SMART|DT EXAMPLES LIBRARY

Blue Set Examples Introduction

Disclaimer

The examples contained in this set are not real problems. They are meant to be a demonstration of how to use the SMART|DT software.

Purpose of the Blue Set Examples

- This set is comprised of 6 examples that aim to introduce the user to SMART|DT's GUI and its basic features through the development of simple example problems.
- Each example has its own **.pdf** document with a step-by-step guide to develop the examples from scratch. This document also contains notes and tips about the features used in the examples.
- The user will also be provided with an **.smdt** file that contains all input and the solved example for comparison purposes.
- Each example showcases different combinations of the features offered in SMART|DT.

Abbreviations Used In The Examples

Blue Set
Examples Introduction

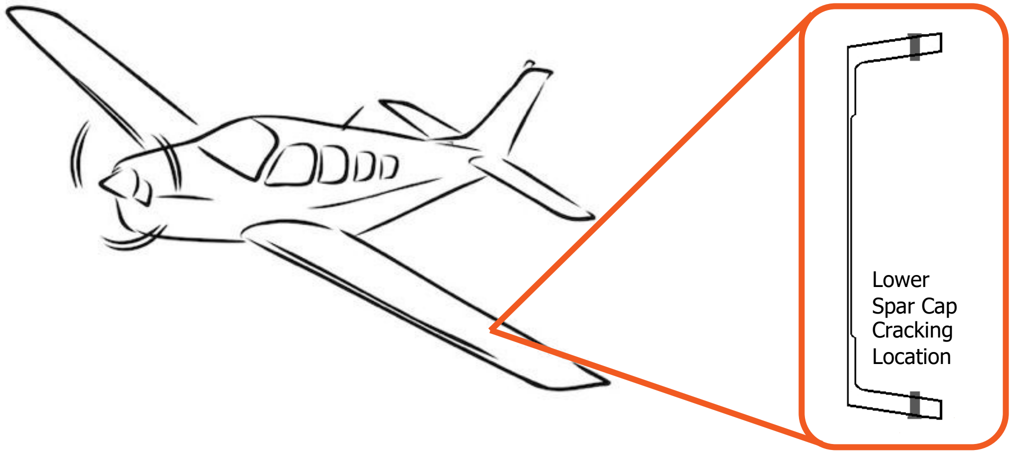
Abbreviation	Expanded name
AMIS	Adaptive Multiple Importance Sampling
CDF	Cumulative Distribution Function
EIFS	Equivalent Initial Flaw Size
EVD	Extreme Value Distribution
PDF	Probability Density Function
POD	Probability of Detection
SFPOF	Single Flight Probability of Failure
POI	Probability of Inspection
SIF	Stress Intensity Factor
ECA	Equivalent Constant Amplitude
VA	Variable Amplitude
HyperGrow	In-house developed ultra-fast crack growth method

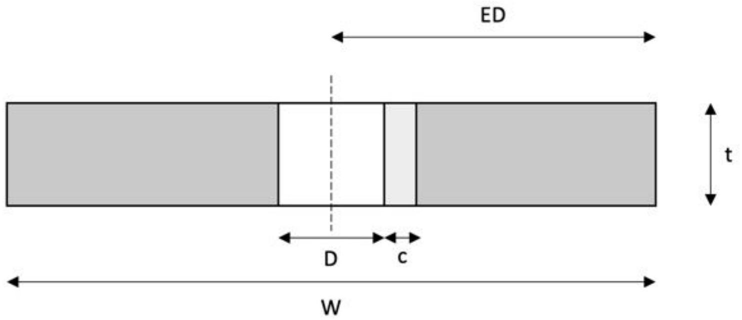
Features Covered in this Example Set

- Master Curve (User Generated and HyperGrow generated crack growth)
- HyperGrow (Internal crack growth code)
- Monte Carlo (Probabilistic method)
- Adaptive Multiple Importance Sampling (AMIS - Probabilistic method)
- Beta table (SIFs) and tabular EIFS
- Built-in probabilistic material and Equivalent Initial Flaw Size (EIFS) databases
- User-specified Extreme Value Distribution (EVD)
- Introduction to Exceedance Curves
- User-defined and minimal cost optimization inspection methods

Problem Statement for the Blue Set Examples

A single engine turboprop has a through crack growing in a rivet hole due to fatigue. The hole is located on a lower spar cap. To simplify the analysis, the spar is represented as a flat plate where the crack growth is equivalent to that in the original geometry. Find the SFPOF for the spar using the information that will be provided next.





