Revolutionary Research . . . Relevant Results

Unified Fatigue Damage Analysis: The UniGrow Model

Briefing for the Condition-Based Maintenance *Plus* Action Group
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OBJECTIVE

- **Introduce UNIGROW fatigue crack growth modeling technology.**
- **Discuss the potential for expanding UniGrow to a broader set of applications**

What We Have: Empirically-based Methodology

Safe life Approach
Stress or Strain Life Model (**40 models**)

- For Design - No crack is assumed.
- Safety Factor to mask the unknowns: e.g. Aging aircraft.
- Environmental effects not included
- Premature component rejection

Damage Tolerant Approach
Crack Growth Model (**70 models**)

- For Maintenance - Crack is assumed
- Curve fitting empirical models
- Environmental effects not included
- Safety & availability

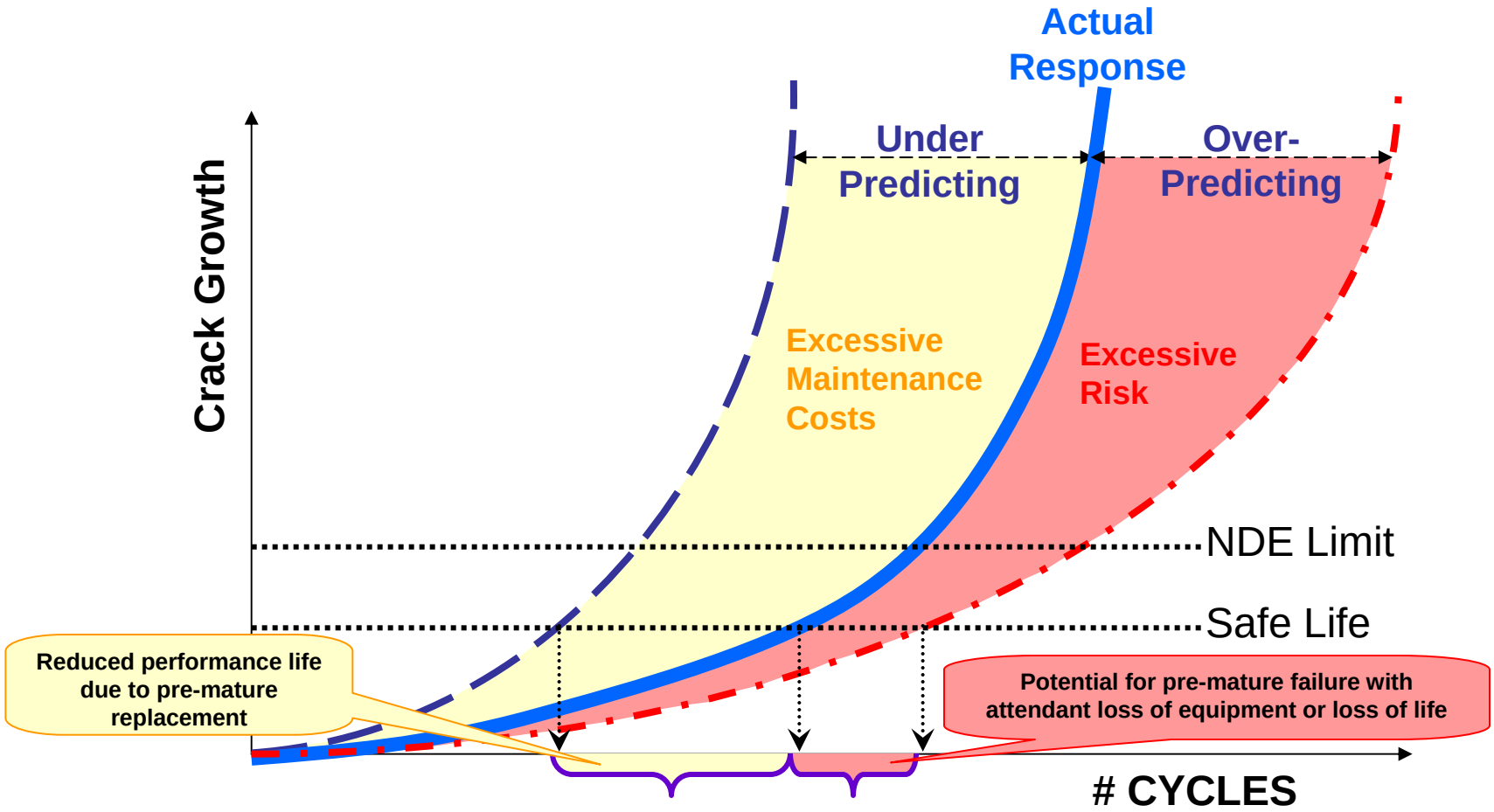
Due to these uncertainties, each time the model was deficient to make the correct Predictions, more new empirical models were proposed

