Probabilistic Risk Assessment – The SMART Approach To Continued Operational Safety

December 3, 2015

Beechcraft AT-11 Kansan

Beechcraft AT-17 Bobcat

Cessna A-37 Dragonfly

Cessna O-2 Skymaster

Textron Aviation is the General Aviation company formed in March 2014 from Cessna Aircraft Company and Beechcraft Corporation

Beechcraft T-34B Mentor

Beechcraft T-1A Jayhawk

Beechcraft T-6A Texan II

Textron Airland Scorpion

Agenda

- Background
- $SMART_{DT}$ Methodology
- Using $SMART_{DT}$
- Model 402C Engine Beam
- Service History
- SMART|DT Analysis
- 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

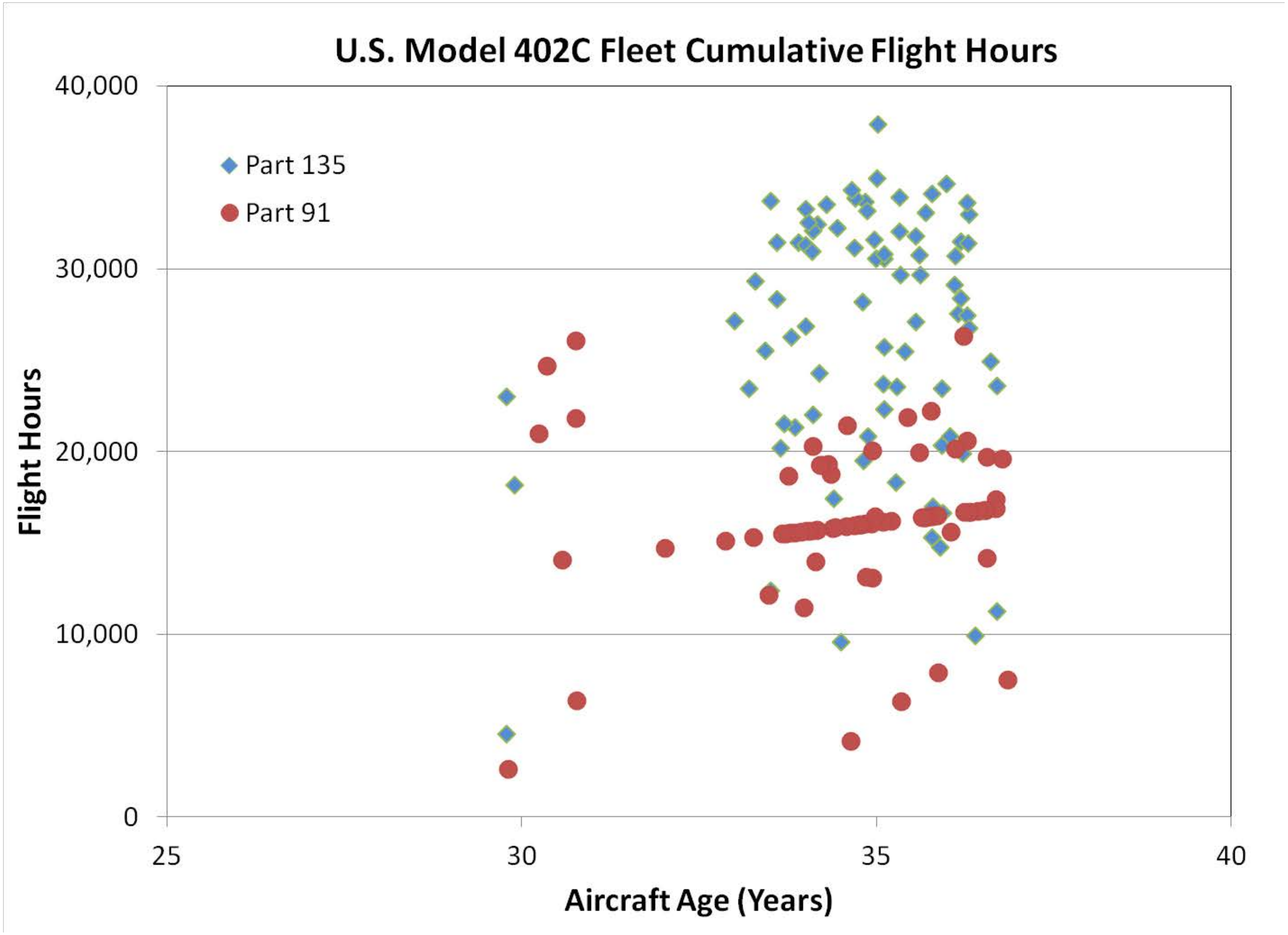
Background

- 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

Background

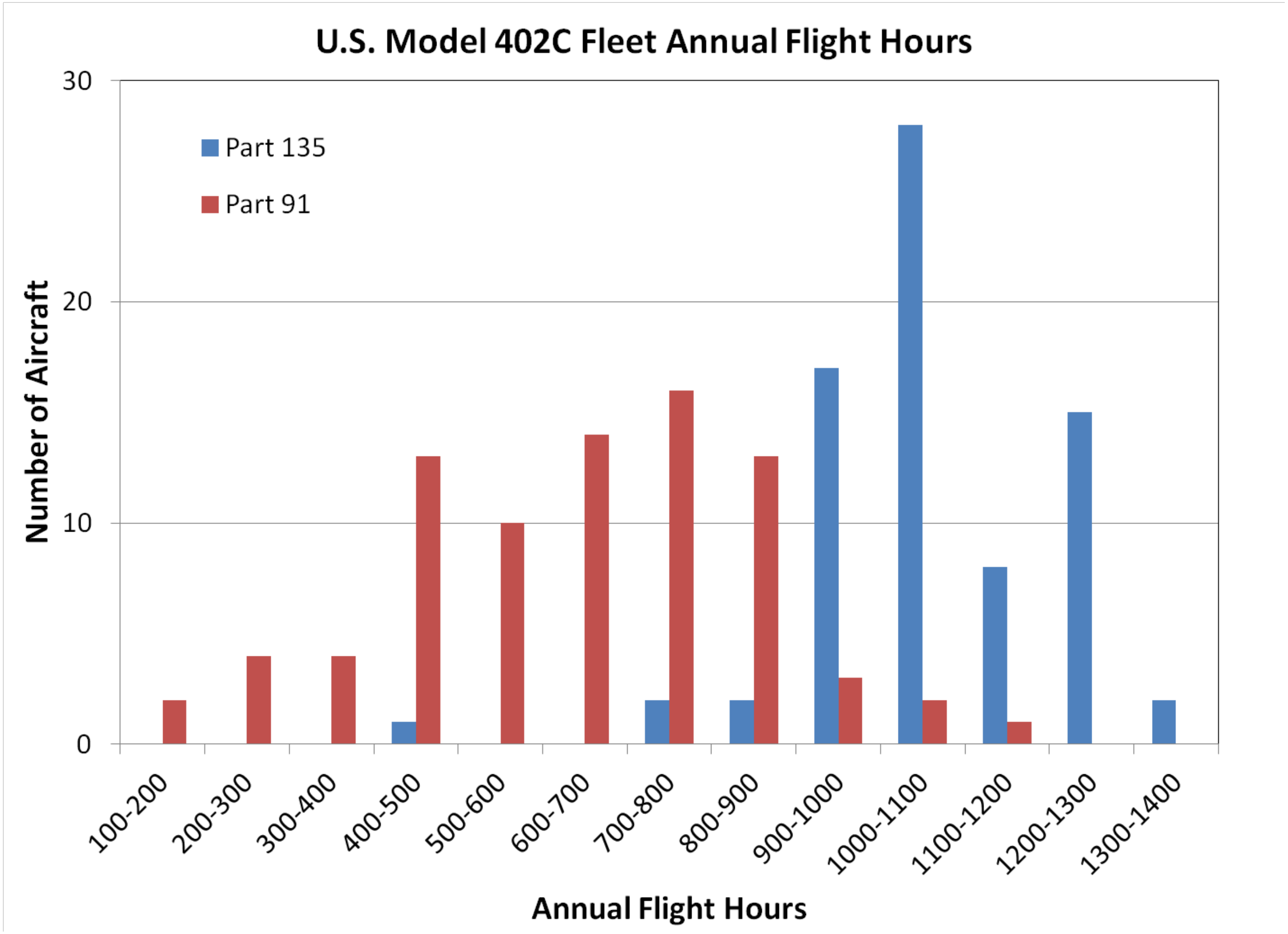
- Cessna was awarded an FAA contract to apply damage tolerance methods to the Model 402C in 1995
  - New development tests, service experience and applications of current technology in the areas of loads, stress, fatigue and fracture mechanics were utilized to identify and establish structural inspections 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

