SMART$_{LD}$ (SMall Airplane Risk Assessment Technology) Technology – A Manufacturer's Perspective

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TEXTRON AVIATION

Cessna

Agenda

- Background
- $SMART_{LD}$ Methodology
- Using $SMART_{LD}$
- Model 402C Wing Analysis
  - Wing front spar at WS 114
  - Wing front spar at WS 81
- Discussion
- Recommendations
- What's Next

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

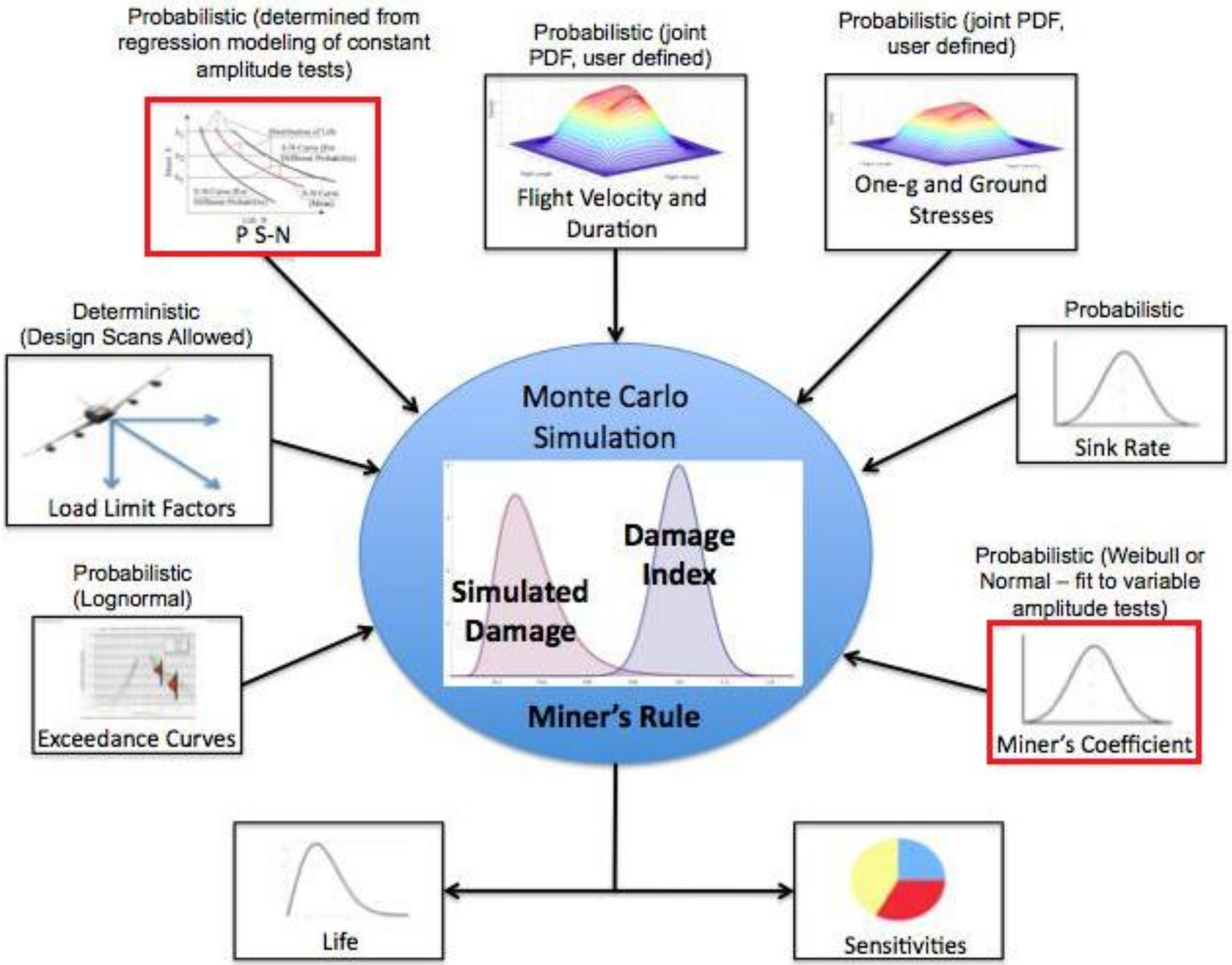
Background

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

Background

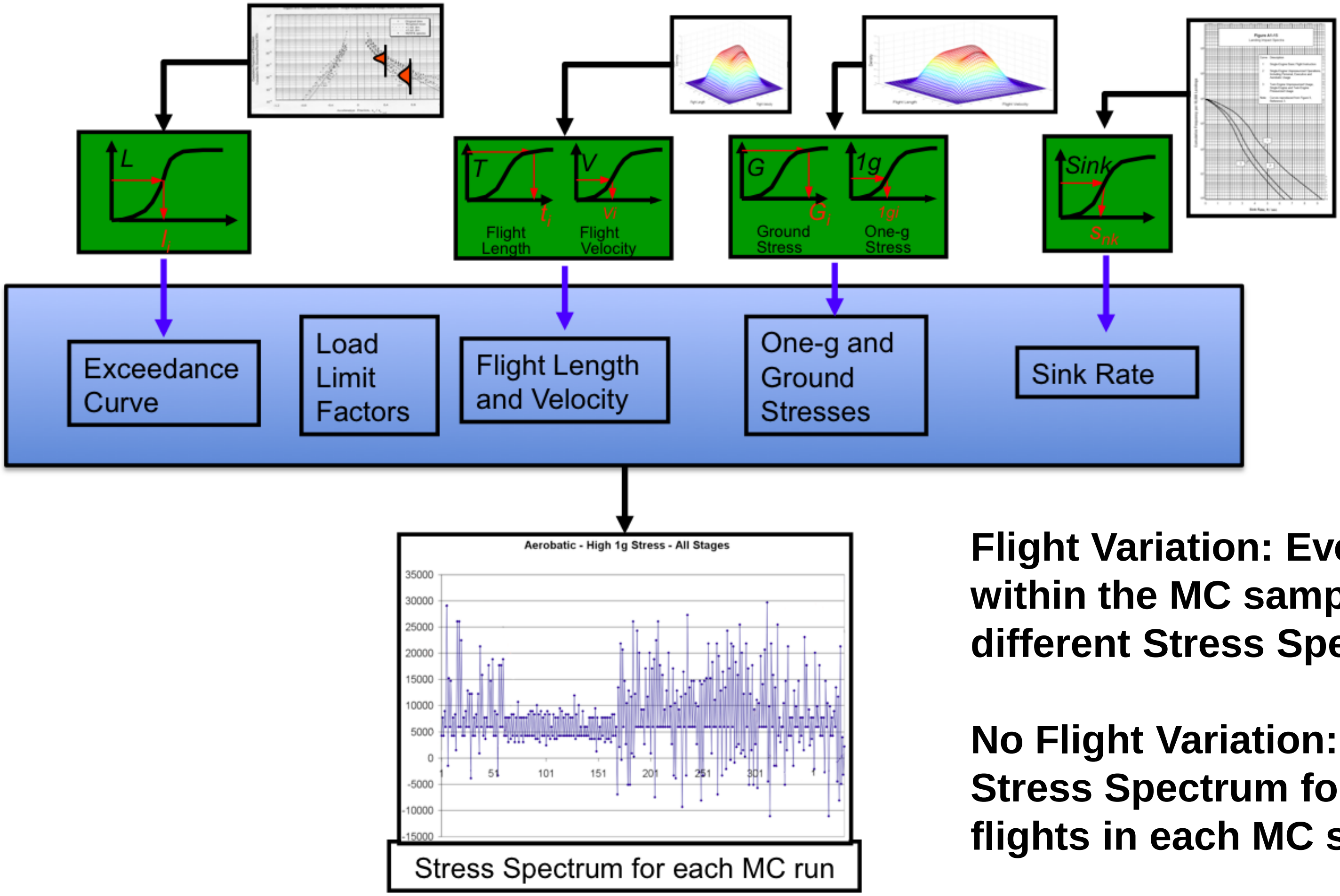
- Cessna was awarded an FAA contract to apply damage tolerance methods to the Model 402C in 1995
  - New development tests, service experience and applications of current technology in the areas of loads, stress, fatigue and fracture mechanics were utilized to identify and establish structural inspections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

SMART$_{LD}$ – Methodology Summary[1]



[1] Ref. Ocampo, J. and Millwater H., 'SMARTLD (SMall Aircraft Risk Technology –Linear Damage) Case Studies Applications', presented at 2011 Aircraft Airworthiness & Sustainment Conference.

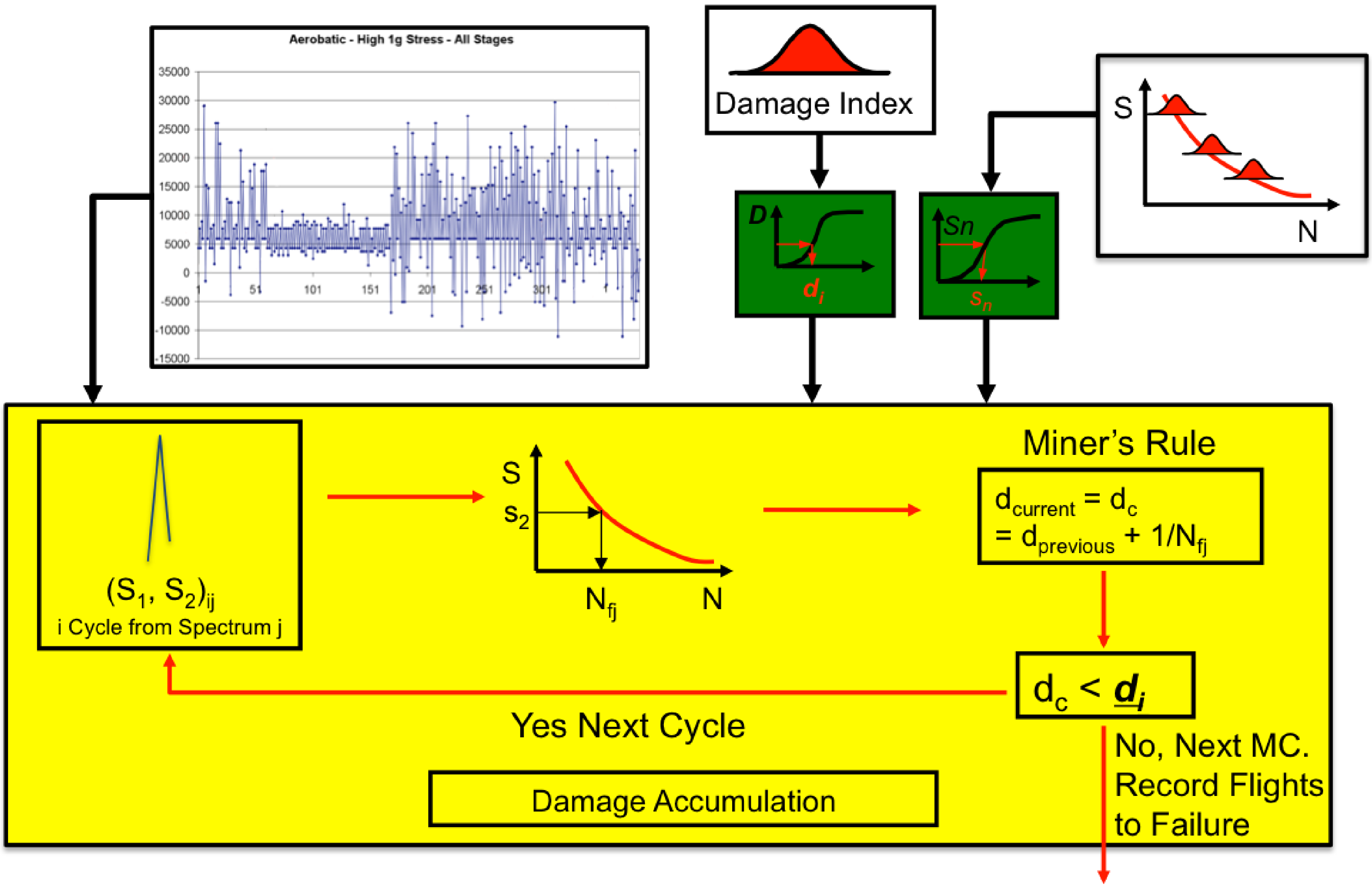
SMART$_{LD}$ – Spectrum Generation Methodology



