GAS TURBINE LUBRICANTS PICTURE - 1960

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ABSTRACT

The present state of the art along with future thinking in gas turbine engine lubricants and lubrication are covered. Basically, lubricant temperature capability plateaus are dictated by aircraft speed. The various classes of lubricants covering these plateaus are discussed with emphasis on the MIL-L-9236 and high-temperature lubricants. Estimated ending conditions which establish lubricant requirements are shown.

Air-breathing applications include reciprocating, gas turbine and ramjet engines. The gas turbines can be broken down further into turbo-prop, turbo-jet and turbo-fan engines. Since the reciprocating engines are about passe so far as research and development work is concerned, we are doing no R & D work in this area. We have no specific program in ramjet lubricants, either, since the ramjets generally inherit their greases and lubricating oils from the gas turbines and other equipment. Of the gas turbine types, the turbo-jets present the most severe lubricating conditions so the great majority of our air-breathing engine work is with the turbo-jets. Therefore, I will confine my paper to turbo-jet engine lubricants and lubrication.

First, let us take a look at the market picture. The MIL-L-6081 oils are still with us. You will remember that these are the light petroleum oils used in the early jets. We are currently buying both Grades 1005 and 1010. This year's Government procurement will come to a little over 1,000,000 gallons at a price of around $0.60 per gallon. These oils will be with us for a number of years yet, although the market will probably drop off quite a bit in the next couple of years.

Several years ago, we predicted that military procurement of the MIL-L-7808 synthetic oils would peak at 2,000,000 gallons per year. Figure 1 shows that our estimate was over-optimistic since it peaked at 1.5 million gallons in 1958 and then settled down to a 1.3 million gallons per year rate. Several things account for this early peaking, the main one being the extension in 1958 of

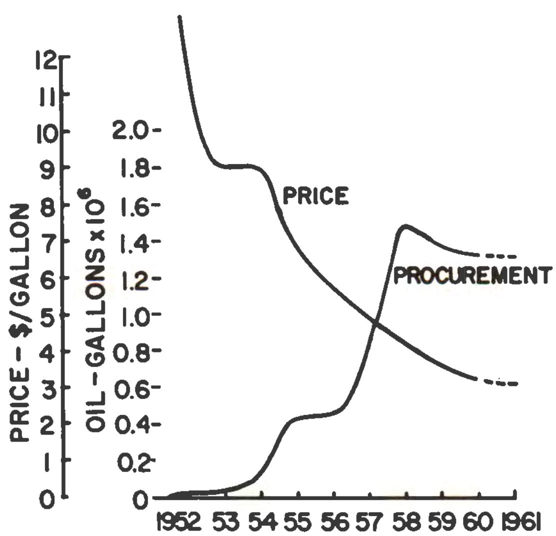

FIGURE 1. MIL-L-7808 OIL PROCUREMENT AND PRICE

the oil drain periods in the B-52 aircraft from 150 to 200 hours. Since the B-52 is our largest 7808 user, a one-third cut materially reduced oil quantity requirements. The new storage stability requirement will also reduce oil procurement since we can get longer shelf life from the oil and will not discard so much oil as a result. New aircraft procurement will, of course, cause the oil quantity to rise. So, all things considered, 7808 procurement has stabilized and the 1.3 million gallon per year level should be maintained for the next 4 or 5 years anyway. As the 7808 procurement increased, the price naturally decreased. It is currently $3.20 per gallon. Unless there is some unexpected breakthrough in materials and/or processing, the price will level off here or possibly a little lower at around $3.00 per gallon. These prices do not include packaging or freight costs.

I wish I could paint as positive a picture for the new synthetic lubricants coming along, especially those defined in MIL-L-9236B. However, due to the uncertain future of new aircraft, I am unable to make any reliable market predictions at this time. There is one interesting aspect of the 9236 oils to keep in mind. If the price should come down into the 7808 ball park, there is a possibility that 9236 would replace 7808, especially if some of the current new aircraft encounter service difficulties which dictate a better oil. Logistic considerations of stocking one oil instead of two would then enter strongly into the decision to switch oils. This is neither a threat nor a promise, but is merely cited for your consideration.

With respect to advanced oils, I can make no predictions whatsoever since such predictions are based on classified projects or on projects which do not even exist yet. There is one point I would like to make clear, however. As pointed out by Col. Anderson and Mr. Schumacher, a fair percentage of the Air Force aircraft inventory will be gas turbine powered for a good many years. So, liquid lubricants are not dead by a long shot, but will be with us for a long time.

