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Australian Government
Department of Defence
Defence Science and Technology Organisation

Effect of models and derivation methods for initial flaw size distribution on probability of failure of airframes

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Probabilistic risk analysis (PRA) of fracture is gaining popularity

- Analysis parameters such as loads, material properties have varying degree of uncertainties;
- Balancing economic benefits and risks;
- Offers flexibility of solutions in solving engineering problems ; and
- Enables interaction between engineers, managers and stakeholders

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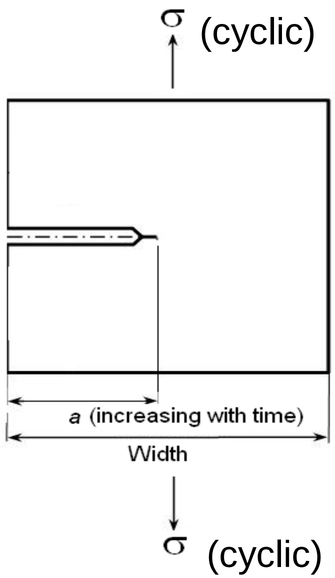
Probabilistic risk analysis (PRA) of fracture



- Risk - probability of failure or unstable fracture
- Failure occurs when; $\sigma \geq \text{Residual strength}$

Probability of Failure (PoF) calculation:

$$PoF = \int_{0}^{\infty} f(a)\left(1 - \int_{0}^{s_{RS}(a_{cr})} f(s)ds\right)$$

Where :

s = stress

a = crack size

a_{cr}= critical crack size

s_{RS}= residual strength

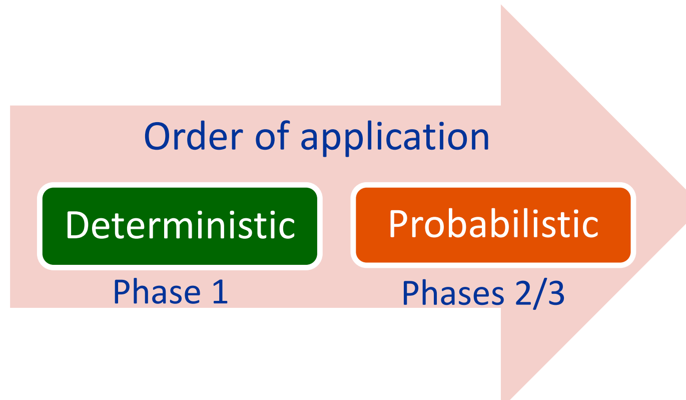
f(a)= crack size probability density function

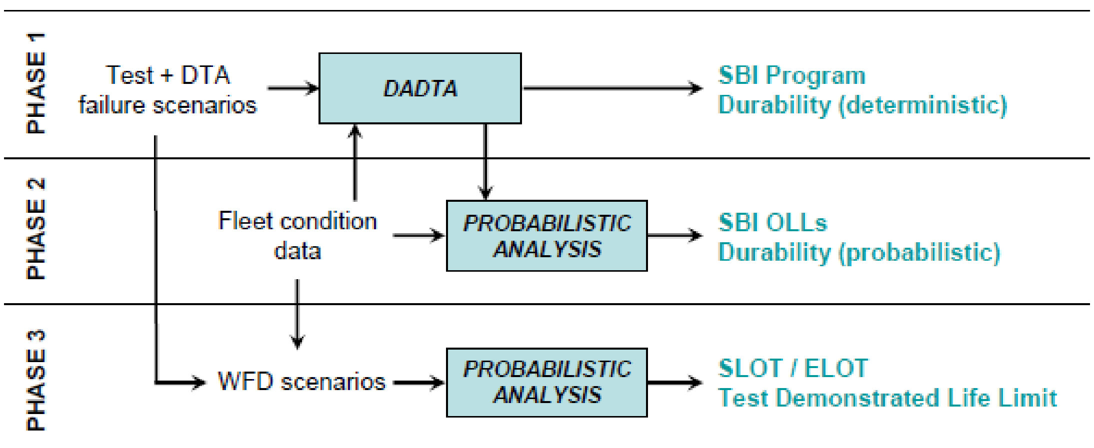
f(s)= stress probability density function

