Detection of Micro-Subsurface Defects in Peened Surfaces to Support the Adoption of Damage Tolerance Methods in Propeller Designs

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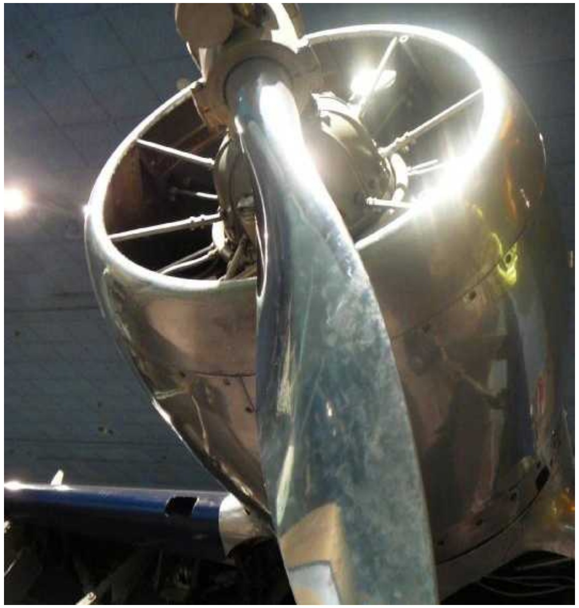

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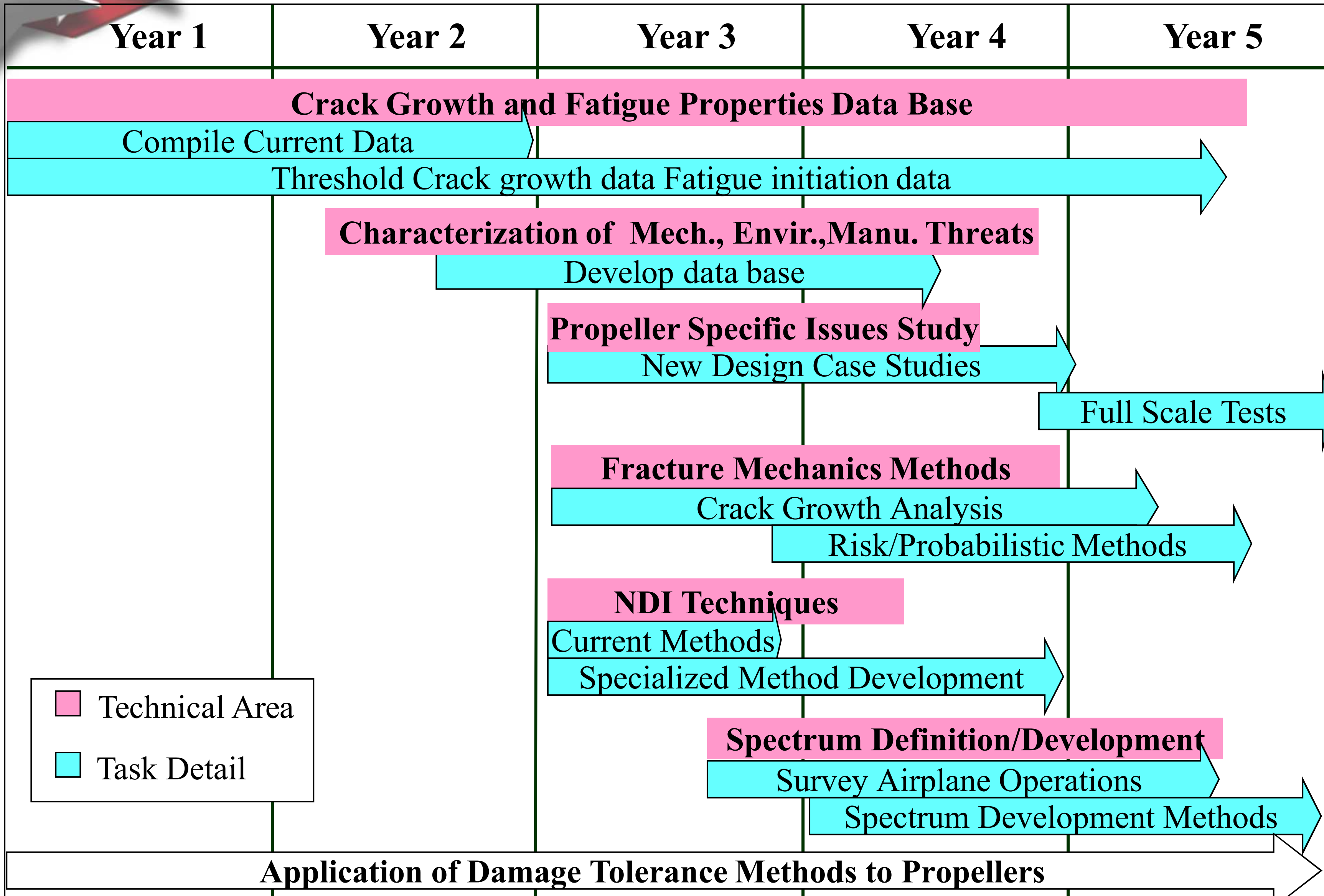
Propeller Damage Tolerance & NDI Program

- Support FAA rulemaking process to implement damage tolerance requirements for propellers
- Determine effects of changing from safe-life (flight hours or fatigue cycles) approach
- Ensure proper monitoring of propeller and hub parts after they are in service

Propeller Damage Tolerance R&D Roadmap



Propeller Damage Tolerance R&D Roadmap

1. <u>Characterization of Mechanical, Environmental, and Manufacturing Threats</u> – assess impact of damage to propeller systems; understand crack and corrosion growth from pitting, scratches, tool marks, etc.

