Prognosis

Bidders Conference and Workshop

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Leo Christodoulou

DARPA/DSO

lchristodoulou@darpa.mil

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Agenda

Introduction

Objectives of the Conference Workshop

DARPA's Vision of Prognosis

Example Technology Elements (by Government team)

Poster Session, Technical and Teaming Discussions (Reception)

Example Technology Elements (by Government team)

Potential Program Implementation Plan

General Discussion, Questions and Answers

Introduction

Welcome!!! Thank you for your interest.

The Defense Sciences Office of DARPA is planning an initiative in Prognosis

- **Any initiative will depend on the availability of funds and subject to Agency priorities and other factors.**
- **If a DARPA Program is instituted it will be announced through a Broad Agency Announcement (BAA).**
- **The Government reserves the right to fund all, any or none of any proposals that are received.**
- **Only a Contracting Officer can obligate the Government (no such person is here today or tomorrow!!!)**

We look forward to your ideas and comments.

Objectives of the Meeting and Workshop

- To Share the Prognosis "vision"
- Provide you with examples of Prognosis technology elements (these are NOT prescriptive)
- Facilitate team building
- Allow the technical community to ask questions and provide feedback and ideas to DARPA

Communicating with DARPA

- www.darpa.mil/dso
- Future programs
  - Prognosis
    - Presentations from this meeting
    - FAQs and Answers
- To submit a question send e-mail to SN0223@darpa.mil

DARPA's Vision of Prognosis

Prognosis

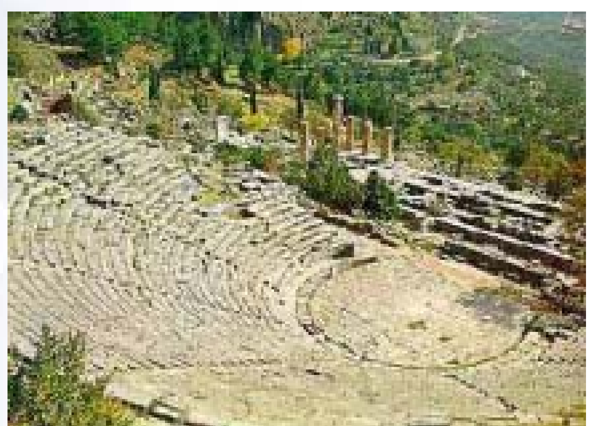
Prognosis

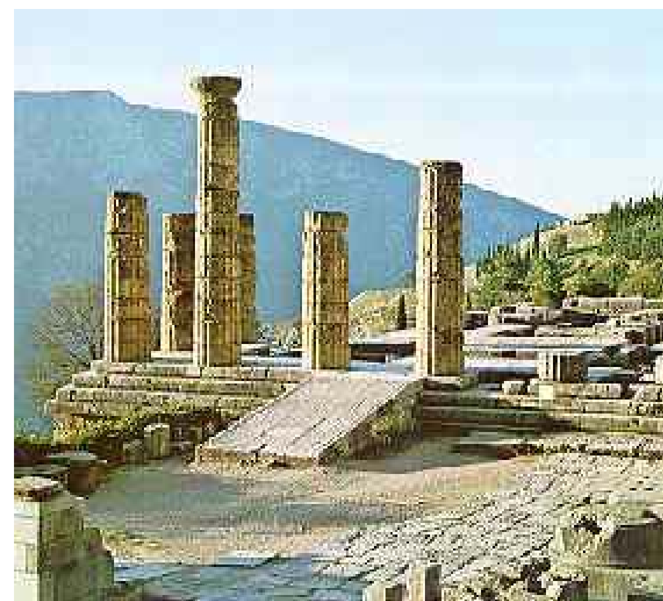
Pro (προτοs) = first, before, ahead, prior

Gnosis (γνωσιs) = knowledge

Power is Knowing the Future

Delphi Oracle





The Premise of The Program

Operational advantage derived from knowing the future performance of individual assets.

1. **System capability/performance (and ultimate failure) must be predicted.**
2. **Individual systems should 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.**
    - c) **asset ‘transformed’ to a different element in a fighting system.**
3. **There will be pervasive impact in air, land, sea, space, manned or unmanned vehicles.**

Mapping Prognosis onto Present and Future Combat Scenarios

- Enhances readiness
- Increases force projection
- Maximizes asset availability
- Reduces logistics burden
- Enhances safety
- Reduces costs
- Enables new operational scenarios
- Empowers the commander

Addresses Present Needs

- Aging assets
- Limited sustainment budgets
- Extended operations

Enables Future Combat Operations

- Expeditionary forces engaged with minimal supply and logistics support.
  - Replacements (or parts) not available
  - Information links rich and robust
- Adaptive asset allocation decisions made by local commanders
- Continuously adaptive elements in a fighting system

Program Context

- This is NOT a maintenance/logistics program (although we expect to see leverage from such activities and positive impact to them).
- This is NOT a life extension program (although we expect to see leverage from such activities and positive impact to them).
- This is NOT a sensor development program (although some sensor activities within the program are likely).
- This is NOT an "information technology" program (although IT is very important).
- This a "physical sciences" program. It will develop the technical modules.
- This program establishes methodologies and tools for prognosis

Focus

Revolutionary (not incremental) technological developments.

