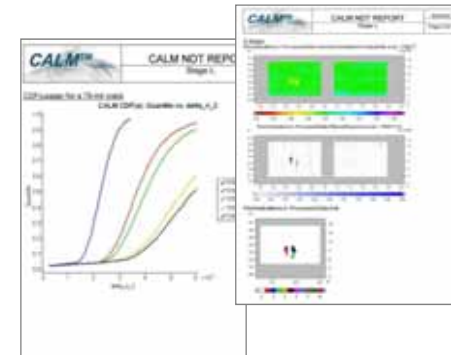
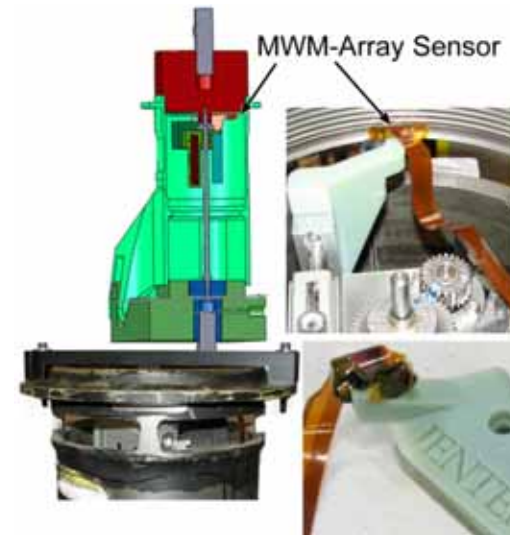


Early Fatigue Detection and Adaptive Life Management

Neil Goldfine, Ph.D.
President and Chief Engineer

JENTEK Sensors, Inc.
Waltham, MA

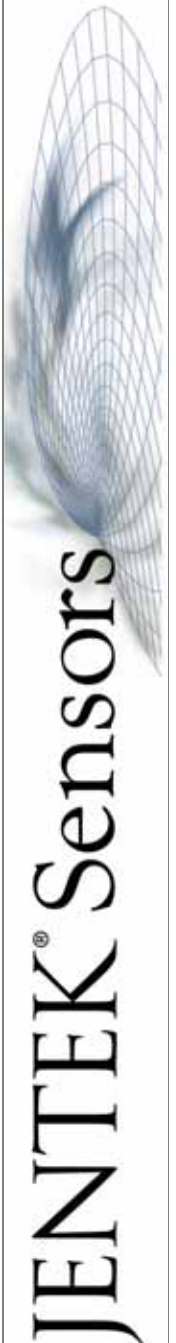
Navy Opportunity Forum, June 2013



Images © JENTEK Sensors, Inc. 2013

MWM sensors and MWM-Arrays are covered by issued and pending patents, including, but not limited to: 8,237,433, 8,222,897, 8,050,883, 7,994,781, 7,876,094, 7,812,601, 7,696,748, 7,589,526, 7,533,575, 7,528,598, 7,526,964, 7,518,360, 7,467,057, 7,451,657, 7,451,639, 7,411,390, 7,385,392, 7,348,771, 7,289,913, 7,280,940, 7,230,421, 7,188,532, 7,183,764, 7,161,351, 7,161,350, 7,106,055, 7,095,224, 7,049,811, 6,995,557, 6,992,482, 6,952,095, 6,798,198, 6,784,662, 6,781,387, 6,727,691, 6,657,429, 6,486,673, 6,433,542, 6,420,867, 6,380,747, 6,377,039, 6,351,120, 6,198,279, 6,188,218, 6,144,206, 5,966,011, 5,793,206, 5,629,621, 5,990,677 and RE39,206 (other US/foreign patents issued and pending).

© JENTEK Sensors 2013



JENTEK Sensors, Inc.

- 20 year old company, 30+ people, 10 PhD's
- Profitable business & growing market opportunities
- Strong Engineering-Science **Team**
- Extensive **IP** – over 50 Patents Issued
- Focus on sale of **products** to meet key customer needs
 - Aerospace & Defense business is growing
 - Oil & Gas business is growing fast

*JENTEK's Digital Eddy Current product line is a **U.S. Navy Standard Practice**, and **“technical aspects are FAA approved”** for some commercial applications.*

Commercial Engine Inspection



Image © JENTEK Sensors, Inc. 2013

Production / Inspection Systems in Use

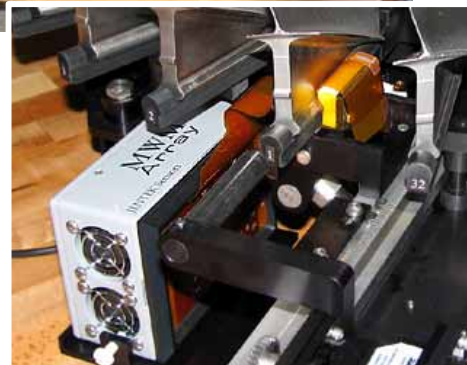
Military

- NAVAIR FRC-E use since April 2005
 - Detected large and small cracks **not detected** by conventional Eddy Current Testing (ET) and Liquid penetrant testing (LPT)
 - Low False Indication Rate, high up-time, very competitive cost

Disk Slots




Blade Dovetails



Commercial

- In use for 1000s of commercial engine inspections, **“Technical Aspects FAA approved”**

AE SERIES PROPULSION SYSTEM Service Bulletin Index  **Rolls-Royce**

LIST OF AE 3007A SERIES SERVICE BULLETINS

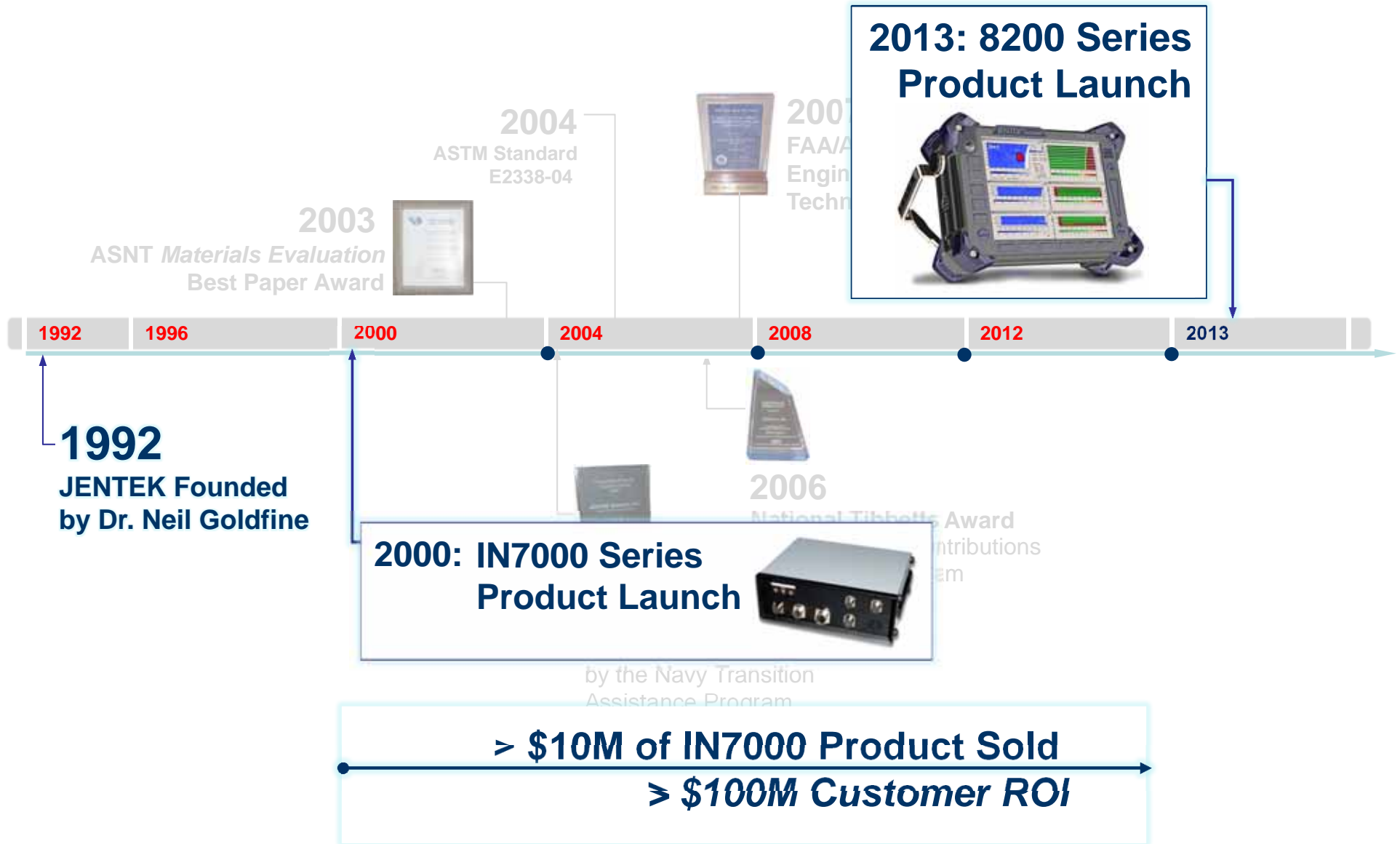
| SB No. | Rev No. | Title | Compliance Category | Date | Models Affected | Module or ATA Locator |
|-----------------|---------|--|---------------------|-----------|--|-----------------------|
| AE 3007A-72-386 | | See AE 3007A-A-72-386 | | | | |
| AE 3007A-72-388 | 1 | Engine - 6th- thru 13th-Stage Compressor Wheel Knife Edge Seals - Jentek Eddy Current Inspection | 8 | 09-May-11 | 7A, 7A1/1, 7A1/3, 7A1, 7A1E, 7A1P, 7A2 | 72-37-00 |

