Abstract – An Apache AH-64A with a VMEP vibration monitoring system experienced a class-A accident where the tail rotor swashplate bearing failed. Data collected from this aircraft was used to create a new vibration feature or Condition Indicator which was applied to all the data from the VMEP fleet of AH-64A and AH-64D aircraft. This data mining exercise successfully found 4 aircraft in the fleet with faulty swashplate bearings in pre-failure stages of degradation.

Introduction

The US Army has embarked on a Condition Based Maintenance program to provide the battlefield commanders and soldiers the ability to support mission requirements with proactive, planned maintenance. The CBM equipped aircraft will provide greater availability with more predictability in fleet health. Another CBM objective is to provide enhanced safety for crews and maintenance personnel. A key enabler to the CBM initiative is to provide vibration data collection and analysis devices such as the Vibration Management Enhancement Program (VMEP) systems. VMEP and related MSPU systems have been installed on 296 aircraft to date including AH-64A, AH-64D, UH-60A, UH-60L, MH-60K, CH-47D, MH-47G, and OH-58D models for the US Army.

One of the first army aircraft types to have VMEP installed was the AH-64A. One of the AH-64A aircraft, tail number 90-00314, experienced a Class-A mishap on April 5th, 2007. The aircraft was destroyed and luckily both the pilot and copilot were not injured. The aircraft after the crash is shown in Figure 1.

Figure 1 - Class A Incident
Analysis of the aircraft after the crash determined that a failed tail rotor swashplate bearing was a factor in the accident. The bearing had 1464 Hours of operation with a TBO limit of 1477 Hours. The bearing failed with indications of fretting, pitting and overheating as shown in Figure 2. Since this aircraft had a VMEP system installed, the data was evaluated to determine how future bearing failures could be detected before an aircraft incident occurs.

![Failed Tail Rotor Swashplate Bearing](image)

**Figure 2 - Failed Tail Rotor Swashplate Bearing from 90-00314**

**Data Analysis from 90-00314**

This aircraft had a VMEP system installed for over 14 months before the accident. The VMEP system consists of the three main components described below. Specific details of the overall VMEP and MSPU system can be found in [1,2].

*On-board system*

The on-board system consists of a Vibration Management Unit (VMU) or Modern Signal Processing Unit (MSPU), a wiring harness, and sensors. The VMU front panel provides the aircrew a simple method of selecting acquisitions at specific flight conditions and receiving system status information. The data is processed on-board and can be saved in raw format for transfer to the PC Ground station. The sensors include tachometers and accelerometers distributed throughout the helicopter’s drive train.

*Ground based station*

The ground-based software runs on a PC based Windows platform. The system is referred to as the PC Ground-Based System (PC-GBS). The operator downloads the processed data from the VMU after data has been captured in flight. The PC-GBS interprets the processed data and presents the user a status of the aircraft and its monitored components.

*iMDS Web Server*

The intelligent Machinery Diagnostics System (iMDS) Web Server is a web based data archiving and data analysis system. Data from the field is automatically sent over the internet back to a centralized database where Army engineers manage the fleet of VMEP aircraft.
Data was acquired from the tail rotor swashplate from an accelerometer mounted on the bearing structure as shown in Figure 3. From this accelerometer, vibration data was measured on the ground at Flat Pitch, 100% when a Survey acquisition was initiated. A vibration spectra was calculated with a bandwidth of 24000 Hz. An energy CI was calculated from the spectra using the frequency bands from 1400 Hz to 2600 Hz. This CI was found to be ineffective at detecting bearing failures as the accident occurred without any indication of an impending fault.

After the accident, the data was reviewed from the data collected from data collected from this aircraft from February 2006 through May 2007. At the same time data was evaluated from 47 other AH-64A and 150 AH-64D aircraft. The VMEP iMDS web server was used as the main tool to evaluate the data. The web sever lets Army engineers download all archived data for local analysis on their ground stations and also has interactive plotting and analysis features to compare outlier aircraft to fleet trends. Figure 4 shows a vibration spectra of aircraft 90-00314 plotted with a vibration spectra from a normal aircraft. Note that on the logarithmic Y axis how the faulty bearing showed obvious differences in the 19000 Hz range. This frequency was well above the original energy CI that was setup for this bearing.
The iMDS VMEP web server has a comparative spectra plot function that will let users compare aircraft by plotting spectra in a waterfall or color map format. This way different aircraft can be viewed simultaneously and features can be discovered when comparing faulty aircraft to non-faulty aircraft. This type of plotting function is similar to what has been used for years by maritime sonar operators as they look at signatures from underwater sonar to identify enemy targets from background noise and friendly ships. The comparative spectra plots from aircraft 90-00314 compared to 8 randomly chosen aircraft from the same unit is shown in Figure 5. The color is related to vibration energy. Blue is the lowest and red is the highest. The yellow and red bands from the faulty aircraft show that a new CI which incorporates these bands would be effective in detecting future faults.
Data Mining to find other Aircraft with same fault.

The VMEP PC-GBS allows Army engineers to create new CIs and to apply the new CIs to all existing aircraft data to evaluate how the new CI will perform. Once they are happy with the new CI, it can then be configured to run on the aircraft in the VMU or MSPU. Based on the results from aircraft 90-00314 a new energy CI around 19000 Hz was applied to all the aircraft in the fleet. From this initial mining exercise, three aircraft were found to have potential swashplate bearing faults. They were tail numbers 88-00263 and 91-00118. Figure 6 shows the Comparative Spectrum Plot for these aircraft and the energy in the frequency ranges near 19000 Hz.

