

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

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

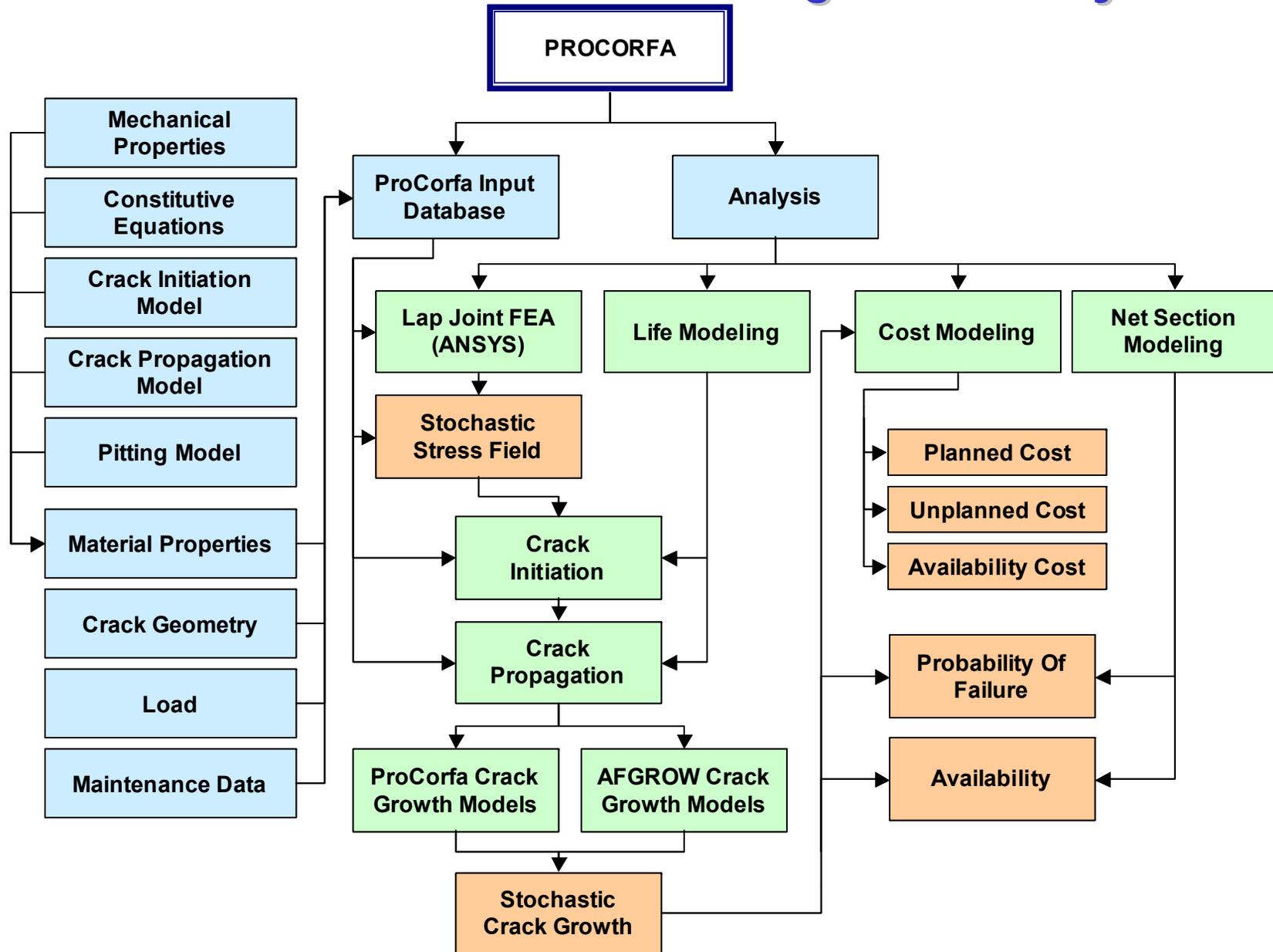
..\..\data\ProCorfaDB.xml

ProCORFA Main Window

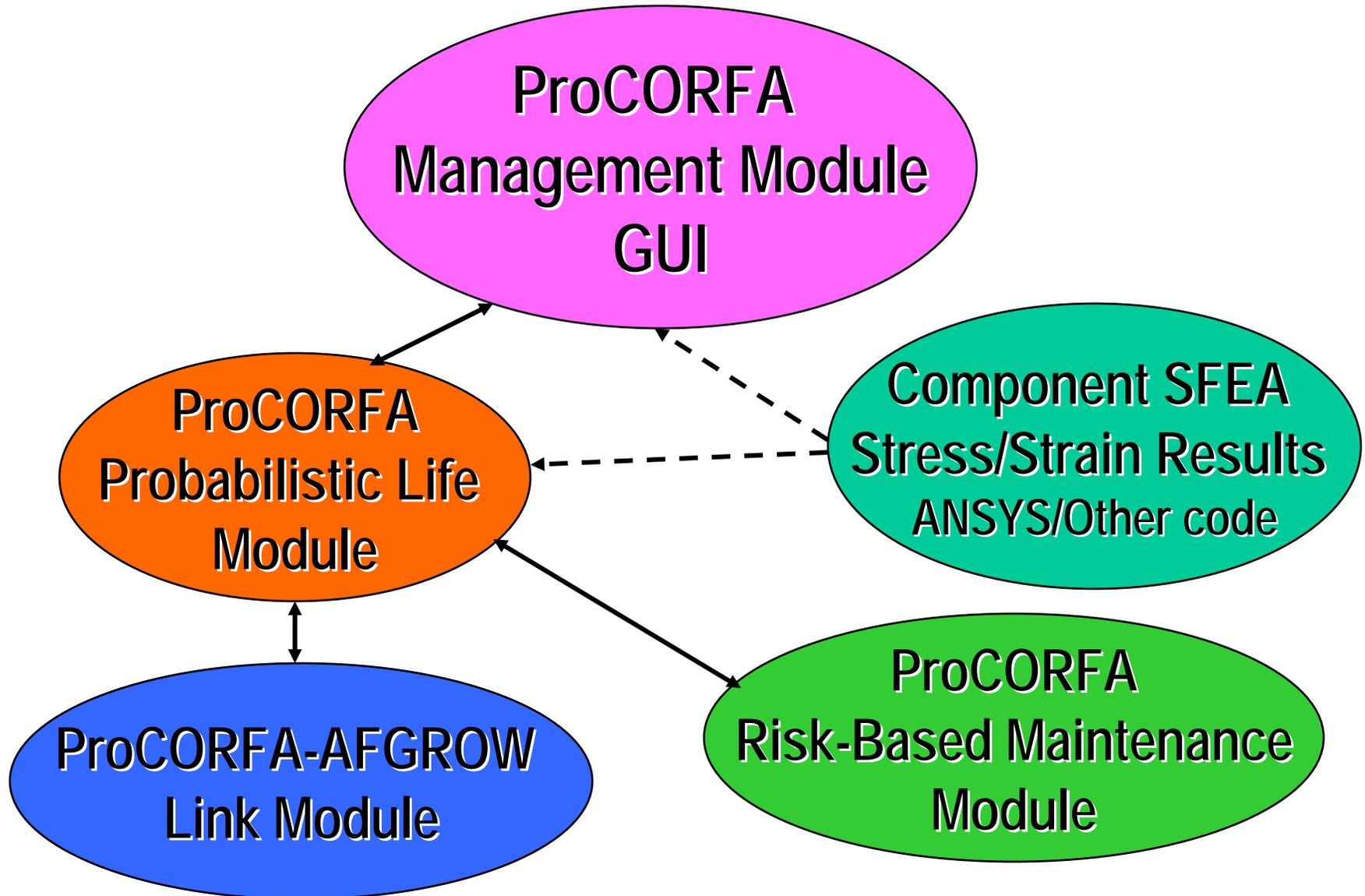
Main Menu Items:

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

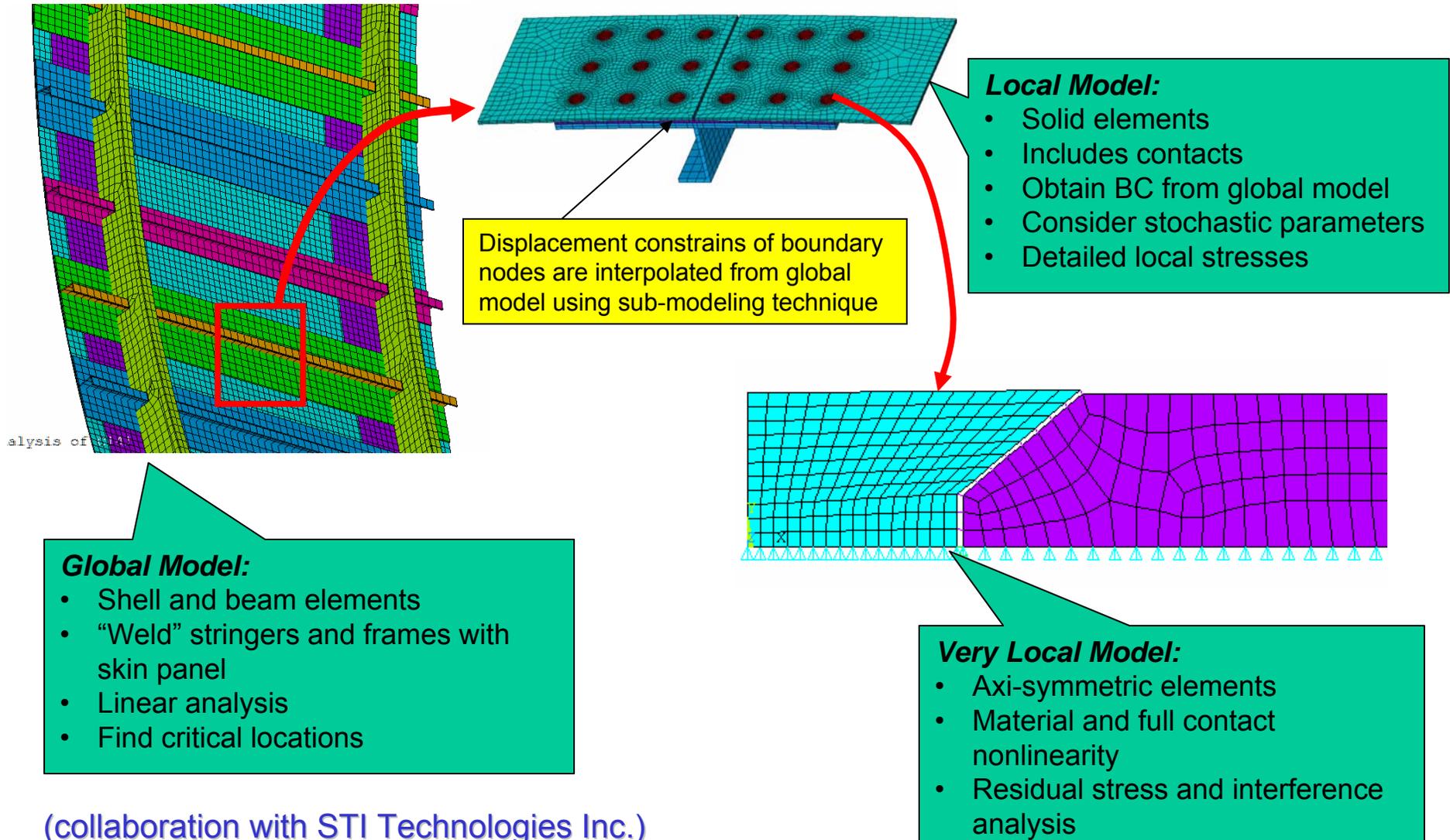
ProCORFA Software Configuration Layout



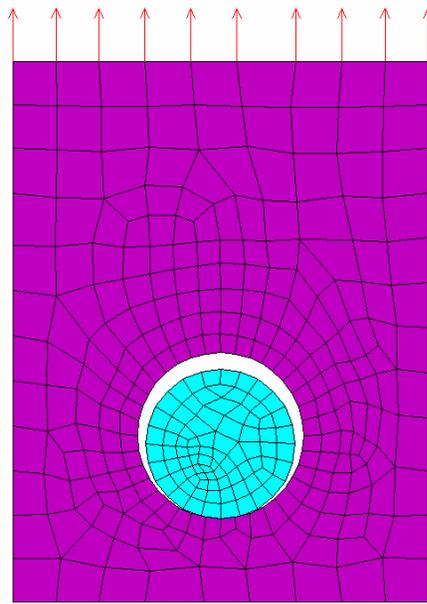
ProCORFA Modular Configuration



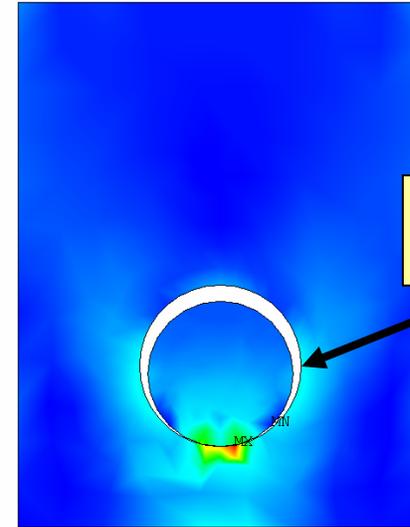
