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

	Aircraft	Number & Mission	Entered Service	Design Age
	CH-47 Chinook	450 Cargo	1961	46+ years
	UH-60 Black Hawk	1600 Utility	1978	29+ years
	AH-64 Apache	700 Attack	1984	23+ years

- 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…

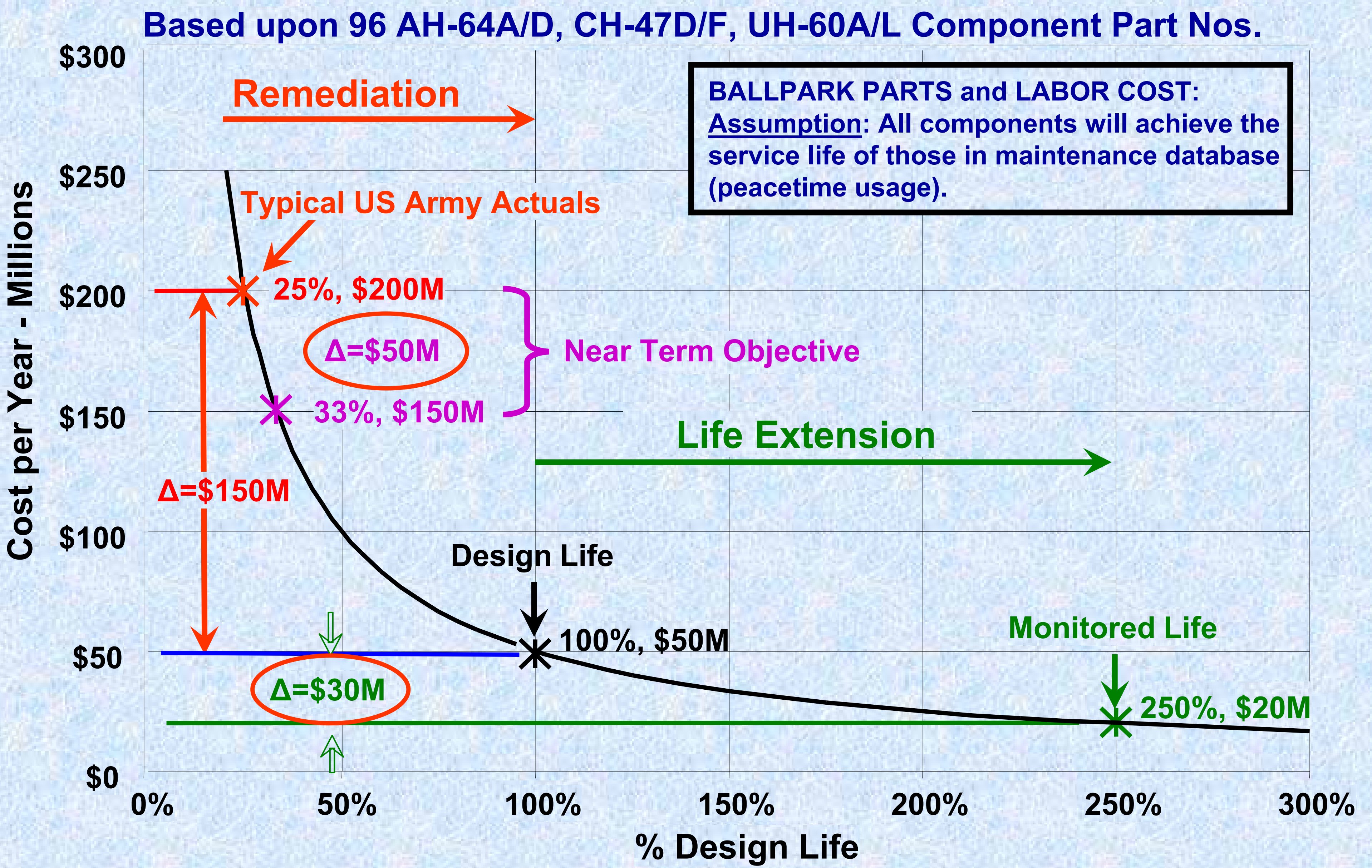
- ► while flying combat OPTEMPO of 3-4x peacetime…
- ► in increasingly harsh environments.