Aircraft 88-00263 only had 71 hours on the swashplate bearing while 91-00118 had 242 hours. Both aircraft had the swashplate bearings removed at the direction of AED and Apache Systems Engineering. The bearing from Aircraft 88-0026 was found to be good and without any signs of fault. The bearing from Aircraft 91-00118 however was inspected by Redstone Technical Test Center (RTTC) and was found to have overheating, corrosion, pitting, and degraded grease. Figure 7 shows the corrosion and overheating on the outer race of the bearing. This aircraft was flying when AED requested the bearing to be removed, so a potential failure and potential aircraft loss was averted.
The data was evaluated again from the iMDS VMEP web server to find modifications to the CI so good bearings like 88-00263 would not be flagged as bad and other fault finds like 91-00118 would be found. It was determined that the energy CI could be modified to include “Reject Bands” that are not included when the energy calculation is computed. The VMEP system has the ability for engineers to setup energy CIs with 6 reject bands defined. A new CI was created that calculates energy from 4950 Hz to 20400 Hz with a reject band from 5150 Hz to 19,000 Hz. When this new CI was processed on all existing AH64 data four more aircraft were identified with potential tail rotor swashplate bearing problems. The effected units were notified and the bearings were removed from operating aircraft. Each of the bearings was found to contain faults. Table 1 summarizes the aircraft and the status of the faults found.

Table 1

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Date Found</th>
<th>Hours on Bearing</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>90-00314</td>
<td>4/5/07</td>
<td>1464</td>
<td>First Aircraft - Accident</td>
</tr>
<tr>
<td>88-00263</td>
<td>4/18/07</td>
<td>71</td>
<td>No fault found – new CI created</td>
</tr>
<tr>
<td>91-00118</td>
<td>4/18/07</td>
<td>242</td>
<td>Overheating, corrosion, pitting, degraded grease</td>
</tr>
<tr>
<td>03-05356</td>
<td>4/24/07</td>
<td>1477</td>
<td>Reached TBO and removed from supply Fretting, overheating, pitting, degraded grease</td>
</tr>
<tr>
<td>04-05473</td>
<td>5/8/07</td>
<td>248</td>
<td>Grease Separated into Oil and Thickener, waiting on final report</td>
</tr>
<tr>
<td>00-05181</td>
<td>5/31/07</td>
<td>1072</td>
<td>Fretting, overheating, pitting, degraded grease</td>
</tr>
</tbody>
</table>
The tail rotor swashplate bearing was replaced in aircraft 91-00118. The data was analyzed after the replacement and showed a drop by a factor of 10 in the new CI value. Figure 8 shows some screens from the PC-GBS and the CI trend across time and the CI trend across different aircraft.

![Figure 8 – Aircraft 91-00118 after the swashplate bearing is replaced.](image)

**Summary**

The initial CI programmed to monitor the tail rotor swashplate bearing on the AH-64A aircraft was unable to detect an imminent fault. After a known bearing failure occurred, the data that was collected and saved from this aircraft became invaluable in that it enabled the creation of a new CI that could find the fault. The VMEP system allows for easy post processing of data and field updating of new CIs as they are discovered. This new CI successfully found 5 other aircraft that were flying in the fleet that had faulty tail rotor swashplate bearings. Now the new CI has been configured to be calculated on-board in the VMU or MSPU and protects the aircraft and operators from future bearing faults.

**Recommendations**

The events described above show how when an aircraft event occurs such as a crash or a catastrophic mechanical failure the data can be used to react and find future faults from other aircraft. This can be viewed a success story that shows the value of vibration based mechanical diagnostics. However, a loftier goal would be to find the fault before the first aircraft crash. This is easy to say, but in reality, many faults and their vibration signatures are not known until the first fault occurs. Also, many times the vibration
sensors are placed in new locations and there simply is not enough historical fault data to find all the faults from the start. The types of faults and the statistical distribution of occurrences play a large part in how the diagnostic algorithms mature. The parts that fail the most frequently obviously get the most attention and have mature diagnostic algorithms. The parts that fail infrequently have a greater chance of reaching the catastrophic level before being detected. Once the first failure occurs, then the data can be analyzed and the next failure is averted.

The best hope for improving this process comes with intelligent Data Mining (iDM). The key to iDM is to first have the mechanism to collect and store the data at a central location. The data has to include the CIs calculated on board as well as the raw and intermediate data that is used to calculate the CI. The next step in iDM is to have advanced algorithms that perform anomaly detection. The anomaly detectors can include neural network approaches as well as advanced modeling methods. The anomaly detectors identify data from some aircraft that are statistically significantly different from the fleet. Once an aircraft is identified, then the mechanism for inspection is required. Many times this can be the hardest part, as it is difficult to ask a unit to remove and inspect a part based solely on the fact that it appears different from the fleet and that there is no known problem. The part just may be different, but not faulty. This is a learning process but can be refined with experience. There is hope for finding the faulty aircraft such as 90-00314 before the first crash and the US Army is forging the path to this goal.

References