PAPER Nr. : 82

THE RELATIONSHIP OF ULTRAFINE FILTRATION AND OIL DEBRIS MONITORING FOR HELICOPTER PROPULSION SYSTEMS

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TENTH EUROPEAN ROTORCRAFT FORUM

AUGUST 28 – 31, 1984 – THE HAGUE, THE NETHERLANDS

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Abstract

The reliability of helicopter drive systems can be improved by increasing bearing and gear fatigue life. It has been demonstrated that fatigue life can be increased by improving oil filtration. Accordingly, there is a trend in the industry to increase the use of ultrafine filters for both commercial and military helicopter drive systems.

Ultrafine filtration affects oil debris monitoring, especially those methods based on oil sampling. Improved debris monitoring techniques must therefore be developed which are effective in well-filtered oil systems.

In a five-year program, the U.S. Army evaluated ultra-fine (3 micrometer absolute) oil filters and an advanced Oil Debris Detection System (ODDS). 80,000 flight hours were accumulated by a test fleet of 38 UH-1 helicopters. The ODDS consisted of full-flow debris monitors with high debris capture efficiency for the engine and main rotor transmission and a "fuzz burn-off" feature to suppress false chip light alarms due to non-significant debris.

The results of the program include complete failure detection effectiveness, reduction of false-alarm chip lights and a significant increase in oil change intervals. High-time oil wetted components were found to be exceptionally clean and "like new".

THE RELATIONSHIP OF ULTRAFINE FILTRATION AND OIL DEBRIS MONITORING FOR HELICOPTER PROPULSION SYSTEMS

1. Introduction

Research published during the last decade[1)-5)] indicates that rolling-element bearing life can be extended considerably by improving lubricant filtration. Disposable ultrafine oil filters with ratings better than 7 micrometers absolute have been commercially available for some time and are being used in several helicopter engines, such as the General Electric T-700 and newer versions of the Lycoming T-55 engine.

At the same time, the requirement for improved reliability and maintainability is driving the development of advanced diagnostic technologies. For helicopter drive systems, the most effective current diagnostic technology is oil debris monitoring. In the form of magnetic plugs, electric chip detectors and spectrometric oil analysis, this technology has been in wide use since the 1950's. In the past, helicopter drive systems have been equipped with relatively coarse filters (typically cleanable screens with ratings of 40 micrometers and above). Therefore, practically all experience concerning oil debris monitoring has been obtained with coarsely filtered systems.

The effect of ultrafine filtration on oil debris monitoring depends on the filter rating and on the technique used. There are two different types of oil debris monitoring techniques in use today; those which involve on-aircraft devices (for example, magnetic plugs and electric chip detectors) and those which are based on oil sampling and remote sample analysis (spectrometric oil analysis and Ferrography).

On-aircraft monitoring devices are aided by ultrafine filtration since it removes background debris produced by normal wear which otherwise tends to accumulate on the debris sensor. This can mask real failures or, in the case of electric chip detectors, cause false alarms.

Ultrafine filtration interferes to some degree with methods based on oil sampling. The degree depends on the filter rating and the wear or failure mode in progress. Field experience with engines suggests that a filter with a rating of 7 micrometers absolute still permits spectrometric oil analysis, although with reduced removal thresholds and greater emphasis on trending. This may not apply to transmissions, however. As will be discussed further below, experience has shown that spectrometric oil analysis becomes virtually ineffective with a filter rated at 3 micrometer absolute. Since Ferrography relies on larger particles than spectrometric oil analysis, it is likely that this technique is more affected by ultrafine filtration than spectrometric oil analysis.

2. U.S. Army ODDS Program

An extensive evaluation of ultrafine filters and advanced oil debris monitoring technology was conducted by the U.S. Army between 1978 and 1983.[6),7)] A test fleet of UH-1 helicopters stationed at the Army flight training school in Ft. Rucker, Alabama was modified with oil filters with a beta 3 of 200 for both the engine and the main rotor transmission. This rating means that the filter passes only one out of every 200 particles with a diameter of 3 micrometers or larger and therefore has a removal efficiency of 99.5% for this size. This can be equated with the less technical rating "3 micrometers absolute". The filters incorporated disposable elements.

