Requirements for Life Cycle Management of U.S. Army Helicopter Structural Integrity

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### US Army Frontline Combat Helicopters are at Mid Life

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Number &amp; Mission</th>
<th>Entered Service</th>
<th>Design Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH-47 Chinook</td>
<td>450 Cargo</td>
<td>1961</td>
<td>46+ years</td>
</tr>
<tr>
<td>UH-60 Black Hawk</td>
<td>1600 Utility</td>
<td>1978</td>
<td>29+ years</td>
</tr>
<tr>
<td>AH-64 Apache</td>
<td>700 Attack</td>
<td>1984</td>
<td>23+ years</td>
</tr>
</tbody>
</table>

- Average design age ~30 years.
- 2000 of these 2750 helicopters will be upgraded to remain in service beyond 2030.
Operational Usage Severity Has Increased Dramatically

Army helicopters must remain available, safe, and affordable...
► while flying combat OPTEMPO of 3-4x peacetime...
► in increasingly harsh environments.

► Combat Maneuvers
► Expanded Envelope
► High Altitude
► Desert Sand
► Ship Operations
► Salt Environment
Components Fall Short of Design Life Expectations

Based upon 96 AH-64A/D, CH-47D/F, UH-60A/L Component Part Nos.

BALLPARK PARTS and LABOR COST:
Assumption: All components will achieve the service life of those in maintenance database (peacetime usage).

Near Term Objective

Monitored Life

Life Extension

Remediation

Typical US Army Actuals

Δ=$150M

Δ=$50M

Δ=$30M

100%, $50M

25%, $200M

33%, $150M

250%, $20M

100%
Component Life Cycle Management Process

- Monitor Usage
  - Flight Parameters
  - Duty Cycles
  - Flight Regimes

- Monitor Loads
  - Flight Load Survey Data
  - Statistical Correlations
  - Monitor Loads/Sequences

- Monitor Strain
  - Digital Optical Correlation
  - Zero Load Strain
  - Material Deformation

- Discard Component

- Continue Usage

- Improve Component
  - Redesign
  - Rework

- Predict Removal
  - Usage Correlation
  - Maintenance Actions
  - Remaining Useful Life

- Inspect Condition
  - Material Condition
  - Degradation Trends

- Monitor Strain
### Structural Condition Monitoring Technologies

**Application Frequency**
- Very High
- High
- Moderately High
- Moderate
- Low
- Minimal

**Technology Readiness Level**
- TRL 9
- TRL 8
- TRL 7
- TRL 6
- TRL 5
- TRL 4
- TRL 3
- TRL 2
- TRL 1

**Structural Integrity Life Cycle Management Technologies**
# Example Applications of Enabling Technologies

<table>
<thead>
<tr>
<th>Application</th>
<th>Technology</th>
<th>Application Frequency</th>
<th>Readiness Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor component usage and environments</td>
<td>Regime recognition and damage accumulation</td>
<td>Very High</td>
<td>TRL 7-9</td>
</tr>
<tr>
<td>Determine dynamic component loads</td>
<td>Relate rotating system loads to fixed system parameters</td>
<td>Very High</td>
<td>TRL 5-7</td>
</tr>
<tr>
<td>Monitor and trend zero load residual strain</td>
<td>Digital Optical Correlation</td>
<td>High</td>
<td>TRL 5-7</td>
</tr>
<tr>
<td>Monitor and trend surface residual stress</td>
<td>X-ray diffraction</td>
<td>Field: Moderate Depot: Low</td>
<td>TRL 7-9</td>
</tr>
<tr>
<td>Monitor and trend material condition</td>
<td>Induced positron analysis</td>
<td>IPA-S: Moderate IPA-V: Low</td>
<td>TRL 5-7</td>
</tr>
<tr>
<td>Improve material and extend life</td>
<td>Ultrasonically induced shot peening</td>
<td>Minimal</td>
<td>TRL 9</td>
</tr>
<tr>
<td>Improve material and extend life</td>
<td>Cold expansion of structural holes</td>
<td>Minimal</td>
<td>TRL 9</td>
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</table>
Monitor Component Usage and Environments

%Time in Regime

%Design Damage by Regime

Operational Environment:

Topography:
- Elevation
- Desert
- Tropical
- Maritime

Climate:
- Hot
- Cold
- Temperate
- etc.

Compare operational usage with design assumptions to:
- Determine potential for safe fatigue life extension
- Isolate component early removal drivers.

