Australian Government
Department of Defence
Defence Science and
Technology Organisation

A Methodology for the Analysis of the Probability of Failure by Fast Fracture of Aircraft Structural Components

Dr. Ribelito Torregosa and Dr. Weiping Hu
Aerospace Division, DSTO, Australia

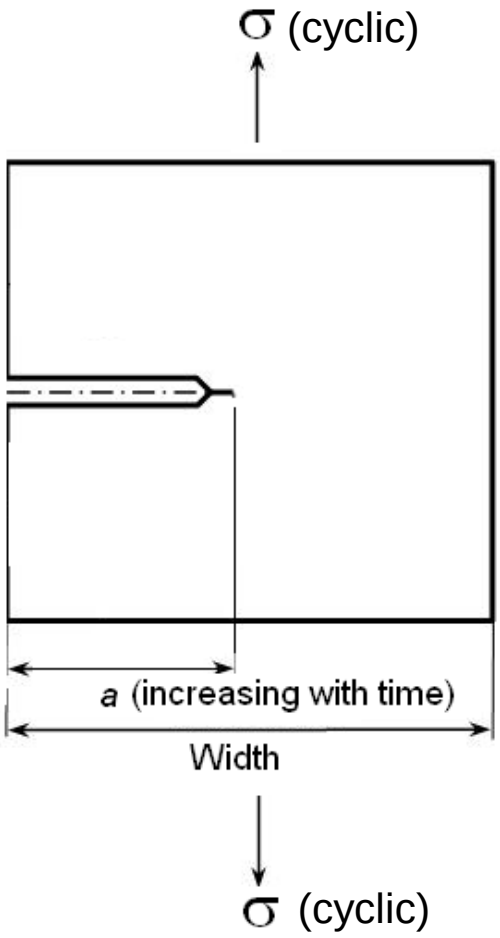
Presented by Ribelito Torregosa

8th International Conference on Structural Integrity and Fracture, Melbourne, 11-12 July 2013

Application of probabilistic risk analysis

- Complement the Damage Tolerance Analysis
- Determine inspection intervals
- Selection of NDI technique
- Aid in making decision on component replacement
- Aid in deciding (military) aircraft retirement

Probabilistic risk analysis (PRA) of fracture



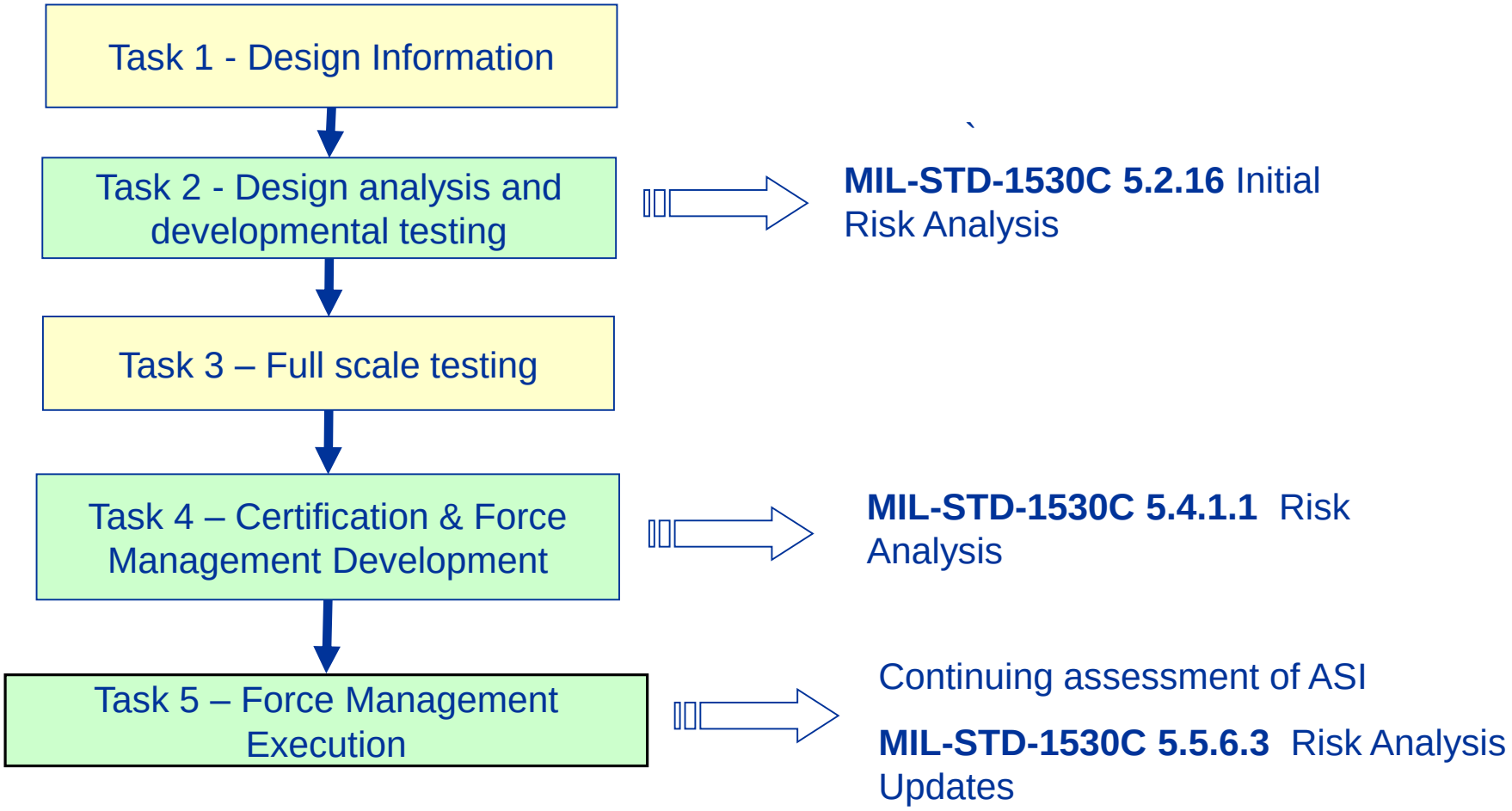
- Risk - probability of failure or unstable fracture
- Failure occurs when;

$$\sigma \geq \text{Residual strength}$$

Parameters needed to conduct a risk analysis of fracture

- Master crack growth curve
- Residual strength curve
- Peak stress exceedance curve
- EIFS distribution – equivalent initial flaw size expressed in probability distribution