2. <u>Crack Growth & Fatigue Properties Data Base</u> – obtain fatigue crack threshold and crack growth (da/dN) data for different residual stresses (i.e. peened, unpeened) and stress spectrums; steel and aluminum materials

3. <u>Propeller Specific Issues Study</u> – case study with redesign of HS 568F propeller using crack growth damage tolerance (CGDT)

4. <u>NDI Techniques Development</u> – specialized NDI methods to reliably detect damage or cracks for propeller load spectrum and operating environment

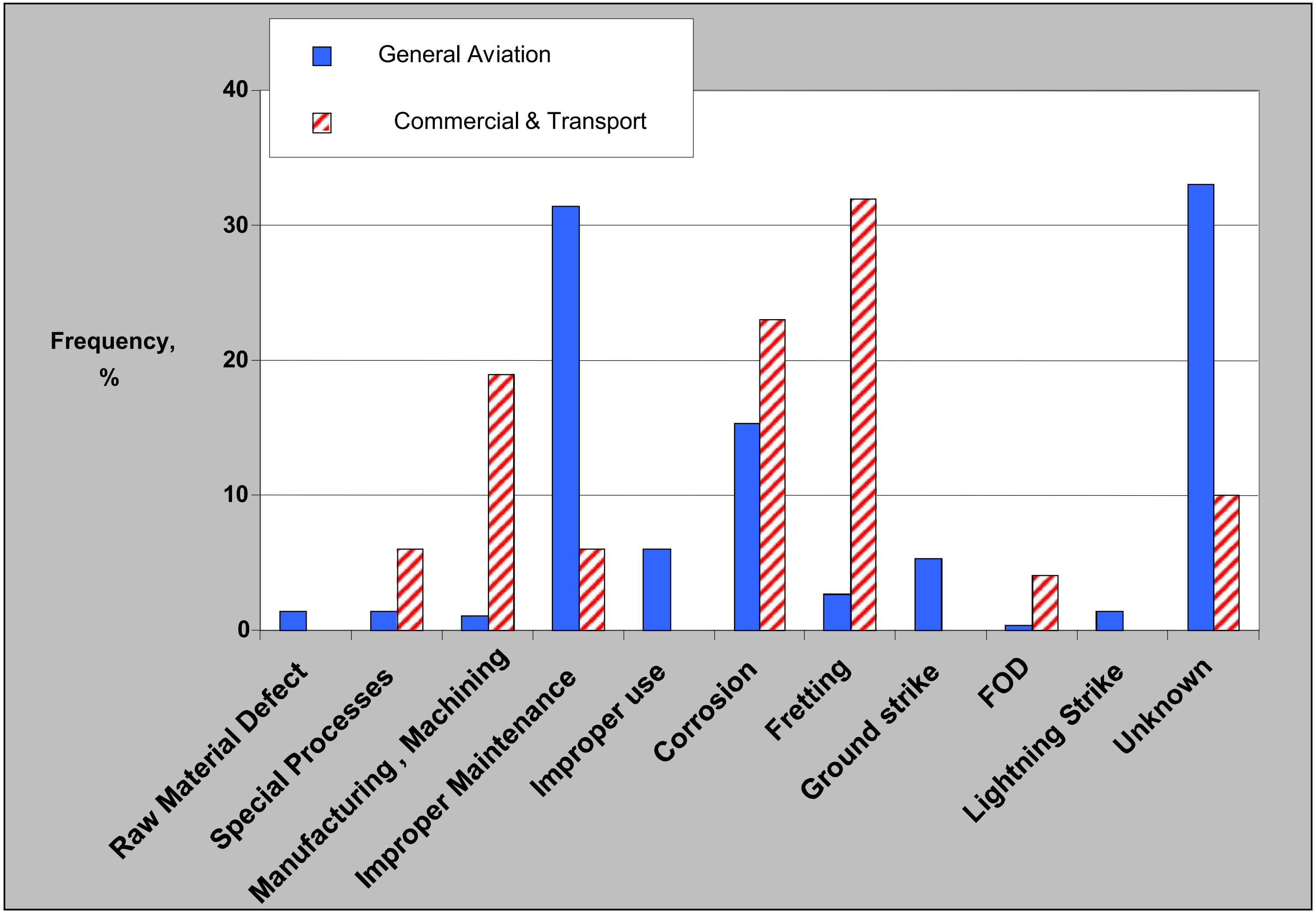
Characterization of Mechanical, Environmental, and Manufacturing Threats

Understand damage mechanisms, fracture mechanics, and alloy specifics – determine the types and frequency of damage

- **Committee on Propeller Damage Tolerance**
- **Cracks, corrosion, & disbonds – defect origins & types**
- **Effects of improper maintenance & repairs**
- **Survey completed on cracking incidents**

Characterization of Mechanical, Environmental, and Manufacturing Threats

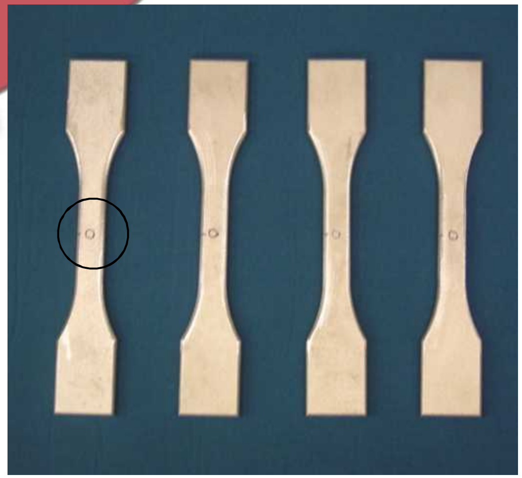
Leading proximate cause of crack formation is corrosion



Crack Growth & Fatigue Properties Data Base

- **Execution of crack growth, fatigue property assessment, & damage tolerance analyses**
- **Characterization of crack growth rates in propeller alloys**
- **Fracture mechanics & residual stress data on shot-peened & unpeened coupons (7075 & D6AC materials)**
- **Calibration & validation of NASGRO solutions**
- **<u>Case study</u>: affects of damage tolerance on new propeller design (568F blade)**
  - **FEA – analysis methods based on CGDT**
  - **Maintain GAG levels below threshold values**
  - **Weight change in blade**
  - **Weight change in subassemblies**
  - **Change in actuator loads**