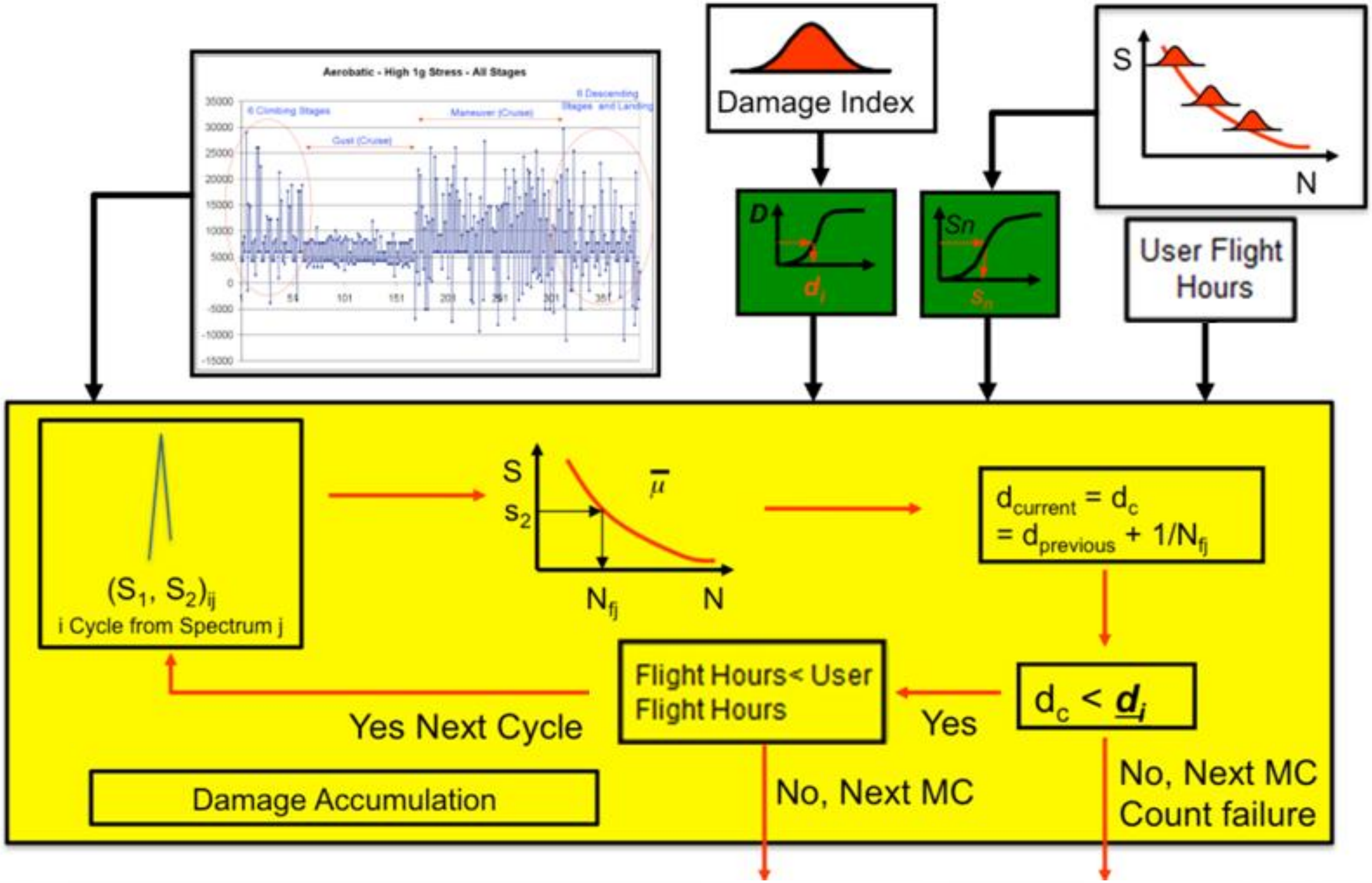
Flight Variation: Every flight within the MC sample has a different Stress Spectrum

No Flight Variation: Same Stress Spectrum for all the flights in each MC sample

SMART$_{LD}$ – Damage Methodology

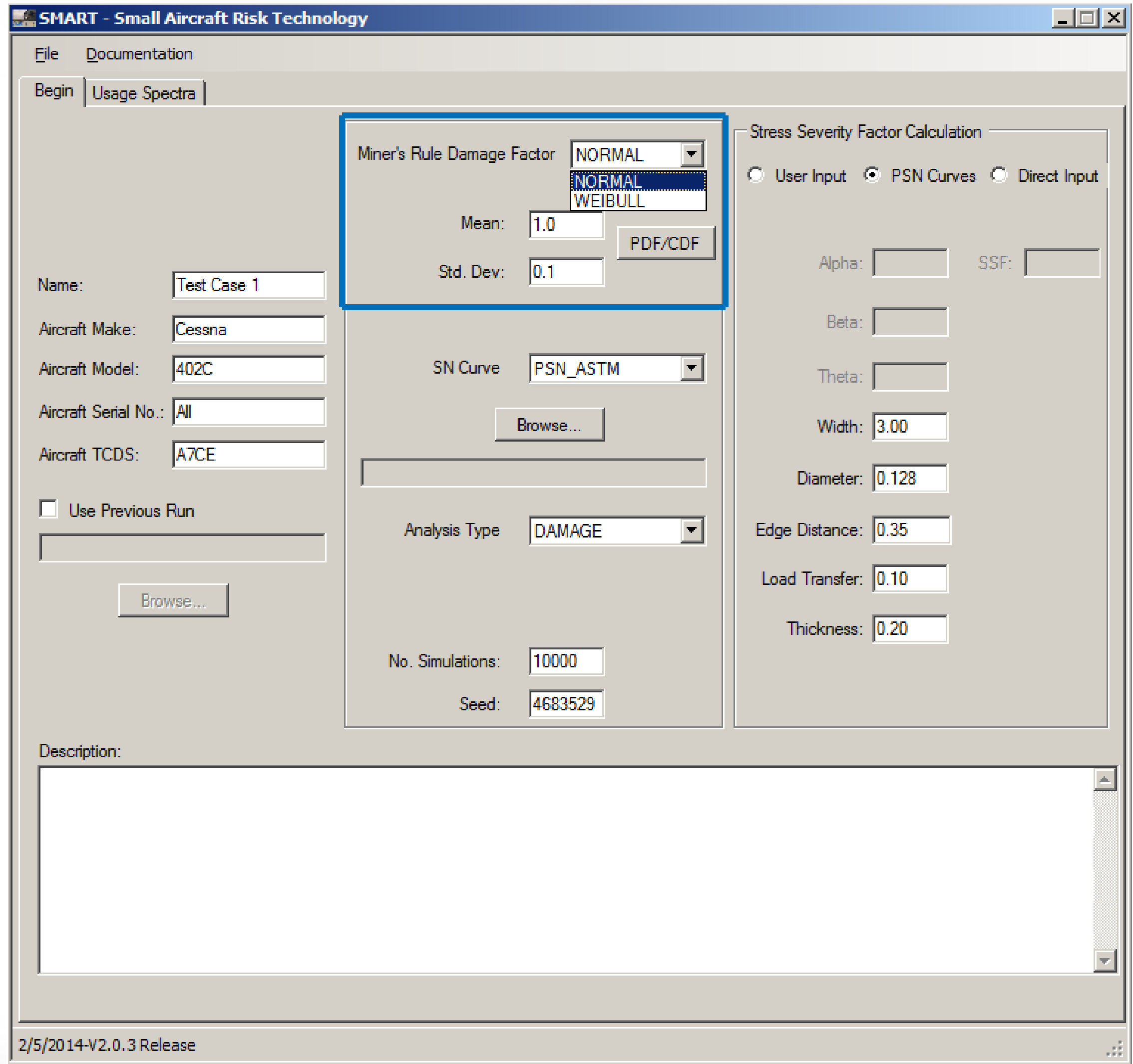


$SMART_{LD}$ – Hours Methodology



Using SMART$_{LD}$

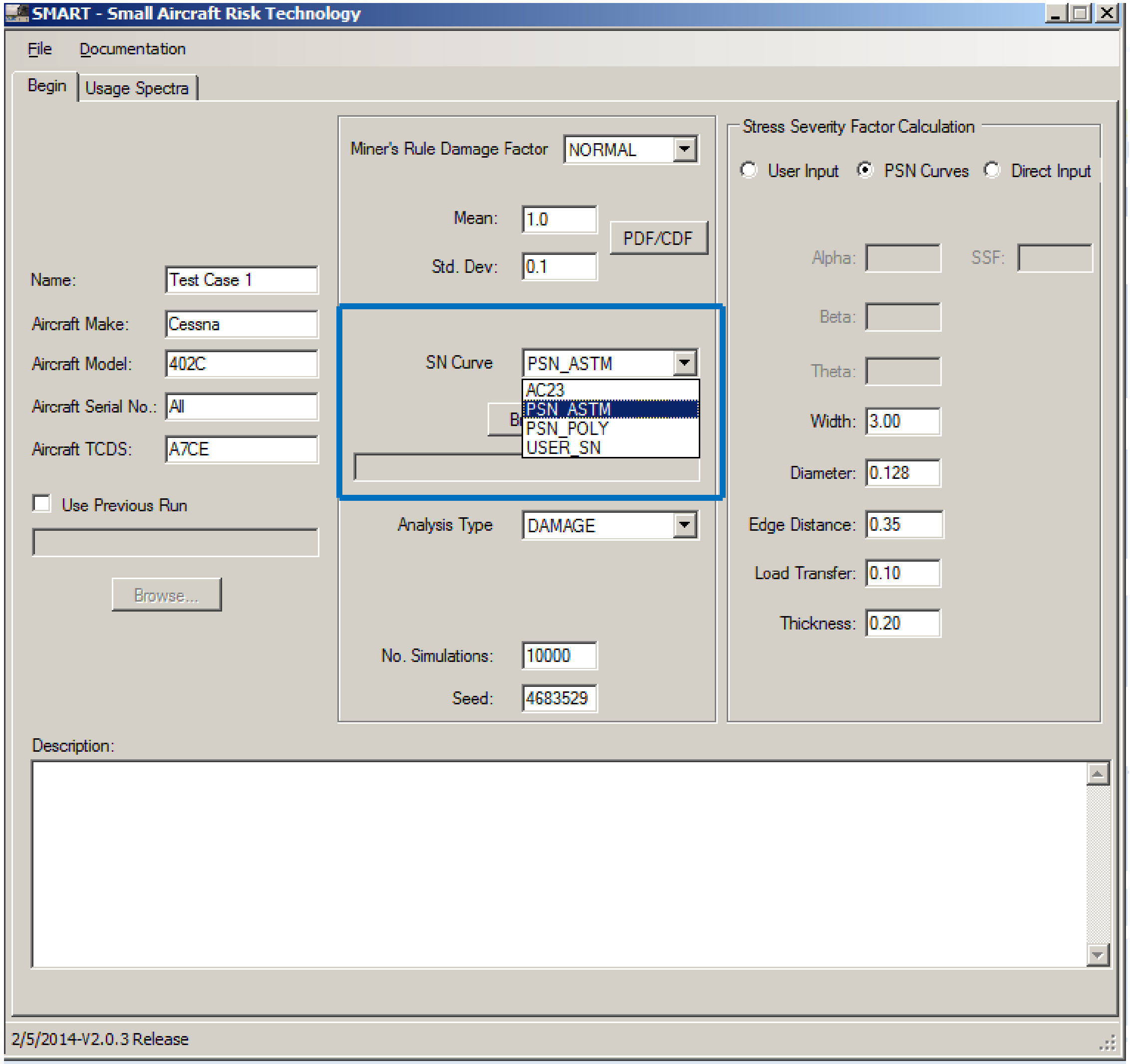
- Miner's rule damage summation
  - Select Normal or Weibull distribution
  - User defines mean and standard deviation (Normal dist.) or scale, shape, and location parameters (Weibull)



Using SMART$_{LD}$

- S-N Curves
  - 2 sets of internal probabilistic S-N data sets:
    - AC23-13A
    - NIAR WSU Open Hole & Joint
      - ASTM fit
      - Polynomial fit
  - Also allows for user defined S-N
    - Entry format is the MMPDS equivalent stress equation

$$SSF = \frac{\alpha \cdot \beta}{S}\left(K_{tb} \times \theta \times \frac{\Delta P}{d \cdot t} + K_{tg} \times \frac{P}{w \cdot t}\right)$$



