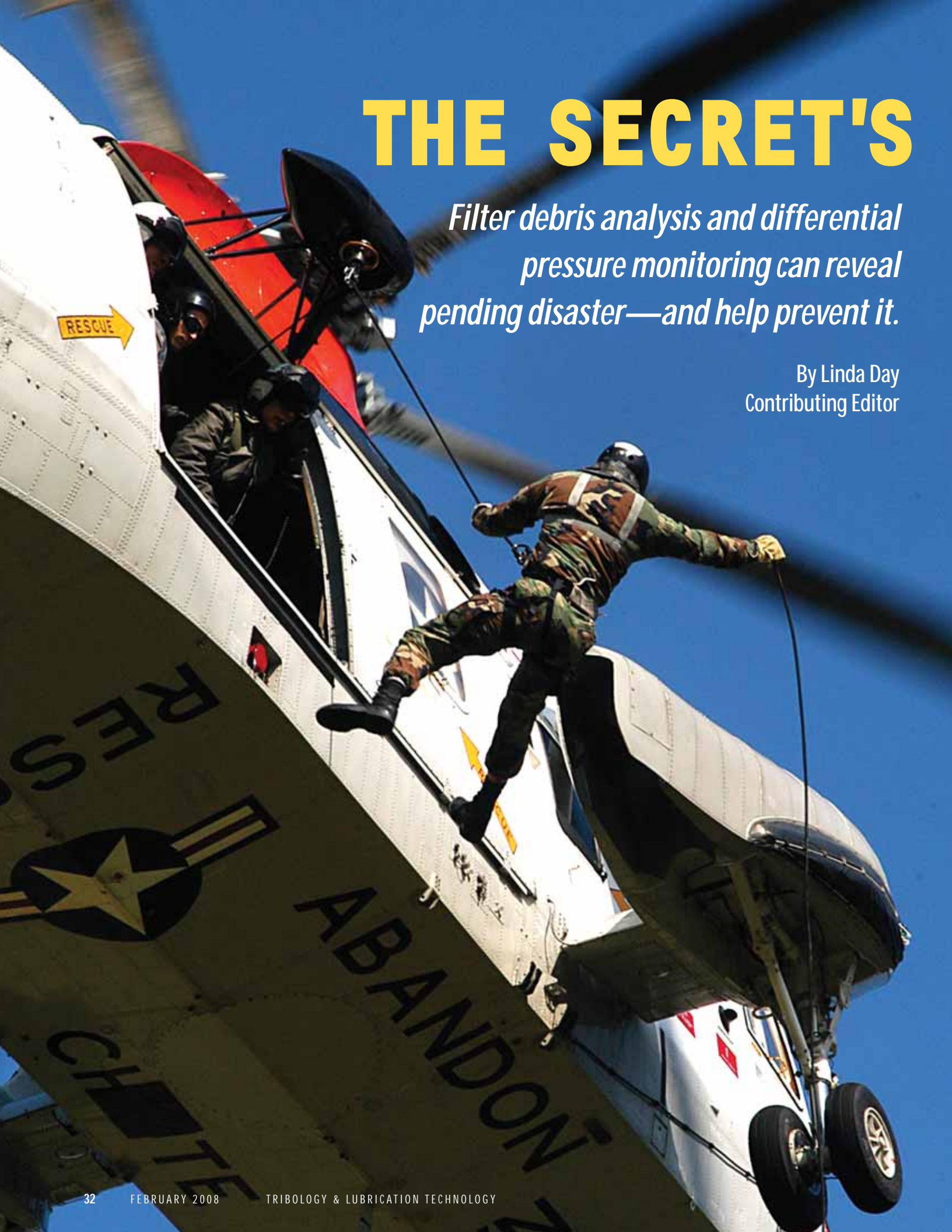


THE SECRET'S

Filter debris analysis and differential pressure monitoring can reveal pending disaster—and help prevent it.

By Linda Day
Contributing Editor



IN THE FILTER

Editor's Note: The subject of this month's feature article was conceived by STLE's Condition Monitoring/Predictive Maintenance Technical Committee.

"To date we've saved 58 EA-6B Prowler aircraft," says Gary Humphrey, a chemist with the Joint Oil Analysis Program Technical Support Center (JOAP TSC), the U.S. Military's testing, evaluation, research and development laboratory. "That equates to \$765 million and 116 air crew."

This accomplishment is every bit as impressive as it sounds. An advanced electronic warfare aircraft, the Prowler jams enemy radar and communications in advance of an assault, giving the U.S. undisputed air superiority. But the Prowler had an Achilles heel: The lubrication for one of its bearings depended on oil flowing through the holes of a castle nut. When these holes plugged up—usually with particles thrown off by a nearby seal—oil starvation resulted and bearing failure was imminent. In the worst case, the plane failed in flight.

