AVIATION LUBRICANT REQUIREMENTS

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ABSTRACT

A general treatise on the subject of aviation lubricant requirements with emphasis on the current need for more thermally and oxidatively stable lubricants resulting from increased severity in powerplant operation. Briefly discussed are practical standard lubricant test methods and equipment and the difficulties which result from indiscriminate tinkering with standard test procedures and equipment. Also presented is the philosophy of lubricant development based on using standard screening tests, forbidding arbitrary changes in test conditions to give desired test results, and emphasizing that the engine builder must be completely free to select the powerplant bill of material.

INTRODUCTION

Developing lubricants and lubrication techniques to satisfy the ever increasing demands for superior aircraft performance in today's rapidly expanding aviation industry is a never ending program. However, this endless task would be less difficult if all participants adhered to a policy based on three simple concepts. This philosophy requires that the engine builder must be free at all times to establish the engine bill of material. Also, the purpose of oil tests is not to determine engine performance; but merely to label oils according to their relative merit. And in addition, because a standard test is preferred to a multitude of tests for the same property, it is necessary to establish, use, and above all, not tinker with standard test procedures and equipment. Today, aircraft operational severity levels are changing so quickly that general operational requirements always overshadow product development in spite of increases in technical knowledge. This is particularly true in the lubrication field where newer, more demanding and exacting operating conditions are constantly appearing even before the present-day needs are satisfied. To illustrate this point it is only necessary to consider that while industry in general has been actively engaged for five years in the development of lubricants to satisfy flight requirements of 400°F oil in engines, the oil change periods in some current operational aircraft have decreased and are now as low as fifty hours.

In conjunction with lubricant research, a general test equipment and procedures development program must be carried out to provide industry with reliable, inexpensive tools which can be used to expedite the manufacture, testing, buying, and selling of lubricants meeting a set of standards acceptable to the ultimate users of the lubricants. During the period when a product is undergoing development, it is usually an economical necessity to devise and use small-scale bench or screening tests in preference to testing the product in its final environment. Generally speaking, satisfactory service operation follows successful completion of these preliminary screening tests. This screening test practice is specifically adaptable to the development of lubricants for use in advanced aircraft gas-turbine powerplants. Lubricants intended for such applications are usually complex mixtures of base stocks, oxidation and/or corrosion inhibitors, viscosity index improvers, dispersants, thickeners, freeze point depressants, and extreme pressure additives. Numerous tests are therefore necessary to accurately determine those properties the lubricant must have to fulfill the requirements of a given application. While chemical analyses determine fluid physical properties, mechanical tests are essential to establish gear scuffing resistance, volatility, gear and bearing fatigue, and air-oil seal operation limits. General discussion of all lubricant properties and lubrication techniques cannot be accomplished in the limited time allotted and therefore I will confine myself to the need for improved lubricants and advanced lubricant test techniques.

LUBRICANT QUALITY

As was indicated before, the lubricants presently being used in operational aircraft are marginal in some applications today. In many cases those lubricants now in use are the same fluids put into service many years ago when the high pressure ratio turbine powerplants first became service operational. The earlier engines operated at relatively low thrust and turbine inlet temperature levels, and corresponding low thrust-to-engine-weight ratios. Increasing turbine inlet temperature to obtain improved engine performance has resulted not only in higher thrust to weight ratios but also in higher heat rejection to the lubricant. As indicated in Figure 1, heat rejection to the lubricant rises sharply with increasing turbine inlet temperature.

