Using SMART|DT to Ensure the Continued Structural Safety of Textron Aviation's Fleet

Beth Gamble, Chris Hurst and Perry Saville

March 24, 2016

Cessna 172 Skyhawk

Beech Bonanza

Cessna 208 Caravan

Beechcraft 1900D

Textron Aviation is the company formed from Cessna and Beechcraft in March 2014 – together 250,000+ airplanes have been delivered

Cessna O-2 Skymaster

Beechcraft T-6A Texan II

Cessna Citation X

Textron Airland Scorpion

Agenda

- Background
- Cessna 402C
- SMART|DT Methodology
- Using SMART|DT
- Service History
- SMART|DT Analysis - Wing
- SMART|DT Analysis - Engine Beam
- Recommendations

Background

- FAA Roadmap for General Aviation (GA) Aging Airplanes Programs
  - A guide to proactively manage the overall airworthiness of aging GA airplanes
  - Prompted by series of primary component failures
  - Development of data-driven risk assessment and risk management methods
- University of Texas – San Antonio (UTSA)
  - Developed a comprehensive probabilistic methodology and computer software to conduct risk assessments of GA airplanes
  - Software is called SMART – SMall Aircraft Risk Technology
    - SMART consists of two modules:
      - » SMART|LD - Linear Damage (fatigue)
      - » SMART|DT - Damage Tolerance (crack growth)
  - Software gives Federal Aviation Administration (FAA) engineers the tools to conduct a risk assessment of general aviation (GA) structural issues in support of policy decisions
- Cessna awarded a contract from UTSA to evaluate SMART using real world examples

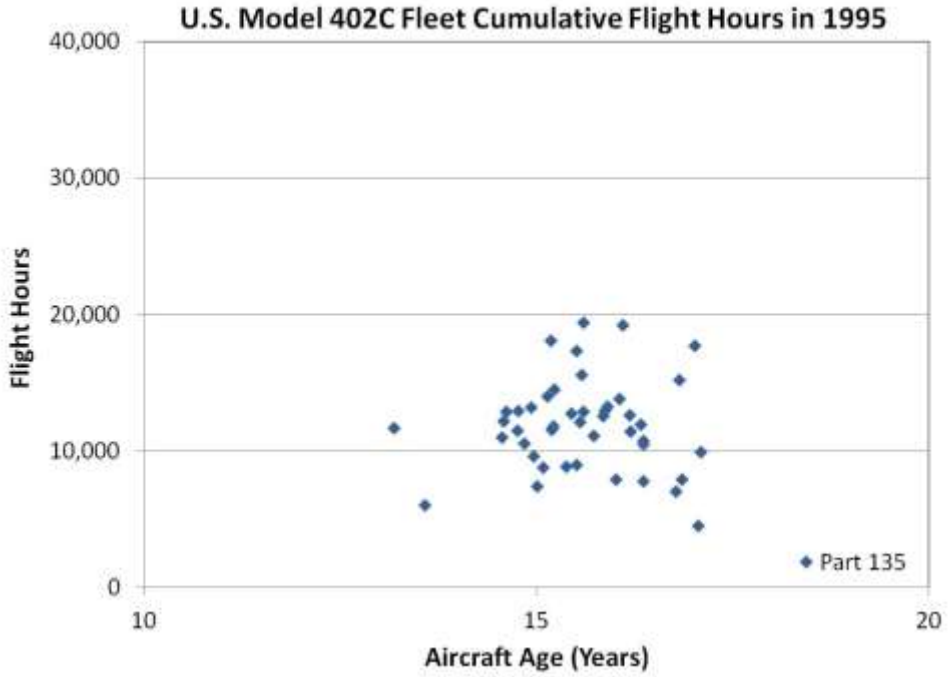
Cessna 402C

- Cessna Model 402C selected to evaluate SMART
  - Twin engine piston
  - Non-pressurized
  - Seats up to 9 passengers
  - Used in Part 135 Commuter
  - 381 402C's manufactured from 1979 to 1985

Cessna 402C

- Cessna was awarded an FAA contract to apply damage tolerance methods to the Model 402C in 1995
  - New development tests, service experience and applications of current technology in the areas of loads, stress, fatigue and fracture mechanics were utilized to identify and establish structural inspections and modifications
  - Resulting inspection program for the Model 402C is based on 3 different usages
    - » Typical Usage – 6 flight profiles, 68 minute average
    - » Grand Canyon Usage – 2 flight profiles, 60 minutes each
    - » Short Flight Usage – 1 flight profile, 25 minutes

Cessna 402C

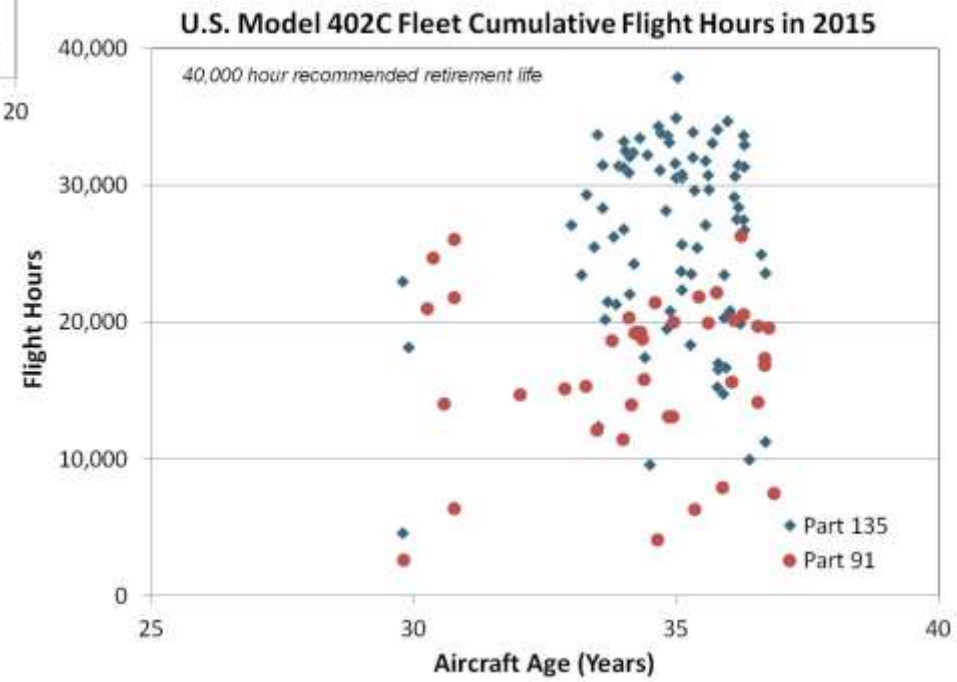


Commercial operations in 1995:

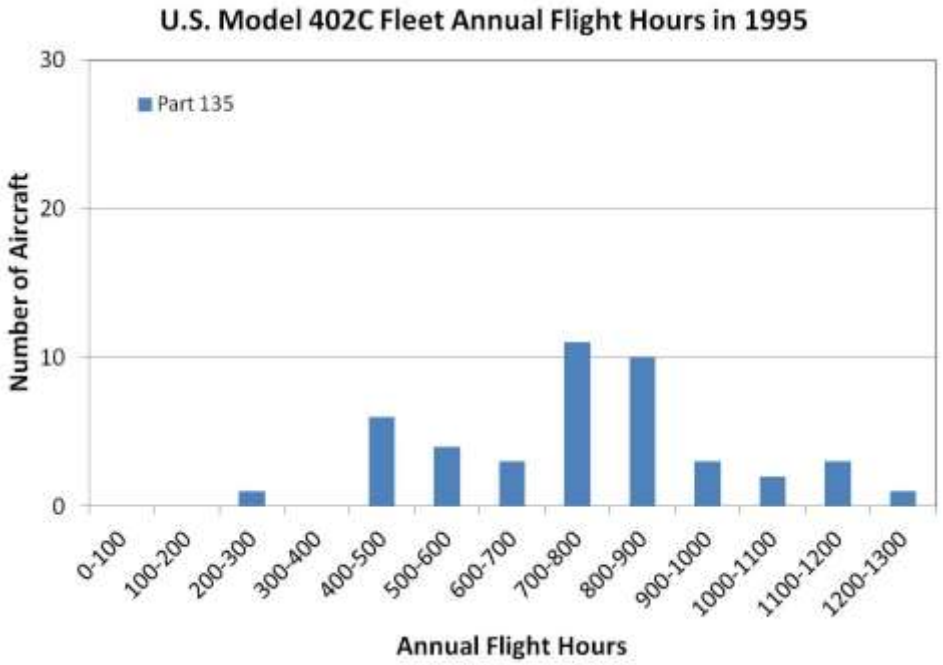
- 45% Short
- 30% Grand Canyon
- 25% Typical

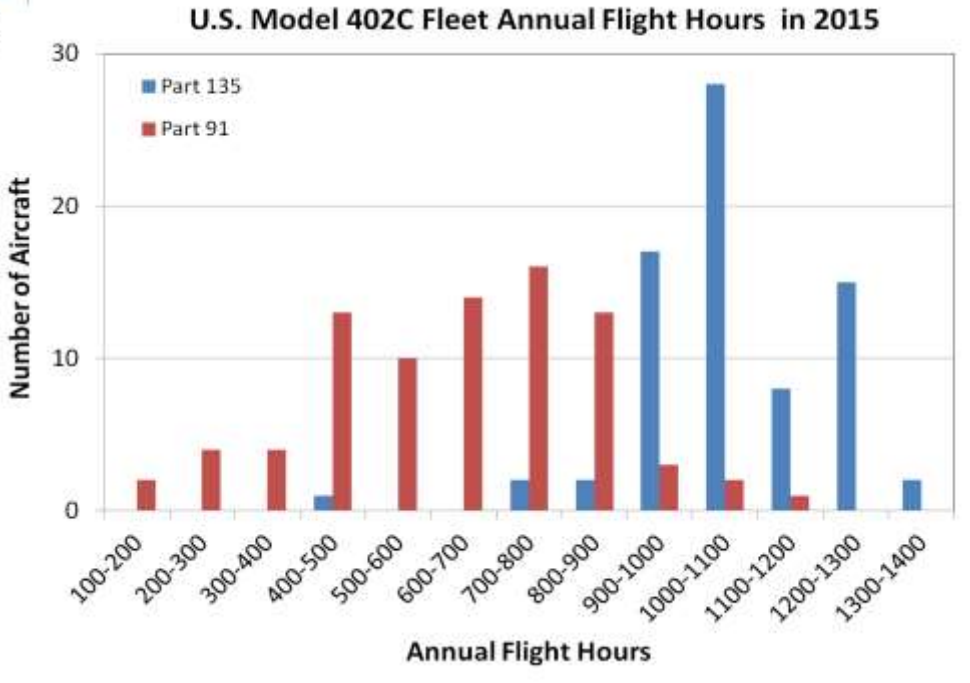
Commercial operations in 2015:

- 67% Short
- 33% Typical



Cessna 402C


U.S. Model 402C Fleet Annual Flight Hours in 1995
Part 135
Number of Aircraft
30
20
10
0
0-100
100-200
200-300
300-400
400-500
500-600
600-700
700-800
800-900
900-1000
1000-1100
1100-1200
1200-1300
Annual Flight Hours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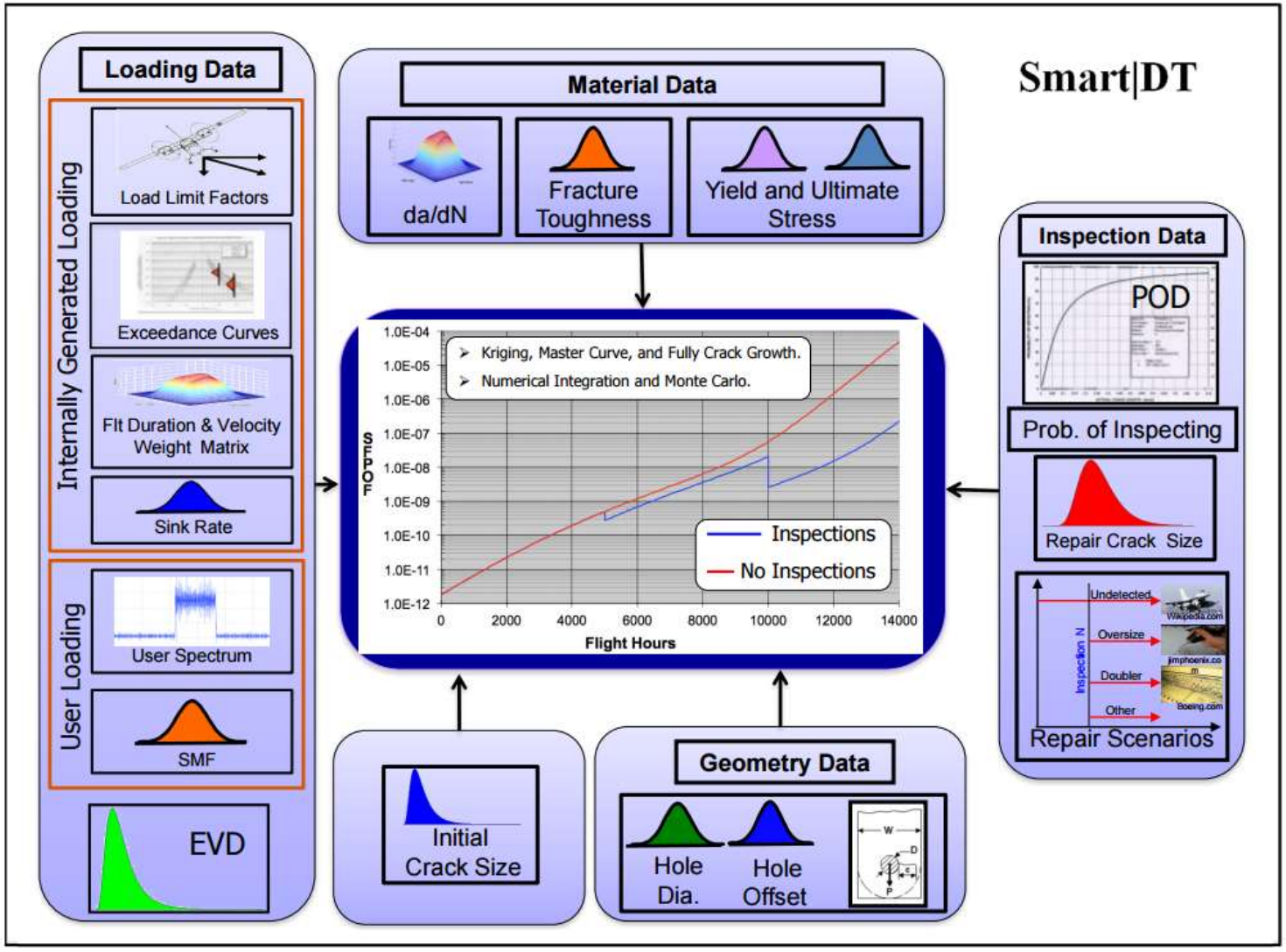
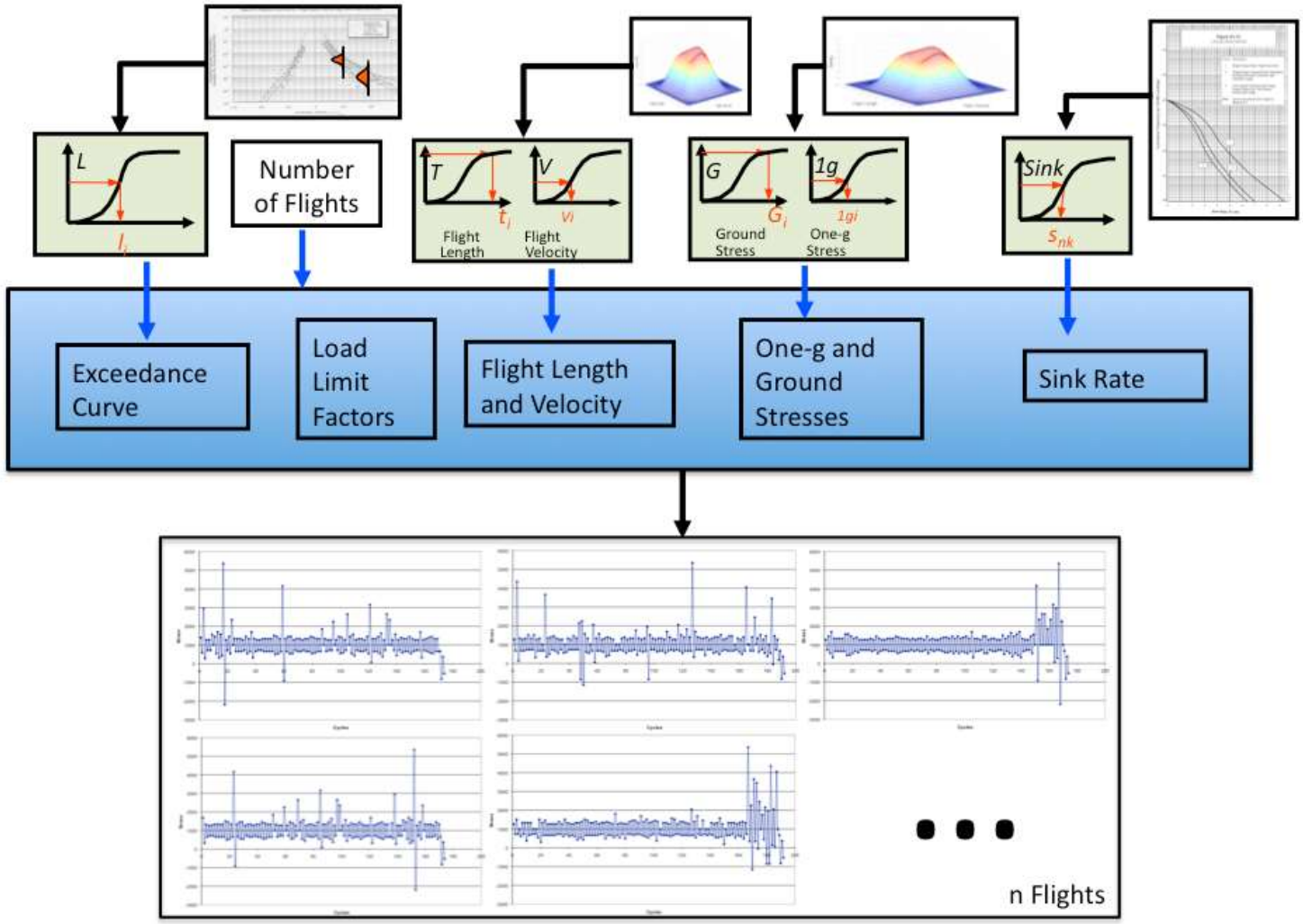
900-1000
1000-1100
1100-1200
1200-1300
1300-1400
Annual Flight Hours

SMART|DT Methodology Summary [1]



1 Millwater H. & Ocampo, J., 'Multiple Repair Scenarios in Aircraft Fleets Using the Weighted Branch Integration Method', presented at 2015 Aircraft Airworthiness and Sustainment Conference.

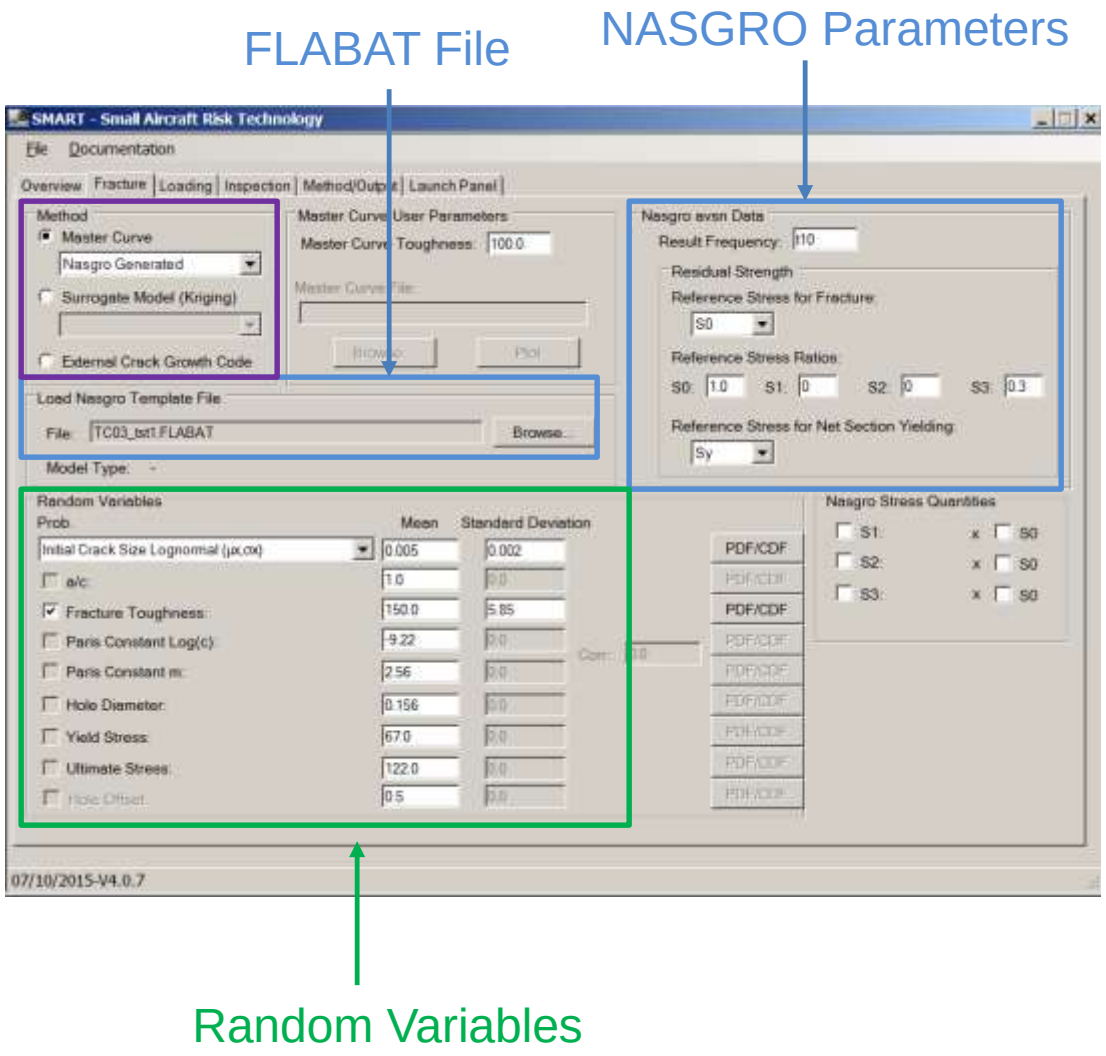
SMART Spectrum Generation Methodology Summary[1]



[1] Ref. Ocampo, J., Castaldo, A. and Millwater H., 'Probabilistic Damage Tolerance Analysis for Small Airplanes', presented at 2012 Aircraft Airworthiness & Sustainment Conference.

Using SMART|DT

- Crack Growth Methods
  - Master Curve
    - NASGRO
    - User Generated
    - AFGROW
    - FASTRAN
  - Surrogate Model
  - External Code
- Random Variables
  - Initial Crack Size
  - Crack Aspect Ratio*
  - Fracture Toughness
  - Paris Constant Log (c)*
  - Paris Constant m*
  - Hole Diameter*
  - Yield Stress*
  - Ultimate Stress*
  - Hole Offset*



* Random variables unique to SMART

Using SMART|DT

- Crack Growth Methods
  - Master Curve
    - NASGRO
    - User Generated
    - AFGROW
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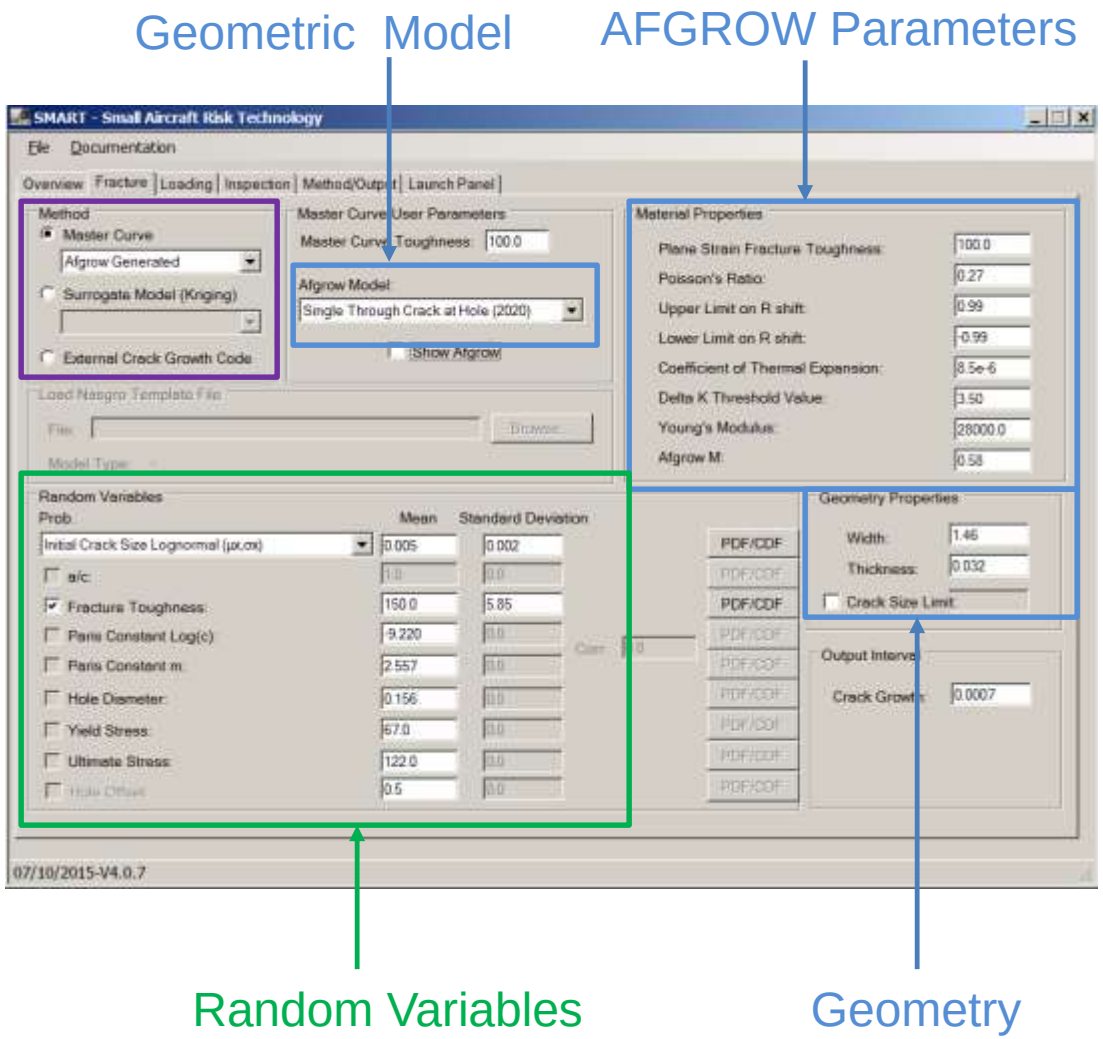

