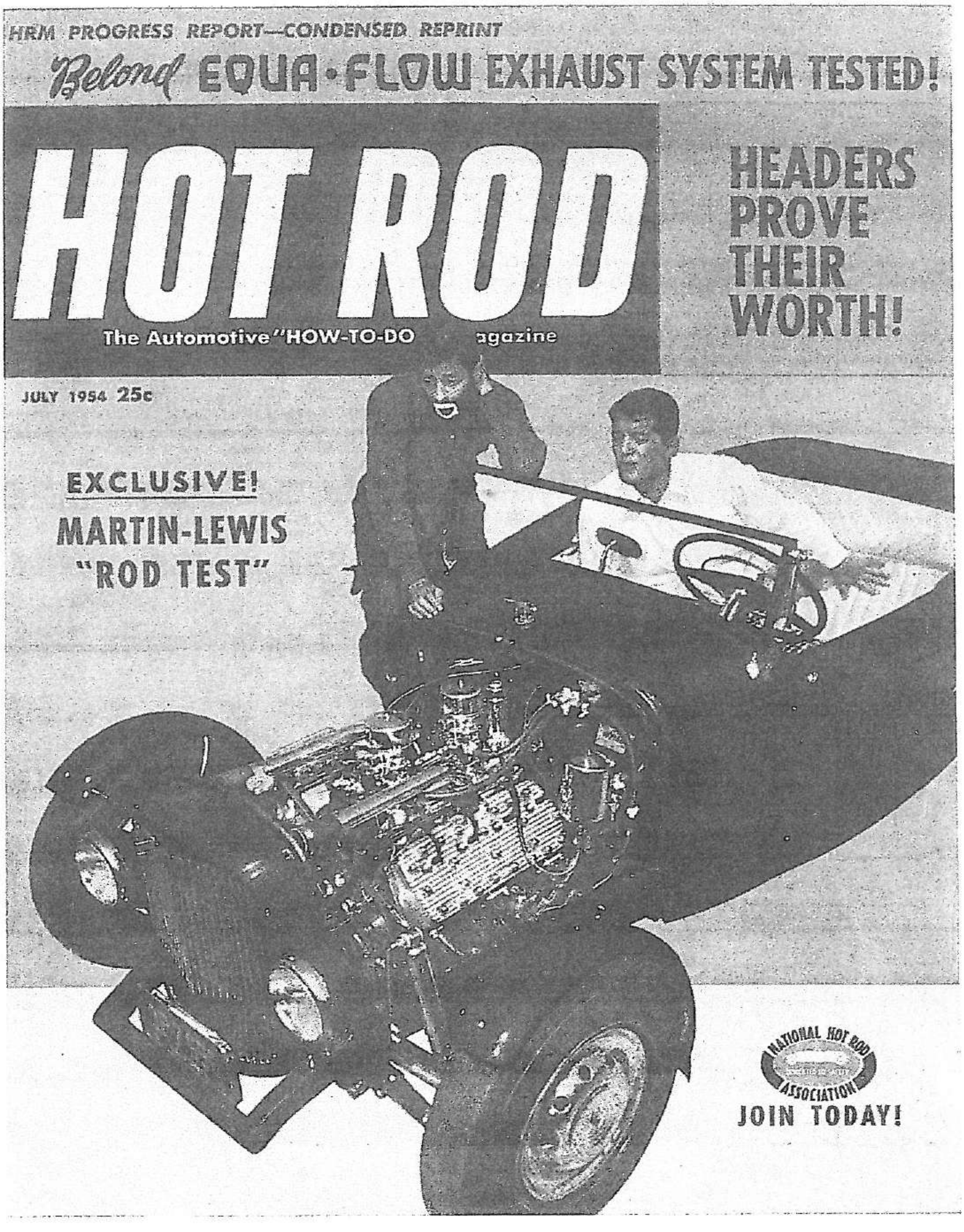
Your *Li'l Gem 4 Tube Receiver* (Feb. '54 S&M) was the best-explained article I have ever seen. Even though experienced in working with radio circuits, sometimes I find it really tough to work with complicated schematics, but that Fig. 5 in your article was really tops. Make that pictorial a little larger and a two-year-old could follow it.

122 Colonial Road **Michael Upsher**
Providence 6, R. I.

And you'll see more pictorials like that in the future, Mike.

200-Hour Buick

This model of a '53 Buick Roadmaster convertible was built to ⅛th scale from pictures and my own plans. It measures 24½ in. long, 10¼ in. wide, and has a 1 in. road clearance. The head and tail lights operate off a switch



