

SMART|LD Safe-Life User Loading and User SN Curve



SMART Short Course
The Aircraft Airworthiness & Sustainment
Conference
Grapevine, Texas – March 21, 2016

Outline



- ✓ SMART|LD Files Overview
- ✓ Safe-Life Analysis
 - ✓ Required Elements Safe-Life Analysis
 - ✓ User Loading
 - ✓ User SN-Curves
 - ✓ Running Example Problem
 - ✓ Pressurization Cycle
 - ✓ Input File
 - ✓ GUI Inputs
 - ✓ Output Files
 - ✓ MonteCarlo Samples
 - ✓ Statistical Results
 - ✓ Hz Function Quick Look
 - ✓ SN Region Percentage Damage
- ✓ Summary

SMART Files Overview



SMART_{DT}

Small Aircraft Risk Technology - Damage Tolerance Analysis

SMART|LD Files Overview



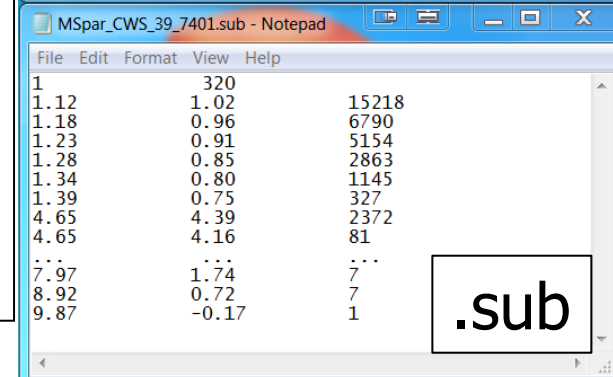
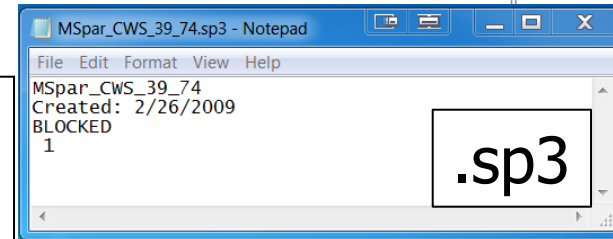
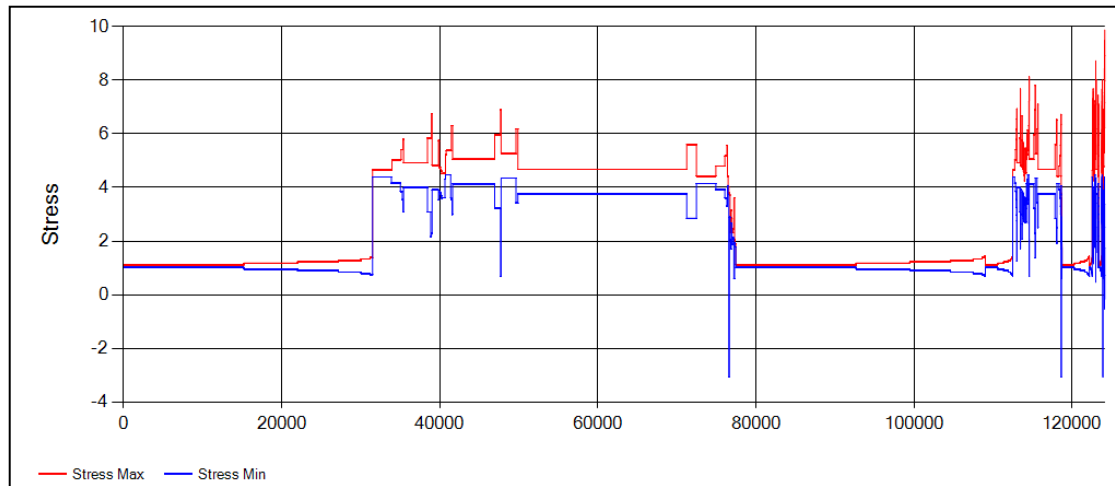
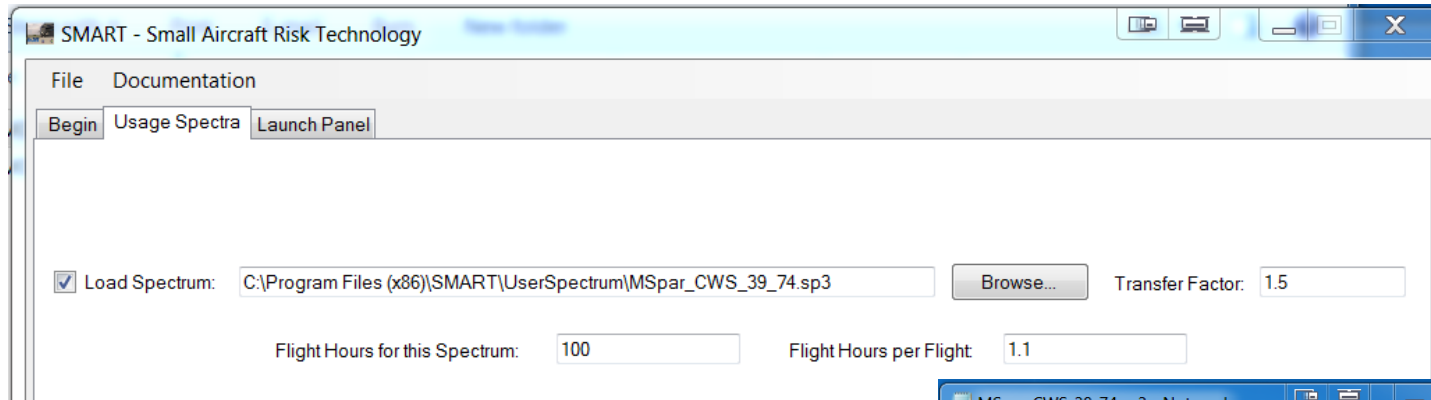
File Type	Description
<code>jobname.dat</code>	Input file containing the keywords and run information
<code>jobname.err</code>	Runtime error file
<code>jobname.wrn</code>	Runtime warning file
<code>jobname.out</code>	File containing a summary of the inputs and statistical results
<code>jobname.txt</code>	File containing the Monte Carlo realizations