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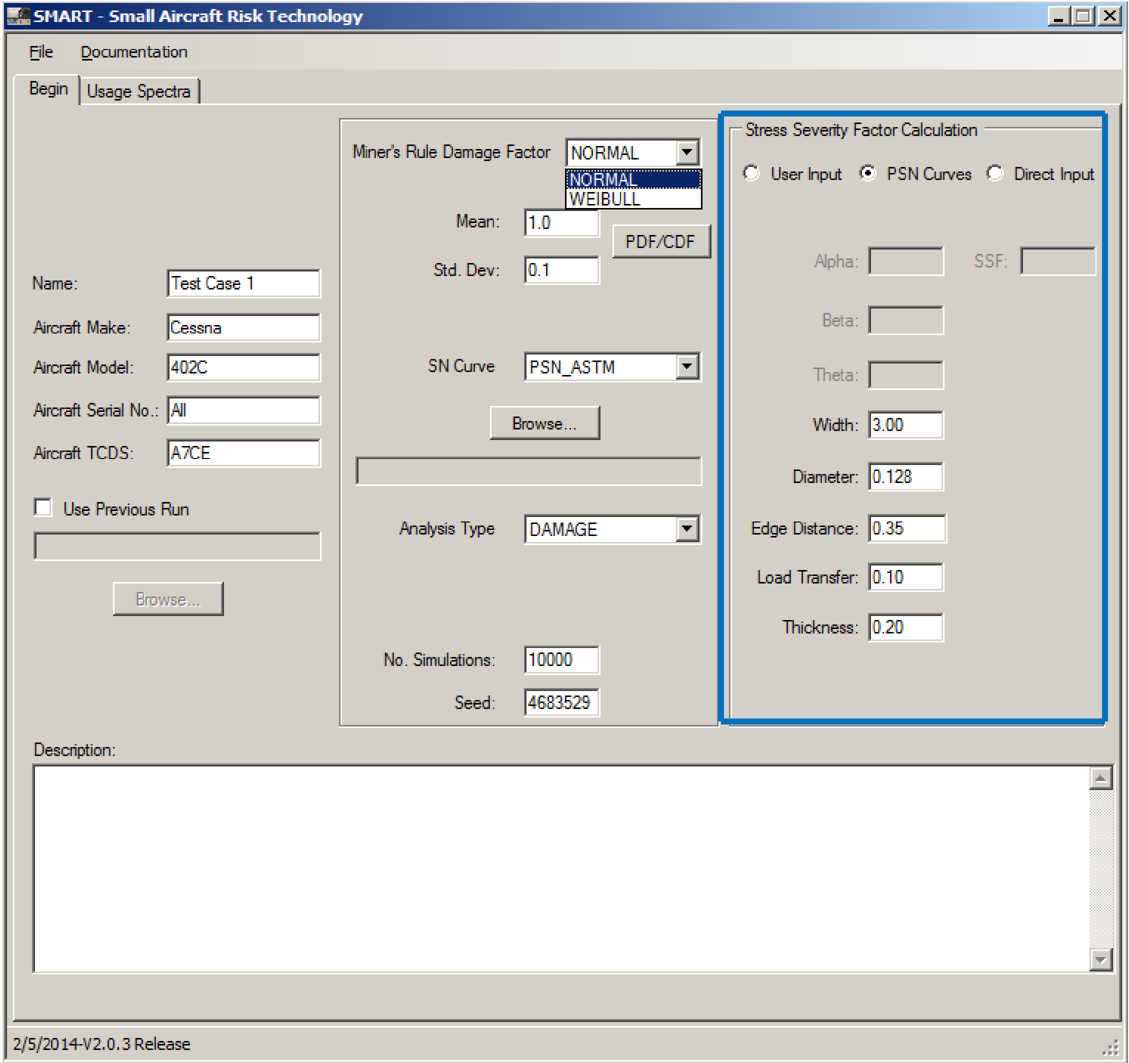
Using SMART_{LD}

- Stress Severity Factor – Three methods available
  - User Input
    - User defines K_t α, β, & θ
    - SMART calculates K_{tg} and K_{tBrg}
  - PSN Curves
    - Calculates β & θ from NIAR joint data
    - Uses NIAR open hole S-N curves
  - Direct Input
    - User calculates SSF



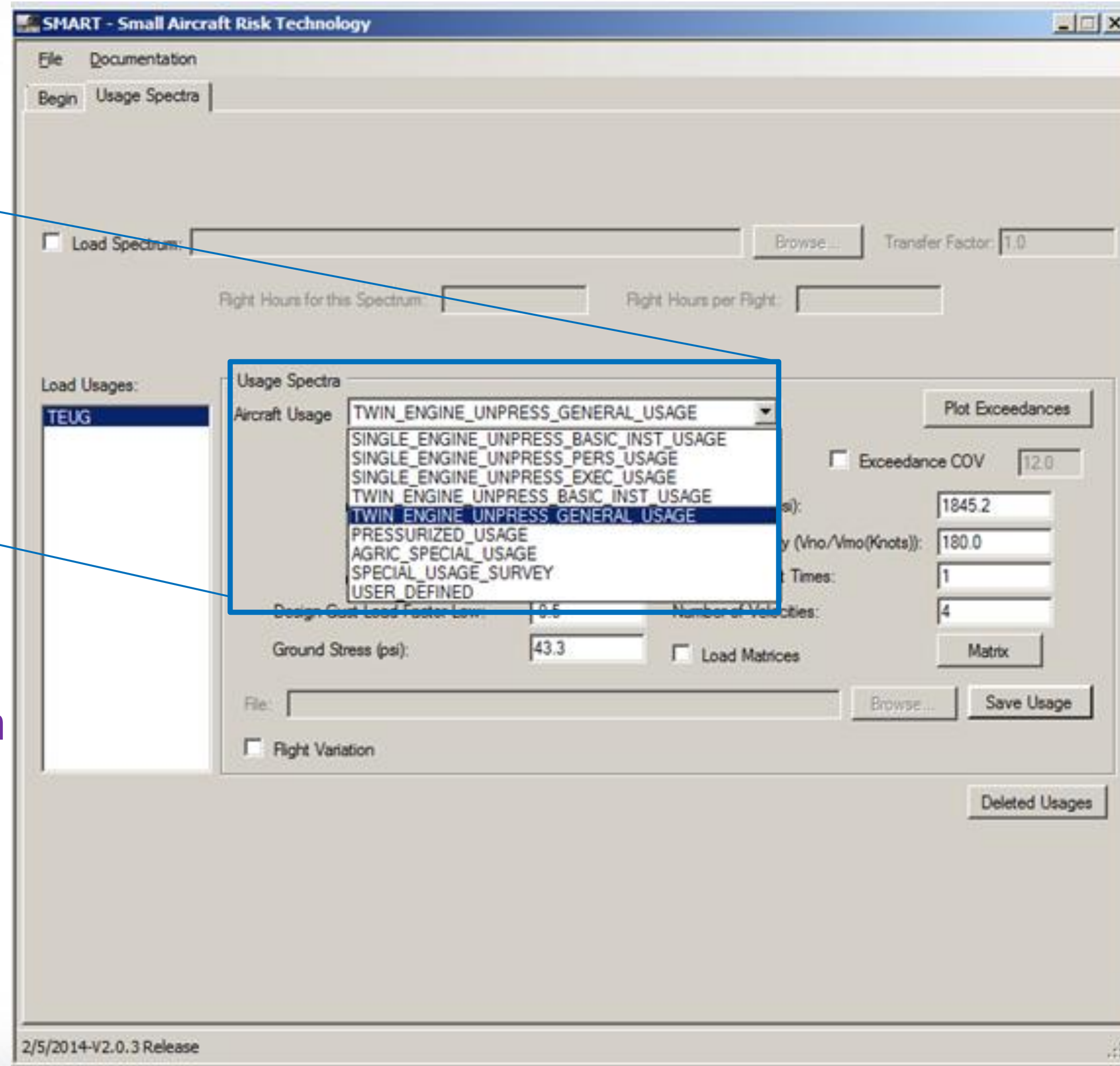
Using SMART$_{LD}$

- Spectrum
  - SMART has two methods for spectrum
    - AC23-13A derived
      - Uses unfactored AC23-13A exceedance curves
      - Spectrum created by entering basic weight, speed, and loads information into SMART
    - User-defined
      - Spectrum generated outside of SMART
      - AFGROW spectrum format