Propeller Redesign Process



Assess depth & affect of cold work

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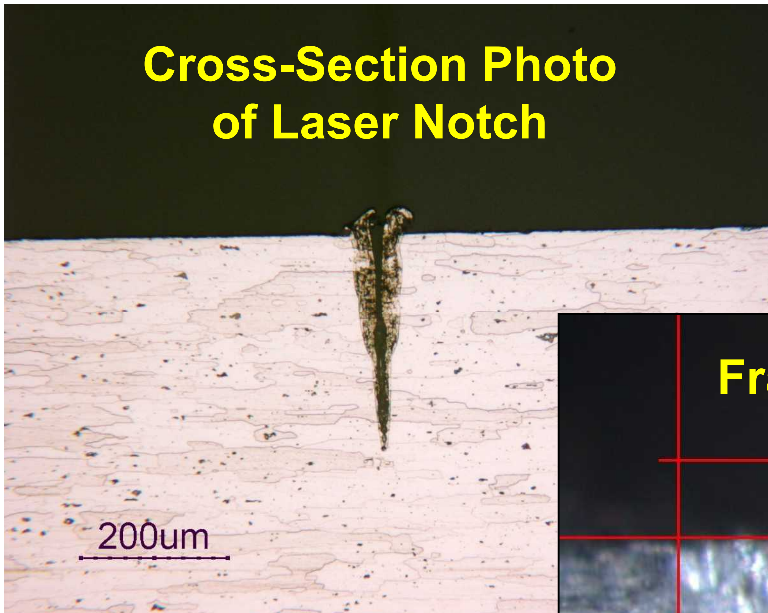
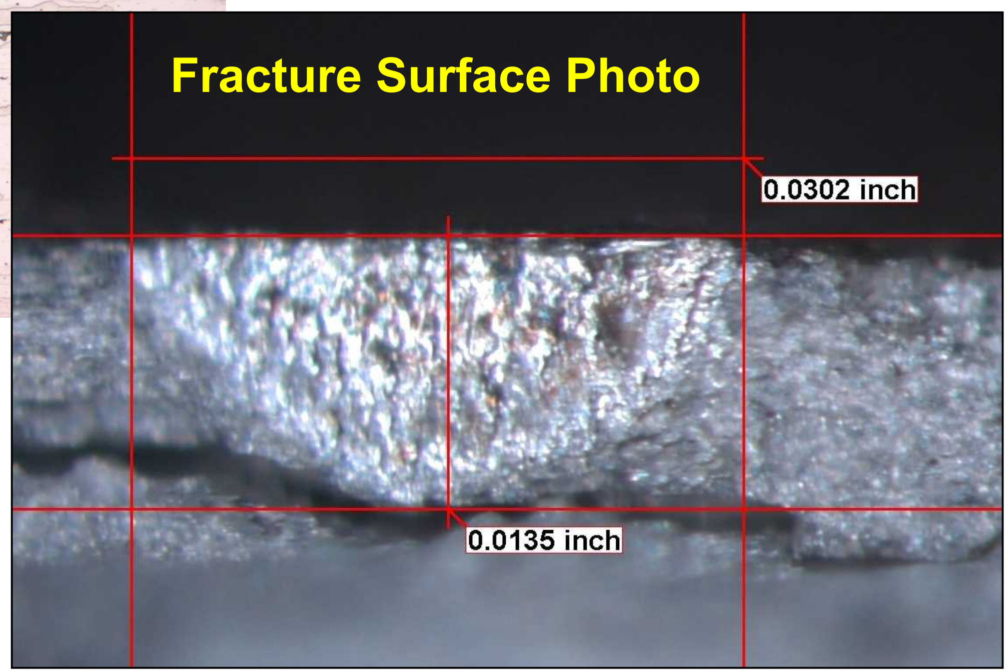
Generation of a Semicircular Crack by Laser Notching

- Traverse rate, pulse frequency, length of travel, and power are all varied with each pass to mill away the desired shape
- The notches evaluated at HS have been 0.013" deep X 0.026" long



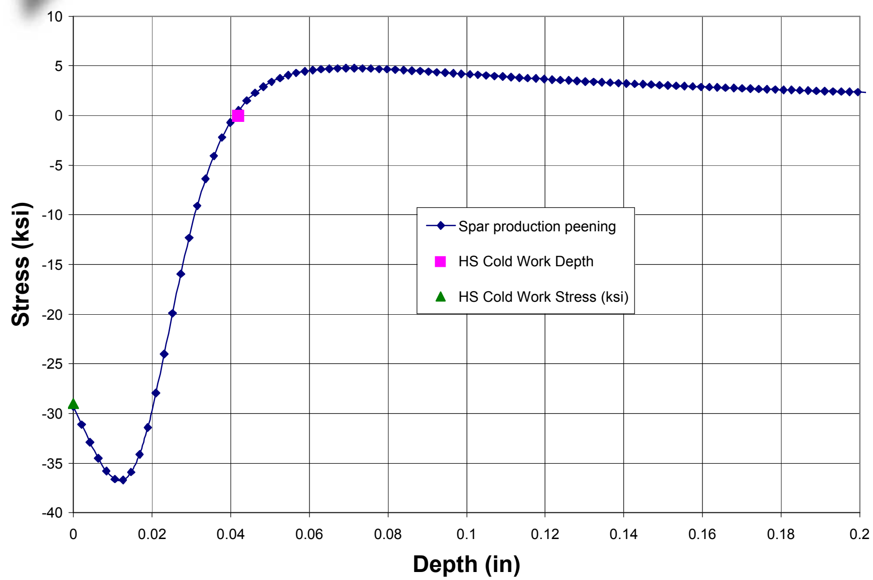


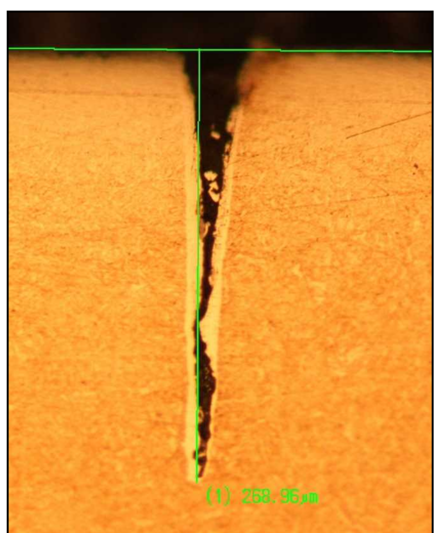
Elliptical Crack Growth and Crack Threshold Stemming from Pits vs. Laser Notches