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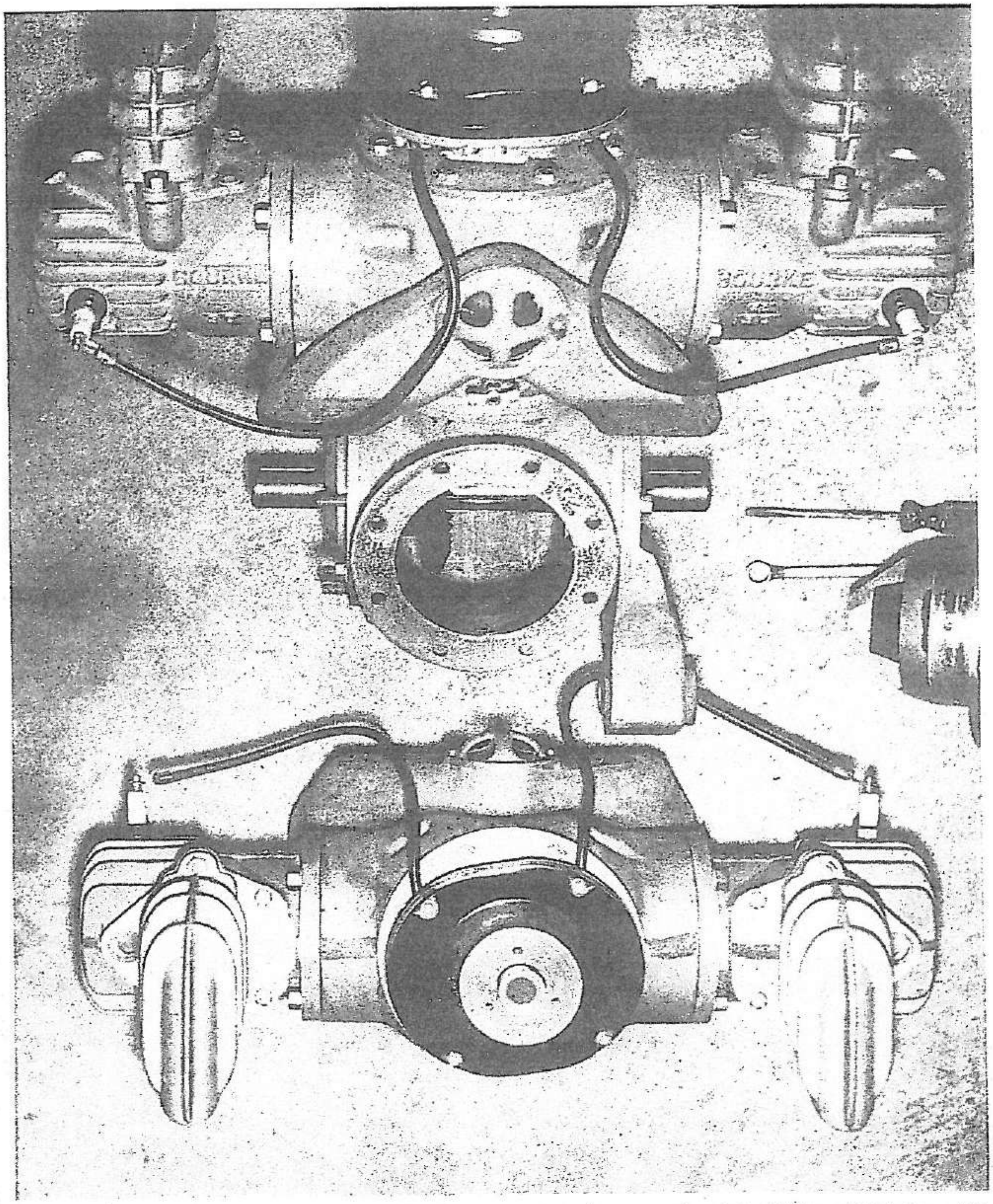


• Unit shown in the bottom of the photograph has been removed to show operation of the V-drive which is base of V-four engine. Ring gear shown on lower shaft of top unit is driven by a pinion mounted to each 30-cubic-inch engine.

The Bourke Two-Stroke

A Revolutionary Engine?

Text and Photos by George Hill

This is an era of *new* engines. We are quite sure this is true for we read all about the revolutionary new engine designs in advertisements everywhere and listen intently as radio and TV personalities explain the remarkable engineering advancements contained in our present day automobile engines. Much has been accomplished in the past few years by beefing up the lower ends, converting to overhead valves, shortening the stroke to reduce piston speed and converting to complex four-throat carburetors.

The basic design, however, has been unchanged for over 50 years. Even longer than that if we care to go way back to the late 1800's or early 1900's when our successful racing engines of today were first put on paper. Designers and engineers of that period knew how to lay out an efficient engine comparable with our best of today, but alas, they were not blessed with the metallurgical advancements used freely in our present day engine laboratories. Their designs were forced to remain on the drawing board until metals were produced that could withstand the tremendous stresses and strains developed in high output four-stroke engines.

Perhaps we are now ready for the Bourke engine, or better yet, now that we have hopped up every Detroit engine to the point of self-destruction, the Bourke engine is now ready for us. It may not be the last word in design, for all designs will be forever improved upon, but at least it is a step in the right direction.

Russell Bourke, of Portland, Oregon, sole designer of this new engine, has long sought an answer to the wasted energies and to the reduction of stresses and strains in the conventional engines. It all began back in 1918 when Bourke was teaching engine theory and maintenance in the Air Service School at Kelly Field, Texas. Endless discussions with other instructors and students soon convinced Bourke that much was left to be desired in the internal combustion engine using the Otto cycle. Heavy, inefficient and employing too many precision parts, they would one day become as extinct as the steam-powered car.

