TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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TEST OF OIL SCRAPER PISTON RING AND PISTON FITTED WITH OIL DRAIN HOLES.

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1. The tests herewith reported were undertaken to determine whether or not a properly located and properly designed oil-scraper piston ring, installed on a piston provided with oil drain holes of sufficient area, would prevent the excessive oiling of the Liberty engine, particularly with the engine run at idling speed with full oil pressure.

Introduction:

2. The Liberty engine, when equipped with production rings, installed as designed and operated at full speed at the designed oil pressure of 50 lb. per sq.in., oils up and throws dense clouds of black oil smoke out of the exhaust ports even when operated with a carburetor setting so lean that the mixture periodically back-fires through the carburetor. For this reason a carburetor setting cannot be obtained by observation of the exhaust, as it has a smokey, over-rich appearance at all settings. When it is attempted to idle an engine equipped as above, the oil pumping is so bad that, after from five to fifteen minutes' operation at idling speed, oil commences to run out of the exhaust ports and the engine must be opened up periodically in order to clean out the spark plugs and keep them functioning.

3. In order to reduce this oiling, holes were drilled in the oil pressure relief valve so that the pressure, under which the oil is fed to the bearings, is reduced from the designed value of 50 lb. per sq.in. to from 30 to 35 lb. per sq.in. at full speed. An engine with the oil pressure so regulated does not oil up as badly, as the original production engine and can be idled for much longer periods before oil is pumped out of the exhaust ports and the spark plugs fouled, but, even so, the course of an airplane equipped with this engine can be traced for over an eighth of a mile by the black oil smoke left floating behind.

4. Following the practice obtaining in automobile engines, the use of an oil pressure relief valve whose opening is regulated

by the manifold vacuum was suggested. This method is similar to that mentioned in paragraph 3, in that the oil pumping is reduced by decreasing the amount of oil fed to the bearings (and, hence, to the cylinder walls) by reduction of the oil pressure, and differs from the former only in that, as the engine speed is reduced by closing of the throttle, the oil pressure is decreased in direct proportion to the increase in vacuum attendant upon the throttle closure.

5. Both of the methods noted in paragraphs 3 and 4 appear dangerous and drastic and not in accordance with common sense or engineering principles when the question is considered from the following viewpoint: All present aeronautical engines are designed, and the bearing clearances adjusted, with the idea of the shafts, pins, etc., running on an oil film which supports and separates them from the bearing proper, and which, consequently, must be supplied under a sufficient pressure to insure the maintenance of this film under any and all conditions likely to be encountered in operation. As far as the bearings themselves are concerned, this pressure can hardly be too great - the greater the pressure, the greater the measure of safety. This is particularly true if, for any reason, the viscosity of the oil is lowered, since the probability of the safety of the bearing, even with a very thin lubricant, is increased the greater the pressure under which the oil film is maintained. The piston also, to function properly as a cross-head, requires a lubricated surface - the cylinder wall - upon which to slide. In addition, the oil serves as the vehicle for dissipation of the very large amount of heat generated in the bearings and absorbed by the piston heads. Any device, therefore, which, in order to prevent oil from pumping past the piston rings, decreases the amount of oil fed (thereby decreasing the cooling of both bearings and pistons) and decreases the certainty of maintenance of the oil film in the bearings, and consequently of the amount of oil fed to the cylinder walls, militates against the safety and length of life of the bearings and the satisfactory performance of the pistons in their function as a cross-head. (Fig.1).

6. The absurdity of the attempted cures in paragraphs 3 and 4 is most forcibly illustrated by considering the analogous case of a pillow block shaft bearing which, due to inefficient oil throwers, allows oil to work along the shaft and out of the bearing. An analogous remedy for this case would be to so limit the supply of lubricant, without regard for the safety of the bearing, that the oil could not possibly work along the shaft, out of the bearing. The remedy, in accord with engineering principles, would be to install redesigned, efficient oil-throwers and to supply more than enough lubricant to insure the safety of the bearings. So, also in the case of the Liberty engine, the logical remedy for oil pumping would be to prevent, or at least greatly reduce, the amount of oil passing the piston rings by some change in the rings themselves.

