Conditioned-Based Maintenance at USC - Part III: Aircraft Components Mapping and Testing for CBM

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Abstract

One of the most expensive and time consuming tasks relating to Condition Based Maintenance involves the testing of mechanical components for CBM. A scientific plan is being developed to identify components that will return the most value within a short time for implementation of CBM. This plan is also based on the historical (TAMMS-A and VMU) data that we have collected and analyzed throughout the past eight years. This paper specifically addresses the component mapping methodologies and the USC CBM test facilities. Furthermore, the CBM testing approach is discussed. The goal of testing is to identify the root causes of components’ failure, failure modes and the identification of ways to improve serviceability of A/C components. Components testing will be carried out for used but serviceable components or with components with intentionally seeded faults. Some component test results are presented and discussed.
Background

History
Since 1998 the University of South Carolina (USC) and the South Carolina Army National Guard (SCARNG) have participated in a number of important projects that were directed at reducing the Army aviation costs through improved logistics technology, better data management, and prompt decision making. This modern aviation maintenance transformation produces higher operational readiness using fewer, more capable resources, provides commanders with relevant maintenance-based readiness information at every level, and shifts the paradigm from preventative and reactive practices to proactive analytical maintenance processes, now commonly referred to as Condition-Based Maintenance (CBM). Per the Office of the Secretary of Defense (OSD), CBM is defined as “set of maintenance processes and capabilities derived, in large part, from the real-time assessment of weapon system condition obtained from embedded sensors and/or external tests and measures using portable equipment.”

The Commander of AMCOM supports the unprecedented transformation from the Industrial Age to the Information Age using existing and emerging technologies that analyze near real-time aviation systems data to provide prediction and response maintenance capability. Several technological advances and initiatives by Army leaders at various levels have made a move toward CBM a reality for Army Aviation. The benefits of these technologies have already been proven for helicopter on combat missions, training, and maintenance flight conditions. Considering the long history of participation with health monitoring systems and data collection, the University of South Carolina is in a position to provide leadership, vision, and a path forward to maximize the effectiveness of these benefits across the broad spectrum of Army Aviation.

The transition to CBM requires a collaborative effort on a massive scale and is contingent on identifying and incorporating enhanced and emerging technologies into existing and future aviation systems. This will require new tools, test equipment, and embedded on-board diagnosis systems. Even more critical, the transition to CBM involves the construction of data-centric, platform-operating capabilities built around carefully developed robust algorithms. This will allow soldiers in the field, support analysts, and engineers the ability to simultaneously, and in real-time, translate aircraft conditional data and proactively respond to maintenance needs based on the actual aircraft condition.

The University of South Carolina has supported the U.S. Army by conducting research to support timely and cost-effective aircraft maintenance program enhancements. Research emphasis has been to collect and analyze data and to formulate requirements for and assist in the transition toward Condition-Based Maintenance for the Armed Forces.

Program Objectives
The research program at USC seeks to deliver results which directly contribute to CBM efforts and objectives as follows:
- Link and integrate maintenance management data with onboard sensor data with test metrics and to quantify the importance of each data field relative to CBM
- Understand the physics and the root causes of faults of components or systems
- Explore the development of models for early detection of faults
- Develop models to predict remaining life of components and systems.

Program Processes
These program goals will be accomplished through the following processes:
- Qualitatively operationalize the CBM objectives through ongoing activities of surveying engineers, pilots, maintainers and crew chiefs on the non-tangible and mission benefits of the VMEP system such as safety, morale, mission capabilities, confidence on the system, and system liability.
- Quantitatively operationalize the CBM objectives through our ongoing quantitative management and vibrations data that are being collected, analyzed and processed. The most obvious outcome of these activities is the cost benefits and mission benefits models.
- Combine the qualitative and quantitative measures from the processes listed above to determine if the current implementation is meeting the planned CBM objectives. The combined measures will also be presented and evaluated mathematically, parametrically, and mechanistically as a diagnosis model or physical model of subsystems or components.
- Create preliminary, predictive mathematical models of component, subsystem, and aircraft performance that serve to guide future CBM activities on individual aircraft. Based on available literatures on prognosis studies, this will be the first scientific step in developing accurate prognosis models of components, subsystems, and entire systems.
- Interrogate and validate the historical field data through the use of component test stands. These test stands will be used to refine and improve our prognosis models by examining the process of component failures in order to correlate their observed conditions with the determined parameters.
CBM Roadmap

