

THE SINGLE SLEEVE VALVE ENGINE

The Society of Automotive Engineers

Metropolitan Section

New York

By A.M. NIVEN

Nov. 15th 1926

- Page 6. Line 22 "call" to read "called" or "named".
- " 11. " 20 "Coate" to read "Coats".
- " 13. " 15 "hood" to read "top" and "screen" to read "windshield".
- " 13. " 16 "hood" to read "top" (twice).
- " 15. " 16 "Daimler Co." to read "Knight & Kilbourne".
- " 16. " 2 "Anglo-French" to read "Franco-British".
- " 16. " 25 "Meetin" to read "meeting".
- " 20. " 122 It is not clear how "M'B for many years the only manufacturer to employ it" (the SSV).
- " 22. " 25 "Superseeded" to read "superseded".
- " 23. " 4 Add the words "at Paisley near Glasgow," after "The works". This to avoid confusion with the Dunfries works mentioned in line 11.
- " 25. " 8 The "balancing" of port height does not effect sealing at working stroke.
- " 25. " 14 "Skew" to read ~~skew~~. *helical*
- " 25. " 23 "with" to read "to".
- " 25. " 23 The ball joint was first introduced in the Wallace (Glasgow) Mark N engine and was never used in pre-war Argyll.
- " 25. " 26 This sentence is incorrect inasmuch as the gear drive is now superseded by the link drive by Continental. The new Aster drive is not patented by Mr. Burt. It consists of the Sergent wobble shaft drive.
- " 26. " 15 After "manufacture" add "outside of Britain".
- " 26. " 25 "and" to read "an"
- " 26. " 27 "lorry" to read "truck" and after "truck" add "the Locomobile Co. also made tests on the engine".
- " 28. " 5 "propeller" to read "airscrew".
- " 28. " 12 "6 H.P." to read "B.H.P."
- " 28. " 14 After "at" add "The Royal Aircraft Factory at"
- " 28. " 18 After "tests" add "it may be pointed out that several contestants withdrew due to broken crankshafts".
- " 28. " 23 "Bailis" to read "Baillie".

Page 28 Line 25 Delete sentence and replace by "Accordingly a
12 cylinder engine with steel sleeves of 100 m.m.
bore was designed to develop 180 to 200 B.H.P."

" 29 " 17 "Head quarters" to read "Headquarters".

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"	43	" 34 "English" " " "British"

THE SINGLE SLEEVE VALVE ENGINEHISTORICAL:

A glance through the patent reference files will convince one that much time and thought has been given to the design of valves and valve operating mechanism for internal combustion engines. The predominating inventive thought would appear to be that of replacing the conventional poppet valve with a valve of a different type, positive and quiet in action. Thus we have rotary valves, piston valves, cuff valves, and sleeve valves. The latter have probably received more consideration than any of the other types, but it would seem that most of the sleeve valve types patented have failed, or would fail commercially, because of complication, the mechanism for imparting the desired motion to the sleeve being so elaborate that the designs are outside the sphere of practical production. Simplicity is the keynote of the only sleeve valve engines that have stood the test of time; namely the double sleeve or Knight and the single sleeve or Burt-McCollum. The latter type forms the subject of this paper. It is thought that a general description of such an engine will prove of interest at this time seeing that there is every indication of intensive production in this country.

First, let us review briefly the historical aspect and so dispel any notion that the single sleeve valve engine is something new and untried.

In the year 1911, after about two years of research work, Argylls Ltd., of Alexandria, Scotland, announced the introduction of a chassis equipped with the Burt-McCollum engine. The car found a ready market, the public's faith in the new type of engine being no doubt strengthened by the knowledge and appreciation of the pioneer

work of Mr. C. Y. Knight, whose double sleeve valve engine had, at that time, been in production at the Daimler Motor Co., Coventry, England for over two years.

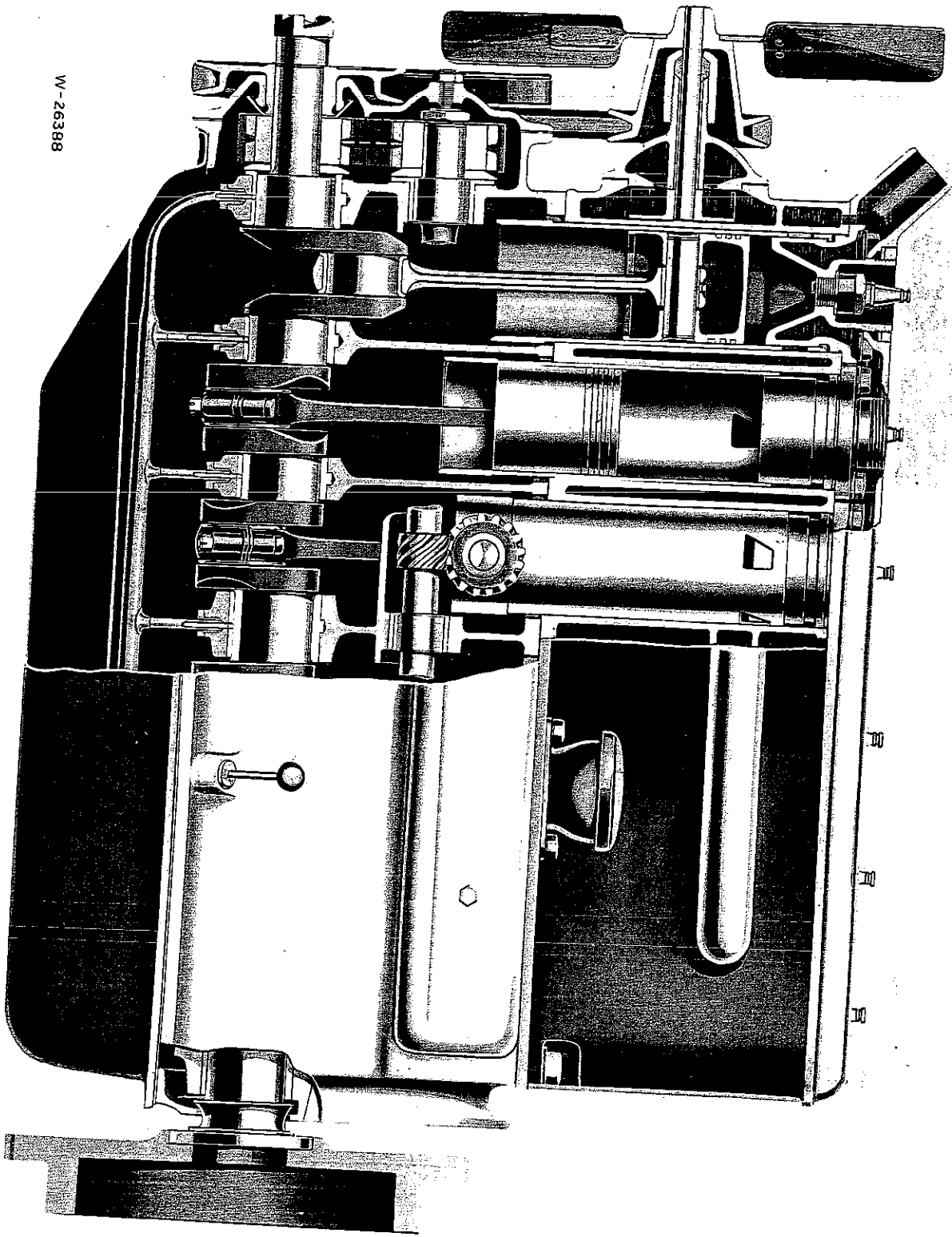
During the years 1909 to 1914 Argylls Ltd., held a monopoly on the engine and manufactured it for their exclusive use. About a month before the outbreak of the war the Argyll concern had the misfortune to be placed in receivership, with the result that the patent rights on the engine reverted to the inventor Mr. Peter Burt.