Theory, History, and Description:

7. When a piston reciprocates in a lubricated cylinder, there are three paths by which the oil gets by the packing rings: 1st, the square edge of the ring scrapes off the oil thrown on to the cylinder wall by the crankpin, leaving on the wall a film whose thickness depends upon the unit radial pressure exerted by the ring on the wall, and upon the viscosity of the oil - which, in turn, depends upon the temperature of the oil. This film, due to cohesion and surface tension, remains upon the wall even after being uncovered by the piston on its downward stroke, and is protected from the combustion by the dead gas film inherently present in every case where heat is being transmitted from a gas or fluid (in this case the combustible mixture) to a solid (the cylinder wall in this case). This dead gas film exists at a temperature intermediate between that of the main body of gas and that of the wall and, consequently, the oil film is probably never subjected to a temperature approaching its flash point; 2nd, the oil scraped off of the cylinder wall by the bottom square edge of the bottom ring piles up against the ring, between piston and cylinder, and is forced through the ring gap to the other side of the ring, to an extent limited only by the exposed cross-sectional area of the gap; and 3rd, the oil piled up against the bottom ring also flows between the lower edge of the ring groove and the ring, which has been forced against the upper edge of the ring groove by the downward movement of the piston, filling the ring groove space under the ring with oil under the inertia pressure. On the reversal of the piston at the bottom dead center, the rings are forced from contact with the upper edge to contact with the lower edge of the ring groove, thus opening a passage, from the space in the ring groove under the ring to that between piston and cylinder on the upper side of the ring, for the flow of the oil which was scraped into this space on the downward stroke. This flow is induced, partly by the splash of the oil in the ring groove, due to the reversal of direction of the piston, but to a greater extent, following the suction stroke, by the vacuum existing above the piston (which vacuum gradually diminishes on passing from ring to ring, due to the packing effect of each ring). In a similar manner the oil passes the several rings on succeeding strokes, until when in the last ring groove, it is acted upon by the full vacuum, is drawn into the combustion chamber, and is burned, causing a smoky exhaust and depositing carbon or unburned oil (if in excess) on the piston head. If it were not for the vacuum existing above the piston on the suction stroke, the flow of oil around the back and through the gap in the rings would be very nearly equal on the upward and downward strokes of the piston. Due to the increase in vacuum with closure of the throttle, the amount of oil pumped past the piston rings naturally increases as the throttle is closed.

8. Many piston rings have been designed with intricate gaps in an attempt to prevent oil pumping. A study of the Liberty en-

gine, considering in each case, the worst permissible inspection clearance, proves the fallacy of any device of this type, viz.: consider a piston skirt diametral clearance of 0.022", a piston ring gap clearance (in the production, diagonal gap rings) of 0.041", and a ring groove clearance between edge of groove and ring of 0.003". Consider further, that the piston is hard against one side of the cylinder and with the ring gap diametrically opposite the point of contact of piston and cylinder. Then the exposed cross-section area for flow of oil through the gap is $0.022 \times 0.041 = 0.000902$ sq.in. and the area for flow of oil between ring groove and ring is $0.003 \times \pi \times 4.625 = 0.003 \times 14.530 = 0.04359$ sq.in. (where 4.625 is the inner diameter of the piston ring when in the cylinder). The percentage of gap area referred to total area for oil flow is, therefore, $\frac{0.000902}{0.000902 + 0.04359} \times 100 = \frac{0.0902}{0.04449} = 2\%$. The above is the worst permissible case for both gap and groove and should be supplemented by considering this same gap condition compared to the minimum permissible groove clearance of 0.00125". In this case the area between ring and groove becomes $0.00125 \times 14.530 = 0.018163$ sq.in. and the gap area is

$$\frac{0.0902}{0.000902 + 0.018163} = \frac{0.0902}{0.019065} = 4\ 3/4\%$$

of the total area. In both cases the clearances taken have been those at atmospheric temperature and would not hold except for a very short interval after starting the operation of the engine. After this interval, the ring gap clearance and diametral clearance of the piston skirt in the cylinder would decrease (both of which changes decrease the exposed gap area) while the groove clearance would increase due to the greater expansion of the aluminum piston than of the cast iron ring. The relative importance of oil leakage through the piston ring gap decreases, therefore, with increase in the operating temperature, below the already insignificant figures quoted above. From the above, it is evident that the use or test of any patented ring, which has nothing to recommend it but a sealing or closure of the gap, is a waste of time, money, and energy.