As the growth and awareness of CBM develop, many ideas and technologies have arisen in efforts to improve CBM. Unfortunately without a plan or path, many of these ideas will never fully mature. There is need for a standardized methodology and roadmap for CBM to reach its full potential. In conjunction with the South Carolina Army National Guard, the University of South Carolina has the resources and channels to develop a roadmap to investigate the transformation of CBM. This can be done in a way that will address a broad array of strategic and tactical issues so as to accomplish the CBM specific objectives. The activities of USC are being performed as a joint industry, academic, and government team.

The roadmap consists of three phases: initial investigation, component and system testing, and the implementation of a fully-capable CBM system. This roadmap is driven by the currently available digital source collectors, which through integration and linking will direct the needs of laboratory testing. The results of this self-refining process will ultimately lead to the development of diagnosis and prognosis algorithms which will facilitate proactive CBM practices.

COMPONENT MAPPING

The previously developed strategy is refined to investigate CBM and its implementation into Military Aircraft that meets the Army’s vision in order to achieve CBM by the end of FY2013. A schematic representation of the CBM roadmap is shown in the Figure-1.

As part of this effort, USC and the army have identified the type of components to be tested based on the following data over a period of eight years, from 1999 till present: 1) TAMMS-A data from hand written log books, ULLS-A 2) Vibration monitoring (MSPU) database 3) Mission databases. The Unit Level Logistics Support – Aviation (ULLS-A) system was used to track parts and man-hour usage. The elements tracked include: part S/N and cost, man-hour for installation and troubleshooting, test-flight hours for confirmation or operational crew hours, identify if part is related or not to vibration and tear-down analysis results, when available. The Vibration Monitoring data has also been tracked using the ULLS-A maintenance database. In order to achieve this, the ULLS-A configuration has been reprogrammed to include VM events/data. Data from the ULLS-A database has been transferred electronically to USC computer. To achieve this, USC has a dedicated computer workstation with a data transfer/translation algorithm. USC has maintained a long-term database of the selected ULLS-A data items, thus overcoming the 6-month limitation of the ULLS-A system.

The operating aircraft models that were used to obtain these data include UH-60A, UH-60L, AH-64A, AH-64D and CH-47D in the following establishments and environments: ALARNG, MOARNG, PAARNG, SCARNG, TNARNG, ATTC, FT CAMPBELL, FT RUCKER, FT STEWART, Aviation School, Kosovo, Korea, Iraq. The data was obtained over 35,000 flight hours and include 145 million data records. A sample of the part failure incidents obtained from the ULLS-A data is as presented in Figure-2. Another sample of the
vibration data obtained via HUMS (MSPU) are depicted in Figure-3. The condition indicators data obtained via MSPU is provided in Figure-4. Based on integration or interrogation of ULLS-A and HUMS data, the developed component mapping strategy is schematically represented in Figure-5.

As part of the DOD’s transition toward Condition Based Maintenance, the Army is utilizing the existing vibration monitoring equipment for monitoring the health of critical mechanical components. The Army developed Modernized Signal Processing Unit (MSPU) grew out of the Vibration Management Enhancement Program (VMEP) and is currently in use on a significant part of the Army helicopter fleet including AH-64, UH-60, and CH-47. The MSPU is a vibration data acquisition and signal-processing device. It acquires data and calculates the condition indicators (CI) used to determine the health of the drive system mechanical components. The next generation of the MSPU system will be utilized for developing and demonstrating advanced diagnostic capabilities for this technological area.