Work on the engine was practically at a standstill during the war years 1914 to 1918, but soon after the Armistice the patents were purchased outright by Wallace (Glasgow) Ltd., who placed on the market a series of stock automobile engines, and granted licenses to other companies for the manufacture of industrial, marine and motor cycle engines, both air and water cooled, so that it was not until 1919 that the single sleeve valve engine was placed on the open market.

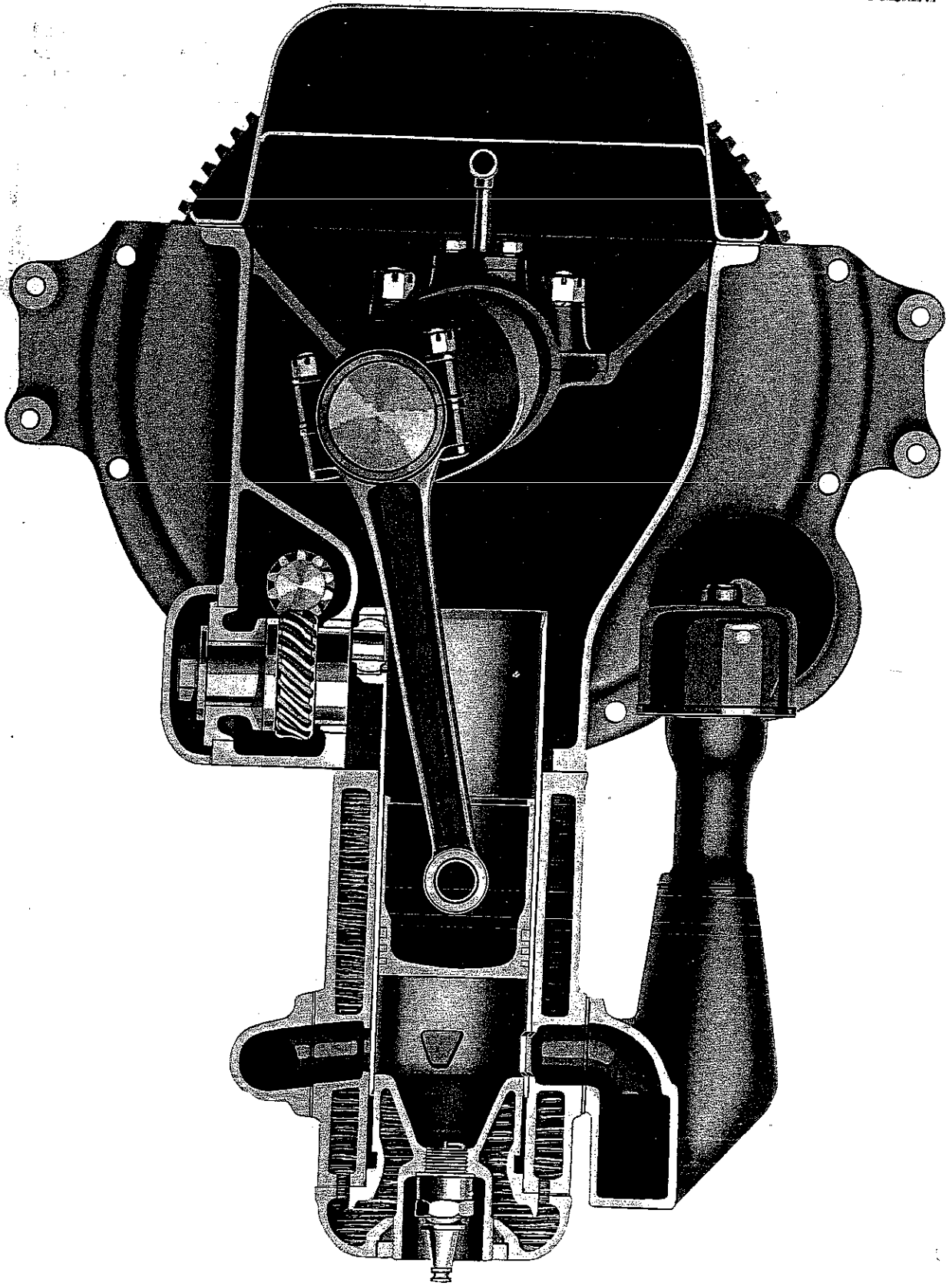
Last year the Continental Motors Corporation negotiated a deal which resulted in their obtaining the World's rights to manufacture and license the single sleeve valve engine under the Burt-McCollum patents.

It may not be out of place to comment briefly on the patent situation, as we are often asked what is the life of the patent and what does it cover. Burt's original patent was filed on August 6th, 1909 and accepted on the 8th of August the following year. A four years extension was granted last year, so that the date of expiration in Britain is August 5th, 1929. Application for an equivalent United States patent was filed on August 3rd, 1910 and granted on July 22nd, 1919, thus giving an expiration date of July 21st, 1936. Perhaps the broadest claim contained in the United States patent is that which reads:

W-26388



W-26387



"A mechanism for the purpose specified, comprising a main cylinder having intake and outlet ports near its head, a piston enclosing cylinder, movably fitting within said main cylinder, to act as a valve and having intake and outlet ports, and movable for bringing the respective ports into alternating registering relation therewith, a piston reciprocating within said enclosing cylinder, and by means for imparting synchronous longitudinally reciprocating and oscillating movement to said piston enclosing cylinder, the range of longitudinal movement being less than the piston movement and greater than the longitudinal dimension of the ports".

J. H. K. McCollum's patents which were assigned to Argylls Ltd., and others, consists of a sleeve outside of the main cylinder instead of between the cylinder and piston, and two operating mechanisms for imparting the reciprocating and oscillating movement to the sleeve.

An interesting side light on the patent situation was the action for infringement brought against Argylls Ltd. by Knight & Kilbourne in November 1911. The case was tried in July 1912 and resulted in judgment for the defendants. An appeal held in February 1913 also went in favor of Argylls Ltd. It should be pointed out, however, that the Knight construction, patented in 1905, under which the suit was brought, was not the double sleeve type, but a cylinder acting as a single sleeve valve, having interrupted reciprocating motion without oscillation.