- ► Combat Maneuvers
- ► Expanded Envelope

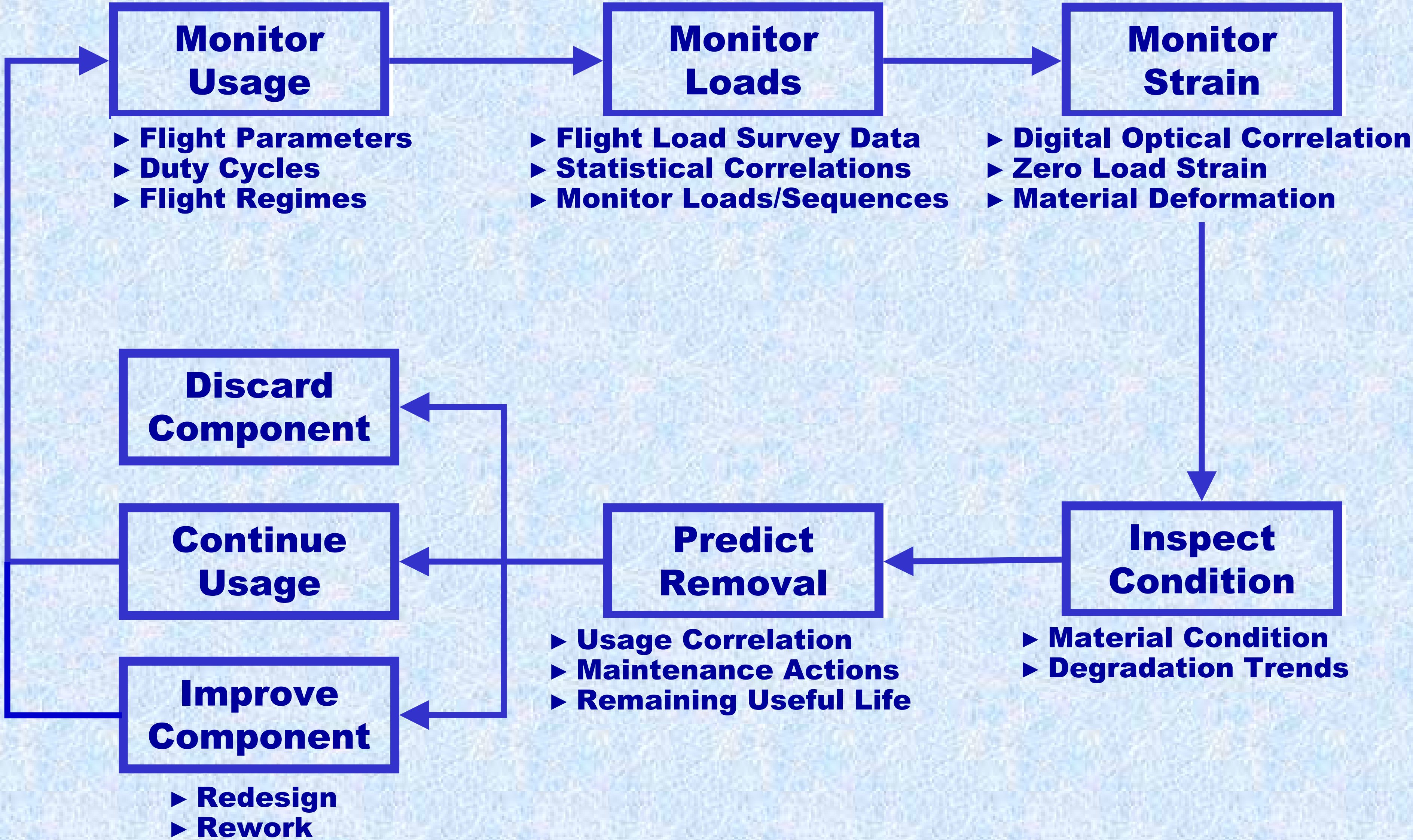
- ► High Altitude
- ► Desert Sand

- ► Ship Operations
- ► Salt Environment

Components Fall Short of Design Life Expectations



Component Life Cycle Management Process

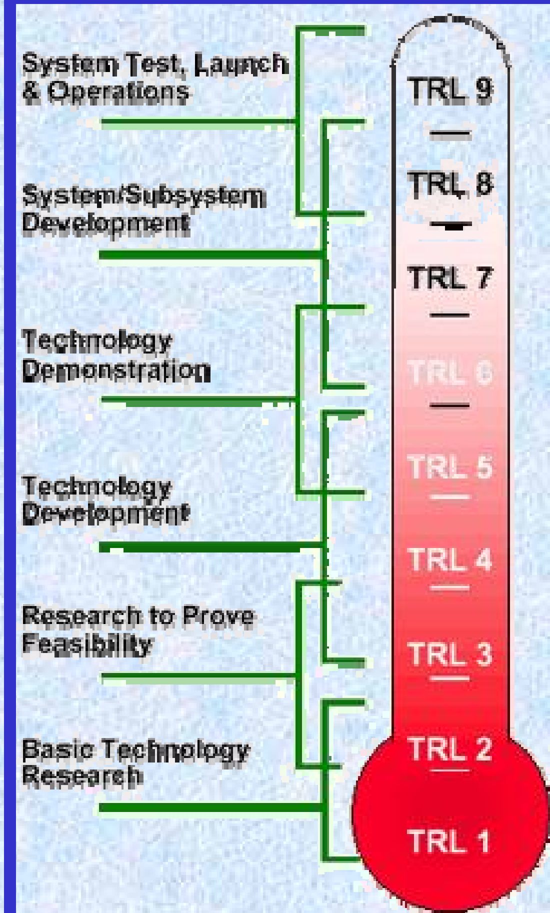


Structural Condition Monitoring Technologies

Structural Integrity Life Cycle Management Technologies

