PROCORFA

User Manual

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Table of Contents

List of Figures

1. INTRODUCTION

PROCORFA is software for performing a Probabilistic Corrosion and Fatigue Analysis of aircraft lap joints. Complete details of the software are provided in the "Software Documentation" and the Final Report. The current document provides the user with step-by-step instructions on the program usage. Procedure to run PROCORFA will be demonstrated in the subsequent sections by solving a sample problem.

1.1. Computer requirements

Hardware:

A typical installation requirement of PROCORFA consists of the hardware: IBM-PC compatible computer with 128MB RAM, 1GB disk.

Software:

Operating system – Windows 2000/NT /XP.
Software needed – PROCORFA Installation CD
Additional software needed – AFGROW, OWC10

1.2. Installation and running the program

Insert the ProCORFA CD and copy the ProCORFA directory to C: Drive. It will create a ProCORFA directory structure as shown in Figure 1-1. The setup program also creates program folders. To run the execute "PCFDB.EXE" located in the C:\ProCORFA\Bin folder.

1.3. Support software

PROCORFA requires the following additional software.

(1) **AFGROW (Version 4.0)**: This is a software for analysis of fatigue crack growth developed by USAF. The software may be obtained from AFGROW website below:

http://afgrow.wpafb.af.mil/

Download, install, and execute a sample problem of AFGROW before running

PROCORFA. **It is essential to run AFGROW at least once prior to attempting to run PROCORFA**.

(2) OWC10.exe: This is a Microsoft software product required by PROCORFA. Download and install the software from the following website:

http://www.microsoft.com/downloads/details.aspx?FamilyID=982b0359-0a86-4fb2-a7ee-5f3a499515dd&displaylang=en

Both software has been included in the installation CD and will be copied into C:\ProCORFA\bin directory. The user doesn't need to download them except a newer version is needed.

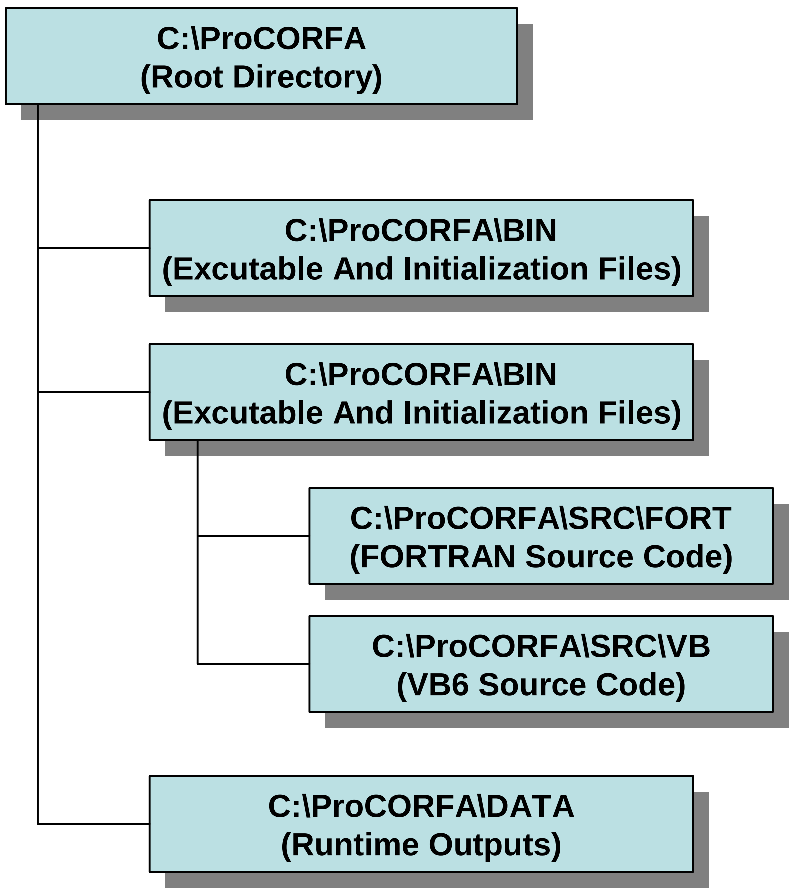


Figure 1-1 PROCORFA Directory Structure

2. PROBLEM SETUP

Prior to running PROCORFA the user needs to perform a stochastic stress analysis of the selected aircraft component. Field data for loading and corrosion environment at the airports that the aircraft may visit during its operation should be collected. The data should be saved in computer files in a format suitable for a subsequent PROCORFA analysis.

2.1. Stochastic stress analysis of selected structural component

A step-by-step description of the analysis by PROCORFA will be demonstrated by a example problem. The example problem is a lap joint in the fuselage of a B707 aircraft shown in Figure 2-1. Prior to using PROCORFA, the user must perform a stochastic stress analysis of the lap joint by finite element or other methods. The lap joint presented herein was analyzed by the finite element program ANSYS. A complete description of the analysis may be found in the final Report.

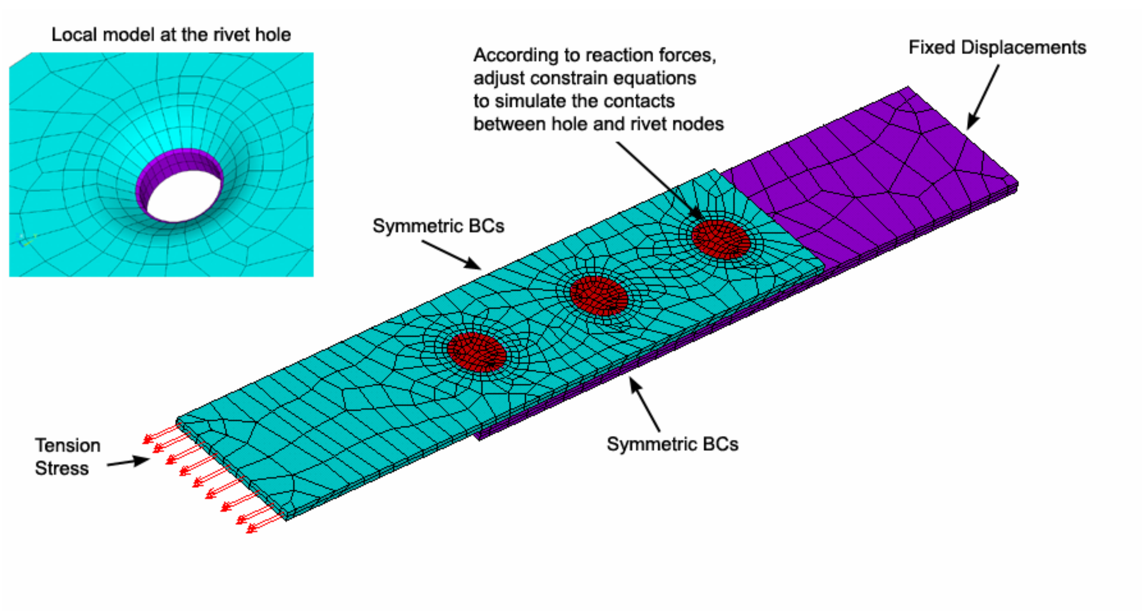


Figure 2-1 B707 Lap Joint

2.2. Prepare input data files

2.2.1. Stochastic stress file

The stochastic stress analysis of the lap joint by provides stresses at critical locations in the joint shown in Figure 2-2. Portions of the stress file for the example problem obtained from FEA analysis is shown in Figure 2-3.

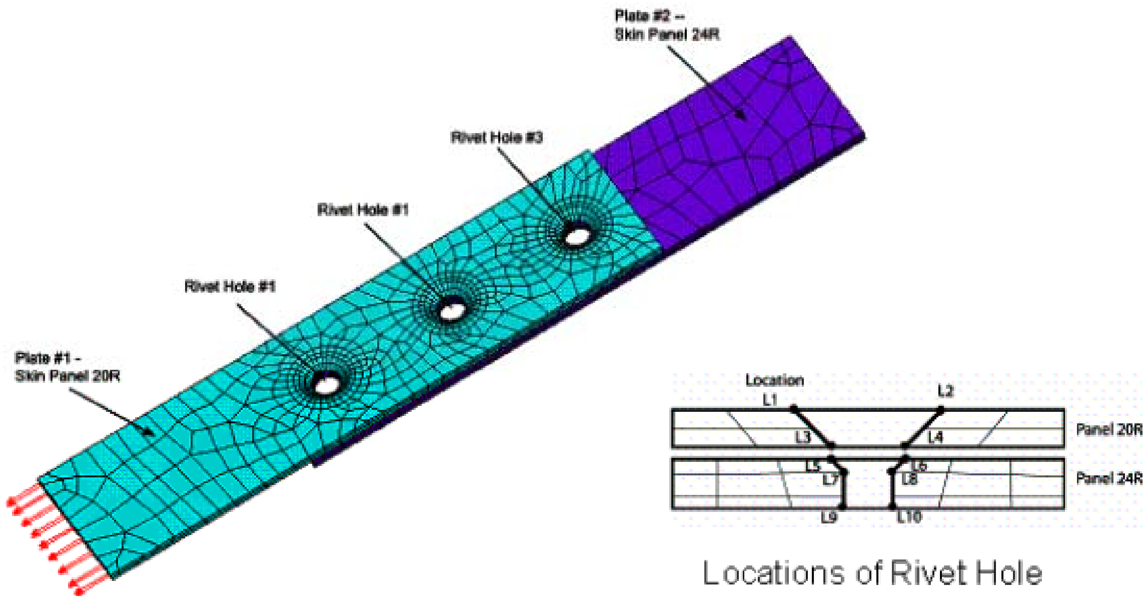


Figure 2-2 B707 Critical Stress Locations in the lap joint

The file format is described as following:

Line 1: Title – A string to describe this file

Line 2: NLOC, NSMP, IFCORR, CORTIM, IUNIT

NLOC: Integer, Number of key locations included in this file

NSMP: Integer, number of stochastic simulation results

IFCORR: =0, only stresses before considering general corrosion are included

=1, include stresses without and with severe general corrosion

CORTIM: Real*8, Corrosion time in years

IUNIT: Integer, stress unit, =0 use MN/m^2, =1 use ksi

Line 3: Key Word "Location"

Line 4: STRLOC – A string to describe the location, it will be used in ProCORFA GUI to select key locations. Repeat this line for NLOC times

Line 5: Title1 – String, header before stress results at each key location

Line 6: S1max, S1min, S2max, S2min (S2max, S2min only needed when IFCORR=1)

S1max – Maximum local stress (stress with load) at given location before considering general corrosion

S1min – Minimum local stress (stress without load) at given location before considering general corrosion

S2max – Maximum local stress (stress with load) at given location after considering general corrosion in CORTIM years

S2min – Minimum local stress (stress without load) at given location after considering general corrosion in CORTIM years

Repeat Line 6 NSMP times

Repeat Line 5 and Line 6 for NLOC times.

```
B707Case1.txt - Notepad
File  Edit  Format  View  Help
B707 Lapjoint Stochastic Stresses for ProCORFA
4    2000     1    20.000000    1
Location
Hole # 1  Location # 3
Hole # 1  Location # 4
Hole # 3  Location # 7
Hole # 3  Location # 8
Data 1 [case=1   hole=1   Loc=3]
     64.79022        8.42472       67.94812        10.72932
     64.64222        2.96222       66.35632         3.84792
     67.88134        8.45344       70.35964        10.89844
     71.10082        3.39862       71.85642         4.28482
     67.90253        5.28493       68.05993         6.66783
---- More Data ----

Data 2 [case=1   hole=1   Loc=4]
     65.43642        8.48642       71.71842        10.88172
     65.69208        2.94248       67.35238         3.77148
     63.00107        8.24587       64.65757        10.48187
     65.69672        3.31652       66.83402         4.24152
     69.77723        5.32073       72.42423         6.76263
---- More Data ----

Data 3 [case=1   hole=3   Loc=7]
     32.38744       14.16984       37.14114        17.37274
     24.25000        7.69370       26.49400         9.48400
      7.89868      -18.04302        9.19278       -17.38582
     26.81931        7.03981       27.01980         8.23991
     18.58416       -1.76144       19.77846         0.01626
---- More Data ----

Data 4 [case=1   hole=3   Loc=8]
     23.20646        5.22236       25.92526         7.45086
     16.95560        0.35560       20.16810         2.68550
     22.58292       -2.58697       25.00253        -1.55547
     18.96207       -0.53883       19.96627         1.18107
     20.41235        0.18265       21.45275         1.51455
---- More Data ----
```

Figure 2-3 FEA Stress File

2.2.2. Load Spectrum file

The file format is described as following:

Line 1: Nspec – Integer, number of points to describe the load spectrum

Line 2: STRES – Real*8, stress points in the load spectrum. Each point in one line, repeat Nspec times. Please pay attention, unlike the stochastic stress file, the stress in spectrum file represents the remote stress instead of the local stress.

A sample load spectrum file is shown in Figure 2-4

```
7
0.0
149.0
90.0
160.0
92.0
150.0
0.0
```

Figure 2-4 Load Spectrum File

2.2.3. Airport rotation file for pit growth

The airport rotation file contains corrosion data for airports at which the aircraft operates. An airport rotation file for the example is shown in Figure 2-5. The file contents are:

Line 1: Nairport – Integer, total number of airports

Line 2: NA, NTIM, Cmean, Cstd, Qmean, Qstd

NA – Integer, the airport number

NTIM – Integer, number of visits of this airport at given period

Cmean – Real*8, mean value of C in power law pit growth equation

Cstd – Real*8, standard deviation of C in power law pit growth equation

Qmean – Real*8, mean value of q in power law pit growth equation

Qstd – Real*8, standard deviation of q in power law pit growth equation

Repeat Line 2 for Nairport times.

Power law pit growth equation: $a_{pit} = C \cdot T^{q}$ where T is the time in days, and a_{pit} is the pit size.

```
5          ---Total number of airports
1,    5,   2.2e-5,   1.1e-5,    0.333,   0.0333    --Airport No., Visit times, Cmean, Cstd, qmean, qstd
2,   10,   1.7e-5,   0.95e-5,   0.298,   0.0411
3,    2,   3.0e-5,   1.43e-5,   0.431,   0.0389
4,    6,   2.5e-5,   1.3e-5,    0.338,   0.0395
5,    4,    10e-5,   4e-5,      0.435,   0.0441




pit size   pit=c*t**q   t is the time in days
```

Figure 2-5 Airport rotation file

3. PROCORFA INPUT

A complete discussion of PROCORFA inputs are given in PROCORFA Software Documentation Manual and SBIR Phase II report. The following sections provide a step-by-step walk through of the input procedure for the selected example problem.

3.1. General Description of GUI

PROCORFA-GUI is shown in Figure 3-1. The GUI consists of several tabs to input the data. At startup for a new job PROCORFA assigns default values to various parameters. The user may select any tab to examine/change these parameters. The GUI consists of an area at the bottom that displays “Background Processor” panel which is displays messages from FORTRAN dynamic link libraries that perform various calculations in the background.

3.2. Input of Random Variables

For random variables, ProCORFA offers six (6) distributions for user to select:

1. Deterministic – User needs to input the deterministic value in the “Mean” box

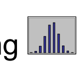
2. Uniform – Input the minimum value in “Mean” box, and maximum value in “Standard Deviation” box

3. Normal – Input the mean value for normal distribution in “Mean” box, and the standard deviation in “Standard Deviation” box

4. Log Normal – Input the mean value for lognormal distribution in “Mean” box, and the standard deviation in “Standard Deviation” box

5. Uniform Exponent – The random number generated by $f(x) = e^x$ where x is a uniform distribution. User needs to input the minimum value of x in “Mean” box, and maximum value of x in “Standard Deviation” box

6. Weibull – Input the scale for Weibull distribution in “Mean” box, and the shape in “Standard Deviation” box

The histogram and CDF plot of random variables can be plotted by clicking  icon.

3.3. Header Data

Click on the ***Header Tab*** of the PROCORFA GUI to display header data shown in Figure 3-1. The header data defines the problem title, user information, units, and numerical controls for Monte Carlo simulations. Units may be "Metric" or "US" units. The units for Force, Stress, Length, and Time are selected automatically by PROCORFA for the two systems. The user must ensure that the units are consistent through out while defining the input parameters.

3.4. Material Properties

Click on the ***Material Tab*** of the GUI as shown in Figure 3-2. From the ***Material Dropdown Box*** select the material ***2024-T3 Aluminum (Metric).*** PROCORFA automatically fills in all the needed material properties into the GUI from built-in material database.

3.4.1. Mechanical properties

Click on the ***Mechanical Tab*** of the GUI (Figure 3-2). Accept or modify the input shown in Table 3-1

Table 3-1 Mechanical Properties

Input	**Description**
Material	Select a material from PROCORFA material database
E	Young's Modulus
ν	Poisson's Ratio
σ_y	Yield Stress
σ_u	Ultimate Stress

3.4.2. Constitutive Properties

Click on the ***Constitutive Tab*** of the GUI (Figure 3-3). Accept or modify the input shown in Table 3-2.

Table 3-2 Constitutive Properties

Input	Description
K’	Cyclic strength coefficient
n'	Cyclic strain hardening exponent
K_f	Notch parameter of Neuber’s model

Constitutive Equation: $$\frac{\Delta\varepsilon}{2} = \frac{\Delta\sigma}{2E} + \left(\frac{\Delta\sigma}{2K'}\right)^{\frac{1}{n'}} \quad (3\text{-}1)$$

Notch parameter is used to transfer the remote load to local stresses. User may input random local stress directly by selecting “Constant Amplitude Loading (Single cycle) with Stochastic FE Input” in “Load” input, or input remote stress by other options.