1. Analysis of fracture of airframes

Probabilistic vs. Deterministic

DSTO involvement in C-130J Full Scale Fatigue Test





credits to : D. Hartley, R. Ogden and L. Meadows

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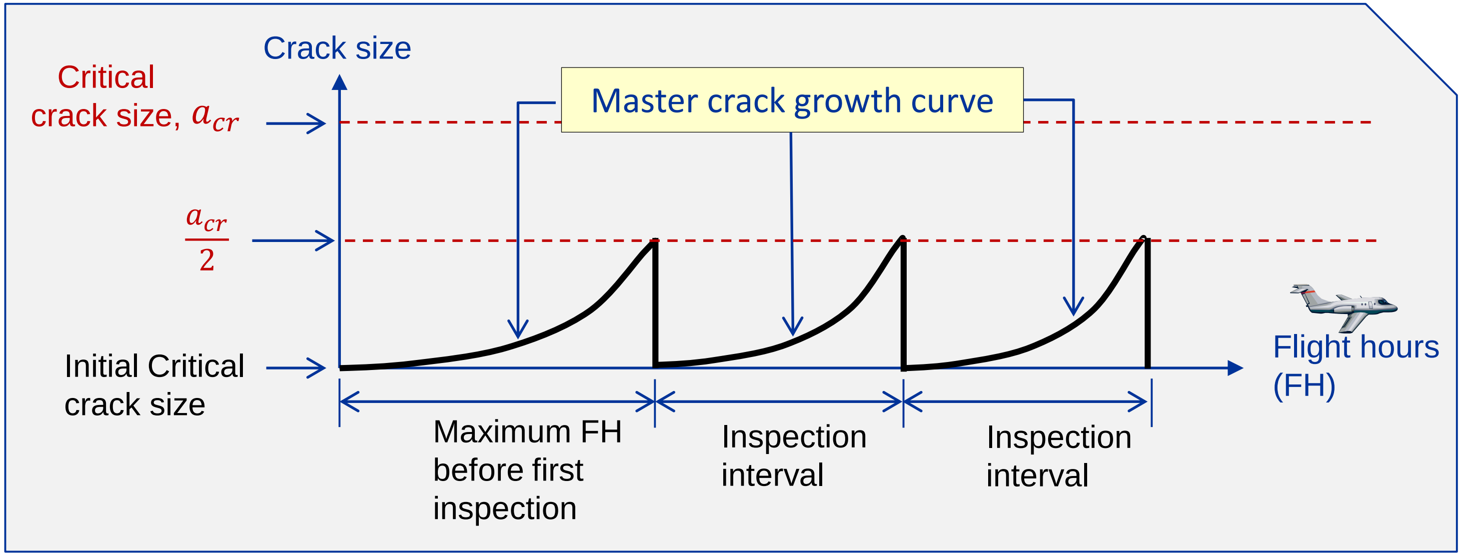
Deterministic approach of fracture prevention on airframes



Determine the critical crack size, a_{cr}

Project the crack size using the master crack growth curve

Conduct inspection at flight hours when crack size is projected to be $\frac{a_{cr}}{2}$

Crack size back to initial size

Weakness of the method :

- Deterministic method implies that safety of an airframe can be maintained indefinitely through inspection

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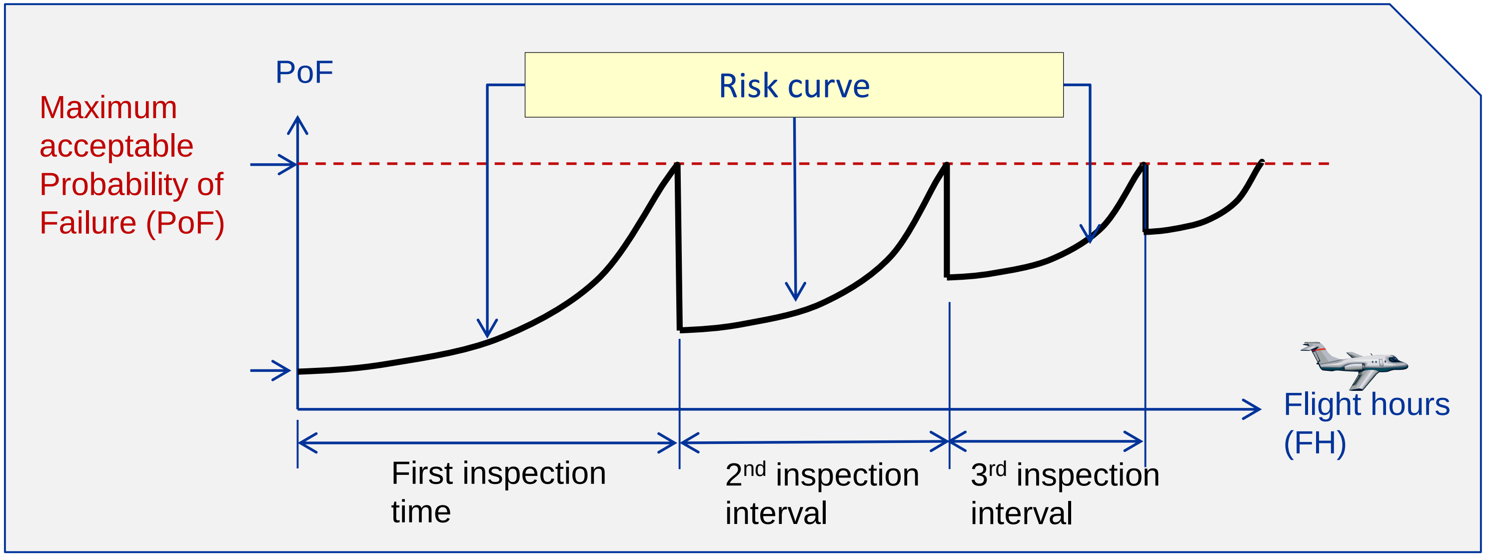
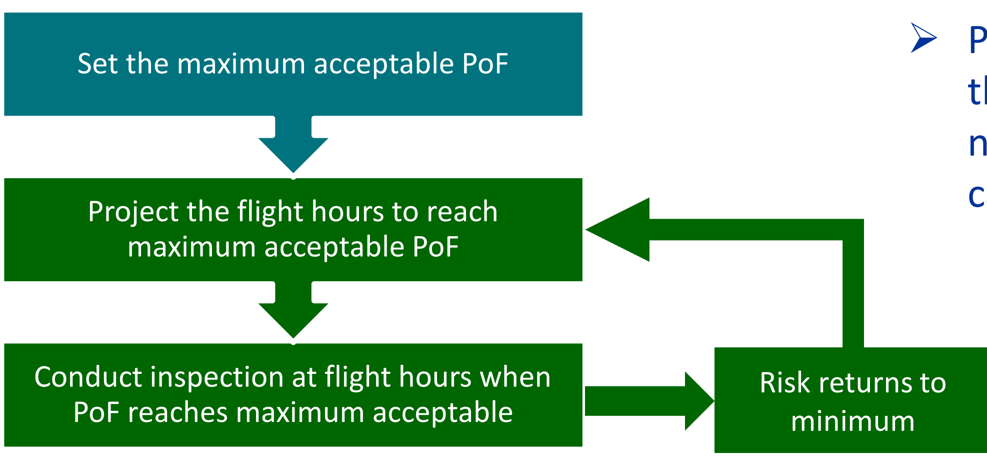
Probabilistic approach of fracture prevention on airframes





