

Achieving the Potential of Materials Prognosis for Turbine Engines

**DARPA Bidders Conference
on Materials Prognosis
26 September 2002**



**J.M. Larsen, S.M. Russ,
A.H. Rosenberger, R. John,
T. Fecke*, and B. Rasmussen**

Materials and Manufacturing Directorate

*** Propulsion Directorate**

Air Force Research Laboratory

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2002		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Achieving the Potential of Materials Prognosis for Turbine Engines				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Materials and Manufacturing Directorate Propulsion Directorate Air Force Research Laboratory				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 25	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			



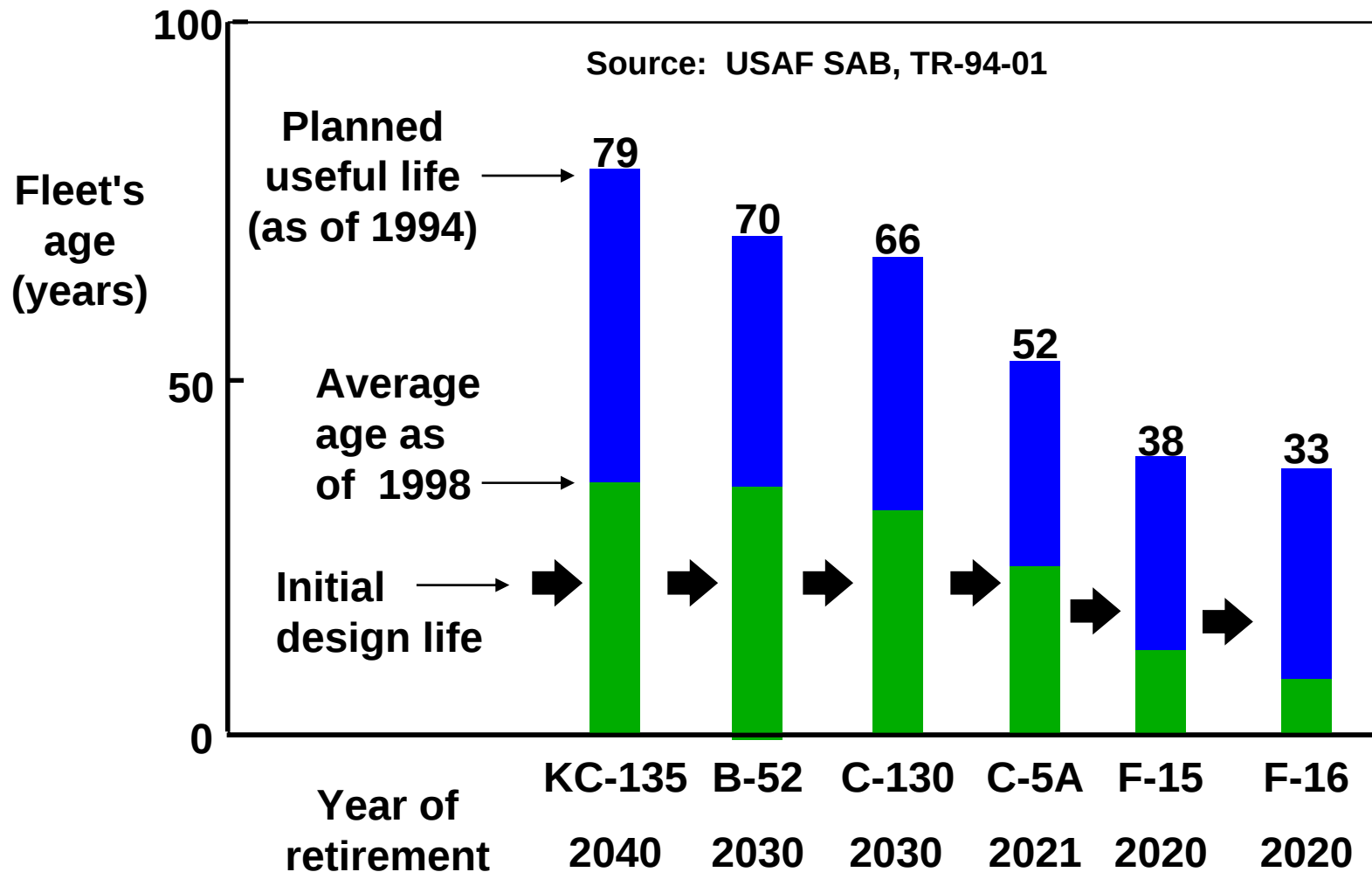
Overview



- **The need for Materials Prognosis of turbine engines**
- **Science and technology outline for Prognosis of Turbine Engine Materials**
- **Future applications and opportunities for technology transition**