At the same time, the test fleet was retrofitted with an advanced Oil Debris Detection System (ODDS) which consisted of:

- full-flow debris monitors for engine and main rotor transmission;
- a "fuzz burn-off" feature to selectively suppress false-alarm chip light indications caused by normal-wear debris (fuzz) and thin slivers.

Currently, most U.S. Army helicopters are equipped with splash-type chip detectors. The difference between splash-type and full-flow chip detectors is illustrated in Figure 1. In full-flow chip detectors, the entire oil stream flows past the debris sensor. They are therefore much more effective than splash-type chip detectors whose effectiveness depends on the (generally low) probability that the oil transports the debris to them.

The "fuzz burn-off" feature consists of a capacitor discharge which occurs when the debris bridges the gap between the electrodes of the electric chip detector. A high, instantaneous discharge current is produced which melts any insignificant particles such as fuzz or the fine, hairlike slivers often found in helicopter gear boxes. Any particle with larger cross section passes the current unharmed and therefore causes a chip light.

The objectives of this program were:

(1) Provide timely and reliable detection of all oil-wetted component failures with a minimum of no-defect removals;

(2) Significantly reduce false-alarm chip light rate from the current level of one in 130 flight hours experienced in the standard fleet;

(3) Extend oil change intervals from 100 to 1,000 hours for the engine and from 300 to 1,000 hours for the main rotor transmission.

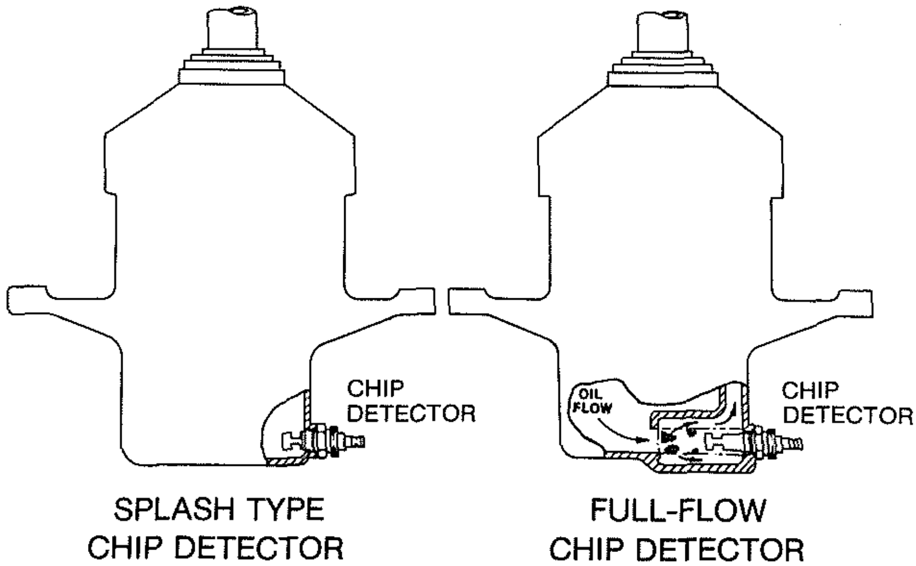

Fig. 1 - Splash-Type Vs. Full-Flow Chip Detection

The ODDS-equipped test fleet consisted of 38 UH-1 helicopters and logged over 80,000 flight hours during the course of the program. A separate control fleet of 12 unmodified helicopters logged 24,000 hours during the same period. The control fleet was equipped with the standard 25-micrometer filters for the engine and approximately 60-micrometer filters for the main rotor transmission. The oil in both test and control fleet engines and gear boxes was never changed, except where required as part of a maintenance action.

