HYDRAULIC FLUID QUALITY IN AIRCRAFT HYDRAULIC SYSTEMS

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ABSTRACT

Ambient temperature variation aircraft hydraulic systems have to withstand can be nearly 90°C. Besides of the ambient temperature the hydraulic systems have to withstand very high variation in system temperature. Due to small fluid volume, limited heat exchanger capacity and high system peak power these systems usually run exceptionally hot and fluid may have to withstand a temperature variation as high as nearly 180 °C. Violent ambient conditions and extreme conditions in the system itself cause hydraulic fluid to be under very exceptional stress in comparison to typical mobile hydraulic systems. Also hydraulic system maintenance and servicing practices in aircraft differ a great deal from practices used in other mobile hydraulic systems.

Fluid contamination and deterioration are normal consequences of the system operation and ambient conditions. Performance, lifetime and reliability of hydraulic components are very sensitive to the quality of the hydraulic fluid used in the system and thus is of great importance to know the overall quality of the fluid in the system and to understand how the quality is affected by maintenance and servicing.

This paper presents results of the fluid quality monitoring study made in two different types of aircraft using different types of hydraulic fluid (mineral oil based and synthetic hydrocarbon). Four individual aircrafts were selected for research and fluid from each
aircraft was sampled periodically. Typical parameters describing the fluid quality (TAN, viscosity, water content etc.) were analysed from samples. Also the level of particulate contamination was determined. Results give an explanation to many typical problems encountered in aircraft hydraulic systems and also point out short comings of typical maintenance servicing procedures used in aircraft hydraulics.

KEYWORDS: Fluid quality, aircraft, MIL-PRF-83282, MIL-PRF-5606

1 INTRODUCTION

A mineral oil-based MIL-H-5606 has been the most widely used type of hydraulic fluid in military aviation since 1940’s and it was widely used also in commercial aviation until 1970’s. It provides excellent operational properties over the temperature range of –54°C to 135°C. It has one major deficiency, which was recognised early in its use, is its high degree of flammability.

Recognition of fire hazards associated with MIL-H-5606 fluids, resulted in the commercial aircraft industry to develop hydraulic fluid based on phosphate esters. However, the phosphate ester based fluids were not adopted by the military because they were not compatible with MIL-H-5606 fluids, nor with elastomer materials used in MIL-H-5606 hydraulic systems. There was also a view that the use of two incompatible hydraulic fluids could result in significant problems if fluids were ever inadvertently mixed.

The commercial aircraft industry found a significant reduction in the number of hydraulic fluid fires since the adoption of phosphate ester hydraulic fluids, and now-a-days all large civil transport aircraft use this type of fluid in their hydraulic systems. Although the military did not move to phosphate ester type fluids they did identify the need for a fire resistant fluid as a direct replacement for MIL-H-5606. As a result a synthetic hydrocarbon-based fluid, MIL-H-83282 was developed. This fluid is completely compatible with MIL-H-5606 fluids and MIL-H-5606 hydraulic system materials. All physical properties of MIL-H-83282 (new designation MIL-PRF-83282) were equivalent or superior to those of MIL-H-5606 (new designation MIL-PRF-5606) except low temperature viscosity. In particular all fire resistant properties of MIL-PRF-83282 are superior to those of MIL-PRF-5606. More recently MIL-PRF-87257 was introduced in order to offer a fluid which has better low temperature viscosity than MIL-PRF-83282.

Hydraulic fluid contamination and deterioration are normal consequences for hydraulic systems. The most common hydraulic fluid contaminants are entrapped air and water, along with particles of metal, rubber or dirt.

Fluid deterioration can be more appropriately called “additive deterioration”. Additives give oil its particular characteristics. These additives are most susceptible to chemical and physical change often caused by chemical reactions with contaminants or high temperatures.
Aircraft hydraulic systems usually have very small fluid volume and limited heat exchanger capacity, which lead to high operational temperature. Also environmental temperature extremes can be very violent. Thus hydraulic fluid is under a very high stresses caused by temperature.