3.4.3. Crack Initiation Model

Click on the ***Crack Initiation Tab*** of the GUI (Figure 3-4). Accept or modify the inputs shown in Equation (3-2). All the parameters are used in Equation (3-2)

Strain Life Equation: $$\frac{\Delta\varepsilon}{2} = \frac{\sigma'_f}{E}\left(2N_f\right)^b + \varepsilon'_f\left(2N_f\right)^c \quad (3\text{-}2)$$

Where σ_f is the fatigue strength coefficient, ε_f is the fatigue ductility coefficient, b is the fatigue strength exponent, c is the fatigue ductility exponent. These parameters are needed to input as random variables in the GUI.

In the “Mean Stress Correction” box, user can select from the drop-down box. The details of mean stress correction method are described in the SBIR final report.

In the “Damage Model” box, if user select “Power Damage Model”, random variable q must be input for strain life damage accumulation as shown in Equation (3-3). For other damage models, no input is need.

Power Damage Model for strain life damage accumulation:

$$D_{strainlife} = \left(\frac{n}{N}\right)^q \quad (3\text{-}3)$$

3.4.4. Crack Growth Model

Click on the ***Crack Growth Tab*** of the GUI (Figure 3-5). There is four crack growth models are included in ProCORFA, the details are described in the SBIR final report. The inputs for each model are:

1. Forman

Forman equation: $$\frac{da}{dN} = \frac{C(1-R)^m \Delta K^n (\Delta K - \Delta K_{th})^p}{\left[(1-R)K_C - \Delta K\right]^q} \qquad (3\text{-}3)$$

$$\Delta K_{th} = \Delta K_{th0}(1-R)^{\alpha} \qquad (3\text{-}4)$$

Where R is the ratio of minimum load and maximum load, ΔK_{th0} is the stress intensity threshold at R=0, ΔK_{th} is the stress intensity threshold at given R, K_c is fracture toughness. C, m, n, p, q are constants in Forman Equation.

Randoms variables C, m, n, p, K_c, ΔK_{th0} and α are needed to input in the GUI if Forman Equation is selected.

2. SinH (Sine Hyperbolic Model)

SinH equation: $$\log\left(\frac{da}{dN}\right) = C_1 \sinh\left\{C_2\left[\log(\Delta K) + C_3\right]\right\} + C_4 \qquad (3\text{-}5)$$

Random variables C_1, C_2, C_3 and C_3 are needed to input in the GUI if SinH model is selected.

3. MSM (Modified Sigmoidal Model)

MSM equation: $$\frac{da}{dN} = e^B \left(\frac{\Delta K}{\Delta K^*}\right)^P \left[\ln\left(\frac{\Delta K}{\Delta K^*}\right)\right]^Q \left[\ln\left(\frac{\Delta K_C}{\Delta K}\right)\right]^D \qquad (3\text{-}6)$$

Random variables ΔK^*, ΔK_C,B,P,Q and D are needed in the GUI if MSM model is seclected.

4. AFGROW

If AFGROW is selected for the crack growth simulation, the following random variables are needed in the GUI:

- Plane Stress Fracture Toughness K_C
- Plane Strain Fracture Toughness K_{ic}
- ΔK threshold at R=0

The ProCORFA program transfers these three random parameters, plus the initial crack length, specimen thickness, corrosion fatigue data and the loads to AFGROW for the crack propagation calculations. Other parameters need to be set in AFGROW directly by click "AFGROW" button. **DO NOT** close AFGROW window after setting the parameters, otherwise ProCORFA cannot continue the crack growth analysis using AFGROW.

3.4.5. Pitting Model

Click on the ***Mechanical Tab*** of the GUI (Figure 3-6) to input pitting models. There are two pitting models can be selected in ProCORFA GUI.

1. Wei Model

Robert Wei's pitting equation: $$a_{pit} = \left\{ \left[\frac{3MI_{p0}}{2\pi nF\rho} \exp\left(-\frac{\Delta H}{RT} \right) \right] t + a_0^3 \right\}^{1/3} \qquad (3\text{-}7)$$

Where t is the time, a_{pit} is the pit size at time t. The detailed description of Wei's model is in the SBIR final report. Random variables I_{P0}, ΔH, ρ, m, n, T are needed in the GUI.

2. Power-law Model

Power law pitting equation: $$a_{pit} = c \cdot t^q \qquad (3\text{-}8)$$

The random variables c and q are needed in the GUI.

3. Airport Rotation

Airport rotation with power-law model requires a list of c and q distributions (normal distributions are used in ProCORFA) at different airports. The user needs predefined the list in a file as described in section 2.2.3. Then input the full file path in "Airport Rotation File" box.

3.5. Crack Geometry Model

Click on the ***Crack Geometry Tab*** of the GUI (Figure 3-7). Accept or modify the input shown.

1. ProCORFA Crack Type – Select "Single Crack in a Hole" or "Two Symmetric Cracks in a Hole". If AFGROW is used for crack growth analysis, ignore this box and the crack type should be input from AFGROW in section 3.4.4
2. a0 – Initial crack size (IDS size)
3. ai – Transition crack size from crack initiation to crack growth model
4. ac – Failure crack size
5. r0 – Hole radius
6. t0 – Plate Thickness
7. Kt – Stress concentration coefficient. If the local stochastic FE stresses are used for the load input, Kt is also used to calculate the equivalent remote stress
$$\sigma_{remote} = \frac{\sigma_{local}}{K_t}$$

3.6. Load Specification

Click on the ***Load Tab*** of the GUI (Figure 3-8). The user inputs are described as the following:

Load Type – Select from the drop down box:

- Constant Amplitude Loading (Single cycle) with User Input
- Constant Amplitude Loading (Single cycle) with Stochastic FE Input
- Variable Amplitude Loading (Block of cycles)

If "Load Type" is "Constant Amplitude Loading (Single cycle) with User Input", the following inputs are needed:

- Number of Missions/Day – Number of flights per day
- Hours/Mission – Average flight hours per flight
- Stress->Maximum – Maximum ***REMOTE*** load as a random variable
- Stress->Minimum – Minimum ***REMOTE*** load as a random variable

If "Load Type" is "Constant Amplitude Loading (Single cycle) with Stochastic FE Input", the following inputs are needed:

- Number of Missions/Day – Number of flights per day
- Hours/Mission – Average flight hours per flight
- Load Factor – A random coefficient to multiply to the stresses in order to simulate the load visibilities.
- Input File – File name that stores the stochastic FE data, the file format is described in section 2.2.1. Unlike other load types, the data in this file are ***LOCAL*** stresses.

- Location – Select a key locations in the stress file from drop down box
- Simulation Option – Select from the drop down box. “Bootstrapping” is recommended if there are enough random local stress samples. Another option is to generate more samples use the simulated joint PDF.

If “Load Type” is “Variable Amplitude Loading (Block of cycles)”, the following inputs are needed:

- Number of Missions/Day – Number of flights per day
- Hours/Mission – Average flight hours per flight
- Flight Time – Flight hours in the block defined in spectrum file
- Ground Time – Ground time in the block defined in spectrum file
- Spectrum File – File name that stores the spectrum load data, the files format is described in section 2.2.2. The data in this file are ***REMOTE*** loads.

3.7. Maintenance Data

Specify maintenance input by selecting the ***Maintenance Tab*** in the main GUI.

3.7.1. General Maintenance Parameters

Click on the ***General Tab*** of the GUI (Figure 3-9). Accept or modify the input shown.

1. Number of Cracks – Number of crack vs time curves will be generated for maintenance simulation
2. Days in service – Total service life in days
3. Crack Growth Calculation:
    - Fit Crack Growth with Equation – Much faster
    - Interpolate Crack Growth by Spline – Slow but maybe accurate
4. Initial Failure Probability
5. Time steps – simulation steps in days
6. Inspection Strategy:
    - Repair when crack reaches reject size
    - Repair whenever crack is detected
7. Rejected Crack Size
8. Repair Efficiency: γ=0 mean no repair at all, γ=1 mean replacement, otherwise the crack size after repair equals γ times crack size before repair.
9. Crack Size for Failure Criteria – Failure crack size

3.7.2. POD Parameters

Click on the ***POD Parameter Tab*** of the GUI (Figure 3-10). Accept or modify the input shown.

3.7.3. Maintenance Calculation Model

Click on the ***Maintenance Calculation Tab*** of the GUI (**Error! Reference source not found.**). Accept or modify the input shown.

3.8. Save Input Data

Before proceeding with the analysis save the input data by selecting the ***File → Save*** or ***File → Save As*** menu of the GUI. For analysis proceed to Section 4.