Advantage of the method :

- Probabilistic method shows that there is a limit to the number of inspections that can be conducted

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2. MIL-STD1530 Standard requirement

Aircraft Structural Integrity Program (ASIP)

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

Task 1 - Design Information

Task 2 - Design analysis and developmental testing

MIL-STD-1530C 5.2.16
(Initial probabilistic risk analysis)

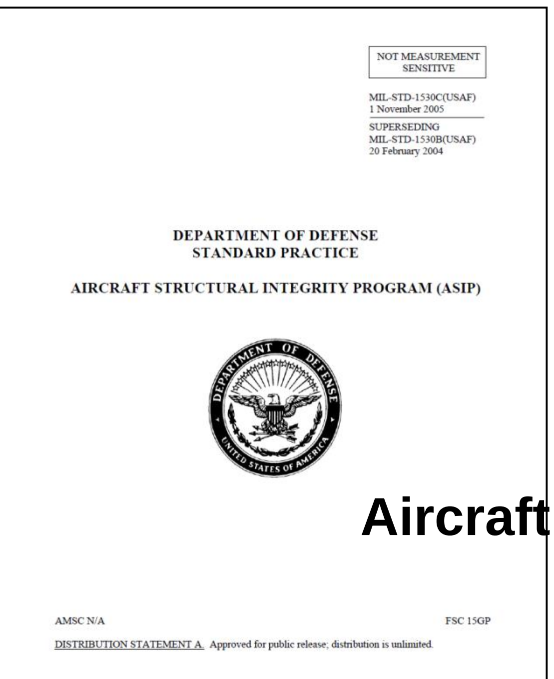
Task 3 – Full scale testing

Task 4 – Certification & Force Management Development

MIL-STD-1530C 5.4.1.1
(Probabilistic risk analysis)

Task 5 – Force Management Execution

MIL-STD-1530C 5.5.6.3
continuing assessment
(Probabilistic risk analysis update)


NOT MEASUREMENT SENSITIVE

MIL-STD-1530C(USAF)
1 November 2005

SUPERSEDING
MIL-STD-1530B(USAF)
20 February 2004

DEPARTMENT OF DEFENSE
STANDARD PRACTICE

AIRCRAFT STRUCTURAL INTEGRITY PROGRAM (ASIP)

AMSC N/A FSC 15GP

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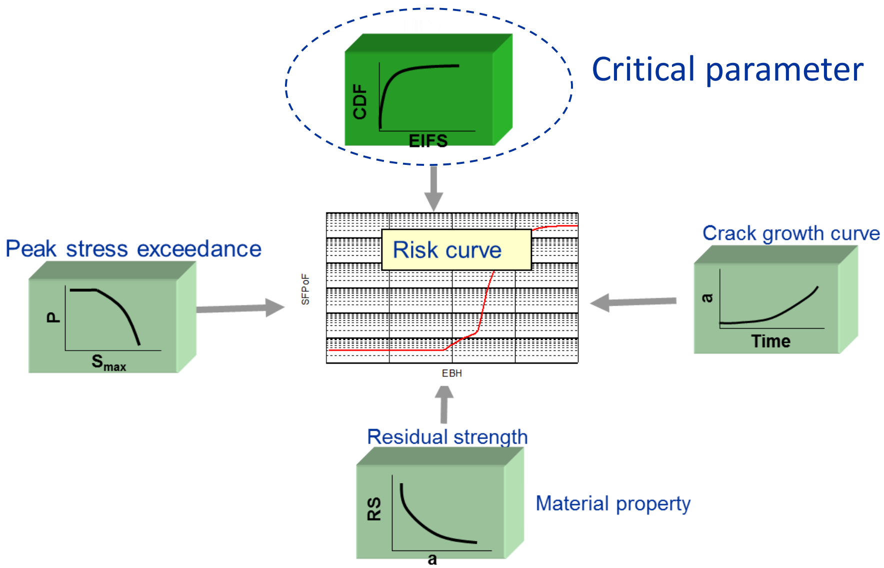
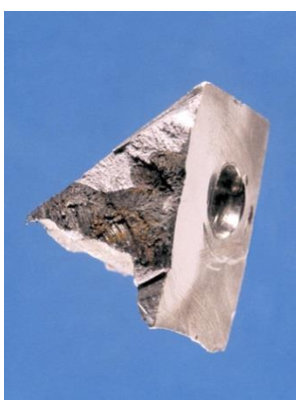
Aircraft Structural Integrity Program (ASIP) Tasks

