

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



- 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 <u>SMall Aircraft Risk Technology</u>
 - 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



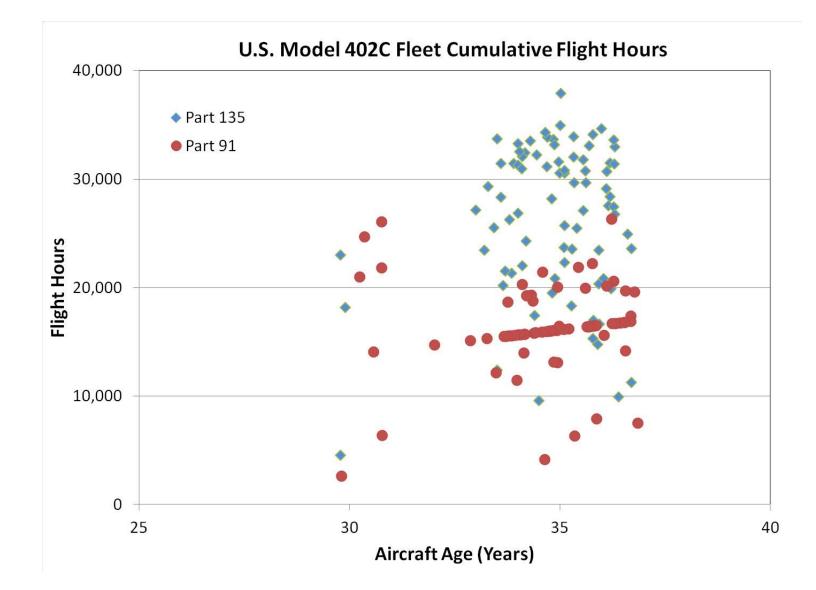
- Cessna Model 402C selected to evaluate SMART
 - Twin engine piston
 - Non-pressurized
 - Seats up to 9 passengers
 - Used in Part 135 Commuter
 - 381 402C's manufactured from 1979 to 1985



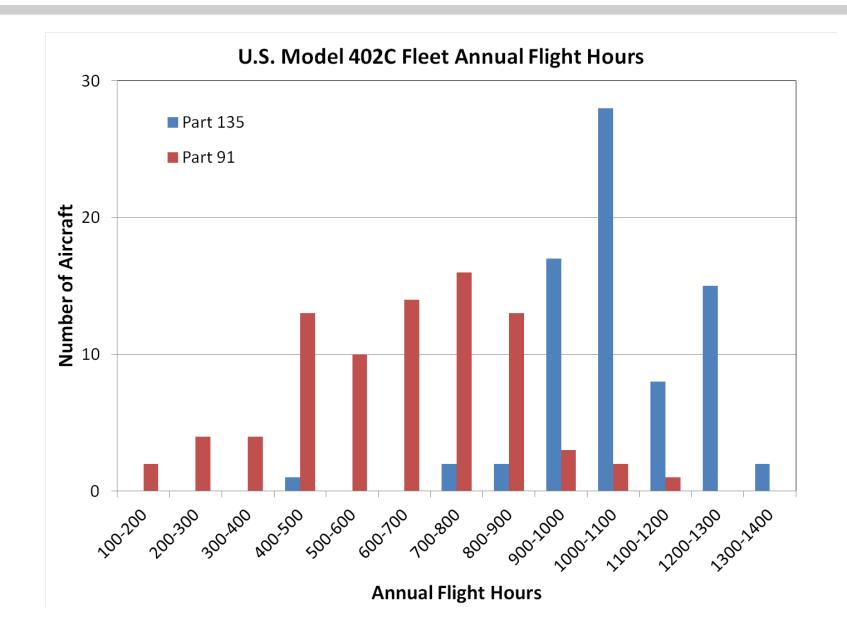


- Cessna was awarded an FAA contract to apply damage tolerance methods to the Model 402C in 1995
 - New development tests, service experience and applications of current technology in the areas of loads, stress, fatigue and fracture mechanics were utilized to identify and establish structural inspections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





