SMART|LD (SMALL AIRCRAFT RISK TECHNOLOGY - LINEAR DAMAGE) TECHNOLOGY – A MANUFACTURER'S PERSPECTIVE

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Agenda

- SMART|LD probabilistic fatigue management software
- How to use SMART
- Analysis of Model 402C wing structure
  - CW-12, wing front spar at WS 114
  - CW-3, wing front spar at WS 80
- Discussion
- Recommendations

SMall Aircraft Risk Technology (SMART)

- Fatigue management program software for general aviation.
- Created by the University of Texas-San Antonio under a FAA contract.
- Provide tools for data driven risk assessment and fleet management.
- Develop damage tolerance based inspections, or replacement/modification time limits for structural elements.
- The SMART software consists of two modules:
  - Linear Damage (fatigue)
  - Damage Tolerance (crack growth)

SMART|LD

- Cessna awarded a contract from the FAA/University of Texas-San Antonio to review SMART fatigue management program software.
- Our job is to validate the software using real-world applications.
- Cessna currently reviewing the linear damage part of the program.

SMART LD

SMall Aircraft Risk Technology – Linear Damage Analysis

History

- Cessna was awarded an FAA contract in 1995 to apply damage tolerance methods to small commuter airplanes.
  - Damage tolerance methods were applied to develop a Supplemental Inspection Document (SID).
    - 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 (SID) for the Model 402C is based on 3 different usages.
    - Typical Usage – 6 flight profiles with 68 min. flight avg.
    - Grand Canyon Usage – 2 flight profiles, both one hour flights
    - Short Flight Usage – 25 minute flight

Cessna Model 402C "Businessliner"/"Utililiner"

- Twin engine (piston), non-pressurized, (up to) 9 passengers
- 381 402C's manufactured from 1979 to 1985
- Service ceiling = 26,900 ft.
- Max speed = 230 knots
- Range = 1,243 NM

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USING SMART|LD

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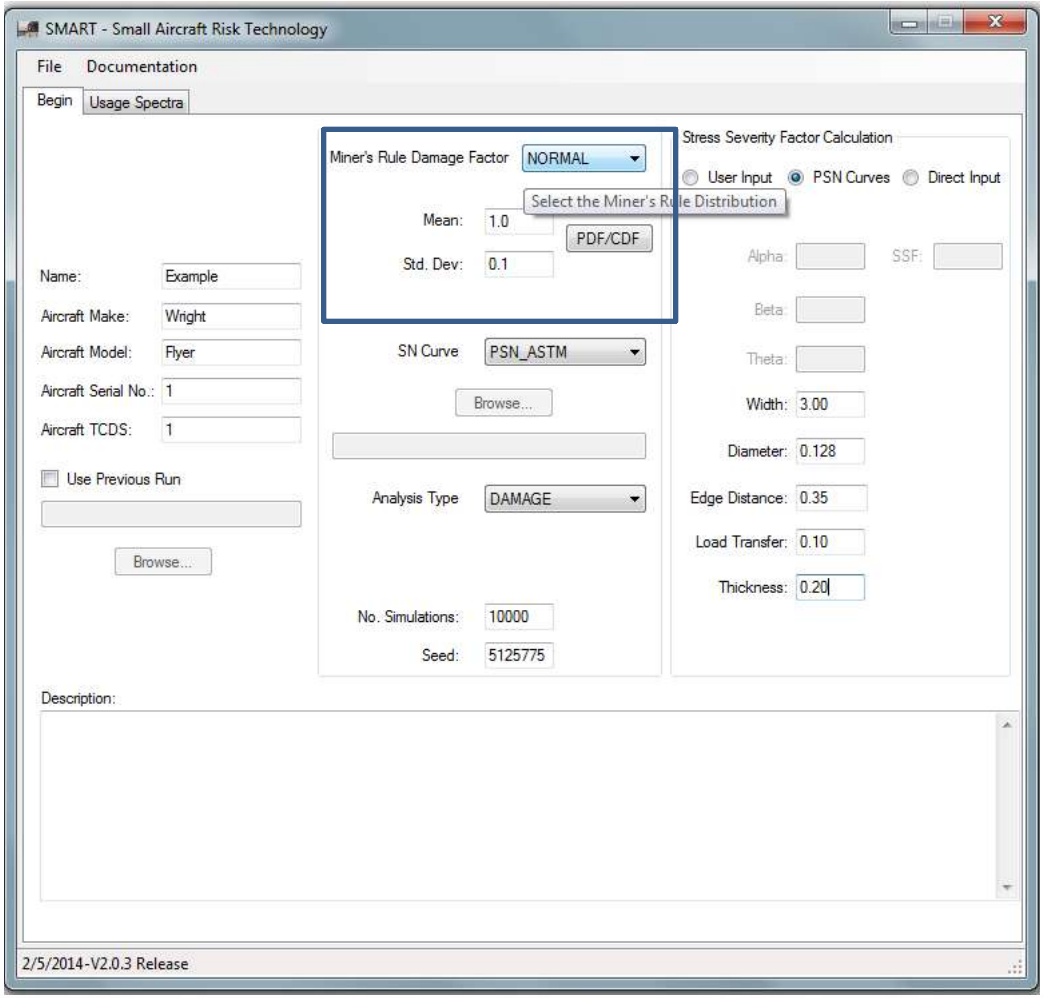
Probabilistic Miner’s Rule Damage Factor

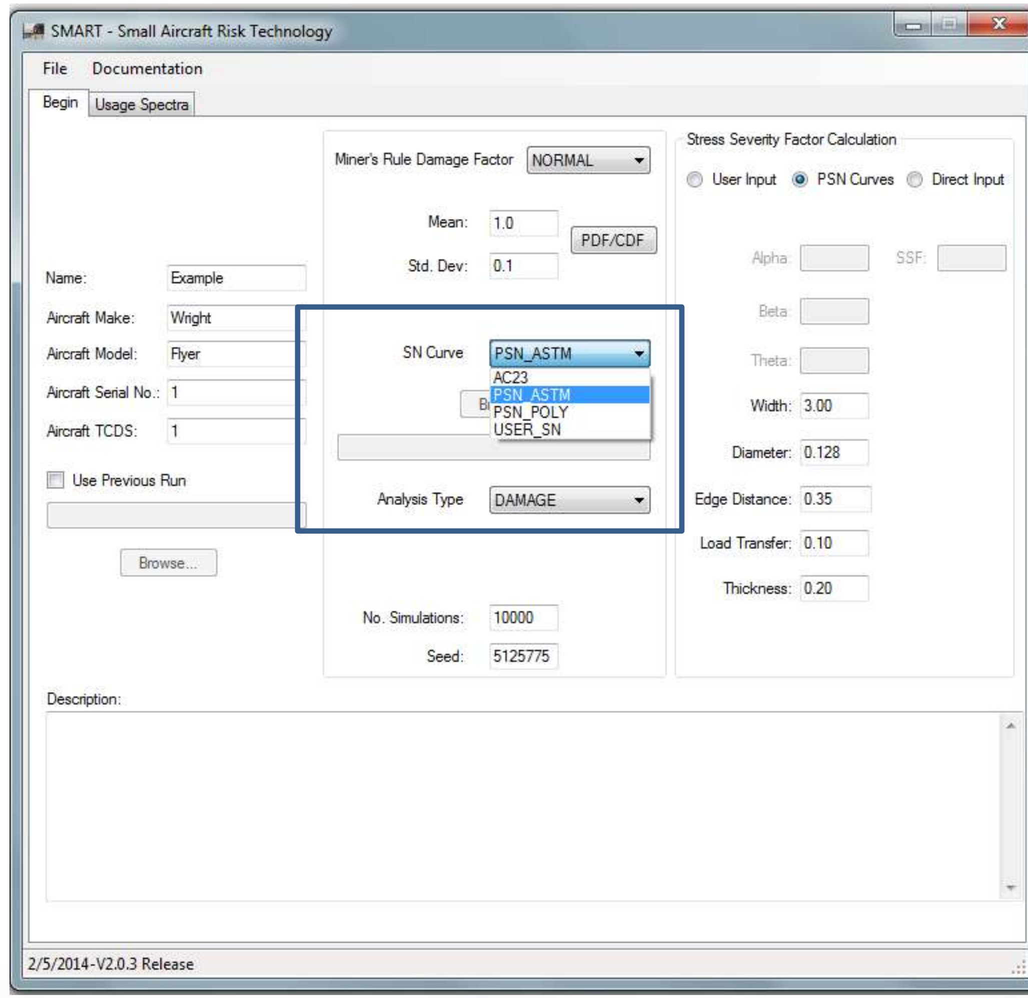
- Probabilistic analysis for Miner’s Rule damage summation.
  - Failure doesn’t always occur when damage sums to 1.
- Analyze for Normal or Weibull distributions.
- User defines mean and standard deviation (Normal dist.) or scale, shape, and location parameters (Weibull).