As an example, the Apache components currently monitored for vibration for CBM, under development by the U.S. Army for diagnostics, are shown in green in Figure-6. Additionally, there is a potential to increase the components and are listed in black. Monitoring of these components has already allowed the Army to eliminate the APU clutch vibration check and the special inspection on the M/R swashplate. In addition, it has allowed for the increase in TBO for the hanger bearings, and time for the APU mount inspection. This resulted in a 5.2% increase in aircraft readiness and an annual savings of $9.3M. Including additional components into CBM will allow for further increases in aircraft availability and annual cost savings.
Some of the aircraft components that were tested under VEMP/CBM framework in the past include the drivetrain, gear box, APU clutch, hanger bearing, swashplate assembly as shown in Figure-7 and described as follows:

Aft Hanger Bearing
In September of 2003, we (McEntire Army National Guard) observed the aft hanger bearing (shown in Figure-8) of one of our Apaches beginning to approach the yellow caution limit. By late October, the vibration level had crossed into yellow and appeared to be increasing at an accelerating rate. An aircraft inspection did not reveal any abnormalities. Production Control assigned a work order and the hanger bearing was replaced on October 23, 2003. After replacement, the vibration level returned to normal for the aft hanger bearing. Once removed, the hanger bearing was inspected and the failed notation checked. While rotating the bearing, a rough spot could be felt.

APU Clutch
Over $100,000,000 was lost in late 2003 due to the failure of three APU clutches (shown in Figure 9). VMEP would have alerted the crew chief that the vibration level of the clutch was approaching critical levels. The Aviation Engineering Directorate (AED) used the three years of APU clutch data from the South Carolina Apaches to help determine the maximum safe vibration level for APU clutches. A procedure using the AVA was then established to measure the APU clutch vibration level every 50 hours. With VMEP, this measurement, along with most rotating components, is measured every time a plot presses the “DO” button.

Main Rotor Swashplate Bearing
The AH-64A Main SP (shown in Figure 10) was at caution consistently starting Nov 2003 due to Swashplate single point-of-failure. The SP CI was observed to be abnormal compared to all other VMEP-equipped A/C. SP passed standard inspection per TM 1-1520-238-23, paragraph 1.137; “Spin & feel for roughness” test subjective. Then, the Data reviewed via iMDS website during caution/exceedance limits review (Large peak in spectral data for aircraft, Sidebands spaced at intervals corresponding to bearing fault frequencies). It was suspected that the problem was due to bad swashplate bearing. Then, raw vibration data was acquired Apr 04 and SP was received May 04 before aircraft was turned-in for D model conversion. When the SP was disassembled by PIF per DMWR Aug 04, Corrosion pitting, broken cage & blackened grease was discovered.

USC Test Facilities and Collaborations
USC leverages its eight years of active research, knowledge and expertise in vibration diagnostic development and the experience from previous CI development to lead the team in the drive systems/mechanical components technology area. The Condition-Based Maintenance Center at the University of South Carolina is one of the key players on the US
Army CBM team. USC has focused on defining and developing a long-term roadmap of methodologies and processes that reinforce CBM activities and objectives. They are providing critical input for the path ahead as the U.S. Army moves towards CBM. State-of-the-art indoor helicopter test stands have been designed and built, and are being used to test rotating components.

The purpose of such testing is to obtain measurements and data relative to the root causes of failure. This information is critical in moving toward Condition-Based Maintenance. The test stands shown in Figures-11 and 12 are capable of testing AH-64 drive train components (bearings, gearboxes, swash plates, oil coolers and shafts). This stand is also capable of handling shaft misalignment requirements while remaining safe. Other stands at USC include an AH-64 hydraulic pump stand, and an AH-64 main rotor swashplate bearing assembly stand.

All test stands utilize several data acquisition systems, including current in-flight monitoring systems such as MSPU and IMD-HUMS, as well as a specialized laboratory data acquisition system capable of recording torque, speed, temperature, vibration, and acoustic emissions. All test stands are controlled based on monitored data measures of torque, speed, and temperature, which are throughout the experiment. All vibration and acoustic emissions data is collected as needed for the experiment. All test stand data files are migrated to a high-speed secure in-house file server with 2-terabyte storage capacity that is also ready to be accessed by Army personnel.