“Technical aspects of the method are FAA approved.”

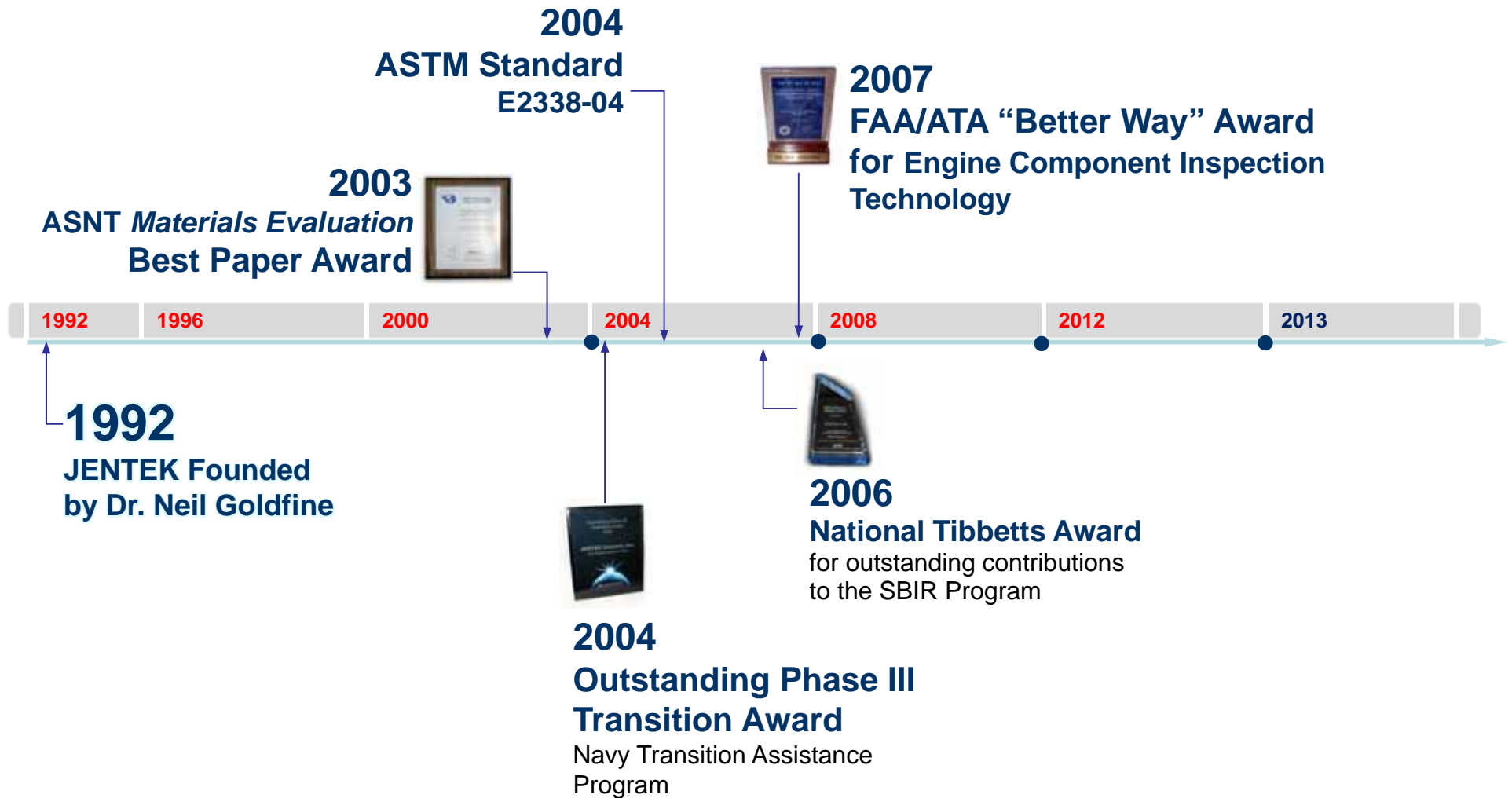


MWM-Array FA43 Sensor

MWM-Array & GridStation Products Provide High Return on Investment, Improved Safety



JENTEK Award-Winning MWM-Array Inspection Technology



Images © JENTEK Sensors, Inc. 2013

Problem: Life Management of Dynamic Components

- **Rapid and Uncertain Damage Evolution**
- Existing NDT and life management approaches not sufficient
- Non-relevant defects that do not grow into fatigue cracks confuse available inspection methods
- **No framework** exists for CBM+ decision support, using advanced NDT data

Solution: *MWM-Array Mapping & Tracking and Component Adaptive Life Management Software (CALM™) with early damage detection*



Public domain photo from wikipedia;
http://commons.wikimedia.org/wiki/File:CH-53_Super_Stallion_2.jpg

CALM™ for Rotorcraft Dynamic Components and Engine Components with NDT Mapping & Tracking

| Features | Advantages | Benefits |
|--|--|---|
| Fuzzy HyperLattices for rapid risk assessment | <ul style="list-style-type: none"> • RUL predictions with confidence intervals • Predicts risk of failure before next inspection in real time on NDT platform • RUL incorporates inspection uncertainties and historical/current inspection results | <ul style="list-style-type: none"> • Immediate feedback to inspector • Immediate scheduling of next inspection based on risk • More accurate RUL predictions enables more cost-effective maintenance • Improved safety margins and readiness |
| Early Damage Mapping & Tracking using MWM-Array | <ul style="list-style-type: none"> • Detects damage prior to rapid growth • Tracks damage growth for historical failure analysis and for RUL/ failure risk prediction • Reliable high resolution images of early fatigue damage with evolution tracking | <ul style="list-style-type: none"> • Enables damage growth rate computations with confidence intervals • High repeatability • More accurate RUL predictions enables more cost-effective maintenance • Improved safety margins and readiness • Proven NDT method, now in-use |
| Fleet-wide statistics recording and individual component tracking | <ul style="list-style-type: none"> • Reliable/repeatable data for all metals • Digital archiving and real-time updating captures damage growth statistics for populations and subpopulations of components across the fleet | <ul style="list-style-type: none"> • Improves fleet condition knowledge / enables improved maintenance planning • Life extension through early damage detection and prompting CBM actions (e.g. repairs and surface treatments) – cost reduction • Improved safety margins and readiness |
| Probability of Detection (POD) verification and real-time updating of inspection confidence intervals | <ul style="list-style-type: none"> • Verification of inspection performance • Real-time verification that POD curve assumptions are still correct for each inspected feature | <ul style="list-style-type: none"> • Substantially improved inspection reliability, improving safety • POD verification enables RUL estimation and risk assessment • Other NDT methods can't provide this |