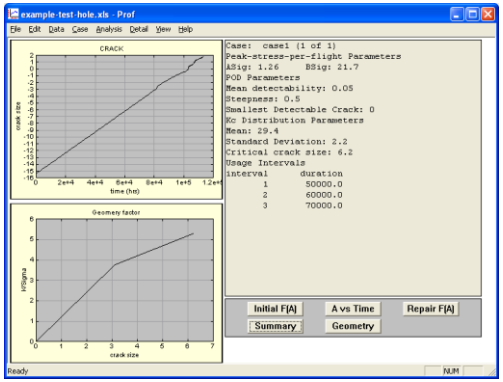
Role of probabilistic risk analysis in ASIP (MIL-STD- 1530C)

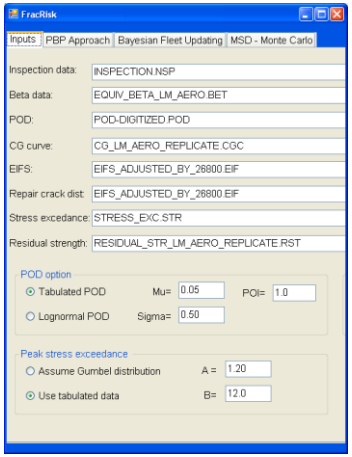


Aircraft Structural Integrity Program (ASIP) Tasks

DSTO

Development of FracRisk - Risk Analysis of Fracture Tool





PROF analysis tool

Distribution models are fixed

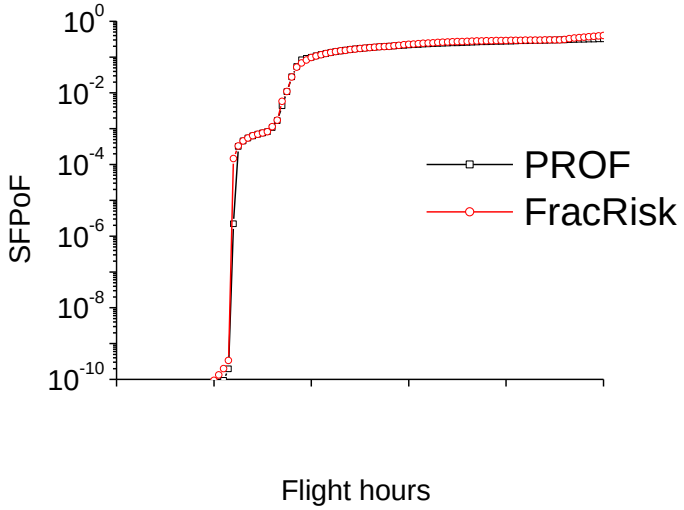
* Peak stress distribution can only be modelled by Gumbel type 1,
* Fracture Toughness can only be modelled by Normal Distribution,
* Probability of Detection (POD) can only be modelled by Lognormal Distribution

FracRisk analysis tool

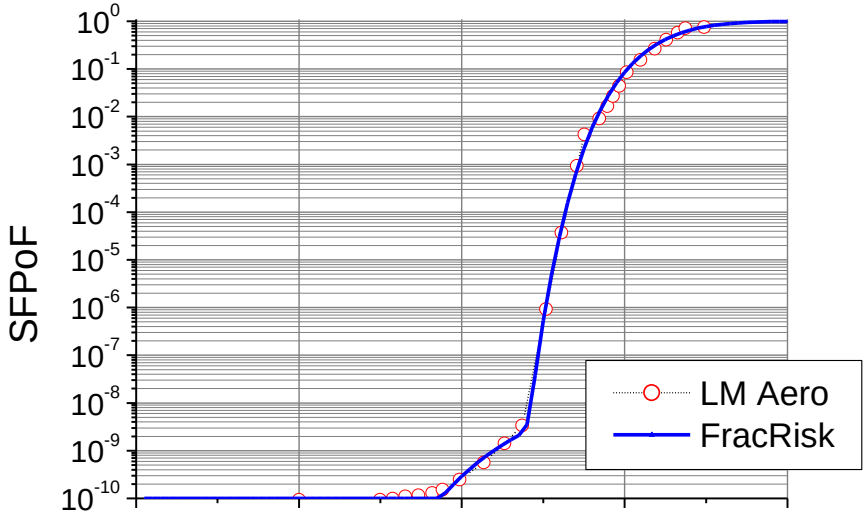
✓ Distribution model in all parameters not restricted, tabulated data also acceptable

