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
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      - ✓ 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

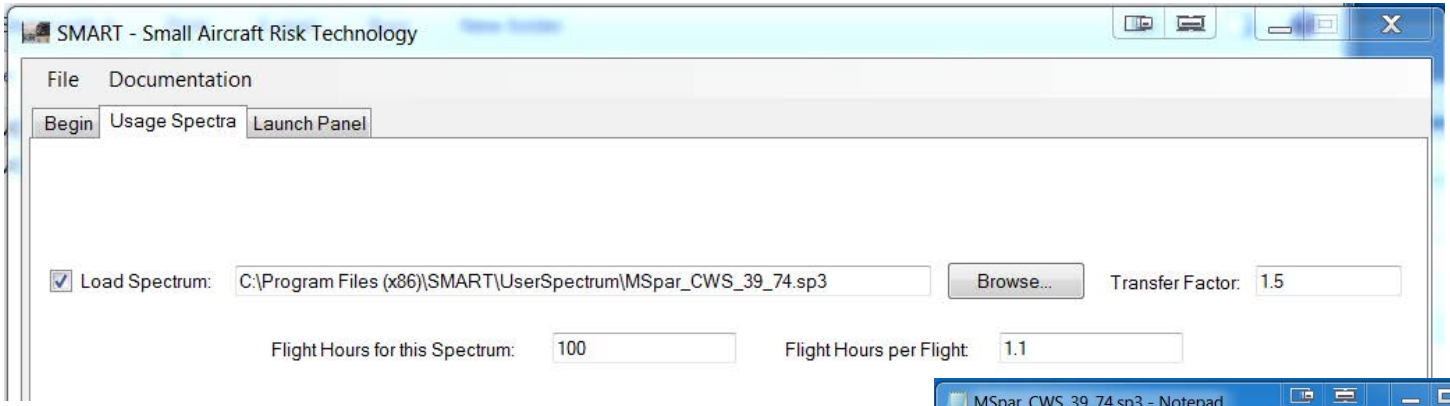
SMART|LD Files Overview

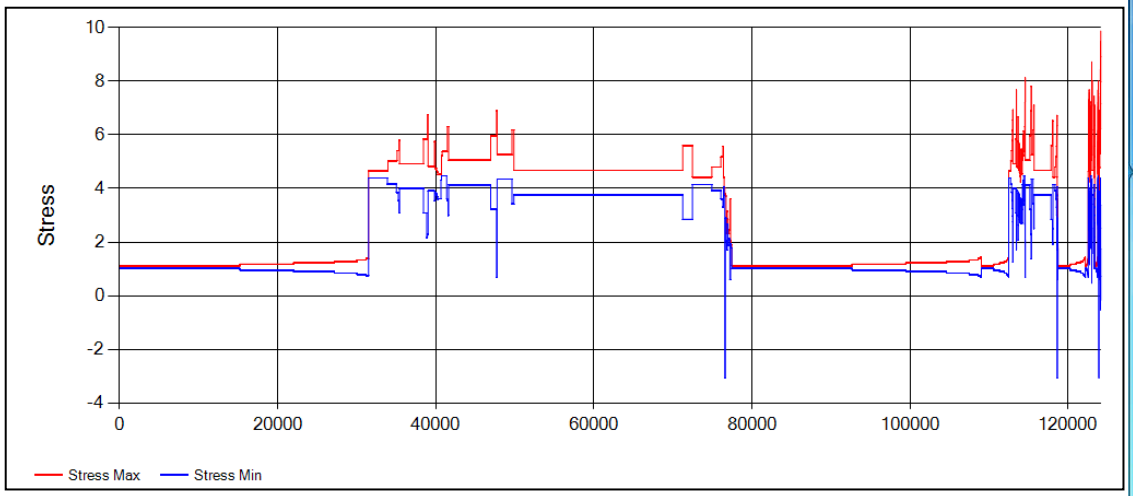
File Type	Description
`jobname.dat`	Input file containing the keywords and run information
`jobname.err`	Runtime error file
`jobname.wrn`	Runtime warning file
`jobname.out`	File containing a summary of the inputs and statistical results
`jobname.txt`	File containing the Monte Carlo realizations