9. If a relieved space, with drain holes leading from this space to the interior of the piston, is provided on the piston immediately below the bottom ring, the oil, which is scraped off of the cylinder wall by the square edge of the bottom ring, will flow into this space, through the drain holes into the interior of the piston, and thence back into the crankcase more easily than into the space between ring and groove. This is especially true if the drain holes are of sufficient area, because such a passage not only offers less frictional resistance to the flow of the oil, but also does not cause the cohesive resistance to flow offered by the

narrow space between ring and groove, which, in most cases, seldom exceeds 0.003" in width. To obtain the most effective action, the relieved space should be located where the oil is piled up, when scraped off of the cylinder wall, i.e., with the deepest space at the ring itself, and should not be separated from the ring by even the narrowest land of original skirt. If, in addition to the relieved space and drain holes, the upper edge of the bottom ring is chamfered or rounded sufficiently to break the square edge, the ring will have a tendency, on its upward stroke, to ride over any oil which has passed it on the downward stroke, rather than having a tendency to scrape it upward, thus allowing the lower, square edge to scrape off and drain away any excess oil on the next downward stroke. Complete constructional details of such relieved space, drain holes, and chamfered scraper ring are fully illustrated in Figure 1. It will be noted that, in the case of the Liberty production rings, the chamfer is carried to a point approximately 0.020" below the bottom edge of the oil groove. If this is not done the bottom edge of the oil groove in the ring acts as a scraper on the upward stroke, with results very nearly as harmful as if no chamfer were provided. If a ring with no oil groove were used the chamfer would need to be carried only for a sufficient distance to break the square upper edge of the ring.

10. The use of oil drain holes and a scraper ring of this type in high speed internal combustion engines dates back many years. In fact, many automobile and marine engines, of both domestic and foreign manufacture, and some aeronautical engines (notably the Mercedes, Fiat, and the earlier Hispano-Suiza engines) were so equipped. Almost invariably, however, this ring, the relieved space and the drain holes were placed at the bottom of the piston skirt, which location is good practice provided the piston is of cast iron and the piston pin is fixed in the piston. If, however, the piston pin is fixed in the connecting rod or floats in both rod and piston (with either a cast iron or an aluminum piston), the location of the scraper ring at the bottom of the skirt is bad practice, since, in either of these cases, the space between the scraper ring and the bottom ring of the group of rings located above the piston pin bosses, fills with oil from the piston pin lubrication, and the oil pumping is very nearly as bad as if no scraper ring had been used. The above statement applies to an aluminum piston even when the piston pin is fastened in the piston, since, due to the great expansion of aluminum, oil will work between pin and piston bosses out into this space. Wherever oil, therefore, from the piston pin lubrication can work into the space between piston and cylinder, the scraper ring, relieved space and drain holes should, without fail, be located above the wrist pin bosses, as illustrated in Fig. 1.

Method of Test:

11. The engine, fitted with production piston rings, was run

for a series of one (1) hour runs with various clubs and at various throttle positions, taking complete power, fuel, and oil consumption readings. After this series of runs, the engine was dis-assembled, the pistons were provided with drain holes and chamfered scraper rings were made from production rings. In both cases, the oil pressure relief valve was set to maintain oil pressure slightly in excess of 50 lb. per sq. in. Following re-assembly of the engine equipped with the scraper rings and drain hole pistons, and after running-in the engine for a sufficient time to insure proper seating of the rings, a similar series of one (1) hour tests were run with the same readings observed and, as far as possible, all operating conditions maintained the same as on the previous series of runs. In order to obtain the most striking comparison possible of the oil pumping, the engine was idled for a long period at the conclusion of this series of runs, and the conditions, both during and at the end of the idling period, were noted.

12. Following this series of runs, the engine was used for incidental tests at various speeds and powers for a period in excess of fifty (50) hours as an endurance test of the system, careful watch being kept in all tests of the functioning of the scraper rings. At the end of this period the engine was dis-assembled and carefully inspected for condition.

