Prognosis of Turbine Engine Materials

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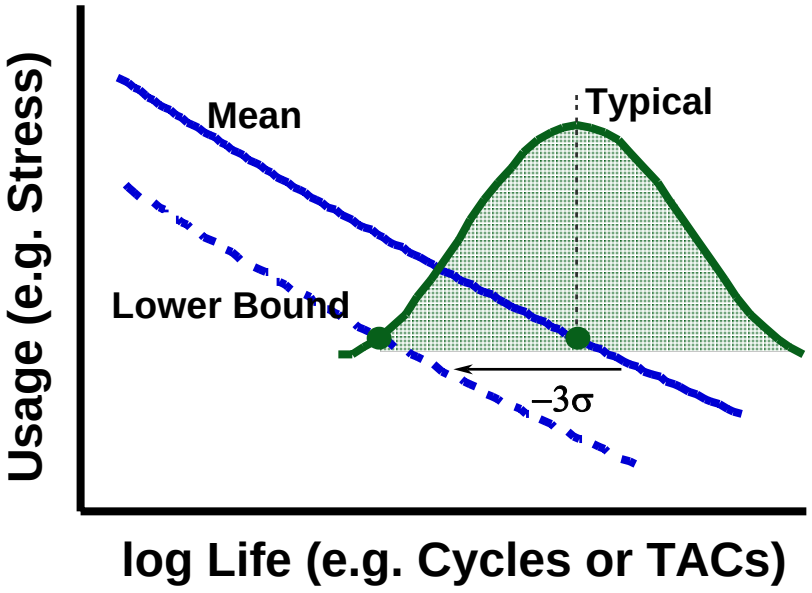
Engine Structural Integrity Program (ENSIP) Design Philosophy

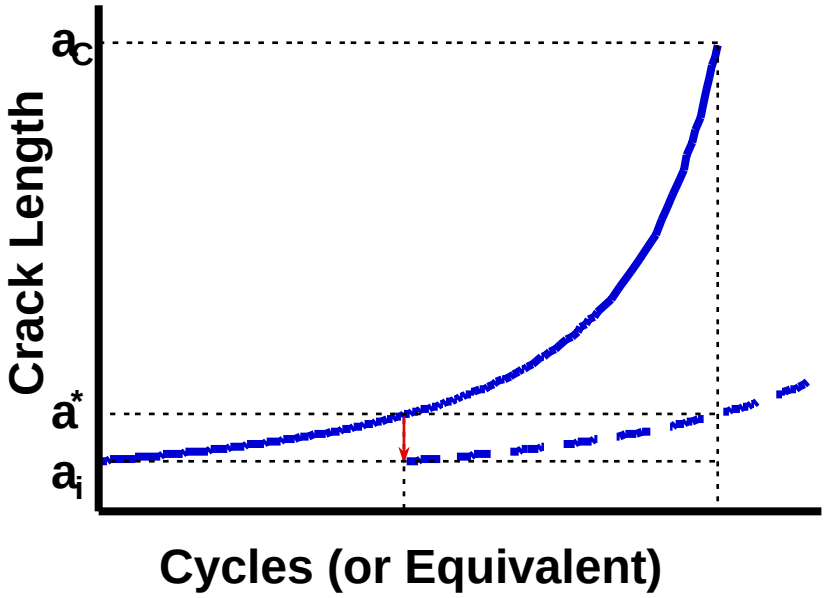
Low-Cycle-Fatigue Design Criteria (safe life)

- Based on statistical lower bound
- 1 in 1000 components predicted to initiate a 0.8 mm crack

Damage-Tolerant Design Criteria (fracture mechanics)