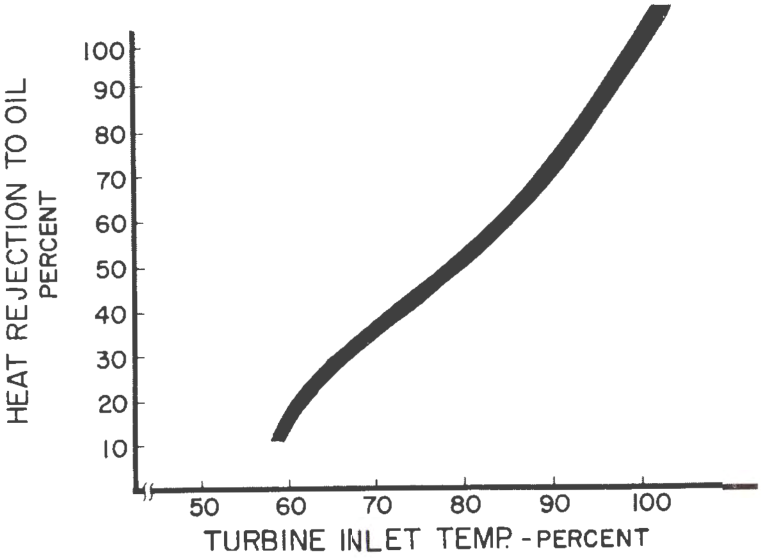

FIGURE 1. TURBINE TEMPERATURE EFFECT ON HEAT REJECTION TO OIL

Heat rejection to the lubricant can also increase as aircraft fly at high altitudes where allowable turbine inlet temperatures are somewhat higher than at sea level. Usually the fuel is used as the most practical and readily available heat sink on board the aircraft, and Figure 2 depicts both the heat rejection due to higher turbine temperatures and the decreasing heat sink capability brought about by the large reduction in fuel flow at altitude. These factors, i.e., increased heat rejection and low fuel flow dictate the need for circulation of the lubricant rather than a once-through, throw-away system, because at the aircraft's operating ceiling the lubricant flow required to cool bearings and seals is many times the engine fuel flow rate. Increased engine performance resulting from higher turbine temperatures usually requires aircraft operation at higher altitude levels and increased flight speeds. When the aircraft flight speeds increase, ram air temperatures rise exponentially, available air cooling capacity is reduced, more severe requirements are imposed on the lubricant; hence the need for more thermally stable fluids. Figure 3 shows the ram air temperature change from relatively cool levels at subsonic speeds to the scorching red-hot temperature levels encountered in high Mach number flight. It is universally acknowledged that design trends in gearboxes are toward increasing power-weight ratios by decreasing gear size and increasing gear speeds, factors which result in higher gear loads and more demanding lubricant properties.