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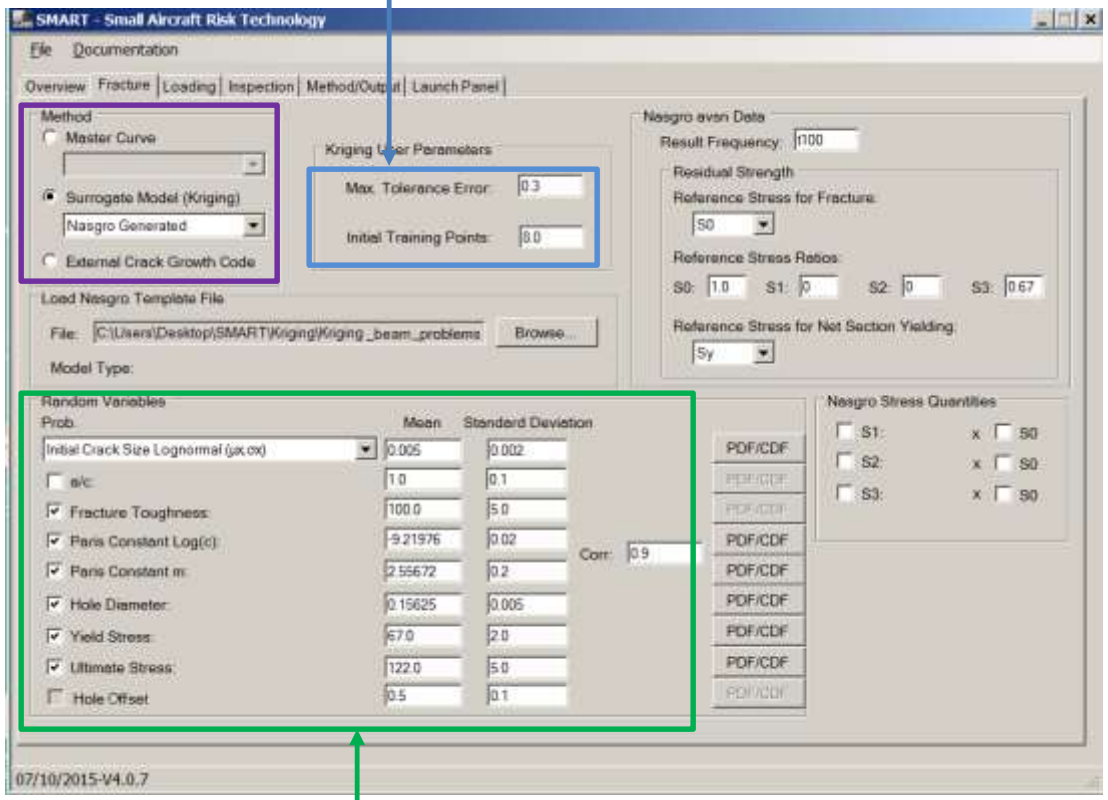
  - Ultimate Stress*
  - Hole Offset*

Kriging Parameters



Random Variables

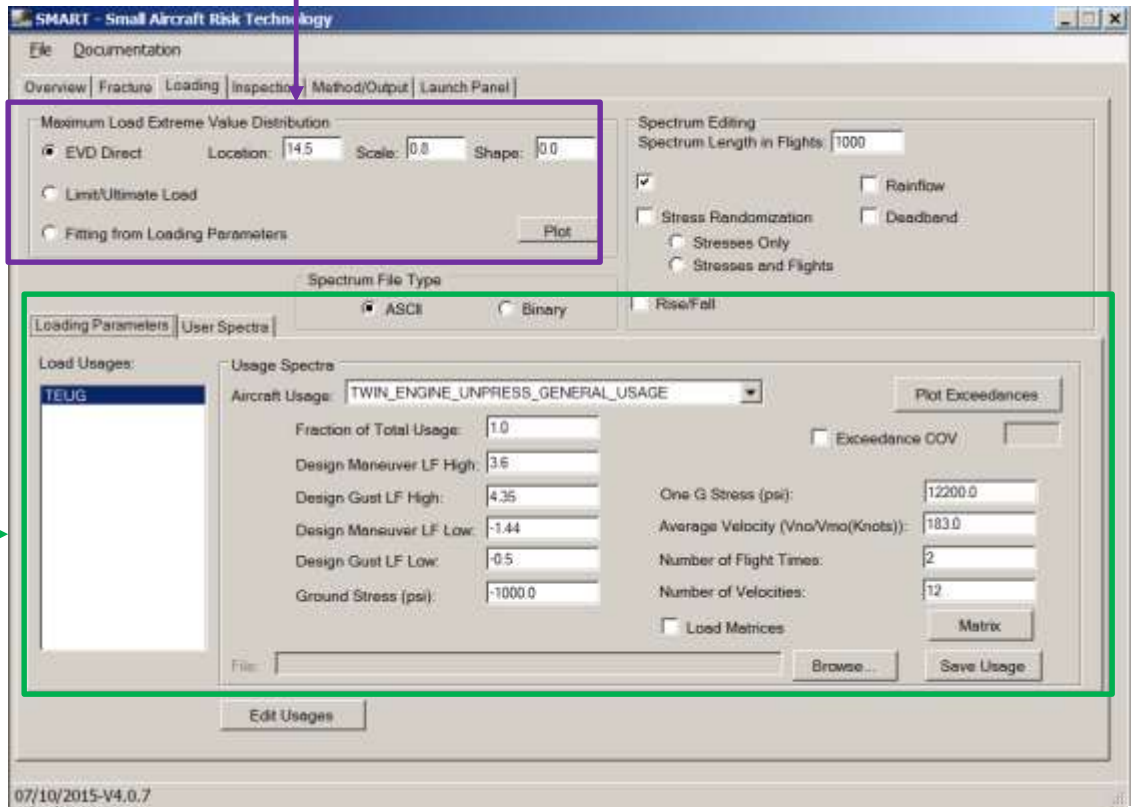
* Random variables unique to SMART

Using SMART|DT

- Spectrum Generation
  - Two Methods
    - User Defined in AFGROW Format
    - AC23-13A Derived
- Extreme Value Distribution
  - EVD Direct
  - Limit/Ultimate Load
  - Fitting from Loading Parameters

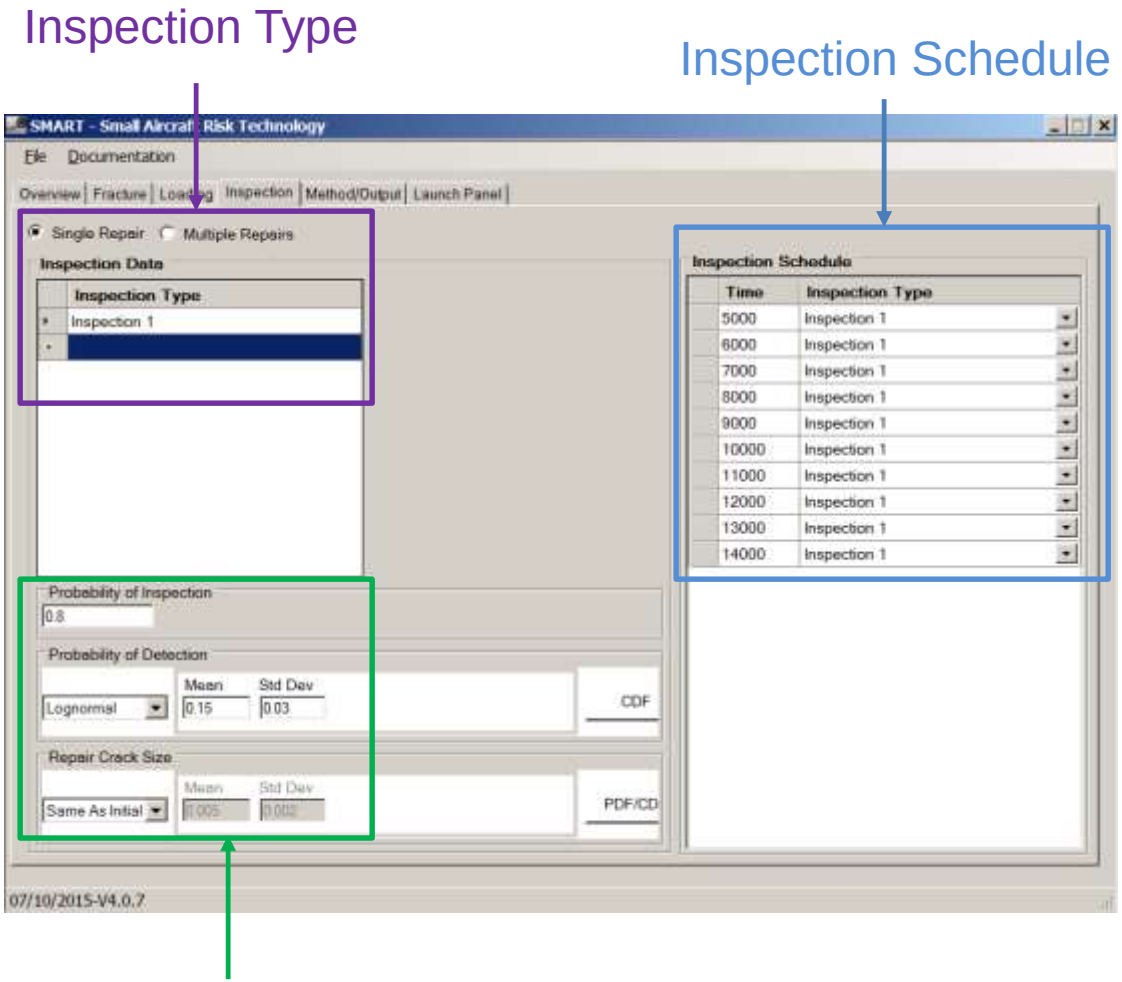
EVD

Spectrum



Using SMART|DT

- Inspection Definition
  - Single Repair
  - Multiple Repairs*
- Inspection Type
- Probability of Inspection
- Probability of Detection
  - Lognormal
  - Deterministic
  - Tabular (user input)
- Repair Crack Size
  - Same as initial
  - Deterministic
  - Lognormal
  - Weibull
  - Tabular (user input)



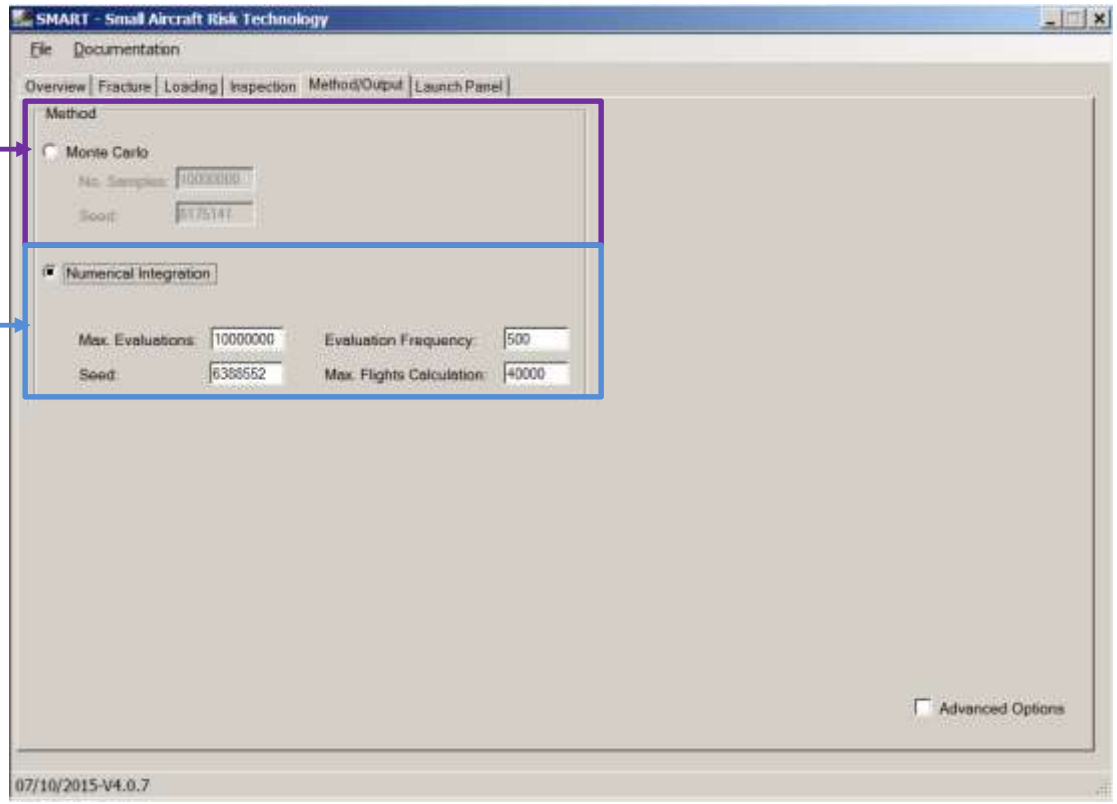
* Capability unique to SMART

Using SMART|DT

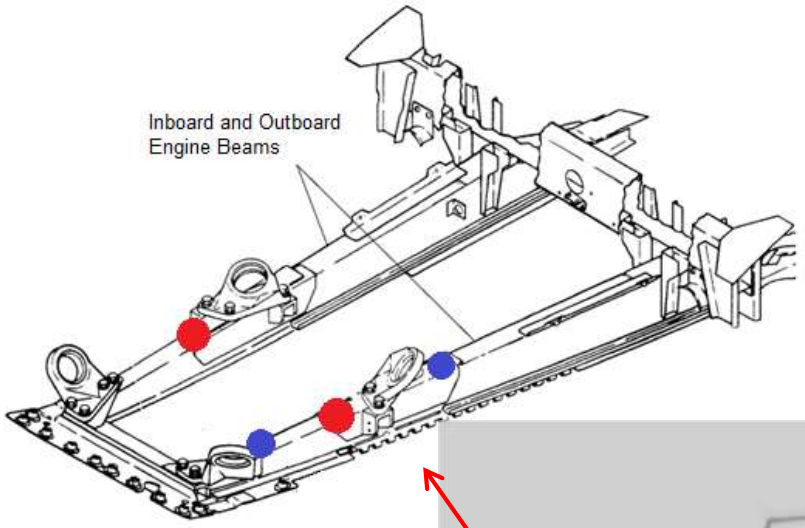
- Two Analysis Methods
  - Monte Carlo
  - Numerical Integration