Results:

13. The results of the comparative tests between production and scraper rings are given in Table I, and the resulting oil consumptions are most forcibly shown graphically in the upper group of curves of Figure 2. It will be seen from these curves that the oil consumption of the engine fitted with scraper rings is only from one-third (1/3) to slightly over one-half (1/2) of the consumption of the same engine when fitted with production rings and unmodified pistons. These figures are especially noteworthy in view of the higher oil pressure maintained throughout the scraper ring tests than obtained during the tests with production rings. The oil consumptions resulting from 75 hr. and 55 min. operation - extending over a period of five (5) months - on incidental tests, are shown in the second, or lower group of curves of Figure 2, and are compared with the oil consumptions of a number of engines equipped with production pistons and rings - thus giving a direct comparison between the average performance of this engine with the average performance of the average production engine. From these curves it is seen that the average oil consumption of the engine fitted with scraper rings is only from 0.45 to 1/3 of the average consumption of the average production engine.

14. At the conclusion of the series of one (1) hour comparison runs, the engine was idled at approximately 550 r.p.m. for ten (10) hours - divided into two (2) periods of five (5) hours each.

During this entire period, the carburetor throttles were not once opened to clean up the plugs; every plug functioned perfectly throughout the entire period, and not a drop of oil was pumped out of the exhaust ports. At the end of the first five hours of idling, the engine was shut down by opening the ignition switches and without opening the throttle. The following morning the engine started without difficulty of any kind with the original spark plugs, which had not even been removed from the engine for inspection. At the conclusion of the ten (10) hours of idling, the engine was shut down in the same manner as at the end of the first five (5) hour period. The plugs were then removed for inspection and were found to be entirely dry and free from oil. Without cleaning or adjustment of any kind, the same set of plugs were then re-installed and the engine started. After warming up at idling speed for fifteen (15) minutes, the throttle was opened wide and the engine responded without miss or hesitation and with every plug firing perfectly. These results are especially noteworthy due to the fact that the oil pressure with scraper rings was maintained, at idling speed, in excess of 50 lb. per sq.in. - whereas with the production rings it fell to approximately 28 lb. at approximately the same speed (see Table I). It was found that, at all speeds, this engine, when equipped with scraper rings, has a very clear exhaust, notably free from oil smoke.

15. At the end of 75 hrs. and 55 min. of operation on incidental tests (endurance test of scraper rings), the dis-assembly of the engine was necessitated because one of the aluminum piston plugs, or wrist pin stops, becoming loose in the piston, was hammered to pieces; thus distributing aluminum particles throughout the lubricating system. As a result of this unfortunate accident, little could be told about the condition of the main and connecting rod bearings, aside from the fact that they were functioning properly up to the time that this accident happened. While the surface of the babbitt in the connecting rod bearings was filled with aluminum particles and badly scored, necessitating the replacement of these bearings, the main bearings were unharmed except for a slight amount of aluminum embedded in the babbitt. This aluminum was scraped out and the same main bearing shells were used when the engine was re-assembled. Both the cylinder walls and piston skirts had an ample oil film when dis-assembled, while the appearance of the bearing surfaces of both piston and cylinder differed in nowise from that of like parts of the average production engine on dis-assembly. In every other respect the engine was in excellent condition and, but for this unfortunate occurrence, which in no way could be traced to the use of scraper rings, apparently would have run and functioned properly for many more hours without overhaul. The carbon deposits were extremely light and were very dry and of a loose, flaky structure, without a trace of oil. The carbon deposits on the cylinder heads were lighter even than those on the piston heads and were of a more sooty structure.

Discussion of Results:

16. The scattering of the plotted points, so noticeable in the curve (Fig. 2), is entirely characteristic of oil consumption data and is inherent, both because of the very small weights involved and because of the almost absolute impossibility of reproducing identical conditions at the beginning and end of each run - when the weights are taken. Considering these difficulties, the agreement and consistency of the oil scraper ring consumptions is remarkable. The choice of the average curve which best represents all of the points in a plot of this character - so aptly described as a "shot-gun plot" - is extremely difficult, and it is believed that the variation with speed, found in the curves representing the ratio of oil consumptions, is due to this difficulty. It is found that the assumption of a constant mean value of this ratio changes the location of either one of the component curves so little as to be hardly noticeable (computing the values of each component curve from the corresponding values of the other curve and the assumed mean constant value of the ratio). The choice of the curves as the best average of the plotted points is, therefore, very closely substantiated, while, at the same time, the probability of the constancy of the oil consumption ratio is very strongly indicated.