For fourteen years he studied the problems and in 1932 came up with a new engine and his first working model. This first engine was basically successful but there was room for many refinements. In 1938 Bourke built a four cylinder radial to be tested for outboard marine use. This engine literally put itself back on the shelf. It had too much torque for existing drives. A less powerful two cylinder opposed unit was then built and it proved successful after 2,000 hours of testing in a boat.

All the lost energies present in the four-stroke engine had been put to work. Like a Judo expert that makes use of his adversary's strength and momentum, Bourke had made every lost motion in the engine perform a needed operation.

The engine and its functions are simplicity exemplified, yet the engineering and development involved are by no means simple. It is of the opposed cylinder, two-stroke type. Co-operative pistons are connected to one rigid connecting rod that shuttles through an oil filled, sealed crankcase. There are only two moving parts in the engine: 1—The piston connecting rod; 2—The crankshaft. All other parts usually found in the conventional engine have been discarded.

There is no flywheel as the crankshaft is dynamically balanced for all speeds and is not connected solidly with the piston rod assembly. Operated through a streamlined, high speed version of the "Scotch-Yoke," all kinetic and inertia forces generated by the piston rod assembly are used directly for charging and compression. The forces delivered to the crank are then one-directional and permit a greater power output with almost instantaneous acceleration under load.

Before we attempt to follow the pistons through a complete crank revolution, let us take a close look at the parts involved.

THE CRANKSHAFT

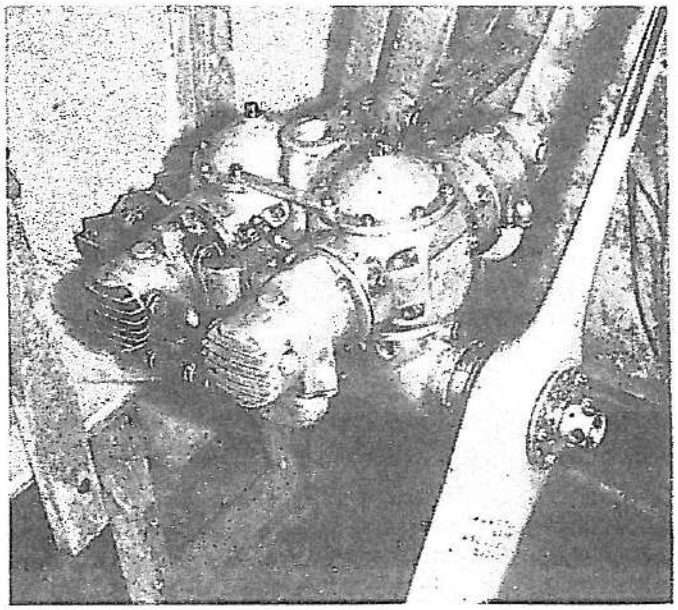
This counter-balanced unit, supported at each end in double row ball bearings, has only one crankpin and on it is mounted a three-in-one bearing. The center (hub) ring turns freely on the crankpin and serves as seat and speed reducer for the middle ring. The outer ring serves as contact point with the rod assembly and through it all energy generated by the pistons is transmitted to the crank. Free to ride up and down in the yoke, it is carried back and forth by the yoke (center of the piston rod assembly) and so develops the rotational action of the crankshaft. The crank can be turned either direction so that the engine can be run clockwise or counterclockwise at will. The direction of rotation is governed by the timing of the ignition.

PISTON ROD ASSEMBLY

The rod assembly is made up of two machined plates that form the yoke; two rod extensions, two pistons with pins that fix them into permanent position (they do not swivel or turn on the piston pin as in conventional engines), and two rings on each

(*Continued on next page*)

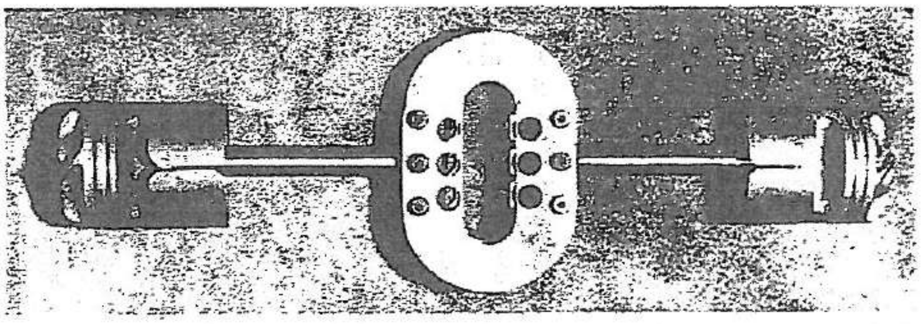
• Check that "foxey" look as Bourke muses, "Look what I have here!" Engine can be expanded in multiples of two cylinders.



• Four-cylinder opposed unit accelerates with such alarming rapidity that hub mounting bolts are sheared from 6-foot prop.

The Bourke Two-Stroke

continued



Piston-rod assembly is one of the two moving parts of engine. Bearing on crankpin slides up and down in the machined yoke. Slot in side of piston allows new charge to begin its escape into transfer jacket, thus allowing smoother fuel flow, without pulsation.

(Continued from preceding page)

piston. The two rod extensions are guided through pressure sealed bushings in the cylinder base of the crankcase.