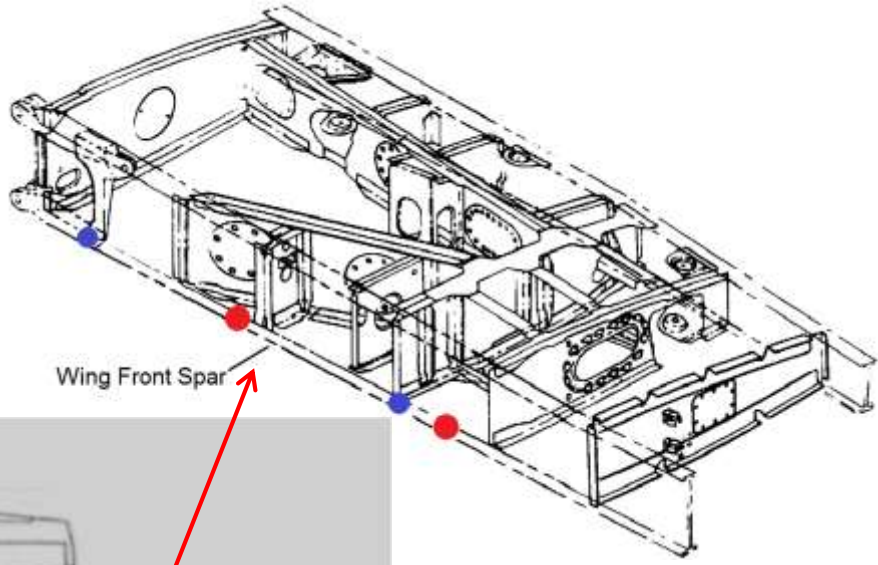
Monte Carlo

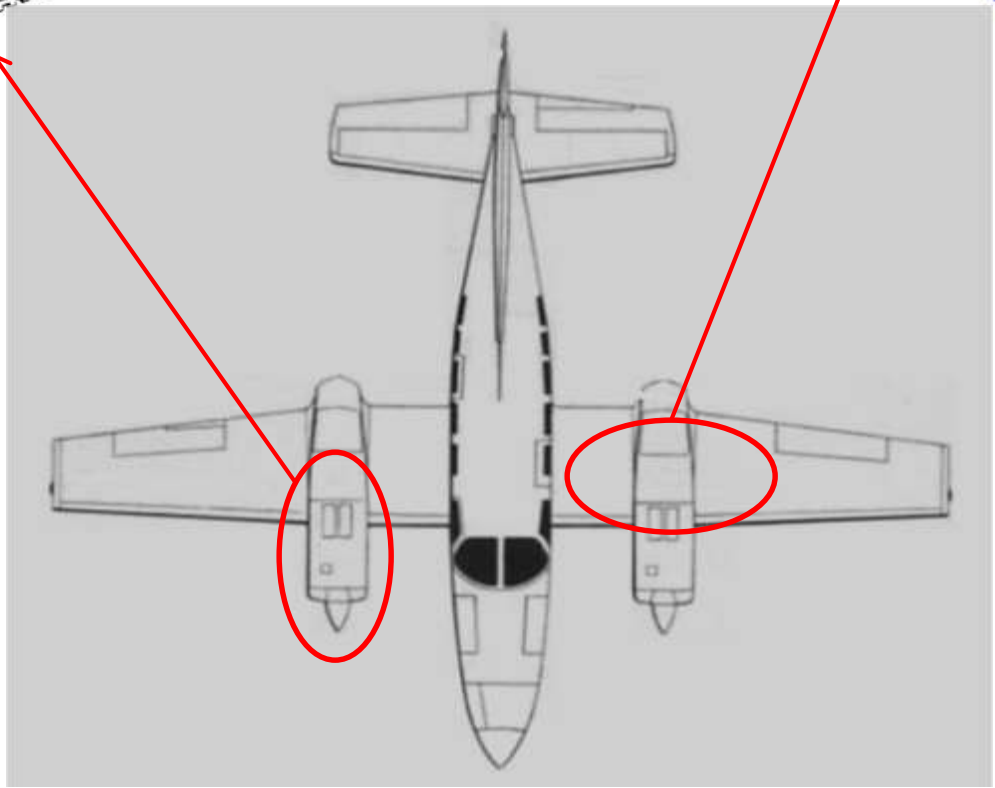
Numerical Integration



Service History

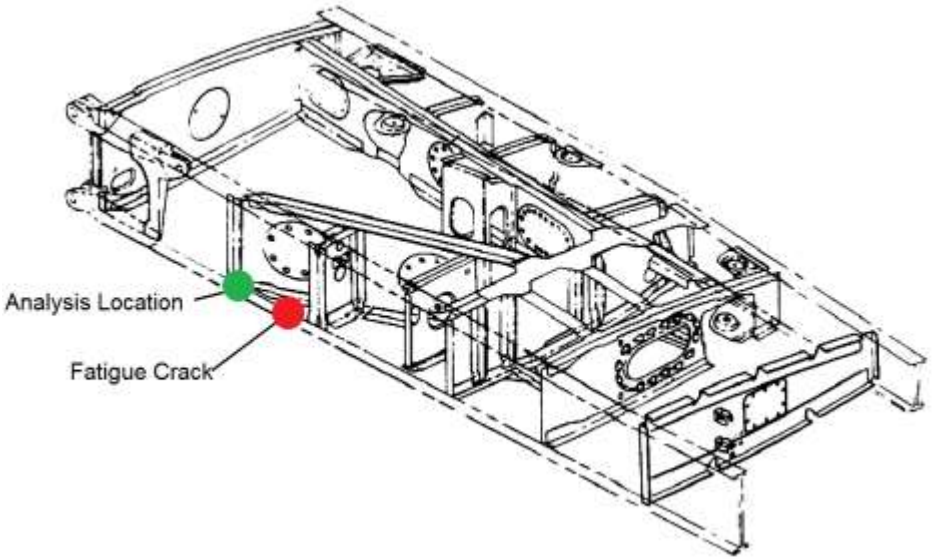






SMART|DT Analysis - Wing

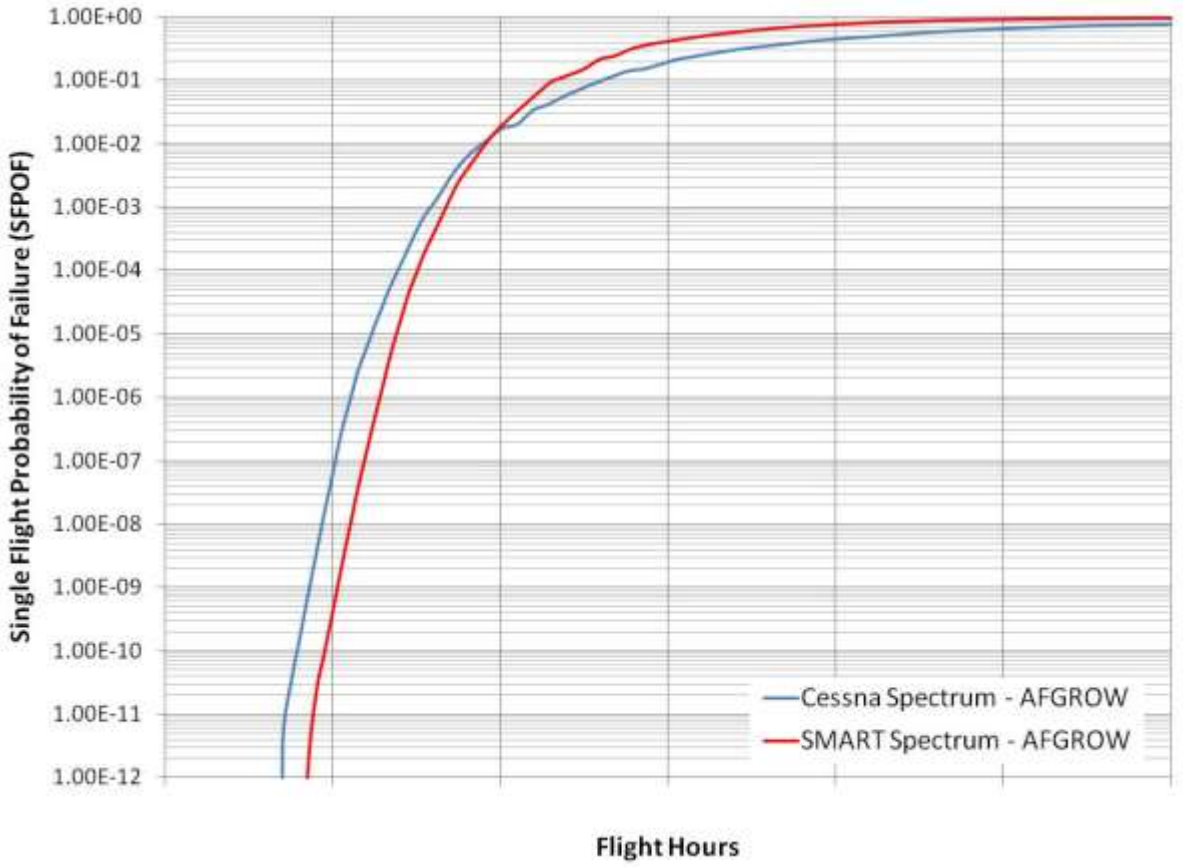
- In 1999, a Cessna 402C wing main spar cracked near WS 86
- Right wing separated in flight as a result
- Airplane had ten owners, one owner operated in Grand Canyon
- At the time of wing failure aircraft was used to carry cargo (typical usage)
- Maintenance records indicated numerous repairs to the right wing, including:
  - Skin cracks
  - Working rivets
  - Wing aux spar straps
- Crack initiated in an area of mechanical damage and rough machining marks
- Airplane had 20,000+ hours



SMART|DT Analysis - Wing

- Analysis Assumptions – W.S. 86
  - AFGROW
  - Grand Canyon Usage
  - Two Spectra
    - Cessna
    - SMART (AC23-13A)
  - Probabilistic Variables
    - Initial Crack Size
  - EVD
    - Limit Load
  - No Inspections

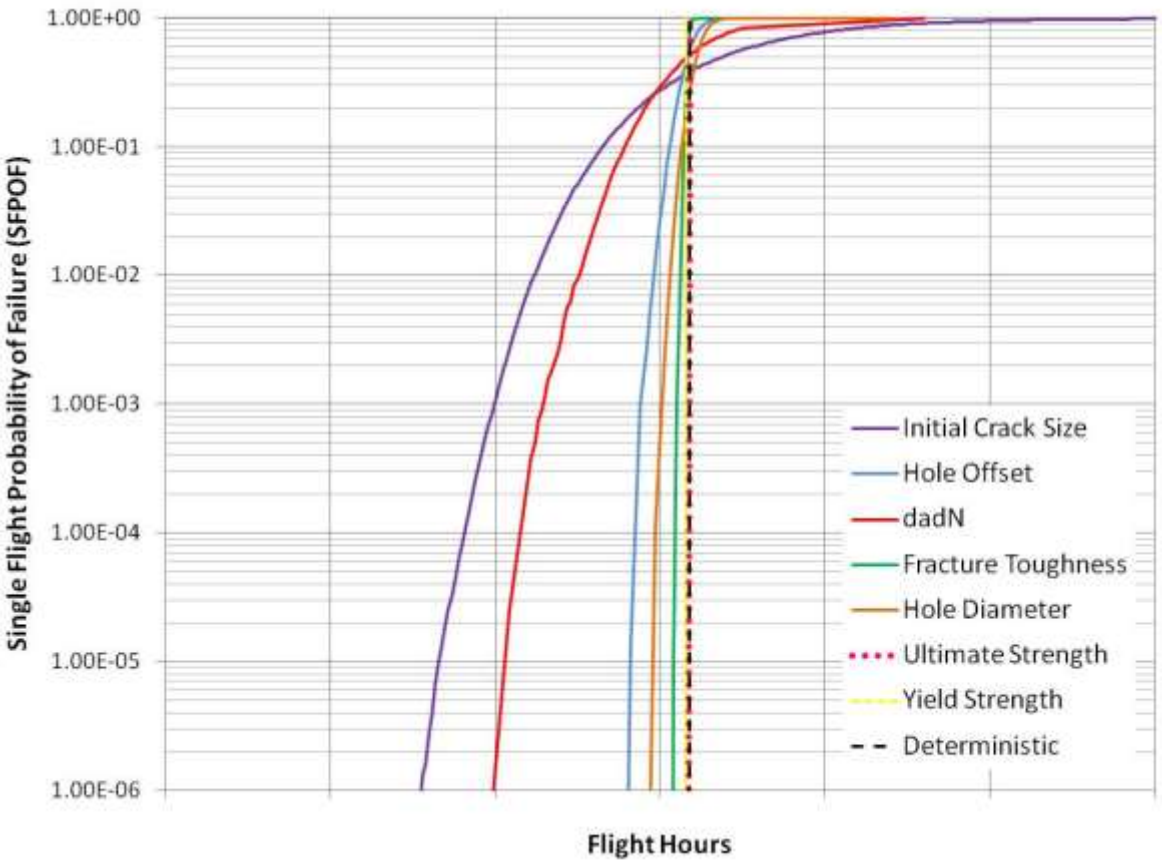
Comparison of Cessna Spectra to SMART Internal Spectra