Verification of FracRisk results

FracRisk and PROF



FracRisk and LM Aero

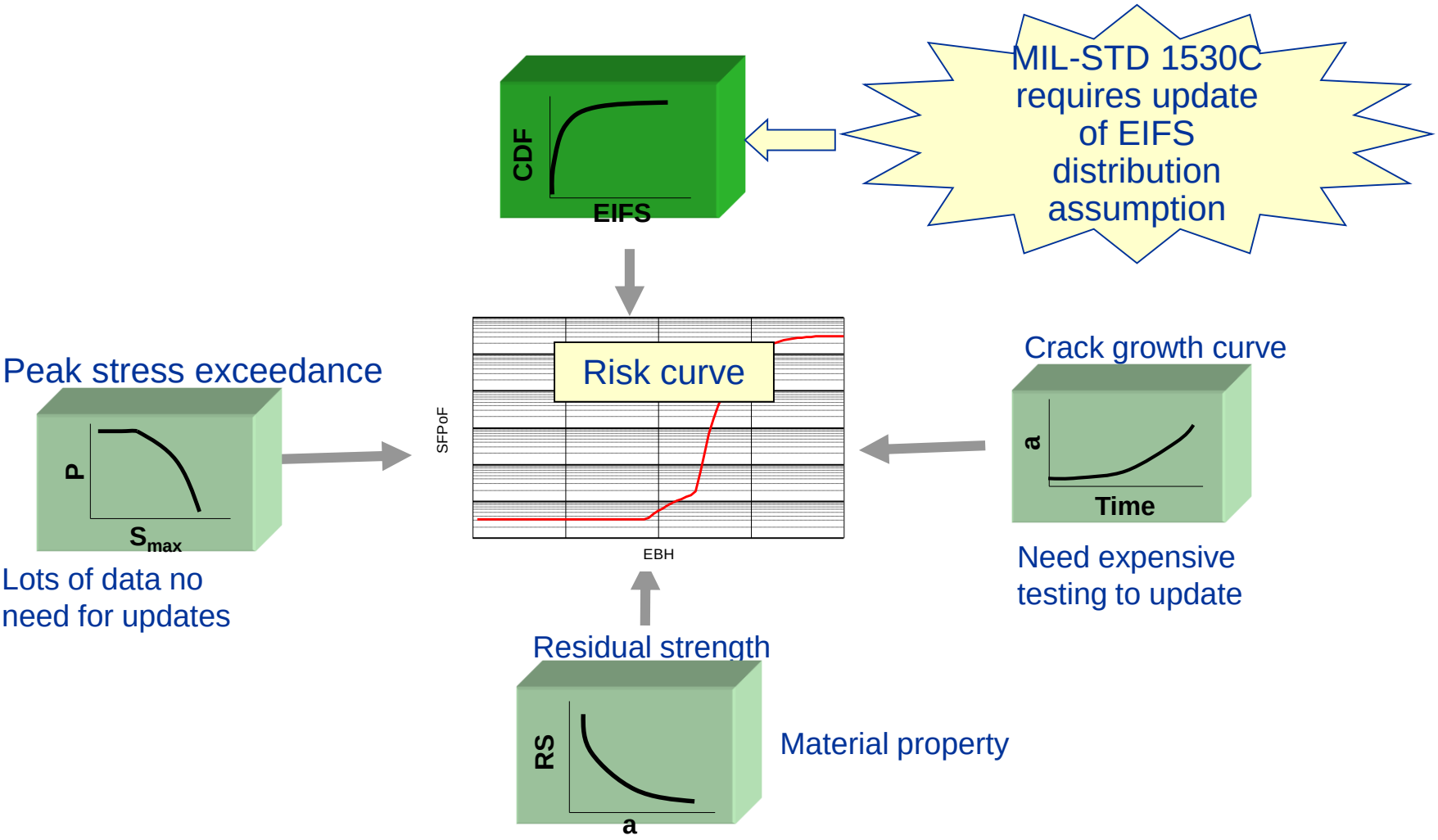


- Data used from *PROF*
- Results are compatible
- Validates the result from FracRisk