Using SMART$_{LD}$

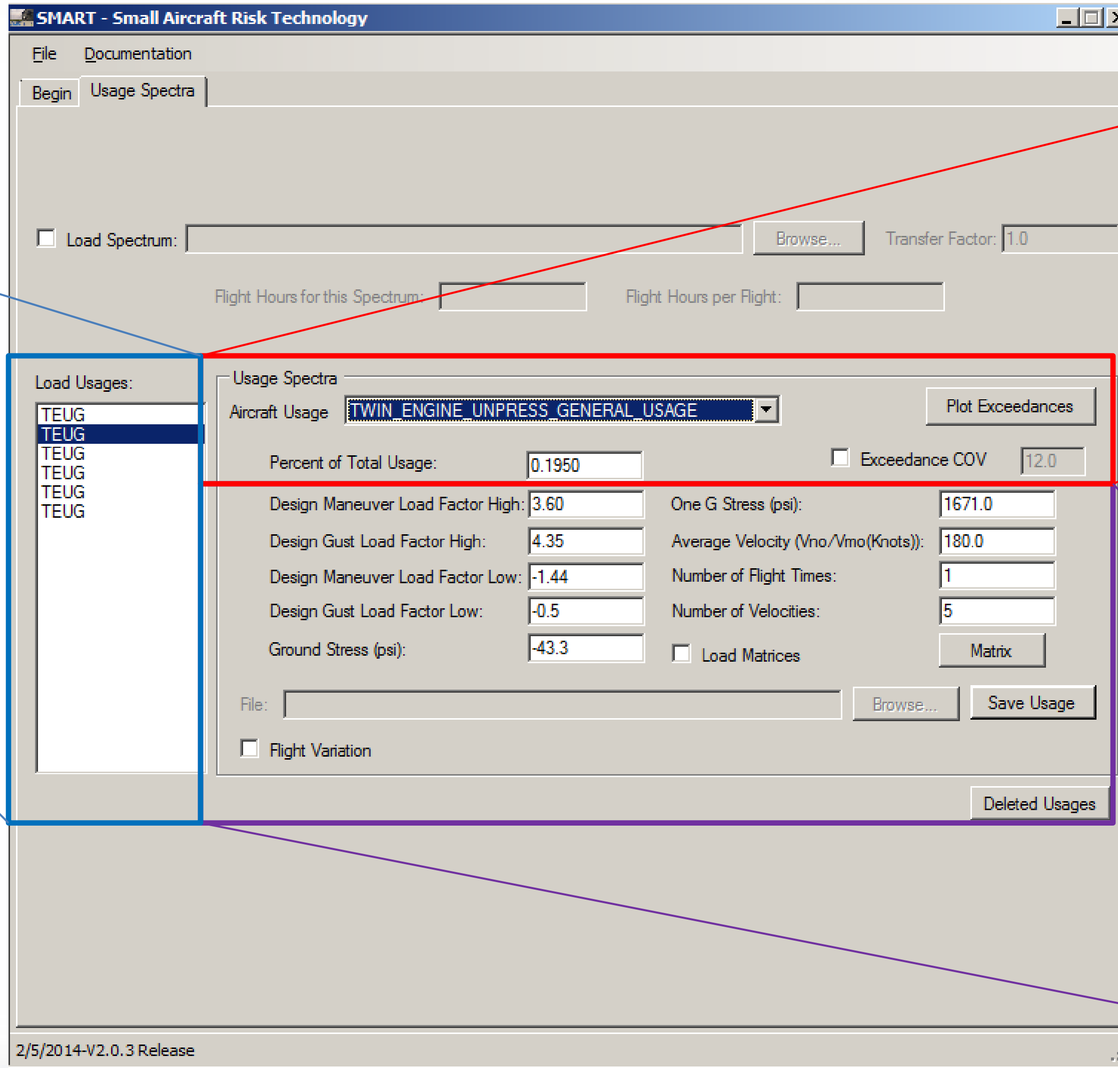
- AC23-13 Spectrum

AC23-13A exceedance curves available for different aircraft and usages



Twin engine unpressurized general usage is best match for 402C missions

Using SMART$_{LD}$



Multiple usages for spectrum

Select type & % of total usage for each usage

Weight, speed, & loads input

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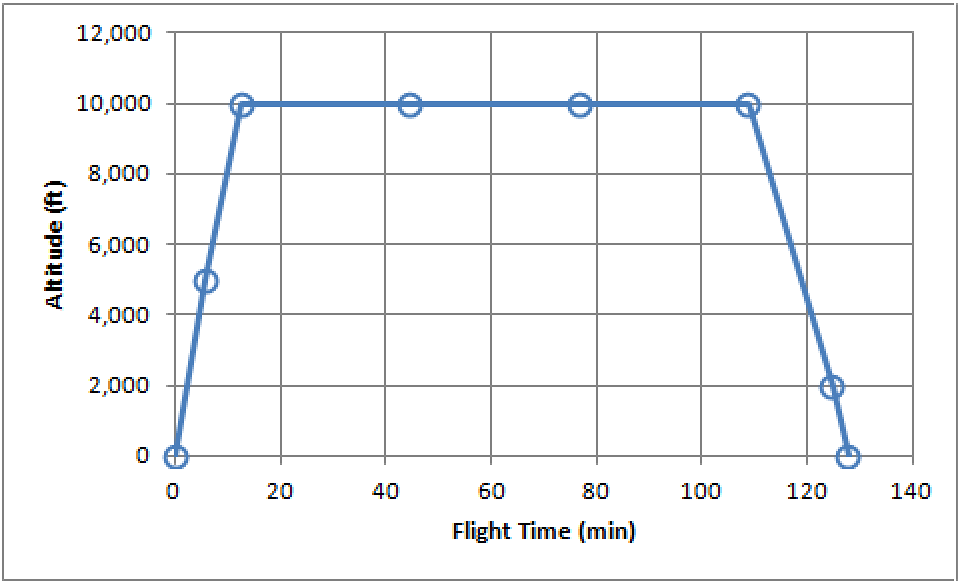
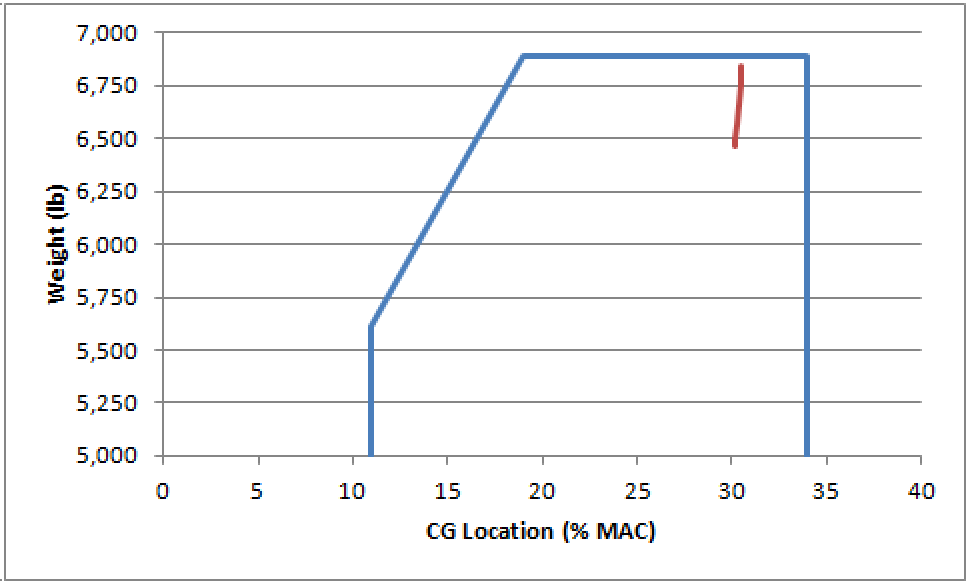
Using SMART$_{LD}$

- Model 402C Profiles
  - Cessna developed profiles for the 3 different usages: Short, Grand Canyon and Typical
    - Profiles based on operator surveys
    - Some usages have multiple profiles representing different types of flights





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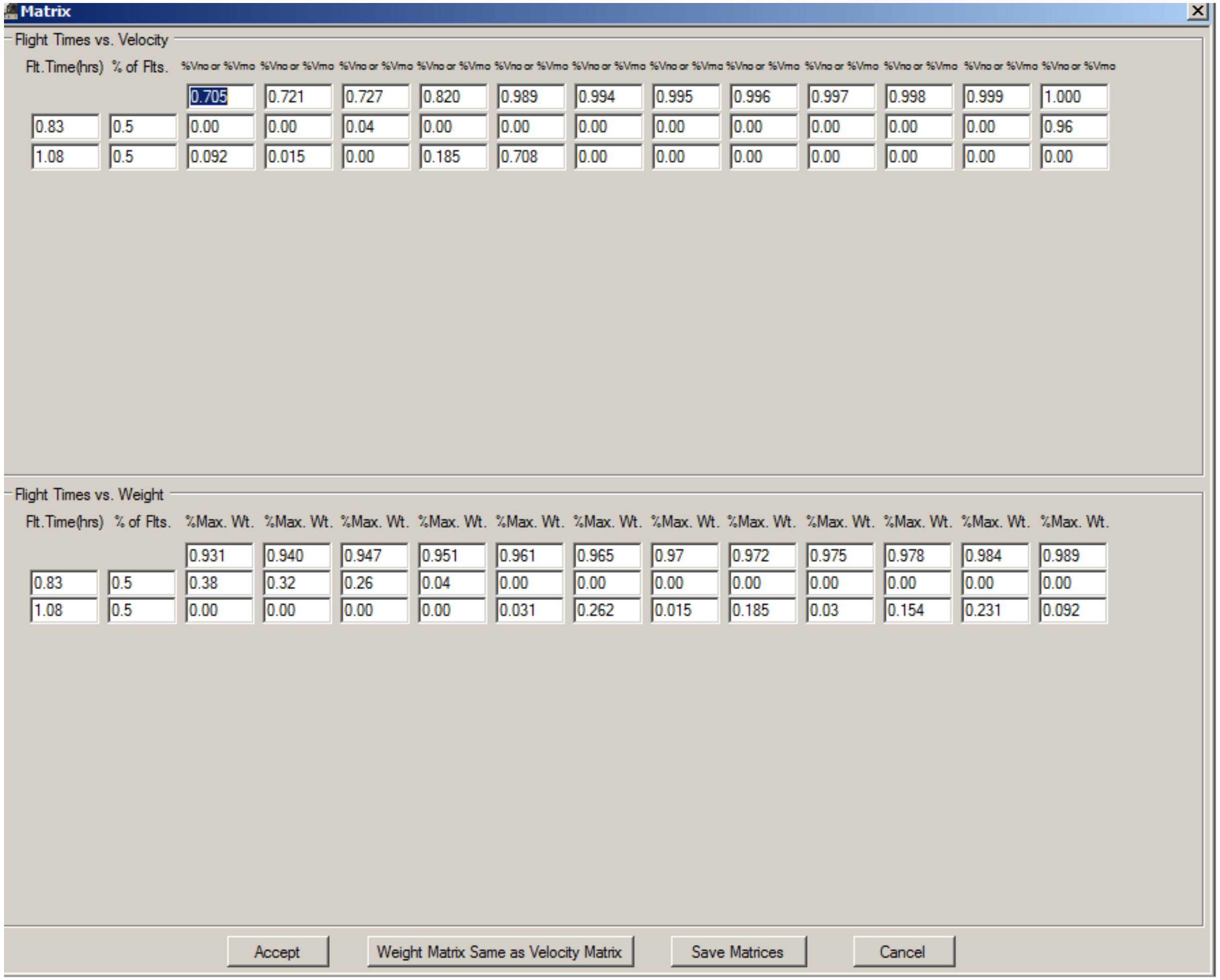
Using $SMART_{LD}$

- Replicated 402C mission profiles in SMART using the velocity and weight tables
- Some missions use multiple matrices
  - i.e., typical mission consists of 6 different weight and velocity matrices
- Velocity is a % of the max cruise speed
- Weight is a % of the max gross weight



Matrix

Flight Times vs. Velocity

Flt.Time(hrs)	% of Flts.	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo	%Vno or %Vmo
		0.705	0.721	0.727	0.820	0.989	0.994	0.995	0.996	0.997	0.998	0.999	1.000
0.83	0.5	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96
1.08	0.5	0.092	0.015	0.00	0.185	0.708	0.00	0.00	0.00	0.00	0.00	0.00	0.00

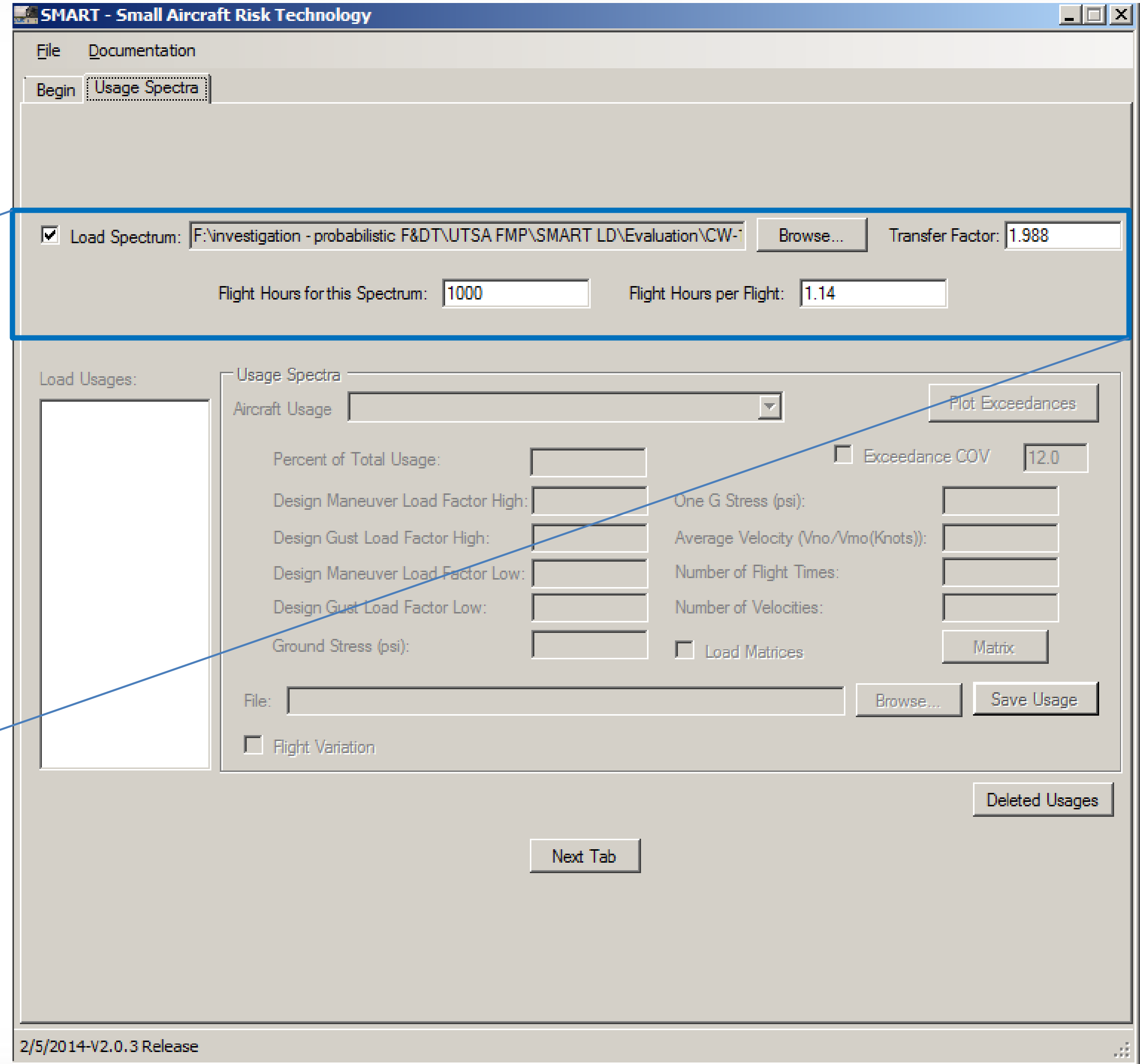
Flight Times vs. Weight

Flt.Time(hrs)	% of Flts.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.
		0.931	0.940	0.947	0.951	0.961	0.965	0.97	0.972	0.975	0.978	0.984	0.989
0.83	0.5	0.38	0.32	0.26	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.08	0.5	0.00	0.00	0.00	0.00	0.031	0.262	0.015	0.185	0.03	0.154	0.231	0.092