Available 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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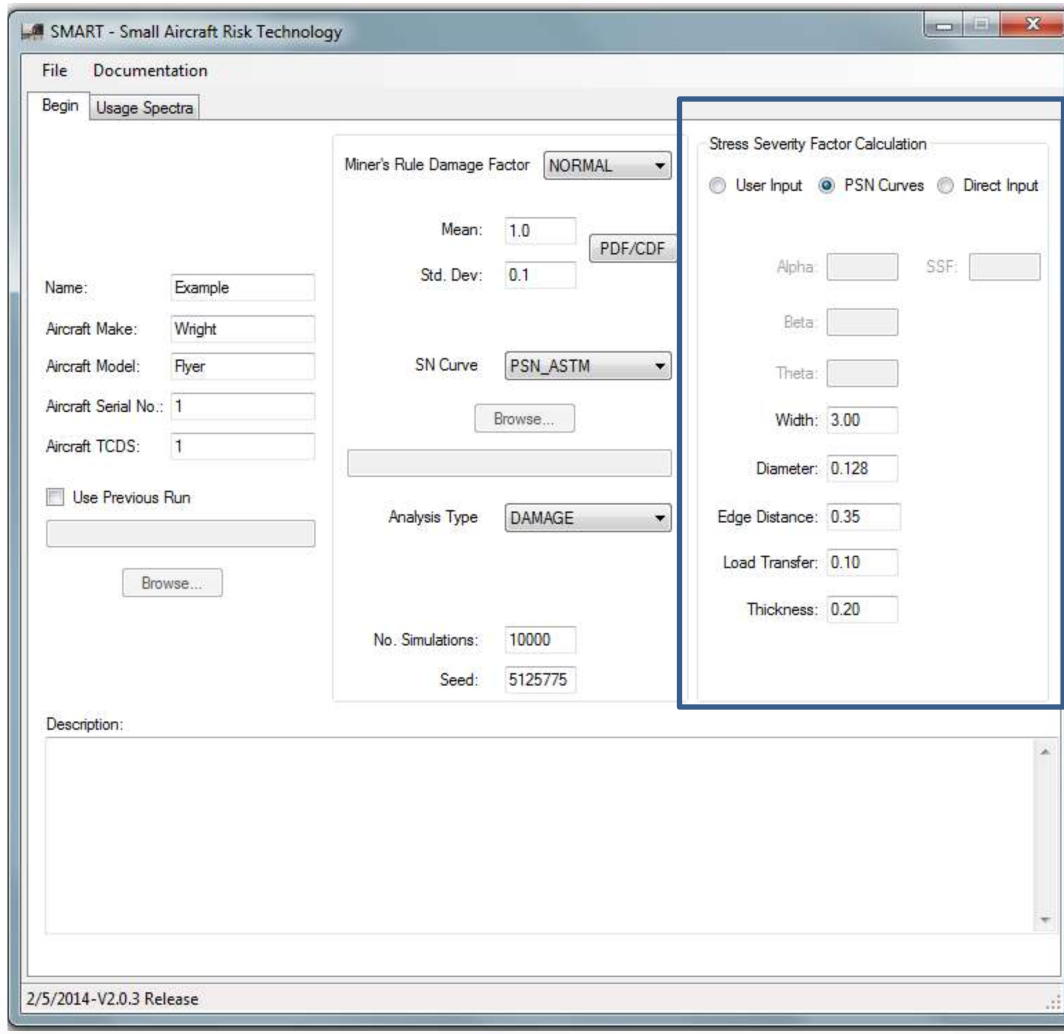
Stress Severity Factor

- 3 different methods available for calculating Stress Severity Factor:
  - 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.

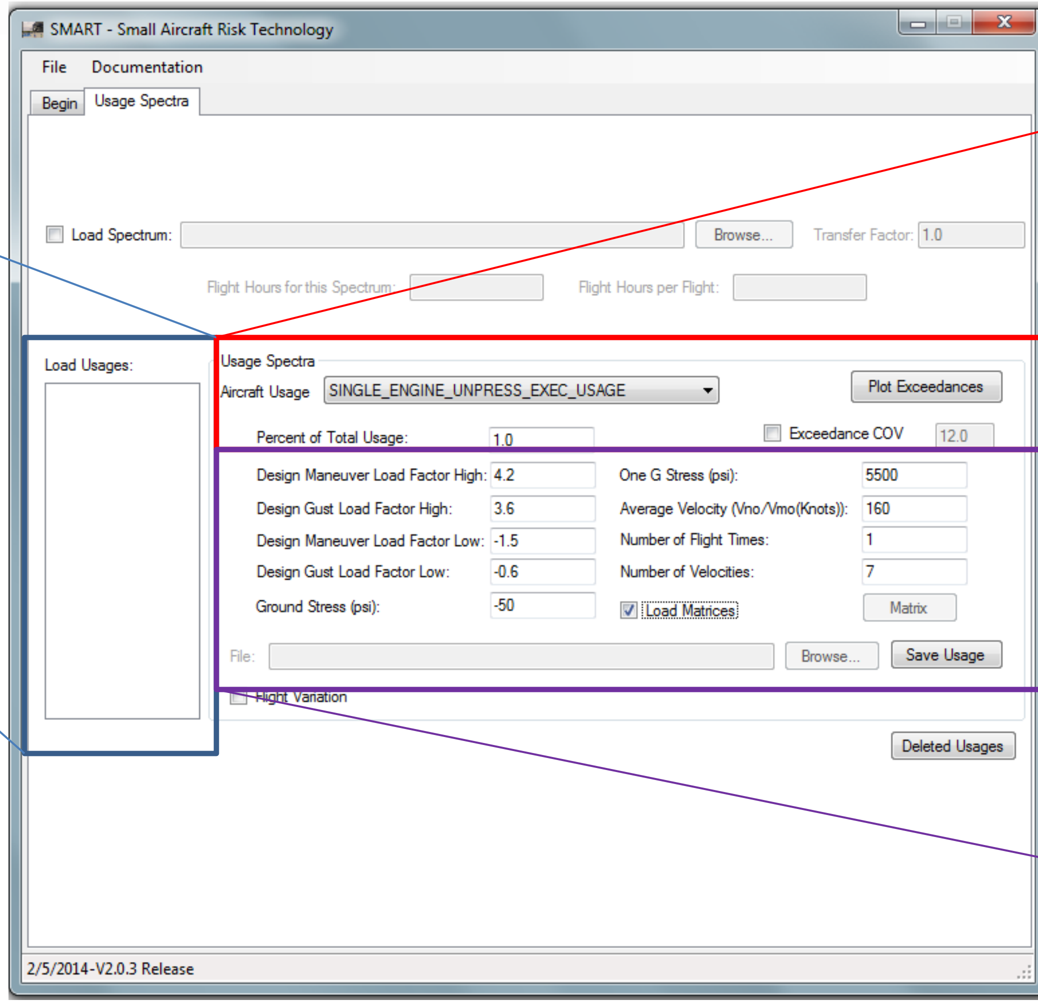


Spectrum

- 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.
      - Need to add NASGRO format in the future.

SMART AC23-13A Spectrum

Multiple usages for spectrum



Select type & % of total usage for each usage

Weight, speed, & loads input.

