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The OUTBOARD RACERS MANUAL

A COMPLETE MANUAL COVERING THE WHATS WHYS AND HOWS OF RACING OUTBOARDS

by

W. R. CARPENTER

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PREFACE

Racing, whether it be motorcycle, automobile, or motor-boat, is a disease that is contagious and almost incurable. Rarely does a person that has been infected ever recover completely. Sometimes an individual can be exposed without being fatally infected, but once the infection has set in the victim is doomed. Doomed to a life of screaming motors, long hours of hard work, study, and research. This book was written for those who have already been bitten by the outboard racing "bug". Even so, it is possible that one who is not interested in racing, but who merely wants to increase the speed and performance of his boat for other reasons, can benefit by this text.

The engines discussed in this writing are those recognized by the American Power Boat Association as racing motors of classes M, A, B, C, and F. Much of the information that is meant for these motors is also applicable to other motors. However, the reader must have a working knowledge of engines in general to be able to understand the text and interpret it. Also, if it is at all possible, the reader should have the parts, assemblies, or other elements of an engine at his finger tips so they may be referred to as they are discussed.

If a winning boat had a red fuel tank it would not be unusual to find at least a dozen more red fuel tanks at the next regatta. This is a bit "far-fetched", but the fact is that most drivers and owners are just plain "copy cats".

This shows that outboard drivers use every possible means to increase performance, however remote the method, but it also shows that many of the practices that are in use, may in reality be without reason or are based upon very thin logic. Before attempting a modification be sure of your reasoning. If you see some change or some "gadget" on someone else's outfit be sure you understand why it was done or why it was used. If the reasoning isn't sound don't waste your time on it, but put your efforts on some other phase that will pay off. Remember that you'll never be on top just copying someone else. You have to be one step ahead of the others.

As is true with any subject concerned with active competition like this writing, it will be found that as this book is being printed, new discoveries and different practices will be evolved. The copy for this writing was compiled in 1949. We sincerely hope that one of our readers will make this book obsolete by using it as a jumping off point for further research. It is to this end and with this thought in mind that this book was written.

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rest of the carburetor, and to the bowl. At this point a calibrated hole is drilled and an adjustment is provided somewhere in the channel to meter the fuel. At another point a hole is drilled to the atmosphere to provide air. When the throttle is closed, a very high vacuum exists in the induction system because air is prevented from entering. When the throttle is cracked (opened a very little bit), a very high velocity is produced at this point and consequently a reduction of pressure. This draws in the mixture from the idling system and the engine operates on this mixture. When the throttle opens further, the velocity is reduced, and the pressure increases, and suction ceases to a point where the idle system can no longer operate. Figure No. 6.

15. The Venturi: The venturi is probably the heart of the carburetor and probably the most misunderstood and abused part. Fortunately most venturis are cast as an integral part of the carburetor body; even so they are often mutilated by amateur mechanics and sometimes even by those who should know better. It seems that the first thing the amateur "soup" artist does is either to increases the jet size or the venturi diameter. Usually needle valve adjustment will compensate for the jet change; but for the venturi, no. The unfortunate fact is he probably will never know what he has done, as the effect probably wouldn't be noticeable in top speed, and acceleration, which is affected, is rarely measured. The proper size of a venturi is the smallest size that will pull full power. As we discussed in the first part of the chapter, the process of pulling the fuel over the top of the discharge nozzle was accomplished by use of Bernoulli's principle. This principle involves the difference in velocities and pressures. If the venturi is so large that these differences are ineffective, other methods to get the fuel over the top of the nozzle must be used. The usual method is to raise the float level to a point where the fuel almost flows over, and naturally because of the small difference in pressure, the well remains full of fuel and becomes ineffective. This may not occur at full throttle, but as velocities are almost proportional to the throttle opening and motor speed, a partially closed throttle may lower the velocity at the venturi to a point where the carburetor may not function at all; then we would say it had a flat spot.

Attempting to eliminate these spots by enriching the mixture usually leads to other conditions, as additional fuel will not mix properly with the incoming air, and distribution to the different cylinders will be bad. Sometimes this condition is so bad as to cause raw fuel to enter the cylinder and foul out spark plugs.

In either the lean or rich case acceleration is affected because only a properly mixed air to fuel mixture will give maximum torque which dictates acceleration. Differences of as small as 1/32 DIA can be detected on a dynometer with a small carburetor.

Venturi shapes and designs are numerous, however, experience and wind tunnel research has taught us that the exit angle must not exceed 7° for best results and that the discharge nozzle should be placed at the minimum throat diameter, as this is where velocities are highest. Design of the inlet end except that it be smooth and clean is not of too much importance. Figure 7.

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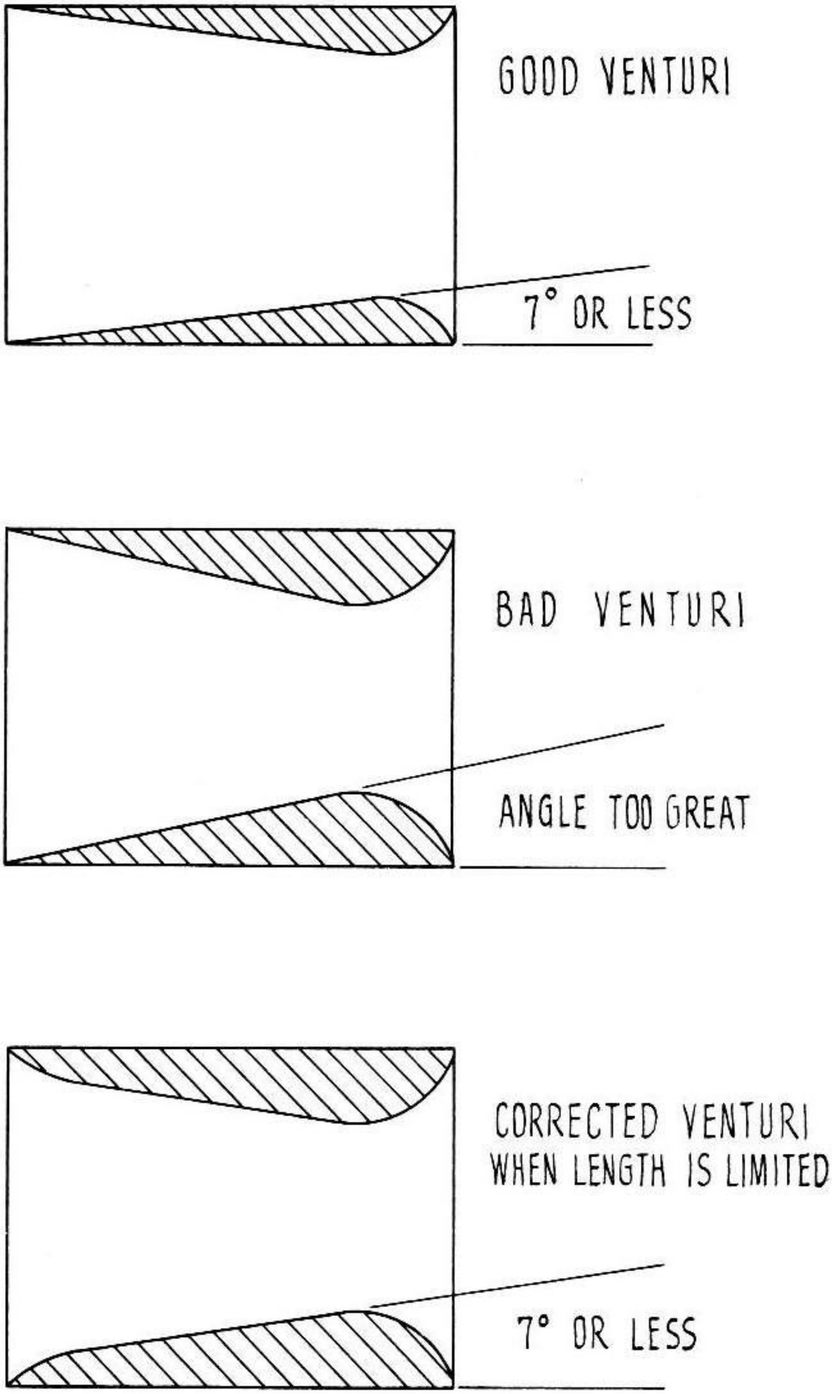

FIG. 7

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16. Conclusion: It might seem that the subject of power loss has been discussed more than ways and means of gaining power. The truth of the matter is that there just isn't any way of getting more energy or power from a quantity of fuel than it possesses; so except for the subject of volumetric efficiency the ways of increasing the output of an engine are merely to attempt to use all the energy that is inherent in the fuel charge. The over-all efficiency of the engine's processes at their best rarely goes over twenty-five to thirty per cent; by far most of the energy that is lost is in the form of heat energy and even the energy that is absorbed by friction is converted to heat. It is apparent, then, that there is a long way to go before we can use all of this energy. This is a long and complicated subject and much too deep and lengthy to discuss in detail in this publication. The scientific name for this subject is "Thermodynamics".

There are several good books on this subject, and the person who expects to really acquaint himself with the possibilities of the output of the internal combustion engine should have a basis of these facts.

Most mechanics and racing enthusiasts spend their efforts along the line of trying to increase volumetric efficiency. This subject involves cleaning and polishing out ports, carburetor calibration, and rotary valve timing. In the case of the Otto cycle engine it involves experiments with camshafts, manifolds, and valve sizes, etc. This subject is more easily understood, and therefore it is generally easier to realize a gain along these lines. It must be understood that one-hundred per cent volumetric efficiency can be obtained only by use of a supercharger, and without its use it is impossible to **double** the horsepower of an already high output engine from a slight increase of volumetric efficiency alone. Most manufacturers are not satisfied to put an engine on the market that is not running at least sixty per cent volumetric efficiency; so if one was able to raise this to eighty per cent, it can be seen that he wouldn't double the horsepower or anything like it; however, even the smallest gain is worthwhile.

The very fact that souped up motors do put out more power than stock motors is due mainly to one important fact, and that is that they produce their power peak at higher speeds. The formula for horsepower is 1 H.P.=33,000 Ft. pounds a minute. The torque or the number of foot pounds being the same, the horsepower is proportional to the speed or RPM. In actual conditions the torque falls off after a certain point, but horsepower is gained as long as RPM is increased faster than the torque falls; when we reach a point where torque decreases faster than the RPM increases, we have gone over the power peak, and from now on an increase in RPM will result in a decrease of horsepower. This fact is almost entirely a function of the engine's volumetric efficiency and friction, and this is the reason that high speed engines generally have larger induction systems and carburetors than other engines of the same size. Notice the example power curve, figure 8. If this engine could be favorably affected by an increase in compression ratio, it would seem that the whole curve should be moved upward. This isn't exactly the case, however, for an increase of, say five per cent, isn't nearly so noticeable near the bottom of the curve as at the top, and also it is impossible to take advantage of a big boost in compression ratio at low speeds, as detonation is much more prevalent at lower speeds than at high speeds.

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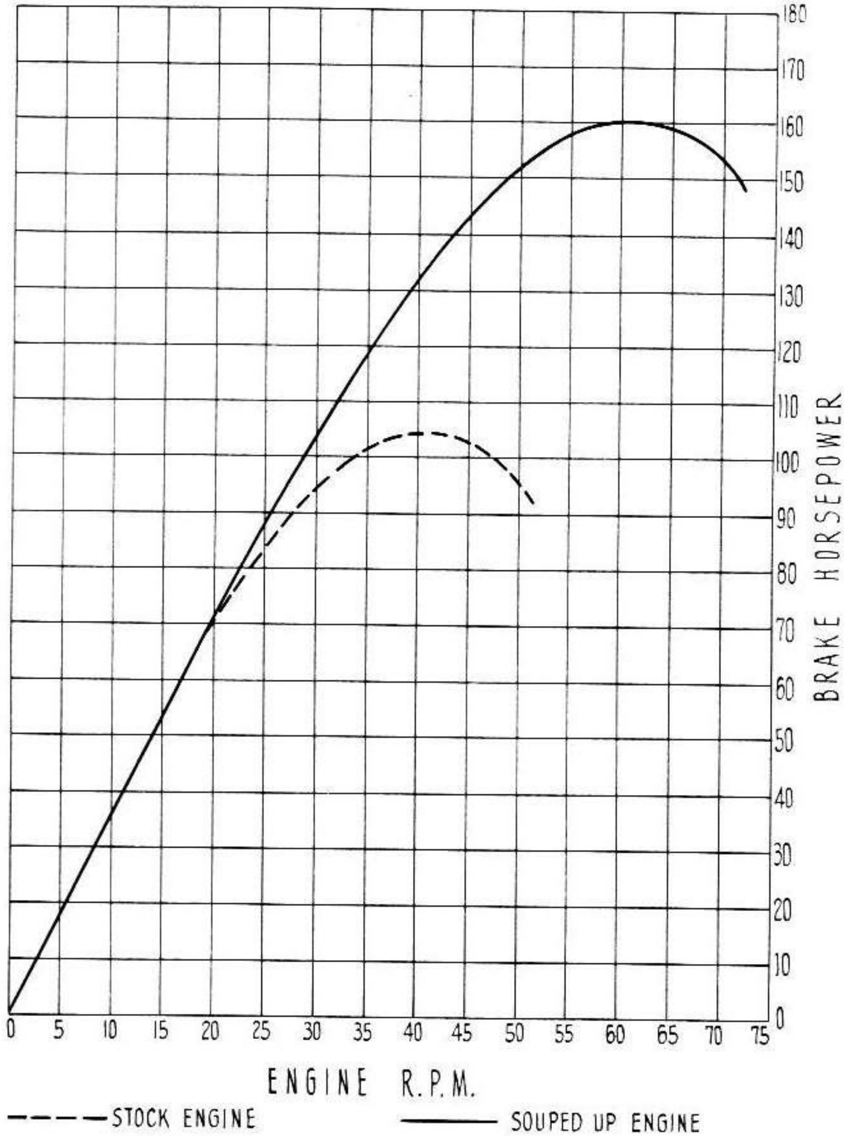

FIG. 8

AUTHOR'S NOTE:—

Many of the example power curves, indicator diagrams, etc., are purposely exaggerated for ease of reading. For this reason they should be used only as typical cases and for example only.

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SECTION II

THE RACING ENGINE

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17. Outboard Racing Engines: In the previous sections we discussed the two-stroke engine in the theoretical sense. This was done to enable the mechanic to better understand the purpose of the practical application of the "Souping Up" process. It was by no means meant to be a complete treatise on the two-cycle engine design, as such a wiring would fill several volumes of this size. It was, however, intended to bring forth the general plan of operation that many users of this type of engine do not understand.

Many times we see references to racing motors as a Draper motor, Neal motor, Vincent motor, etc. This description of a motor is misleading, as it does not refer to the manufacturer of the motor or even to its owner. It refers to the company or individual who rebuilt the engine, and in the text that follows we are going to try to explain just what these magicians do.

We must expect that the reader is familiar with the various parts of an engine and is acquainted with the correct nomenclature of the various assemblies and elements.

It must be understood that we are not revealing any corporation, firm, or individual's trade secrets as, to our knowledge, none exist. The reason that there are organizations that do the work we are going to describe is that they are master craftsmen at their work and are well equipped from all angles to take care of it.

It is false economy to attempt any of the procedures that follow if you do not possess the necessary skill, if you do not have the necessary equipment, or if you do not understand exactly what is necessary. Many good parts and assemblies have been ruined because some one tried to save a few pennies. And last, but not least, with modern competition the best is none too good.

18. The Flywheel Protractor: When referring to timing events, it is very desirable to use a unit of measurement that is common to all engines. This unit is the flywheel degree. A flywheel contains three hundred sixty degrees regardless of its diameter, and everytime it rotates one revolution, an arbitrary point on this wheel will pass through all the various events and processes that are involved in our type of engine.

The circumference of the flywheel itself can be laid out in degrees, or the top marked off in these units, but the easiest method is to use a flywheel protractor. Construction of such an instrument is not difficult and it can be used over and over again.

To make one, merely lay out a circle the same size as the outer diameter of the flywheel, on a sheet of stiff cardboard. Now very carefully divide this up into three hundred sixty degrees and connect each point to the center. Making the markings at each ten degrees heavier than the rest will make reading easier. Dividing the circumference into degrees can be done with a compass by stepping off the radius six times, bisecting this distance and then bisecting it again until one or two degree intervals are obtained. If one is careful, a small protractor such as is used in high school math classes can be used.

When this is finished, cut a hole in the center the same size as the flywheel cover plate pilot and install it on the flywheel, using the cover as a clamp. Figure 9. When working with the ignition system, it is sometimes necessary to leave the cover off; when this is done, Scotch tape can be used to keep it in place.

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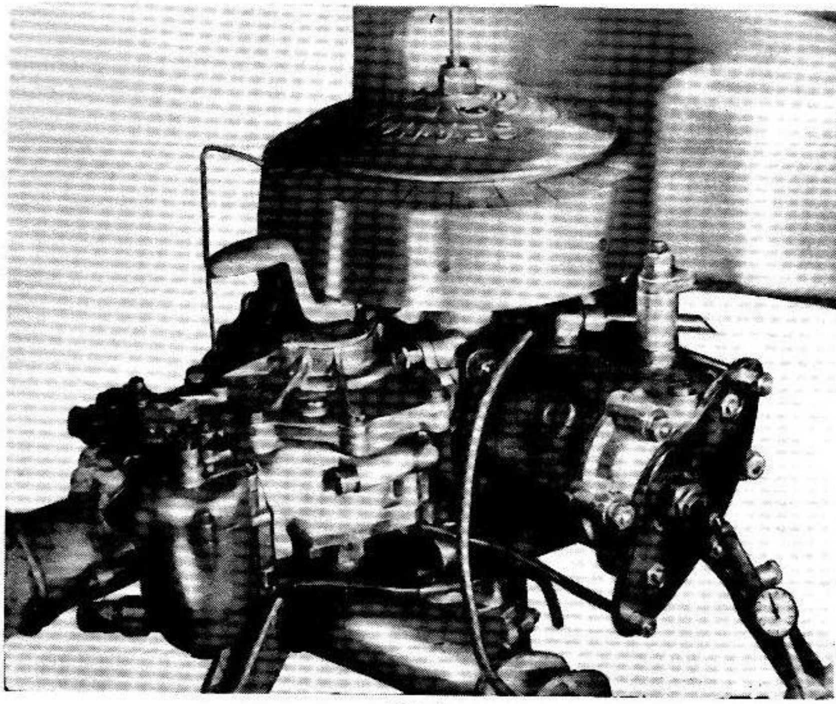

FIG. 9

In conjunction with the protractor we must have a pointer. This can be made of a piece of coat hanger wire. Flatten and point one end. After attaching the other end to some convenient stud or bolt, bend it until the sharpened end just clears the marks.

19. Top Dead Center: The pointer is set at TDC or 0° to start measurements. This can be determined with a dial indicator on the piston head or with the use of a sight type indicator. This consists of an old spark plug that has the porcelain removed and a six-inch length of one-fourth inch glass tubing installed in its place. To use this you fill the cylinder with oil when the piston is not quite at TDC. After the indicator is installed, the crank is rotated slowly, and the oil will rise in the tube. When it has reached the top of its travel, the cylinder is at TDC.

Because of the short stroke and great bearing clearance, the outboard engine is not very sensitive when determining TDC. Generally it is necessary to average up the distance when the maximum indicator reading is first observed and when it starts to drop.

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THE CYLINDER

20. The Cylinder: The cylinder of the outbard engine might be called the main part, for if the cylinder is not good, nothing can be done to make the engine "fast" even though the rest of the engine is in excellent condition. A good cylinder is one that is round, smooth, and straight, and remains this way when the engine is running. Also it must have a good porting arrangement and have the ports in the right places. Most drivers prefer to rework a used cylinder. If you have a new set, be sure that it has undergone a normalizing or aging process.

The first step in preparation of a racing cylinder is a complete inspection of the raw cylinder (barrel). Inspect it all over for minute flaws and cracks, and if the cylinder has been used in a salt water district, make particularly sure that the water jacket is in good shape and that it is not plugged up or corroded out. Generally a little rust is present, so don't be too concerned with this. Check the location of the cylinder bore in relation to the water jacket. If it is very much eccentric don't go any further. A cylinder with thick and thin walls is very unpredictable. Usually it doesn't stay round when running. If the cylinder passes all these tests, the bore should be checked for squareness with the base contact surface. If it checks within about .020, the cylinder is alright to start work on. The first actual work that should be done, is on the ports. There is a good reason for this, for if a gouge is made on the cylinder wall, while working on the ports, it can generally be removed when machining out the bore.

At this point we have use for our flywheel protractor. Assemble the engine loosely and without gaskets. Select a scrap piston that fits loosely in the bore and cut the deflector head off at the indexing edge. Figure No. 10. Be careful that no metal is removed from the indexing

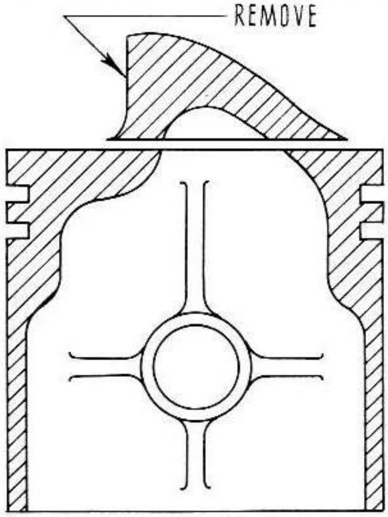

FIG. 10

edges. When this is completed, install it on a connecting rod and the whole assembly on the crank shaft. Paint the inside of the cylinder bore with the layout dope and assemble on the crankcase. Find TDC and set the protractor at 0°. Now turn the flywheel very slowly until the index-

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ing edge of the timing piston starts to open the exhaust ports. If the ports are irregular, use the one that opens first. Note the exhaust event and continue to turn until the intake ports start to open. There should be a difference of from 10° to 12° between these two events. If there isn't, start at the intake port and rotate on the up stroke until there is a difference of 11°; then with sharp stylus scribe a line on the exhaust port side.

If there is more than 12° but not more than 14°, it will be all right, but do not file any more off the port timing edges even if they are ragged. If there isn't enough difference, merely file the exhaust ports to the scribed line. If a small hand grinder is available, the ports can be squared up and cleaned out with this.

The end exhaust ports on Johnson "B" and "C" cylinders are made with the bottom on an angle. **Do not** square this up. This web seals off the rod relief in the piston when it is at TDC. The bottom edge of the exhaust port has no effect on timing or breathing, so too much work here is wasted effort.

Do not reduce the width of the port bridge excessively. Remember that the entire pressure of the rings is divided up between these bridges when the piston is at this point of its travel. The narrower these bridges are, the higher the unit pressure will be, and consequently they will wear out sooner.

21. Transfer Ports And Passages: Johnson "B" and "C" motors have transfer ports that go through the piston walls. These have been a source of worry to many drivers as they don't understand their purpose. Actually their purpose is to reduce the width of the cylinder assembly and thus keep the rotary valve closer to the crankcase. Instead of putting a separate runner on the outside of the cylinder from the crankcase to the intake ports, the charge is merely directed through these openings in the piston and cylinder walls to the intake ports. Figure 11.

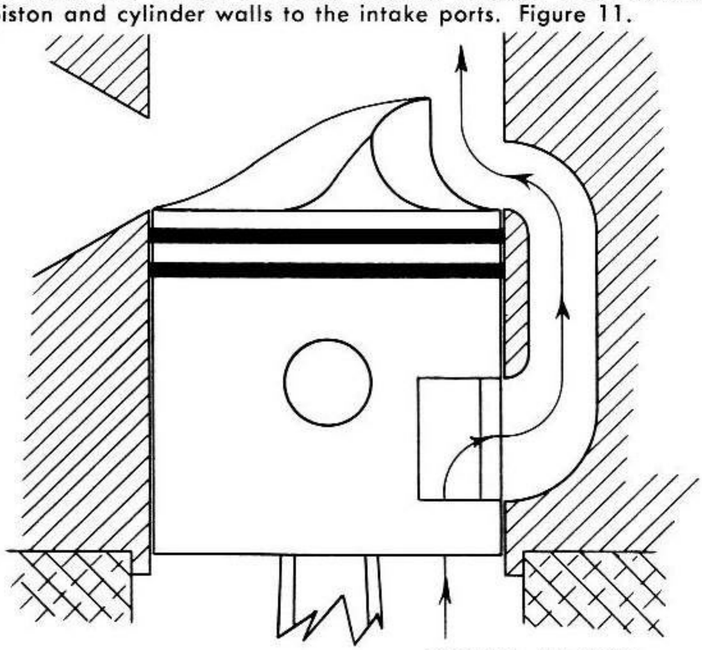

FIG. 11

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1. The Two-Stroke Cycle Internal Combustion Engine: Nearly every boy in the United States today is familiar with the plan of operation of the Otto cycle or four-stroke internal combustion engine. This subject is taught in high school science and physic classes and in auto-mechanic classes that are offered in the larger schools. First-hand experience is often gained by tinkering with the family automobile or working after school hours in the neighborhood garage. In fact, the automobile has become such an important part of the American way of life that it is almost impossible for one to successfully get along without understanding even a little about how it operates. The same cannot be said about the two-stroke cycle engine. Its use is rather limited; and therefore, except for the outboard motor, most people do not come in contact with it. This is probably why the average user has so little knowledge of this type of engine.

