CBM+ Examples for Aircraft Applications

Presented By:
Jeff Banks
Research Engineer
The Applied Research Laboratory at
The Pennsylvania State University
CBM+ is supported by automated maintenance information systems that seamlessly integrate with other logistic systems.

This leads to more efficient maintenance, better readiness, and the cost savings associated with smaller logistics footprints.

Reference: Air Force Condition Based Maintenance + Fact Sheet
- Operational Loads Measurement
  - Strain gage
  - Parametric models
  - Safe-Life and Damage Tolerant models
- Structural Overload Measurement
- Auxiliary Structural Data collection
- Corrosion Environment Monitoring
SPHM: Load and Fatigue Monitoring

- **Load Source Monitored**
  - **All Variants** – Center Fuselage Bending, Wing Root Bending/Shear, Vertical Tail Bending/Shear, Horizontal Tail Bending, Flaperon Bending, Forward Fuselage Bending, Aft Fuselage Bending
  - **CV** – Launch Bar Axial, Wingfold Shear

- **SPHM Sensors Data Acquisition Rate Sufficient to Detect Dynamic Response**
- **Present on All A/C**
SPHM: Load and Fatigue Monitoring

Indicative Positions of Strain Gauges

Frame 609 LH Side – View Looking Outboard

Frame 609 LH Side – View Looking Inboard
SPHM: Load and Fatigue Monitoring

- SPHM Operational Loads Monitoring (OLM)
  - SPHM Area Manager Fed Various Flight Parameters
  - Most Data Sources SOF
  - Time History Captured
  - Parameter Cycle Counting and Usage Statistics Calculated by SPHM Area Manager
  - Fatigue Life Expended for Control Points Tracked
  - Results stored for ALIS download and further force life management
  - Future updates are table driven, not OFP changes
  - Requirement for 98% Accurate data collection
SPHM: Corrosion Detection

- Replace scheduled inspections with “on condition” inspections
- Sensors in 2 locations on SDD aircraft
  - Demonstrate reliability and refine models
  - Growth capability exists as needs emerge
  - Difficult access, high value locations chosen
- Sentinel Resistance sensors
  - Resistance changes as pre-calibrated strips on sensor begin to corrode
  - Tied into aircraft bus to automatically record data at start and end of flight
The history is 2 months+ (88 days) on ground and 32 days in the air.

The following are the accumulated calculations for duration 3 months+ (120 days).

<table>
<thead>
<tr>
<th>Part</th>
<th>Accumulation (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sloping Longeron</td>
<td>638 µm</td>
</tr>
<tr>
<td>Centre Wing</td>
<td>559 µm</td>
</tr>
<tr>
<td>Outer Wing</td>
<td>424 µm</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>473 µm</td>
</tr>
<tr>
<td>Forward Avionics Bay</td>
<td>406 µm</td>
</tr>
<tr>
<td>Under Deck - Rear</td>
<td>509 µm</td>
</tr>
<tr>
<td>Under Deck - Forward</td>
<td>483 µm</td>
</tr>
<tr>
<td>Upper Wing Surface</td>
<td>445 µm</td>
</tr>
<tr>
<td>Fuselage</td>
<td>390 µm</td>
</tr>
<tr>
<td>Main Landing Gear Bay</td>
<td>801 µm</td>
</tr>
</tbody>
</table>

The history sequence was:

1. 'Fast Mission, Low TOW - 4 hours' (A97-005-001)
2. 'On ground, wet base - 8 hours' (A97-005-002)
3. 'Fast Mission, Medium TOW - 4 hours' (A97-005-003)
4. 'On ground, dry base - 8 hours' (A97-005-004)
A Demonstration of a Health Management Information Portal for U.S. Army Helicopter ISHM Systems

Jeffrey Banks
Penn State Applied Research Laboratory
P.O. Box 30
State College, PA  16804-0030
814-863-3859
jcb242@psu.edu
Global Readiness
Air Unit Readiness

**NORTHERN -- ARMY -- NATIONAL GUARD -- South Carolina National Guard (SCARNG)**

**UH-60**
- Tail # 91-28328 Status: PMCM Location: IRA Location: A2
- Tail # 91-28328 Status: PMCS Location: SC Location: C4
- Tail # 91-28330 Status: PMCS Location: SC Location: C6
- Tail # 92-28445 Status: PMCS Location: IRA Location: A3

**AH-64**
- Tail # 88-08962 Status: NMCOS Location: IRA Location: A5
- Tail # 88-08961 Status: NMCOS Location: IRA Location: A6
- Tail # 88-08960 Status: NMCOS Location: SC Location: B6