- Deterministic
- 1 or 2 safety inspections during service life

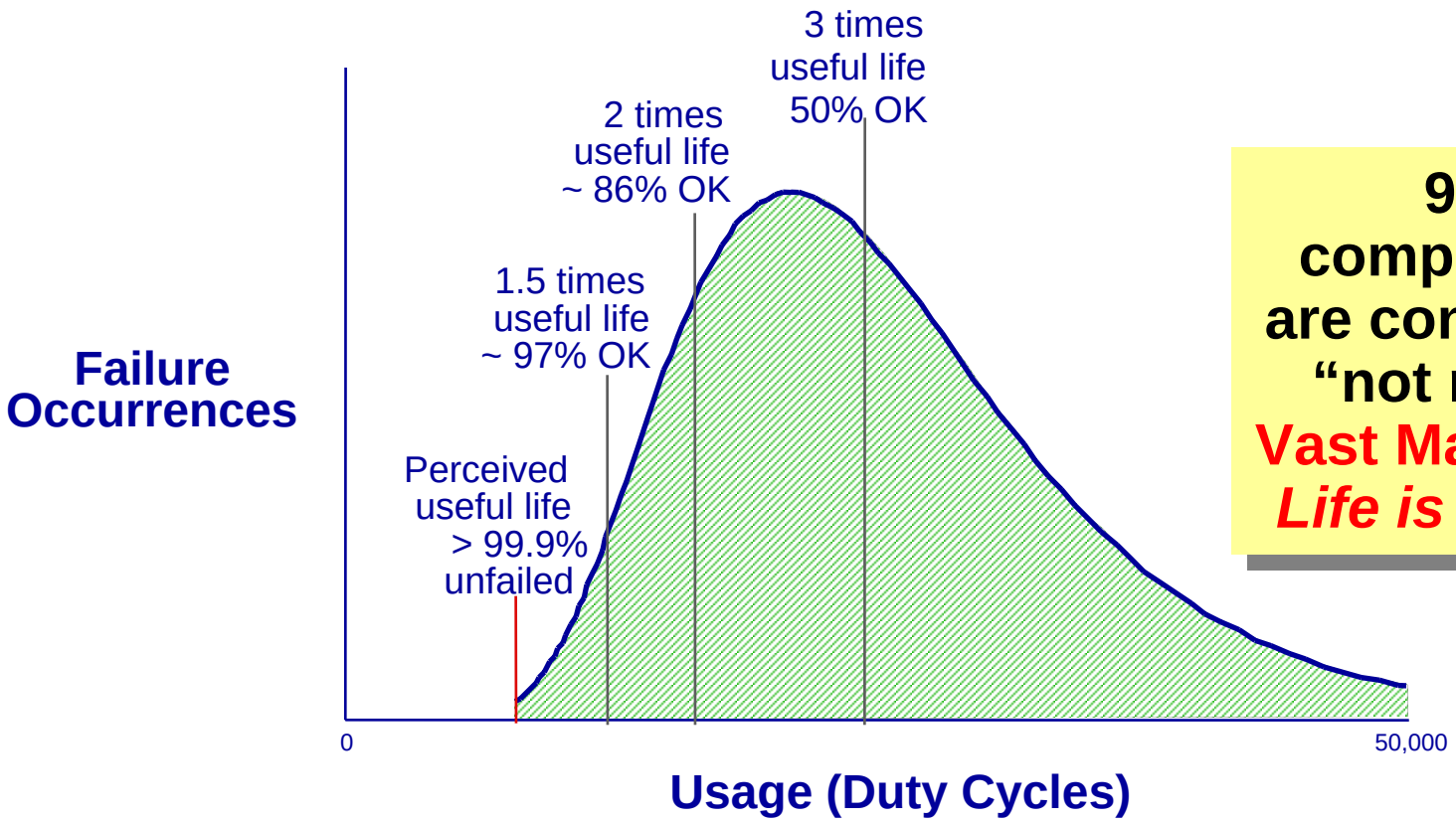




Both design criteria are met at all critical locations on a component

Current Safe-Life Approach for Low Cycle Fatigue

Throw away 1000 components to remove the unknown one
that is theoretically predicted to be in a “failed state”



999 components are considered “not ready”
Vast Majority of *Life is Wasted*

Log normal distribution viewed on a linear scale
~ one order of magnitude assumed for ±3σ
Median at 24,000 cycles, - 3σ at 8,000 cycles

Life Management
Driven by Uncertainty

Inspect

Empirical Criteria

(Cycles or Flight Hours)

Decision

Database:
Mission History and Design

Yes → Service

"Book Life" Today

Failure Occurrences

Book life:
1 out of 1000
damaged

Usage (Duty Cycles)