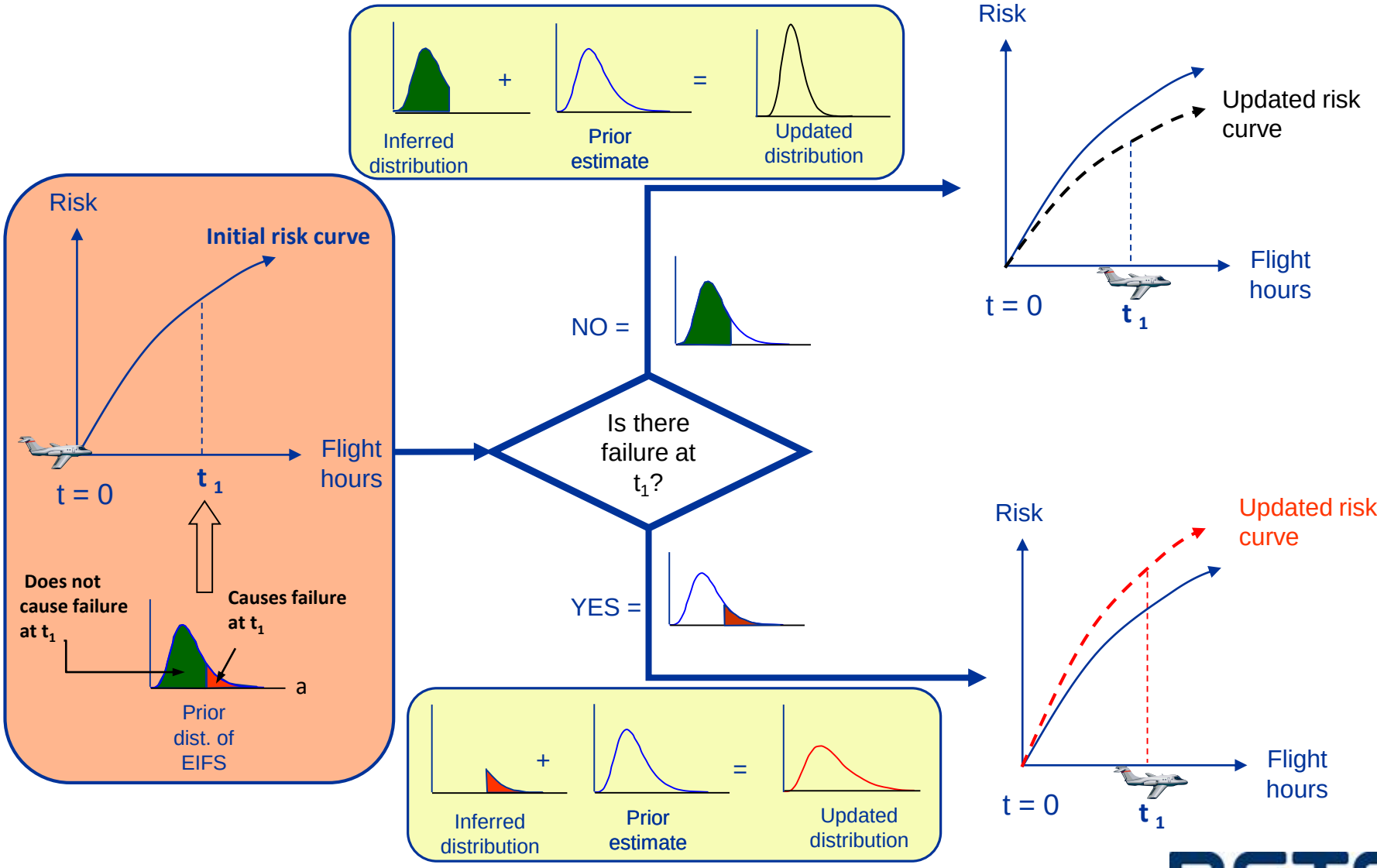
Bayesian Updating of Risk Analysis

DSTO

Bayesian updating of EIFS Distribution

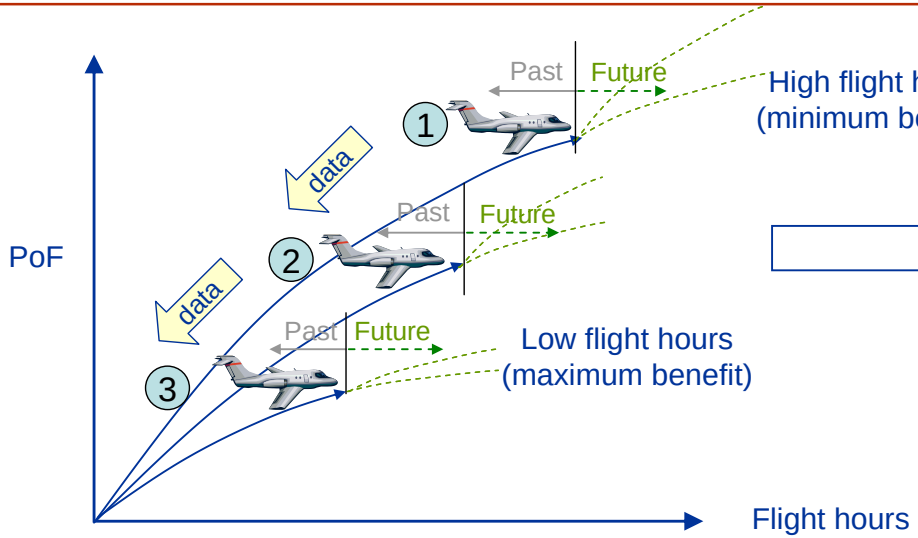


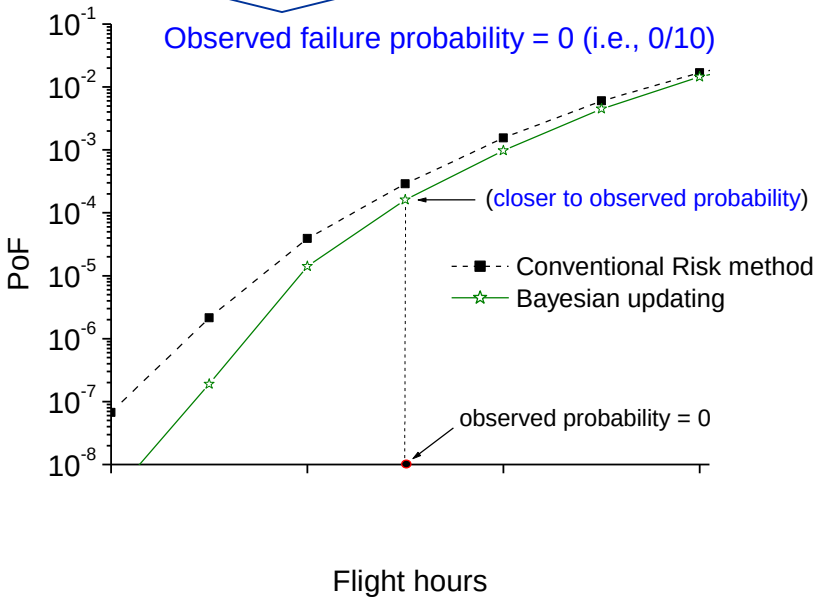
1) Bayesian aircraft risk updating



2) Bayesian fleet risk updating (when no observed failure)

Hypothetical example = 10 aircraft in a fleet

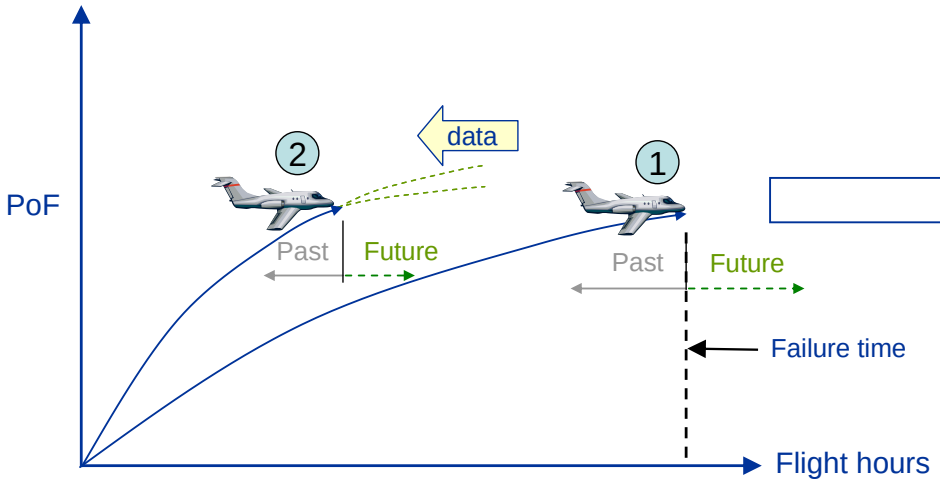


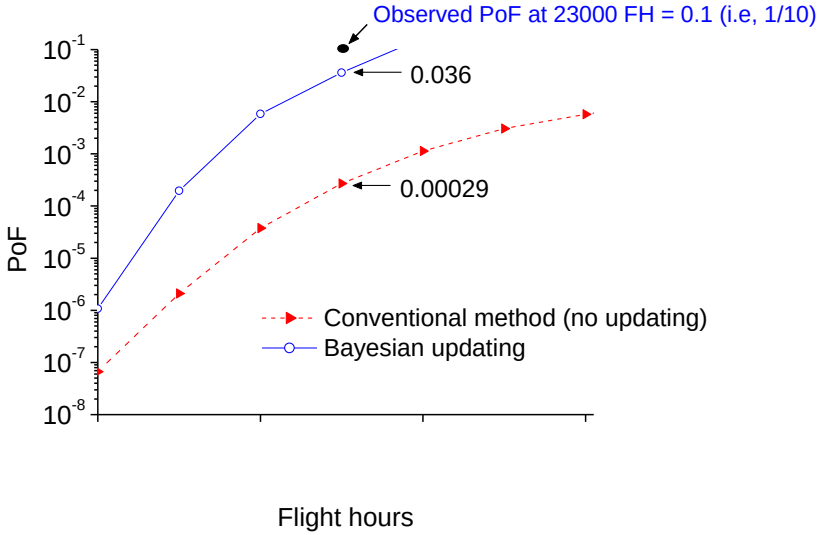


- Reduction of risk at all flight hours
- Updated risk closer to observed PoF than conventional risk output

2) Bayesian fleet risk updating (with observed failure)