Now let us take a look at the lubrication picture. In Figure 2, we see ram air temperature and bulk oil temperature versus speed curves. Below Mach 2 or so, no particular difficulties are encountered from the increasing ram air temperature. The air can still be used as a heat sink or,

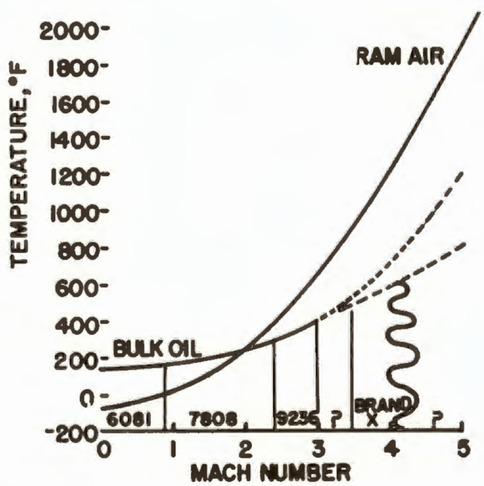

FIGURE 2. BULK OIL AND RAM AIR TEMPERATURE VS. SPEED

at least, it does not affect bulk fuel and oil temperatures too much so we can still reject enough heat into the fuel to keep oil and engine temperatures down to a respectable level. Up to this point, the heat rejected to the oil from the engine is mostly internally generated from compression, combustion, friction, etc. Above Mach 2, the ram air is lost completely as an oil heat sink. More significantly, a good percentage of the engine heat rejected to the oil is brought into the engine by the ram air. Also, due to aerodynamic heating, the bulk fuel temperature increases with increasing speed, thus reducing the unit heat that can be rejected to the fuel. Add to this that the higher speed engines generate more power resulting in increasing internally generated heat to be rejected to the oil. Thus, there is no practical way to hold down bulk oil temperatures. Looking at Figure 2, up to Mach 3, the bulk oil temperatures are pretty well defined. Beyond Mach 3, we are not certain, so I have shown a band which is not definite by any means but is our estimate of where bulk oil temperatures are going. The ram air curve, by the way, is definite since it is defined by aerodynamic principles. The only possibility of affecting this curve would be to cool inlet air which would be quite a task.

Again looking at Figure 2, we see the curves are broken into areas for each of the engine lubricants under consideration. The subsonic applications up to Mach 0.9 are generally lubricated with the MIL-L-9081 light petroleum oils which are performing satisfactorily. No R & D work has been performed on these lubricants for years. The Mach 0.9 to somewhere over Mach 2 range is covered by the 7808 synthetic oils. Service experience with the 7808's has generally been good. We had a horrible storage stability problem for awhile, but that has been resolved and we anticipate no more difficulties here. An accelerated oven test has been introduced in the MIL-L-7808D under the qualification requirements. Any oil which can pass this test should give at least three years storage life. Esso, the Navy and ourselves are currently working on a faster test which can be used for batch acceptance. The present qualification test takes 56 days. We hope to develop a test that will take seven days or less, so we do not extend the batch acceptance testing time which is currently established by the 7-day rubber swell test.

The next oils, for use up to Mach 3, are the MIL-L-9236 oils, the latest version being 9236B which was released last March. This version was written around the new triesters which have been successfully tested at 425°F. I will not go into all the details of the new specification, but there are a few points worth mentioning. There is no corrosion-oxidation test listed in 9236B. The 500°F test in 9236A has proven to be practically useless. In fact, at times it was downright misleading. We are working on a 425°F version which shows a lot of promise but was not ready when the specification was revised. Celanese did a lot of the ground work on the test which is now in final evaluation. It should be ready for inclusion in 9236 next year. A -65°F capability was retained with the 21,000 centistokes maximum requirement at this temperature. The 13,000 centistoke limit we have been quoting for starting purposes is actually hit at -60 to -62°F and is close enough to satisfy our weapons system people.

The gear load carrying ability was reduced somewhat from the 7808 level of 68%. The 56% relative rating in 9236B was dictated by the triesters' capabilities without any load carrying additives. We recognize we compromised the load carrying ability in order not to jeopardize the fluid high-temperature properties. However, with the new vacuum melt steels now available, we feel this level of load carrying ability will do the job. If service experience proves otherwise, load carrying additives, which are currently under investigation, will be introduced.