NO → Retire

Prognosis will Enable Transformation in Asset Management

Dr. Leo Christodoulou
DARPA DSO DEFENSE SCIENCES OFFICE

Failure physics, damage evolution, predictive models

Interrogation

State Awareness

Prognosis

Yes → Service

"Book Life" Today

Failure Occurrences

"Book Life" Tomorrow

Usage (Duty Cycles)

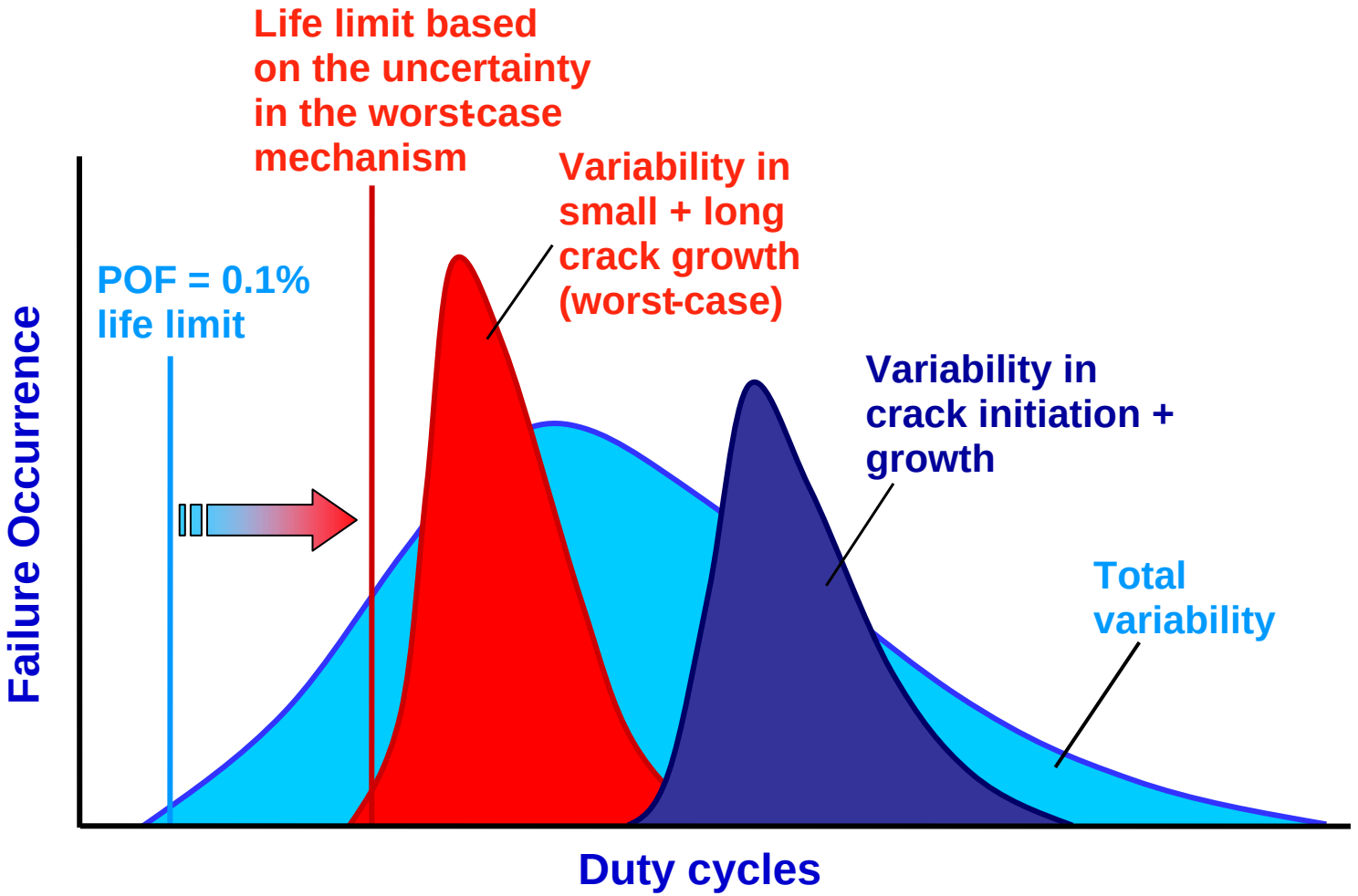
Reduce and Manage Uncertainty

NO → Retire

Engine Maintenance Logistics Infrastructure (EMLI) [CBM+; AF/A4I]