**CH-47**
- Tail # 88-08884 Status: PMCM Location: IRA Location: A1
- Tail # 88-08883 Status: PMCM Location: IRA Location: A2

**READINESS STATUS.**

Legend:
- Fully Mission Capable
- Partially Mission Capable
- Not Mission Capable

Pre-Deployment Planning
Mission Degradation Mitigation Analysis
PM Planner
Maintenance History
Birth Control Board
Helicopter Readiness

**Legend**

- **EXCEEDED**

**PART. -- Engines**

**STATUS. -- NMC - SUPPLY**

The Engines are not functioning properly and are in need of repair.

<table>
<thead>
<tr>
<th>NIIN</th>
<th>PART DESCRIPTION</th>
<th>PART ORDER STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>11142211</td>
<td>Aircraft Turbine Engine</td>
<td>Due (14NOV2004)</td>
</tr>
<tr>
<td>13240298</td>
<td>Cover, Aircraft Engine</td>
<td>Due (05JAN2005)</td>
</tr>
<tr>
<td>11659450</td>
<td>Bolt Assembly, Engine Mount</td>
<td>Received</td>
</tr>
<tr>
<td>11594472</td>
<td>Bracket, Engine Mount</td>
<td>Received</td>
</tr>
</tbody>
</table>

**SCHEDULED MAINTAINER**

- SPC SMITH

**SCHEDULED MAINTENANCE HANGER**

- West Hanger

**SCHEDULED MAINTENANCE DATE**

- 05JAN2005

**ESTIMATED MAINTENANCE TIME**

- 0800
PHM Data

Spectral Energy - Forward viscous bearing overall vib for mode=FLIGHT, state=FPG100, algorithm=SP4, 900 Hz band around 500 Hz. Limit change on 12-3-02, goal and caution 10 to 3, exceedance 20 to 6.

Part Number: 1321354A-132
Last Install: 01/15/2004
Last Serviced: 09/10/2004
Scheduled Replacement: 12/17/2004

Flight Regime
Information:
Maintenance conducted
Time: 26FEB2002 15:44:41
Sensor Reading: 1.5
Flight Regime

- Roll: +11.5 Degrees
- Yaw: -7.5 Degrees
- Altitude: 1500 feet
- Pitch: -10 Degrees
- Airspeed: 130 knots
Maintenance Video

View IETM

Maintain Aircraft  Sensor Analysis
## Maintenance History

![Maintenance History](image)

<table>
<thead>
<tr>
<th>MWO</th>
<th>MWO Title</th>
<th>WUC</th>
<th>Date Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>55-1520-210-30-54</td>
<td>Inspected Spherical Bearing Assy</td>
<td>05A01L02</td>
<td>05-Feb-03</td>
</tr>
<tr>
<td>55-1520-210-30-60</td>
<td>Replaced Left Tie Rod Assy</td>
<td>11D13</td>
<td>24-Jun-03</td>
</tr>
<tr>
<td>55-1520-210-30-72</td>
<td>Inspected Auxiliary Power Unit</td>
<td>15B</td>
<td>14-Sep-03</td>
</tr>
<tr>
<td>55-1520-210-30-20</td>
<td>Replaced oil Cooler Visc Bearing</td>
<td>06H18E</td>
<td>07-Jan-04</td>
</tr>
<tr>
<td>55-1520-210-30-78</td>
<td>Repaired Stabilator Actuator</td>
<td>11025</td>
<td>18-Apr-04</td>
</tr>
<tr>
<td>55-1520-210-30-84</td>
<td>Replaced Alt Tie Rod Suit Fitting</td>
<td>11D05</td>
<td>23-Jun-04</td>
</tr>
</tbody>
</table>

### AH-64 -- 14

<table>
<thead>
<tr>
<th>MWO</th>
<th>MWO Title</th>
<th>WUC</th>
<th>Date Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>55-1520-210-30-12</td>
<td>Replacement of Elastomeric Mount</td>
<td>02C15K02</td>
<td>15-Mar-03</td>
</tr>
<tr>
<td>55-1520-210-30-22</td>
<td>Inspection of Shaft Driven Compressor</td>
<td>07D02</td>
<td>03-Feb-03</td>
</tr>
<tr>
<td>55-1520-210-30-40</td>
<td>Repair of Tail Rotor Actuator</td>
<td>11C25</td>
<td>20-Oct-03</td>
</tr>
<tr>
<td>55-1520-210-30-51</td>
<td>Installation of Cyclic Actuator F&amp;A</td>
<td>11D01D</td>
<td>14-May-04</td>
</tr>
<tr>
<td>55-1520-210-30-58</td>
<td>Inspection of Auxiliary Power Unit</td>
<td>15B</td>
<td>14-May-04</td>
</tr>
<tr>
<td>55-1520-210-30-68</td>
<td>Installation of Spar Box Assy Vert Stabl</td>
<td>02G15D</td>
<td>08-Jun-04</td>
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### CH-47 -- 0