Application Frequency
Very High
High
Moderately High
Moderate
Low
Minimal

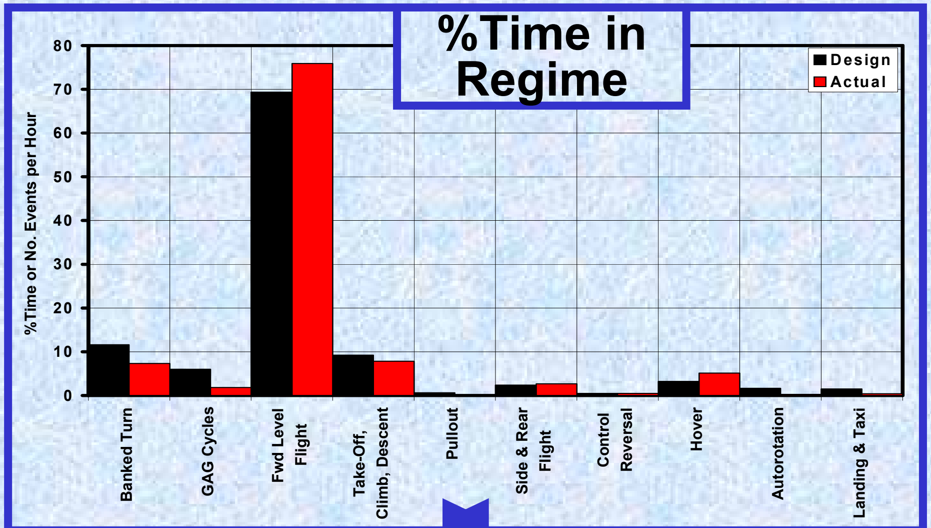
Technology Readiness Level

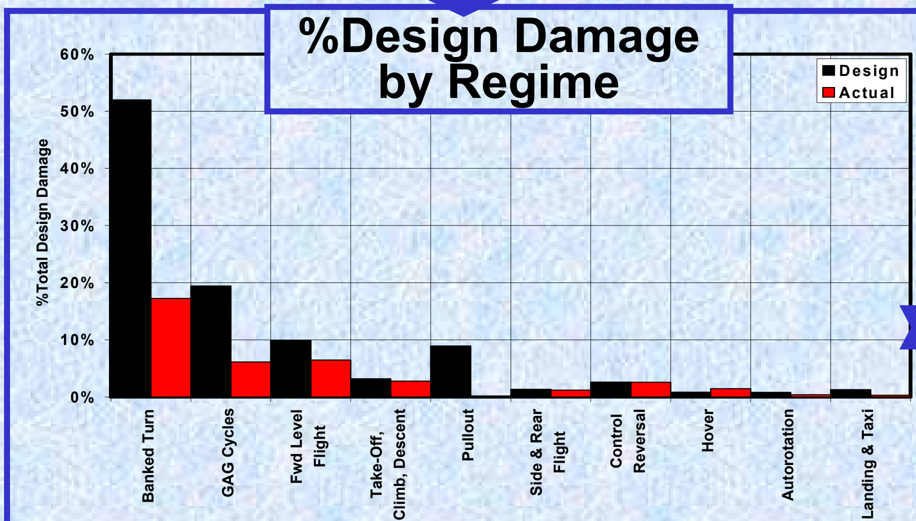


Example Applications of Enabling Technologies

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

Monitor Component Usage and Environments





Compare operational usage with design assumptions to:

- ▶ **Determine potential for safe fatigue life extension**
- ▶ **Isolate component early removal drivers.**

Operational Environment:

Topography:	Climate:
▶ Elevation	▶ Hot
▶ Desert	▶ Cold
▶ Tropical	▶ Temperate
▶ Maritime	▶ etc.

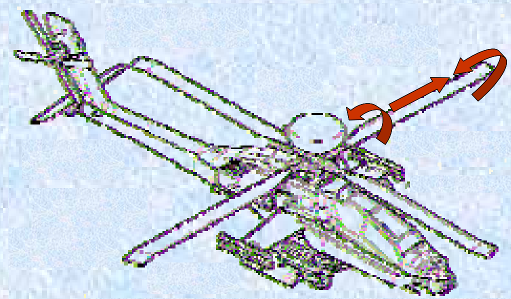
Usage monitoring application and benefits being demonstrated for AH-64 and UH-60.

Determine Dynamic Component Loads

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:

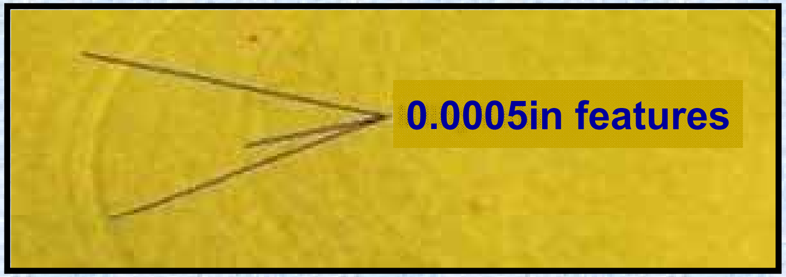
- ▶ Monitor high fidelity loads and sequences
- ▶ Analyze fatigue damage accumulation in dynamic components

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.
- Applicable to:
  - Micro measurements
  - Macro measurements