Usage monitoring application and benefits being demonstrated for AH-64 and UH-60.
Regime-based damage accumulation is conservative and does not account for load sequence effects. Analyze Flight Loads Survey data using appropriate statistical methods:
- Neural Networks
- Genetic Algorithms
- Holometrics
- Regression Analysis

Develop algorithms that relate:
- Flight parameters and fixed-system strains
- Dynamic component loads and strains

Apply algorithms to fleet aircraft to:
- Monitor high fidelity loads and sequences
- Analyze fatigue damage accumulation in dynamic components

Algorithms reproduce flight recorded loads to accurately predict dynamic component fatigue damage.

Loads monitoring is being evaluated by the Aviation Engineering Directorate.
Monitor and Trend
Zero Load Residual Strain

- Non-contact measurements of surface deformation.
- Deformation corresponds to plastic strain.
- Trends indicate accumulated fatigue damage.

Features and benefits:
- Portable, single-camera system
- Fast 3D capture and processing
- Uses available lighting
- Network-enabled
- Variable-zoom lens
- High-resolution surface maps
- S/W produces accurate 3D surface info

- Analyze deformation
- Assess surface damage
- Detect and characterize defects

3D digital optical correlation is being evaluated by AMRDEC for:
- Metal alloy strain deformation
- Composite material delamination

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Surface Features

Critical Surface

Sensor
Monitor and Trend Surface Residual Stress

Use x-ray diffraction (XRD) to measure, map, and trend changes in residual stress to assess usage-related degradation and predict impending rework or retirement.

Approach:
► Map residual stress
► Correlate residual stress with usage
► Assess adverse trends
► XRD is applied in the field or at the depot

Track residual stress:
► Obtain XRD data over time
► Map stress distribution
► Track degradation
► Relate to operational usage
► Augment decisions:
  • Rework?
  • Continue use?
  • Retire?
  • Modify use?

Benefits:
► Reduce Cost
► Increase Readiness
► Enhance Safety
Inspect, Trend Component Material Condition

- Induced Positron Annihilation (IPA) measures, maps, and trends component material condition at the lattice level.
- Monitor material degradation prior to crack initiation and assess continued safe usage, rework, or retirement.

Key Features:
- High Sensitivity: Positrons probe interstitial lattice sites.
- Defects have more low momentum free electrons.
- Atomic level impurity provides unique signatures.
- S-parameter quantifies mechanically induced defects.
- Damage quantified as compared to material baseline.

Benefits:
- Map and track degradation.
- Correlate with usage.
- Assess adverse trends.
- Predict impending failures.
- Predict remaining useful life.

IPA is being evaluated by AMRDEC and SOAR(A) on retired Chinook aft rotor shafts.
Ultrasonic Peening: Enhance structural integrity by introducing compressive residual stresses in components.

Principle:
- Sine wave generated by acoustic block, amplified and transmitted to balls in treatment chamber
- Chamber tailored to each application
- Random ball displacement results in uniform peening

Benefits of Ultrasonic Peening:
- High quality peening
- Maximum fatigue life improvement
- Clean, quiet, and easy to control
- Directly on part
- In situ / minimum disassembly

- Balls sized for each application
- Computer controls peening:
  - Intensity
  - Time

Avion and Sonats are teamed on Army Phase I SBIR to demonstrate field repair of blended surfaces with portable ultrasonic peening.
Cold expand dynamic component fatigue-susceptible holes:
► Split Sleeve
► ForceMate Bushings

Forestalls fatigue crack initiation and fatigue crack growth and extends the safe useful life by a factor of at least 3:1.

Cx reduces maintenance cost and increases fatigue life of dynamic components.
► Simple, one-sided operation
► Works on common materials
► Applicable in production
► Applicable in rework

ForceMate bushings are being installed in UH-60; being considered for AH-64.
US Army combat helicopters are 30-year old designs, at mid-life, and are flying increasingly intense usage in harsh environments.

Proven technologies are available to manage dynamic component continuing safe operational usage.

Monitor usage and damage accumulation:
- Regime recognition
- Loads monitoring

Monitor and trend zero load residual strain:
- 3D Digital Optical Correlation
- Trend fatigue damage

Measure, map, and trend dynamic component:
- Residual stress
- Material condition

Improve dynamic component safe useful life:
- Acoustically peen surface
- Cold expand holes