

# ProCORFA GUI: Main Window Dialog

**ProCORFA - Reliability Analysis of Aircraft Components**

File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

Title: B707-300C LapJoint Under Corrosion-Fatigue - High Severity  
Author: Dan M. Ghiocel  
Date: 4/21/2004

Units  
System: Metric  
Force: N  
Stress: MPa  
Length: m  
Time: Days

**ProCORFA**  
Program for Corrosion Fatigue

Ghiocel Predictive Technologies Inc. sti technologies  
turning experience into value

Beta Version  
April, 2004  
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GP Technologies, Inc.  
STI Technologies, Inc.

Numerical  
Parameters (Samples): 1200  
Random Seed: 327680

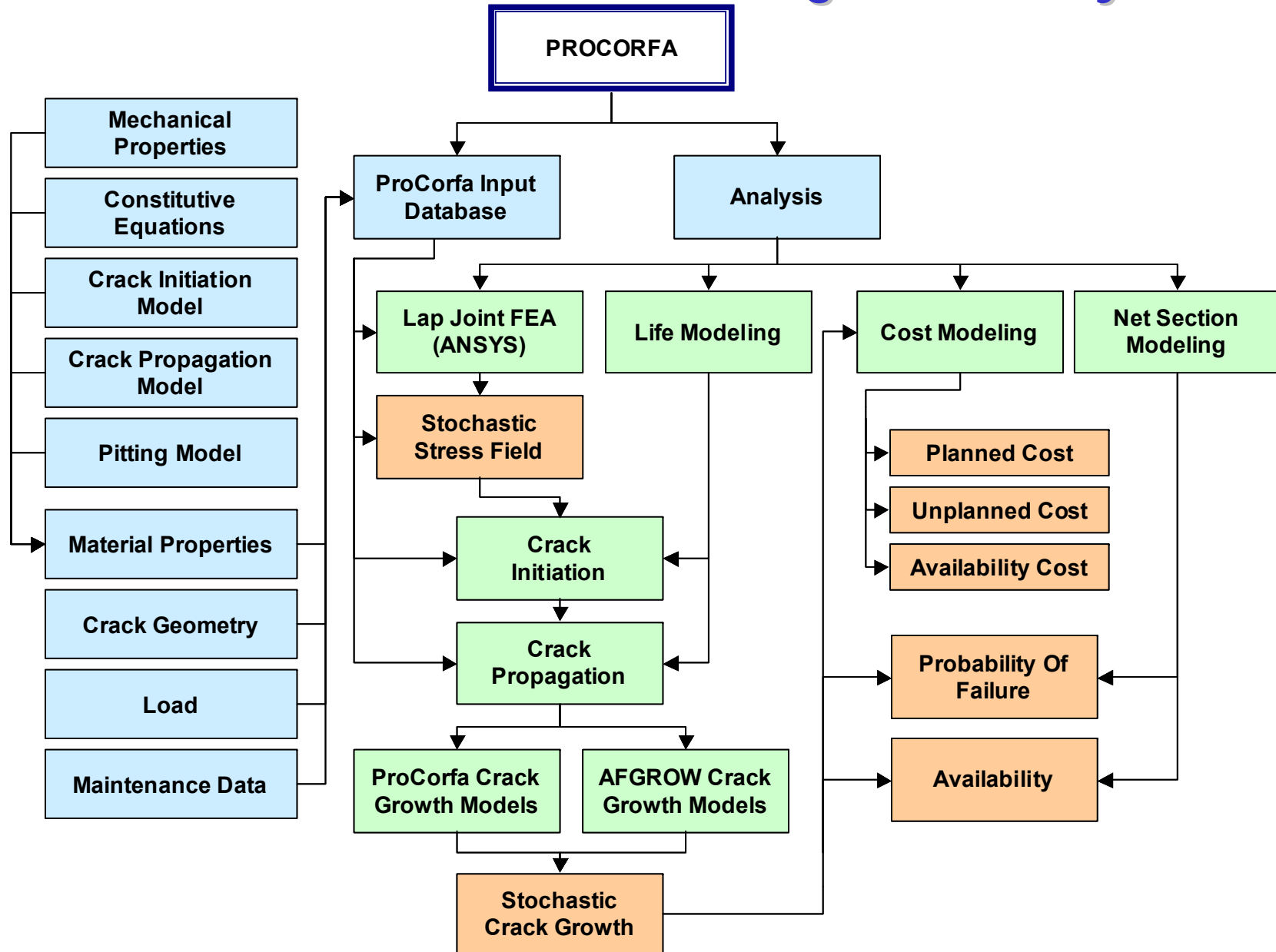
..\..\data\ProCorfaDB.xml

## ProCORFA Main Window

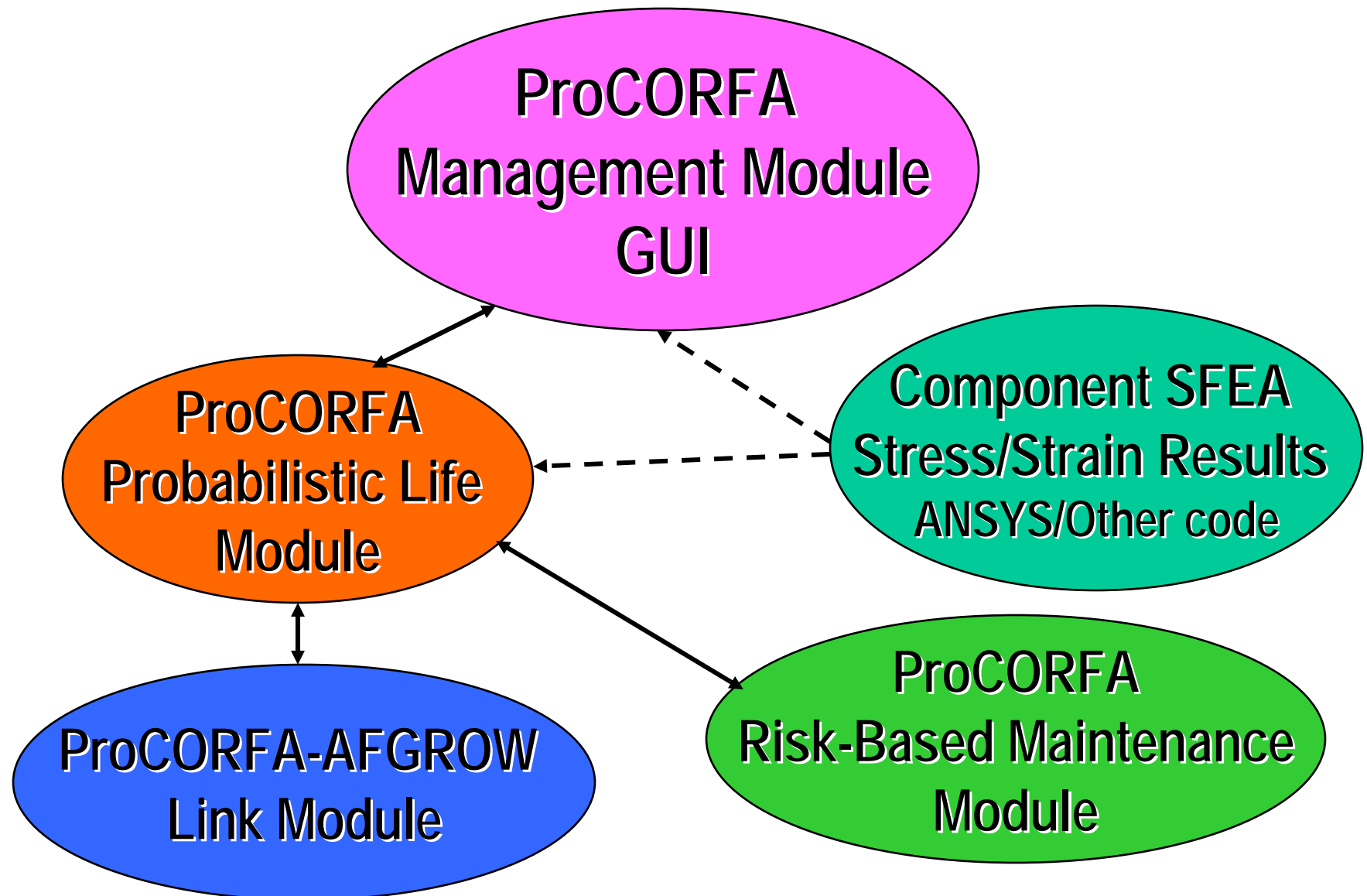
### Main Menu Items:

- File
- Input Data
- Component Model
- Analysis Options
- Review Results
- Graphics
- Setting
- Help

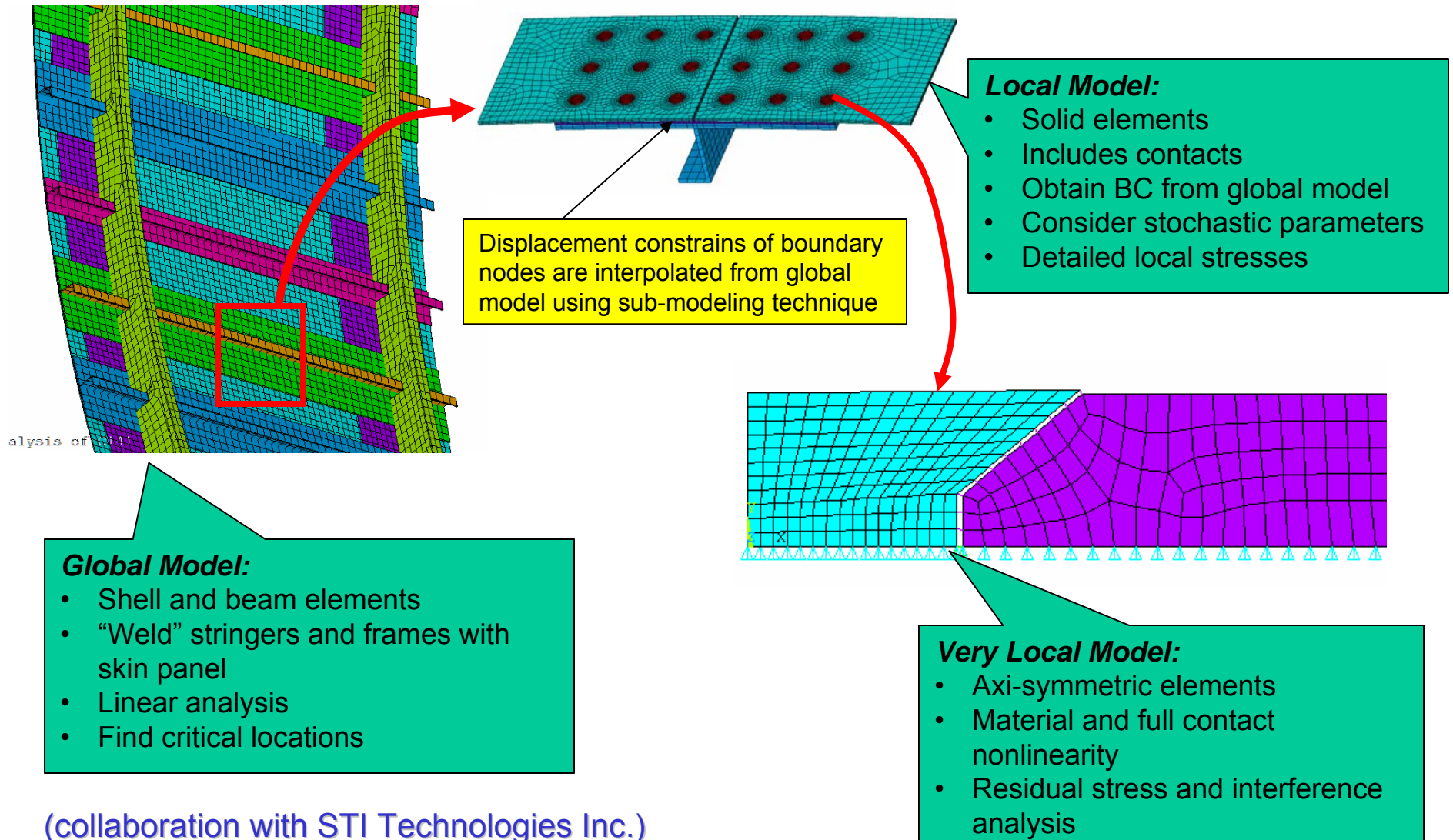
# ProCORFA Software Configuration Layout