The basic difference between the two-stroke cycle engine and the four-stroke cycle or Otto cycle engine is that in the two-stroke cycle there is one firing stroke per cylinder, per revolution, while in the four-stroke cycle engine there is one firing stroke per cylinder, per each two revolutions. From first impressions it would seem that the output of the two-stroke engine would be double that of the four-stroke engine. But this is not the case, as will be explained later.

In the crankcase compression type of two-stroke engine (all outboard motors are this type) the bottom and inside of the piston does the work that the top of the piston does in one revolution of the Otto cycle engine. This may need some explaining. The four-stroke cycle consists of the following; intake stroke, compression stroke, combustion stroke or power stroke, and exhaust stroke. The two-stroke cycle consists of the following: compression stroke and power or combustion stroke. The intake stroke is a function of the inside of the piston, and the exhaust gases are displaced by the inrushing intake charge.

2. The Two-Stroke Cycle of Events: Let's follow the operation of one cycle of events step by step. As the piston travels upward in the cylinder, an emptiness or vacuum is left in the crankcase. This is satisfied by the air of the atmosphere rushing through the carburetor, where it is mixed with minute particles of fuel. When the piston reaches top dead center and starts on its downward stroke, a valve device between the carburetor and crankcase, closes (rotary valve in the case of racing engines) and the charge undergoes compression. But before the piston reaches bottom dead center, it uncovers openings or ports in the cylinder wall. On one side these ports are open to the atmosphere; these are the exhaust ports, and on the opposite side the ports are connected to the crankcase. These are the intake ports. The exhaust ports are so arranged that they open slightly before the intake, thus reducing the pressure in the cylinder to almost atmospheric pressure when the intake port opens. Now getting back to the crankcase, the intake port to the cylinder has just opened, and the compressed charge in the crankcase finds an escapement in the cylinder, which is about at atmospheric pressure and rushes in balancing out the pressures. Still the piston has some downward travel left, and in this part of its travel it forces the remaining charge left in the crankcase into the cylinder by direct displacement. Now the charge entering the cylinder tends to fill it; so by careful design of the piston deflector top the charge is directed to the top of the cylinder, and the remaining exhaust gases are forced out by the incoming intake charge.

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If your cylinder is of this type, measure the area of the intake ports and that of the openings in the piston and cylinder (transfer ports). Generally they have from 1-1/2 to 2 times the area of the intake ports. If for any reason they should have less area, they will have to be enlarged. If the piston openings are adequate, slip an undersize piston into the bore and line up the indexing edge of the intake ports and the piston; then lower it in the bore so as to just crack it open. Now observe the transfer ports in the piston without moving the piston from this position. Generally you'll find that they have already opened, but if they haven't, they'll have to be filed or ground until they are open. If this is correct, lower the piston indexing edge until it is about 3/16 inch down from the timing or top edge of the intake ports. Figure the intake port area at this opening and also the transfer port. The transfer port area should be about one and one-half times larger than the intake port. If this is the case, no further work need be done with these ports. Cutting these ports to fancy shapes, such as the "church window" design, is a lot of wasted effort, for it is really a matter of area and as long as the transfer port area is always greater than the intake port, nothing else can be gained. Drilling holes in the crankcase contact face or opening up a passage way to the transfer port at this point, is useless and only weakens the cylinder.

It is almost universal practice to invert a left hand four stud "B" cylinder and use it on the right in place of the original one with the release charger. A cylinder so inverted hasn't any tank mounting boss or water outlet hole. The water outlet is drilled and tapped in approximately the same position as the other cylinder. A substitute tank boss is made by extending the steering rod bracket and bending it in the same location as the boss would have been located. A stud and spacer is then installed just as if this were a part of the cylinder.

22. Reinforcing: When the porting is completed, the cylinder should be reinforced by welding or brazing. This operation is not necessary for increased output; however, it is very good insurance for all the effort and expense that is involved in preparing a set of good cylinders. When a racing motor turning 6500 to 7000 RPM is suddenly upset or submerged, it draws in water instead of air. Now it is a basic law of hydraulics that liquids are incompressible; so naturally when a cylinder is filled with water and the energy in the spinning flywheel is transmitted back to the piston top, something has to give. Sometimes the rods bend, and sometimes the cylinders are blown off. Reinforcing the cylinder flange generally causes the rod to bend, although reinforced cylinders are occasionally blown off, too; however, as was stated before, reinforced cylinders are good insurance. Notice Figure 12. A piece of fourteen guage sheet steel is brazed to the flange and to the transfer port bulge. This is the weak part of most cylinders. Also a small piece of metal is brazed to the exhaust port and to the flange, forming a bridge. This seems to give as good protection as any method the author has discovered so far. On some of the older "A" and "B" cylinders, the water jacket isn't sufficiently supported at the head contact face. To remedy this, it is usually filled in to a depth of about one-fourth inch by brazing, and redrilled with a series of small holes leaving small bridges between the holes. Figure 12. It isn't necessary to weld "six-stud Class 'B' " cylinders as their design and material make them extra strong. Vincent Marine Company cylinders also require no reinforcing.

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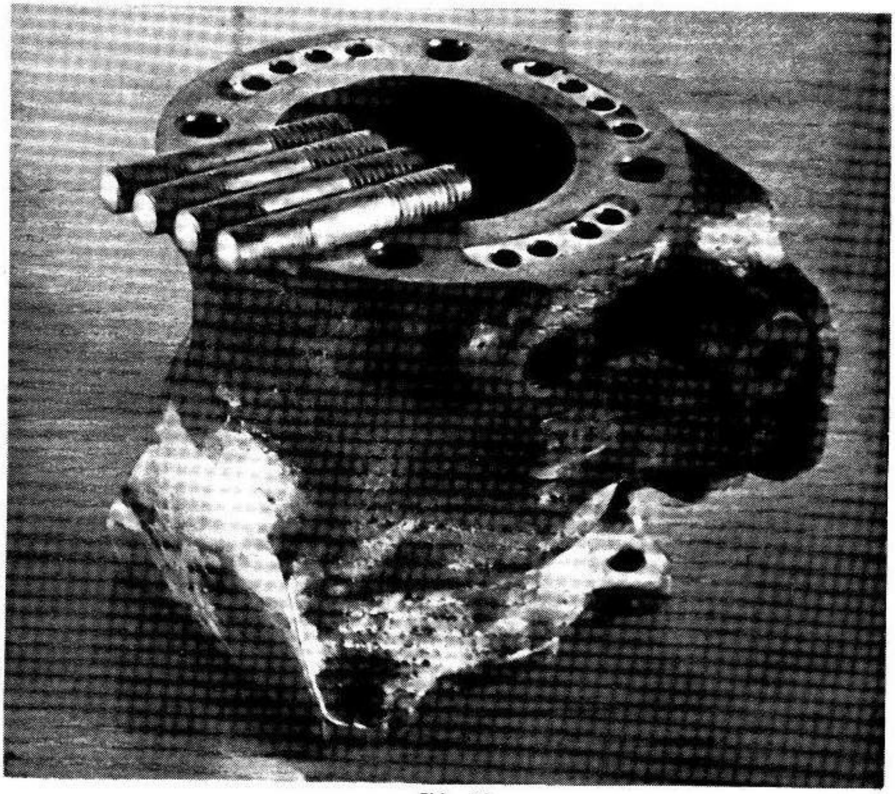

FIG. 12

As an added assurance against blowing off the cylinders in the event of a spill, some drivers construct plates and tie rods to add some support at this point. The motor in Figure 24 has these installed. Notice how they pull against each other. In the case of an alternate firing engine the rods are attached to the crankcase head studs and to the steering bar. Exercise extreme caution in tightening these down as they can easily pull the whole engine out of alignment.

23. The Cylinder Bore: Most automotive shops do not possess equipment that is of the correct size to service outboard cylinders. Even if they did, it is not often wise to trust these men with your cylinders as they are not used to working with the tolerances that are necessary to produce a fast motor.

The first operation is to select the one with the largest bore and either have it bored out on an accurate lathe or ground out on an internal grinder. This must be done with extreme care and accuracy and only enough metal removed to clean up the bore. When this is done, the flange contact face should be faced off until cleaned up or within ninety per cent with not more than .001 low spots. This face should be as square as possible with the bore and is usually done without removing from the boring setup. The second one should be bored out to the same size as the first.

If the cylinder is to be plated with hard chromium, it is sent to the plater at this stage. If it is not, it is now ready for lapping. This is done

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with a very fine hone and a generous supply of lubricant. Lapping proceeds until a very fine finish is produced and all irregularities in the surface are removed.

This may seem simple but it requires a lot of time and effort, as well as experience. The importance of a good job cannot be over emphasized, for if the surface is not perfect, the rings will not seal and, of course, compression and efficiency will be lowered. A cylinder that has good compression when the flywheel is revolved manually, may not have good compression at high speeds because of ring dance or toss. If the cylinder has an irregularity on its surface the ring may flutter all the way to TDC. This subject will be discussed later in more detail.

24. Chrome Plating: Reference was previously made to chrome plating. Chrome is exceedingly hard and resistant to wear and has a low co-efficient of friction. The life of an iron cylinder is very short, sometimes only a few races; while the life of the plated bore is usually good for several seasons of races. Plating is usually cheaper in the long run even though the initial cost is high.

Plating the cylinder requires experience, and it is recommended that it be done only by those who are prepared for this sort of work. Almost all platers think they can do a good job on outboard cylinders. Few of them can. After about .020 is deposited on the walls, the cylinder is again returned to the grinder and the chrome is then ground out until it cleans up. This generally leaves about .005 on a side. Of course the lapping process is administered when the grinding is completed.

25. The Piston: In order to take advantage of a good set of cylinders you must have a good set of correct fitting pistons. The outboard piston has several functions. The main one is to convert the heat energy released in the combustion process to reciprocating mechanical energy. If this were its only duty, our problem would be greatly simplified. But our piston and its ring assemblies have to dissipate the unwanted heat that is liberated in the combustion process; it has to form the base of the combustion chamber, besides controlling the port timing and directing the scavenging process.

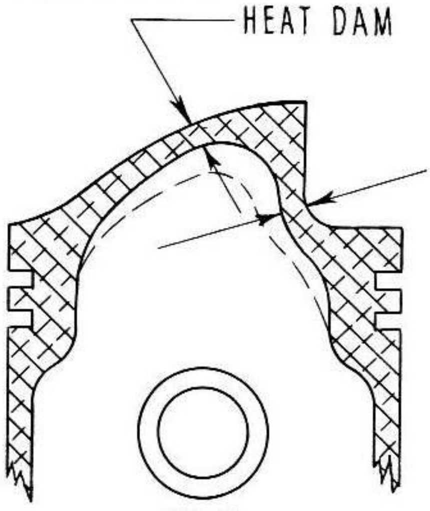

FIG. 13

Courtesy of Boatsport.org

A piston dissipates heat by conduction to the cylinder walls and from then to the water in the jacket. In this process the heat is absorbed by the piston head, and if the piston is of good design, heat flows through the ring belt and rings out to the cylinder walls. When selecting a piston for racing, besure that there aren't 'any heat dams in the design of the upper section. A heat dam is a thin section that restricts the flow of heat just like a valve in a water pipe. Figure 13.

In some extreme cases where the entire head hasn't sufficient heat capacity the piston will reach a temperature where it either melts or burns.

Figure 14 shows a section of a piston with a strutted pin boss. In this case the strut not only acts as reinforcement for the pin boss, but it provides a large channel to carry away heat from the piston head. The importance of keeping the piston cool can be better understood if one will familiarize himself with Charles' Law of expanding gases. Probably only then can one comprehend its effect on volumetric efficiency.

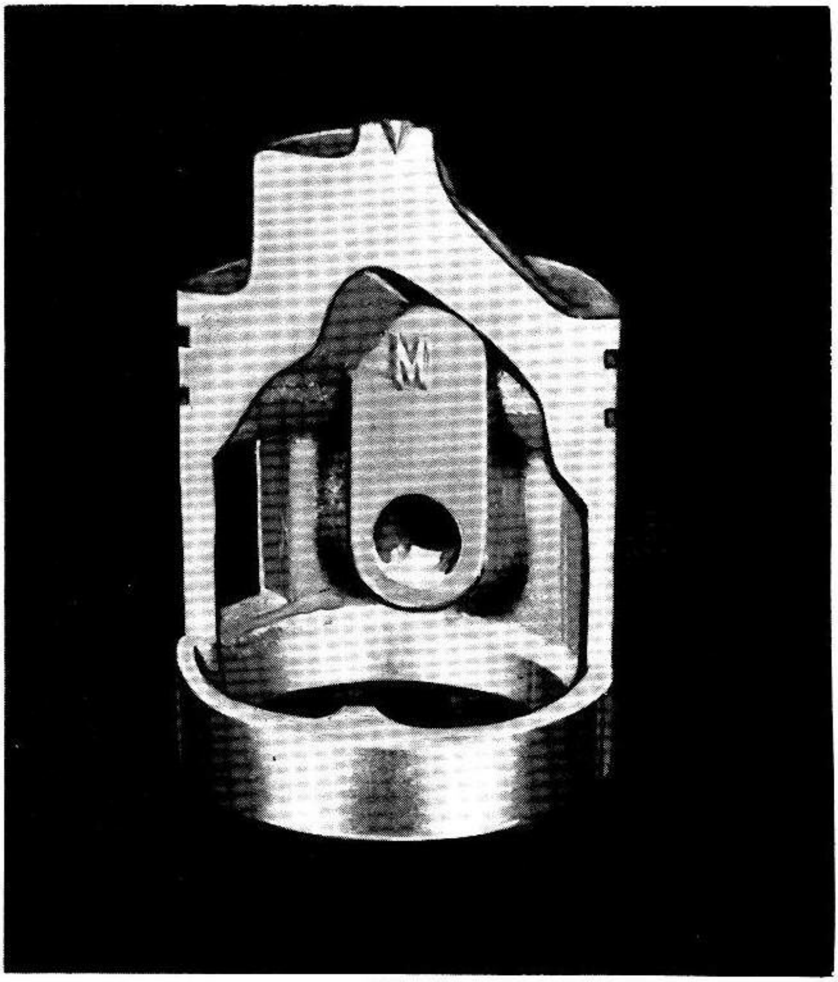

FIG. 14

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26. Piston Ring Location: A good many manufacturers are furnishing semi-finished pistons without ring grooves. This is done because nearly every driver has his own theory on the location and number of rings that should be used, and to make sure that the grooves are absolutely square with the piston they should be cut on the same set-up that the diameter is turned or ground on. The author prefers to keep his rings about one-fourth inch down from the indexing edges because the added distance gives greater protection to the top ring by keeping the fire farther from it, thus prolonging its life; and also it eliminates the possibility of a thin section expanding irregularly and pinching the top ring.

27. Fitting Pistons: It is common knowledge that metals expand when heated. Some metals expand more than others for the same temperature increase. These are said to have a high co-efficient of expansion. Of the popular materials used, aluminum and its alloys have one of the highest co-efficients of expansion. This may seem to be a disadvantage, but the advantage of a low specific weight and high thermal conductivity more than offset this. Besides, careful experimenting has shown us how much to allow for this expansion. Pistons expand more on the top because the heat is more intense there. To compensate for this the piston is machined with more clearance on the top than at the bottom. The subject of piston to cylinder bore clearance will always be one for discussion. Figure 15 is a chart that has been compiled from the author's experience. This is for pistons made of metal containing at least ten per cent silicon, such as Lo-Ex and is the minimum safe clearance.

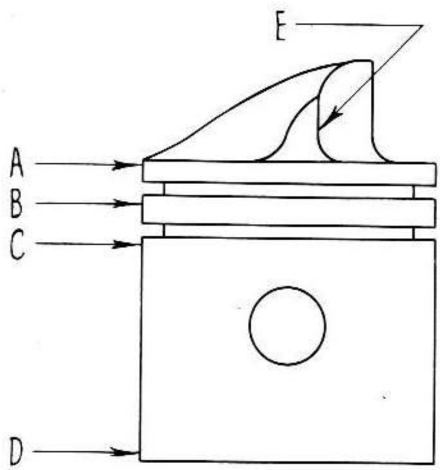

FIG. 15

Cylinder Bore Dia.	A	B	C	D	E
1-3/4	.0075	.005	.0040	.0020	.020
2-1/8	.010	.007	.0055	.0030	.025
2-3/8	.011	.008	.0060	.0035	.028
2-3/4	.013	.009	.0070	.0045	.034

Courtesy of Boatsport.org

It seems to be the trend to fit pistons too tight rather than too loose. Why some drivers continually fit pistons tighter than necessary is something we'll probably never understand. There's absolutely no advantage in a tight fitting piston. In fact there is a decided disadvantage. A piston should be just tight enough to properly seal off the ports. A fit that is closer than necessary only causes excessive friction. When a piston sticks or (siezes), it usually binds across the pin bosses. This is because of more metal at these points. It is a good idea to relieve this area by dressing it down with emery cloth. .001 inch on a side is usually sufficient. This may eliminate some friction, to say nothing about preventing the piston from sticking. Figure 16.

Scoring this area with the point of a drill to form a honey comb effect helps to keep this area lubricated. Do not strive for a polished finish on the piston walls, as a little roughness also aids lubrication.

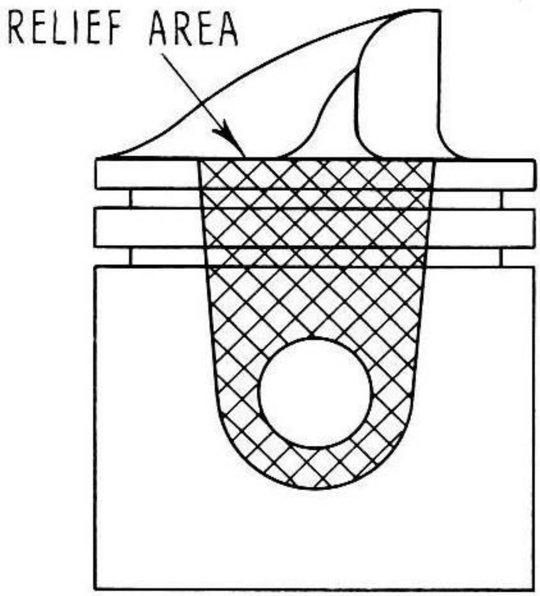

FIG. 16

28. Piston Rings: If the engine had to depend upon the piston to seal off compression, it would be a very unsatisfactory machine. Yet the way some mechanics install rings they might just as well not be there. Maybe it would be well to describe the way in which the ring seals. Figure 17. Notice how the ring makes contact with the cylinder wall and the bottom of the ring groove. These are the sealing surfaces. Fitting the ring too tight in the groove or without sufficient groove depth is a dangerous practice and of no advantage. Outboard engines can get by with very little side clearance on the rings. Even though this is true, it is of very little advantage as can be seen from Figure 17. Some drivers fit their rings with less than .0005 side clearance and very little extra groove depth. Clearances such as these don't allow much room for oil and it is the author's theory that the presence of oil behind the ring has the effect of a hydraulic shock absorber and actually helps to reduce ring toss or dance. We recommend a side clearance of .001 and a groove

Courtesy of Boatsport.org

depth at least .014 deeper than the thickness of the ring. Ring grooves are generally cut to the same width as the ring and the top of the ring is lapped down on fine emery paper until the correct side clearance is obtained.

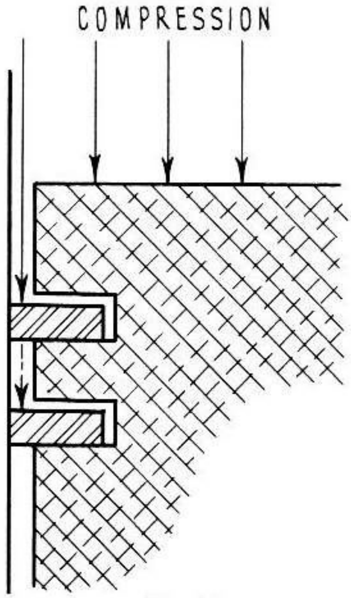

FIG. 17

We like to imagine the rings as holding tight against the cylinder walls at all times. This is what would happen if everything were perfect. However, in most engines at high speeds the rings are fluttering and dancing and contact the cylinder walls only part of the time. The smoother the bore and the better the finish the less likely are the chances for the ring to toss.

If the ring is caused to ride over an irregularity at high speeds, it doesn't immediately return to the cylinder wall but skips over the irregularity like a skier going off a ski jump. When it does contact the cylinder surface again, it probably won't remain there but bounce right off again like a rubber ball and continues to do this until it spends all the energy that it absorbed when it was compressed over the bump.

Increasing ring tension tends to reduce this effect, but this means that more energy will be required to compress it over the same bump, and if it doesn't spend its energy bouncing it gives it up in the form of heat from friction. The disadvantage with this solution of the problem is that it requires quite an increase in tension to be effective and the results are more ring and cylinder wear, besides a slight loss in power.

A better approach to the ring dance problem is to reduce the amount of energy the ring absorbs when it is compressed. This may seem contradictory as by adding tension we improved the situation. The fact is that the ring tension is proportional to its thickness, and gap when expanded. If we reduce the **width** of the ring by one-half and leave the thickness as it is, we reduce its weight or mass by one-half, and therefore the inertia effect is cut in half. By using a 1/16 width ring instead of a conventional 1/8 we have a ring with the same unit pressure but

Courtesy of Boatsport.org

only one-half as sensitive to the force of inertia. Actual tests have proved that 1/16 width rings wear equally as well as the 1/8 and reduce cylinder wear substantially. Compression pressures at high speeds are almost always increased with their use.

The effect of ring toss is almost proportional to piston speed. It is almost absent in slow heavy duty type engines and becomes especially troublesome when the piston velocity exceeds 2,500 feet a minute. Piston speed is calculated by doubling the engine's stroke and multiplying by the RPM.

29. Ring Pinning: Rings in a racing motor should always be pinned. If they were allowed to rotate, the ends would eventually find their way into an open port and be damaged. The two most popular methods are shown in Figures 18 and 19.

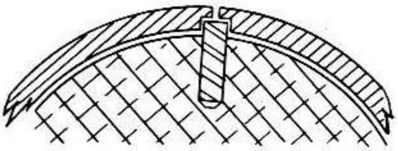

FIG. 18

FIG. 19

In Figure 18 a groove half the diameter of the pin is milled or filed in the top of the ring at the joint. The pin is placed half in the groove and half in the piston wall. The disadvantage of this type is the difficulty in drilling the pin hole unless it is drilled before the groove is cut. In Figure 19 the pin is placed in the center of the groove and about one-half the thickness of the groove down. A socket is cut in back of the ring end to receive the pin.

These pins are usually made of steel. Three thirty-seconds diameter is almost standard although other sizes could be used. When pinning 1/16 width rings, the 3/32 diameter pin is still used; however, it is set so that only a small part of it projects into the ring groove.

Be sure that the pin is below the surface of the piston.

30. Ring Butt Clearance: Piston rings expand because of heat just as the piston does. Clearance for this expansion is left at the joint or butt. To check ring clearance insert the ring in the bore and "square it up" by inserting the skirt end of a piston, then check gap with a feeler guage. Engines have operated successfully with as little as .004 clearance at this point. However, opening up this clearance to .020 showed no loss in compression pressures or engine performance, proving that this feature isn't very sensitive. The author has settled on a ring gap of .006—.008 for all his engines. Rings are generally bought oversize and filed to the proper clearance with a fine file.

31. Special Rings: All the discussion so far has been about plain cast iron or semi-steel **compression rings.** Reference here to special rings means all other types.