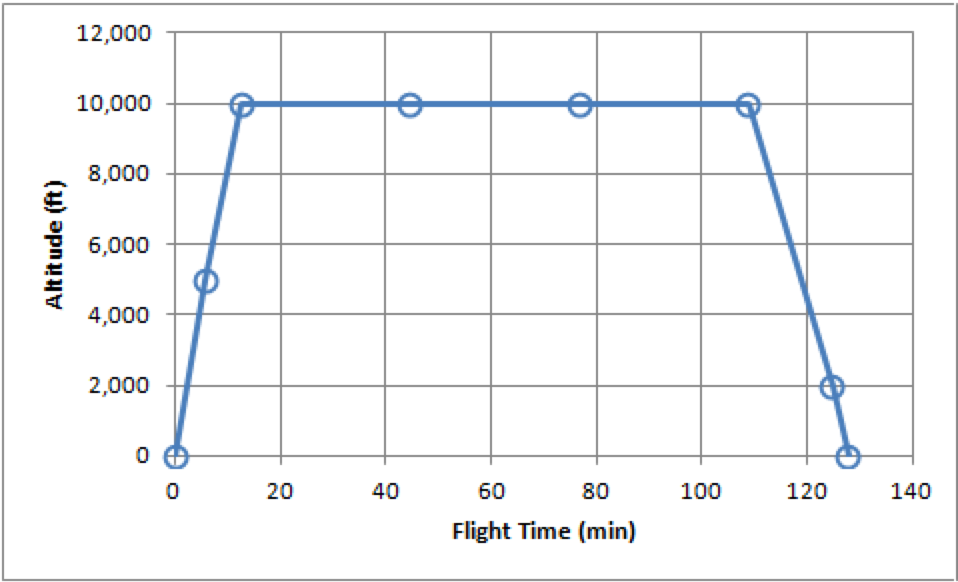
AC23-13A Usages

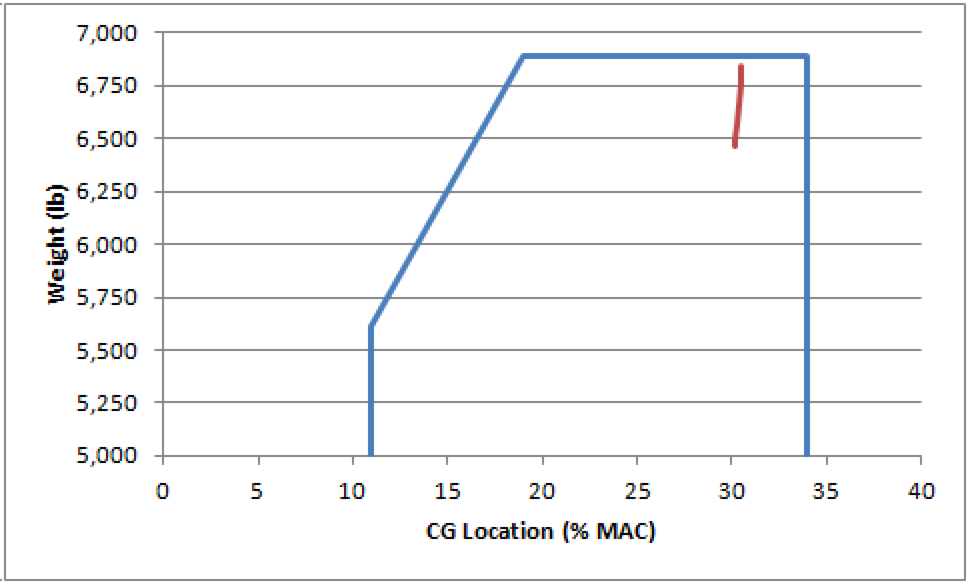
- AC23-13A exceedances curves available within SMART for different types of aircraft and usages:
  - Single engine
    - Unpressurized, basic instructional usage
    - Unpressurized, personal usage
    - Unpressurized, executive usage
  - **Twin engine**
    - Unpressurized, basic instructional usage
    - **Unpressurized, general usage**
  - Pressurized usage
  - Agricultural special usage
  - Special usage survey
  - User-defined

Best match for the 402C missions. Use weight & velocity matrices to adjust for Typical, Short, & Grand Canyon missions.

402C Profiles

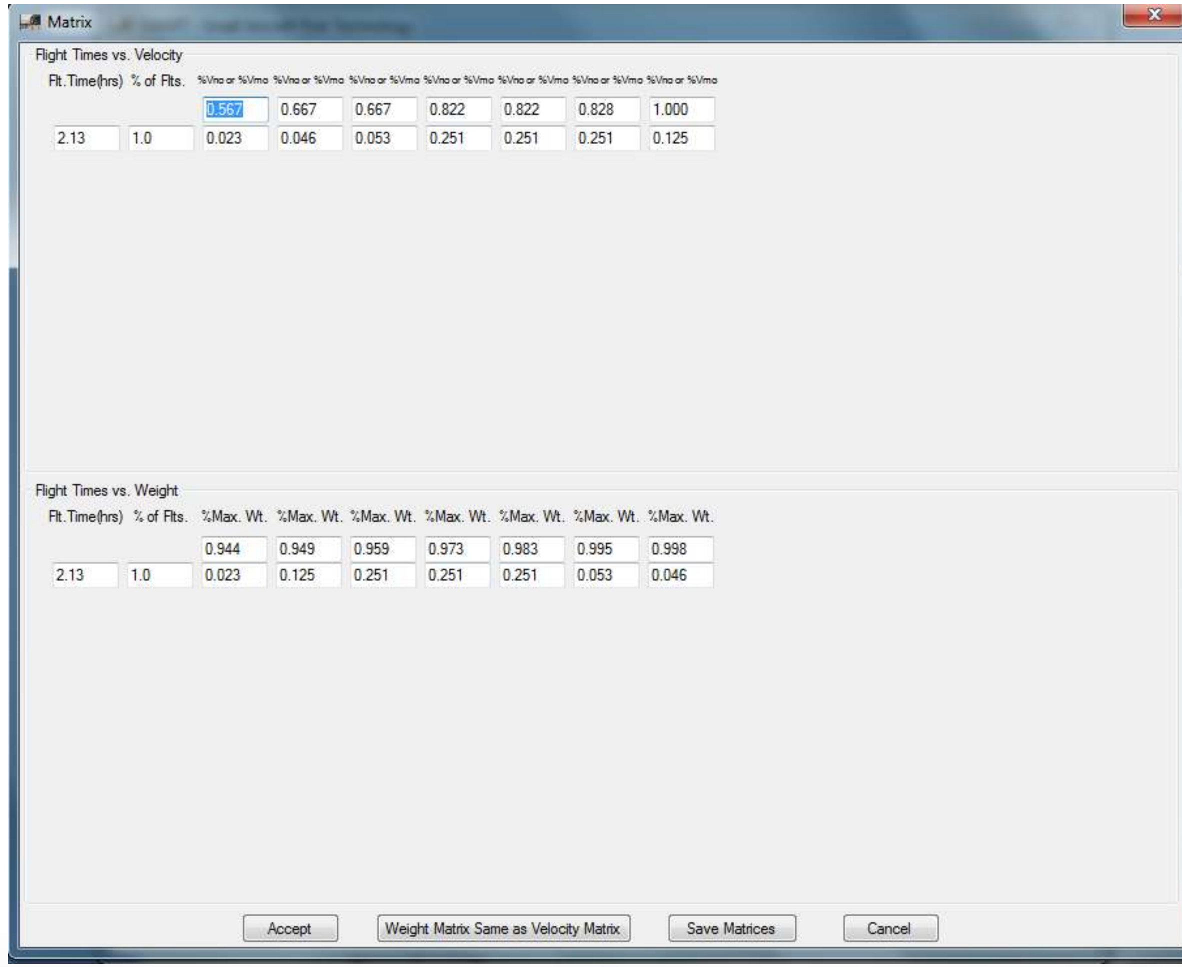
- Cessna developed profiles for the 3 different usages (Short, Grand Canyon, Typical).
  - Some usages have multiple profiles representing different types of flights.
- Represent typical operations based on owner surveys.