"Initially the armed forces were having an average of one in-flight shutdown per month," says Humphrey. "But now that's down to one shutdown every four years, because we can predict failure by analyzing debris in the filter—and because they've made design changes to the way the bearing is lubricated based on our work."

The device that JOAP uses to check for wear debris in aircraft filters is the Filter-CHECK made by GasTOPS, a supplier of condition monitoring products and services. The development of FilterCHECK goes back more than 20 years.

What about oil analysis?

What initially drew attention to filter debris analysis were the limitations of oil analysis.

First, there are limitations inherent in used oil itself. "Wear is not continuous," says STLE member Allison Toms, technical director for GasTOPS, Inc. "When bearings fail,

they shed particles in bursts, and if you're not collecting oil during that moment you'll miss the wear debris. We know because we've monitored a lot of bearing failures from inception of the fault through failure."

Second, even if you manage to catch the wear debris in a bottle, wear particles from bearing faults may be so big—from 100 to 1000+ microns—that they are not measurable by common analytical techniques.

According to Toms:

- Inductively coupled plasma mass spectrometry (ICP-MS) is generally effective only for particles ranging in size from 1-3 microns. Larger particles can be dissolved in acid and detected, but this involves hazardous materials and waste disposal issues.
- Atomic Emission Spectroscopy (AES) only detects particles from 1-10 microns.
- Rotrode Filter Spectroscopy (RFS), a variation of AES, can detect particles greater than 10 microns, but its upper limit still falls short of the particle sizes in bearing wear debris.
- Analytical Ferrography is typically used only when there is already an indication of a problem, as it requires separating particles from the sample and viewing with an optical microscope.

And third, even if you do happen to sample oil during a burst, and even if the wear particles happen to be fairly small, you may still not see them in an oil sample bottle because the oil filter has removed them. "The industry has moved to finer filtration in an attempt to prevent secondary damage from wear debris," says Toms. "These filters

Article highlights:

- *The limitations of oil analysis.*
- *Automating the filter debris analysis process.*
- *Benefits of monitoring differential pressure across the filter.*

CONTINUED ON PAGE 34



collect about 25% more debris and prevent an additional 25% of wear issues, but they also eliminate the means of detecting the wear through oil analysis.”

As evidence of the problematic nature of oil analysis, Toms cites work on the J52 engine of the Prowler. “Filter debris analysis detects about 95% of the wear debris,” she says, “while oil analysis detects less, closer to 35%.”

The birth of FDA

The history of filter debris analysis (FDA) goes back to 1986 when Aiden Donahue, currently manager of condition assessment services for GasTOPS, was a senior Air Force technician working with Canadian Defense Research on a filter debris analysis project.

“We were having serious failure issues with the main rotor gearbox on our Sea King helicopters,” Donahue says, “and we were looking for some way of identifying problems and predicting the failures. Spectrometry wasn’t working because the debris particles were too big to detect. We didn’t know exactly what to do, but we knew that anything coming off the gears and the bearings would be captured in the filter.”

Donahue initially set about removing the debris from the filters in an ultrasonic cleaner, capturing it on a 10-micron filter patch and then sending it to Defense Research for examination of the particles under a scanning electron microscope (SEM). “This was so successful that the maintenance community for Sea King implemented it as part of their maintenance

program,” Donahue says. “But to get a set of filters and do the full analysis took about 6-8 hours if the helicopter was on site and days or weeks if it was deployed. With a fleet of 32 helicopters deployed around the globe, the Canadian Air Force couldn’t accept the long analysis time.”

In the early 1990s, another Defense Research project was initiated to look at automation of the filter debris analysis process. Although imaging technology was not highly developed at that time, GasTOPS had an inductive oil sensor that could separate ferrous and nonferrous particles and provide a count and size distribution, so they were awarded the project. The first Filter Debris Analyzer used a pulsating back-wash of air and oil to clean the filter and send all debris through an in-line inductive particle counter. Later models included a provision to capture a representative sample of the debris on a filter patch; if the number of particles of a particular size was excessive, the patch could be sent off for elemental analysis (*see Figure 1*).

“GasTOPS succeeded at the research project,” says Donahue, “but the instrument was huge, and the Canadian military wanted something that would be deployable.”

In 1997 GasTOPS hired Donahue and went to work on a smaller instrument that would ultimately become the FilterCHECK.

“Even without the x-ray technology that we have now, we could tell a whole lot about the condition of the components from the number and size of the particulates,” says Donahue. “In addition to the main gearbox, we started working with oil and fuel filters on the Sea King’s gas turbine and the smaller gearboxes.”

But identifying the presence of wear debris still left the major question unanswered: How could they prove exactly where the debris was coming from? This is where the JOAP TSC comes in.