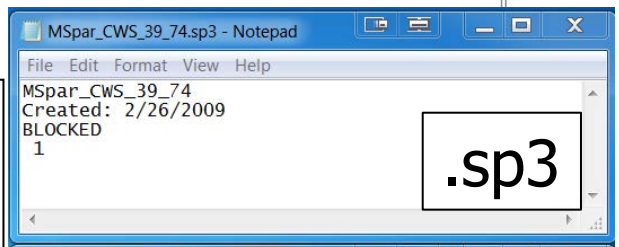
Input
output

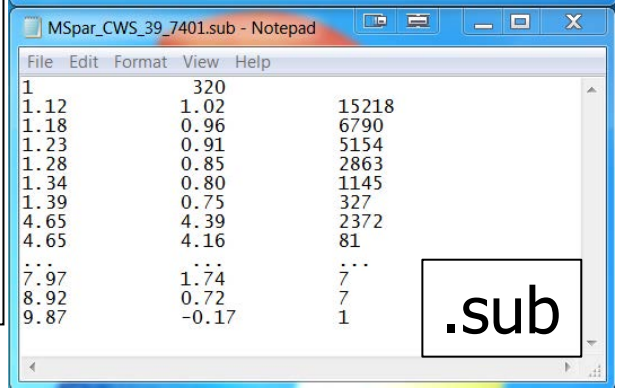
Smart User Spectra

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

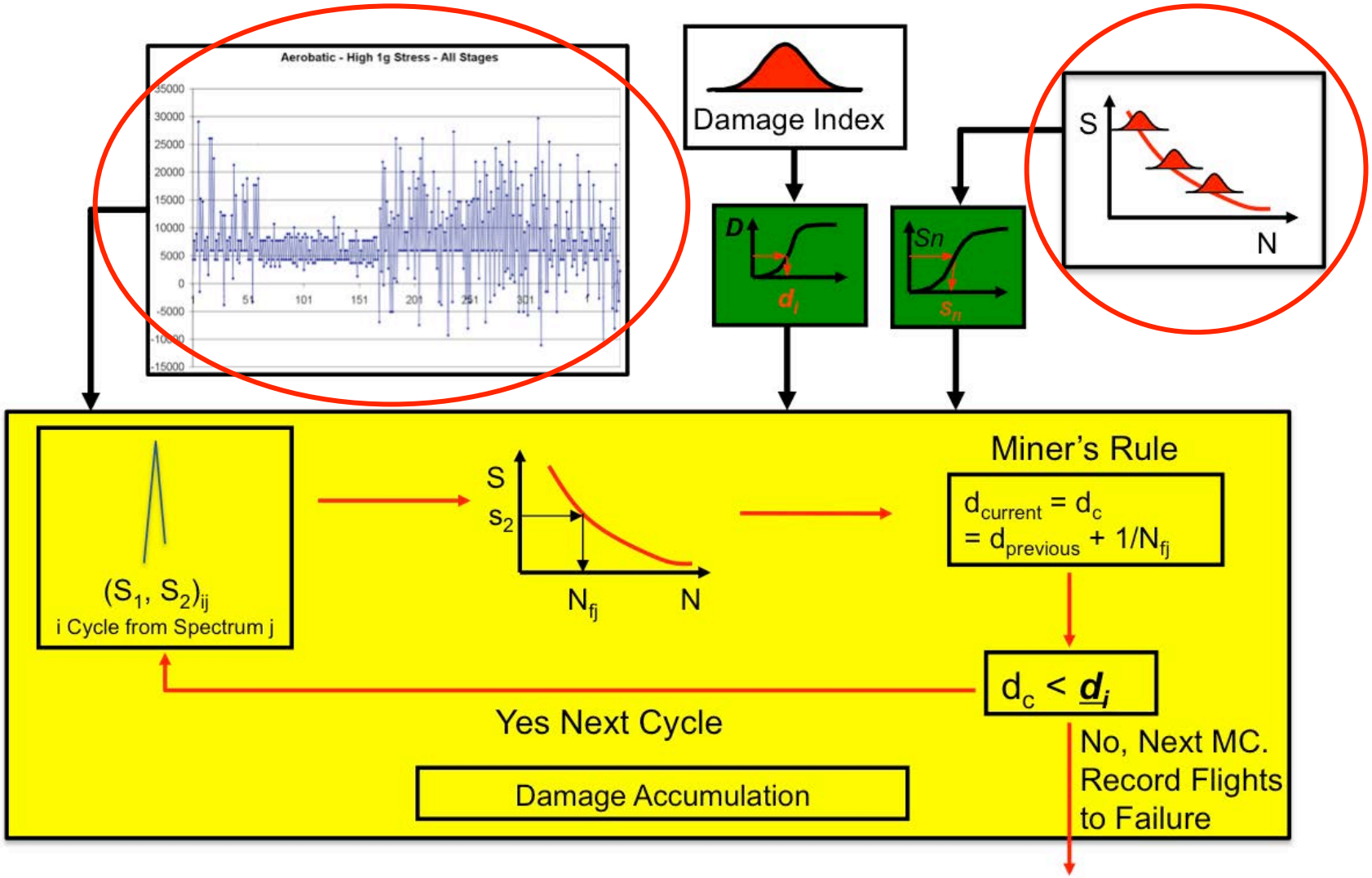








Damage Methodology (Safe Life)



User SN

MMPDS Methodology

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

$$Seq = S\max \cdot (1 - R)^{D}$$

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

A, B, C, and *D* = Regression Parameters
N = Fatigue Life in cycles
Stdev = Standard deviation
Seq = Equivalent Stress
R = Stress Ratio *(Smin/Smax)*,
Z~N(0,1) = Standard normal