MWM-Array Damage Mapping & Tracking for CALM

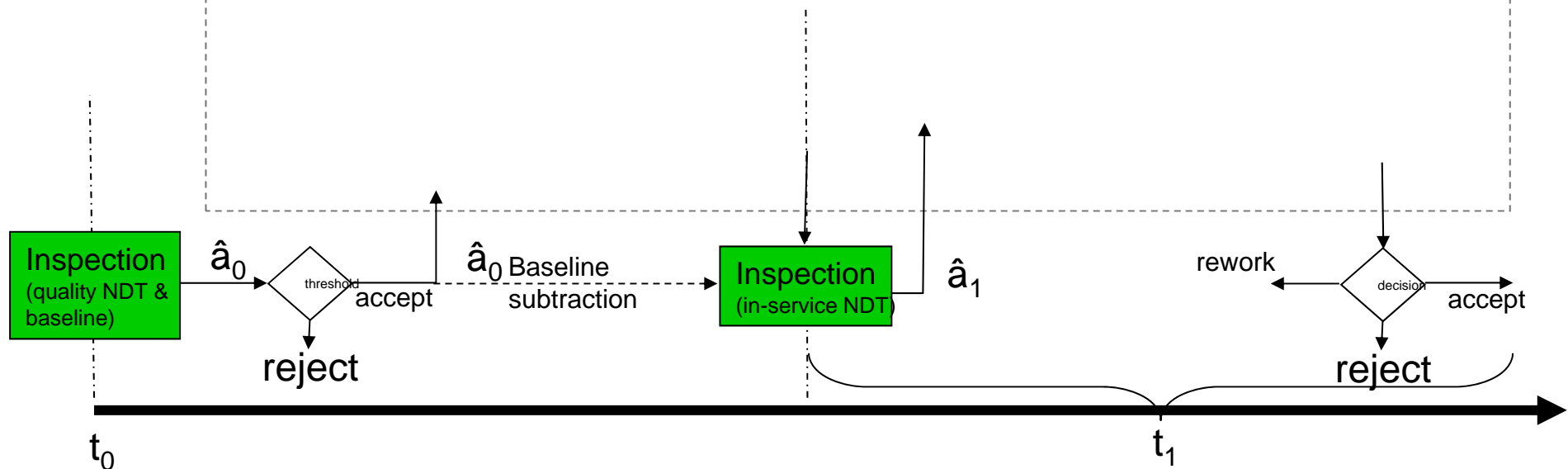
| Features | Advantages | Benefits |
|--|---|--|
| <p>MWM-Array sensor Flexible linear-drive eddy current array</p> | <ul style="list-style-type: none"> • Rapid scanning/inspection of wide areas and complex features • Dramatically outperforms conventional and other advanced eddy current testing (ET) methods | <ul style="list-style-type: none"> • Technical aspects FAA approved for some commercial engine inspections • Current US NAVY standard practice • Faster, more accurate, more cost-effective maintenance |
| <p>GridStation parallel architecture instruments with new 8200 product launch, providing 18 to >100 channels</p> | <ul style="list-style-type: none"> • Many fully parallel channels with extremely high fidelity impedance data over a wide frequency range • High quality impedance data | <ul style="list-style-type: none"> • Rapid inspection and rapid data acquisition, providing frequency data with for up to four frequencies simultaneously • Suitable for model-based inverse methods <i>No other systems provide this quality of data</i> |
| <p>Grids (2-unknowns), Lattices (3-unknowns) and HyperLattices with hierarchical inverse methods</p> | <ul style="list-style-type: none"> • Rapid data analysis • Extremely reliable inspections with real-time assessment of POD performance and verification of POD assumptions • Real-time confidence interval calculations for NDT results | <ul style="list-style-type: none"> • Only ET method providing real-time feedback to operator on coverage and lift-off (proximity of sensor to surface) for each inspected location throughout inspection region • Improved RUL and risk prediction estimates |
| <p>GridStation Software for data acquisition, visualization, archiving and decision support</p> | <ul style="list-style-type: none"> • User friendly software interface • Grid-based MWM-Array data visualization and high resolution imaging support • Provides POD performance verification and statistics needed for RUL estimation and risk assessment | <ul style="list-style-type: none"> • Provides substantially improved inspection reliability, leading to improved safety and more cost-effective maintenance • Reduces inspection burden • <i>Next generation software will be platform independent</i> |