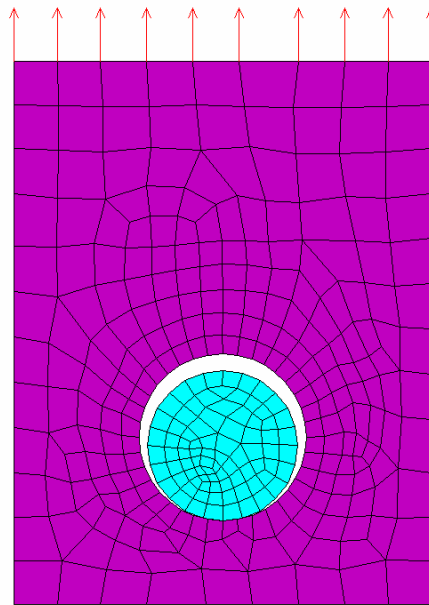
# ProCORFA Modular Configuration



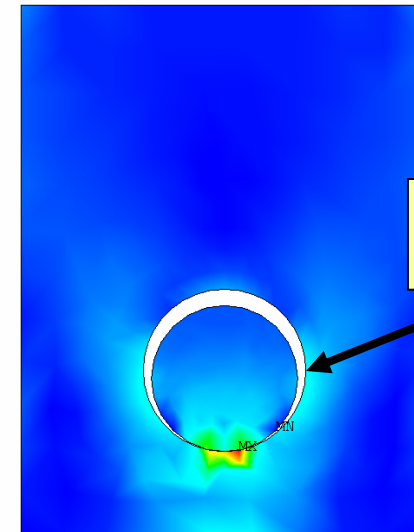
# Multi-Scale Stochastic FE Approach



(collaboration with STI Technologies Inc.)

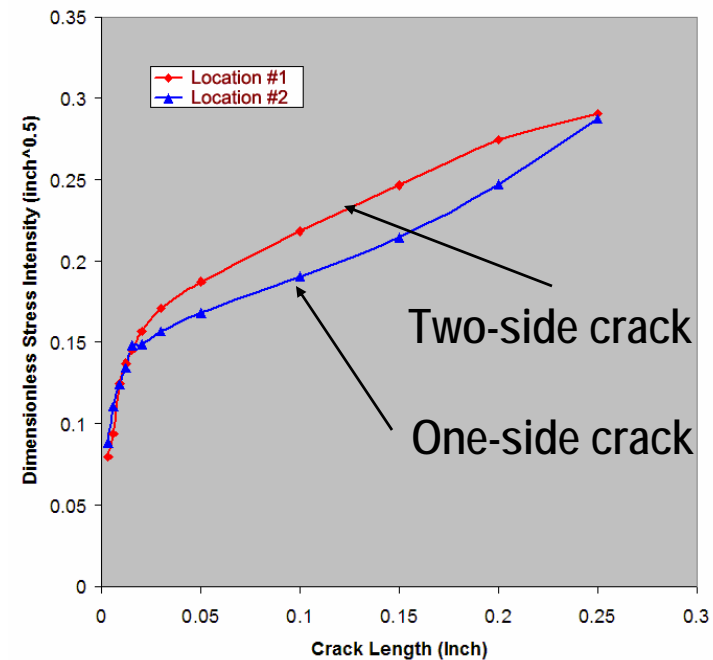
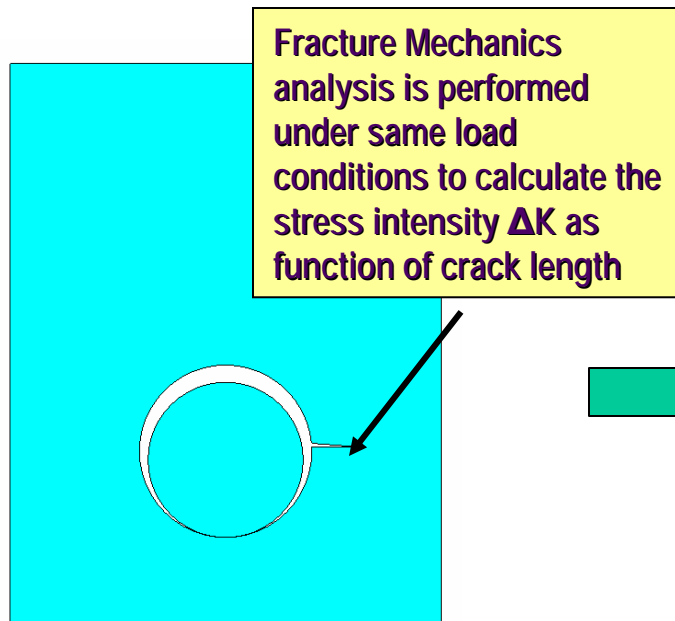