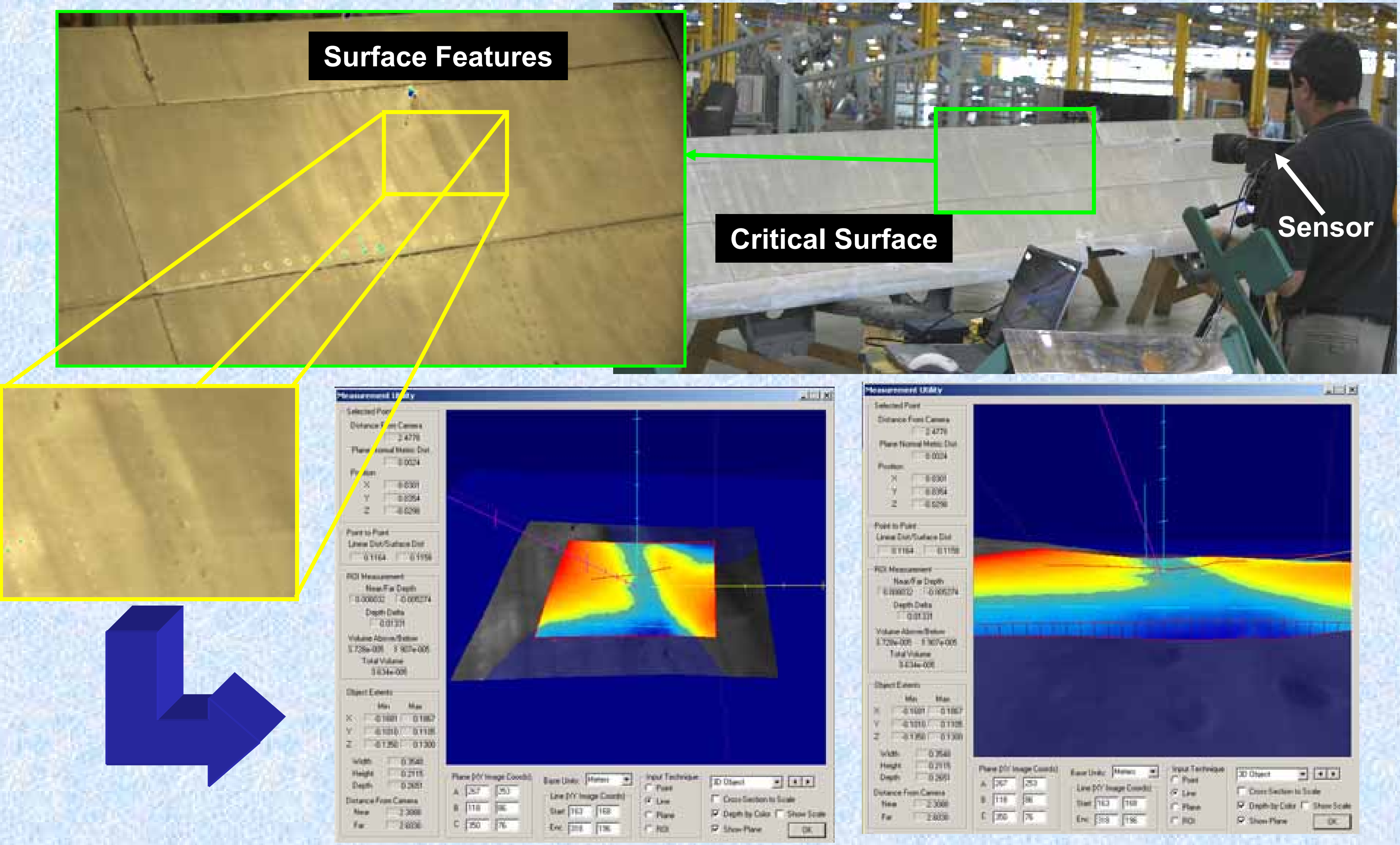


- Analyze deformation
- Assess surface damage
- Detect and characterize defects

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

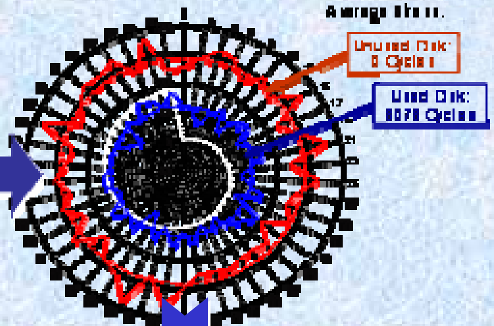
Features and benefits:
- Portable, single-camera system
- Fast 3D capture and processing
- Uses available lighting
- Network-enabled
- Variable-zoom lens
- High-resolution surface maps
- S/W produces accurate 3D surface info

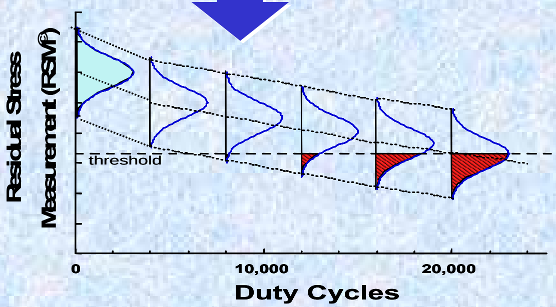
Monitor and Trend
Zero Load Residual Strain



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

Depot/Rework Facility XRD

- Heavy Duty
- Accurate
- Repeatable
- Fast
- Flexible
- Auto Data

Field Portable XRD

- Heavy Duty
- Accurate
- Repeatable
- Fast
- Flexible
- Auto Data

Benefits:

- ▶ Reduce Cost
- ▶ Increase Readiness
- ▶ Enhance Safety

Track residual stress:

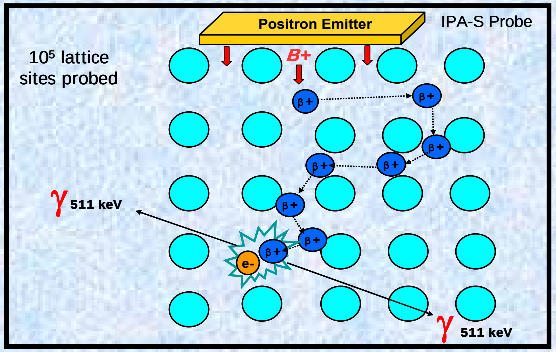
- ▶ Obtain XRD data over time
- ▶ Map stress distribution
- ▶ Track degradation
- ▶ Relate to operational usage
- ▶ Augment decisions:
  - Rework?
  - Continue use?
  - Retire?
  - Modify use?