THE CRANKCASE

The crankcase is a precision machined aluminum casting with two face plates (in which the crank bearings are contained) that is completely sealed when the engine is buttoned up. No gaskets are needed or used. No oil filter is needed and Bourke claims that the crankcase oil is good for the life of the engine. The level must be kept up, however, to compensate for any possible leakage and ring usage. As the case is sealed off from the cylinders, and consequently the products of combustion, the oil is free of contamination. Being devoid of any potential lubrication failures, the engine can be run up to top rpm under full load on a cold start. One test engine has run over 1100 hours at between 1,000 and 10,000 rpm with no sign of wear on either of the moving parts and the oil looks as good as new.

THE CYLINDERS

Cast of Alcoa 365 heat treated aluminum alloy, as are all the other aluminum castings, the two cylinder blocks contain many odd features. At first glance, the inside walls of the cylinders appear to be full of holes. These are the ports for intake and exhaust and their arrangement is one of the reasons why the engine is so successful. They replace, in effect, the operation of valves, cams and all the other breathing mechanism upon which the conventional four stroke engine is so dependent.

LUBRICATION SYSTEM

Both parts in the crankcase are bathed in oil. Oil is supplied between the two rings at the bottom of the stroke from a small hole in the cylinder wall. Oil reaches this opening via matching rifle drilled holes in both the cylinder block and the upper part of the crankcase. Pressure to drive the oil through this passage is in reality the centrifugal force of the oil as it leaves the whirling crankshaft and flies into the opening. As long as pistons and rings are well supplied with oil no more oil feeds, but as oil is lost from the rings it is replaced by fresh oil, making lubrication automatic, economical and dependable.

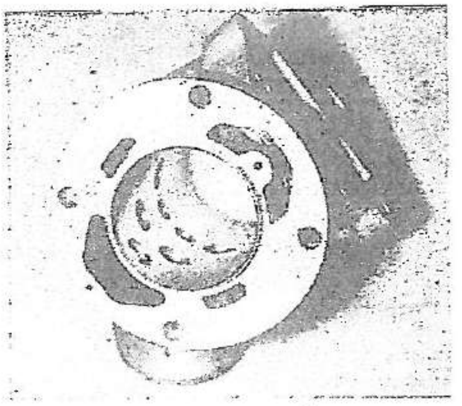
THE BOURKE CYCLE

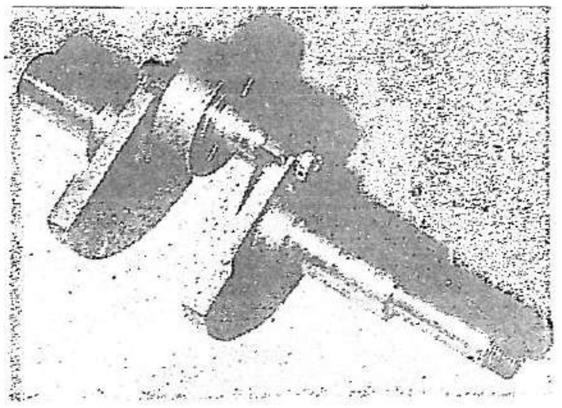
Now let's follow the piston-rod assembly through one crank revolution: As the crank bearing rolls across the yoke, the piston is stopped at the top of its stroke for a measurable amount of crank travel, approximately 45 degrees, holding the burning gases until they are consumed, no further flame, and the maximum pressure is developed. At the same time, the intake ports are opened by the piston skirt and the area between the piston and crankcase facing (approximately 30 cubic inches) has filled with air/fuel mixture. Power is generated at the top of the piston forcing it inward as soon as the crankpin reaches a point of mechanical advantage. Moving inward, it transmits all energy to the crank through the yoke and the skirt closes the intake port so that the air/fuel mixture underneath the piston is compressed against the crankcase facing surface. Piston skirts drop deep into recesses that are machined into the crankcase facing, thus allowing compression of the air/fuel charge to a pressure of 50 psi. As the piston stops at the end of its inward travel (for another 45 degrees of crank rotation), a port in the piston skirt is aligned with a port in the cylinder wall. The air/fuel mixture (now under pressure) is allowed to escape into the jacket outside the cylinder wall and enter the cylinder again through another port above the piston. A turbulating fin and the surface design angle on the piston join in directing the air/fuel mixture, in a swirling motion, to the top of the chamber. As the mixture continues its expansion, it moves down into the cylinder and forces the exhaust through the now open exhaust port in the opposite wall. At this time, the opposite piston is receiving its power impulse and is ready to start inward, closing the transfer and exhaust ports and compressing its fresh air/fuel charge as it moves. The outward motion also creates a vacuum beneath the piston to draw in the air/fuel mixture for the next cycle. About 90 degrees before top dead center, ignition occurs and compression continues. The intake port under the piston now opens and the air/fuel mixture (only air if injectors are being used) is allowed to enter under the piston. As head compression increases, the fuel mixture burns more rapidly and a force, or cushion, is built up sufficient to stop the movement of the mass (piston and rod assembly) and as the crank moves across top dead center, the burning charge is completely consumed and the pressure is released to send the mass back, so ending the second 180 degrees of crank travel.