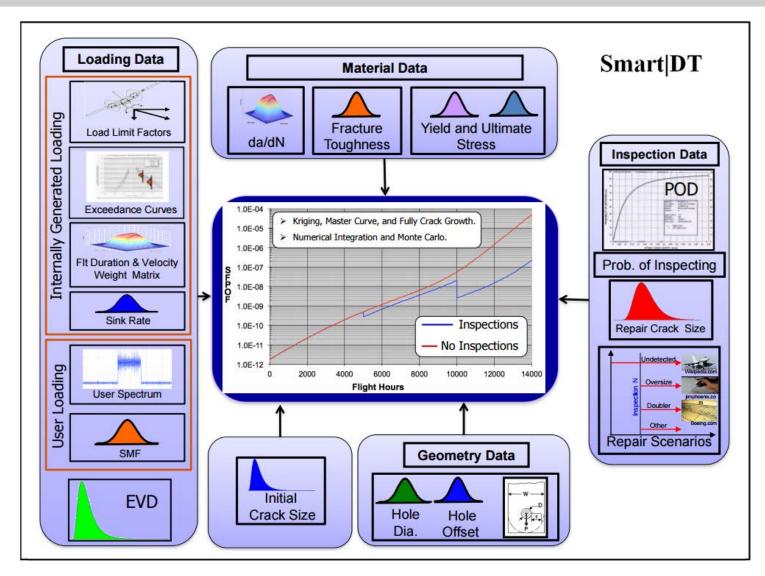




SMART|DT Methodology Summary¹



TEXTRON AVIATION

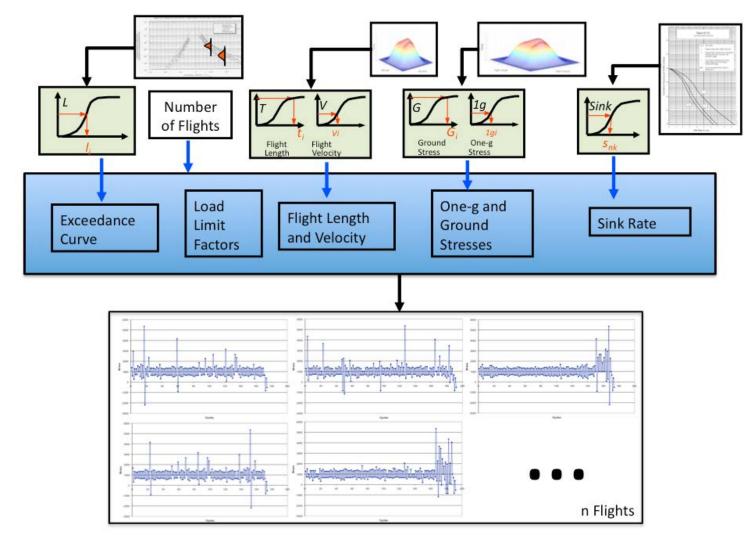


¹ Millwater H. & Ocampo, J., 'Multiple Repair Scenarios in Aircraft Fleets Using the Weighted Branch Integration Method', presented at 2015 Aircraft Airworthiness and Sustainment Conference.

SMART Spectrum Generation Methodology Summary¹



TEXTRON AVIATION



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



NASGRO Parameters

- 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*

SMART - Small Aircraft Risk Technology ile Documentation		
verview Fracture Loading Inspection Meth		
Method	er Curve User Parameters er Curve Toughness: 100.0	Nasgro avsn Data Result Frequency: [10
	er Curve File:	Reference Stress for Fracture:
C External Crack Growth Code	Browse Plot	Reference Stress Ratios:
Load Nasgro Template File		S0: 1.0 S1: 0 S2: 0 S3: 0.3
File: TC03_tst1.FLABAT	Browse	Reference Stress for Net Section Yielding:
Model Type: -		Sy 💌
Random Variables Prob.	Mean Standard Deviation	Nasgro Stress Quantities
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a/c:	1.0 0.0	PDF/CDF S3: × S0
Fracture Toughness: Paris Constant Log(c):	-9.22 0.0	
Paris Constant m:	2.56 0.0 Co	
Hole Diameter:	0.156 0.0	PDF/CDF
Yield Stress:	67.0 0.0	PDF/CDF
Ultimate Stress:	122.0 0.0	PDF/CDF
Hole Offset	0.5	PDF/CDF
/10/2015-V4.0.7	1	