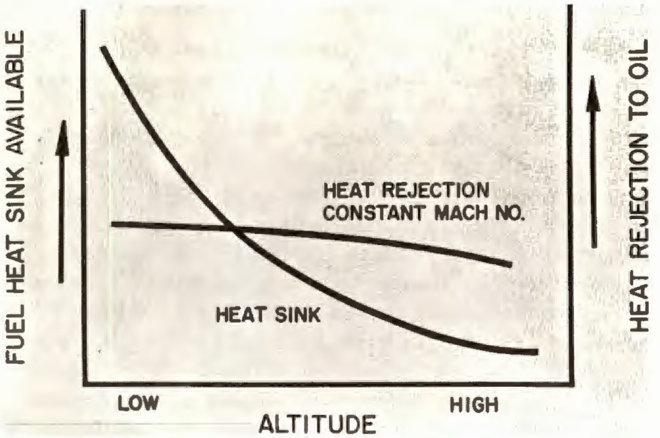

FIGURE 2. OPERATIONAL SEVERITY AT ALTITUDE

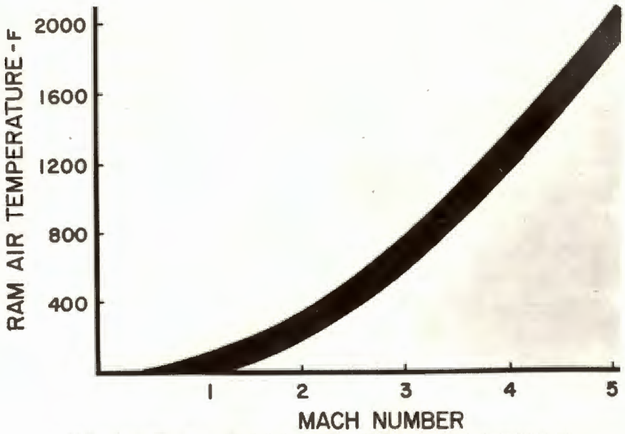

FIGURE 3. RAM AIR TEMPERATURE RISE VS. MACH NUMBER

The consequence of all these operating conditions is that the severity of operation inevitably increases with increased aircraft performance. Figure 4 presents current drain practices for some operational aircraft. It is seen that as the severity of operation increases the engine oil change interval decreases very quickly. Engines in subsonic bomber and tanker aircraft which operate for long periods at cruise conditions can tolerate drain periods of 200 hours. On the other hand, supersonic bombers and fighter aircraft operating at higher temperature levels must be held to engine oil drain intervals as low as fifty hours to prevent powerplant damage resulting from lubricant degradation. Very clearly shown is the fact that lubricants formulated to meet engine needs ten years ago are not satisfactory for long operating periods in many current aircraft. If these facts are plotted as shown in Figure 5, the need for improved lubricants is reflected in the increased oil drain periods which could be realized by using lubricants having increased oxidative and thermal stability. Giving further consideration to these thoughts naturally leads to the conclusion that improved lubricants at reasonable prices could reduce operating costs by substantial amounts. Actual savings will depend upon the aircraft, its flight schedules, lubricant consumption, inventory practices, and last but not least, the lubricant cost itself.

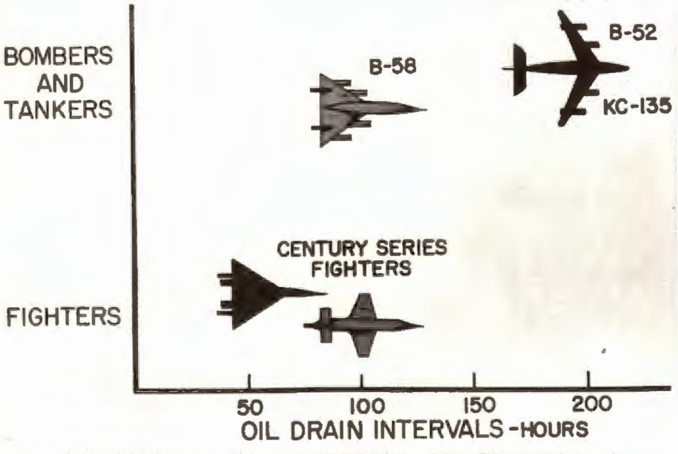

FIGURE 4. OPERATIONAL AIRCRAFT OIL DRAIN PERIODS

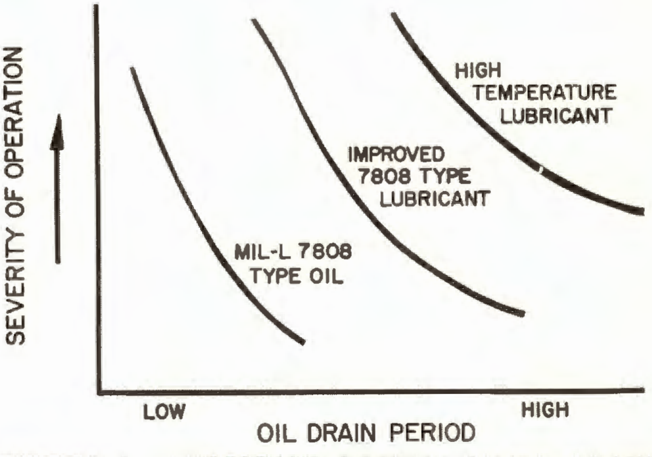

FIGURE 5. LUBRICANT EFFECT ON OIL DRAIN INTERVAL

TEST EQUIPMENT AND PROCEDURES

Many lubricant suppliers have now accepted the challenge represented by these low drain periods and are actively engaged in fluid research and development to satisfy advanced aircraft requirements. In attacking this problem area of more thermally stable fluids, the formulator is constantly faced with a major problem, i. e., what screening tests should be used to insure the satisfactory performance of these experimental fluids when they are placed in the final environmental equipment? The most important factor to remember in any lubricant screening program is that the final objective is to place those fluids being tested in their proper relative order of merit with respect to the property being tested. Changing test methods, procedures, and specification requirements to conveniently fit a particular set of circumstances is usually not considered to be an acceptable approach to the problem.