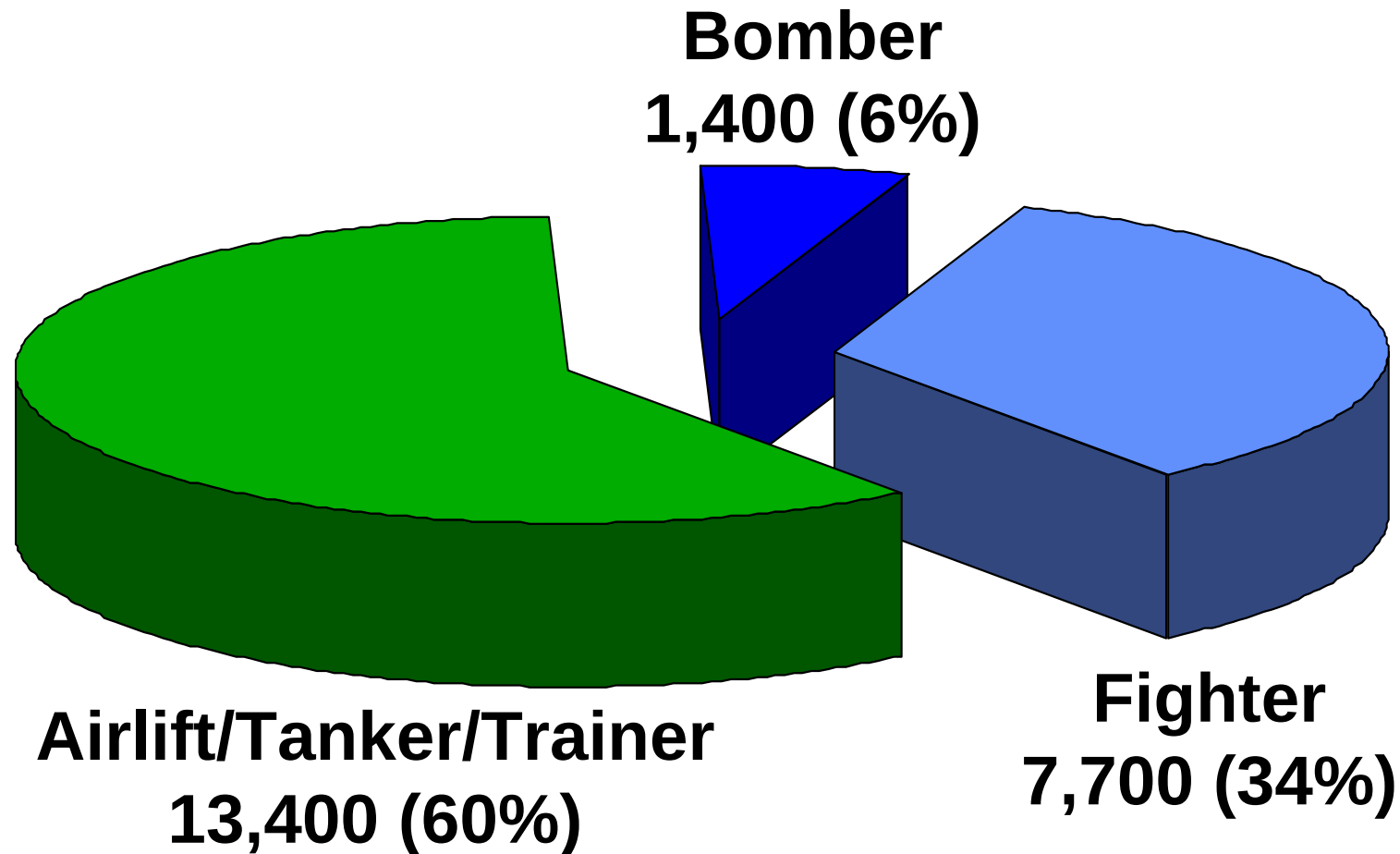


Many Aircraft Systems Now In A Second Life





USAF Propulsion Product Group Engine Inventory



~ 22,500 Engines / \$33.3B Value



Field Maintenance



**Reliability Improvements Are
Riding on the Backs of our
Maintainers with Additional
Borescope and Engine
Inspections**



Field Maintenance



**Those of Us in 72°F
Climate-Controlled Offices
Have a Responsibility to
the Maintainers Who
Often Have to Do Their
Jobs in 120°F Heat or
- 40°F Cold...**



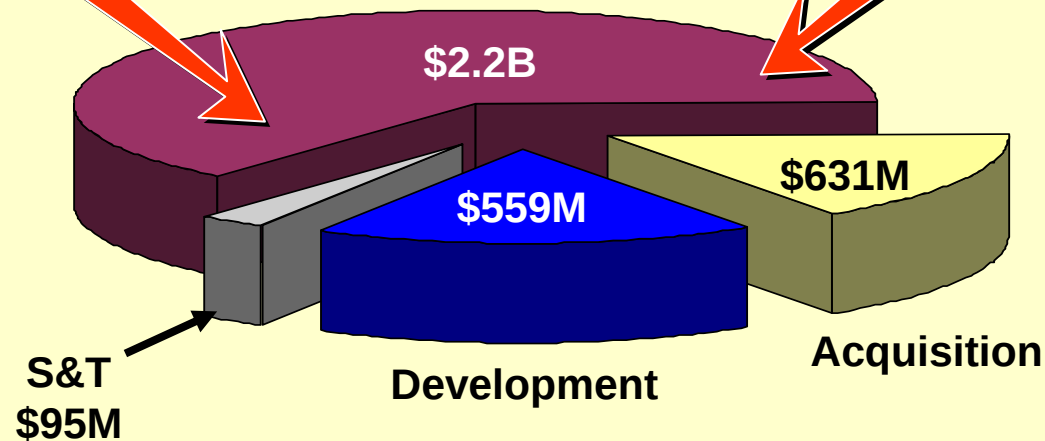


Engine Sustainment Burden



USAF Gas Turbine Propulsion Budget

Sustainment (63%)