Random Variables

EL ARAT EILO

* Random variables unique to SMART



AFGROW Parameters

- Crack Growth Methods
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 - Crack Aspect Ratio*
 - Fracture Toughness
 - Paris Constant Log (c)*
 - Paris Constant m*
 - Hole Diameter*
 - Yield Stress*
 - Ultimate Stress*
 - Hole Offset*

Master Curve Maser Curve Afgrow Generated Surrogate Model (Kriging)	hod/Outp t Launch Panel) ter Curve User Parameters ter Curve Toughness: 100.0 ow Model: gle Through Crack at Hole (2020) IShow Atgrow: Browse	Material Properties Plane Strain Fracture Toughness: Poisson's Ratio: Upper Limit on R shift: Lower Limit on R shift: Coefficient of Thermal Expansion: Delta K Threshold Value: Young's Modulus: Afgrow M:	1000 027 099 099 8.5e-6 3.50 280000 0.58
Random Variables Prob. Initial Crack Size Lognormal (µx,ox) □	Mean Standard Deviation ● 0.005 0.002 10 0.0 5.85 -9.200 0.0 2.557 0.156 0.0 67.0 122.0 0.0 0.0 0.5 0.0 0.0	PDF/CDF Width: PDF/CDF Width: PDF/CDF Crack Siz PDF/CDF Output Interv PDF/CDF PDF/CDF PDF/CDF Crack Grow PDF/CDF PDF/CDF PDF/CDF PDF/CDF PDF/CDF PDF/CDF	e Limit:
07/10/2015-V4.0.7 Rando	m Variables	Geor	metry

Geometric Model

* Random variables unique to SMART



NASGRO Parameters

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 - Hole Offset*

SMART - Small Aircraft Risk Technology <u>File</u> <u>D</u> ocumentation						
Overview Fracture Loading Inspection Meth	od/Output Launch Par	nel			,	
Surrogate Model (Kriging) Nasgro Generated C External Crack Growth Code Load Nasgro Template File File: [C:\Users\Desktop\SMART\Kriging\	iging User Parameter Max. Tolerance Erro Initial Training Points ging _beam_problems	r: 0.3	Resid Refe S Refe S0:	Frequency: 1 dual Strength - rence Stress fo rence Stress Ra 1.0 S1: 0 rence Stress fo	r Fracture: atios:	
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7/10/2015-V4.0.7						

Random Variables

Kriging Parameters

* Random variables unique to SMART



- Spectrum Generation
 - Two Methods
 - User Defined in AFGROW Format
 - AC23-13A Derived

Spectrum

- Extreme Value Distribution
 - EVD Direct
 - Limit/Ultimate Load
 - Fitting from Loading Parameters

EVD	
SMART - Small Aircraft Risk Technology	_ <u> </u>
File Documentation	
Overview Fracture Loading Inspection Method/Output Launch Panel	
Maximum Load Extreme Value Distribution Spectrum Editing	
• EVD Direct Location: 14:00 Scale: 10:00 Shape: 10:00	
C Limit/Ultimate Load	
C Fitting from Loading Parameters Plot C Otherse Oats	
C Stresses Only	
Spectrum File Type	
Loading Parameters User Spectra	
Load Usages: Usage Spectra TEUG Aircraft Usage: TWIN_ENGINE_UNPRESS_GENERAL_USAGE	
	<u> </u>
Fraction of Total Usage: 1.0 Exceedance COV	
Design Maneuver LF High: 36	
Design Gust LF High: 4.35 One G Stress (psi): 12200.0	
Design Maneuver LF Low: 1.44 Average Velocity (Vno/Vmo(Knots)): 183.0	
Design Gust LF Low: 0.5 Number of Flight Times: 2	
Ground Stress (psi): -1000.0 Number of Velocities: 12]
Load Matrices Matrix	
File: Browse Save Usage	
Edit Usages	
07/10/2015-V4.0.7	.::