Level of the particulate contamination in the system is kept low by fine filtration and periodic flushing of the system. However hydraulic fluid typically is never completely renewed, but the system is topped up with new fluid as needed. Topping up is a common practice also in hydraulic units used for flushing and system testing. Due to mixing new and used fluid the chemical quality, i.e. stage of deterioration, of the fluid in the system is unknown.

The performance, life and reliability of hydraulic components are very sensitive to the quality and maintenance of the hydraulic fluid used in the system.

2 FLUID SAMPLING PROGRAM

To study hydraulic fluid chemical quality a periodic fluid sampling program was planned. Program included 10-12 fluid samples taken on regular intervals from hydraulic systems of:

- Two jet fighters (MIL-PRF-83282 fluid)
- Two jet trainers (MIL-PRF-5606 fluid)
- Two portable hydraulic test stands for each aircraft type

From each fluid sample following physical properties were tested:

- Viscosity at 40°C and 100°C
- Viscosity index
- Total acid number
- Water content

Samples taken from test stands were also tested for foaming. Reason for not testing samples from aircrafts for foaming was high fluid volume needed for test.

Random samples went also through spectrometric analysis to study if it is possible to trace additive deterioration from samples. Some samples went also through particle counting, but results of particle counting were known to be unreliable because of sampling (bottle samples) and long storage time before counting [1].

Samples of new barrel clean fluid were analysed for reference. Analyses made are further explained in following chapters.

2.1 Viscosity and Viscosity Index

Viscosity is commonly considered to be the single most important property of a hydraulic fluid. Decreased viscosity is generally a sign of additive deterioration. However oxidation and some contaminants can also increase the viscosity of the fluid.
Viscosity index is a measure of fluid's change of viscosity with temperature. The higher the viscosity index, the smaller the relative change in viscosity with temperature.

Viscosity was determined according to ASTM D 445. Viscosity index was determined according to ASTM D2270.

2.2 Total Acid Number (TAN)

Total acid number is the quantity of base, expressed in milligrams of potassium hydroxide, which is required to neutralize all acidic constituents present in 1 gram of sample.

TAN depends on both the base oil and additives. Increase in TAN is usually due to oxidation which on the other hand can be caused by several different factors (air, temperature, water etc). Typical TAN values for new hydraulic fluids are 0.02...0.5 mgKOH/g. TAN value of two times the value of a new fluid is commonly considered to the maximum value acceptable.

Total acid number was determined according to ASTM D 664.

2.3 Water Content

Because of its affinity for other liquids, water is present in some concentration in most hydraulic systems. The hygroscopic nature of liquids causes them to pick up a certain amount of water simply from contact with humid air.

Each fluid has its own saturation level for water. Below the saturation level, water will be completely dissolved in the fluid. For oil-based hydraulic fluids, the saturation level is likely to be in the range of 0.01% to 0.1% (100 to 1,000 ppm) at room temperature. At higher temperatures, the saturation level is greater. Above the saturation level, water takes the form of relatively large droplets, which is also called free water. It is also possible that, due to mixing action, undissolved water is emulsified so that it exists as very fine droplets suspended in the oil.

Water reacts with almost everything in a hydraulic system. Water promotes corrosion through galvanic action by acting as an electrolyte to conduct electricity between dissimilar materials. Water reacting with antioxidation additives produces acids. At operating temperatures above 60° C, water reacts aggressively with zinc-type antiwear additives (For example, zinc dithiophosphate (ZDTP) is a popular boundary lubricant added to hydraulic fluid). When this type of additive is depleted by its reaction with water, abrasive wear will accelerate rapidly. Water can also act as an adhesive which causes particles to clump together in a larger mass.