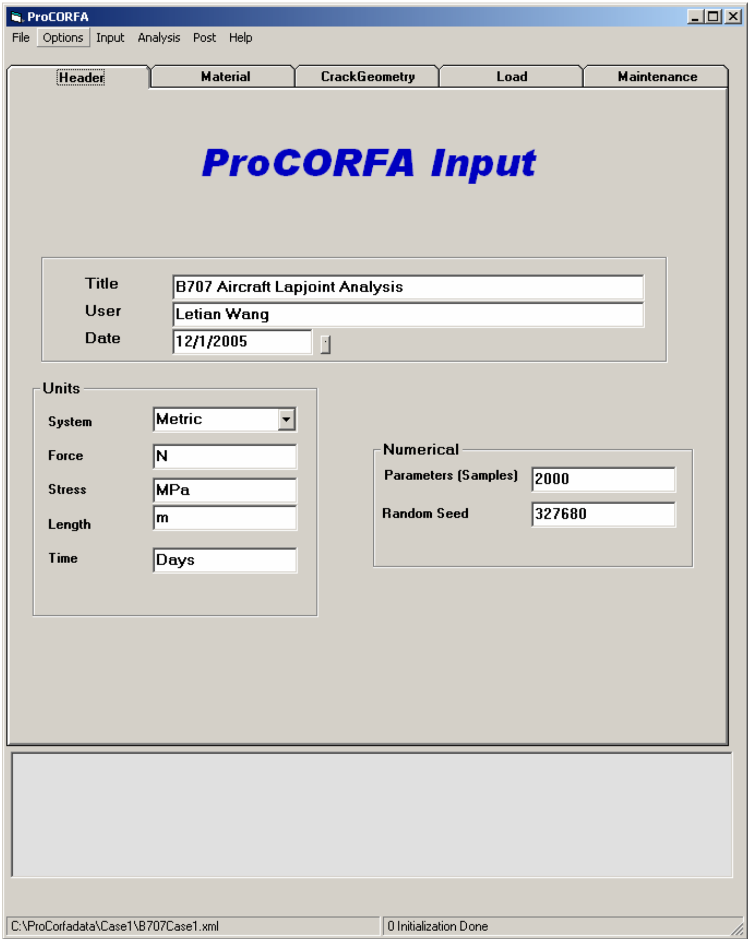


Figure 3-1 Header Input

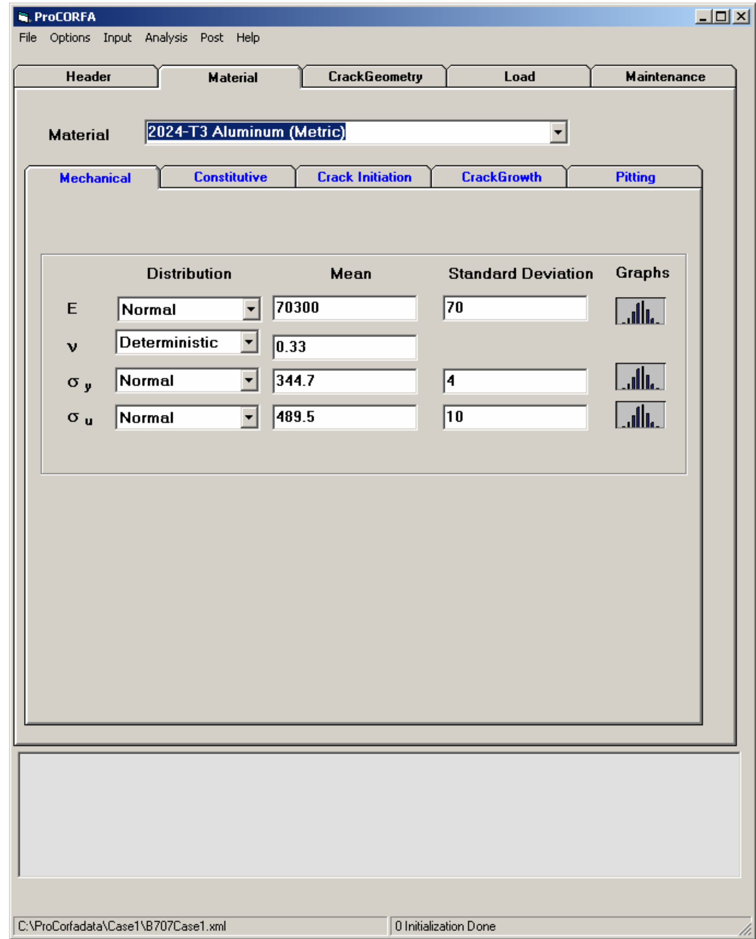


Figure 3-2 Mechanical Properties

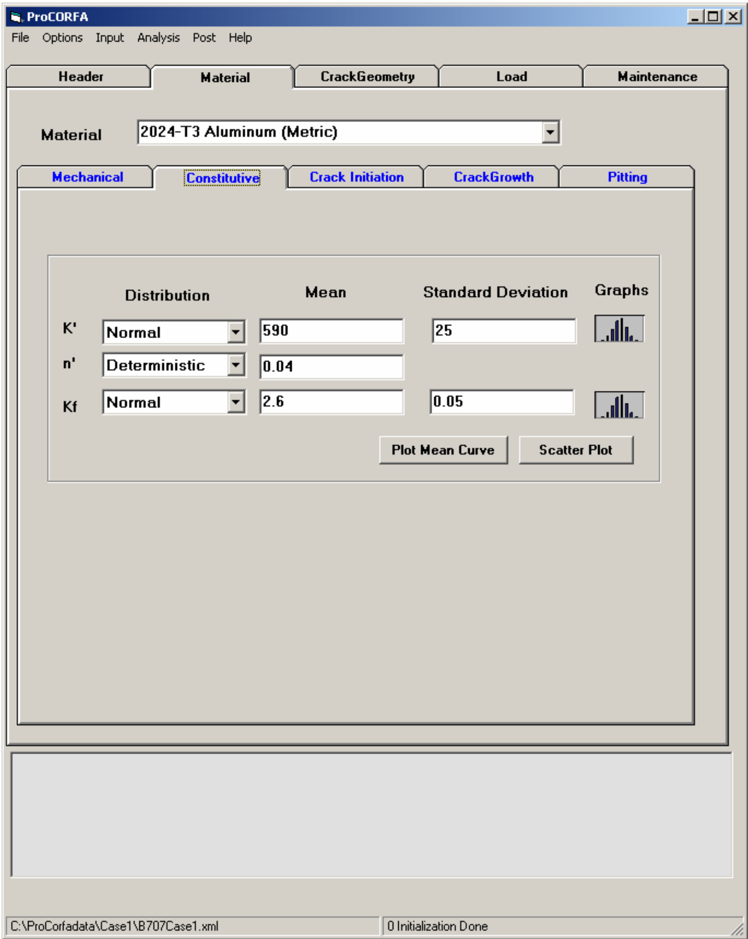


Figure 3-3 Constitutive Properties

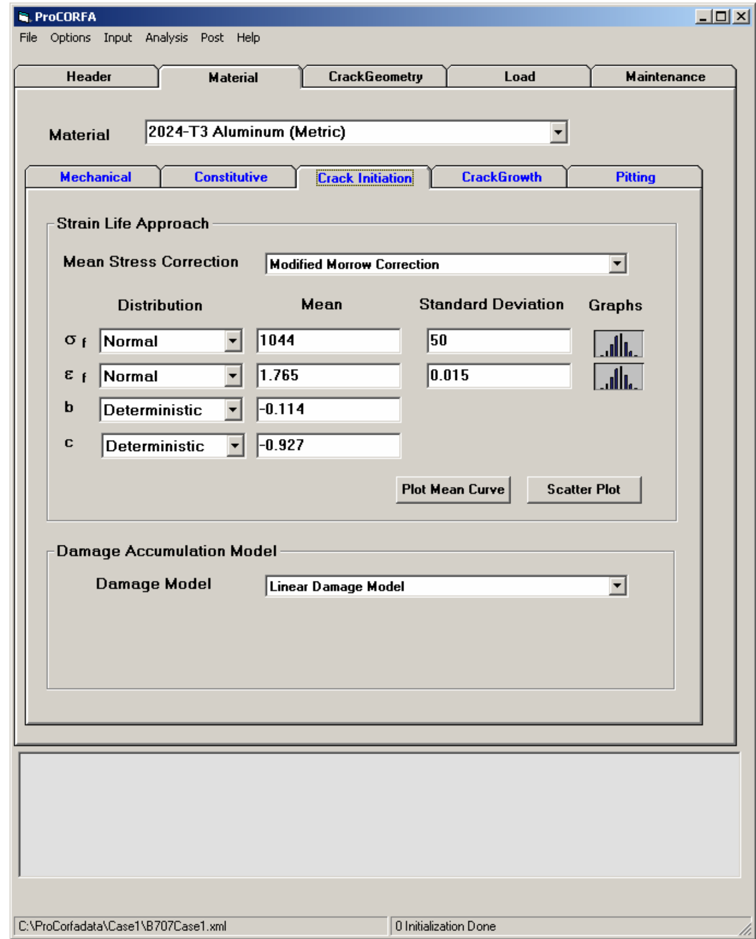