Contact FEA



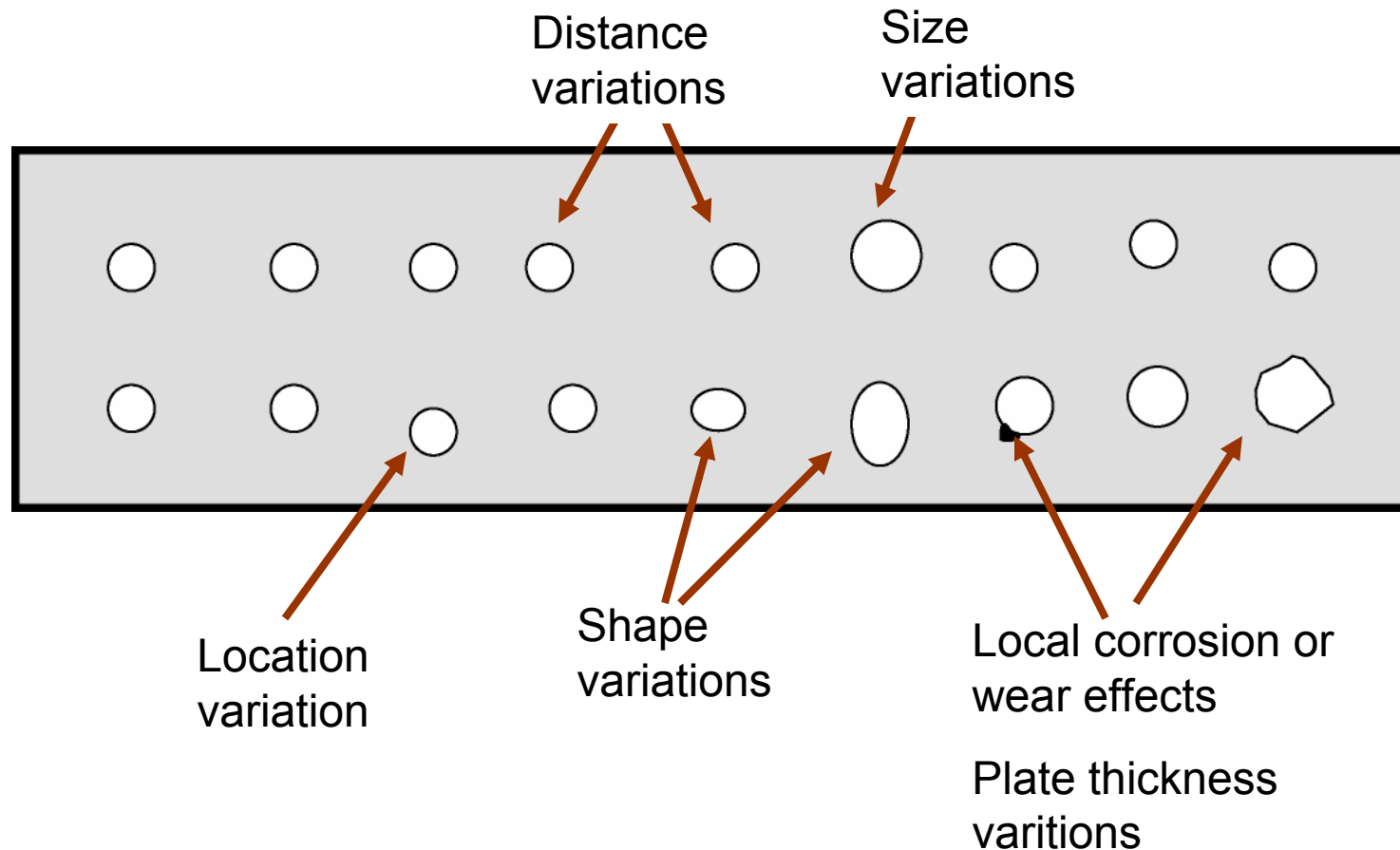
Obtain local stress  $\sigma$  at key locations

Single hole plate-rivet model



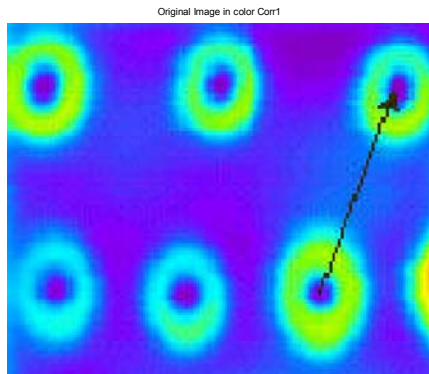
Dimension less stress intensity  $\beta(a) = \frac{K}{\sigma\sqrt{\pi a}}$

# Stochastic FE Analysis for Local Stress Distribution

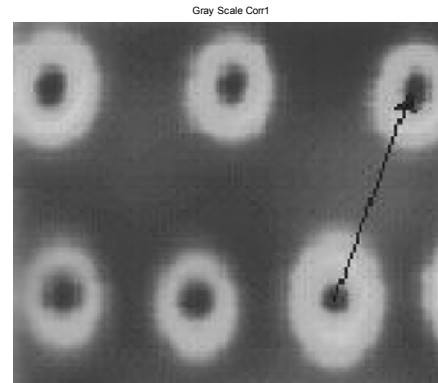


- Obtain the local stress distribution considering all the random variabilities.
- Perform fatigue analysis assuming the same dimensionless stress intensity  $\beta$  obtained from the single-hole model shown in the previous slide

# Stochastic Corrosion Surface Topographies

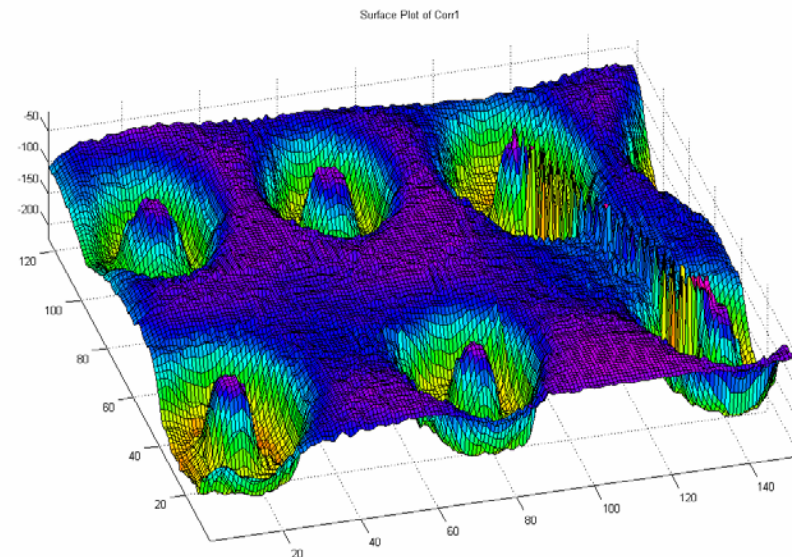
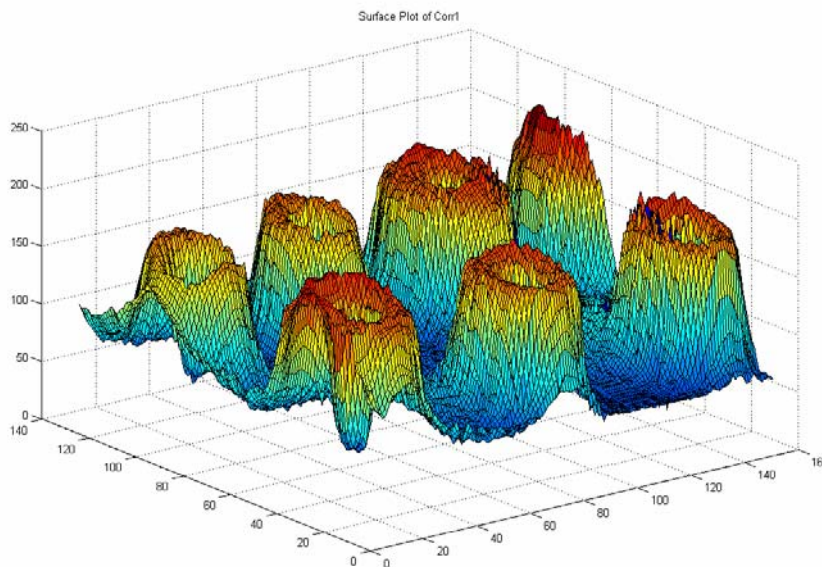