Profiles in SMART

- Replicated 402C mission profiles in SMART using the weight and velocity tables.
- Some missions used 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
		0.567	0.667	0.667	0.822	0.822	0.828	1.000
2.13	1.0	0.023	0.046	0.053	0.251	0.251	0.251	0.125

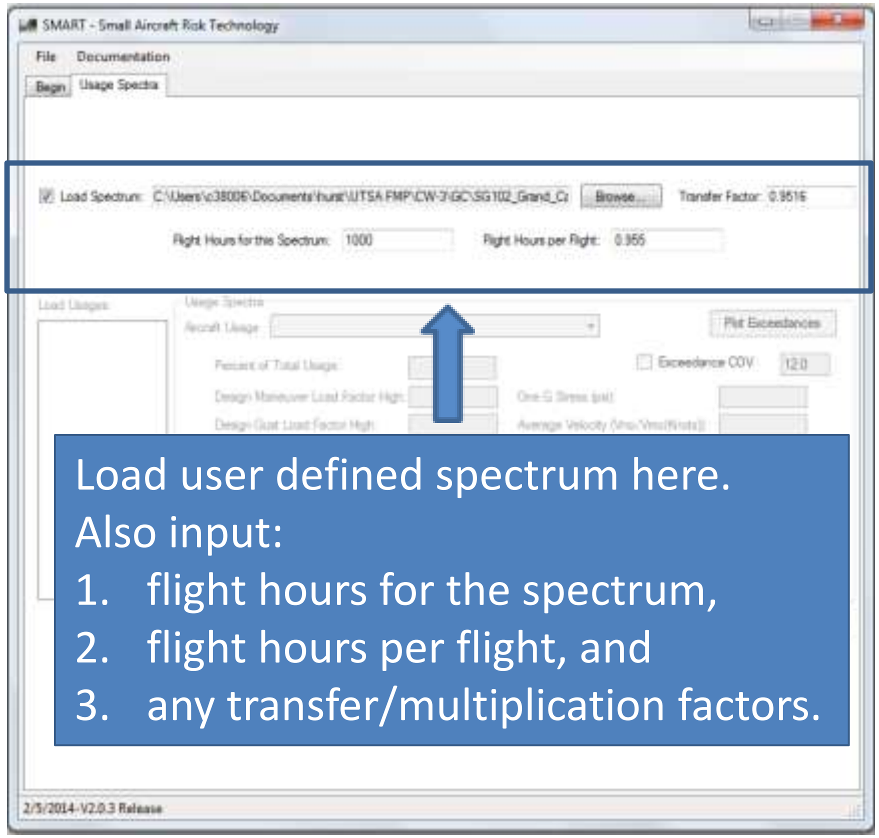
Flight Times vs. Weight

Flt.Time(hrs)	% of Flts.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.	%Max. Wt.
		0.944	0.949	0.959	0.973	0.983	0.995	0.998
2.13	1.0	0.023	0.125	0.251	0.251	0.251	0.053	0.046

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

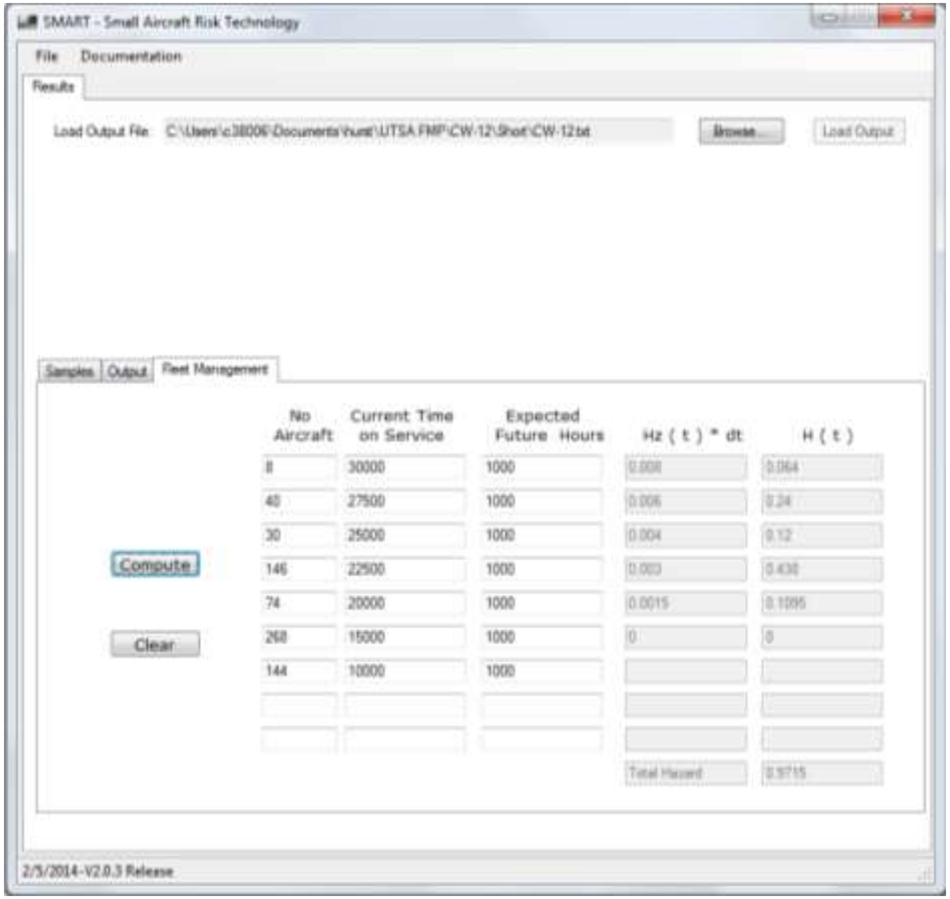
Cessna Spectra

- 1G Stresses based on strain gauges from static and flight test data.
  - For each point in the profile.
- Exceedances
  - Maneuver = consolidated fit using data from AFS-120-73-2, NASA SP-270 & DOT/FAA/CT-91/20
  - Gust = ESDU 69023
    - Modified VGH data
  - Taxi = AFS-120-73-2
  - Landing impact – time history from flight test landings
- Cycle counted
  - No specific GAG cycle identified. Different than SMART.



Calculating Hazard Functions

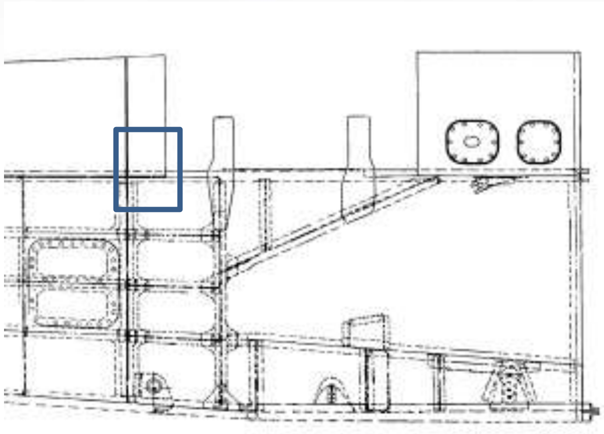
- After running an analysis, the user can calculate the Hazard Function within SMART.
- Use to determine:
  - Current risk to the fleet.
  - Risk for different inspection or modification programs.
- Calculation takes into account:
  - Current distribution of time in service.
  - The expected time until the next inspection/modification.