Parameter	Value
Width [W]	2.0 in
Hole diameter [D]	0.25 in
Thickness [t]	0.1 in
Edge distance [ED]	1.0 in
Crack size [c]	-

Overview of the Examples Contained in the Blue Set

Feature	Example 1.1	Example 1.2	Example 1.3	Example 1.4	Example 1.5	Example 1.6
Crack growth	Master curve – user defined	Master curve – user defined	Master curve – HyperGrow	HyperGrow	HyperGrow	HyperGrow
Crack type	Through	Through	Through	Through	Through	Through
Geometry factor	Hole	Hole	Hole	Hole	Beta table (for a through crack in a hole)	Hole
Failure definition	Kc	Kc	Kc	Kc	Kc	Kc
Probabilistic method	Monte Carlo – 1 sample	Monte Carlo – 1E7 samples	Monte Carlo – 1E7 samples	AMIS - COV = 0.1	AMIS - COV = 0.1	AMIS - COV = 0.1
SFPOF Formulation	Lincoln	Lincoln	Lincoln	Lincoln	Lincoln	Lincoln
Material	Custom – deterministic	Probabilistic from library	Probabilistic from library	Custom probabilistic	Probabilistic from the library	Probabilistic from library
EIFS	Custom – deterministic	Probabilistic from library	Probabilistic from library	Custom probabilistic	Tabular	Probabilistic from library
Type of EVD	User specified EVD	User specified EVD	User specified EVD	User specified EVD	User specified EVD	EVD generated from user defined Exceedance Curves
Inspection Schedule type				User Specified	Minimal cost	
Probability of Detection (POD)	None	None	None	Probabilistic from library	Probabilistic from the library	None
Repaired crack size				Same as original	Same as original	
Probability of Inspection (POI)				1	0.9	

How are the Examples in this Set Related?

- All 6 examples share the same problem statement, geometry, material, EIFS, EVD and Equivalent Constant Amplitude Loading values, which will in turn produce similar Single Flight Probability of Failure (SFPOF) results.
- Examples build off each other and their complexity increases along the way.