Component, Adaptive Life Management – CALM™

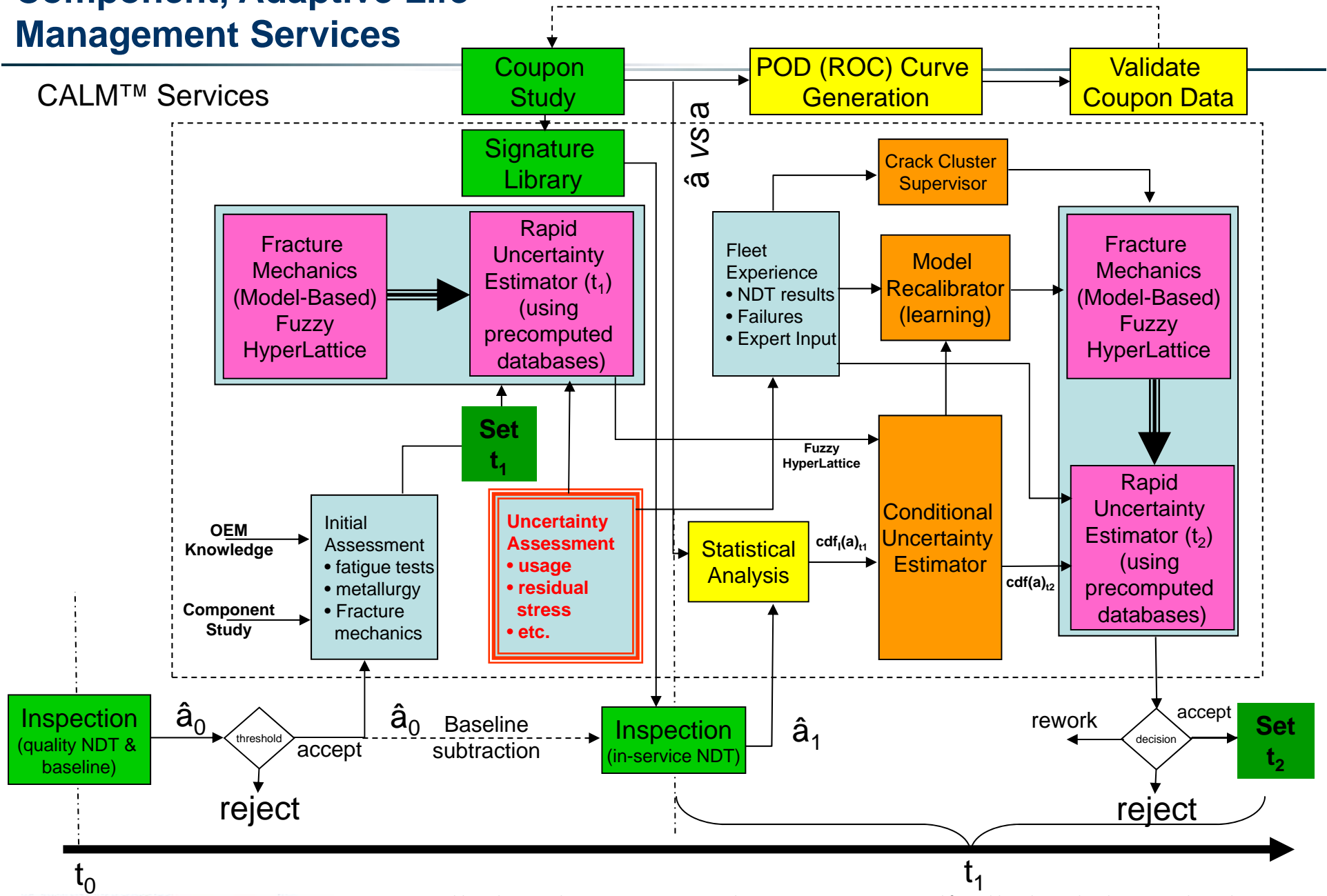
CALM™ Services

Providing a Framework to

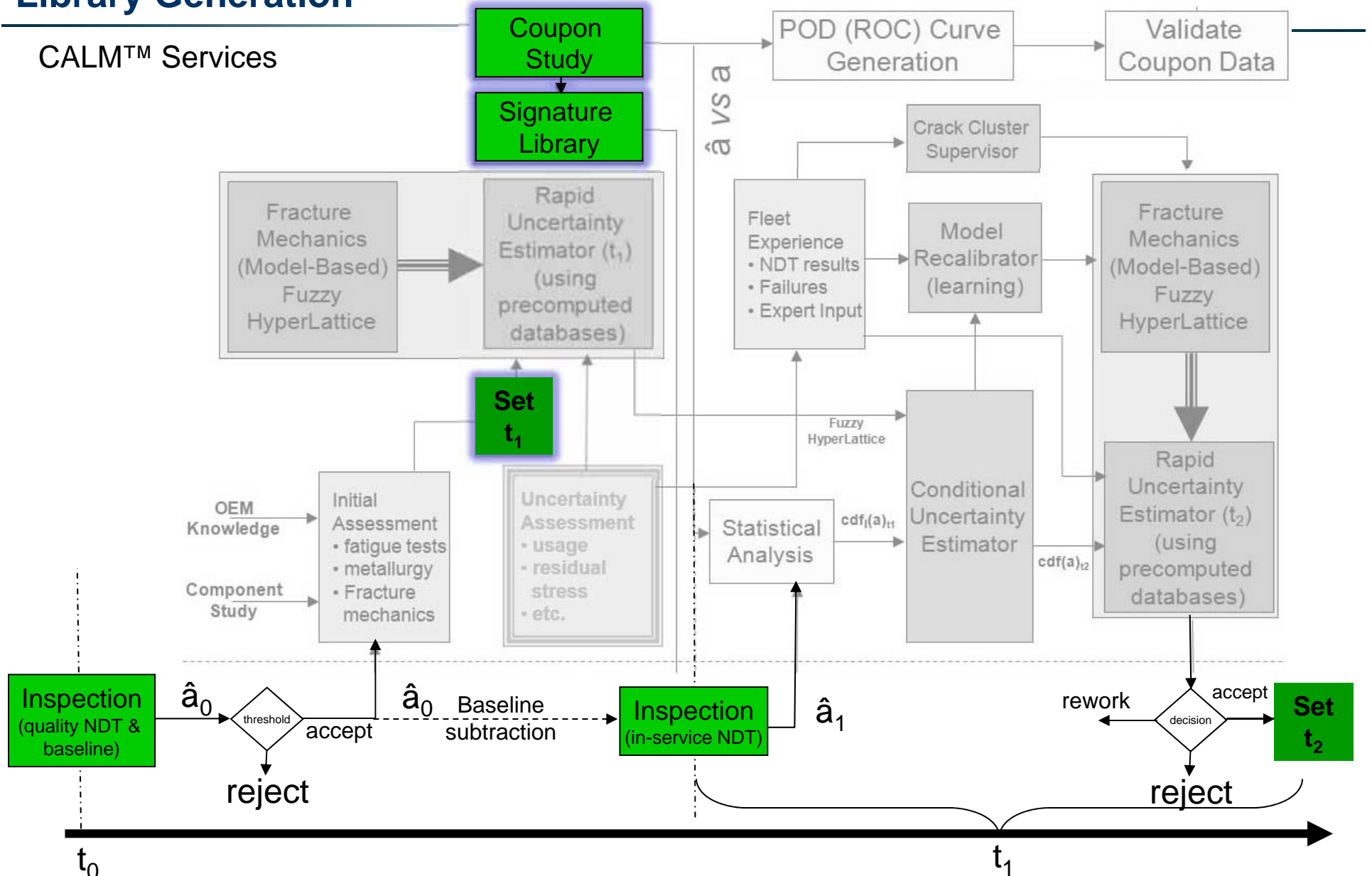
- track digital inspection data
- record events (e.g. impact damage)
- assess risk of failure before next inspection



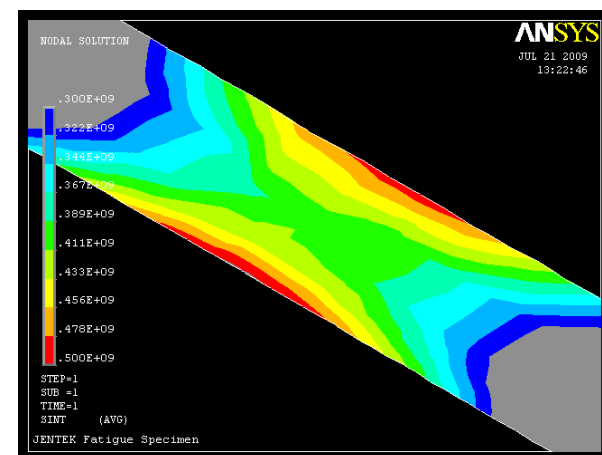
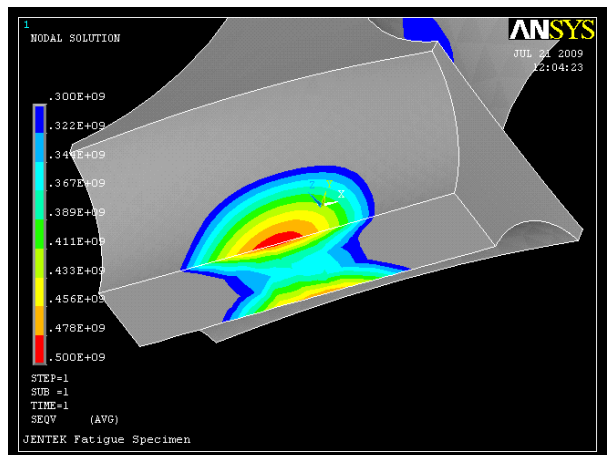
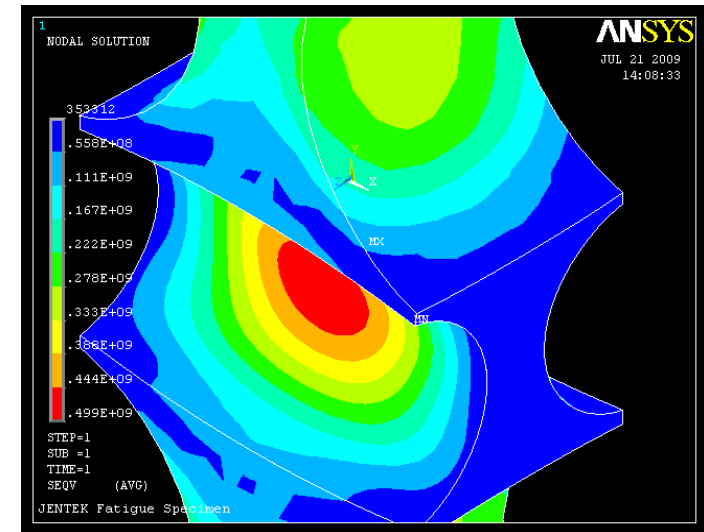
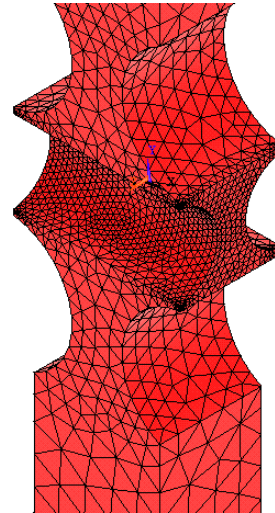
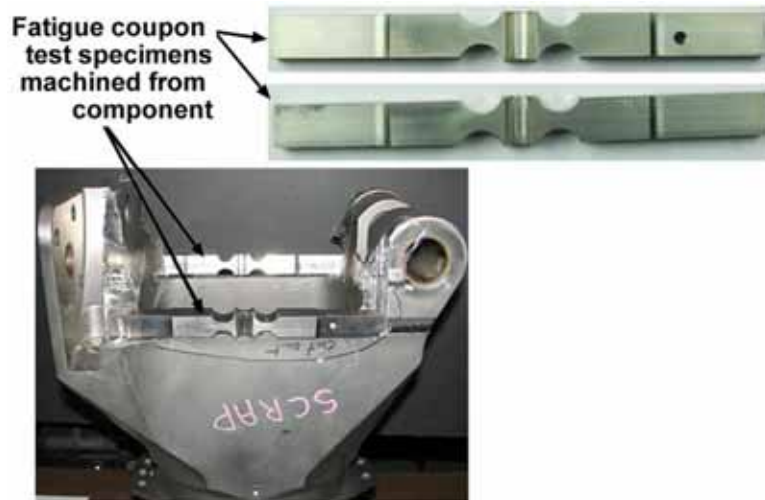
Component, Adaptive Life Management Services



