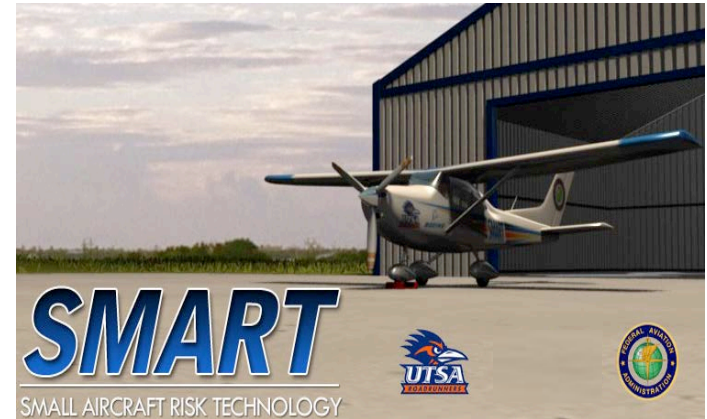


# SMART|LD Hours Mode – POF Calculations



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

# Outline



- ✓ SMART|LD Files Overview
- ✓ Hours Mode Analysis
  - ✓ Required Elements Hours Mode Analysis
    - ✓ Loading
    - ✓ SN-Curves
    - ✓ Random Miner's D
    - ✓ Total Flight Hours
  - ✓ Running Example Problem
    - ✓ Input File
    - ✓ GUI Inputs
    - ✓ Output Files
      - ✓ MonteCarlo Samples
      - ✓ Statistical Results
      - ✓ SN Region Percentage Damage
- ✓ Summary