Oil samples were taken every 50 hours from both test and control fleet aircraft for spectrometric oil analysis and to determine lubricant condition. Special oil samples were also taken when a chip light occurred. These samples were analyzed spectrometrically and filtered through a .45 micrometer membrane. Any residue was evaluated microscopically with respect to quantity, morphology (size, shape and surface characteristics), color and type of material. This technique was especially effective in confirming bronze bearing cage failures in the engine.

For flight safety reasons, the new full-flow chip detectors and the old splash-type chip detectors were operated side-by-side and were connected to different sets of chip lights. On experiencing a chip light from either system, the pilot made a precautionary landing. The debris on the chip detector was then evaluated by field maintenance personnel who initiated a chip detector incident report. The chip detector with the debris still in place was sent to the oil laboratory at the base where it was photographed. The debris was then removed, washed and placed between glass microscope slides for examination. Quantity, morphology, color and type of material were noted. When chip detectors or oil samples contained significant amounts of metallic debris, filter screens and filter bowls were also inspected and the debris found was analyzed in the same manner.

In addition, the decision to remove a component made use of other diagnostic and crew-reported discrepancies where they were available, including unusual noise or vibration, over-temperature, over-speed, over-torque, oil pressure, etc. However, the chip detectors were by far the most consistent and important criteria in making a removal decision.

After each component removal, a teardown inspection was performed and the results thoroughly documented and correlated with chip light history. Components showing wear or damage were photographed. In this way, the diagnostic loop consisting of chip indication, debris assessment and teardown analysis was closed.

Forty-one components (31 engines and 10 transmissions) were removed from the aircraft fleet and inspected. Of this group, 21 (15 engines and 6 transmissions) were removed as a result of multiple chip detector indications with the diagnosis that a failure was in progress. In all cases, this was confirmed by subsequent teardown inspection. The other 20 components were removed for reasons other than metal contamination, e.g. FOD, oil consumption and seal leakage.

The ODDS detected the early stages of all oil wetted component wear, including gear pitting, bearing surface fatigue failures and bearing race rotation. Bronze cage failures were indicated after release of ferrous material from rolling elements. The system produced timely, repeated indications related to failure progression, whereas the standard splash-type chip detectors produced none, one, or sporadic indications. Spectrometric oil analysis proved ineffective in detecting failures in progress in the test fleet.

Figure 2 shows the onset of an engine No. 1 bearing spall which was indicated by the full-flow chip detector with three chip lights; 29.5, 2.6 and 0 hours before removal. Each time, granular debris found on the chip detector confirmed that a failure was in progress. The teardown analysis showed that the spall was still confined to one ball.