Conclusions:

17: The advantages to be derived from the use of oil scraper rings with modified pistons, group themselves naturally into two (2) classes - military and economic. The military advantages, as shown by these tests, are: 1st, the tactical advantage due to no oil smoke, since the course of the airplane through the air cannot be traced by this means, and 2nd, the chances during glides and idling, for trouble, which may easily lead to loss of life, of the airplane, or of both, are greatly lessened or entirely removed due to the almost positive insurance provided by this device against fouling of the plugs. The economic advantages are; 1st, the economic feature of the second military advantage; 2nd, the very marked reduction in oil consumption of from one-half (1/2) to two-thirds (2/3) of the usual consumptions (amounting to a saving of approximately one (1) gallon per hour at the usual operating speeds); 3rd, the very strong probability of very greatly increased life of the engine between overhauls, together with increased absolute life of the parts of the engine due to the formation of less carbon and to the lengthened life of the bearings (due in turn to the maintenance of a better oil film and to the better heat dissipation); and 4th, lessened chances for burned out bearings or wrecked connecting rods and crankcases caused by accidentally or unavoidably thinned oil (since the higher pressure carried increases the probability of maintenance of oil film in the bearings even with very thin oil).

18. The apprehension, when these rings were first installed, that the scraping action would be too severe - thus leaving too thin an oil film on piston skirts and cylinder walls - is dispelled by the general conditions of the engine on dis-assembly, the finding of the actual presence of an ample oil film on piston skirt and cylinder walls, and by the general satisfactory appearance of these two bearing surfaces.

19. The difference in the appearance of the exhaust from the scraper ring engine and from a production engine is so marked that, when both this engine and a production engine are running at the same time, even non-technical observers, who are unfamiliar with the changes that have been made, notice and remark upon it. Due to the very much reduced oil pumping, this engine can be idled for hours at a time without pumping oil out of the exhaust or fouling the spark plugs.

20. In view of the foregoing facts, it is strongly recommended that scraper rings and pistons, modified in accordance with Figure 1, be adopted as standard for aeronautical engines - when fitted with both low and high compression pistons - and that, without exception, the oil pressure relief valve be set to maintain an oil pressure never less than specified pressure, irrespective of speed.