<table>
<thead>
<tr>
<th>MWO</th>
<th>MWO Title</th>
<th>WUC</th>
<th>Date Applied</th>
</tr>
</thead>
</table>

---

**Legend**

- **Depot in Hrs**
- **SCARNG**
## PM Planning

### Readiness Status

### Part # | Nomenclature | Op Hrs | TBO Hrs | TBR Hrs | Overhauls | Delay Time
--- | --- | --- | --- | --- | --- | ---
7-31130001-5 | Main Transmission Assembly | 2.150 | 2.500 | 8.800 | 2 | 15
7-31130008-3 | Hanger Bearing, Fwd | 4.789 | 10.800 | 0 | 42
7-311820011 | Main Rotor Actuator | 15.876 | 10.800 | 0 | 42
7-311411096 | Plate, Upper | 1.500 | 10.800 | 0 | 42
7-211710013-9 | Shaft Driven Compressor | 2.980 | 10.800 | 0 | 42
7-311411088 | Lower Rotor Assembly | 3.241 | 10.800 | 0 | 42
--- | --- | --- | --- | --- | --- | ---
7-31150007-3 | Hanger Bearing, Aft | 6.410 | 2.500 | 8.800 | 2 | 15
7-311411080 | Plate, Lower | 8.240 | 10.800 | 0 | 42
7-311257038-7 | Tail Rotor Swashplate Assembly | 1.350 | 260 | NA | 5 | 22
7-311300119 | Lead Lag Damper | 0.990 | 8.200 | 0 | 140
7-311320001-3 | Nose Gearbox Assembly, LH | 1.486 | 4.500 | 0 | 265
7-211320003 | Quill Shaft Assembly | 1.232 | 4.500 | 0 | 56

---

PreDeployment Planning | Mission Degraders | Cost Benefits Analysis | PM Planner | Maintenance History
## Degrader Analysis

### Table: Ready Status

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>UH-60</td>
<td>9</td>
</tr>
<tr>
<td>AH-64</td>
<td>14</td>
</tr>
<tr>
<td>CH-47</td>
<td>0</td>
</tr>
</tbody>
</table>

### UH-60

<table>
<thead>
<tr>
<th>WUC</th>
<th>WUC Description</th>
<th>Part #</th>
<th>Aircraft Count</th>
<th>Hrs Unavail</th>
</tr>
</thead>
<tbody>
<tr>
<td>03A01</td>
<td>Fwd Fixed Gear Shock</td>
<td>70250-12051-042</td>
<td>1</td>
<td>520</td>
</tr>
<tr>
<td>05A01</td>
<td>Main Rotor Spindle Assy</td>
<td>70070-10030-042</td>
<td>1</td>
<td>520</td>
</tr>
<tr>
<td>05A01T7</td>
<td>Control Horn Assy</td>
<td>70102-08111-043</td>
<td>6</td>
<td>336</td>
</tr>
<tr>
<td>06A</td>
<td>Main Transmission Module</td>
<td>70351-08111-053</td>
<td>1</td>
<td>264</td>
</tr>
<tr>
<td>06A10A</td>
<td>Dowel Pin Front Bridge</td>
<td>70351-08404-103</td>
<td>3</td>
<td>222</td>
</tr>
<tr>
<td>06A10B</td>
<td>Main Rotor Shaf</td>
<td>70351-08131-044</td>
<td>2</td>
<td>116</td>
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</table>