MECHANICAL DESCRIPTION:

Referring to the Cross Sectional Arrangement, Fig. 1, it will be seen that the crankshaft, connecting rod, and piston are of the

conventional design and not necessarily different from those used in a poppet valve type of engine. The essential difference lies in the substituting of a single sleeve valve of cylindrical form in place of the usual poppet valves.

The cylinder is open ended and has port openings cut in its circumference immediately below the bottom edge of the cylinder head or stationary piston. Intake and exhaust ports are on opposite sides of the cylinder block so that separate manifolds are employed.

The water jacket surrounding cylinders is free from pockets and tortuous passages and provides inspection access to water cores between the exhaust port passages through openings on top face of cylinder. A water header casting encloses the top of water jacket, the necessary water joint being made by securing header to cylinder by means of ring nuts on cylinder head. Over the water header is placed a stamped cover which acts as an ignition wire carrier and serves to enhance the appearance of the engine.

The tubular sleeve valve is interposed between the cylinder and the piston, and has ports cut at its upper end to register with those in the cylinder wall.

The valveshaft, equivalent to the camshaft in a poppet valve engine, is located below the sleeves and at one side, its axis lying parallel to that of the crankshaft. It is driven at engine speed by chain or gear train from the crankshaft, and has a worm gear situated at the centerline of each cylinder.

At the foot of each cylinder, at right angles to the axis of the crankshaft, and immediately above the valveshaft, lies the sleeveshaft, consisting of a single cranked shaft and a worm wheel mounted on suitable bearings within the crankcase. The worm wheel meshes with the valveshaft worm gear, and rotates at a ratio of one to two or half engine speed.

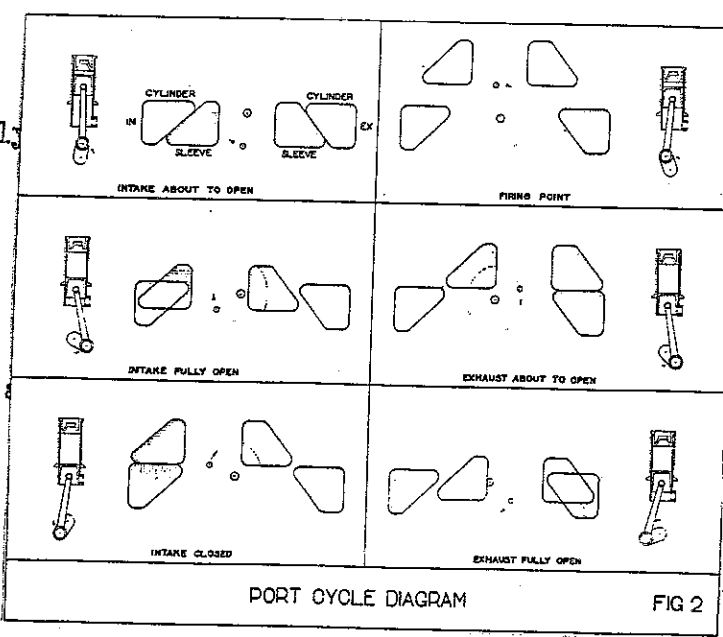
A universal coupling or ball and socket connection is placed within a housing provided at the foot of the sleeve valve, the socket being fixed to the sleeve while the sphere zone is free to rotate and slide on the sleeveshaft crankpin which engages in the bore of this member.

Rotation of the sleeveshaft imparts to the sleeve a partly rotating and partly reciprocating movement. Any point on the sleeve surface travels in a closed curved path elliptic in shape. The path of travel of the sleeveshaft crank and universal coupling at point of actuation is circular, but when projected on the sleeve wall it becomes elliptical owing to the radius of the sleeve surface being less than the distance from axis of cylinder to point of actuation, and the fact that the sleeve oscillates around the cylinder axis.

The general appearance of a typical engine may be seen from the inlet and exhaust side views.

Port Cycle Diagram, Fig. 2, shows one complete cycle of sleeve

movement, the of the piston diagrammatically the drawing. of the intake is at its and all ports As the piston sleeve moves the lower left the travel



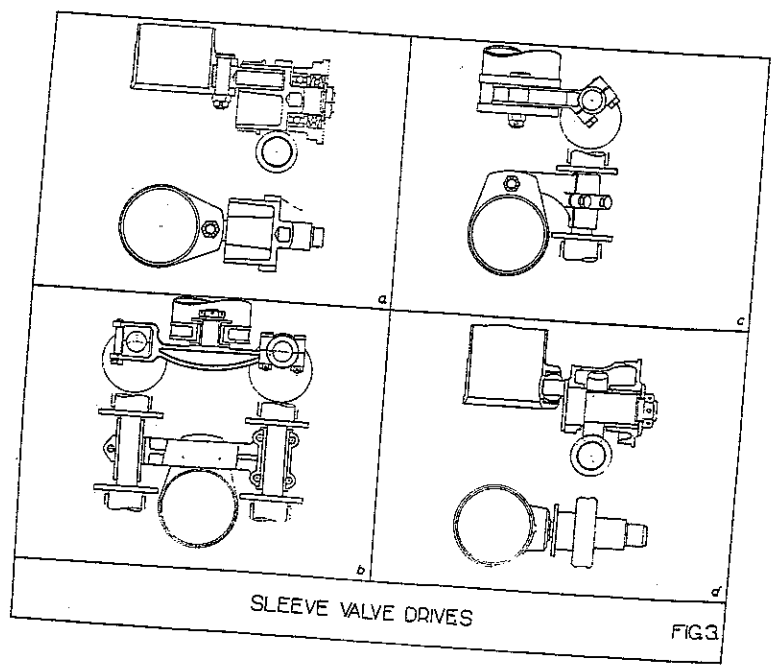
relative positions being indicated at the side of At the beginning stroke the sleeve bottom center, are closed (a). descends, the around and up hand portion of ellipse, the in-

take ports in the sleeve uncovering the intake ports in the cylinder(b)

Intake closing occurs when the bottom straight edge of the sleeve port coincides with the top straight edge of the fixed port in the cylinder (c). As the piston turns on the compression stroke, the sleeve continues upwards, reaching its top center at the same time as the piston (d). During the power stroke the sleeve moves over and down the top right hand portion of the travel ellipse. Exhaust opening takes place when the bottom edge of the sleeve exhaust port meets the top edge of the port in the cylinder as shown at (e), the sleeve moving downward as the piston moves upward on the exhaust stroke. At (f) maximum exhaust opening occurs, the sleeve travelling on the lower right hand portion of the ellipse until the flank edges of ports coincide, closing the ports and completing the cycle.

SLEEVE DRIVING MECHANISM:

The design of mechanism for actuating the sleeve is an interesting problem and many schemes have been tried out from time to time. However, all things considered, the gear type drive in various forms has proven the most satisfactory. Some of the drives in use are shown in Fig. 3.