Prognosis Translates Knowledge and Information Richness to Physical Capability

An Alternate Paradigm of Fatigue Variability



Prognosis: Health Monitoring & Asset Management

Material Monitoring

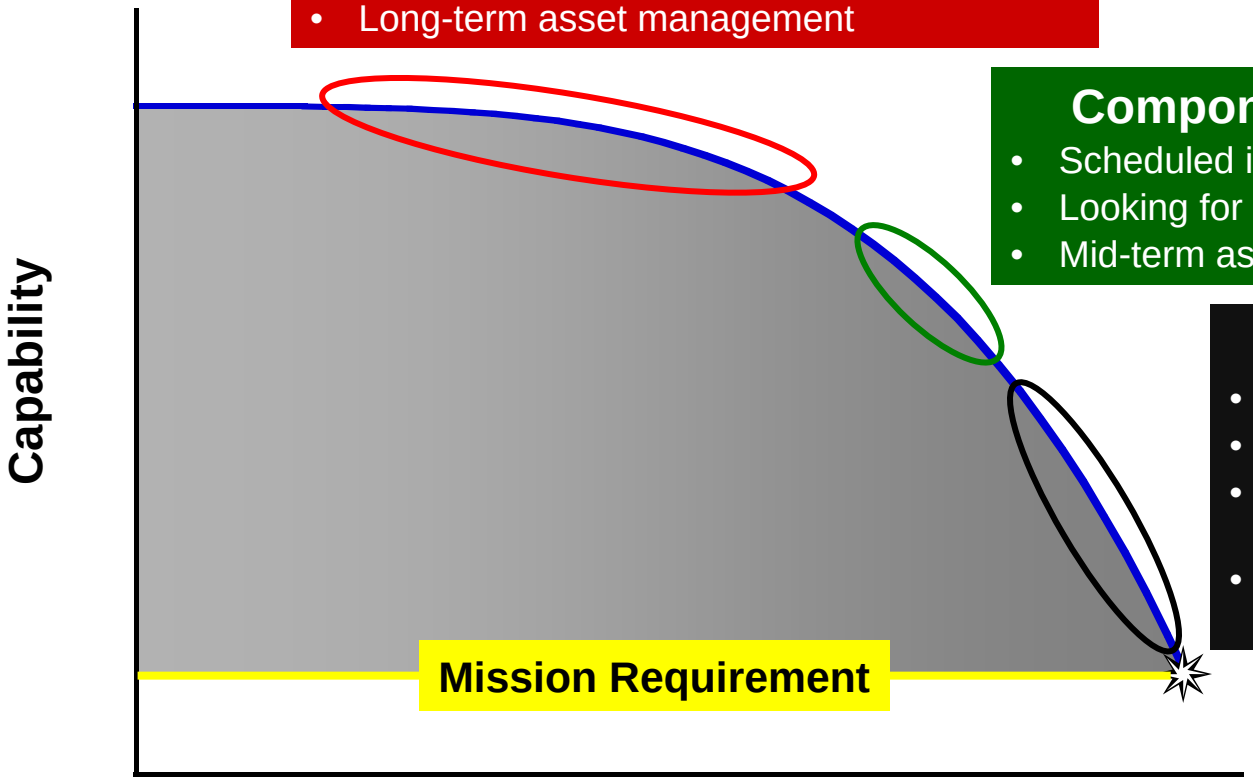
- Global characteristics / continuum damage
- Identify tails of life distribution
- Long-term asset management