SMART|DT Analysis - Wing

- Analysis Assumptions – W.S. 86
  - NASGRO
  - Typical Usage
  - SMART Spectrum
  - Probabilistic Variables
    - Initial Crack Size
    - Hole Offset
    - dadN
    - Fracture Toughness
    - Hole Diameter
    - Ultimate Strength
    - Yield Strength
  - EVD
    - Limit Load
  - No Inspections

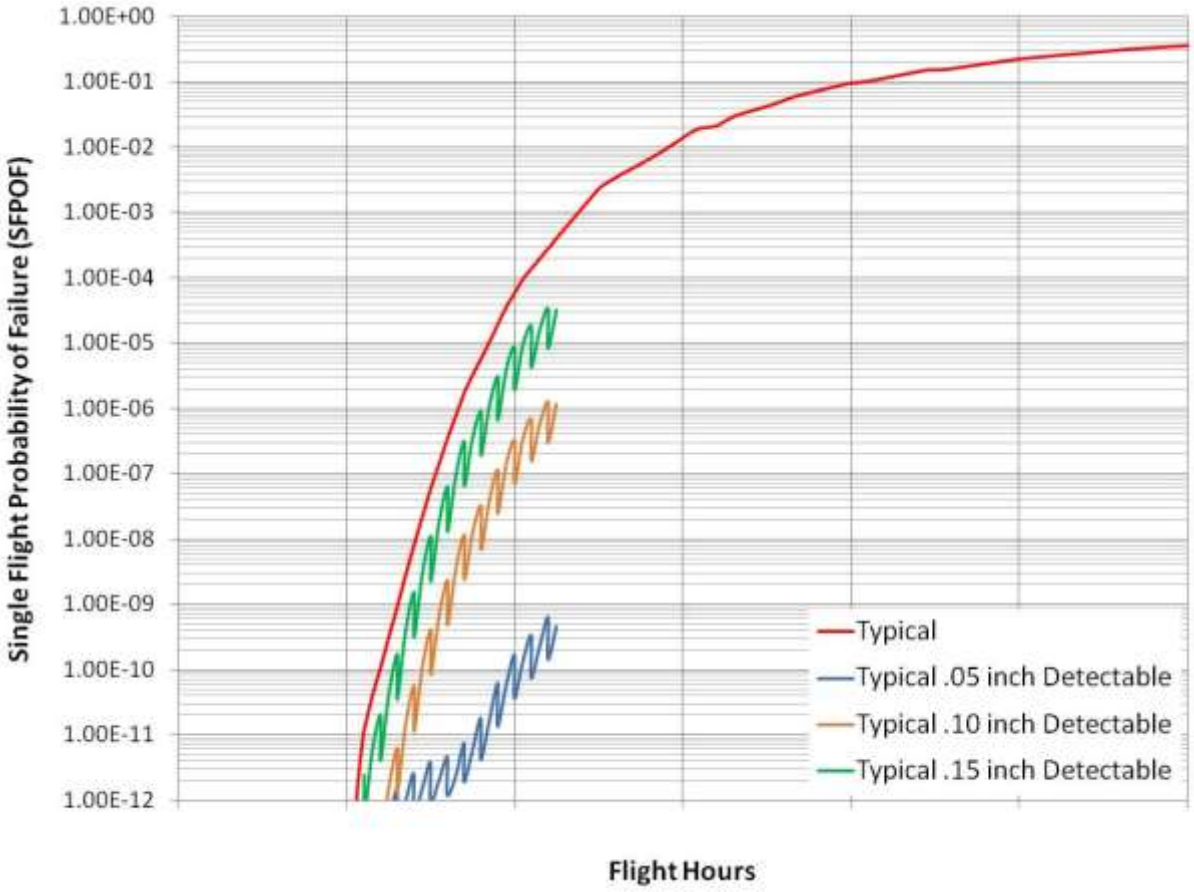
Comparison of Probabilistic Variables



SMART|DT Analysis - Wing

- Analysis Assumptions – W.S. 86
  - AFGROW
  - Typical Usage
  - Cessna Spectrum
  - Probabilistic Variables
    - Initial Crack Size
  - EVD
    - Limit Load
  - 80% POD
  - 1000 hour Inspections
    - .05” Detectable
    - .10” Detectable
    - .15” Detectable

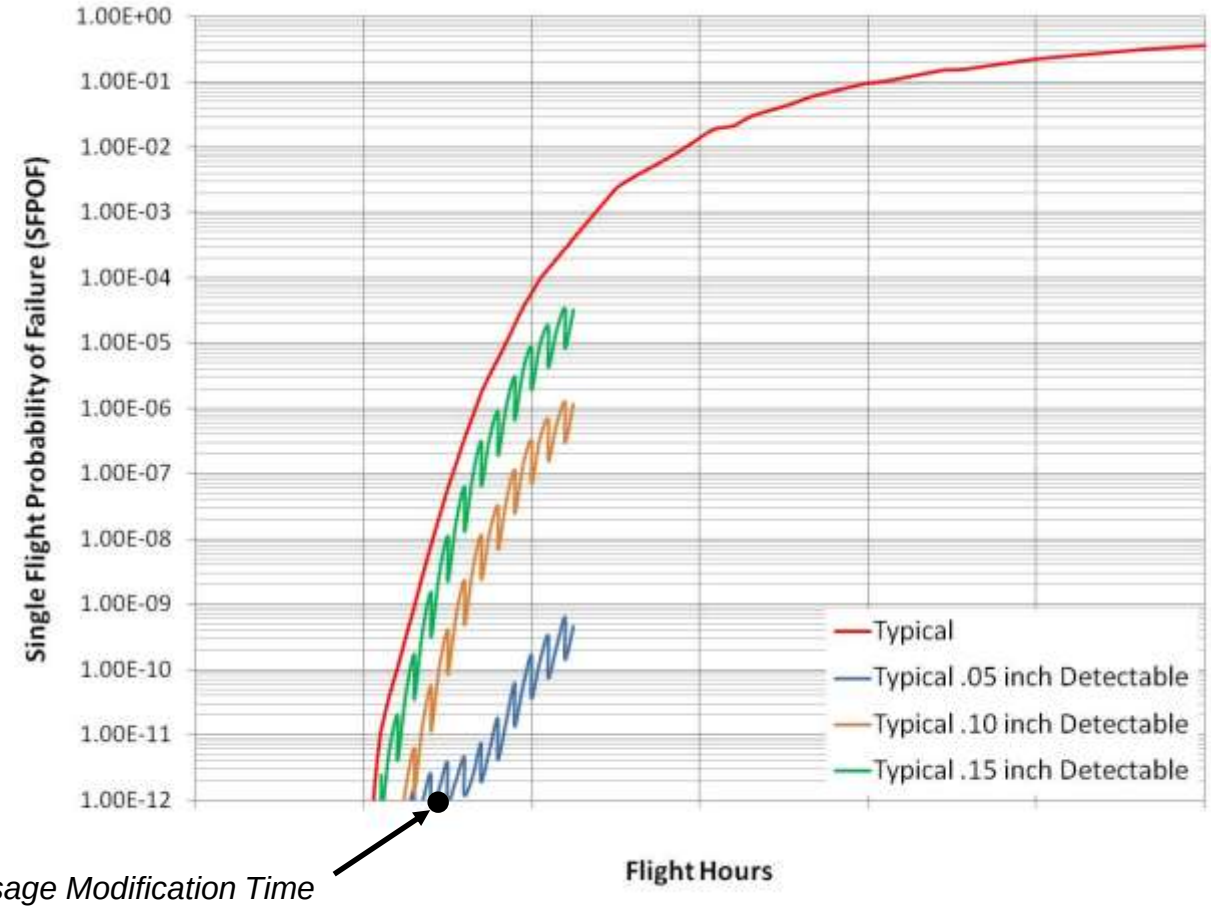
Comparison of Detectable Flaw Sizes – Typical Usage



SMART|DT Analysis - Wing

- Analysis Results – W.S. 86
  - Detection of cracks < .15” is not practical
  - Modification Required
  - SFPOF < $1.0E^{-07}$

Comparison of Detectable Flaw Sizes – Typical Usage

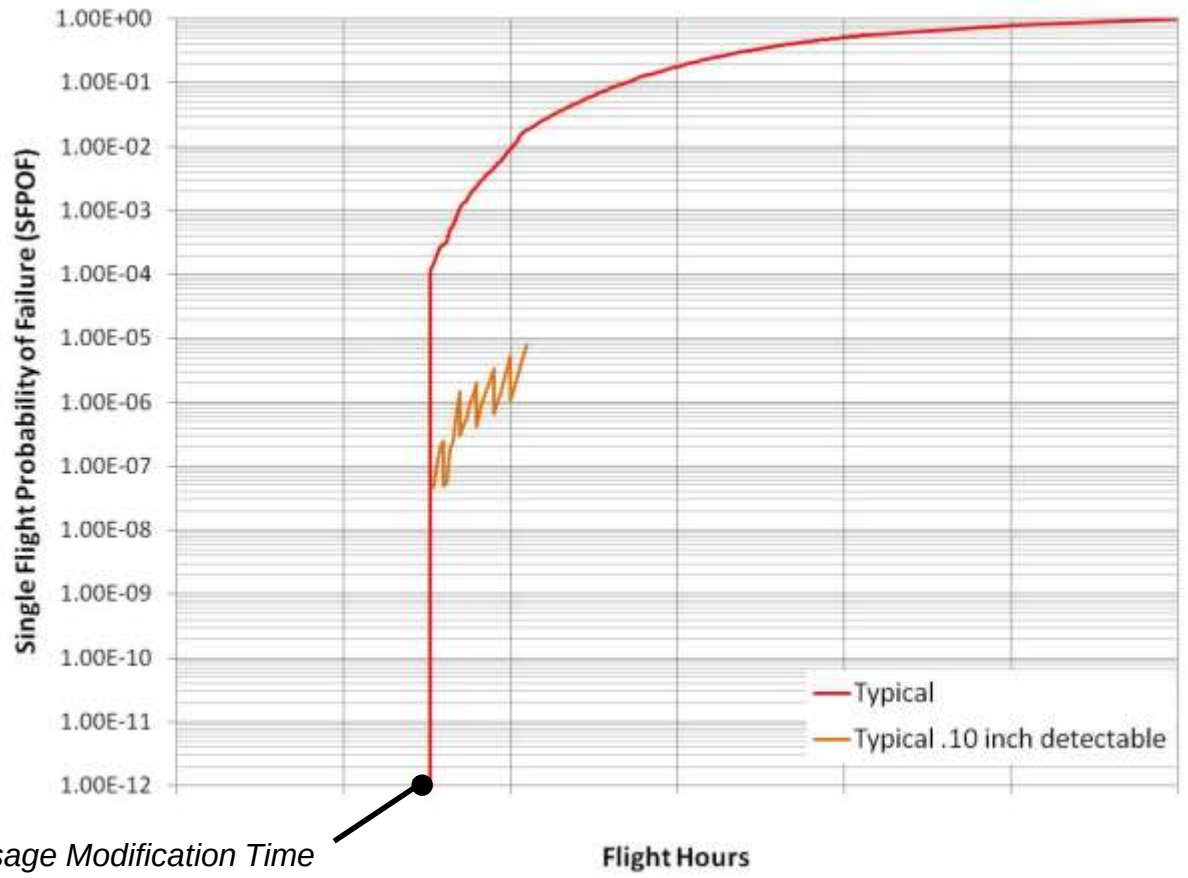


Typical Usage Modification Time

SMART|DT Analysis - Wing

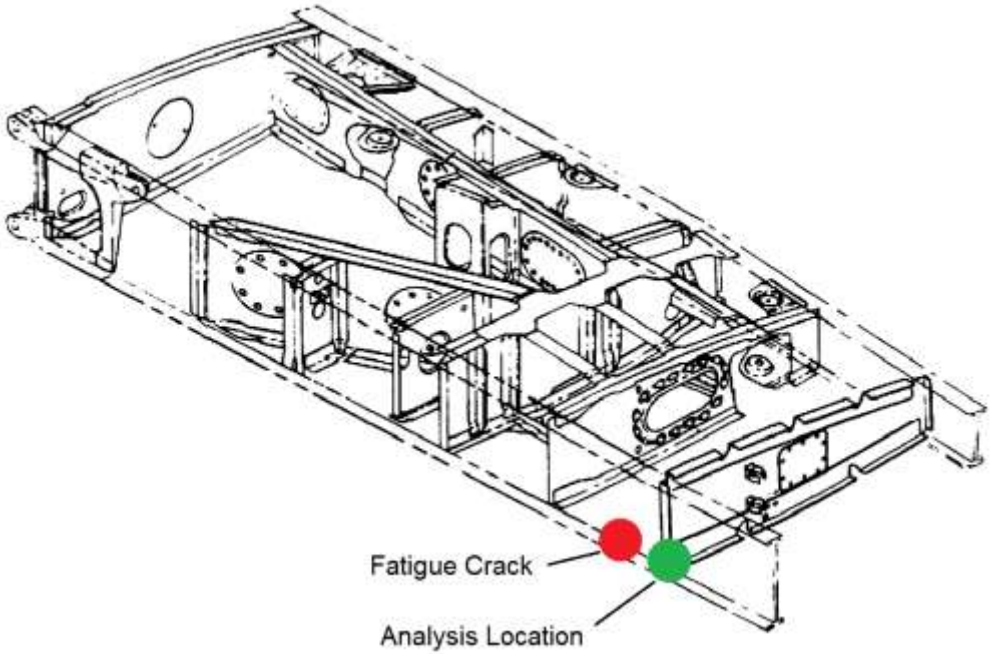
- Analysis Assumptions – W.S. 86
  - NASGRO
  - Typical Usage
  - SMART Spectrum
  - Probabilistic Variables
    - Initial Crack Size
    - Hole Offset
    - dadN
  - EVD
    - Limit Load
  - 80% POD
  - 1000 Hour Inspections
    - .10” Detectable