Figure 11 - USC Helicopter Drive Component Test Stand

Figure 12 – USC Tail Rotor Drive Train – TRDT (left) and Main-Rotor Swashplate Assembly - MRSP (right) Test Stands

The TRDT test stands are designed to be flexible and practical for multiple purposes, while facilitating the ability to scientifically understand and interrogate the actual condition of components as they relate to TAMMS-A inspection, vibration signals, health and usage monitoring systems output, and other data sources. This data is needed for the development of comprehensive and accurate diagnosis algorithms and prognosis models. The testing capabilities are structured to test new and existing drive train components of military and civilian aircraft; with particular emphasis on AH-64, ARH-70, CH 47 and UH-60. Testing aircraft components will also support data requirements necessary for accurate diagnosis and proper maintenance of aging aircraft.

The specific test facilities, other research facilities, safety considerations and research collaborations are described as follows:
**TRDT Test Stand Specifications, Requirements and Features**

The test stand emulates tail rotor drive train system from the main gearbox tail rotor takeoff to the tail rotor swashplate assembly. All drive train parts on the test stand are actual aircraft hardware. The test stand was designed to handle shafts installed at the maximum allowed misalignment of over 2.0 degrees and balanced to the maximum allowed imbalance. The test stand mounting structure, instrumentation and data acquisition systems and schemes are in accordance with military standards. The test stand configuration, geometry and speed, and loading capabilities emulate airframe loads and flight regimes. The test stand was designed and built to accommodate the use of multiple Health and Usage Monitoring Systems (HUMS).

**MRSP Test Stand Specifications, Requirements and Features**

The swashplate test stands were designed based on loading requirements and the shapes and sizes of the AH-64, UH-60 & CH-47 swash plates. The test stand is driven by an electric 50 hp A/C motor. This motor normally has an operating rpm of 1750, but by using an existing variable A/C vector drive the rpm is adjustable. These motors, when operating under their normal operating rpm, act as constant hp motors which will provide around 147 lb-ft of torque. If in the future motor torque is needed the motor may be run at operating speeds and have the rpm reduced through a gear reduction. As much as 908 lb-ft of torque can be obtained.

The drive motor provides the power and speed up through the center of the stand via a shaft; from here the shaft transmits power to a plate. In addition to transmitting the power, this plate provides a mounting place that accepts the scissors and the pitch links mounts, while supporting the loads of both. This plate will always run horizontally therefore provided a consistent plane in which the upper pitch link ends will rotate. The lower ends of the pitch links will attach to the non-rotating portion of the swash plate bearing which will be attached to the loading structure through its mounting holes.

Next, the loading structure is supported beneath the main rotor swash plate bearing mount table and a hydraulic cylinder applies the loading to the table mount which loads the pitch links. The loading cylinder is controlled via a highly accurate, electronically controlled constant pressure, valve. Each of the pitch links are instrumented with strain gauges for actual load monitoring. All strain gauge signals are amplified and passed through a slip ring before being recorded. By directly monitoring the pitch link loads, while precisely controlling our load an accurate reproduction of the loading is capable. This all occurs while rotating a portion of the swashplate bearing at the specified operating speeds relative to the non-rotating portion of the swash plate bearing. This stand is capable of rotating from ~50 to ~ 656 rpm.

**Other Capabilities Available at USC**

The other capabilities available at USC to support the CBM research include: other data acquisition systems, modeling and simulation capabilities/software, state-of-the-art-metrology and measurement facility, tribology, lubrication and oil analysis equipment, vision and imaging equipment and other sensing devices, materials preparation and characterization equipment, manufacturing and fabrication machines.

**USC Test Stands Safety Considerations**

All test stands are enclosed in a single, safe and secure area. Safety, hazards, security and fire features are inspected and approved by both the USC Safety and Risk Management, and the USC Fire Department. The safety features of all USC test stands consist of physical barriers around each stand to prevent any debris from reaching personnel near the testing area if breakage occurs during testing. Access near the testing area is prohibited during actual testing. Each test stand is featured with an emergency stop button to disable the test stand in the event the operator determines there is an unsafe/emergency condition.

**Intelligent Automation Corporation**

Intelligent Automation Corporation (IAC) is a machinery diagnostics company with a unique blend of research, systems engineering, manufacturing, and field support expertise. IAC proposes to leverage their extensive experience in drive train monitoring systems for Army and commercial helicopters to provide a system that can detect rotorcraft drive system faults with a high degree of accuracy. IAC proposes their recently developed SuperHUMS (IAC-1239, Figure 13) system for this application. The IAC SuperHUMS system is an advance Health and Usage Monitoring System (HUMS) featuring state of the art field programmable gate array technologies.