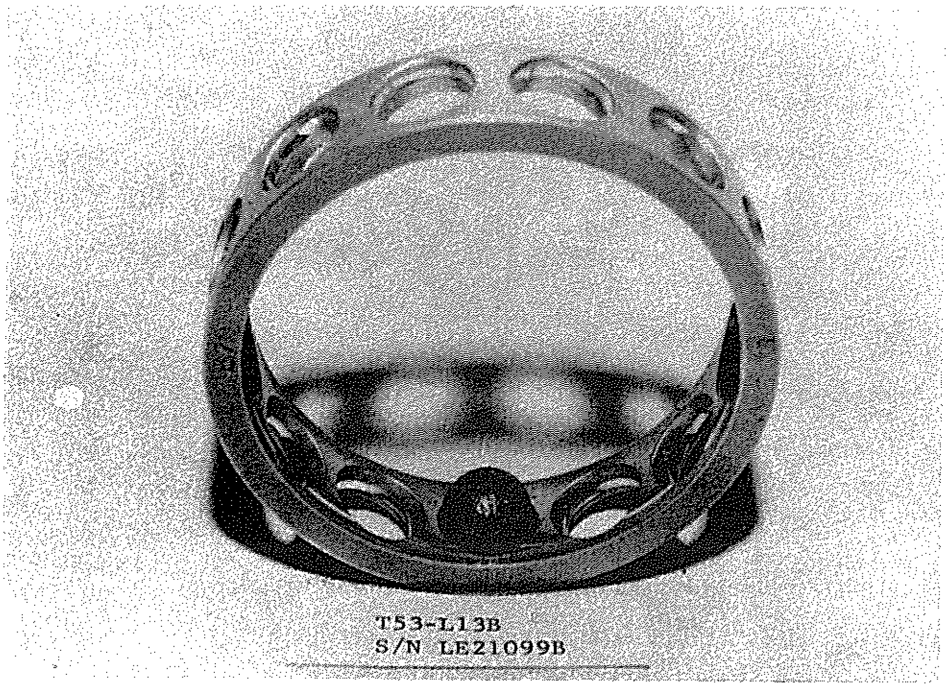

Fig. 2 - Engine No. 1 Bearing Spall

Figure 3 shows a spall on one pinion gear of the upper planetary gear assembly of the main rotor transmission. This had been indicated by four chip lights (174, 120, 29 and 0 hours before removal) and confirmed with debris found on the chip detector.

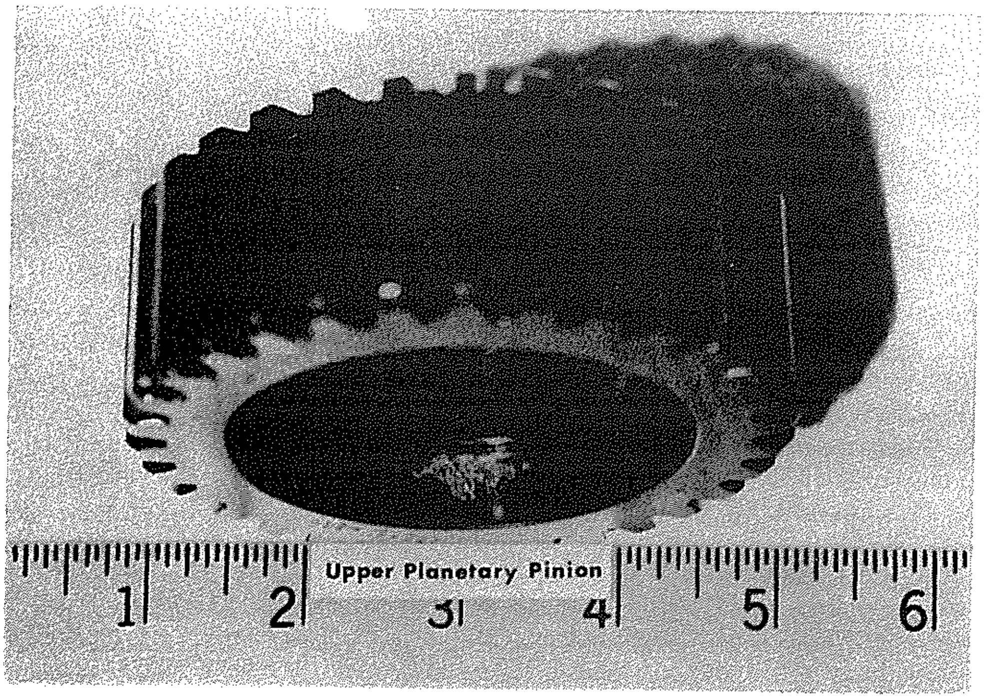

Fig. 3 - Planetary Pinion Bearing Failure

The granular and flaky debris which was found on the chip detectors when failures of this type were in progress is shown in Figure 4. For both the T-53 engine and the main rotor transmission, this type of debris was the most indicative of component failure. It could invariably be traced to bearing spalling (surface fatigue failures) or a spinning bearing race. An important characteristic of failures of this type was that debris continued to reoccur and therefore caused multiple, sequential chip light indications.