Input
output

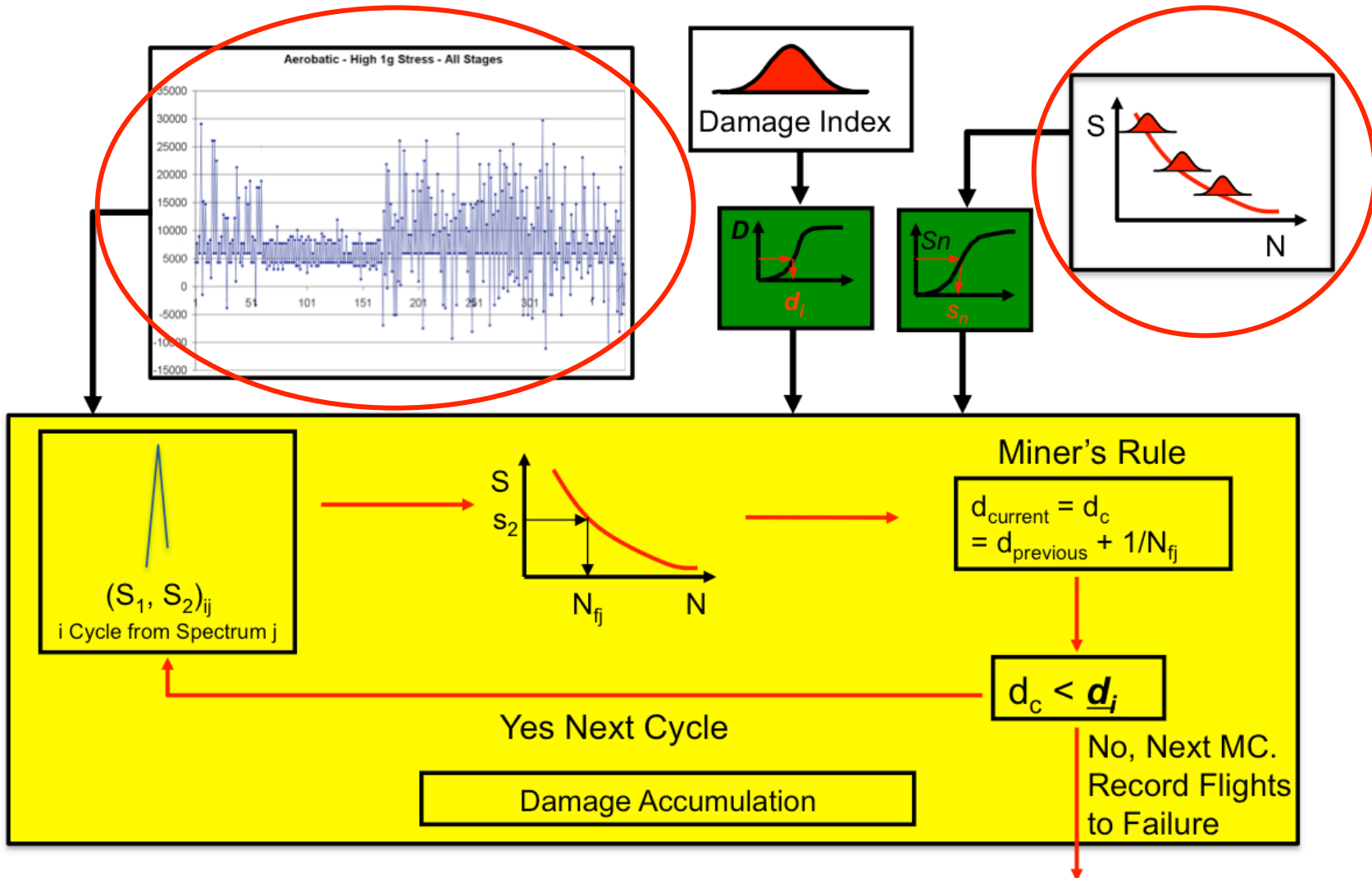
Smart User Spectra



Afgrow files (sp3 and sub). The GUI will read the ".sp3"



Damage Methodology (Safe Life)



User SN

MMPDS Methodology



$$\log(N) = A + B \cdot \log(Seq + C) + Z \cdot stdev$$

$$Seq = Smax \cdot (1 - R)^D$$

$$Z \sim N(0,1)$$

$A, B, C,$ and D = Regression Parameters

N = Fatigue Life in cycles

$Stdev$ = Standard deviation

Seq = Equivalent Stress

R = Stress Ratio ($Smin/Smax$),

$Z \sim N(0,1)$ = Standard normal

S-N file must have ".sn" file extension.