Life prediction in service requires accurate load-history records + Environmental effects

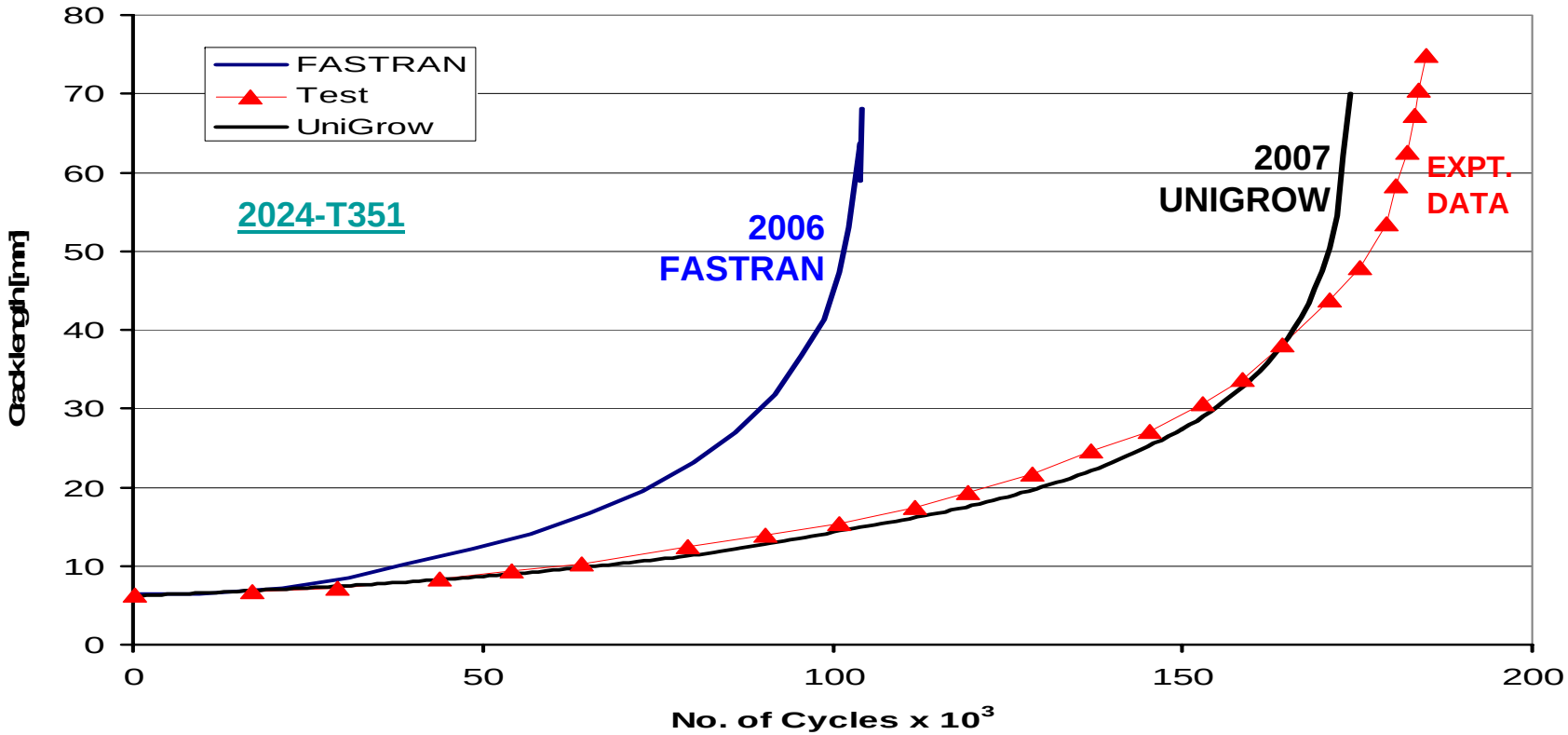
New Methodology - Integrate the Two Approaches