At (a) the original Argyll type is shown. This employs skew gears to transmit the drive from the valveshaft to the sleeveshaft. On the inner face of the sleeveshaft a hole is bored parallel to, and at a definite distance from the shaft axis. Into this hole the actuating pin is entered, the head of the pin being machined with flats to form a hinge connection with the lugs at the base of the sleeve by the aid of a pivot pin. The actuating pin is free to oscillate in the sleeveshaft hole and so compensate for the variance of transverse distance between the centerline of sleeve and the axis of hinge pin during operation. This mechanism works satisfactorily but is somewhat heavy and costly, partly owing to the liberal use of ball bearings and ball thrusts.

The second type shown (b) was used by Piccard-Pictet et Cie of Switzerland. This gives a rigid and practically wearless mechanism, but has the disadvantage of being much too heavy, the placing of the sleeve lugs between the cylinders adding considerably length to the engine. Two valveshafts are employed; one at each side of the engine. These run at half engine speed and are identical, taking the form of small throw crankshafts, having a throw for each cylinder. The throws are connected by means of a cross link, one end of which is floating to allow for slight inaccuracies in synchronism. At the center of each link connection is made with the sleeve by means of a hinge joint as at (a). It would seem that this type of drive is best suited for extra large engines of bus type. The cross link could be made of duralumin or other light alloy.

A modification of type (b) is shown at (c). This is known as the link drive and was first used on the 1919 model Argyll "Mark A" engine. It is lighter and cheaper than type (b), but obviously inferior mechanically. The necessary lengthening of the engine is

a disadvantage as is also the fact that, like type (b) assembly of driving mechanism has to be done in position in crankcase. An advantage which should not be overlooked is the coupling effect of driving each sleeve from a common valve crankshaft, so that the valve timing is fool-proof.

The present sleeve driving mechanism is shown at (d), and in Cross Sectional Arrangement Fig. 1; this it will be seen, is a modification of the original type (a) drive. Introduced in 1921 in the "Mark II" engine it has given entire satisfaction. The adoption of a universal ball and socket connection has many advantages; it is lighter, occupies less space, and allows for any inaccuracies in the alignment of parts. The distance from the cylinder axis to center of actuation is less than in any previous drive, thus giving a smaller sleeveshaft stroke for a given area of port opening. If the port area of type (d) for a given stroke is one square inch, then the area of the other types would be .85 square inches.

The sleeveshaft and worm wheel in type (d) are built up as a unit in a bearing housing, the outside of ^{dia.} which is ~~concentric~~ to the bore in order to facilitate assembly. It will be noticed that gears run in a constant level oil bath.

An interesting drive is incorporated in the new Aster engine. The sleeve is actuated between cylinders by means of a small auxiliary crankshaft and duralumin connecting rod, the latter being pivoted at its center within a sliding cross head, the connection to the sleeve being made with the conventional ball and socket joint. The travel of sleeve surface is approximately D shaped instead of elliptic.

Apart from the fundamental design considerations, the desirable qualities of a mechanism for imparting the elliptic motion to sleeve are that it be free from awkward assembly operations, such as

connecting parts together in position inside the crankcase; each sleeve should be similiar, the center distance form axis of cylinder to point of actuation kept at a minimum, and the length of drive kept within the diameter of cylinder.

SLEEVE VALVES:

The characteristic twisting motion of the sleeve has many inherent advantages, although primarily conceived for the purpose of obtaining the proper sequence of valve operation when using one sleeve instead of two, it subsequently proved to be a decided benefit in other respects. It is a natural lubricating motion, the oil being rolled evenly over the entire sleeve surface, and not localized and sheared, as in the case of a sleeve or piston having a reciprocating movement only. Oil grooves are not necessary on the surface of a single sleeve valve.

The movement of the sleeve approaches harmonic motion, and does not call for a sudden reversal of direction of travel as does a sleeve with purely reciprocating movement.

Again, the twist dissapates heat loss to the sleeve wall over a larger area, giving more even temperatures, therefore, reducing distortion to a minimum. During compression and power strokes, when the sleeve is subjected to the greatest pressure, it is moving with the piston, and the sleeve ports are protected between the water cooled surfaces of cylinder and cylinder head.

It has not been found necessary to fit sealing rings to the cylinder head, as used in the double sleeve valve engine. This is no doubt due to the baffle effect caused by the twisting movement which smooths out minute surface irregularities, coupled with the fact that there is a sealing surface at both sides of the sleeve

wall during compression.

The fact that piston and sleeve move in the same direction at different speeds during pressure strokes results in a considerable reduction in piston rubbing speed compared to that of the conventional poppet valve engine, and so reduces piston wear. The wear of the sleeve surface is practically negligible. It will be noticed that the sleeveshaft crank is near the 90° position at the time of intake closing and exhaust opening, so that the sleeve is moving with maximum velocity and practically in a vertical direction, therefore, giving the desirable quick opening and closing of valve ports. The motion is a friction reducing one and may be likened to the action of the replacing of a cork in a bottle.

Sleeves are usually made of cylinder cast iron, cast in a rotating mould, although ordinary sand castings are entirely satisfactory if carefully made. The wall thickness of sleeve is really governed by what the machine shop can handle without fear of breakage. This will be found ample for strength working conditions. The wall thickness, in practice, ranges from $5/64$ " for $2-3/4$ " bore to $9/64$ " for 5" bore.

Steel sleeves are sometime used when high engine speeds are desired. It is usual to manufacture them from solid drawn steel tubing, the boss for actuating being formed by extruding operations.

A sleeve of average diameter is fitted to the cylinder bore with a tight $.003$ " and a slack $.002$ " feeler.

The ball socket connection has evolved from a self aligning ball bearing of the S.K.F. type, to the present sphere zone, having a pressure die-cast babbitt socket cast in position. It is found that the fit of ball in socket can be varied by the pressure applied. The diameter of sphere zone is generally made $.35D$ while the sleeveshaft crank pin approximates $.19D$, where D equals the outside

diameter of the sleeve. Originally ball and socket were made detachable but this reduced bearing area due to flats milled on ball to allow of assembly.

CYLINDER HEAD:

A detachable head per cylinder has the advantage of obviating the use of a large casting and gasket. ~~Any~~ cylinder may be examined without disturbing the joint of the remainder. Explosion balance is assured as the combustion space is completely machined, while spark plug is ideally placed and effectively water cooled.

Cast iron is usually employed, although aluminum is satisfactory and is used where weight is of the first importance.

Many shapes of combustion chambers have been tried, and although the hemispherical type is theoretically ideal, it does not prove in practice to be as good as the cone frustum type.

The head is made a light push fit in the sleeve, and secured to the cylinder by four cap screws, an extra thin gasket being interposed between the head flange and cylinder. It should be noted that the head joint is not subjected to direct explosion pressures.

In common with other sleeve valve engines the power output improves as carbon builds up around the head.

A standard spark plug is used, the long reach plug and extension, characteristic of the early models has been discarded due to adoption of cone frustum type cylinder head.