Accept | Weight Matrix Same as Velocity Matrix | Save Matrices | Cancel

Using SMART$_{LD}$

- User Defined Spectra

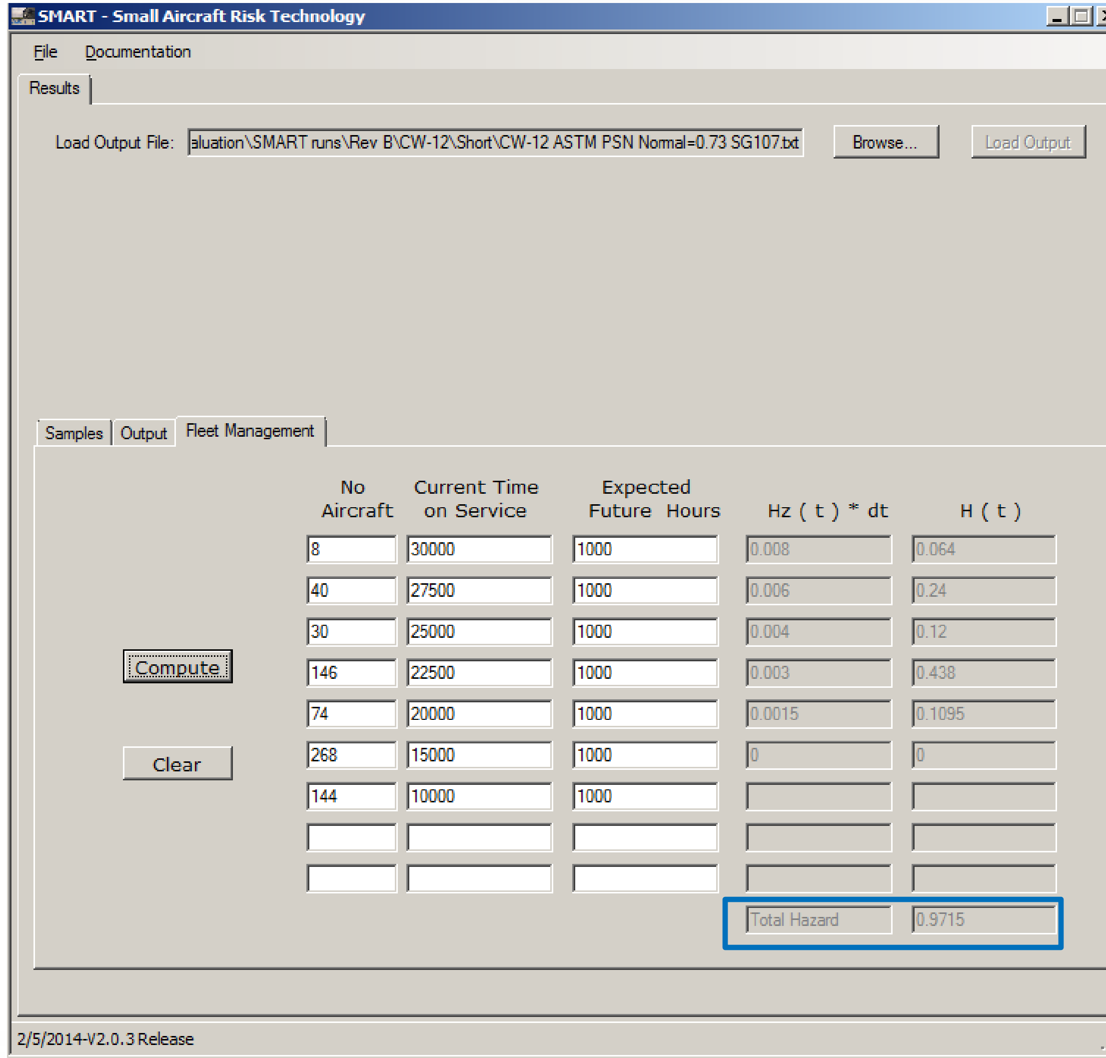


Load user defined spectrum here.
Also input:

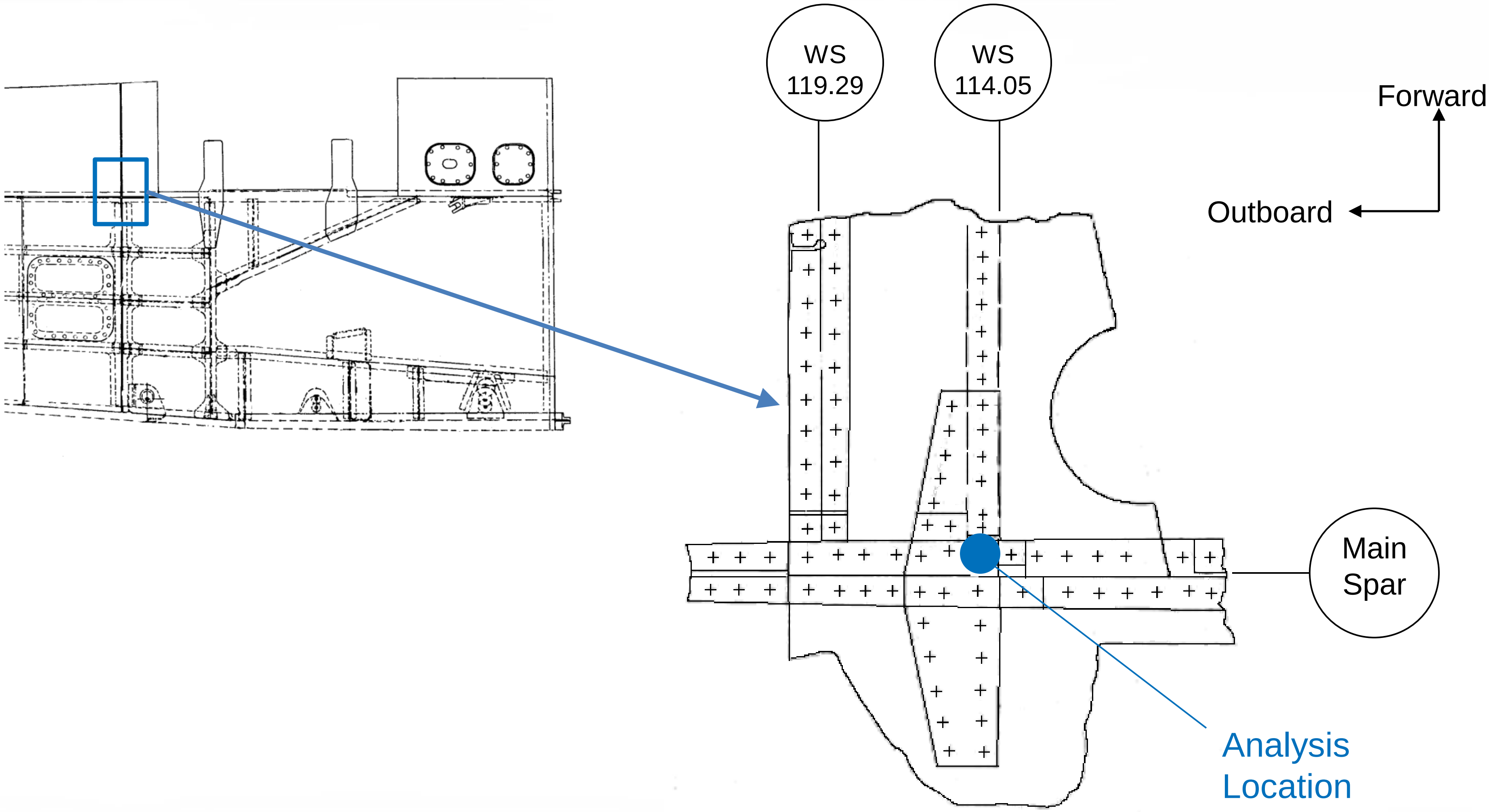
1. Flight hours for the spectrum
2. Flight hours per flight
3. Transfer/multiplication factors

Using SMART$_{LD}$

- Hazard Analysis
  - Use to determine:
    - Current risk to the fleet
    - Risk for different inspection or modification programs
  - Calculation takes into account:
    - Current distribution of time in service
    - The expected time until the next inspection