* FY00 USAF Budget+Sources



Problem

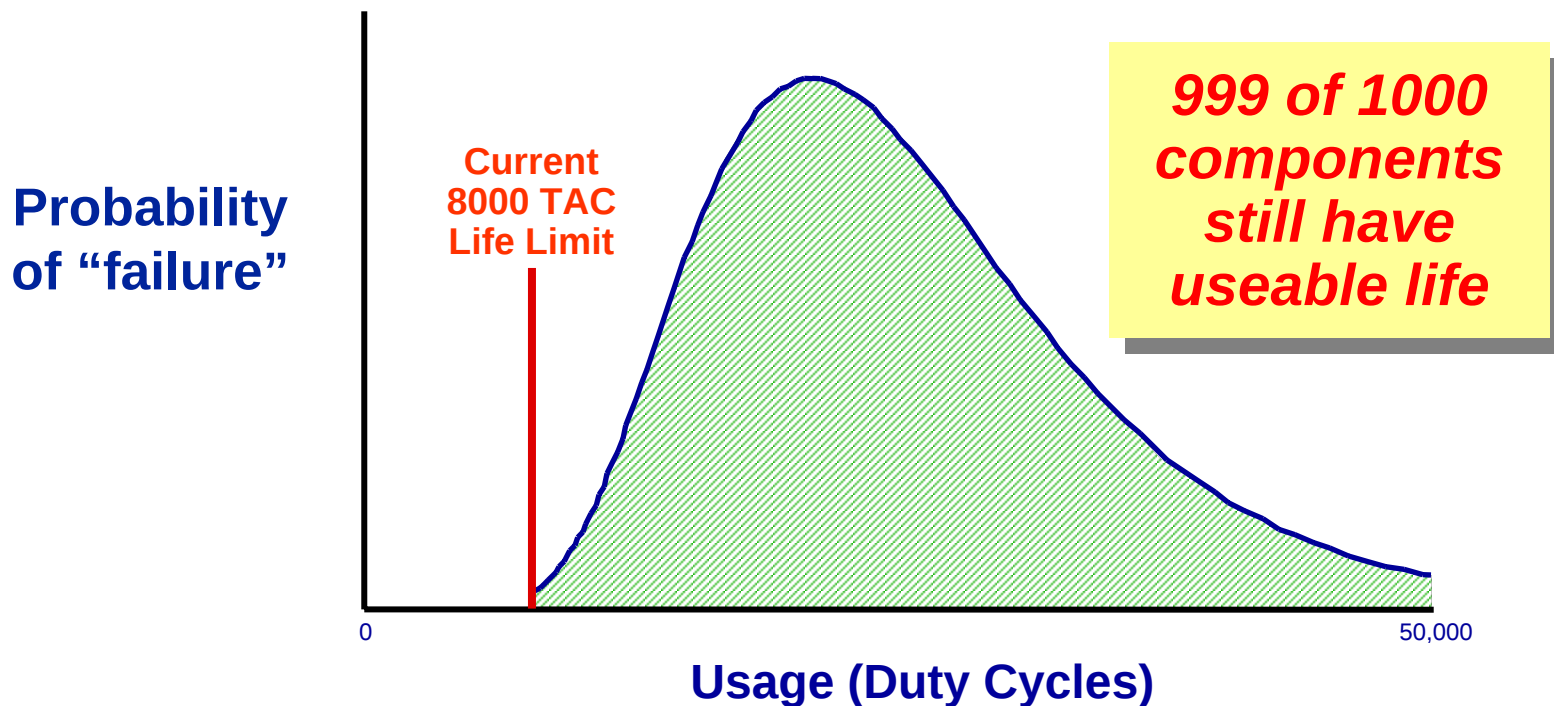
Turbine engine disks must not fail





The Problem / Opportunity

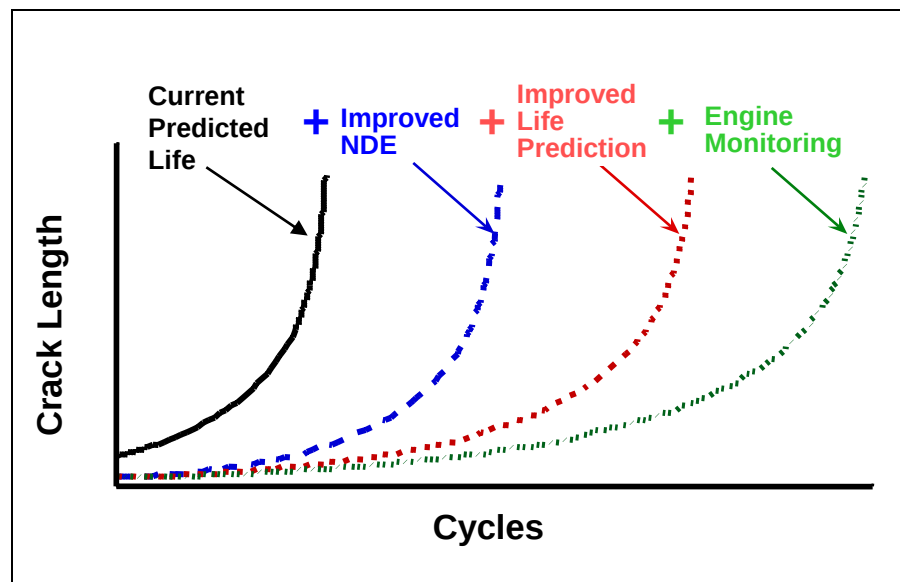
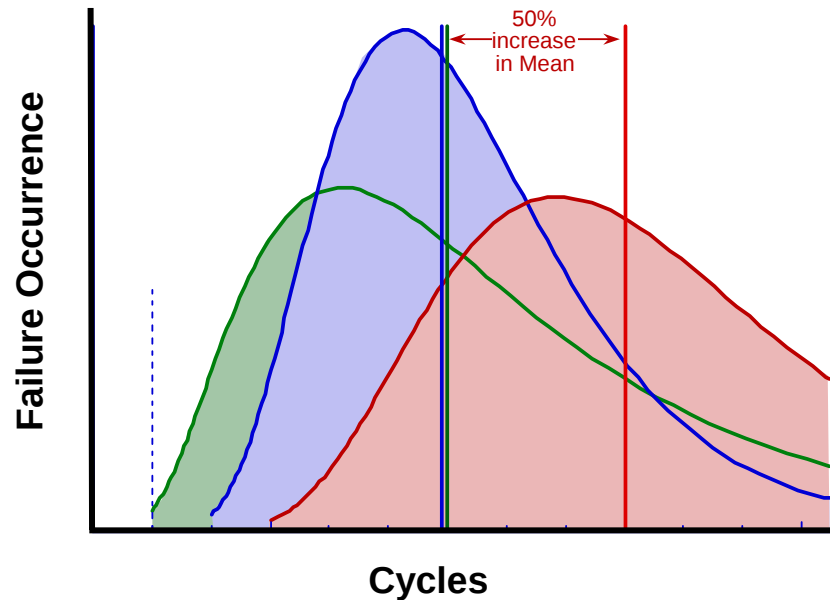
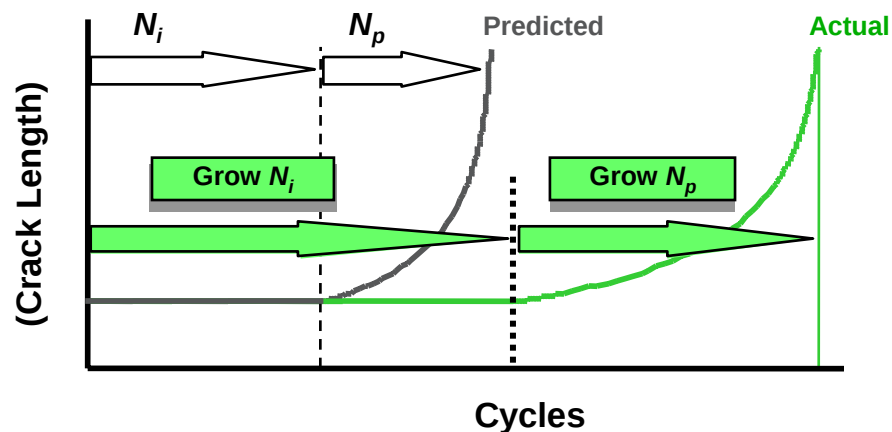
We currently throw away 1000 components to remove the unknown one that is theoretically predicted to be in a “failed state”



Goal: Recover wasted life without increasing risk



Life Prediction Potential for Improvements





High-Payoff Demonstration Problem: Turbine Engines



- Turbine engines are the primary powerplant for all DoD Services
- Turbine engines represent a crucial, high technology system, that often controls asset readiness
- Turbine engines contain a wide variety of components, and pose a range of levels of difficulty for Materials Damage Prognosis:
 - Disks, blades, vanes, cases, bearings, shafts
 - Range of materials, temperatures, damage modes, and usage and state-awareness sensors
 - Hot flow path is a particularly aggressive environment, requiring improved tools for health assessment and prediction
- Development of Materials Prognosis science and technology offers a major payoff for both the military and commercial sectors:
 - Safety
 - Readiness
 - Asset management
 - Reliability
 - Life extension
 - Reduce maintenance burden



DARPA - Materials Prognosis



Engine Health Monitoring



Real-time Usage Data

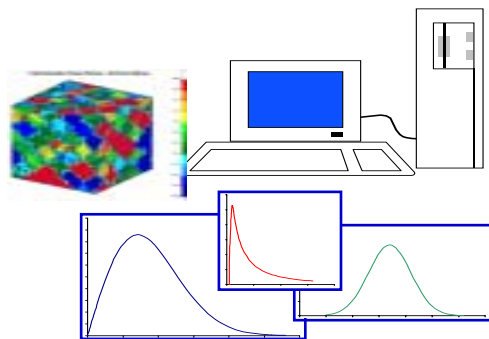


Robotic Inspection "Worms"

