Research and Education in Aerospace Composites at UW/FAA Center of Excellence

Presented to

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By

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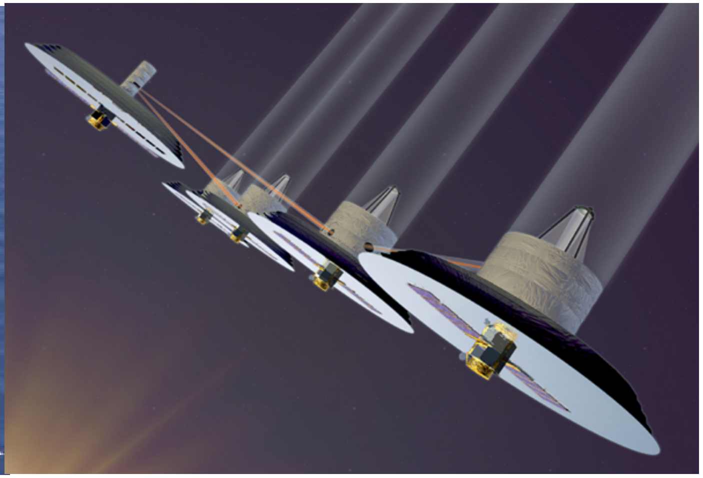
Seattle, WA

Department of
Aeronautics and Astronautics

http://www.aa.washington.edu

1928: Guggenheim Foundation funds construction of aeronautics building, one of 7 such grants nationwide.

1930: Guggenheim Hall dedicated at UW; first aeronautics baccalaureates granted

FAA Centers of Excellence (CoE)

- Funded through cooperative agreements among academic institutions, their affiliate industrial partners, and the FAA
- Funded in three phases over a period of 3-10 yrs
- Expected to be self-supporting thereafter

FAA Centers of Excellence

- Center of Excellence for Airport Technology
(U. Illinois lead…established 1995)
- National Center of Excellence for Aviation Operations Research
(NEXTOR…UC-Berkeley, MIT, U. Maryland, VPI co-leads…established 1996)
- Airworthiness Assurance Center of Excellence
(AACE…managed by FAA via Hughes Res Center…established 1997)
- Center of Excellence for General Aviation Research
(CGAR…Embry-Riddle lead…established 2001)
- Center for Aircraft Noise and Aviation Emissions Mitigation
(MIT lead…established 2003)
- **Center of Excellence for Advanced Materials**
(JAMSCO…UW and WiS co-lead…established 2003)

UW Center on Advanced Materials for Transport Aircraft Structures (AMTAS)

- Overall mission:
    - Perform ***research*** studies
    - Provide ***educational*** opportunities
    - facilitate ***technology transfer***

  pertinent to the use of "advanced materials" in transport aircraft

- "Advanced materials" meant to imply (at least initially!):
    - ***Polymeric-based composite*** materials and structures
    - New materials developed via nanotechnologies

UW Led FAA Center of Excellence

- Academic Members:
    - University of Washington (Lead)
        - Director: Mark Tuttle
    - Washington State University, Oregon State University, Edmonds Community College

- Industrial Members:
    - Boeing
    - Toray America, Hexcel, Heatcon, Composite Solutions, etc.

UW Faculty Collaborators

- Aeronautics and Astronautics
  - **Ken Lin, Eli Livne**, Keith Holsapple
- Chemical Engineering
  - Jim Seferis, Bradley Holt
- Industrial Engineering
  - Zelda Zabinksy
- Material Science and Engineering
  - Raj Bordia, Brian Flinn
- Mechanical Engineering
  - **Mark Tuttle (Director)**, Minoru Taya, Mamidala Ramulu, Vipin Kumar

Center Mission: *Education*

- Train new composites engineers
  - Enhance existing undgrad/grad composites courses
  - Develop new courses as necessary
  - Increase number of distance-learning courses
- Provide continuing education programs
  - Develop short courses intended for practicing engineers
  - Develop short courses intended for composite technicians