Figure 3-4 Crack Initiation Model

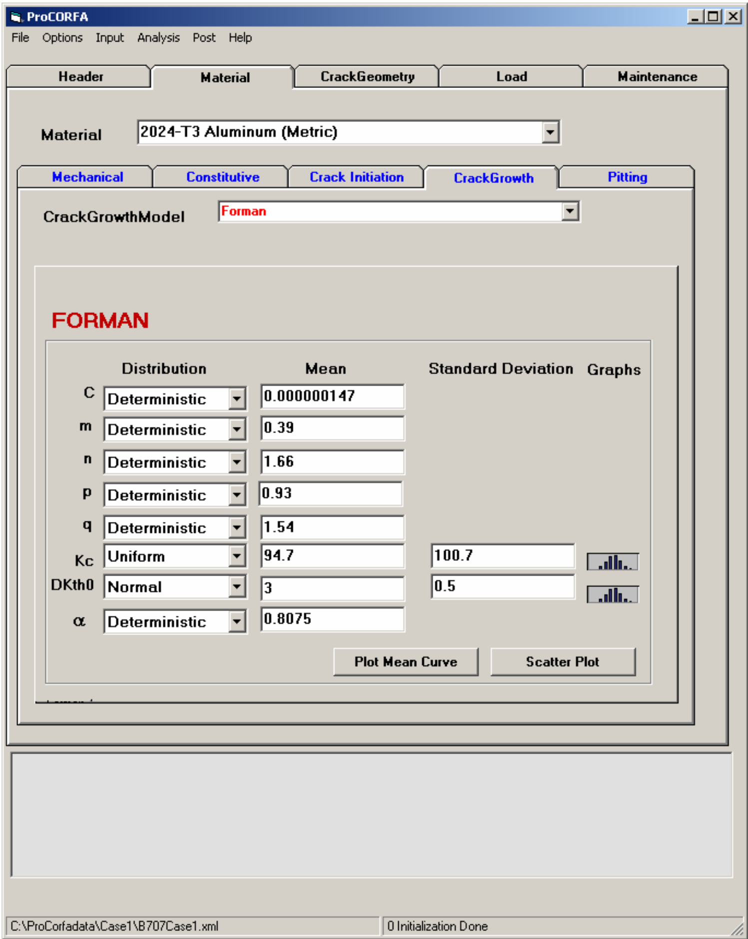


Figure 3-5 Crack Growth Model

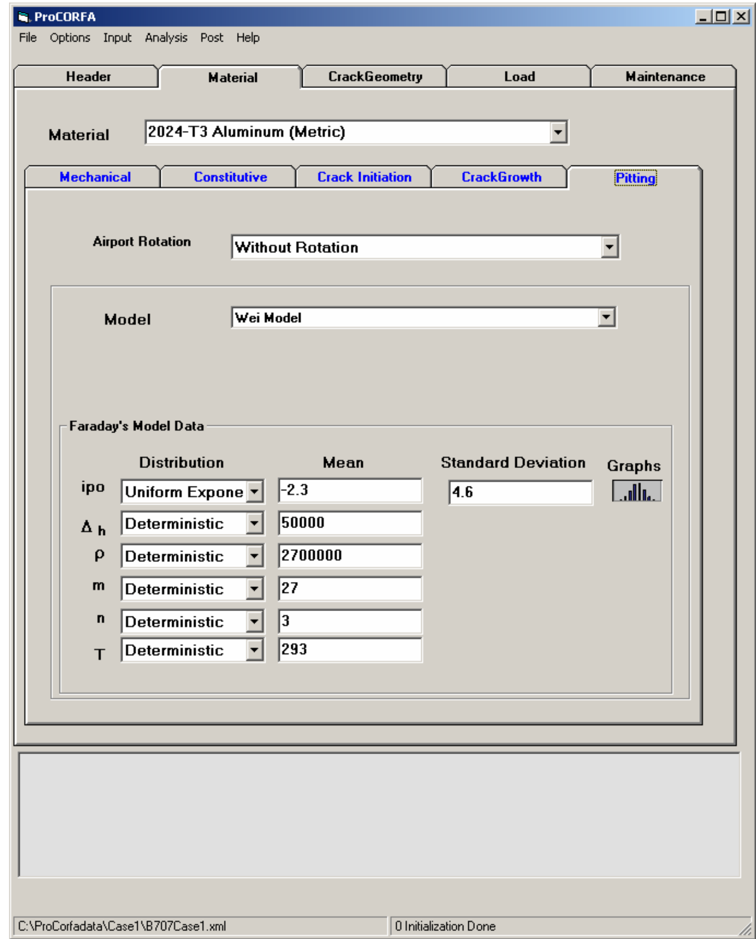


Figure 3-6 Pitting Model

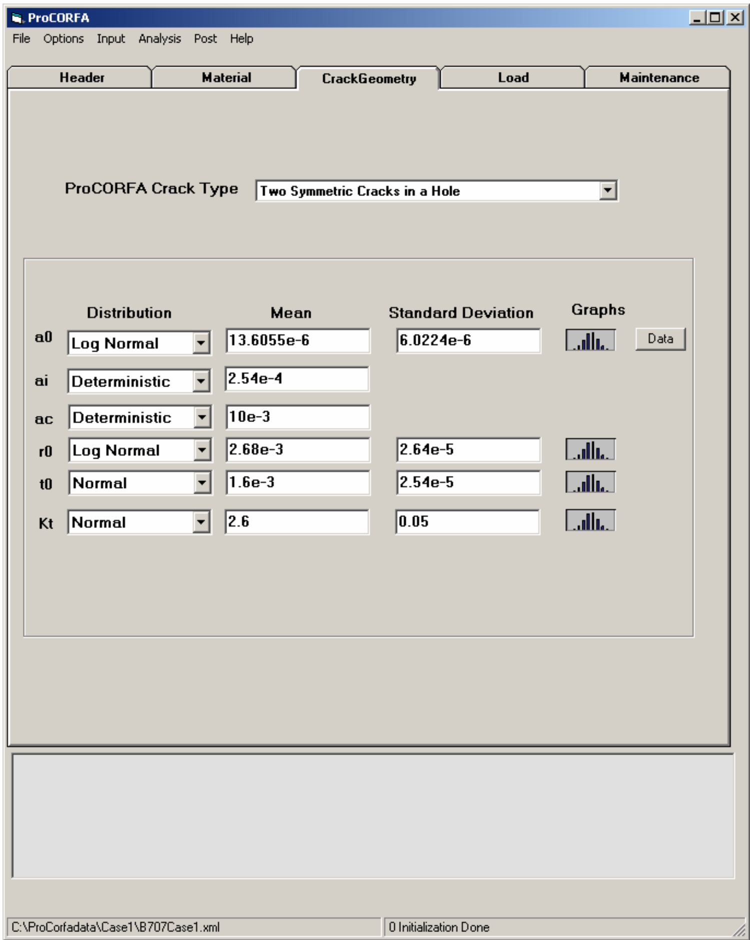


Figure 3-7 Crack Geometry Model