Since the same action takes place at the other end of the mass movement and since the forces generated are equal, the moving mass can be likened to a tennis ball being batted back and forth between two players of equal strength. As the mass is not tied solidly to the crankshaft, it simply imparts its energy to it in passing. No energy is absorbed from the crankshaft to complete the cycle.

Low grade fuel has proven to be the most satisfactory in the Bourke engine. Its slow burning characteristics build a cushion and its high heat potential is released at high compression, while the piston is held at top dead center and all of the fuel mixture completely burned. Since all heat is extracted at the top of the piston travel, temperatures over 2,000 degrees and pressures over 1,000 psi are generated, the flame dies out completely, and the rapid expansion of the gases on the inward stroke cool themselves and create, in fact, a refrigeration stroke. Paper matches held in the exhaust port will not light and the gases at the port feel only warm to the hand when all adjustments are correct. Best results to date have been achieved with a mixture of three parts white gas to one part stove oil, but can be varied to suit local fuels, altitude, etc.

From the foregoing, it is obvious that this cannot be thought of wholly as a conventional reciprocating engine. The power





*• **CYLINDER, LEFT**—Showing intake ports in cylinder wall and transfer jacket. Flat machined surface on right side is for mounting aluminum exhaust stacks.*

*• **CRANKSHAFT, LEFT**—Second of the two moving parts, is a bolted-up unit that is assembled inside of the crankcase after bearing has been fixed to the yoke.*

curve is similar to that of a turbine. It has, however, the advantage of extreme economy which is not possible with a turbine. Engine speeds approaching those of turbines will be possible when a faster firing ignition system can be devised.

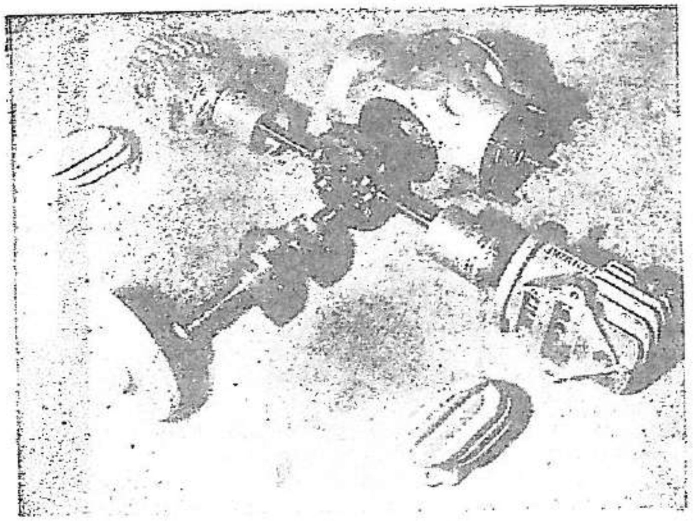
In summing up the operation of this all-new engine, we discover quite a number of outstanding features: 1—A reduction of moving parts to complete the cycle. 2—No dead stroke to absorb power. 3—Reduction of weight as no flywheel, camshaft, cam gears or valves are necessary. 4—A far greater power output for any given displacement as the engine can be operated at much higher rpm without appreciable power fall-off. Naturally, valve float is non-existent in an engine that has no valves. 5—There is absence of both shearing stresses and cylinder wear as the pistons operate in a straight line and never come into contact with the walls. Rings, serving as a compression seal only, are made of low tension material and create only a minimum of friction and wear on the cylinder walls. 6—The engine has no mechanical sounds, can be operated in any position desired, can be run clockwise or counterclockwise at will, all parts are interchangeable, and there is no need of specialized tools or machinery to manufacture it. 7—It operates on low quality fuel with practically no exhaust fumes, no flame and very little heat.

These facts are all very interesting but the thing that will be of primary interest to hot rodders everywhere is the fact that these 30 cubic inch, two-cylinder opposed units can be bolted together in clusters to achieve an engine of almost any displacement desired. You will note in the photographs where a V4 and an opposed four have been operated successfully and also that a six can be formed by adding one unit to the V4. These units can be bolted together, however, in the same manner as the opposed four, with an end result of a 4, 6, 8, 10 or even 12 cylinder engine. The total weight of each 30 cubic inch unit is only 38 lbs. The V4, with its combined drive unit, weighs only 84 lbs.

The next question on every hot rodder's lips is, "How many horses will it deliver?" The final answer to this one is an unknown factor. The horsepower is limited only by the number of rpm obtainable and the only mechanical part of the engine that limits rpm is the ignition system. The K2A-205 Bendix Scintilla magneto, used on "Mecury" outboard engines and guaranteed to 4200 rpm only, has been reworked by Bourke to operate at 10,000 rpm where the 30 cubic inch unit is developing about 76 brake horsepower. Bourke's own special-built battery ignition will turn up to 15,000 rpm, or an estimated 114 brake horsepower. Experiments have been made using glow plugs and with them the engine is reported to have turned well in excess of 20,000 rpm.

Glow plugs, however, will hardly be acceptable in closed competition for the engine cannot be shut off at will. There are possibilities of adapting an efficient fuel valve, built into the engine near the injector nozzles, that could shut the engine down in short time. Perhaps a compression release, similar to diesel installations, would work even better.