During the past twenty or thirty years, many and varied test procedures have been devised and tried in a search for tests which will adequately define particular oil properties. Some tests have fallen by the wayside, but among the many which have survived the most notable is the Ryder gear machine test which is used to determine a lubricant's performance in a gear mesh operating under fixed test conditions. Substantiated by many years of actual engine experience, the Ryder gear machine load carrying ability test method can be used to determine the load carrying abilities of these more thermally stable fluids. The factor to remember here (in the Ryder gear machine test) is that the lubricant and not the gear material is being tested, first to define load carrying ability and second to determine which lubricant is superior with respect to this property. As will be shown presently, the standard Ryder rig is entirely suitable for use at temperatures exceeding 400°F for research purposes, but tests performed at normal temperatures are found to rate oils in the same order as high-temperature tests. Since the purpose of the test is not to determine engine performance, but merely to label oils according to their relative merit, nothing is gained by making the test more difficult to conduct. Standard test conditions should be used until it is known that such tests will fail to predict the order of merit which will ultimately be found in full-scale use of the oils.

The objection to continually changing test procedures is that if some new set of standards is used to measure load carrying ability, it is possible to obtain just about any value desired as indicated in the following example. Figure 6 shows three different values in load carrying ability obtained for the same test oil; in one case the test oil temperature was raised, in another the gear material was changed, and the other line represents standard test conditions. Little is to be gained by deviating from the standard procedures; test gears of exotic materials are difficult and expensive to manufacture. Raising the test temperature complicates the screening machinery, and raises the cost of testing but not the validity of the test results. The decrease in load carrying ability with increasing test oil temperature has been well documented both in the United States and abroad and is shown in Figure 7 where the decrease is orderly and has no abrupt changes in slope. However, there is one fact which cannot be overlooked. An oil which is limited to three hundred degree operation because of volatility, additive depletion, or thermal breakdown should not be expected to yield meaningful results if tested at four hundred degrees in gear or bearing tests.