Background



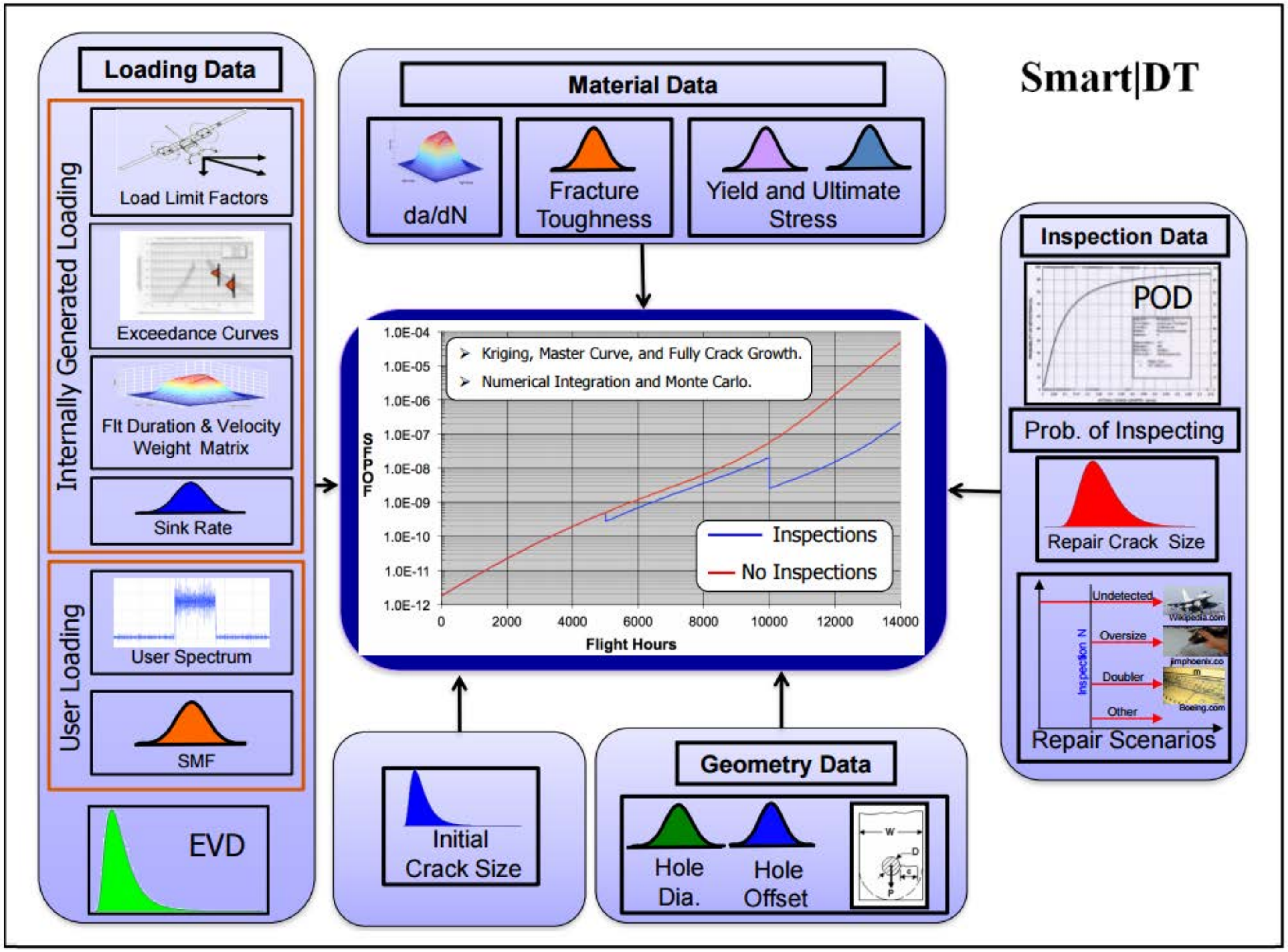
U.S. Model 402C Fleet Cumulative Flight Hours
Part 135
Part 91
Flight Hours
40,000
30,000
20,000
10,000
0
25
30
35
40
Aircraft Age (Years)

Background



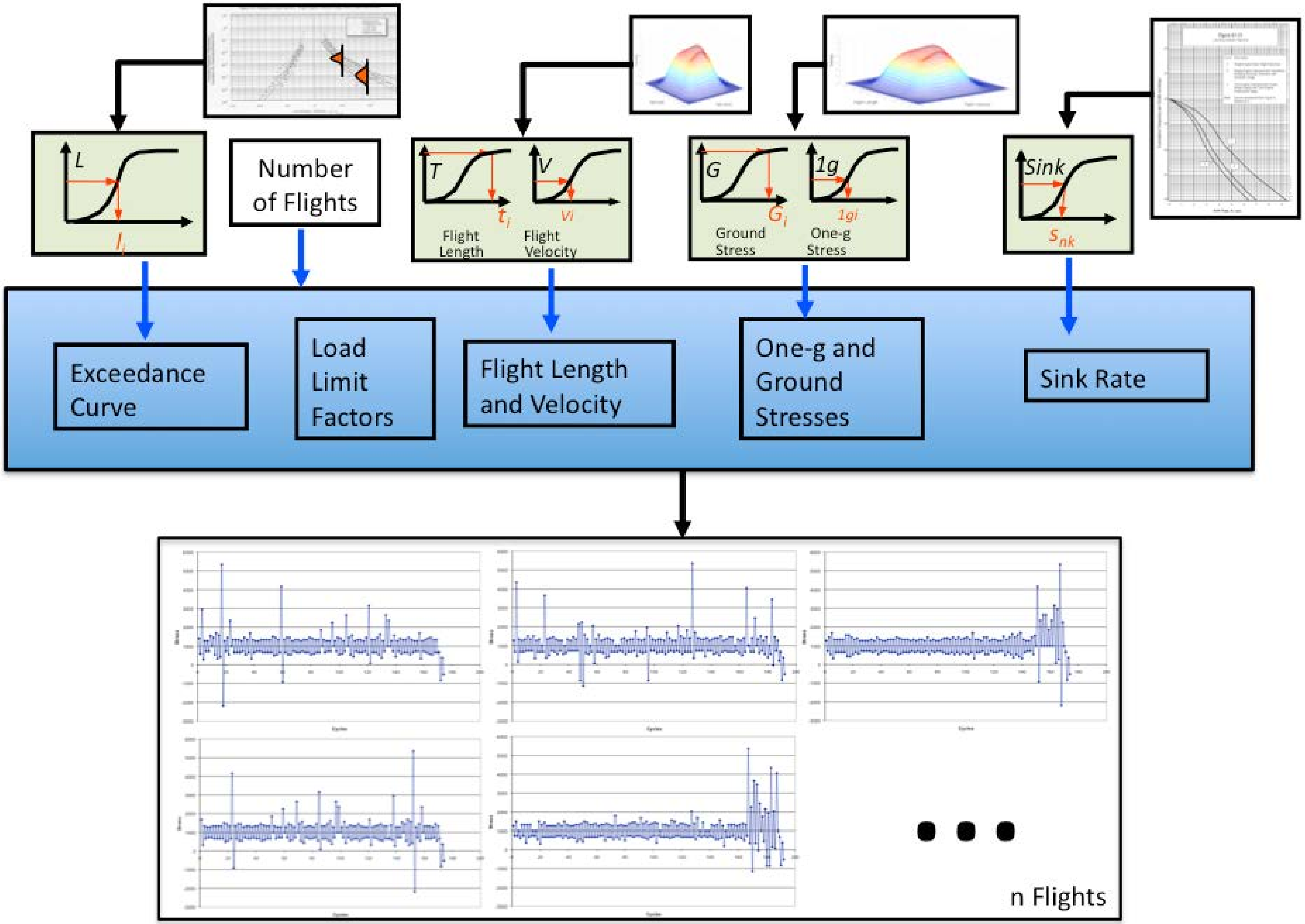
U.S. Model 402C Fleet Annual Flight Hours
Part 135
Part 91
Number of Aircraft
30
20
10
0
100-200
200-300
300-400
400-500
500-600
600-700
700-800
800-900
900-1000
1000-1100
1100-1200
1200-1300
1300-1400
Annual Flight Hours

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.