(Continued on page 52)



• Exploded view of the Bourke engine shows the two moving parts, cylinder blocks, crankcase, crankcase facing and both exhaust stacks. This is one of the 30-cubic-inch units, weighs 38 lbs.

• Bourke prepares to add a two-cylinder unit to a V-four to make a six-cylinder, 90-cubic-inch engine. Utilizing an opposed drive, however, any number of even cylinders can be formed.

THE BOURKE TWO-STROKE

(*Continued from page 21*)

ACCELERATION CHARACTERISTICS

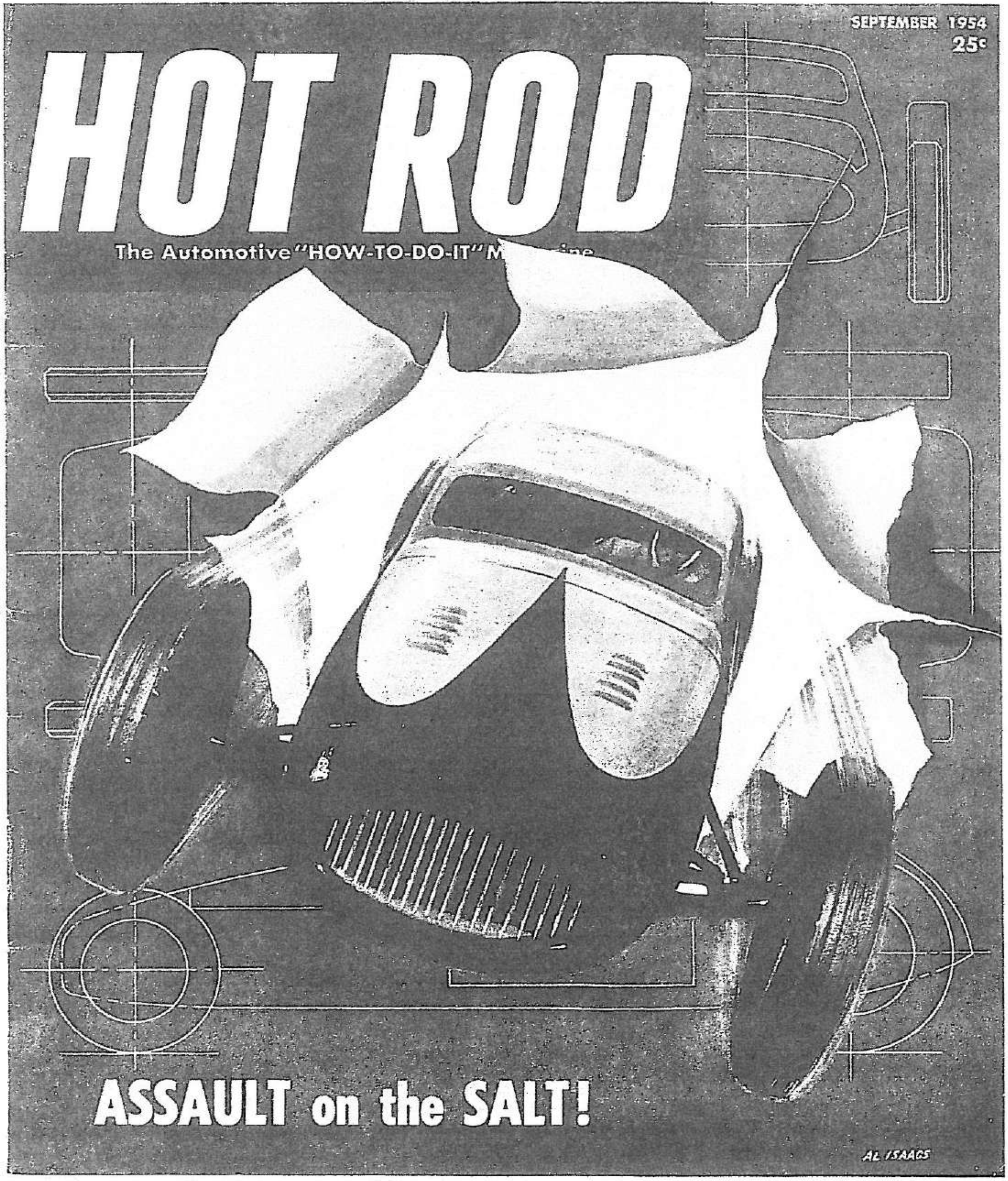
This engine will idle at very low rpm and yet is reported to follow the throttle lever, without any hesitation and as fast as the lever can be thrown, up to its top rpm—*under full load*. Bourke states that he can shear the pin from the propshaft of a heavy-duty Evinrude lower unit at will, while using only one 30-cubic-inch unit. The opposed four, mounted to a six foot airplane prop, is said to have sheared the heads from the hub mounting bolts when the throttle was not feathered to top rpm.