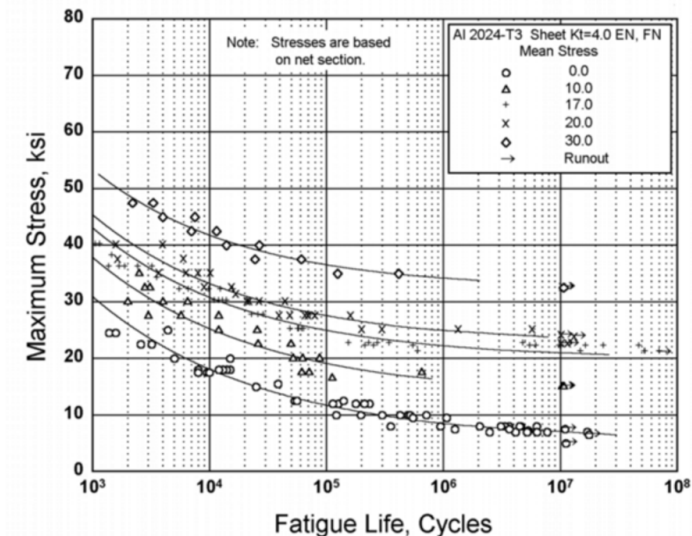
```

AI2024-T3_Kt4-0_SD=0.sn - Notepad
File Edit Format View Help
! LOG(N) = A + B * LOG (Seq + c) + Z*stdev
! Seq = Smax*(1-R)^D
! E = Endurance limit
! Z ~ N(0,1)
! 2024-T3_Kt=4.0
*** SN PARAMETERS ***
A = 8.3
B = -3.3
C = -8.5
D = 0.66
E = 0.0
Stdev = 0.0
  
```

Lines starting with a character other than a letter are not read by SMART

Constants used to describe the S-N curve

User-defined PSN



Example Problems



SMART_{LD}

Small Aircraft Risk Technology – Linear Damage Analysis

Example 1

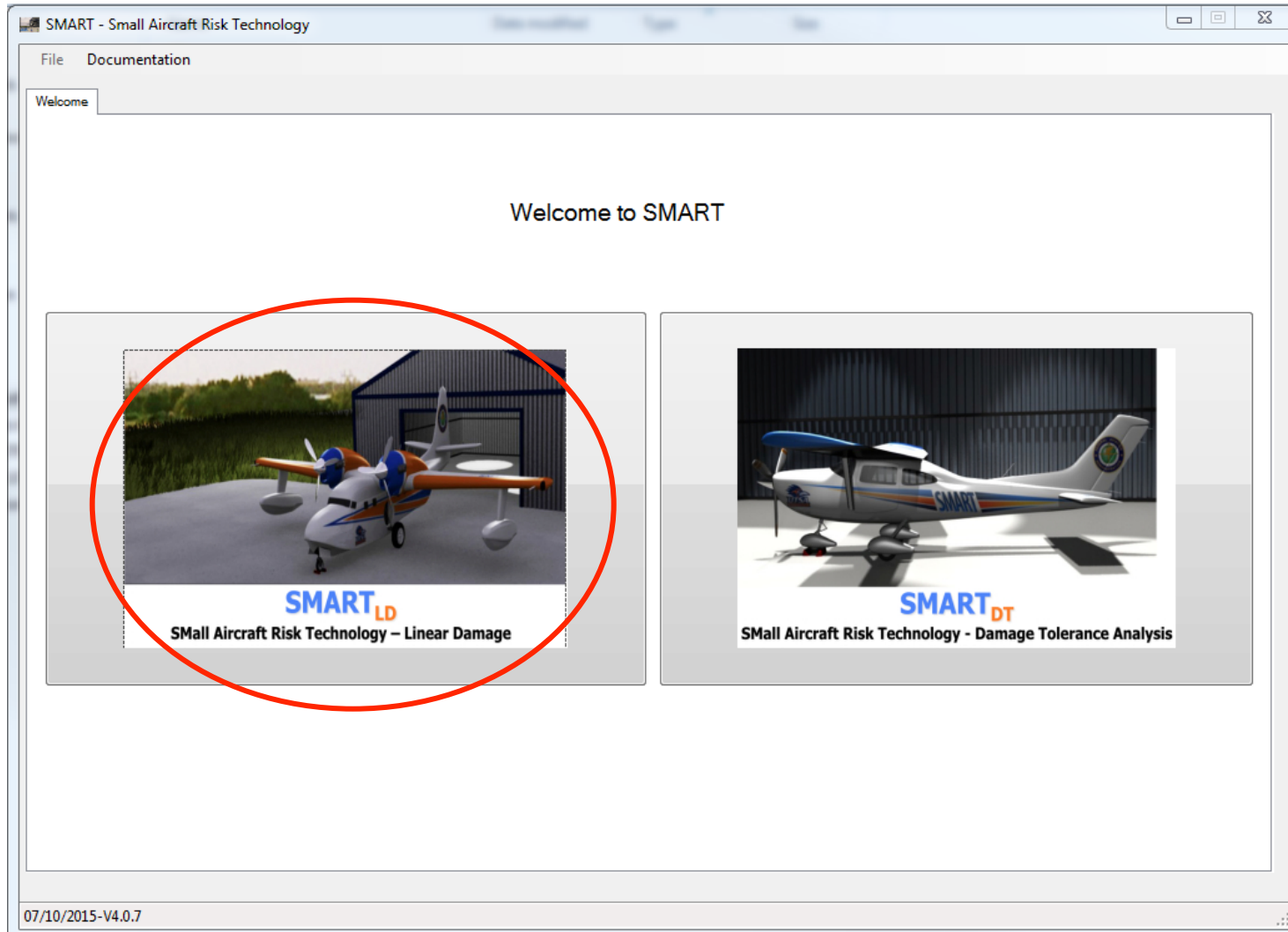


Variable	Characteristics
Loading	User Spectrum Single Load
Damage Index	Normal distribution with mean 1.0 and standard deviation 0.0
SN Curve	User SN Curve

Deterministic Run

LD Example 1

(Select SMART|LD)



LD Example 1 (Begin Tab)



SMART - Small Aircraft Risk Technology

File Documentation

Begin Usage Spectra

Name:

Aircraft Make:

Aircraft Model:

Aircraft Serial No.:

Aircraft TCDS:

Use Previous Run

Description:

Miner's Rule Damage Factor:

Mean:

Std. Dev:

SN Curve:

C:\Users\pze593\Dropbox\FAA_FMP\SMART_AA&S_2016_Trainir

Analysis Type:

No. Simulations:

Seed:

Stress Severity Factor Calculation

User Input PSN Curves Direct Input

Alpha:

Beta:

Theta:

Thickness:

Width:

Diameter:

Edge Distance:

Load Transfer:

SSF:

07/10/2015-V4.0.7

LD Example 1 (User SN)



The image shows the SMART - Small Aircraft Risk Technology software interface. The 'Usage Spectra' tab is active, displaying various input fields for aircraft information and analysis parameters. A red circle highlights the 'Browse...' button next to the 'SN Curve' dropdown menu, which is currently set to 'USER_SN'. An 'Open a Text File' dialog box is open, showing the file 'AI2024-T3_Kt4-0.sn' selected in the file list. The dialog box also shows the file name and type in the bottom bar.

SMART - Small Aircraft Risk Technology

File Documentation

Begin Usage Spectra

Name: User_SN_Load

Aircraft Make: None1

Aircraft Model: None2

Aircraft Serial No.: None3

Aircraft TCDS: None4

Use Previous Run

Browse...

Description:

07/10/2015-V4.0.7

Miner's Rule Damage Factor: NORMAL

Mean: 1.0

Std. Dev: 0.0

PDF/CDF

SN Curve: USER_SN

Browse...

Analysis Type:

No. Simulations:

Seed: 7212362

Stress Severity Factor Calculation

User Input PSN Curves Direct Input

Alpha:

Beta:

Theta:

Thickness:

SSF:

Open a Text File

Dropbox > FAA_FMP > SMART_AA&S_2016_Training > Runs > LD_safe_life_User_SN_Load

Search LD_safe_life_User_SN_L...

Organize New folder

Name	Date modified	Type	Size
AI2024-T3_Kt4-0.sn	2/29/2016 8:03 AM	SN File	1 KB

File name: AI2024-T3_Kt4-0.sn

Text Files(.sn) (*.sn)

Open Cancel

LD Example 1 (Loading)



SMART - Small Aircraft Risk Technology

File Documentation

Begin Usage Spectra

Load Spectrum: C:\Users\pze593\Dropbox\FAA_FMP\SMART_AA&S_2016_Training\Runs\LD_safe_life_User_SN_Load\O Browse... Transfer Factor: 1.0

Flight Hours for this Spectrum: 1.0 Flight Hours per Flight: 1.0

Load Usages:

Usage Spectra

Aircraft Usage: [Dropdown] Plot Exceedances

Percent of Total Usage: [Input] Exceedance COV 12.0

Design Maneuver Load Factor High: [Input] One G Stress (psi): [Input]

Design Gust Load Factor High: [Input] Average Velocity (Vno/Vmo(Knots)): [Input]

Design Maneuver Load Factor Low: [Input] Number of Flight Times: [Input]

Design Gust Load Factor Low: [Input] Number of Velocities: [Input]

Ground Stress (psi): [Input] Load Matrices Matrix

File: [Input] Browse... Save Usage

Flight Variation

Deleted Usages

Next Tab

07/10/2015-V4.0.7

Ex5_OneCycleSpectrum.sp3 - Notepad

File Edit Format View Help

```
Ex5_OneCycleSpectrum
Created: 2/25/2014
BLOCKED
1
```

Ex5_OneCycleSpectrum01.sub - Notepad

File Edit Format View Help

```
1
20.0          1
              0.00          1
```

LD Example 1 (Launch Panel Tab)



SMART - Small Aircraft Risk Technology

File Documentation

Begin Usage Spectra **Launch Panel**

```

!-----!
!           AIRCRAFT INFORMATION
!-----!
TITLE = User_SN_Load
AC_MAKE = None1
AC_MODEL = None2
AC_SERIAL_NUM = None3
AC_TCDS = None4
!-----!
!           SN-CURVE, MINERS AND SSF
!-----!
SN_CURVE = USER_SN C:\Users\pze593\Dropbox\FAA_FMP\SMART_AA&S_2016_Training\Runs\LD_safe_life_User_SN_Load\AI2024-T3_Kt4-0.sn
MINERS_D = NORMAL 1.0 0.0 0.0
SSF_TYPE = DIRECT
SSF = 1.00
!-----!
!           METHOD
!-----!
MCSAMP = 1
SEED = 7212362
INPUT_FILE = NO
ANALYSIS_TYPE = DAMAGE
!-----!
!           LOADING PARAMETERS
!-----!
USER_SPECTRUM = C:\Users\pze593\Dropbox\FAA_FMP\SMART_AA&S_2016_Training\Runs\LD_safe_life_User_SN_Load\OneCycleSpectrum.sp3
TRANSFER_FACTOR = 1.0
SPECTRUM_HOURS = 1.0
HOURS_PER_FLIGHT = 1.0
!-----!
!           DESCRIPTION
!-----!

```

Run

07/10/2015-V4.0.7

Input & Output Summary .out File

... Lines were removed from this output ...

```
                Mean Results
  Lower Bound          Upper Bound
 90%   95%   99%   F-T-F Mean   90%   95%   99%
63051. 63051. 63051.   63051.   63051. 63051. 63051.

  Lower Bound          Upper Bound
 90%   95%   99%   H-T-F Mean   90%   95%   99%
63051. 63051. 63051.   63051.   63051. 63051. 63051.

                Stdev Results
  Lower Bound          Upper Bound
 90%   95%   99%   F-T-F Stdev   90%   95%   99%
  0.   0.   0.   0.   0.   0.   0.

  Lower Bound          Upper Bound
 90%   95%   99%   H-T-F Stdev   90%   95%   99%
  0.   0.   0.   0.   0.   0.   0.
```

... Lines were removed from this output ...

```
SN REGION          TOTAL
BELOW 1 KSI:       0.00
BETWEEN 1 AND 2 KSI: 0.00
BETWEEN 2 AND 3 KSI: 0.00
BETWEEN 3 AND 4 KSI: 0.00
BETWEEN 4 AND 5 KSI: 0.00
BETWEEN 5 AND 6 KSI: 0.00
BETWEEN 6 AND 7 KSI: 0.00
BETWEEN 7 AND 8 KSI: 0.00
BETWEEN 8 AND 9 KSI: 0.00
BETWEEN 9 AND 10 KSI: 0.00
BETWEEN 10 AND 11 KSI: 0.00
BETWEEN 11 AND 12 KSI: 0.00
BETWEEN 12 AND 13 KSI: 0.00
BETWEEN 13 AND 14 KSI: 0.00
BETWEEN 14 AND 15 KSI: 0.00
BETWEEN 15 AND 16 KSI: 0.00
BETWEEN 16 AND 17 KSI: 0.00
BETWEEN 17 AND 18 KSI: 0.00
BETWEEN 18 AND 19 KSI: 0.00
BETWEEN 19 AND 20 KSI: 0.00
BETWEEN 20 AND 21 KSI: 100.00
BETWEEN 21 AND 22 KSI: 0.00
BETWEEN 22 AND 23 KSI: 0.00
BETWEEN 23 AND 24 KSI: 0.00
BETWEEN 24 AND 25 KSI: 0.00
BETWEEN 25 AND 26 KSI: 0.00
BETWEEN 26 AND 27 KSI: 0.00
BETWEEN 27 AND 28 KSI: 0.00
BETWEEN 28 AND 29 KSI: 0.00
BETWEEN 29 AND 30 KSI: 0.00
BETWEEN 30 AND 31 KSI: 0.00
BETWEEN 31 AND 32 KSI: 0.00
BETWEEN 32 AND 33 KSI: 0.00
BETWEEN 33 AND 34 KSI: 0.00
BETWEEN 34 AND 35 KSI: 0.00
BETWEEN 35 AND 36 KSI: 0.00
BETWEEN 36 AND 37 KSI: 0.00
BETWEEN 37 AND 38 KSI: 0.00
BETWEEN 38 AND 39 KSI: 0.00
BETWEEN 39 AND 40 KSI: 0.00
ABOVE 40 KSI:     0.00

TOTAL STAGE PERCENTAGE 100.00
```

... Lines were removed from this output ...



TEXTRON AVIATION

Safe-life Results

from .out File



Mean Results

Lower Bound				Upper Bound		
90%	95%	99%	F-T-F Mean	90%	95%	99%
63051.	63051.	63051.	63051.	63051.	63051.	63051.

Lower Bound				Upper Bound		
90%	95%	99%	H-T-F Mean	90%	95%	99%
63051.	63051.	63051.	63051.	63051.	63051.	63051.

Stdev Results

Lower Bound				Upper Bound		
90%	95%	99%	F-T-F Stdev	90%	95%	99%
0.	0.	0.	0.	0.	0.	0.

Lower Bound				Upper Bound		
90%	95%	99%	H-T-F Stdev	90%	95%	99%
0.	0.	0.	0.	0.	0.	0.

Safe-life Results

from .out File



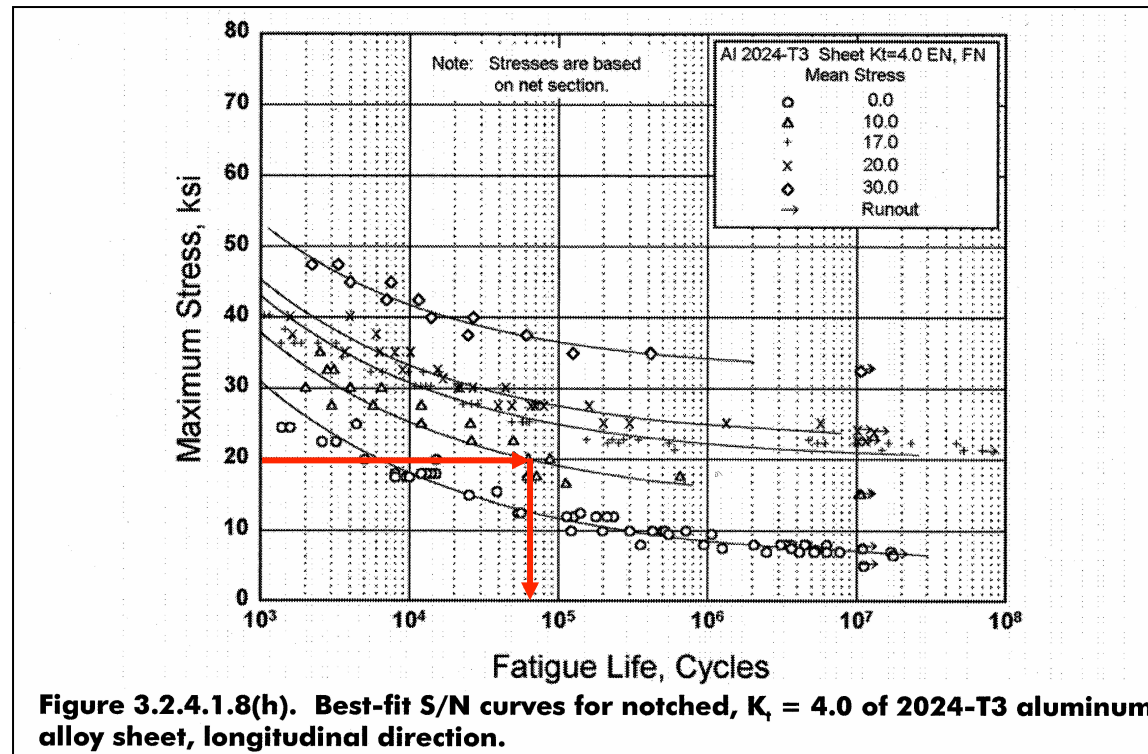
$$\text{Log}(N) = A + B(\text{Log}(S_{eq} + C)) + Z(\text{Stdev})$$