Speaking of experience, the 9236B oils have been subjected to considerable testing. On the whole, the testing has been generally satisfactory. I would like to go into one problem area that has given us considerable difficulty. This area is the face riding main shaft seals. Figure 3 is

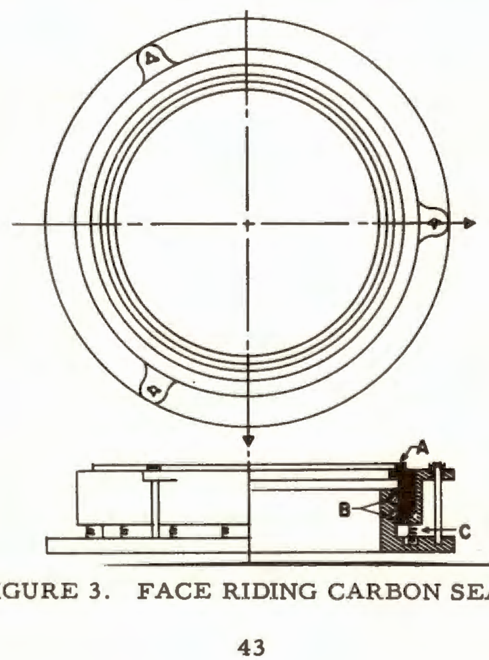

FIGURE 3. FACE RIDING CARBON SEAL

a sketch of a representative carbon face seal. "A" is the primary seal which rides on a metal face plate (not shown here) which is mounted on the rotating shaft which comes through the seal. "B" is the secondary seal which is a piston ring affair, usually metal, which rides on the inside diameter of the carbon element. Sometimes, the carbon element will have a steel sleeve and the rings are carbon. The problem is the same with either arrangement. "C" is the loading springs which controls the movement of the seal element by loading the seal. Hot seal air leaks through both "A" and "B" from the ID to the OD in both cases. Thus, in this case, the OD is the oil side of the seal. The difficulty is in the secondary seal area. Any oil which gets back into this area has no positive way of getting out so it sits there and is cooked by the hot seal air. Degradation products deposit on the ID of the seal element. Then as the seal moves back during transient air flow conditions which occur during power changes, the seal rings stick on these deposits causing the seal to hang open, thus permitting great quantities of hot seal air to leak by the primary seal. This causes oil breakdown in the whole seal area until the springs get so loaded with deposits they freeze in the open position. As the large volume of seal air continues to flow, it drags oil from the sumps when it escapes out the sump breather lines. With a badly hung seal, all the oil in an engine can be dumped overboard in a matter of minutes. Thus, no oil - no engine, and possibly no aircraft, since a failure of this type can cause a catastrophic engine failure. With the seal air temperatures going above 1100°F these days, fire becomes more and more of a possibility also. We are initiating a program to study the seal problem.

The 9236 oils were developed specifically for the Mach 3 B-70 aircraft. These oils will be satisfactory for the prototype aircraft but due to up-grading of performance requirements in the production version of the aircraft, a better oil will be needed. We have some pad in the 9236 oils since they are actually qualified at 425°F but this is not enough. A 450 to 500°F will be required. This takes us into our next category. Looking at Figure 2 again, we see the next oil above 9236 is a question mark. An interim specification has been prepared but no number has been assigned yet so let us call this one MIL-L-?. The requirements are divided into the two usual categories, namely, properties and performance. Table 1 lists some of the more important properties. You will note we are asking for more data this time, such as specific gravity, specific heat, vapor

TABLE 1. PROPERTIES OF MIL-L-? LUBRICANT

1.	Viscosity at 500°F, cs min.	1.0
2.	Viscosity at 30°F, cs max.	13,000
3.	Spontaneous Ignition Temperature, °F	Report
4.	Specific Gravity, 60/60°F	Report
5.	Specific Gravity, 500/60°F	Report
6.	Specific Heat, Btu/lb-°F at 100°F, min.	0.35
7.	Specific Heat, Btu/lb-°F at 500°F, min.	0.45
8.	Vapor Pressure at 500°F, mm Hg. max.	5.0
9.	Evaporation at 500°F, 6-1/2 hrs, 29.9 in. Hg., % max.	10.0
10.	Evaporation at 500°F, 6-1/2 hrs, 5.5 in., Hg., %	Report