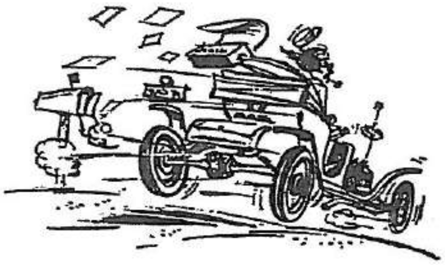
Recent attempts at running the V4 in a midget race car chassis only proved again that the engine needs a heavy power brake before man can control the almost instantaneous acceleration. This was no great disappointment to Bourke, for he was not primarily interested in race cars, or boats, or in any other type of speed competition. His sole aim was to design and build an economical engine that would take advantage of the power losses in conventional engines. Practical economy was the designer's prime requisite. It can be manufactured cheaply, can be run for exceptionally long periods of time without need of being torn down (parts in one unit after more than 2,000 logged hours are still as good as new—as is the oil that was used during the entire running time) and it is economical to operate. The twin (30 cubic inch) will run hour after hour, day after day, at 6500 rpm while using only one gallon of cheap fuel per hour. Consumption approaching two gallons an hour indicates too rich a mixture, and rpm and power will be lost. Comparable thrifty consumption figures exist for operating either of the four cylinder combinations.

During his 35 years of research into the development of the Bourke Cycle, Russell Bourke has discovered answers for many of the problems that only now have begun to plague the engine designers in our automobile factories. How can we minimize destructive friction in the combustion engine? Is it possible to build a four stroke engine without using poppet valves? How can our present-day engines be made to turn extremely high rpm by adding one small part to the stock valve assembly while using the mildest of springs?

Russ has answers for these problems and many others too numerous to mention here. One day, all his proven theories will be put to work, but probably not until our present day engineers finally realize they are facing the blank wall Bourke foresaw 35 years ago. Hot rodders will not have to wait too long before seeing the Bourke engine in action. Some of these units will be present at the 1954 Bonneville Nationals, and I feel sure that from that time on the name of Bourke and the "Bourke Cycle" will demand respect wherever hot rodders or engine designers meet.

Hot Rodding Your Hydra-Matic!





"Idle Chatter"

LOOK WHAT WE STARTED!

Sirs:

Some of the points brought out on the Bourke two-stroke engine in the July issue are incorrect. For instance, it was stated that all inertia forces developed by piston, rod and crank motion were put to work in some new way to aid cylinder filling and compression. Actually, the Bourke layout is quite similar to a conventional engine in regard to the inertia forces. Technically, it will behave as if it had a connecting rod of *infinite* length. With equal stroke, RPM, and reciprocating weight the maximum inertia force over the cycle will be about ⅕ less than on a conventional engine . . . that is, say at 5000 rpm, 3½ inch stroke, and with 3 lbs. reciprocating weight, the reciprocating inertia force at top center would be 4660 lbs. on a conventional engine and 3720 on the Bourke. This force could hardly be said to aid compression or charging, since it would *oppose* crank rotation as soon as the crank passed top center. It was further stated that the pistons *stopped* for 45° of crank rotation at top and bottom of their stroke; if the yoke is not permitted to move axially relative to the crankpin, as implied in the text, this would not be possible. (That is, unless the crankpin can move in *two* dimensions in the yoke, the pistons would have to follow a motion as if they had conventional con rods of infinite length.) For example, with a 3½ inch stroke a conventional piston would move through a distance of .166 inch while the crank is rotating 45° over top center; the Bourke would move .135 inch. At bottom center the Bourke would be the same, but the conventional would move only .100 inch. It also implied there was no piston side thrust on the cylinder walls because there is no angularity of the con rods. If this were true the engine would develop no torque, since piston side thrust is a necessary *reaction* to the developed torque. Actually piston side thrust on the Bourke would be equivalent to a conventional with a long rod, maybe 10 or 12 inches center-to-center. As far as I can see, the only advantage of the Bourke design is that the dynamic *balance* is a little better than a conventional opposed-piston design, which should permit somewhat higher RPM . . . but certainly not 10,000-20,000 rpm and 2-3 bhp per cu. in. from unblown two-strokes as they speak of!!!

Roger Huntington, S.A.E.
Lansing, Michigan

The highly controversial Bourke engine has flooded this office with letters, pro and con. A few are contained in this column. Fantastic though some of the claims on the engine's behalf may sound, we hardly feel within our rights to vindicate or renounce a product that has yet to receive its final test. For those mental giants who wish to pin ye old editor to the mat, we call attention to the question mark at the end of the Bourke story title. We, like you, would like a little more "proof of the pudding." Ready on your end, Mr. Bourke?—ED.

AN OLD FRIEND RUSHES IN

Sirs:

I just wanted to drop you a few lines to let you know that I thought your article by George Hill on the Bourke engine was something out of this world. For the length of the article you have about covered it all but it would take your whole magazine to really tell the Bourke story. But from all reports, the Bourke engine will be telling its own story in the next few months. As one who has seen the Bourke engine perform I would say that the article was pretty conservative.

I worked for Mr. Bourke at Mare Island Navy Yard during World War II and it was there that I learned of his mechanical genius, or should I say learned from it. For what I learned from Russ would fill a book in itself.

R. N. Sullivan
San Diego 36, Calif.

BARNES IS BURNED!