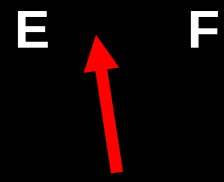
Materials Prognosis:

- **Physics of failure**
- **Interrogation techniques**
- **Feature extraction**
- **Mission Needs**

Physically-Based Probabilistic Life-Prediction Models



Engine Health



Life Gauge

- Life prediction will analyze real-time data, learn, & calculate remaining life
- Sensors will evaluate the state of assets, and mission trends
- Future-mission needs and life calculations will dictate asset allocation



Vision: Materials Damage Prognosis for Turbine Engines



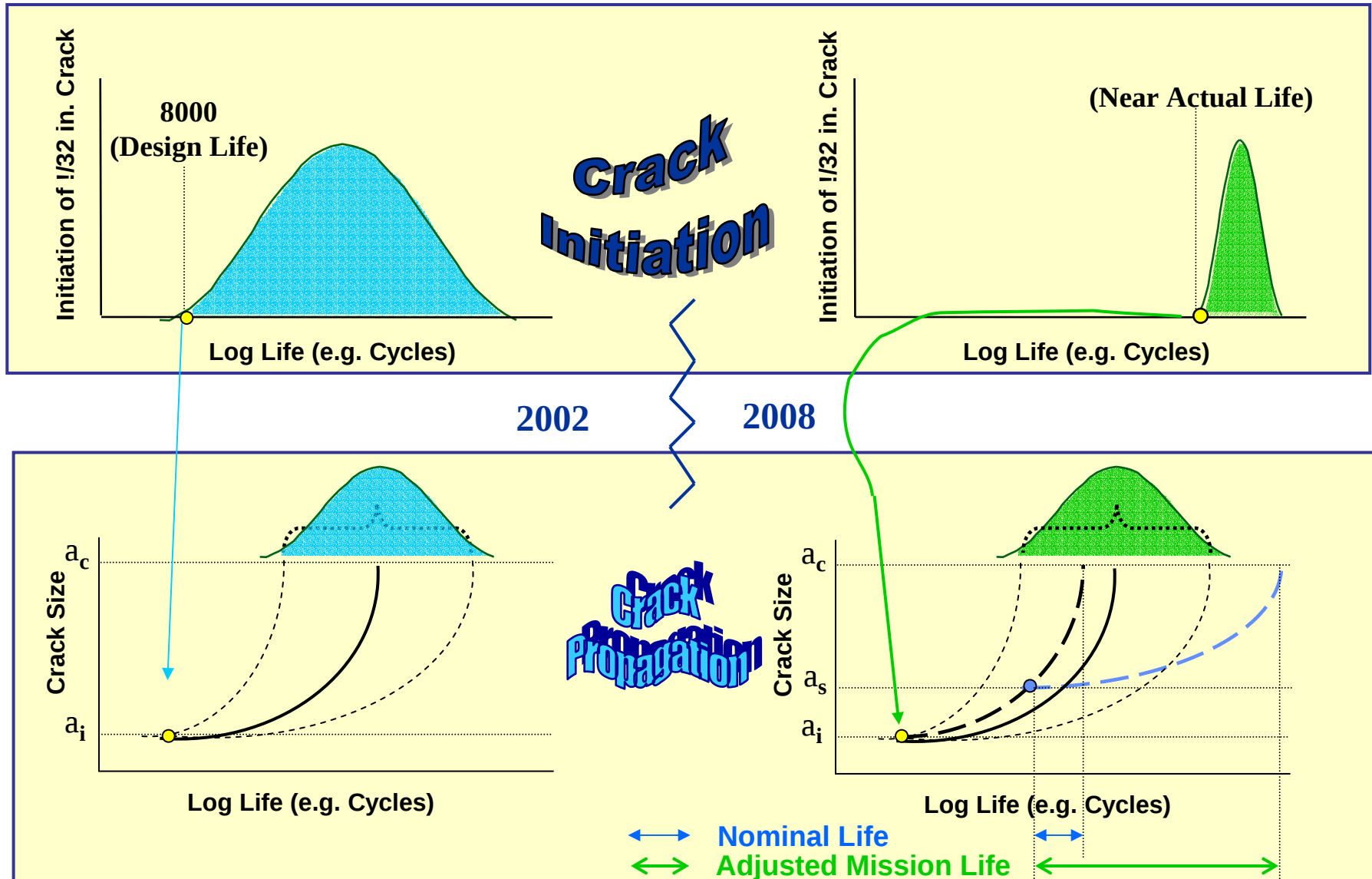
VISION: Develop tools for a reliable, robust, quantitative, integrated life assessment and management system using physics-based models enhanced by information from state-awareness sensors

Key science and technology disciplines

- **Coupled physics-based models of materials damage and behavior**
 - Interaction of multiple damage/failure mechanisms
 - Multi-scale, mechanism-based
 - Microstructurally-based stochastic behavior
 - Integrated information from state-awareness tools
- **Interrogation of damage-state**
 - Intelligently exploit existing sensors
 - Feature extraction from global sensors
 - Materials-damage-state interrogation techniques and recorders
- **Data management and fusion**
 - Component history and pedigree
 - Component usage data
 - Capability matched to mission



