SmartPlot: Visualization Tool for Aircraft Probabilistic Damage Tolerance Analysis

Daniel Ocampo Millán[a]

Harry Millwater[b]

[a]docamp10@eafit.edu.co, EAFIT University, University of Texas at San Antonio UTSA
[b]Harry.Millwater@utsa.edu, University of Texas at San Antonio

Abstract

SmartPlot is an application that reads and plots the files produced by SMART|DT (SMall Aircraft Risk Technology - Damage Tolerance) probabilistic damage tolerance software. SmartPlot provides users with features such as selecting the data to be plotted, comparing results from multiple executions, and exporting plots as vector graphics in Portable Document Format. This application is based on a Finite State Machine (FSM) that automatically detects the characteristics of the file to be plotted. SmartPlot is written in Java, uses free software, and can be distributed as a Java ARchive (JAR) file that will run on any machine with Java Runtime Environment (JRE) 8.

Keywords: Aircraft, Probabilistic Damage Tolerance Analysis, PDTA, Probability Of Failure, POF, SmartDT, SVG, visualization.

1 Introduction

The University of Texas at San Antonio is developing a probabilistic damage tolerance analysis software tool, Smart|DT, under sponsorship from the Federal Aviation Administration (FAA) to provide engineers and regulators data-based software tools to help ensure the safety of aircraft. A probabilistic damage tolerance analysis (PDTA) approach provides a mechanism whereby inspection and maintenance operations can be included into a simulation, thus providing engineers the opportunity to assess the benefits of maintenance actions and to design effective inspection protocols. This paper describes a new user-friendly graphical plotting program that can be used to effectively assess the effects of maintenance and repair actions.

2 Smart|DT

SmartDT is a software program enables structural engineers to evaluate the effects of aging and maintenance in small aircrafts through a comprehensive probabilistic damage tolerance analysis (PDTA). Both the Federal Aviation Administration (FAA) and United States Air Force (USAF), currently use PDTA to support airworthiness certifications, supplementary inspection schedules, and maintenance actions.

Smart|DT allows engineers to correctly detect the effects of aging in the general aviation (GA) fleet, and develop the applicable maintenance plans. It allows engineers to test conditions of small airplanes through a probabilistic approach, along with the capability of simulating the effects of inspection and maintenance operations in the same model, so that engineers can conduct a risk assessment of a GA structural issue in support of policy decisions.

After Smart|DT executions, in which a PDTA is applied to the whole loading spectrum in fatigue areas for small airplanes, the outcome is shown in form of text files containing the probability-of-failure (POF) per flight considering random initial crack sizes, fracture toughness and maximum load per flight [4]. A recursive probabilistic sampling algorithm is also developed, whereby the reuse of crack growth histories is possible. These concepts are going to be explained in more detail in the next sections.

For Smart|DT users to be able of interpret the output files generated after executions, *SmartPlot* was developed to provide graphical evaluation. SmartPlot.jar is a Java based executable program that allows users to select the files to be shown, create charts showing its behavior, as well as compare different executions and save them in Scalable Vector Graphics (SVG) format.

In order for engineers to interpret properly some of the files that SmartDT produces, graphical representation is needed. Mainly, files with .pof and .avsn extension, which represent probability-of-failure and crack size vs flight number, respectively. The description of these files is given below:

2.1 Probability OF Failure (.pof) Files

POF files consist of text, have an file name extension *'.pof'*, and include the main statistical results. The meaning of each column is as follows (see figure 1):

- Flight Number: Number of flight hours for the plane(s) to assess.

- POF No-Survival: The No-Survival POF column is accounting for the probability that an extreme load will exceed the residual strength or net section strength for the analyzed structure.

- POF Survival: Is defined as the probability that a extreme load will exceed the residual strength or the net section strength, given that the aircraft have survived to the whole amount of flights up to the current one. This is calculated multiplying the No-Survival POF by a survival term.

- Hazard Function: The Hazard Function column is an alternative characterization of the random variable that accounts for POF, but as an instantaneous rate of failure.

- Cumulative POF: Cumulative POF or cumulative damage is the Summation of POFs for a single specified *Flight Number*.