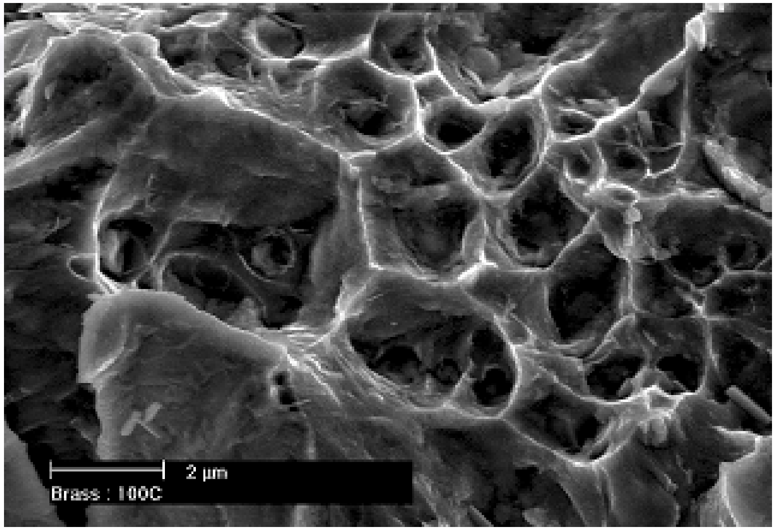
Focus on materials and structures (not electronics, control software)

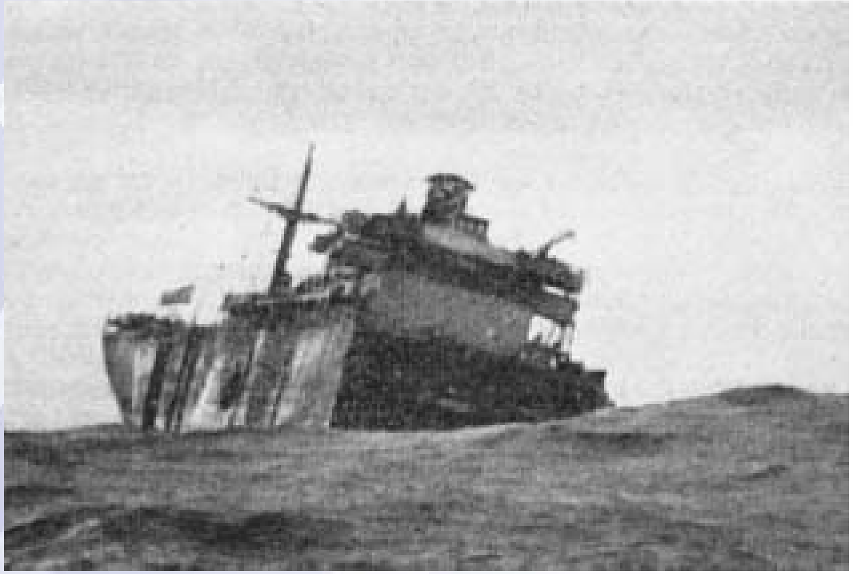
We Must Change the Present Paradigm

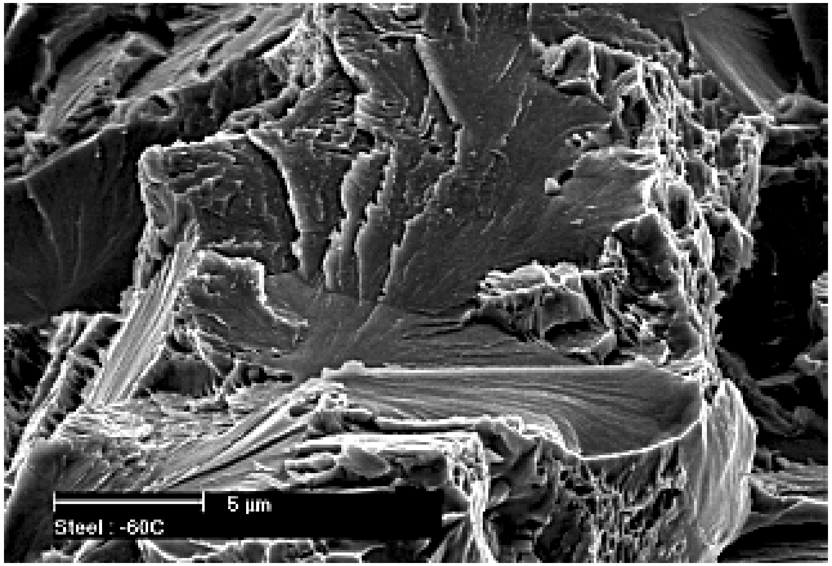
Presently, "Fear of Failure" controls our design, management, deployment and use of all critical elements of combat systems (aircraft, helicopters, space vehicles, submarines, ships, UCAVs, fighting vehicles,…).

