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LOAD SUPPORT CHARACTERISTICS
OF
AIRCRAFT GREASES



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LOAD SUPPORT CHARACTERISTICS OF AIRCRAFT GREASES

INTRODUCTION

With the return to commercial aviation following World War II, the deficiencies of the military lubricants became apparent, especially with regard to both stability and service performance. It was soon recognized that, for many aircraft applications, the chief function of the lubricant was as a rust preventive and as a sealant to prevent moisture, dirt, etc. from entering the bearing. In other instances it was desirable that the product have load support properties and act as a lubricant for the contacting metal surfaces.

The problem of lubricating bearing surfaces on aircraft relates primarily to the following:

- Gears
- Anti-friction bearings
- Journal bearings
- Screw thread mechanisms, e.g. actuators

The lubrication of aircraft gears is currently being investigated by another group, and it has therefore been eliminated from consideration in this project.

Greases in general possess adequate load support qualities for the lubrication of anti-friction bearings used in current airframe design, and consequently consideration has not been given to this phase of the problem.

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LOAD SUPPORT CHARACTERISTICS OF AIRCRAFT GREASES

1. OBJECTIVE: The objective of this work was to develop a relatively simple bench test or performance test, or a combination of tests, which would be valid for evaluating greases in respect to load support characteristics, when the greases were used in journal bearings or in actuator-type mechanisms.

2. SUMMARY AND CONCLUSIONS:

- 2.1 No single convenient laboratory test method, currently available can be employed for evaluating load support characteristics of lubricants and for predicting the performance of greases in all airframe mechanisms.
- 2.2 Of the airframe mechanisms presenting load support problems, it would appear that the screw-thread actuator is the most critical.
- 2.3 It was found that a test method employing a typical actuator is the most practical means for evaluating the load support characteristics of aircraft greases.

A test method which describes such a typical actuator installation, and a recommended procedure for conducting grease tests are presented.

3. DISCUSSION:

- 3.1 Grease Samples: The characteristics of the SAE S-5C Aircraft Lubricants Committee are shown in Table I.

These greases represented a wide variation in composition, and at the same time they were greases for which some service performance information was available. Further information upon the greases may be found in A.S.T.M. Special Technical Publication No. 34, "Symposium on Functional Tests for Ball Bearing Greases".

Of the above greases only M-2, M-4 and L-6, were known to perform satisfactorily under service conditions. Greases M-3, the same as M-2, but without additives, L-2 and L-4, were known to be unsatisfactory. Otherwise the service performance histories of the greases were not known except perhaps to the extent that the greases were in a highly questionable category as far as actuator lubrication was concerned.

- 3.2 Journal Bearings: The acceptable lubrication of journal bearing surfaces on aircraft is a matter of importance in respect to aircraft performance and maintenance. The effectiveness of the lubricant used in minimizing wear or preventing seizure, will depend upon the particular metal combination in the bearing as well as upon the properties of the grease. It is clear that a bench test that can rate or predict the relative merit of a grease, in respect to load support characteristics and for a specific use, is also a test that may permit the selection of a proper metal combination. This is a very important matter to the airframe manufacturer. For such a test to have maximum value, it must correlate well with performance under service conditions.

The only known test which was believed to meet the above requirements was the Lockheed Friction Test¹. However, the apparatus involved is rather expensive and complicated, and at this time its use is not a reasonable proposition for the average grease laboratory.

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1. Described in a paper "Friction Testing for Aircraft Greases and Bearing Metals" presented by M. H. Stalker before 1946 A.S.M.E. Aviation Meeting in Los Angeles, June 4, 1946.

In view of the above, the cooperative samples undertest were submitted to the Lockheed Aircraft Corporation for evaluation in their friction tester. The results of their tests upon the cooperative greases are presented in their report of January 7, 1949, entitled "Lubricating Comparison Test of The Proprietary Greases". A copy of this report is attached as Appendix A.

The test data presented in the Lockheed report are extremely interesting for a number of reasons, and they merit a broader discussion than the separate subject of load support permits. The coefficients of friction for the different greases at different loads (200-2,500 psi) do not show any consistent pattern, suggesting thereby that a number of factors contribute to the final value. Some trends are to be noted, however. The H-type greases, generally containing the most viscous oils, show the lowest values, which are uniform over a wide range of load. The L-type grease, containing the least viscous fluids or oils, which are also of a rather diverse chemical character, show high friction values which tend to decrease as the load is increased. The M-type greases show a mixed trend, with medium coefficient of friction values.

