Prognosis:
A New Fleet Management Strategy

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Enterprise Technology Strategy
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Acknowledgements

Organizing Committee

DARPA

AFRL
NAVAIR

DARPA teams on Prognosis

GE

Northrop Grumman (Will use Structural Integrity Prognosis System (SIPS) as an example)

Pratt and Whitney

The Boeing Company

Premise of Prognosis

1. Operational advantage can be derived from the ability to predict the future performance of individual platforms.
2. System capability/performance (and ultimate failure) is predictable.
3. Individual platforms can be robustly and adaptively deployed based on their current and future capability state:
    a. specific assets assigned to specific missions.
    b. mission profiles changed to remain with capability profile and still achieve desired result.
4. There is a value proposition for all stakeholders.

The Prognosis Vision

Interrogation

State Awareness

Failure physics;
Damage evolution;
Predictive models

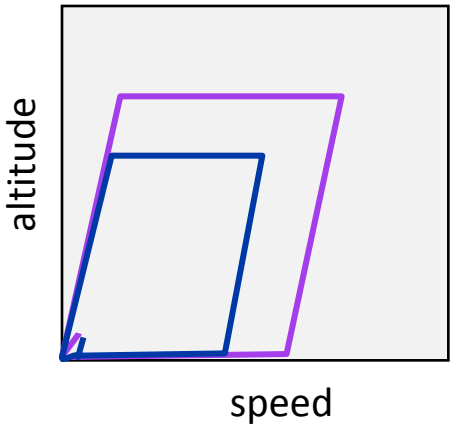
Prognosis
(Reasoning)
System

Database:
Mission History, Maintenance,
Life Extension and Design.

Go

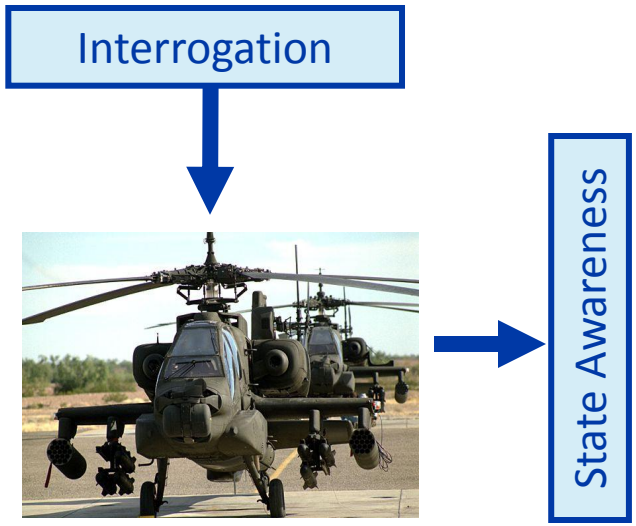
No Go

Capability Profile, e.g



Objective: Translate Knowledge and Information Richness to Physical Capability

Interrogation and State Awareness



Conceptual:

- Not inspection
- Data management

Practical:

- Local (embedded/in-situ) or global information
- Multi-spectral, -spatial, temporal
- May require external perturbation or pre-defined maneuver(s)
- Benchmarked (initially and subsequently?)
- MAY demand inspection (last resort)

Computational:

- Feature extraction
- Dimensionality reduction
- Reliable error estimation

Existing Database (History and Past Missions)

Database:
Mission History,
Maintenance,
Life Extension
and Design.

DO REALLY use past mission history.

- Identify salient features of every mission.

DO take into account knowledge of the system behavior.

- Track trends.

DO take into account maintenance history.

Exploit expert knowledge.

Leverage previous efforts.

Exploit IT revolution.

Damage Evolution

Failure physics, damage evolution, predictive models

Use knowledge of applicable physics.

Invoke and exploit coupled and interacting mechanisms.

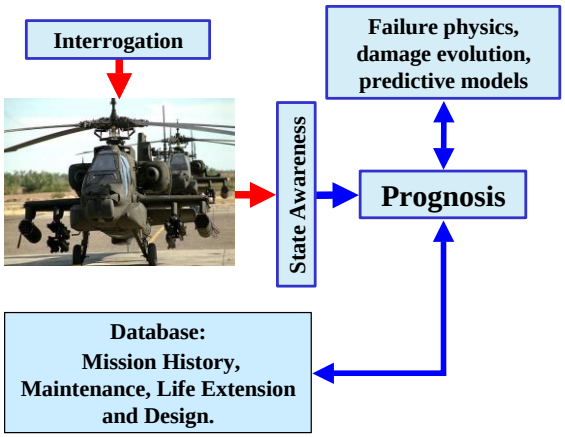
Use multiple failure models.

Physics-based and data-driven models will evolve—allow for updates.

Reduced (locally) and full (centrally) order models as necessary .

Sensors (including humans!) can modulate and inform model predictions.

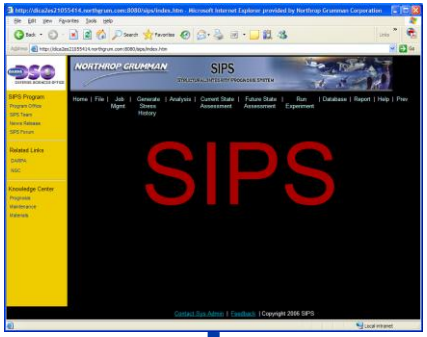
Prognosis (Reasoning) System

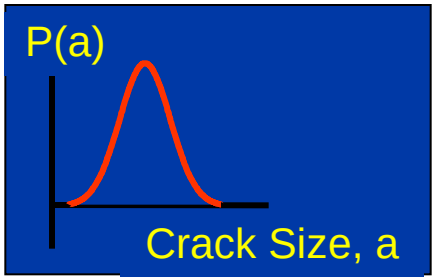


- Integrates of all elements, system knowledge and logic
- Predicts capability (not just status)
- Provides multiple decision makers the required information (operator,/local commander, theatre director/enterprise director, maintenance, etc.)
- Provides confidence levels on predictions
- Employs sophisticated and evolving “reasoners”
- Conveys pertinent information for easy assimilation
- Relies on local and rapid e.g. onboard (reduced) response and more complete at control center system models
- Benchmarked at convenient times and locations
- Based on open and modular architecture

Prognosis Concept as Implemented by SIPS

Individual Aircraft Flight Data (CAG, SDRS, etc)





SIPS Software

- Generate Stress History
- Analysis
- Current State Assessment
- Future State Assessment
- Validation/ Benchmark
- Database

Technical Challenges and Breakthroughs

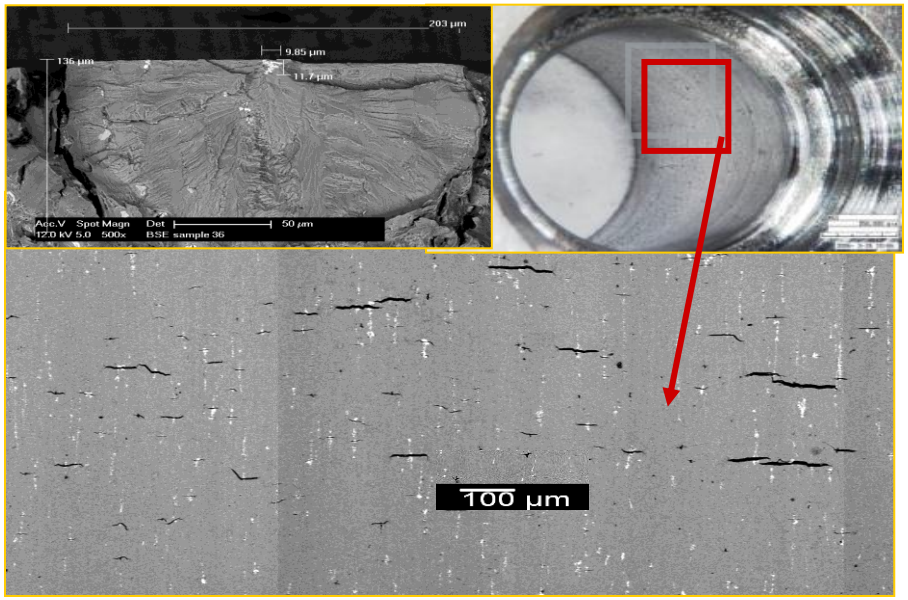
Capturing local stress state based on flight loads

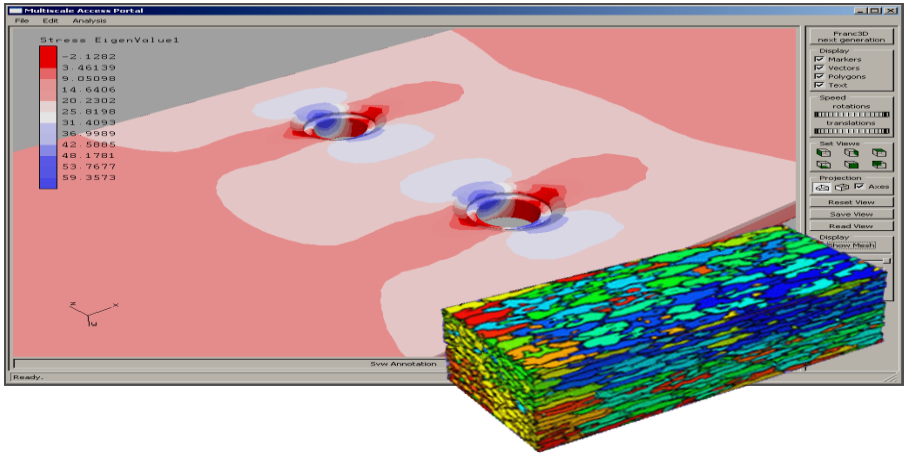
Transmitting that stress state to local discontinuities (fastener holes)

Predicting nucleation and growth of cracks

Exploiting Baysean approaches

EA-6B outer wing panel bolt hole

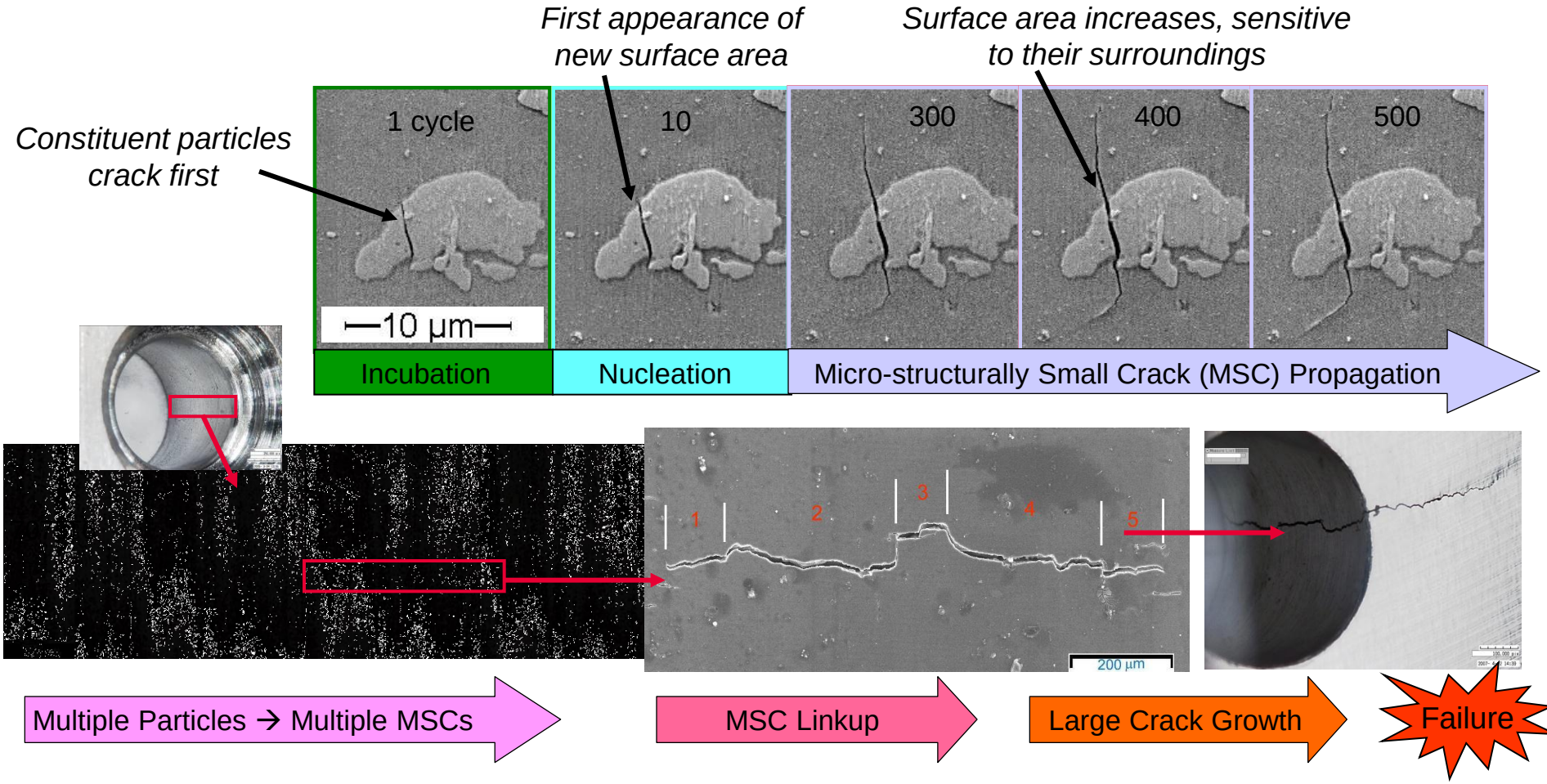




Credit & Source: Northrop Grumman DARPA SIPS team. Previously approved for public release

SIPS Models Capture Crack Physics From Initial State to Failure

Credit & Source: Northrop Grumman DARPA SIPS team. Previously approved for public release



The incubation and nucleation periods provide the crack size distribution function for the start of small crack analyses

* Typical images from multiple samples

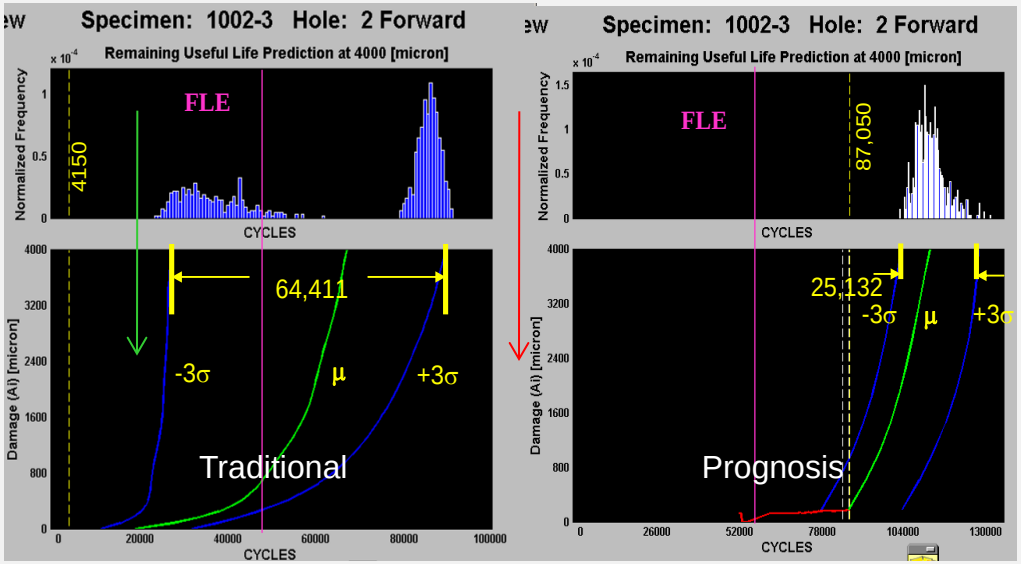
SIPS Prognosis System Output

Prognosis system output provides a probabilistic prediction of future state

Note: Also predicts early damage states

Output:

EA6B Outer Wing Panel Life Prediction



- Approximately 3-fold reduction on the uncertainty of the prediction
- Extends life expectancy from ~47,000 cycles to 87,000 cycles with no increase in risk
- SIPS verified by an 18 month flight test program on a P-3 Navy aircraft

Credit & Source: Northrop Grumman DARPA SIPS team. Previously approved for public release

There Could be Millions of Reasons for not Proceeding…

The New York Times

"The machine which will really fly might be evolved by the combined and continuous efforts of mathematicians and mechanics in from one million to ten million years"

October 9, 1903

"We started assembly today"

Orville Wright's Diary

October 9, 1903