pressure and evaporation under vacuum conditions. This type of data has been difficult to obtain on the 9236 oils so by requiring it here, we can more readily generate these data. In an attempt to be realistic, we set the 500°F viscosity at 1.0 centistokes minimum. Then using a VI of 150, we arrived at a -300°F viscosity of 13,000 centistokes maximum. These limits are by no means binding but are cited for guidance. In fact, these figures could change before the specification is released since coordination has not been completed yet. By the way, industry comments will probably be solicited before the specification is released. In Table 2, some of the performance requirements are listed. On load carrying ability, again we are starting out high. The rubber swell is based on Viton B and is highly optimistic. In fact, our rubber people may up these limits before release of the specification. We plan on using the Erdco Bearing Rig with the high-temperature head for the bearing test. Bulk oil temperature will be 525°F and bearing outer race 625°F. 1.5 cfm of air will be dumped into the oil which will be changed every 25 hours, if necessary. The CRC Bearing Test Panel will be asked to coordinate this test with industry to arrive at a standard set of test conditions. We list a corrosion-oxidation test although no test is currently available. The same goes for the engine test. We hope in the not too distant future to have higher temperature engines available, but this is a gray area right now. Storage stability, compatibility and foaming are standard tests.

TABLE 2. PERFORMANCE MIL-L-? LUBRICANT

1. Load Carrying Ability at 165°F, % RR min.	100
2. Load Carrying Ability at 500°F, lb/in.	Report
3. Gear Fatigue at 500°F, hr	Report
4. Rubber Swell at 500°F, MIL-R-25897, %	12 to 25
5. Bearing Test, 100 hrs at 525/625°F	Pass
a. Viscosity Change at 100°F at 25 hrs, % max.	25
6. Oxidation-Corrosion Test	Pass
7. 100-Hour Engine Test	Pass

As for the type of oil which will meet MIL-L-?, we have some starting points. The polyphenyl ethers will meet the upper temperature requirements of the specification now. If their low-temperature properties can be improved, they will be a strong candidate. Heavier esters with suitable oxidation inhibitors are another possibility. As in the past, we will look at any and everything which shows any promise whatsoever. In our past programs, we have always looked for a 100-hour oil right from the start. However, at this level, we may have to back off on the operational time, at least in the early stages of the program. In other words, we may have to be satisfied with performing only one or two aircraft missions before an oil change is in order. This remains to be seen.

Let us go back to Figure 2 again for a look at the next oil category. As you can see, this covers Mach 3.5 to some nebulous range over Mach 4. I cannot tie this down any closer due to a lack of developed information. But, at least, we can do some planning. When I first laid down some preliminary requirements for this specification, I thought I would call it MIL-L-Brand X, figuring Brand X must be good for something. But since that time, I understand that Brand X has been applied to such products as cigarettes, whiskey and various other boons to mankind. However, I chose the name and I am stuck with it.

With this specification, we are really going ape. Table 3 will give you an idea of what I mean. Starting with the 1.0 centistoke minimum at the contemplated bulk oil temperature of 700°F and again using a VI of about 150, we arrive at 1200 centistokes maximum at 100°F which does not allow much for low temperatures. However, here we will take our usual tack of seeing what can be obtained at the high end of the scale. Then, when we have some fluids to work with, we still look at the lower end. Notice that the bearing test is scheduled for 725°F bulk oil temperature and 825°F bearing outer race. The present research head should be able to handle these temperatures. If not, it will be redesigned. We cite the seal rig test since we hope to have a good seal test available by the time we start looking at candidate fluids. The engine test, of course, is contingent upon the availability of engines which will operate at 700°F oil temperature.

TABLE 3. MIL-L-BRAND X REQUIREMENTS

1. Viscosity at 700°F, cs min.	1.0
2. Viscosity at 100°F, cs max.	1200
3. Spontaneous Ignition Temperature, °F min.	1200
4. Evaporation at 700°F, 6-1/2 hrs, % max.	10.0
5. Bearing Test at 725/825°F, hrs	Report
6. Seal Rig Test	Report
7. Load Carrying Ability at 700°F, lb/in.	Report
8. Gear Fatigue at 700°F, hrs	Report
9. Engine Test, ? hrs	Report

MIL-L-Brand X will strain organic materials to the limit. In fact, we are not sure they can even be used. Organo-metallic materials will bear looking into, also. If we are successful in developing suitable fluids, engine design will be greatly simplified since a recirculating liquid lubricating system would be possible.

And now back to good old Figure 2 for one last look. Beyond Brand X that question mark is a bonafide question mark. Not much thought has been given to this area by WADD insofar as liquid lubricants for gas turbine engines are concerned. It is a little premature to make any predictions yet. Possibly by the next conference, we will have some information to give you in this area.

To sum up, let me reiterate that air-breathing engines will be around for a long time, so any work done on lubricants for these engines will be useful. Another facet to remember is - anytime a new product is developed, commercial as well as military markets can be developed. Many domestic materials on the commercial market today were originally developed for aircraft use.