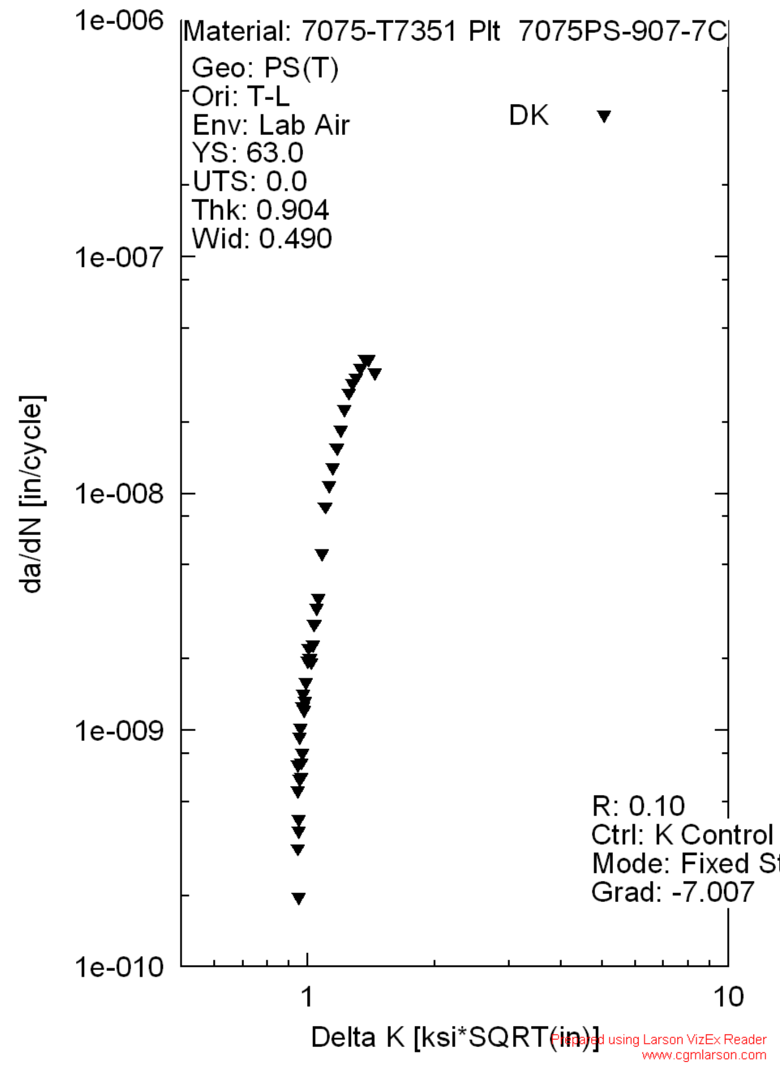
- Non-elliptical crack growth
  - Corrosion pitted specimens: c/a = 1.29 - 1.49
  - Laser notched specimens: c/a = 1.14 - 1.27
- Software development underway to calculate da/dN vs. dK

Crack Growth & Fatigue Properties Data Base

Estimated Shot Peening Residual Stress Profile for 0.125" shot, 5-7 Y and spar thickness>0.64 in.







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Application of Advanced NDI to Address Damage Tolerance Requirements

- Use DTA work to define critical flaw size (0.030” initiation)
- Acquire representative structure to support NDI development
- Produce statistical array of specimens with engineered flaws for proper control (e.g. applicability of corrosion thinning POD)
- Complete a set of inspections using promising NDI to calculate POD & false call levels
  - Assess sensitivity, resolution, reliability and repeatability
  - Assess human factors issues on inspection process, equipment deployment, equipment cost, speed of coverage, & versatility
  - Include all variations/impediments including geometry, coatings, accessibility, depth of penetration, effects of shot-peening

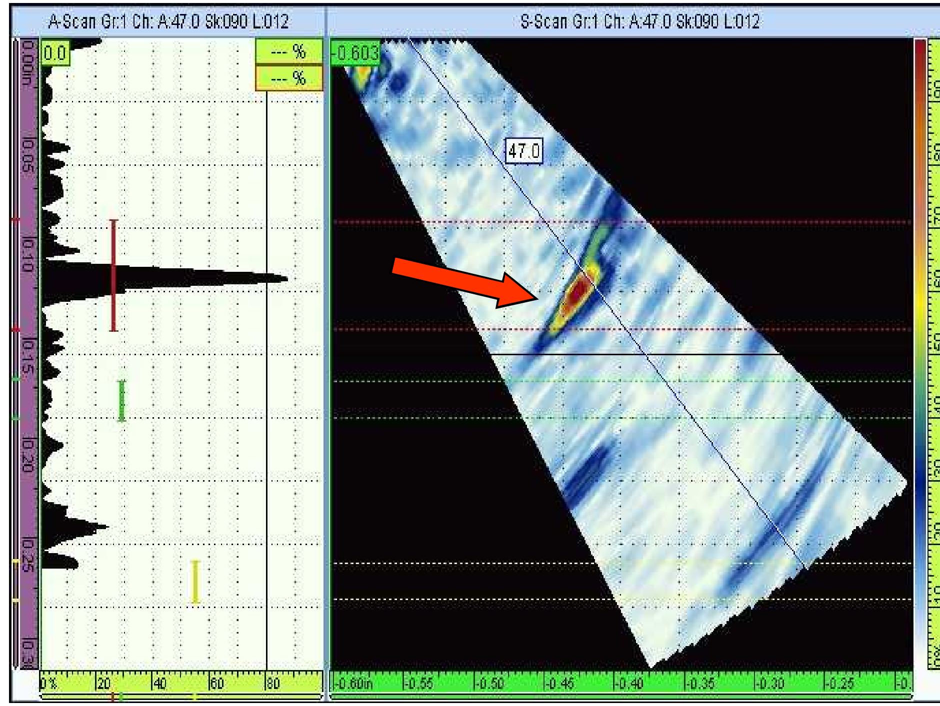
Application of Advanced NDI to Address Damage Tolerance Requirements