Input Data for Probabilistic Risk Analysis of Fracture on Airframes



Equivalent initial flaw size (EIFS) distribution

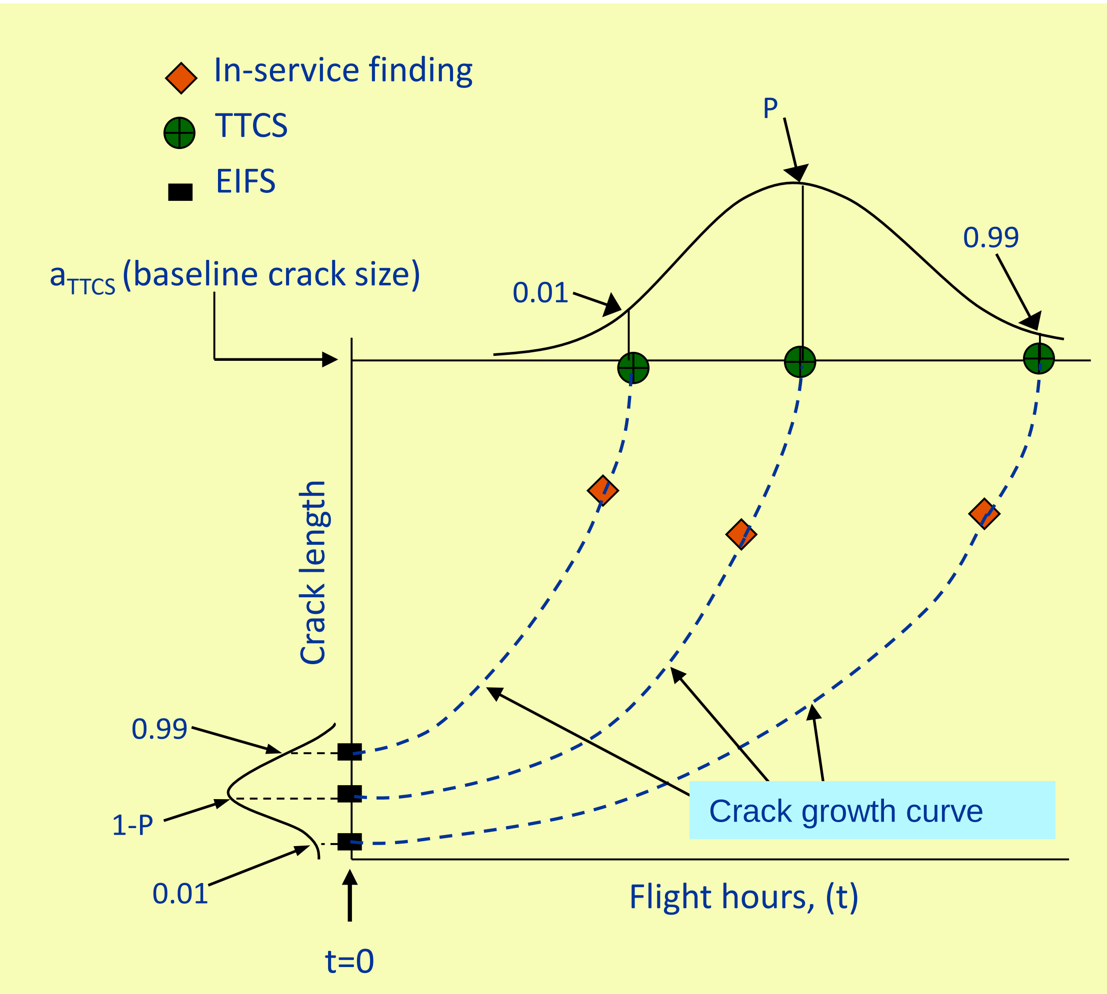
- Most critical parameter
- Very high influence to the risk analysis
- Least understood
- Different methods to obtain and each method giving different values



In this study : **Discrepancy of PoF values based on methods of deriving the EIFS distribution is investigated**

3. Methods of derivation the EIFS Distribution

Time to Crack Size (TTCS) Method of Deriving EIFS Distribution



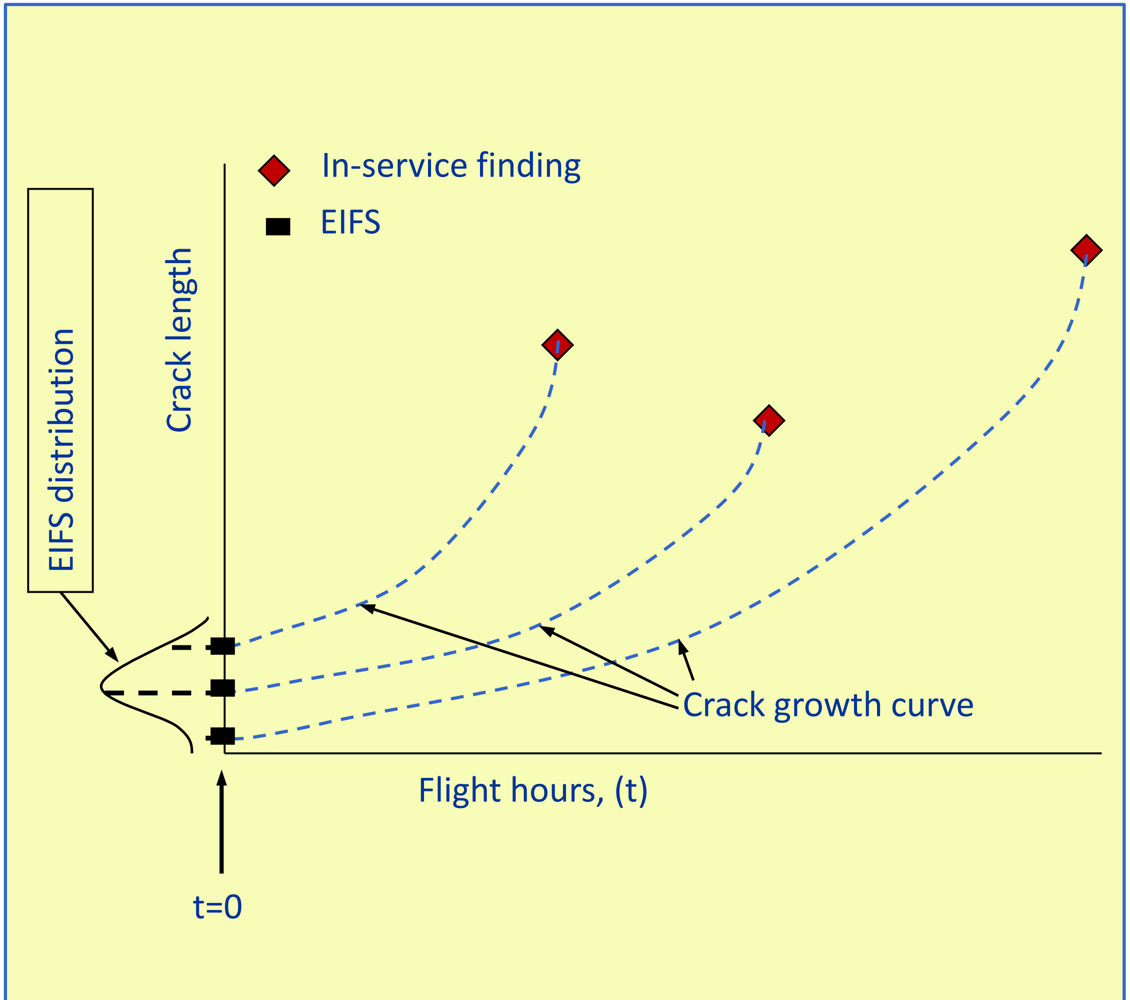
Advantage of the method :