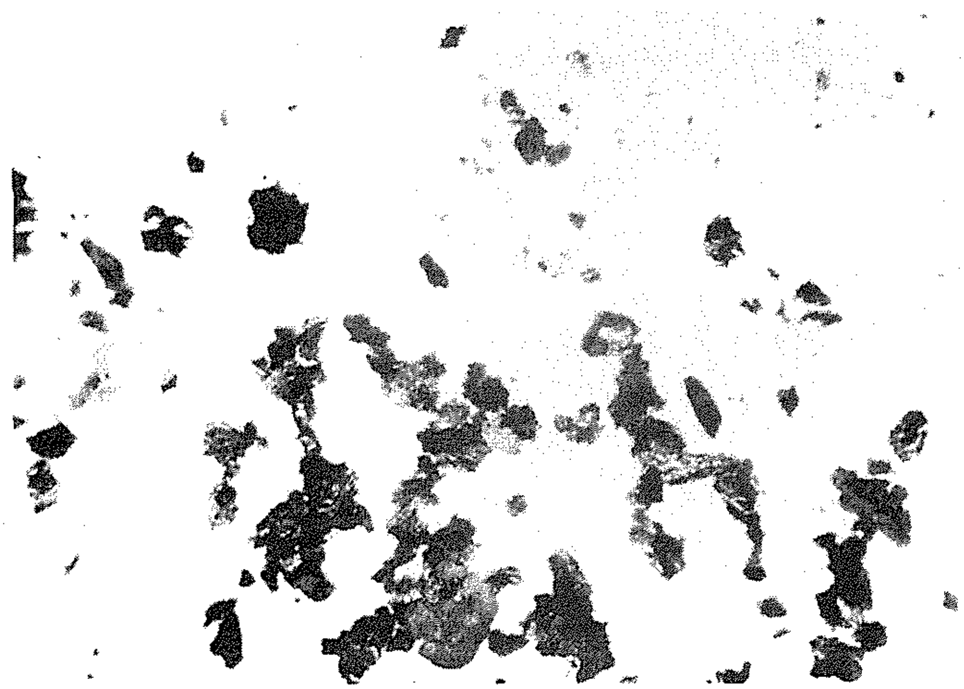

Fig. 4 - Granular Debris (Magnification 40X)

There were no removals of intermediate or tail rotor gear boxes caused by oil-wetted component failures.

Unfortunately, the T-53 engine turned out to be a producer of great amounts of benign, hair and wire-like debris (see Figure 5) which was traced to scoring of the torque meter cylinder (Figure 6) and of a bearing retainer plate. This characteristic undoubtedly contributes to the relatively high false-alarm and no-defect removal rate the engine experiences in the standard UH-1 fleet. In the ODDS program, this type of debris was easily identifiable and was generally disregarded.

Compared to a chip light frequency of .00758 chip lights/hour (one in 130 flight hours) for the standard U.S. Army UH-1 fleet, the ODDS reduced the test fleet chip light frequency to .00395 chip lights/hour (one in 253 flight hours).