6. Supplemental structural insight – perform residual strength tests to assess DT in light of NDI sensitivity
7. Integration of results into aircraft operations
   - SB, AD, AC (procedural)
   - Training & Beta site testing
   - Support harmonization of NDI methods – address need to meet NDI requirements within a widely varying tech base

Phased Array Ultrasonic Inspection of Propeller Coupons

OMNI Scan UT Inspection Unit

(10 MHz Phased Array Probe)

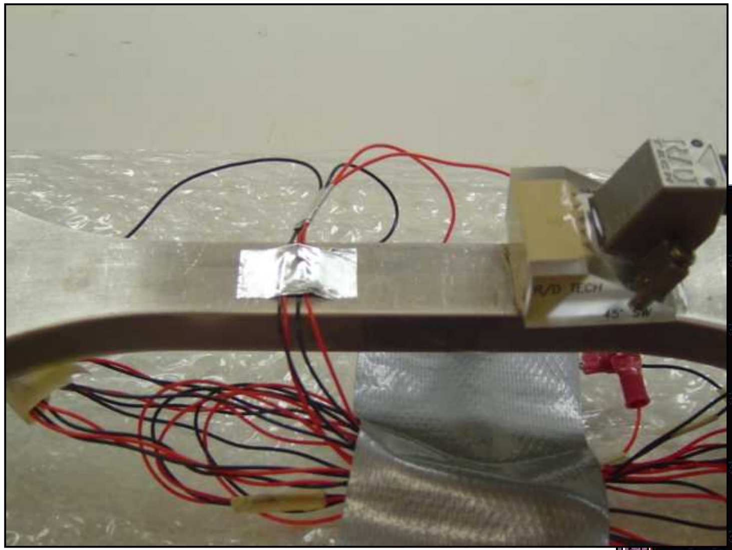


A-Scan signal

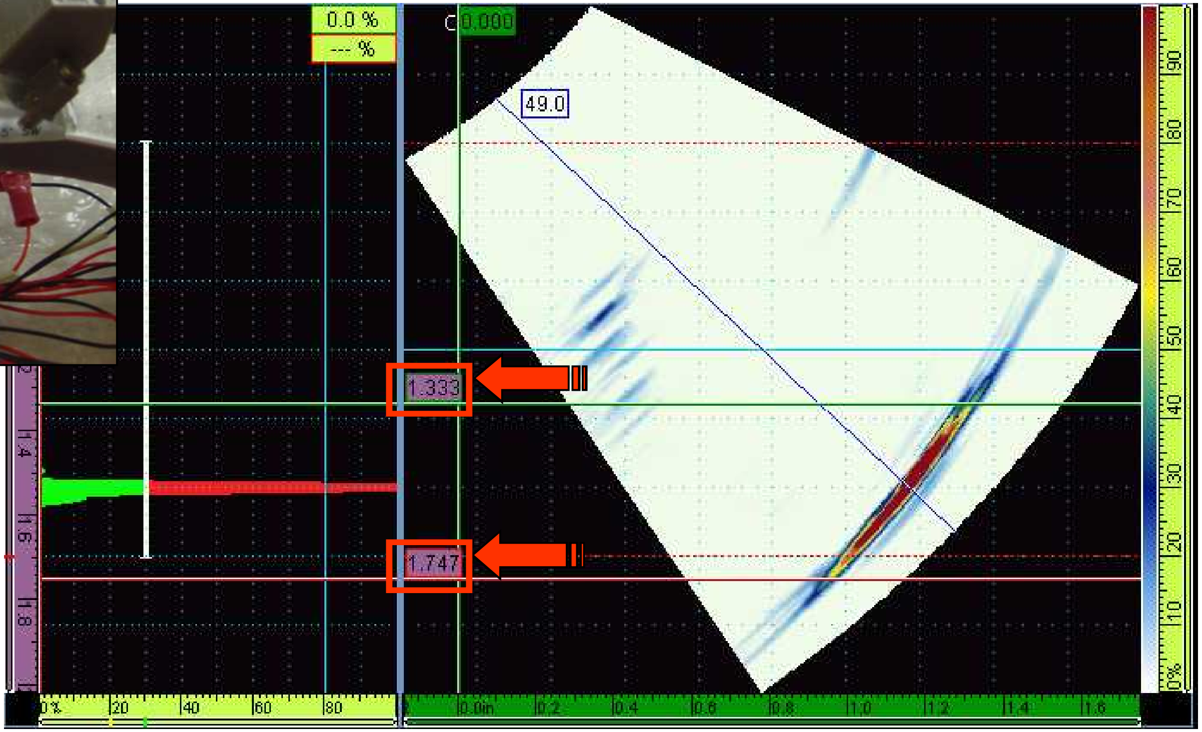
Sectoral-Scan
(Collection of A-Scans)

Measured Length = 0.038”

Dogbone Semi-Circular Laser Notch/Crack Specimens for Fatigue Property Assessment & NDI Evaluation



0.5" th. Dogbone Specimen with Center Crack, Potential Drop Leads & UT Array Probe