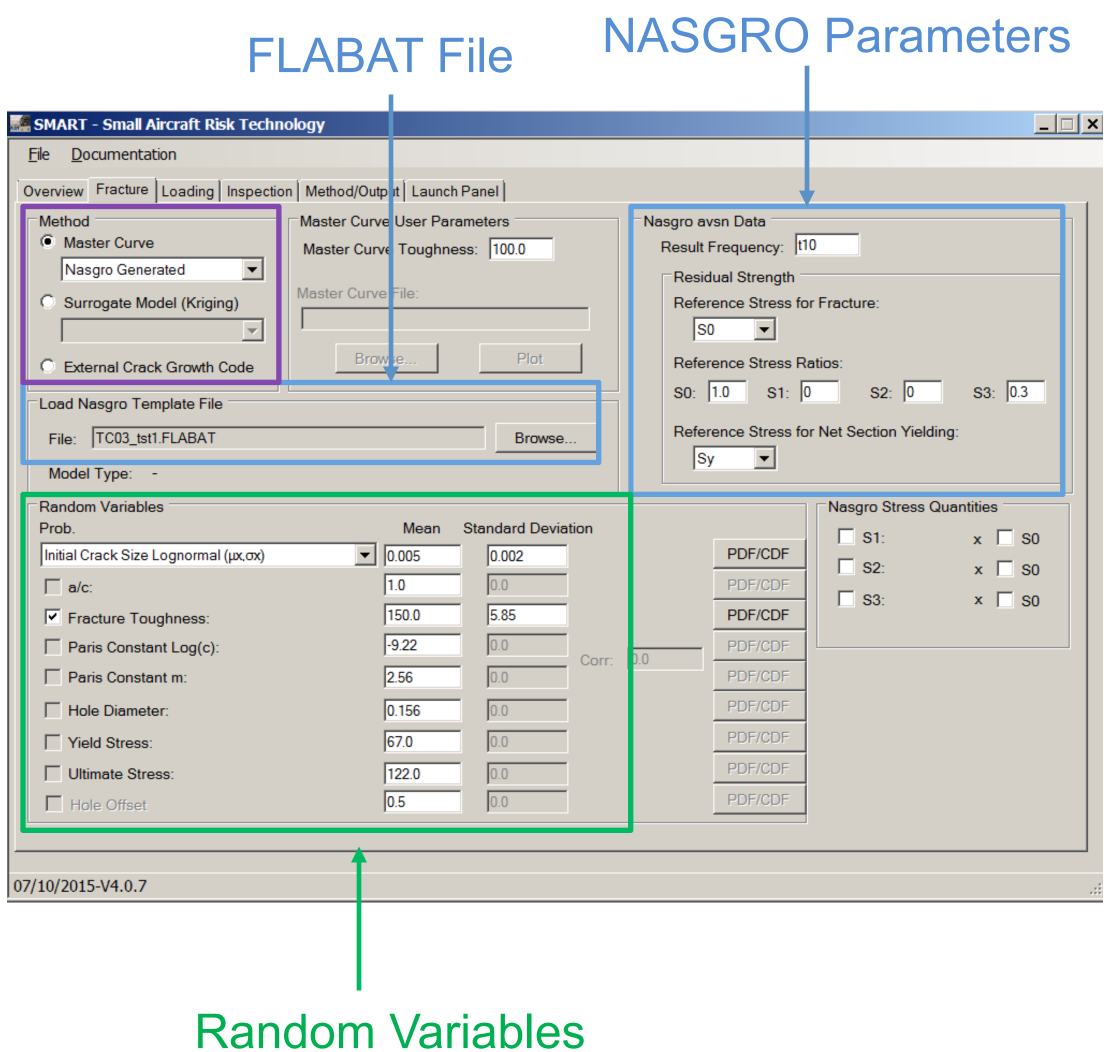
SMART Spectrum Generation Methodology Summary[1]



[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

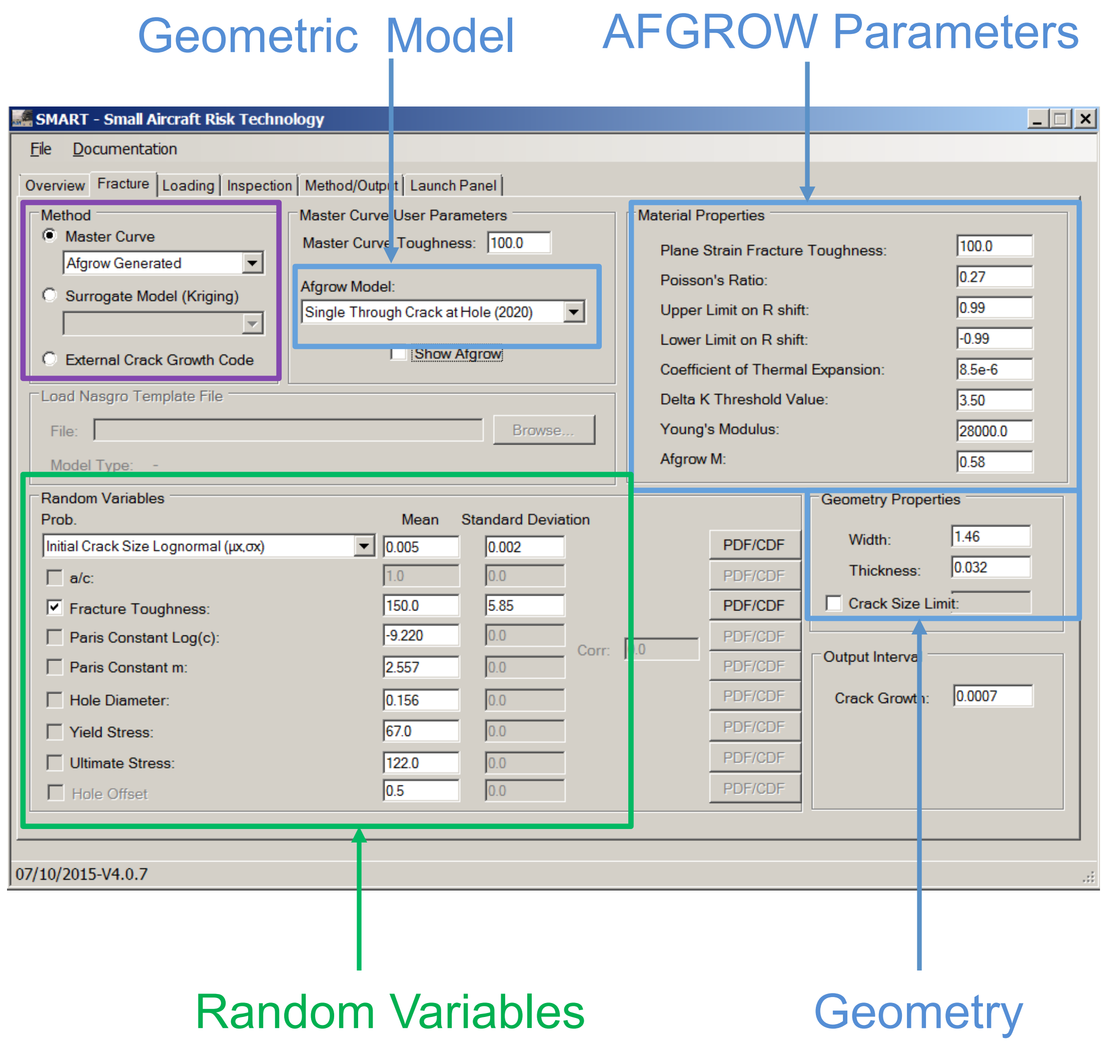
- Crack Growth Methods
  - Master Curve
    - NASGRO
    - User Generated
    - AFGROW
    - FASTRAN
  - Surrogate Model
  - External Code
- Random Variables
  - EIFS
  - Crack Aspect Ratio*
  - Fracture Toughness
  - Paris Constant Log (c)*
  - Paris Constant m*
  - Hole Diameter*
  - Yield Stress*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