$$S_{eq} = 20(1-0)^{0.66} = 20 \text{ KSI}$$

$$\text{Log}(N) = 8.3 - 3.3(\text{Log}(20 - 8.5))$$

$$\text{Log}(N) = 4.7997$$

$$N = 63052 \text{ cycles}$$





TEXTRON AVIATION

PSN Region Accumulated Damage



**** SN REGION PERCENTAGE DAMAGE ****

SN REGION	TOTAL
BELOW 1 KSI:	0.00
BETWEEN 1 AND 2 KSI:	0.00
BETWEEN 2 AND 3 KSI:	0.00
BETWEEN 3 AND 4 KSI:	0.00
BETWEEN 4 AND 5 KSI:	0.00

... Lines were removed from this output ...

BETWEEN 10 AND 11 KSI:	0.00
BETWEEN 11 AND 12 KSI:	0.00
BETWEEN 12 AND 13 KSI:	0.00
BETWEEN 13 AND 14 KSI:	0.00
BETWEEN 14 AND 15 KSI:	0.00
BETWEEN 15 AND 16 KSI:	0.00
BETWEEN 16 AND 17 KSI:	0.00
BETWEEN 17 AND 18 KSI:	0.00
BETWEEN 18 AND 19 KSI:	0.00
BETWEEN 19 AND 20 KSI:	0.00

BETWEEN 20 AND 21 KSI:	100.00
BETWEEN 21 AND 22 KSI:	0.00
BETWEEN 22 AND 23 KSI:	0.00
BETWEEN 23 AND 24 KSI:	0.00
BETWEEN 24 AND 25 KSI:	0.00
BETWEEN 25 AND 26 KSI:	0.00
BETWEEN 26 AND 27 KSI:	0.00
BETWEEN 27 AND 28 KSI:	0.00
BETWEEN 28 AND 29 KSI:	0.00
BETWEEN 29 AND 30 KSI:	0.00

... Lines were removed from this output ...

BETWEEN 39 AND 40 KSI:	0.00
ABOVE 40 KSI:	0.00

TOTAL STAGE PERCENTAGE 100.00

Example 2



Variable	Characteristics
Loading	User Spectrum
Damage Index	Normal distribution with mean 1.0 and standard deviation 0.1
SN Curve	User SN Curve

LD Example 1 (Begin Tab)



SMART - Small Aircraft Risk Technology

File Documentation

Begin Usage Spectra

Name:

Aircraft Make:

Aircraft Model:

Aircraft Serial No.:

Aircraft TCDS:

Use Previous Run

Description:

Miner's Rule Damage Factor:

Mean:

Std. Dev:

SN Curve:

Analysis Type:

No. Simulations:

Seed:

Stress Severity Factor Calculation

User Input PSN Curves Direct Input

Alpha:

Beta:

Theta:

Thickness:

Width:

Diameter:

Edge Distance:

SSF:

07/10/2015-V4.0.7

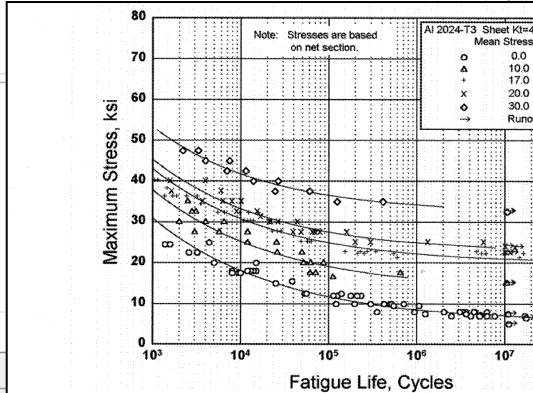


Figure 3.2.4.1.8(h). Best-fit S/N curves for notched, $K_t = 4.0$ of 2024-T3 aluminum alloy sheet, longitudinal direction.

LD Example 1 (User SN)



SMART - Small Aircraft Risk Technology

File Documentation

Begin Usage Spectra

Load Spectrum: C:\Users\pze593\Desktop\BenchmarkProblems\Example3_LD\Example_3LD_Spectrum.sp3 Transfer Factor: 1.0

Flight Hours for this Spectrum: 1000 Flight Hours per Flight: 1.1

Load Usages:

Usage Spectra

Aircraft Usage:

Percent of Total Usage: Exceedance COV: 12.0

Design Maneuver Load Factor High: One G Stress (psi):

Design Gust Load Factor High: Average Velocity (Vno/Vmo(Knots)):

Design Maneuver Load Factor Low: Number of Flight Times:

Design Gust Load Factor Low: Number of Velocities:

Ground Stress (psi): Load Matrices

File:

Flight Variation

07/10/2015-V4.0.7

Example_3LD_Spectrum01.sub - Note...