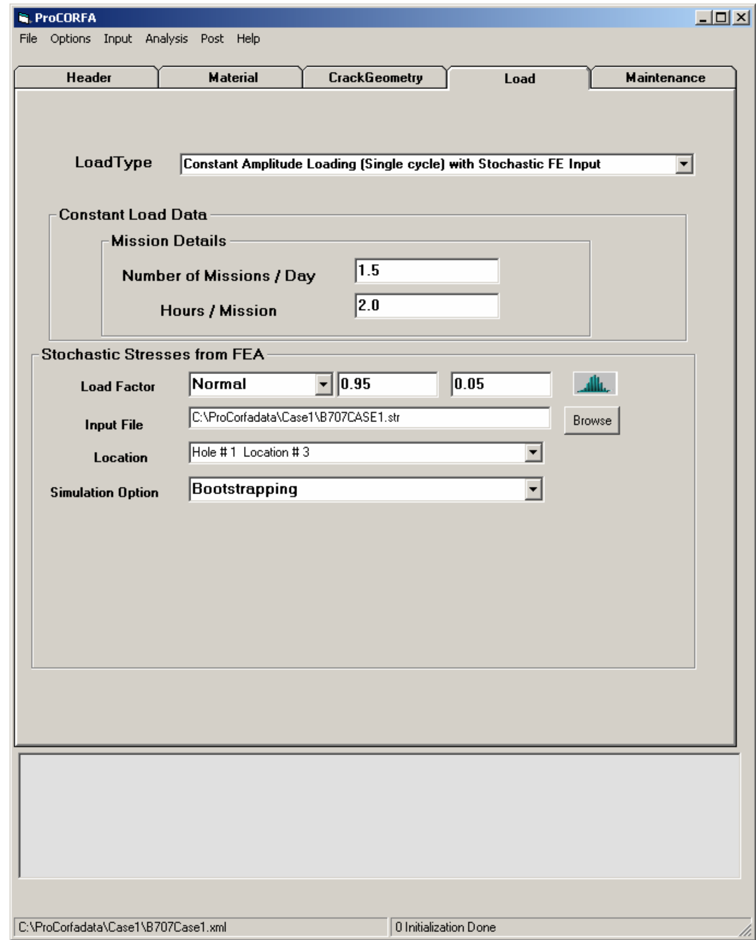


Figure 3-8 Load Specification

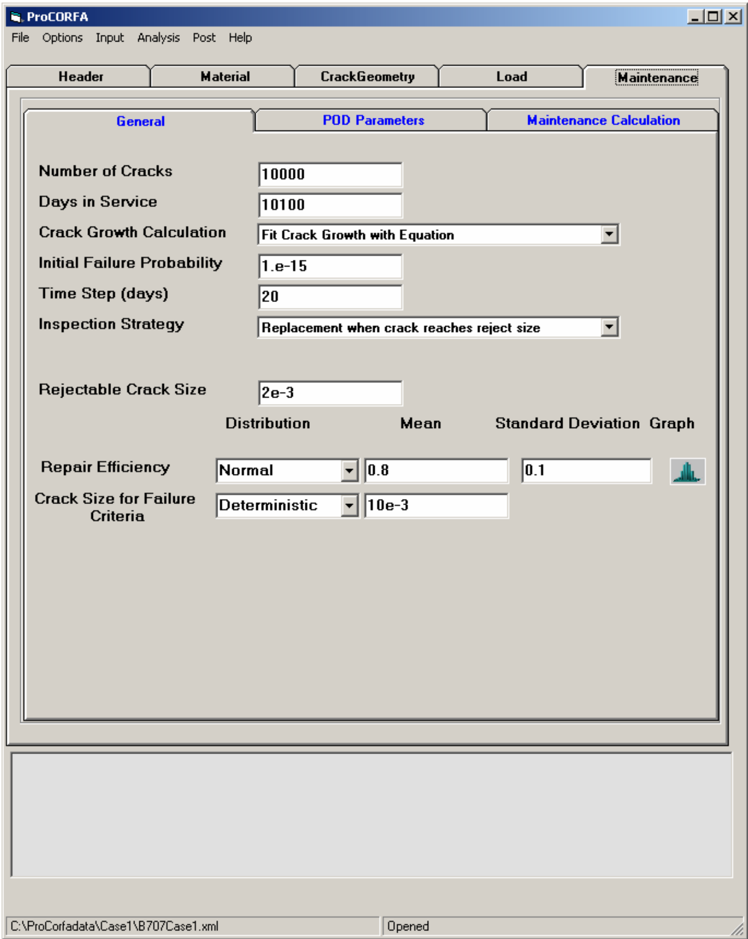


Figure 3-9 Maintenance General Parameters

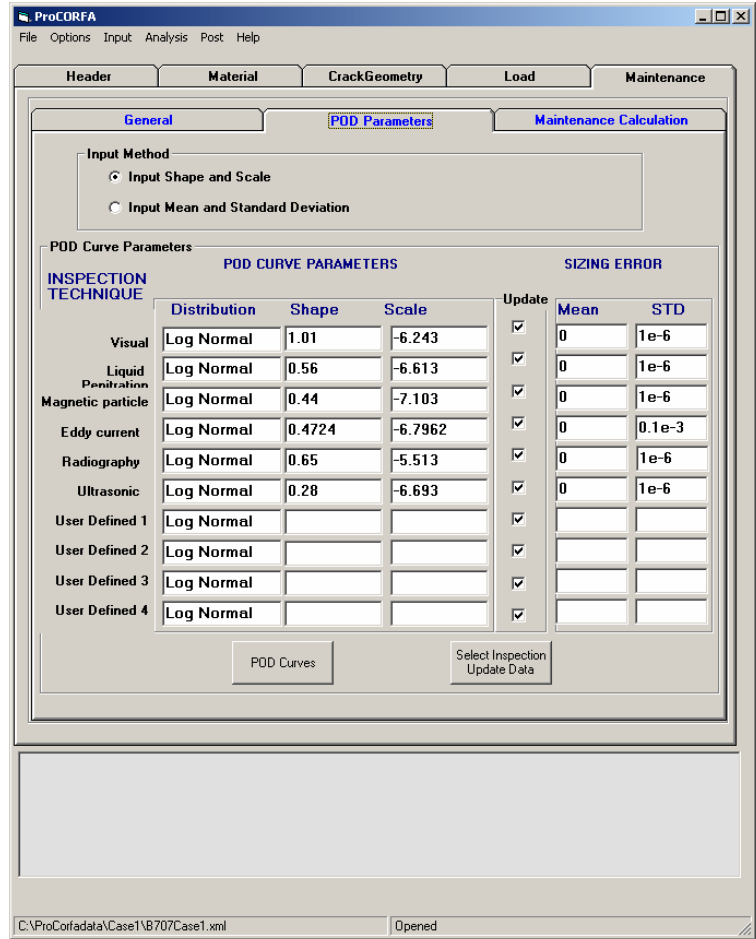
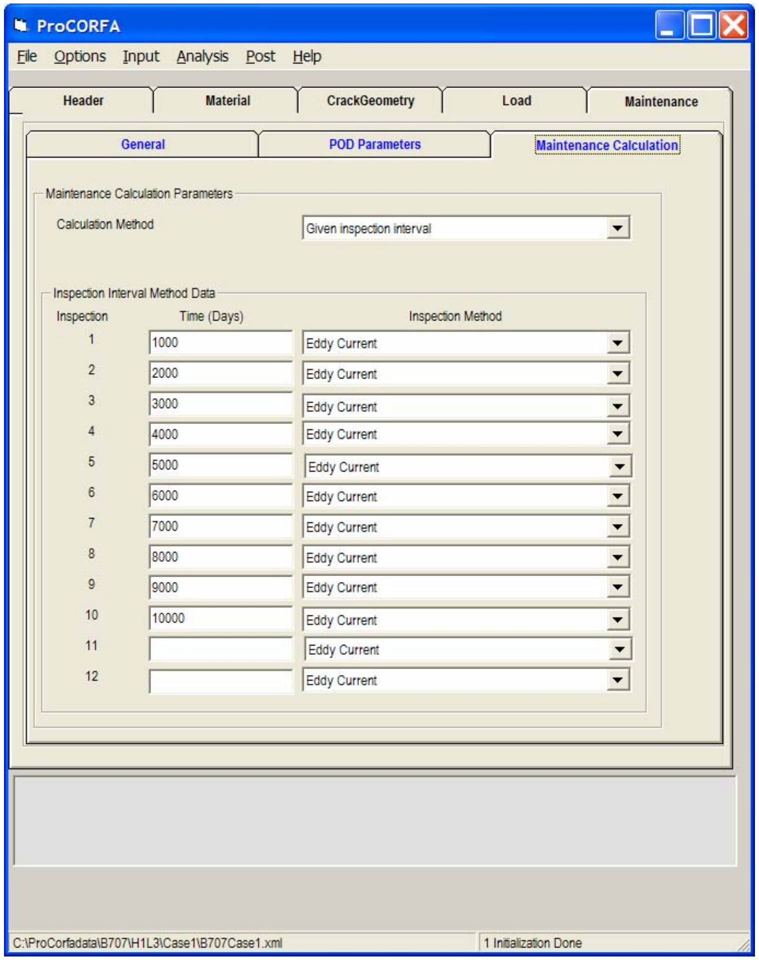