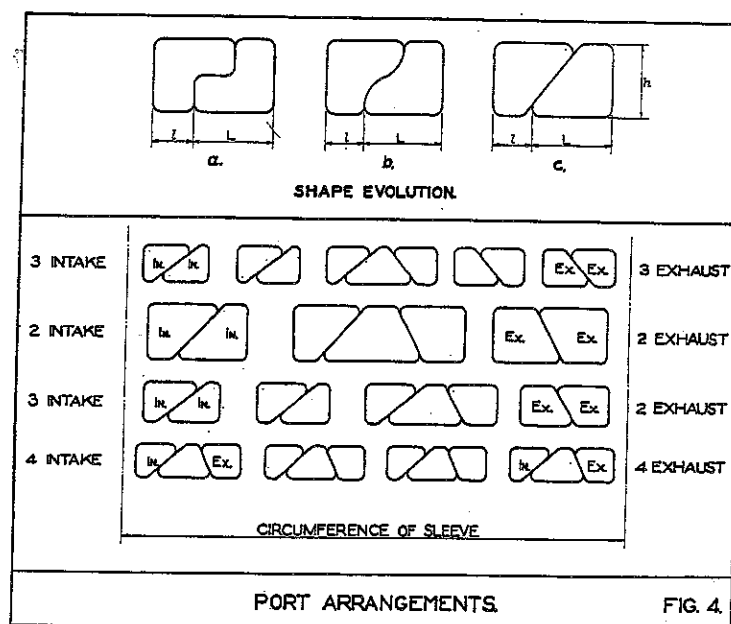
Freezing troubles have not been experienced in connection with the cylinder head, although at first sight this would appear a probable source of trouble. A syphoning tube is sometimes fitted.

Due to the shape of the combustion chamber it is possible to adopt a comparatively higher compression ~~ratio~~ ratio without fear of detonation, 5 to 1 being generally used on automobile engines.

SLEEVE PORTS:

The size and shape of ports is determined by the area and valve timing required. In common with the poppet valve these can only be settled by experience, each particular type of engine being considered according to the performance required of it.

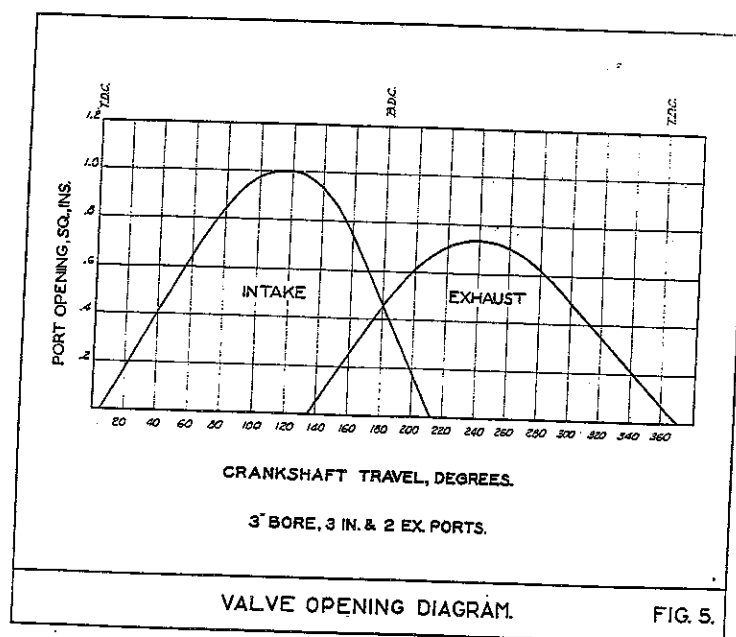
Maximum area with minimum travel is obtained by using a port shaped as shown in Fig. 4 at (a) but, apart from machining difficulties



such a shape is impractical owing to interference between sleeve and cylinder ports on the downward stroke of the sleeve. This interference is overcome by rounding off the corners of all ports as indicated at (b). In order to simplify the machining of the port cutting cam it is usual to modify the port outline to give a straight flank edge as shown at (c). This results in a slight reduction in area for a given sleeveshaft stroke, but gives a better machining proposition. The radius at corner of port is usually made $1/8$ " this being considered as small as possible consistent with cutter upkeep. The back edge of port need not be vertical, but may be curved to conform with path of travel.

The number of ports incorporated in the design of engines of

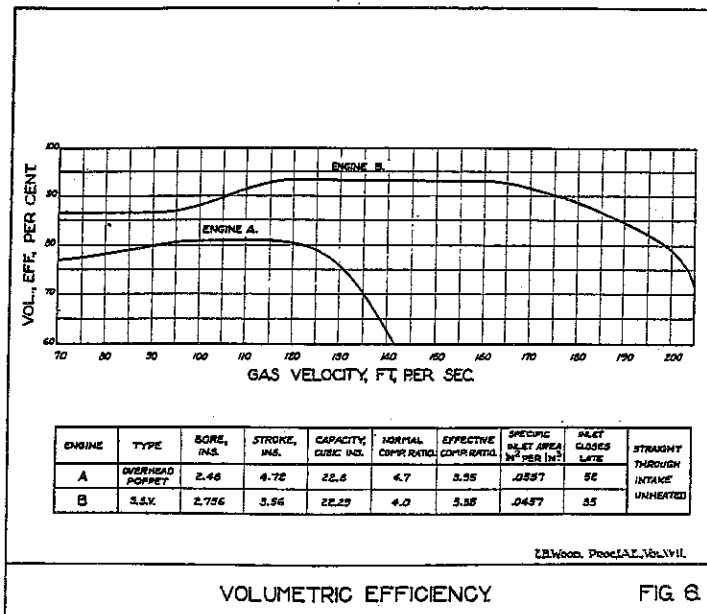
different types ranges from two intake and two exhaust, to four intake and four exhaust. Some of the possible arrangements are shown in Fig.4. Taking a given area, the fewer the ports, the greater is the sleeve-shaft throw required; so like many other engineering conditions a compromise is made. Three intake and two exhaust ports have been found



to be the best all-around combination for automobile engines. This arrangement gives a sleeveshaft throw of moderate dimension, practicable water cores between the cylinder ports, while the maximum port opening obtainable compares favorably with good poppet valve practice, a condition which has proven satisfactory for average engines.

In each of the port settings, it will be noted that one of the sleeve ports acts alternately as intake and exhaust. This is known as a "double purpose" port, and is really the joining together of adjacent intake and exhaust ports. Its inclusion serves to give a greater valve area, as full use is made of the sleeve circumference, in case of a single cylinder engine, it is possible to make every port in the sleeve of the "double purpose" type. This results in maximum port area but complicates manifolding.