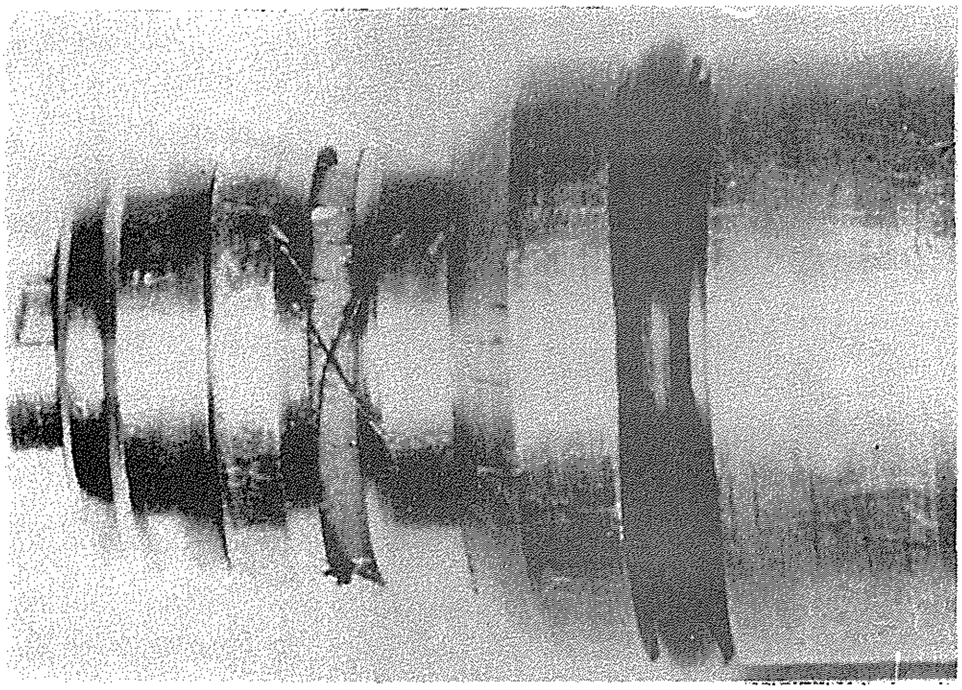

Fig. 5 - Torquemeter Cylinder Scoring Debris
on Chip Detector

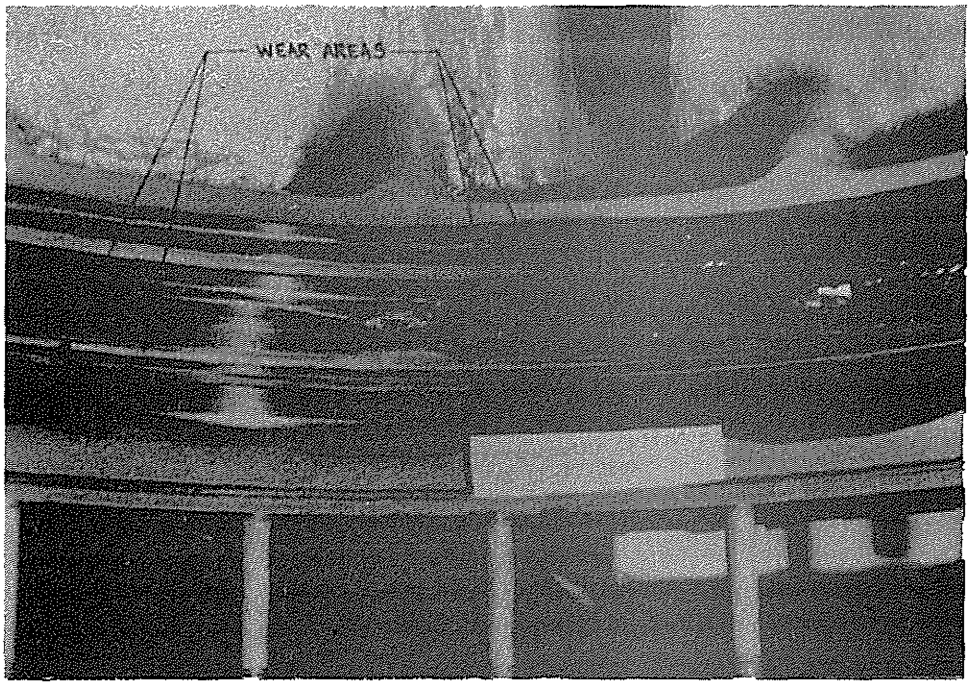

Fig. 6 - Scored Torquemeter Cylinder

Broken down by component, the chip light frequency was as follows:

	Standard Fleet Chip Lights/Hr.	ODDS-Equipped Fleet Chip Lights/Hr.
Engine	.00125	.00333
42 degree/ 90 degree gear boxes	.00500	.00004
Main rotor transmission	.00133	.00058

These figures include chip lights followed by component removals, as well as false alarms.