Current State of Structural Fatigue Life Models

- **Poor prediction for "long time" service load histories**
- **Mostly underpredicts the experimental data**
- **Can over-predict the experimental data, in specific circumstances**
- **Continuous 'tuning' of adjustable parameters to fit the experimental data**
- **Unreliable accounting for environmental/corrosive effects**



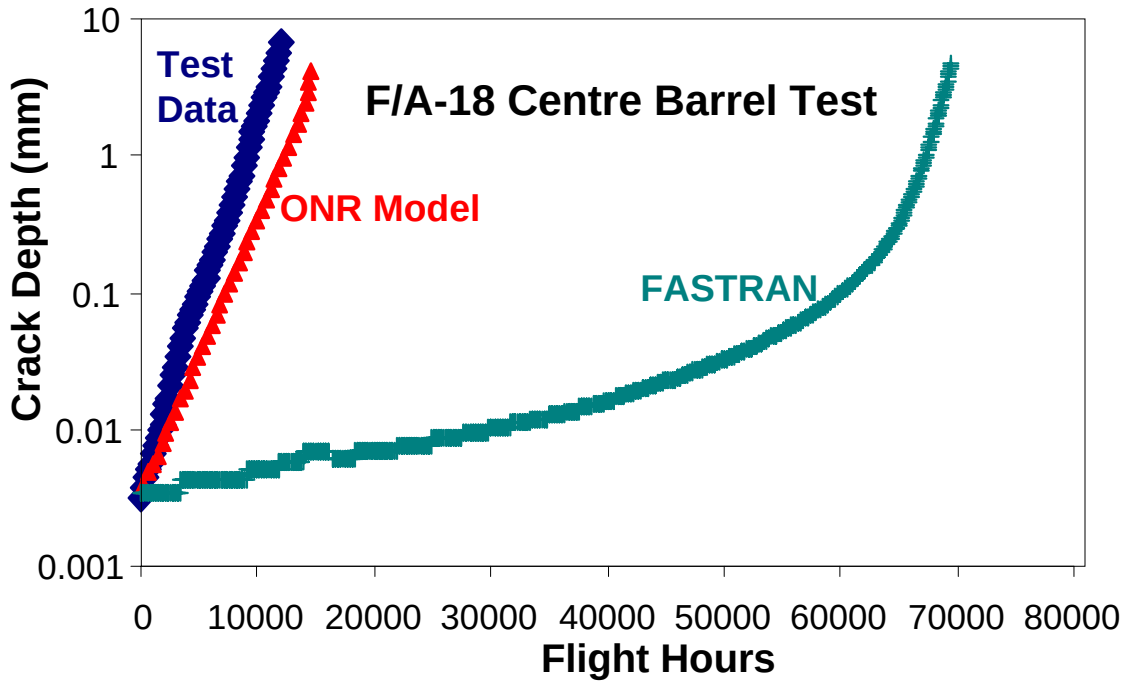
Worse Case Example of Under-Predicting Structural Fatigue Life



Cost of Under-Estimating Structural Fatigue Life

- **Premature Replacement of Life Limited Parts**
- **Higher Support Costs**
- **Reduced Availability**

Worse Case Example of Over-Predicting Structural Fatigue Life



Cost of Over-Estimating Structural Fatigue Life

- **Reduced Safety**
- **Reduced Availability**

UNIGROW Program

Motivation

Need for a more reliable, less empirical structural fatigue life prediction model with increased accuracy based on improved fundamental understanding of crack initiation and short crack growth

Strategy

Eliminate or drastically minimize the limitations of current structural fatigue life models

- Develop a single physics based model from crack initiation through growth prediction
- Enable reliance on a single material specific variable for calibration and training
- Expand the model to address environmental, including corrosion effect, degradation of the base metal

Benefits

Improved safety and availability of aircraft due to

- Higher accuracy basis for structural life usage monitoring
- Improved knowledge of airframe structural integrity