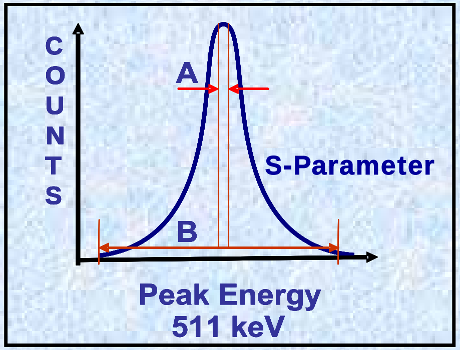
Inspect, Trend Component Material Condition

- 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.

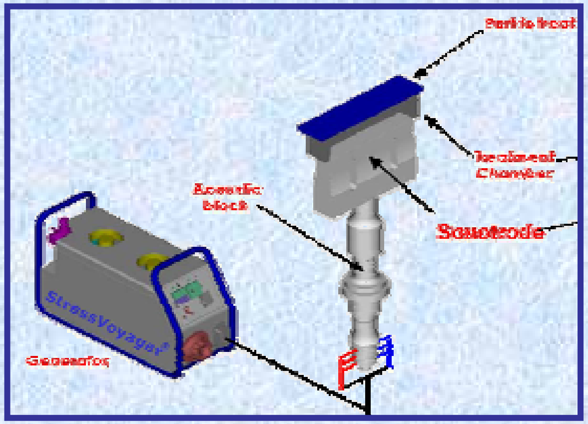
IPA is being evaluated by AMRDEC and SOAR(A) on retired Chinook aft rotor shafts.

Improve Safe Life of Dynamic Components

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

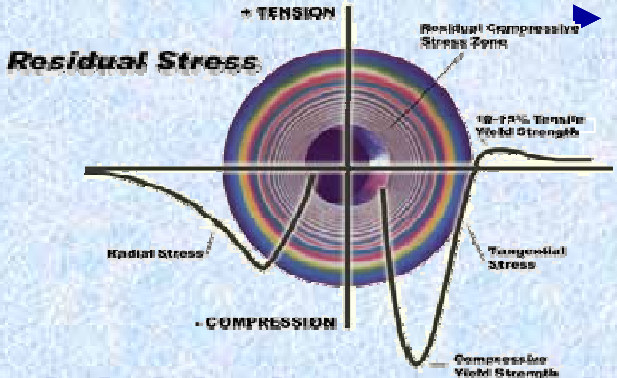
- Balls sized for each application
- Computer controls peening:
  - Intensity
  - Time

Avion and Sonats are teamed on Army Phase I SBIR to demonstrate field repair of blended surfaces with portable ultrasonic peening.

Improve Safe Life of Dynamic Components

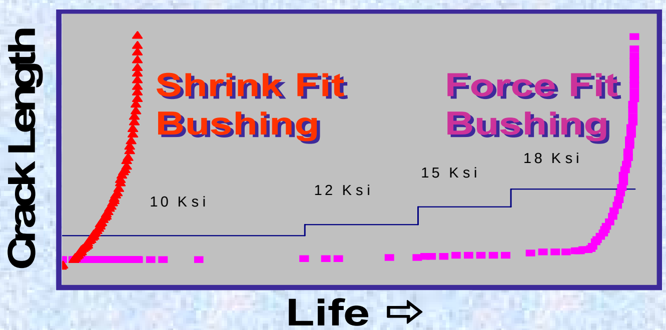
Cold expand dynamic component fatigue-susceptible holes:

- ► 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.



- ► Cost effective
- ► Adds no weight
- ► Arrests small cracks
- ► Alternative to redesign

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.

Structural Integrity LCM Technologies are Available

- ► 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