Component Monitoring

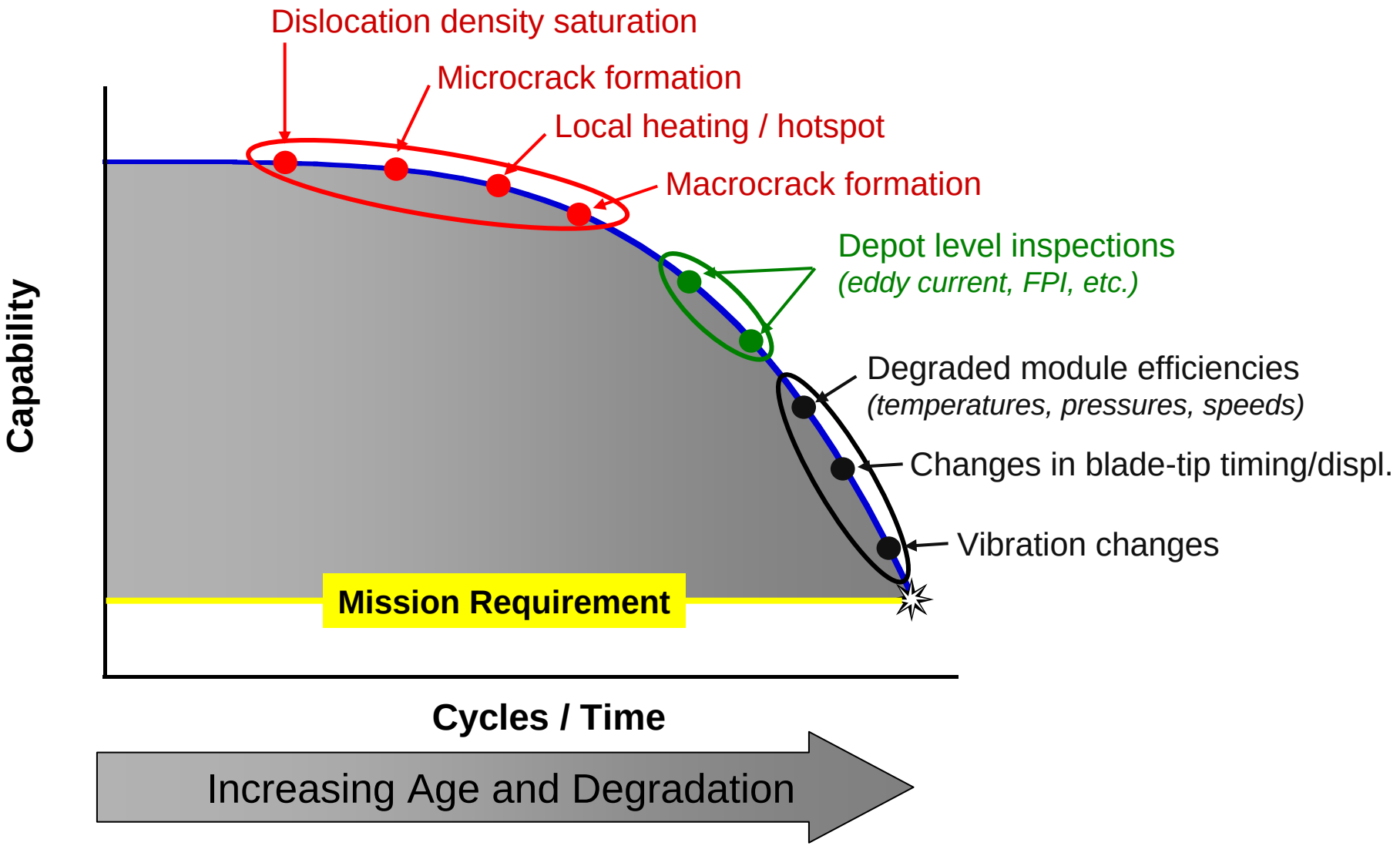
- Scheduled inspections
- Looking for local damage / cracks
- Mid-term asset management (years)

System Monitoring

- Continuous
- Rate of damage progression
- When CAPABILITY approaches MISSION REQUIREMENT
- Short-term asset management (months / weeks)