In Figure 5 of the Lockheed report it is of interest to note how the L and M-type greases tend to possess almost the same friction value at very high loads, this value being considerably higher than that for the H-type greases.

It is not possible to offer a clear-cut explanation for the divergence in values, because of the effects of unknown factors. The influence of film temperature upon the viscosity of the grease film and upon syneresis might explain in part the behavior of the greases. In this connection a series of tests at different ambient temperatures on several of the greases would be most interesting. Tied in with this point might be the viscosity of the mineral oil content.

Since all of these greases appear to possess adequate load support for the type of bearing surface in question, the measured friction value is of principal interest from the viewpoint of power requirement. Although the Lockheed test has served as a satisfactory guide in selecting greases for landing gear equipment, there seems to be no basis evident in the data obtained to date that will permit relating the amount of wear, as determined in any of the tests studied, to measured friction values. However, it is possible that some such basis might be developed by correlating the friction values with wear values obtained in further extensive Timken tests, Falex tests, etc. upon a series of different greases at different loads, temperatures, etc.

Inasmuch as M-2 and M-4 have shown satisfactory performance in the actuator tests on the greases it might be inferred that greases which performed satisfactorily in actuators would also perform acceptably in journal bearings, provided the greases were satisfactory in all other respects than wear characteristics. This is of interest of course where a single grease is desired to do the work of AN-G-10 and AN-G-15 greases on the types of bearing surface in question. More data are required to support this thesis.

3.3 Actuators: As far as wear is related to load support, the point of major interest is the actuator surfaces. And, as a matter of fact, that is the principal subject of study under this assignment.

In typical actuator operation, a 4130 - hardened steel screw rotates within a stationary phosphor bronze nut. A grease containing no load-carrying additive permits limited operation, possibly 5,000 cycles, before wear becomes excessive and the power requirement runs high.

When a suitable additive is present in the grease, the life of the actuator may be extended as long as 40,000 cycles, and the power requirement remains low. Replacement of actuators can be both complicated and expensive. Consideration was given to possible bench tests that might serve to facilitate the evaluation of greases as lubricants for actuators. Running the greases in actual actuators to failure is a potentially desirable test, but, as a research tool, it is slow and expensive. Consequently, consideration was given to a number of well-known test procedures already in laboratory use.

- 3.3.1 Test Methods Considered: The Falex test procedure was one of the first methods considered in this work. The procedure is simple and inexpensive and simulates in some degree actuator service conditions, provided the same metal combination is used as in the actuator. Since it was the most promising method of those considered, it received the major share of study, and the results are considered in detail in Section C below.

Other test methods investigated included the Timken Tester, the Three-Disc Wear Tester, and the Four-Ball Machine. Data developed in the study of these tests methods are presented in Appendix B. As indicated therein, for one reason or another, including lack of spread in the results, none of these methods were considered at the time to be as promising as the Falex method.

- 3.3.2 Examination of the Falex Test: Considerable study was devoted to modifying the Falex test in the hope of developing a rapid bench or screening test for distinguishing the acceptable from the non-acceptable greases for actuators. For much of the experimental work, a modified procedure, as outlined in detail in Appendix C, was employed. This consisted essentially in running a phosphor-bronze pin on steel jaws with a 500-pound jaw load at 300 r.p.m. for a period of 30 minutes. The amount of wear of the pin was determined by observing its weight loss. In all instances the temperature rise and the torque paralleled the wear taking place; however, in some instances the correlation was not good enough to be useful.

Under the above conditions it was observed that some greases gave rise to little wear while others gave rise to much wear. This is evident from the data in the appended Table II or Appendix B where results of tests on several of the Committee's standard greases are listed. From the data in the appended Table III and Appendix B, it is apparent that repeatability of the test is not as good as might be desired. These data show that, because of poor repeatability, several tests on any grease should be run, and an average of these be used rather than a single test result.

In an attempt to improve the repeatability of the test, as well as to obtain a more significant correlation between the performance of the grease in the test and its known performance in actuators, a number of variables were investigated. The investigation is described in the following paragraphs:

- 3.3.2.1 Effect of Load: It was thought that the use of a particular load in the test might give more consistent results that would also show better correlation with service. The data in the appended Table III and Appendix B clearly show that there is no clear-cut preference in favor of any one load. It is interesting to note that L-6 and M-4 showed little increase in wear with increased load; an AN-G-25 grease actually showed considerable decreased wear with increased load; and M-2 and M-3 showed increased wear with load. Since L-6, M-2 and M-4 are reported to be satisfactory in actuator service, it would seem possible, based solely upon these trends, that a jaw load of 500-lbs. was in too low a zone to correspond with service performance. However, Falex tests under a 750-pound load on M-3 and M-4 showed still lower wear for M-3 than M-4, and a

test on M-4 with a 1,000-pound load showed very rapid and high wear even after 20 minutes. Consequently, it does not seem possible, upon the basis of available data, to select one particular Falex load as being especially significant in relation to the known actuator performance of the grease under test.