- Eliminates unreasonably large EIFS values

Disadvantage of the method :

- Dependent on arbitrary value of baseline crack size
- Different baseline crack size give different EIFS values

Direct Method of Deriving EIFS Distribution



Advantage of the method :

- EIFS distribution can be expressed in a closed form equation

Disadvantage of the method :

- Unrealistically large EIFS values due to unbounded right tail of distribution

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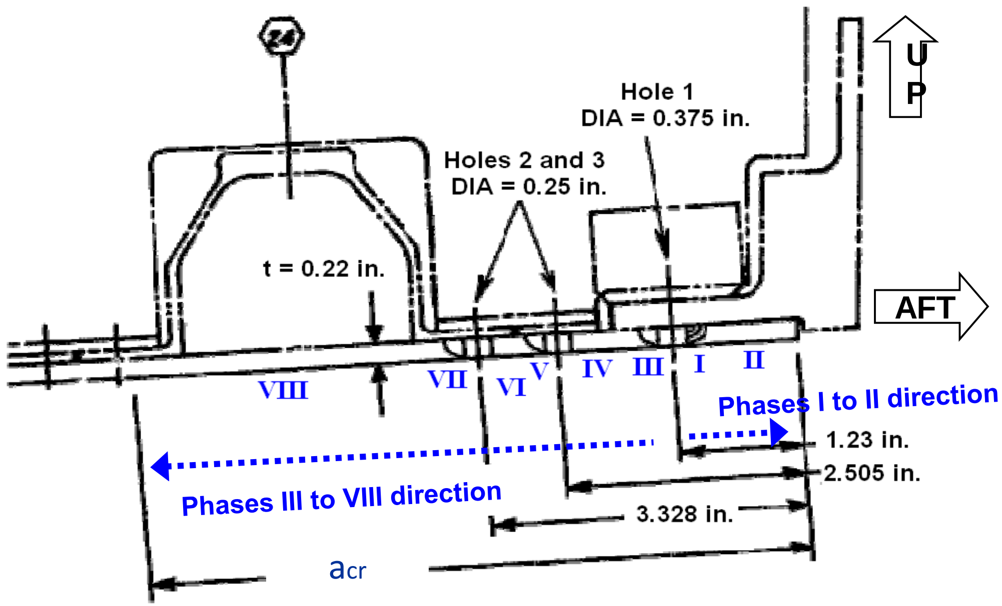
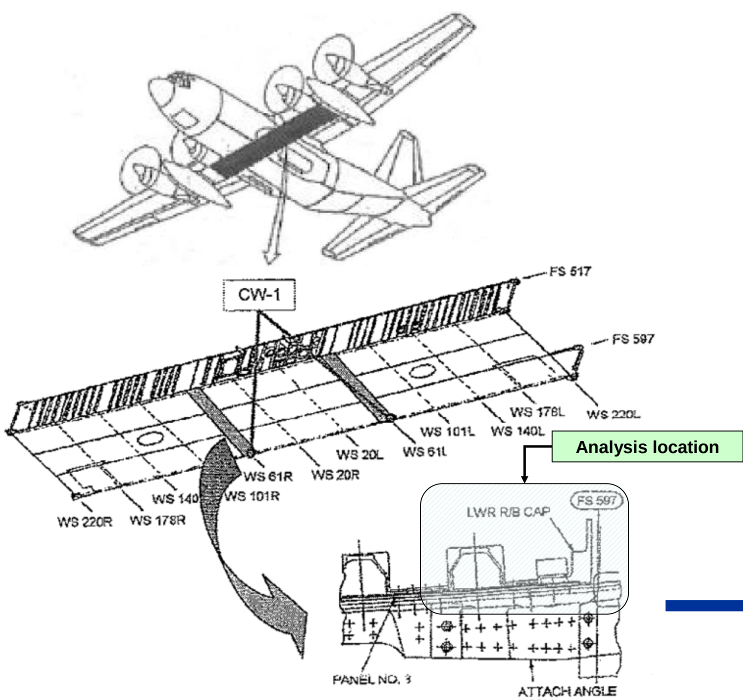
4. Test case