The FPGA architecture is optimized for performing filtering, FFT, and other convolution functions that are the core of vibration related fault monitoring. With reduced software overhead, SuperHUMS can handle a wide variety of diagnostics. In addition to the FPGAs, included with the system are three general purpose CPUs and high speed vibration input channels (96 KHz bandwidth) as well as up to 48 general purpose analog inputs that can be sampled up to 125kHz. The SuperHUMS system has the capability to host diagnostics algorithms developed by Boeing. IAC’s diagnostics technologies that include existing diagnostic algorithms and neural network based anomaly detection techniques will enable the program goals by providing a
The South Carolina Army National Guard

SCARNG has been in the forefront of the VMEP development for several years. SCARNG currently has 16 AH-64A equipped with the VMEP system. With coordination from the U.S. Army AED, SCARNG will provide aircraft access for condition indicator demonstration. At the conclusion of the test stand testing and the CI enhancement, the VMEP/MSPU system on selected aircraft will be modified through the IAC database setup tool to incorporate enhancements to the vibration condition indicators. Data downloaded to the aircraft will be used to demonstrate effectiveness of the enhanced CIs on the ground station.

United States Army Aviation Engineering Directorate (AED)

The U.S. Army AED will provide the AH-64 drive system faulty components and seeded fault components for testing in the test rig at USC. Test plan and diagnostics enhancement approaches to be developed on the test rig will be closely coordinated with AED. AED will provide the Air Worthiness Release (AWR) required for incorporating and testing the diagnostics enhancements on selected aircraft at SCARNG.

CBM Test and Diagnostics Approach

A schematic of the CBM test and diagnosis procedure and its impact on achieving the CBM objectives are schematically shown in Figure 14. The procedures used for testing the mapped components using the CBM research facility are described as follows:

Test Preparation

USC generates the test plan and diagnostics enhancement approaches that are developed on the test rig, which are coordinated with AED. IAC and USC identify the instrumentation requirements and signal acquisition for the test stands at USC. The Figure 15 shows the schemes of data sampling and acquisition for the test. The IAC and USC team also develop advanced diagnostics algorithms. IAC prepares a MSPU setup for the testing at USC, drawing on previous experience and technical support from IAC.

Seeded Fault Component Testing

USC conducts the test at their test stand with IAC and AED support. USC collects all instrumentation data. AED makes arrangements for post test teardown and inspection of the components. IAC supplies the MSPU system for testing. A schematic of integration of test measurements with historical data is depicted in Figure 16.
The advanced diagnostics effort utilizes previous CI’s developed in conjunction with dynamic component testing. These components have known faults as well as components with seeded faults to correlate, validate, and enhance the CIs toward their future use on the Apache aircraft. The program acquires aircraft dynamic components with known faults. These components are run on a test stand and the progression of failure is monitored until a failure or near failure condition. Next, these components undergo a formal inspection / teardown in order to correlate back to the findings from their testing. Newly developed CIs are then implemented on aircraft to further enhance their development and as a threshold validation between aircraft and test stand levels. The focus of the proposed diagnostics solution is to minimize missed and late detections while maintaining an acceptable false alarm rate. Both make use of the substantial amount of data that has been collected at the University of South Carolina using the IAC VMEP/MSPU system as well as the TAMMS-A Data of the same aircraft.

Data Acquisition
While testing using TRDT test stand, all measured data (vibration, speed, load, temperature, etc.) are digitally acquired, warehoused and analyzed. It is possible to test multiple aircraft components simultaneously. The input speeds and loading are variable up to 120% of flight conditions (input speeds from 0 ~ 5000 rpms and loading from 0 to 1200 Hp).