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           -------------RESULTS WITHOUT INSPECTIONS--------    -------------RESULTS WITH INSPECTIONS-------
Flight       POF         POF        Hazard     Cumulative       POF         POF        Hazard     Cumulative
Number     No-Surv.      Surv.      Function      POF         No-Surv.      Surv.      Function      POF
0          4.303E-014  4.303E-014  4.303E-014  4.303E-014    4.303E-014  4.303E-014  4.303E-014  4.303E-014
200        6.090E-014  6.090E-014  6.090E-014  1.034E-011    6.090E-014  6.090E-014  6.090E-014  1.034E-011
400        8.543E-014  8.543E-014  8.543E-014  2.485E-011    8.543E-014  8.543E-014  8.543E-014  2.485E-011
600        1.189E-013  1.189E-013  1.189E-013  4.512E-011    1.189E-013  1.189E-013  1.189E-013  4.512E-011
800        1.647E-013  1.647E-013  1.647E-013  7.325E-011    1.647E-013  1.647E-013  1.647E-013  7.325E-011
1000       2.269E-013  2.269E-013  2.269E-013  1.121E-010    2.269E-013  2.269E-013  2.269E-013  1.121E-010
1000       2.269E-013  2.269E-013  2.269E-013  1.121E-010    1.425E-013  1.425E-013  1.425E-013  1.121E-010
```

Figure 1: POF sample file *hnd_insp.pof*.

At each inspection, two paths are possible (non-detect and detect) based on the Probability Of Detection (POD) value of the crack size at the time of inspection. The remaining columns (*RESULTS WITH INSPECTIONS*) are the result of applying the same described concepts to the path where eventually there is crack detection.