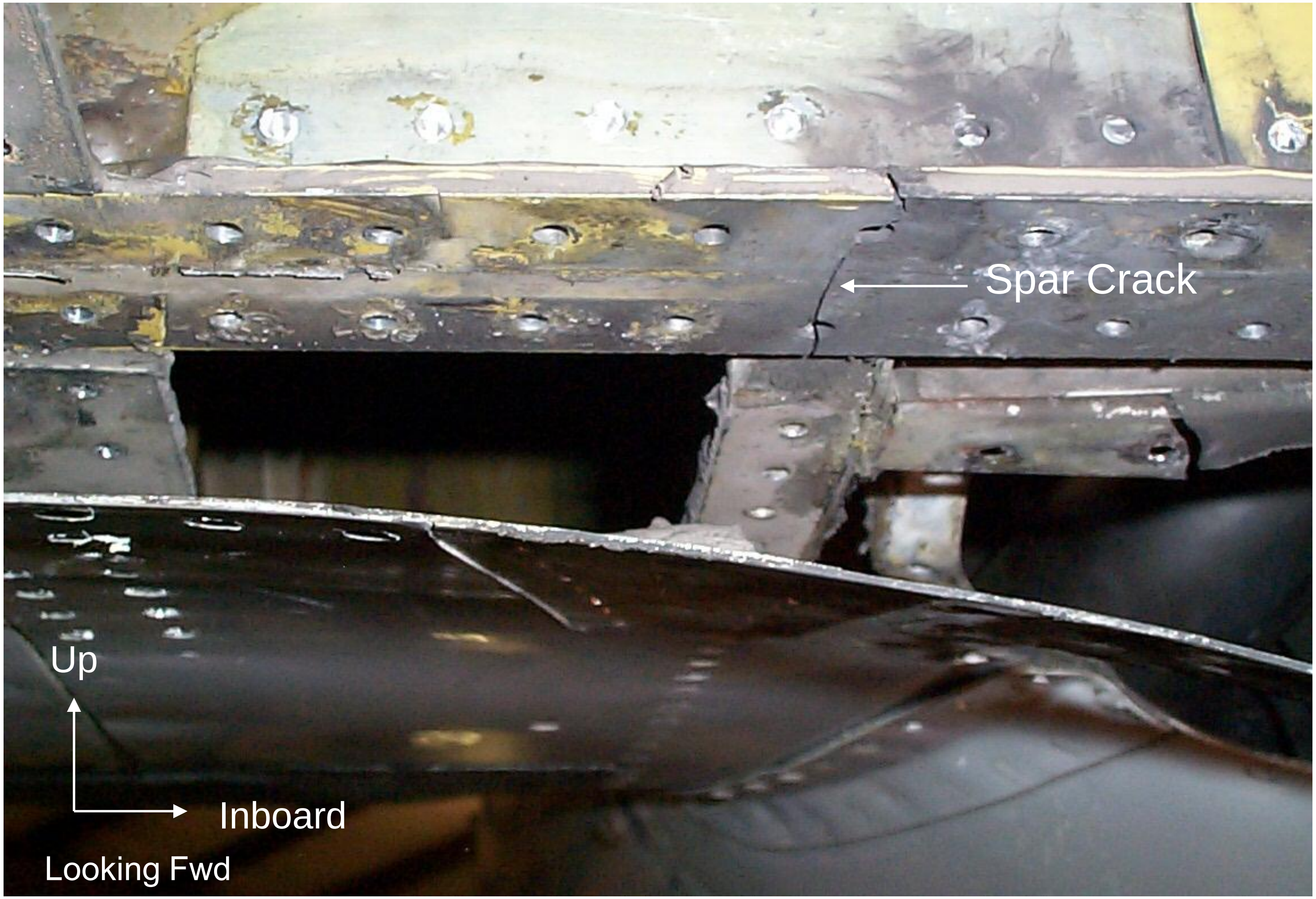
Model 402C Wing Analysis – WS 114



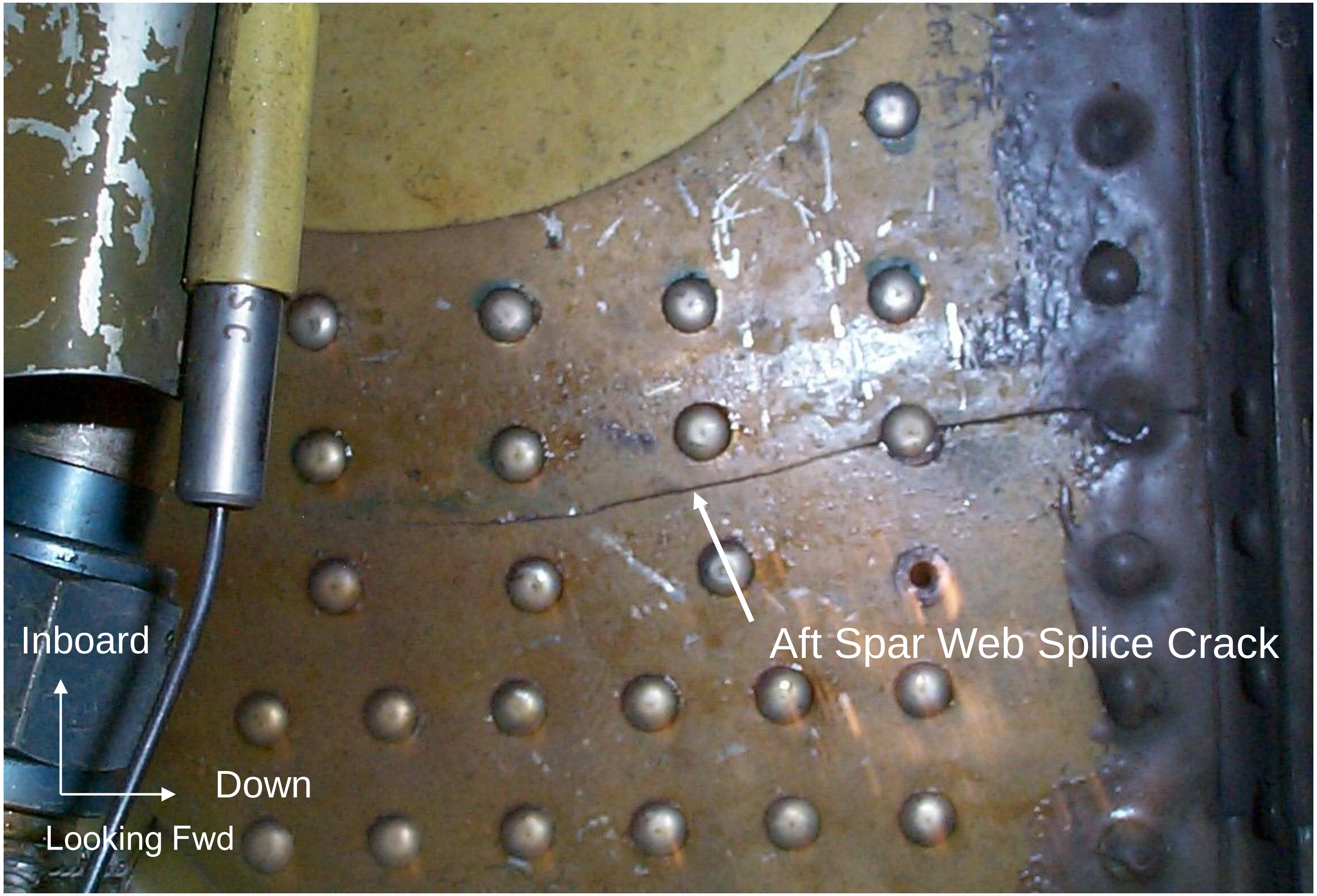
Model 402C Wing Analysis – WS 114

- Field History
  - Cracks found in the main spar and skin for 2 aircraft
    - One aircraft had cracks on both the right and left sides
    - Both aircraft had >20,000 flight hours when cracks were discovered
  - Both airplanes operating in passenger service
  - Current mission representative of short spectrum
  - High time aircraft, but not fleet leaders

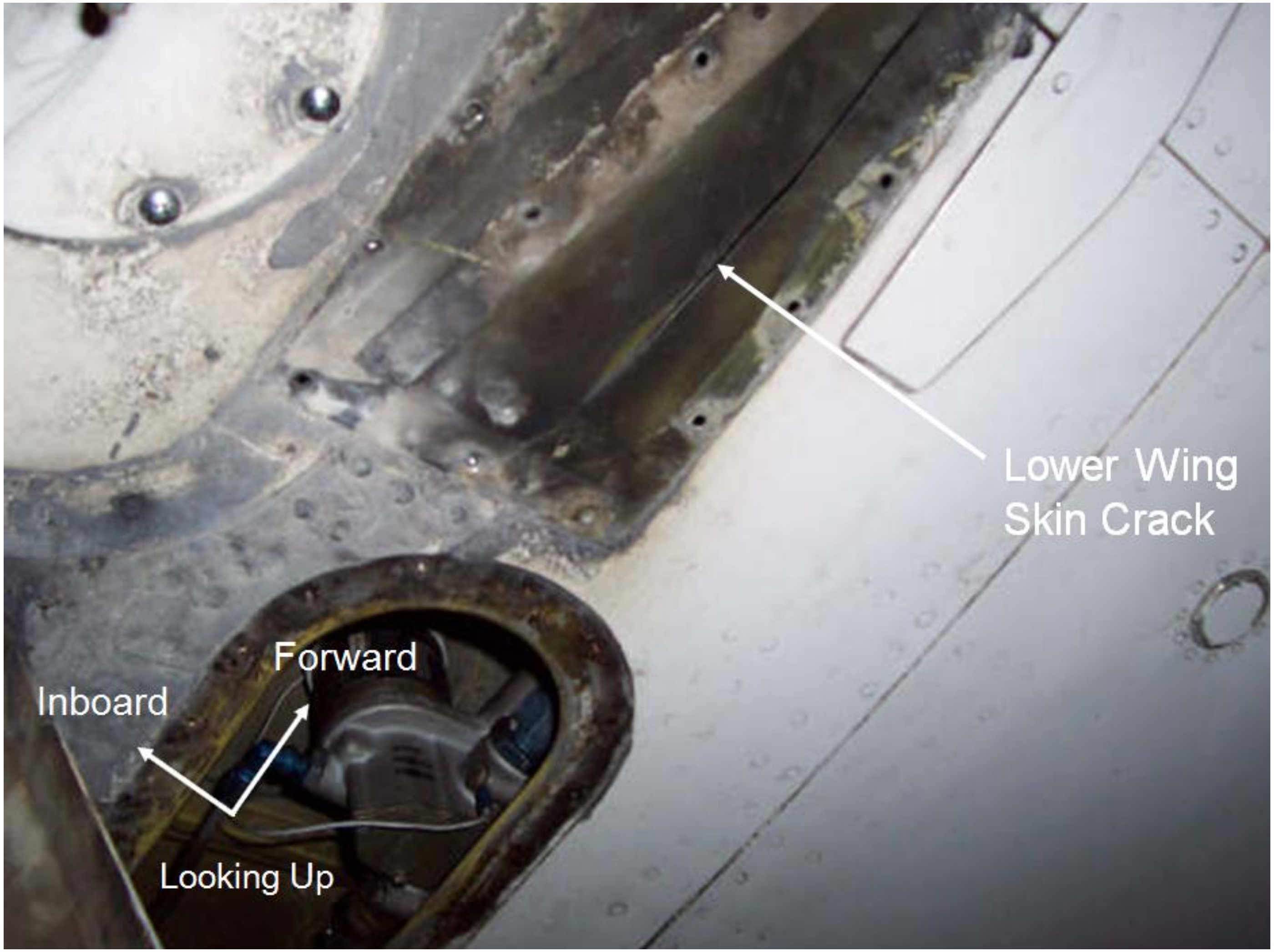
Model 402C Wing Analysis – WS 114



Model 402C Wing Analysis – WS 114

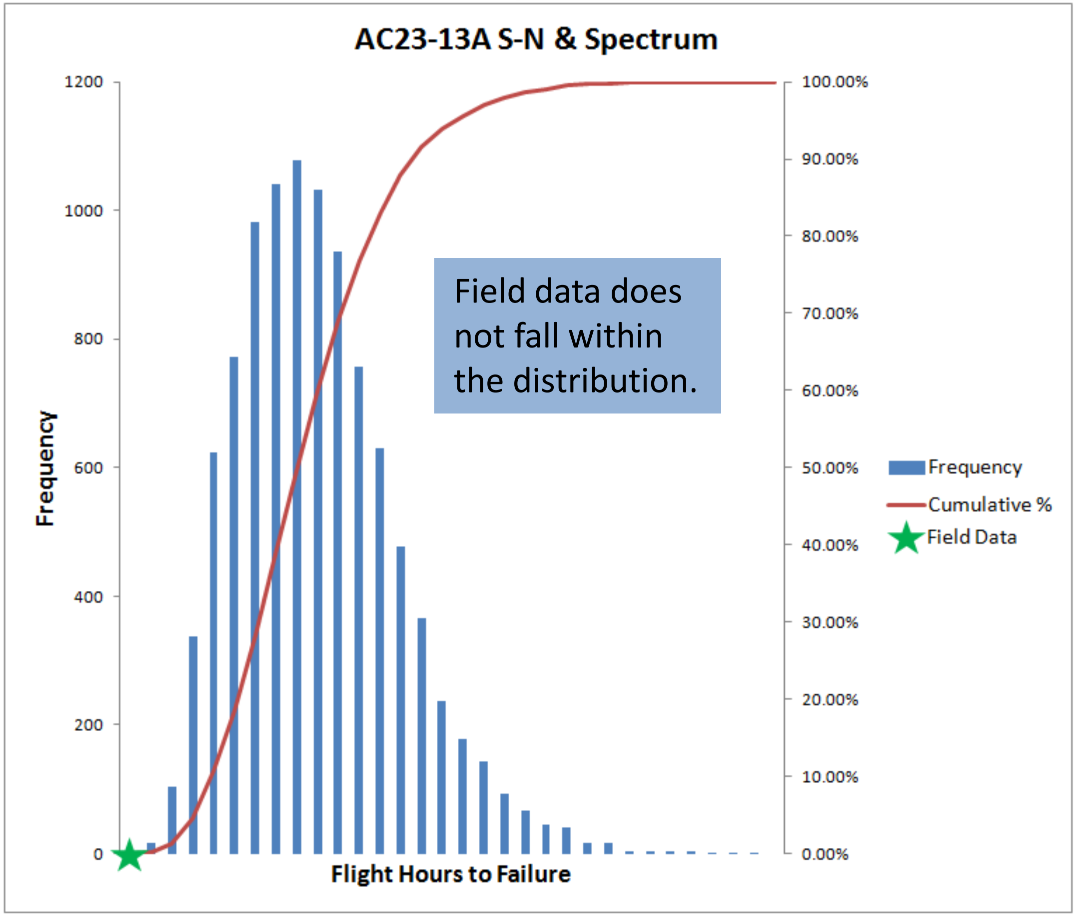


Model 402C Wing Analysis – WS 114



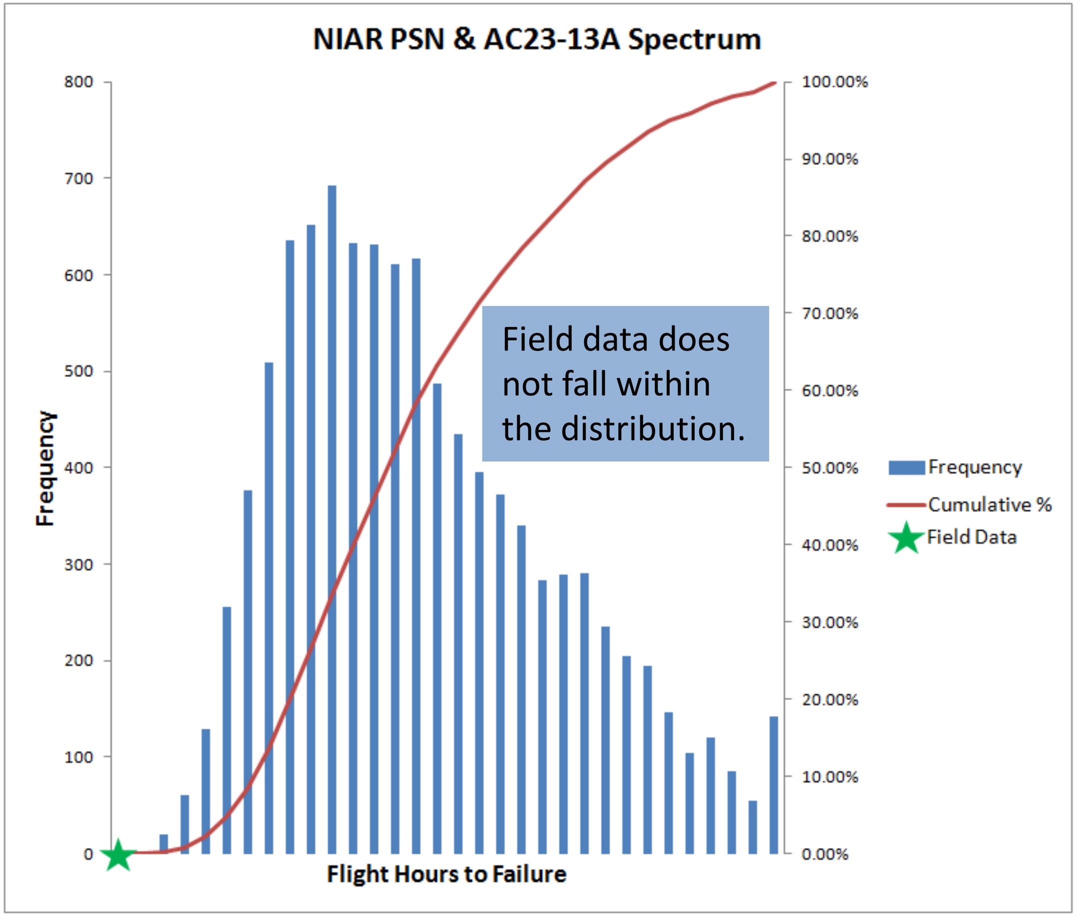
Model 402C Wing Analysis – WS 114

- Analysis Assumptions:
  - User does not know many details about airframe & operations
  - AC23-13A S-N
    - Doesn't need geometry & load transfer as an input
  - AC23-13A Spectrum (Short mission weights & velocity)
  - 10,000 simulations
- Result: field findings not represented by simulations
- Takeaway: need to refine analysis
- Next step: refine S-N data