# SMART Files Overview



**SMART**<sub>DT</sub>

**Small Aircraft Risk Technology - Damage Tolerance Analysis**

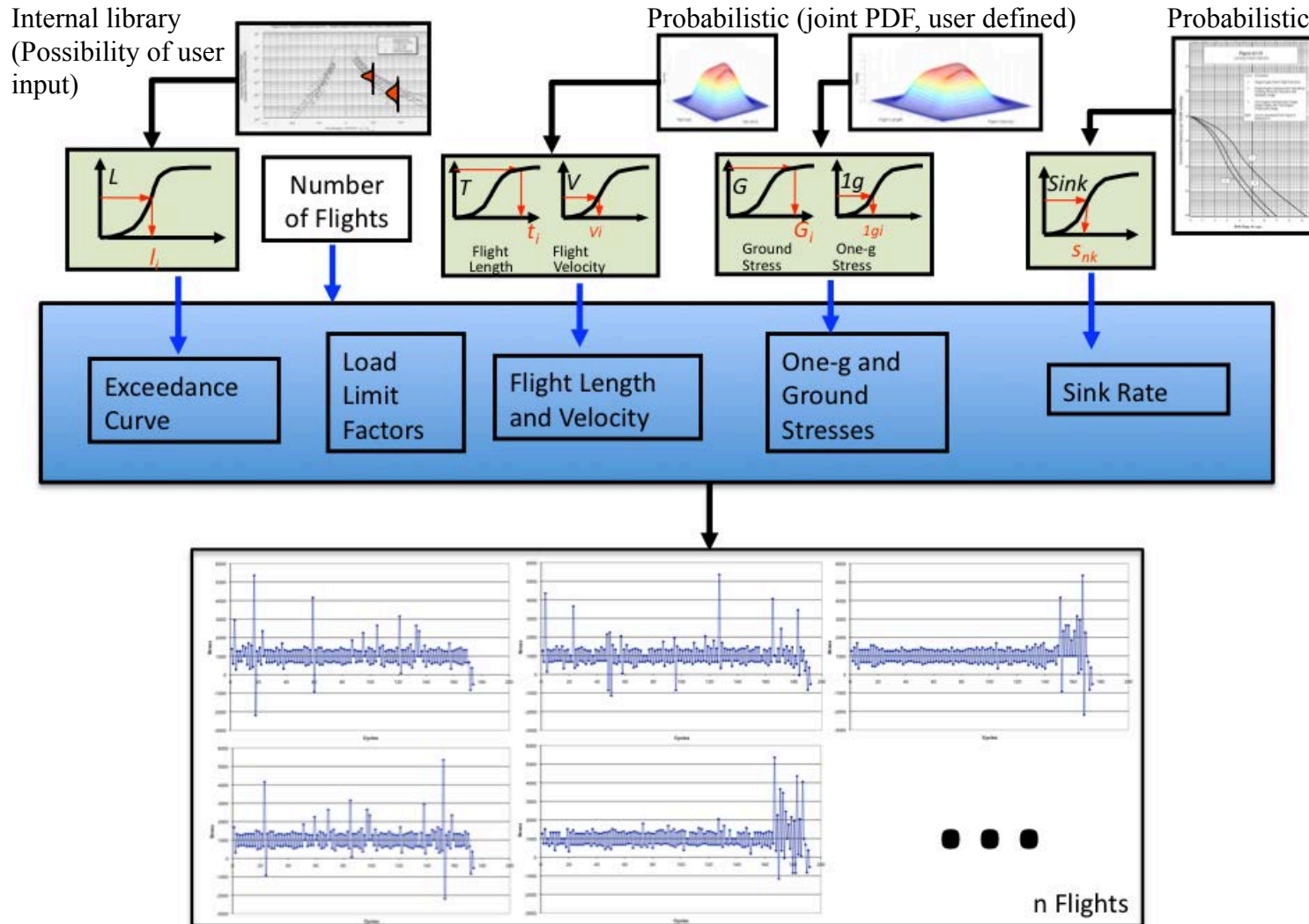
# SMART|LD Files Overview



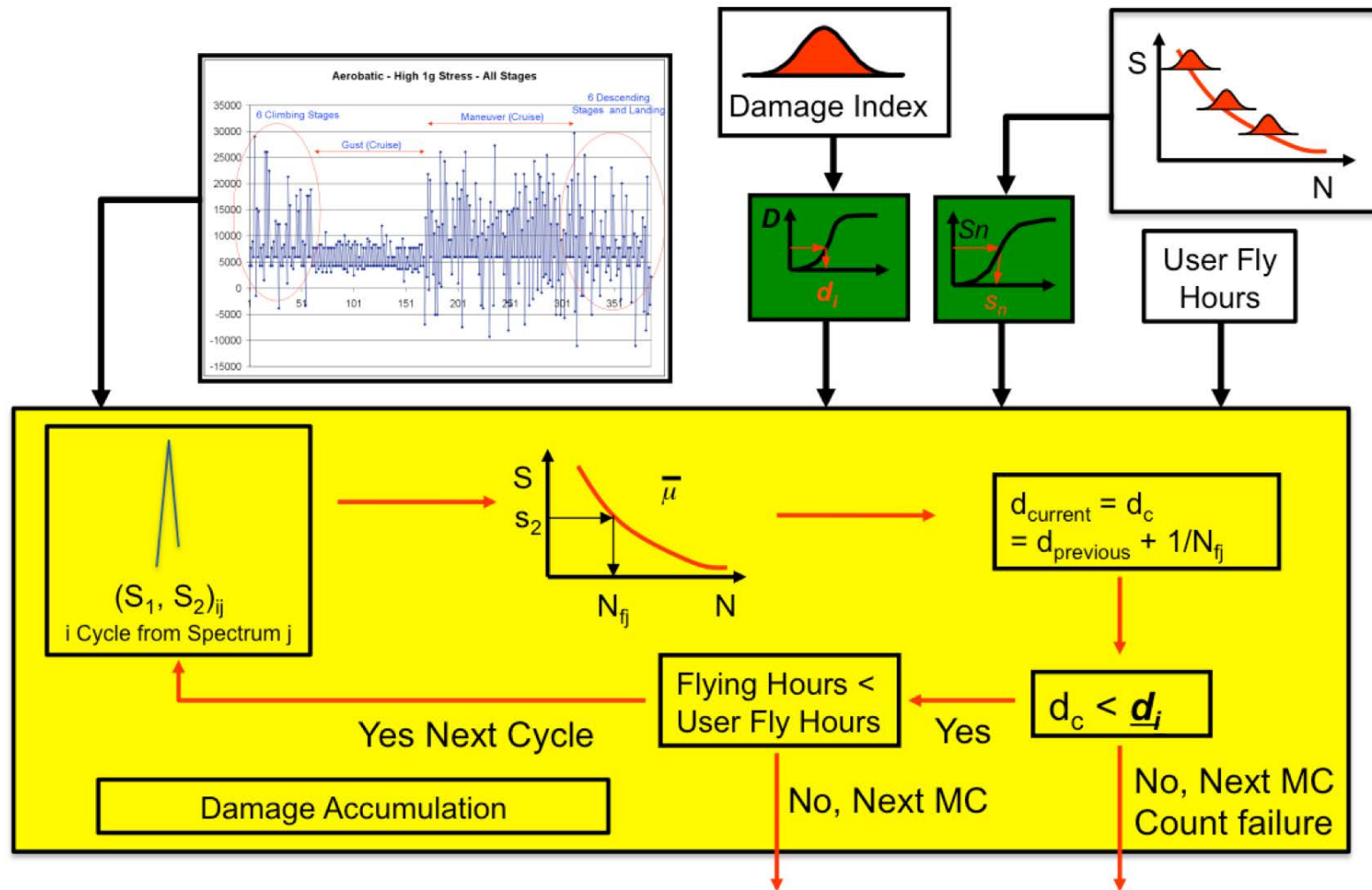
File Type	Description
<code>jobname.dat</code>	Input file containing the keywords and run information
<code>jobname.err</code>	Runtime error file
<code>jobname.wrn</code>	Runtime warning file
<code>jobname.out</code>	File containing a summary of the inputs and statistical results
<code>jobname.txt</code>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