Hypothetical example = 10 aircraft in a fleet

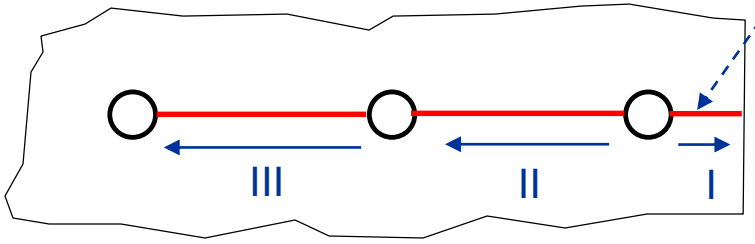




- Big increase of risk
- Updated risk closer to observed PoF than conventional risk output

Multi-site Fatigue Damage (MSD)

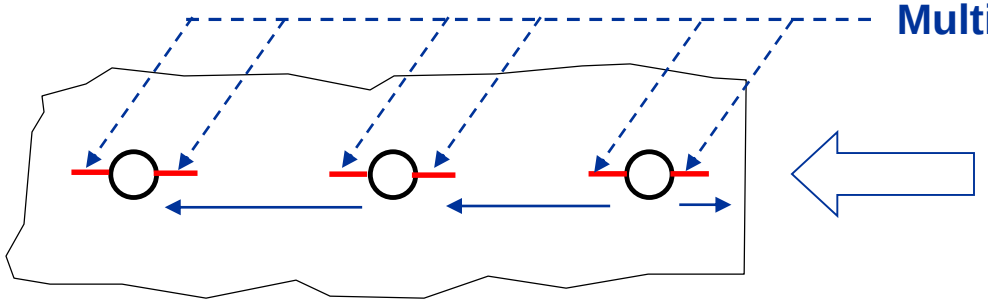
Multi-site Damage (MSD) Probabilistic Risk Analysis



Crack grows in phases

- Simple and easy to analyze
- commonly used method

1) Phase by phase approach



Multiple cracks grow simultaneously

- Complicated procedure
- Realistic

2) Multi-site damage (MSD)

DSTO

Why MSD analysis important?

Maintaining structural integrity

"**multiple-site damage** could cause many small cracks in the structure, which grow slowly by themselves, to join one another over time, creating a much larger crack, and significantly reducing the expected time until failure"

Required by standard

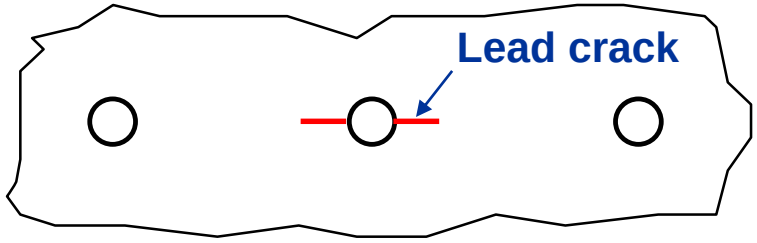
"Durability criteria apply to all airframe structural components and shall include criteria that pertain to the onset of **widespread fatigue damage**"

MIL-STD-1530C (USAF) 5.1.3.4

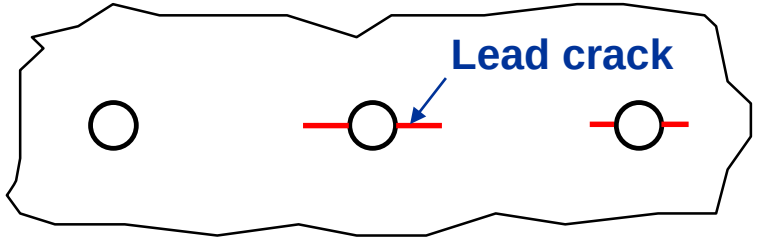
Mandated by Federal Aviation Administration (FAA)

requires aircraft manufacturers and other certification applicants to establish a number of flight cycles or hours a plane can operate and be free from WFD without additional inspections for fatigue.

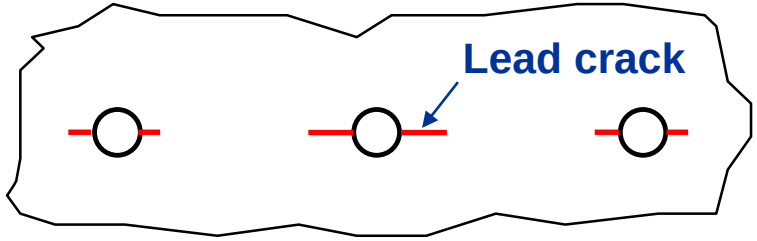
Effect of multiple cracks to the residual strength