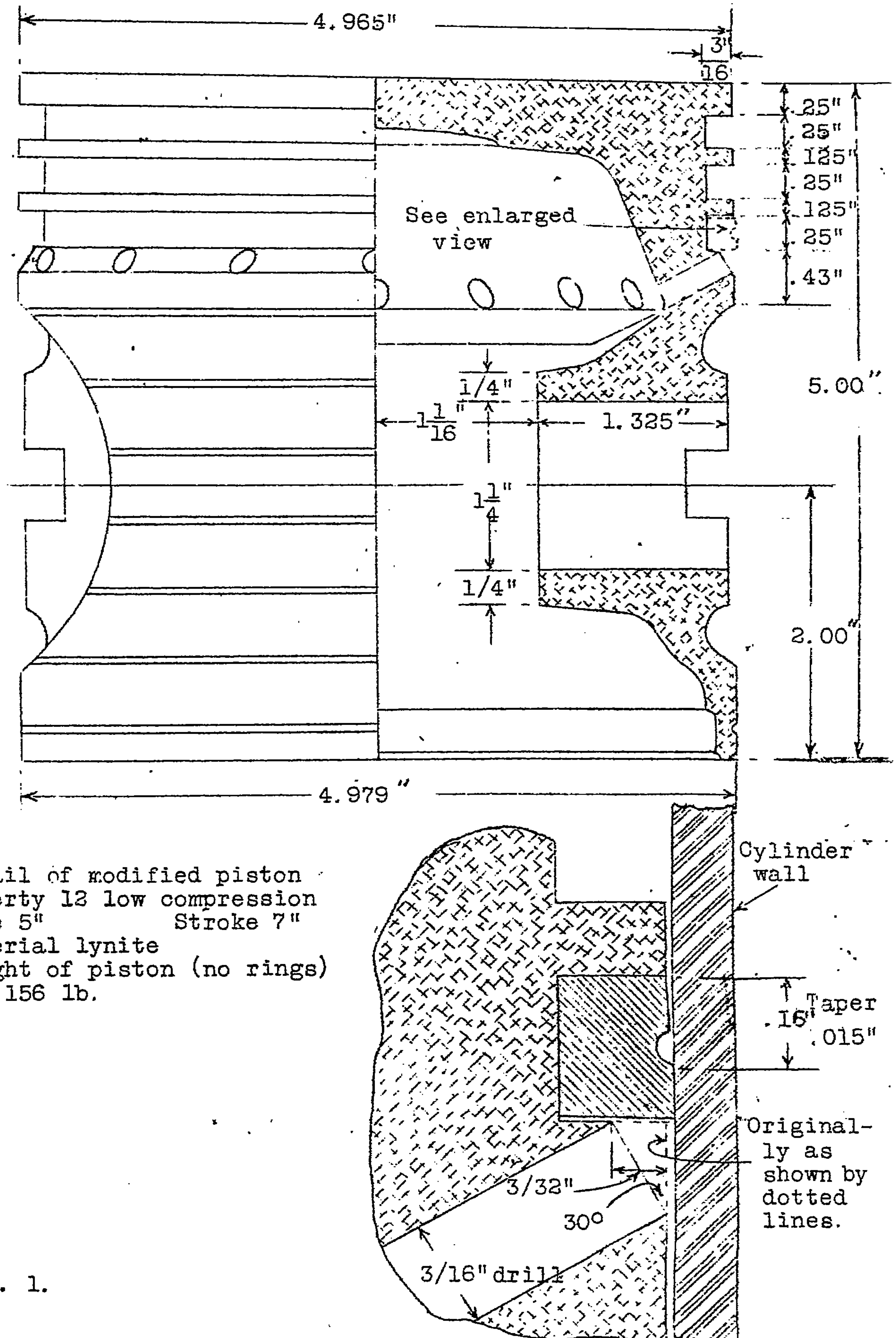
TABLE I.

Low Compression Liberty Engine #0925, Fitted with
Production Piston Rings.

Run No.	Date	Duration hr.	Club	N r.p.m.	HP St. Dry	Oil pressure lb/sq.in	Oil consumption lb/hr	Oil consumption lb/HP act/hr.
1	1/25/19	1	1700	1744.5	403.3	48.0	14.5	0.037
2	26	1	1700	1485.1	248.8	50.0	13.4	0.054
3	26	1	1700	577.0	14.6	27.7	2.25	0.155
4	26	1	1500	1515.0	375.3	50.0	8.5	0.025
5	27	1	1300	1284.4	321.8	47.3	7.0	0.015
6	27	1	1500	1501.6	365.4	50.0	9.0	0.026
7	27	1	1700	1737.0	398.1	47.6	12.6	0.034

Low Compression Liberty Engine #0925, Fitted with
Oil Scraper Piston Rings.

Run No.	Date	Duration hr.	Club	N r.p.m.	HP St. Dry	Oil pressure lb/sq.in	Oil consumption lb/hr	Oil consumption lb/HP act/hr.
8	2/25/19	1	1700	1210.8	134.8	52.4	2.9	0.022
9	25	1	1700	508.5	10.0	51.8	0.58	0.058
10	26	4	1700	1745.9	404.3	58.4	5.79	0.014
11	3/28/19	1	1700	1693.1	368.7	52.6	5.74	0.0154
12	28	1	1700	1523.1	268.4	54.4	4.24	0.0157
13	28	1	1700	1210.8	134.8	56.0	2.44	0.0179
14	29	1	1700	528.1	11.2	53.2	1.04	0.0920
15	29	1	1300	1283.7	321.2	52.0	3.74	0.0117
16	29	1	1300	1182.4	251.1	52.3	2.64	0.0101
17	29	1	1300	468.3	15.6	53.6	0.78	0.0415
18	31	1	1300	1293.9	328.9	52.0	3.20	0.0099
19	31	1	1700	1759.4	413.7	55.0	3.60	0.0089
20	31	1	1700	1511.5	262.3	54.0	2.20	0.0085
21	31	1	1700	1216.8	136.9	53.0	2.58	0.019



Detail of modified piston
Liberty 12 low compression
Bore 5" Stroke 7"
Material lynite
Weight of piston (no rings)
3.156 lb.