Aerospace Workforce Training

- To Work with Boeing LEAD Group to Develop an Integrated Composite Product Lifecycle Management (PLM) Training Curriculum
- Identify the Competencies Required by Engineers and Technicians to Design, Produce, Deliver, and Support Aircraft Composite Structures
- Offer Courses, Workshop, and Certificate Programs to Practicing Engineers
- Integrate CoE Research Findings into Classroom Teaching
- Explore the Concept of Virtual Global Learning Collaboration Center (VGLCC) to Support the 7E7 Extended Enterprise
- Work with Edmonds C.C., WSU, OSU on Additional Educational and Training Programs

Center Mission: *Research*

- Material Standardization and Shared Databases
- Bonded Joints Processing Issues
- Structural Substantiation
- Damage Tolerance and Durability
- Maintenance Practices
- Advanced Material Forms and Processes
- Flammability and Crashworthiness
- Nanotechnology for Composite Structures
- Life Management of Materials for Improved Aircraft Maintenance Practices

Potential Research Projects

- Development of Reliability-Based Damage Tolerant Design Methodology
- Aeroservoelastic Response of Damaged Composite Structures
- Quick Permanent Repair of Composite Structures
- Development NDI Techniques for Bond Strength
- NDI Methods for Accurate Depth Inspection and Substructure at Joints
- Substantiation Methods for Resin-Infused Structures
- Thermoplastic Structures Characterization
- Advanced Health Monitoring System Using Embedded Sensors
- Advanced Methods for Damage Analysis
- Fatigue of Laminated Composites Under Out-of-Plane Stress
- Long-Term Performance of Composites
- Degradation Rates of Composite Materials
- Aging Effects on Polymeric Composites

Development of Reliability-Based Damage Tolerant Design Methodology

- **Interested Organizations**
  - UW, Boeing, NASA, FAA
- **Investigators**
  - K.Y. Lin (UW); Boeing
- **Objectives**
  - To establish a workable definition of acceptable structural "Level of Safety" based on probabilistic assessments of in-service accumulated damage to aircraft components, and the ability of non-destructive inspection methods to detect such damage
  - To develop a time-dependent probabilistic method to estimate structural component reliabilities that can be validated by using damage size data from scheduled inspections to update the reliability over the life cycle
- **Payoffs**
  - The level of safety and structural efficiency throughout the aircraft can be quantitatively defined
  - This development will allow aircraft manufacturers, operators, and flight certification authorities to evaluate the risk associated with structural failures in an aircraft fleet

Background

Designer's Objective:

Maximize Performance while Minimizing Risk

- Randomness Introduces Uncertainty (Risk)

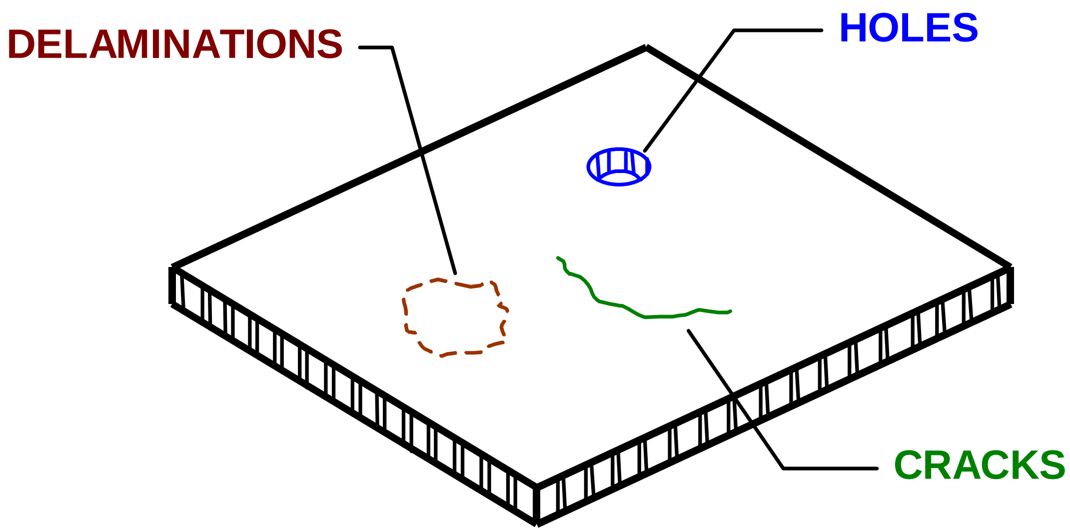
Variables:

- » Environment
- » Utilization
- » Damage Threat
- » Materials
- » Loads
- » Geometry

Damage Threat, Environment $\Rightarrow$ High Variability, High Risk

— Need a Probabilistic Approach —

COMPOSITE STRUCTURAL DAMAGE



- High Payoff in using Probabilistic Methods
- Account for Damage Sizes and Detection Capability
- Quantitative Measures of “Level of Safety”

“Level of Safety” Formulation

Compliment of Probability that a flaw size larger than the critical flaw size for residual strength of the structure and that the flaw will not be detected.

$$LOS = 1 - PF$$

$$where\ PF = P(A \geq a_c, D = d_2)$$

a_c – Design Critical Damage Size

d_2 – Damage is Not Detected

- Single Detection Event
- Single Flaw Present
- No growth with Time

"Level Of Safety" Formulation

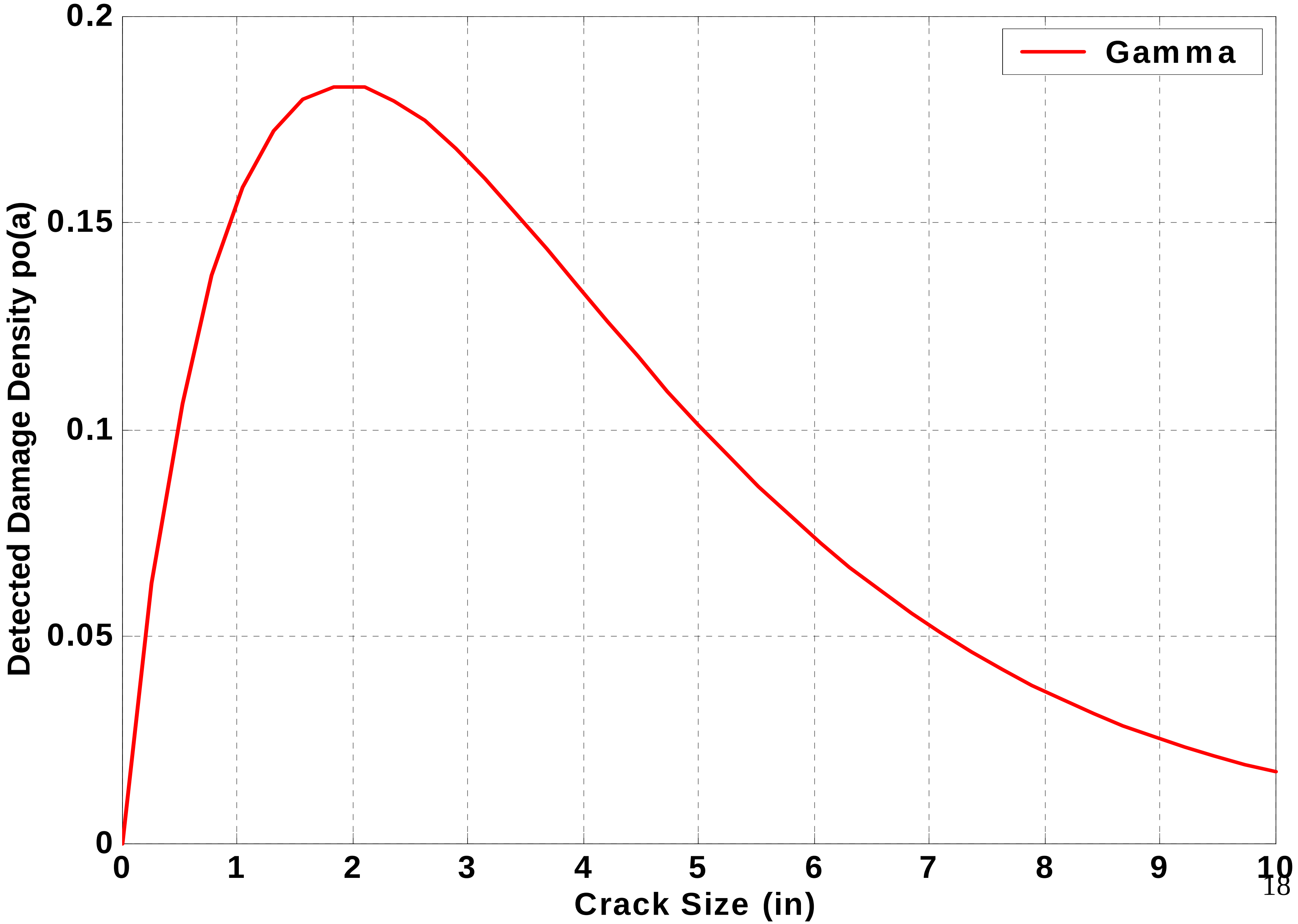
$$LOS = 1 - \frac{\int_{a_c}^{\infty} \frac{p_o(a)}{P_D(a)} \left[1 - P_D(a)\right] da}{\int_{0}^{\infty} \frac{p_o(a)}{P_D(a)} da}$$

