ProCORFA GUI: Main Window Dialog

ProCORFA
Main Window

Main Menu Items:
- File
- Input Data
- Component Model
- Analysis Options
- Review Results
- Graphics
- Setting
- Help
ProCORFA Software Configuration Layout

- Mechanical Properties
- Constitutive Equations
- Crack Initiation Model
- Crack Propagation Model
- Pitting Model
- Material Properties
- Crack Geometry
- Load
- Maintenance Data

- ProCorfa Input Database

- Analysis
- Lap Joint FEA (ANSYS)
- Life Modeling
- Cost Modeling
- Net Section Modeling

- ProCorfa Crack Growth Models
  - AFGROW Crack Growth Models

- Stochastic Crack Growth

- Probability Of Failure
- Availability
- Planned Cost
- Unplanned Cost
- Availability Cost

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ProCORFA Modular Configuration

- ProCORFA Management Module
  - GUI
- ProCORFA Probabilistic Life Module
  - Component SFEA
    - Stress/Strain Results
      - ANSYS/Other code
- ProCORFA-AFGROW Link Module
- ProCORFA Risk-Based Maintenance Module
Multi-Scale Stochastic FE Approach

Global Model:
- Shell and beam elements
- “Weld” stringers and frames with skin panel
- Linear analysis
- Find critical locations

Local Model:
- Solid elements
- Includes contacts
- Obtain BC from global model
- Consider stochastic parameters
- Detailed local stresses

Very Local Model:
- Axi-symmetric elements
- Material and full contact nonlinearity
- Residual stress and interference analysis

Displacement constrains of boundary nodes are interpolated from global model using sub-modeling technique

(collaboration with STI Technologies Inc.)
Fracture Mechanics analysis is performed under same load conditions to calculate the stress intensity $\Delta K$ as function of crack length.  

Obtain local stress $\sigma$ at key locations.

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

Corrosion Sample # 1

Original RGB Image

Grayscale Image

Surface Plots from different Views
Simulated Stochastic Corroded Surfaces for FE Model
Mechanical Properties & Constitutive Model

ProCORFA - Reliability Analysis of Aircraft Components

Material: 2024-T3 Aluminum

Mechanical Properties
- E: Uniform, 73004.43
- v: Deterministic, 0.33
- σ_y: Normal, 344.7
- σ_u: Deterministic, 489.5

Constitutive Model
- Distribution of kp: Log Normal, 580.0
- Distribution of np: Normal, 0.04
- Distribution of kf: Normal, 1.0

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Strain Life, Fatigue Damage Model and Pitting

ProCORFA - Reliability Analysis of Aircraft Components

Material: 2024-T3 Aluminum

Model: Morrow Correction
Cumulative: Damage Curve Approach

Distribution | Mean | Standard Deviation | Graphs
--- | --- | --- | ---
\( q \) | Deterministic | 1.5 |  
\( \sigma_f \) | Deterministic | 1044 |  
\( \varepsilon_f \) | Deterministic | 1.765 |  
\( b \) | Deterministic | -0.114 |  
\( c \) | Deterministic | -0.927 |  

Airport Rotation: Without Rotation

Model: Wei Model

Faraday's Model Data

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<th>Graphs</th>
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Corrosion Pitting

Strain Life and Damage Model
Variable Loading and Statistical Crack Population

Variable Loading

Statistical Crack Population
Multiple Inspections

NDI POD Curves

Maintenance Info: POD Curves, Inspection Times
Life Prediction and Risk-Based Condition Assessment

Probabilistic Pit Growth

Risk Analysis

Graph Options

- 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

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
  
  . \( A(t) > a_{cr} \) => replaced (failure)
  
  . \( a_d < A(t) \leq a_{cr} \) => repaired
  
  . \( A(t) \leq a_d \) => 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, \ldots, t_n) = $ inspection times
Total Cost and Failure Probabilities:

- Total cost at $t = \tau$:

- Failure probabilities:

$$\hat{P}_f(t) = \frac{\# \left\{ A(t) > a_{cr} \right\}}{\# \{ \text{samples} \}}$$
- **Optimization algorithm:**

- Problem statement:

\[
\min_{t_1, \ldots, t_n} \{ q_n (c^*; t_1, \ldots, t_n) \} \quad \text{under}
\]

\[
P_f (0) \leq p_{f,0}, P_f (t_1) \leq p_{f,0}, \ldots, P_f (t_n) \leq p_{f,0}, P_f (\tau) \leq p_{f,0}
\]

and \(0 \leq t_1 \leq t_2 \leq \ldots \leq t_n \leq \tau\)

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

- Feasible region for \(n=2\):