Multi-Scale Stochastic FE Approach



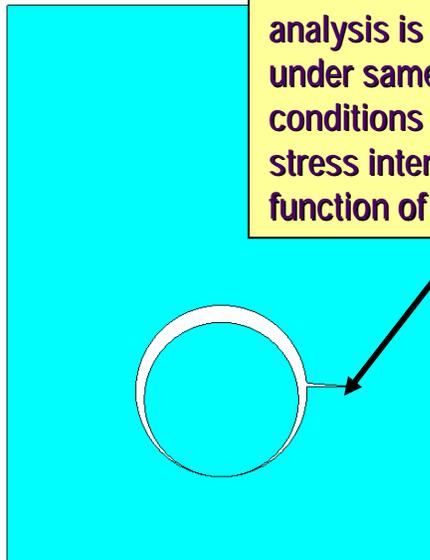
(collaboration with STI Technologies Inc.)



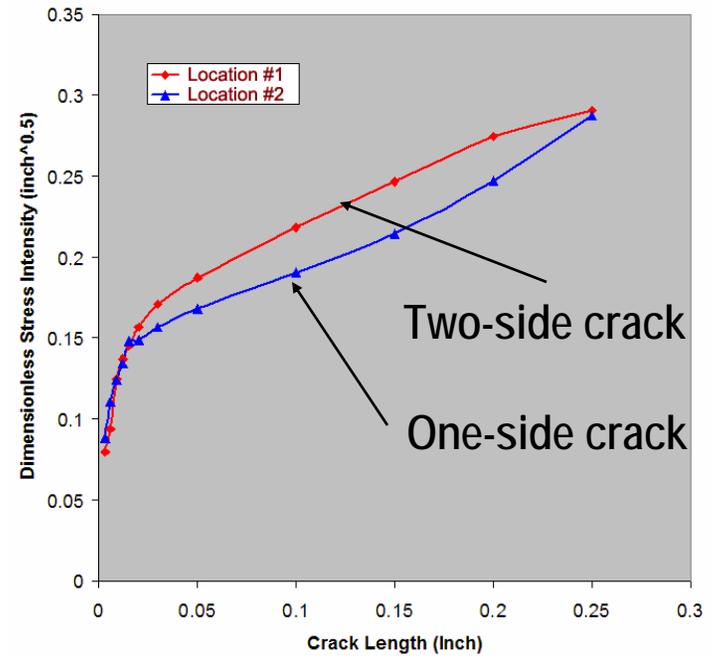
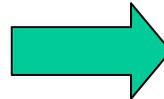
Contact FEA