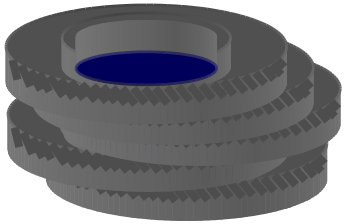


Prognosis: Fatigue Damage Characteristics

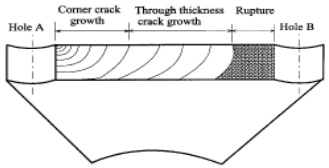


Life Management of Turbine Engine Disks

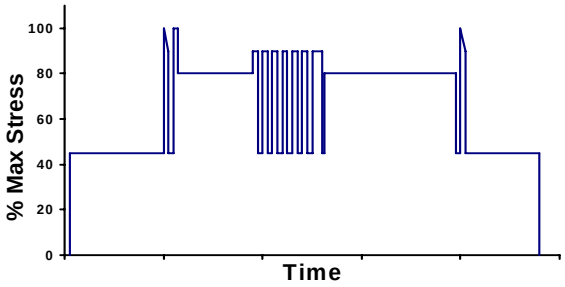
Tools for Physics-based Prognosis AFRL



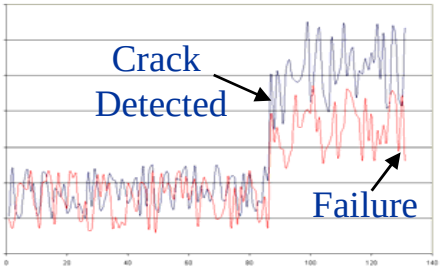
Retired components



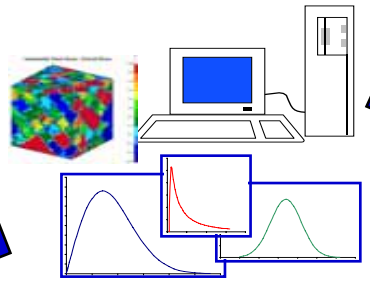
Damage Hot spots identified



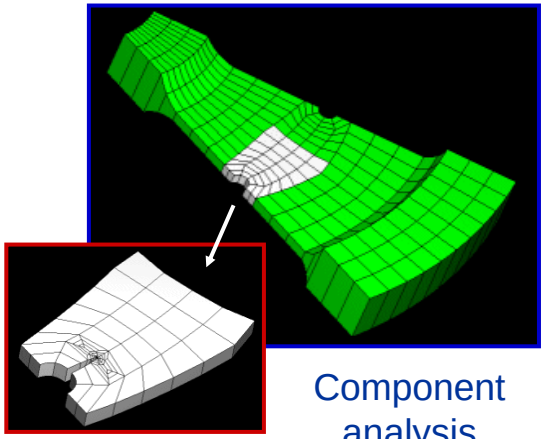
Effect of Mission Loading assessed analytically & experimentally



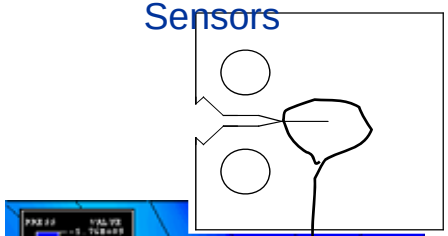
State Awareness Sensors

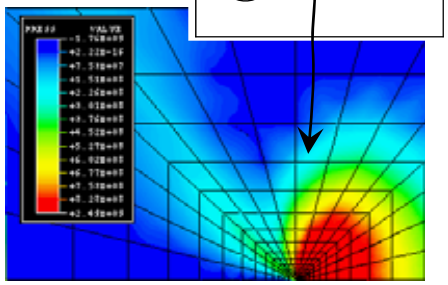


Physically Based Life Prediction Models
(Incorporating State Awareness Tools And Probabilistics)

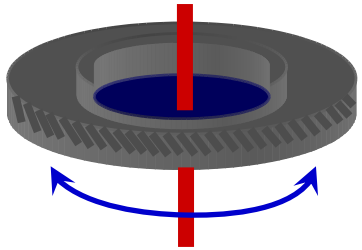


Component analysis





Laboratory specimen experiment & analysis



Component spin-pit demonstration

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Validation

Summary

- **Implications of the Engine Structural Integrity Program (ENSIP)**
  - **Safe-life + damage tolerance**
- **DARPA Engine System Prognosis (ESP) vision**
  - **Integration of state awareness and usage information**
  - **Reasoning to determine health**
  - **Risk based prediction of future capability**
- **Validation and certification to support risk-base life, capability, and logistics management**