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Oppau Report No. 567.

Testing of Eleven Aviation Oils

Synopsis: Investigations on the eleven aviation oils were carried out with five different apparatus, using different metals and alloys. In some cases good agreement of results was obtained despite the fact that the instruments were widely different, so that it should be possible to draw conclusions which apply to practical problems. It is impossible to place the lubricants in an order of merit which applies to all combinations of working substances, but it can be done in the case of a particular pairing of metals.

A. Object of the research

This was to test the lubricating efficiency of eleven aviation oils supplied by the Air Force Research Station at Rechlin. At the same time these tests would enable a comparison to be made between the various test apparatus.

B. Description of Apparatus and Method of Test

1) Almen-Wieland Machine: A description of this machine and instructions regarding its use can be obtained from previous publications. The test is, first of all, carried out on the test pieces used originally, i.e. on a shaft and bearings made of unhardened steel; also on bearings of Aeterna VL 22 and light metal ("Mahle 124") unannealed and with shafts of unhardened silver steel, all made at the Research Station. In carrying out this test the basic procedure for the rest of the work was laid down. The test gives the relation existing between the circumferential friction force acting on the shaft, and the load, and hence the coefficient of friction, as well as the load at which seizure commences. Seizure, however, is observed only with the use of the original bearings, as the pairing of steel with steel (unhardened) is particularly liable to seize.

2) Wire Friction Test Apparatus: This is a development of the chain apparatus described in Report No.512, the principle adopted remaining the same. The pinchback chain is replaced by a wire of 0.3 mm. dia., the wires used being made of iron, copper, brass and aluminium. Instead of the balance used in the original instrument, this piece of apparatus is equipped with a heavy pendulum and an oil damping arrangement. The method of the test is the same as before, measurements being made at peripheral speeds of 0.84 mm/s., under a load on the wire of 400 grammes. A more detailed description will appear in a report to be published soon.

3) Grinding (Einschliff) apparatus: This is described more closely in Report No.542. With a load of 16 kg., 3 cuts were produced by a hard metal disc, for each oil and each working substance; discs made of hardened steel were also used, apart from the hard metal ones, and their surfaces were brought to the same degree of roughness by sand blasting. The roughness of the disc diminishes rapidly during the test, so that the cuts obtained consecutively will show a uniform decrease in length; each lubricant is tested with two discs on each metal employed, three cuts being made with each disc.

4) Wear Apparatus: A closer description of this is given in Report No.518. In the tests dealt with in this report, the wearing pins were made of iron wire of the type used for welding, bearing on sand-blasted steel strips, under a load of 10 kg. All other experimental data remained the same as in previous tests, wear measurement being related to temperature.

5) "Four-Ball" Machine: The construction of this apparatus is well known from previous publications, and is also more closely described in Report No.486. In the tests here described the bearing balls were not made of steel but of cast iron: steel balls may be the ideal material for tests on oils used in gear drives and in weapons but they are hardly suitable for the investigation of engine oils. On the other hand, tests using cast iron balls may throw some light on the wear that takes place on piston rings, for in an engine cylinder cast iron slides on cast iron or on unhardened steel. The tests were made at room temperature under a load of 150 kg., over periods of 1 minute each, the diameter of the wear scars being measured on the three bottom balls.

6) Plans for further tests: Yet another instrument is being completed in addition to these five machines. In this, increasing loads are applied to a flat, hard steel ring, which runs with its face in contact with a flat plate made of bearing metal. A future report will deal with the tests made with it on the oils dealt with at present. If possible, it is also planned to use bearing alloys such as lead bronze, "Thermit", etc., in the wire friction machine and the Wieland apparatus, as well as tin, zinc, silver and lead.

The following table gives some of the physical properties of the oils tested.

Group	Reference No.	Viscosity c.St. 20°C	50°C	100°C	V.I.	m	W_p
I	SS 607	394	62.0	10.4	77	3.74	2.29
	SS 707	318	58.5	10.65	97	3.56	1.94
	SS 807	283	52.0	10.0	99	3.57	1.91
II	SS 903	865	152.2	24.5	114	3.06	1.58
	SS 960	958	141.3	20.9	101	3.33	1.87
	MP oil	955	142.0	21.9	107	3.26	1.80
	Rotring D	885	127.8	18.8	95	3.4	1.94
III	SS 1593	187.7	46.6	9.98	124	3.26	1.48
	Synth. Running in oil	96.8	25.8	6.91	130	3.38	1.43
	ASM	1080	143.1	21.1	100	3.38	1.97
	SS 960 + 2% KSE	907	132.2	20.3	104	3.33	1.87

For the sake of clarity in the tabulation of the results, the lubricants were classified under 3 headings. Groups I and II contain hydrocarbon oils of natural and synthetic origin while Group III contains oils mixed with additives to improve their lubricating power.