* Random variables unique to SMART

Using SMART|DT

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

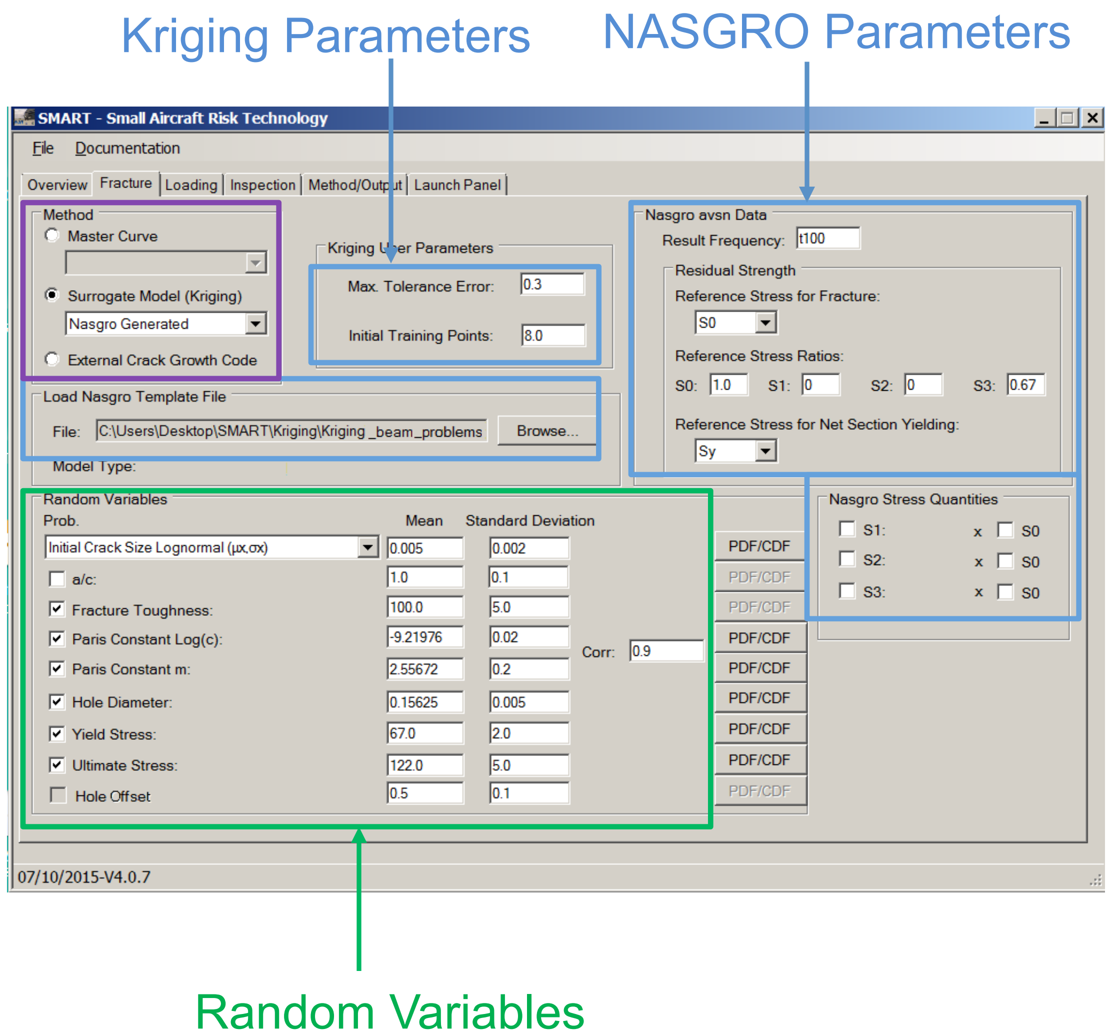


* Random variables unique to SMART

Using SMART|DT

Beechcraft | Cessna | Hawker
TEXTRON AVIATION

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



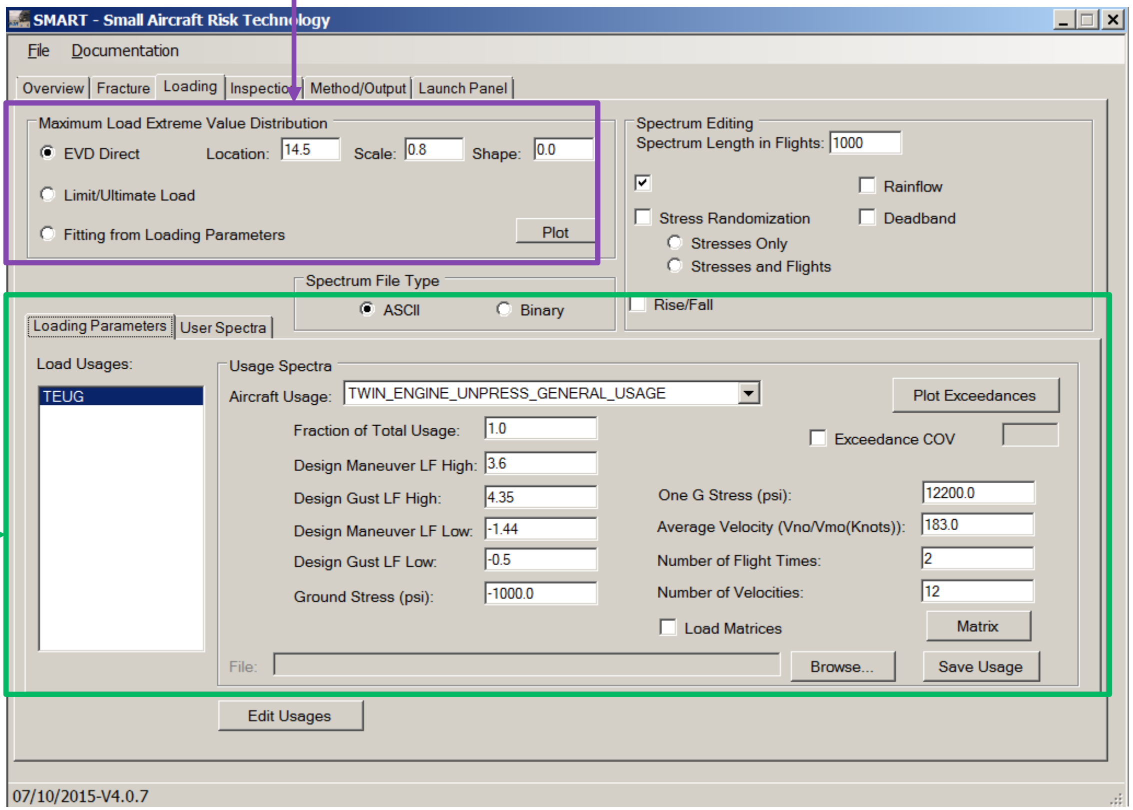
* Random variables unique to SMART

Using SMART|DT

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

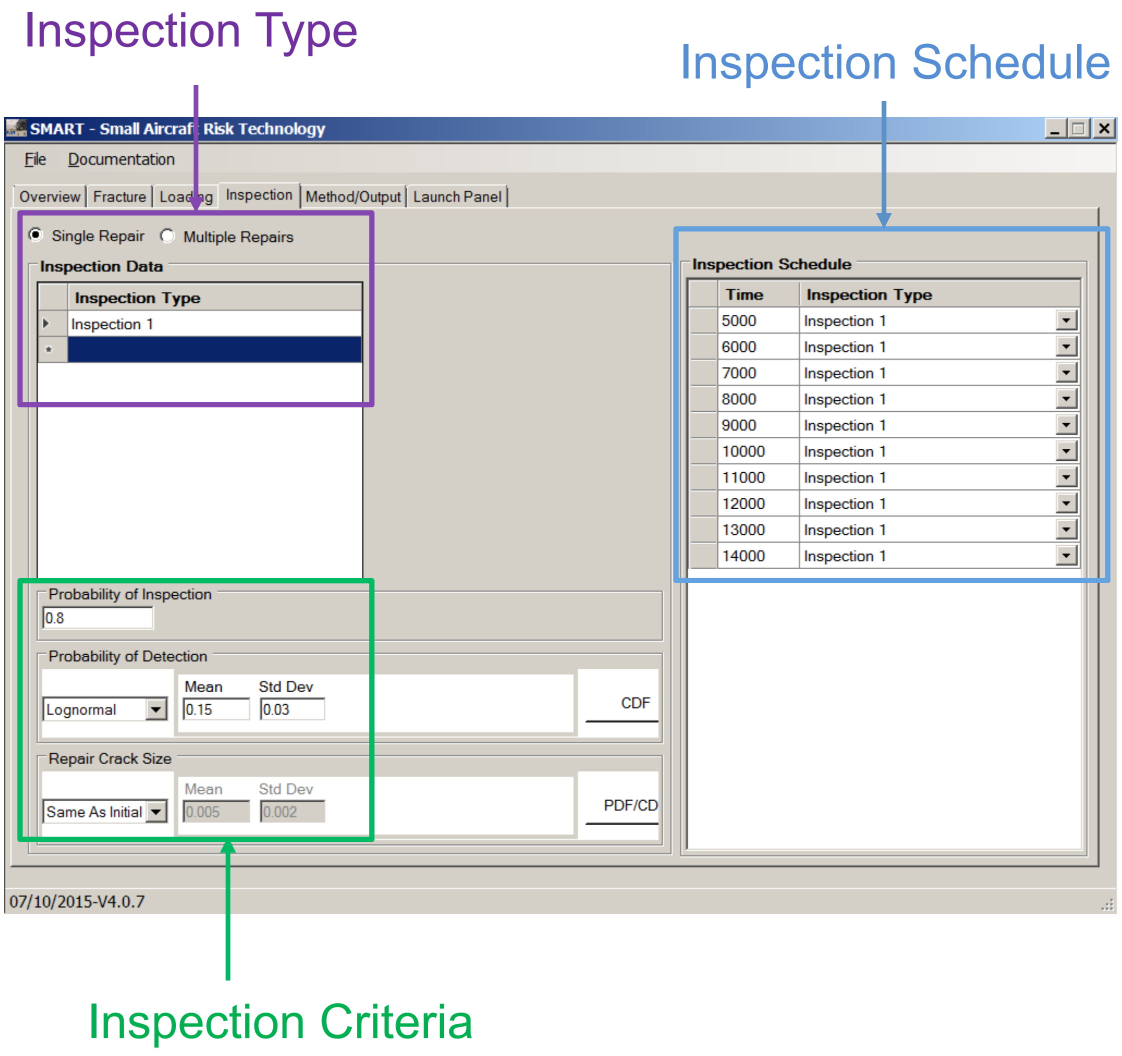
EVD

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)