Validation of Diagnostics
USC performs data analysis and algorithm development to examine CIs for proper threshold levels and development of additional CIs. This is schematically shown in Figure 19. USC utilizes an automated data mining approach to automatically determine optimized CI threshold settings from both normal and validated fault data. An automated data mining approach is also used to automatically determine optimized prognosis algorithms and, in turn develops models for components life predictions (shown in Figure 20). IAC provides technical support for validation.
An automated data mining approach has been developed. The approach automatically determines optimized threshold settings using CIs developed from both normal and validated fault data. The faulted CI data is used to determine detection performance while normal data is used to determine false alarm rates. In addition, the efficacy of all CIs for detection of a given fault will be assessed. Different CIs for a given fault have different false alarm performance due simply to different processing noise. Integration of complementary CIs improves detection performance while reducing false alarms. The CIs tend to be complimentary in detecting faults while falsely alarming in different places. Trending (slope estimate) of CIs are included in the detection. IAC investigates and includes trend analysis to improve detection performance in the Apache HUMS.

Results and Discussion

The following section contains some sample data that has been collected to date.

Figure 21 shows the progression of temperature over the duration of testing. Three different intermediate gearboxes were tested with no additional fans; only OEM IGB input fan. The graph below indicates that as tests progressed on the first gearbox (TB_001), temperatures steadily increased, and eventually had to be replaced. Causes of the sudden spike during test 7 (in pink) in the GB temperature are currently being investigated by RTTC. Upon replacement, the recorded temperature was considerably lower, as represented by the yellow and red lines.

Figure 22 shows a comparison of a seeded fault bearing (the pink) with a normal bearing. Note that in addition to added noise at all frequencies, there are considerably higher peaks at the revolution frequency (4863 Hz). This bearing is presently still on the stand, and will continue to be run to failure.

Figure 23 shows a GBS plot of the same bearing. Note the similarities in the peaks. Ground Base Station (GBS) is the analysis tool provided by the OEM manufacturer of the MSPU, IAC. USC uses both systems as a means of ensuring redundancy and accuracy of data collection.
Figure 25 – Aft HB data for high grit bearing show over time

Figure 24, again shows the same bearing as it progresses over the duration of testing. Red areas indicate excessive levels of vibration. The bearing was run, as can be seen from the graph, over the span of October 23 – 26. As testing on the bearing continues, it is expected that the frequencies that are beginning to have red peaks will progressively get worse, and cause the bearing to fail.

Appendix A—Common Terms

Condition Based Maintenance:
Condition-Based Maintenance (CBM) is the nomenclature assigned to a maintenance process that is based upon the electronically determined condition of a component, sub-system or system.

Condition:
Condition is based upon electronic measurements that can be related to condition without the need to disassembly and inspect through conventional means.

General CBM Objectives:
• Reduce unscheduled maintenance and maintenance workload.
• Decrease maintenance and logistics footprints.
• Perform and integrate advanced engineering, maintenance, and information technologies.
• Maintain only upon evidence of need.
• Improve diagnosis and prognosis capabilities.
• Use real-time assessments of material condition obtained from embedded sensors and/or external tests and measurements using portable equipment.
• Increase operational availability.

Condition Indicators (CI):
Condition indicator algorithms come in many varieties and capabilities. These condition indicators are in turn used to develop Health Indicators (HI).

Health Indicator (HI):
The Health Indicator (HI) is a non-dimensional metric that is constructed (calculated) by the manipulation of related condition indicators (the output of condition algorithms). The time history of a perfect HI would identically track (match) the time history of the CI.

Diagnosis:
Faults in bearings, gears and shafts can be detected. These detections are reported as magnitudes. Faulted shafts are the easiest to detect, and bearing faults are the most difficult.

Prognosis:
When it is possible to detect an increase in the magnitude of a detection algorithm output as a function of a tangible usage metric, it is possible to predict the useful service life remaining. This prediction is known as prognosis. A tangible usage metric is that usage metric that relates most directly to the loads and cycles causing the fault (or incipient fault) to propagate. In the case of a helicopter power train, there are many potential metrics:
• Flight time
• Operating time (running time)
• Power spectrum
• Time integral of applied power (throughput power)
• Time integral of applied power normalized for the system S-N Characteristic (Normalized Throughput Power.)

Usage of Mechanical Systems:
Usage is defined as time integral of the power applied to the mechanical system. This usage is also known as generic system usage.