Sirs:

After some consideration I find it impossible to permit the report on the Bourke engine (July '54 HOT ROD) to pass without comment. If it were not that I am fairly familiar with two-stroke engines both in principle and practice the article content would have only been misleading. As it is, I can state plainly that the engine as well as the article is confused.

The claims made as to power output and fuel consumption are thermodynamically preposterous and excepting that these are not authenticated in any way they could be called deliberate misrepresentations of fact. The engine is an interesting mechanism, not because it is a technical accomplishment of note, but because it illustrates a queer combination of principle and practice proving it is possible to do some things even though so doing is of no value. Tying a crankshaft to a free piston is a new idea to me, that is, while still leaving the piston assembly

(*Continued on page 8*)

IDLE CHATTER

(*Continued from page 6*)

free. It is amazing that the writer of the article failed to evince any curiosity about the oil filled crankcase, it is amazing that the editor of a magazine interested in engines of high output let such a feature pass without comment. If anyone thinks that such an arrangement is friction free, let him play around with a stick in a bucket of oil and then attempt to visualize how much drag there would be at 10,000 RPM. Any mechanical quietness the engine has is due to this very inefficient feature; with a more normal lubrication arrangement the engine would be reminiscent of a blacksmith on a busman's holiday.

There is a fairly large clearance between the crankpin roller and the working faces of the cross-head, the effect of a loose connecting rod bearing is well known, it is probably a little worse in a slide crank arrangement than in the more common variety. This is a slide crank in spite of the crankpin roller, it happens to be a wedge film bearing, a type that has attained some note in thrust bearings for unidirectional loads on big jobs, the Kingsbury is one well known kind. Because this is not unidirectional, the problem of establishing a new oil wedge on reversal exists, only submergence could begin to assure enough oil in the right place and even then it is probably not instantaneously formed, the roller does get a change to roll. Since the roller must reverse its rotational direction four times per crankshaft revolution it must accelerate from a standstill to whatever maximum rotation it achieves four times a revolution. It spends most of its time skidding, completely unable to make up its mind which way it wants to go, only the wedge film between the roller and the cross head face permits the bearing to live. Meanwhile, the cross head acts as a dashpot plunger reciprocating through the oil filled case. Admittedly it is one of the sloppier shock absorber piston fits but it is still a dashpot damper and whether this is necessary or not is a superficial question so long as it is inevitable. It cannot be construed as especially efficient.

The implication that the particular piston-crank arrangement eliminates piston friction would be delightful news in some steam engine circles if it were true. But piston friction is a very adequate figure even without side thrust and incidentally in this engine there is side thrust on the piston-rod gland bearings. Piston friction is very largely ring friction and ring friction is a direct function of combustion gas pressures in the ring grooves behind the ring. Ring tension is primarily a matter of preventing ring flutter and consequent collapse and excepting worn bore replacement rings is not liable to make much difference to frictional losses. The piston itself, if it fits the bore at all, is not friction free; two-strokes often give remarkably low bore wear figures so this is not an especial feature of the Bourke engine.

Precompression of the fresh charge to 50 lbs. per square inch (this figure is suspect) is an expensive contribution to the functioning of the engine. Precompression is never desirable, in the two-stroke it is usually unavoidable but it always should be the lowest pressure compatible with adequate charging. The inevitable result of compression is heat; heat in the charge prior to combustion is inefficiency; inefficiency is neither power output nor economy. If 50 lbs. pressure is required for charging, it is a high price to pay for the high rate of revolution. The use of low octane fuel suggests that the charging isn't very good; neither TDC dwell point nor two-stroke characteristics will obviate the usual internal combustion engine limitations and if anti-knock performance is attained with any admixture of stove oil it means the charging is lousy.

The ability to shear pins is not necessarily a practical demonstration of ability to accelerate, it may be merely evidence that the engine is too coarse in characteristics to be practical. In any case, two-strokes are often tremendous accelerative performers, sometimes far better than the BHP would lead one to expect; it seems that in this case an engine vice is being advertised as a virtue.

One gallon per hour fuel consumption will not produce the shadow of 78 BHP regardless of RPM, regardless of anything mentioned in the article. 78 BHP hour @ 2 GPH consumption is sufficiently fantastic to send every diesel expert in the world into hysterical delirium if the least proof were attached to it. At one gallon per hour the engine might develop 15 BHP and this is not very noteworthy for a 1½ liter engine. Two-strokes developing 1 BHP per cubic inch are not especially rare but any claims to extreme economy at such outputs are rare.

There are a great many other points, which could be discussed; it isn't necessary to go any farther; there is nothing apparent which will weight in favor of this curious engine; it is not a practical contribution and somebody should apologize and explain.

George Barnes, Jr.
Livonia, Michigan

You've already done a powerful lot of explaining. Let's give Bourke his turn at bat.—ED.

WE'LL BUY IT

Sirs:

It has been a great pleasure to see in Hot Rod a writeup on the Bourke two-stroke engine; we wish to congratulate you upon any educational program in regard to 2 cycle engines which should revolutionize auto races due to their superior

HOT ROD

The Automotive "HOW-TO-DO-IT" Magazine

DRAGS!

COAST
TO
COAST

OCTOBER 1954
25c

Dick Kraft's
Roadster

See Page 14