- 3.3.2.2 Temperature of Equipment At The Start of the Test: Tests on three of the cooperative greases were made in which the grease cup and samples were held either at elevated or reduced temperatures. In each case, the system was also heated or cooled during the tests.

<u>Temperature of Test</u>	<u>Grease</u>	<u>Wt. Loss of Pin. mg.</u>	<u>Wt. Loss of Pin Under Normal Test Conditions, mg.</u>
Approximately 40°F. above normal	M-2	2.7	9.8
" " "	M-3	11.3	54.4
" " "	M-4	79.5	77.6
" " "	M-4	89.6	77.6
Approx. 20°F. below normal	M-4	81.5	77.6

It is clear from these data that, in general and within the limits studied, the test temperature fluctuation is not a serious overall factor. The reduced wear shown in the case of Sample M-3 does suggest perhaps the desirability of controlling the temperature within rather narrow limits as a part of standard test procedure.

- 3.3.2.3 Replenishing Grease on Test Pieces During Test: During several tests the load was released, and a fresh supply of grease was forced between the test pieces, after which the test was resumed:

<u>Replenishments</u>	<u>Grease</u>	<u>Pin Loss. mg.</u>	<u>Normal Pin Loss, mg.</u>
Once during test, system not cooled	M-3	44.6	54.5
2 times during test, system cooled each time	M-4	66.6	77.6
4 times during test, system not allowed to cool	M-4	88.7	77.6

It appears that replenishment of the grease supply did not radically affect the wear characteristics of M-3 and M-4. This conclusion is supported also by the data in Appendix B.

- 3.3.2.4 Rate of Applying Load: The average wear for seven tests on M-4 when applying the load manually in 15 seconds and without preliminary run-in, was 77.2 mg. When the load was applied automatically in 30 seconds, the average wear in the four tests was 78.8 mg. It was concluded that this variation in load application for M-4 had no serious influence upon the test result. In the Appendix B limited data are presented for greases M-2 and M-3 which show that some decrease in wear accompanies a decrease in loading rate. Available data are too limited to permit any general conclusion as to the effect of loading rate upon wear.

- 3.3.2.5 Length of Test: Information is presented in Appendix B to show that the amount of wear appears to be a straight line function of time.

3.3.2.6 Surface Condition of Pin and Bushing: Evidence is presented in Appendix B which indicates that most consistent test data on any single grease are obtained when the physical dimensions of the bushing and pin closely approximate the correct or specified values. Limited data, not presented in this report, suggest that when the hole in the pin is off center, or when the hardness of the surface varies, the test result is affected by such deviations. However, in general, although the test data may be improved in respect to repeatability, the relative magnitude of wear for the different greases will not be greatly changed. In other words, M-2 would still consistently show lower wear than M-3 or M-4, whether the pins and bushings were polished or unpolished, etc.

3.3.2.7 Effect of Preliminary Run-In: The data in the Appendix B indicate that the use of a preliminary run-in period can have some effect upon the final test result depending upon the load and time used for the run-in period. This feature should be given careful consideration in any standardization of the method. However, the relationship between greases in respect to relative amount of wear was not greatly altered when the preliminary run-in period was changed independently of other variables, and this is the aspect of principal interest in correlating the Falex wear test with wear in the actuator for suitable or unsuitable greases.

The reproducibility of the test results was found to be fair in the case of two laboratories, provided the same procedure was used and the same precautions exercised. In the case of a third laboratory (Laboratory A), however, where the Falex machine was known to require reconditioning the test data were fairly consistent for separate runs on the same grease, but the final rating of the greases was different from that of the other two laboratories. The general conclusion reached was that, provided the machines were in good condition and the same test procedure used, reproducibility could be expected to be sufficiently satisfactory to allow similar relative ratings of lubricants by different laboratories.