File Edit Format View Help

1	7	
15.0	5.0	27000
19.0	2.0	2000
19.0	-4.0	500
22.0	-4.0	400
25.0	-4.0	90
29.0	-7.0	9
36.0	-13.0	1

LD Example 1 (Launch Panel Tab)



SMART - Small Aircraft Risk Technology

File Documentation

Begin Usage Spectra **Launch Panel**

```

!-----
! AIRCRAFT INFORMATION
!-----
TITLE = Example3_DT
AC_MAKE = None1
AC_MODEL = None2
AC_SERIAL_NUM = None3
AC_TCDS = None4
!-----
! SN-CURVE, MINERS AND SSF
!-----
SN_CURVE = USER_SN C:\Users\pze593\Desktop\BenchmarkProblems\Example3_LD\A16061-T6.sn
MINERS_D = NORMAL 1.0 0.1 0.0
SSF_TYPE = DIRECT
SSF = 1.00
!-----
! METHOD
!-----
MCSAMP = 10000
SEED = 123
INPUT_FILE = NO
ANALYSIS_TYPE = DAMAGE
!-----
! LOADING PARAMETERS
!-----
USER_SPECTRUM = C:\Users\pze593\Desktop\BenchmarkProblems\Example3_LD\Example_3LD_Spectrum.sp3
TRANSFER_FACTOR = 1.0
SPECTRUM_HOURS = 1000
HOURS_PER_FLIGHT = 1.1
!-----
! DESCRIPTION
!-----

```

Run

07/10/2015-V4.0.7



SMART - Small Aircraft Risk Technology

File Documentation

Results

Load Output File: C:\Users\pze593\Desktop\BenchmarkProblems\Example3_LD\Example3_DT.txt Load Output

Pareto

Hours to Failure Plot

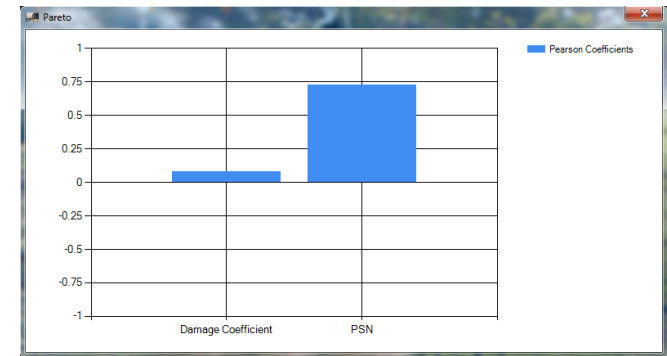
Samples Output Screen out Fleet Management

	Lower Bound			H-I-F Stdev	Upper Bound		
	90%	95%	99%		90%	95%	99%
	47729.	47624.	47419.	48284.	48853.	48963.	49179.

**** PEARSON CORRELATIONS ****

	Damage Coefficient	PSN
FTF	0.08051	0.72741
HTF	0.08051	0.72741

07/10/2015-V4.0.7



Input & Output Summary .out File

```

... Lines were removed from this output ...
***SMART RESULTS***

      Probability      Flights-to-Failure      Hours-to-Failure
      0.500000          14892          16381
      0.100000          3295          3624
      0.010000          1033          1136
      0.001000           432           475
      0.000223           257           282

                          Mean Results
      Lower Bound      Upper Bound
      90%      95%      99%      F-T-F Mean      90%      95%      99%
27983.      27843.      27575.      28703.      29423.      29563.      29831.

      Lower Bound      Upper Bound
      90%      95%      99%      H-T-F Mean      90%      95%      99%
30782.      30627.      30333.      31574.      32365.      32520.      32814.

                          Stdev Results
      Lower Bound      Upper Bound
      90%      95%      99%      F-T-F Stdev      90%      95%      99%
43390.      43294.      43108.      43894.      44411.      44511.      44708.

      Lower Bound      Upper Bound
      90%      95%      99%      H-T-F Stdev      90%      95%      99%
47729.      47624.      47419.      48284.      48853.      48963.      49179.

-----
**** PEARSON CORRELATIONS ****

      Damage      PSN
      Coefficient
-----
FTF      0.08051      0.72741
HTF      0.08051      0.72741
-----

**** SN REGION PERCENTAGE DAMAGE ****
-----

      SN REGION      TOTAL
      BETWEEN 10 AND 11 KSI:      0.00
      BETWEEN 11 AND 12 KSI:      0.00
      BETWEEN 12 AND 13 KSI:      0.00
      BETWEEN 13 AND 14 KSI:      0.00
      BETWEEN 14 AND 15 KSI:      0.00
      BETWEEN 15 AND 16 KSI:      8.11
      BETWEEN 16 AND 17 KSI:      0.00
      BETWEEN 17 AND 18 KSI:      0.00
      BETWEEN 18 AND 19 KSI:      0.00
      BETWEEN 19 AND 20 KSI:      44.14
      BETWEEN 20 AND 21 KSI:      0.00
      BETWEEN 21 AND 22 KSI:      0.00
      BETWEEN 22 AND 23 KSI:      31.26
      BETWEEN 23 AND 24 KSI:      0.00
      BETWEEN 24 AND 25 KSI:      0.00
      BETWEEN 25 AND 26 KSI:      12.39
      BETWEEN 26 AND 27 KSI:      0.00
      BETWEEN 27 AND 28 KSI:      0.00
      BETWEEN 28 AND 29 KSI:      0.00
      BETWEEN 29 AND 30 KSI:      3.01
      BETWEEN 30 AND 31 KSI:      0.00
      BETWEEN 31 AND 32 KSI:      0.00

... Lines were removed from this output ...

```




TEXTRON AVIATION

Safe-life Results

from .out File



Probability	Flights-to-Failure	Hours-to-Failure
0.500000	14892	16381
0.100000	3295	3624
0.010000	1033	1136
0.001000	432	475
0.000223	257	282

Mean Results

Lower Bound				Upper Bound		
90%	95%	99%	F-T-F Mean	90%	95%	99%
27983.	27843.	27575.	28703.	29423.	29563.	29831.

Lower Bound				Upper Bound		
90%	95%	99%	H-T-F Mean	90%	95%	99%
30782.	30627.	30333.	31574.	32365.	32520.	32814.

Stdev Results

Lower Bound				Upper Bound		
90%	95%	99%	F-T-F Stdev	90%	95%	99%
43390.	43294.	43108.	43894.	44411.	44511.	44708.

Lower Bound				Upper Bound		
90%	95%	99%	H-T-F Stdev	90%	95%	99%
47729.	47624.	47419.	48284.	48853.	48963.	49179.



TEXTRON AVIATION

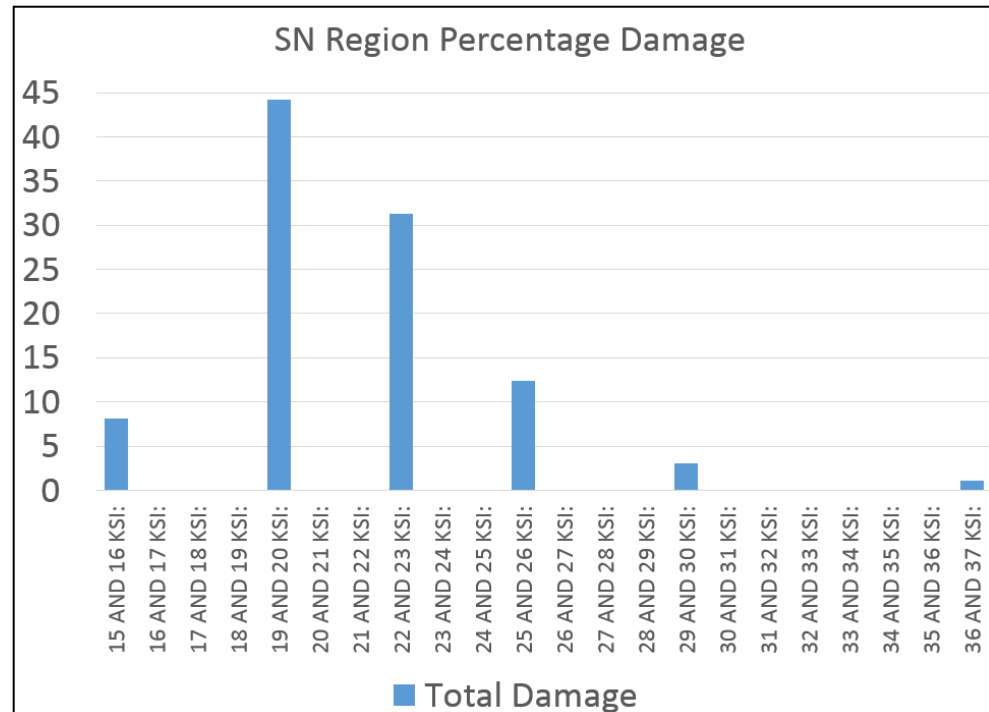
PSN Region Accumulated Damage



**** SN REGION PERCENTAGE DAMAGE ****

SN REGION	TOTAL
BELOW 1 KSI:	0.00
BETWEEN 14 AND 15 KSI:	0.00
BETWEEN 15 AND 16 KSI:	8.11
BETWEEN 16 AND 17 KSI:	0.00
BETWEEN 17 AND 18 KSI:	0.00
BETWEEN 18 AND 19 KSI:	0.00
BETWEEN 19 AND 20 KSI:	44.14
BETWEEN 20 AND 21 KSI:	0.00
BETWEEN 21 AND 22 KSI:	0.00
BETWEEN 22 AND 23 KSI:	31.26
BETWEEN 23 AND 24 KSI:	0.00
BETWEEN 24 AND 25 KSI:	0.00
BETWEEN 25 AND 26 KSI:	12.39
BETWEEN 26 AND 27 KSI:	0.00
BETWEEN 27 AND 28 KSI:	0.00
BETWEEN 28 AND 29 KSI:	0.00
BETWEEN 29 AND 30 KSI:	3.01
BETWEEN 30 AND 31 KSI:	0.00
BETWEEN 31 AND 32 KSI:	0.00
BETWEEN 32 AND 33 KSI:	0.00
BETWEEN 33 AND 34 KSI:	0.00
BETWEEN 34 AND 35 KSI:	0.00
BETWEEN 35 AND 36 KSI:	0.00
BETWEEN 36 AND 37 KSI:	1.08
BETWEEN 37 AND 38 KSI:	0.00
BETWEEN 38 AND 39 KSI:	0.00
BETWEEN 39 AND 40 KSI:	0.00
ABOVE 40 KSI:	0.00

TOTAL STAGE PERCENTAGE 100.00



Summary



- ✓ We Reviewed:
 - ✓ SMART|LD Files Overview
 - ✓ Safe-Life Analysis
 - ✓ User Loading
 - ✓ User SN-Curves
- ✓ Ran Safe Life Example Problems:
 - ✓ User spectrum Single Load User SN Curve

Questions