Single Flight Probability of Failure for Typical Usage

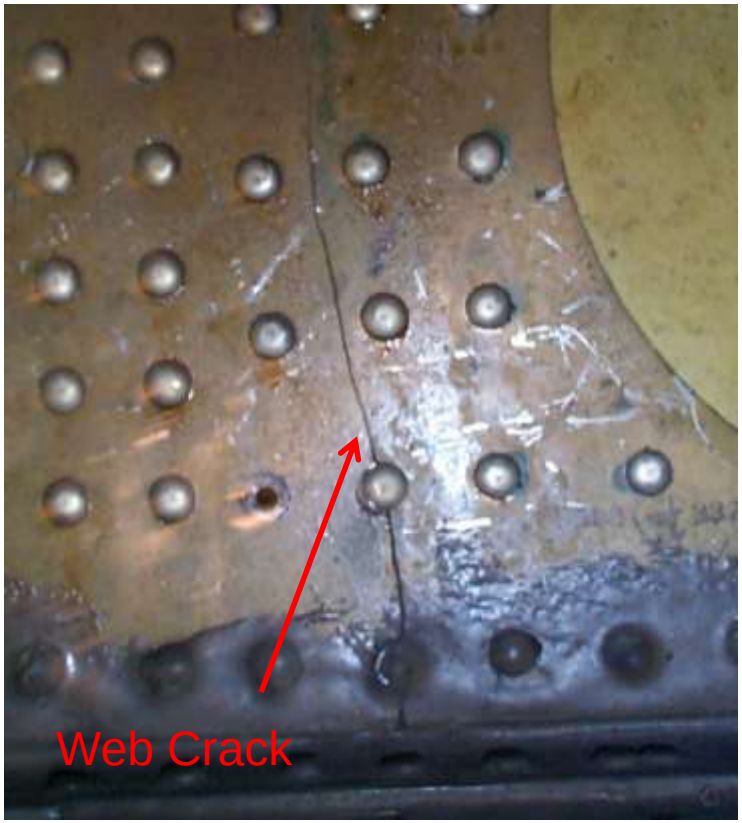


SMART|DT Analysis - Wing

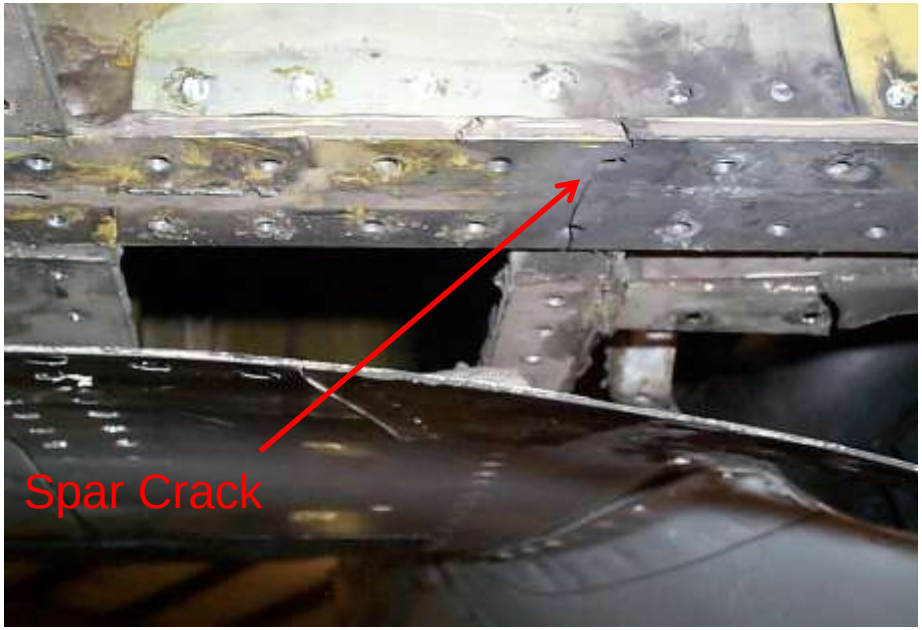
- In 2005, main spar and skin cracked near WS 107 on two Model 402Cs
- One aircraft had cracks located on both the right and left sides
- Both aircraft had 20,000+ flight hours when cracks were discovered
- Both airplanes operated in passenger service when cracks were discovered
  - Current usage representative of short spectrum
- Airplanes previously flew in Grand Canyon
- Higher time aircraft, but not fleet leaders



SMART|DT Analysis - Wing



View looking forward at front spar

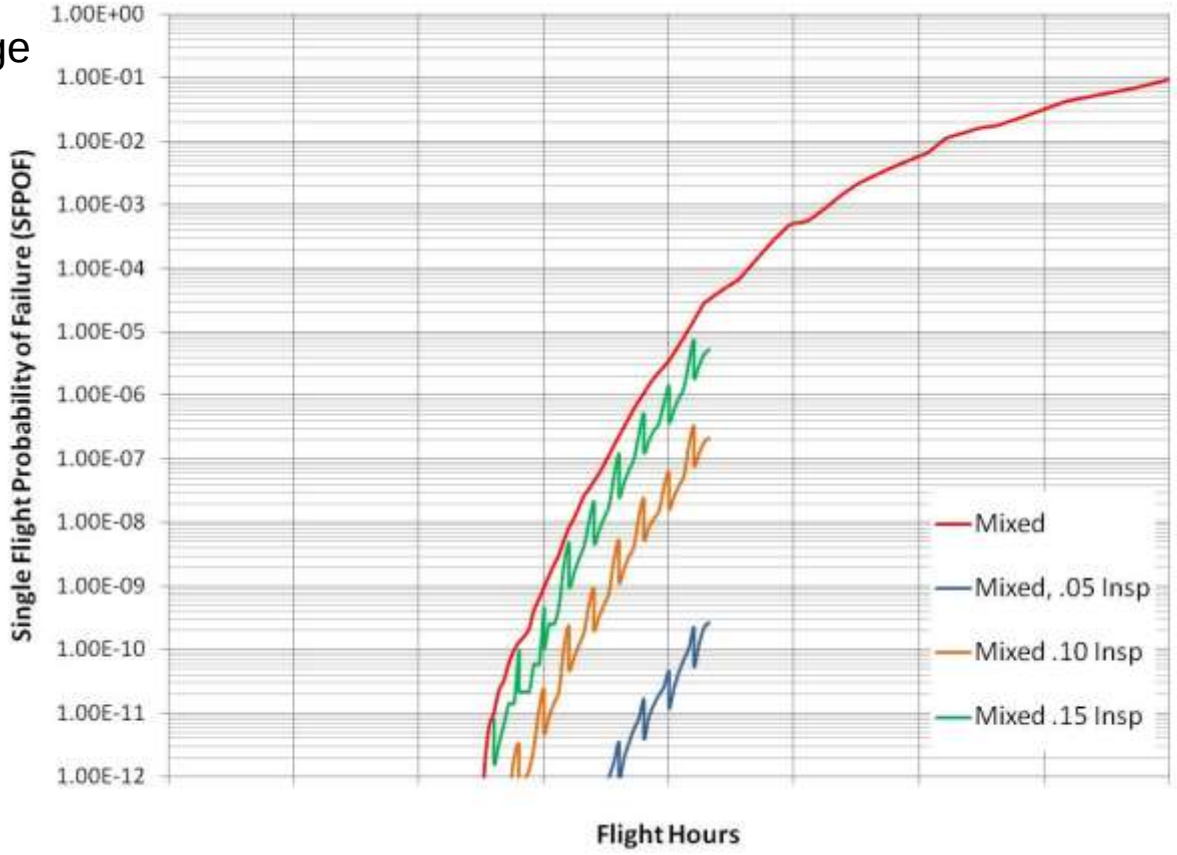


View looking forward at front spar

SMART|DT Analysis - Wing

- Analysis Assumptions – W.S. 107
  - AFGROW
  - Short & GC (Mixed) Usage
  - Cessna Spectrum
  - Probabilistic Variables
    - Initial Crack Size
  - EVD
    - Limit Load
  - 80% POD
  - 1000 Hour Inspections
    - .05” Detectable
    - .10” Detectable
    - .15” Detectable

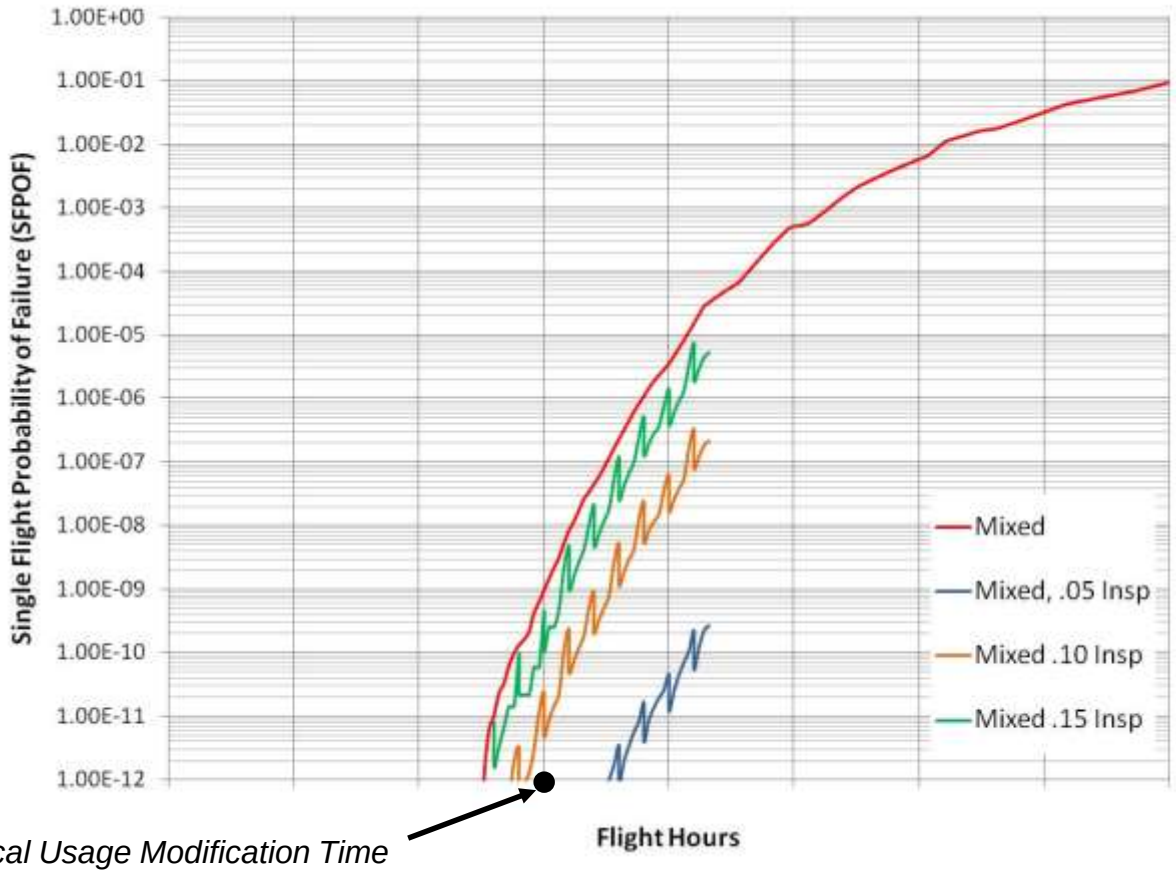
Comparison of Detectable Flaw Sizes – Mixed Usage



SMART|DT Analysis - Wing

- Analysis Results – W.S. 107
  - Detection of cracks < .15” is not practical
  - Modification Required
  - SFPOF < $1.0E^{-07}$