Flight Profile:
A flight profile is a series of ground and flight phases (or events). The simulation program is limited to the simulation of mechanical power train health during flight operations and ground operations when the rotor is turning. The analyst (user) will be able to create flight profiles or use an existing flight profiles. For the purposes of this simulation, the program needs to know the sequence of the various phases and the time spent in each phase.

References
20. Unfunded Mandates - DOD – CBM Memorandum Dated: 20 November 03, Develop CBM as One of Six Future Logistics Enterprise Initiatives
21. Unfunded Mandates - DA, G4 – Army CBM Plus Plan Dated: 14 April 04, Shifts From Preventive and Reactive Maintenance to Proactive CBM
22. Unfunded Mandates - CG, AMCOM Initiative Proof of Principle for Feasibility of CBM
24. Unfunded Mandates - Task Force Goal Achieve Full CBM Within Aviation By FY 2015
25. Unfunded Mandates CG, AMCOM Sets Initial Operating Capability Objectives FY 2011
26. Unfunded Mandates - DA, G4 – Army CBM Plus Memorandum Sets Plans for Implementation Dtd: 08-17-05
Appendix B—Biographies

Abdel-Moez E. Bayoumi, Ph.D., has over 25 years teaching and research experience. Dr. Bayoumi is Director of the Condition-Based Maintenance Center, Director of the Biomedical Engineering and Professor of Mechanical Engineering at the University of South Carolina College of Engineering and Computing. Before joining USC, he was a Professor of Mechanical and Aerospace Engineering at North Carolina State University, a project manager at Hewlett-Packard Company, and Professor of Mechanical and Materials Engineering at Washington State University. He has been actively involved in developing strong programs in mechanical systems. His research activities have been focused in mechanical behavior of materials and design, diagnosis and prognosis of mechanical systems, and design for manufacturability. He has published over 100 papers and supervised fourteen doctoral and thirty-five masters’ students.

Ronak Shah received his B.S. degree in Economics from the Moore School of Business at USC in May 2007 specializing in Applied Microeconomics with a minor in Computer Science with a focus on Database design and development. Throughout his college career, he has been involved in a number of open source projects through the Open Source Developers Network, and has developed a programming background and skills in web applications development and content management. Ronak is currently working on a M.A. in Economics at USC while working with the Condition-Based Maintenance center in conjunction with the US Army on Cost-Benefit Analysis modeling for CBM objectives.

Nicholas Goodman received his B.S. degree in Mechanical Engineering in May 2006 with a minor in Mathematics and Computer Science, specializing in Artificial Intelligence. Following a six month language study trip to East Asia, he began working towards a M.S. in Mechanical Engineering, with a specialization in Mathematics. Nicholas is also a seasoned programmer who has significant experience in working with control systems and software development. He is currently investigating the development of neural network algorithms for the analysis of rotorcraft vibrations and maintenance data in support of CBM objectives for the U.S. Army.

Dr. John Keller received his B.S. (1995) in Aerospace Engineering from Penn State University. He went on to receive his M.S. (1997) and Ph.D. (2001) in Aerospace Engineering from Penn State University, with a Fellowship from the Rotorcraft Center of Excellence. Dr. Keller has been an Aerospace Engineer with the Aeromechanics Division of the Aviation Engineering Directorate since 2001.

General Lester D. Eisner is currently serving as the Deputy Adjutant General, South Carolina Army National Guard. He was commissioned into the U.S. Army in 1976. BG Eisner has held key various staff and command positions including battalion and brigade command. He has logged over 5000 hours in various U.S. Army fixed and rotary winged aircraft, including the UH-60 and AH-64. He is a graduate of the U.S. Army War College. BG Eisner has provided key leadership for many years in the development of embedded diagnostics technology for the U.S. Army helicopter fleet. He served as the Director of the Vibration Management Enhancement Program.

Chief Warrant Officer Five Lemuell Grant graduated from Georgia State University with a BS in Criminal Justice. He served over 40 years as an Army Aviator, Instructor Pilot and Maintenance Test Flight Examiner. During his career, he was twice awarded The Distinguished Flying Cross, fifty-six Air Medals and the Broken Wing Award. He was instrumental in the development of the Army Vibration Analyzer (AVA) and the Vibration Management Enhancement Program (VMEP). He continues to work in the field of Conditioned Based Maintenance.