The data indicate a dramatic improvement for the main rotor transmission and the tail and intermediate gear boxes (from one in 158 to one in 1,612 flight hours). This was partly compensated by an increase in engine chip light frequency as a result of the engine's habit to produce benign debris as described previously and of the high capture efficiency of the full-flow chip detectors. A second factor is also that engine failures were more numerous than gear box failures and the ODDS indicated each with multiple chip lights. This is usually not the case with the splash-type chip detectors used in the standard fleet.

It may be assumed that the 3-micrometer ultrafine oil filters had a beneficial effect on chip light frequency. This could not be shown explicity since the ODDS included full-flow chip detectors and a "fuzz-burn" feature, in addition to the finer filters. However, the absence of "fuzz" on chip detectors and of sludge when the components were visually inspected after teardown, justifies this assumption.

The effectiveness of the "fuzz-burn" feature, on the other hand, is directly reflected in the 125-fold improvement in chip light frequency for the tail rotor and intermediate gear boxes since there were no other modifications to these components.

The program demonstrated that failure progression of any component occurs over a considerably longer period of time than any one particular flight. It was found that, with an effective debris monitoring system, no single chip light is of importance, since components produce several chip lights during the progression of a failure. Hence, the cockpit indicating light could be placed in the maintenance bay of the helicopter and included as a post-flight inspection item with no decrease in diagnostic effectiveness. In so doing, precautionary landings due to chip light indications would be eliminated entirely.

The extension of oil service life turned out to be independent of the degree of filtration. In both the test and control fleets, neither the oil samples nor teardown inspections showed any adverse effects when the oil was not changed for 1,000 hours or more. A total of 27 engines and 26 transmissions exceeded 1,000 hours without an oil change and the highest-time engine and transmission reached over 2,000 hours. A recommendation was therefore made to the U.S. Army to increase oil change intervals in the UH-1 fleet to 1,000 hours even before the program was completed.

Teardown inspection of high time test fleet components showed significantly reduced seal wear and "like new" condition of bearing and gear contact surfaces. Although the program was not structured to yield comparative data on mean time between component failure, the excellent condition of bearings and gears supports the conclusion that ultrafine filtration contributes to extended fatigue life.

It is generally assumed that the life of ultrafine filters is shorter than that of coarser filters. In this program, the opposite turned out to be the case. The oil systems required initial cleanup as the test fleet was switched over to ultrafine filters. The initial elements had to be replaced soon after installation (about 350 hours) since they became loaded with residual particles. After the first replacement, the average filter life increased to 1,000 hours as the systems became cleaner. The high-time filter reached 1,400 hours. It appears that much less debris is being generated due to abrasive wear as a result of the high cleanliness level of the oil. This, in turn, reduces the rate of contamination of the filter.

3. Summary

In over 80,000 flight hours of evaluating ultrafine oil filtration and full-flow chip detectors with "fuzz-burn" capability, the program demonstrated the following:

(1) Full-flow chip detectors provide effective, reliable and multiple indications of impending component failure.

(2) Presently used spectrometric oil analysis equipment is not effective in oil systems with 3-micrometer (absolute) filtration.

(3) Regardless of filtration level, oil change intervals can be extended safely to at least 1,000 hours without detrimental effect on component condition.

(4) False-alarm chip lights can be reduced drastically by "fuzz-burn" chip detectors, even if they are of the full-flow type and have high debris capture efficiency. However, this may not be the case if the component is a prolific producer of benign wear debris, such as the T-53 engine.

(5) Visual inspection of high-time components showed that ultrafine filtration results in much cleaner components and less seal wear. Longer component life may be inferred.

(6) Once the oil system is cleaned up, the life of ultrafine filters can be substantially higher than that of coarser filters.

(7) The microscopic analysis of debris found on chip detectors, in oil sample residues, debris separator and filter bowls and in screens can provide valuable additional information which strongly contributes to failure detection effectiveness and removal decision accuracy.

In addition to these conclusions, the absence of "fuzz" on the chip detectors and the clean condition of all components justifies the conclusion that ultrafine filtration contributes to lowering false-alarm chip lights.

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