Benefits of Prognosis for Turbine Engines

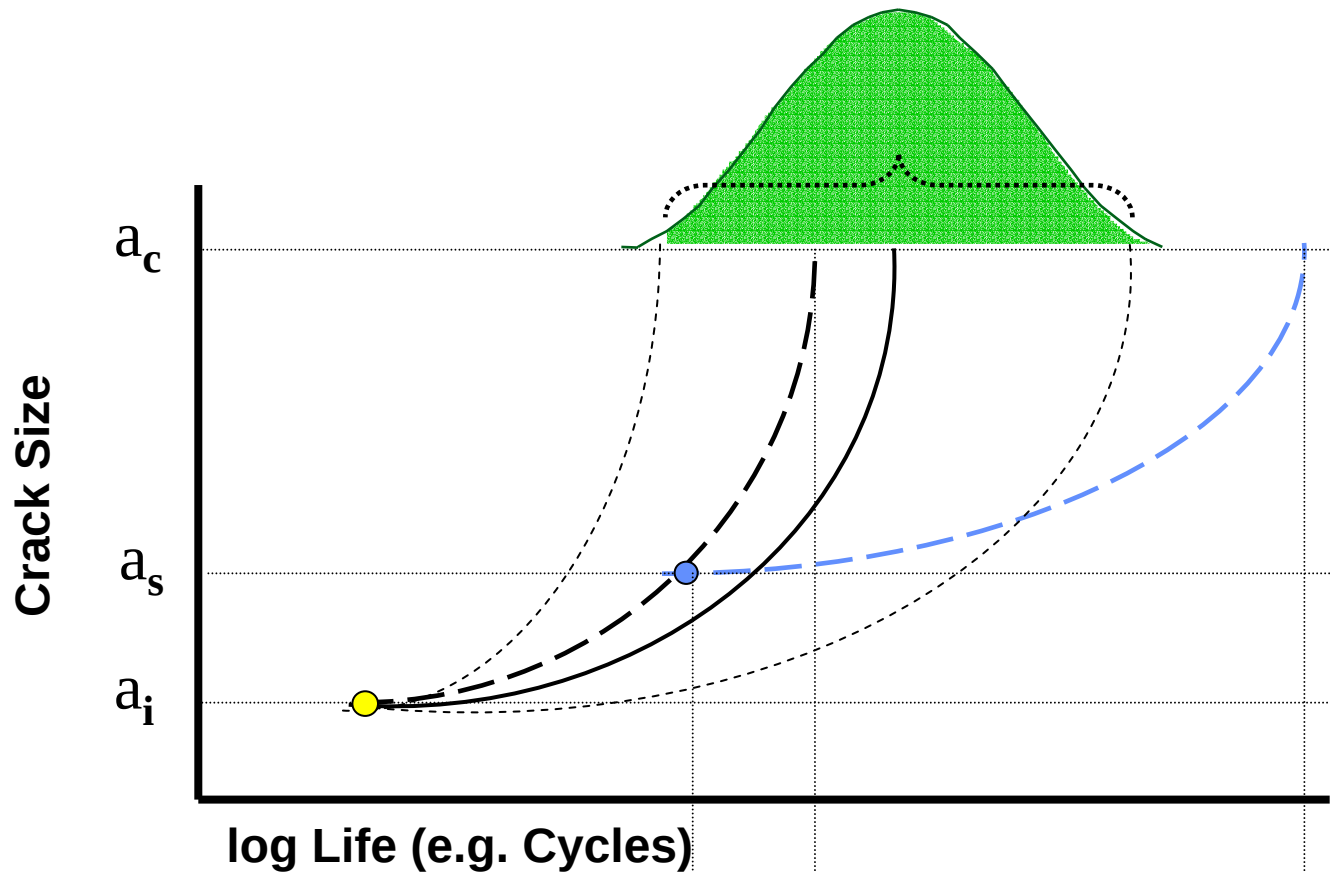




Benefits of Prognosis for Turbine Engines



Crack Propagation



↔ Nominal Life

↔ Adjusted Mission Life

↔

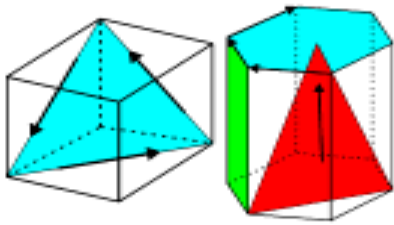
↔



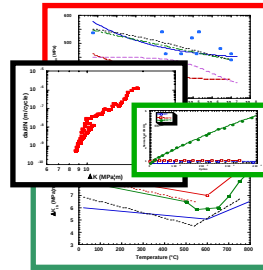
Physics of Failure

Model Development

Crystal Plasticity Models



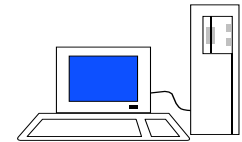
Auxiliary Models



- Subscale Processes
- Subscale Properties
- Defect Distributions
- Microstructural Data
- Residual Stresses

Scalable Computational Models and Algorithms

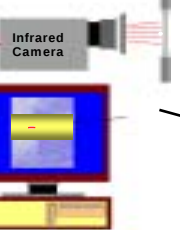
- Explicit FEA
- Adaptive Meshing
- Multi-scale Models



**Physically Based
Life Prediction Model**

Model Validation

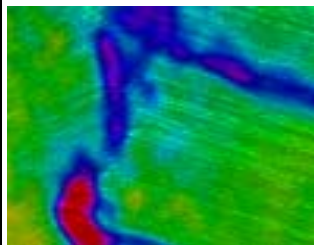
IDDS



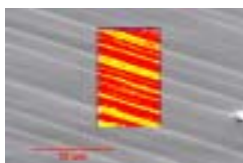
Interactive Analysis
and Experiment



Deformation
Field Mapping



OIM

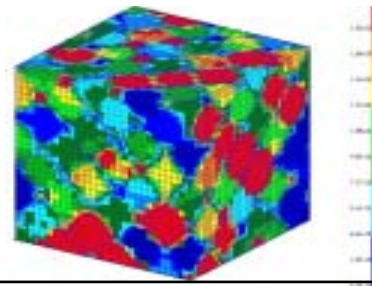
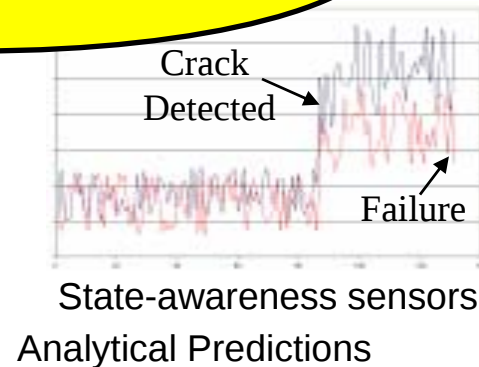
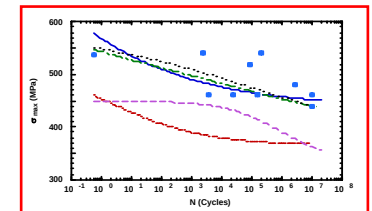


Conventional
Testing



Life Prediction

Probabilistic Material
Characterization



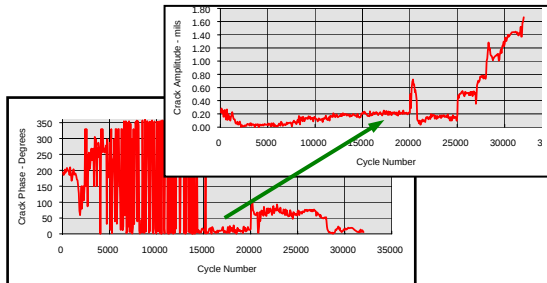
**Crack Initiation and
Growth Prediction**