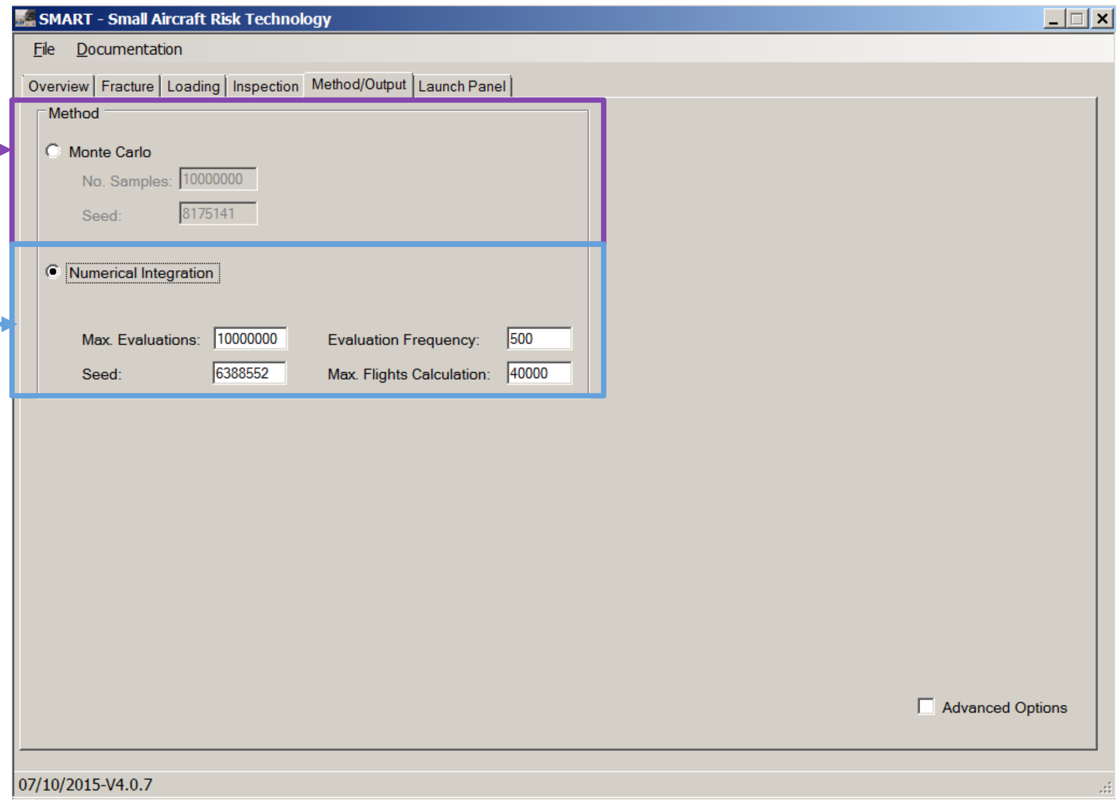
* Capability unique to SMART

Using SMART|DT

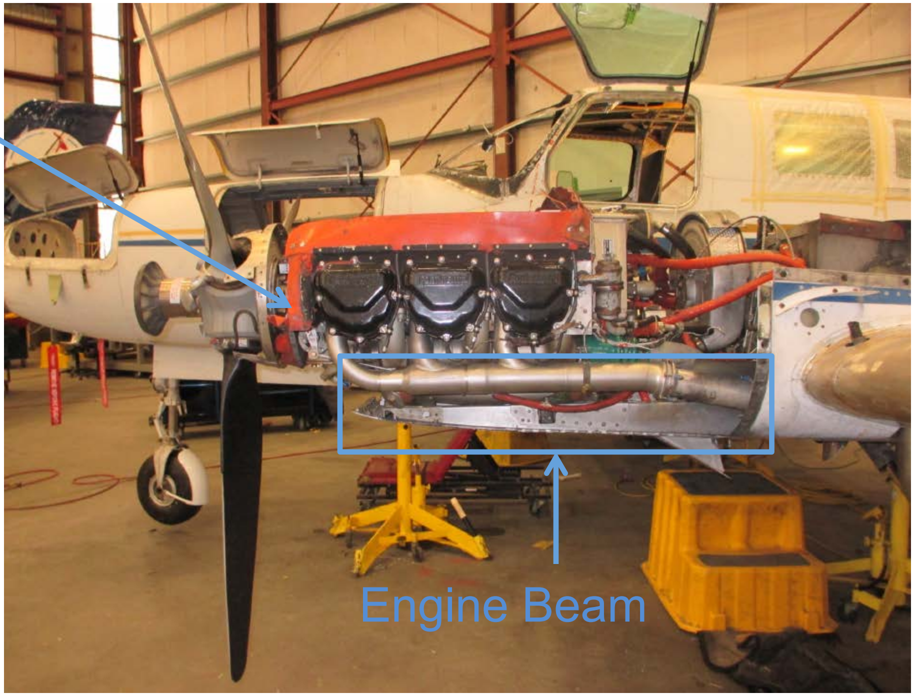
- Two Analysis Methods
  - Monte Carlo
  - Numerical Integration

Monte Carlo

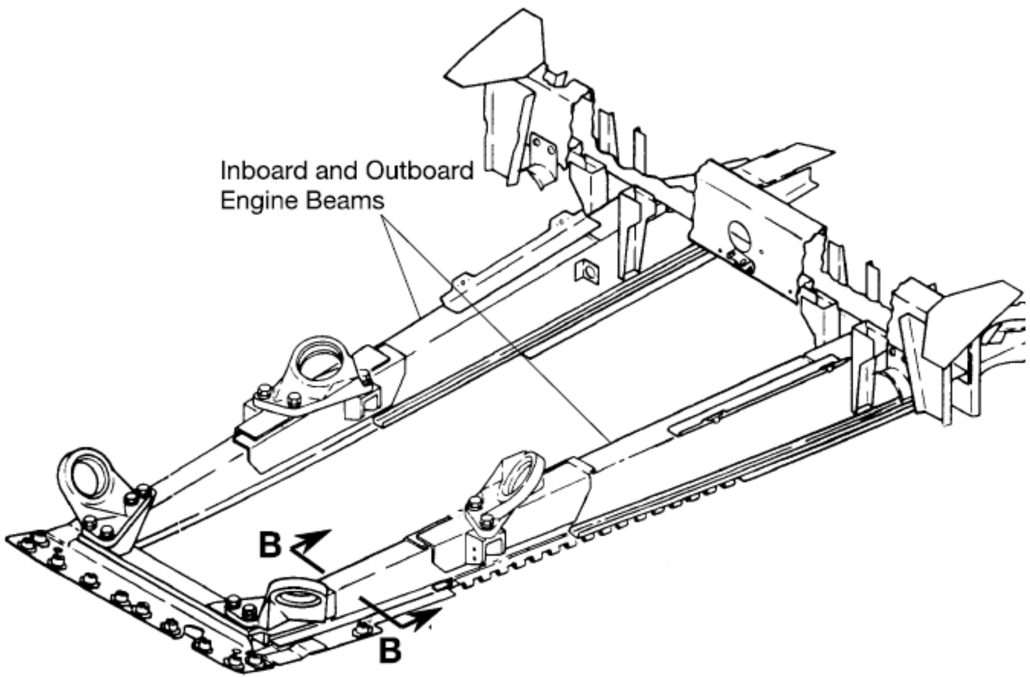
Numerical Integration



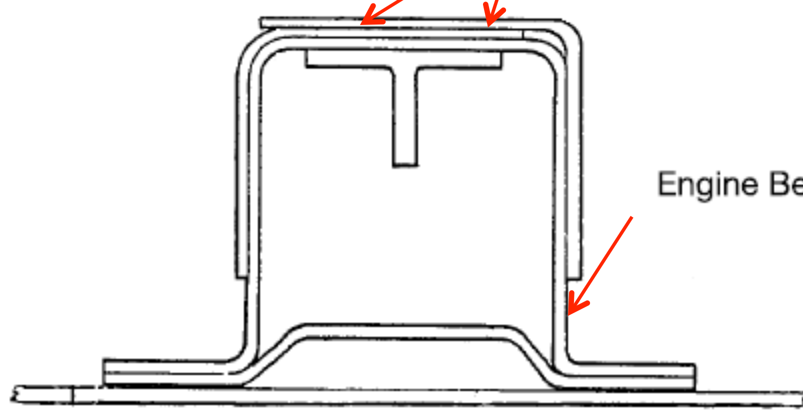
Model 402C Engine Beam



M402C Engine Beam



Engine Beam – 301 ¼ Hard Steel
Internal Tee – 2024-T3511

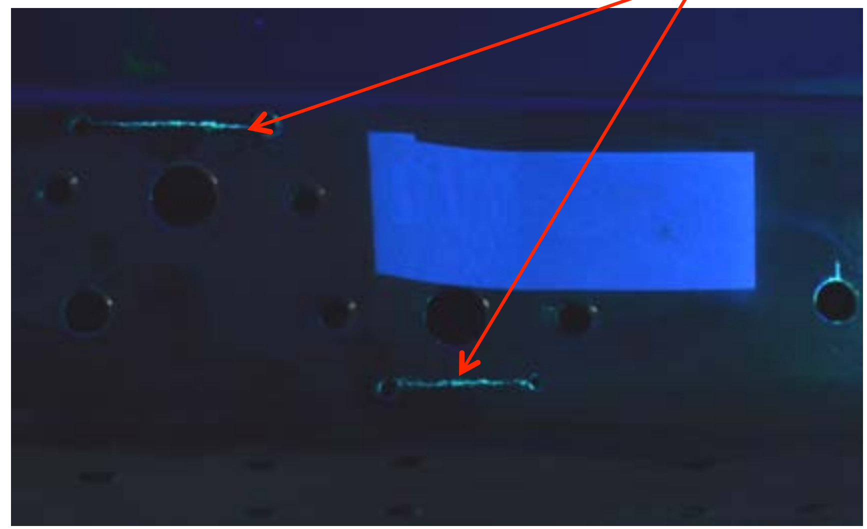


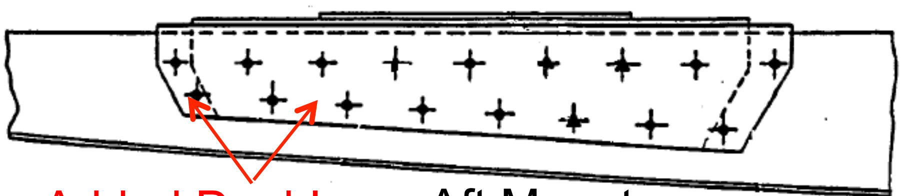
VIEW B-B

Service History

- In 1985, cracks in the fore and aft direction were found
  - Doublers installed under engine mount
  - Aft engine mount redesigned