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

Al2024-T3_Kt4-0_SD=0.sn - Notepad

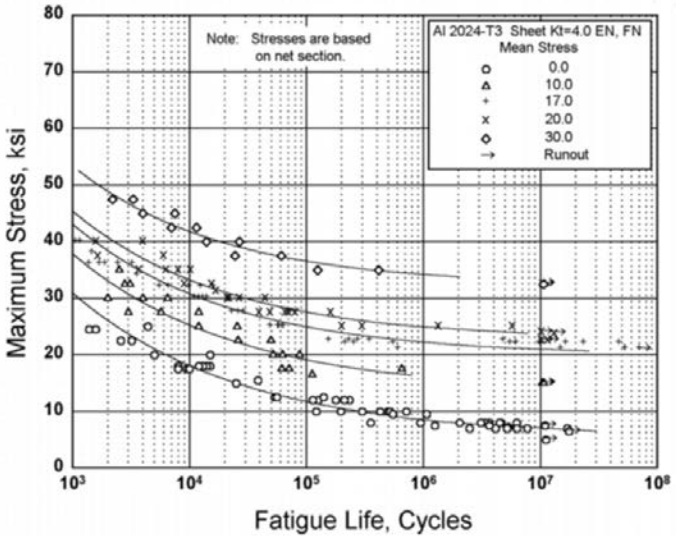
File Edit Format View Help

```
! 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$_{LD}$

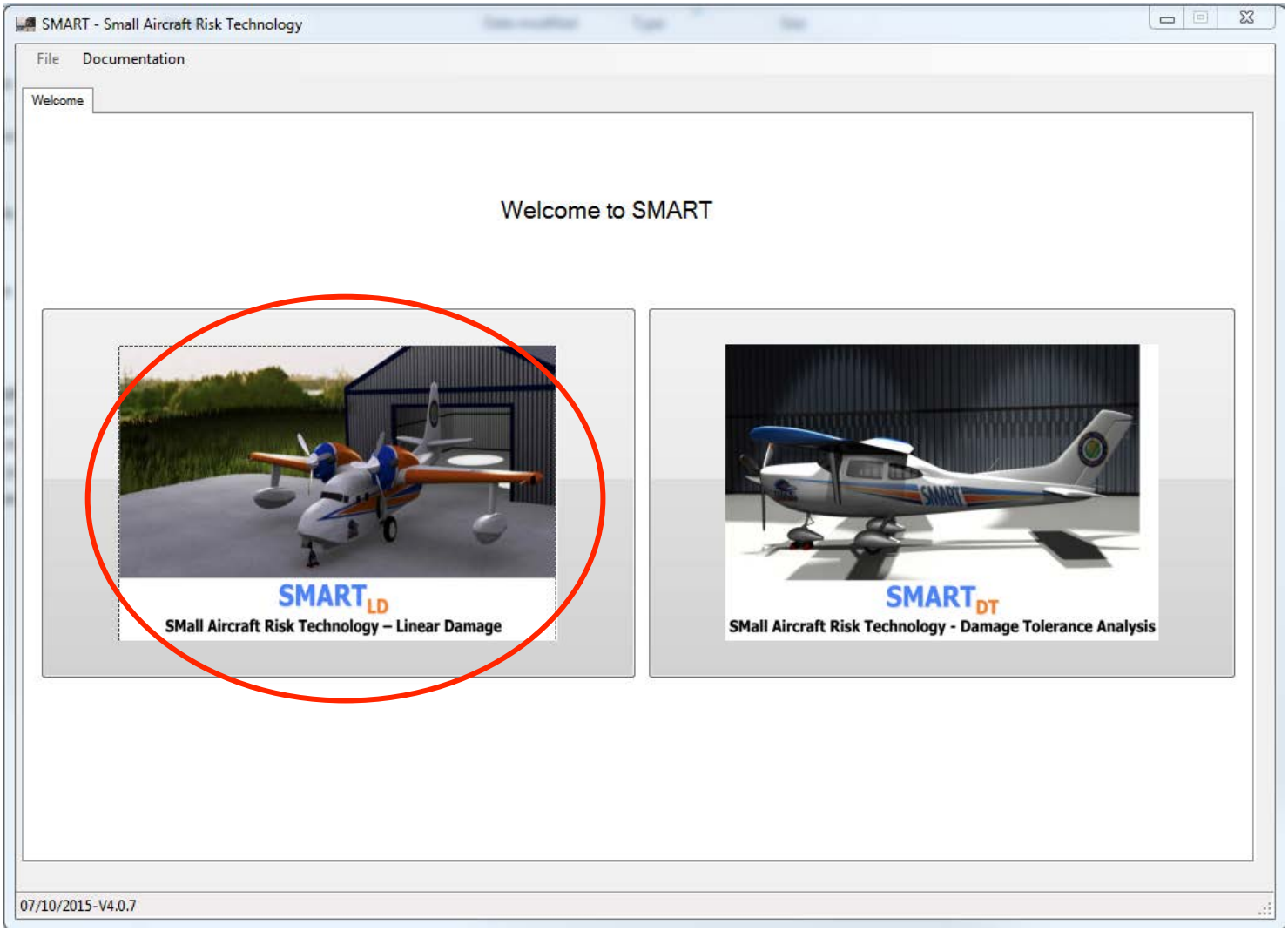
SMall Aircraft Risk Technology – Linear Damage Analysis

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: User_SN_Load

Aircraft Make: None1

Aircraft Model: None2

Aircraft Serial No.: None3

Aircraft TCDS: None4

Use Previous Run

Browse...

Description:

Miner's Rule Damage Factor: NORMAL

Mean: 1.0

Std. Dev: 0.0

PDF/CDF

SN Curve: USER_SN

Browse...