A typical valve opening diagram is shown in Fig. 5. This shows the quick opening and closing, also the decided "dwell". A sleeve valve port will admit more air in a given time, than will a poppet valve of equal area, due to lower temperature of intake charge and reduction in restriction and friction; that is one of the reasons

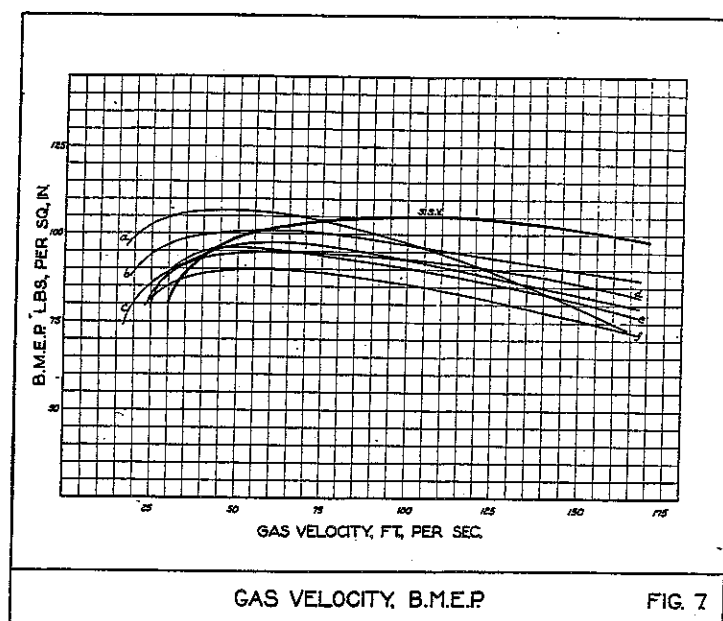


why equal areas are sufficient in ordinary practice. This is borne out in the volumetric efficiency tests contained in a paper on Sleeve Valve Engines, by E. B. Wood # in which it is shown that under equal conditions the single sleeve valve engine has at least 20% better volumetric efficiency than the poppet valve engine; tests were made with a straight-through carburetor without external heat. Mr. Woods volumetric efficiency graph of a poppet valve and a single sleeve valve engine of equal capacity is reproduced in Fig. 6.

Another point to be noted is the fact that in a single sleeve valve engine the brake mean effective pressure does not fall off until a gas velocity of 110 ft. per second is reached, whereas in the case of a poppet valve engine, the falling off takes place in the

See Proc. I.A.E. (London) vol. XVII page 289.

in the region of 60 ft. per second. This is shown graphically in Fig. 7 where several modern poppet valve engines are plotted against the latest single sleeve valve engine. Fig. 6 and 7 make it clear that the intake system on a single sleeve valve engine has to be considered somewhat differently from that of a poppet valve engine. In common with poppet valve engines, the sleeve valve

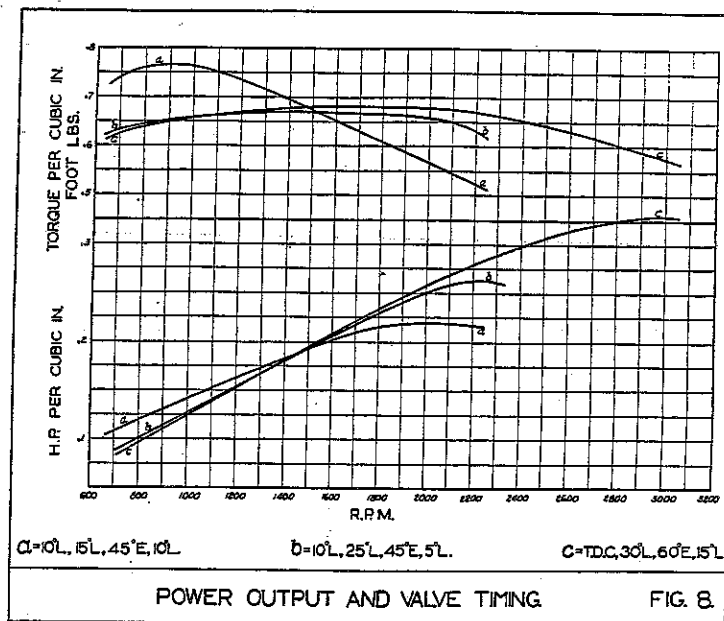


timing varies according to the engines requirements but, unlike the poppet, it is constant irrespective of engine speed.

Average single sleeve valve practice is as follows:

<u>Type of Eng.</u>	<u>Intake Opens</u>	<u>Intake Closes</u>	<u>Exh. Opens</u>	<u>Exh. Closes</u>
Low Speed	10°L	15° L	45°E	10°L
Medium	10°L	20° L	45°E	10°L
High Speed	5°L	30° L	60°E	15°L
Timing tolerances allowed on production	2°E to 5°L	4°E to 4°L	4°E to 4°L	5°E to 2°L

Fig. 8 shows the power output per cubic inch of three engines having valve timing as given in table. The engines from which curves were taken differed mechanically in some respects so that an absolutely true comparison of effect of timing only is not represented.



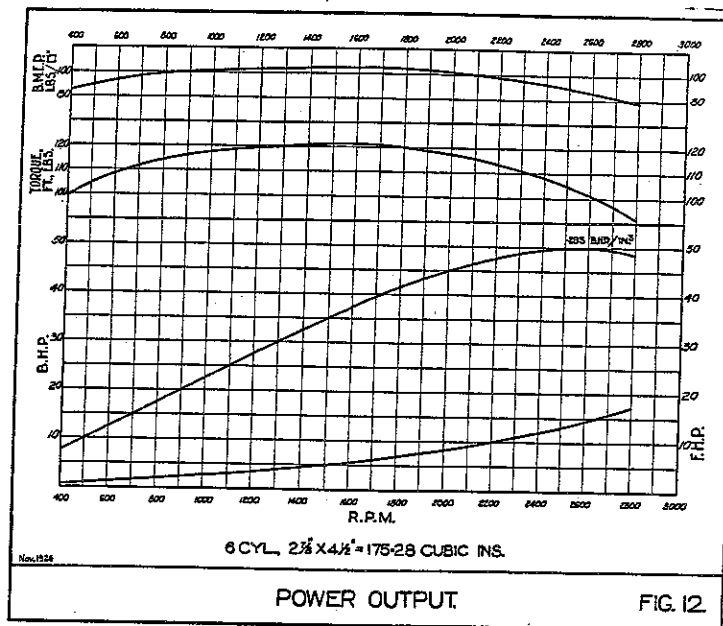
GENERAL:

The chief advantages of a single sleeve valve engine are, sustained operating efficiency, good power output, and silence in operation.

A thousand hour test run under full load at 2000 R.P.M. was recently made on a six cylinder 2-7/8" bore by 4-1/2" stroke engine. During the first hundred hours the power output gradually built up to 44 B.H.P. after which it remained constant until the completion of test. Measurement of sleeve driving gear backlash was made by means of an extended arm attached to the sleeveshaft and although a maximum increase of .017" on pitchline was recorded, the gears ran as quiet as at the start of test. On dismantling the engine it was found that the maximum wear on the piston skirt was .001" while the wear on the outside diameter of sleeve was undetectable. Fig. 12 shows a power output curve taken from this engine after the 1000

hour run.

The adoption of a sleeve valve obviates such things as "grinding in" of valves, ingress of unwanted air through worn valve guides, valve distortion or sticking, clearance adjustment, valve spring breakage and frequent decarbonizing.



The rapid opening of ports, the type of port opening obtained, positive timing, unobstructed intake passages, and increased compression ratio all contribute to good power output.