**Input**  
**output**

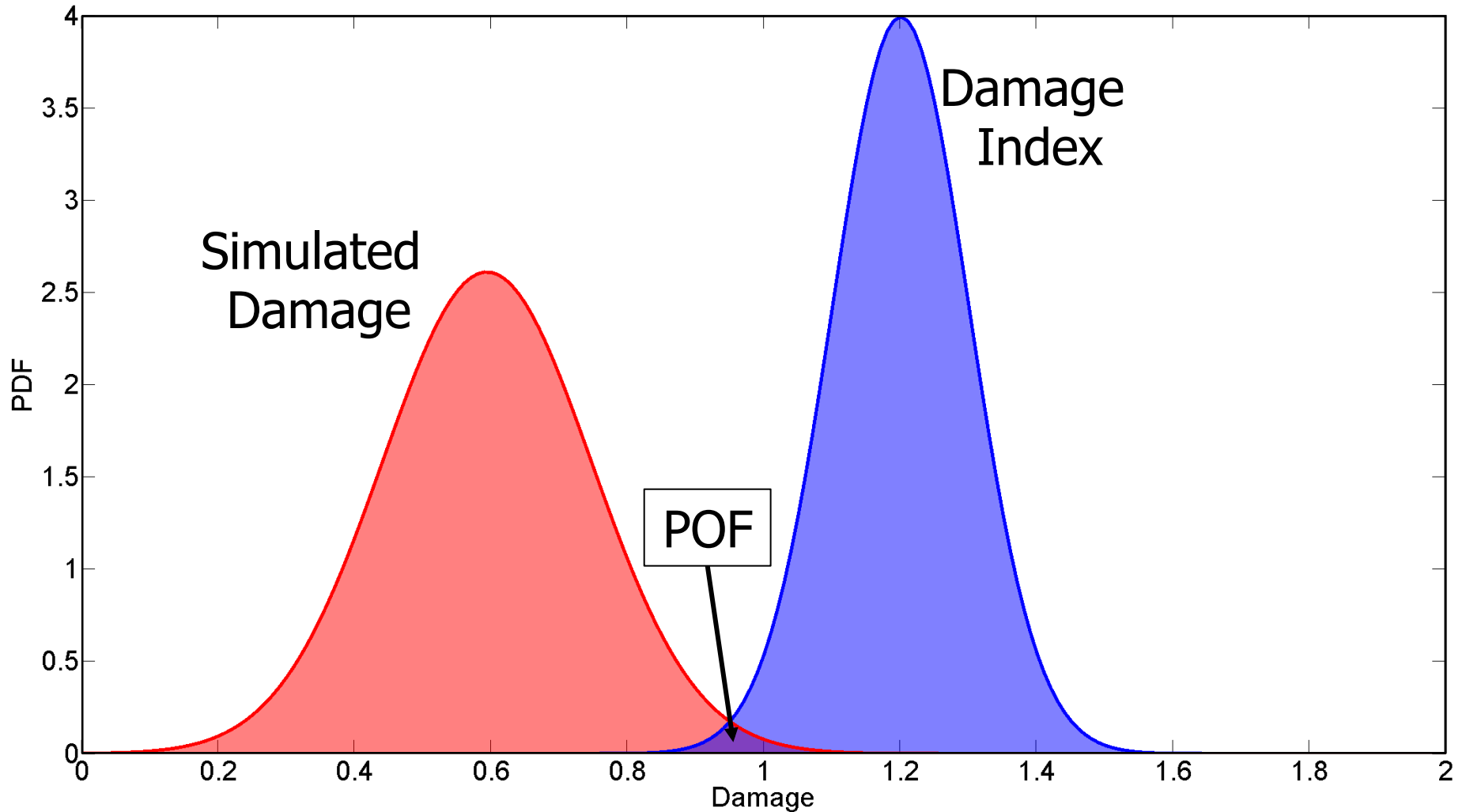
# Loading Generation



# Hours Methodology (Current-Future Risk)



# POF Calculations





NuSS  
Sustainment  
Solutions

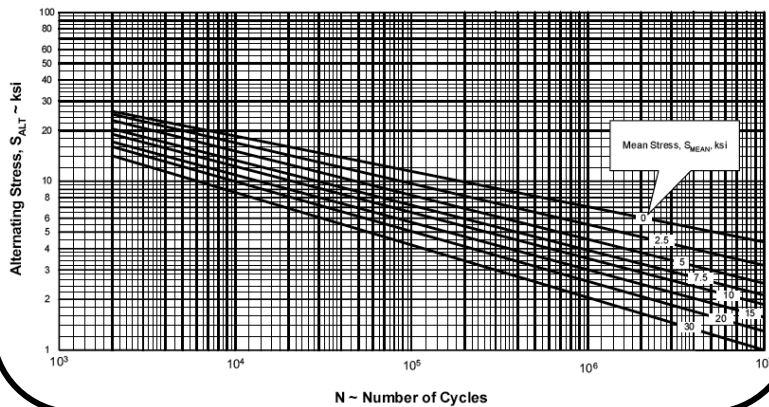
TEXTRON AVIATION

# Stress Life Curves

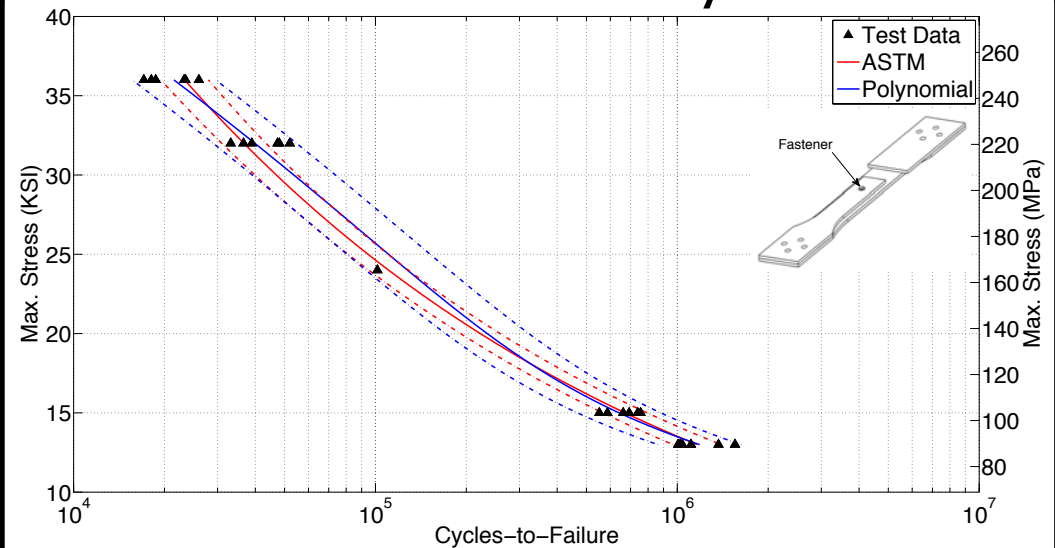
Risk Methodology



## FAA AC-23-13A



## ASTM E739-91 & Polynomial



```
AI6061-T6.sn
! LOG(N) = A + B * LOG (Seq + C) + Z*Stdev
! Seq = Smax*(1-R)^D
! E = Endurance limit
! Z ~ N(0,1)
```