32. Chrome Plated Rings: Chrome plated rings are plain compression rings prepared with a layer of hard chrome deposited on the face. These are for use on iron or steel bores only. (Not chrome plated bores) Usually they are used only in the top ring groove. Their use protects the other rings and prolongs the life of the whole cylinder. They are especially valuable in dusty conditions, lasting five times as long as cast iron rings.

Courtesy of Boatsport.org

33. Taper Face Rings: Taper face rings are the same as plain compression rings except that the face is cut on a slight taper just as the name implies. The large side is placed at the bottom of the groove, and thus, as the contacting surface is very small and the unit pressure high, it wears in, or seats very rapidly. After it is seated, it becomes a plain compression ring. When installing these rings, be sure that the identification mark is placed toward the top of the piston. Figure 20.

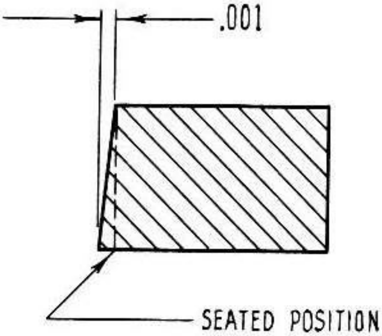

FIG. 20

34. Wrist Pins Or Piston Pins: The wrist pin, more properly called piston pin, is the connecting link between the piston and the connecting rod. It is a simple little part and doesn't rate much discussion except for the fact that it is not locked in the piston as is common practice. This feature of the outboard racing engine follows the practice of most aircraft engines in that the piston pin is equipped with small aluminum buttons at each end and floats in the piston bosses. This is a big advantage in a racing engine because when an engine is disassembled for an official inspection, the piston pin need only be pushed out with the fingers and the piston left with the rings compressed in the bore.

The pin hole in the piston is bored or reamed so that the pin can be just shoved through with fingers.

The Randolph Hubbell Company is manufacturing a plastic wrist pin button that is supposed to be lighter and easier on the cylinder walls. The material is Formica.

Courtesy of Boatsport.org

THE COMBUSTION CHAMBER

35. Combustion Chambers: In the chapter on engine design we discussed how a small combustion chamber minimized detonation because of the shortened distance the flame front has to travel. The unfortunate thing about detonation in racing engines is that it usually can't be detected above the sound of the exhaust, and consequently we know of its existence only when it is too late and has caused some damage.

There are many contributing and controlling factors in regard to the combustion chamber design. For one thing we have to have a deflector on the piston head. Actually all the complicated bumps and bulges are not pertinent to scavenging for if we just placed a piece of sheet metal on the piston in front of the intake ports, we could probably get equal scavenging. Figure 21.

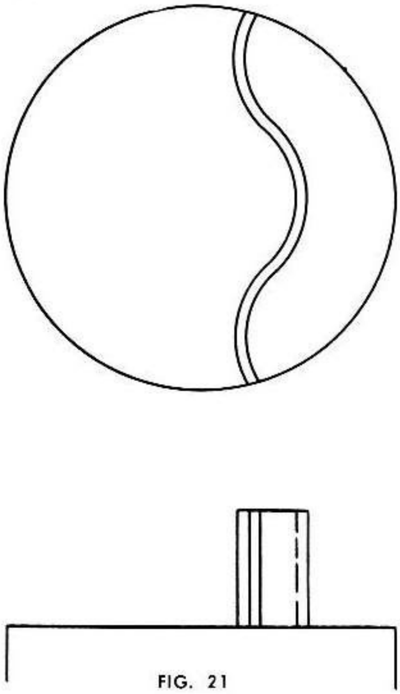

FIG. 21

The purpose of the deflector is to keep the intake ports from discharging across and out the exhaust ports, and also to direct the charge toward the top of the cylinder to displace the exhaust which is left up there.

It isn't hard to see that it would be difficult to obtain a good compression ratio with a piece of sheet metal sticking up on top of the piston, and, besides, it couldn't be cooled. To remedy this situation the exhaust side is filled in, and this gives us the shape of the deflector that we use at the present time.

Most cylinder heads are merely negatives of the piston head with the spark plug placed at the center. Figure 22. This has worked out quite satisfactorily as the bore of outboard engines is relatively small. A much better and more up-to-date design is used on the six-stud class

Courtesy of Boatsport.org

In actual conditions some of the exhaust gases remain in the cylinder and mix with the incoming intake charge. Exhaust scavenging isn't 100% efficient. Now as the piston starts on its upward stroke again, compression occurs in the cylinder; and after being ignited, energy is delivered to the crankshaft. This is the cycle of events for an engine going at a very slow rate of speed; however, it is basic and must be fully understood before one can hope to comprehend what takes place at high speed. **Figure 1** is a cycle diagram of these events. Imagine looking at the flywheel of such an engine; as it is rotated, one point on the wheel will pass through all these events.

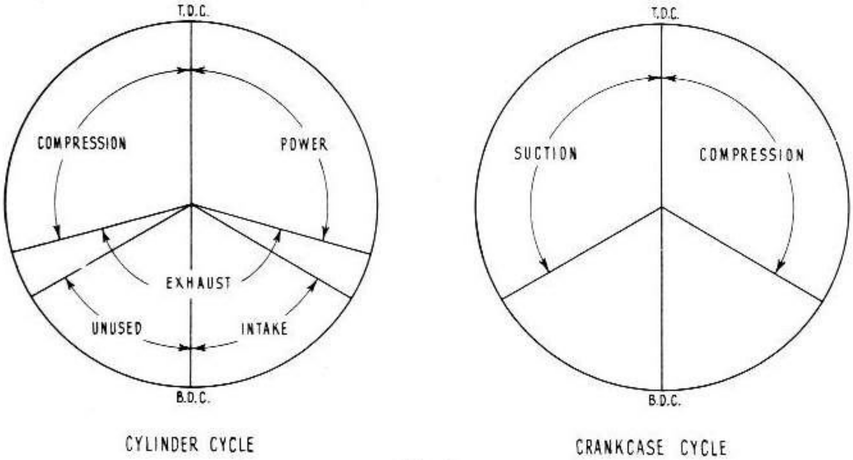

FIG. 1

3. Slow Speed Inefficiency: Notice the part of cycle marked unused on the cycle diagram. This unused part of the cycle is one reason why slow speed engines of this type are not very efficient. The following is what happens when this part of the cycle occurs. The piston has reached bottom dead center and starts to travel upward. Both intake and exhaust ports are open, and as the piston is moving upward, it is causing a reduction in pressure in the crankcase. To satisfy this negative pressure, some of the charge in the cylinder is drawn back into the crankcase, and then to satisfy the loss of charge in the cylinder, air comes into the exhaust port and dilutes the remaining charge. This last phenomena is not as serious as it may seem as it is compensated for by having an initially rich mixture.

4. Volumetric Efficiency: In a high speed engine the picture changes somewhat, and volumetric efficiency is increased. The term, volumetric efficiency, refers to the ability of the piston to displace or pump air, and is usually expressed as a percent. it is computed by dividing the amount of air the engine actually pumps by the amount of air it would pump if it were pumping one-hundred percent of its displacement.

$$\text{V.E.} = \frac{\text{Actual Air Used}}{\text{Displacement x RPM}}$$

Example: A thirty cubic inch motor running at four thousand RPM should pump sixty-five cubic feet of air per minute, but actually this engine pumps only 42.25 cubic feet per minute. Then 42.25 divided by

Courtesy of Boatsport.org

"B" motor, but for some reason most drivers haven't accepted this with too much favor. The author has done considerable experimenting with this type and found that it works very well. Probably it will become more popular when more drivers become acquainted with its principle. Figure 23.

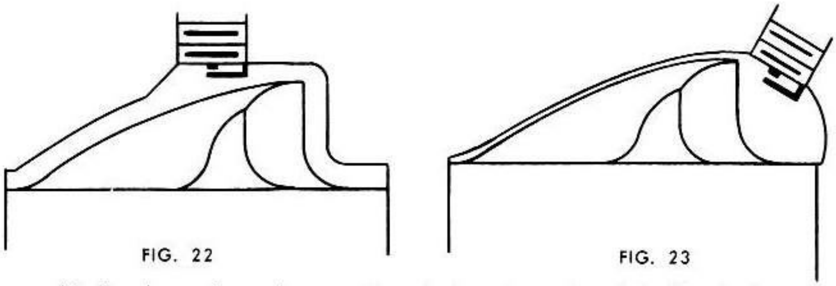

FIG. 22 FIG. 23

Notice how the exhaust side of the piston head is fitted close to the cylinder head forcing the charge out of this region under high pressure and into the cavity or combustion chamber on the intake side of the piston. This squeezed out charge causes the charge in the main combustion chamber to be in constant motion or in a condition of turbulence. This action produces more complete combustion. Notice how small and compact the combustion chamber is. The spark plug is placed over the intake side in this case. It's possible that the drivers who were disappointed in this design did not take sufficient care in fitting the exhaust side of the piston to the cylinder head and allowed too much clearance at this point, defeating the whole purpose of this design. If this was the case, they would have the same chamber as the old type but with the spark plug in one corner of the cylinder, doubling the distance the flame front has to move. Some companies supply a piston with an extra full exhaust side deflector to be trimmed to fit the head. An easy way to measure this clearance is to place a lead shot on the piston head with a dab of grease and rotate the flywheel with the head tightened down with a couple of nuts. This will compress the lead, and it can be measured when removed. Solder works well for this, too. There should be a minimum of .020 clearance at this point.

36. Cylinder Head Material: Both aluminum and copper are used for cylinder heads. Aluminum has a co-efficient of thermal conductivity of .48, while copper has one of .92. Brass has only .26. This means that copper can carry away almost twice the heat that aluminum can in the same time. For this reason copper makes a better cylinder head.

In practical usage the difference in performance is slight. However, it is easier to maintain good spark plug threads in the copper head and also flatness of the contact face; so adding up all the facts the preference is for the copper head. The Vincent Marine Company is manufacturing a reinforced aluminum alloy cylinder head that will hold a flat contact surface and not distort.

37. Compression Ratio: In the first chapter we discussed how confining the fuel charge converted more of its potential energy to mechanical energy and less to heat energy. The limit to which confinement can be carried is determined by the ratio at which detonation becomes apparent or where physical strains are excessive. Even if these didn't occur there's a limit at which any more increase in power can be realized.

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Raising the compression ratio from 5:1 to 6:1 gives a greater increase in output than raising it from 6:1 to 7:1 and so on. In fact if we could use a ratio of 13:1 we probably would get less than a one per cent increase over a 10:1 ratio. Outboard engines are designed with pretty husky parts, and it hasn't been the author's experience to have a part fail because of the strains of high compression. This leaves detonation and preignition as the limiting factors for the compression ratio of outboard racing engines.

There are so many factors that contribute to detonation that it is difficult to prescribe any definite compression ratio even for identical engines. The altitude at which an engine is to be used is a factor as are also the fuel, combustion chamber efficiency, ignition timing, volumetric efficiency, and conditions of the cylinder bores and rings. As a rule an engine that has poor volumetric efficiency or bad rings and cylinders can run a higher compression ratio, as the lack of air supply or compression, lessens compression pressures, and in reality such an engine has no higher compression pressures even with a higher compression ratio than an engine in good shape and a lower ratio. This is why an engine at high altitudes can run higher compression ratios. Remember how the air is pushed into the carburetor by the weight of the air column or atmosphere. At high altitudes this column of air is shorter and its unit pressure is less, so less air is put through the carburetor.

Whenever the subject of the two stroke engine's compression ratio is discussed, an argument concerning the proper method of calculating it usually follows. Some engineers favor computing it on the basis of the cylinder volume with the ports just closed, and some favor figuring it on the full stroke. In this publication we consider it as being figured on the full stroke. Our arguments are that if it is figured on only part of the cylinder volume, then this volume should be used when figuring the engine's displacement; and also by figuring it on the full sroke basis we can more easily compare it to other types of engines. Some manufacturers have it figured both ways in their specifications.

To figure compression ratio divide the piston displacement of one cylinder plus the volume of the combustion chamber by the volume of the combustion chamber.

$$\frac{\text{cyl. vol.} + \text{combustion chamber vol.}}{\text{combustion chamber vol.}} = \text{C.R.}$$

To determine the combustion chamber volume remove the spark plug and place the engine in such a position that the spark plug hole is vertical. Rotate the flywheel until the piston is at TDC and then from a graduated cylinder or burette fill the combustion chamber to the top of the spark plug threads or to the counterbore, with fuel oil or kerosene. Figure 24. Note carefully how much fluid was used. If the burette was graduated in cubic centimeters of mili-liters subtract 1.8 for the volume of the spark plug shell and divide the difference by 16.39. This will give the volume in cubic inches or in the same unit as the engine's displacement is expressed in. Example: Class "A" motor has a combustion chamber and spark plug hole volume of 13 cc. 13-1.8 = 11.2 cc. combustion chamber volume.

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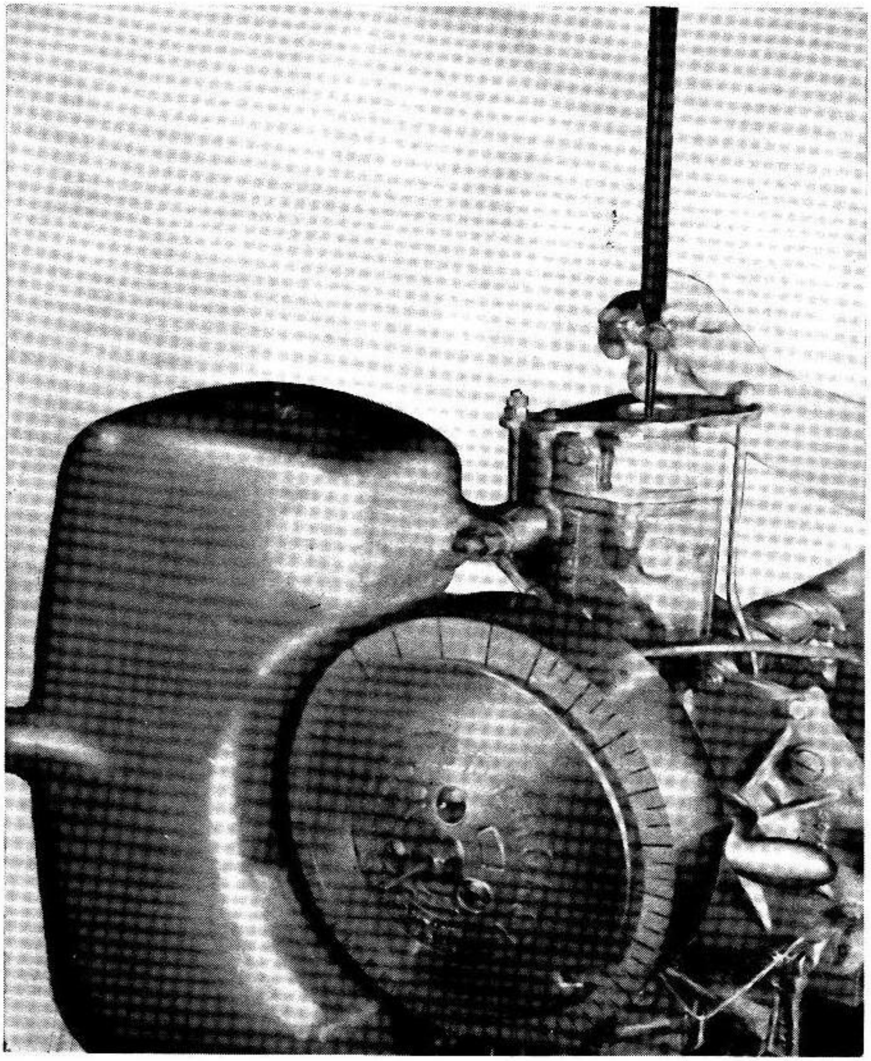


FIG. 24

$$\frac{11.2}{16.39} = .685 \text{ cu. in.}$$

Class "A" displacement = 14 cu. inches—7 cu. in. per cylinder

$$\frac{7.0. + .685}{6.85} = 11.2{:}1 \text{ C.R.}$$

We advise the beginner not to use a high compression ratio until he becomes more experienced, because as we stated before, the detonation in outboards except at very low speed is inaudible and can generally be detected only when it has done some damage.

The subject of compression ratio selection will be discussed more in the chapter on fuels.

Courtesy of Boatsport.org

THE CONNECTING ROD

38. Connecting Rods: The purpose of the connecting rods is to transmit the motion or energy of the piston to the crankshaft. This is one part that, except for balancing, doesn't require any changing. Some drivers go to a lot of work smoothing and polishing their connecting rods. Figure 25. A nice appearing part is always commendable and if the driver or mechanic has the time and ambition to do such a job, we will not discourage it although finding any increase in output will be very disappointing. There is one advantage in polishing connecting rods, and this is that it eliminates scratches and small surface checks that may be the starting point for crystallization.

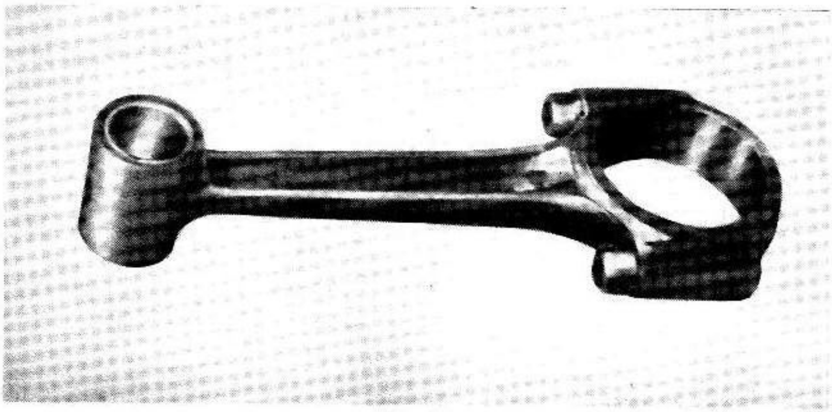


FIG. 25

It is important that the connecting rod be in alignment. It takes little imagination to see what would happen if the connecting rod were not straight. Friction would be increased, and if the condition was really bad, serious piston and bearing wear would be the result.

Many straight rods have been damaged during the assembly process and sometimes without the mechanic's even knowing it. The rods in the smaller classes can be bent by a strong person with only his hands. The weight and leverage of a cylinder when being assembled can be sufficient to do damage unless supported properly. Also many mechanics unconsciously lean on the connecting rods when they tighten the bolts.

Some rods are supplied with a socket head dowel screw to maintain alignment between the rod and the cap; others depend on the skill of the mechanic to insure a proper match. If yours is of this type, you'll notice that there is a flat spot ground on both sides of the rod and cap. This is to aid in alignment. Tighten the screws until they are just snug and then with a blunt punch, tap the cap and rod against the crank flange or cheek; then with a sharp pencil or scriber feel the joint and see if either the cap or rod projects away from the other. If it does, tap it back until no joint can be felt. After this is done, tighten the rods' screws and again check. If still no joint can be detected, it is ready to run.

Socket head screws make good replacements as the material is better than average, and if an accident should occur where a rod is twisted and wedged in between the crank cheeks, it might be impossible to reach a conventional type cap screw to remove it.

Courtesy of Boatsport.org

39. Bearing Fits: The piston pin bushing I.D. should be at least .0008 larger than the piston pin. A good working tolerance is .0008 to .0015; however, some drivers use much more than this with no ill effects.

The manner of fitting the rods and rollers on the crank has been a subject of varied opinions. The author fits his with from .0010 to .0015 clearance. Some drivers fit theirs tighter, others looser; in fact, we have come to the conclusion that the fit isn't of too much importance unless one would go to an extreme.

If the bearing race in the rod is rough or out of round, it can generally be salvaged by lapping out on a good automotive piston pin hone. Care must be taken, if this is done, not to go through the case hardening and not to remove too much material, making it impossible to obtain the necessary oversize rollers.

Cutting away the inner web or drilling it full of holes is not advised as it will only weaken the rod, and decreasing the weight at this point **will not affect output.**

Courtesy of Boatsport.org

THE CRANKSHAFT

40. The Crankshaft: The crankshaft might be considered the heart of the engine. Its purpose is to convert the reciprocating motion of all the other parts to pure rotary motion or torque.

Except for balancing, which will be discussed in a later chapter, the crankshaft as supplied by the manufacturer requires no changes. Some drivers grind a small radius under cut at the corners of the keyways, the theory being that this radius will prevent a crack developing from this point. Figure 26. The author has processed several cranks this way and has had some crack at this point even with this treatment. We hesitate to give any opinion on this subject because of lack of information. Some cranks were made with keyways cut with a radius at the corners.

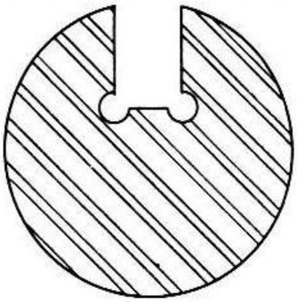


FIG. 26

No mention has been made here of crank shafts that incorporate rotary valves, as any changes at this point will be taken up under the subject of rotary valves.

41. Salvaging Worn and Damaged Crankshafts: No one likes to discard an expensive part because of a minor defect or imperfection, but many times it is the cheapest way out. Often the salvage process becomes more expensive than a new shaft and then results in a failure. Most of the following methods were developed during the war as new shafts were not available at any cost.

42. Straightening Crankshafts: For good operation a shaft should be straight within .001 run-out. It is desirable to have it even straighter if possible. Straightening a shaft should not be attempted by one not experienced in this work, the procedure being to locate the vertex of the bend and apply pressure at this point. Some firms straighten shafts by warping them in position with an oxy-acetylene flame.

43. Crankshaft Main Journals: Scored or worn main bearing surfaces can be salvaged by grinding them undersize and applying hard chrome and regrinding to size. This is an expensive procedure and should be completely investigated before being attempted as sometimes the cost can be more than that of a new crank.

44. Crank Pins: Hard chrome will not work satisfactorily on the crank pins. It is brittle and does not resist the shock loads that are imposed at this point. Stellite can be used as a surface for the pins, but its cost is generally prohibitive.

If the pin is only slightly scuffed or out of rounds, it can be lapped by hand and oversize rollers fitted. An easy way to construct a lap is to take two old connecting rods and remove the caps and bolt them together as if one were the other's cap. When this is done, clamp a piece

Courtesy of Boatsport.org

of sheet metal on each side of the hole that is formed and pour full with lead. This is then bored and reamed to the same size as the crank pin and then sawed into two halves. To lap a crank pin, apply lapping compound to the lead and assemble to the crank pin. Tighten to a point where a slight drag is felt. Now using the two rods as handles rotate the assembly until the pin is made satisfactory. The size should be constantly checked during this operation to make sure too much is not removed. The hardness at this point should also be checked. Fifty-six to sixty-two on the Rockwell "C" scale is considered satisfactory.

45. Damaged Key Ways: The author hasn't found any method that is satisfactory for salvaging badly damaged keyways. Welding has always resulted in failure. A keyway that is just slightly enlarged can be ground out square and oversize keys made; however, they will have to be stepped in order to be used in a standard flywheel.

Courtesy of Boatsport.org

THE CRANKCASE AND CRANKCASE HEAD

46. The Crankcase and Crankcase Head: The crankcase, like all other parts of the engine, should be given a good visual inspection for small cracks and flaws. If the case passes this inspection, it should be relieved of all burrs, fins, and casting parting line irregularities. This can generally be done with a few small files and a bearing scraper.

When the case is "clean", the fit between the crankcase head and the crankcase should be checked. This should not have more than .0005 clearance and still not be so tight that it is difficult to assemble. If it is too loose, it can be fixed by machining down the diameter of the head and installing a sleeve that can be accurately fitted to the case. An alternate method is to tin the head with aluminum solder and then build up with babbitt. When sufficient babbitt is applied, it is turned down to fit the case. Naturally as the babbitt is softer, this method is not as durable as a steel or bronze sleeve.

47. Ball Bearings: Most racing engines, except the Midget, come supplied with some sort of non-friction crankcase bearing setup generally roller bearings, and any improvement in out-put from altering this setup will be discouraging. However, there are some advantages in replacing the roller bearing setups with ball bearings. They are as follows:

1. Less wear on the crankshaft because the ball bearings do not use the crank as their inner race.
2. Ball bearings can absorb a thrust load as well as radial loads.
3. Misalignment of the case can be corrected by installing ball bearings.
4. Ball bearings operate with less radial clearance.