- Forces undue conservatism (large safety factors) reducing performance.
- Severely impacts combat system availability and readiness.
- Forces non-optimal use of available assets.
- Results in high cost.

Fear is Justified: Materials Failure Matters!







Fear is Justified: Materials Failure Matters!

Fear is Justified: Materials Failure Matters!

PROBABLE CAUSE: "The National Transportation Safety Board determines that the probable cause of this accident was the inadequate consideration given to human factors **limitations in the inspection** and quality control procedures used by United Airlines' engine overhaul facility which resulted in the **failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in a critical area of the stage 1 fan disk** …….. The subsequent catastrophic disintegration of the disk result in the liberation of debris in a pattern of distribution and with energy levels that exceeded the level of protection provided by design features of the hydraulic systems that operate the DC-10's flight controls." (NTSB/AAR-90/06)

Date: 19 JUL 1989
Type: McDonnell Douglas DC-10-10
Operator: United Air Flight 232
Registration: N1819U
Year built: 1973
Total airframe hrs: 43401 hours
Cycles: 16997 cycles
Total: 111 fatalities / 296 on board
Location: Sioux City-Gateway, IA

The Present

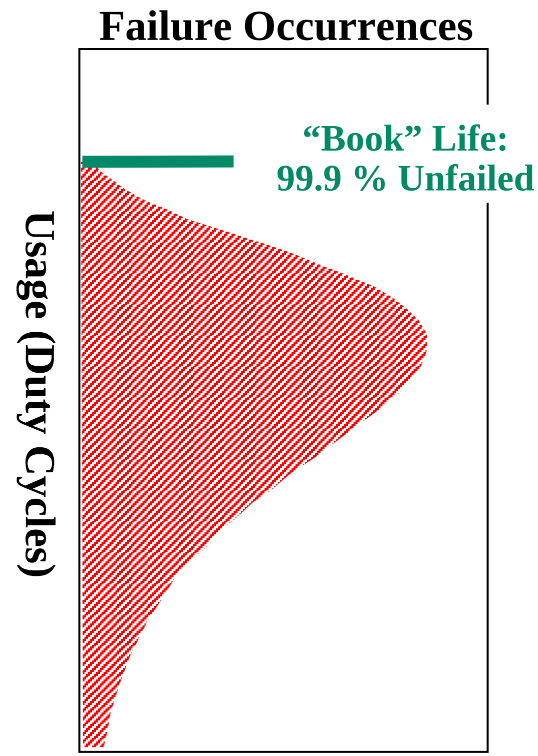
Management, deployment and use of combat systems is dominated by our fear of failure

Inspect

Empirical Criteria

Decision

Yes



NO

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

Prognosis-based Asset Management Approach

- Management, deployment and use of assets based on PROGNOSIS -- knowledge of future performance based on reliable prediction capability of individual platforms.
  - Managing according to knowledge of the individual and actual remaining performance
  - Managing uncertainty by reliable (physics-based?) predictive capability
  - Enabling material “state awareness”

The Prognosis Vision

Interrogation

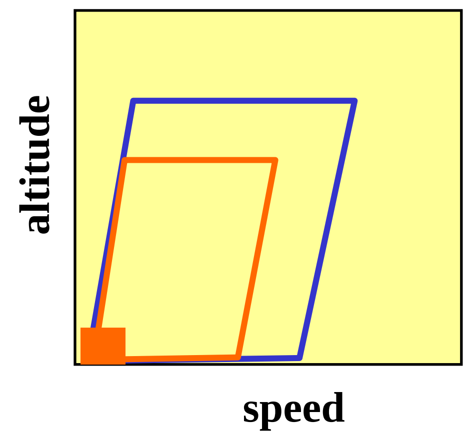
State Awareness

Failure physics, damage evolution, predictive models

Prognosis

Yes

Capability Profile, e.g



NO

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

Prognosis Translates Knowledge and Information Richness to Physical Capability

Interrogation and State Awareness

Conceptual:

- Not inspection
- Allows the material and structure to communicate its state

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)

Analytical/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 models (if available).

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

Reduced and full models.

Sensors can modulate model predictions.

Failure is Neither Random or Unpredictable

Failure mode DOMAINS well defined (fatigue, creep, corrosion, etc.)