X-ray fluorescence

At the JOAP TSC in the early '90s, Gary Humphrey was tasked to find a method of analyzing debris from oil filters. Six months of literature research uncovered a British program that had failed dismally and a program run by Garrett Aviation that claimed a 95% success rate in predicting catastrophic



(Courtesy of Aiden Donahue, GasTOPS)

Figure 1. The filter patch on the left shows debris from an operational engine. The patch on the right shows debris from an engine in failure.

failures. Encouraged, Humphrey began exploring x-ray technology and understanding the meaning of energy dispersive x-ray fluorescence (EDXRF) signatures.

"You might have 40-50 alloys shedding particulates," Humphrey says, "so you have to figure out what is important and what isn't. The x-ray gives you the elemental composition of the debris, but to make sense of it you have to know the composition of various parts in the engine. Some parts use exotic alloys that have a unique x-ray signature; for example, bearings use M-50, a combination of vanadium and molybdenum. That's what I keyed in on—I could determine bearing wear by the occurrence of vanadium and molybdenum together."

Everything Humphrey did at that time was manual and extremely time-intensive—cleaning the filters, gathering the debris and x-raying it with borrowed equipment. Nevertheless, Humphrey demoed his analytical approach to the Air Force, which responded with funds for an "alpha" prototype and six "beta" prototypes.

Now GasTOPS re-enters the picture. "Looking back, you could say their equipment was rudimentary at that time," Humphrey says. "But it was a good starting point because it had a reproducible way to clean filters and count particles."

The total solution eventually included a miniature x-ray system from X-Ray Specialty Instruments of Ypsilanti, Mich., and software from Crossroads Scientific. "We had to do a lot of modification to the FilterCHECK machine to make a filter patch, accommodate the x-ray and use computer control for the cleaning cycle," says Humphrey. "It's important that the cleaning cycle is exactly the same for every filter, so that the only difference is the amount of wear experienced in the system."

The six beta prototypes were sent out to different Air Force bases to gather data in 2001. About this time, Prowlers were falling from the skies over the Persian Gulf in the first Gulf War. Humphrey boldly told the Air Force that he could predict the catastrophic failures that were occurring in these aircrafts' 4½ bearings—failures that could not be captured by the Rotrode Atomic Emission Spectroscopy then in use.

"Within about three weeks I was able to



(Courtesy of Gary Humphrey, Joint Oil Analysis Program Technical Support Center)

Figure 2. Broken 4½ bearings (like the one shown here) could cause the Prowler aircraft to fail in flight.

put together the data to identify four engines with too much M50 in the filters," Humphrey says. "I sent my patches to Pratt & Whitney, and they did scanning electron microscopy on them and found the M50 signature. And when they opened up those four engines, they found broken 4½ bearings (see Figure 2) in all of them. At that point, they called all of our machines out of the field where the Air Force was testing them and deployed them into the Navy. These prototypes weren't designed for heavy-duty use—they were all wires, no solid state!—but they got put around the world, and I went around the world with them to train people. Then the military decided to buy the machines and contracted with GasTOPS to build an improved FilterCHECK."

FDA technology implications

The use of the FilterCHECK not only saved aircraft, it led to maintenance and design changes. Today, Prowler filters are changed every 50 hours and used for FDA, and new engines are designed with an oiler tube that takes oil directly to the 4½ bearing without relying on the holes in the castle nut.

Humphrey sees significant potential for FDA outside the military: "Commercial aircraft definitely should do it," he says. He notes that chip detectors—a magnetic plug meant to capture ferrous debris in the oil stream—have limited scope because the oil is moving too fast to allow particles to be caught, and only particles larger than 50 microns are caught at all. "With EDXRF, you can look at every kind of wear, from alu-

CONTINUED ON PAGE 36

minum to uranium,” he says.

“Filter debris analysis is for anyone with filtered systems,” says Allison Toms. “It is currently used in aircraft and marine applications, and we are penetrating power generation and other industrial markets. In large sumps it’s very difficult to do good atomic emission analysis because there’s a tremendous dilution factor. But all the debris is in the filter, and we will be able to do both an elemental and metallurgical analysis. The main benefit is that this is a reproducible, repeatable and reliable process.”

Continuous monitoring

The obvious limitation to FDA is that it is a discreet batch process that can be performed only when the filter is changed out.

Gary Rosenberg, marketing manager at Pall Corp., an international supplier of filters and separation equipment with headquarters in East Hills, N.Y., has an approach that expands the role of the filter.

“We can tell if there’s a system problem by monitoring the performance of the filter as it operates,” Rosenberg says. “This doesn’t tell you the source of the material that’s blocking the filter, but it does tell you not to wait until you normally change filters to figure out the problem. A filter may be in a system more than a year, and you want to catch problems early—if you don’t, there’s the potential for collateral damage and equipment failure.”