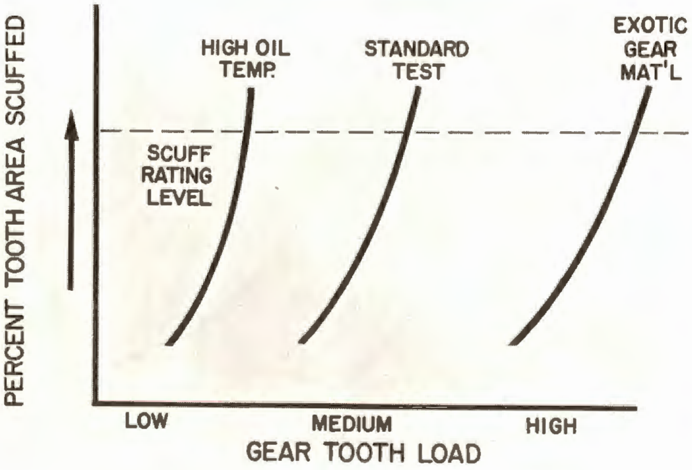

FIGURE 6. TEST PROCEDURE EFFECT ON GEAR TOOTH SCUFFING

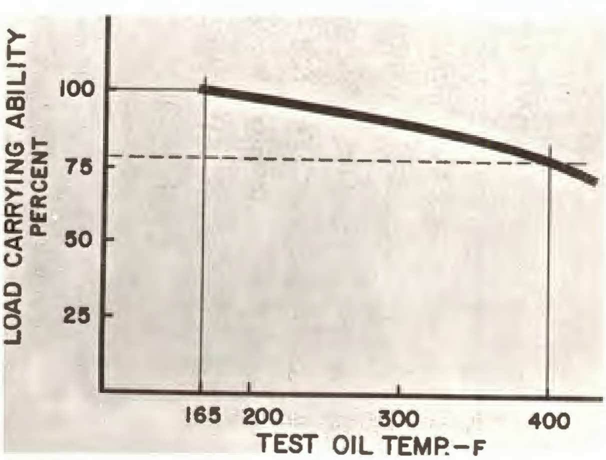

FIGURE 7. LUBRICANT LOAD CARRYING ABILITY AT INCREASING TEST OIL TEMPERATURES

Now a great many pros and cons have been expressed regarding lubricant testing at elevated temperatures and with more or less exotic gear material in special high-temperature machines. Like every piece of machinery that has ever been invented for a specific purpose and sooner or later is used for other research purposes, the Ryder gear machine can be adapted to a variety of test procedures. One question frequently asked is: What are the high-temperature capabilities of the Ryder gear machine? The Ryder gear machine in its present form can be used to rate oils at test oil temperatures exceeding 400°F and the data shown in the previous slide was obtained on a standard Ryder gear machine. As pictured in Figure 8, by adding a high frequency induction heating coil to the Ryder machine, wiring the test oil tank heaters in parallel, using high-temperature shaft seals, and adding suitable insulation to the test oil system, it is possible to conduct tests at 650°F. This statement obviously raises a question in the minds of many, i.e., is the standard Ryder gear suitable for these temperature levels? If a little prudence is used in interpreting the results, the standard gear can be used at these temperature levels and has been so used many times. Also, another thought occurs to many: Use a high-temperature material for the test gear. And now an important decision must be made: Is the purpose of the test procedure to determine the relative performance of lubricants or is this test procedure to be used in an all encompassing program to test any and all combinations of materials and lubricants? There must be a line of demarcation in this matter and it can be expressed as follows. Selection and development of gear and bearing materials are tasks which are incumbent on the engine builder, are best handled in component testing by the engine builder, are not the responsibility of the lubricant formulator, and should not be made part of an industry-wide lubricant development program. It is a relatively simple matter for engine builders to determine load carrying ability requirements at engine conditions, and translate these requirements into standard Ryder test values. It cannot be emphasized too strongly that selection of gear and bearing material are tasks for the engine builder, and the engine builder is obligated to express his lubricant requirements in terms which can be readily applied to standard screening tests.