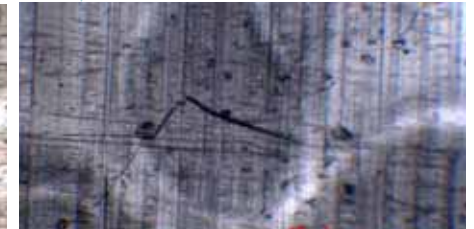
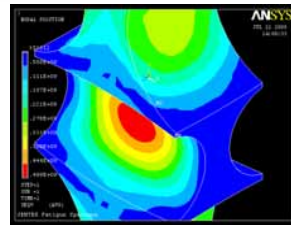
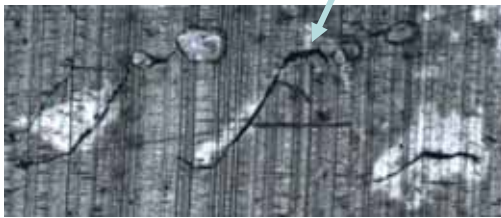
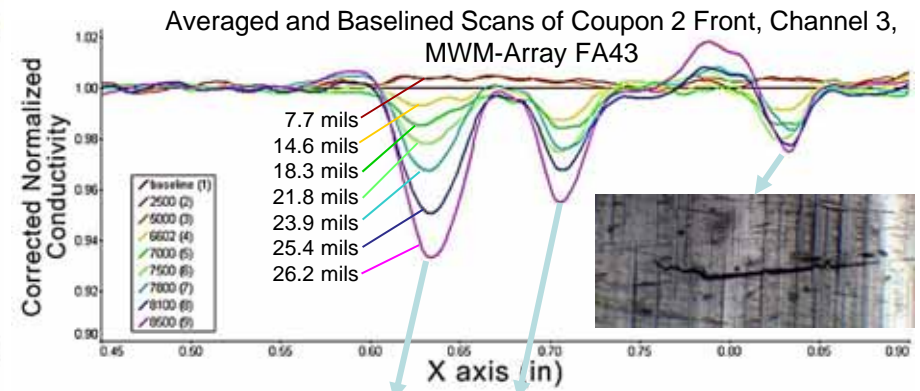
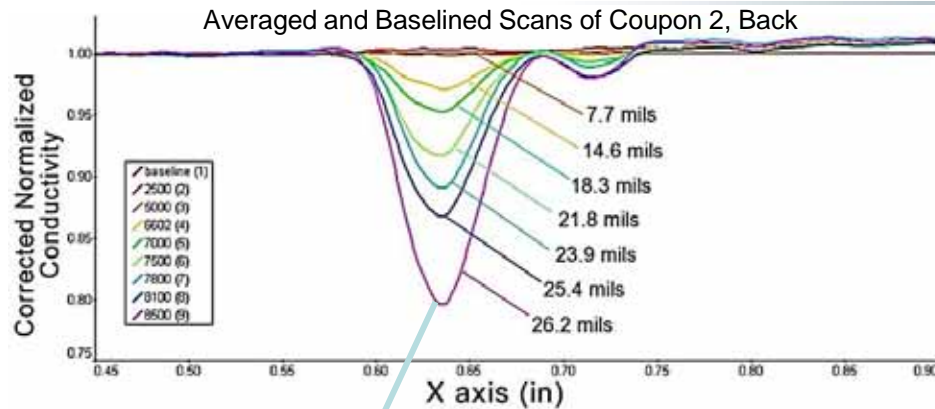
Coupon Study and Signature Library Generation