3.3.3 Comparison of Service Data with Laboratory Test Data: The amount of confirmed actuator performance data available for the Committee's standard greases is unfortunately very small. Greases M-2, M-4, and L-6, are reported to give satisfactory performance in actuators, while L-2, L-4 and M-3 are reported to be unsatisfactory. In appended Table IV, a comparison is presented of the foregoing actuator performance information with laboratory test data.

The Falex test data tend to classify M-4 as the poorest of this group, which is in disagreement with the actuator results. From the data presented in Table IV it is apparent that altering the Falex test load from 500 pounds to 125 pounds does not improve this situation, since M-4 is still rated as poor at the lower load. M-2 is rated as good in both Falex tests and actuator service, while M-3 is moderately poor in both. L-2 is unsatisfactory in actuator performance and is poor in Falex tests; however, L-4, which is poor in actuator performance, is reasonably good in the Falex test. Thus, almost half of the observed results show a disagreement between Falex test results and actuator performance.

From the foregoing comparison, it is concluded at this time that the Falex test with the 500-lb. load, or with higher or lower loads is of questionable value in indicating the nature of the actuator performance of greases.

3.3.4 Examination of the Actuator Test: Actuator tests performed in three of the laboratories on several of the acceptable greases using the same general method showed that these greases could be expected to possess superior wear characteristics in service. In appendices D and E attached are presented outlines of the methods used by the Shell Oil Company and the Union Oil Company of California. These were similar to the method used by the AiResearch Corporation at its Los Angeles laboratories. The Texas Company has also developed an actuator test procedure similar to those mentioned above, and a brief outline of that procedure is also attached in Appendix F.

Inasmuch as it has not been found possible to use the Falex test as a satisfactory means of predicting service in actuators, it appears necessary to resort to the practice of testing the greases in actuators under simulated service conditions. Accordingly, a general outline of a proposed actuator procedure is presented in the Appendix G with the thought in mind that this would serve as a basis for any future standardization. The proposed procedure embraces the favorable features of the four procedures listed above as being used by various companies interested in the problem. In this connection, it might be mentioned that, should a future effort be made to standardize the procedure, proper precaution should be taken against the possibility of testing actuators rather than greases by careful selection of actuators in respect to uniformity.

Finally, it is pointed out that failure of actuators may occur for reasons other than failure in the lubricant. And this is a consideration that should be kept in mind in any future work upon the same project.

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Lockheed Aircraft Corp., Burbank, Calif.
The Texas Company, New York, N. Y.
Dow-Corning Corp., Midland, Michigan

TABLE I
SAE COMMITTEE S-5C COOPERATIVE TEST
GREASES

FINISHED GREASE						
S-5c Code No.	ASTM Worked Penetration	ASTM Dropping Pt. °F	Soap Type	Soap Content	Base Oil	
					Vis. at 100°F	V.I.
L-1	304	358	Li	15%	61 SSU	50
L-2	313 - 319	380 - 385				
L-3	312	400+				
L-4	273	371				
L-5	310	365				
L-6	345	300 min.	Li	21%	56 SSU	40
M-1	248	300	Na-Ca	19%	159 SSU	97
M-2	243	400+	Sr	22%	130 SSU	52
M-3	265	400+	Sr	22%	130 SSU	51
M-4	279	380	Li	8%	115 SSU	40
H-1	295 - 311	343 - 363	Na	14.6%	210 SSU	41
H-2	237	400+	Na	35%	414 SSU	55

TABLE II
FALEX LOAD SUPPORT DATA FOR S.A.E. S5c
COMMITTEE GREASES^a

Sample	Test No. 1 Weight Loss, mg.	Test No. 2 Weight Loss, mg.	Test No. 3 Weight Loss, mg.
L-1	15.6	27.6	21.6
L-2	34.0	58.5	46.0
L-4	11.9	21.3	16.5
L-5	91.0	21.5	49.7
M-1	13.7	29.8	7.7
M-2	8.6	0.8	4.8
M-3	33.0	48.2	75.5
M-4	27.2	73.4	69.0
H-1	114.9 ^b	154.1 ^b	-
H-2	135.8 ^c	144.6 ^c	-

a. Test Conditions

Load 500 pounds
Duration 30 minutes
Test specimens. (bronze pins
 (steel jaws

b. A second laboratory running Falex tests on the same grease by the same procedure obtained a wear value of 0.7 and 1.0.

c. The same laboratory as in (b) obtained wear values of 55.6, 24.4, and 62.4, on this grease.