Figure 3-10 POD Parameters



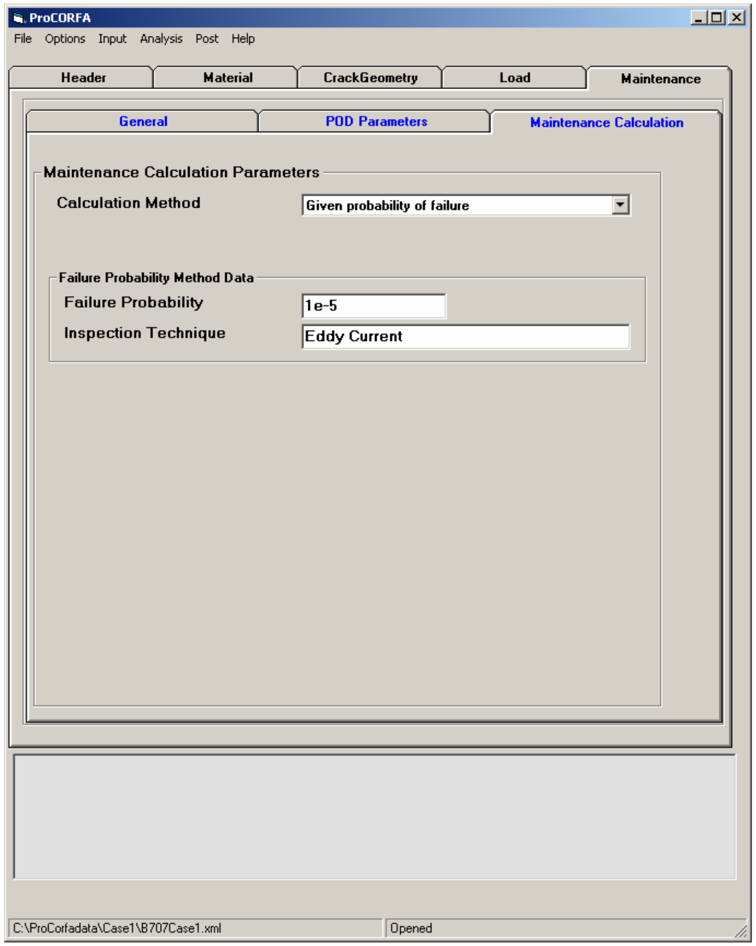


Figure 3-11 Maintenance Calculation Model

4. ANALYSIS

4.1. Probabilistic Corrosion Fatigue Analysis

4.1.1. Input

Select ***Analysis → Probabilistic Corrosion Fatigue Analysis Menu*** from GUI as shown in Figure 4-1. The analysis options window Figure 4-2 is displayed. Check the boxes: ***Crack Initiation***, ***Crack Propagation***, and ***Maintenance***. Select ***ProCorfa*** option. Accept or modify the numerical controls. Click the ***RUN*** button. PROCORFA executes the analysis in the background. Depending on the type of computer the run may take several minutes. Upon completion select ***Post Menu*** of the GUI to examine the results of analysis.

4.1.2. Output

LIFE PREDICTION OUTPUT

Select ***Post → Life Prediction*** Menu option as shown in Figure 4-3.

Life Distribution

Life Prediction are displayed as shown in Figure 4-4 to Figure 4-8. Figure 4-4 (a) shows the probability distribution of Predicted Life. Click the ***CDF*** button to display the Cumulative Distribution shown in Figure 4-4 (b).

Crack Length Growth

Select ***Crack length Option*** to display the crack length growth shown in Figure 4-5 (a). Figure 4-5 (b) shows the probability distribution of crack length. Click the ***CDF*** button to display the Cumulative Distribution shown in Figure 4-5 (c).

Pitting Size

Select ***Pitting Size Option*** to display the growth of pitting size shown in Figure 4-6 (a). Figure 4-6 (b) shows the probability distribution of pitting size. Click the ***CDF*** button to display the Cumulative Distribution shown in Figure 4-6 (c).

Pitting Factor

Select ***Pitting Factor Option*** to display the growth of pitting factor shown in Figure 4-7.

Stress Intensity Variation

Select ***Stress Intensity Option*** to display the variation of stress intensity shown in Figure 4-8 (a). Click Distribution Button to display sample distribution shown in Figure 4-8 (b). Click the ***CDF*** button to display the Cumulative Distribution shown in Figure 4-8 (c).

INSPECTION OUTPUT

Select ***Post → Inspection*** Menu option as shown in Figure 4-9. The failure risk and reliability results window shown in **Error! Reference source not found.**.

Crack Length Statistics Evolution

Select ***Crack Length Statistics Evolution Option*** in Figure 4-10 to display crack length evolution shown in **Error! Reference source not found.**.

Failure Risk Evolution

Select ***Failure Risk Evolution incuding Maintenance Option*** in Figure 4-10 to display the failure risk evolution shown in **Error! Reference source not found.**.

Reliability Function Evolution

Select ***Reliability Function Evolution Option*** in Figure 4-10 to display the reliability function evolution shown in **Error! Reference source not found.**.

Reliability Index Evolution Including Maintenance

Select ***Reliability Index Evolution including Maintenance Option*** in Figure 4-10 to display the reliability index evolution shown in Figure 4-14.

Cumulative Number of Repairs

Select ***Cumulative Nymber of Repairs Option*** in Figure 4-10to display the evolution of cumulative repairs shown in **Error! Reference source not found.**.

PDF of Predicted Life

Select ***PDF of Predicte Life including Maintenance Option*** in Figure 4-10 to display the evolution of PDF of fatigue life shown in Figure 4-16.

Number of Failures per maintenance Interval

Select ***Number of Failures Per Maintenance Interval Option*** in Figure 4-10 to display the evolution of number of failures per maintenance intervalshown in Figure 4-17.

Hazard failure Rates per Maintenance Interval

Select ***Hazard Failure Rates Per maintenance Inteval Option*** in Figure 4-10 to display the evolution of hazard failure rates per maintenance interval shown in Figure 4-18.