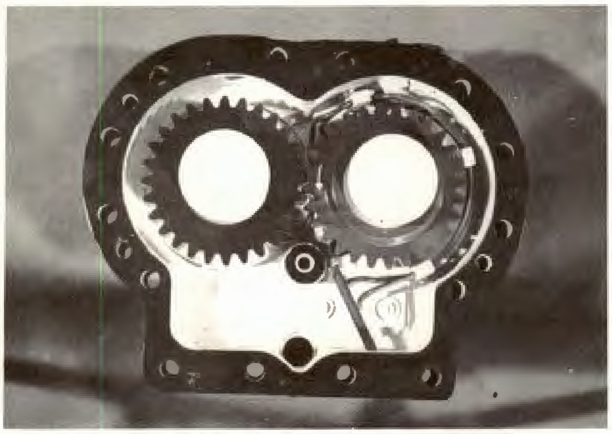

FIGURE 8. HOT GEAR RIG END COVER, INTERNAL VIEW

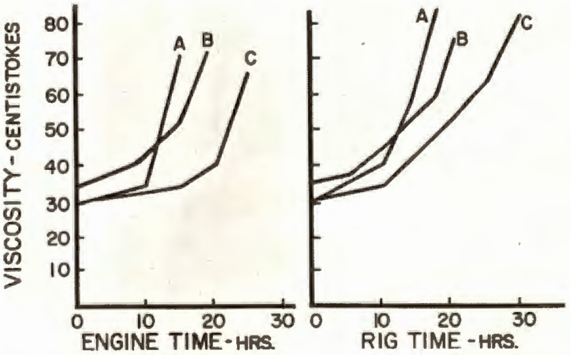

FIGURE 9. PERFORMANCE OF THREE LUBRICANTS IN THE WADD ENGINE AND THE ERDCO BEARING HEAD

Thermal and oxidative stability of advanced lubricants are predicted quite accurately through use of the Erdco high-temperature bearing head operating at predetermined test conditions. This test can also be used to predict the performance of MIL-L-7808 type fluids as well as fluids for six and seven hundred degree environments. Procedures and operating conditions have been established for the various levels of operational severity desired and, generally speaking, these levels are classified as Type I, II, or III, with Type I applying to MIL-L-7808 fluids, Type II being applicable to fluids intended for engines with 400 degree oil-in temperatures and Type III conditions being used for fluids in the 500 to 600 degree category. The Type I test is extremely reliable; its results are widely accepted throughout industry and are substantiated by millions of hours in flight service. Results of Type II testing are not as well known for the simple reason that a substantially smaller number of candidate fluids are available for test. Numerous lubricants suitable for 350 degree oil-in applications are available for tests but the number of fluids capable of 400 degree engine operation is extremely small. Discussion of all Type II testing cannot be presented here, but the capabilities of the Type II test procedure are illustrated in Figure 9, where the viscosity increase of three MIL-L-9236 candidate fluids tested in the Erdco high-temperature bearing head, is shown and compared to the viscosity increase of these fluids in the MIL-L-9236 engine test. It can be clearly seen from the two sets of curves shown that the break in the viscosity-time curve occurs for all intents and purposes at the same hour of test endurance for both the engine and the Erdco high-temperature bearing head tests. Coke and sludge deposits within the bearing head were indicative of the products accompanying thermal and oxidative breakdown and have been indicated to be comparable to the engine deposits.

Just as the number of 400-degree lubricants is much smaller than the number of MIL-L-7808 fluids, the number of oils formulated to operate at five and six hundred degree applications is extremely small. Of course, test results in this temperature range are classified, but it can be stated that the rig tests are duplicates of the full-scale testing. However, the test procedure is not classified and some discussion would appear to be in order. Because the temperature levels involved are high, thermal radiation to the ambient environment is high and requires complete insulation of the test oil system to prevent excessive thermal stressing of the oils during the warm-up cycle and during the test. The same basic equipment is used in all three types of test conditions; the only changes made are the test oil and test bearing temperatures. Structurally, the test section of this versatile machine is satisfactory for operation at temperatures exceeding six hundred degrees. The test bearing itself is made of high-temperature bearing steel and is stabilized for seven hundred degree operation. Table 1 shows the test conditions for Types I, II, and III tests.

TABLE 1. ERDCO HIGH-TEMPERATURE BEARING TESTS

Type of Test	I	II	III
Bulk Oil Temperature, °F	340	440	540
Oil Into Rig Temperature, °F	300	400	500
Bearing Temperature, °F	500	500	600
Bearing Radial Load, lb	500	500	500
Shaft Speed, rpm	10,000	10,000	10,000
Oil Flow, cc/min	600	600	600
Air Flow, cfm	0.30	0.30	0.30
Duration of Test, hr	100	100	100

CONCLUSIONS

In closing it seems advisable to emphasize once more some of the more important points concerning lubricants, test procedures and equipment:

(1) The engine manufacturer must be free to select any and all materials to be used in the powerplant.

(2) There are many standard screening tests available to measure various lubricant properties. One standardized test for each property is sufficient to label that property.

(3) Tinkering with the standard test procedures only creates confusion and chaos. Until the ultimate application or use of the lubricant indicates deficiencies in the screening test, there is no requirement or need to change the test equipment or procedure.

(4) There is a need for improved lubricants in some of the current operational aircraft.