Original RGB Image



Grayscale Image

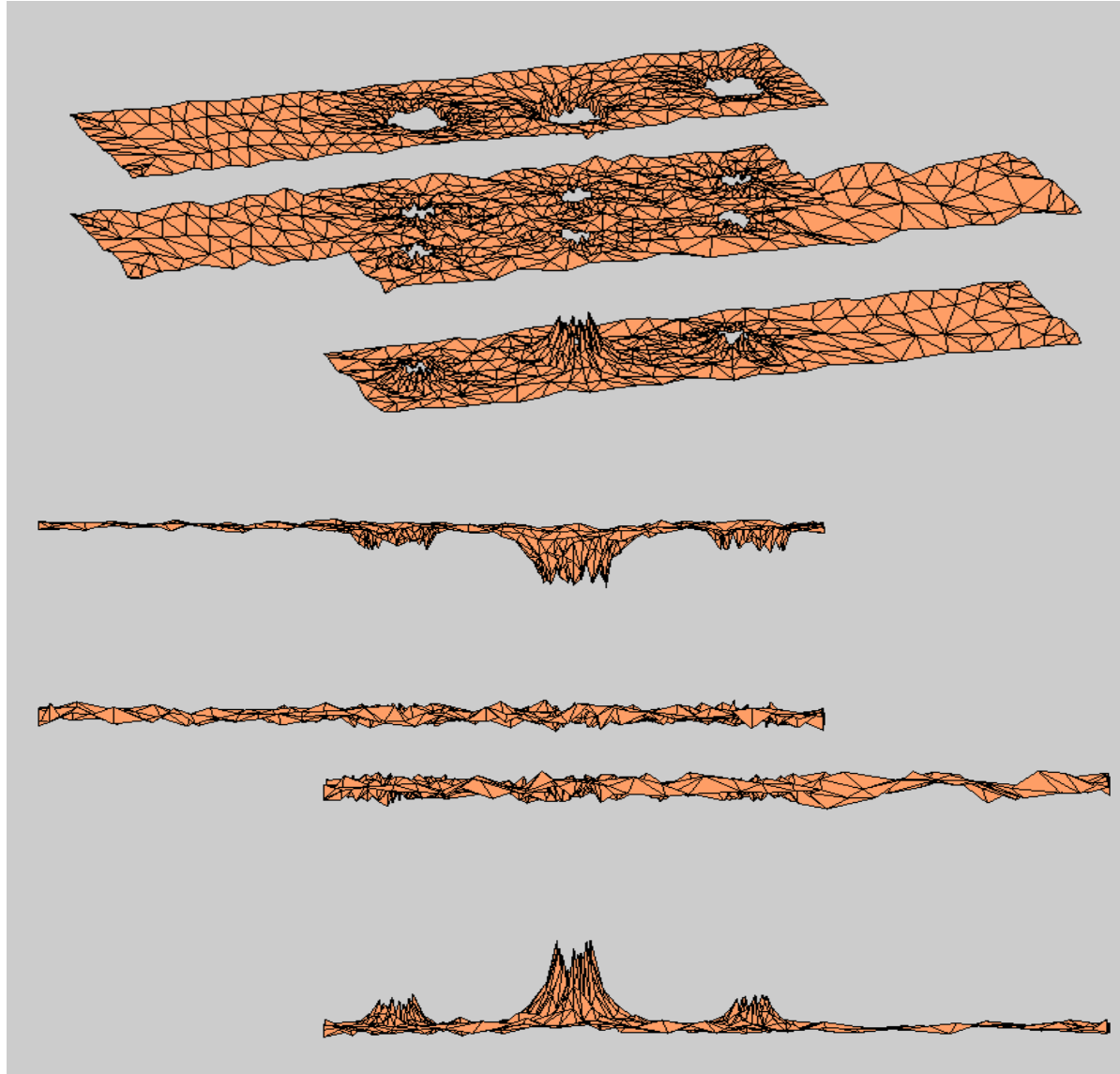
Corrosion Sample # 1



Surface Plots from different Views



# Simulated Stochastic Corroded Surfaces for FE Model





# Mechanical Properties & Constitutive Model



ProCORFA - Reliability Analysis of Aircraft Components

File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

Material 2024-T3 Aluminum

Mechanical Constitutive Strain Life CrackGrowth Pitting

	Distribution	Mean	Standard Deviation	Graphs
E	Uniform	73084.43	78	
$\nu$	Deterministic	0.33		
$\sigma_y$	Normal	344.7	34	
$\sigma_u$	Deterministic	489.5		

Mechanical Properties

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ProCORFA - Reliability Analysis of Aircraft Components

File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

Material 2024-T3 Aluminum

Mechanical Constitutive Strain Life CrackGrowth Pitting

	Distribution	Mean	Standard Deviation	Graphs
kp	Log Normal	590.0	2	
np	Normal	0.04	0.01	
kf	Normal	1.0	0.1	

Constitutive Model

...\\data\ProCorfaDB.xml

# Strain Life, Fatigue Damage Model and Pitting

ProCORFA - Reliability Analysis of Aircraft Components

File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

Material 2024-T3 Aluminum

Mechanical Constitutive Strain Life CrackGrowth Pitting

Model Morrow Correction

Cumulative Damage Curve Approach

	Distribution	Mean	Standard Deviation	Graphs
q	Deterministic	1.5		
$\sigma_f$	Deterministic	1044		
$\epsilon_f$	Deterministic	1.765		
b	Deterministic	-0.114		
c	Deterministic	-0.927		

Strain Life and Damage Model

...data\ProCorfaDB.xml

ProCORFA - Reliability Analysis of Aircraft Components

File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

Material 2024-T3 Aluminum

Mechanical Constitutive Strain Life CrackGrowth Pitting

Airport Rotation Without Rotation

Model Wei Model

Corrosion Pitting

Faraday's Model Data

	Distribution	Mean	Standard Deviation	Graphs
ipo	Uniform	0.5	0.25	
$\Delta h$	Deterministic	50000		
$\rho$	Deterministic	2.7e6		
m	Normal	27	2.7	
n	Deterministic	3		
T	Deterministic	293		

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# Variable Loading and Statistical Crack Population

ProCORFA - Reliability Analysis of Aircraft Components

File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

LoadType Load Block

Flight Time (hr) 2.8

Ground Time (hr) 5.0

Spectrum File C:\Old\_Files\osd\_cbm\data\load.txt Browse

Plot Spectrum

Variable Loading

..\data\ProCorfaDB.xml

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File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

General POD Parameters Maintenance Calculation

Number of Cracks 500

Days in Service 8000

Crack Growth Calculation Fit Crack Growth with Equation

Initial Failure Probability 1.e-8

Time Step (days) 10

Inspection Strategy Replacement when crack reaches reject size

Rejectable Crack Size 0.00001

Crack Size for Failure Criteria 0.4

Statistical Crack Population

..\data\ProCorfaDB.xml

# Maintenance Info: POD Curves, Inspection Times

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File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

General POD Parameters Maintenance Calculation

Input Method

☐ Input Shape and Scale

☒ Input Mean and Standard Deviation

POD Curve Parameters

INSPECTION TECHNIQUE	POD CURVE PARAMETERS		SIZING ERROR	
	Mean	Std	Mean	STD
Visual	1.01	-2.57	0	1e-6
Liquid Penetration	0.56	-2.94	0	1e-6
Magnetic particle	0.44	-3.43	0	1e-6
Eddy current	0.70	-4.26	0	1e-6
Radiography	0.65	-1.84	0	1e-6
Ultrasonic	0.28	-3.02	0	1e-6
User Defined 1				
User Defined 2				
User Defined 3				
User Defined 4				

POD Curves

**NDI POD Curves**

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File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

General POD Parameters Maintenance Calculation

Maintenance Calculation Parameters

Calculation Method: Given inspection interval

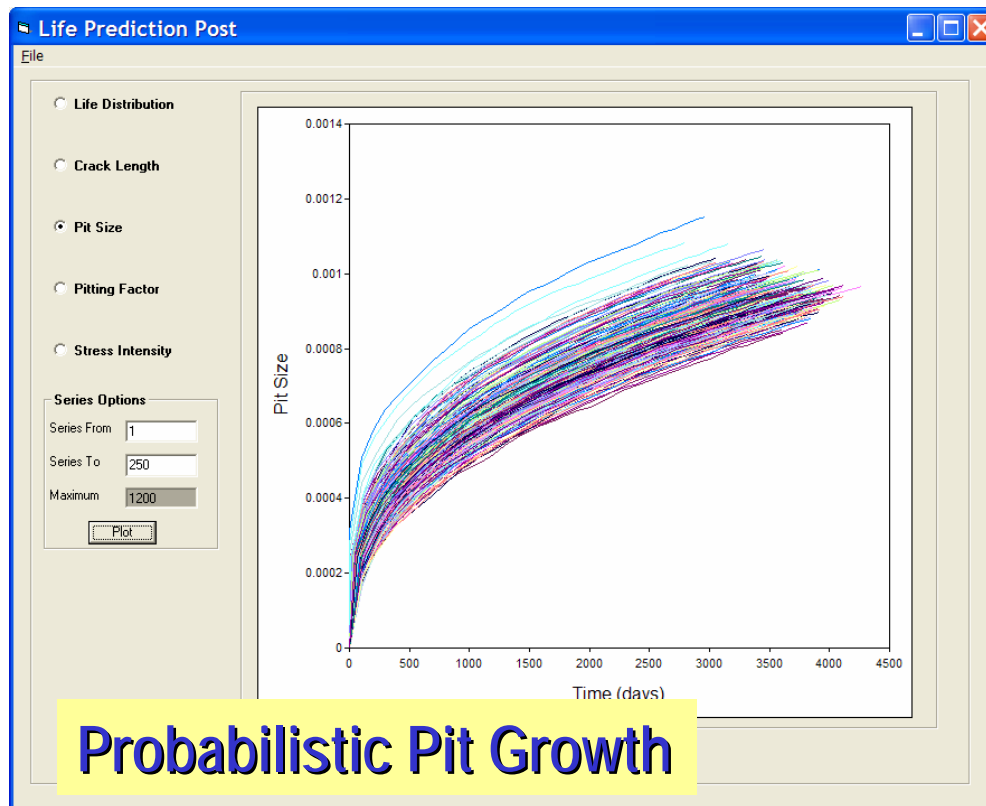
Inspection Interval Method Data

Inspection	Time (Days)	Inspection Method
1	5000	Eddy Current
2	10000	Eddy Current
3	15000	Eddy Current
4	20000	Eddy Current
5		User Defined 4
6		User Defined 4
7		User Defined 4
8		User Defined 4
9		User Defined 4
10		User Defined 4
11		User Defined 4
12		User Defined 4

**Multiple Inspections**

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# Life Prediction and Risk-Based Condition Assessment



**Graph Options**

**Risk Analysis**

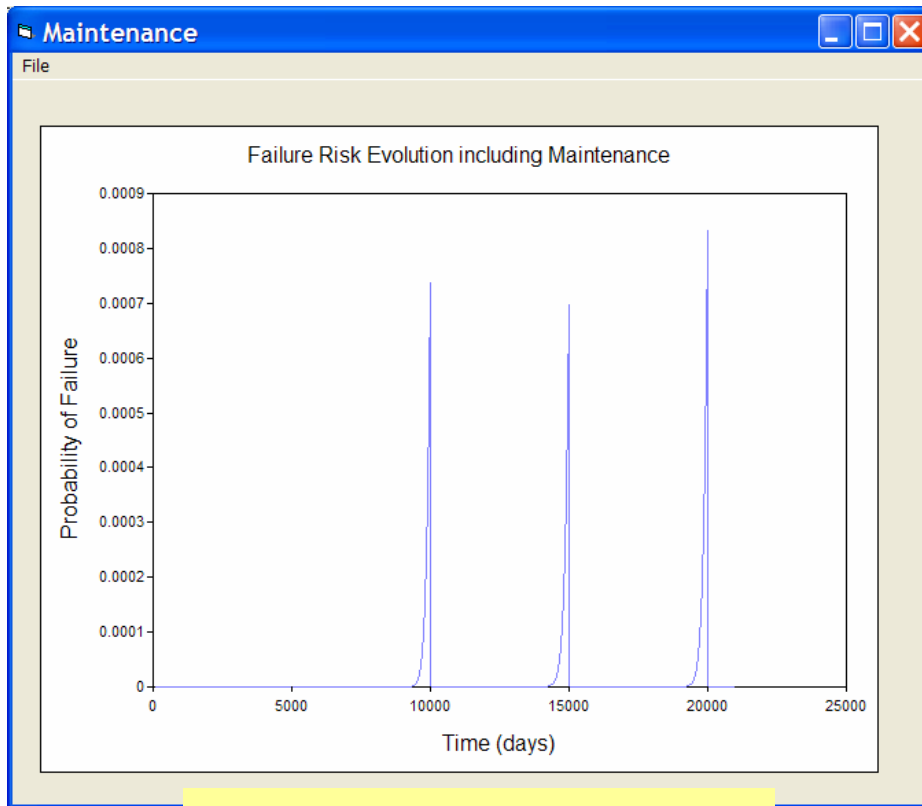
**Graph Types**

- ☐ Crack Length Statistics Evolution
- ☒ Failure Risk Evolution Including Maintenance
- ☐ Reliability Function Evolution
- ☐ Reliability Index Evolution Including Maintenance
- ☐ Hazard Failure Rate Evolution Including Maintenance
- ☐ PDF of Predicted Life including Maintenance
- ☐ Number of Failures Per Maintenance Interval
- ☐ Hazard Failure Rates Per Maintenance Interval

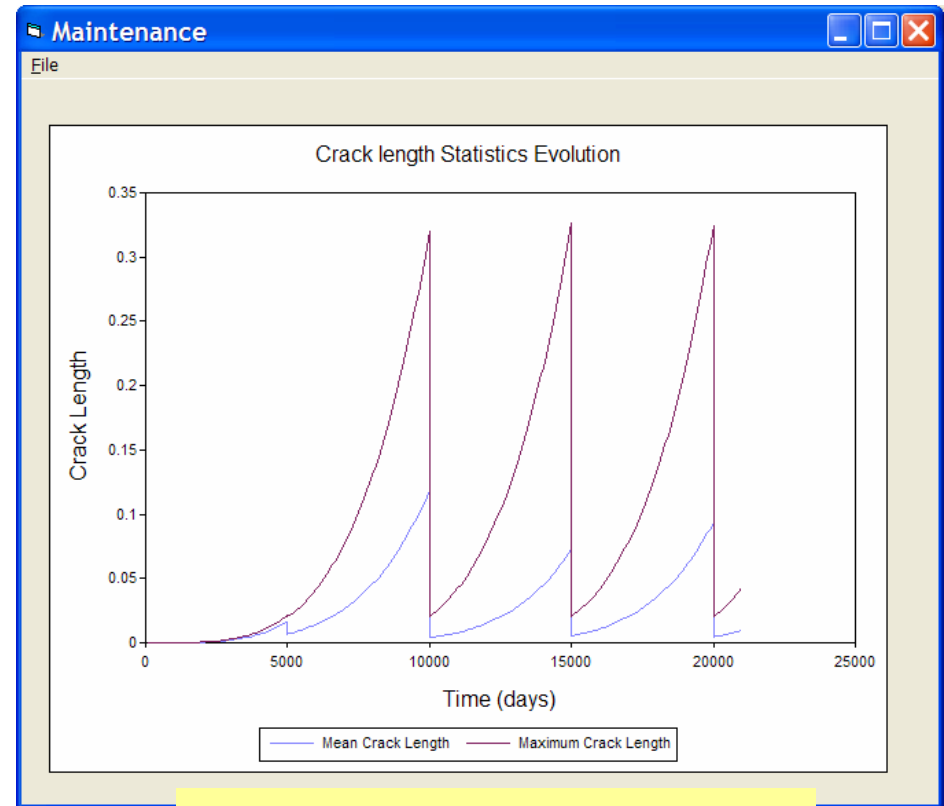
**Plot Settings**

- ☒ Linear Scale
- ☐ LOG Scale

# Crack Statistics & Risk-Based Condition Assessment



**Failure Risk Evolution**



**Crack Growth Statistics**

# Probabilistic Optimal Life-Cycle Cost Analysis

◆ **Objective:** Develop an optimal inspection program that minimizes cost under reliability constraints

◆ **Assumptions:**

- Crack growth model:

$$A(t) = A_0 \exp(\Lambda t), t > 0 \quad (A_0 \text{ and } \Lambda \text{ are random})$$

- Cracks with length

.  $A(t) > a_{cr} \Rightarrow$  replaced (failure)

.  $a_d < A(t) \leq a_{cr} \Rightarrow$  repaired

.  $A(t) \leq a_d \Rightarrow$  undetected

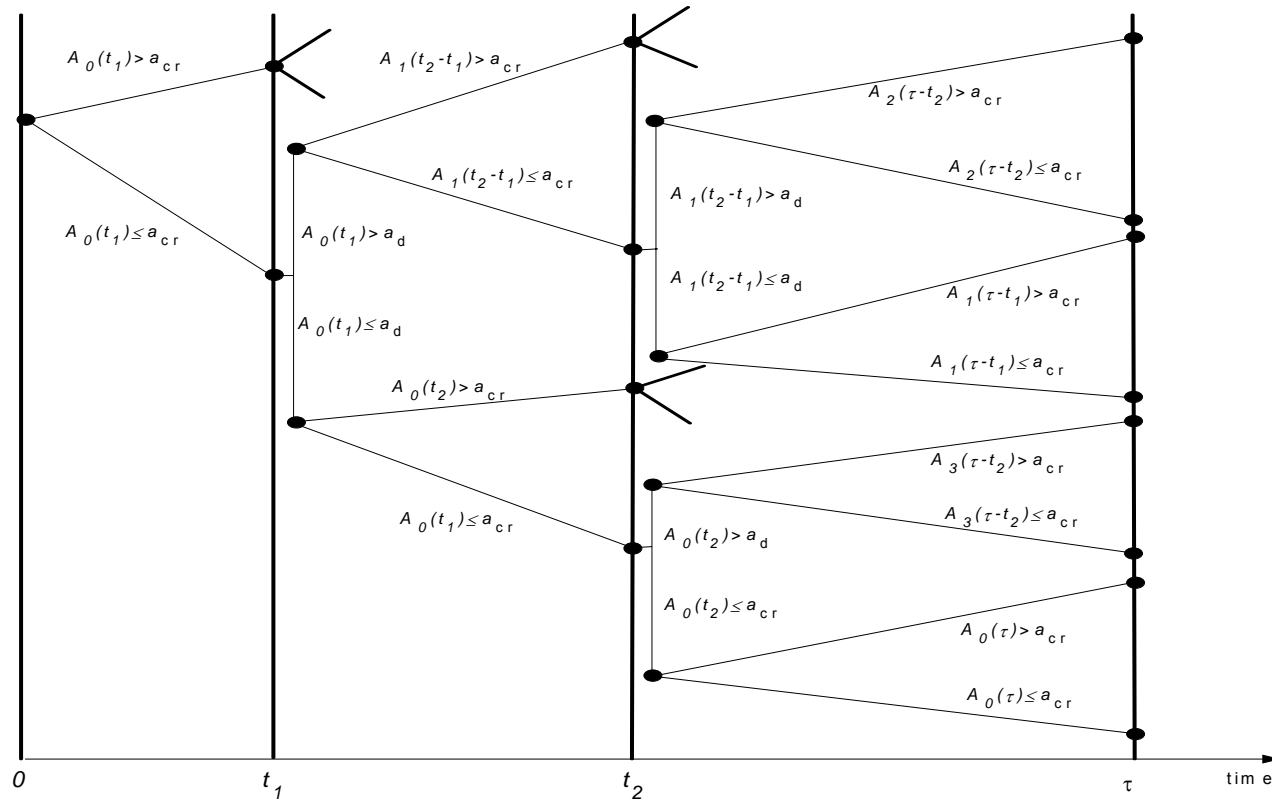
- System failure probability  $P_f(t) > p_{f,0}$  at all times

(collaboration with Professor M. Grigoriu, Cornell University)

DOCUMENT DOWNLOADED FROM GP TECHNOLOGIES INC. WEB SITE at [http:// www.ghiocel-tech.com](http://www.ghiocel-tech.com)



## ◆ Inspection and Maintenance Policy:

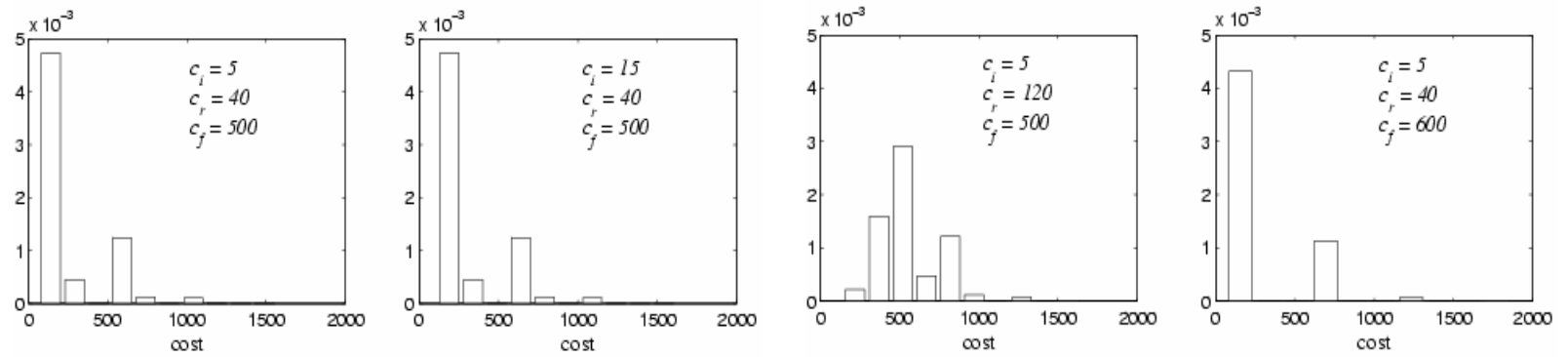


## ◆ Model parameters:

- Cost:  $c_i$ ,  $c_r$  and  $c_f$  = inspection, repair, failure costs
- System life:  $\tau > 0$
- Inspection schedule:  $(t_1, \dots, t_n)$  = inspection times

◆ Total Cost and Failure Probabilities:

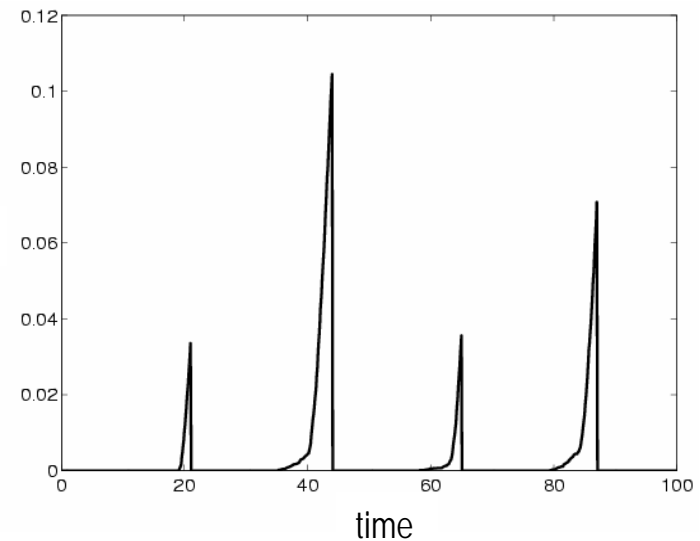
- Total cost at  $t = \tau$ :



- Failure probabilities:

$$\hat{P}_f(t) = \frac{\# \{A(t) > a_{cr}\}}{\# \{ \text{samples} \}}$$

$$\hat{P}_f(t)$$



◆ Optimization algorithm:

- Problem statement:

$$\min_{t_1, \dots, t_n} \{q_n(c^*; t_1, \dots, t_n)\} \text{ under}$$

$$P_f(0) \leq p_{f,0}, P_f(t_1) \leq p_{f,0}, \dots, P_f(t_n) \leq p_{f,0}, P_f(\tau) \leq p_{f,0}$$

$$\text{and } 0 \leq t_1 \leq t_2 \leq \dots \leq t_n \leq \tau$$

(where  $q_n(c^*; t_1, \dots, t_n)$  = probability that total cost at  $t = \tau > c^*$ )

- Feasible region for  $n=2$ :