Water content was determined according to ASTM D 1744

2.4 Spectrometry

There are several different methods of spectrometric hydraulic fluid analysis. Basically these methods can be divided in atomic spectrometry and molecular spectrometry.
According to their names the first one is for determining atomic concentrations and the latter one for molecular concentrations. Both methods need a great deal of expertise in analysis, but can give very accurate results. Spectrometric analysis can be used for tracing wear metals, contamination and additives.

Method used in these analyses was atomic spectrometry.

2.5 Foaming

Foam depressants are usually a part of the additive packages in many oils. Additive deterioration and contamination are the usual causes of foaming.

The foaming test consists of three temperature sequences, 24°C, 93.5°C, then back to 24°C, using the same sample for the last two sequences. At each temperature sequence, air is blown into a cylinder containing the oil through a diffusion stone for five minutes. At the end of five minutes, the amount of foam generated is measured. At the end of 10 minutes settling time, the amount of foam remaining is again reported. Quality lubricants generally have 0 ml foam after about 5 minutes.

Foaming was determined according to ASTM D 892.

3 RESULTS

Results for one of each aircraft type are presented in this paper.

3.1 Jet Fighter

The hydraulic fluid used in the system is MIL-PRF-83282 type. During test period the aircraft systems were topped up several times due to maintenance, repairs and system deaeration. Total usage of new fluid can not be determined.

Total FH during program  135.2 FH
The hydraulic fluid used in the system is MIL-PRF-5606 type. During test period the aircraft systems were topped up several times due to maintenance, repairs and system deaeration. Total usage of new fluid can not be determined.

Total FH during program 159.15 FH
3.3 Portable Hydraulic Test Stand for Jet Trainer

The hydraulic fluid used in the system is MIL-PRF-5606 type. During test period the system was topped up several times. Total usage of new fluid can not be determined.
Total running hours during program: 14 h

Figure 5. Hydraulic fluid viscosity [cSt], reference curves – new fluid

Figure 6. Total acid number [mgKOH/g], reference curves – new fluid. Water content [weight %], reference curves – new fluid
Figure 7. Foaming [ml], reference (red lines) - new fluid

In figure 7 foaming values are presented only for first two phases of test, third phase value is omitted in figures because its values are identical to the first phase. Visible bars present the foam after air mixing, foam after settling time is zero and thus not visible.

3.4 Portable Hydraulic Test Stand of Jet Fighter

The hydraulic fluid used in the system is MIL-PRF-5606 type. During test period the system was topped up several times. Total usage of new fluid can not be determined.

Total running hours during program 31 h

Figure 8. Hydraulic fluid viscosity [cSt], reference curves – new fluid
Figure 9. Total acid number [mgKOH/g], reference curves – new fluid. Water content [weight %], reference curves – new fluid

Figure 10. Foaming [ml], reference (red lines) - new fluid

In figure 10 foaming values are presented only for first two phases of test, third phase value is omitted in figures because its values are identical to the first phase. Visible bars present the foam after air mixing, foam after settling time is zero and thus not visible.
3.5 Results of Spectrometry

Spectrometry analysis results for the first batch of samples are shown in figure 11. All other analyses gave similar results.

Possible origins of traces found in samples are:

<table>
<thead>
<tr>
<th>Element</th>
<th>Origin of Trace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca (Calcium)</td>
<td>Oil additives, water, grease, dirt</td>
</tr>
<tr>
<td>P (Phosphorus)</td>
<td>Additives</td>
</tr>
<tr>
<td>Si (Silicon)</td>
<td>Dirt intrusion, seal material, additive</td>
</tr>
<tr>
<td>Sn (Tin)</td>
<td>Additives, wear metal</td>
</tr>
<tr>
<td>Zn (Zinc)</td>
<td>Neoprene seals, additives, wear metal</td>
</tr>
<tr>
<td>Ba (Barium)</td>
<td>Additives, water and grease</td>
</tr>
<tr>
<td>Cu (Copper)</td>
<td>Wear metal</td>
</tr>
</tbody>
</table>

![Figure 11 Spectrometry results for the first batch of samples](image)

3.6 Particle Counting

Particle counting was done on several fluid samples during the test. As was expected results were inconclusive. This is mostly due to long storage time of samples before the counting could be done, but also sampling itself could have some effect on results.