Fig. 1.

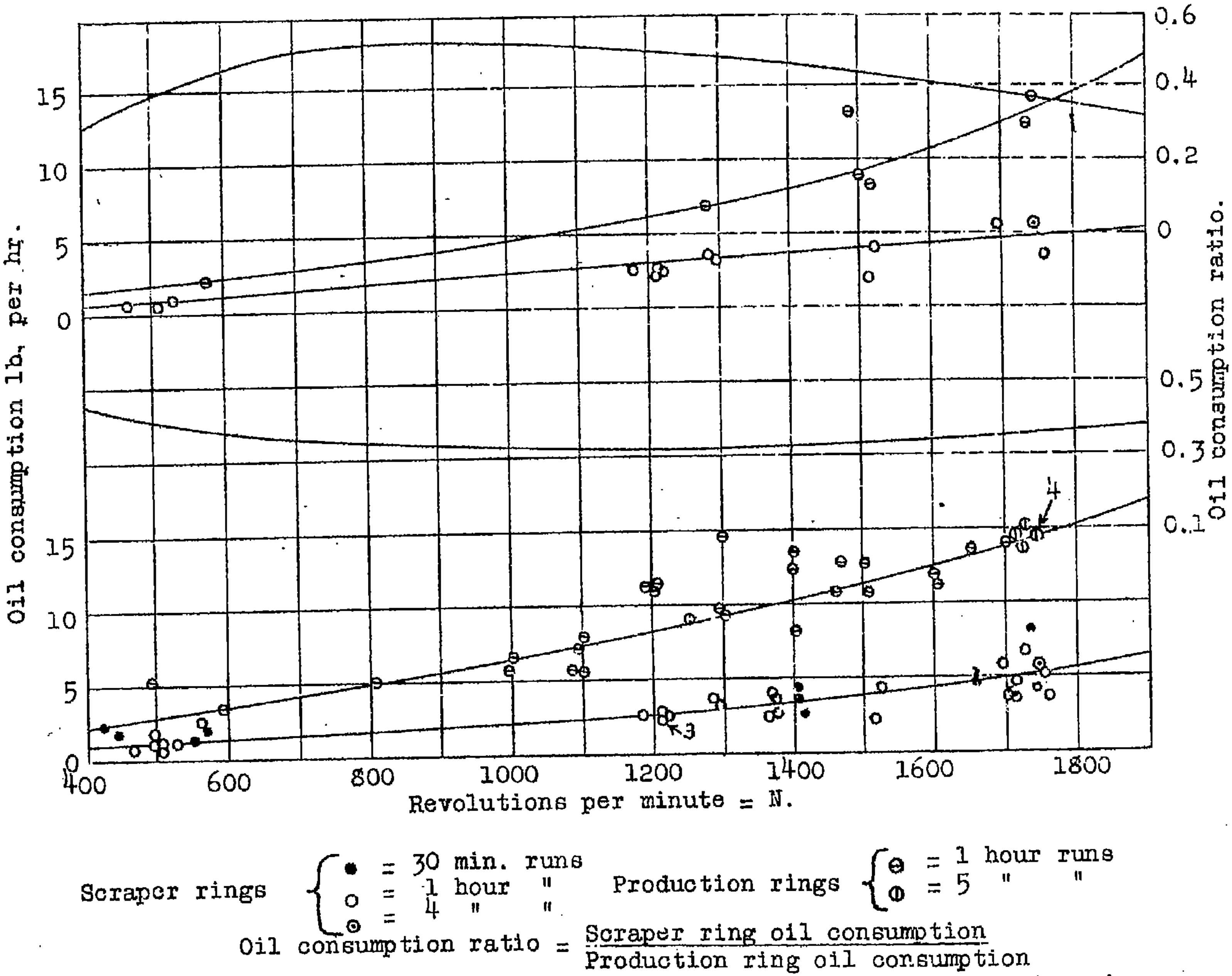


Fig. 2. Oil consumption with oil scraper piston rings and production piston rings.