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

Analysis Type: DAMAGE

No. Simulations: 1

Seed: 7212362

Stress Severity Factor Calculation

User Input | PSN Curves | Direct Input

Alpha:

SSF: 1.0

Beta:

Theta:

Thickness:

Width:

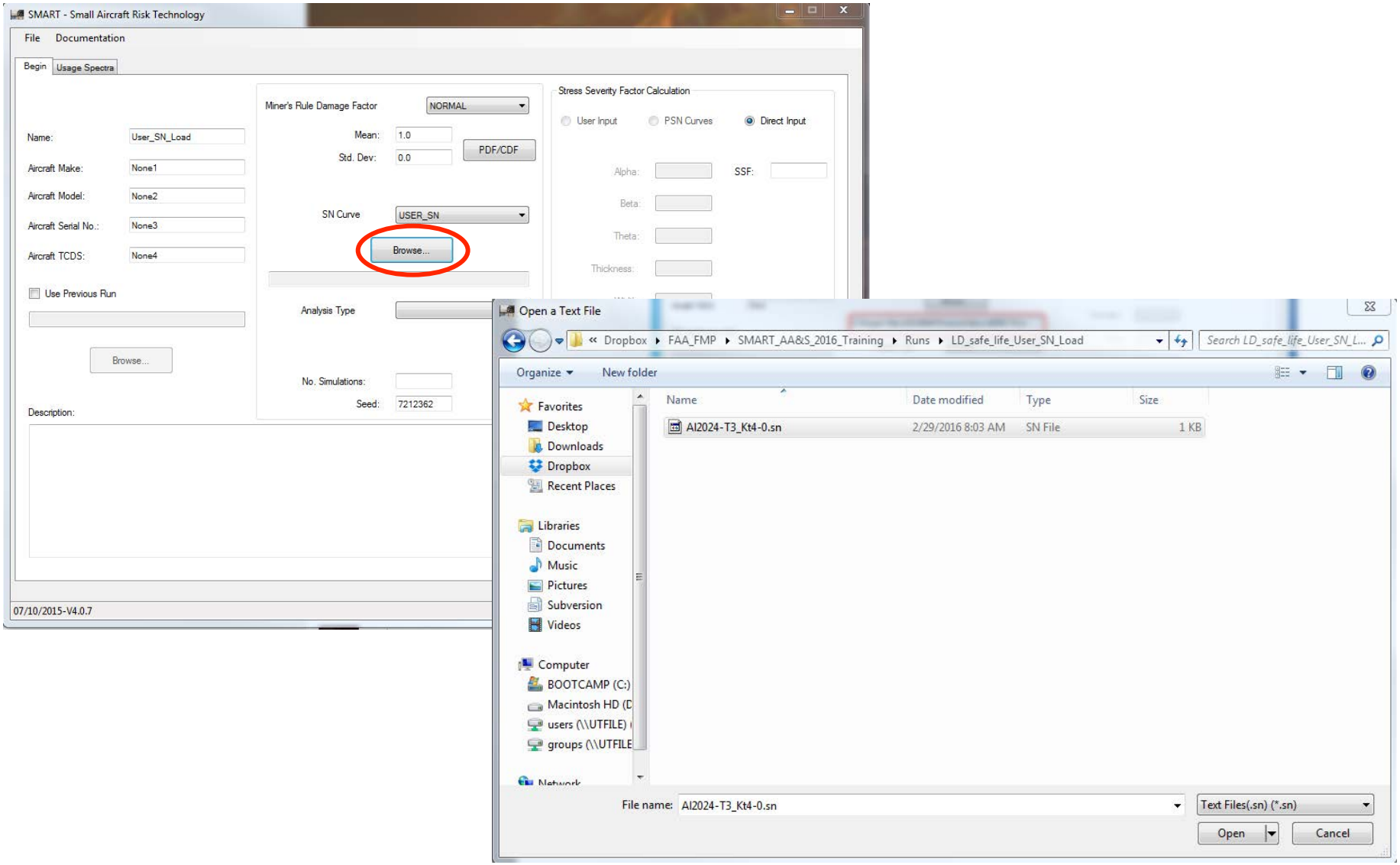
Diameter:

Edge Distance:

Load Transfer:

07/10/2015-V4.0.7

LD Example 1 (User SN)



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 | Plot Exceedances

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 | Matrix

File: 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                    1