$\boldsymbol{p_o(a)}$ = PDF of Detected Damage Size

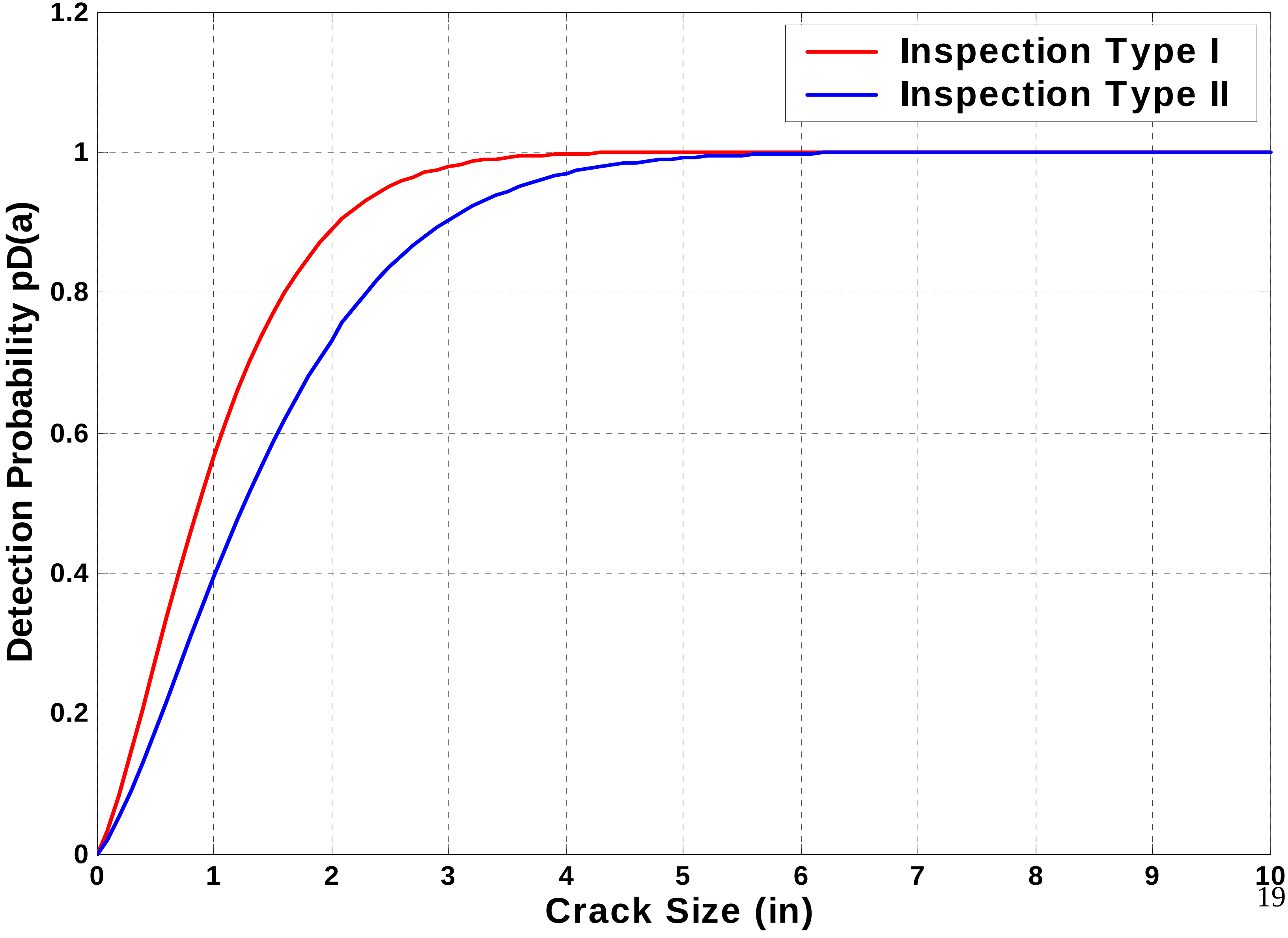
$\boldsymbol{P_D(a)}$ = Probability of Detection (POD)