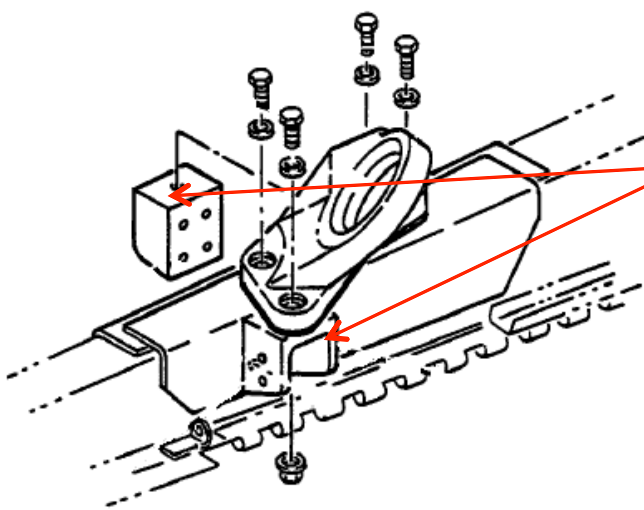
Cracks





Added Doublers

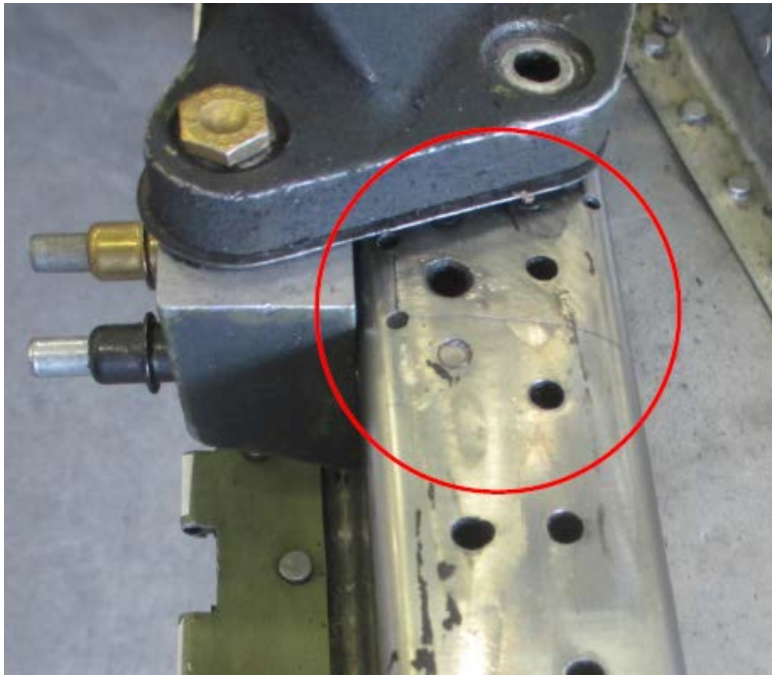
Aft Mount



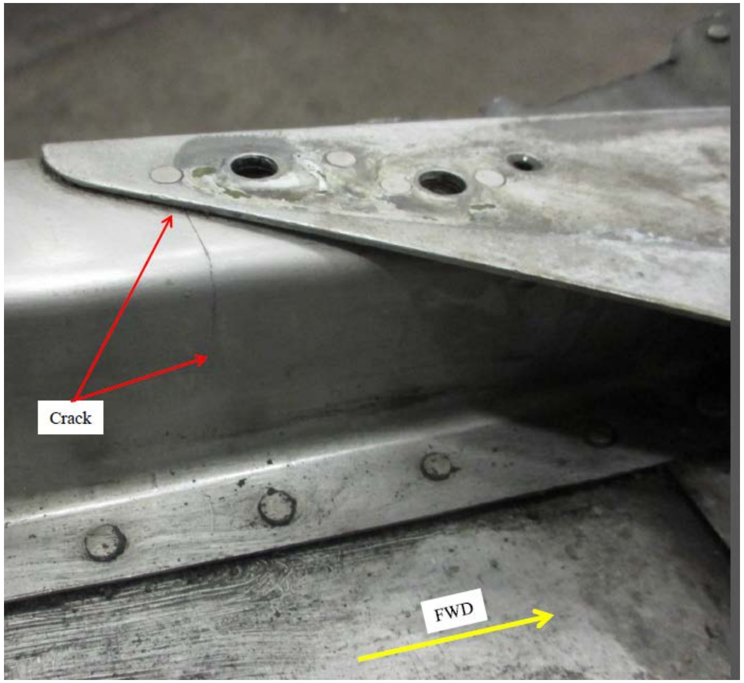
Added Fittings

Service History

- February 2015 - Engine Beam Cracks Under Forward and Aft Engine Mounts



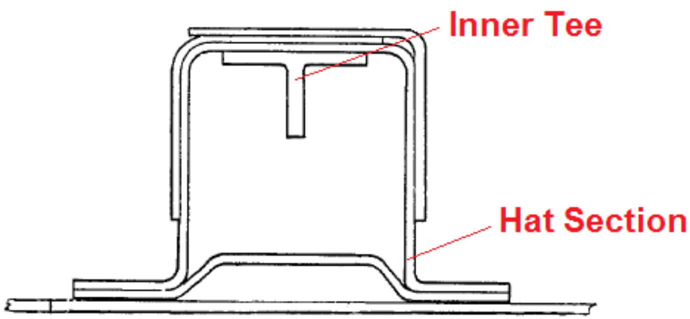
RH Outboard Beam
Fwd of Aft Engine Mt

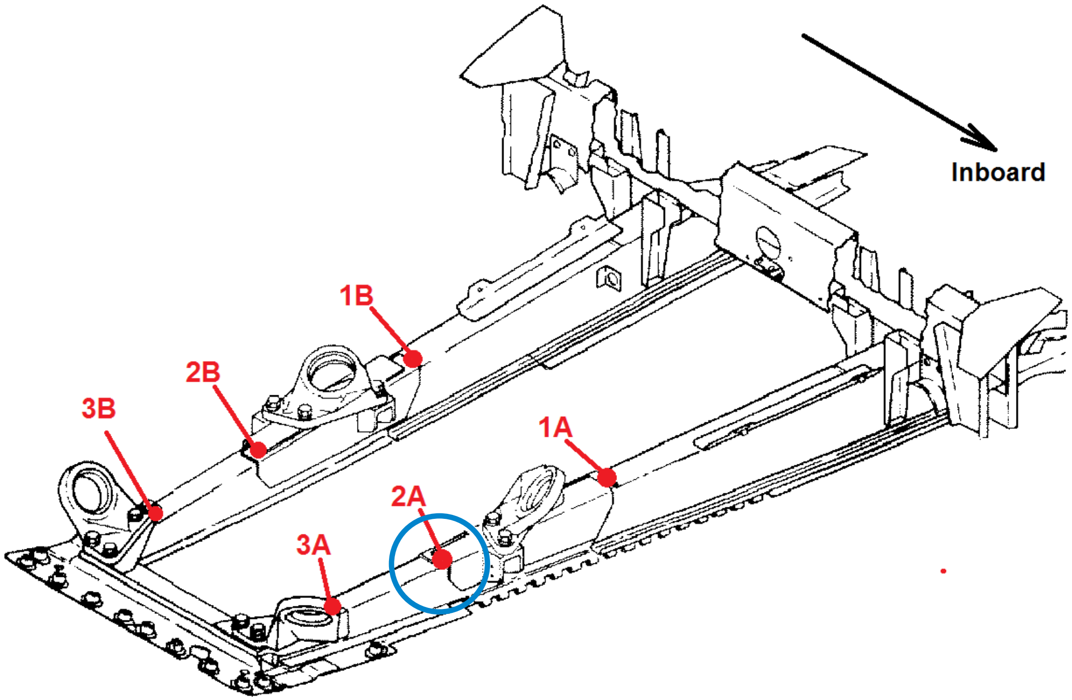


RH Inboard Beam
Aft of Fwd Engine Mt

SMART|DT Analysis

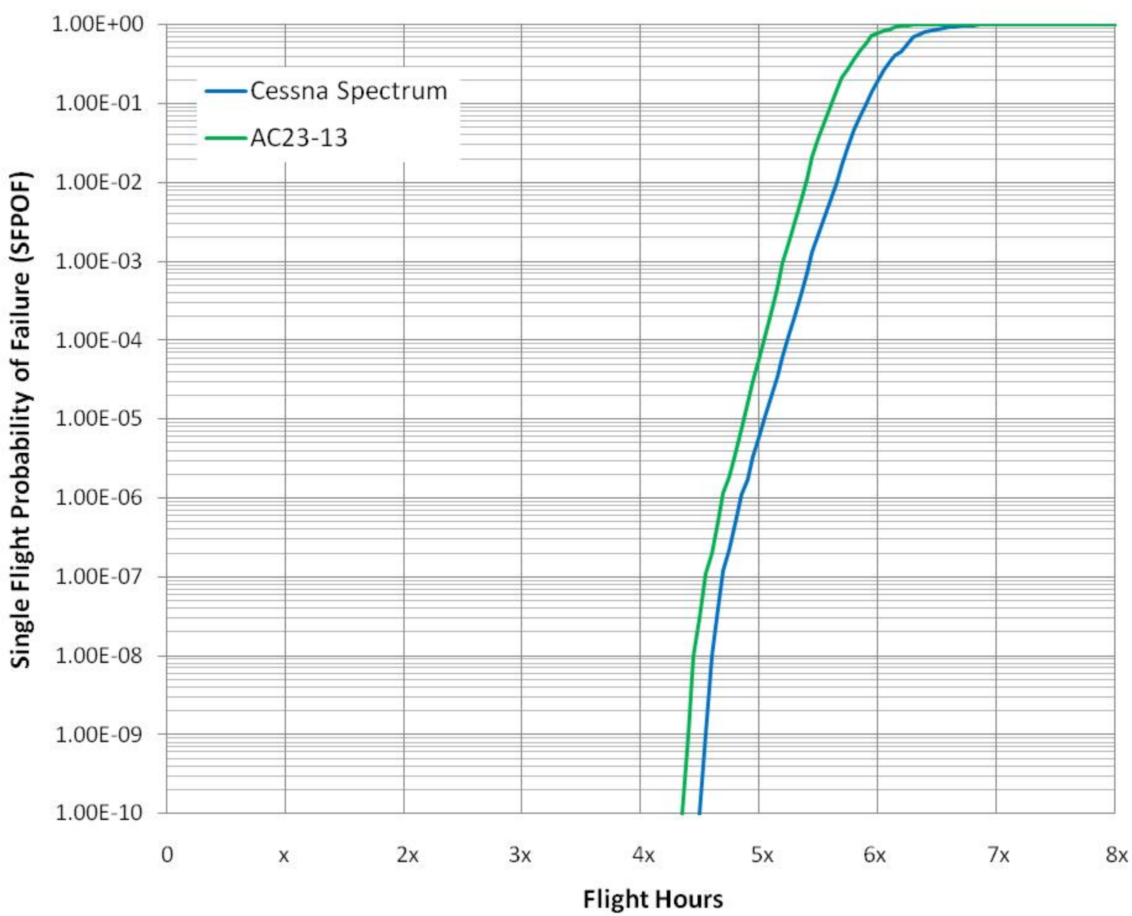