Comparison of Detectable Flaw Sizes – Mixed Usage

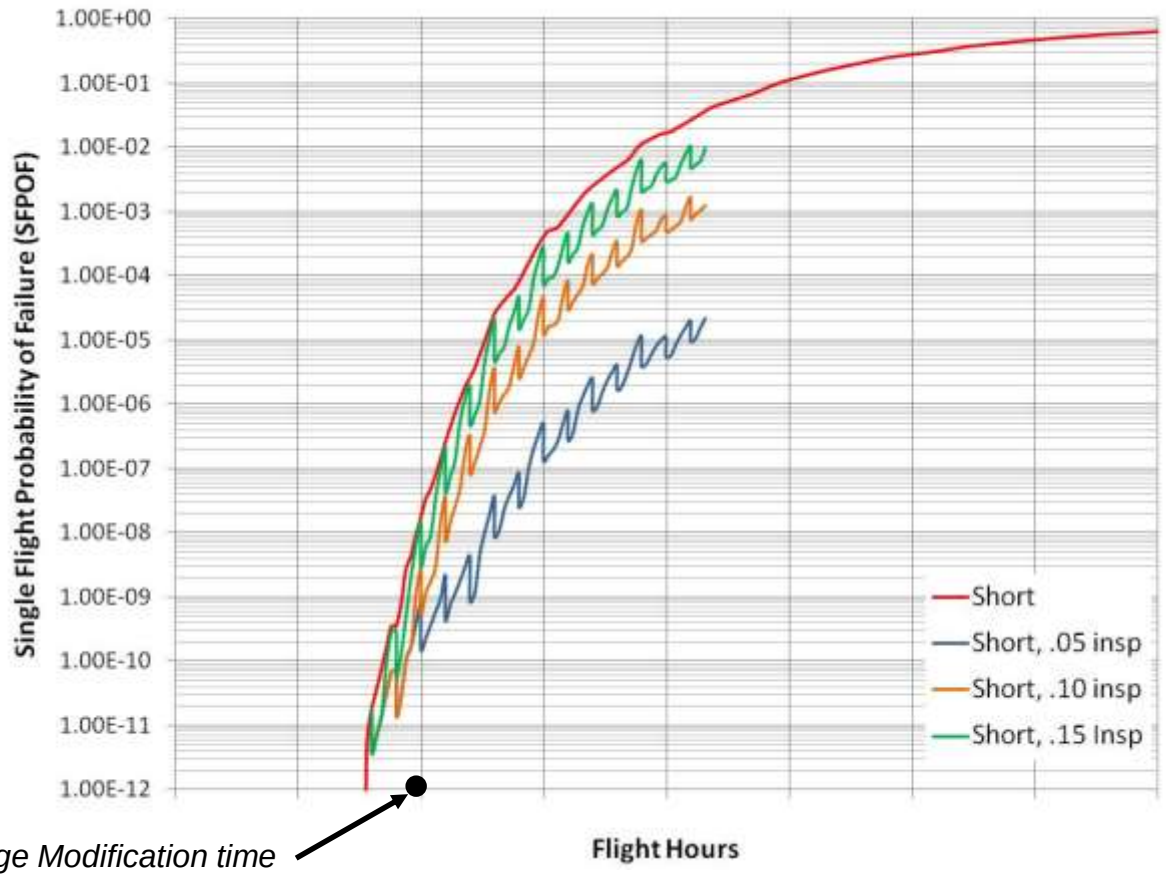


Typical Usage Modification Time

SMART|DT Analysis - Wing

- Analysis Assumptions – W.S. 107
  - Same Analysis Inputs
  - Short Usage

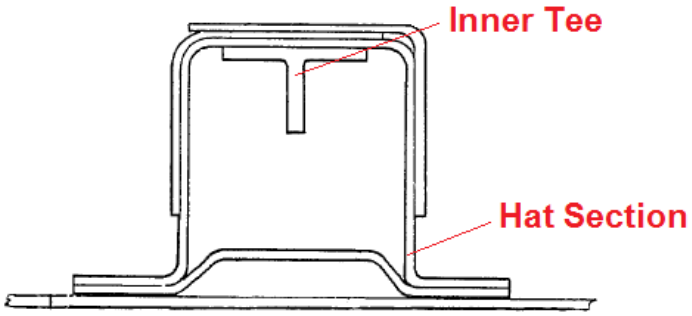
Comparison of Detectable Flaw Sizes – Short Usage

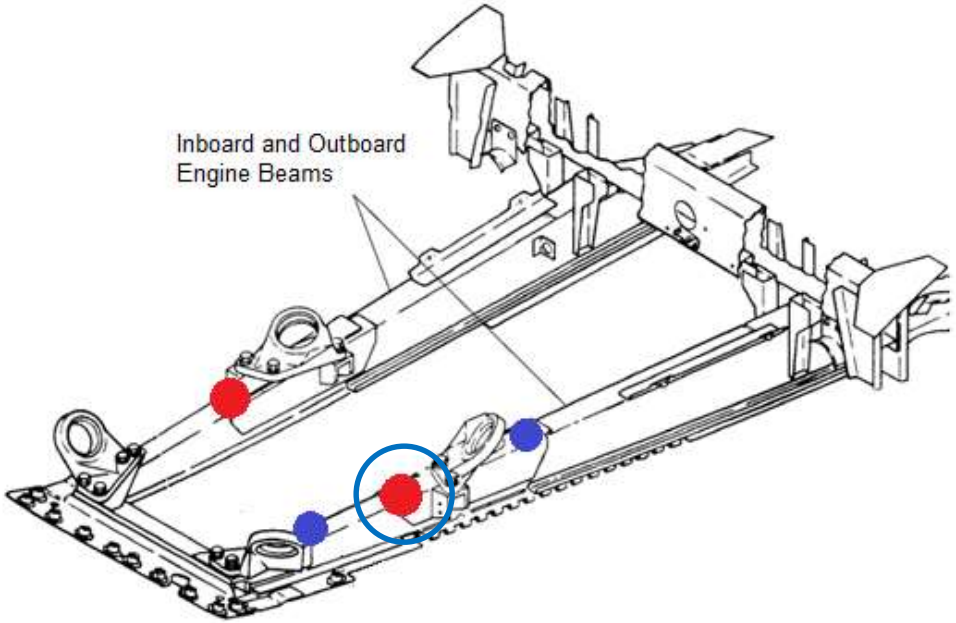


Short Usage Modification time

SMART|DT Analysis - Engine Beam

- In 2015, engine beam support structure “hat section” cracked on 8 airplanes
  - Four cracks on inboard beam and four cracks on outboard beam
  - Six of the eight cracks were just forward of aft engine mount
- Airplanes had 29,000 - 34,000 flight hours when cracks were discovered
- Each airplane was operating in passenger service at the time (short usage)
- Airplanes flown approximately 40% in Grand Canyon and 60% in Short Usages

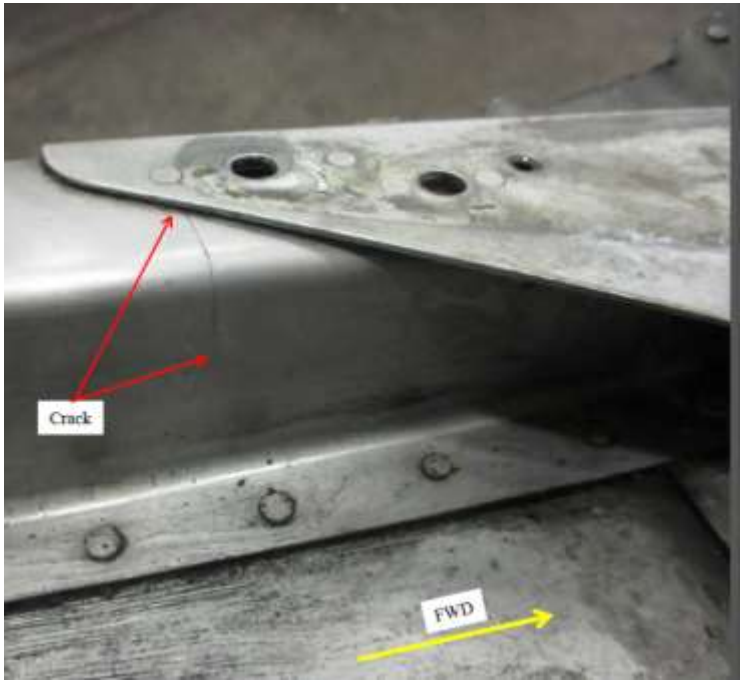




SMART|DT Analysis - Engine Beam

- Engine Beam Cracks Under Forward and Aft Engine Mounts

RH Outboard Beam
Fwd of Aft Engine Mount

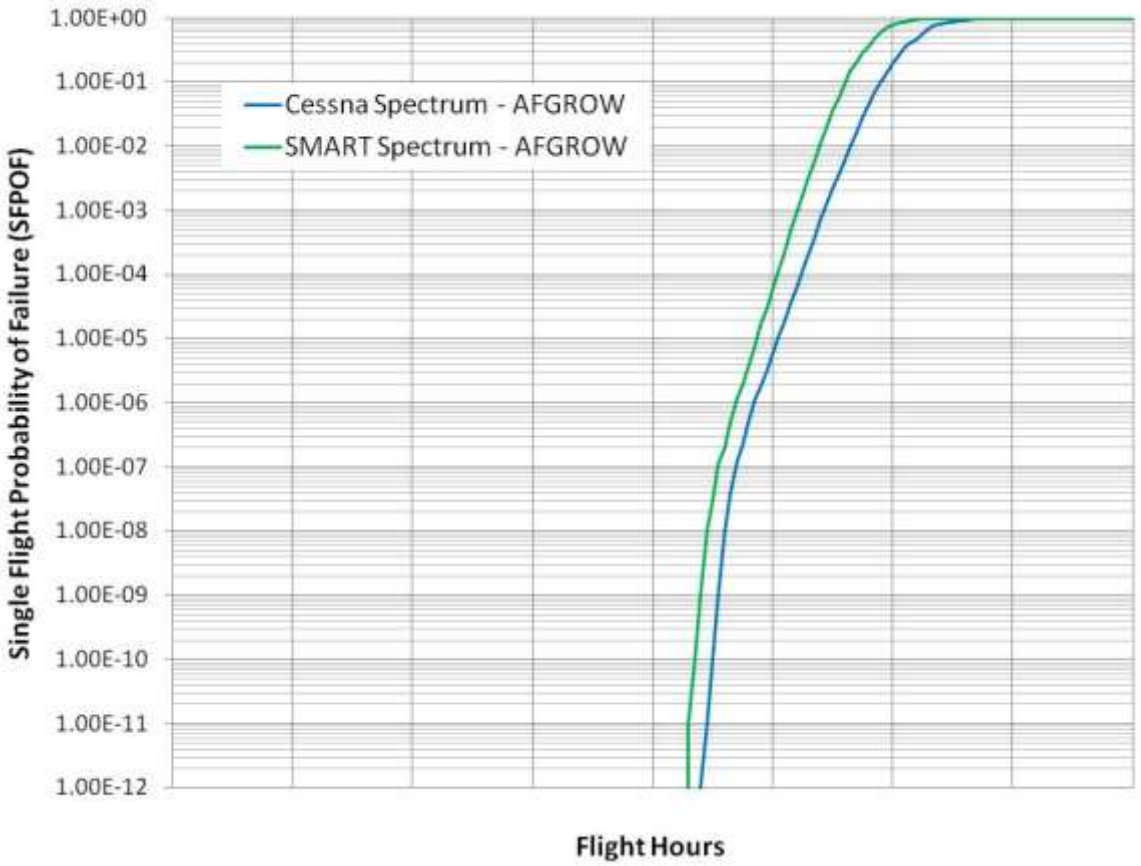


RH Inboard Beam
Aft of Fwd Engine Mount

SMART|DT Analysis - Engine Beam

- Analysis Assumptions
  - AFGROW
  - Grand Canyon Usage
  - Two Spectra
    - Cessna
    - SMART (AC23A-13)
  - Probabilistic Variables
    - Initial Crack Size
  - EVD
    - Limit Load
  - No Inspections