Inspection Schedule

- 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)

Inspection Type

view Fracture Loading Inspection Metho Single Repair C Multiple Repairs	`	Г		+	
nspection Data			nspection \$		
Inspection Type			Time	Inspection Type	
Inspection 1		_	5000	Inspection 1	
		_	6000	Inspection 1	
		_	7000	Inspection 1	
	-		8000	Inspection 1	
		_	9000	Inspection 1	
		_	10000	Inspection 1	
		_	11000	Inspection 1	
		_	12000	Inspection 1	
		_	13000	Inspection 1	
			14000	Inspection 1	
Probability of Inspection 18 Probability of Detection					
ognormal		CDF			
Repair Crack Size					
Same As Initial		PDF/CD			

Inspection Criteria

* Capability unique to SMART



- Two Analysis Methods
 - Monte Carlo
 - Numerical Integration

	SMART - Shall All Clark Risk Technology	
	File Documentation	
Monte Carlo→	Overview Fracture Loading Inspection Method/Output Launch Panel Method	
Numerical Integration ——	Max. Evaluations: 10000000 Evaluation Frequency: 500 Seed: 6388552 Max. Flights Calculation: 40000	
	Advanced Op	ptions
	07/10/2015-V4.0.7	.::

Model 402C Engine Beam



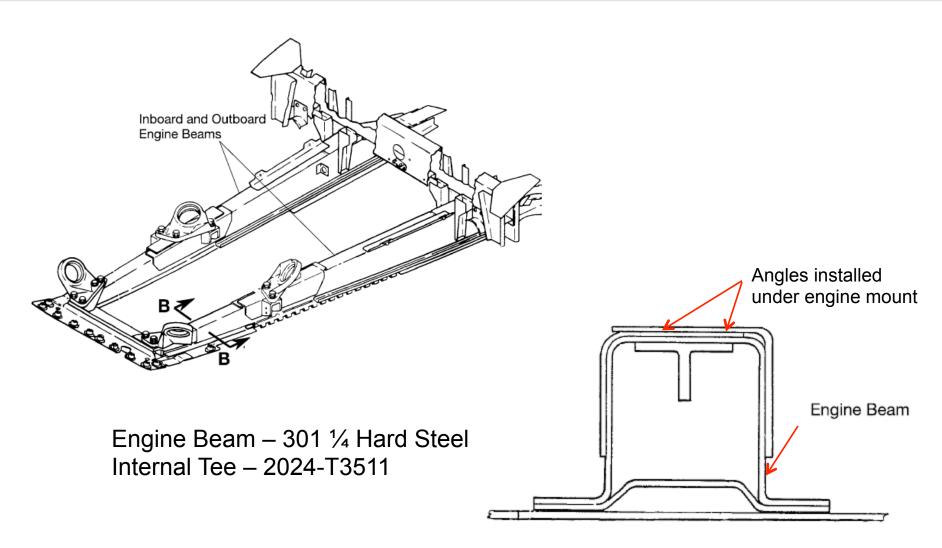
TEXTRON AVIATION



M402C Engine Beam



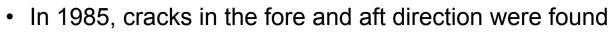
TEXTRON AVIATION



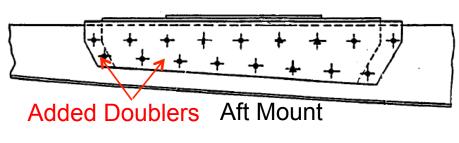
VIEW B-B

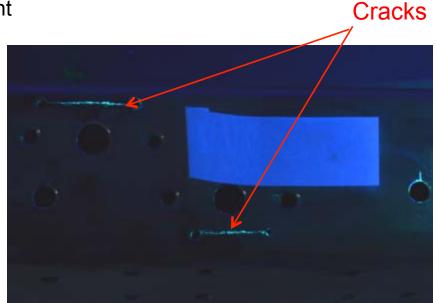
Service History

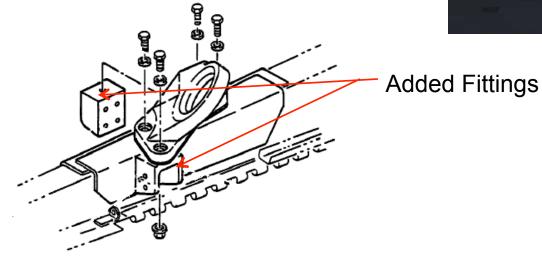




- Doublers installed under engine mount
- Aft engine mount redesigned





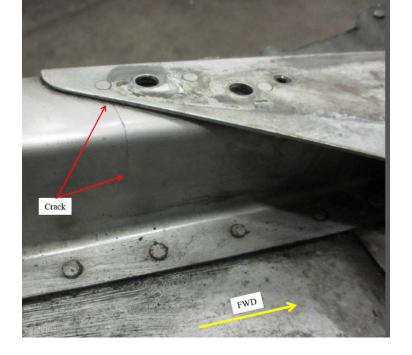


Service History



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

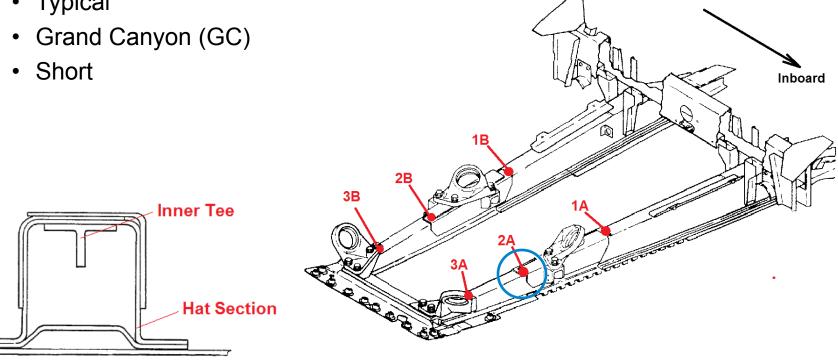




RH Outboard Beam Fwd of Aft Engine Mt RH Inboard Beam Aft of Fwd Engine Mt

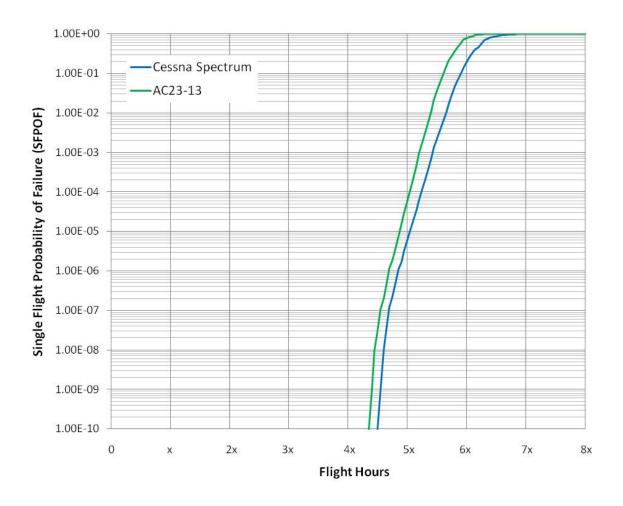


- Analysis conducted at 6 locations on the engine beam •
- Analysis conducted for:
 - Engine beam hat section (All Locations)
 - Inner tee and inner tee with hat section failed (Locations 1 & 2)
- Spectra developed for three usages:
 - Typical •