In aircraft the sampling point is typically in the system return line before filters. Due to systems being constant pressure systems with variable displacement pump there is almost no flow in the system when system is on idle. Even though it is possible to drain a sample good enough for chemical analysis it is not possible to get a good sample for particle analysis.
Results showed cleanliness of NAS 1638 class 7 – 9, whilst the target cleanliness is class 6. This gives a reason to expect that cleanliness is not on level it should be, but does not prove it. However without system modifications or somehow taking sample from a system running on full flow this is impossible to confirm.

4 DISCUSSION

Results of analyses show no signs of time dependency in the deterioration of hydraulic fluids. This was an expected result since it was known that new fluid is constantly introduced to systems and old fluid is bled out, thus it is natural that an equilibrium state in fluid quality is formed.

An equilibrium is also formed in between the fluid quality of test stands and aircrafts due to mixing of fluids when units are used.

From results it can be clearly seen that the synthetic fluid retains its viscosity better than the mineral oil based fluid. Viscosity changes in MIL-PRF-83282 are minimal in comparison to ones found in MIL-PRF-5606, even though the system using MIL-PRF-83282 fluid is known to have much higher operating temperature.

Possibly because of the hydraulic system operating temperature TAN values of fluid in fighters and their test stands are very high (approx. seven times the value of a new fluid). Also the foaming tendency values are in used MIL-PRF-83282 are very high in comparison to level of the new fluid, however as an absolute value they still are below the level of the new MIL-PRF-5606 fluid. Increased foaming tendency can be interlinked with air problems encountered in hydraulic system of fighters.

Used fluid of trainers and their test stands have TAN values of approx 3-4 times the value of the new fluid. Foaming tendency values of used fluid are significantly higher than value of the new fluid.

Water content of fluids in all systems is relatively close to starting values. This however does not necessarily mean that water is not introduced to systems but only that the amount of dissolved and undissolved water is low.

Results of spectrometric analysis were inconclusive. There are some traces of possible additives visible, but they can not be unambiguously identified as additives. For example zinc, phosphorus, calcium and barium are all common constituents of oil additives, but they also can be traces of contamination. To be able to clearly identify additives and contamination a molecular spectrometry should be used instead of atomic spectrometry.

All results indicate depletion of additives in fluid. Additive depletion can be in some extent interlinked with all wear problems encountered in systems and also with system deaeration problems encountered in fighters.
5 CONCLUSIONS

There is nothing to be done in maintenance procedures and schedules of aircraft to improve the quality of hydraulic fluid. System constructions do not make it possible to implement same procedures (i.e. periodic fluid renewal, flushing, reservoir cleaning etc) used in other hydraulic systems to maintain the fluid quality. However the fluid quality could be improved by introducing new maintenance procedures for test stands and by improving test stands themselves. Test stands have much higher fluid volume than aircraft and thus their effect on the fluid quality is relatively high.

Fluid quality could be improved by:

- Introducing periodic fluid renewal and reservoir cleaning to maintenance schedule of test stands
- Improving breather filtration in ground units
- Improving filtering of ground units by offline deep filtering system capable to remove water and resins from fluid
- Periodic fluid sampling (particle count, chemical analysis)

Air in aircraft hydraulic systems is a very common maintenance problem for many aircraft types, especially modern fighters which almost all use MIL-PRF-83282 fluids or equivalent. Results showed that foaming tendency of fluid in aircraft and their test stands is significantly higher than the one of new fluid. Therefore test stand reservoirs should be designed extremely carefully to allow fluid to deaerate in the reservoir and not to introduce more air into the fluid in reservoir.

Bad fluid quality in one aircraft can only cripple one aircraft - Bad fluid quality in one test stand can cripple the whole squadron.

6 REFERENCES