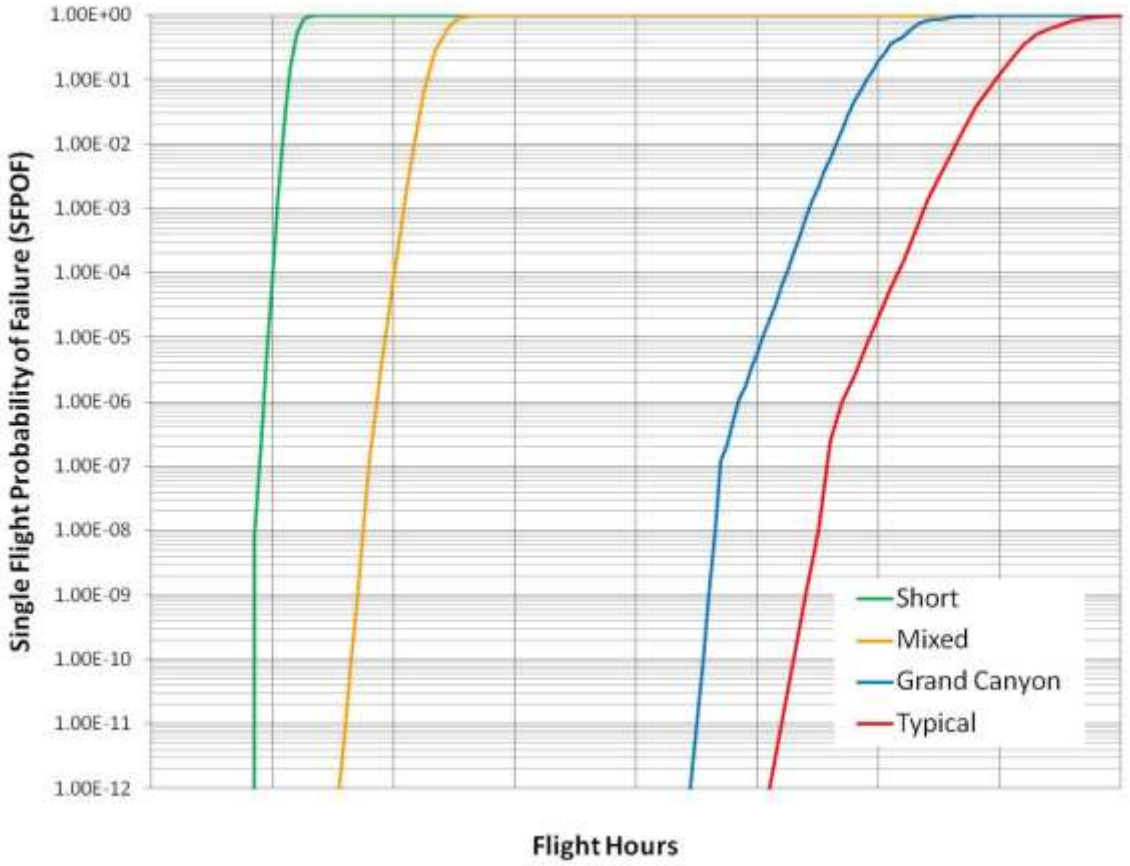
Comparison of Cessna Spectra to SMART Internal Spectra



SMART|DT Analysis - Engine Beam

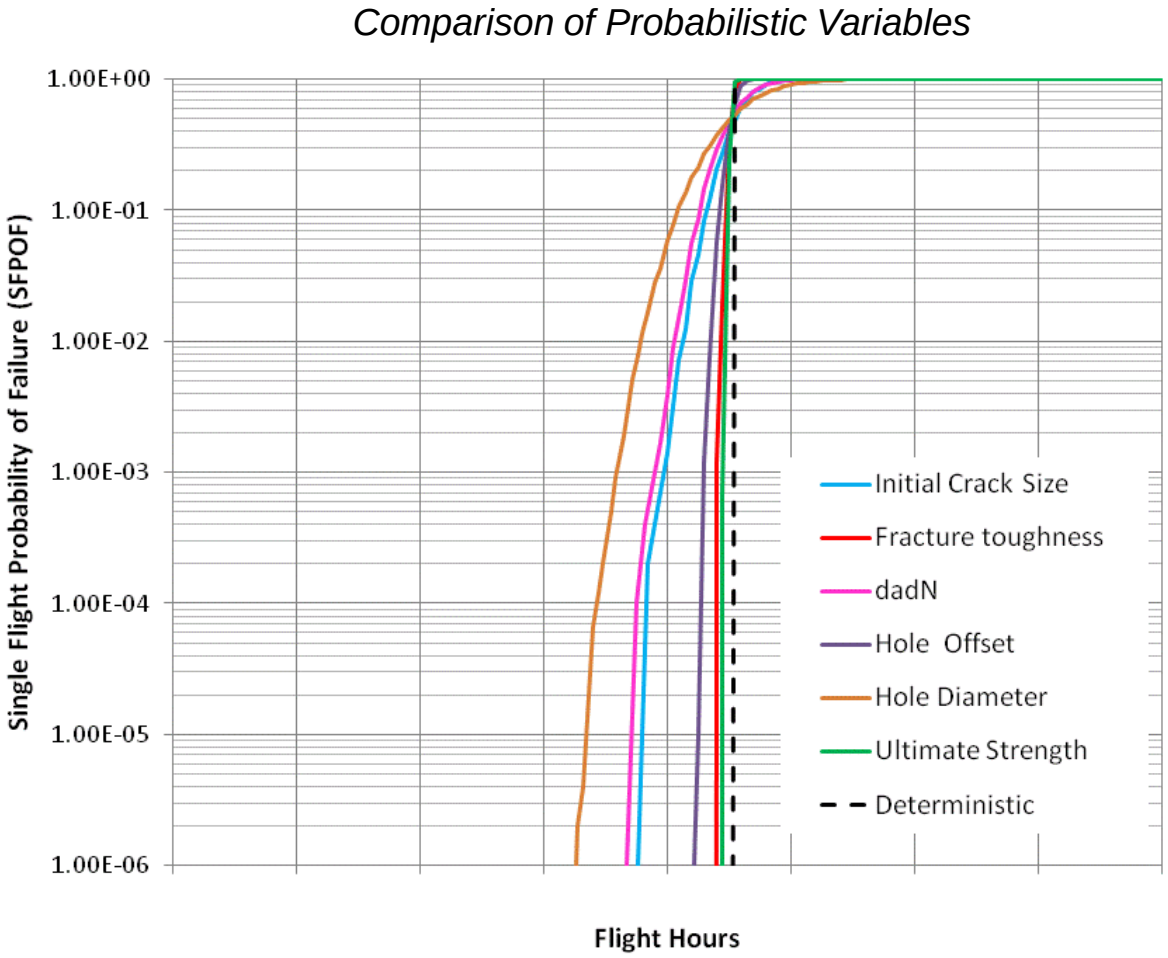
- Analysis Assumptions
  - AFGROW
  - Four Usages
    - Grand Canyon
    - Short
    - GC & Short (Mixed)
    - Typical
  - Cessna Spectrum
  - Probabilistic Variables
    - Initial Crack Size
  - EVD
    - Limit Load
  - No Inspections

Comparison of Four Flight Usages



SMART|DT Analysis - Engine Beam

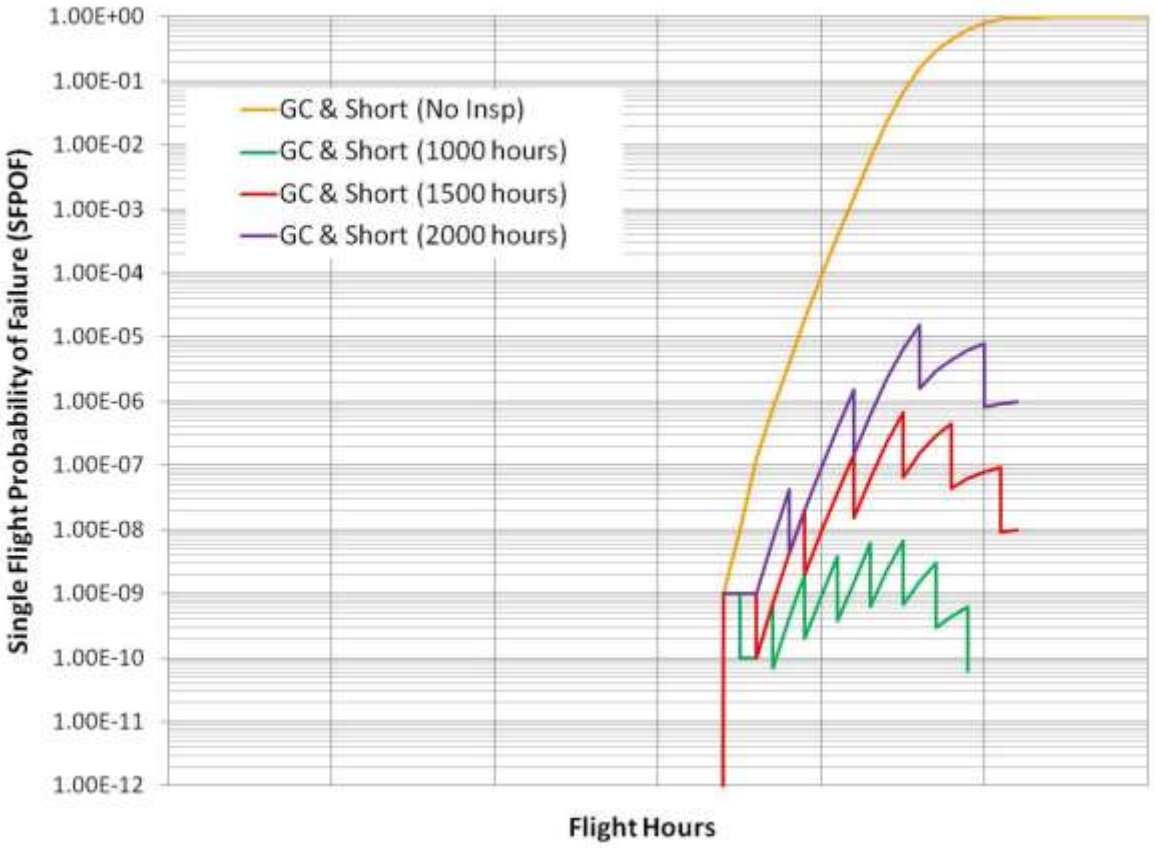
- Analysis Assumptions
  - NASGRO
  - Grand Canyon Usage
  - SMART Spectrum
  - Probabilistic Variables
    - Initial Crack Size
    - dadN
    - Fracture Toughness
    - Hole Offset
    - Hole Diameter
    - Ultimate Strength
  - EVD
    - Limit Load
  - No Inspections



SMART|DT Analysis - Engine Beam

- Analysis Assumptions
  - AFGROW
  - GC & Short (Mixed) Usage
  - Cessna Spectrum
  - Probabilistic Variables
    - Initial Crack Size
  - EVD
    - Limit Load
  - With Inspections
    - 1000 hours
    - 1500 hours
    - 2000 hours

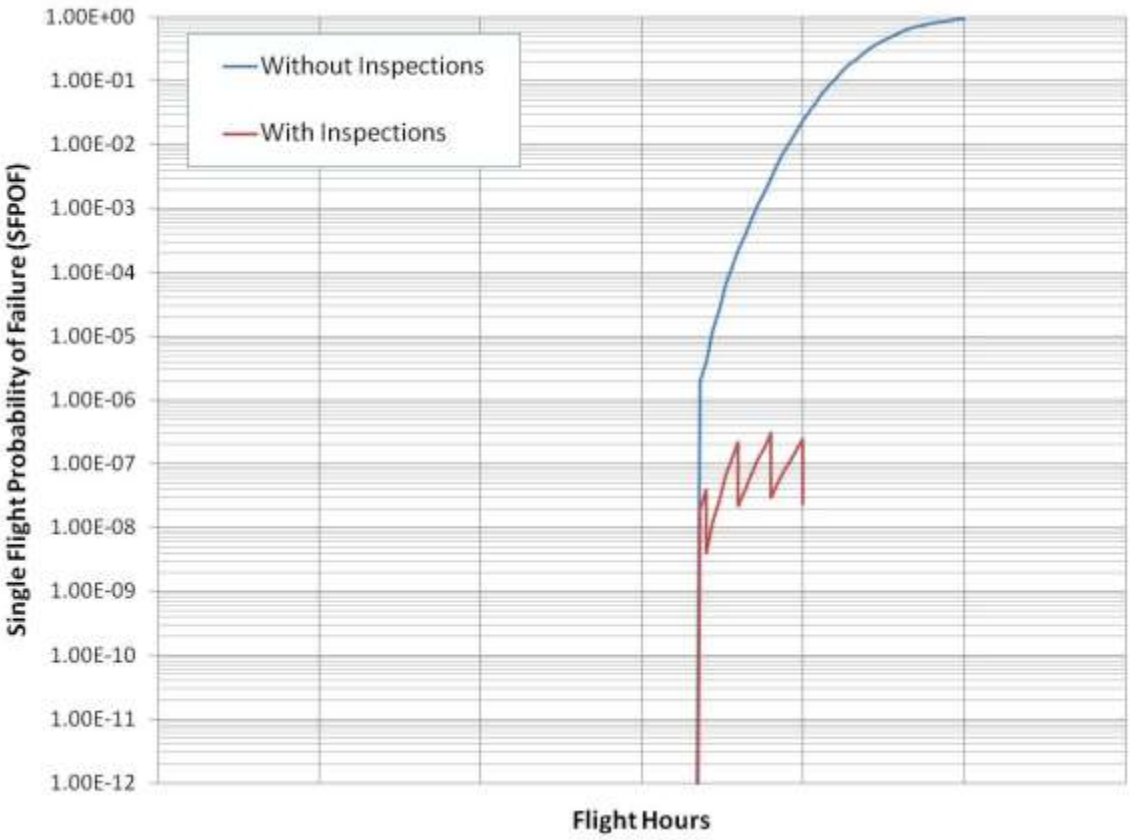
Comparison of Inspection Intervals



SMART|DT Analysis - Engine Beam

- Analysis Assumptions
  - NASGRO
  - Grand Canyon Usage
  - SMART Spectrum
  - Probabilistic Variables
    - Initial Crack Size
    - dadN
    - Hole Offset
  - EVD
    - Fitting
  - 1000 Hour Inspections

Single Flight Probability of Failure for Grand Canyon Usage



Recommendations

- SMART|DT is a powerful tool that allows user to tune analysis based on available information
- Enhancements yet to come
  - Build in 2 or 3 frequently used K solutions
  - Incorporate libraries of random variables
  - Reduce the computational time
    - Implement advanced sampling methods