If it is found that the setup as supplied is not in exact alignment, then money can be saved by having ball bearings installed. We don't intend to go through the whole mechanics of installing ball bearings in a crankcase as this would involve a whole course in the machinist's trade. If you do not have the experience or facilities to do very accurate machine work, you should not attempt this change, but send it out to one of the many companies that exist for this type of work. **Don't** take it down to the corner machine shop and expect a good job, for the chances are 100 to 1 that the operator won't understand how to set it up and you'll end up paying for a lot of experimenting and an unsatisfactory job.

The procedure is to cut off the bottom of the steel roller race and bore a recess to take the ball bearing. If the bearings are to be installed directly in the aluminum case, this socket is left from .001 DIA. to .002 smaller than the bearing. When installing, the case is heated to about 250° F. and the bearing tapped in place. A better way and one recommended by the bearing manufacturers is to press in a steel cup where the bearing is to be installed and fit the bearing so that it is a very light tap or push fit, mathematically .0002 tight to .0003 loose. Figure 27. This will allow the bearing to creep or the outer race to rotate very slowly, and thus the points of high loading will be distributed evenly to all the bearing surface, and wear will not be all in one area.

Courtesy of Boatsport.org

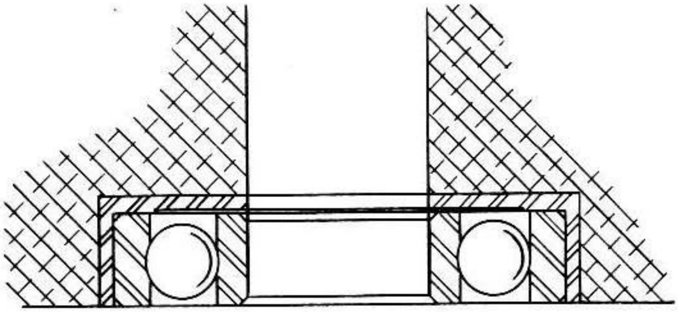


FIG. 27

The rollers are generally left in the top of the crankcase, as the amount of material at this point is not sufficient to permit a ball-bearing to be installed. When the steel roller race is ground away at the bottom to make room for the ball-bearing, several grooves on its exterior will be opened up to the inside of the case. These were originally for lubrication purposes, but as our new setup does not make use of these, they can be plugged with a sliver of copper or wood. Also the external oil lines and fittings can be removed and pipe plugs installed in their place. With a properly fitted seal the rollers will receive adequate lubrication as crankcase pressure and capillary action will cause oil to work its way up.

The ball bearings closest to the crank cheeks are usually installed deeper than the thrust faces of the original setup, and steel shims are placed between the ball bearing and the crank to regulate end play, and center the crank pins with the cylinder bore.

A popular practice is to set the crankcase head up with only one ball bearing and make a seal that extends all the way down to the crank shaft spline.

48. Fit On Shaft: The bearing manufacturers recommend that the inner race be pressed tight on the shaft. Usually this is impossible as the crankshafts are generally ground a few ten-thousandths of an inch undersize. The author has used several shafts that were like this and the bearings assembled on them by hand. No ill effects were found after even as long as six seasons of operation. In fact, this condition might even be preferred because of the ease of assembly. If an extreme condition is encountered, the shaft can be brought to size by chrome plating.

49. Main Bearing Seals: A seal that is installed between two ball bearings or a ball bearing and a roller bearing, can be fitted much tighter than one that is not. This is so because the ball bearings absorb the load. Seals used in this manner can be made of the following material: aluminum, bronze, or babbitt. Babbitt types are usually bronze with babbitt bonded to the inner diameter. The latter type is probably the best, as the softer babbitt material is less injurious to the crank in case of accident or if an error is made in the seal clearance. To make such a seal, merely bore 1/32 out of a bronze type and tin the inner diameter with solder. After a coating of solder is applied over the entire inside surface, it is poured full of a good high speed babbitt and bored and reamed to the proper clearance.

Courtesy of Boatsport.org

DIAMETRIC CLEARANCE

Crank DIA	Bronze	Babbitt	Aluminum
7/8	.0025	.0020	.0025
1	.0030	.0025	.0032
1-1/4	.0035	.0025	.0035
1-3/8	.0035	.0030	.0035

The crankcase head seal can use the same clearance provided it is not too long. If it is the extended type, allowance will have to be made, usually about .0015 inch per inch of length.

50. Contact Faces: When it is certain that the bearings and seals are in perfect alignment, the contact faces must be checked for parallelism. This is best done by inserting a mandrel in place of the crank, and supporting the ends on lathe centers or in vee blocks on a surface plate and indicating these surfaces with a dial indicator. If they are only slightly out of alignment, they can be hand scraped until true. If they are off more than a few thousandths, they had best be milled true. If this operation is by-passed, all the effort and money spent to straighten the rods is wasted.

No mention has been made in this chapter about crankcases that incorporate internal rotary valves. These will be discussed under rotary valves.

51. Rotary Valve Gear Chamber Seals: Rotary valve gear chamber seals are sometimes incorrectly referred to as "crankcase seals". Up until a short while ago these were considered as illegal by the racing rules. Why they were even mentioned in the rules is a mystery to the author. As their name implies, their purpose is to seal off the rotary valve gear chamber from the main crankcase chamber, the theory being that crankcase pressure would be increased and also volumetric efficiency. What this theory doesn't consider is that the rotor gear nearly fills this cavity and the little volume that is reduced by sealing off this chamber is only a very small per cent of the total crankcase volume; so any raise in pressure would be proportional to this difference. Besides, volumetric efficiency is not so dependent on crankcase pressure as is sometimes thought. As was stated in Section I, the charge is drawn into the crankcase by direct displacement of the pistons, and compressed on the downstroke, but as the ports are opened, the charge finds an escapement and thus uses its energy which it absorbed in the compression process to move itself through the ports and into the cylinder; however, the rest of the stroke fills the cylinder by direct piston displacement on the down stroke. No more charge can be rammed into the cylinder than is drawn into the crankcase regardless of what the compression ratio is in the crankcase.

These seals are generally constructed by installing a bronze ring in the crankcase and machining it so that the top cheek of the crankshaft runs in it with very little clearance and thus seals off the gear chamber.

Some of the replacement part crankcases possess a natural seal at this point.

Courtesy of Boatsport.org

sixty-five equals sixty-five or sixty-five percent; so this engine would have a volumetric efficiency of sixty-five percent.

5. Induction System Ram: Air when in motion acts like a large truck on a level road in that it requires all the energy and force necessary to put it in motion, to brake or stop it. This is considering friction and wind resistance as forces. This is called inertia or the tendency for a body in motion to continue in motion or a static body to remain static. The air entering the carburetor of an engine is affected in the same manner; and once it is started in motion, the tendency is to keep moving. To take advantage of this fact, we hold the rotary valve at the crankcase open after TDC. This is the point where crankcase suction ceases, and then the action of the charge in motion rams the crankcase with more charge. This effect is great enough at high speeds to make it possible to hold the rotary valve open through what would be more than one-half of the crankcase compression stroke.

6. Induction System Resonance: Another factor that improves volumetric efficiency is a resonance effect of the induction system. Almost everyone has thrown a pebble into a pool of still water and watched the rings develop from the point of contact. A similar effect takes place in the induction system of a motor, and if the system is of the correct length, advantage can be taken of these pressure waves so that the pressure side of the wave strikes the rotary valve or port when it is open. When this occurs, the system is said to be tuned. This same thing can be done with the exhaust system by use of different length stacks. However, there is one fact about this phenomena that makes it difficult for practical application, and that is that tuning exists only at the one speed for which it was calibrated. So if an engine is tuned, one must be careful that it is operated at this speed.

7. Temperature Vs Volumetric Efficiency: Up to now we have discussed methods of increasing volumetric efficiency. Probably the worst drawback to getting really good volumetric efficiency in this type of engine is its plan of operation. So much heat is lost by the fuel in the carburetor process (latent heat of evaporation) that the inside of the induction system operates at near freezing temperature, and on the other side of the piston head, only about five-sixteenths of an inch away, we have temperatures that approach the melting point of the metal involved; however, much of the heat travels through the piston head, and contacts the intake charge.

When the incoming charge strikes this hot piston interior, it expands and tends to hold the dense energy packed charge from entering. Very little can be done about this fact, except to provide all the piston cooling possible.

8. Hi-Speed Cycle: Figure 2 is a diagram of the crankcase cycle of an engine designed to operate at better than six-thousand RPM. The cylinder cycle of events remains the same as our basic diagram except, that the inactive part of the cycle has become a continuation of the intake process. This occurs because at high-speeds the duration of this event isn't sufficient to transfer the contents of the crankcase.

9. Compression Ratio and Compression: A good example of why compression is necessary is the case of ordinary gunpowder. A charge placed on the ground and ignited will burn with a sputtering flame, but put this same charge into a confined cartridge and ignite it, and an entirely different reaction occurs.

Courtesy of Boatsport.org

ROTARY VALVES

52. Rotary Valves: The modern racing engine employs rotary valves of the following types: internal barrel type integral with the crank, such as the Class "A" motor; flange, or "pie cut" type as used in the Midget; and the one-half speed externally geared type as used in Classes "B" and "C".

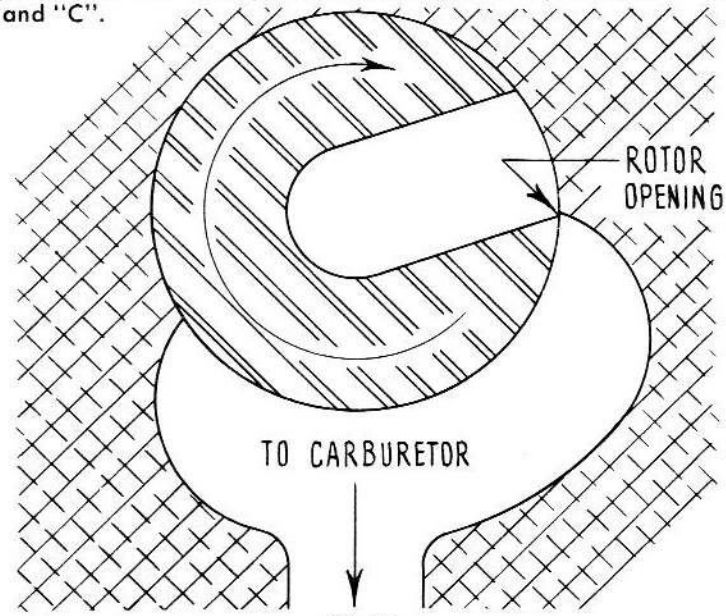


FIG. 28

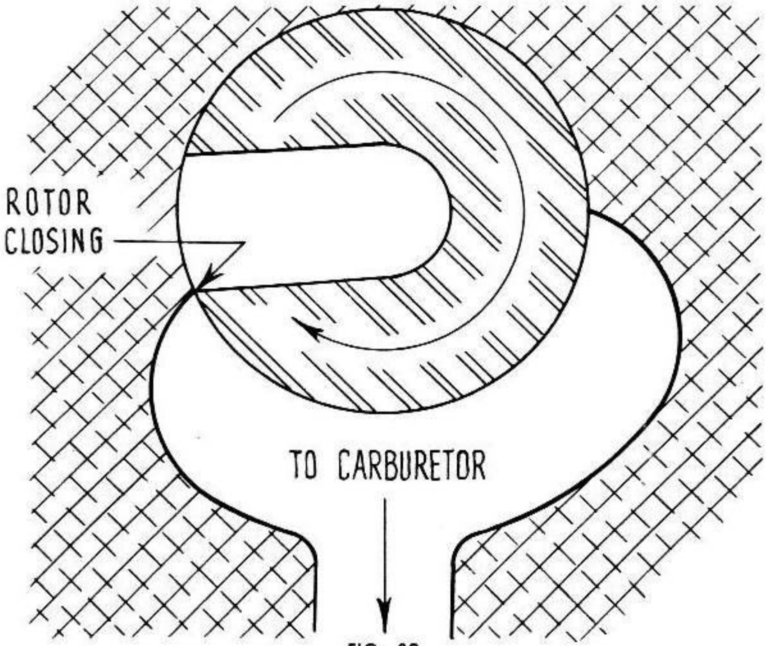


FIG. 29

Courtesy of Boatsport.org

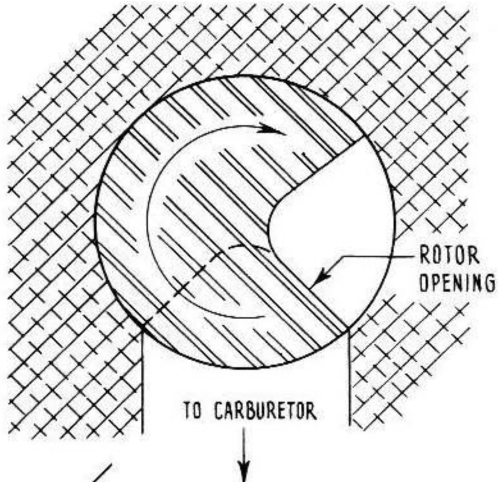


FIG. 30

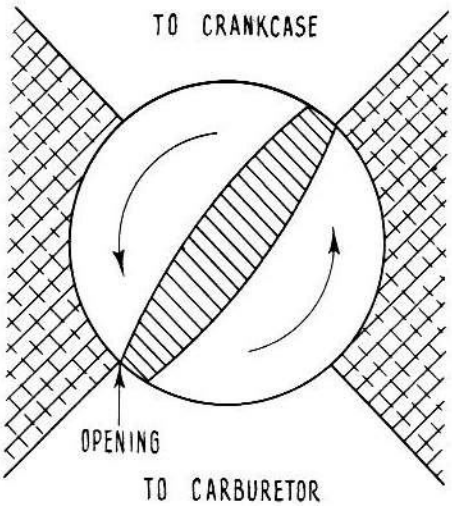


FIG. 31

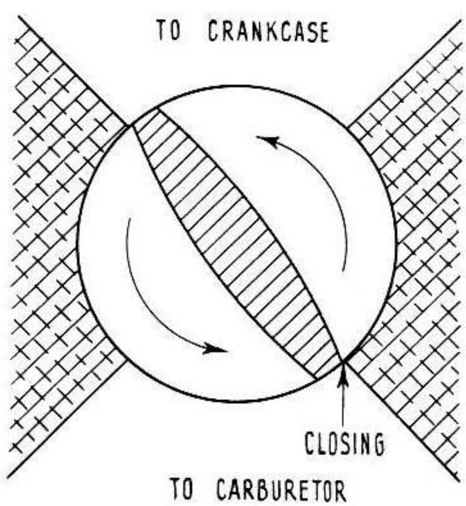


FIG. 32

Courtesy of Boatsport.org

The barrel type indexes as illustrated in Figure 28 and 29.
The flange type indexes as illustrated in Figure 30.
The external rotor indexes as illustrated in Figure 31 and 32.

In the discussion on engine design we pointed out how the rotary valve is held open past TDC to make use of the advantage of inertia of the fuel charge. The degree to which this is done depends upon the speed at which the engine operates. The graph in figure 33 gives the approximate number of degrees that the rotor is held open after TDC for different speeds. Although a gain is made in peak output by holding the rotor open longer, a much greater loss in peak torque is realized than the gain in power output. Acceleration is a result of torque or excess HP at slow speeds rather than peak horsepower; so if the motor is to be used on a very short course there may be an advantage in retaining the torque and sacrificing some horsepower. The author has standardized on sixty-eight degrees for this event for his own motors. The rotor opening event doesn't seem to be quite as important as the closing event. Generally it is near enough to open the rotor when the intake port in the cylinder closes. In four stroke engines it is common practice to open the intake valve before the suction stroke begins; this practice does not show any advantage in our type of engine. In fact, if this is done, the engine will definitely be harder to start and no apparent difference in output will be noted.

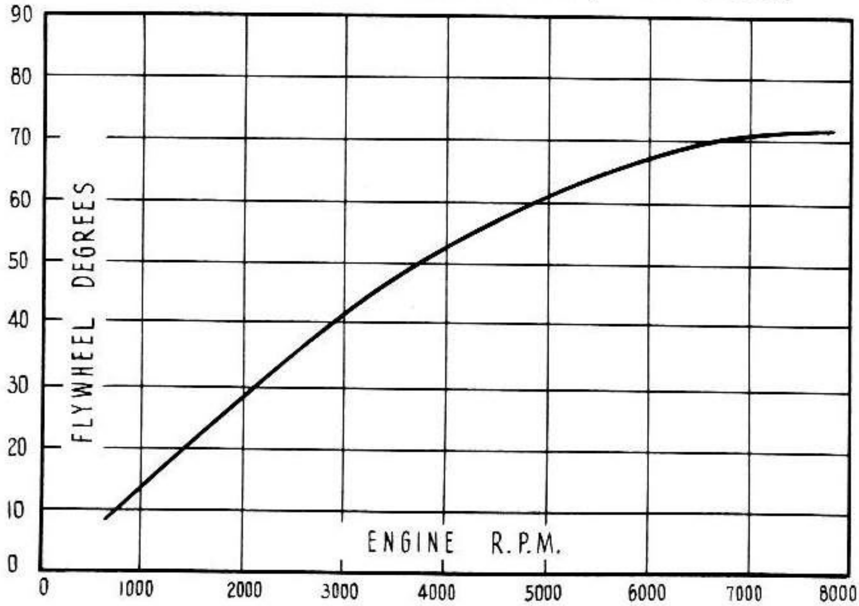


FIG. 33

After you have completely familiarized yourself with the operation of the rotary valve, you should check the timing. To do so you'll need the same flywheel protractor that you used in selecting cylinders. Set it up in the same manner with the 0° mark at TDC. Rotate the flywheel until the piston passes BDC and moves upwards and just closes the intake port. Now check the rotor opening for this respective cylinder. It should be just ready to open. If it isn't, determine how this event can be corrected, and correct it. As a rule it is better to alter the crankcase rather than

Courtesy of Boatsport.org

the crankshaft. B and C rotors will not be right; however they will be discussed in a special section and this will be taken up then.

Granting that this event is correct or it has been corrected, rotate the flywheel past TDC until it has reached the predetermined number of degrees hold over. For example: if it is sixty-five degrees ATC, we would turn the flywheel until sixty-five degrees was reached. Generally this event has to be altered. In the case of the Class "A" the crankshaft has to be ground to obtain this setting as it is impossible to cut away enough from the case. Figure 34.

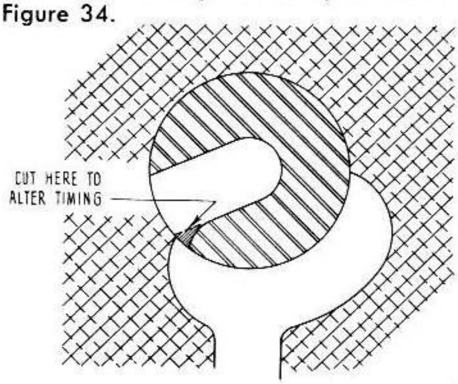


FIG. 34

This is also the case with some flange rotors. A common practice is to bevel the corners of the indexing edges so that the blunt corner doesn't cause turbulence of the inflowing charge.

53. Class "B" and "C" External Rotors: If these rotors are set so that they open as the intake port closes, they will close at about fifty-two degrees ATDC. Naturally this would not give us peak output. If we set it so that it just closed at sixty-eight degrees, we would lose a lot of the suction stroke. The trouble is that the rotor event is too short. To lengthen it we must file out some of the rotor case. Figure 35.

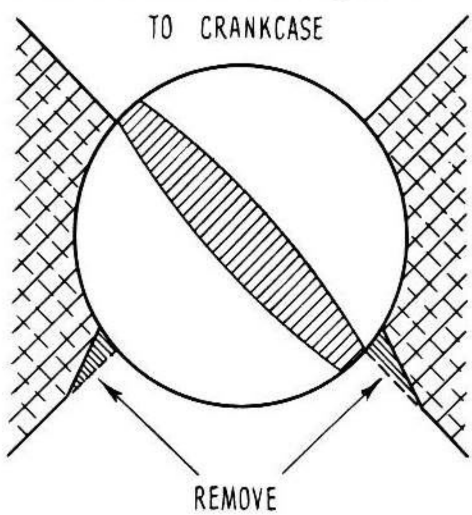


FIG. 35

Courtesy of Boatsport.org

To do this apply layout dope to the inside of the rotor case and install so that the error in timing is divided up. Now turn the flywheel until the necessary hold over is reached, and mark the case along the rotor. It will be necessary to remove the rotary valve to do this, so use every precaution to see that it doesn't turn during removal. The same procedure is used to determine the opening event.

Once these positions are scribed, the material can be removed by filing.

As the openings in the rotor are only cored in, they are apt to be rough and should be cleaned up. Care must be taken that the center section isn't altered excessively as this might affect timing. The other sides can be enlarged and filed to any extent as they do not index or seal.

The top bearing and retainer for this assembly has been difficult to obtain, and for this reason many rotors are altered to make use of a standard 202 bearing at this point. See Figure 36.

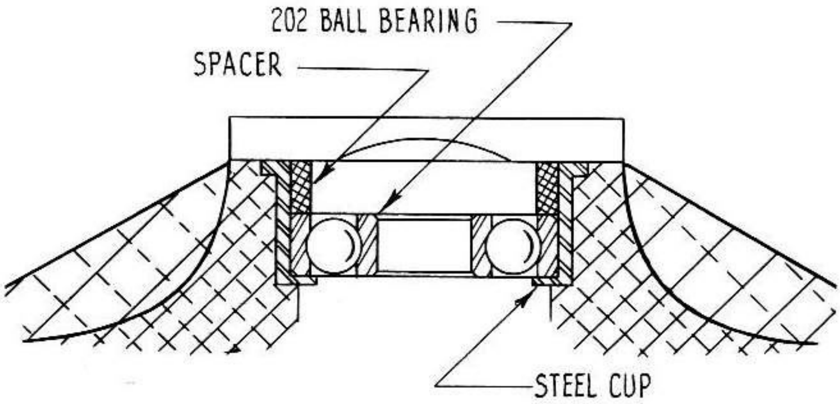


FIG. 36

54. Rotor to Rotor Case Clearance: A lot of drivers and mechanics spend many hours and much effort fitting the rotor to its case with very little clearance. If one is very careful, this can be done and have a free running assembly, or in the case of the internal rotors, a free running crankshaft. Our experiments have shown this to be of no advantage, especially as a tight fit always multiplies the chances for friction and seizure.

We have found that the diametrical clearances from .003 to .006 on a Class "A" gives best performance. Class "B" and "C" motors need slightly more or from .004 to .0065.

If for some reason your rotor clearance is in excess of the above figures, it can be corrected as follows: by installing an oversize rotor, by babbitting the crankcase or rotor case, and by installing a bushing or sleeve. Probably the cheapest method is the babbitted case. This is done by tinning the case with aluminum solder and puddling a layer of babbitt over this. Of course, this surface has then to be bored or machined to the required fit. This seems to be a very popular and practical method of reducing clearances, but it requires some experience to do a good job, and it is therefore recommended that anyone attempting the use of this procedure, practice on some pieces of scrap aluminum first.

Courtesy of Boatsport.org

Sleeving rotor cases is expensive and it requires much experience. Because of the port openings the sleeve must be made very thick so that it will not be distorted or deformed when it is pressed in place. After this, it is bored to size and the openings filed out clean. Generally the inner diameter or the case is left slightly under size and the outer diameter of the rotor is turned to provide a clean, true surface. When this procedure is used, care must be taken to see that the bottom bearing pilot fits the case perfectly.

When sleeves are put in a Class "A" crankcase, the crankcase inner diameter is bored oversize about 3/16 on the diameter, and a sleeve made to fit it, but as the sleeve is too large to go through the crankcase head opening, it is cut into two halves, and these sections are then secured to the crankcase by means of short 6 x 32 screws or rivets. After the pieces are in place, the joints are filled with solder and the rotor surface bored to fit the crank. Sometimes this sleeve is made oversize and the entire rotor surface tinned and babbitted. This method covers up all rivets and screw holes and perhaps is easier on this crank; however, a babbitt lining will have no effect on output.

Oversize rotor castings for Class "B" and "C" motors can be obtained and machined to fit these rotors.

Flange type rotors are treated in a manner similar to the other types. Babbitt can be applied to the lips of the crankcase opening and the end play of the crank adjusted slightly tight so that these surfaces will wear in to form a tighter seal at this point.

55. Rotor Port Areas: It might be generally stated that the cylinder ports are the limiting factor in volumetric efficiency of this type of two stroke racing engine. This isn't difficult to comprehend as one can easily understand why the size of the cylinder ports is limited. As a rule any opening or port in any other part of the induction system should be at least twenty-five per cent larger than the cylinder ports. In fact, it might be well to enlarge these ports even more if sufficient material makes this possible.