- Analysis conducted at 6 locations on the engine beam
- Analysis conducted for:
  - Engine beam hat section (All Locations)
  - Inner tee and inner tee with hat section failed (Locations 1 & 2)
- Spectra developed for three usages:
  - Typical
  - Grand Canyon (GC)
  - Short





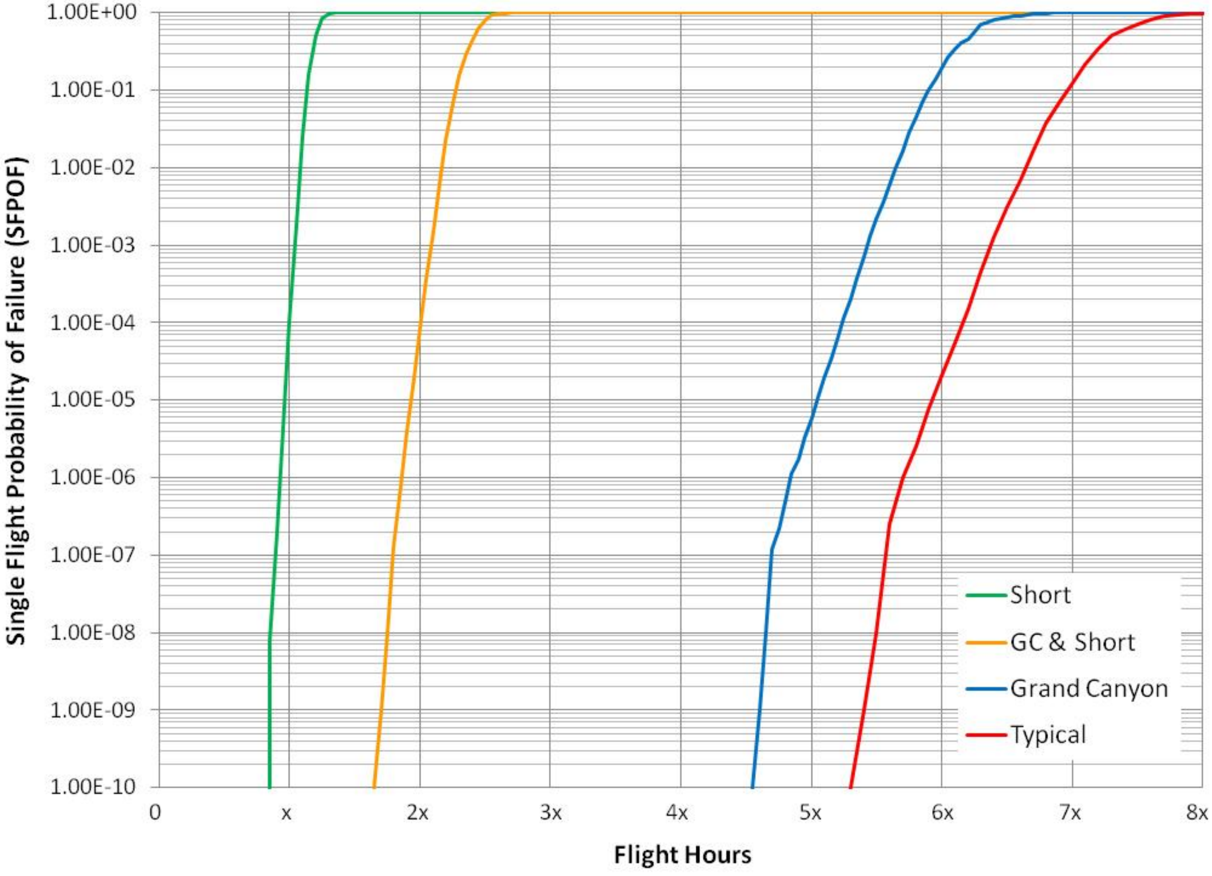
SMART|DT Analysis

- Analysis Assumptions
  - AFGROW
  - Two Spectra
    - Cessna
    - AC23-13
  - Probabilistic Variables
    - EIFS
  - EVD
    - Limit Load
  - Grand Canyon Mission
  - No Inspections