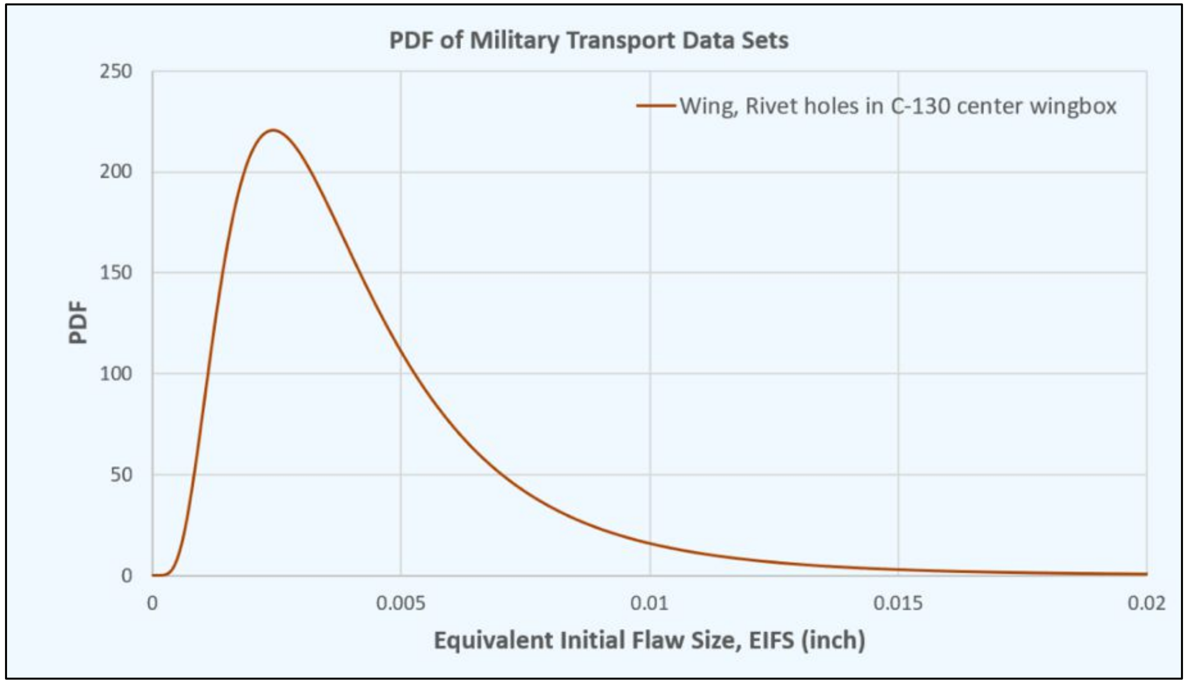
Data Shared Between Examples

Parameter	Name	Distribution type	Values	Source
Material	Al 2024 – T3511 (Extrusion L)	Fracture Toughness - Normal	Mean = 38.0 ksi Stdev = 2.6 ksi	Built-in material library
		Yield Strength - Normal	Mean = 51.0 ksi Stdev = 2.8 ksi	
		Ultimate Strength - Normal	Mean = 68.0 ksi Stdev = 4.2 ksi	
EIFS	Military Transport – Wing – Rivet Holes in C-130	LogNormal	Mean = 0.004292387 in Stdev = 0.002922037 in	Built-in EIFS library
EVD	-	Frechét	Location = 10.0211 Scale = 0.6610 Shape = 0.1205	Extracted from Exceedance Curves in Example 1.6
Equivalent Constant Amplitude Loading	-	-	Cycles per flight = 106.0940 Maximum stress = 5.7457 ksi	

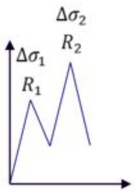
Data Shared Between Examples (cont.)

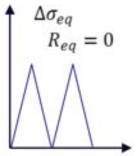
Notes:

1) Since an EIFS for a single engine airplane is not available in SMART|DT's library, the C-130 data was chosen for the purpose of demonstration. The C-130 was manufactured with similar materials and in the same time frame as many single engine airplanes.



Data Shared Between Examples (cont.)





$$N_{total} = N_1 + N_2 = \int_{a_0}^{a_1} \frac{1}{f(\Delta\sigma_1, R_1, a)} + \int_{a_1}^{a_2} \frac{1}{f(\Delta\sigma_2, R_2, a)}$$

$$N_{total_{eq\_stress}} = \int_{a_0}^{a_2} \frac{1}{f(\Delta\sigma_{eq}, R_{eq}, a)}$$

$$N_{total} = N_{total_{eq\_stress}}$$

$$\Delta\sigma_{eq} = \left[\sum_{i=1}^{K} \frac{n_i}{N_{Tot}} \left((1 - R_i)^{(m-1)n} \right) \Delta\sigma_i^n \right]^{1/n}$$

$$Cycles\ per\ filght = \frac{N_{total_{eq\_stress}}}{N_{flights}}$$

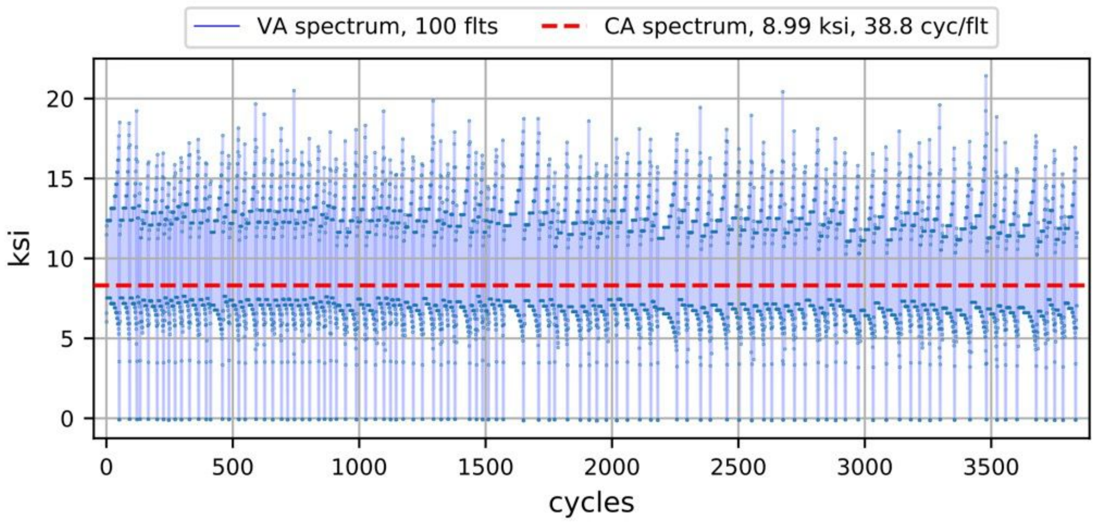
Notes:

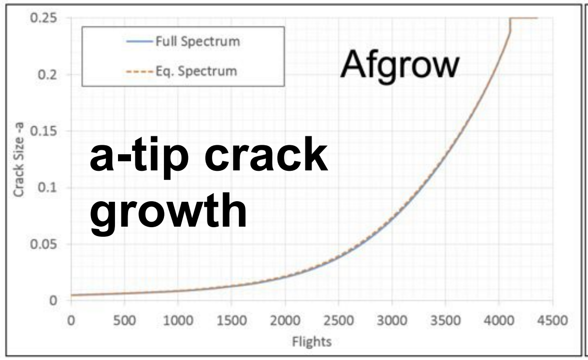
2) The **Equivalent Constant Amplitude Loading** values are the result of a procedure performed by SMART|DT, where an Equivalent Constant Amplitude (ECA) stress spectrum is computed to produce equivalent crack growth to the one from the Variable Amplitude (VA) spectrum. The ECA approach is significantly faster than traditional crack growth methods. As a result, the crack growth's runtime is reduced.

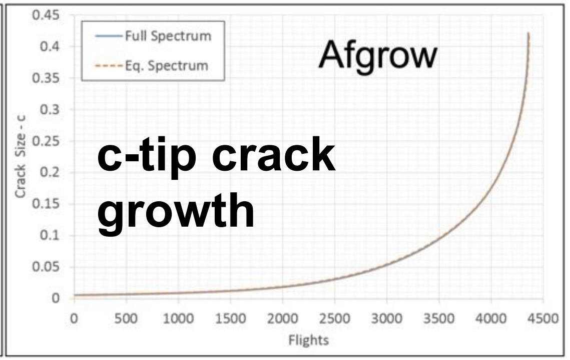
3) The equations shown on the left show a summary of the procedure to obtain the equivalent stress and the cycles per flight. For more information about this procedure, see reference [1].

[1] Xiang, Y., & Liu, Y. (2016). Equivalent stress transformation for efficient probabilistic fatigue-crack growth analysis under variable amplitude loadings. *Journal of Aerospace Engineering*, *29*(2), 04015052.

Data Shared Between Examples (cont.)







Notes:

4) The image on the top left shows an example of a VA spectrum, drawn in blue, where the stress varies from 0 to ~22 ksi, over 100 flights. The ECA spectrum, in red, depicts a constant stress of 8.99 ksi, with 38.8 cycles per flight.

5) The bottom two images show an example of how the crack growth compares for a corner crack in a hole when using VA and ECA. The results for both approaches are nearly identical.

6) Example 1.6 shows the procedure to obtain the **Equivalent Constant Amplitude Loading** values from the GUI when using user-defined Exceedance Curves. These values are those used in Examples 1.1 – 1.5.

Summary of the Examples Contained in the Blue Set

- **Example 1.1:** Introduces the SMART|DT GUI and uses a defined Master Curve. Deterministic material and EIFS values are inputs. A single Monte Carlo sample is chosen, with the purpose of replicating the SFPOF results calculated in SMART|DT using an Excel spreadsheet. This example also shows how to input a user defined EVD.
- **Example 1.2:** Uses the same Master Curve from Example 1.1, but now probabilistic values from the built-in material and EIFS libraries are used. The number of Monte Carlo samples are increased to 10 million. The same user defined EVD is input.

Summary of the Examples Contained in the Blue Set

- **Example 1.3:** Uses the same settings from Example 1.2 except the Master Curve HyperGrow capability is implemented. This feature generates the .avsn file that contains the user defined Master Curve used in Examples 1.1 and 1.2. The same SFPOF results from Example 1.2 are observed.
- **Example 1.4:** Introduces the HyperGrow and AMIS features, which significantly reduce the run time of the simulation. This example shows how to input a custom probabilistic material and EIFS, using the same values from Examples 1.2 and 1.3. The same user specified EVD is input. User specified inspections are introduced. The resulting output plot of SFPOF results is smoother than the one from previous examples.

Summary of the Examples Contained in the Blue Set

- **Example 1.5:** Uses the same settings from Example 1.4, but the probabilistic material data comes from the built-in library. The user-defined beta table feature is introduced. The EIFS is input in tabular format, using the same values from the previous examples. Minimal Cost Inspections are introduced. The resulting SFPOF results are the same as in Example 1.4.
- **Example 1.6:** Uses the same settings from Example 1.5, with probabilistic material data and EIFS taken from the built-in libraries. A simple case of Exceedance Curves is introduced. The aim of this example is to show where the EVD and Equivalent Constant Amplitude Loading parameters for the previous examples were taken from.