Model 402C Wing Analysis – WS 114

- Refine S-N Data
  - Assumptions:
    - User has some geometry and loads data
    - NIAR PSN
      - User has geometry & load transfer data
    - AC23-13A Spectrum (Short mission)
    - 10,000 simulations
  - Result: field findings not represented by simulations
  - Takeaway: not a widespread field issue or need to refine analysis
  - Next step: refine spectrum



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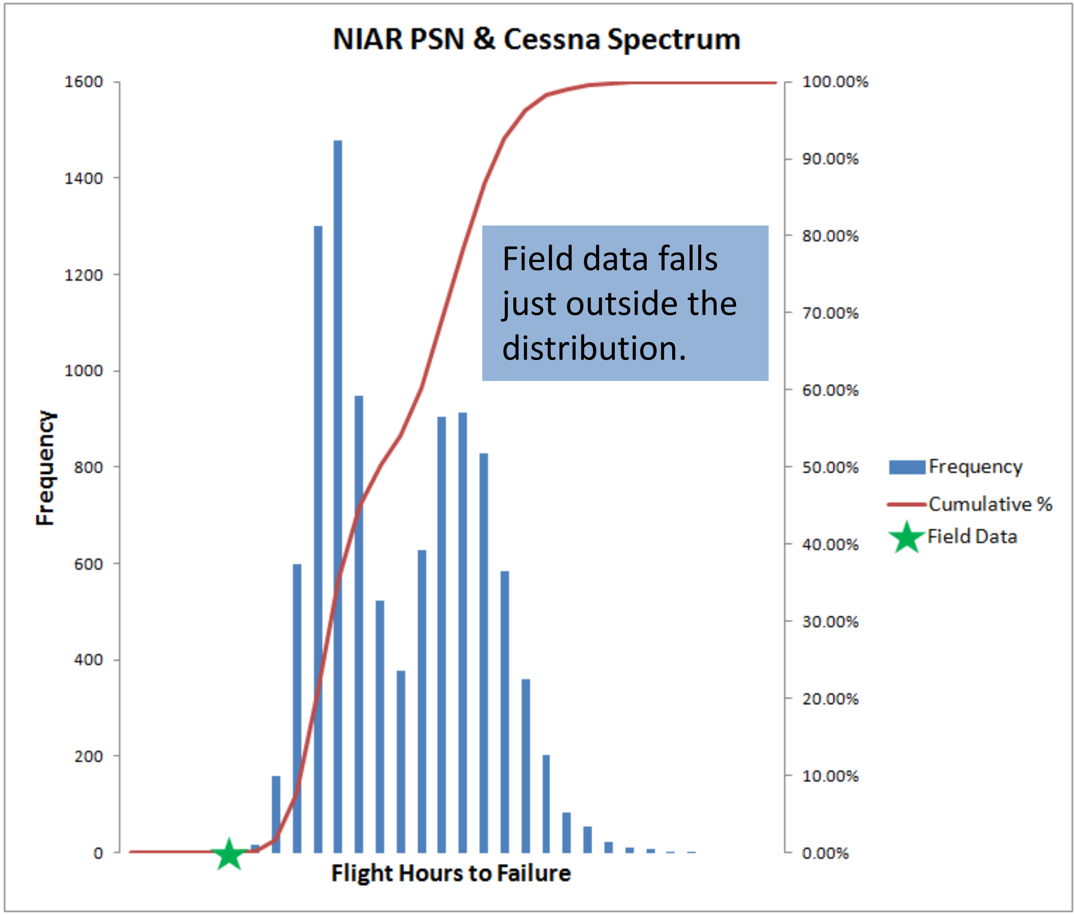
Model 402C Wing Analysis – WS 114

- Refine Spectrum
  - Assumptions:
    - User has spectrum data
    - NIAR PSN
      - User has geometry & load transfer info
    - User Spectrum (Short mission)
    - 10,000 simulations
  - Result: field findings fall just outside the distribution
  - Takeaway: May not expect to find additional field damage
  - Next step: refine Miner's Rule distribution



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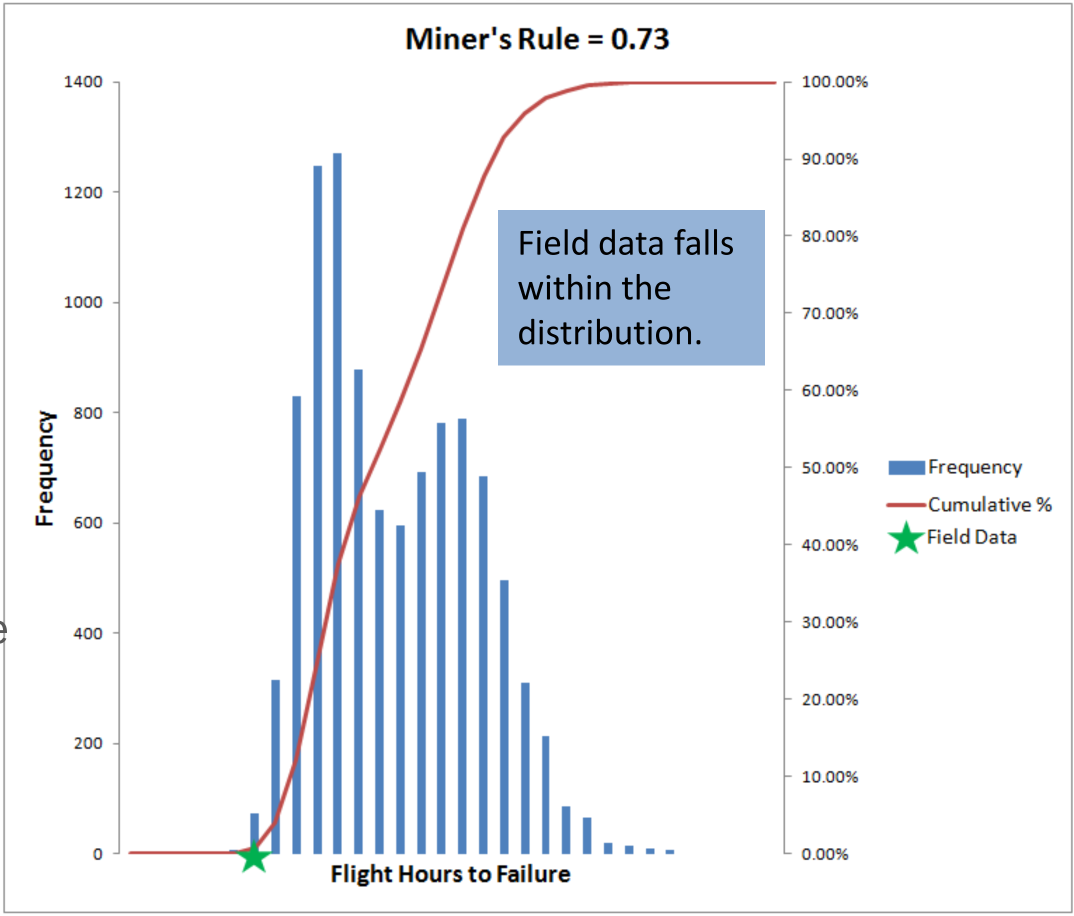
Model 402C Wing Analysis – WS 114

- Refine Miner's Rule Distribution
  - Assumptions:
    - User has spectrum data
    - NIAR PSN
      - User has geometry & load transfer info
    - User Spectrum (Short mission)
    - 10,000 simulations
  - Result: field findings fall within the distribution, but are extreme outliers
  - Takeaway: May find additional field damage in high time aircraft



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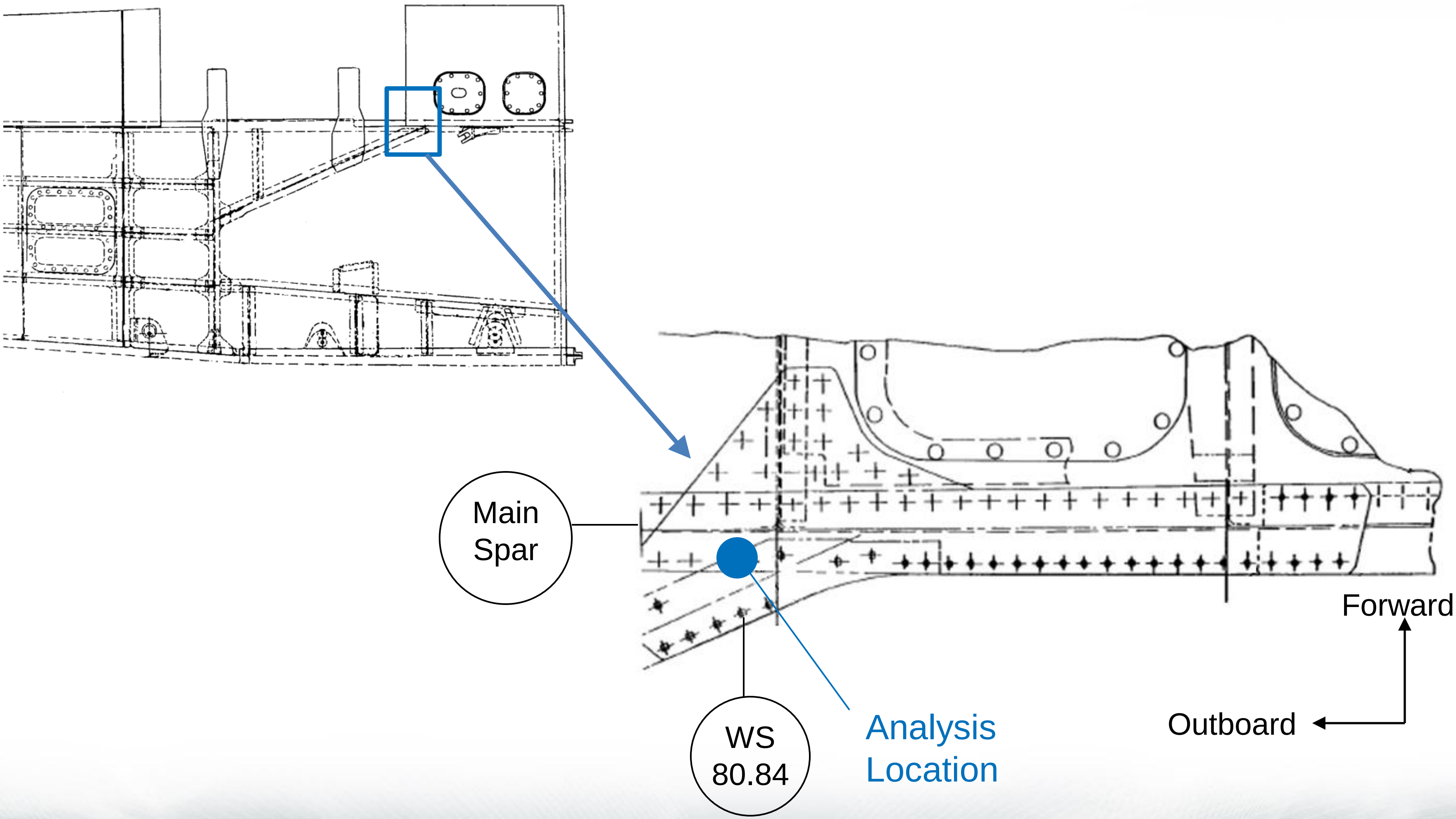
Model 402C Wing Analysis – WS 114

# of Aircraft / Locations	Current time on service	Expected future hours	Hz(t)*dt	H(t)
8	30,000 FH	1,000 FH	0.008	0.064
40	27,500 FH	1,000 FH	0.006	0.240
30	25,000 FH	1,000 FH	0.004	0.120
146	22,500 FH	1,000 FH	0.003	0.438
74	20,000 FH	1,000 FH	0.0015	0.1095
268	15,000 FH	1,000 FH	-	-
144	≤10,000 FH	1,000 FH	-	-
			Total Hazard	0.9715

381 a/c in service (x2 locations)
10,000 SMART simulations

For the 402C fleet, the analysis predicts in the next 1,000 hours 1 wing to be affected. Cessna has seen 3 occurrences in service.