20.0                 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\Al2024-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 …

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

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

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

$$Log(N) = 8.3 - 3.3(Log(20 - 8.5))$$

$$Log(N) = 4.7997$$

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

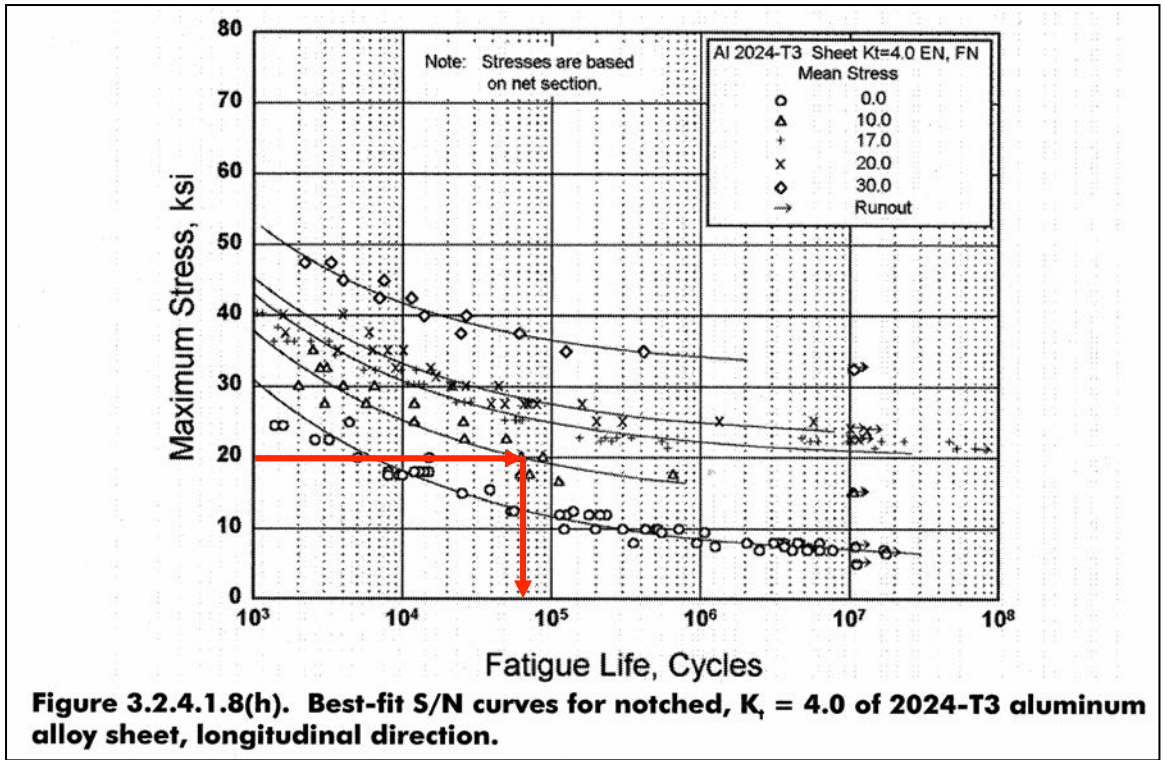


Figure 3.2.4.1.8(h). Best-fit S/N curves for notched, K_t = 4.0 of 2024-T3 aluminum alloy sheet, longitudinal direction.

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: Example3_DT

Aircraft Make: None1

Aircraft Model: None2