Failure is progressive:

NUCLEATION/INITIATION

PROPAGATION/ESCALATION

COALESCENCE

Reliable failure PREDICTION will be accomplished by combination of;

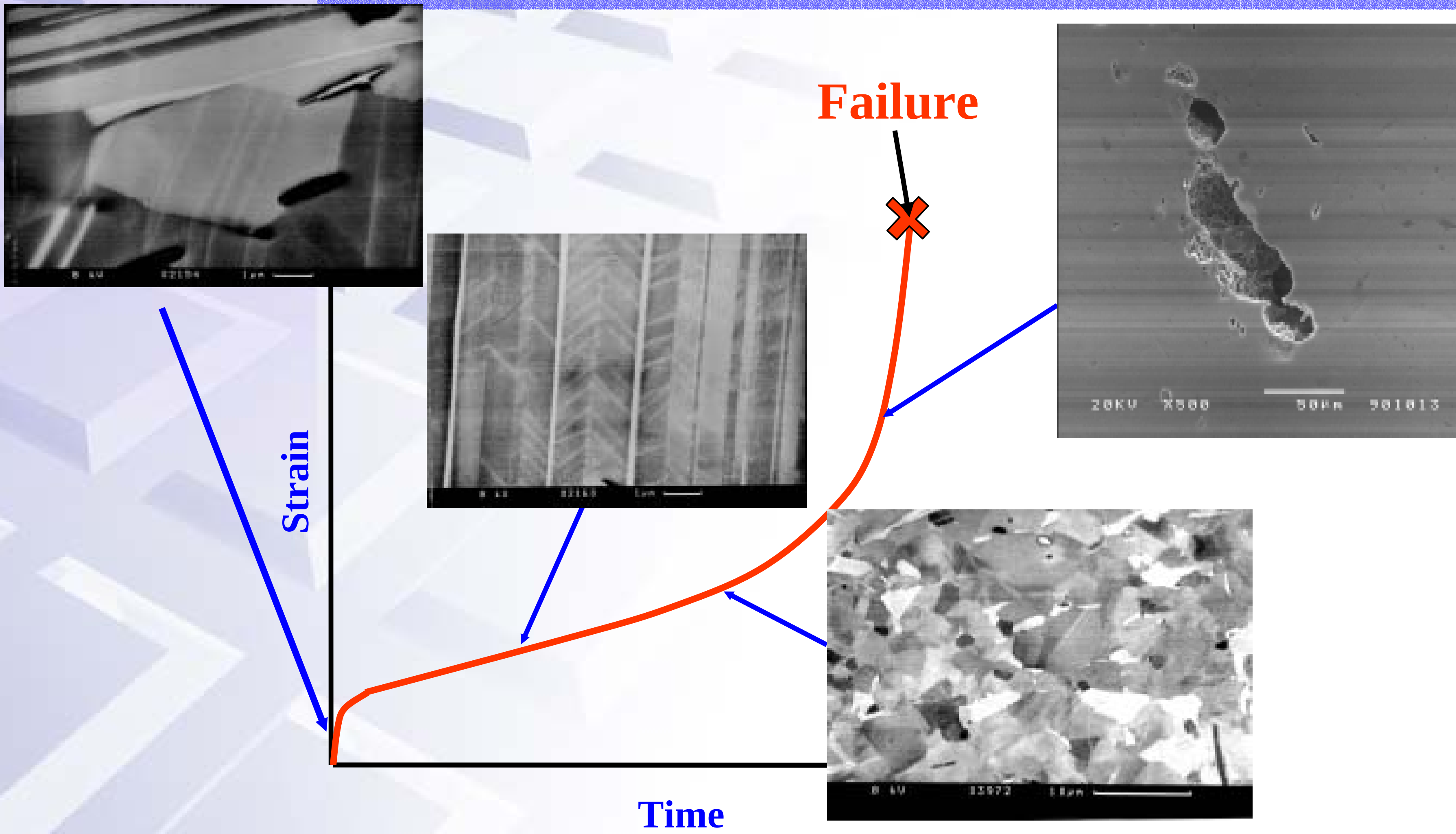
1. Models of physics of failure

- **Evolution of damage**
- **Coupled effects**

2. Interrogation tools for state awareness

- **Local AND global**
- **Signature manifestations**

Physics of Failure: Damage Evolution



Physics of Failure: Damage Evolution

$$\dot{\varepsilon} = \frac{A}{X d_{rec}^{2} + (1-X) d_{init}^{2} (1-D_d)} \sinh\left[\frac{\sigma(1-H)}{\sigma_0(1-\omega)}\right]$$

d_{rec} and d_{init} are lengths representative of the microstructure (e.g., grain size)