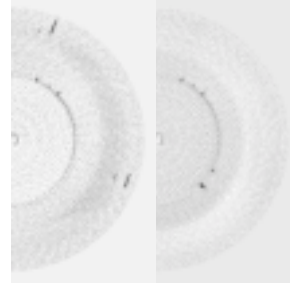
Interrogation Techniques

Crack Detection

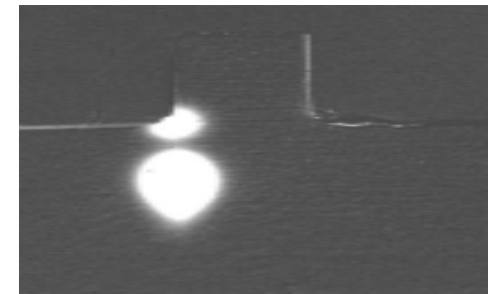
In-situ Monitoring



Whole-field Imaging



Off-line Inspections

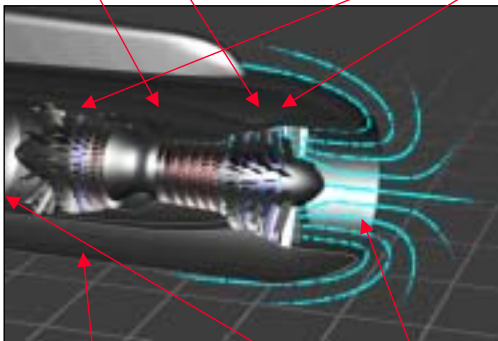


State-Awareness Interrogation

Holistic Monitoring

Eddy Current or Capacitance Sensors

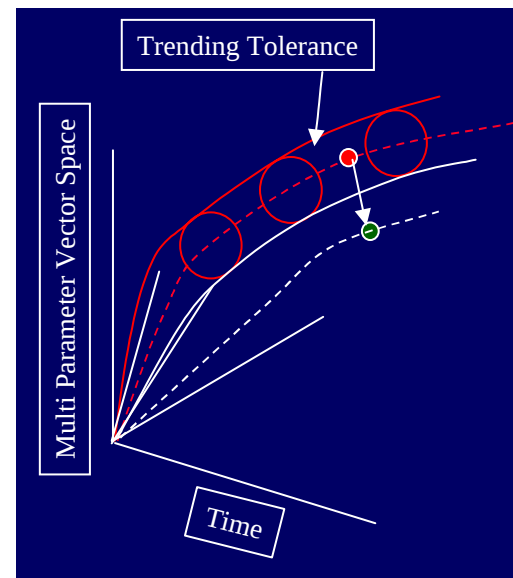
Vibration Monitors



Oil Analysis

Electrostatic Debris Monitors

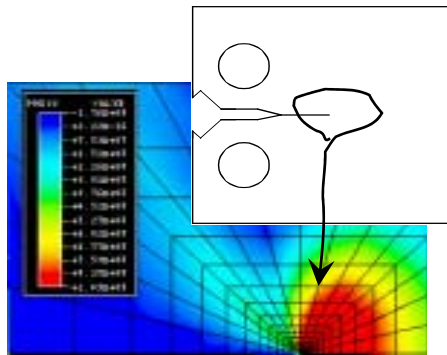
Engine Parameter Trending



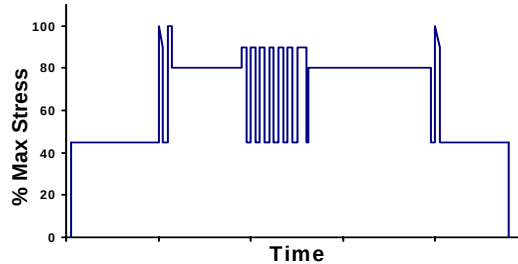
- Metal Temperatures
- Rotational Speeds
- Pressures
- Other ...



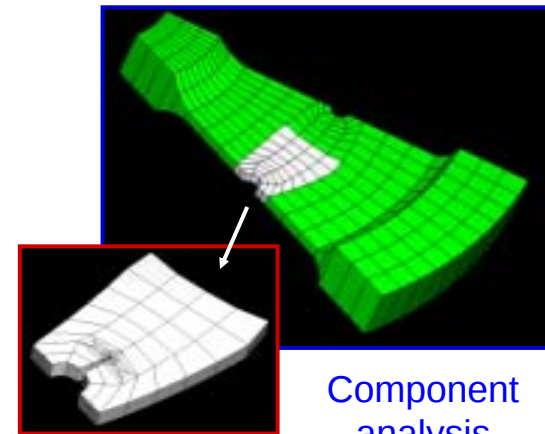
Component Damage Assessment and Prediction