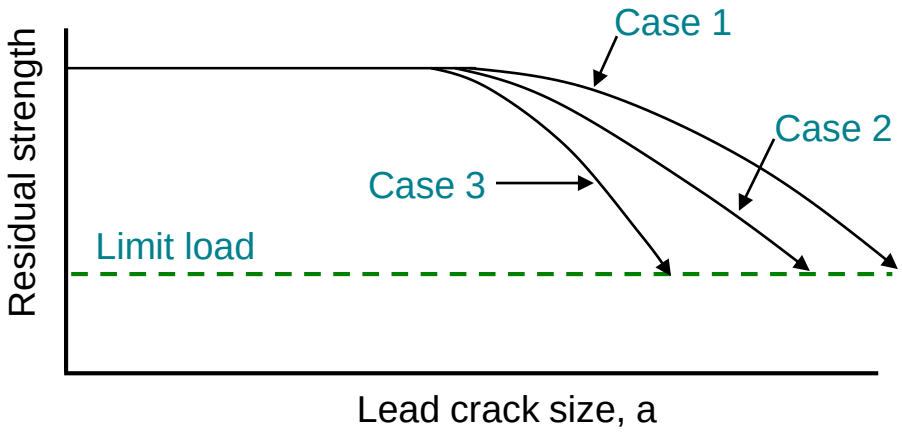
Case 1- Single crack



Case 2- MSD 2 cracks



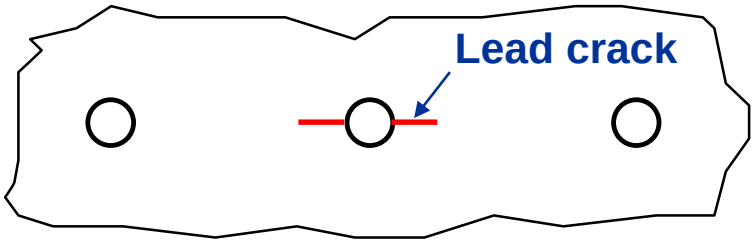
Case 3- MSD 3 cracks



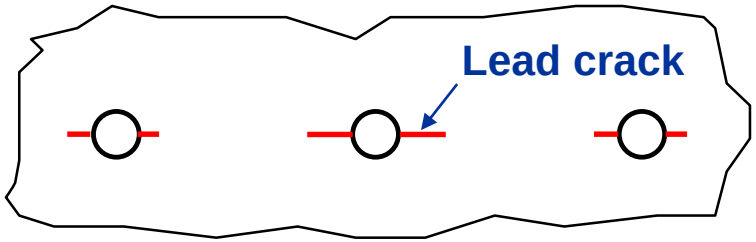
MSD reduces the residual strength

DSTO

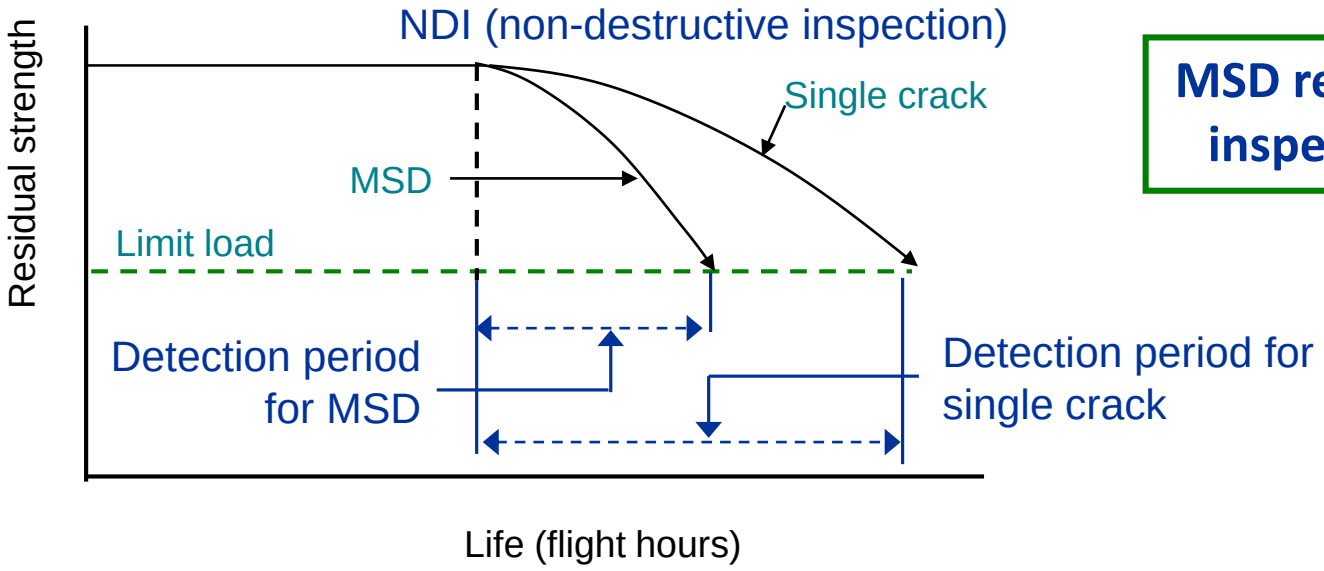
Effect of multiple cracks to the inspection interval