\*\*\* SN PARAMETERS \*\*\*

```
A = 11.3196
B = -5.4083
C = 0.0
D = 0.0
E = 0.0
Stdev = 0.5
```

User-defined PSN

Testing  
Data





# Example Problem



**SMART**<sub>LD</sub>

**Small Aircraft Risk Technology – Linear Damage Analysis**

# LD Example 1



Variable	Characteristics																
Usage 1	TWIN ENGINE UNPRESS GENERAL USAGE																
Design LLF Maneuver	+3.6 -1.5																
Design LLF Gust	+3.3 -1.5																
Ground Stress	-4300																
One-g stress	7850																
Average Velocity (Vno/ Vmo(Knots))	175																
Flight length and Velocity Matrix	<table border="1"> <thead> <tr> <th colspan="2"></th> <th colspan="2">Average Speed During Flight, %V<sub>NO</sub> or %V<sub>MO</sub></th> </tr> <tr> <th>Flt. Time, Hrs</th> <th>Percentage of Flights.</th> <th>0.90</th> <th>1.00</th> </tr> </thead> <tbody> <tr> <td>1.00</td> <td>0.50</td> <td>0.40</td> <td>0.60</td> </tr> <tr> <td>1.50</td> <td>0.50</td> <td>0.60</td> <td>0.40</td> </tr> </tbody> </table>			Average Speed During Flight, %V <sub>NO</sub> or %V <sub>MO</sub>		Flt. Time, Hrs	Percentage of Flights.	0.90	1.00	1.00	0.50	0.40	0.60	1.50	0.50	0.60	0.40
		Average Speed During Flight, %V <sub>NO</sub> or %V <sub>MO</sub>															
Flt. Time, Hrs	Percentage of Flights.	0.90	1.00														
1.00	0.50	0.40	0.60														
1.50	0.50	0.60	0.40														
Flight length and Weight Matrix	<table border="1"> <thead> <tr> <th colspan="2"></th> <th colspan="2">Weight Percentage</th> </tr> <tr> <th>Flt. Time, Hrs</th> <th>Percentage of Flights.</th> <th>0.90</th> <th>1.00</th> </tr> </thead> <tbody> <tr> <td>1.00</td> <td>0.50</td> <td>0.40</td> <td>0.60</td> </tr> <tr> <td>1.50</td> <td>0.50</td> <td>0.60</td> <td>0.40</td> </tr> </tbody> </table>			Weight Percentage		Flt. Time, Hrs	Percentage of Flights.	0.90	1.00	1.00	0.50	0.40	0.60	1.50	0.50	0.60	0.40
		Weight Percentage															
Flt. Time, Hrs	Percentage of Flights.	0.90	1.00														
1.00	0.50	0.40	0.60														
1.50	0.50	0.60	0.40														

# LD Example 1



Variable	Characteristics									
Usage 1	User Defined									
Design LLF Maneuver	+3.1 -1.6									
Design LLF Gust	+3.2 -1.5									
Ground Stress	-4800									
One-g stress	8100									
Average Velocity (Vno/ Vmo(Knots))	175									
Flight length and Velocity Matrix	<table border="1"> <thead> <tr> <th></th> <th></th> <th>Average Speed During Flight, %V<sub>NO</sub> or %V<sub>MO</sub></th> </tr> </thead> <tbody> <tr> <td>Flt. Time, Hrs</td> <td>Percentage of Flights.</td> <td>1.00</td> </tr> <tr> <td>1.00</td> <td>1.00</td> <td>1.00</td> </tr> </tbody> </table>			Average Speed During Flight, %V <sub>NO</sub> or %V <sub>MO</sub>	Flt. Time, Hrs	Percentage of Flights.	1.00	1.00	1.00	1.00
		Average Speed During Flight, %V <sub>NO</sub> or %V <sub>MO</sub>								
Flt. Time, Hrs	Percentage of Flights.	1.00								
1.00	1.00	1.00								
Flight length and Weight Matrix	<table border="1"> <thead> <tr> <th></th> <th></th> <th>Weight Percentage</th> </tr> </thead> <tbody> <tr> <td>Flt. Time, Hrs</td> <td>Percentage of Flights.</td> <td>1.00</td> </tr> <tr> <td>1.00</td> <td>1.00</td> <td>1.00</td> </tr> </tbody> </table>			Weight Percentage	Flt. Time, Hrs	Percentage of Flights.	1.00	1.00	1.00	1.00
		Weight Percentage								
Flt. Time, Hrs	Percentage of Flights.	1.00								
1.00	1.00	1.00								