Aircraft Serial No.: None3

Aircraft TCDS: None4

Use Previous Run

Browse...

Description:

Miner's Rule Damage Factor: NORMAL

Mean: 1.0

Std. Dev: 0.1

PDF/CDF

SN Curve: USER_SN

Browse...

C:\Users\pze593\Desktop\BenchmarkProblems\Example3_LD\Al6t

Analysis Type: DAMAGE

No. Simulations: 10000

Seed: 123

Stress Severity Factor Calculation

User Input | PSN Curves | Direct Input

Alpha:

SSF: 1.000

Beta:

Theta:

Thickness:

Width:

Diameter:

Edge Distance:

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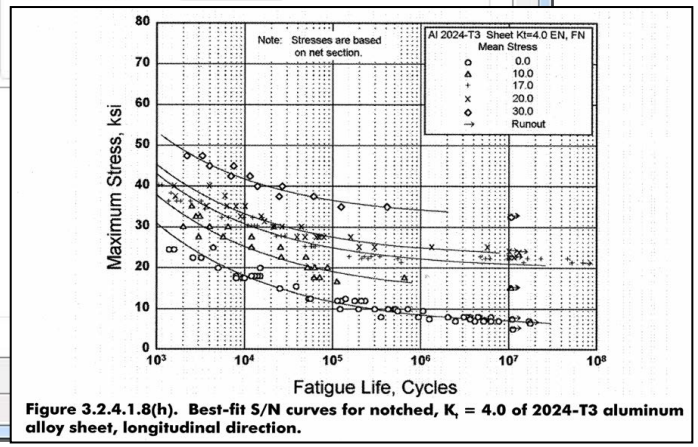

Figure 3.2.4.1.8(h). Best-fit S/N curves for notched, K_t = 4.0 of 2024-T3 aluminum alloy sheet, longitudinal direction.