C. Results

I. General remarks applying to the factors investigated: Before we go more fully into the details of the results obtained with each apparatus, we must know exactly how much importance attaches to each factor investigated. No difficulties in that respect arise when, say, the coefficient of friction, under conditions of boundary or mixed friction, is investigated in the Almen-Wieland machine or the Wire Friction Apparatus: a low friction co-efficient is always a sign of good lubricating properties, while a high coefficient means the opposite.

With the problem of wear, matters are somewhat more complicated. Distinction must be drawn between two types of wear, that connected with seizure and that where gradual abrasion of the metal takes place. The former occurs chiefly when equal or similar metals are in rubbing contact and it is a result of the high temperatures developed on the metal surfaces. High speeds of rotation help to quicken the process. Seizure of the contact surfaces causes serious damage and if the oil is able to prevent seizure as much as possible, favourable judgement can be passed on it. If seizure cannot be completely avoided then at least the oil should act so that wear on the seizing parts is as little as possible. The Almen-Wieland and the "Four-Ball" machines are examples of oil testing gear used to investigate wear effects of that kind; a high seizure-producing load obtained in the former, and a small degree of wear in the diameter of the balls in the latter, being points in favour of the oil.

These conditions do not however apply to the other form of wear. Abrasion occurs chiefly when the test metals concerned differ widely in hardness. Increased roughness of the wearing element, i.e. the harder of the test pieces, favours abrasion. The wear apparatus and the grinding apparatus both work under these conditions, and it was established that the very lubricants which go furthest in preventing seizure, produce most abrasion. This applies not only to extreme pressure lubricants, where chemical processes are not probably involved, but also to pure hydrocarbons and ester oils. This rule, which will be dealt with later on, is easily demonstrated in the case of simple oils but the effect becomes obscured with blended oils, as in the tests described in this report. It can be further established that, subject to certain conditions being fulfilled, high abrasion is coupled with a low coefficient of friction. If, furthermore, one bears in mind that the very oils which in practice are known to be good lubricants, like vegetable oils, for instance, produce very high abrasion, then it seems proper to consider abrasion of the lubricated surfaces as a point in favour. Moreover, it seems feasible that for each separate lubrication process a certain optimum state of abrasion exists, and that any abrasion in excess of that amount would be more detrimental than advantageous. Whether or not such an optimum condition actually exists and what its value is, we cannot say from our present knowledge of lubrication. In what follows, it is therefore assumed that high abrasion is an indication that the oil possesses favourable properties for technical lubrication purposes.

II. Results obtained with each Test Apparatus

a) Almen-Wieland machine

Original Bearings (sheets 1 - 3)

The differences observed are expressed mainly by variations in the seizure-producing loads. The satisfactory conduct of SS 807 as opposed to that of SS 607 and SS 707 (sheet 1) is striking. Remarkable, too, is the high seizing load obtained with "Redband D" (sheet 2), because Red Band Standard Oil (obtained from widely different sources) had never before yielded so good a result. Experience with the Almen-Wieland machine has taught us that the least quantity of certain (polar) substances, e.g. fatty acids, etc., can cause a sharp increase in the seizing load, and it appears that in the case of "Red Band", too, this high load can be attributed to the presence of small quantities of such substances. ASM (sheet 3), surprisingly enough, does not yield a very good result, while the effect of blending 2% KSE with SS 960 is considerable (sheets 2 and 3).

Bearings made of Aeterna VL 22 and Light Metal

Bearings made of these two metals did not seize at all, so that the lubricants must be judged on their coefficients of friction. The results are indicated on sheets 4 - 6 (Aeterna bearings) and 7 - 9 (Light Metal bearings). Scattering of experimental points is within moderate limits, being somewhat greater only in the case of SS 1593 and the synthetic running-in oil (sheet 6), using Aeterna. The results obtained with Aeterna bearings show differences which are still fairly well discernable, whereas in the case of light metal such differences are very difficult to observe:- also, with Aeterna bearings there are great fluctuations in the value ~~of the~~ coefficient of friction. With certain lubricants, like SS 903, ASM and SS 807, the coefficient of friction falls sharply as the load increases. On the other hand the coefficients remain more or less constant in the case of light metal bearings.

b) Wire Friction Test (sheets 10 - 15)