# LD Example 1



Variable	Characteristics
Miner's Rule Damage Factor	Normal 1.0 ( $\mu$ ) 0.1( $\sigma$ )
MCSAMP	1,000
SEED	8520
S-N Curve	AC23
Analysis Type/ Print POF Every	HOURS (9,000 Hours) / (3,000 Hours)

# LD Example 1 (Select SMART|LD)




SMART - Small Aircraft Risk Technology


File Documentation

Welcome

Welcome to SMART



**SMART<sub>LD</sub>**  
Small Aircraft Risk Technology - Linear Damage



**SMART<sub>DT</sub>**  
Small Aircraft Risk Technology - Damage Tolerance Analysis

07/10/2015-V4.0.7

# 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:

Total Hours:

Print Interval:

No. Simulations:

Seed:

Stress Severity Factor Calculation

User Input  PSN Curves  Direct Input

Alpha:

SSF:

Beta:

Theta:

Thickness:

Width:

Diameter:

Edge Distance:

Load Transfer:

12/23/2014-V3.1 Workshop

# LD Example 1 (Usage Spectra Tab)



SMART - Small Aircraft Risk Technology

File Documentation

Begin Usage Spectra

Load Spectrum:  Browse... Transfer Factor: 1.0

Flight Hours for this Spectrum:  Flight Hours per Flight:

Load Usages:

- TEUG
- USER

Usage Spectra

Aircraft Usage: TWIN\_ENGINE\_UNPRESS\_GENERAL\_USAGE

Percent of Total Usage:   Exceedance COV

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:  Browse...

Flight Variation

12/23/2014-V3.1 Workshop

Matrix

Flight Times vs. Velocity

Flt Time(hrs)	% of Flts.	%Vno or %Vmo	%Vno or %Vmo
1.0	0.5	0.90	1.0
1.5	0.5	0.4	0.6

Flight Times vs. Weight

Flt Time(hrs)	% of Flts.	%Max. Wt.	%Max. Wt.
1.0	0.5	0.9	1.0
1.5	0.5	0.4	0.6

# LD Example 1 (Usage Spectra Tab)



SMART - Small Aircraft Risk Technology

File Documentation

Begin Usage Spectra

Load Spectrum: [ ] Reuse: [ ] Transfer: [ ] 1.0

GUST						MAN					
a.f	freq. inc/nm	cov	a.f	freq. inc/nm	cov	a.f	freq. inc/nm	cov	a.f	freq. inc/nm	cov
0.10	4.89089e-01	12	-0.10	5.23163e-01	12	0.10	7.33909e-02	12	-0.10	9.43311e-02	12
0.15	1.02496e-01	12	-0.15	1.42205e-01	12	0.15	3.10201e-02	12	-0.15	2.52461e-02	12
0.20	2.92114e-02	12	-0.20	2.58887e-02	12	0.20	1.24950e-02	12	-0.20	7.01403e-03	12
0.25	6.42846e-03	12	-0.25	5.78260e-03	12	0.25	5.78913e-03	12	-0.25	2.39671e-03	12
0.30	1.72636e-03	12	-0.30	1.47005e-03	12	0.30	2.88616e-03	12	-0.30	8.10359e-04	12
0.35	5.29138e-04	12	-0.35	4.02850e-04	12	0.35	1.49257e-03	12	-0.35	2.59770e-04	12
0.40	1.75933e-04	12	-0.40	1.15839e-04	12	0.40	7.81164e-04	12	-0.40	7.83959e-05	12
0.45	6.17108e-05	12	-0.45	3.43822e-05	12	0.45	4.08616e-04	12	-0.45	2.25858e-05	12
0.50	2.22439e-05	12	-0.50	1.04158e-05	12	0.50	2.13868e-04	12	-0.50	6.35568e-06	12
0.55	8.13099e-06	12	-0.55	3.18763e-06	12	0.55	1.11666e-04	12	-0.55	1.78592e-06	12
0.60	8.13099e-06	12	-0.60	9.77026e-07	12	0.60	5.77180e-05	12	-0.60	4.99339e-07	12
0.65	1.08834e-06	12	-0.65	2.99611e-07	12	0.65	2.96562e-05	12	-0.65	1.39008e-07	12
0.70	3.97802e-07	12	-0.70	9.18643e-08	12	0.70	1.52687e-05	12	-0.70	3.86933e-08	12
0.75	1.45412e-07	12	-0.75	2.81719e-08	12	0.75	7.86651e-06	12	-0.75	1.07704e-08	12
0.80	5.31542e-08	12	-0.80	8.63825e-09	12	0.80	4.04972e-06	12	-0.80	2.99796e-09	12
0.85	1.94290e-08	12	-0.85	2.64897e-09	12	0.85	2.07852e-06	12	-0.85	8.34490e-10	12
0.90	7.10186e-09	12	-0.90	8.12323e-10	12	0.90	1.06846e-06	12	-0.90	2.32282e-10	12
0.95	2.59604e-09	12	-0.95	2.49104e-10	12	0.95	5.48253e-07	12	-0.95	6.46564e-11	12
1.00	1.57931e-09	12	-1.00	1.16195e-10	12	1.00	6.23090e-07	12	-1.00	2.61517e-11	12