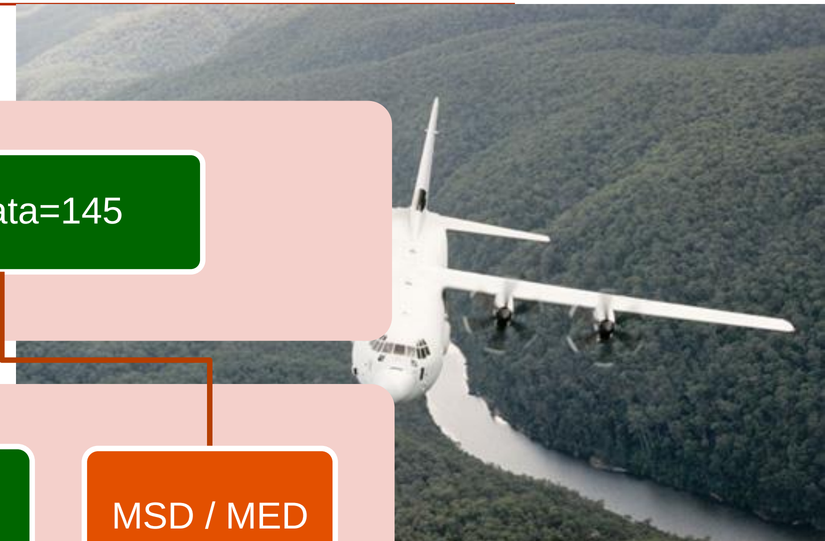
Application of various EIFS distribution models to the Probabilistic risk analysis of fracture of a military aircraft

Probabilistic Risk Analysis of C130-H CW-1 Location





Data Used for EIFS Distribution Regression Analysis



Collection of teardown inspection data

Raw data=145

Filtering of data

Non-MSD

MSD / MED

Regression analysis

Data = 65

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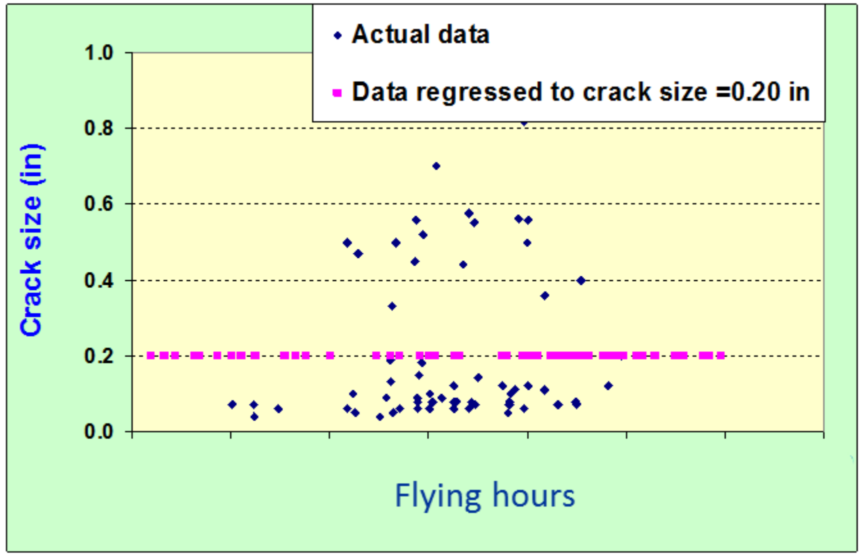
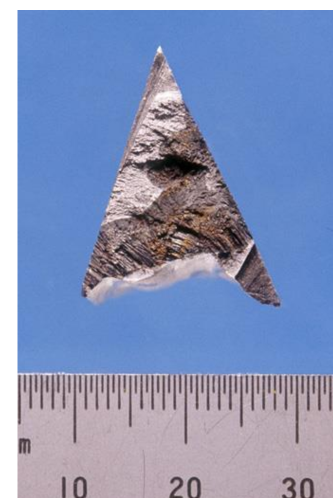
Data Used for EIFS Distribution Regression Analysis

Mean crack size of actual data = 0.206 in.



Four EIFS distribution were developed:

1. Direct EIFS
2. TTCS Method with baseline crack size = 0.10 in
3. TTCS Method with baseline crack size = 0.20 in
4. TTCS Method with baseline crack size = 0.30 in