2.2 Crack size a vs Flight Number n (.avsn)

The Survival POF is defined as the probability-of-failure on the next flight assuming that no failures occurred until that flight. It happens when unstable fracture occurs, which is, when stress intensity factor generated by Load EVD is greater of equal than the fracture toughness. Equivalently, can be said that failure occurs when the maximum load to which the structure is subjected, is greater or equal than its residual strength.
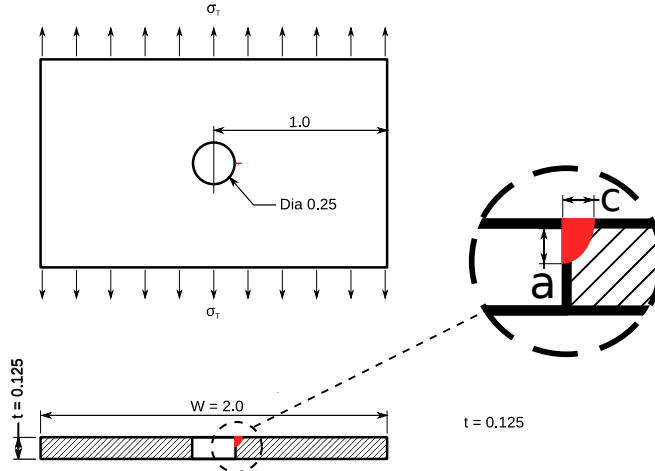
Figure 2: Description of crack geometry [3].

AVSN files, whose extension format is *'.avsn'*, provide both the crack geometry and the residual strength as functions of the *Flight Number*. These columns represent some of the parameters used to calculate the POF, which are explained furthermore in [4].

The description of the columns of the file shown in figure 3 is as follows:

- *Flt_no* : Flight Number.

- *a, c, a1, c1* : Description of crack geometry. An example is shown in figure 2.

- *RS_by_Kc* : Residual strength calculated with fracture toughness criteria [4].

- *RS_by_NSY* : Residual strength calculated with Net-section-yield criterion [2, 1].

Flt_no	a	c	a1	c1	RS_by_Kc	RS_by_NSY
0	x	0.0001	x	x	584.2903	584.2903
100	x	0.000103	x	x	575.82646	575.82646
200	x	0.000106	x	x	567.48621	567.48621
300	x	0.0001092	x	x	559.26776	559.26776

Figure 3: AVSN sample file.