Single hole plate-rivet model

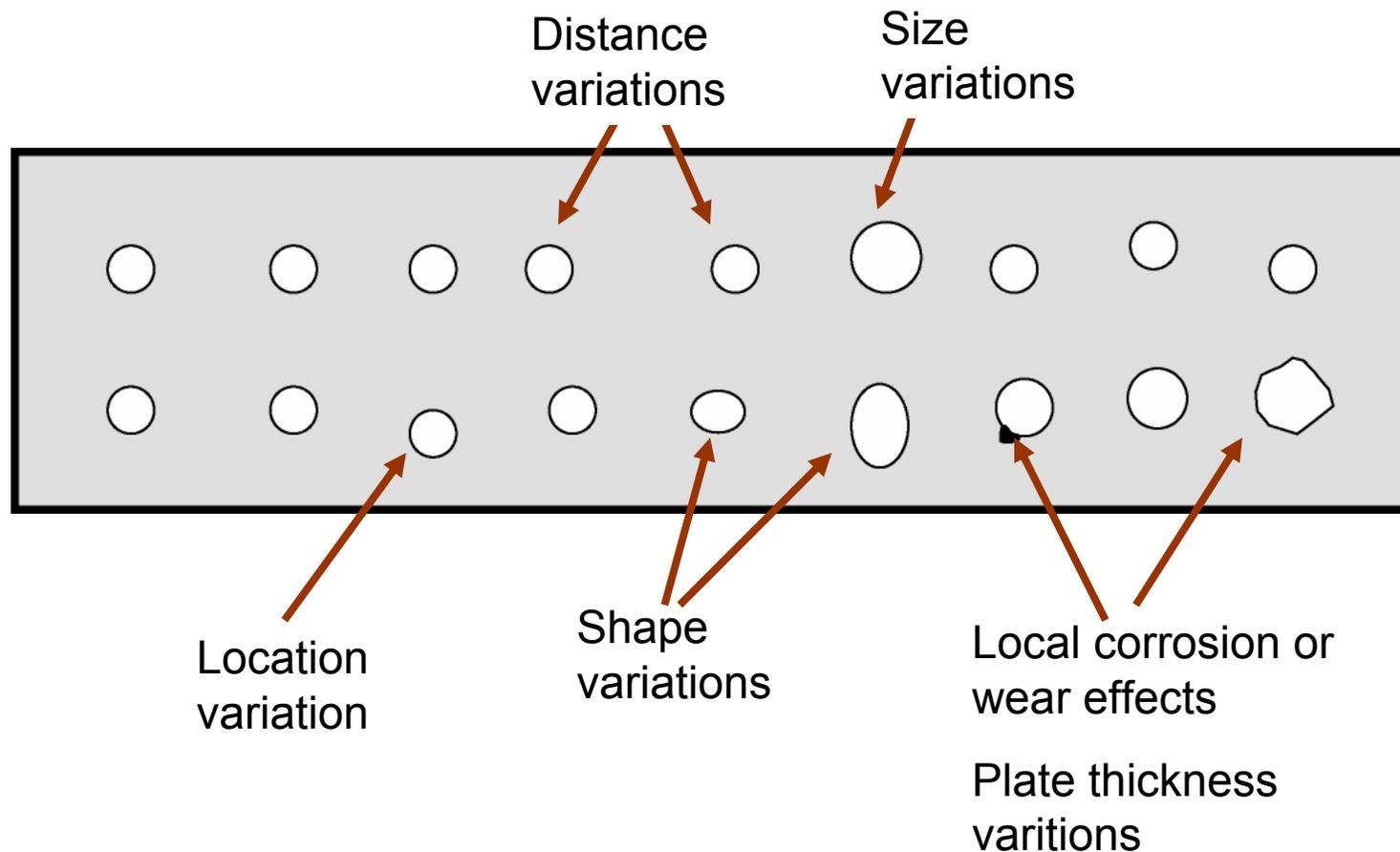


Fracture Mechanics analysis is performed under same load conditions to calculate the stress intensity ΔK as function of crack length



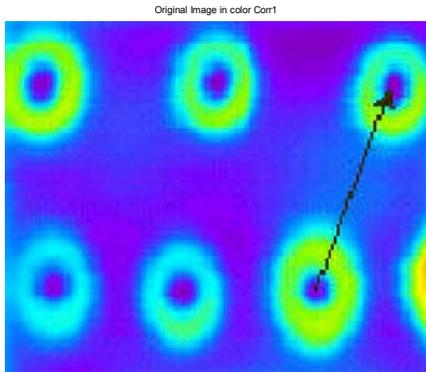
Dimension less stress intensity $\beta(a) = \frac{K}{\sigma\sqrt{\pi a}}$

Stochastic FE Analysis for Local Stress Distribution

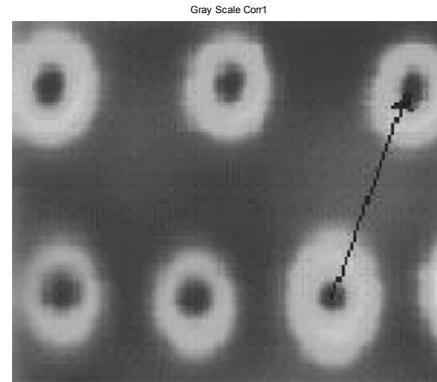


- Obtain the local stress distribution considering all the random variabilities.
- Perform fatigue analysis assuming the same dimensionless stress intensity β obtained from the single-hole model shown in the previous slide