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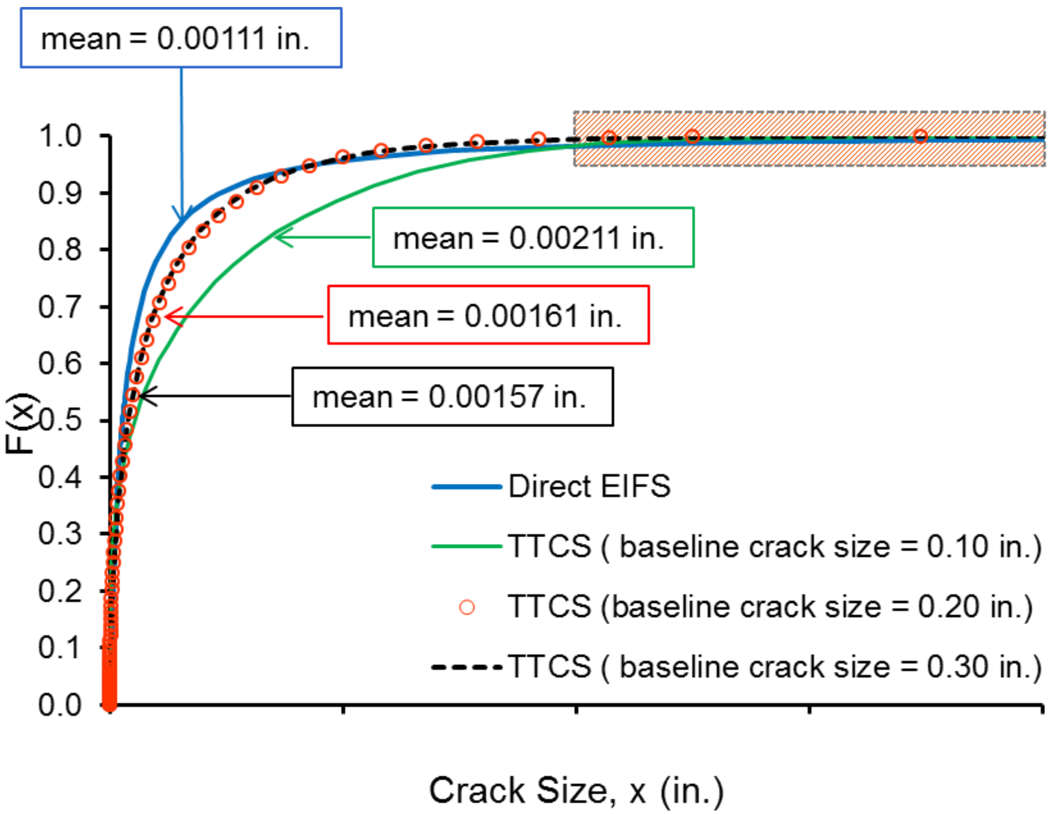
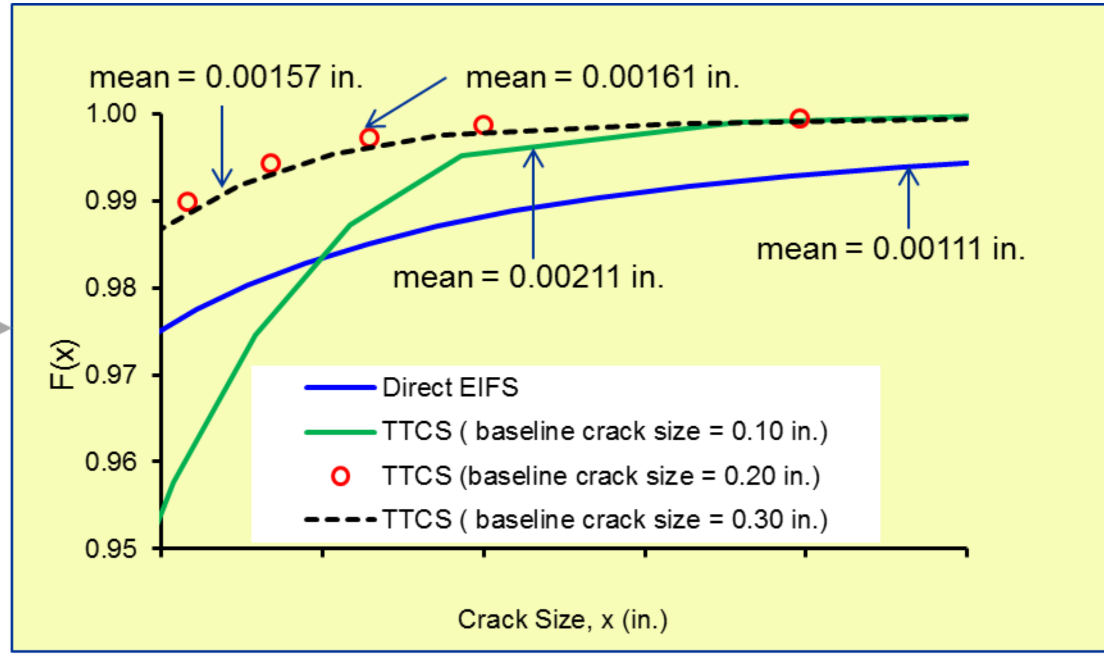
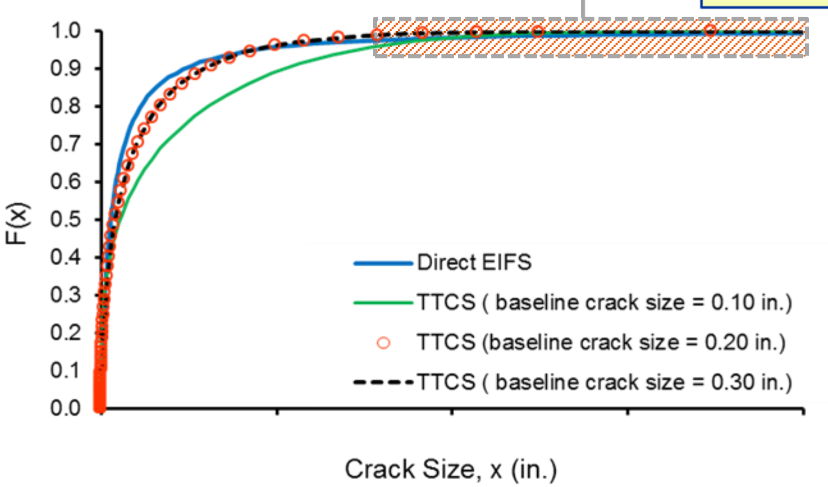
Comparison of Cumulative Distribution Curves



- One set of data may result to different EIFS distributions
- TTCS models may result to different EIFS distributions

Comparison of Cumulative Distribution Curves





1. Direct EIFS methods shows a flat curve far from F(x) =1.0 which means that there is a large proportion of large initial crack sizes
2. TTCS Method immediately converges to F(x)=1.0 which means that there are no large initial crack size