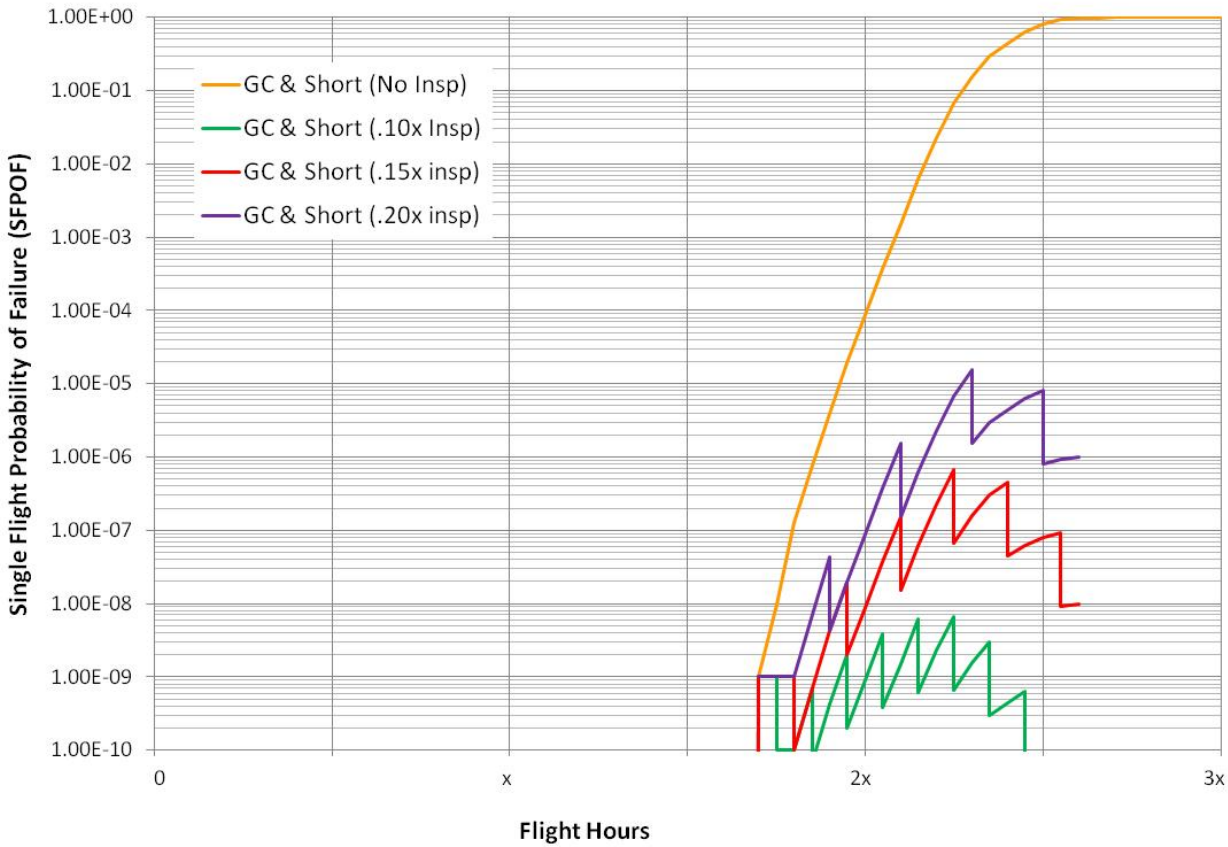
SMART|DT Analysis

- Analysis Assumptions
  - AFGROW
  - Cessna Spectrum
  - Probabilistic Variables
    - EIFS
  - EVD
    - Limit Load
  - Four Missions
    - Grand Canyon
    - Short
    - GC & Short
    - Typical
  - No Inspections



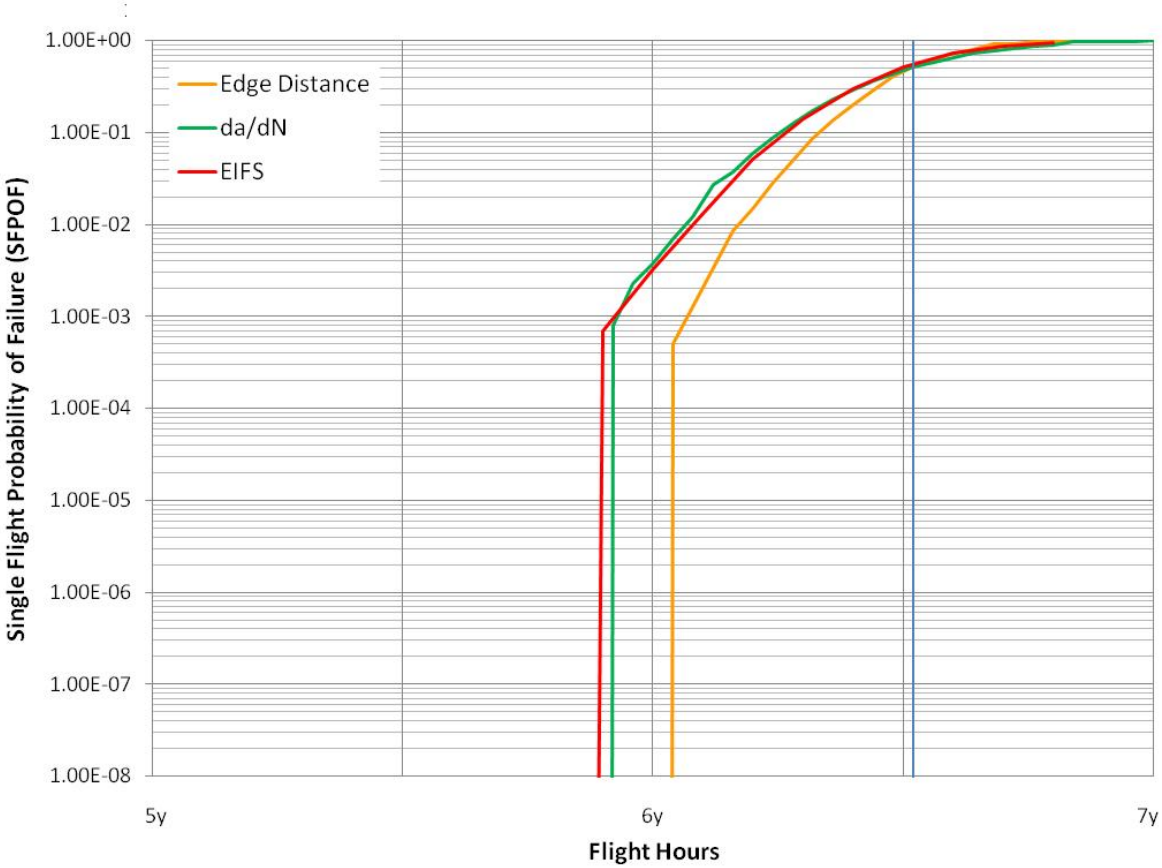
SMART|DT Analysis

- Analysis Assumptions
  - AFGROW
  - Cessna Spectrum
  - Probabilistic Variables
    - EIFS
  - EVD
    - Limit Load
  - GC & Short Mission
  - With Inspections
    - .10x
    - .15x
    - .20x



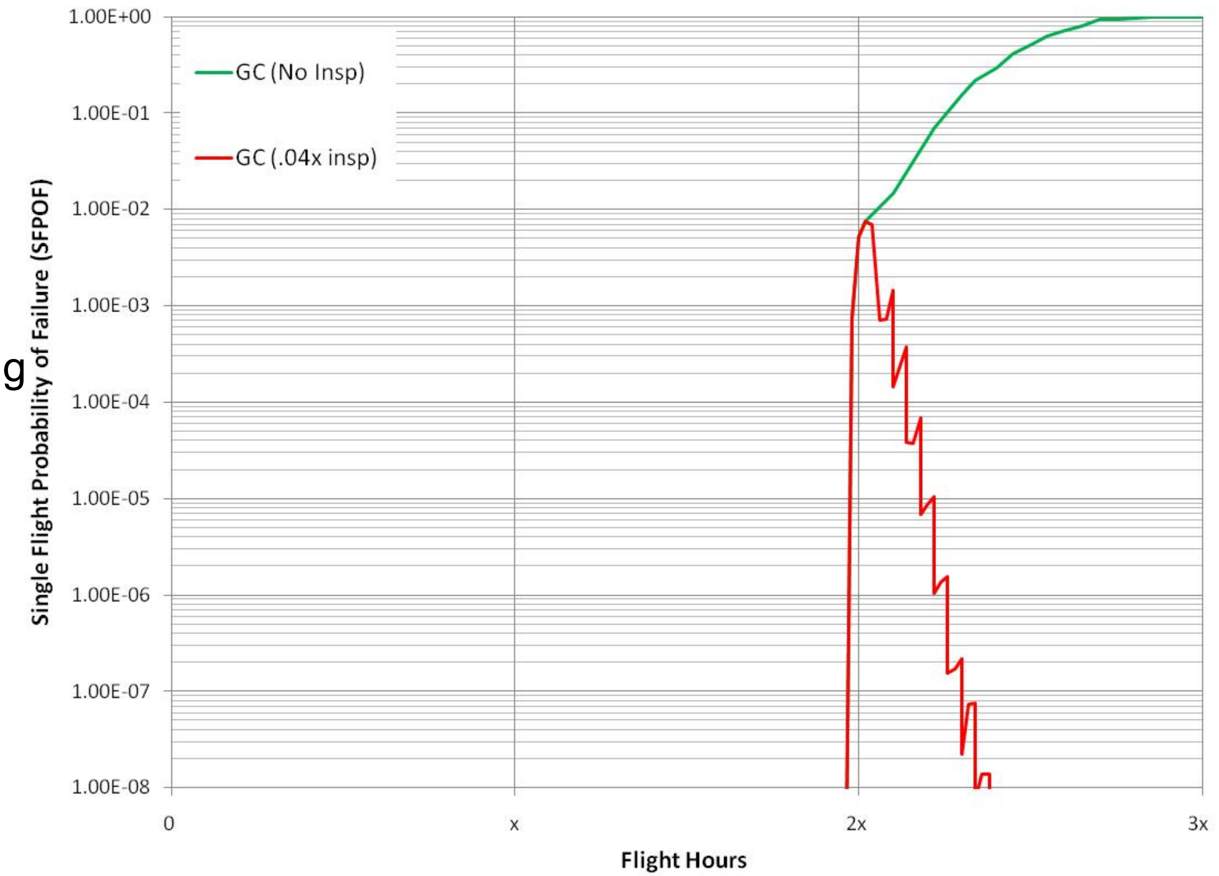
SMART|DT Analysis

- Analysis Assumptions
  - NASGRO - Kriging
  - AC23-13 Spectrum
  - Probabilistic Variables
    - EIFS
    - da/dN
    - Edge Distance
  - EVD
    - Limit Load
  - Grand Canyon Mission
  - No Inspections



SMART|DT Analysis

- Analysis Assumptions
  - NASGRO - Kriging
  - AC23-13 Spectrum
  - Probabilistic Variables
    - EIFS
    - da/dN
    - Edge Distance
  - EVD
    - Fitting From Loading Parameters
  - Grand Canyon Mission
  - With Inspections
    - .04x



Recommendations

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