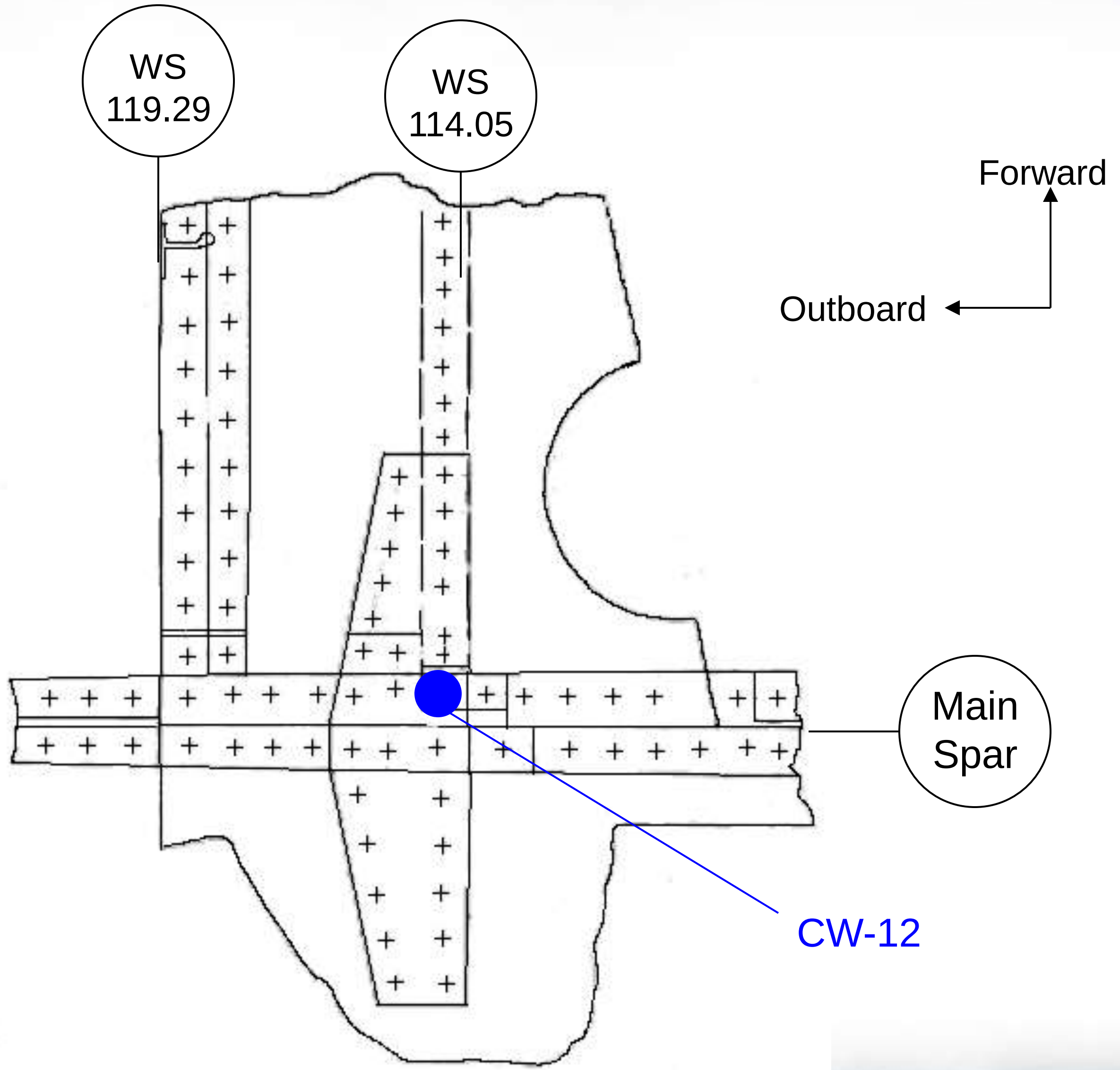


CW-12 ANALYSIS LOCATION

MAIN SPAR AT WS 114

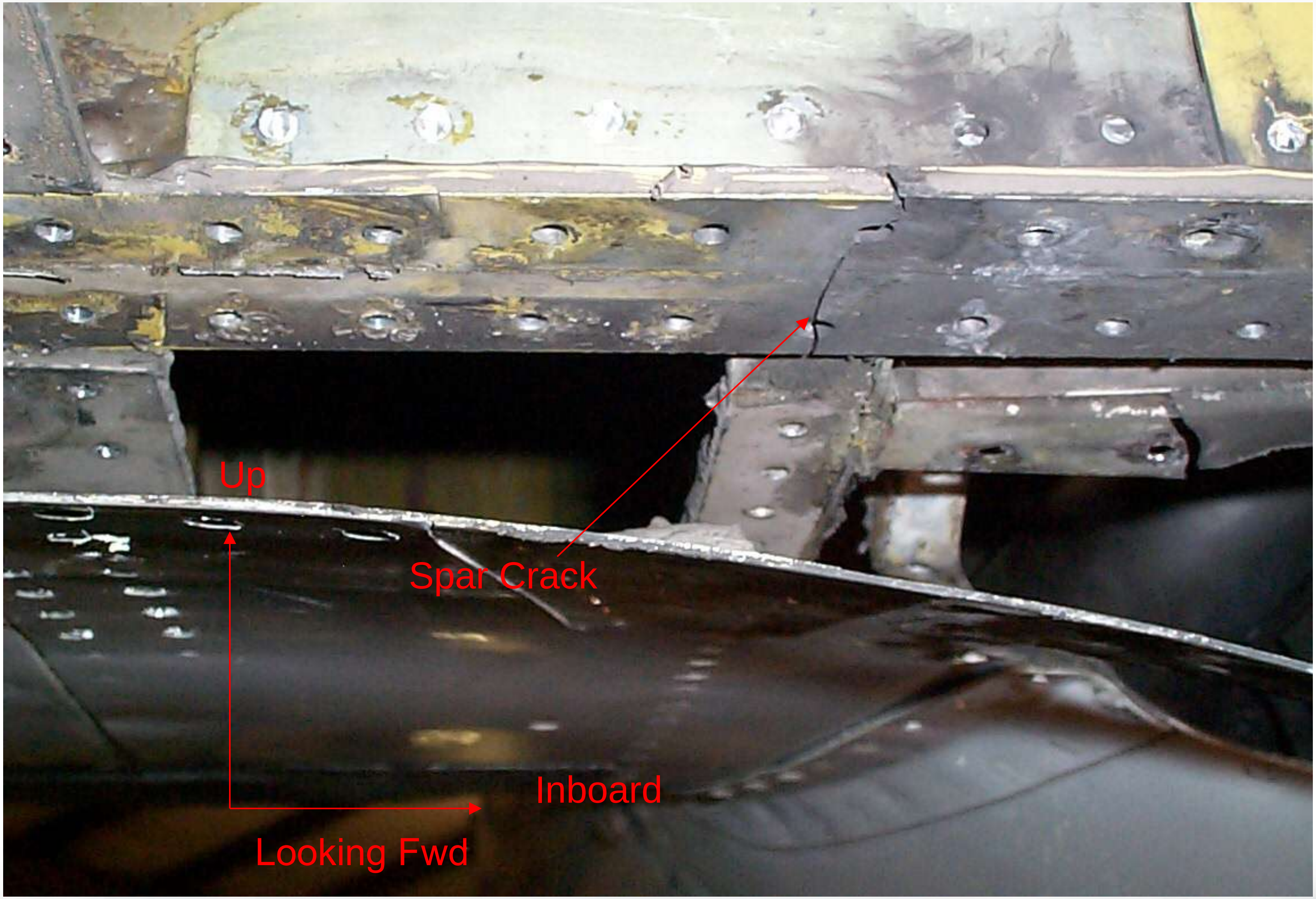
CW-12 Analysis Location - Wing



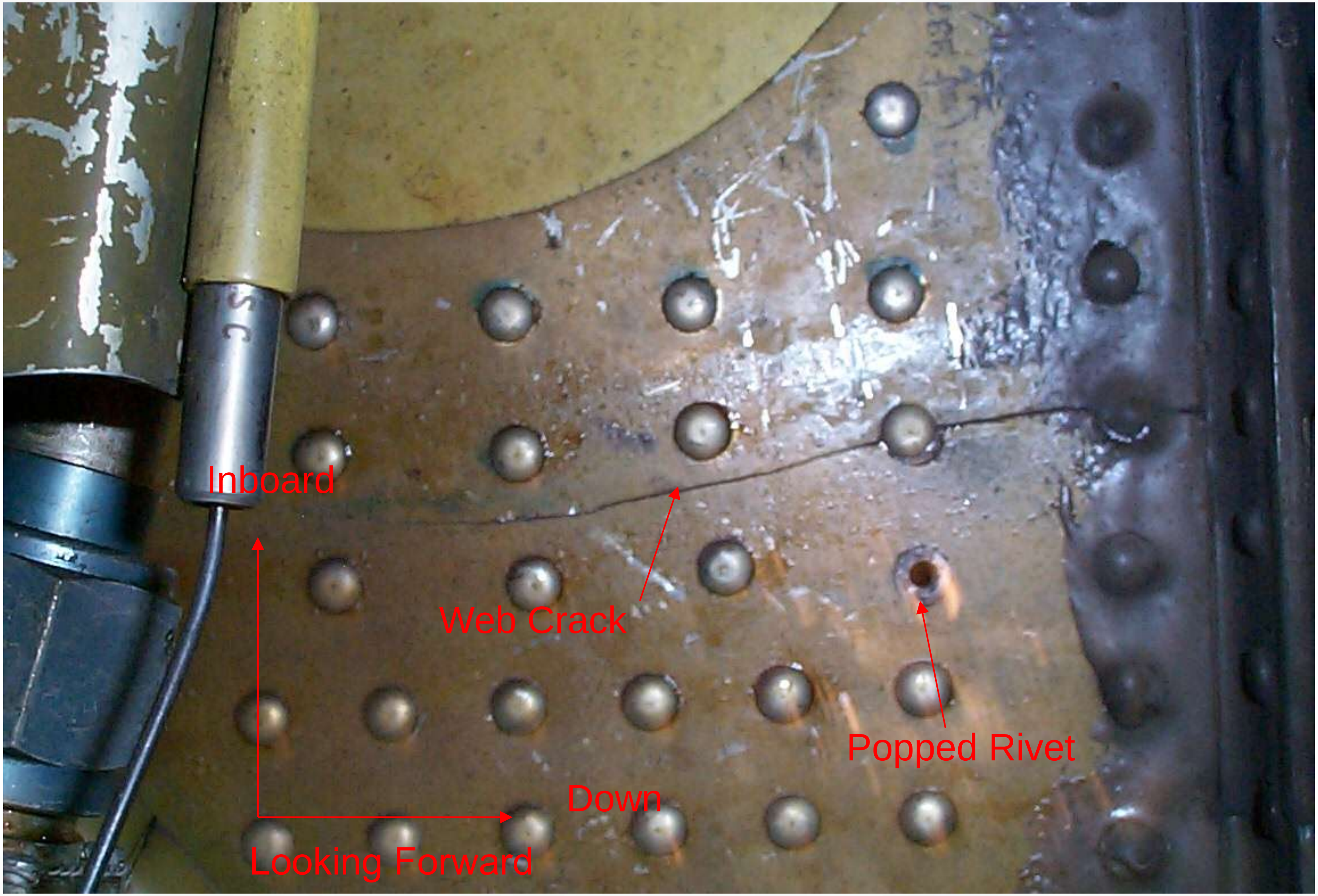


Field History

- Cracks found in the main spar and skin for 2 aircraft.
  - One aircraft had cracks located on both the right and left sides.
  - Both aircraft had >20,000 Flight Hours when cracks were discovered.
- Both A/C operating in passenger service.
- Mission representative of short spectrum.
- Higher time aircraft, but not fleet leaders.



Spar Cap

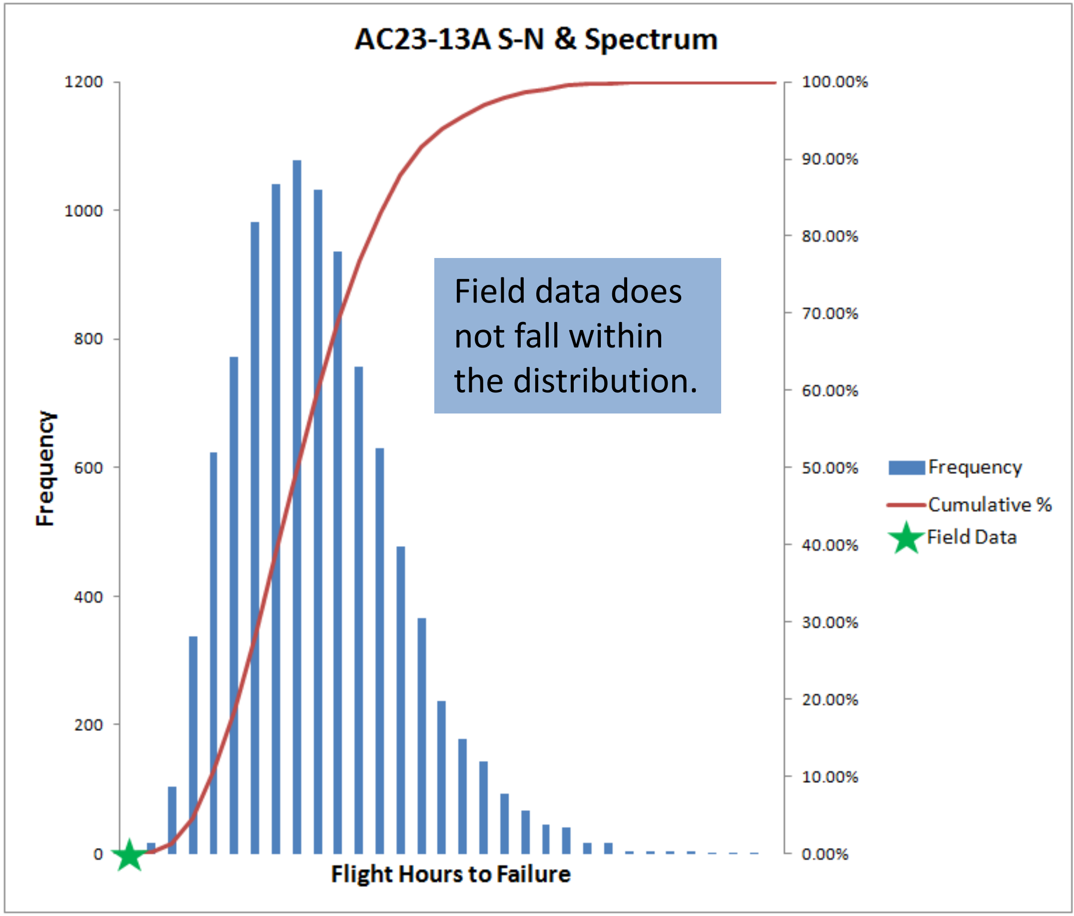


Aft Spar Web Splice

Lower Skin

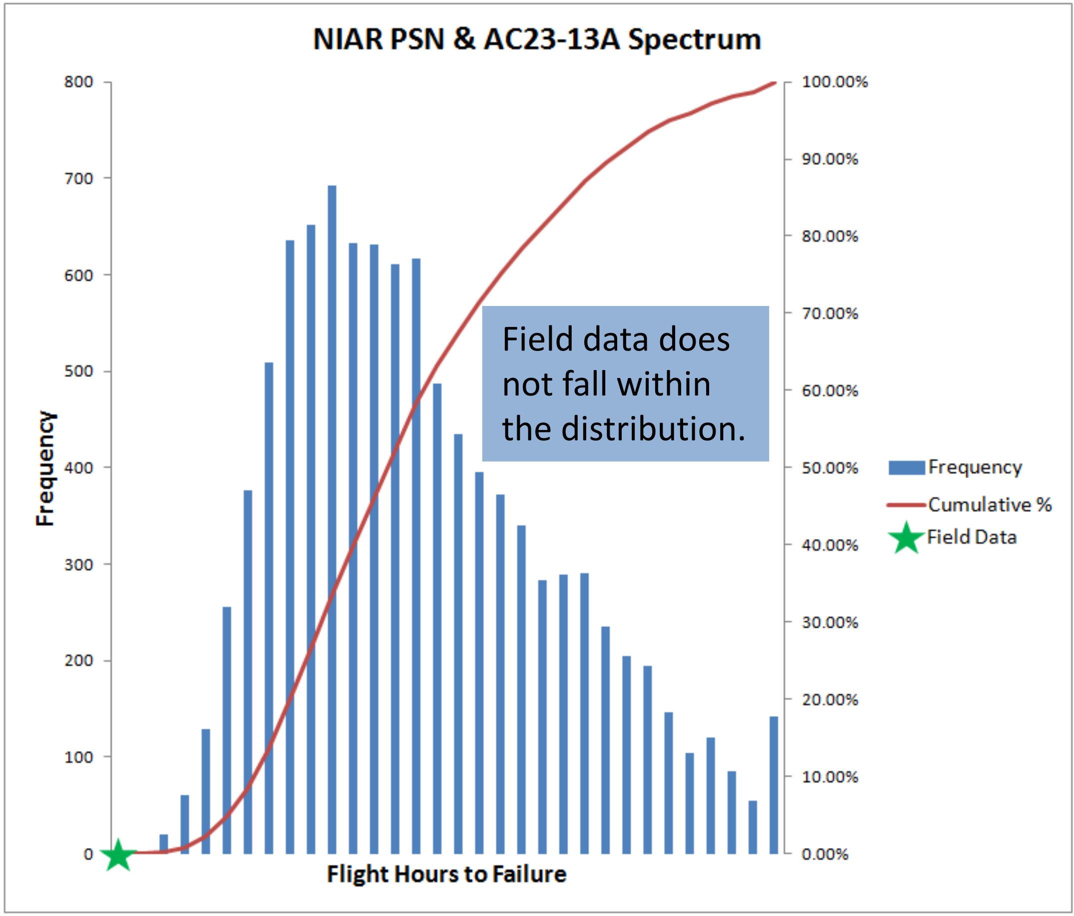
CW-12 Initial Analysis

- 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.