Laboratory specimen experiment & analysis



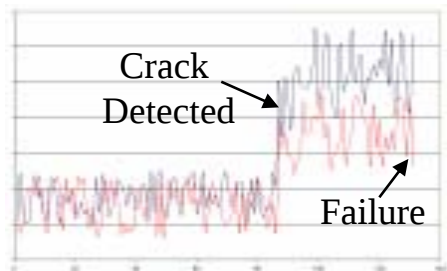
Effect of mission loading



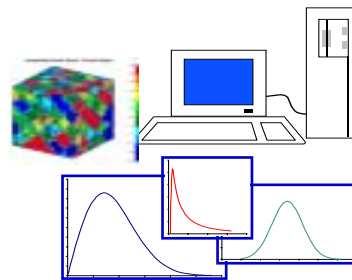
Component analysis



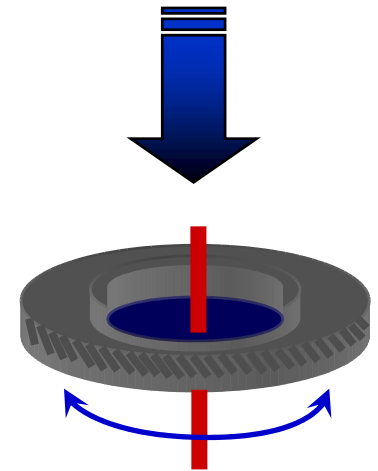
Field experience



State-awareness sensors



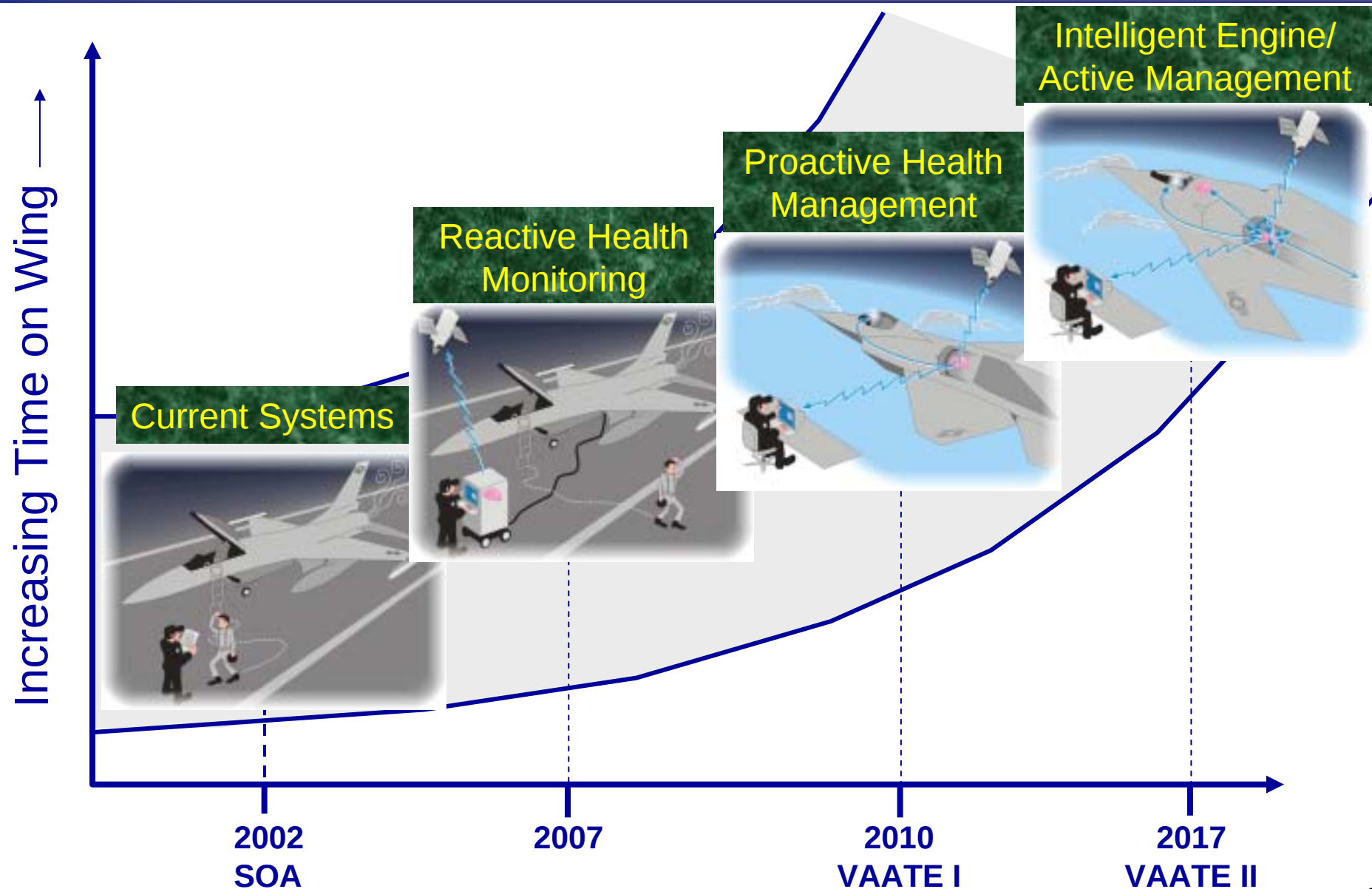
Physics-based
Life Prediction Models
(incorporating state-awareness
input & probabilistic tools)



Component demonstrations



Engine Health Management Time-Phased Descriptors





Turbine Engine Science and Technology Plan

Tri-Service/NASA/Industry Coordinated



Integrated High Performance Turbine Engine Technology (IHPTET)...Constant Life (F119)

- 2X Propulsion Capability
 - +100% Engine Thrust/Weight
 - 40% Fuel Burn
 - 35% Production & Maintenance Cost
- National HCF S&T Program



Versatile, Affordable, Advanced Turbine Engines

- 10X Propulsion Affordability (Capability / Cost)
 - National Durability Program
 - Maintenance Friendly Versatile Core
 - Ultra-Intelligent Adaptive Engine
- Environmental Efficiencies
- Dev/Prod/Maint Cost Reduction Focus

TODAY

1987

2002

2005

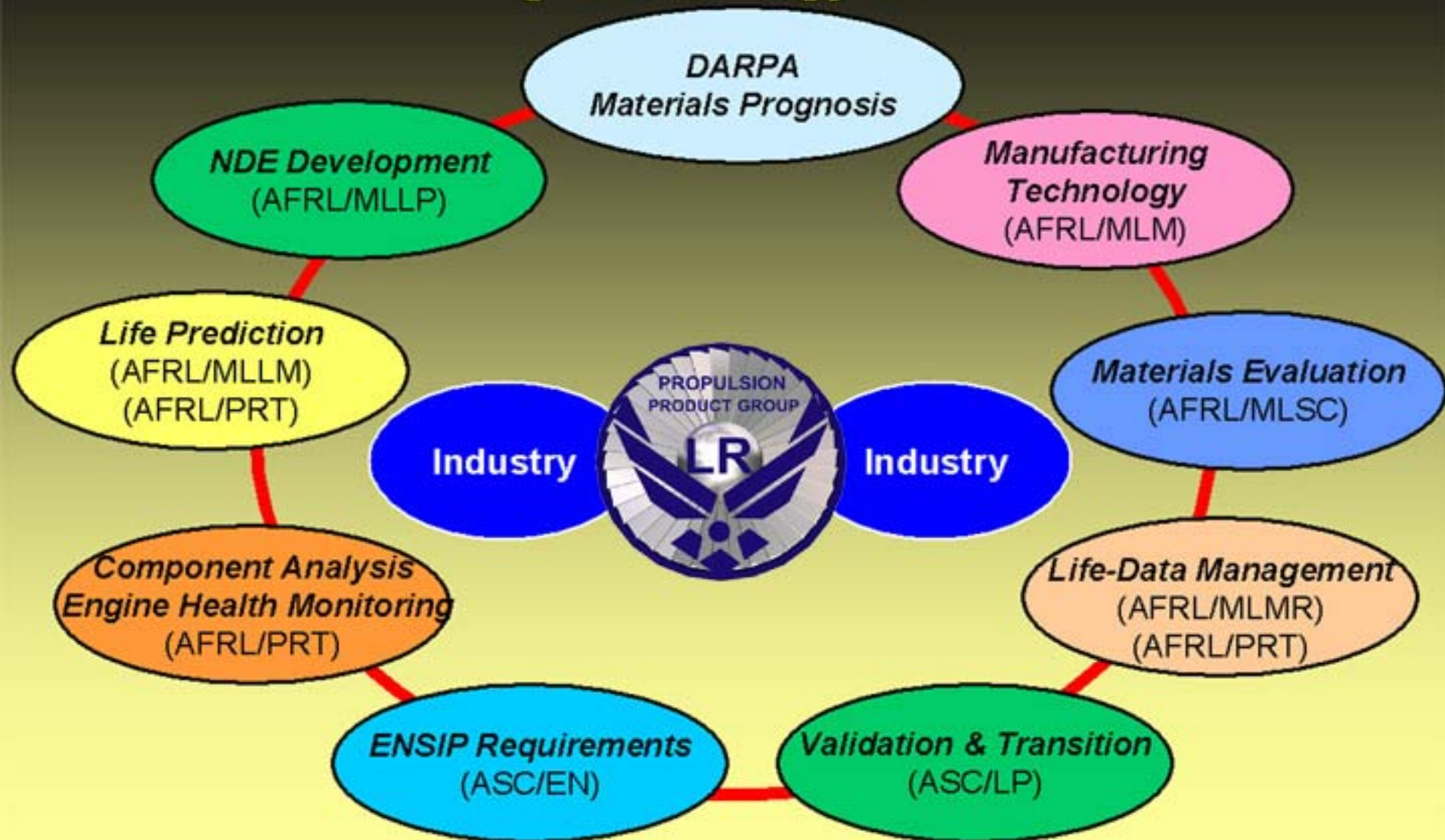
2017



Engine Life Management



Enabling Technology Transition





Transition to Service



“The Materials Prognosis Program has huge potential for us in the propulsion community, both today with our legacy engines, and for the future engines like JSF, as well as those which will be derived from the AFRL VAATE initiative.”