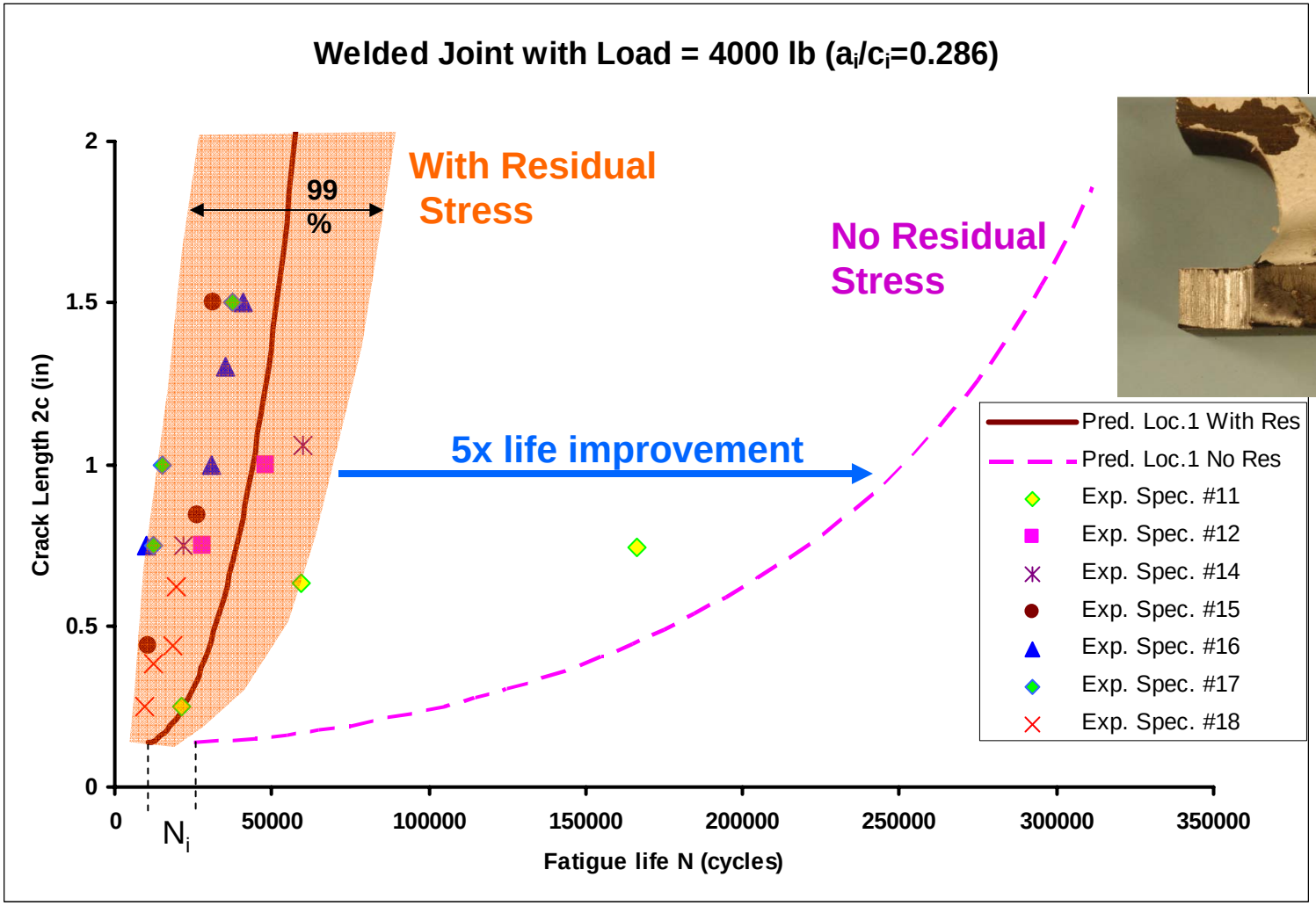
Reduced maintenance costs due to

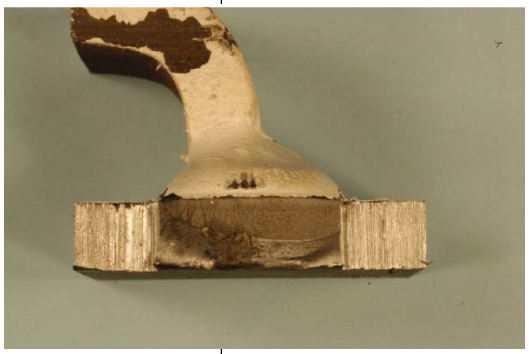
- Reduced labor intensive structural inspections
- True condition-based component replacement

UNIGROW Attributes

- **Reliable predictive model for service loads using lab coupon tests data**
- **Predictive accuracy from crack initiation through final failure with a single equation**
- **NO adjustable parameters**
- **Tested against constant amplitude fatigue crack growth data for Al 7075, Ti-6Al-4V, and 4340 steel alloys**
- **Accurately predicts the experimental data for P-3 Aircraft Service Load Spectra for a Al 7075 alloy under tension & compression dominated loads**

Understanding and Accounting for Residual Stresses in Weld Joints





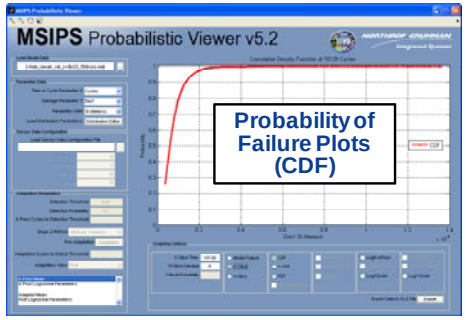
Integrating UNIGROW into a Structural Health Concept

Objective

- Integrate the UNIGROW fatigue crack growth model into the NGC/DARPA Structural Integrity Prognosis System (SIPS) software including the provision of a probabilistic wrapper
- Evaluate UNIGROW against the methods currently used within the SIPS program to determine its feasibility for use for SIPS material/structural systems and prediction accuracy within the SIPS probabilistic framework

Approaches

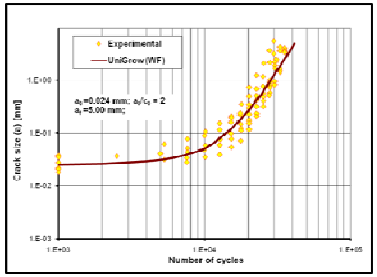
- Integrate UNIGROW into the SIPS probabilistic software system, MatLab-SIPS (MSIPS)



- Demonstrate predictive capabilities for benchmark cases representative of a critical location in a naval aircraft

Key Experimental Results

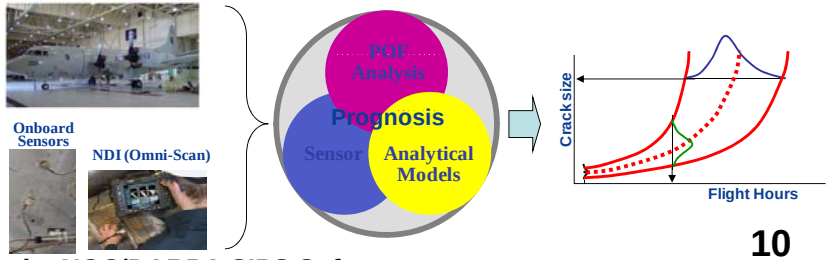
- Excellent agreement to experimental measurements of crack sizes from initiation to final failure with limited material data
- Load interaction effects captured without variable-amplitude model-calibration experiments
- Short crack regime simulated without the need for expensive small crack growth rate testing



Future Plans

Evaluate MSIPS/UNIGROW software on operational aircraft

- Develop UNIGROW fatigue life models for selected aircraft
- Incorporate SIPS reasoning & adaptive framework
- Update predictions based on sensor/flight data

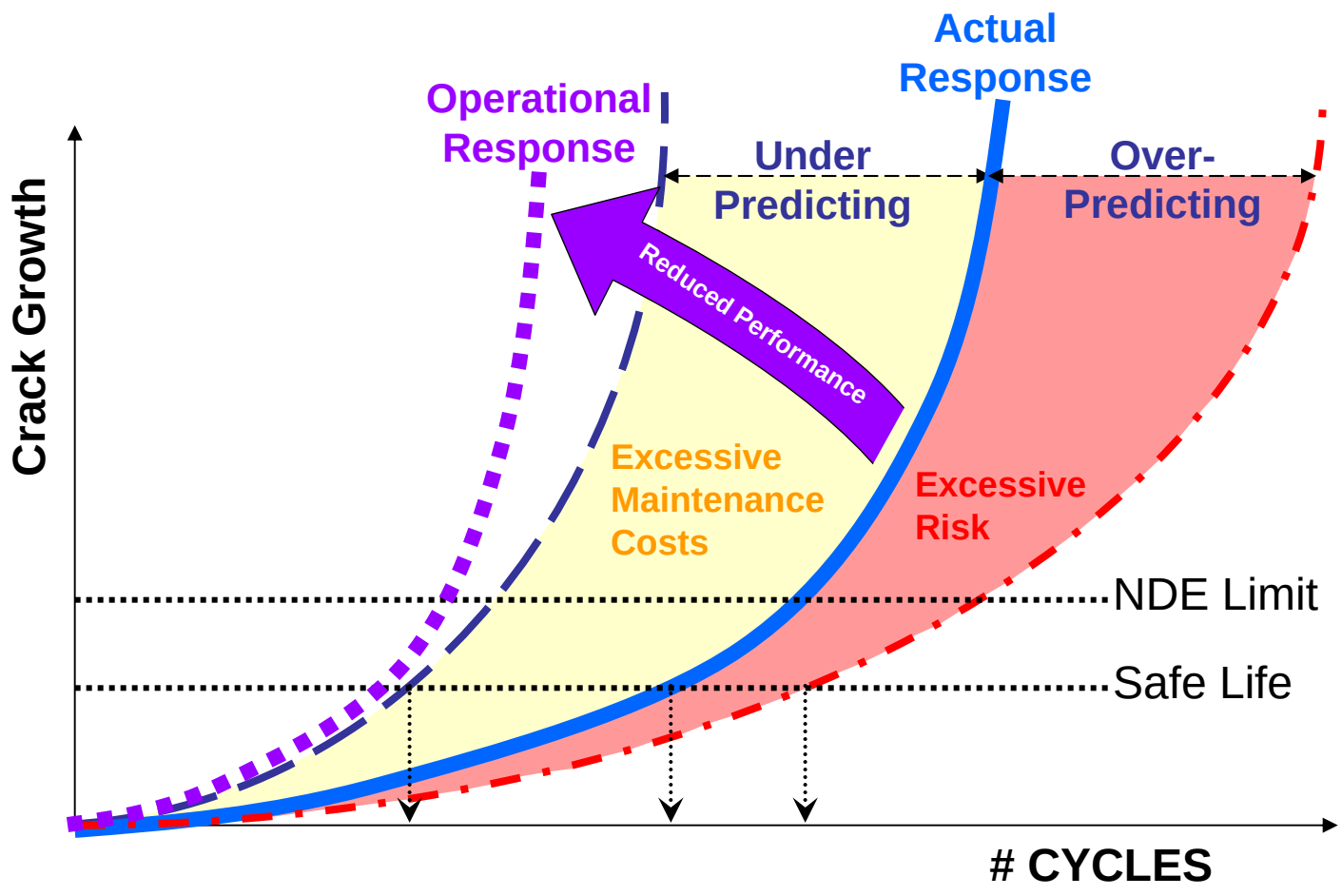


N-00014-09-C-0330: Integration of UNIGROW into the NGC/DARPA SIPS Software

PI: Elias L. Anagnostou, Advanced Programs & Technology, Northrop Grumman Corporation (NGC)

Next Hurdle: Addressing Environmental Effect Impacts

The next step is to extend UNIGROW to accurately account for the deleterious effects of the demanding operational environments on the base-metal



Pursuit of Transition Opportunities

- **Continue UNIGROW integration into SIPS for potential transition to operational aircraft platforms**
- **Assess potential for UNIGROW integration into Helicopter Health and Usage Monitoring Systems (HUMS)**
- **Identify other fleet assets and structural health monitoring systems that could benefit from the integration of UNIGROW**

Timely Opportunity for the NAVY:
Improve Safety and Increase Readiness
while Reducing Operational Maintenance Costs

A Current UniGrow Opportunity

Innovative Approaches for Improving Progressive Damage Modeling & Structural Life Prediction of Airframes: SBIR Topic # N091-008

- **Fatigue Life Prediction is specific to Component Part Geometry**
- **Develop a tool kit that integrates a FEM Package for SIF solutions & Advance crack growth Program (UNIGROW) for Life Prediction of Complicated Geometry in aircraft &ship structures**
- **SBIR Phase I Demonstrated proof of concept of the tool kit**
- **SBIR Phase 2 has been accepted - to develop the tool kit to expand to many component geometries**
- **Are There Specific Problem Parts in Other Vehicles That are Candidates for This Program ?**