3   SmartPlot

The SmartPlot application is an end user program able to graph the output files produced by SmartDT executions. That is, it can plot any column(s) required from SmartDT output files. This program is capable of plotting POF files without regard to whether or not they have inspection columns, and Crack size a vs Flight Number n (AVSN) files.

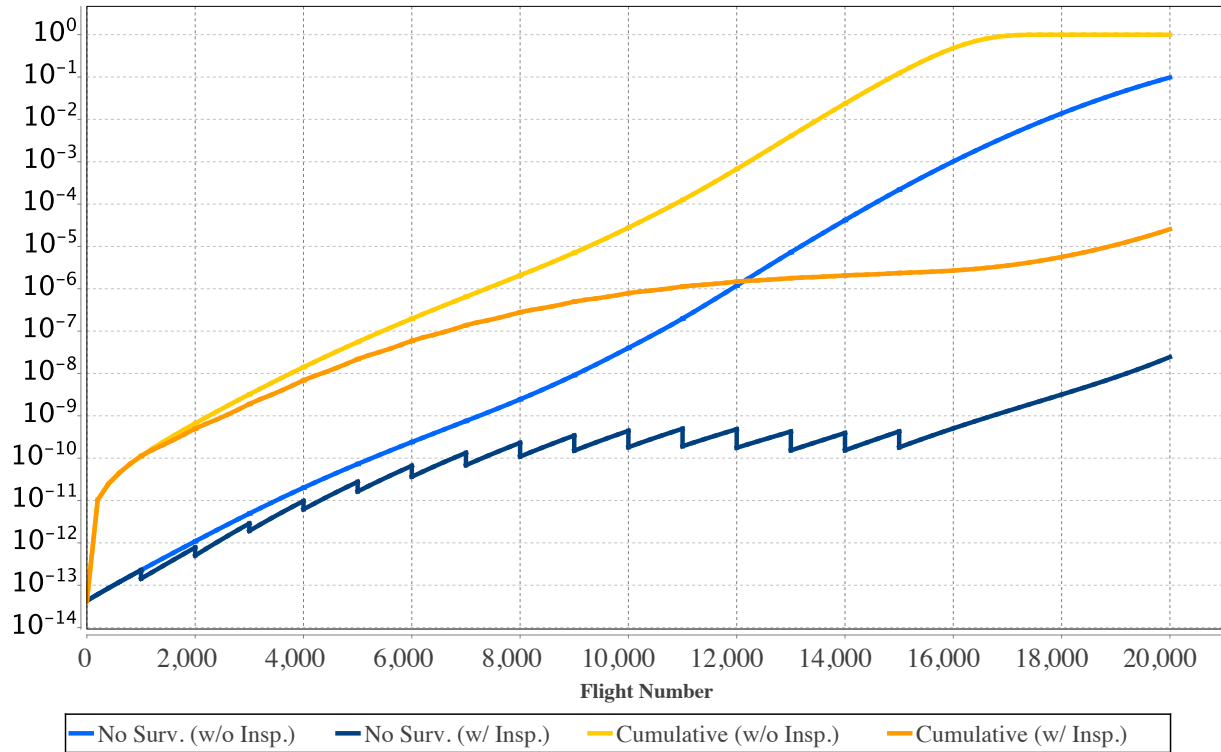Running SmartPlot with the file shown in figure 1 as input produces the figure shown in figure 4.

Figure 4: Processing sample file in *figure 1* with SmartPlot.jar.

Similarly, after executing SmartDT, producing the results shown in figure 3, SmartPlot.jar can be run to plot the a vs. n and residual strength plots (see figure 5).
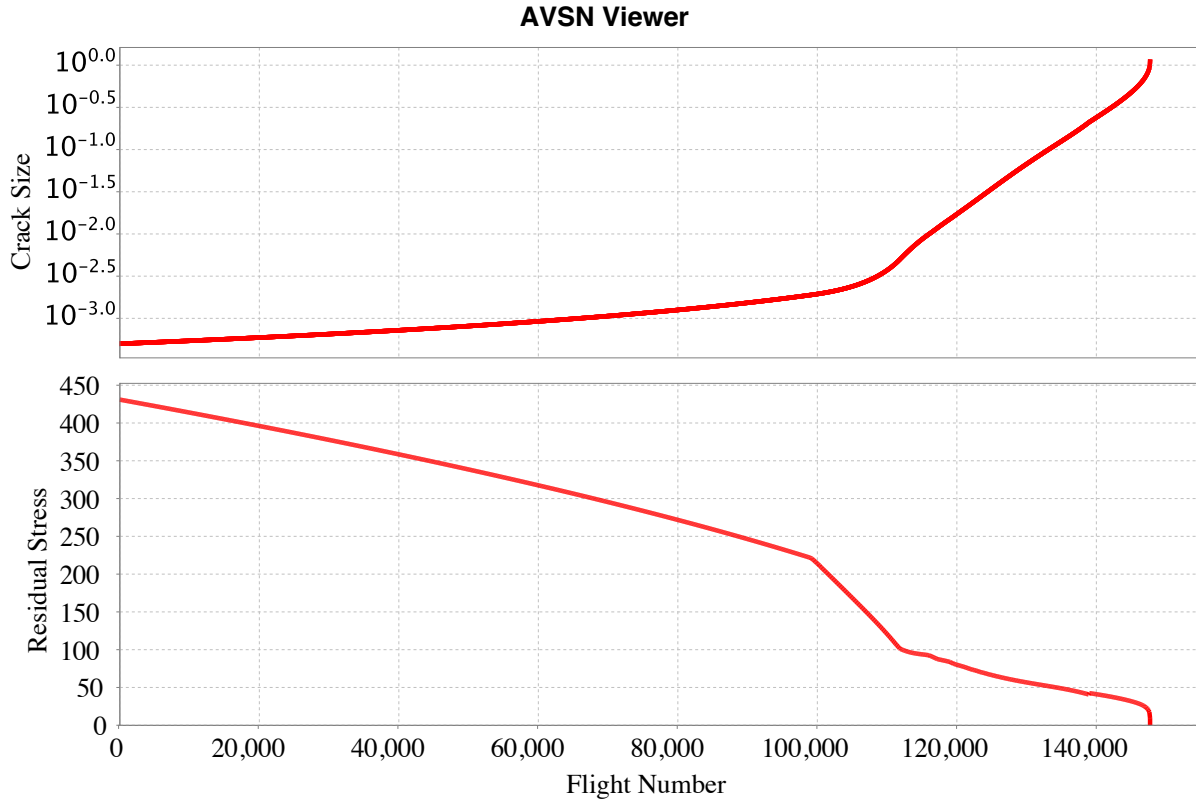
Figure 5: AVSN sample file.

Both the POF and the AVSN viewer have additional features, as shown in figure 6:

- Load: Opens the file explorer (finder in mac devices) to charge a different file.

- Compare : Allows the user to compare two different files graphically. This feature will be explained furthermore in the next subsection.

- Create PDF: Immediately creates a copy of the current view in PDF format. Allowing the user to select both the containing folder and the desired file name. The image is created in Scalable Vector Graphics (SVG) format.

- Semi-log axis: The application has a crack size semi-log checkbox, which turns on/off the semi-log axis in Crack size graph.