Stochastic Corrosion Surface Topographies

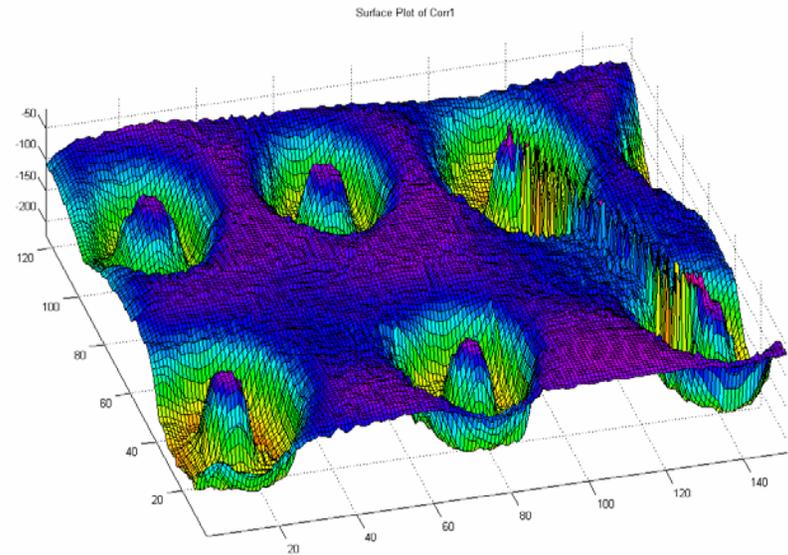
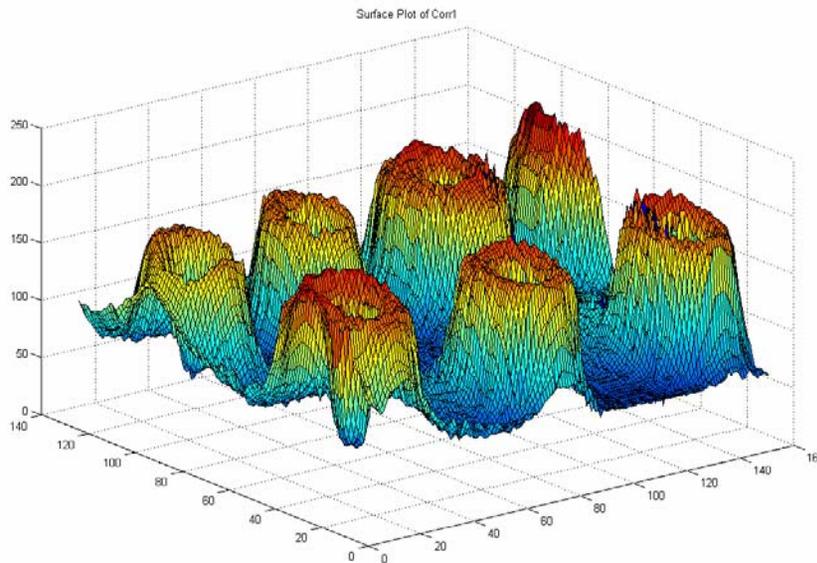