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 Browse... Transfer Factor: 1.0

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

Load Usages:

Usage Spectra

Aircraft Usage | Plot Exceedances

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 | Matrix

File: Browse... Save Usage

Flight Variation

Deleted Usages

Next Tab

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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

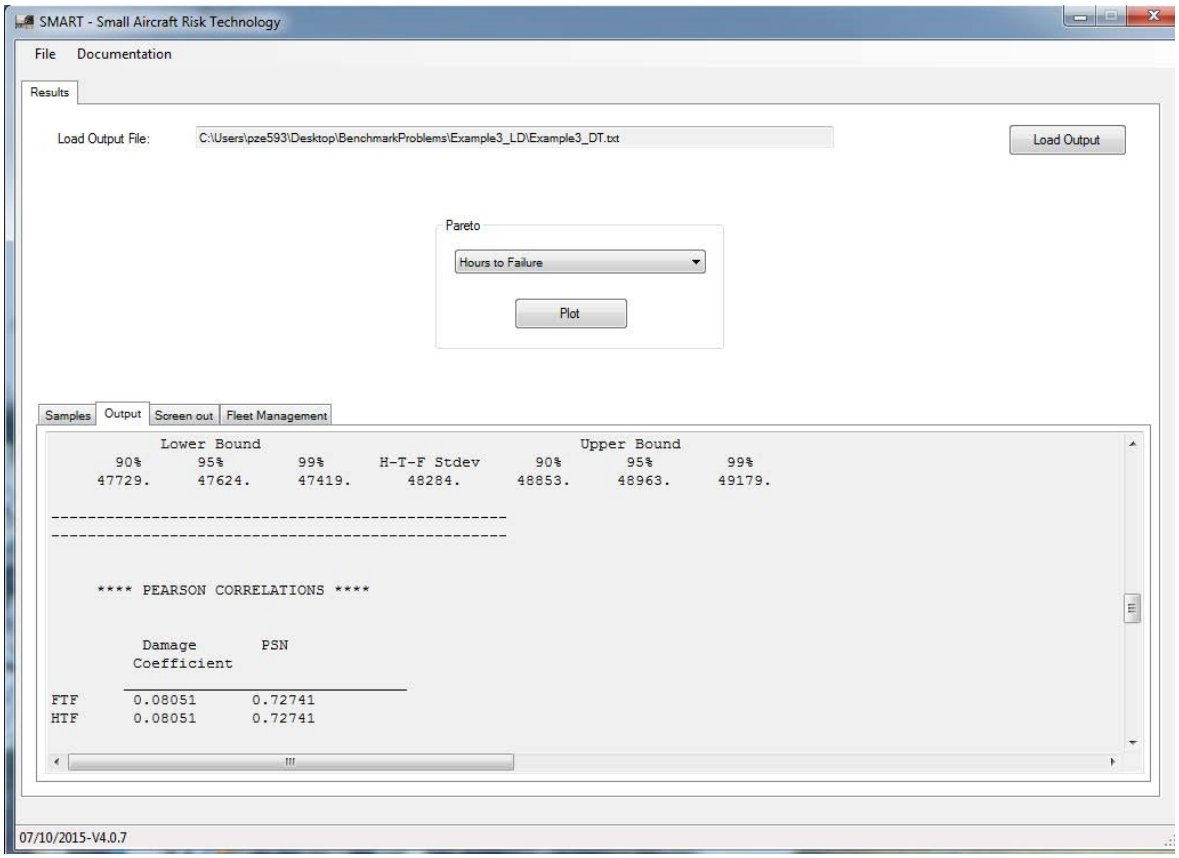
File | Documentation

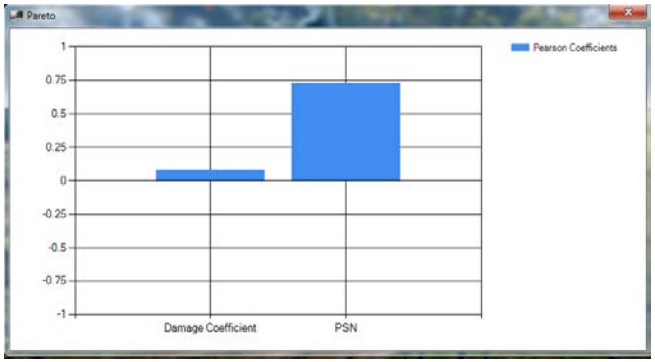
Begin | Usage Spectra | Launch Panel