Remember that in the case of an opposed cylinder arrangement with a common crankcase chamber the rotor opening must be twenty-five per cent larger than the sum of the areas of both cylinders' ports. In some engines the rotor definitely restricts volumetric efficiency, so any work here really pays off.

56. Carburetors: The two most popular carburetors for racing motors are the Horizontal SAE one inch Tilitson and the Vacturi.

In the author's opinion both of these are inadequate and entirely out of date. The discharge nozzle arrangement of the Vacturi makes it impossible to calibrate smaller venturis, and the well around the discharge nozzle is practically worthless in the Class "A" carburetor. The APBA racing rules states that any carburetor that has been supplied as standard equipment on any outboard motor can be used for racing. The use of these two carburetors seems to be a habit or custom, and any driver who has the opportunity to do some careful experimenting on the adaptability of some of the new service motor carburetors might find a definite improvement.

Remember that the proof of a good carburetor is not found at top speed, but in the mid ranges. Any carburetor that is of adequate size will generally pull full power, but it takes a good carburetor to give good acceleration and performance throughout the entire range. The theory

Courtesy of Boatsport.org

of carburetion was pretty well discussed in the early section of the publication, so it won't be dealt with here.

57. Air Horn: One of the first things that the amateur mechanic does to try to improve output is to construct a funnel on the airhorn. This is really wasted effort as it requires that the pressure of the air stream must be approximately 1/4" of mercury in order for any difference in output to be detected. The pressure at 60 MPH is about 2" of water or 5/32" of Hg. This ram effect isn't even practical on ordinary airplanes.

Courtesy of Boatsport.org

THE FLYWHEEL

58. The Flywheel: The flywheel is a much more important part of the engine than it is given credit for. In fact, without it the engine could not operate. The duty of the flywheel is to distribute the energy of the power impulse to all the other points of the cycle. It does this by making use of the law of inertia. At the power impulse it absorbs energy, and it releases it at the other parts of the cycle. This means that strains on the keyway and hub of a one cylinder or two cylinder opposed type are completely reversed during one revolution. Multiply this by 7000 RPM and the result is that strains change direction 14,000 times per minute. Experience has shown that aluminum hubs just can't take it for long. To correct this weak point an alloy steel hub is installed. The usual method is to construct the hub with a large flange and rivet this securely to the wheel. Figure 37.

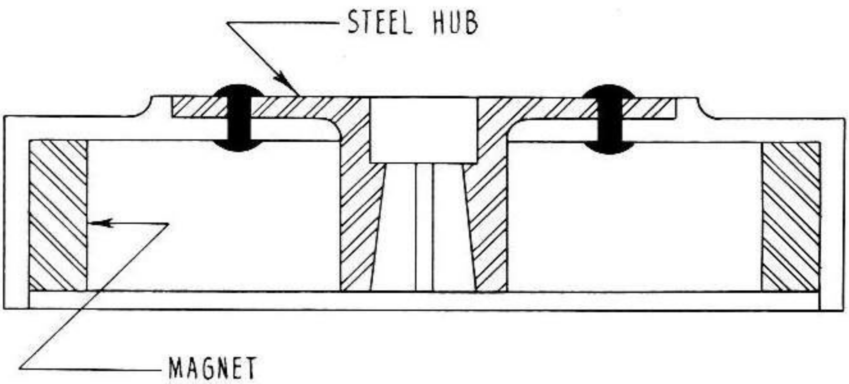


FIG. 37

The taper in this hub must fit the crankshaft perfectly. If there is just the slightest amount of "wobble", the whole assembly and crank can be ruined, not to mention the personal damage that may result.

To insure good performance from the magnets it is wise to have them charged frequently.

59. The Magneto: Probably the best thing that can be done to the magneto is to leave it alone. Of course, if the magneto is a used one and oil soaked and coated with dirt, this is a different matter. If this is your case, soak the entire plate in carbon tetrachloride and scrub the dirt off with an old tooth brush or something similar. After it is clean, disconnect all the wires and remove the points. If an outboard repair service with up-to-date ignition equipment is available, have the coils and condensers checked. If one isn't available, send the plate to the manufacturer for this test.

If these parts check OK, assemble the points and the rest of the plate. If the points show signs of pitting and erosion, install new ones. Use new wires to connect the coils to the points and also to the condenser lead. Use radio or resin core solder, **never acid core.** These wires should be replaced every second season or oftener as they are inclined to become crystallized from vibration and break. This happened to the author at the start of the second heat of the 48 Nationals after he had won the first heat of Class "A", Division I.

Courtesy of Boatsport.org

Many drivers install double springs on the point arms. This isn't necessary if the spring is up to "new" tension. In an outboard engine with one breaker per cylinder the points break 6000 times per minute at 6000 RPM. You can see that this isn't excessive as automobiles break two times as fast and still encounter no trouble.

Much trouble can be eliminated on Class "A" and similar motors if the armature plate is locked securely in place. This is done in the case of the Class "A" by constructing a clamp that utilizes two of the crankcase head studs. Never tighten up the split clamp on the armature plate flange too tight. There is some growth of the crankcase head when the engine is running and if too tight, the casting may be broken or undue friction at the top bearing may result.

Courtesy of Boatsport.org

GAS TANK

60. Gas Tank: The gas tank is a rather simple part on a racing motor but as simple as it is, it can be very troublesome. Many a race has been lost by the gas tank **flying off.**

Most tanks hold about 16 pounds of fuel and are supported on three little 1/4 inch ears. Actually the static strength of these mountings is several times stronger than necessary, but in a running condition the fuel is sloshing back and forth, sometimes placing all the load on one ear. Even so, the gas tank could probably stay together if it wasn't for the fact that the empty portion of the tank acts as a sounding box and sets up a resonance condition with a very high frequency. These vibrations cause fatigue in the ear material, and consequently, they break. For this reason the gas tank should be kept full so that the fuel can dampen these vibrations.

These ears can be reinforced by welding, but this is a job for an expert, as bad technique can weaken the metal to a point where it is worse than if it were left alone.

Fuel line fittings should have at least a 5/16 inch inner diameter, especially if an alcohol base fuel is used.

It is common practice to raise the fuel tank in order to create more pressure at the carburetor. When this is done, the utmost care must be used to see that the spacers and risers are of sufficient size and rigidity so that the tank won't set up a vibration of its own.

61. Fuel Lines: Every imaginable type of material has been used for this item; however, nearly all experienced drivers will say that a flexible type works best, their main reason being that these types do not crystallize from vibration, and break. Another advantage is that fuel can be flowed through these lines easier under the same vibrating conditions. A good set up is 3/8 inch inner diameter Neopreme tubing with "Areo-Quip" fittings. See Figure 38.

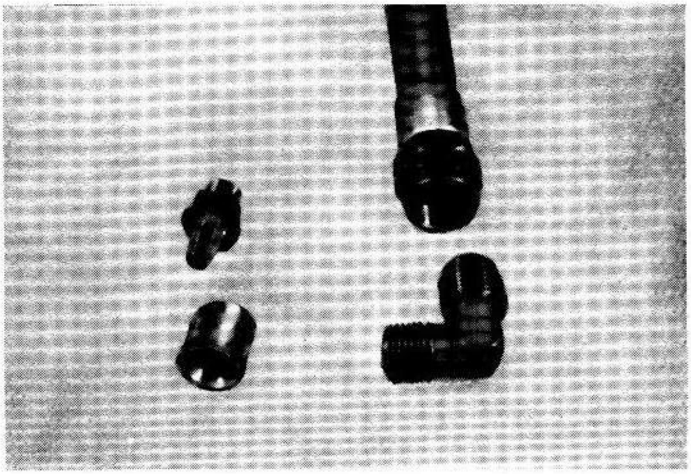
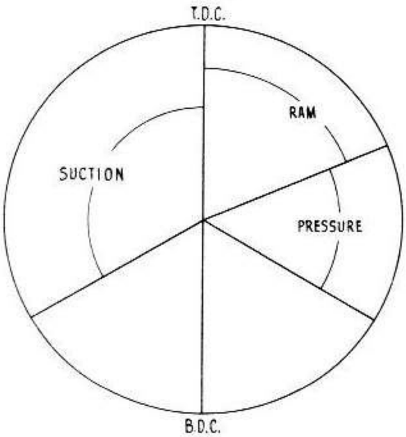


FIG. 38

Courtesy of Boatsport.org



CRANKCASE CYCLE
6000 R.P.M.

FIG. 2

A similar case occurs in the cylinder and combustion chamber. The charge of gun powder fired in the open possesses just as much energy as the charge fired in the cartridge. Only in the case of the powder in the open, all the energy was liberated in the form of heat, while in the case of the powder in the cartridge mechanical energy was also liberated. This also is true in the cylinder of an engine. The more confined a charge becomes before combustion, the more mechanical energy will be liberated and less heat. There are certain limitations, however. For one thing, as more power is taken from the charge and greater pressures are developed in the cylinder, mechanical strains may develop beyond the strength of the parts and assemblies, and then mechanical destruction will be the result. The real limitation, however, is detonation or spark knock.

10. Detonation: All experienced mechanics are familiar with the "ping" caused by bad gasoline or improperly set timing. This is technically called detonation.

It can be seen by the indicator diagram, figure 3, that combustion is really begun in what should be the last of the compression stroke.

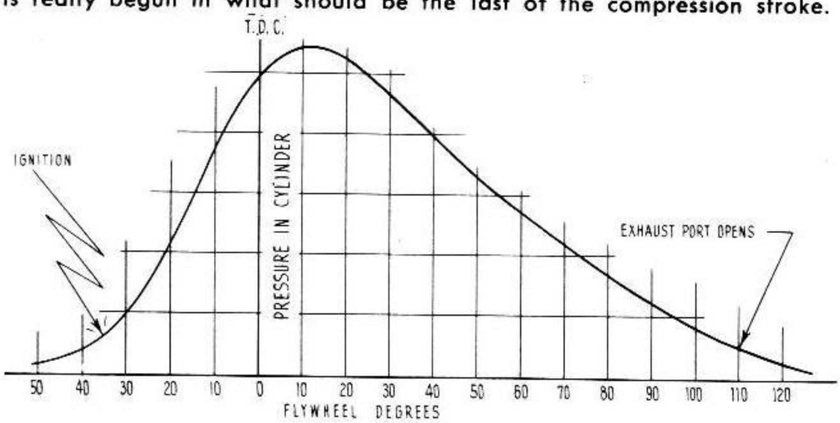


FIG. 3

Courtesy of Boatsport.org

62 Fuel Tank Caps: Perhaps many readers wonder why such a minor item as this should even be included in our discussion. The fact is that this minor item has lost many a race.

If your cap has a threaded type air vent, remove it. These things have a habit of vibrating closed even when they are screw out tight.

Remove the chain that keeps the cap from dropping out when pouring in fuel, and put an extra cap in your tool box. It is almost impossible to keep this chain from coming loose and finding its way over the fuel line fitting.

Always tighten the cap in place with a pipe wrench or battery pliers. A piece of strap metal welded across the top makes a good handle and can easily be tightened by rapping with some heavy object.

Courtesy of Boatsport.org

THE DRIVE SHAFT HOUSING

63. Drive Shaft Housing: This is another seemingly unimportant part that can cause a lot of trouble on some motors. The drive shaft housing or torque tube has to withstand the thrust of the propeller and torque of the engine. The torque amounts to less than forty foot pounds in the larger engines, but the thrust exceeds several hundred pounds; so probably it is a combination of the thrust, vibration, and shock that causes this part to fail and not torque.

Class "A" housings are particularly susceptible to breaking. In fact it is just a matter of time before the original "A" factory housings will let go. The critical place is directly under the power head, and trying to reinforce this point by welding is impractical. The price of a heavy replacement housing is good insurance when one figures the cost of the entire engine against it.

Class "B" and "C" housings are not as subject to fatigue as the "A" and "F", but they do have one feature that should be corrected, and that is the fit of the projection that pilots in to the crankcase head. Originally this part was made to pilot into a crankcase head that had been bored for a bronze bushing only. When this head was bored out larger to accommodate a bearing race sleeve, it left a lot of room around this pilot which the factory neglected to correct. This means that the location of these parts is controlled by the studs, which is a very indefinite way of locating. To correct this trouble, and to minimize "universaling" at the drive shaft spline, install a ring or bushing over the housing pilot and machine it down until it is a good fit into the crankcase head.

It seems to be a rather common practice to drill a 3/32 vent hole near the top of the housing. This is supposed to relieve any vacuum in the housing caused by the crankcase processes. If a vacuum existed, it would tend to pull grease out of the lower-unit and pull in water to replace the grease.

Drive Shaft Housing Bearing: This item receives about the same punishment as the drive shaft housing itself. Most of these parts are now made of bronze, as almost all the aluminum ones have failed and therefore are extinct. If you should have an aluminum one, you would be wise to replace it. An aluminum cap is entirely satisfactory as it is subjected to almost a pure tensile strain which it can withstand.

Some drivers encounter trouble with the cap mounting studs coming out. This can usually be corrected by placing automotive connecting rod shims between the cap and hinge and calibrating them so that a definite drag is felt when the cap is tightened down. This puts more tension against the threads and locks them better. In real stubborn cases a hole can be drilled through the hinge and through the stud and a small taper pin installed. **Always safety wire the cap nuts after tightening.**

64. The Stern Bracket: If reasonable care is used when the motor is secured to the transom, and the clamps are not over tightened and strained, this part should give very little trouble.

Do not unscrew the clamps too far as doing so will remove the transome pads.

Courtesy of Boatsport.org

THE LOWER-UNIT

65. The Lower-Unit: The lower-unit study could be very extensive and involved. The ordinary engineering standards and formulas apply to the gearing and shafting; however, the external shapes and contours deal with the science of hydro-dynamics. In this chapter we are going to deal with theory only where there is an immediate connection to the practical.

In the author's opinion the mechanical parts of the lower-unit are adequate and no change is required. Some drivers favor replacing the top pinion shaft bushing with ball-bearing in the Class "A" lower-unit. A ball-bearing will have greater endurance than the bushing, but increased output from this change would be difficult if not impossible to measure.

Some drivers use stainless steel propeller shafts. This is to reduce rust and corrosion. They might be especially desirable in salt water areas. Fresh water doesn't give too much trouble if the parts that are submerged are wiped off with an oily rag after use.

Sometimes the pinion shaft drops down and causes the gears to feel rough when the propeller is rotated manually. This is not too serious, as the upward thrust keeps it in position when running. If you suspect this condition, turn the unit upside down and rotate it. If the roughness is gone, it was likely the trouble. Some drivers correct this condition by installing a sheet metal clamp to hold the bearing and shaft up where it belongs.

66. Lower-Unit Contours: Generally speaking, the streamlining factor of a lower-unit is controlled by the proportion of length to width or length to diameter. When a given length is enforced as by the APBA

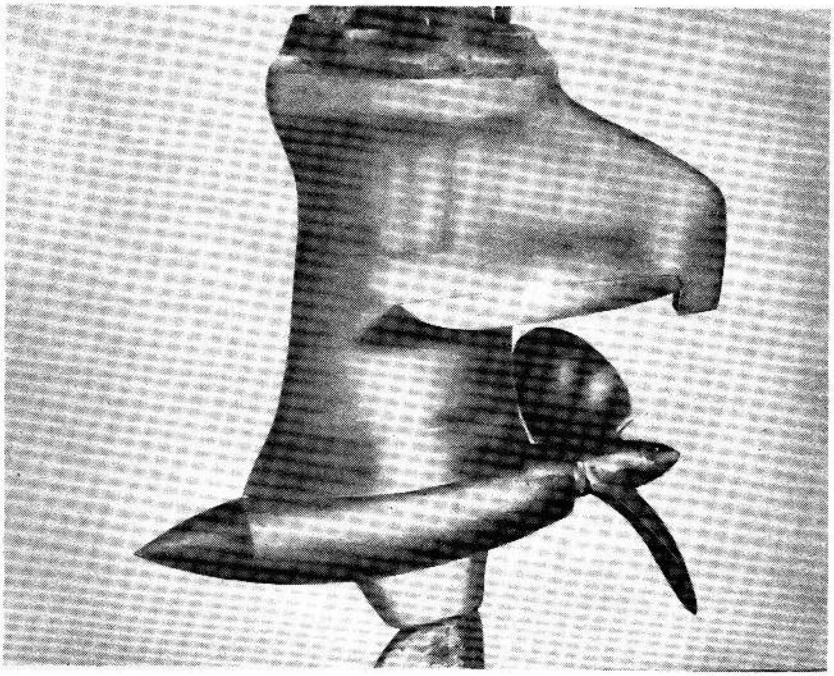


FIG. 39

Courtesy of Boatsport.org

rules, the only thing left to do is to reduce the diameter or width, and these are limited by the internal machined dimensions if not by the rules. The position of the maximum cross sectional area is also important. Our experience has shown this to be just slightly ahead of center for best results. If it is too far forward, it will present too blunt a point and not part the water correctly, and if it is too far back, the water will not close in behind. Center is considered as being midway between the point of the cap and the point of the propeller nut.

The skeg presents more of a cross sectional area than might be imagined and therefore should be thinned down and all that it not absolutely necessary removed.

If no rules have to be followed, the lower-unit can be improved by longer caps and other leading edges.

Figure 39 shows a cut down racing lower-unit.

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SECTION III

ASSEMBLY

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Up until now the discussion has revolved around individual parts and assemblies. The purpose of this chapter will be to coordinate all these individual units into a complete engine. Naturally all the precision that was built into these individual parts must be applied to the assembly process if this effort is not to be wasted.

We are assuming that the reader had some sort of motor stand to perform the disassembly operation on. If not, one should be obtained or constructed. In an emergency a stand can be made by nailing a plank across a doorway. Have plenty of light and above all make sure that everything is immaculately clean.

67. Stern Bracket Assembly: To start with, place the stern-bracket on the stand and snug up the clamps. Assemble the hinge and drive shaft housing. Be sure to check all the studs and make sure that they are tight.

68. Crankcase and Shaft: Loosely assemble the crankshaft in the case and with a pair of dividers center the crankpins with the cylinders. Sometimes this can't be done exactly because of the spacing of the pins. If this is so, the difference should be averaged up. When the location of the crank is established, determine the distance between the bottom crank thrust surface and the bearing, with feeler guages. If your case has a ball-bearing at this point, it will only be necessary to provide a spacer or shims equivalent to this distance. If it has a thrust surface of bronze, this can be raised by placing the shims under it. When this is done, assemble the entire crankcase with a gasket at the head and tighten down until snug. Attach a dial indicator on the case so that the spindle rests on the top of the crank. Now with a screw driver pry the bottom crank cheek up and note its travel. Again if the motor is equipped with a ball-bearing at this point, you need only add shims of the equivalent distance, minus, of course, the allowance for end clearance, between the top cheek and bearing. If the case hasn't a ball bearing and the clearance is excessive at this point, some other method will have to be devised to reduce this clearance. Longer bushings could be made or the original one pressed down if this distance isn't too great. The case assembly can be set up on the drive shaft housing now, and all the nuts torqued down to specifications. Spin the crank with the fingers and see how free it feels. If for any reason there is a tight spot or a drag, locate it **now** and correct it.

69. Connecting Rods: When the case assembly is as near perfect as you can make it, you can hang the connecting rods. A good way to keep the rollers in place is to coat them with a dab of vaseline. **Do not lean on the connecting rods when tightening the bolts.** Use a torque wrench on the bolts and do not over tighten. Aligning the caps was discussed under the subject of connecting rods.

70. Cylinders: To assemble the cylinders we need our protractor again. Place the flywheel on the crank and spin the nut on by hand. Now set up the protractor. Again we have use for our timing piston which we constructed earlier when working on the cylinder; so install this on one rod and install this cylinder, but without a gasket. Two nuts should be sufficient for this purpose.

Rotate the flywheel until the intake ports just open. This should be from 118° to 122° ATDC, but it probably won't be, as the metal that was removed from the cylinder contact face changed the timing. If this is the case, install enough gaskets to correct the timing. If the total thickness of all gaskets that are necessary to calibrate the port timing should

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exceed .030, they must be replaced with metal ones. This is done as insurance against distortion and is particularly necessary in the Class "A" motors. The spongy effect of the gaskets lets the ears bend slightly and consequently distorts the case.

A metal spacer or gasket can be made from sheet aluminum or annealed copper. Be very careful when cutting that the metal is not buckled or kinked. The thickness of the metal should be about .006 thinner than necessary, and a .003 paper gasket placed on each side.

This may seem like a lot of unnecessary work. It is a lot of work; however, it was a lot of work to set up the crankcase and true up the cylinders, and all this effort could be wasted by haphazard and hurried assembly at this point.

This procedure should be applied to all cylinders and the intake port opening events should be exactly the same. This is especially true on opposed engines.

If the cylinder is ported correctly, there will be about 10° to 12° difference between the opening events of the intake and exhaust ports.

71. Pistons: Assemble the rings on the pistons, being very careful that the ring ends do not score the piston. Apply some light oil to the rings and rotate it into the gooves. Oil up the piston skirt and the cylinder bore and insert the piston into the base of the cylinder. Work the rings in with great care and shove the piston in until the piston pin hole just projects out. Oil up the piston pin and start it in the bottom of the piston. Now holding the rod in place push the piston pin in place and shove the cylinder against the crankcase. Take care that the weight of the cylinder does not rest on the rod while this is being done. Spin on a couple of nuts and snug them up. Rotate the crankshaft and check the clearance between the opposite connecting rod and the piston skirt.

72. Cylinder Head: Put the head gasket in place and put a dab of heavy grease on several points of the piston head. Place a small lead shot or piece of solder in the grease. After you have assembled the head, rotate the crank and pass TDC. Some resistance will be felt but continue until you are over the "hump". When you remove the head, you can get a pretty good idea of the piston to head clearance by the thickness of the lead. This should be at least .020 at all points, even on the Hi-Turbulence type. If this point is OK, install the head and check the compression ratio. In all probability you will want to raise the compression ratio somewhat. The chart below will tell how much to face off the head to remove 1 c.c. volume. This applies to heads that are round at their contact face.

Bore size	1 c.c. or M.L.
2-1/8	.0155 in.
2-3/8	.0125 in.
2-3/4	.0095 in.

When the correct compression ratio is reached, the lead test for clearance should be applied again. If there are any tight spots, they will have to be scraped off the head.

Now we are ready to tighten down the cylinder and head permanently. Use shake proof lock washers under the cylinder nuts and tighten each just a little at a time while you rotate the crank. Use a torque wrench

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on the head nuts and follow the chart in the apend.

73. Rotary Valve: If your engine has an external rotary valve, it should be installed at this time. Put the rotary valve assembly on the crankcase without any gaskets and draw up snug with a couple of nuts. Now reach into the mouth and grasp the center bar of the rotor and see if you can shake it from side to side. This is to check for gear clearance. If no motion is felt, add gaskets until you can just detect some motion and then add .004 more. This should give about .005 clearance. If motion is felt without any gaskets, weave a piece of scotch tape in and out a few teeth and assemble the valve. If this takes up the clearance, it means that there was about .004 clearance; so use a piece of writing paper for a gasket. This will give a little more than .005 clearance but isn't too important, the important thing being that there is at least .005 clearance. When the correct clearance is obtained, you can time the rotary valve and assemble it permanently. Use a torque wrench on the nuts so as not to distort the valve or the crankcase.

74. Lines: Now is a good time to install the water lines, oil lines and other small accessories, as on some motors they are not accessible when the flywheel is in place.

75. Crankshaft Keys: When installing these keys, be sure that they do not fit too tight. **Do not drive them in.** Doing so can break a

FIG. 40

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roller or damage a bearing, not to mention the strain it places on the keyways of the crankshaft. If they are too tight, lap them down on a piece of emery cloth. Never use a key that is too loose, either, as this will allow the parts to chuck and wear out. A light tap fit is desirable.

Do not tighten the flywheel nut down "for keeps" yet. It might have to be removed again for ignition timing alterations.

76. Ignition Timing: To check the ignition advance you must again use the protractor, and when you are through, be sure that the flywheel is tightened securely by a few hammer blows on the wrench.

No two engines require exactly the same ignition advance. So many things influence the timing curve that it is impossible even to approximate a setting. A very simple and safe rule is to use no more advance than will give full power. As has been stated in previous chapters, detonation is inaudible at high speeds, and one sure way of causing it is to overly advance the ignition timing.