Single crack



MSD

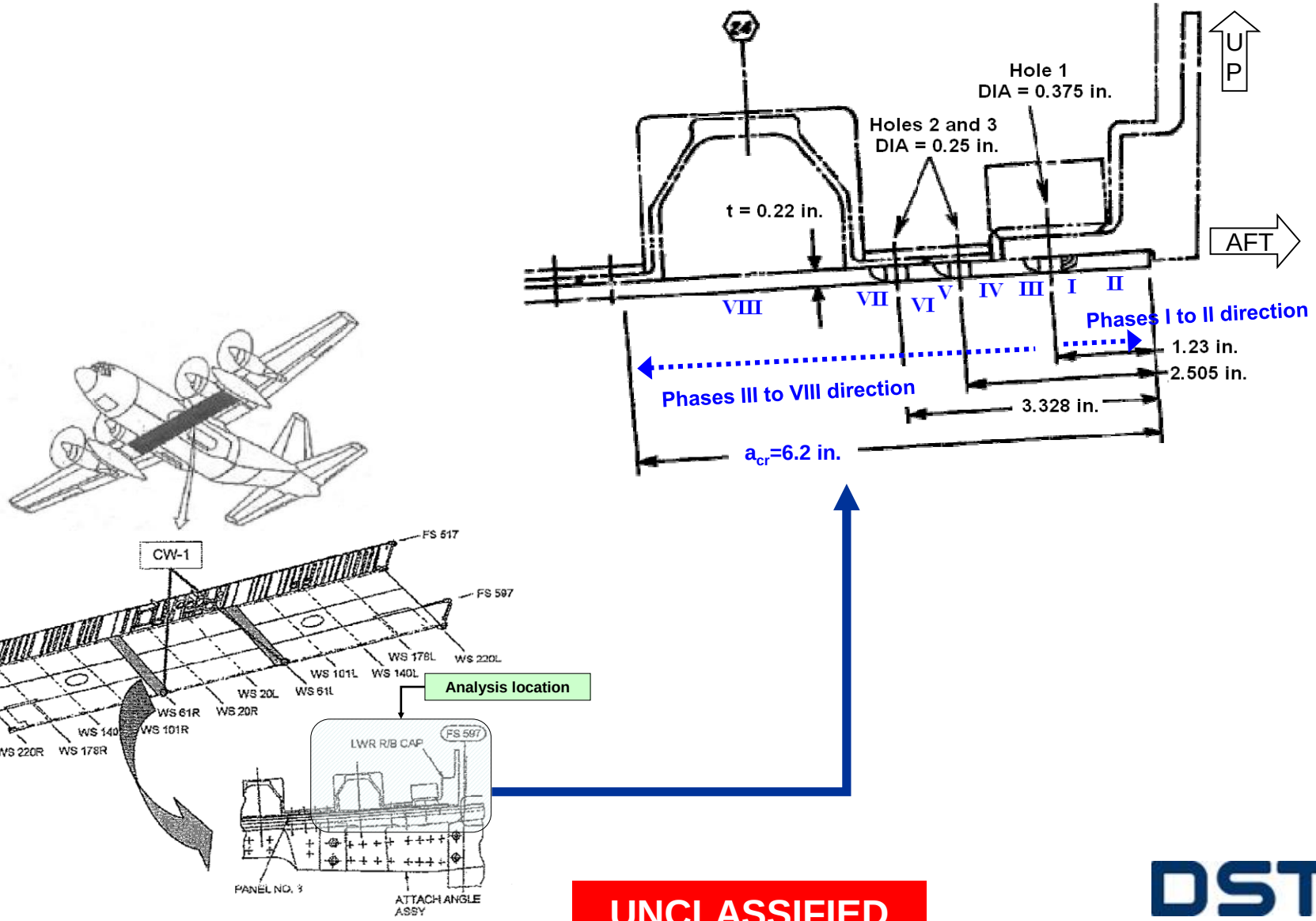


MSD reduces the crack inspection interval*

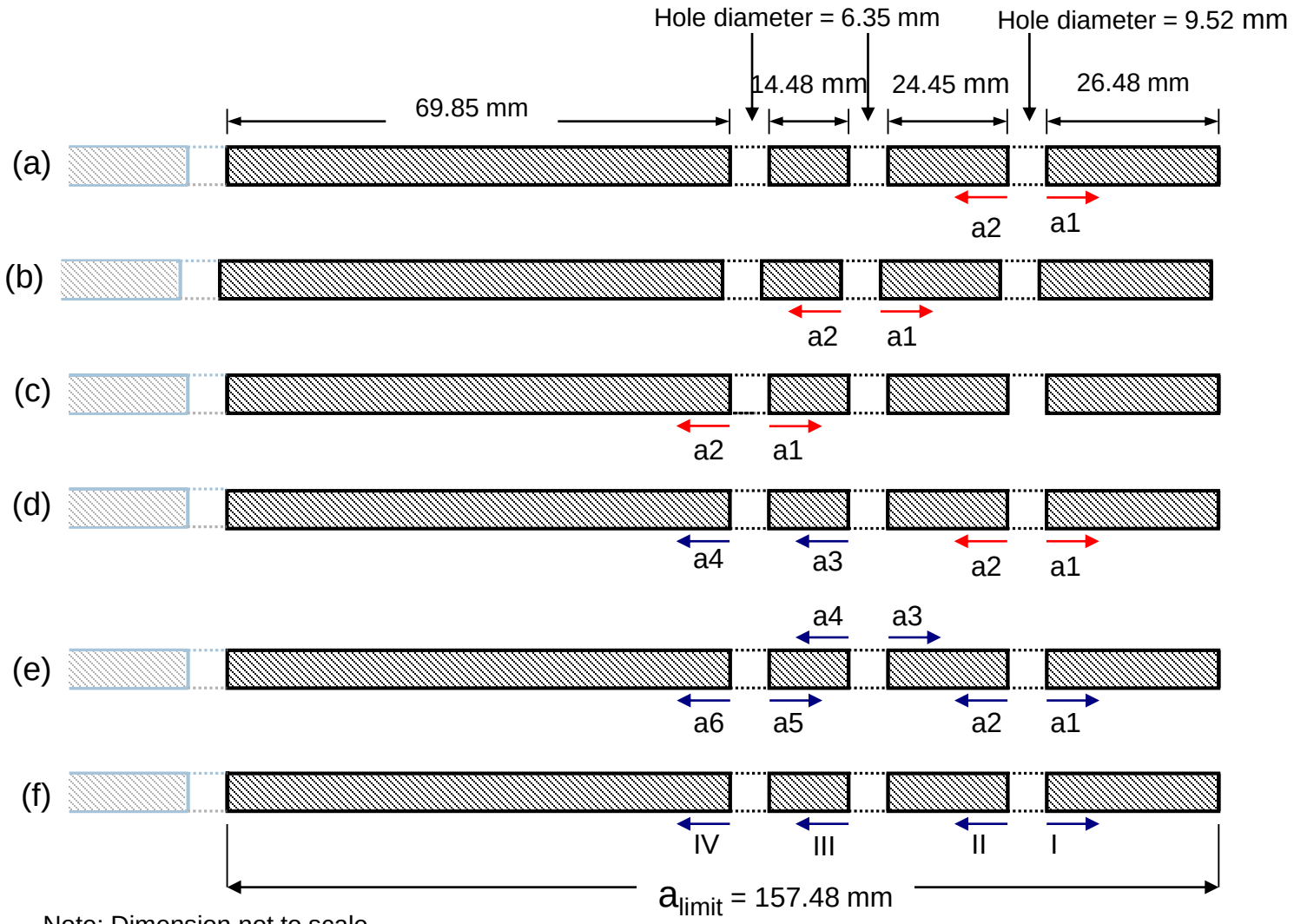
* Alain Santgerma, et. al. (AA&S Brisbane, 2012)

DSTO

MSD Risk Analysis of C130-H CW-1 Location



C130-H CW-1 MSD crack scenarios analysed (a to e)