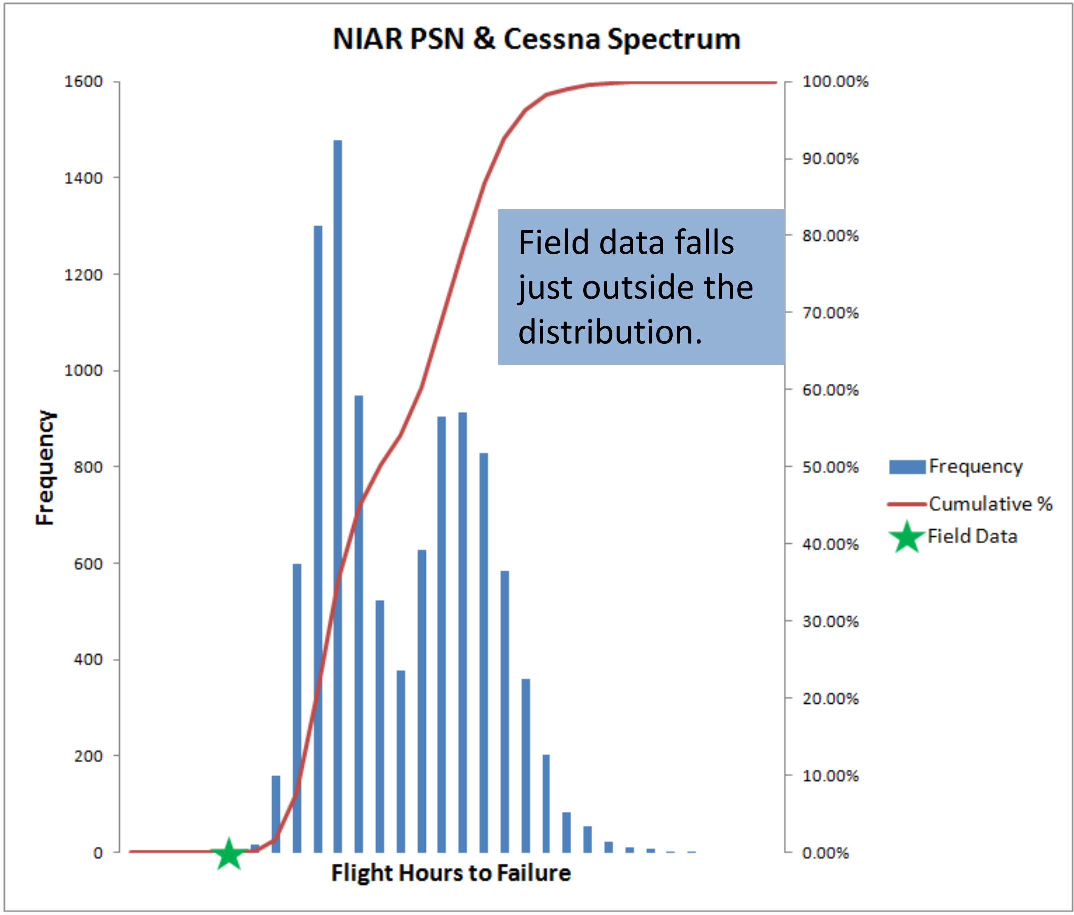
CW-12 Refine S-N Data

- Assumptions:
  - User has some geometry and loads info.
  - NIAR PSN
    - User has geometry & load transfer info.
  - 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.



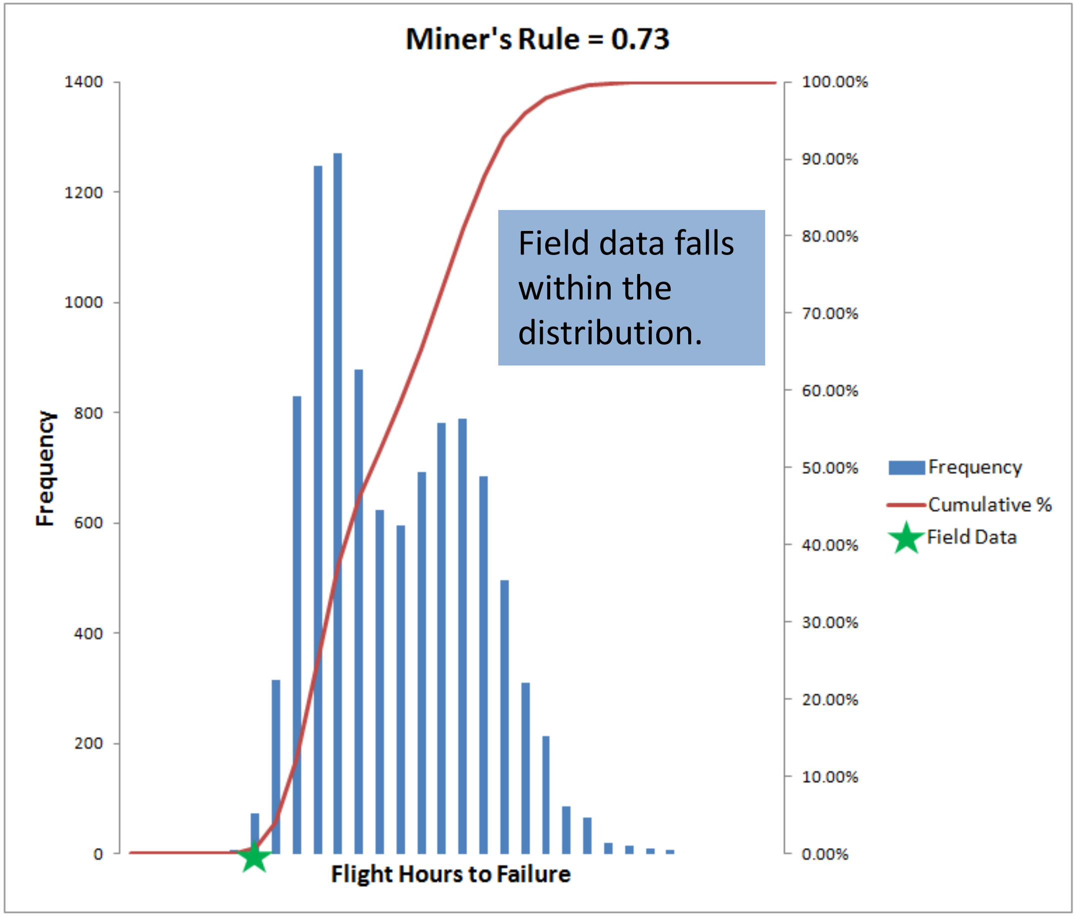
CW-12 Refine Spectrum

- 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.



CW-12 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.



CW-12 Hazard Function

# 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

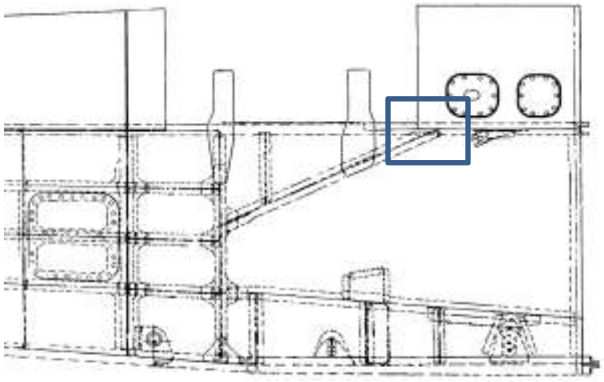
381 a/c in service (x2 locations)
10,000 SMART simulations

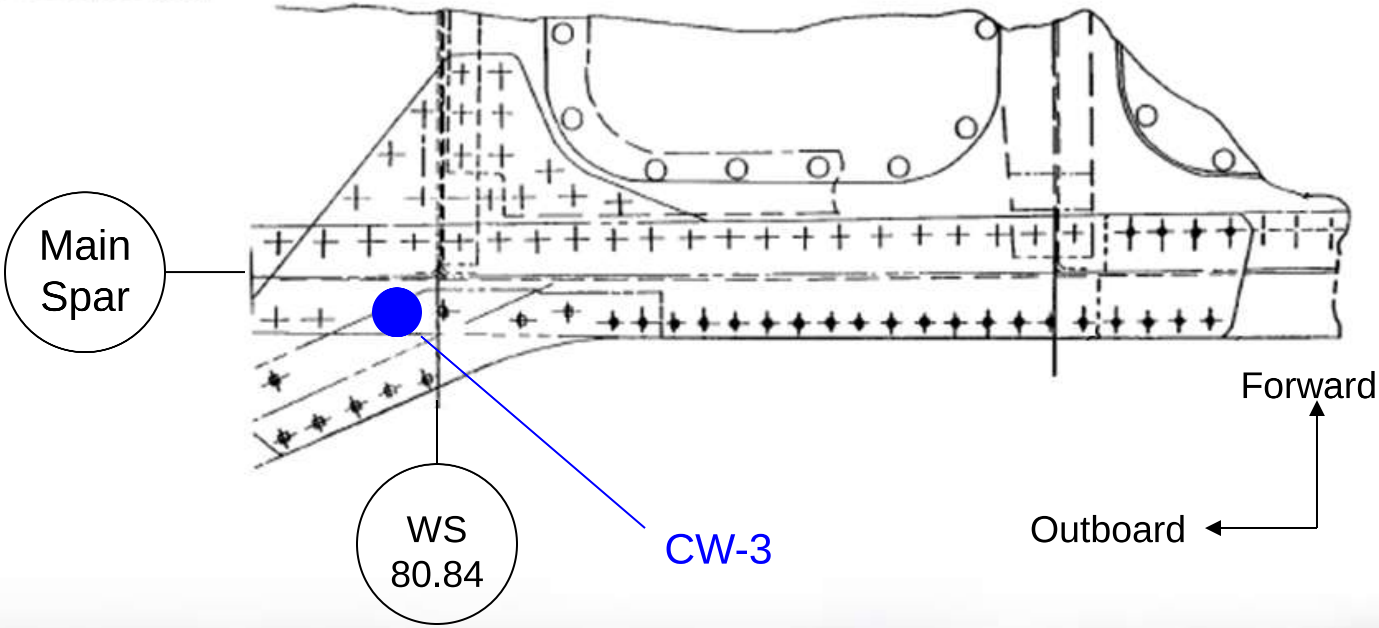
For the 402C fleet, the analysis predicts in the next 1,000 hours 1 wing to be affected. Cessna has seen 3 occurrences in service.

CW-3 ANALYSIS LOCATION

MAIN SPAR AT WS 80

CW-3 Analysis Location – Wing



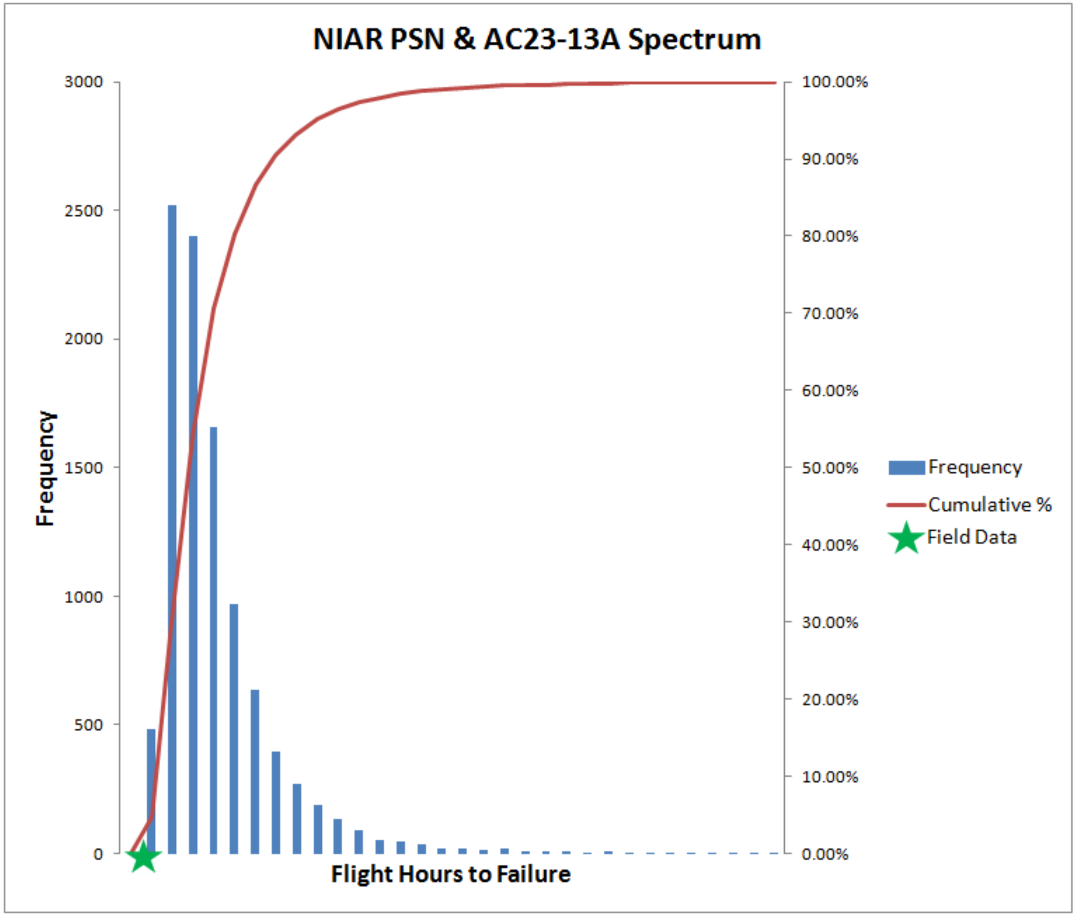


Field History

- 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.

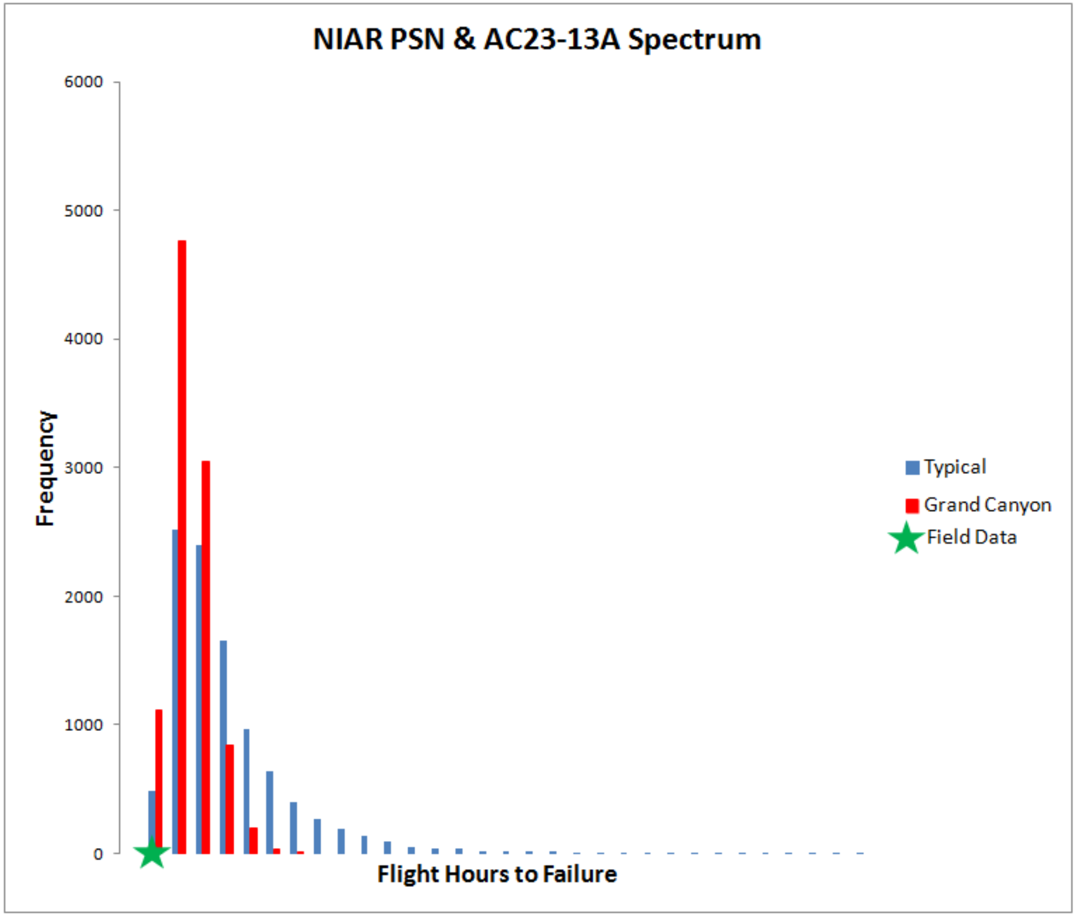
CW-3 Analysis

- 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.



Usage Comparison

- Aircraft had 10 owners in its lifetime & Cessna does not know what missions it flew.
  - 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



DISCUSSION

Tuning PSN Analyses

- 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.
  - Beware of “garbage in, garbage out.”
- 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 for Software Enhancements

- 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 user's to fully utilize.
  - Base on test or field data.
- Need to analyze more locations with SMART.
  - To date we have only run 3 different wing locations. Small sample size.
  - Need to analyze other types of structure.
    - Fuselage, Empennage, etc.

Questions