A good way to obtain a setting is to make a test with the spark set at about 34° BTDC and then advance it a few degrees. If no increase in speed is obtained, retard it to 32° BTDC and continue to retard it until a definite loss is encountered.

The photo in Figure 40 is of a piston that had been run under detonation without the driver realizing it.

Many drivers who run their compression ratio on the limit, construct a stop on the rotary valve of B and C motors so that they merely set the spark lever against this when they are running. This device may save a piston or keep the engine from overheating and losing power after a few laps.

Once the correct timing is obtained, it should be checked and noted in flywheel degrees so that it can be had for reference in case it is necessary to replace the armature plate, breaker cam, etc., or even adjust points.

77. Timing Light: The easiest way to do this is with a timing light. This can be constructed very simply with a couple of flash light batteries and bulb. See Figure 41.

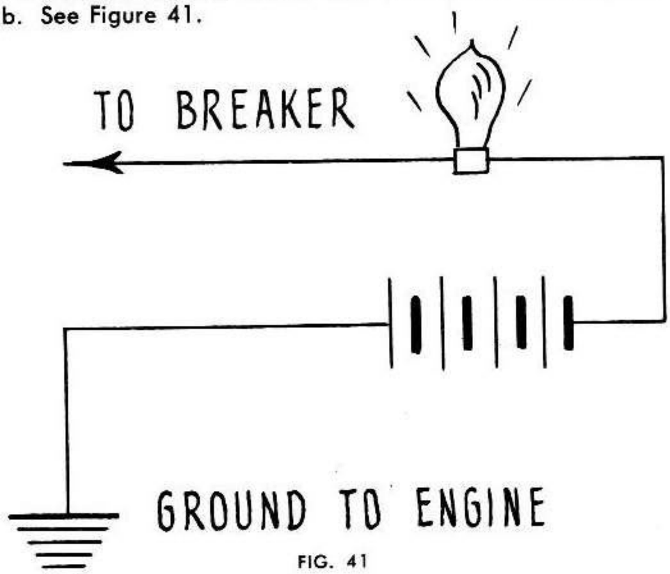

FIG. 41

Courtesy of Boatsport.org

sixty-five equals sixty-five or sixty-five percent; so this engine would have a volumetric efficiency of sixty-five percent.

5. Induction System Ram: Air when in motion acts like a large truck on a level road in that it requires all the energy and force necessary to put it in motion, to brake or stop it. This is considering friction and wind resistance as forces. This is called inertia or the tendency for a body in motion to continue in motion or a static body to remain static. The air entering the carburetor of an engine is affected in the same manner; and once it is started in motion, the tendency is to keep moving. To take advantage of this fact, we hold the rotary valve at the crankcase open after TDC. This is the point where crankcase suction ceases, and then the action of the charge in motion rams the crankcase with more charge. This effect is great enough at high speeds to make it possible to hold the rotary valve open through what would be more than one-half of the crankcase compression stroke.

6. Induction System Resonance: Another factor that improves volumetric efficiency is a resonance effect of the induction system. Almost everyone has thrown a pebble into a pool of still water and watched the rings develop from the point of contact. A similar effect takes place in the induction system of a motor, and if the system is of the correct length, advantage can be taken of these pressure waves so that the pressure side of the wave strikes the rotary valve or port when it is open. When this occurs, the system is said to be tuned. This same thing can be done with the exhaust system by use of different length stacks. However, there is one fact about this phenomena that makes it difficult for practical application, and that is that tuning exists only at the one speed for which it was calibrated. So if an engine is tuned, one must be careful that it is operated at this speed.

7. Temperature Vs Volumetric Efficiency: Up to now we have discussed methods of increasing volumetric efficiency. Probably the worst drawback to getting really good volumetric efficiency in this type of engine is its plan of operation. So much heat is lost by the fuel in the carburetor process (latent heat of evaporation) that the inside of the induction system operates at near freezing temperature, and on the other side of the piston head, only about five-sixteenths of an inch away, we have temperatures that approach the melting point of the metal involved; however, much of the heat travels through the piston head, and contacts the intake charge.

When the incoming charge strikes this hot piston interior, it expands and tends to hold the dense energy packed charge from entering. Very little can be done about this fact, except to provide all the piston cooling possible.

8. Hi-Speed Cycle: Figure 2 is a diagram of the crankcase cycle of an engine designed to operate at better than six-thousand RPM. The cylinder cycle of events remains the same as our basic diagram except, that the inactive part of the cycle has become a continuation of the intake process. This occurs because at high-speeds the duration of this event isn't sufficient to transfer the contents of the crankcase.

9. Compression Ratio and Compression: A good example of why compression is necessary is the case of ordinary gunpowder. A charge placed on the ground and ignited will burn with a sputtering flame, but put this same charge into a confined cartridge and ignite it, and an entirely different reaction occurs.

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The wire to the breaker assembly is threaded through the hole that was drilled for the short-out wire, and is attached at the stationary point. The wire from the coil must be removed as this would cause a permanent ground.

Set up the flywheel protractor and rotate the flywheel toward TDC until the light just goes out. This is when the breaker opens and when ignition occurs.

Motors that use more than one breaker must have the breakers synchronized. The timing light is very convenient for this purpose. To synchronize these points, set them so they both fire at exactly the same number of degrees. This is generally done by adjusting the point gap, as usually the necessary adjustment can be made within the point gap tolerance, .016 to .022 inch.

Another way to obtain the point opening event is to insert a very thin feeler or strip of cellophane between the points and out the inspection hole in the flywheel. Apply an easy pull to the feeler and rotate the flywheel until the feeler just frees up. This is the firing point. The error is in the thickness of the feeler.

78. Gas Tank and Carburetor: After an ignition study has been completed, the gas tank, carburetor, and other accessories may be installed to complete the engine. Be sure that the control hardware is in good operating condition. Many a race has been lost by the bowden wire coming loose or the throttle arm dropping off. The best engine in the world cannot compete against neglect of these small items.

79. Dirt: Keep the engine clean and free of dirt. Never leave the engine with the ports and carburetor uncovered. If the location of the race is in a dusty area, plug the ports and carburetor between heats.

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SECTION IV
BALANCE

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Balance: This is a mystifying subject and one that is always associated with souped up motors. It hasn't been discussed before in either the section on parts or the one on assembly. This was because so many of the moving parts under discussion are concerned with the balance problem that if it had been taken up in relation to each part, it would have added excessive length to the book as a whole.

We've heard the terms static and dynamic balance expressed quite often, but what are they? Well, to begin with, static means at rest and dynamic means in motion. So dynamic balance is balance under motion and static balance is balance at rest.

80. Static Balance: Naturally static balance is the easiest to understand, and as it is the basis of dynamic balance, it must be considered first. A simple experiment will illustrate the elements of static balance. A small disc is cut from cardboard and the center pierced with a needle. If the disc is accurately cut and the center located true, it will automatically be in balance when allowing the disc freedom to rotate. If the disc has a heavy side, it will be pulled to the bottom by gravity. Figure 42.

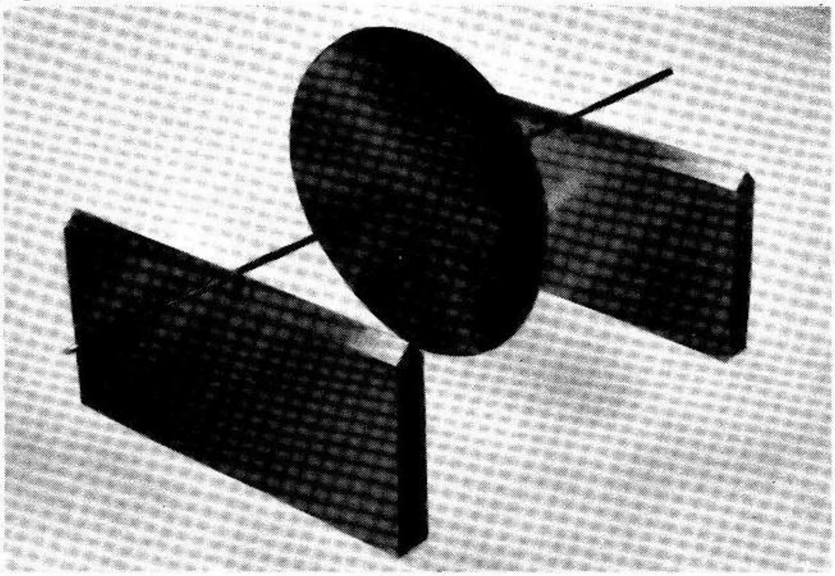

FIG. 42

Now purposely cause an out-of-balance condition by cutting a section out of the disc. Notice how readily this lightened side finds its way to the top. Figure 43. This should give you an idea of how an out-of-balance flywheel is affected. Balance is expressed in inch ounces or inch grams, the inch referring to the radius, and the weight to the difference between the light side and the heavy side. (In objects with a thin cross section such as a rotor gear, dynamic balance must occur with static balance.) When an out-of-balance object is rotated, this heaviness becomes affected by centrifugal force and tends to fly off at a tangent to the circumference, but as this is not possible, it continues to revolve around on its radius, exerting this unnecessary force on the bearings and other vital parts.

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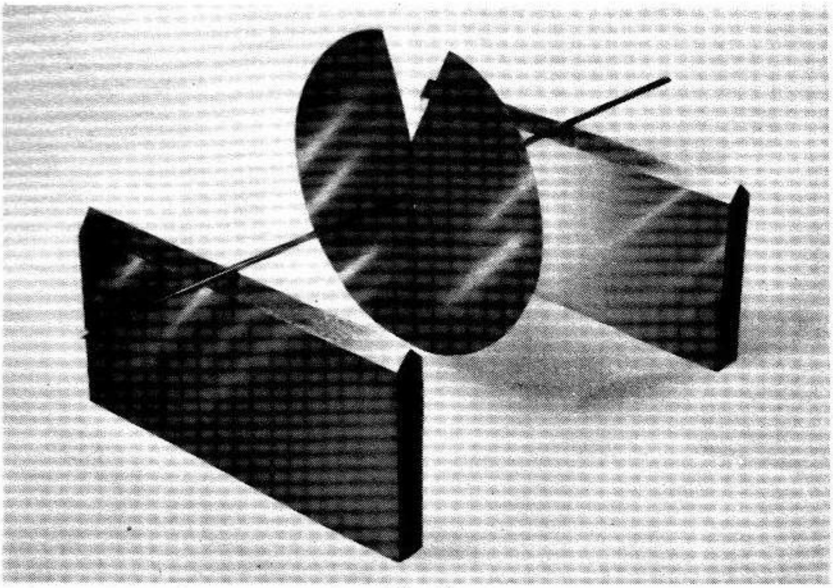

FIG. 43

To static balance a part, we must have a mandrel that will accurately support our part, and a level and smooth set of balancing ways. For small parts a lathe bed may be used as a substitute for these balancing ways. The overlapping disc type balancer is not to be desired for high speed outboard parts. If you possess or can construct the necessary equipment, you can balance many parts like the flywheel, rotor and gear, propellers, connecting rods, etc. The technique involved follows the same principle as our experiment with the pasteboard disc. First the heavy side is determined, and a line is drawn through this point and the center. A small weight is then added to the light side until it is possible to cause this line to balance out horizontally. Modeling clay makes a good weight. Once this line balances, a line is drawn at 90° to it and the procedure is repeated for this line. This will give four balancing

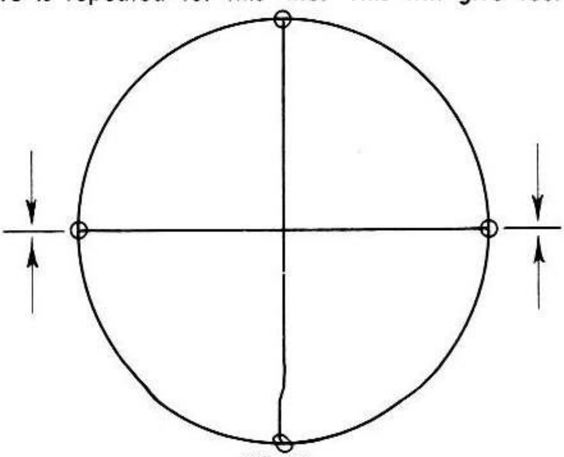

FIG. 44

Courtesy of Boatsport.org

points and the object is to adjust the weights so that the part will remain at rest in anyone of these positions. Figure 44. When this is accomplished, try a few intermediate points; Generally these will be good, too, but if they aren't, make some compensations. When perfect balance is obtained, the part will be able to lie at rest on any part of its revolution.

Weights equivalent to the clay may be fastened to the part, or metal removed for permanent balance. **Be sure** that this is done at the same radius as the clay was applied. Figure 45.

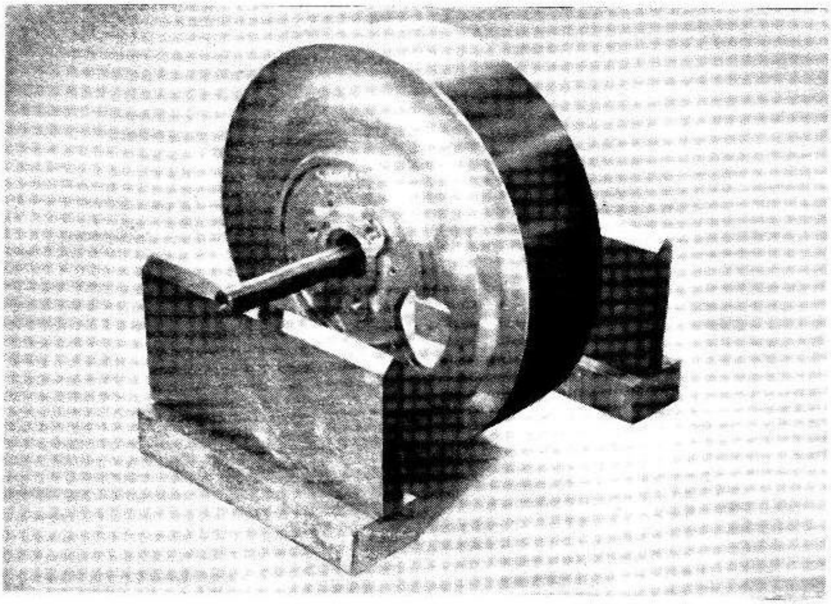

FIG. 45

81. Dynamic Balance: If we take two out-of-balance pasteboard discs and push a knitting needle or piece of welding rod through them so that the cut away portions are directly opposite, we have an assembly that is in static balance. Figure 46. Yet each disc in itself is out of balance. Common sense will tell us that such a combination will not operate successfully as the forces caused by the individual discs being out-of-balance haven't been compensated. This is the condition that occurs when a flywheel and crankshaft are static balanced as a unit, and all the changes in weight location are made at the flywheel. In such a case the flywheel might be thrown badly out-of-balance in itself and still have no effect on the crankshaft balance. Naturally balancing a crankshaft requires elaborate equipment and experience as each crank cheek and pin must be counterbalanced and in itself in static balance. If we could break the crank down into its component parts and static balance these individually, we would have a dynamically balanced assembly. But this isn't possible; so such parts should be sent out for this operation. Dynamic balance of a crank shaft can be simply checked by supporting it in two greased string slings or hangers and belting it to a small motor. If the part runs true with little or no wobble, or tramp, it can be considered satisfactory. Actually the maximum radii of outboard cranks is so small that they give little trouble even if not balanced. Be-

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sides, if we were working toward the nth degree in balance, we would have to hang a weight equivalent to the big end of the connecting rod on each crank pin. In fact, in some cases it just isn't possible to obtain correct balance in the outboard engine. As a rule opposed engines are in better balance as the forces are counteractive.

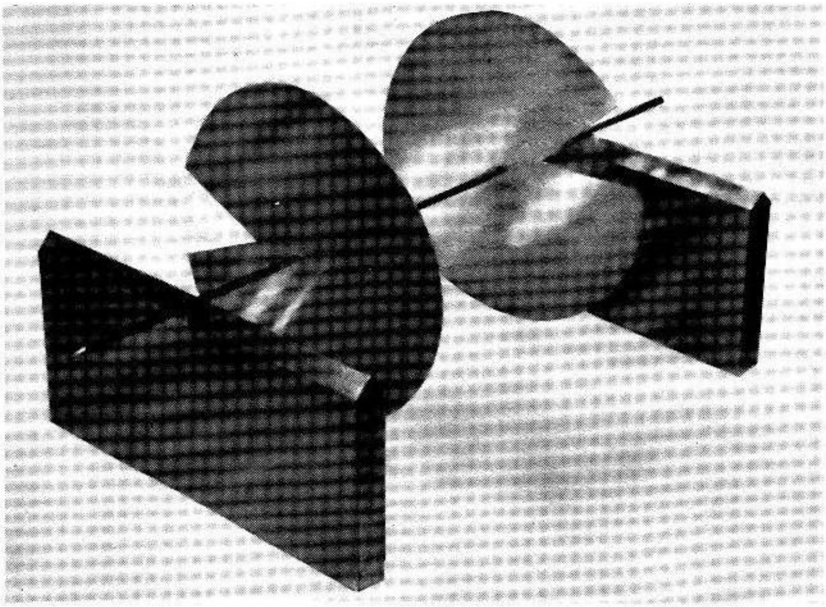

FIG. 46

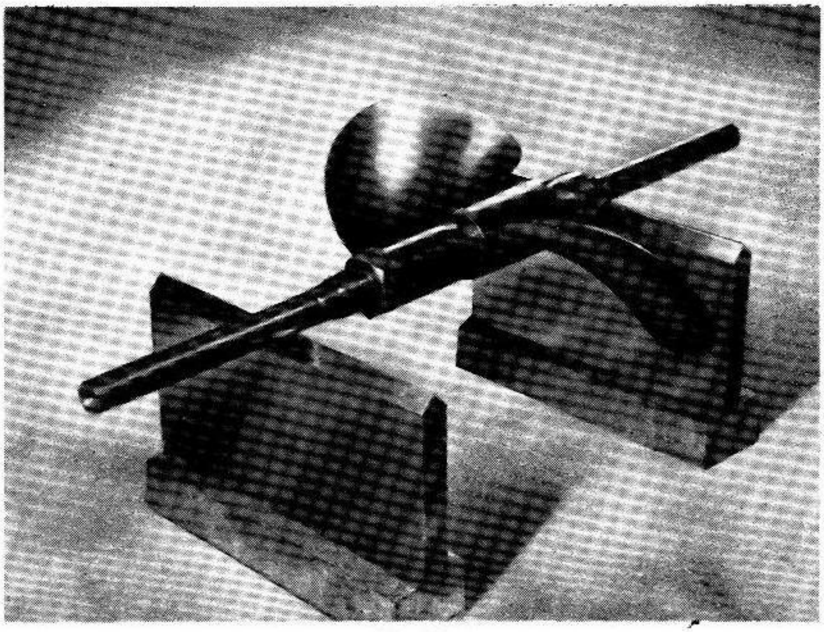

FIG. 47

Courtesy of Boatsport.org

Pistons, wrist pins, and connecting rods should all be balanced. For the pistons and pins it is sufficient that they be of the same respective weights. This is best done on small chemical type balances. Connecting rods should be balanced for over all weight and for static balance. To static balance the connecting rods, mount them on a mandral (a tractor wrist pin is good for this) so that the little ends are directly opposite and balance on ways until they balance out horizontally. Propellors are balanced in much the same manner. Figure 47.

The process of balancing becomes pretty tedious and monotinous and for this reason it is sometimes completely neglected. If you will only wrap a piece of tape around one blade of an electric fan, or operate a high speed grinder with a nicked or broken wheel, then your appreciation for this matter will be immediately restored. And remember, the grinder is going only about one-half the speed of your outboard flywheel.

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SECTION V

SPARK PLUGS

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SPARK PLUGS

82. Spark Plugs: Racing type spark plugs differ from ordinary plugs in that they have shielded electrodes. This shielding is done by building the electrodes up into the shell. Figure 48.

Because racing motors operate under a much more severe temperature than other motors, spark plugs must be built with more provision for cooling. This is done by providing more insulator contact with the shell. This in turn conducts the heat to the head which transfers it to the cooling water. At part throttle conditions, this added cooling is not necessary, and in fact it is a definite disadvantage, as this extra cold condition can cause incomplete combustion and in extreme cases spark plug fouling. A good rule to follow in selecting plugs is to choose the hottest plug that will work satisfactorily.

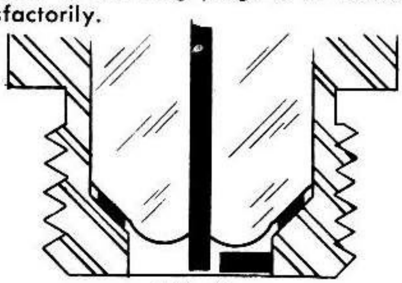

FIG. 48

The key to spark plug temperature is in the insulator and electrode color. A plug that is too hot will have a chalky white colored insulator and an indication of draw colors on the electrode. Sometimes the insulator has a shiny appearance as if it had been graphited. A plug that is too cold will have a sooty appearance. The right plug will have yellow to brown color. Always stop the motor as fast as possible after a hard run to examine plugs, as prolonged running at part throttles will cause the plug to appear to be running colder than is really the case.

All plugs in the same engine should be of approximately the same color and appearance. If they are not, it is a good indication that something is wrong, maybe the wrong compression ratio at one cylinder or leaky rings or an imperfect cylinder. A very common cause is bad fuel distribution. This can be caused by any number of different things and is most usual in a Class "A" engine. Generally this is the fault of bad carburetion.

Before installing a new plug, be sure to crimp or solder the terminal end so that it is impossible for this part to be unscrewed over the end. A lot of races have been lost because of this part's working its way off the thread.

Spark plugs should be cleaned at close intervals and be discarded if there is any doubt this condition. To remove oil and dampness, soak in laquer thinner or acetone. If there is any "build up", it should be scraped off with a pocket knife. If sand blasting is considered, great care must be taken that the glaze on the insulator is not removed. Set the gap at .013 to .017, but never bend the center electrode to do so.

Carbon tetrachloride is often used to dry up plugs; however, there is a theory that this solvent can deposit a fine layer of carbon on the plug and cause it to short out. The author has no information on this subject, but has used carbon tetrachloride without such effect.

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SECTION VI

FUELS

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conditions are right for detonation, the increasing pressure of the fired charge and its resultant heat may ignite a part of the unburned charge in some corner of the combustion chamber before the actual flame front reaches this area. If this happens, detonation occurs; see Figure No. 4. It can readily be seen that the smaller the combustion chamber is, the less chance there is for detonation. Spark plug location is also a contributing factor. Dual ignition can be used to advantage if the combustion chamber is very large.

The reason for this is that spark plug ignition would occur at the correct time and the burning be progressive, while that connected with detonation would be spontaneous and result in high opposing pressures at the critical point of piston travel.

The heating effect concerned with detonation can be said to be accumulative. That is, a part of the combustion chamber that is designed without sufficient cooling may be the cause for detonation, and as detonation liberates heat, this part usually becomes hotter and thus more detonation occurs. This affects volumetric efficiency because of the heating of the incoming charge by this over-heated part or area.*

11. Friction: Each gallon of motor fuel contains a definite amount of potential energy. If we could get the same amount of energy at the crankshaft that is contained in the fuel we burn, we would have an one-hundred per cent efficient engine. However, man has never built a perfect machine, and it is doubtful if he ever will; the internal combustion engine is certainly no exception. As discussed in the previous section, when the fuel charge is burnt, some of the energy is transmitted to the crankshaft, and some is lost in the form of heat. It was discussed how raising the compression ratio converted more of this energy from the form of heat to mechanical energy; but still there is some loss of energy between the piston head and flywheel, and this is in the form of heat from friction. Every bit of friction that can be eliminated in an engine can be realized at the flywheel.

Considering that clearances and lubrication are correct, the friction of an engine is proportional to the area of the sliding surfaces, their speed, and their loading. Ball and roller bearings have almost negligible friction as very little sliding action is present. Needles are low in friction, but not equal to a ball as they slide more than the latter. The piston has many times the sliding area of all the bearings and is therefore responsible for most of the friction.

Offhand one would think it logical to reduce piston area by shortening the piston skirt or by a machined in relief, but it must be remembered that the piston skirt acts to seal off the cylinder ports during part of the cycle, so the necessary length must be present, and also if a relief is contemplated it must be so designed as not to open a by-pass between the exhaust ports and the crank case or to each other. This leaves only an area near the piston pin hole that can be worked on, and it is very small. Cam grinding, which is an effective way to reduce friction in the Otto cycle engine, is impractical in the two-stroke engine because a cam of .003 or more tends to promote leakage. Probably the only practical way to attack this problem is to fit the piston as loose as possible and still maintain an adequate seal at the skirt.