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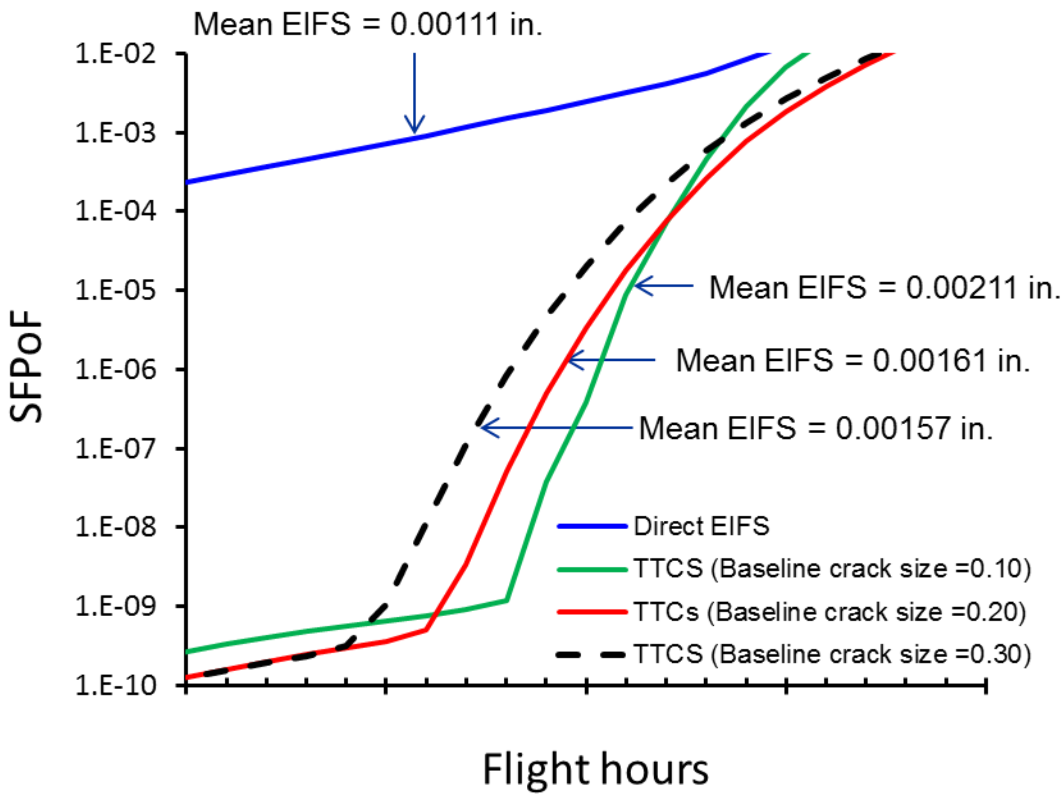
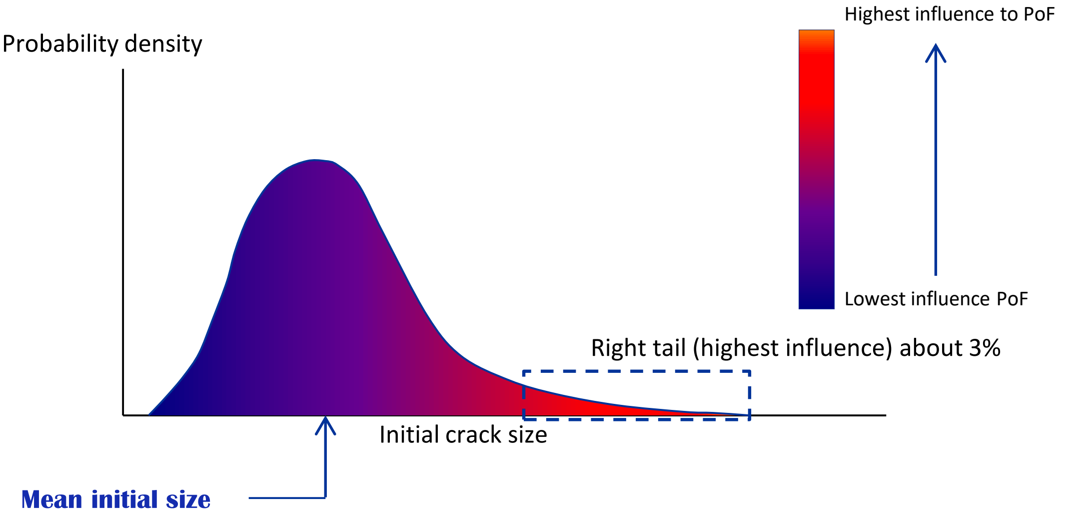
Comparison of Probability of Failures



- Direct EIFS method :
  - smallest mean EIFS
  - highest PoF values
- TTCS method :
  - mean EIFS values do not give directly correlation to PoF values

Probability distribution's degree of influence on PoF



This study shows that :

1. **Mean value of the distribution has no influence on the Probability of Failure (i.e, <u>no correlation between mean EIFS and PoF</u>) ;**
2. **Right tail of the distribution has very high influence on the risk values; and**
3. **Distribution model must accurately model the extreme values of initial flaw sizes**

Conclusions

1. **EIFS distribution derived by the Direct Method may over-estimate the probability of failure, when an unbounded distribution model is used;**
2. **EIFS distribution derived by the TTCS Method give probability of failure which are sensitive to the assumed baseline crack;**
3. **The mean of the EIFS distribution has very little influence on the SFPoF values; and**
4. **More accurate and realistic assumption of the upper bound of the EIFS distribution is necessary in analysing the fatigue failures of aircraft structures.**

Future works :

1. To address unrealistically large EIFS, the use of bounded distribution such as Beta distribution will be investigated.
2. Apply probabilistic risk of fracture to the test interpretation of the on-going C-130J RAF and RAAF collaborative full scale fatigue test

Questions?