For iron, copper and brass the coefficients of friction lie between 0.12 and 0.19, SS 707 being the only exception, while for aluminium they are considerably higher, about 0.2 to 0.3. Since the friction curves frequently intersect it is not always easy to evaluate ~~the~~ lubricants. For the sake of clarity the actual experimental points have been omitted on the curves. Nevertheless to give an impression of the extent to which the points were scattered on the graph, the following may suffice. This scattering was least with iron and copper (about 5%), followed by brass (about 8%) and aluminium (8 - 12%). As in all other apparatus for testing lubricating properties, it varies from one oil to the next. The measured differences between the oils were least apparent in the case of iron and copper, while they became more marked with brass and aluminium.

c) Grinding Apparatus (sheets 16 and 17)

Tests carried out with this instrument, using a hard metal disc, show particularly interesting results (sheet 16). The behaviour of synthetic running-in oil and SS 1593 is particularly striking. For instance, these two lubricants produced very little abrasion on a brass cylinder and very high abrasion on a light metal one. There is no connection between the amounts of abrasion produced on steel and cast iron cylinders. It is also interesting to compare the results obtained with a hard metal disc and those yielded by steel discs (sheet 17). Tests carried out with these discs on light metal and steel cylinders resulted in the oils being arranged in almost the same order of merit (Translator's note: a printing error seems to have occurred on sheet 16 - the first oil on the top line is quoted as "SS 907": actually none of the oils tested bears this reference number which should be replaced by "SS 607"). Bronze seems to provide an exception in which synthetic running-in oil and SS 1593 seem to act in a particularly contrasting manner. This phenomenon may be presumed to be due to the following: in these tests, bronze is subject to high abrasion, which is especially troublesome with the slightly rougher steel discs. So that towards the end of the trial it is no longer a case of steel running on bronze, but one of bronze running on bronze. Under these circumstances it can hardly be supposed that uniform abrasion is still taking place; rather one might suspect that bronze running on bronze will cause seizure. The results obtained with a steel disc on a bronze cylinder are therefor unreliable, but are neverhheless evaluated with the others.

d) Wear Apparatus (sheets 18 and 19)

Slight differences only are obtained with oil groups I and II, the results being quite consistent. Abrasion is considerably higher for group III, and scattering of the points more noticeable, SS 1593 and synthetic running-in oil showing surprisingly high abrasion. With soft iron bearing on rough hardened steel surfaces, this is an example of "ideal" abrasion conditions, and thus the results applying to group III must be considered as favorable.

c) "Four-Ball" machine (sheet 20)

Whilst the tests on the wear apparatus deal with abrasion, the "Four-Ball" machine deals with wear accompanied by seizure. It is not surprising, therefore, that group III, in contrast to the results (i.e. the recorded results) obtained in the wear apparatus, produces the least wear in this test. The results are reasonably consistent, though the uniformity of the cast iron bearing balls leaves much to be desired. An exception is provided by the tests employing "Red Band" D and SS 960, with which oils the conditions of the test appear to produce results which, on plotting, show little tendency to lie on a smooth curve.

III. Summary of Results: From the large number of results obtained it is difficult to form a clear picture of the lubricating power of each separate oil. In order to put all the oils on a common basis, so to speak, a points system was introduced, the number of points allotted (ranging from 1 - 10) being in direct proportion to the quality of the oil. This effects a clear representation of the results, from which the order of merit of the oils and how they differ from one another, can be obtained. This point valuation is shown in the table on the separate sheet: the first columns distinguishing between apparatus and working substances. To sum up, the arithmetic means of the points allotted are ascertained for equal or similar metals and alloys. Where the results differ from one instrument to another, these differences will be ironed out, whereas where they agree, any such differences will be strongly emphasised. The following conclusions can then be drawn with some degree of certainty.

In Group I, SS 607 reacts better on light metal and aluminium than do SS 707 and SS 807, a result which is confirmed by all instruments. On the other hand, SS 807 reacts better on copper-zinc alloys than SS 607 and 707: the same applies to iron and steel, though here the result is not quite so convincing. Good results for SS 707 appear only with lead-bronze, though it must be stated that no final conclusion may be drawn from this one experiment. In Group II, SS 960 and MP oil fall behind Red Band D, throughout. Only the use of light metal causes a scarcely perceptible movement in favour of SS 960 and MP oil. All the oils in Group III react favourably on iron, steel and cast iron, while particularly good results were obtained with SS 1593 and synthetic running-in oil on light metal. Their superior qualities are demonstrated equally in all instruments. The other two oils, ASM and SS 960 + 2% KSE, on the other hand, react well on copper and copper alloys, an effect which is again well demonstrated by all instruments with the exception of the tests with steel on bronze in the grinding apparatus (column 10) which have already been discussed.