Silence in operation is achieved by avoiding the hammer and anvil blows of a poppet valve, and the fact that the valve actuating mechanism does not extend outside of the engine body. The sleeve valve engine not only can be made to run quietly, but it stays quiet.

The weight of a single sleeve valve engine compares favorably with that of a poppet valve. When a separate cylinder block is used, the added depth of engine body due to the shortness of the sleeve valve cylinder gives strength and rigidity and allows the use of

aluminum. A cast iron sleeve for an engine of 2-3/4" bore weighs about 2 lbs., while the weight of valves, springs, and tappets for a poppet valve engine of even bore approximates 1-1/4 lbs., a saving of 3/4 lb. per cylinder in favor of the poppet. It should be borne in mind, however, that the sleeve valve cylinder head construction is considerably lighter than that of the poppet valve. In practice it is found that a single sleeve valve engine of average bore, with an aluminum casing, is about 50 lbs. lighter than a poppet valve engine with the conventional cast iron construction, other things being equal.

The lubrication of the crankshaft and connecting rod bearings is pressure feed of orthodox design. A pressure lead is connected to the valveshaft tunnel in the walls of which are overflow holes placed so as to maintain an oil bath for the sleeve gears. The sleeve and piston are lubricated by oil mist, care being taken to avoid direct splashing of oil on sleeves.

The Engine Sub-Committee of the British Aeronautical Committee in their report for 1925-26 make the following comments regarding the single sleeve valve engines:

"During the course of the year the Sub-Committee have given considerable attention to the results that have been obtained in the development of single sleeve valve engines (Burt-McCollum type). They are of the opinion that these engines offer definite advantages for use in aircraft. It has been proved without any doubt that the absence of hot exhaust valves diminishes the tendency to detonation, and in consequence allows a sleeve valve engine to be used at a higher compression value than a poppet valve engine of corresponding size. The increase in efficiency so obtained is important. It also appears that the weight of a complete engine is not likely to be substantially increased by the substitution of single sleeve valves for poppet valves.

The Sub-Committee consider that the research work has now reached such a stage that the development of multi-cylinder aircraft engines using sleeve valves should be encouraged."

In a supplement to the above report the following appears:

"For some time past, work has been in progress on the evolution of the sleeve valve engine suitable for aircraft purposes. In a recent report on the present position, Mr. H.R. Ricardo stated that as the result of from nine months to two and a half years' running experience on several engines the conclusion has been reached that the single sleeve valve gives better performance than the poppet valve engine of the same size, maintains its performance far longer and possesses very considerable mechanical advantages.

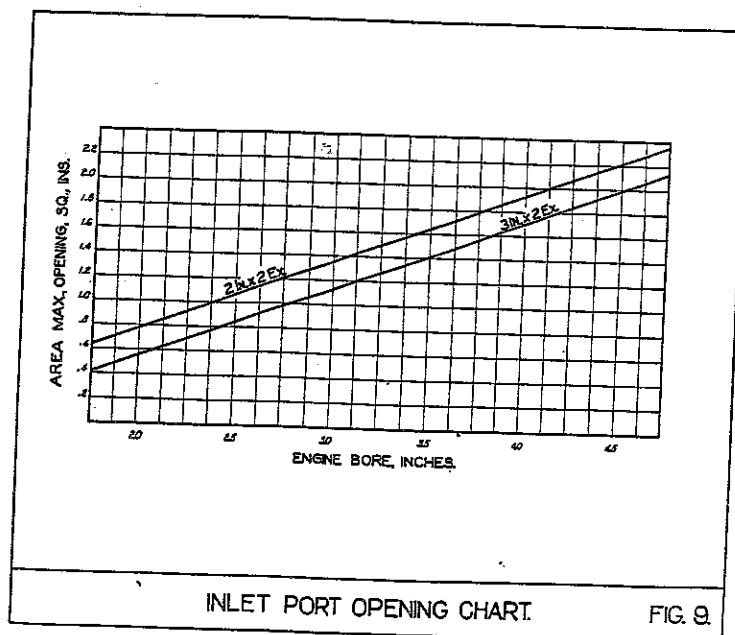
The Sub-Committee have examined in detail the results of all tests undertaken, and consider that the potential value of the single sleeve engine for aircraft purposes has been fully demonstrated. In particular, experience has shown that it is possible to keep the sleeve fully lubricated without an excessive oil consumption, and that the absence of hot exhaust valves in a sleeve valve engine reduces the tendency to detonation of the fuel, and therefore allows the use of higher compression ratios than a poppet valve engine of similar size."

APPENDIXPORT CALCULATION:

Before proceeding with the calculation of ports the following particulars require to be settled:

- A = Arrangement and number of ports.
- D = Outside diameter of sleeve in inches.
- C = Distance from axis of cylinder to center of actuation in inches
- T = Throw of sleeveshaft crank in inches.
- V = Valve timing.

As already mentioned, it is desirable to use three intake and two exhaust ports, this combination being a compromise between fewer ports with larger sleeveshaft crank throw, giving greater overall height of engine, and larger number of ports, with smaller crank throw, reducing the height of engine, but complicating coring in cylinder and increasing port cutting time. Reference should be made to Intake Port Opening chart, Fig. 9, from which the maximum area



in square inches for different arrangements of port settings may be seen. If three intake by two exhaust does not give sufficient area

for a particular engine, taking a poppet valve as a basis, then two intake and two exhaust should be adopted.

The outside diameter of the sleeve D is obviously determined by the bore of engine and thickness of sleeve wall.

Using the ball and socket type of coupling, the distance from axis of cylinder to centerline of ball equals,

$$C = .625D \text{ to the nearest even dimension} \quad \text{-----}1$$

The sleeveshaft crank throw T is determined by the outside diameter of sleeve, the center distance C , and the port arrangement A given as the total number of ports per cylinder. The stroke of sleeveshaft crank is approximately equal to the width of port, and space between ports, so that, if the circumference of sleeve outside diameter be divided by twice the number of ports, minus one, - there being less space than ports, the approximate stroke of sleeve is obtained:

$$T = \frac{\pi D}{2A - 1}$$

The sleeve wall is at a different distance from the axis of cylinder than is the point of actuation, therefore, an allowance must be made in calculating the crank throw T .

$$T = \frac{\pi D \times .625D}{(2A-1) \times .5D} = \frac{1.96D}{2A-1} \quad \text{-----}2$$

or $T = .218D$ for three intake and two exhaust -----3

and $.28D$ for two intakes and two exhaust -----4

Taking a 2-3/4" bore engine of the passenger car type for example of port calculations, the necessary particulars are first determined. A poppet valve engine of even bore and conventional design has a maximum intake valve diameter of half the engine bore, so that with a 1/16" deep seating the port diameter equals,

$$(.5 \times 2.75) - .125 = 1.25" \text{ diameter.}$$

therefore,

$$= \text{Angular Travel} = 20^{\circ} 10' \times 2 = 40^{\circ} 20'$$

The horizontal travel or lateral movement of sleeve measured on the outer surface of sleeve wall has next to be found,

$$\begin{aligned} H &= \text{Horizontal Travel} = \frac{\alpha \pi D}{360} = \alpha \times D \times .00872 \text{ -----} 6. \\ &= 40.33^{\circ} \times 2.9 \times .00872 = 1.0229 \end{aligned}$$

The length of port is obtained by subtracting an allowance for seal from the horizontal travel. This seal, or cover, as it is called, is necessary in order to prevent pressure leakage during the passage of a sleeve port between adjacent ports in cylinders. The amount of cover may be varied in order to bring the port length to an even dimension, but should never be less than .05".