*Recent work with liquid cooled exhaust valves in 4-stroke engines has shown no improvement in V.E. Probably this is also only theoretical in respect to detonation heat in outboards too.

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FUELS

83. Octane: The term "souping up" was first used in connection with special fuels or "soup", as it was referred to then. A few years back ordinary gasoline was of such low octane that low compression ratios were common and high compression ratios impossible. By doctoring up gasoline with acetone, benzol, etc., the octane could be raised and also the compression ratio. Because the compression ratio was so very low, a rise at this point gave a substantial gain in output and therefore the term "souped up" was coined.

Octane rating has been an ever existing subject for argument, and it is not our desire to go into it here. A high octane fuel is one that can be used with a high compression ratio without causing detonation. The high octane agents that are blended with gasoline tend to slow down the burning rate and smooth out the pressures of the power stroke. Figure 49.

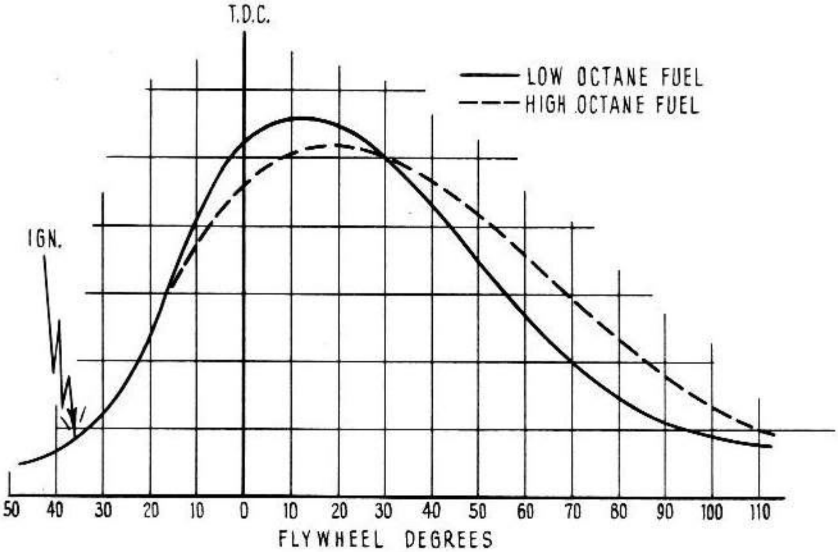

FIG. 49

84. Fuel Additives: Most laymen are under the impression that high peak pressure is desirable. This is definitely not the case. What we are working for is a high average pressure or MEP (mean effective pressure). The most common way of raising the octane value of a fuel is with tetra-ethyl lead. Blending this is complicated and dangerous and should not be attempted by amatuers. Additives that can be used safely are benzol, acetone, and iron-pentacarbonal. The charts in Figure 50 give blending proportions.

85. Alcohol Fuel: Alcohol is becoming more and more popular as a fuel for racing. Actually it doesn't contain as much potential energy as the same unit of gasoline, and for this reason a fuel to air ratio of richer proportions must be used.

The reason that alcohol makes such a good fuel is that it possesses a latent heat of evaporization of about three times that of gasoline. When a liquid is changed into a gas or evaporated, a lowering in temperature is involved. This is called the latent heat of evaporization and results

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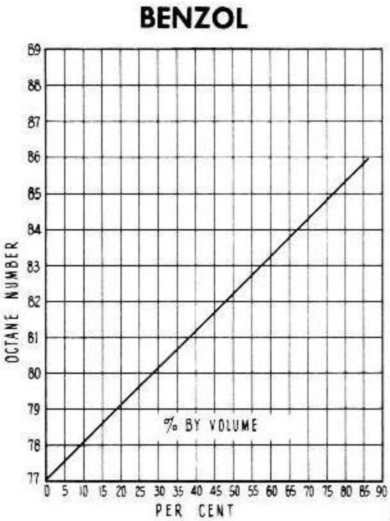

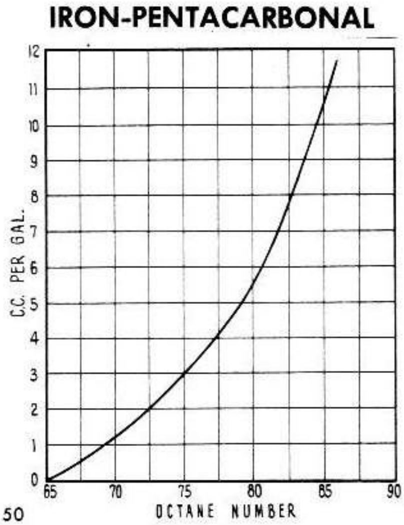

FIG. 50

from the loss of heat energy that is used in the process of changing the liquid into a gas.

Because of the lowering in temperature a heavier or denser charge is drawn into the cylinder and consequently volumetric efficiency is increased.

There are many problems that the use of alcohol brings on. For one thing the carburetor calibration has to be changed in order to compensate for the richer fuel to air mixture requirements. Another problem is its lack of solvency of lubricants. Generally castor oil is used as it can be mixed into a very fine suspension. Also, because alcohol's vapor pressure is somewhat lower than that of gasoline, it causes hard starting in cool or cold weather. This is generally remedied by the addition of benzol or some other additive.

The proof of the alcohol refers to the quantity of water it possesses. In the case of methanol two hundred proof would be pure alcohol and no water. A condition like this wouldn't last long, for as soon as the alcohol is uncovered, it absorbs moisture from the atmosphere. However, the higher the proof the more energy we can get out, as water is incombustible.

A good all around alcohol fuel can be made by mixing nine per cent, by volume, of benzol, nine per cent of castor oil, and eighty-two per cent of high proof methyl alcohol or methonal. The lubricant can be cut down slightly for smaller motors and increased for larger motors. Good quality and purity of materials are an absolute necessity. If you aren't absolutely sure of the source, you had better invest in some of the prepared fuels.

86. Compression Ratios: The available fuels play a large part in the selection of a compression ratio. Local racing rules and agreements sometimes restrict the type of fuel that is allowed. Naturally high compression ratios can be used with high octane fuels and vice versa. Alcohol doesn't limit the compression ratio as its octane value is almost unlimited; however, its use doesn't mean that unlimited compression ratios can be used, as other factors, such as spark plug temperature, tend to limit it.

Gasoline isn't so generous in its tolerance toward high compression

Courtesy of Boatsport.org

ratios as alcohol, and with the lower octane gasolines the compression ratio is definitely limited. Figure 51 shows the approximate maximum compression ratio that can be used in outboard motors with water cooled heads.

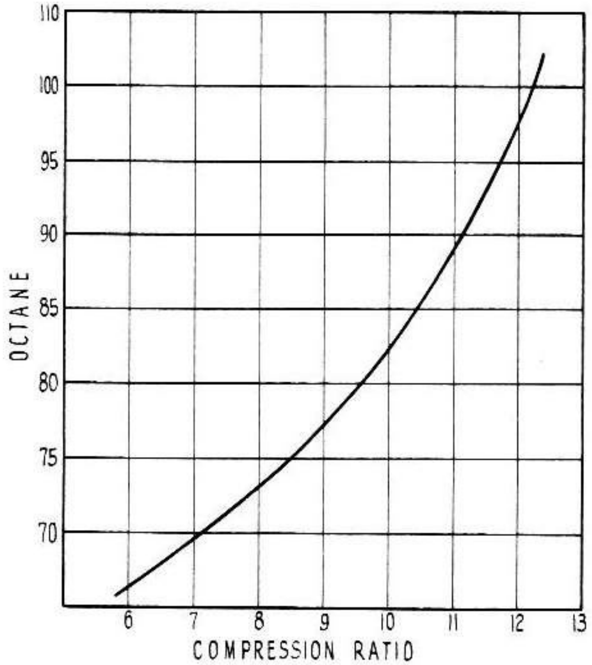

FIG. 51

Courtesy of Boatsport.org

SECTION VII
SERVICE MOTORS
USED FOR RACING

Courtesy of Boatsport.org

Rules and regulations regarding service and stock boat racing differ so greatly, depending on the locality, that it would be impossible for the author to be acquainted with all these differences. In some parts the rules are so tight that even non-stock propellers can't be used, while in other sections a motor can legally be converted into a racing engine. In the discussion that follows we are going to treat the service motor without regard to any rules. The reader is advised to familiarize himself with his own local rules, and if there is any doubt as to their interpretation, to consult the chairman of the rules committee.

As its name implies, the service motor was built for service. For the sake of safety and for reason of better endurance, the service motor wasn't intended to be operated at as high a speed as the racing motor. Its parts and assemblies have a much greater factor of safety than those of a racing motor; the compression ratio is low as it must be capable of using inferior grade fuels without harm; its lower-unit is large and massive and able to withstand shocks and abuse that the thin-skinned racing lower-unit would crumple under; and besides, at the speed at which the service motor generally operates, the lower-unit drag would not be excessive, anyway.

When a motor is used for racing, endurance becomes a secondary item. If the engine will last long enough to finish a couple of races and be free of part failures, we are generally satisfied. Sure, we would like to have a motor last indefinitely, but as a racing motor it is entirely worthless unless it has the ability to run in the "money". If we have the privilege of installing ball or roller bearings, we can prolong the life of the crankshaft and also that of the bearing set up. If cylinders are chrome plated, much wear can be eliminated at this point. In fact, except for the lower-unit, the service motor can be converted into a racing motor. Several companies manufacture short drive shaft housings and stern-brackets, and some even special high speed lower-units.

If such a conversion is considered, the reader can refer to the discussion on racing engines and treat his service motor just as if it were a racing motor. The Johnson S and P motors are particularly well suited for conversion; however, it must be remembered that this process will generally cost more than the price of an out and out racing engine and if the competition rules do not bar a racing engine, one should be considered before attempting work of conversion.

87. Ball Bearings in Service Motors: Generally the crankcase of a service motor is too thin to accommodate the installation of a ball-bearing. To remedy this situation many racing enthusiasts add more material by welding. This brings on other problems such as warpage, drawing, and leaks.

A better system is the flanged cup, Figure 52. The crankcase head in Figure 52 is from a Johnson PO motor. If the recess for the bearing was merely cut into the head, it would break out into "thin air". In this case the breaking through was disregarded and a combination seal and cup was made from bronze and installed in place of the original bottom main bushing. Three-thirty secondths of an inch is faced off the top of the crankcase head to make it possible to use a flange. The outer diameter of the seal section is the same as the outer diameter of the original bushing, and it is pressed in its same socket. Two 6 x 32 x 1/2 flat head screws are used to help hold it in position.

The same seal clearance is used as on racing engines.

Courtesy of Boatsport.org

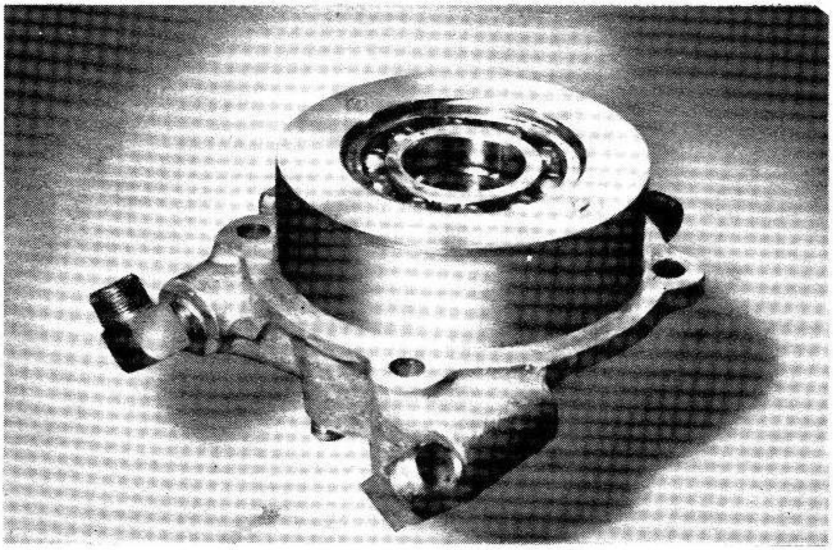

FIG. 52

This same kind of set up can be used in the crankcase proper. Generally the armature plate hub is completely removed, and the cup extension is used in its place. A needle bearing is placed directly under the flywheel to absorb the gyroscopic pressure at this point.

88. Flywheel: As is the case with the racing motor, a steel hub should be installed if the motor is turned faster than the manufacturer's recommendations, particularly if it contains integral magnets and is in the heavy class. Methods of installing the hub vary with different wheels; however, the hub is basically the same as in the racing motor and makes use of a large diameter flange riveted to the upper deck of the wheel.

89. Rotary Valve: The rotor timing of a service motor almost always has to be changed. Sometimes altering the crankcase indexing edges is sufficient, but in other cases the crankshaft has to be changed. When this is the case, pay particular attention to its balance.

External geared type rotary valves should be treated in the same way as the racing type. If the valve is equipped with a fibre gear, this gear should be replaced with a steel one, as the fibre will not last at high speed.

90. Reed Valves: The use of reed valves in the crankcase for induction timing is a very popular and inexpensive way of manufacturing a two stroke cycle engine. As the name implies, the crankcase is constructed with a metal reed in much the same manner as a harmonica is constructed. When a vacuum is formed in the crankcase, the reed is drawn away from its seat, and air and fuel are allowed to enter; when the crankcase is under a pressure condition, the reed is forced against its seat, and the crankcase is sealed off. The advantage of the reed is a variable timing effect; that is, the reed operates only when the demands of the engine dictate. This means very good low speed performance and acceleration because of high maximum torque. The disadvantages are the limited size of the reed and its openings and the fact that the beginning and closing

Courtesy of Boatsport.org

The best compression ratio for a service motor can be obtained by raising it a little bit at a time until the maximum in speed is found and then not going any further with it.

93. Service Motor Cylinder: The cylinders of the service motor follow the same elements of design as in the racing motor, but they are generally built lighter as they are not subjected to such severe strains. Many of them are made of an aluminum alloy with steel sleeves fitted into the bore. This seems to make a highly satisfactory set up. Some of these cylinders have an area surrounding the transfer port runner that doesn't receive much cooling. This section does not get excessively hot, however, because it gives off its heat to the fuel charge. This is bad for maximum power. It is much better to keep the incoming charge cold and dissipate the heat of combustion and friction into the water. This can be accomplished by the fabrication of a sheet metal water jacket around this vicinity, and bleeding off some of the water from a discharge at the top of this secondary jacket.

94. Mufflers: So far in our discussion we have taken for granted that the muffler would be discarded. If because of some local rule you have to use one, be sure of the following items: That there is sufficient looseness on the mounting studs, i.e. clearance between mounting studs and mounting holes; that it is free from carbon (carbon is a good insulator and causes overheating by keeping the heat in); and that the exhaust openings are of adequate size so that back pressure is kept at the absolute minimum.

Courtesy of Boatsport.org

SECTION VIII

THE RACING BOAT

Courtesy of Boatsport.org

One might think that the piston rings create quite a bit of drag or friction. It's true they do create friction, and for this reason no more rings than absolutely necessary should be used, but compared to piston friction, ring friction is a small item. Experiments with different ring tensions to eliminate friction have been very disappointing.

There is not much that can be done to lessen the friction of ball or roller bearings except to be certain that the alignment and lubrication is correct. Plain type bearings and bushings, especially those that are not pressure lubricated, should have ample clearance as well as correct alignment.

12. Pumping Loss: There is still another loss of energy in the internal combustion engine, and this is the energy that is spent in pumping in air. For although air is a gas, it is still affected by the laws of friction and at velocities that approach and sometimes exceed 16,000 ft. per min., this friction can be a noticeable item. Remember that although air is invisible, it has weight and volume (although variable) and requires energy to move it.

Reducing friction in the induction system does a two-fold duty as it is the aim of racing engine designers to see to it that all the air that can be possibly drawn in, is taken in and the sharp corners and the roughness of the induction system walls make drawing in air just that much more difficult.

It is sometimes thought that high compression pressures present resistance to rotation. This is true only at very low or cranking speeds as the energy that is used in compressing the charge is given back again after the piston passes TDC, with exception of that which is given off in the form of heat in the compression process.

13. Carburetors: We have discussed what takes place after the fuel charge enters the crankcase, but up to this point we haven't considered how the fuel and air are mixed. All outboard motor carburetors are based on the "Bernoulli's Principle". The following is Bernoulli's Principle: In a fluid in motion there is an increase of pressure when the velocity decreases and a decrease in pressure when the velocity increases. This same principle is true with gases as well as fluids.

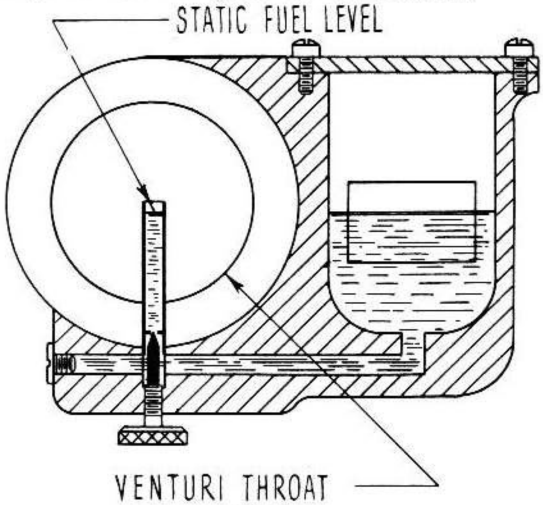

FIG. 5

Courtesy of Boatsport.org

The racing boats that we are going to consider in this publication differ from the ordinary type boat in the fact that they ride or move on top of the water rather than in or through it. This type of boat is known as a hydroplane and is the most efficient type of hull that is known today. There are several types of hydroplanes; continuous plane or runabout, single step, multiple step, three-point suspension, and the hydro foil. The runabout, single step, and three-point suspension types are most popular for outboard racing. We will discuss these individually in the text that follows; however, the subject is fairly limited, as technical information is at a minimum and those boats that have been successful are without a theoretical or mathematical background. Even those boats that are successful have little in common and it seems that a design that works well for one driver will be wrong for another; so the old idea of trial and error seems to be the present procedure of hydroplane design.

95. The Runabout: In racing circles the runabout is not referred to as a hydroplane. The increased size and the fact that it runs in a class by itself is probably responsible for this.

The efficiency of the runabout hull is proportional to the amount of wetted surface. Therefore a boat with very little of its bottom in the water is a fast one. This is generally accomplished by balancing the boat so that the most of the weight is concentrated at the rear or stern of the hull. This has the effect of causing the bow to lift, and divorcing it from the water. Such a condition works well enough when little or no wind is present, but can be treacherous in a heavy wind as a heavy gust can blow the sensitively balanced bow up and over backwards. The fact that buoyancy increases with velocity lends a solution to this problem, and that is to calibrate the fullness of the forward sections so that just enough buoyancy is obtained to give satisfactory lift at high speeds. This is the reason for the needle nose boats. And in the event of a heavy wind, the buoyancy, or air support, isn't so great as to cause it to fly like a kite.

The cross section shape of the planing area is of great importance and still we are after a minimum amount of wetted surface. The flat bottom seems to have preference in this respect, but it is too difficult to turn because the square corners cause tripping, This can be remedied by the addition of a bevel or non-trip chine. Figure 54.

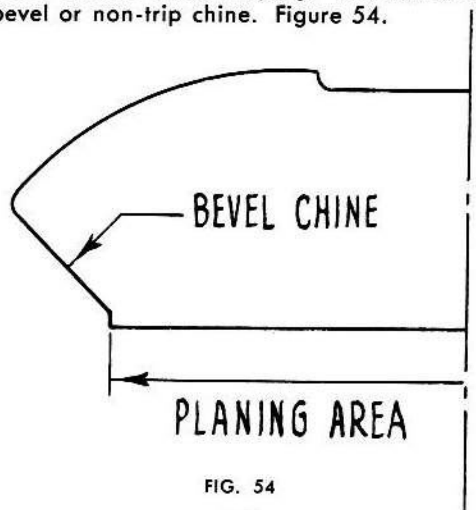

FIG. 54

Courtesy of Boatsport.org

96. Surface Tension: Figure 54 is the shape used on the modern racing runabout. Sometimes a very slight vee is added to the bottom to increase stability, but care should be exercised when this is done. Notice how the planking is extended over the junction of the chine and bottom. This is done to avoid the adhesion effect of the water. Pour a quantity of water into a small glass and notice how the water immediately next to the glass tends to climb up the sides. This is because the adhesion properties of water and many other liquids is greater than its cohesion properties. The adhesion of water can be compared to the stickiness of glue except that glue is much more intense. However, even a little stickiness spread over a large surface can cause unwanted friction on a racing boat's bottom.

A round chine boat is particularly susceptible to this effect. As the point of planing is not definite, the adhesion of the water causes it to climb up the chine a short way and cause unnecessary friction. Figure 55.

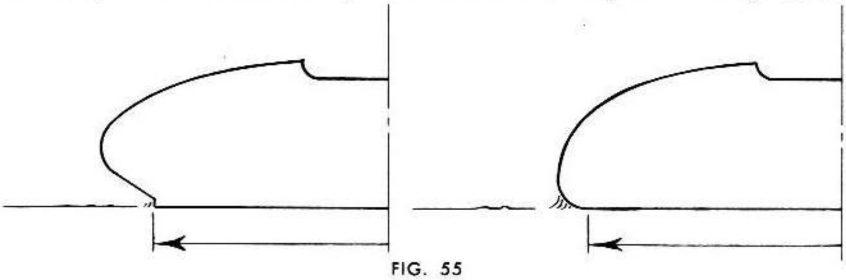

FIG. 55

97. Hooked Bottom: Another common loss in boat efficiency is caused by a concavity or hook in the planing section. In a condition such as this the bottom cannot breathe and thus a partial vacuum is formed and the hull is pulled lower into the water just as if this section were a large suction cup. Even a little hook is detrimental. Sometimes this is built in because of poor workmanship or design, and sometimes the thrust of the propeller and consequent pull on the transom can cause this condition. In any case it isn't good and should be corrected if it exists.

98. Porpoising: Porpoising, or the teeter-tottering, hopping and leaping of the boat is particularly prevalent in runabouts, as the balance is so sensitive. (This is a very good example of the lack of technical knowledge on the subject of planing hulls.) No real information can be given on this phenomena except that it seems to appear when the center of gravity occurs more than sixty percent back from the front of the **water line.** This is only an average rule, though, as there are many good performing boats that have CG locations considerably different from this. Then, too, a boat that is a bad porpoiser in smooth water may be perfectly stable in rough water and vice versa.

Adjusting the motor, or propeller shaft angle, may relieve this action if it isn't too severe; however, if it is necessary to adjust the propeller shaft so that it is very much different from being parallel to the water surface, investigation should be made to determine other methods of correction.

Some manufacturers extend the bottom planking over the back of the transom. This seems to relieve the trouble somewhat, as it increases the waterline length and consequently changes the center of gravity, but it also puts more surface into the water and efficiency is reduced.

Courtesy of Boatsport.org

99. Wind Resistance: Except for the fastest racing runabouts wind or air resistance isn't too great a factor. Nevertheless, this aspect should not be overlooked completely in the design of a racing boat of the runabout type. The determining of effectiveness of streamlining is based on frontal or maximum cross sectional area, and if this is kept at a minimum, streamlining will be fairly good.

100. Single Step: This type of hydroplane falls into the class of racing boat referred to as a "conventional hydro." The step that classifies this type of boat is the one that is right angles to the boat's linear center line and not the small lifts or steps that reduce planing area width.

Again we are after minimum wetted or planing surface, but unlike the runabout the center of gravity location is not too sensitive, and thus shorter and more maneuverable boats can be built of this type. The idea of the step is to reduce planing surface. Its theory can be best described by figure 56.

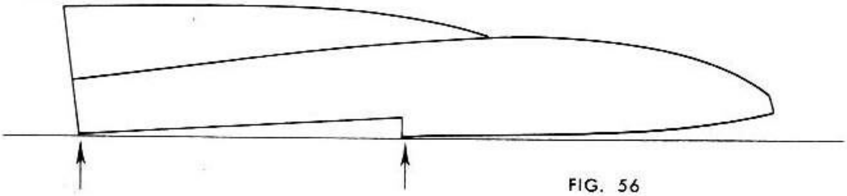

FIG. 56

Notice how the hull is supported by the end points of each plane and how the rest of the hull rides free of the water. This accounts for the increased efficiency of this type of hull.