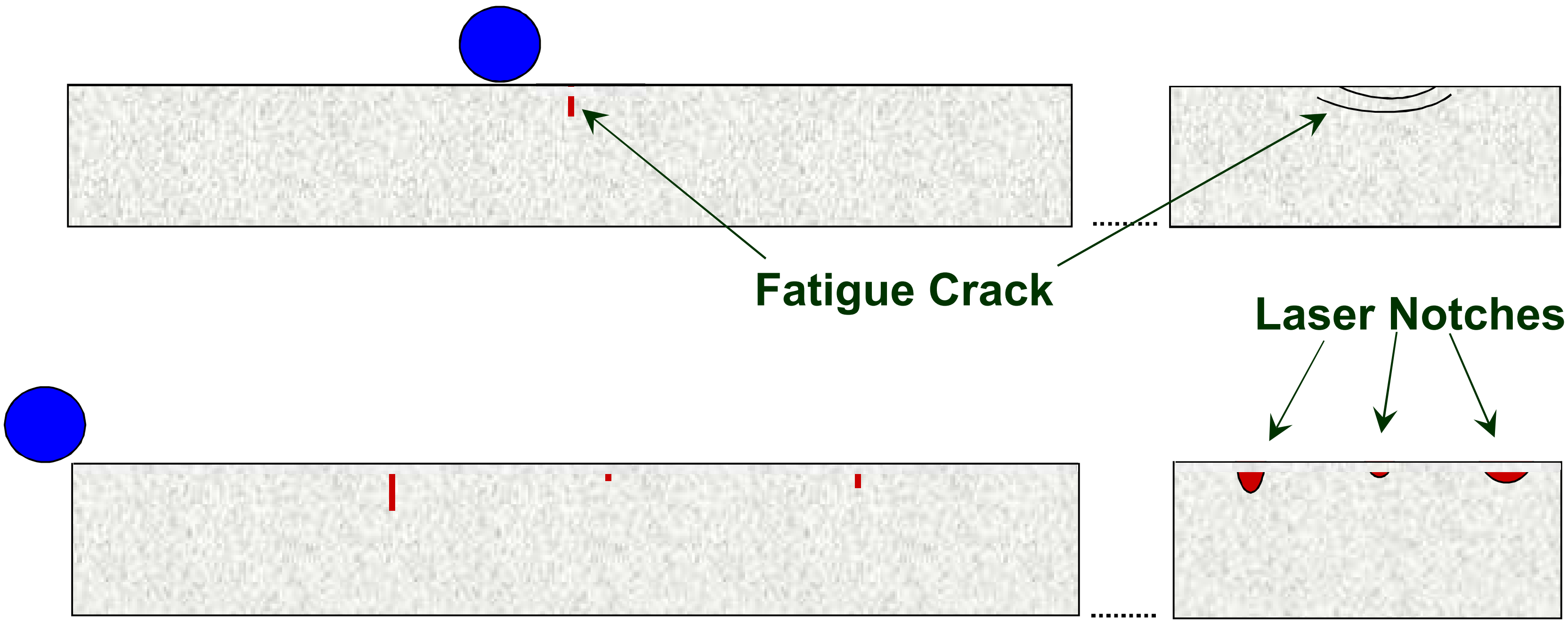
PD measurement = 0.414"

UT measurement = 0.414"

Full set of 44 Alum. Specimens Characterized

Ultra-Small Elliptical Crack Specimens for NDI Evaluation

Specimens = 3.5” W X 6” H X 0.125” th.
Cracks = 0.014” – 0.080” L X 0.006” – 0.035” D



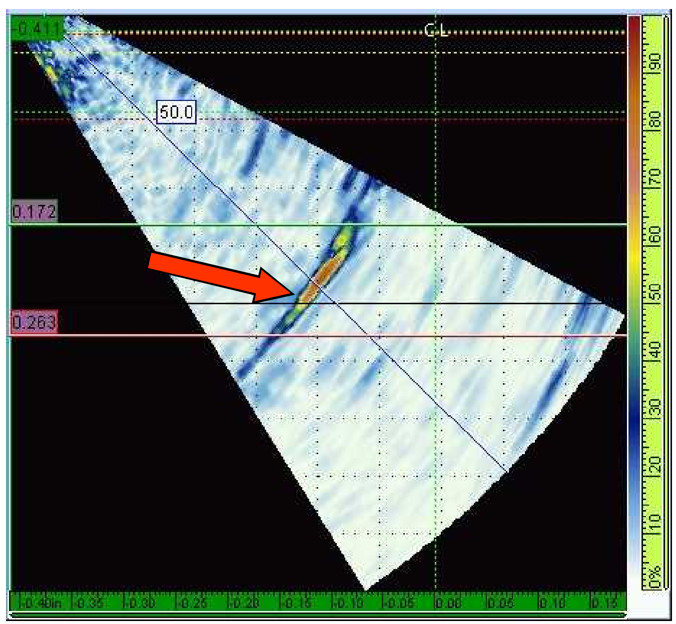
Machining process removes visual indication of crack