The application has checkboxes in the upper-right corner of the window. This allows to able/disable the desired columns in the graph. For the example shown, the Survival curve is disabled, whereas No-Survival and Cumulative are enabled. Both axes auto-range to the available data. There are also vertical and horizontal grid checkboxes, which serve to turn on/off the gray color grid as background.
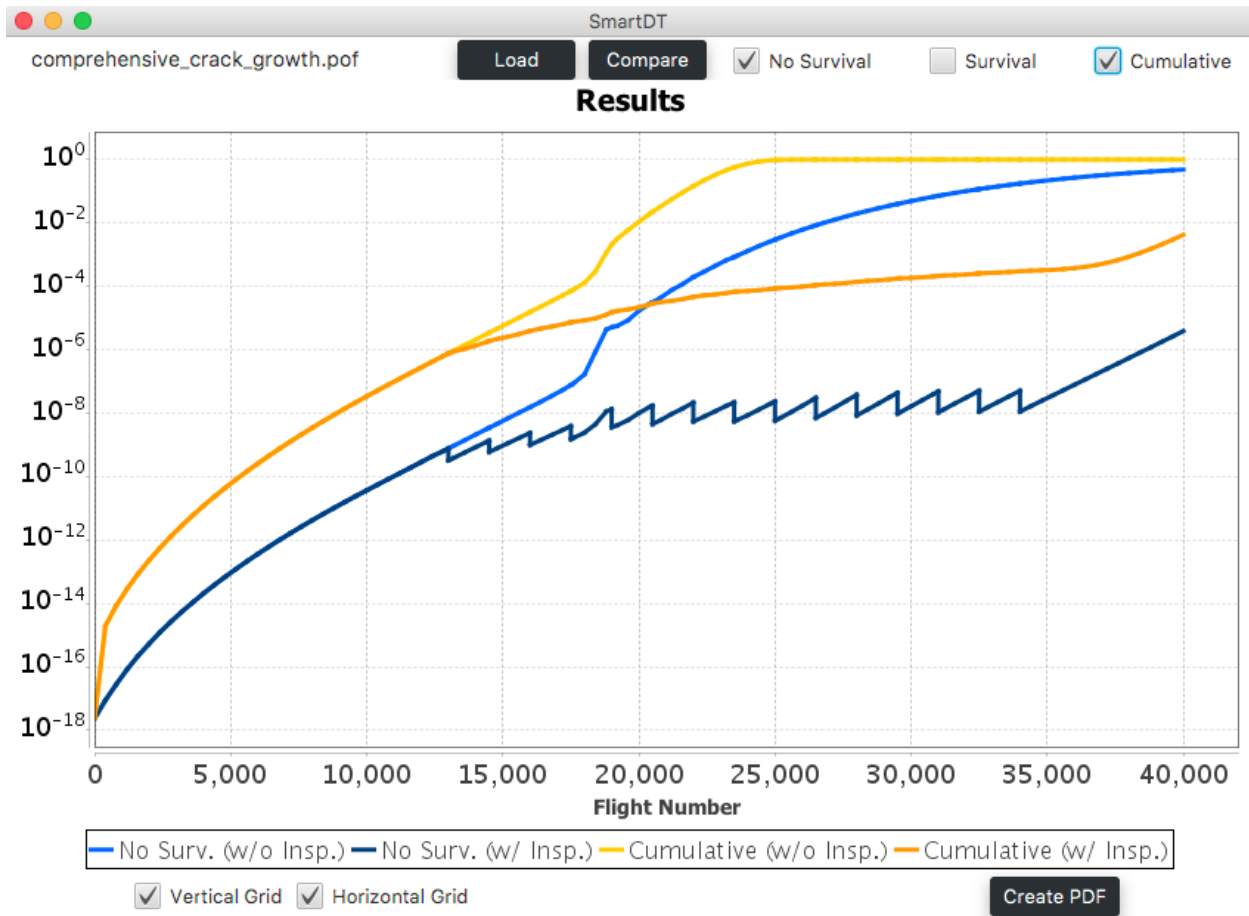
Figure 6: Interface of SmartPlot.jar showing sample file.

3.1 Compare Function

SmartPlot offers the possibility of comparing two different files visually. The compare button provides SmartDT users with the possibility of loading two different, either POF or AVSN files in only one plot.

Users only have to select one of the files, then press the compare button and select the file to be compared. A second window will be opened with the visualization of the files in the same graph, including the same features described for the main file viewer. An example of this feature is shown in figure 7.
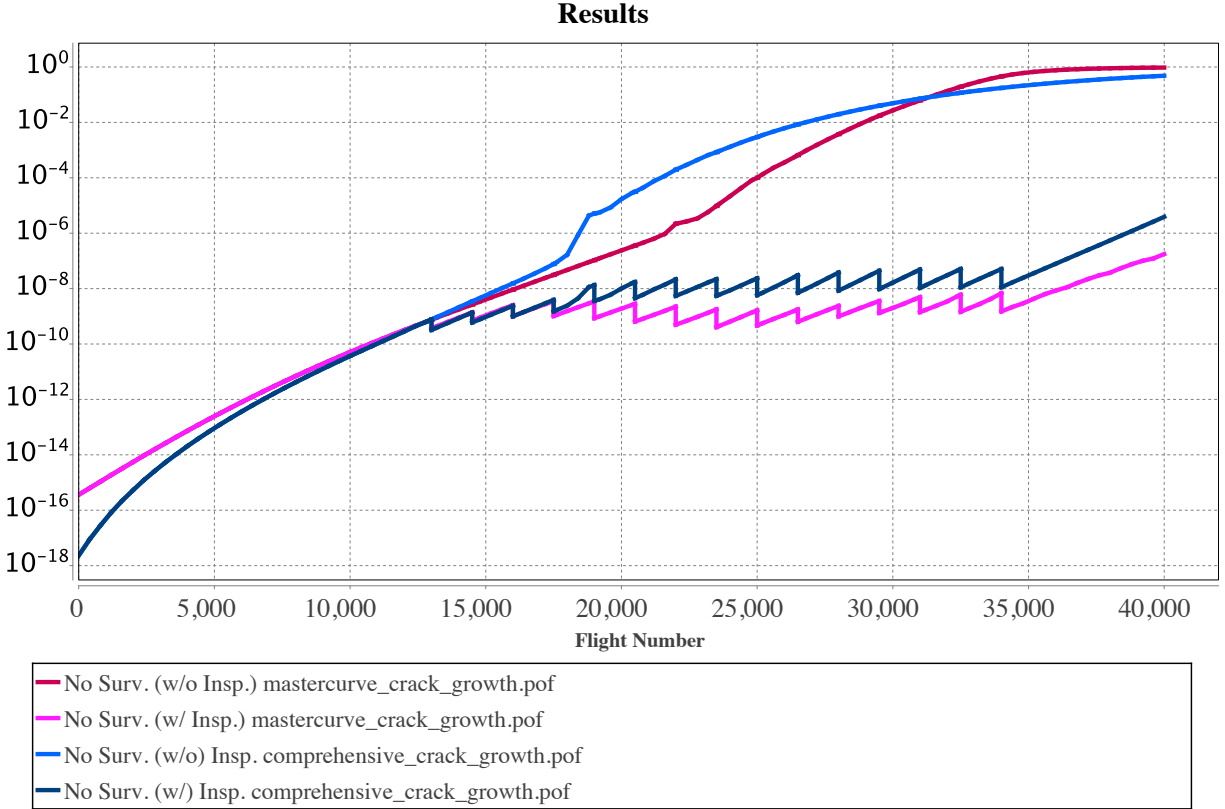
Results

No Surv. (w/o Insp.) mastercurve_crack_growth.pof
No Surv. (w/ Insp.) mastercurve_crack_growth.pof
No Surv. (w/o) Insp. comprehensive_crack_growth.pof
No Surv. (w/) Insp. comprehensive_crack_growth.pof

Figure 7: Comparison of sample POF files.

3.2 Execution mode

The SmartPlot's execution mode is based on the class called Scanner, directly from Java utilities library. A Scanner is an object enabled for reading data from text files, breaking its input into tokens using a delimiter pattern. The resulting tokens may then be converted into values of different types using its various available methods.

SmartPlot makes use of the open source Java chart Library JFreeChart. JfreeChart is open source or, more specifically, free software. It is distributed under the terms of GNU Lesser General Public License (LGPL), which permits use in proprietary applications. A Finite State Machine is implemented to assign the read blocks of data to the different Arrays used by JFreeChart as input parameters.

4 Future work

The main next step for the automated read and visualization of text files is the creation of a Java Class Library (JCL) so that this automation can be loaded dynamically at runtime and be implemented inside another applications.

5 Conclusions

The development of SmartPlot adds value to the probabilistic aircraft damage tolerance analysis provided by Smart|DT by allowing its users to view graphical representation of both input and output files.

The Java language, through its event-driven approach, provides benefits such as scene switching efficiency and interactive interfaces. Moreover, Java has a wide range of open source libraries to perform input/output and user interface functions.

6 Acknowledgements

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