- A General Formula
- Independent of Materials & Damage Type or Configuration
- Enables Safety Comparisons Between Different Structures
- Assumes Residual Strength, Damage Detection Capability Parameterized by Single Characteristic Dimension

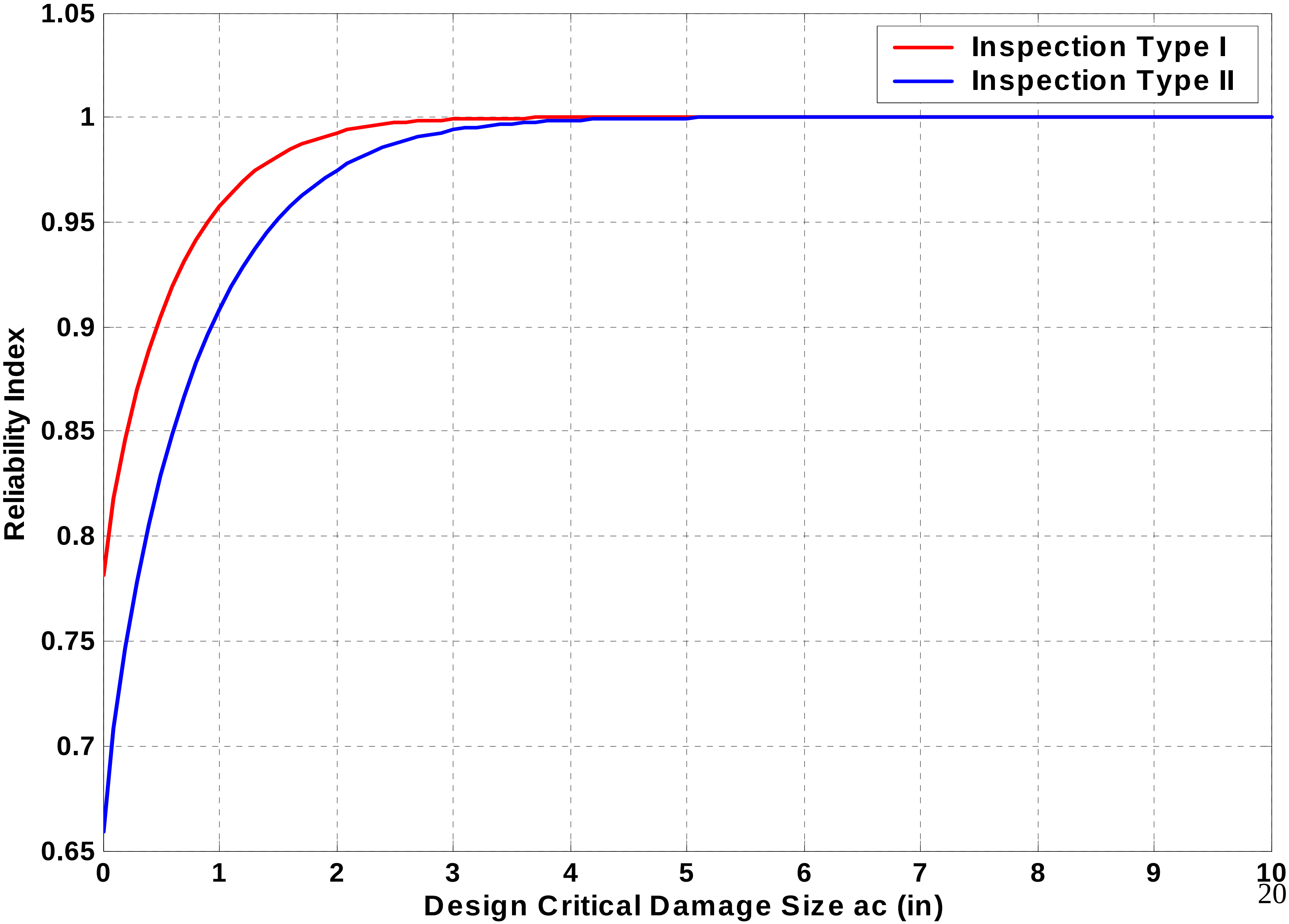
Detected Crack Size Distributions (Composites 0-10 in.)



Detection Probability Functions (Composites 0-10 in.)



"Level of Safety" vs. Design Critical Damage Size (Composites 0-10 in.)



Approach

- Mine data to collect all available flaw size and damage data from the existing Boeing and Airbus fleet, the FAA service difficulty report database, and other sources for damage size to apply to the existing probabilistic “Level of Safety” model

- Extend the existing “Level of Safety” formulation to incorporate a stochastic analysis of the time dependency of damage sizes and inspection intervals

- Apply the method to evaluate the “reliability index” of metal and composite aircraft structural components subjected to discrete-source and fatigue damage

- Develop an optimum inspection procedure for aircraft composite structures over the structural life cycle

Integrated Aeroservoelastic-Damage Tolerance-Reliability of Full-Scale Composite Aircraft

- **Interested Organizations:**
  UW, FAA, Boeing, USAF
- **Investigators:**
  E. Livne, K.Y. Lin, M. Tuttle
- **Objectives:**
  - Develop better understanding of effects of local structural and material variations on overall aeroservoelastic integrity
  - Develop computational tools (validated by experiments) for local/global analysis of integrated structures/ aerodynamics / control systems subject to multiple local variations/ damage
  - Establish a collaborative expertise base for response to FAA and industry needs, R&D, training, and education
- **Payoffs:**
  - Better understanding of the underlying physics, identification of damage sensitive areas, and development of cost-effective fleet maintenance for a consistent level of safety
  - Tools for rapid evaluation of digital flight control system modifications on load redistribution, local stresses, and resulting aeroservoelastic integrity
  - Foundation for future extension to advanced structures technology

Local / Global

- **Challenge:**

  Variation (over time) of local structural characteristics might lead to a major impact on the global aeroservoelastic integrity of flight vehicle components

- **Mechanisms of Local Degradation/ Structural Change:**
  - Material stiffness degradation
  - Moisture absorption (and changes in inertial characteristics)
  - Crack propagation and loss of local stiffness
  - Damage /repair effect on local stiffness
  - Delamination /delamination growth
  - Growth of a disbond
  - Joints/ hinges: nonlinearities, stiffness & damping variation
  - Discrete source damage (bird strike, etc.)