Initial UT Detection Results for Small Cracks

Instrument: ONMIScan MX

Transducer: 10 MHz, 16 element phased array

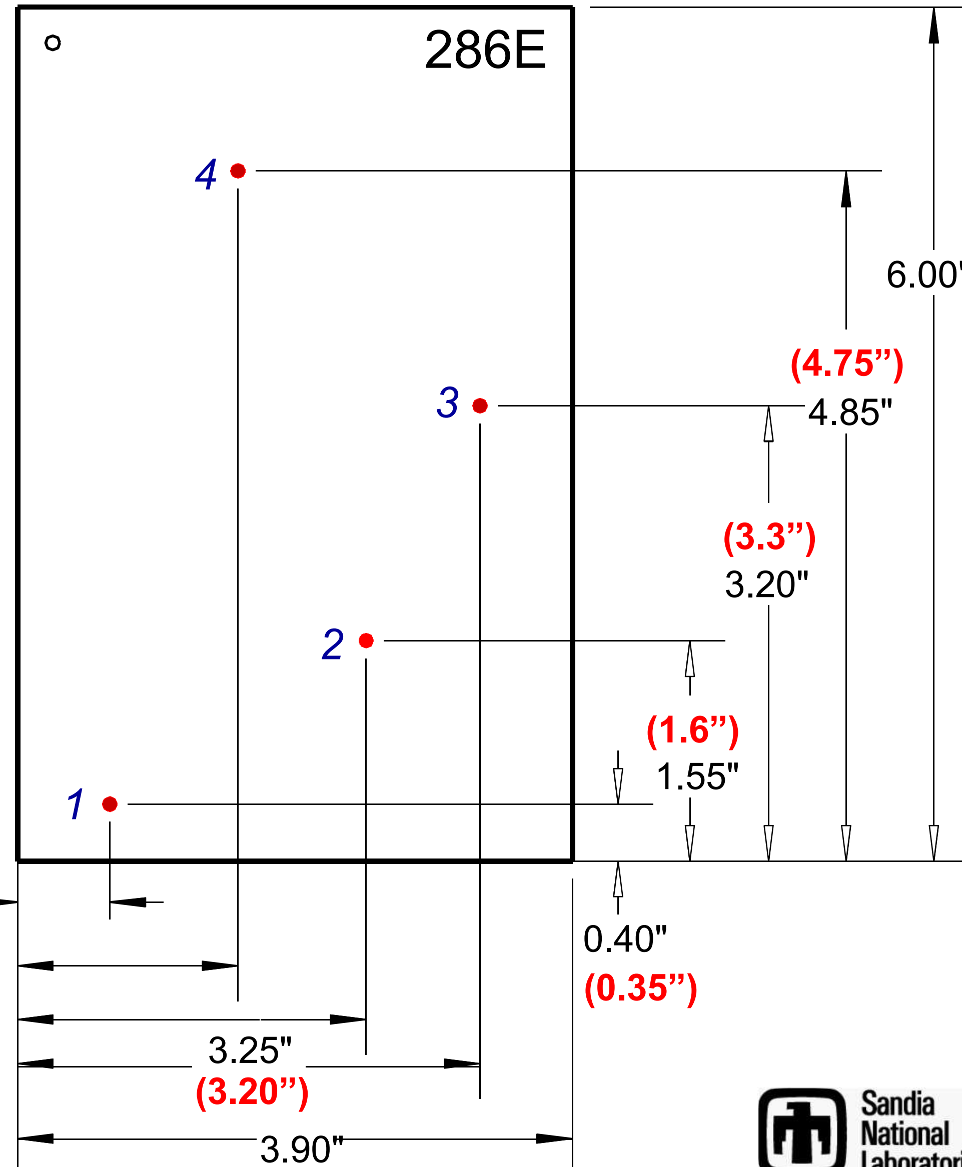
Set-up: Shear wave using A-scan along with a Sectorial view (collection of A-scans)



2024-T8 Specimen
3.5” W X 6” H X 0.125” th.

Initial UT Detection Results for Small Cracks

Specimen	Hit	Miss	Final Length	Length Predicted
2H10	X		0.051	0.046
374D	X		0.037	0.025
55Z2	X		0.116	0.122
	X		0.021	0.027
58K9	X		0.067	0.046
	X		0.054	0.056
	X		0.056	0.047
58M3	X		0.018	0.190
	X		0.018	0.190
2U58	X		0.078	0.086
	X		0.110	0.113
	X		0.089	0.090
	X		0.067	0.070
40U2	X		0.080	0.079
481S	X		0.071	0.067
	X		0.086	0.104
		X	0.024	N/A
	X		0.104	0.101
4A47		X	0.082	N/A
	X		0.034	0.046



Phased Array UT Method

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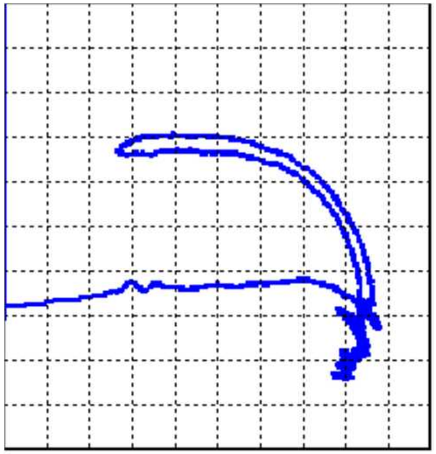
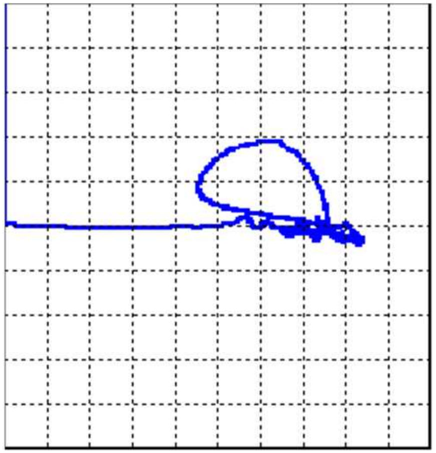
Small Crack Detection Using Eddy Current

EC is limited to Non-Peened Surfaces

Actual Crack Lengths	Crack Length Predictions
1) 0.094”	1) 0.230”
2) 0.080”	2) 0.175”
3) 0.102”	3) 0.230”
4) 0.070”	4) 0.160”