Coupon Testing to Build NDT Performance Statistics

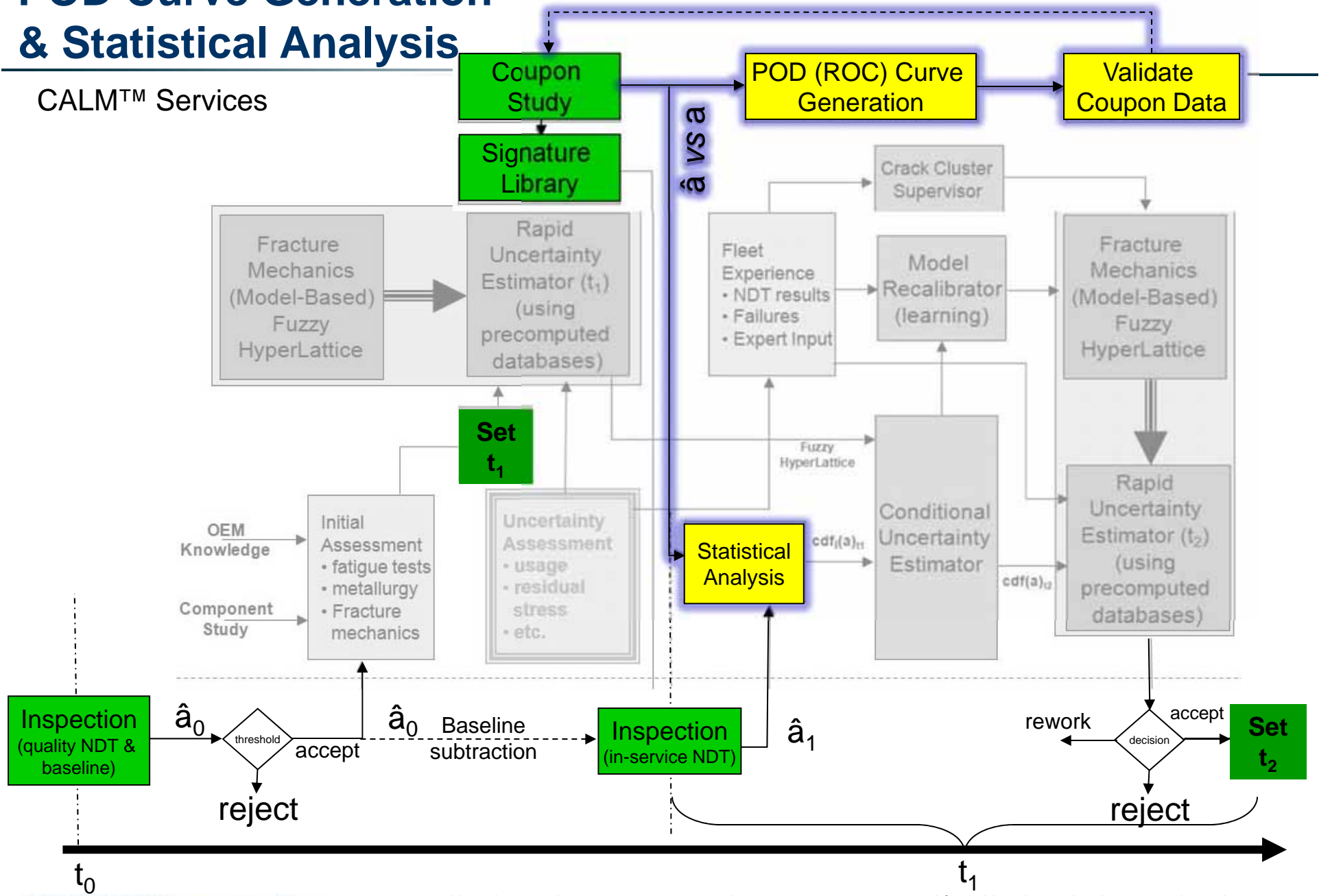


Mapping & Tracking Damage with Validation/Verification



POD Curve Generation & Statistical Analysis

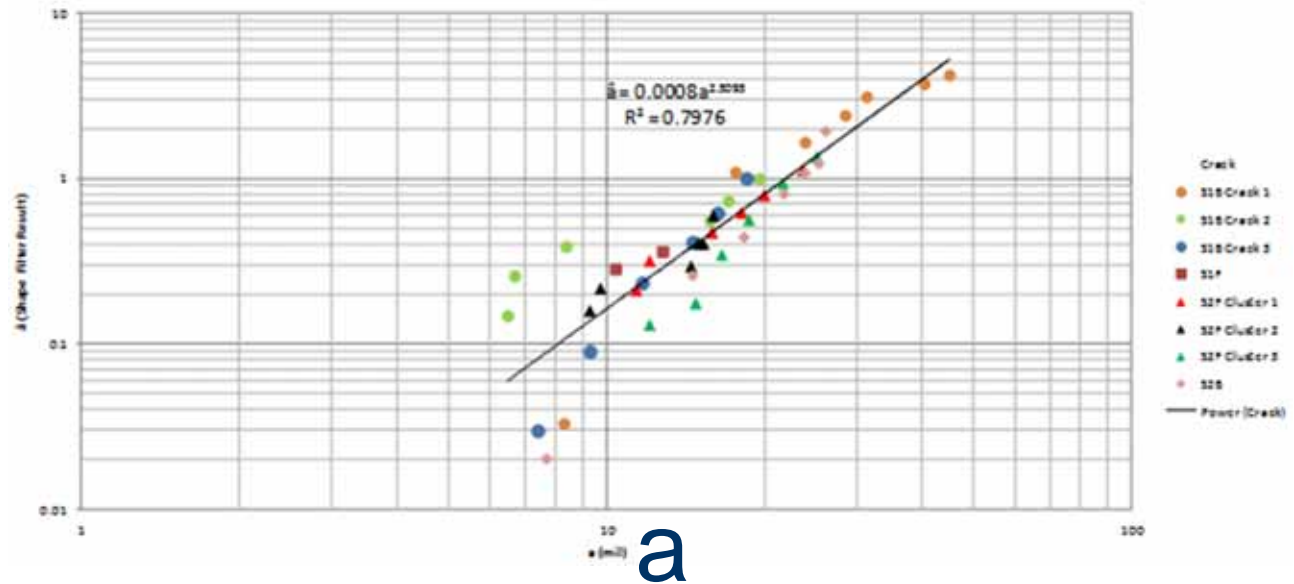
CALM™ Services



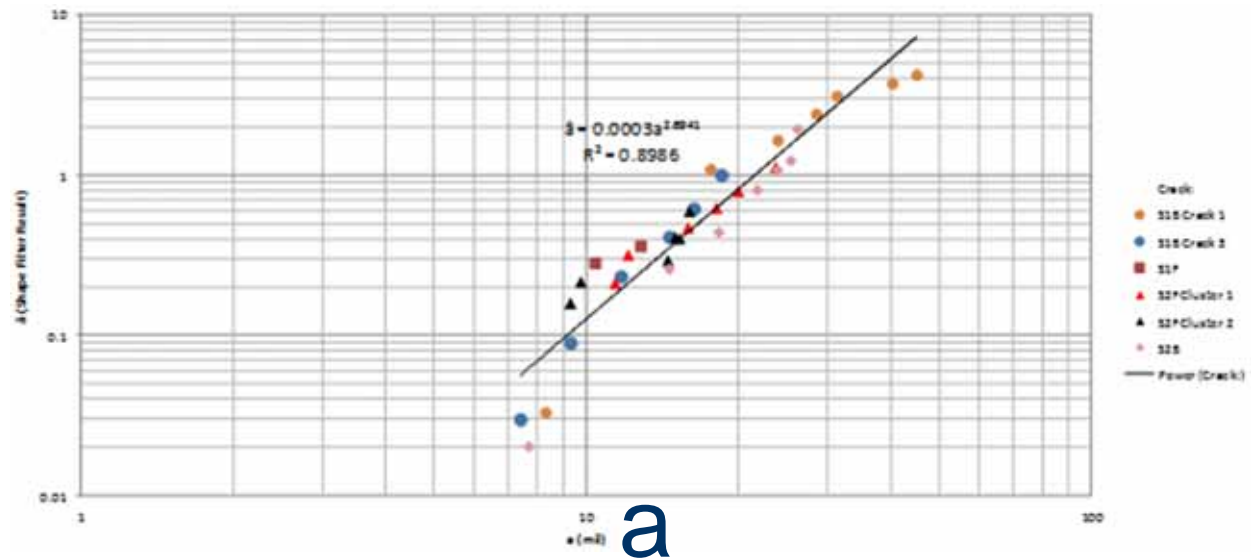
\hat{a} vs a Coupon Results for POD Curve Generation

Using
Mil-Hdbk-1823
Methodology

\hat{a}

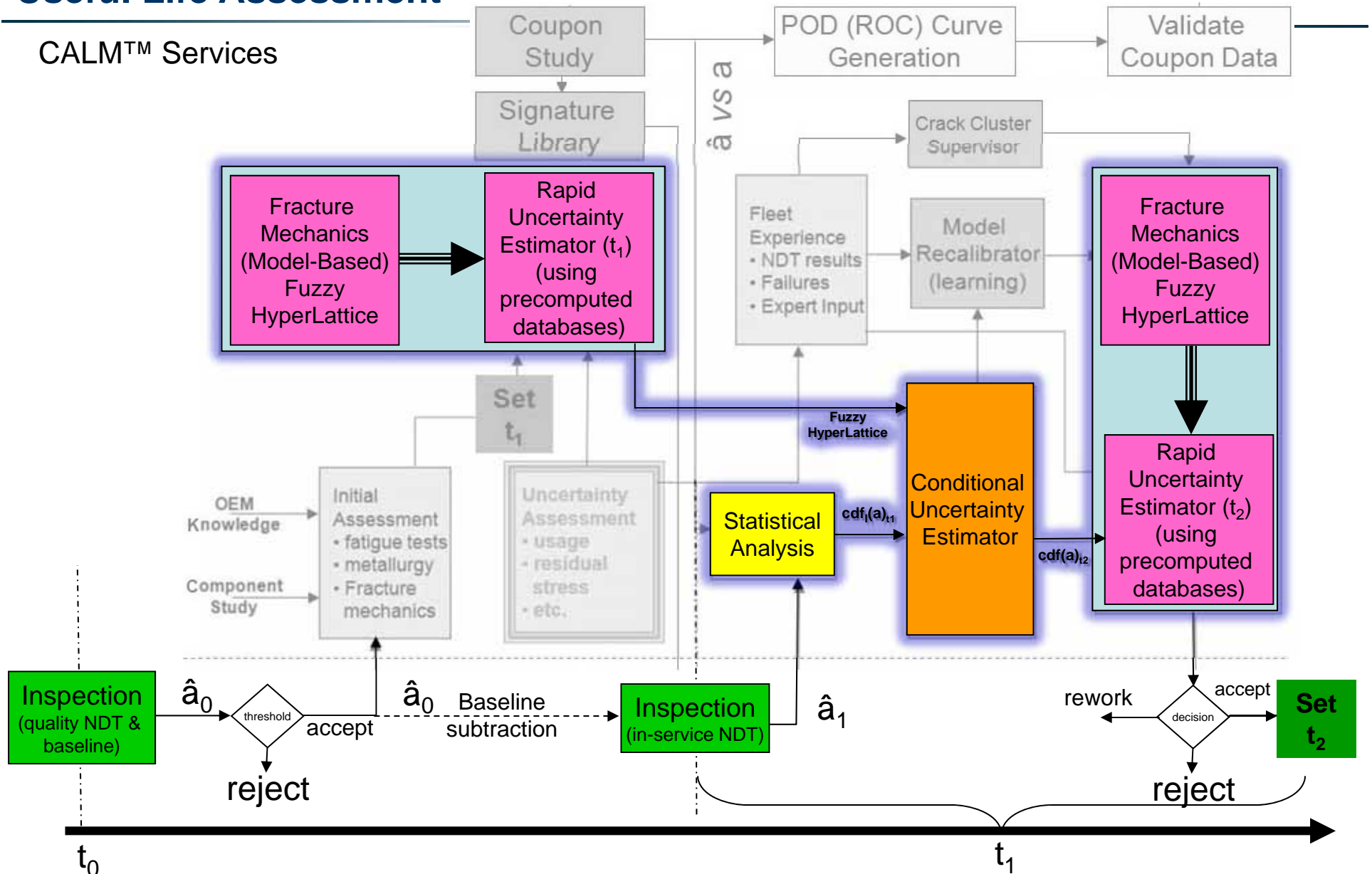


\hat{a}



Rapid Risk and Remaining Useful Life Assessment

CALM™ Services



CALM™ Services

Component Adaptive Life Management

- POD curve generation for NDT & embedded sensors
- Risk assessment & RUL estimation
- Fleet transition support
- After market decision support