Model 402C Wing Analysis – WS 81

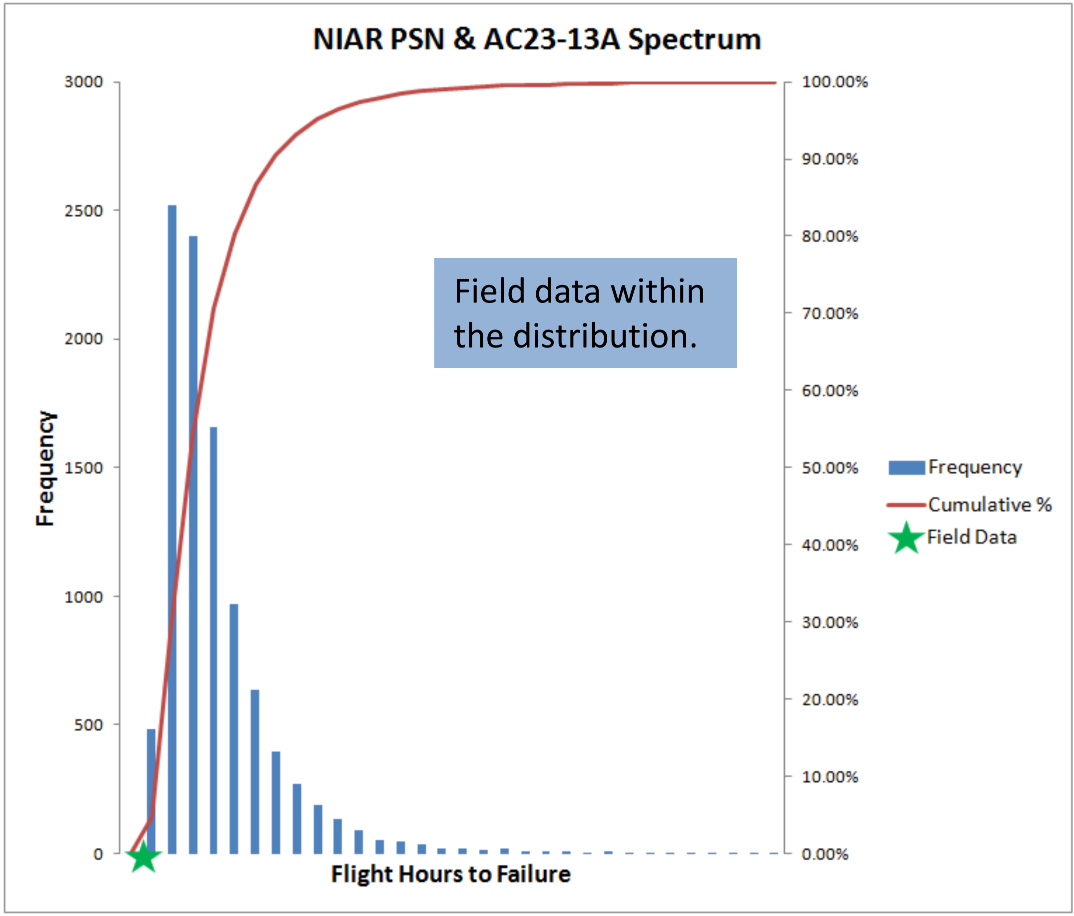


Model 402C Wing Analysis – WS 81

- Field History
  - 1 instance of field damage near analysis location
  - Crack located at WS 86.00, five inches from analysis location CW-3
  - Wing separated in flight due to failure of the main spar
  - Airplane was used to carry cargo at the time of wing failure
  - Maintenance records indicated numerous repairs to the right wing, including:
    - Skin cracks
    - Working rivets
    - Wing aux spar straps
    - Right main landing gear damage
  - Initiated at an area of mechanical damage and rough machining marks

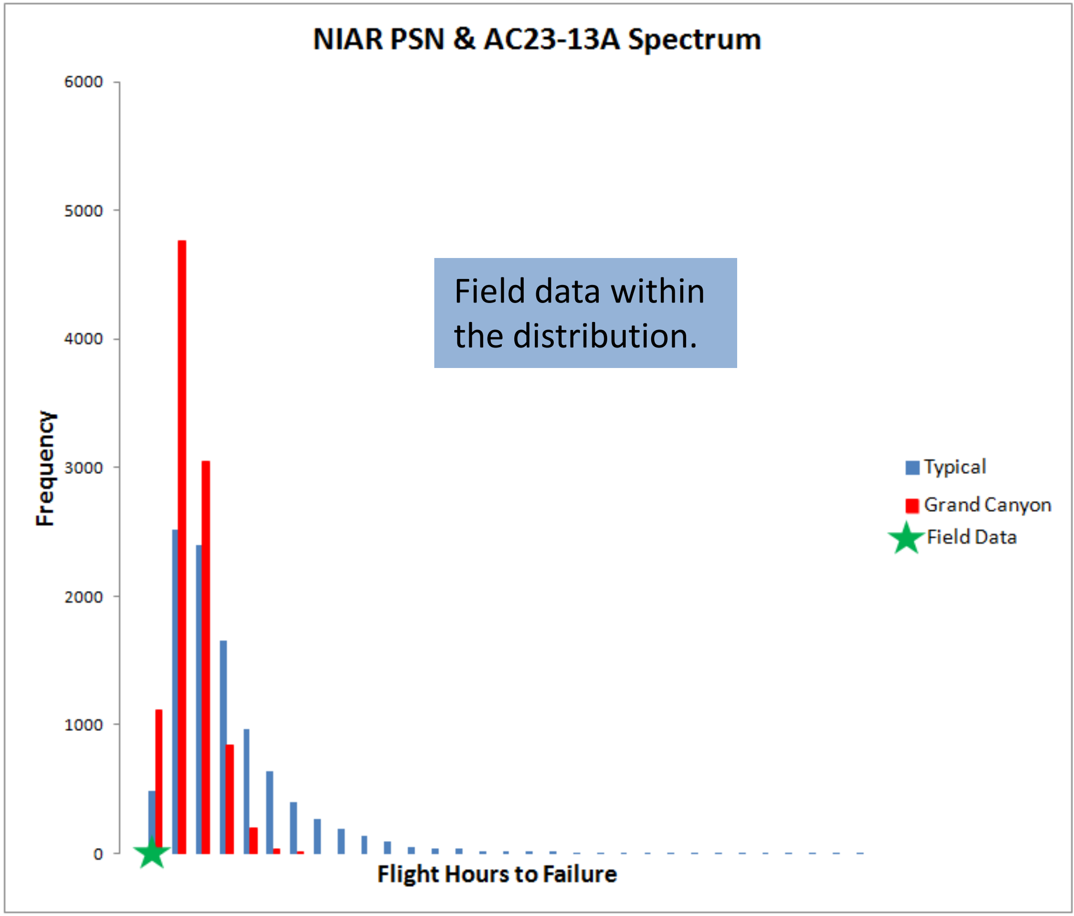
Model 402C Wing Analysis – WS 81

- Analysis Assumptions:
  - NIAR PSN
  - AC23-13A Spectrum (Typical mission)
  - 10,000 simulations
- Result: field finding within the distribution, but an extreme outlier
- Hazard function = 0.224
- Field findings: pre-existing flaw led to premature crack initiation
- Takeaway: Rogue flaw. Define inspection program using $SMART_{DT}$



Model 402C Wing Analysis – WS 81

- Usage Comparison
  - Aircraft had 10 owners in its lifetime & Cessna does not know what type of missions were flown
    - 1 owner in Las Vegas operated a/c for 5 years
  - What if the aircraft had flown the Grand Canyon mission instead of the typical mission?
  - Hazard function:
    - Typical = 0.224
    - Grand Canyon = 0.355



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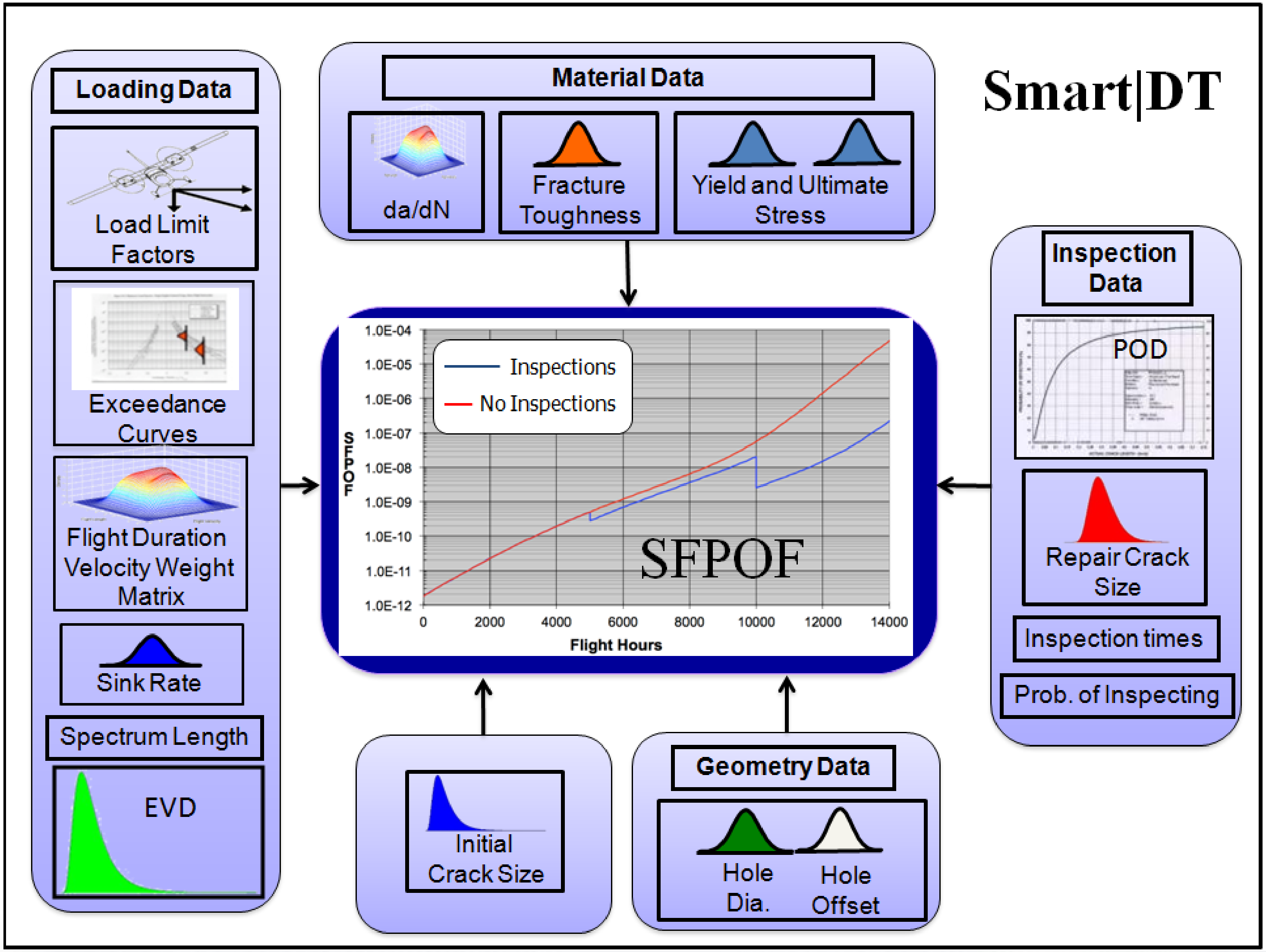
Discussion

- SMART|LD is a powerful tool that allows user to tune analysis based on available information
  - Requires good engineering judgment to pick “best” or “right” solution
- Why so much difference between different analysis methods?
  - NIAR PSN joint data accounts for effects of:
    - Fastener clamp up and friction
    - Fretting failure mechanism for low load transfer
    - Secondary bending
  - Different calculation of KT β and θ between NIAR PSN and traditional SSF
  - Different S-N data
  - Different spectrum derivations
    - Cycle counted vs. uncycle counted plus GAG
    - Calculation of gust, maneuver, landing, & taxi loads

Recommendations

- Test more S-N joint configurations
  - NIAR joint S-N data is good, but there were limited samples tested
    - OK for experimental efforts, but not enough data to generate allowables
  - Need more repeats to fully develop probabilistic S-N
  - Need data for 100% load transfer and more data for low load transfer scenarios
    - Representative of most wing structure
- Provide additional guidance for probabilistic Miner's Rule
  - Potentially powerful tool, but not enough data for users to fully utilize
  - Base on test or field data

What's Next


Smart|DT
Loading Data
Load Limit Factors
Exceedance Curves
Flight Duration Velocity Weight Matrix
Sink Rate
Spectrum Length
EVD
Material Data
da/dN
Fracture Toughness
Yield and Ultimate Stress
Inspections
No Inspections
SFPOF
Flight Hours
Inspection Data
POD
Repair Crack Size
Inspection times
Prob. of Inspecting
Initial Crack Size
Geometry Data
Hole Dia.
Hole Offset

Questions?

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