Pall’s monitoring systems—either built-in or retrofit—continuously track the increase in differential pressure (ΔP) across the filter as it becomes plugged by debris. “We evaluate whether the change and rate of change in the pressure drop represents a normal or abnormal condition,” Rosenberg says, “and we can be very subtle in our understanding of the performance in the system. The beauty of it is that it’s an early indication that happens before you get vibration or other failure indicators.

“My general recom-



The Pall filter can be disassembled so that debris can be analyzed in situ.



(Photos courtesy of Gary Rosenberg, Pall Corp.)

A diagnostic filter element used in the lubrication system of a gas turbine engine.

mendation is not to burden the operator with ΔP information unless the pressure drop reaches a critical stage,” Rosenberg continues. “Then you can pull the filter and run FilterCHECK.”

Rosenberg lists the benefits of ΔP monitoring as:

- It is appropriate for all types of filters and fluid systems.
- It is highly repeatable.
- Nothing has to be removed or changed in the system to run the test.
- The test supports condition-based maintenance (CBM).
- Continuous monitoring makes it easy to determine what represents normal operation and what constitutes abnormal wear.



(Courtesy of Aiden Donahue, GasTOPS)

The new FilterCHECK.

"We've been doing ΔP monitoring since the early '90s," Rosenberg says, "and we've had good customer acceptance." Post-analysis is carried out by Pall in-house, using x-ray fluorescence, scanning electron microscopy and atomic emission.

One other approach offered by Pall is diagnostic filter elements with a removable media layer. "The beauty of this approach is that the system itself generates the sample," says Rosenberg. "No human hand has touched it. The filtration materials we use are transparent to XRF."

The real secret

Everyone interviewed for this article agrees on one thing—the importance of using the

filter as a diagnostic tool. "The filter is already in the system," says Rosenberg, "so if people are not utilizing all the information it can provide, they're short-changing themselves. All of these analysis methods can improve the visibility into the performance of the system, which improves reliability and safety. This leads to more effective use of maintenance labor and less equipment downtime. It's real, it's simple and it works." **TLT**

Linda Day is a free-lance writer based in Houston. You can reach her at linda@daycreative.com.

References and additional information

- Forster, N., Thompson, K., Horning, S. and Toms, A., "Assessing the Potential of a Commercial Oil Debris Sensor as a Prognostic Device for Gas Turbine Engine Bearings," ISHM, August 2005.
- Toms, A.M. and Cassidy, K., "Filter Debris Analysis for Aircraft Engine and Gearbox Health Management," Presented at MFPT 2007, Virginia Beach, Va., April 2007.
- Toms, A.M. "How Filter Debris Analysis Can Enhance Your Condition Monitoring Program," Presented at STLE's 61st Annual Meeting & Exhibition, Calgary, Alberta, Canada, May 7-11, 2006.
- Toms, A.M., Jordan, E. and Humphrey, G.R., "The Success of Filter Debris Analysis for J52 Engine Condition Based Maintenance," *Proc. of 41st AIAA*, Tucson, Ariz., July 2005.
- Lastinger, W. Overman, R. and Yates, L. (2006), "Finding Bearing Failure through Filter Debris Analysis," *J. RIAC*, 1st qtr., **14** (1), pp. 8-12.
- Donahue, A. (2004), "Filter Debris Analysis: A Reliable First Line Condition Monitoring Tool," Presented at the Canadian Machinery Vibration Association's Annual Conference.
- Humphrey, G.R., Rojas, J., Churchill, D.C., Gorzen, D. and Cross, B., "Prototype Instruments Built for PRAM," *Proc. of 2002 JOAP International Condition Monitoring Conference*, Humphrey, G., ed., JOAP-TSC, Pensacola, Fla., April 2002.
- Madhavan, P. and Rosenberg, G., "Condition Monitoring of Aerospace Hydraulic and Lubrication Systems via Filter Debris Analysis," Presented at the JOAP International Condition Monitoring Conference, April 2004.
- Rosenberg, G., "Fluid System Health Monitoring," Presented at the Canadian Forces Conference on Emerging Condition Monitoring Technologies, September 2004.
- Rosenberg, G., "Filter Element Data Supports Fluid System Health Management," Presented at the SAE Propulsion Systems Health Management Meeting, April 2005.

Diagram showing the process of analyzing filter debris.



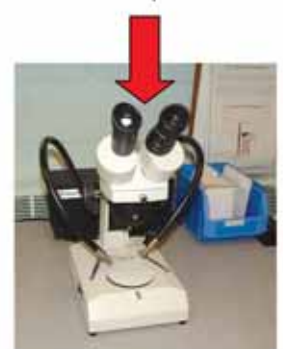
Ultrasonic Cleaner



Magnetic Particle Separation



Patch Preparation



Microscope

(Courtesy of Aiden Donahue, GasTOPS)