Control / Structures

- **Challenge:**

  Digital flight control systems can be subject to considerable modifications over the life of an airplane. As a result, dynamic loads on the airframe can significantly change, affecting fatigue characteristics and the life span of the airframe

- At the same time, modifications of flight system control laws can be used to re-distribute loads and relieve stresses in critical areas. If, in the life of a fleet, fatigue problems are found in particular problem-areas, stresses in these areas can be relieved through activation of controls and load redistribution, reducing the cost and schedule of massive structural modifications

Approach

- Create computational capability for both deterministic and probabilistic analysis
- Utilize techniques of multidisciplinary design optimization for sensitivity and repetitive analyses of systems subject to large numbers of variations
- Test case selection for fundamental studies, guided by FAA and industry needs/ interests
- Computational studies of selected test cases, and selection of systems/ sub-systems for experimental work
- Construction of selected test systems, followed by structural and wind tunnel experiments and correlation with analytical predictions
- Example: effects of structural damage (skin delamination, debonding) and moisture on the aeroelastic response of aileron /wing section systems

University of Washington Aeronautical Laboratory (UWAL) Built in 1936

Test model in 8’x12’ Kirsten wind tunnel.

UW's Composite Aircraft Construction and Test Capabilities

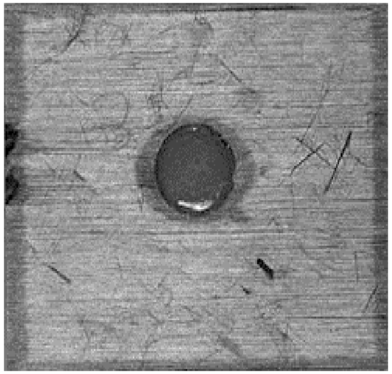
Project on Maintenance Practices

- Heating Methods and Repair of Composite Structures with Complex Geometry
- Quick Permanent Repair of Composite Structures
- NDI Methods for Accurate Depth Inspection and Substructure at Joints

Heating Methods and Repair Techniques for Composite Structures with Complex Geometry

- **Interested Organizations**
  - UW, Heatcon, Boeing, FAA, NAVY
- **Investigators**
  - K. Y. Lin, Heatcon, Boeing
- **Objectives**
  - Develop a reliable heating method to generate uniform temperature distribution over a non-contoured repair surface
  - Develop a convenient repair technique for composite structures of complex configuration
- **Payoffs**
  - A more reliable repair and a safer aircraft structure
  - A great savings for the airlines !

"In-Situ" Electron Spectroscopy of Chemical Analysis (ESCA) Surface Characterization of IM7/BMI



Problem

Polymeric composite (IM7/BMI) is widely used for high speed aerospace application. However, this material degrades under high temperature operation for a long period of time.

Research Objectives

- Understand chemical characteristics of fiber (IM7) and matrix (BMI) separately under the controlled environment (Oxygen, controlled heat).
- Site the degradation mechanisms to make to create more heat resistant composites.

Research Procedure & Results

- Customized ESCA in MSE department to create the vehicle operation environment.
- Succeeded to prove certain chemical attack due to the environment make material weaker.

Summary

- The FAA Center of Excellence (CoE) for Advanced Materials Has Been Introduced.
- Research and Education in Aerospace Composites at University of Washington Has Been Presented.
- Current Research Projects in Damage Tolerance Aeroservoeslasticity, Repair, Aging of Composite Materials Has Been Discussed.