Original RGB Image



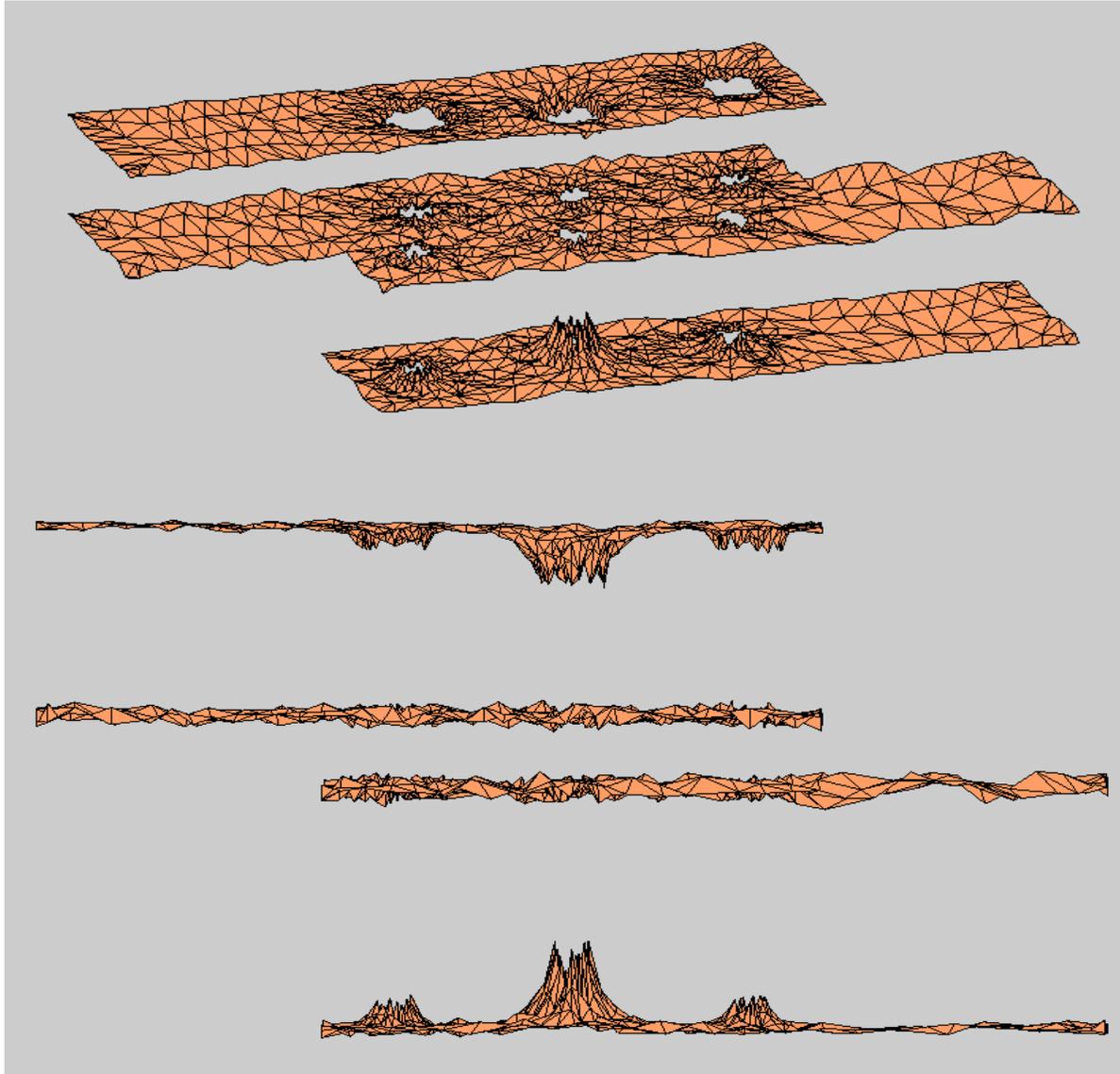
Grayscale Image

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	
ν	Deterministic	0.33		
σ_y	Normal	344.7	34	
σ_u	Deterministic	489.5		

Mechanical Properties

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ProCORFA - Reliability Analysis of Aircraft Components

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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		
σ_f	Deterministic	1044		
ϵ_f	Deterministic	1.765		
b	Deterministic	-0.114		
c	Deterministic	-0.927		

Strain Life and Damage Model

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ProCORFA - Reliability Analysis of Aircraft Components

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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
i_{po}	Uniform	0.5	0.25	
Δh	Deterministic	50000		
ρ	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

ProCORFA - Reliability Analysis of Aircraft Components

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

ProCORFA - Reliability Analysis of Aircraft Components

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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ProCORFA - Reliability Analysis of Aircraft Components

File Options Input Analysis Post Help

Header Material CrackGeometry Load Maintenance

General POD Parameters Maintenance Calculation

Maintenance Calculation Parameters

Calculation Method:

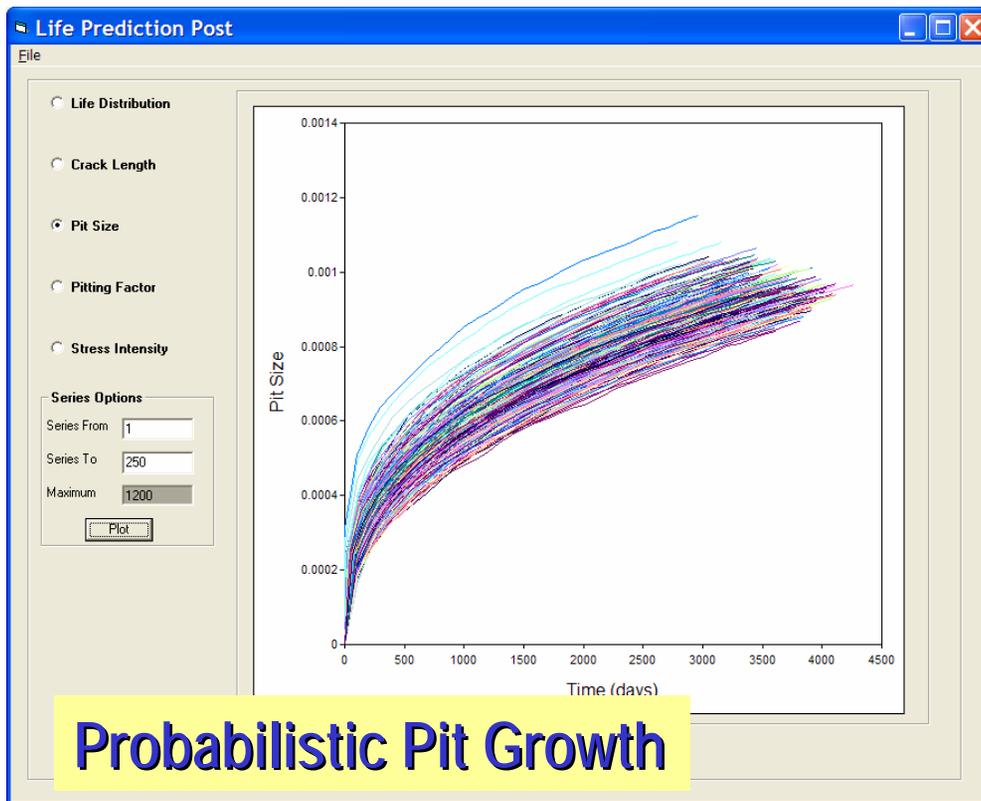
Inspection Interval Method Data

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

...data\ProCorfaDB.xml

Life Prediction and Risk-Based Condition Assessment



The 'Graph Options' window shows settings for the graph. The 'Graph Types' section has 'Failure Risk Evolution Including Maintenance' selected. The 'Plot Settings' section has 'Linear Scale' selected. A 'Plot' button is visible.