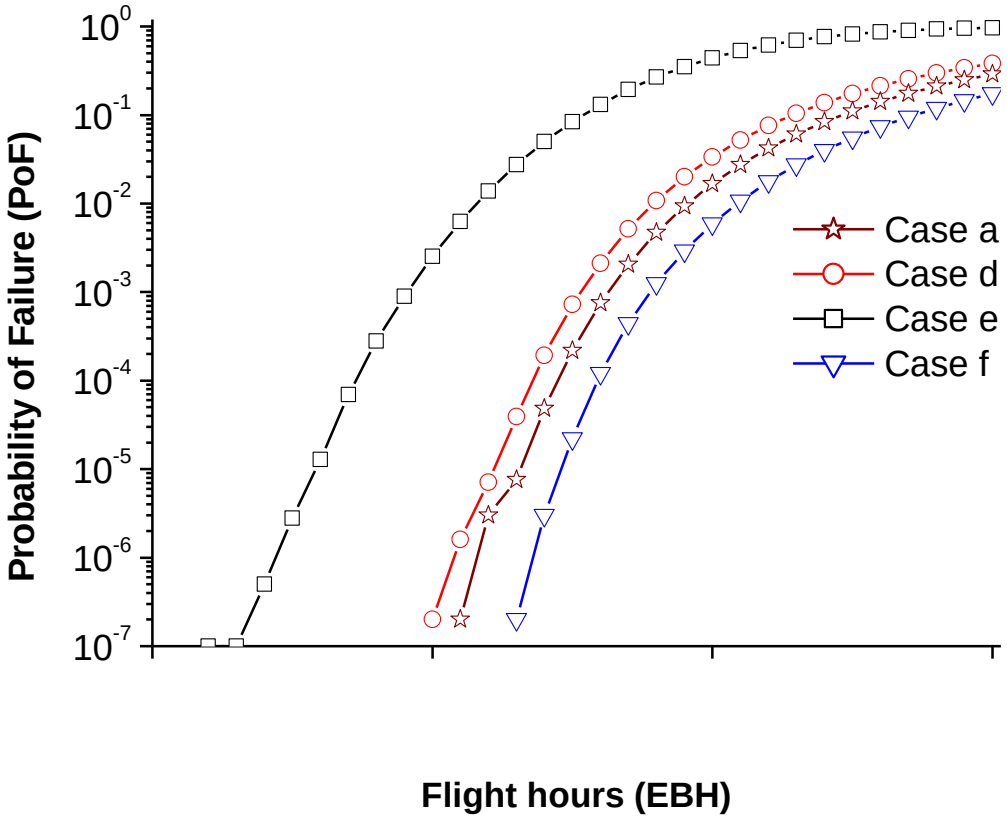
Note: Dimension not to scale

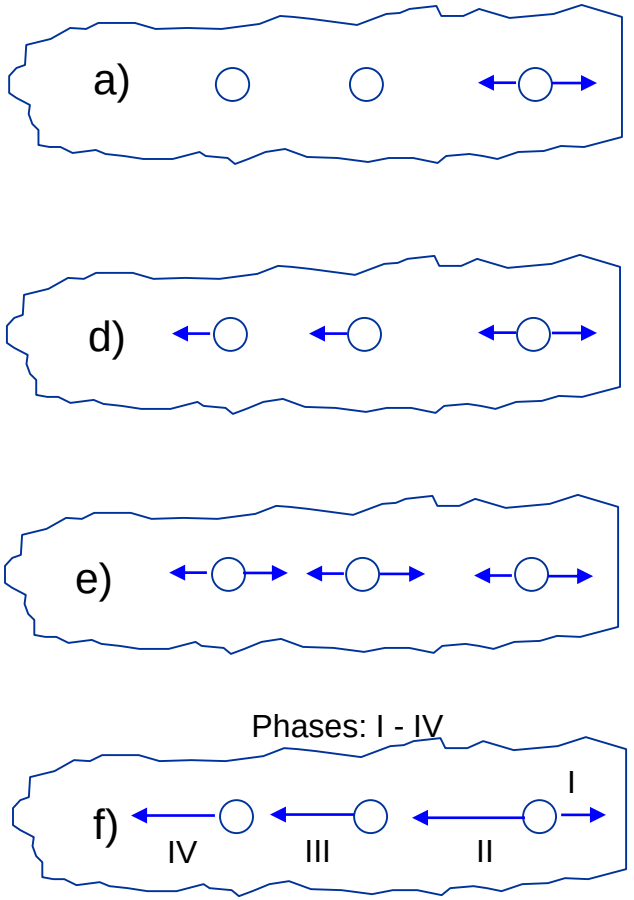
Legend:

Lead crack

Probability of Failure (PoF) with increasing cracks numbers

☞ **Probability of failure increases with the increase of the number of cracks**



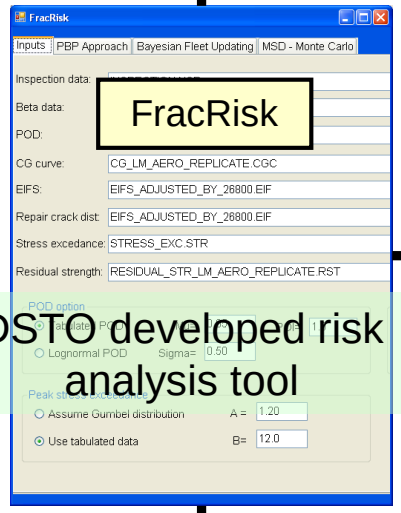


Summary of FracRisk capabilities

Probabilistic risk analysis of failure tool - FracRisk

Capabilities

Risk Curves



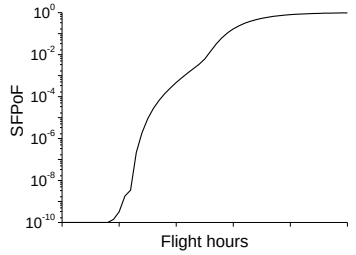
FracRisk

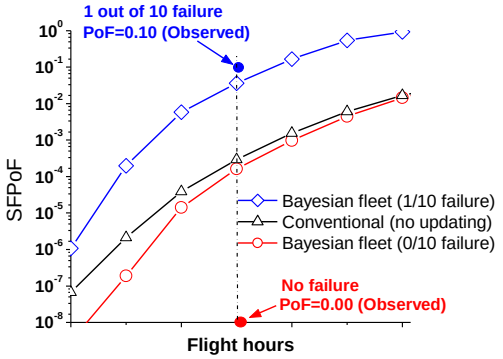
DSTO developed risk analysis tool

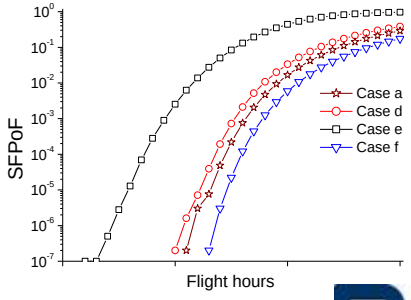
PROF method

Bayesian risk updating

Multi-site damage (MSD) risk analysis







Conclusions

- Capability of FracRisk as a risk analysis tool is demonstrated
- Bayesian updating of risk analysis improves the accuracy of the risk analysis
- Bayesian updating is a potential tool for inexpensive update of the risk analysis
- An increase in the number of cracks resulted to a corresponding increase in the risk of fracture

Where do we go from here?

- Enhancing the MSD risk analysis capabilities of FracRisk

(e.g., replace master crack growth curve with crack growth calculation based on local geometry and fracture mechanics, using handbook solutions or FEA)

DSTO

Questions?

Outline of the presentation

- Relevance of Probabilistic Risk Analysis (PRA) of Fracture to aircraft structural integrity assessment
- Development of risk analysis tool FracRisk
- Bayesian updating of risk analysis
- Multi-site damage (MSD) risk analysis
- Conclusion