It can be seen, then, that certain lubricants produce especially good effects with light metals while others excel when tested on copper and copper alloys. The former include SS 1593, synthetic running-in oil, and SS 607: the latter, ASM, SS 960 + 2% KSE and to a lesser extent, SS 807. Comparison between SS 960 and SS 960 + 2% KSE enables us to observe the effect of an additive. A considerable improvement is caused by adding KSE in tests on iron, cast iron, steel, copper and copper alloys. In the tests on aluminium and its alloys, the addition has no effect, good or bad.

The tests have shown therefore that, despite the differences existing between the various forms of apparatus employed, the results obtained show a certain all-round measure of agreement. It is naturally imperative to distinguish between the separate materials, or groups of materials.

The fact that totally different instruments pass the same verdict on the lubricants, leads one to conclude that the step from experiment to practice is not particularly risky. In the tests just described, agreement was not reached on all points: nevertheless there is hope that by adding to available data a still greater improvement in this field will be possible, by further comparisons with pairs of working metals.

1 - 9 Tests with the Almen-Wieland machine: (friction force/load curves)

sheet 1 working substance: steel (original bearings)
2 " " " " "
3 " " " " "
4. " " Aeterna VL 22
5 " " " "
6 " " " "
7 " " "Mahle 124" (unannealed)
8 " " " "
9 " " " "

10 - 15 Wire Friction Tests (co-efficient of friction/ temperature curves)

16 - 17 Tests with the Grinding Apparatus
duration of test: 10 mins. (volume ground out)
load 16 kg.
no. of revs. 210 r.p.m.

sheet 16 hard metal disc on (Mahle 124) bronze
light metal (annealed)
steel
cast iron
lead-bronze

" 17 test conditions as before.
The values shown represent the mean values of 2 series of tests, with 3 attempts each. Each series was carried out with a new steel disc on:-
a) bronze
b) light metal annealed
c) steel

18 - 19 Tests in the Wear Apparatus (shortening of pin/ temperature)
duration of test 20 mins.
surface pressure 142 kg/sq.cm.
~~material of pin iron (welding rod)~~

20 Tests in the "Four-Ball" machine
material of balls: cast iron
load 150 kg.
speed of rotation: 1500 r.p.m.
duration of test 1 min.

TABLE

Oil	Almen Wieland app.			Wire Friction Test				Grinding Apparatus								Wear App.	4-Ball Machine	Summing up of Results					
	Bearing made of			Wire made of				Steel disc on			hard metal disc on							Arithmetic Means of Column:					
																		2,5,9,12,17	13,18	6	3,7,10,14	15	4,8,11,16
	Steel	Aeterna	Light metal	Iron	Copper	Brass	Aluminium	Steel	Bronze	Light metal	Steel	Cast iron	Bronze	Bronze contg. lead	Light metal	Iron on hardened steel	Cast Iron on Cast Iron	Iron, Steel	Cast Iron	Copper	Aeterna, brass, bronze	bronze contg. lead	Aluminium Light metal
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
SS 607	4	3	5	5	3	4	5	3	3	6	5	5	7	4	4	1	4	3.6	4.5	3	4.25	4	5.0
SS 707	2	6	4	4	4	1	2	4	1	4	6	5	7	8	3	1	2	3.4	3.5	4	3.75	8	3.25
SS 807	6	8	4	5	4	7	2	4	3	4	5	4	7	5	3	3	3	4.6	3.5	4	6.25	5	3.25
SS 903	6	7	6	5	5	5	3	5	4	3	4	8	6	4	3	2	7	4.4	7.5	5	5.5	4	3.75
SS 960	4	6	5	4	4	3	5	3	3	4	3	5	5	3	4	1	5	3.0	5.0	4	1.25	3	4.5
MP oil	3	5	5	4	4	4	2	4	3	5	4	5	2	3	5	1	3	3.2	4.0	4	3.5	3	4.25
Rotring D	6	7	4	6	6	5	5	4	3	4	4	5	4	5	3	2	5	4.4	5.0	6	4.75	5	4.0
SS 1593	5	4	6	4	4	4	8	4	8	9	4	4	2	5	10	9	8	5.4	6.0	4	4.5	5	8.25
Synth. run.-in oil	5	2	6	4	5	5	9	6	9	10	6	3	2	6	10	8	8	5.8	5.5	4	4.0	6	8.75
ASM	3	7	4	8	9	6	6	4	5	5	4	6	5	6	6	5	7	4.8	6.5	8	5.75	6	3.75
SS 960 + 2% KSE	7	6	4	5	6	8	5	4	6	4	4	6	5	6	5	5	8	5.0	7.0	5	6.25	6	4.5