CALM™ CALM NDT REPORT 6/2/2010
Stage 1₁ Page 1 of 5

Application data

Instrument: FA57
GridStation Version: 4.12x3 - JENTEK Test Release
Algorithm Version: 1, 0, 0, 0 (May 27 2010)

GridStation Configuration Data

Session: C:\jente\Gession\Helling\PlugTesting\Titanium\Indications2 testing for Titanium.sen
Frequencies: 1.5848 MHz, 2.51188 MHz, 8.30957 MHz, 15.8489 MHz
Analysis grid set: C:\jente\Gession\Helling\PlugTesting\Titanium\FA35 Grids
Calibration grid set: C:\jente\Gession\Helling\PlugTesting\Titanium\FA35 Grids

Algorithm Configuration Data

Analysis Frequency: 15.84 MHz
Norm Window Min X Value: 0.8 in.
Norm Window Max X Value: 0.15 in.
Analysis Area Min X Value: 0.8 in.
Analysis Area Max X Value: 0.15 in.
Analysis Area Min Channel: 4
Analysis Area Max Channel: 18
Shape Filter Signature File: C:\jente\Gession\Helling\PlugTesting\Titanium\CrackSignatures.dat
Filtered Response Threshold: 0.5
Baseline Scan Data File: C:\jente\Gession\Helling\PlugTesting\Titanium\T143F1 Baseline.jib

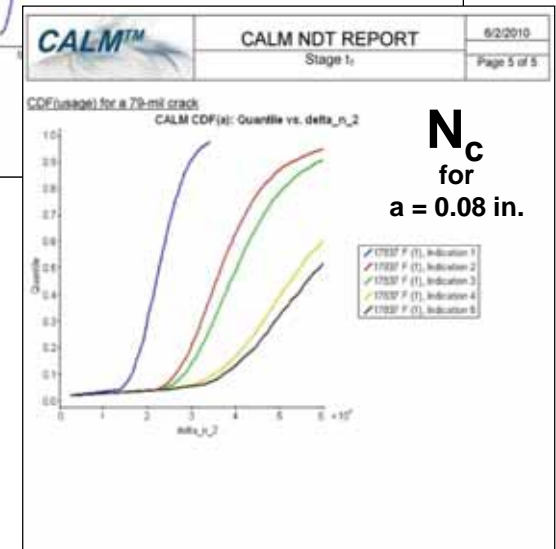
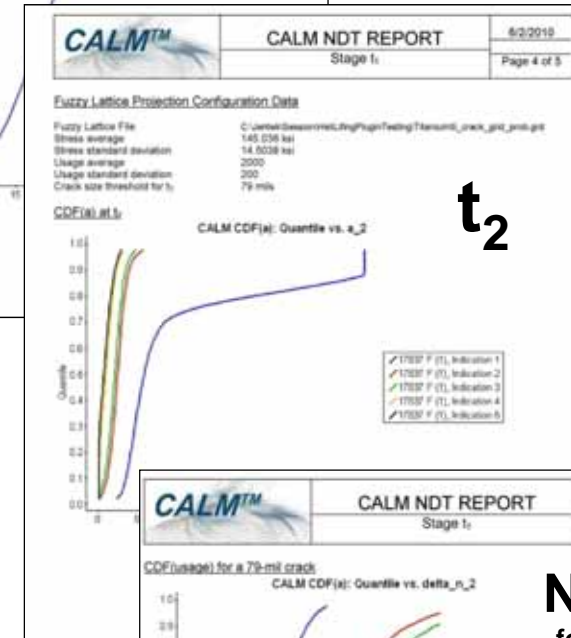
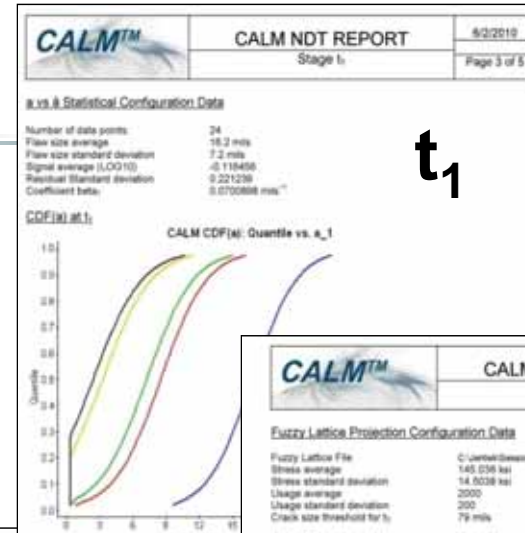
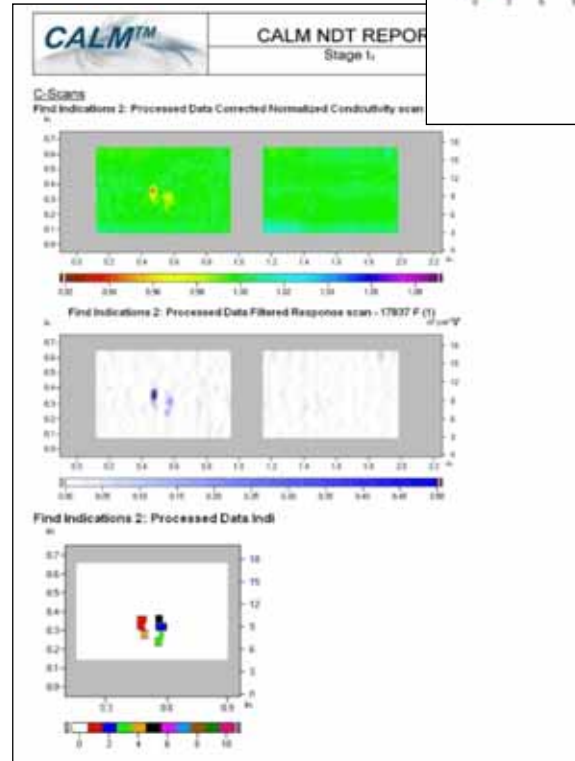
Component Metadata

Aircraft: Model 8000
Serial number: 12-00-2
Component: FA-43
Component serial number: FA-43-01
Operator: Ti-6Al-4V
Date: shot peened
Time: none
Temperature (°F): none
Relative Humidity: none
JENTEK Instrument: Model 8000
JENTEK Instrument Serial Number: 12-00-2
Sensor: FA-43
Sensor Serial Number: FA-43-01
Material: Ti-6Al-4V
Component surface treatment: shot peened
Previous CBM action: none