TABLE III

FALEX LOAD SUPPORT DATA FOR S.A.E.
S5c COMMITTEE GREASES^a

Test No.	Weight Loss, mg.	Test No.	Weight Loss, mg.	Test No.	Weight Loss, mg.
1	0.8	1	48.2	1	73.4
2	8.6	2	75.5	2	69.0 _b
3	4.8	3	33.0	3	27.2
4	8.1 _b	4	37.0	4	65.5
5	84.6	5	69.1	5	72.0
6	2.1	6	48.8	6	72.9
7	24.9	7	65.1	7	70.2
8	3.4	8	65.8	8	83.9
9	2.6	9	47.3	9	93.0
10	2.8			10	90.4
11	36.3			11	81.2
12	27.8	: number of values used = 9		12	88.1 _b
13	2.6			13	98.4 _b
14	2.7	: mean value = 54.4 mg.		14	54.0
number of values used = 13		: average deviation = 12.8 mg.		15	87.8
		: standard deviation = 14.1 mg.		16	84.8
Mean value = 9.8 mg.				: number of values	
average deviation = 9.2 "				: used = 14	
standard deviation = 11.3 mg.				: mean value = 77.6 mg.	
				: average deviation	
b. This value not used in obtaining averages				: = 9.4 mg.	
				: standard deviation	
				: = 10.8 mg	
				: b. These values not	
				: used in obtaining	
				: averages	

a. <u>Test Conditions</u>	
Load	500 pounds
Duration	30 minutes
Test specimens. . .	(bronze pins
	(steel jaws

TABLE IV
RELATIONSHIP BETWEEN JAW LOAD AND WEAR IN FALEX TESTS
UPON VARIOUS SAE-S5c GREASES^a

Grease Tested :	Reported Actuator Performance :	Weight Loss of Pin, mg. at Various Loads				
		125 lb. :	250 lbs. :	500 lb. :	750 lb. :	1,000 lb. :
L-2 :	Unsatisfactory :	- :	- :	46.2 :	- :	- :
L-4 :	" :	- :	- :	16.6 :	- :	- :
M-3 :	" :	(10.5, :	(36.2, :	(54.4, :	23.0 :	- :
		(15.5 :	(20.5 :	(42.3 :		
L-6 :	Satisfactory :	3.3 :	3.6 :	3.9 :	- :	- :
M-2 :	" :	(1.8, :	(0.9, :	(9.8, :	- :	- :
		(2.7 :	(3.5 :	(14.3 :		
M-4 :	" :	(56.9, :	35.8 :	(77.6 :	82.0 :	91.0 ^b :
		(42.7 :		(38.7 :		

- a. Test conditions - 30-sec. run-in at no load
- specimens tested as received
- load applied in 30 secs.
- 30-min. test at 300 r.p.m.

In some cases tests were run by two different laboratories and the values reported are shown separately as a matter of possible future interest.

- b. Test stopped because of high noise and rapid wear.

APPENDIX A

LUBRICITY COMPARISON TEST OF TEN PROPRIETARY GREASES

Abstract:

Lubrication evaluation tests were made on ten different greases in cooperation with the SAE S-5C Aircraft Bearing Committee. Principal data are curves of bearing load versus coefficient of friction at room temperature, with a rotational speed of 46.5 RPM.

References:

1. IDC: R. R. Richolt to J. M. Gerschler, Friction Tests, dated March 22, 1948.
2. Interoffice Notebook data sheets 80552 to 80598.

Object:

To compare the coefficients of running friction of ten greases when used in a plain bearing at various loads.

Summary of Results:

1. Greases H-1 and H-2 show the lowest friction-load characteristics of the greases tested and the variation in friction is comparatively small over the entire pressure range.
2. Lubricants M-2, M-3 and M-4 are the next best greases and are similar in their lubricating properties.
3. The L-2, L-4 and L-5 greases are similar in lubricating qualities. The friction coefficient decreases with increased load pressure.
4. Friction indications vary considerably over the complete pressure range for both the L-1 and M-1 greases.

Parts Tested:

1. Ten greases submitted for lubrication comparison tests were identified by the following code numbers: H-1, H-2, L-1, L-2, L-4, L-5, M-1, M-2, M-3 and M-4.
2. Fifty pairs of 1 inch diameter x 3/4 inch length aluminum bronze bearing specimens and X-4130 steel journals to suit test machine were furnished by Douglas Aircraft Company.

Introduction:

Ten greases, identified only by code numbers, were submitted by the SAE S-5C Aircraft Lubricant Subcommittee for comparative lubricity tests at normal room temperatures. A rotative speed of 46.5 RPM and a load range of 200-2500 PSI were selected.