### AH-64

<table>
<thead>
<tr>
<th>WUC</th>
<th>WUC Description</th>
<th>Part #</th>
<th>Aircraft Count</th>
<th>Hrs Unavail</th>
</tr>
</thead>
<tbody>
<tr>
<td>02C15D</td>
<td>Spar Box Assy Vert Stab</td>
<td>7-311122601</td>
<td>1</td>
<td>423</td>
</tr>
<tr>
<td>05A01</td>
<td>Main Rotor Head Assy</td>
<td>7-3111411003</td>
<td>1</td>
<td>420</td>
</tr>
<tr>
<td>05A01-W</td>
<td>Trunnion, Damper</td>
<td>7-3111411187</td>
<td>1</td>
<td>420</td>
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<tr>
<td>05A02</td>
<td>Main Rotor Blade</td>
<td>7-3111412000</td>
<td>1</td>
<td>420</td>
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<tr>
<td>05A03C</td>
<td>M/R Pitch Link Assy</td>
<td>7-3111511135</td>
<td>3</td>
<td>331</td>
</tr>
<tr>
<td>05B01N</td>
<td>Tail Rotor Fork Assy</td>
<td>7-3111410083</td>
<td>1</td>
<td>300</td>
</tr>
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</table>

### Additional Notes
- PreDeployment Planning
- Mission Degraders
- Cost Benefits Analysis
- PM Planner
- Maintenance History
Cost Benefit Analysis

VMEP 2 Year Impact

<table>
<thead>
<tr>
<th></th>
<th>McEntire</th>
<th>Alabama</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>+16%</td>
<td>+15%</td>
</tr>
<tr>
<td>Sense of Safety</td>
<td>+30%</td>
<td>+11%</td>
</tr>
<tr>
<td>Performance</td>
<td>+21%</td>
<td>+28%</td>
</tr>
<tr>
<td>Mission</td>
<td>+18%</td>
<td>+15%</td>
</tr>
<tr>
<td>Morale</td>
<td>+11%</td>
<td>+18%</td>
</tr>
<tr>
<td>Confidence</td>
<td>+20%</td>
<td>+27%</td>
</tr>
<tr>
<td>Morale &amp; ...Performance</td>
<td>+35%</td>
<td>+27%</td>
</tr>
<tr>
<td>Ease of ...Troubleshooting</td>
<td>+32%</td>
<td>Strongly Agreed</td>
</tr>
</tbody>
</table>

Information:

Date: Year 1 1st 6mo
Amount: 1.05

Chart:
- Premature Parts Failures per 100 Flight Hrs - AH64
- Days in Maintenance per 100 Flight Hrs - AH64
- Unscheduled Maintenance per 100 Flight Hrs - AH64
- Scheduled Maintenance per 100 Flight Hrs - AH64
- Surprise Maintenance per 100 Flight Hrs - AH64
- Mystery Maintenance per 100 Flight Hrs - AH64
## Pre-Deployment Planning

### Readiness Status

**NORRTH. - ARMY. - NATIONAL GUARD. - SCARNG.**

#### Deployment Dates:
- 23 JUL 2004 - 02 FEB 2005

<table>
<thead>
<tr>
<th>Model</th>
<th>Qty</th>
<th>NIIN</th>
<th>Nomenclature</th>
<th>WBS Desc</th>
<th>Unit Price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UH-60.</strong></td>
<td>9</td>
<td>12493892</td>
<td>Bearing Assy, Rotor</td>
<td>Rotor Group</td>
<td>$1,832.00</td>
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<tr>
<td></td>
<td></td>
<td>13104978</td>
<td>Blade, Rotary Wing</td>
<td>Rotor Blades</td>
<td>$102,174.00</td>
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<tr>
<td></td>
<td>24</td>
<td>3954643</td>
<td>Nut, Self-Locking Ex</td>
<td>Basic Structure</td>
<td>$12.09</td>
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<tr>
<td></td>
<td></td>
<td>13261804</td>
<td>Manifold, Hydraulic</td>
<td>Basic Structure</td>
<td>$44,524.00</td>
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<td></td>
<td>15</td>
<td>9002139</td>
<td>Battery, Nonrecharge</td>
<td>Electrical Subsys</td>
<td>$7.81</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>3251528</td>
<td>Cable, Special Purpose</td>
<td>Other</td>
<td>$0.96</td>
</tr>
</tbody>
</table>

| **AH-64.** | 14  | 13122387   | Blade, Rotary Rudder        | Rotor Group       | $10,774.00     |
|            |     | 11547076   | Strap Assy, Main Rotor      | Rotor Blades      | $5,632.00      |
|            | 38  | 11823840   | Roller Conveyor             | Guns              | $2.07          |
|            |     | 13383589   | Sight, Infinity             | Target Acquisition | $111,515.00   |
|            | 26  | 6351536    | Cable, Special Purpose      | Other             | $0.86          |
|            | 4   | 14123893   | Receiver Transmitter        | Direction Finding | $192,687.00   |