Results

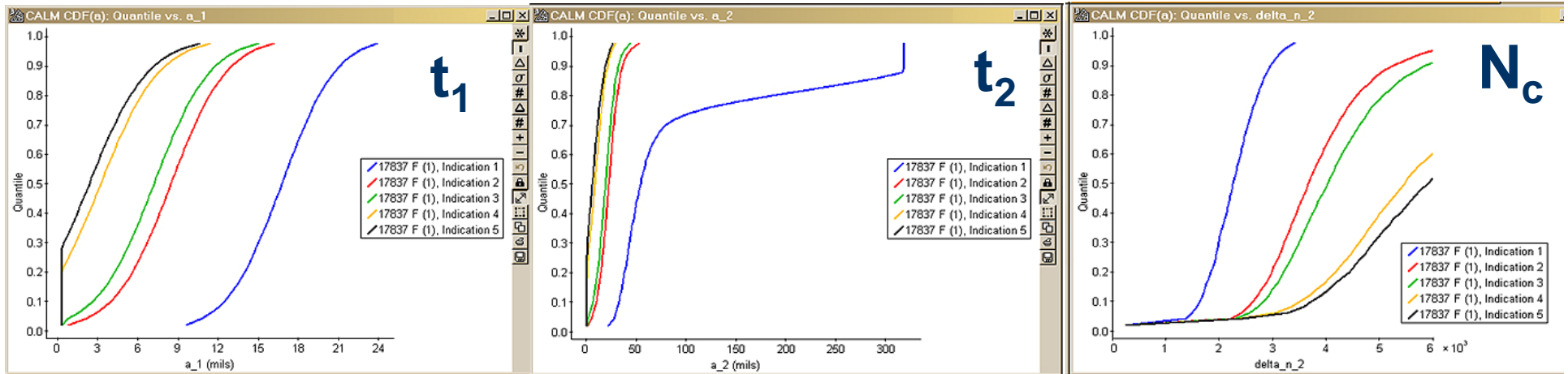
| Indication | X_pos | Channel | δ | Status |
|--------------|--------|---------|----------|--------|
| Indication 1 | 0.4776 | 10.00 | 0.8379 | Reject |
| Indication 2 | 0.5829 | 8.000 | 0.2200 | Track |
| Indication 3 | 0.5595 | 7.000 | 0.1791 | Track |
| Indication 4 | 0.4898 | 8.000 | 0.09417 | Track |
| Indication 5 | 0.5622 | 10.00 | 0.08197 | Track |

JENTEK Sensors, Inc. GRIDSTATION Report
Telephone: 761-442-9666, Email: jentek@shore.net
Indications are reported based on customer-approved thresholds.



Rapid Risk Assessment from NDT Data

Component Adaptive Life Management (CALM) software

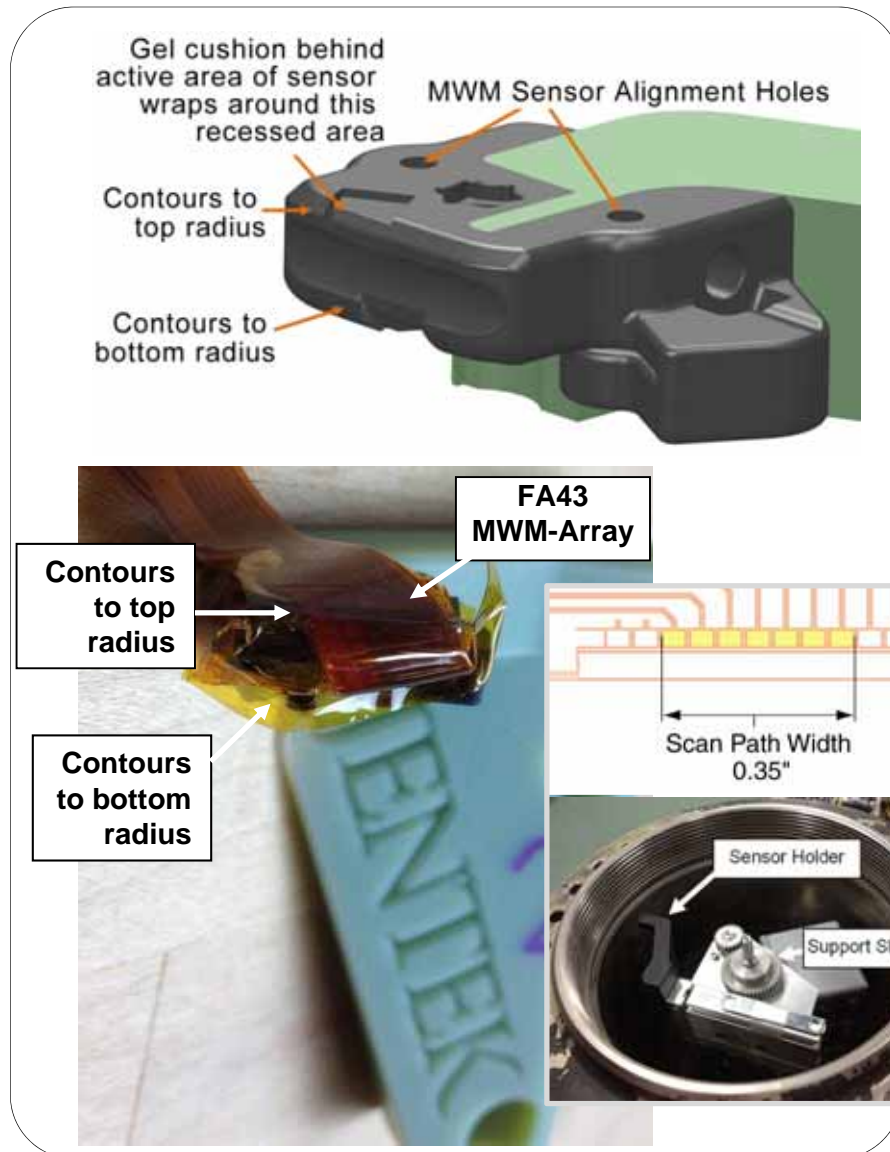


Cumulative probability distributions for crack size at Time t_1

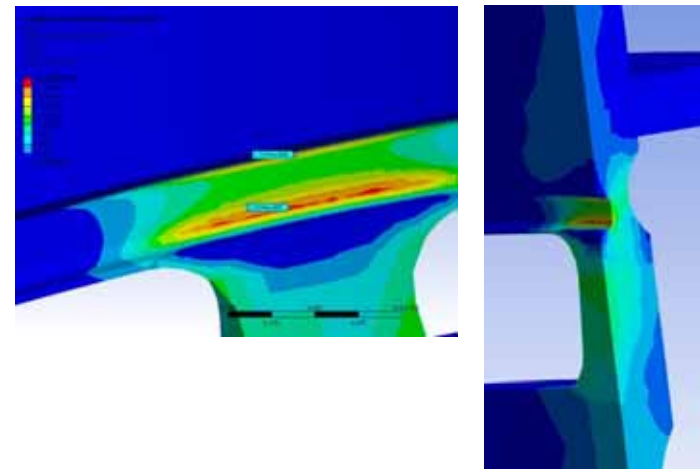
Cumulative probability distributions for crack size at Time t_2

Cumulative probability distributions for cycles remaining to reach critical crack size (0.08 in.)

CH-53E Component Inspection



- Representative of in-service damage evolution
- Test repeatability and reliability
- Combine with coupon data to produce POD curves



Development Milestones Completed

| Milestone | TRL | Risk | Measure of Success | TRL Date |
|---|-----|----------|--|-----------|
| Demonstrate reliable crack detection with MWM-Array on similar components (e.g., engine components) | 9 | Low | Federal Aviation Administration – Air Transport Association (FAA-ATA) Better Way Award: Fleet Readiness Center (FRC) standard practice | Jan 2008 |
| Perform subcomponent demonstration | 5 | Moderate | Demonstrate improvement over conventional NDT | June 2009 |
| Develop adaptive asset management approach | 5 | Moderate | Establish sufficient capability for target application | Oct. 2009 |
| Adapt measurement and calibration methods for mapping & tracking | 7 | Moderate | Crack detection performance on coupons | Oct. 2012 |
| Perform component fatigue test for actual rotorcraft dynamic component | 7 | Moderate | Crack detection and CALM performance on component | Nov. 2012 |

Next Steps

- Transition to Fleet for Target Applications
 - Deliver Mapping & Tracking solution to FRC
 - Record data for two years
 - Apply CALM and initiate life extension in 3rd year
- Partner with OEMS and FRCs
 - Transition numerous targeted life extension solutions
- Broaden CALM Services
 - Fleet-wide data analysis & life management
 - Fleetwide CBM+ services

**CALM &
MWM-Array**



***Reduced total ownership costs,
... Improve readiness and safety***

*Provided by
JENTEK
Sensors*

Partners Sought

- **Program Office Support**
 - Further technology development
 - T&E for first CALM™ application
 - Transition to FRC-E and Navy depots
- **Partnerships and Customers**
 - Rotorcraft Primes
 - Sikorsky, Boeing and others
 - Army



Questions?

Come see us at Booth # A-416

Neil Goldfine, Ph.D., President

JENTEK® Sensors, Inc.

Phone: 781-642-9666

Email: jentek@jenteksensors.com

Website: www.jenteksensors.com