We are again handicapped by the lack of information and technical data on planing hulls. We haven't even laws or formulas by which we can even figure the necessary angles of the planes. Most production racing boats have been developed after much experimenting and considerable time spent going through the procedure of trial and error in the development procedure. These hulls may not be the last word in boat design; however, to improve on them would require going through all development work that produced the present models. Generally speaking, it is better to secure one of the popular racing boats than to build one.

101. Plane Angles: A rule of thumb on plane angles is to make the forward plane angle two degrees less than the rear plane angle. Bouncing and excessive lift of the forward plane is usually caused by too severe an angle on the forward plane; and conversely, if the hopping seems to originate at the rear of the boat, the rear plane angle is possibly too great.

The height of the step is usually not important and is usually determined by the height developed by the angle and the length of the rear plane. However, as the step must breathe through the opening left at the sides, this height must be great enough to give an area that is large enough to permit enough air to enter or the step will act as a hook in the bottom of a runabout. Another way of relieving such a vacuum is to place ducts through the bottom and vent it to the atmosphere. If such ducts are used, they should be placed so that they project slightly above the top of the deck so that in case of a spill they will not vent the air trapped in the deck and cause the boat to sink.

Courtesy of Boatsport.org

102. The Three Point Suspension Boat: The theory of minimum wetted surface still holds for three point suspension boats, but in this design a slight increase in wetted surface can still give increased efficiency because all the planes ride on undisturbed water. In the case of the single step hydroplane the rear plane rides on water that has previously been roughed by the forward plane. The rear plane of the three point design is not affected in this manner as the two forward planes are spaced on the outside of the rear plane. The three point design was developed and patented by Arno Apel, a well known marine designer. There is probably more technical information on this type than on the others, but still there is much to be learned. Unfortunately, most of this information applies to inboard types of boats whose greatest weight is supported by the front planes. In some cases the balance is so well worked out that the rear plane rides free of the water and what little weight there is at this point appears to be supported by the propeller. This position of balance where the greatest weight is forward, reduces the tendency of the boat to fly or to kite. This tendency seems to be the big objection to outboard hulls of this type. In an outboard hull the major portion of the weight is to the rear, and as the air foil shape of the forward deck causes a slight lift, combined with the lift of the air stream underneath the boat, the boat literally takes off when a gust of wind is encountered. Even so, this type of boat is the most efficient, and many drivers are willing to risk the danger for the few extra miles per hour that this type gives. It seems that experiments with the motor placed in the center of the boat through a well in the bottom or placing the driver to the front would be worthwhile.

When the motor is placed on the transom, great care must be exercised to determine the minimum motor angle at which the boat will operate. This will lessen some of the tendency to become air borne. Also the use of as large a propeller as the engine is capable of swinging, placed as high up on the transom as is possible will help to keep the front down as this seems to cause a slight upthrust on the rear plane and counteracts some of the overbalanced condition.

103. Boat Bottom Finishes: Most racing boats use a bottom finish that consists of five or more coats of hard drying spar varnish which is rubbed down slightly between coats and after the last. Sometimes prepared waxes and clear shoe polishes are used as a final help to reduce friction.

At the time of this writing the author has not been able to discover anything that will give better results; however, new and supposedly better finishes are being developed everyday and one of these might be an improvement.

Courtesy of Boatsport.org

SECTION IX

FACTORS THAT REDUCE SPEED

Courtesy of Boatsport.org

The outboard racing outfit has three primary kinds of resistance that must be kept at a minimum for maximum speed. They are the following:

1. Wetted surface or skin friction.
2. Air or wind resistance.
3. Parasitic or appendage drag.

104. Skin Friction: As we have discussed previously, or wetted surface drag is proportional to the amount and finish of the boat bottom that strikes the water when underway. This is dependent on the hull's design and the quality of workmanship during its construction, and also upon the care and service that it receives between races.

105. Wind Resistance: Air or wind resistance isn't too great a factor at the ordinary speeds that outboard racing boats obtain, but air resistance doesn't increase in a direct ratio to speed; in fact, it increases much faster than the velocity of a vehicle; so while one may be operating at a speed where air resistance is negligible, an increase of five to ten in M.P.H. might be enough to bring it to a point where it is serious.

Wind Resistance Formula:

$$\text{In lbs.} = SKV^2$$

$$\text{In HP} = \frac{SKV^3}{375}$$

S=Frontal area

K=Resistance coefficient
(.0016 for hydros
.0017 for runabouts)

V=Forward speed MPH

106. Parasitic Drag: Parasitic Drag is the friction of the fin, keel, and lower-unit. This is another case where the resistance increases much faster than the velocity. In the case of some outboard hydroplanes the lower-unit resistance is as great as the boat or skin friction and air friction combined. The formula that follows can be used to figure the approximate parasitic drag of such parts.

$$R = PSK$$

R—Resistance in pounds

P—Impact Pressure (pounds per sq. in.)

S—Maximum frontal area

K—Streamlining factor

P at 50 MPH equals approximately thirty-four pounds per square inch. If a one inch square block were attached to the bottom of a racing boat, it would be subjected to thirty-four pound pressure at fifty MPH.

By the following formula this thirty-four pounds can be converted to horsepower.

$$\frac{34\ D\ \text{(per min.)}}{33{,}000} = HP$$

$$\frac{34\ \text{(4,620 ft. per min. @ 50 MPH)}}{33{,}000} = HP$$

$$HP = 4.75$$

This means that our one inch block will require 4.75 HP to move it through the water at 50 MPH. If we streamline this block, figure 57, we

Courtesy of Boatsport.org

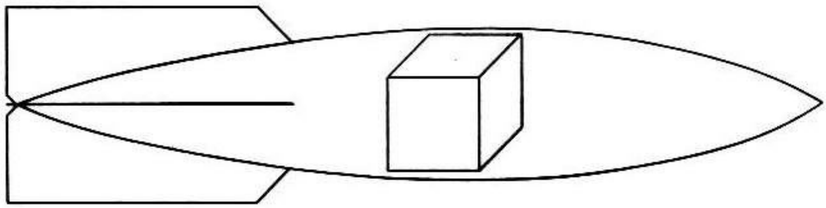

FIG. 57

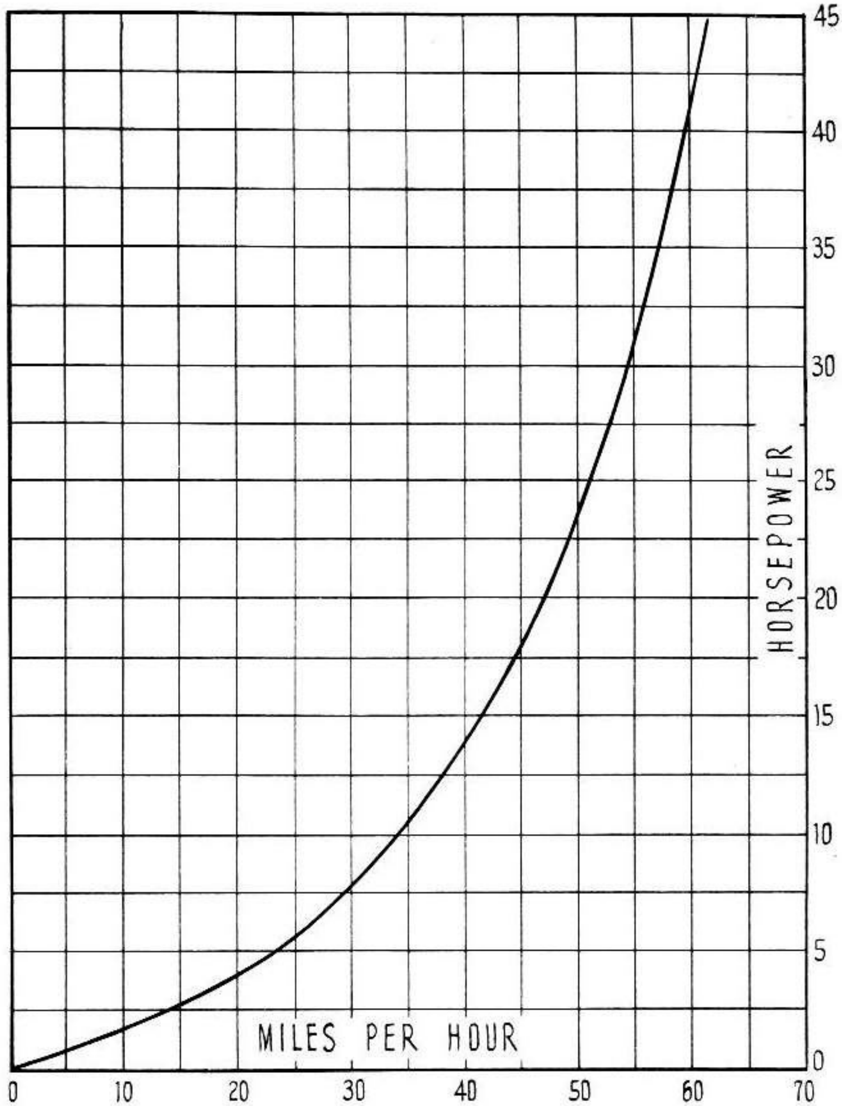

FIG. 58

Courtesy of Boatsport.org

can reduce this figure considerably. The efficiency of the streamlining is expressed by the quantity K in the resistance formula. This factor has to be determined by trial; however, it is a function of length to width or diameter to length. Figure 58 is a load curve for a one hundred-fifty pound three point out-board hydroplane with driver and motor and all necessary equipment. Notice how the curve approaches a straight vertical line as the speed or velocity increases. If it ever reached such a condition, it has reached its terminal velocity and will go no faster no matter how much more power is applied. Even at present day speed of fifty-five to sixty MPH the amount of power necessary to gain only a few miles an hour more is tremendous. Working along the lines of reducing resistance and drag really pays off at high speeds, as a few extra pounds of resistance at sixty MPH can mean the difference of an "also ran" and a winner.

107. Transom Height: Raising the propeller close to the bottom of the hull has a two fold purpose: For one thing it reduces the quantity of lower-unit that projects into the water; and secondly, it permits the propeller to operate in the less dense surface water. This adjustment is more sensitive than one would imagine, and sometimes even a sixteenth of an inch is noticeable. Adjustment is generally accomplished by setting a thin strip of wood on the top of the transom before the motor is secured down. These shims are referred to as "rev-sticks" by race drivers and are as important to a well balanced outfit as is the propeller or carburetor. Different conditions of water require different motor elevation, so these sticks are generally calibrated during trial runs at the race course site before the race begins.

Courtesy of Boatsport.org

SECTION X
PROPELLER

Courtesy of Boatsport.org

At this time it might be well to clear up some important points in regard to the subject of air. Air must be considered as a gas with a definite weight and variable volume just like the gas from your kitchen range. This air or gas surrounds the earth to a height of several miles, and, as we said before, it has weight; consequently any object that supports this weight is subject to a unit pressure proportional to the weight and height of this column. Standard sea level pressure is accepted as being 29.92 inches of mercury or 14.7 pounds per square inch. When a piston of an engine moves and causes a vacuum condition, this atmospheric pressure pushes its way in to fill the vacancy. This is called suction and is in reality merely an act of air pressure.

In the carburetor, in Figure 5, we see how the fuel is drawn out of the discharge nozzle and mixed with air. This mixture is far from being complete, so to improve the mixing of fuel and air, an additional chamber called the "well" is added, and this acts just like a "Bobby-soxer" drinking a bottle of soda pop through a straw. When he nears the bottom of the bottle, he gets not only pop but a mixture of pop and air and a gurgling sounding noise; this same principle is used in a carburetor. As the speed and load of the engine change, so does the mixture requirements. It is possible to calibrate a carburetor with a well to meet most of those requirements. This is done by varying the size of the discharge nozzle, the air vent in the well, the size of the fuel opening to the well, and in some cases some of the vacuum in the induction system is by passed to the volume over the float, and then an air vent in the float chamber is calibrated. The why and wherefore of these changes is a lengthy subject that would take too much time to discuss here.

The adjustment that is known as the high speed needle valve is an adjustment that is placed where the fuel enters the nozzle.

14. Carburetor Idling System: The idling system is usually separate from the rest of the carburetor. It isn't difficult to see that when the butterfly throttle valve is closed, the reduction of pressure at the mouth of the venturi and discharge nozzle isn't going to be sufficient to pull the fuel over. To make it possible to run with a nearly closed throttle a separate system is provided. This consists of a channel drilled along side of the carburetor barrel to the position where the butterfly seals off the

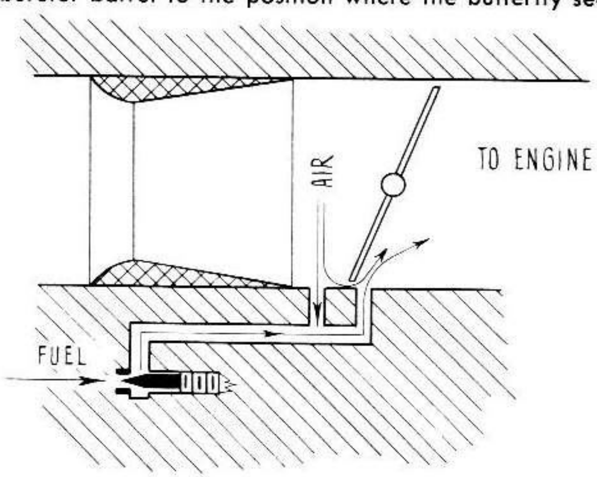

FIG. 6

Courtesy of Boatsport.org

THE PROPELLER

108. The Propeller: The outboard racing propellers of today are a product of theoretical development plus systematic use of the trial and error method. Only thereby can the factors of propeller design be adequately blended to produce the built-in precision and efficiency found in the modern racing propeller.

Properly applied the modern racing propeller is a surprisingly efficient machine. Do not confuse slippage with efficiency when considering propellers. Efficient equals "Work Out" divided by "Work In", thus

$$\%E = \frac{\text{Work Out}}{\text{Work In}}$$

"Work In" is the horsepower applied to the propeller hub. "Work Out" is the horsepower effectively used, and is roughly measured by the volume and speed of the water moved by the propeller. The difference or loss is due to friction and turbulence. Friction losses consist of "skin" friction of the blades plus a type of parasitic drag similar to that acting on the underwater appendages of the boat. The interaction between hull and propeller also basically affects these propeller performance factors. Turbulence is caused by the inability of the water to follow smoothly across all sections of the blade and results in non uniform pressure areas which combined with other hydraulic phenomena (largely effect of vapor pressure) gives rise to cavitation. Propeller manufacturers reduce these friction, drag and turbulence losses to a minimum by:

(1) Selection at total blade area and the proper distribution of that area between hub and blade tip.

(2) Properly fairing or streamlining the blade sections so as to provide the proper "camber" or ratio of blade section width to section thickness thereby obtaining the most favorable "lift" per blade section possible.

(3) Using the smallest possible hub.

(4) Proper propeller selection to fit hull characteristics and load.

Consideration of the above has led the propeller manufacturers to the small diameter, wide blade propeller now so popular. Blade area is gained by blade width instead of blade diameter. Fortunately we have high strength alloys which permit the use of the desirably thin blade sections.

The diameter, pitch and blade area regulate the amount of thrust or the amount of water a propeller can move for a given RPM. Therefore the size and area of the propeller is controlled by the efficiency of the boat and lower-unit. A propeller that is too large will move more water than is necessary and use power that can be used in increasing the boats speed. Conversely speaking, one that is too small will not supply enough thrust to move the boat at its maximum speed, and increasing the propellers pitch to reduce excessive motor speed, with such a condition, doesn't increase boat speed, as the necessary thrust is still lacking and only propeller slippage will be increased.

When selecting a propeller for large lower-units and particularly those of service motors, the effective area locations must be determined. On such units, at high speeds, the water doesn't close in fast enough and this leaves the hub area with very little water. This is why there is a trend toward the "Simitar" shaped blades for these motors.

The pitch or angle of the propeller blades largely controls the vel-

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ocity of the water stream or thrust stream aft from the propeller and likewise the boat's speed. Propeller slippage is the difference between the velocity of this stream and that of the boat's speed. Pitch is expressed in inches and refers to the theoretical distance the boat would move for one revolution of the propeller. This is assuming that there isn't any slip. This figure is a poor indication of actual boat speed as slip can only be determined by actual trial. Slip is expressed as a percent ratio of propeller speed to actual boat speed, and can be calculated as follows:

V=Boat speed in miles per hour.

P=Propeller pitch

N=RPM of propeller shaft. (not engine RPM)

Propeller theoretical speed in MPH=P X N X .0009496.

Percent of slip=Propeller speed minus boat speed divided by propeller speed, or

$$\text{Slip \%} = \frac{(\text{Propeller Speed}) - (\text{Boat Speed})}{\text{Propeller Speed}}$$

Normal propeller slip will vary with hull form and loading. The usual range being 5% to 20%.

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SECTION XI
APPENDIX

Courtesy of Boatsport.org

TABLE OF EQUIVALENTS

1 ft. water=.4355 # sq. in.
1 Atmosphere=14.7 # sq. in.
1 B.T.U.=778 ft. lbs.
1 HP=707 B.T.U. per sec.
1 HP=746 Watts
1 inch=2.54 cm.
1 meter=39.37 in.
1 mile=1.509 km.
1 knot=1.152 mi.
1 cu. ft.=62.43 lbs. of water
1 in. Hg.=1.133 ft. water
1 US Gal.=231 cu. in.
1 US Gal.=8.345 lbs. of water
1 HG.=2.205 lbs.

COEFFICIENT OF LINEAR EXPANSION 1°C.

Aluminum	0.000023
Brass	0.000018
Copper	0.000017
Gold	0.000014
Iron	0.000010
Lead	0.000029
Silver	0.000019
Steel	0.000011

RELATIVE THERMAL CONDUCTIVITY

Silver	100
Gold	71
Platinum	16
Aluminum	48
Brass	26
Copper	92
Iron	14
Steel	11

AVERAGE TENSILE STRENGTHS

	Lbs. per sq. in.
Aluminum	20,000
Brass	45,000
Copper	35,000
Tin	4,500
Iron	20,000
Lead	2,420
Zinc	5,000
Steel	100,000

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COMMON FORMULAS

Area of a circle $= \pi R^2$

Area of a sphere $= \pi D^2$

Volume of a sphere $= .5236D^3$

Circumference of a circle $= \pi D$

Volume of a cylinder $= \pi R^2 H$

HP = 33,000 foot lbs. per min.

HP = 550 foot lbs. per sec.

Wgt. of air flowing through a round orifice

$$\text{Wgt.} = 2\ \text{Ft.}\sqrt{2Pg.}$$

Wgt. = Wgt. of air in pounds
F = Area of hole in sq. ft.
g = Density in pounds per cubic ft.
t = Time in sec.
P = Pressure lbs. per sq. in.

TORQUE WRENCH TABLE FOR OUTBOARDS

Stud Diameter	Thread	Torque in Ft. Lbs.
5/16	18	16-22
5/16	24	20-25
3/8	16	34-38
3/8	24	32-42
7/16	14	64-68
7/16	20	66-72
1/2	13	82-86
1/2	20	86-90

TABLE OF DECIMAL EQUIVALENTS

1/64	.0156	17/64	.2656	33/64	.5156	49/64	.7656
1/32	.0312	9/32	.2812	17/32	.5312	25/32	.7812
3/64	.0468	19/64	.2968	35/64	.5468	51/64	.7968
1/16	.0625	5/16	.3125	9/16	.5625	13/16	.8125
5/64	.0781	21/64	.3281	37/64	.5781	53/64	.8281
3/32	.0937	11/32	.3437	19/32	.5937	27/32	.8437
7/64	.1093	23/64	.3593	39/64	.6093	55/64	.8593
1/8	.1250	3/8	.3750	5/8	.6250	7/8	.8750
9/64	.1406	25/64	.3906	41/64	.6406	57/64	.8906
5/32	.1562	13/32	.4062	21/32	.6562	29/32	.9062
11/64	.1718	27/64	.4218	43/64	.6718	59/64	.9218
3/16	.1875	7/16	.4375	11/16	.6875	15/16	.9375
13/64	.2031	29/64	.4531	45/64	.7031	61/64	.9531
7/32	.2187	15/32	.4687	23/32	.7187	31/32	.9687
15/64	.2343	31/64	.4843	47/64	.7343	63/64	.9843
1/4	.25	1/2	.5	3/4	.75	1	1.0

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OUTBOARD BOAT RECORDS

1 MILE AS OF DECEMBER 15, 1950

Class M Out. Hydro.	42.303	3/21/49	Lake Alfred, Fla.	....	Eleanor Shakeshaft	Jacoby	Evinrude
Class A Out. Hydro.	50.281	11/19/45	Salton Sea, Calif.	S-1	Tom L. DeWitt	Fillinger	Johnson
Class B Out. Hydro.	57.234	10/29/40	Salton Sea, Calif.	....	Jack Henckels	Neal	Johnson
Class C Out. Hydro.	63.549	11/19/45	Salton Sea, Calif.	Y-200	Thom. Cooper	Fillinger	Johnson
Class C Serv. Hydro.	51.471	10/30/50	Lake Alfred, Fla.	Heyl Wait!	Glenn Burke	Neal	Elto
Class F Out. Hydro.	66.234	6/8/40	Port Mercer, N. J.	....	James Mullen II	Jacoby	Evinrude
Class X Out. Hydro.	79.04	5/20/39	Paris, France	....	Jean Dupuy	Jacoby	Dupuy
Class X Out. Hydro.	78.44	11/1/39	Worcester, Mass.	....	Clinton R. Ferguson	Jacoby	Eldredge
Class C Serv. Out. Run.	51.613	5/21/49	San Diego, Calif.	Miss Santa Barbara	Tommy Newton	DeSilva	O.M.C.
Class E Serv. Out. Run.	42.654	6/5/33	Seattle, Washington	....	Stanley Donogh	Zimmerman	Evinrude
Class C Rac. Run.	58.445	10/30/50	Lake Alfred, Fla.	Whot.Hopponed	Byron King	Willis	Johnson
Class F Rac. Out. Run.	57.935	9/16/40	Worcester, Mass.	Muscat Kid V	J. Kovacevich	Zimmerman	O.M.C.
Fla. Family Out. Run.	41.964	3/19/48	Lake Alfred, Fla.	....	John A. Stanford	Dodd	Johnson

OUTBOARD BOAT RECORDS

5 MILES IN COMPETITION AS OF DECEMBER 15, 1950

Class M Out. Hydro.	38.379	9/4/49	Worcester, Mass.	J-13	Donald Whitfield	Jacoby	Evinrude
Class A Out. Hydro.	47.344	10/26/41	Salton Sea, Calif.	....	Frank Vincent	Fillinger	Johnson
Class B Out. Hydro.	53.004	10/13/47	Salton Sea, Calif.	....	W. G. Sweitzer	Neal	Johnson
Class C Out. Hydro.	57.325	4/7/46	New Orleans, La.	Flying Scott IV	Vic Scott	Jacoby	Elto
Class C Serv. Hydro.	48.124	10/28/50	Lake Alfred, Fla.	Nighthawk	Bud Wiget	Neal	Elto
Class F Out. Hydro.	58.785	8/24/40	Red Bank, N. J.	....	James Mullen	Jacoby	Evinrude
Class X Out. Hydro.	61.392	8/20/38	Red Bank, N. J.	....	Clinton Ferguson	Jacoby	Eldredge
Class C Serv. Out. Run.	47.480	4/25/50	Friant, Calif.	Miss Santa Barbara	Tom Newton	DeSilva	Evinrude
Class E Serv. Out. Run.	42.352	8/15/37	Red Bank, N. J.	....	C. Ward Frauenthal	....	O.M.C.
Class C Rac. Out. Run.	53.571	2/11/50	Lakeland, Fla.	F-444	John A. Stafford	Willis	Johnson
Class F Rac. Out. Run.	52.693	8/20/39	Merced, Calif.	Narollu V	Ernie Millot	Rockholt	Evinrude
Fla. Family Out. Run.	42.333	3/6/49	Lakeland, Fla.	F-50	Jimmy Whitt	Ramsey	Johnson

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PROPERTIES OF LIQUIDS

Liquids	sp. g.	Freezing Point oc	Boiling Point oc	Heat of vaporization, cal. per gram at boiling point.
Ethanol	0.80	-130	78.3	205
Methanol	0.80	-95	65.0	267
Ether	0.72	-117	35.0	90
Gasoline	0.70	—	80.0	70
Fuel Oil	0.80	—	225.0	—