Deleted Usages

07/10/2015-V4.0.7



# LD Example 2 (Launch Panel Tab)



```
SMART - Small Aircraft Risk Technology
File Documentation
Begin Usage Spectra Launch Panel
!-----!
!          LOADING PARAMETERS          !
!-----!
NUMBER_OF_USAGES = 2
USAGE = TWIN_ENGINE_UNPRESS_GENERAL_USAGE 0.5
LLF_MAN = 3.6 -1.5
LLF_GUST = 3.3 -1.5
GROUND_STRESS = -4300
ONEg_STRESS = 7850
AC_VEL = 175
FLT_VEL_MATRIX =
0.90 1.0
1.0 1.5
1.0 0.5 0.4 0.6
1.5 0.5 0.6 0.4
WEIGHT_MATRIX =
0.9 1.0
1.0 1.5
1.0 0.5 0.4 0.6
1.5 0.5 0.6 0.4
USAGE = USER_DEFINED 0.5
EXC_FILE_LOC = C:\Program Files (x86)\SMART\Example files\exceedances\User_exced.exc
LLF_MAN = 3.1 -1.6
LLF_GUST = 3.2 -1.5
Run
12/23/2014-V3.1 Workshop
```

# LD Example 2 (.dat file)

```
! -----  
!                               AIRCRAFT INFORMATION  
! -----  
TITLE = Example2  
AC_MAKE = None  
AC_MODEL = None  
AC_SERIAL_NUM = None  
AC_TCDS = None  
! -----  
!                               SN-CURVE, MINERS AND SSF  
! -----  
SN_CURVE = AC23  
MINERS_D = NORMAL 1.0 0.1 0.0  
! -----  
!                               METHOD  
! -----  
MCSAMP = 1000  
SEED = 8520  
INPUT_FILE = NO  
ANALYSIS_TYPE = HOURS 9000  
PRINT_POF_EVERY = 3000  
! -----  
!                               LOADING PARAMETERS  
! -----  
NUMBER_OF_USAGES = 2  
USAGE = TWIN_ENGINE_UNPRESS_GENERAL_USAGE 0.5  
LLF_MAN = 3.6 -1.5  
LLF_GUST = 3.3 -1.5  
GROUND_STRESS = -4300  
ONEg_STRESS = 7850  
AC_VEL = 175  
FLT_VEL_MATRIX =  
0.90 1.0  
1.0 1.5  
1.0 0.5 0.4 0.6  
1.5 0.5 0.6 0.4  
WEIGHT_MATRIX =  
0.9 1.0  
1.0 1.5  
1.0 0.5 0.4 0.6  
1.5 0.5 0.6 0.4  
USAGE = USER_DEFINED 0.5  
EXC_FILE_LOC = User_exced.exc  
LLF_MAN = 3.1 -1.6  
LLF_GUST = 3.2 -1.5  
GROUND_STRESS = -4800  
ONEg_STRESS = 8100  
AC_VEL = 175  
FLT_VEL_MATRIX =  
1.0  
1.0  
1.0 1.0 1.0  
WEIGHT_MATRIX =  
1.0  
1.0  
1.0 1.0 1.0  
FLT_VARIATION = NO
```

# LD Example 2 (Results Tab)



SMART - Small Aircraft Risk Technology

File Documentation

Results

Load Output File: C:\Users\pze593\Desktop\BenchmarkProblems\Example2\_LD\Example2\_LD.txt Load Output

Pareto  
Damage No Hours Plot

Samples Output Screen out

DAMAGE Results						
Lower Bound					Upper Bound	
99%	95%	90%	Damage Mean	90%	95%	99%
0.37632	0.38043	0.38259	0.39363	0.40468	0.40683	0.41094

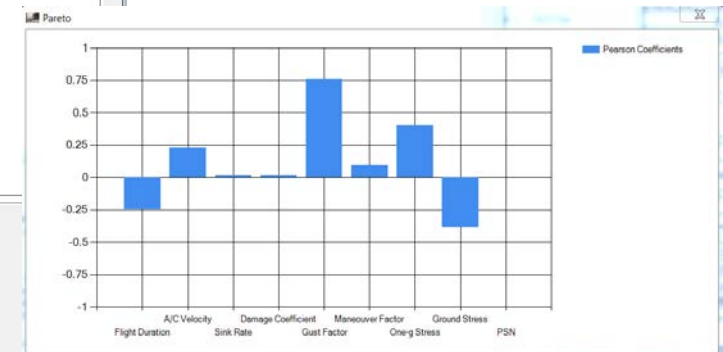
  

Damage Stdev						
Lower Bound				Upper Bound		
99%	95%	90%	Damage Stdev	90%	95%	99%
0.20132	0.20402	0.20543	0.21296	0.22112	0.22273	0.22593

POF(P[Dc>Dm]) Results						
Lower Bound				Upper Bound		
99%	95%	90%	Damage POF	90%	95%	99%
0.02559	0.02568	0.02574	0.02600	0.02626	0.02632	0.02641