```
! ------------------------------------------------------------
!                  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\Al6061-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
Upper Bound
90% 95% 99% H-T-F Stdev 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


Pareto
Pearson Coefficients
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
Damage Coefficient
PSN

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 …
```

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

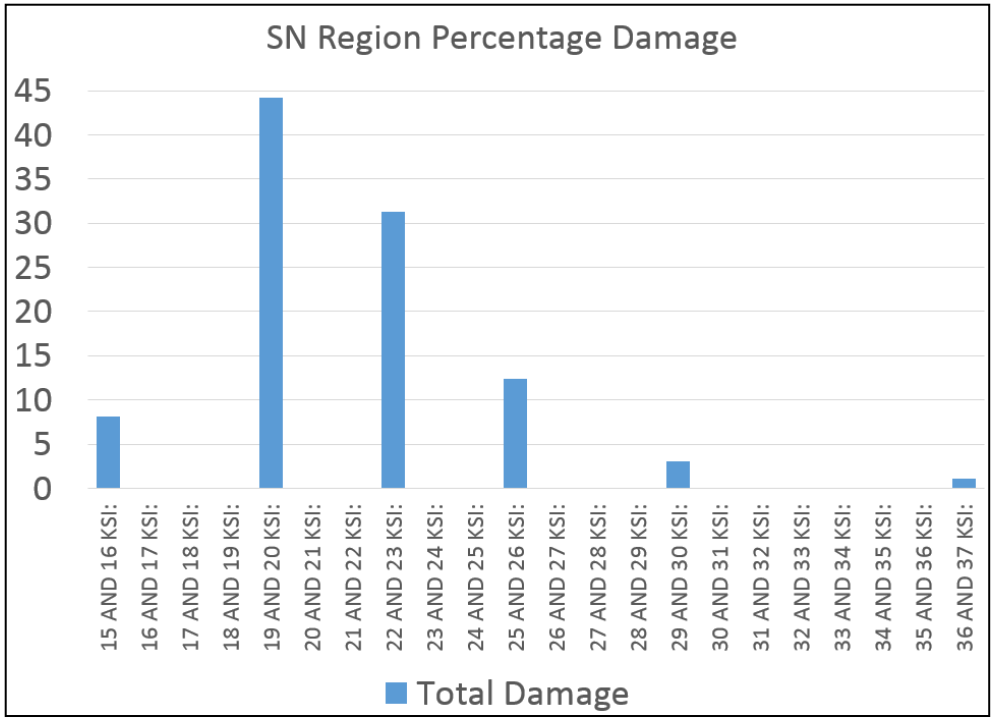
Lower Bound				Upper Bound		
90%	95%	99%	F-T-F Stdev	90%	95%	99%
43390.	43294.	43108.	43894.	44411.	44511.	44708.

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

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