**Mr. Timothy Dues, SES
Manager, Propulsion Product Group
U.S. Air Force
17 September 2002**



“Materials Prognosis: Integrating Damage-State Awareness and Mechanism-Based Prediction”

San Diego, California, USA, March 2-6, 2003

In conjunction with the 132nd Annual Meeting & Exhibition of TMS

Sponsored by: Structural Materials Division

Program Organizers: James M. Larsen: Air Force Research Laboratory - 937-255-1357
Leo Christodoulou: Defense Advanced Research Agency - 703-696-2374
J. William Hardman: Naval Air Systems Command - 301-757-0508
Andrew Hess: Naval Air Systems Command - 703-604-6033, ext. 223
J. Wayne Jones: University of Michigan - 734-764-7503
Stephan M. Russ: Air Force Research Laboratory - 937-255-1356

Scope: This symposium is intended highlight scientific tools and approaches for development of a comprehensive damage prognosis technology for materials. The objective of such a prognosis capability is to enable continual assessment and prediction of the current and future health of materials in a complex mechanical system or subsystem, such as a turbine engine, helicopter gearbox, or aircraft. The ultimate goal is the development of quantitative models that relate a system's-level structural response to material's-level microstructural events.

Areas of emphasis include:

- (1) methods for in situ interrogation of the damage state of a material, such as that from fatigue and/or creep,
- (2) physically-based models of the formation and growth of material damage under realistic loading, and
- (3) coupled state-awareness and life models, including probabilistic and uncertainty approaches. The symposium is expected to attract participants from diverse but interdependent disciplines including materials science, mechanical engineering, physics, and diagnostic state-awareness engineering



General John Jumper Chief of Staff, USAF



General John Jumper
Chief of Staff USAF

“the two most important things we do: flying and fixing airplanes.”

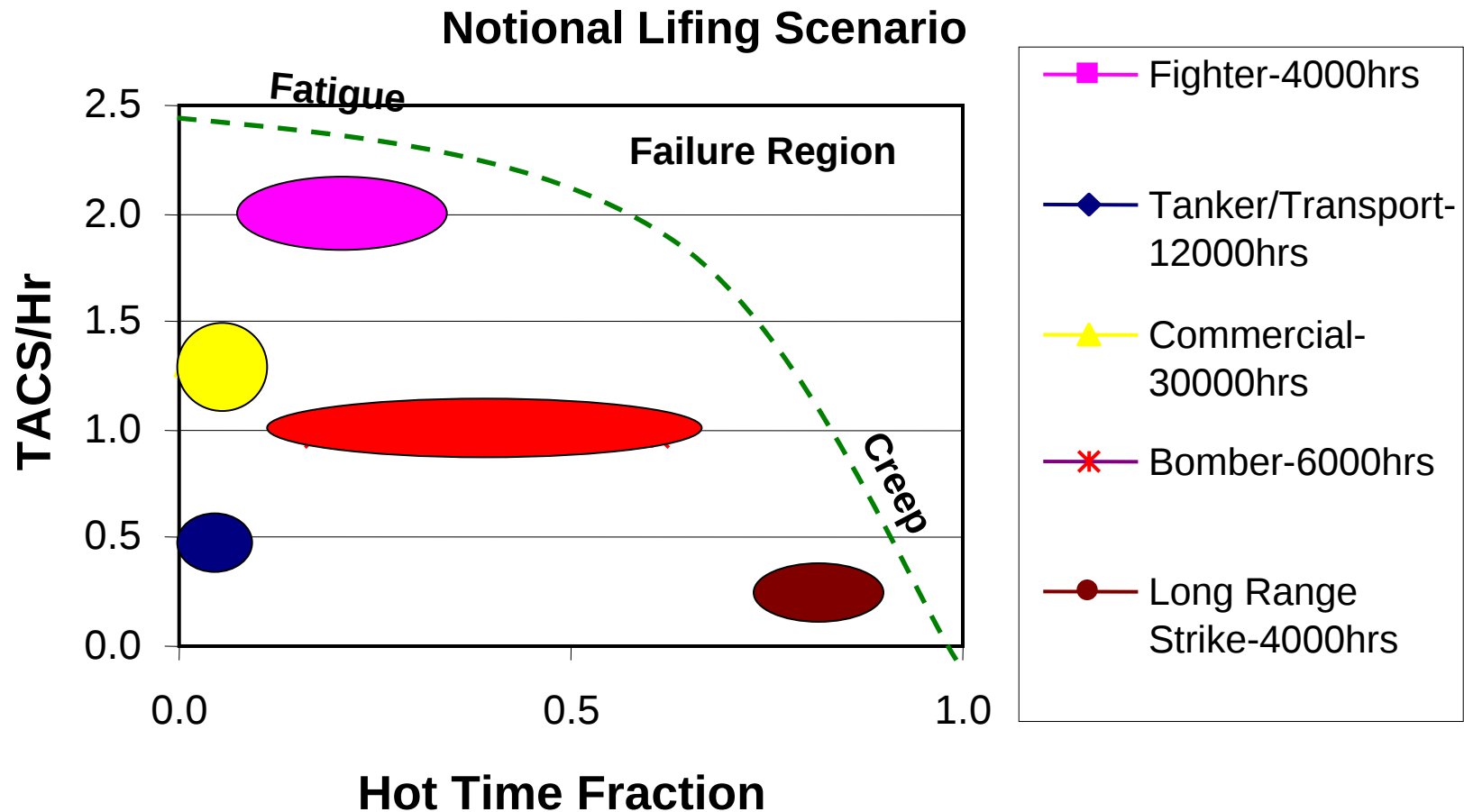
That doesn't mean that you're not important if you're not pulling on a pole in the cockpit or turning a wrench on the flightline. It means that the importance of the rest of us is how we contribute to flying and fixing airplanes.”

Source Air Combat Command News Service:
“Jumper looks back, looks ahead”
Released: Aug. 30, 2001



Durability Failure Modes

Modes are Mission Dependent



Need a method to compare multi-application life requirements, while maintaining common parts