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

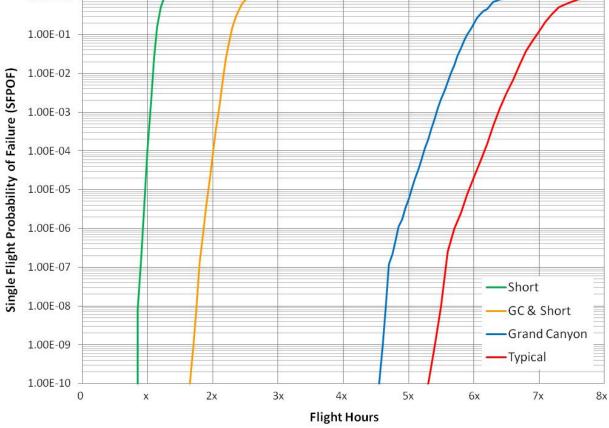




- Analysis Assumptions
 - AFGROW
 - Cessna Spectrum
 - Probabilistic Variables

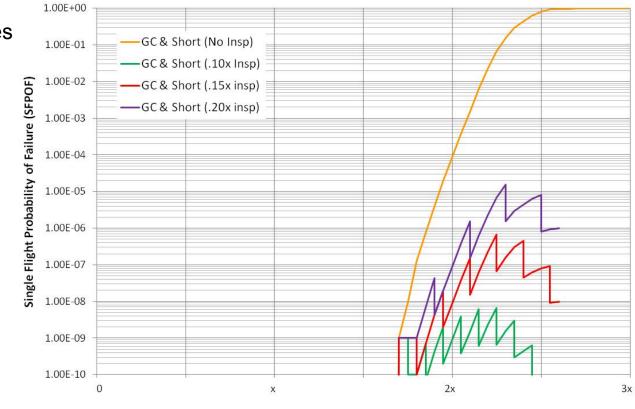
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- EIFS
- EVD
 - Limit Load
- Four Missions
 - Grand Canyon
 - Short
 - GC & Short
 - Typical
- No Inspections





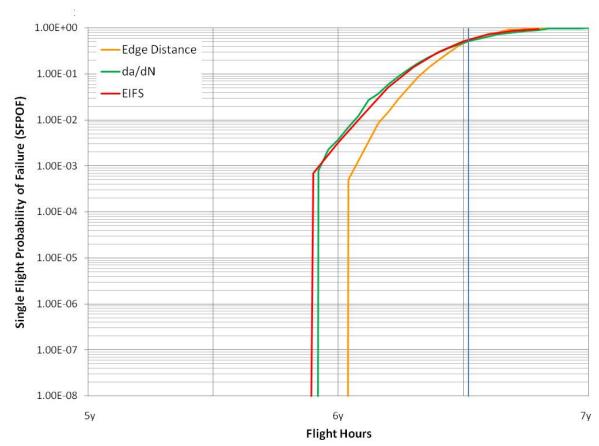
- Analysis Assumptions
 - AFGROW
 - Cessna Spectrum
 - Probabilistic Variables
 - EIFS
 - EVD
 - Limit Load
 - GC & Short Mission
 - With Inspections
 - .10x
 - .15x
 - .20x



Flight Hours

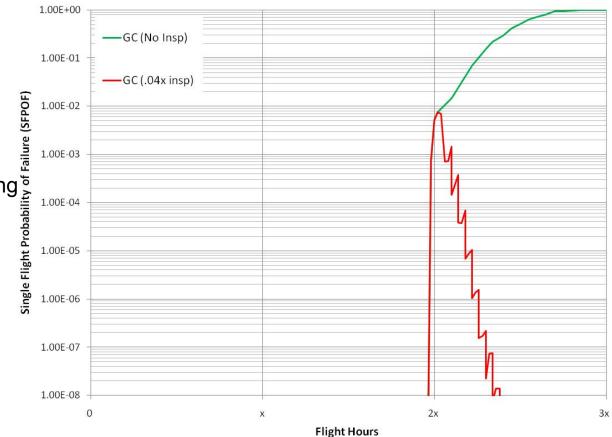


- Analysis Assumptions
 - NASGRO Kriging
 - AC23-13 Spectrum
 - Probabilistic Variables
 - EIFS
 - da/dN
 - Edge Distance
 - EVD
 - Limit Load
 - Grand Canyon Mission
 - No Inspections





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





- 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