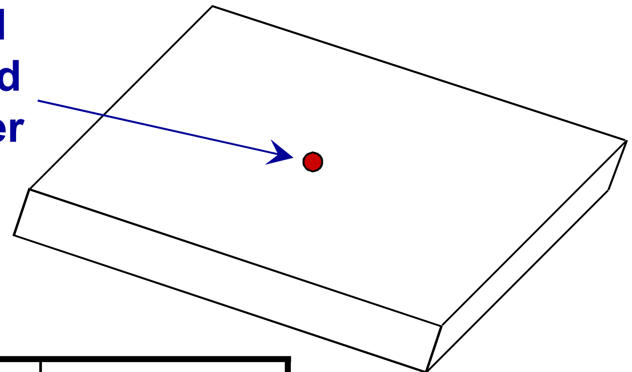


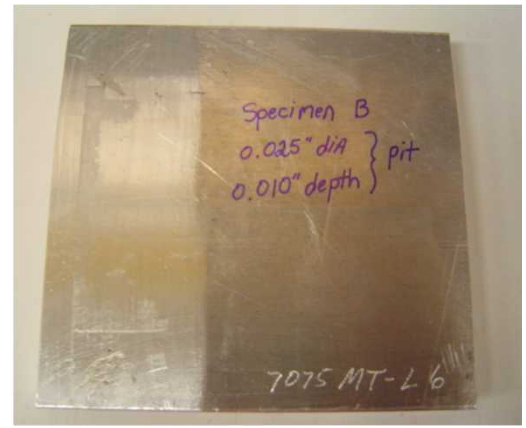


Detection of Corrosion Pits Using Phased Array Ultrasonics

Corrosion Pits – crack nucleation sites

Chemically-controlled corrosion pit measured with optical micrometer



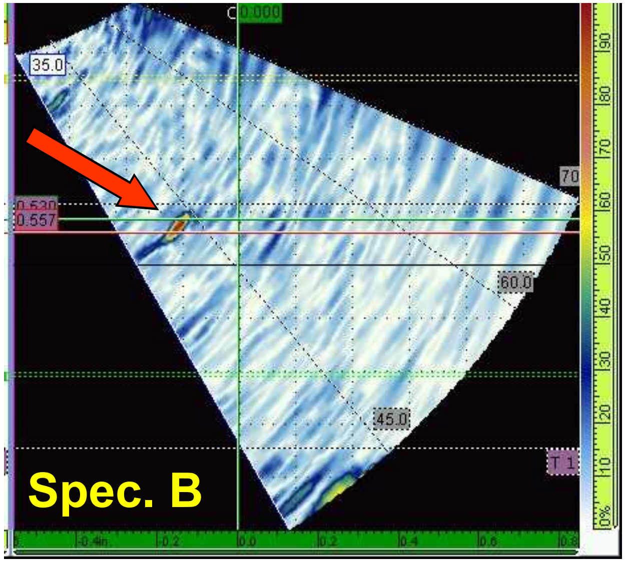


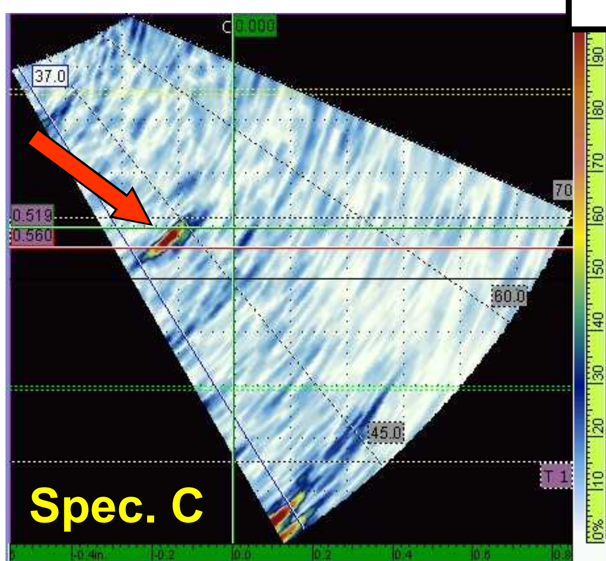
Aluminum 7075
(4" X 4" X 0.5" th.)

Specimen	Pit Depth	Pit Diameter
B	0.010	0.025
C	0.018	0.040
D	0.022	0.065

UT Inspection From Back Surface

Detection of Corrosion Pits Using Phased Array Ultrasonics





Specimen	Actual Corrosion Diameter	Estimated Corrosion Diameter
B	0.025	0.027
C	0.040	0.041
D	0.065	0.065

Conclusions

- Fracture mechanics study will determine crack threshold and crack growth characteristics for propeller materials
- Small fatigue cracks and crack nucleation from pits are damage scenarios of concern
- Phased array UT shows sensitivity to detect small cracks & corrosion pits
- Crack NDI needs to address geometry and edge effects further
- Seek to improve understanding of corrosion process - initiation, progression, and nucleation of cracks
- Disbonds in metal-composite blades are detected by UT
- Propeller redesign effort will study viability of CGDT for propeller system designs.

Detection of Micro-Subsurface Defects in Peened Surfaces to Support the Adoption of Damage Tolerance Methods in Propeller Designs

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Federal Aviation Administration

The FAA is planning to initiate a rule-making process to implement damage tolerance (DT) requirements for propellers. While damage tolerance methodology has been extensively and successfully used in fixed-wing aircraft structures, and has begun to be used for dynamic components in rotorcraft, propeller systems have been exclusively designed and certified using the safe-life approach (i.e., fatigue cycles or flight hours to crack formation). This paper describes FAA-sponsored research and development efforts to make DT technology more viable for use on propeller systems. The effort also seeks to generate critical data and improve propeller design methodology to aid the rotorcraft and propeller industries. The program consists of the following elements: 1) crack growth and fatigue properties database, 2) characterization of mechanical, environmental, and manufacturing threats, 3) propeller design using the damage tolerance approach, 4) fracture mechanics and crack growth analysis, and 5) nondestructive inspection (NDI) techniques development. This paper will introduce each of these elements but focus on the NDI initiative. The damage tolerance approach recognizes the impossibility of establishing complete structural redundancy – the fail-safe design premise – and places greater emphasis on inspection to ensure safety and reliability. The regime in which propeller NDI must work is significantly different than for structures on the fixed wing aircraft itself because a large number of load cycles are generated in a short time. Hence, smaller flaws must be detected to allow for the implementation of damage tolerance approaches. Ongoing activities are aimed at producing inspection methods to reliably detect uniquely-shaped cracks, or crack nucleation sites, that are as small as 0.015” deep by 0.025” wide. The load spectrum and operating environment for propellers often produce these cracks such that they do not pierce the inspection surface (burrowing cracks). Realistic test specimens are being produced using laser notching methods and subsequent NDI testing is being performed to calculate Probability of Detection (POD) and false call levels in the most promising techniques. Customized procedures and hardware are being evolved to optimize NDI sensitivity. The overall NDI effort is addressing the affect of all inspection impediments on performance including: geometry, coatings, accessibility, depth of penetration, effects of shot-peening, equipment deployment and other human factors issues. Residual strength tests are being conducted to assess damage tolerance in light of NDI sensitivity. The results accumulated to date will be presented along with the master plan to integrate DTA and associated advanced NDI into propeller aircraft.