Graph Options

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

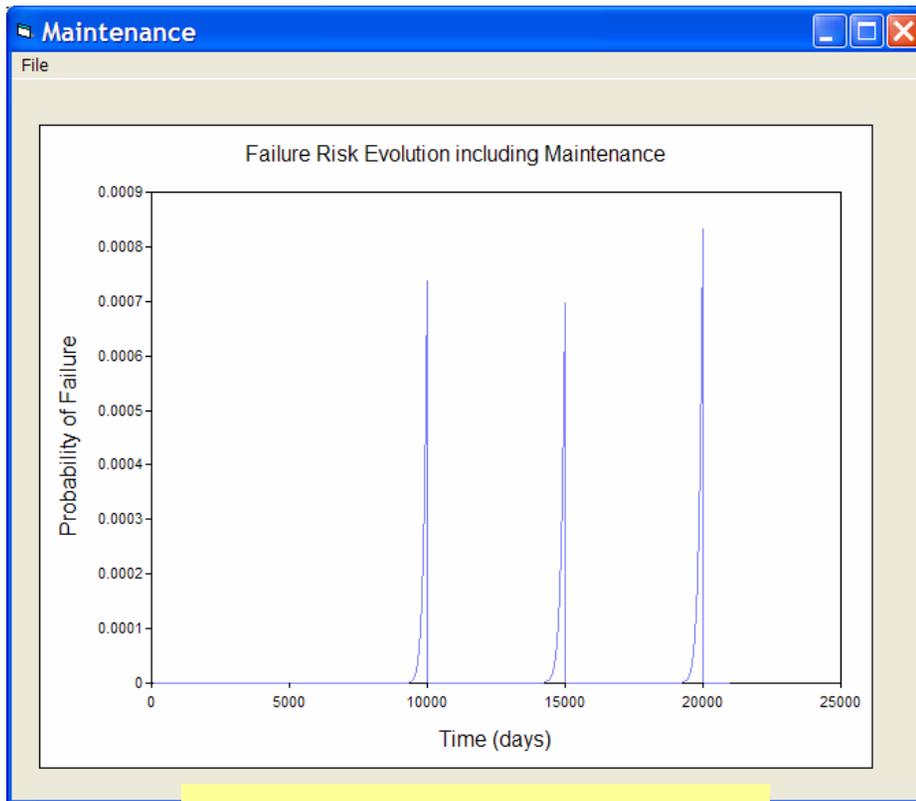
Risk Analysis

Plot Settings

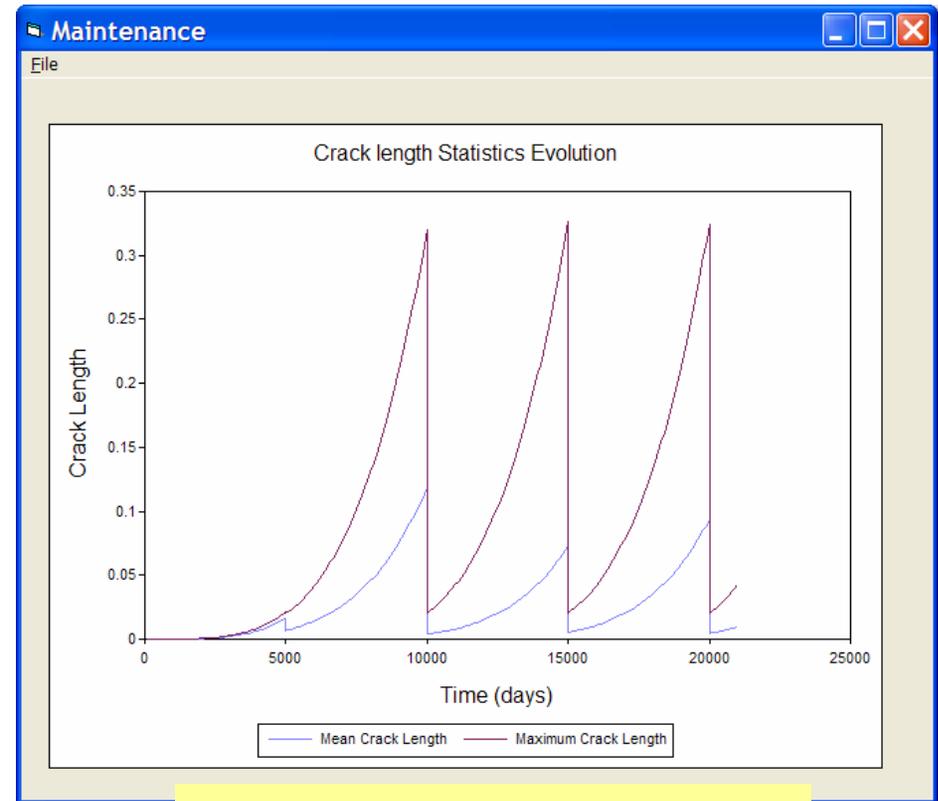
- Linear Scale
- LOG Scale

Plot

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)