Length of port equals:

$$L = H - \text{Cover} = 1.0029 - .0529 = .97" \text{ -----} 7$$

Next, the width of the large spaces between ports is found by adding a variable cover allowance to the horizontal travel, so that a space equals:

$$W = H + \text{Cover} = 1.0029 + .0501 = 1.073" \text{ -----} 8$$

Having length ~~and width of port~~ of port and width of large space, the spacing of ports around the cylinder circumference can now be settled. In the 3 intake and 2 exhaust port arrangement under consideration these are:

$$5 \text{ Ports at } .97" = 4.85"$$

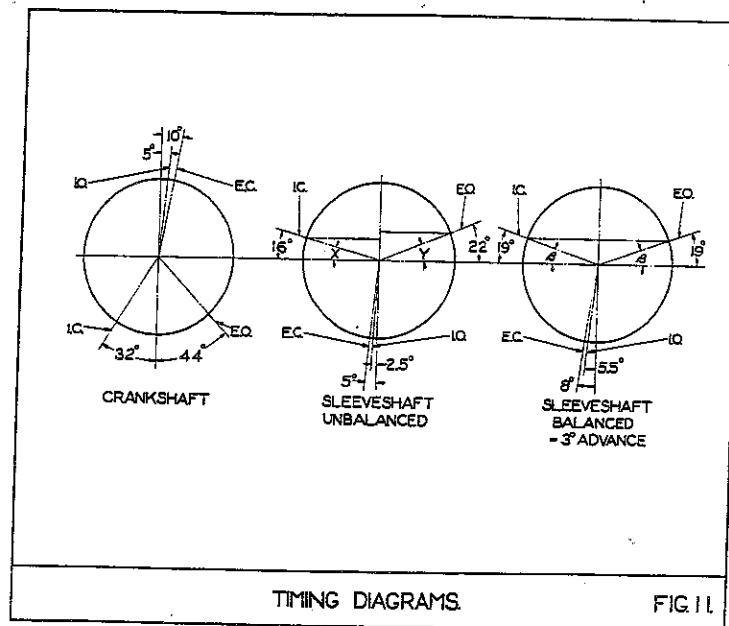
$$3 \text{ Spaces at } 1.073" = \underline{3.219"} \quad 8.069"$$

$$8.069"$$

so that this figure subtracted from the circumference of the sleeve outside diameter gives the sum of the remaining small spaces. Therefore a small space equals:

$$.5 (.7854 D^2 - 8.069) = .5 (9.1302 - 8.069) = .5 \times 1.0612 = .5306\#$$

The height of ports is controlled by the throw of the sleeveshaft and the valve timing at the intake closing and exhaust opening positions. In Fig. 11 three Timing Diagrams are given, the first being the crankshaft or flywheel timing, while the second shows the same timing transferred to the half engine speed sleeveshaft. The third is simply the center diagram with the datum points moved around or advanced so as to bring the intake closing and exhaust opening points to a uniform distance from the horizontal centerline, the timing periods remaining unchanged. The advance or angular distance through which



the sleeveshaft crank is moved ahead of crankshaft equals $(X - Y) \div 2$ degrees on sleeveshaft, this for the example taken equals

$$\frac{22 - 16}{2} = 3^{\circ}$$

It should be clearly understood that this advance does not alter the timing in any way, but simply changes the relative position of sleeveshaft to crankshaft; so that when the latter is at its top center, on

compression stroke, the former is 5° over top center, or in other words, when the sleeveshaft crank is on its top center, the crankshaft is $3^\circ \times 2 = 6^\circ$ before its top center.

The height of port equals the sleeveshaft crank throw plus the product of the throw multiplied by the sine of the intake opening or exhaust closing angle taken from the balanced timing diagram,

$$h = T - (T \sin \theta) \text{-----}10$$

$$= .625 - (.625 \times \sin 19^\circ) = .8284$$

It will be seen that the object of advancing the sleeveshaft crank in relation to the crankshaft is primarily to make intake and exhaust ports of equal heights and so simplify port cutting operation. There is, however, another advantage which should not be overlooked. The height of cylindrical portion of the combustion space is governed by the height of port, that is, the top of piston at top center coincides with the lower edge of cylinder ports, while the foot of the cylinder head is placed about $1/32''$ above the top edge of ports. A reduction in port height, due to balancing, allows a reduction in height of cylindrical portion with a corresponding increase in the height in cylinder head. This tends to promote better gas turbulence and at the same time raises the spark plug out of a deep pocket, a characteristic of early model engines, which had intake and exhaust ports of different heights calculated direct from an unbalanced timing diagram.

The port flanks angles which govern the opening of intake and closing of exhaust are next determined. To obtain these dimensions l_1 and l_2 are first solved.

$$\text{Intake port tail} = l_1 = .5H - (T \sin \delta \frac{.5D}{C}) \text{-----}11$$

$$= .5 \times 1.0229 - (.625 \times \sin 5-1/2^\circ \times .8017)$$

$$= .4634''$$

$$\begin{aligned}
 \text{Exhaust port tail} = l_e &= .5H + (T \sin \gamma \frac{.5D}{C}) \text{-----}12 \\
 &= .5 \times 1.0229 + (.625 \times \sin 8^\circ \times .8017) \\
 &= .5812"
 \end{aligned}$$

Solution of flank angles is as follows:

$$A = h - 2r$$

$$B = L - (l_i \text{ or } l_e - 2r)$$

$$\tan \theta = B : A$$

$$E = B : \sin \theta$$

$$\sin \phi = r : .5E$$

$$Z = 90^\circ - \theta$$

$$X = Z - \phi$$

For the example taken the flank angle X equals:

$$\text{Intake -----}42^\circ 47'$$

$$\text{Exhaust ----}51^\circ 38'$$

Having all port dimensions it is a simple matter to construct a port opening diagram. Adjacent intake and exhaust on cylinder, and the sleeve travel ellipse are drawn on an enlarged scale, say ten times full size. The travel ellipse being constructed geometrically from the sleeveshaft stroke and the horizontal travel, using 10° divisions for convenience. Sleeve timing marks should be clearly indicated. Next the sleeve ports, one intake and one exhaust, are drawn on a separate piece of tracing paper, and placed over the cylinder port drawing so that ports are in line, with intake port flanks coincident and ~~the~~ in this position a mark is placed over the travel ellipse at the point of intake opening. Keeping ports horizontal ~~and~~ the mark is moved around the travel ellipse, the area of opening being measured by planimeter at every 10° of travel. After making correction for enlarged scale and actual number of ports, the readings are plotted against crankshaft travel to give a port opening diagram.