**CH-47.** | 0   |            |                             |                   |                |

### Additional Information:
- Pre-Deployment Planning
- Mission Degraders
- Cost Benefits Analysis
- PM Planner
- Maintenance History

**Legend:**
- Consumable
- Repairable
**TotalCare® Aftermarket Model**

**Benefits**
- Reduced acquisition costs
- Improved budgetary control
- Optimised operating expenditure
- Minimised operational disruption
- Reduced administration burden

**TotalCare®** allows Rolls-Royce to be truly focused on achieving the same goals as our customers

**TotalCare®** has been selected by 95% of Trent Customers
Airlines demand predictable operation

- Passengers demand a dependable service
- Cost of disruption is significant, for example, an in-flight shut-down (IFSD) can lead to:
  - diversion to remote site
  - overnight accommodation for passengers
  - replacement aircraft
  - hiring a freighter to deliver a replacement engine
  - crew costs
  - disruption to follow-on flights

- In addition, a failed engine is often more expensive to overhaul than an engine removed before failure
... but are expected to achieve long on-wing lives

- Engine maintenance costs are directly related to time between overhauls
  - modern engines achieve
    - 8-10,000 cycles
    - 25-30,000 hours
- Service events, such as IFSDs, are to be avoided
  - ETOPS approval requires fleet IFSD average < 1 event every 12 yrs
  - airlines expect engines to be significantly better:
    - Trent 800 IFSD < 1 event every 75 yrs

\[
\text{Cost of Ownership} = \frac{\text{Number of Shop Visits} \times \text{Cost per Shop Visit}}{\text{Maintenance burden}}
\]
Acquire

- Aircraft Condition Monitoring Function (ACMF) is an aircraft based system that captures data at predefined conditions:
  - snap-shot reports (take-off, climb, cruise)
  - triggered reports (gas-path, mechanical)
  - summary reports
- ACMF is supplemented by the Engine Monitoring Unit (EMU)
Transfer

- Airliners are fitted with Aircraft Communication and Addressable Reporting System (ACARS)
  - SatCom
  - VHF

- This automatically transfers EHM data to the ground network for analysis
Analyse

- Optimized Systems & Solutions (OSyS) are a wholly owned subsidiary company of Rolls-Royce
- They provide a fleet-wide EHM analysis service
  - 24x7 data processing and trending of engine data
  - alert list showing equipment / engines requiring urgent maintenance action
  - alert notifications sent by email or text message
  - detailed analysis of equipment health
Rolls-Royce define Alerting levels based on experience from development, flight test and service

- **Alerts** - issued by OSyS if the EHM signature suggests a risk of impact on airline’s operation

All Alerts are actively managed through the Operations Centre

- discussed with airlines
- focused trouble-shooting advice
- Rolls-Royce fleet-wide knowledge
- All alerts are positively closed
• **ALIS integrates a broad range of capabilities** including operations, maintenance, prognostics, supply chain, customer support services, training and technical data.
  - A single, secure information environment provides users with up-to-date information on any of these areas using web-enabled applications on a distributed network.

• **ALIS will serve as the information infrastructure for the F-35**, transmitting **aircraft health and maintenance action information to the appropriate users** on a globally-distributed network to technicians worldwide.

• **ALIS receives Health Reporting Codes while the F-35 is still in flight** via an radio frequency downlink.
  - The system **enables the pre-positioning of parts and qualified maintainers** on the ground, so that, when the aircraft lands, downtime is minimized and efficiency is increased.

Autonomic Logistics Information System (ALIS)

- https://www.youtube.com/watch?feature=player_embedded&v=WU30Fmfyflw
Once that data is collected, ALIS will provide an information infrastructure that captures, analyzes (autonomously or with human intervention), identifies, and communicates F-35 characteristics and data, providing information and decision support for every F-35 customer via a global network.

- The F-35 aircraft’s health and maintenance orders, and even the location of parts, will be generated through ALIS. To close the loop, ALIS will contain easily-updated interactive technical manuals, and track maintenance issue resolution.

ALIS integrates a variety of commercial-off-the-shelf applications:
- Supply chain management
- Interactive technical manuals
- Aviation maintenance management
- CRM communications, maintenance request tracking, etc.

Autonomic Logistics Information System (ALIS)

- Single, Secure Information Environment
- Distributed Network Based on Web Technologies
- Capabilities Integrate Broad Range of Domains
  - Operations
  - Maintenance
  - Supply Chain
  - Customer Support Services
  - Training
  - Tech Data
  - External Interfaces
- Key enabler supporting Performance Based Logistics (PBL) for the F-35