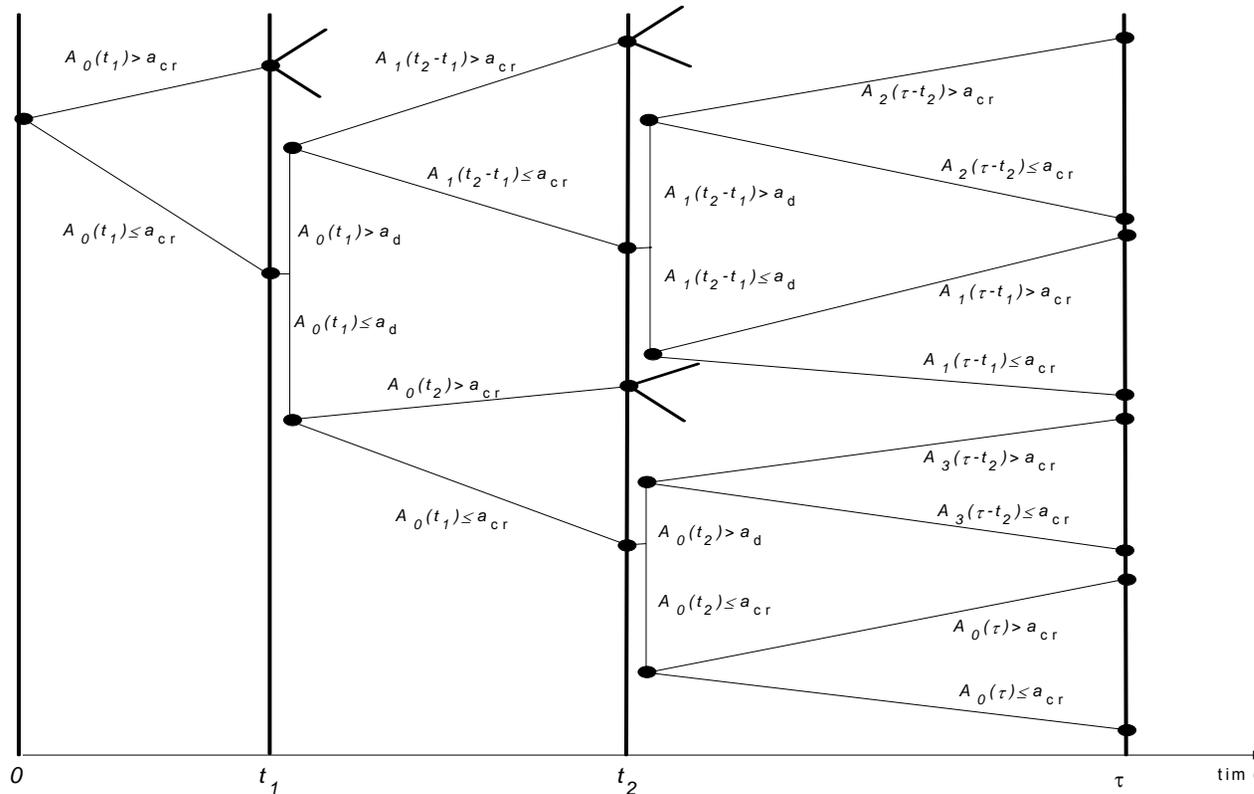
. $a_d < A(t) \leq a_{cr} \Rightarrow$ repaired

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

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

(collaboration with Professor M. Grigoriu, Cornell University)

◆ Inspection and Maintenance Policy:

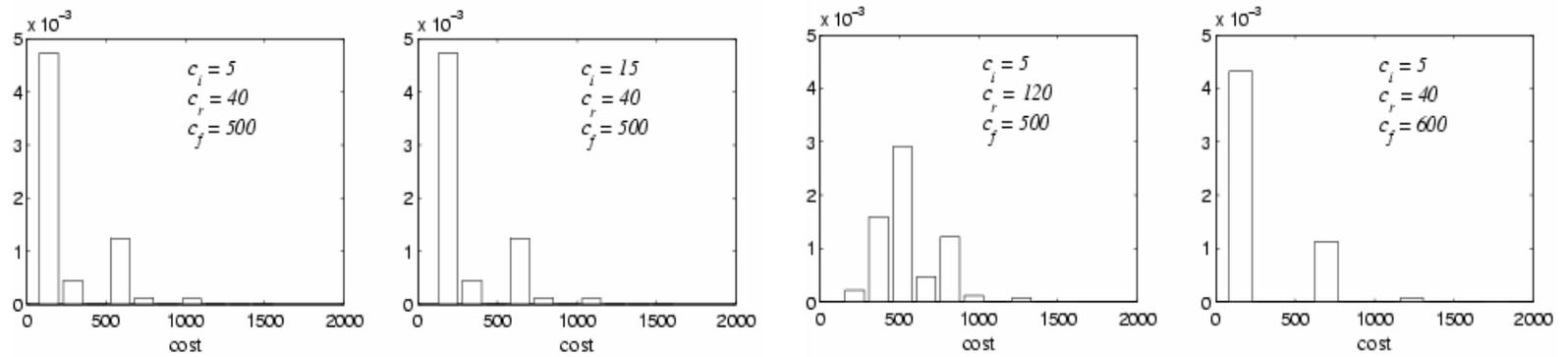


◆ Model parameters:

- 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:

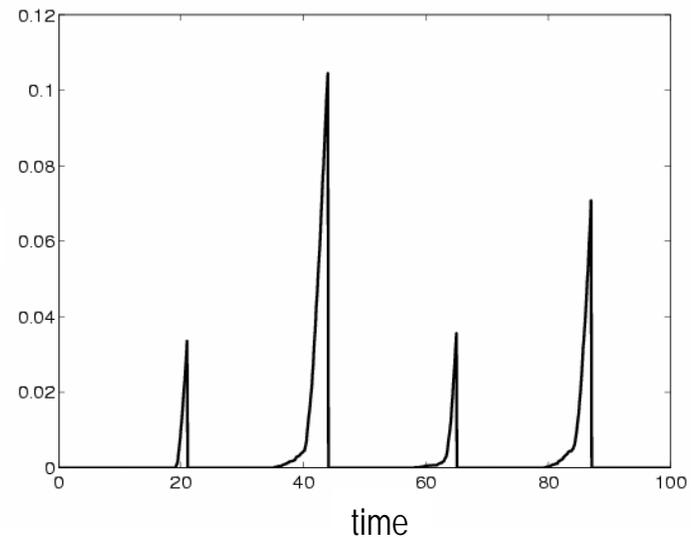
- Total cost at $t = \tau$:



- 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 $n=2$:

