GENERAL ELECTRIC VIEWS ON JET ENGINE LUBRICATION

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ABSTRACT

The MIL-L-7808 family of oils is handling the needs of the current fleet service, both military and commercial. The MIL-L-9236 family of oils promises to meet the lubricant needs for the family of high performance engines just beyond the horizon. However, new and fantastic demands for engine lubricants are foreseen to handle industry and military requirements for the period 5 to 10 years hence. New fluids and new handling methods will be required to assure adequate fleet operation.

One of the bearing companies uses the slogan "Nothing rolls like a ball.." Those of us in the jet engine business know all too well that "Nothing rolls worse than an unlubricated ball." Certainly there are no needs in our aircraft industry today more important than the need for adequate use of the proper lubricant in turbojet engines.

In reviewing General Electric's views on jet engine lubrication, let us review briefly the history of jet engine lubrication. The first jet engines built in this country were General Electric engines which were lubricated with light mineral oils. These light mineral oils satisfactorily filled the requirements for oils for over a decade. The most famous engine family to use this lubricant was the General Electric J47 engine family in US Air Force aircraft such as the Convair B-36, North American F-86 and Boeing B-47. These engines were able to live with the relatively low temperature capability mineral oils because the duty cycle requirement of the aircraft matched the characteristics of this oil family. We find that this matching of the aircraft duty cycle to the lubricant characteristics is the major item in determining the lubricant requirements for jet engines. The B-36, B-45, B-47 and F-86 type aircraft were subsonic or barely sonic aircraft and, as such, did not require a lubricant to operate over 200° F. However, these aircraft did require -65° F starting capability and hence the use of the light mineral oils.

Figure 1 is a chart which shows graphically the progress of lubricant development since the early engine systems. By plotting lubricant bulk oil temperature alongside aircraft ram air temperature, you can see clearly why I have stated that the matching of the aircraft duty cycle to the lubricant characteristics is of major importance in determining lubricant requirements for jet engines. Let us keep this chart in our minds for future reference and go on with our review of engine lubricants.

The next significant advance in the search for a wider temperature range lubricant came in the form of the MIL-L-7808 family of lubricants. Generally, the diester base fluids are compounded to meet the needs of increased thermal stability, foaming stability, gear load carrying capacity, etc. These lubricants have been highly successful in the temperature range for which they were designed to be used, -65 to 300° F. This is the class of oil used in General Electric's J79 Mach 2 family of engines, including the subsonic CJ805 commercial engine. Such military aircraft as the USAF's Convair B-58 Hustler, Lockheed F-104 Starfighter and the Navy's McDonnell F4H Phantom II and North American A3J Vigilante craft as well as the Convair 880 commercial airliner use the diester family of oils - successfully. Again, these oils have been tailored to a specific class of aircraft, those which are generally limited to approximately Mach 2. This oil has been the mainstay of our current fleet of jet aircraft using General Electric engines as well as competitive engines.

The next important step in lubricant development occurred around 1956 when the military requested industry to conduct research to obtain lubricant candidates to fulfill the conditions of the MIL-L-9236A Specification. This required an oil to operate between -65 and +400° F. As many of

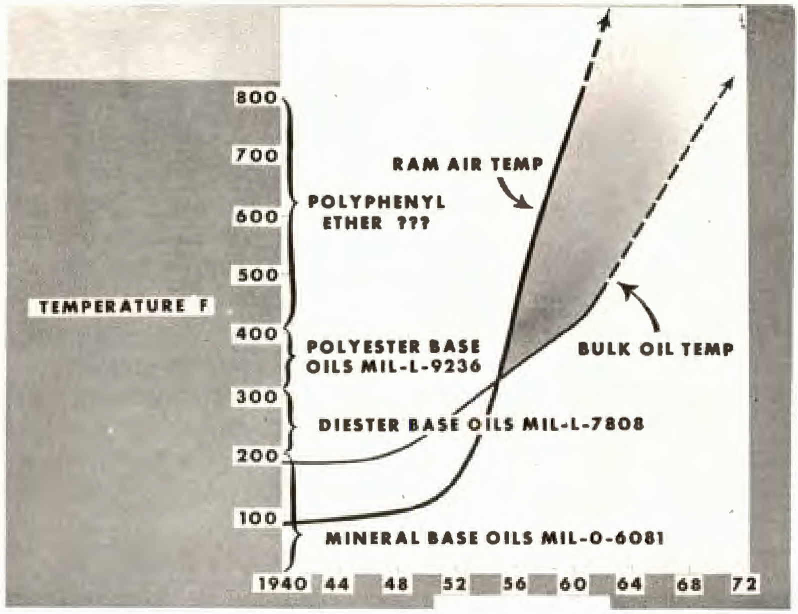

FIGURE 1. PROGRESS AND FUTURE REQUIREMENTS OF OIL TECHNOLOGY

you know, the next few years were filled with much disappointment for the oil industry, the engine industry and the military. Fluids which exhibited good high-temperature stability had poor low-temperature characteristics; fluids which had good low-temperature viscosity had poor oxidative stability; and fluids with good viscosity characteristics at both high and low temperatures had unfavorable products of decomposition. However, considerable progress has been made in the past 18 months in identifying and testing fluids to meet a modification of this specification, the MIL-L-9236B Specification. Our company has tested many different oils with varying degrees of success. We have identified many significant parameters in marrying an oil to an engine. In many cases it is almost impossible to call out in a specification the important considerations which make a succesful oil. In the final analysis, the engine itself is the specification.

The oil development programs at General Electric have been aimed at determining the operational behavior of the oils when run at the maximum temperature conditions with components such as gears, bearings, pumps and seals. There often is little similarity in the results from these tests. For example, the best gear lubricant turned out to be incompatible with seals. The process of choosing an oil requires a compromise in the operation of each of these components. This compromise must then be factored into the mechanical design of the engine in terms of reduced gear loading, special materials, increased oil flow, etc. The marriage of the lubricant to the engine then is like any other marriage. It requires compromises between the parties or components involved in order to obtain a harmonious relationship!

Fortunately, the requirements and the availability of candidates for the MIL-L-9236B Specification are approaching balance today. There are fluids which meet the conditions of the MIL-L-9236B Specification which relaxes some of the requirements of the "A" Specification. However, fluids better than MIL-L-9236B will be required to help assure successful operation of the high Mach aircraft now being evolved. An additional 100° F of temperature capability is needed in order to give adequate performance margins. There are indications that this is feasible if we are willing to sacrifice at the low temperature end of the oil spectrum and accept -40° F as a target rather than -65° F.

The stability of these fluids under the operating conditions expected in the field has yet to be demonstrated. A number of problems are expected. Some of them are:

(a) Useful Life of the Oil. In field service will frequent oil changes be required in order to keep aircraft serviceable?

(b) Logistics Problems. Experience shows the new high-temperatures oils to be highly sensitive to contamination. What happens if someone puts in a quart of the wrong oil? Or even more serious, what happens if the various oils which meet the MIL-L-9236 Specification are not compatible when mixed with each other? Will the thermal stability of the mixture be equal to the original fluids?

(c) Component Life Problems. Under types of service expected in fleet operation, will products of oil decomposition adversely affect engine components as overhaul life requirements increase?

Now, let us look into the future. What are the requirements for the next family of oils for high performance engines? Table 1 summarizes these requirements for an ideal oil. These requirements are demanding, but anything less ideal than these requirements is a compromise which requires special design techniques in the engine. Ram air temperature corresponding to only Mach 4 is approximately 1200° F. With Mach 3 system development well underway, it is a matter of a relatively short time before we operate in these extremes. Within the next decade these will be realistic requirements. The engine and aircraft people are prepared to make certain compromises, realizing the magnitude of the requirement for developing such an ideal lubricant. However, the compromise will cost weight and range of the weapon system.

TABLE 1. REQUIREMENTS FOR IDEAL ENGINE OILS

1. Viscosity - Temperature Characteristics:

   -65° F - <13000 cs
   +1200° F - 3 cs

2. High Load Carrying Ability
3. Non-Flammable
4. Low Volatility
5. Good Lubricity
6. Non-Coking - No solid products of decomposition
7. Low Specific Weight
8. High Specific Heat
9. High Thermal Stability
10. Non-Foaming
11. Non-Toxic
12. Good Rolling Fatigue Properties
13. Available

Let us go back to the original chart I used to show the pace of lubricant development versus time. Figure 2 is the same as Figure 1 except for the middle line. If we interpret this chart literally, we would say that the aircraft industry is moving faster than the lubricant industry because the "Ram Air Temperature" line, denoting speed of flight, has a sharper slope than the "Bulk Oil Temperature" line. The area between these lines shows where the aircraft design has to be compromised by providing auxiliary cooling means such as water boilers, fuel coolers, or refrigeration.

In fairness to the lubricant industry, look at the middle line in Figure 2. This represents a significant new advancement by the industry in keeping pace with aircraft needs by use of a new family of fluids, the polyphenyl ethers. These fluids have considerable improvement in high-temperature stability at the expense of greatly increased viscosity at the low temperature end of the scale. Unfortunately, the pour point of these fluids is not much less than room temperature. Obviously, this requires a definite compromise on the part of the engine and aircraft, because of the need for special provisions in order to live with this special characteristic of the fluid. Either auxiliary heaters or other special means are needed in order to use such a fluid. Mother Nature has a strange rule which is not very accommodating to the lubricant developer. In practically all of the fluids, you gain at the higher temperature end only at the expense of the lower temperature end of the temperature scale. Unless a major chemical breakthrough occurs, the next engine development will not have a lubricant with -65° F capability and the aircraft industry and the military will have to accept special methods of handling aircraft in extreme temperature environments.

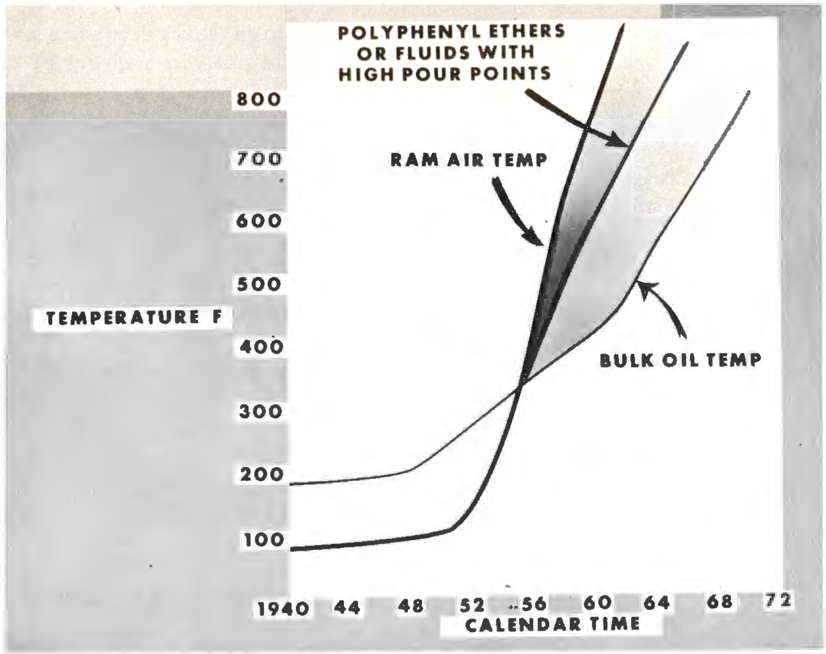

FIGURE 2. FUTURE REQUIREMENTS OF OIL TECHNOLOGY

Since the requirements in Figure 2 might be a little too "blue sky", what are some specific needs for the lubricant for the next family of engines? Several months ago General Electric studied this problem for the purpose of supplying this information to the lubricant industry as a guide in their research for the immediate future. This conference is an extremely opportune time to present this to you for use in planning your research programs for engine lubricants.

The next few figures are intended as a guide to the military and the lubricant industry personnel as to what we at General Electric currently believe to be the requirements. Table 2 shows the physical properties which are significant and gives limits or conditions for the specific properties. Where temperatures and pressures are given, they represent the operational limits which the engine will impose on the fluids. Where no limit is specified, the fluid properties should be reported. Obviously there are many other special oil tests which should be made in the course of the development program. I am sure our list will be revised as we learn more about the oils.

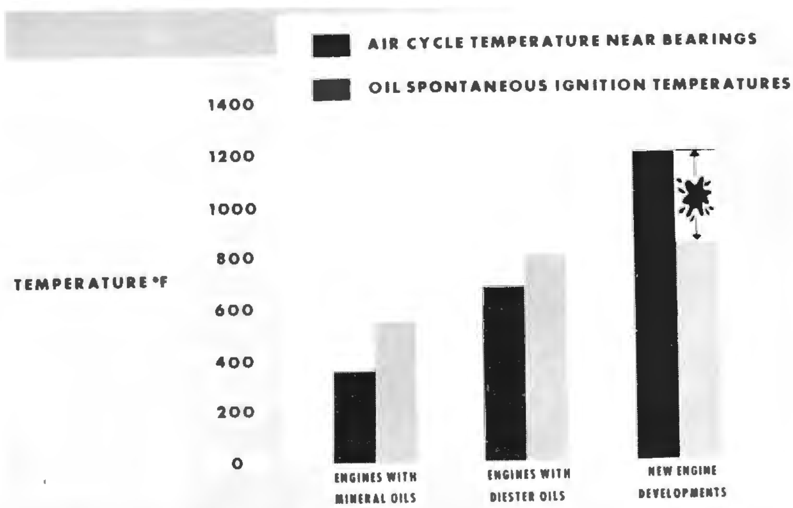

FIGURE 3. COMPARISON OF SPONTANEOUS IGNITION TEMPERATURES

I would like to draw special attention to Item No. 13, flash and spontaneous ignition temperatures. This is an area where the least amount of work has been done, but one which has become increasingly vital as newer high performance engines are developed. Figure 5 shows what has happened

TABLE 2. OIL DEVELOPMENT REQUIREMENTS

	Physical Properties	Condition Or Limit
1.	Viscosity vs Temperature	<13000 cs at -65°F >2 cs at 700°F
2.	Specific Heat vs Temperature	Rm. temp. to 700°F
3.	Specific Gravity vs Temperature	0 to 700°F
4.	Compatibility with Other Materials (includes effect on either the oil or the material) Carbons, steels, monel, silver, silicone rubber, Viton A & B rubber, etc.	Rm. temp. to 800°F
5.	Oxidative Stability	500 - 800°F
6.	Evaporation Rate	400 - 700°F, 7.5% Max.
7.	Panel Coking	Oil temp. 400 - 700°F Panel temp. 600 - 1000°F 100 mg Max., 8 hr.
8.	Viscosity vs Pressure & Temperature	Rm. temp. to 700°F to 150,000 psig
9.	Decomposition Products	Report
10.	Foaming	1.5 - 14.7 psia Rm. temp. to 800°F
11.	Water Tolerance or Hydrolytic Stability	Report
12.	Lubricity (Shell 4-Ball Test)	1 & 10 kg load to 700°F - Report
13.	Flash & Spontaneous Ignition Temperatures	Report - Press. 1.5 - 100 psia

in engine development in the past few years. While earlier engines had air-cycle temperatures in the vicinity of the lubricated engine bearings which were less than spontaneous ignition temperature of the lubricants, newer engines do not. This places a very serious additional requirement on a lubricant to be fire-resistant. Very little work has been done toward improving the spontaneous ignition temperature of engine lubricants, although some work has been accomplished in other fields. It is high time that we began concentrating on this as a critical engine requirement.

Table 3 shows component screening tests required to classify a potential lubricant after its physical property evaluations have been made. Only at this point does the engine designer begin to learn whether or not a potential oil candidate warrants further tests on full-scale component rigs which can simulate the maximum oil conditions imposed at high Mach numbers. Our experience has told us that static sea-level engine tests cannot substitute for simulated tests at conditions similar to maximum Mach number. In the final analysis, the only real proof of an oil is running it in the actual engine at the worst evnironmental conditions. It is extremely important to bear this in mind in conducting lubricant evaluations. The process is tedious, it is costly, but it is necessary in order to assure obtaining a lubricant capable of doing its job.

TABLE 3. OIL DEVELOPMENT REQUIREMENTS

Component Tests	Condition Or Limits
1. Gear Screening Tests	Scoring limit 300 - 700° F. , 2500 lb/in min.
2. Bearing Screening Tests	Scale bearing Weibull Plot at 1/2 Co load 300 - 700° F (Should meet AFBMA predicted life)
3. Seal Screening Tests	Engine type seal at 700° F oil temp. 1500° F air side
4. Cold Fluid Systems Tests (Pumpability Limits)	Rm. temperature to -65° F

Summarizing, we currently have 400° F lubricants available. We need to push this lubricant up to 500° F and may need to compromise low-temperature viscosity to do it. The next engine family (3-5 years away) requires a 700° F lubricant. Within the decade we predict the need for a 1200° F fluid.