07/10/2015-V4.0.7



# Input & Output Summary .out File

```

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

***SMART RESULTS***

Probability      Damage_for_Number_of_Hours
0.500000        0.34686
0.100000        0.21733
0.010000        0.15279
0.001000        0.10424
0.000223        -----

DAMAGE Results
Lower Bound      Upper Bound
99%  95%  90%  Damage Mean  90%  95%  99%
0.37632  0.38043  0.38259  0.39363  0.40468  0.40683  0.41094

Damage Stdev
Lower Bound      Upper Bound
99%  95%  90%  Damage Stdev  90%  95%  99%
0.20132  0.20402  0.20543  0.21296  0.22112  0.22273  0.22593

POF (P[Dc>Dm]) Results
Lower Bound      Upper Bound
99%  95%  90%  Damage POF  90%  95%  99%
0.02559  0.02568  0.02574  0.02600  0.02626  0.02632  0.02641

Hours Range Results
Lower Bound      Upper Bound
No Hours  Damage Mean  90%  95%  99%  POF  90%  95%  99%
3000.0  0.1312  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
6000.0  0.2624  0.00587  0.00585  0.00580  0.00600  0.00613  0.00615  0.00620
9000.0  0.3936  0.02574  0.02568  0.02559  0.02600  0.02626  0.02632  0.02641

-----
-----

**** PEARSON CORRELATIONS ****

Flight      A/C      Sink      Damage      Gust      Man      One-g      Ground      PSN
Duration  Velocity  Rate      Coefficient  Factor      Factor      Stress      Stress
-----
Damage -0.12359  0.17922  0.02317  0.02814  0.80557  0.11155  0.26215  -0.24456  0.00000

-----
-----

Summary Results per Usage
Usage = TWIN_ENGINE_UNPRESS_GENERAL_USAGE
Mean Accumulated Damage = 0.3480874
Usage = USER_DEFINED
Mean Accumulated Damage = 0.4391734

Total cpu time = 0.2652017 secs
... Lines were removed from this output ...

```



TEXTRON AVIATION

# Safe-life Results

from .out File



\*\*\*SMART RESULTS\*\*\*

Probability		Damage_for_Number_of_Hours	
0.500000		0.34686	
0.100000		0.21733	
0.010000		0.15279	
0.001000		0.10424	
0.000223		-----	

DAMAGE Results						
Lower Bound				Upper Bound		
99%	95%	90%	Damage Mean	90%	95%	99%
0.37632	0.38043	0.38259	0.39363	0.40468	0.40683	0.41094

Damage Stdev						
Lower Bound				Upper Bound		
99%	95%	90%	Damage Stdev	90%	95%	99%
0.20132	0.20402	0.20543	0.21296	0.22112	0.22273	0.22593

POF (P[Dc>Dm]) Results						
Lower Bound				Upper Bound		
99%	95%	90%	Damage POF	90%	95%	99%
0.02559	0.02568	0.02574	0.02600	0.02626	0.02632	0.02641

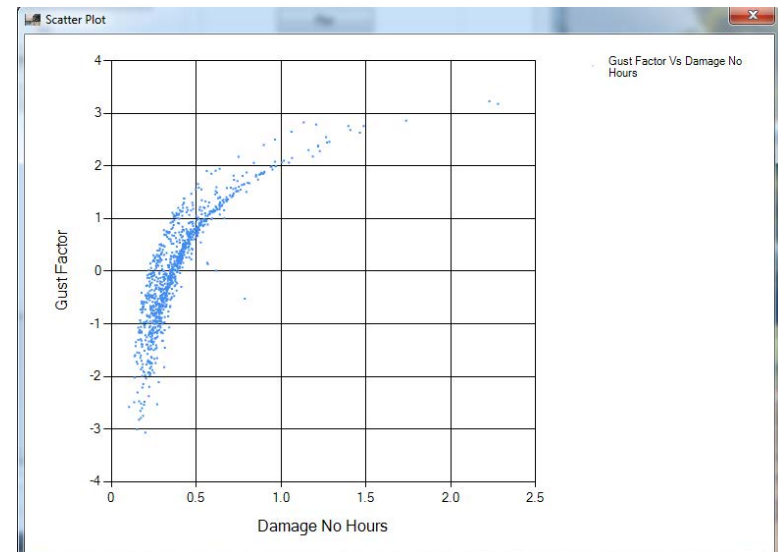
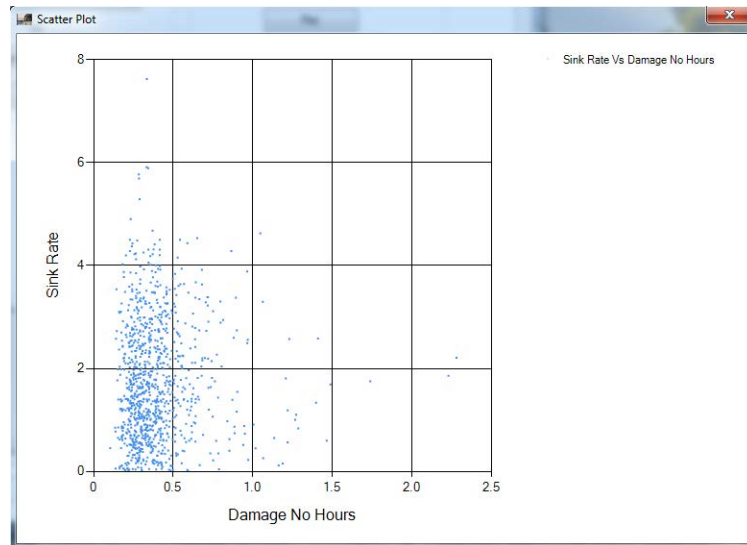
Summary Results per Usage	
Usage =	TWIN_ENGINE_UNPRESS_GENERAL_USAGE
Mean Accumulated Damage =	0.3480874
Usage =	USER_DEFINED
Mean Accumulated Damage =	0.4391734

# Correlation Sensitivity Analysis



\*\*\*\* PEARSON CORRELATIONS \*\*\*\*

	Flight Duration	A/C Velocity	Sink Rate	Damage Coefficient	Gust Factor	Man Factor	One-g Stress	Ground Stress	PSN
Damage	-0.12359	0.17922	0.02317	0.02814	0.80557	0.11155	0.26215	-0.24456	0.00000