H describes the internal stress

$$\dot{H} = \frac{h'}{\sigma}\left(1 - \frac{H}{H^*}\right)\dot{\varepsilon}$$

D_d describes the contribution of the dislocation density

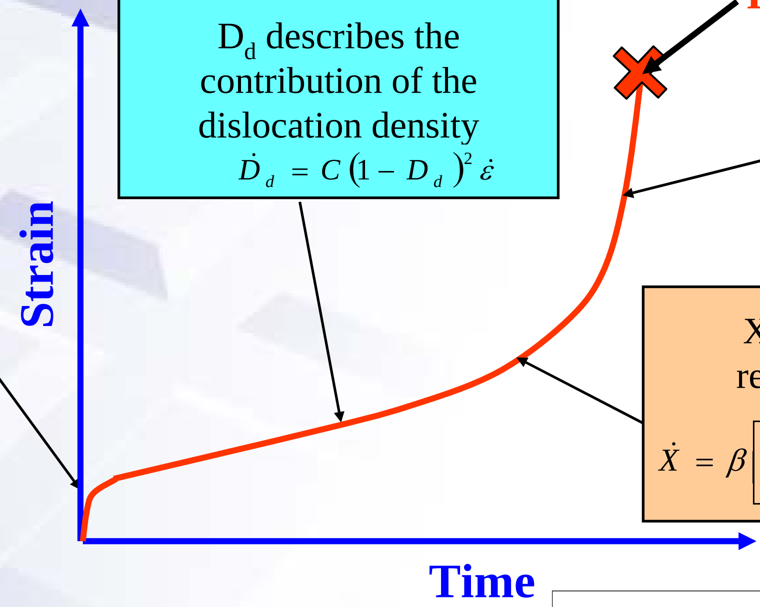
$$\dot{D}_d = C(1-D_d)^2\,\dot{\varepsilon}$$

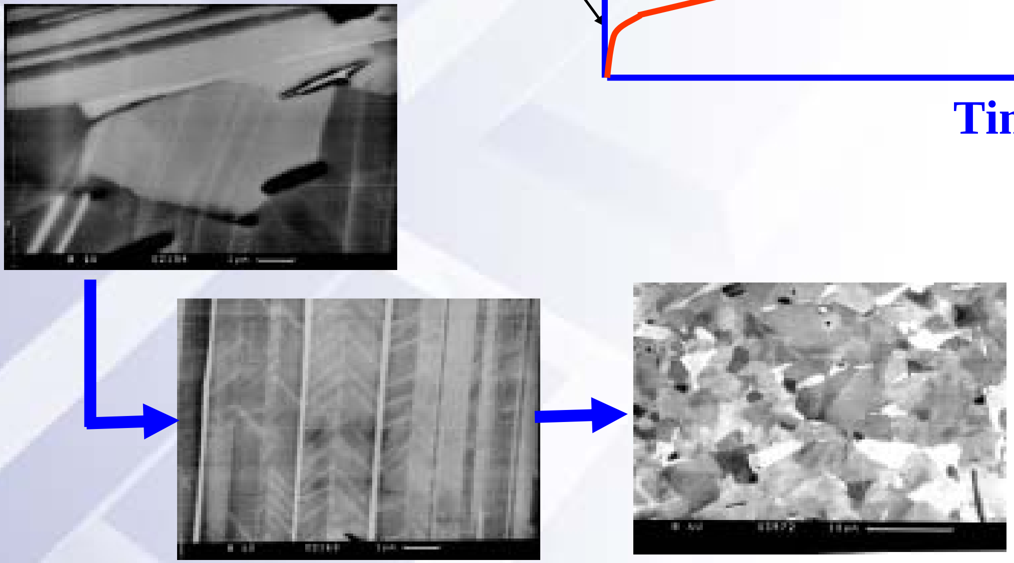
ω is the fraction of cavities nucleated

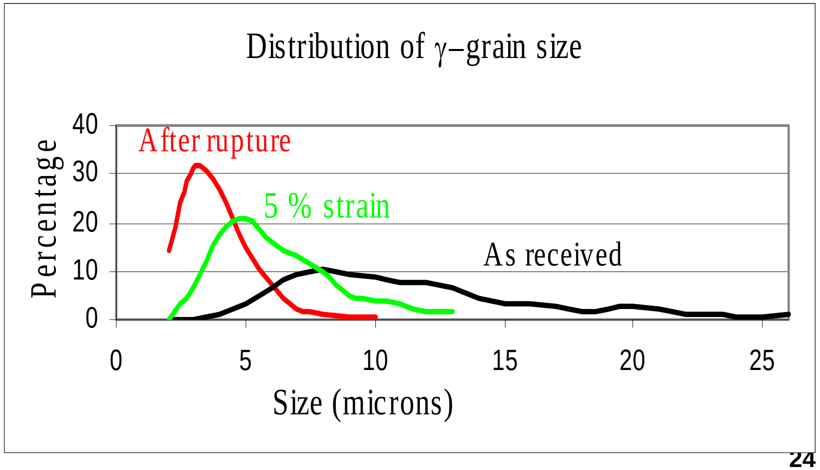
$$\dot{\omega} = \frac{k_N}{\varepsilon_u}\dot{\varepsilon}$$

X is the fraction of recrystallized phase

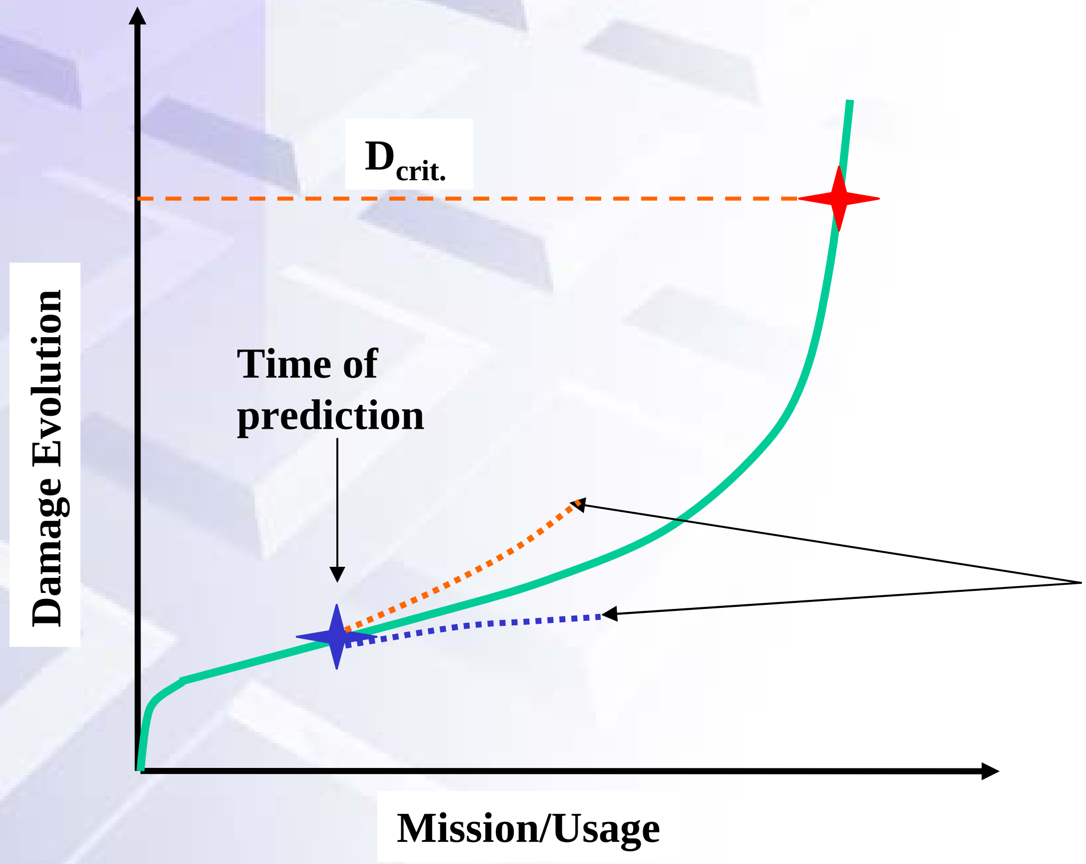
$$\dot{X} = \beta\left[\ln\left(\frac{1}{1-X}\right)\right]^{1-\frac{1}{\alpha}}(1-X)D_d$$







Conceptual Model/State Awareness Fusion



Knowledge of failure domains establishes functional behavior of damage evolution.

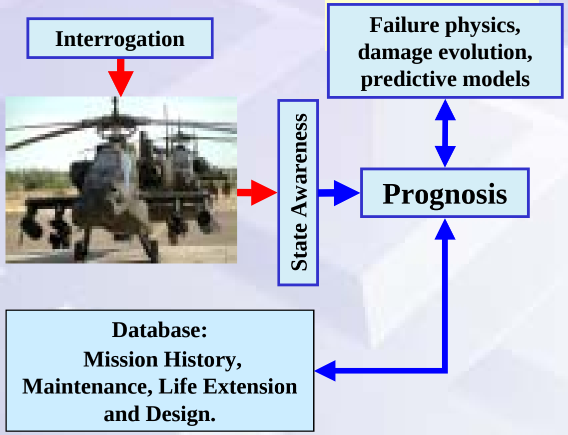
Tracking changes not absolute values.

Fidelity/reliability increases with prognosis system usage and maturity.

Short term predictions more reliable than long term “lifing” predictions.

Uncertainty in model predictions modulated by state awareness tools and pedigree.

Prognosis System



Integrates all elements, system knowledge and logic

Predicts capability

Provides multiple decision makers the required information (operator, local commander, theatre 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 e.g., CONUS, control center (full) system models

Benchmarked at convenient times and locations

Based on open and modular architecture

Example Technical Approach

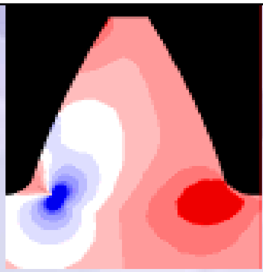
How would one do Prognosis?

What would one actually do?

The Link

System Parameters (throttle setting)

CFD, FEM



Temperature, stress, time, environment, etc. (incl. distribution)

Component, e.g., disk

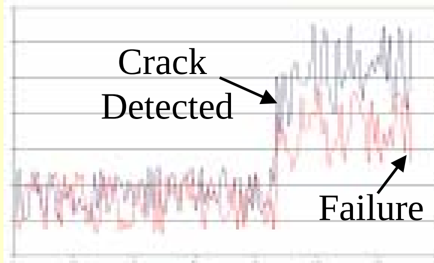
Interrogation Tools for State Awareness

Global

Thermal

Acoustic

Vibration



Local

Laser Ultrasonics

Thermoacoustic

Thermoelectric

Physics of Failure

Temperature, stress, time, environment, etc. (incl. distribution) inputs to state equations

Creep ←?→ **HCF** ←?→ **LCF**

Fret. ←?→ **Embr.** ←?→ **Envr.**

Evolving Material Microstructure

Example Link

System Parameters (throttle setting)

Heuristic-based Approaches

Sensitive to individual system (from design

Require training (moderated by CFD and FEM)

Do not deal well with previously un-encountered domains of behavior

Benchmarking required

Component, e.g., disk

Testbeds with KNOWN flaws

Physics-based Approaches

Relies on key state variable-microstructure*

Intrinsic to individual material classes

Predictive (with high accuracy in short term)

Deterministic/Probabilistic (uncertainty can be estimated)

We can re-register -- can verify/recalibrate at a convenient time

Benchmarking easy and inexpensive

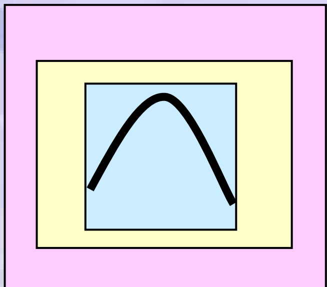
Microstructure evolves according to physical laws

Manageable dimensionality- Computationally tractable

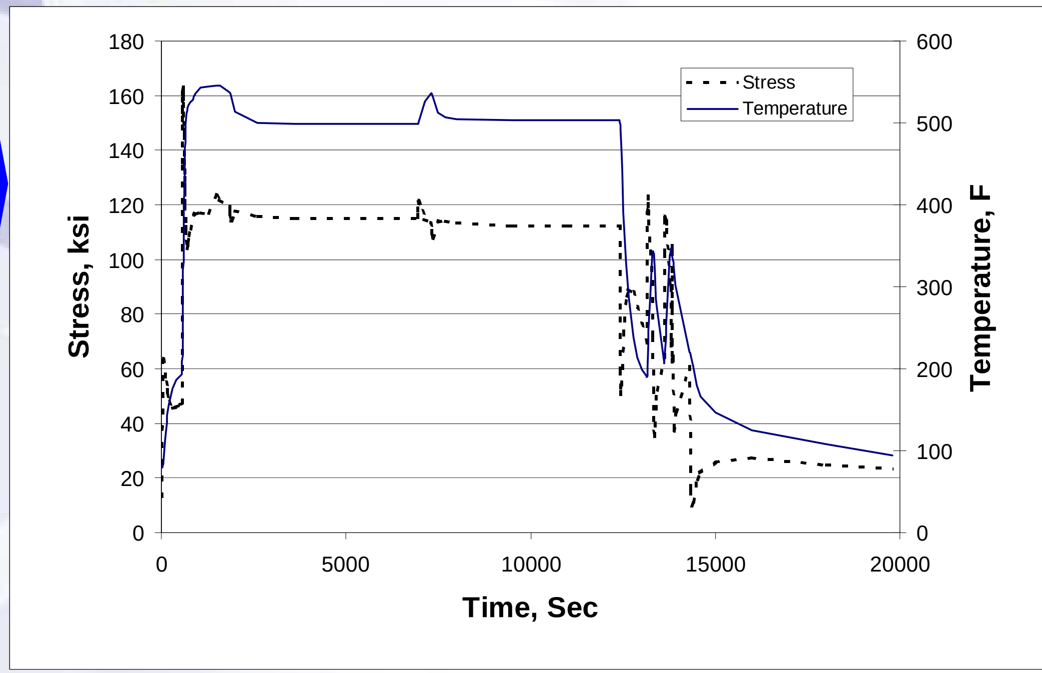
Evolving Material Microstructure

How Does it Work?

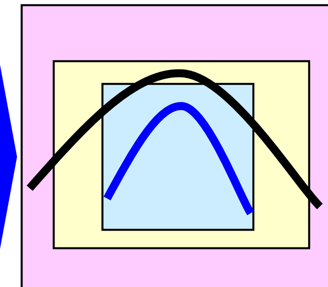
State at time, t

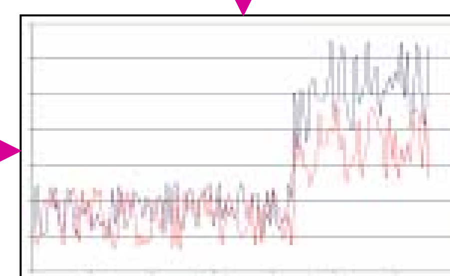


Model Mission



State at time, t+Δt





Signature of "new state" provides confidence that model prediction is within expected regime.

Prognosis Likely Content

- Develop Science and Technology
  - Develop predictive, coupled, multi-scale damage evolution/physics of failure models
  - Develop (non-intrusive) state awareness techniques and tools.
  - Apply/develop the math techniques for feature extraction and characterization of the state of the system.
  - Develop performance projection capability based on current state.
  - Synthesize adaptive mission strategies and (on-board) reasoning/intelligence system
  - Develop the tools to give multiple users reliable and accurate capability status in “real time”
- Exploit Technology
  - Employ existing/develop test beds to validate tools and models
  - Leverage data fusion technologies to implement Prognosis architecture and reasoning system implementation
  - Exploit effective data mining techniques (from IT?)
- Deliver Demonstrations
  - Demonstrate impact through analysis and physical demonstrations
  - Deliver decision tools for pervasive (sub)system manned or unmanned systems.

We Will Look For

Revolutionary (not incremental) technological developments

Address the hard problems (coupled and interacting failure modes, physics of failure, techniques for rapid interrogation of structure, establishing predictive capability, feature extraction, managing uncertainty, data fusion, reasoning system, etc

Leverage of developments in information technology, data fusion, etc.

Focus on materials and structures (not electronics, control software)

Focus on decision makers (immediate, short and medium term) for asset management, deployment and use based on capability

Open architecture

Modular architecture

Applicability to new and legacy systems

Robust, logical transition plans

Program Context

- This is NOT a maintenance/logistics program (although we expect to see leverage from such activities and positive impact to them).
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Questions?

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Example Technology Elements (by Government team)

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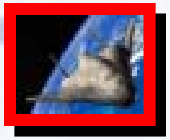
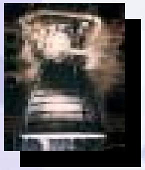
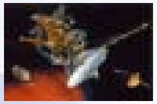
General Discussion, Questions and Answers

Anticipated Program Structure

DARPA PROGNOSIS ROAD MAP


Space

- Engine Bearings
- Structures
- Tanking Materials
- Gimbals

Aviation

- Legacy/new
  - Propulsion
  - Structures
  - LO
  - All Subsystems
- UCAVS & UAV

Ships

Ground

Prognosis Program

Phase 2

Interrogation tech

Failure Models

Dimensionality reduction

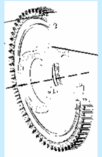
Seedling Projects

Helo Gear Crack

Feasibility Demo

Phase 1

- Engine Disk Crack
- Integrate Models
- Detection Sensors




PHASE 2!!!!!

Anticipated Program Structure

- Integrated teams (1-3)
  - Industry, academia, research institutions, Government/National labs
- Clearly defined and justifiable challenge problem (system/subsystem)
- 3-4 year effort
- Technical milestones with Go/No Go decisions
- First milestones (Go/No Go Decision) no later than 18 months from start
- Clearly defined payoffs and deliverables
- (Blind?) demonstration(s) at the system/subsystem level
- (Multiple) transition plan(s)
- Inhabited or uninhabited systems
- Air, Land, Sea or Space systems

Likely Proposal Evaluation Criteria

1. Technical Merit

   Revolutionary and enabling

   Technical rationale

   Technical tasks relative to SOA

   Metrics of success

2. Impact to DoD
3. Experience/personnel/facilities
4. Cost realism and value to the Government

Anticipated Schedule of Events

Bidders Conference and Workshop	Sept. 02
Technical Community Feedback	Oct.-Nov. 02
BAA Announcement (new or amendment to BAA01-42)	1st/2nd Q FY03
Proposals due	2nd/3rd Q FY03
Preliminary selection	2nd/3rd Q FY03
Presentations to DARPA by selected bidders	2nd/3rd Q FY03
Awards	3rd/4th Q FY03

Funding

The total level of investment in the initiative has not been determined.

The value of any contracts under the initiative will be strictly dependent on the quality of the proposal(s) received.

Any proposals received may be fully or partially funded and/or combined with others.

Communicating with DARPA

- www.darpa.mil/dso
- Future programs
  - Prognosis
    - Presentations from this meeting
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Questions?