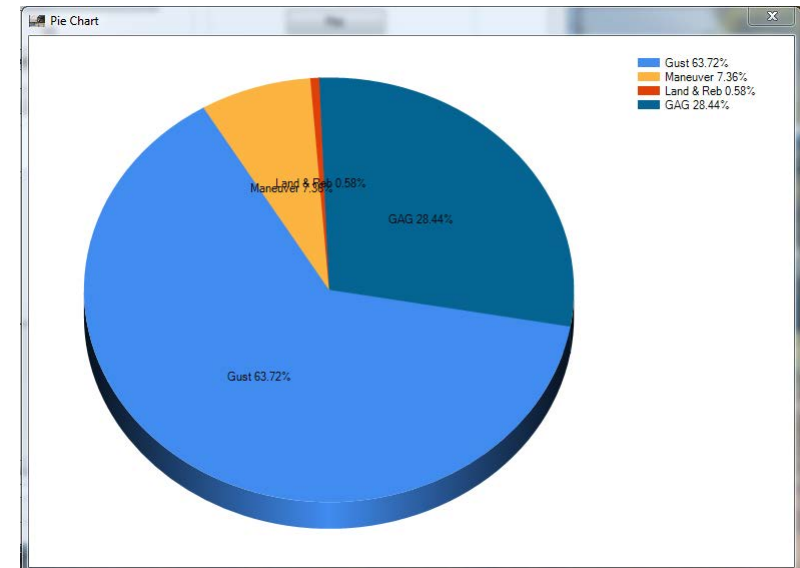




# PSN Region Accumulated Damage



SN REGION	TOTAL	GUST	MAN.	TAXI	Land&Reb.	GAG
BELOW 1 KSI:	0.00	0.00	0.00	0.00	0.00	0.00
BETWEEN 1 AND 2 KSI:	0.00	0.00	0.00	0.00	0.00	0.00
BETWEEN 2 AND 3 KSI:	0.01	0.00	0.00	0.00	0.01	0.00
BETWEEN 3 AND 4 KSI:	0.03	0.00	0.00	0.00	0.03	0.00
BETWEEN 4 AND 5 KSI:	0.08	0.00	0.00	0.00	0.08	0.00
BETWEEN 5 AND 6 KSI:	0.37	0.00	0.00	0.00	0.37	0.00
BETWEEN 6 AND 7 KSI:	0.00	0.00	0.00	0.00	0.00	0.00
BETWEEN 7 AND 8 KSI:	0.00	0.00	0.00	0.00	0.00	0.00
BETWEEN 8 AND 9 KSI:	0.00	0.00	0.00	0.00	0.00	0.00
BETWEEN 9 AND 10 KSI:	3.59	3.48	0.12	0.00	0.00	0.00
BETWEEN 10 AND 11 KSI:	15.07	13.35	1.71	0.00	0.00	0.00
BETWEEN 11 AND 12 KSI:	14.28	12.47	1.47	0.00	0.00	0.33
BETWEEN 12 AND 13 KSI:	27.02	13.39	1.12	0.00	0.00	12.50
BETWEEN 13 AND 14 KSI:	21.05	9.65	0.65	0.00	0.00	10.74
BETWEEN 14 AND 15 KSI:	6.25	4.24	0.54	0.00	0.00	1.48
BETWEEN 15 AND 16 KSI:	3.48	2.99	0.33	0.00	0.00	0.16
BETWEEN 16 AND 17 KSI:	2.87	2.64	0.23	0.00	0.00	0.00
BETWEEN 17 AND 18 KSI:	2.00	1.82	0.17	0.00	0.00	0.00
BETWEEN 18 AND 19 KSI:	1.20	1.10	0.11	0.00	0.00	0.00
BETWEEN 19 AND 20 KSI:	0.91	0.83	0.08	0.00	0.00	0.00
BETWEEN 20 AND 21 KSI:	0.67	0.61	0.05	0.00	0.00	0.00
BETWEEN 21 AND 22 KSI:	0.40	0.37	0.03	0.00	0.00	0.00
BETWEEN 22 AND 23 KSI:	0.27	0.25	0.02	0.00	0.00	0.00
BETWEEN 23 AND 24 KSI:	0.27	0.26	0.01	0.00	0.00	0.00
BETWEEN 24 AND 25 KSI:	0.11	0.11	0.01	0.00	0.00	0.00
BETWEEN 25 AND 26 KSI:	0.08	0.07	0.01	0.00	0.00	0.00
BETWEEN 26 AND 27 KSI:	0.00	0.00	0.00	0.00	0.00	0.00
...	...	...	...	...	...	...
ABOVE 40 KSI:	0.00	0.00	0.00	0.00	0.00	0.00
<b>TOTAL STAGE PERCENTAGE</b>	<b>100.00</b>	<b>67.62</b>	<b>6.67</b>	<b>0.00</b>	<b>0.48</b>	<b>25.22</b>



# Summary



- ✓ We Reviewed:
  - ✓ SMART|LD Files Overview
  - ✓ Hours Mode Analysis
    - ✓ Required Elements Hours Mode Analysis
      - ✓ Loading
      - ✓ SN-Curves
      - ✓ Random Miner's D
      - ✓ Total Flight Hours
  - ✓ Ran Example Problem
    - ✓ Input File
    - ✓ GUI Inputs
    - ✓ Output Files
      - ✓ MonteCarlo Samples
      - ✓ Statistical Results
      - ✓ Hz Function Quick Look
      - ✓ SN Region Percentage Damage



# Questions