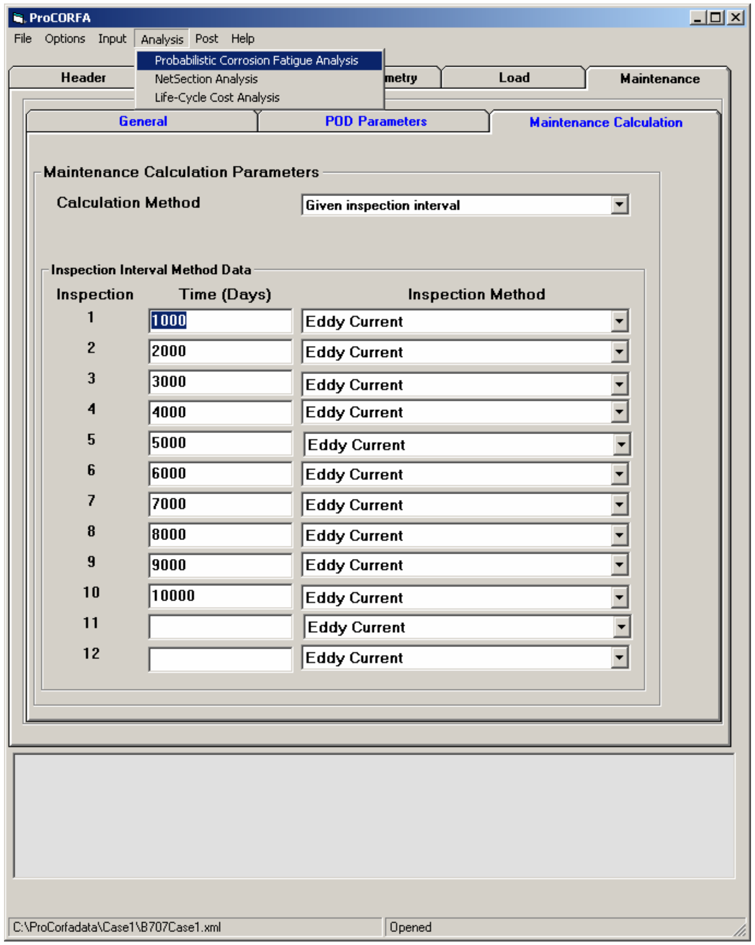


Figure 4-1 Analysis menu

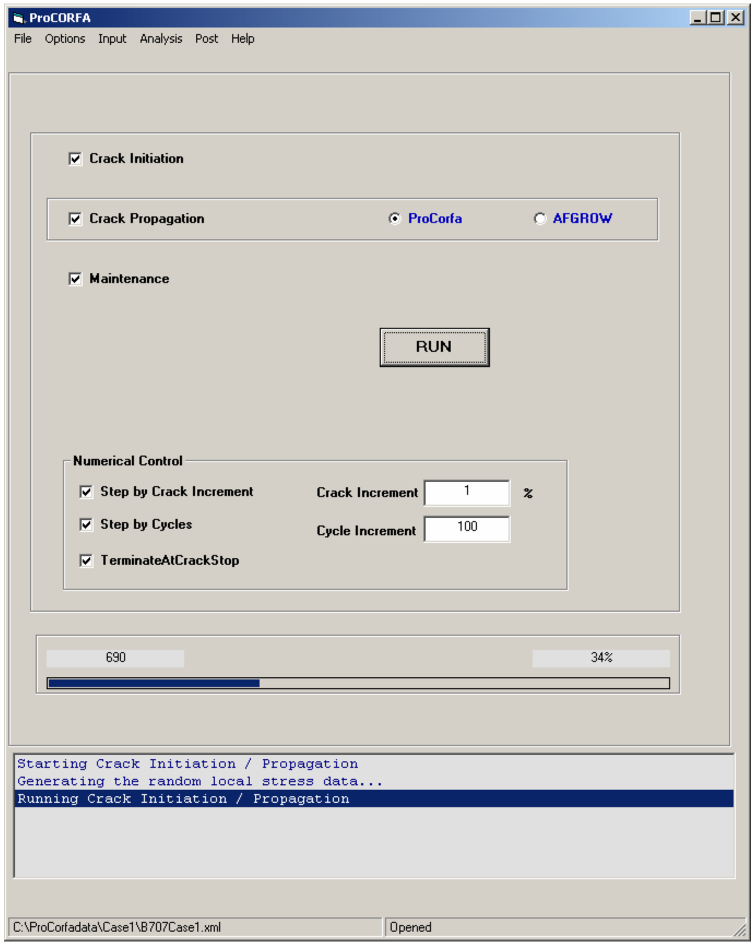


Figure 4-2 Probabilistic Corrosion Fatigue Analysis

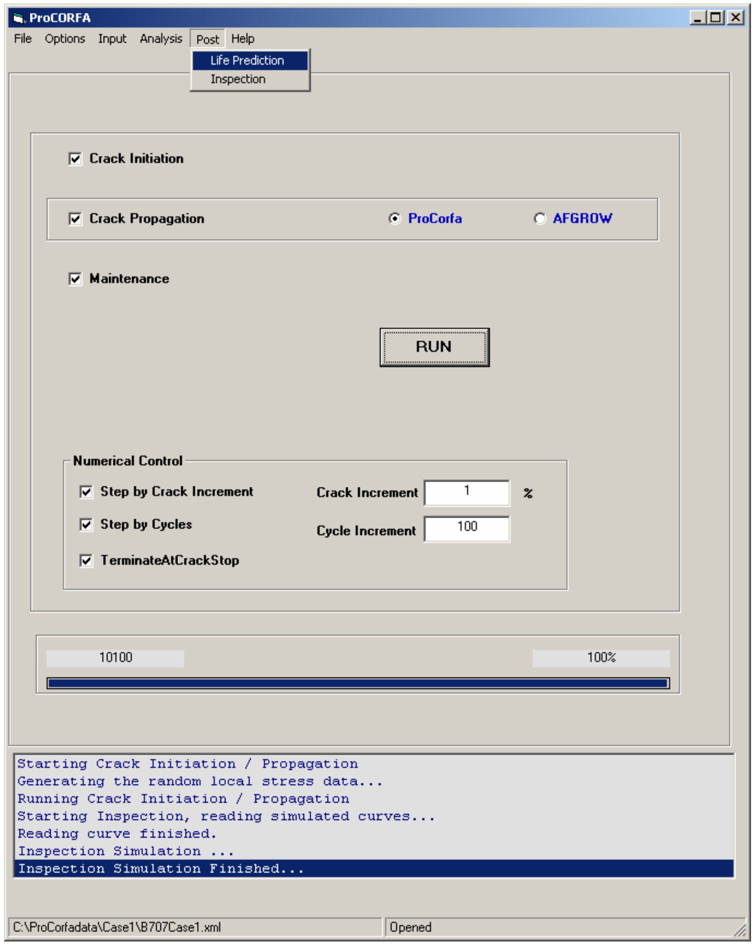
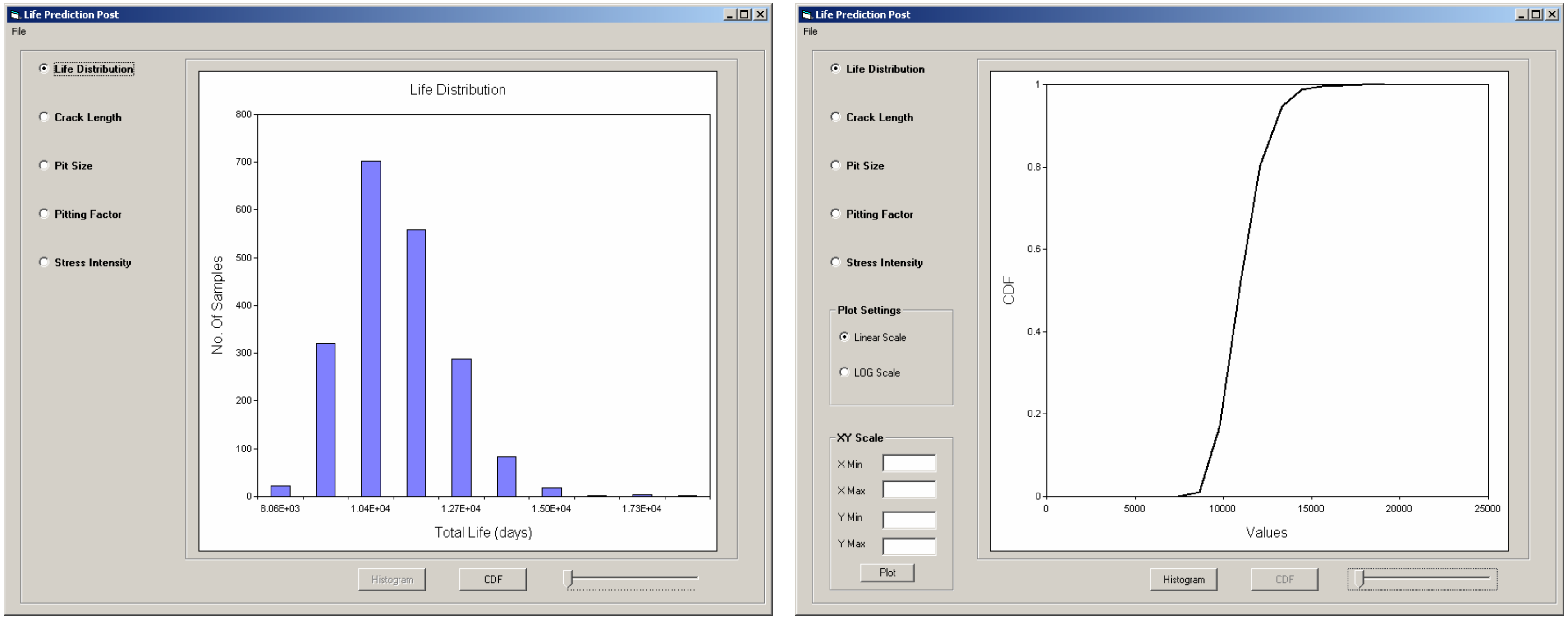
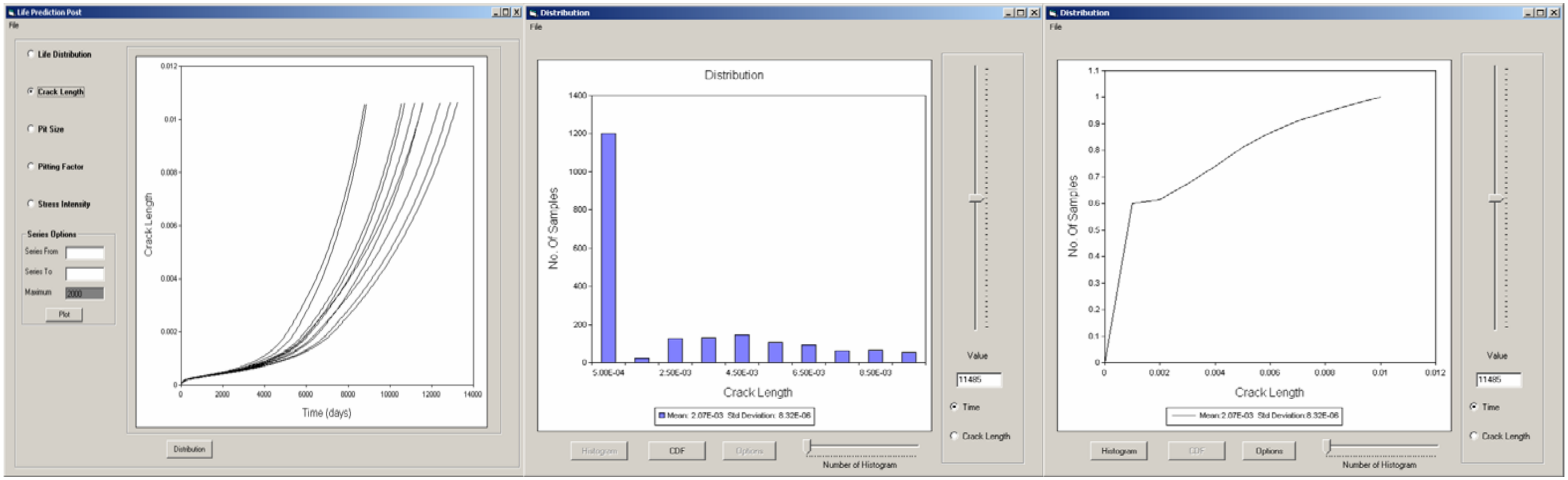


Figure 4-3 Post-Processor menu for Life Prediction



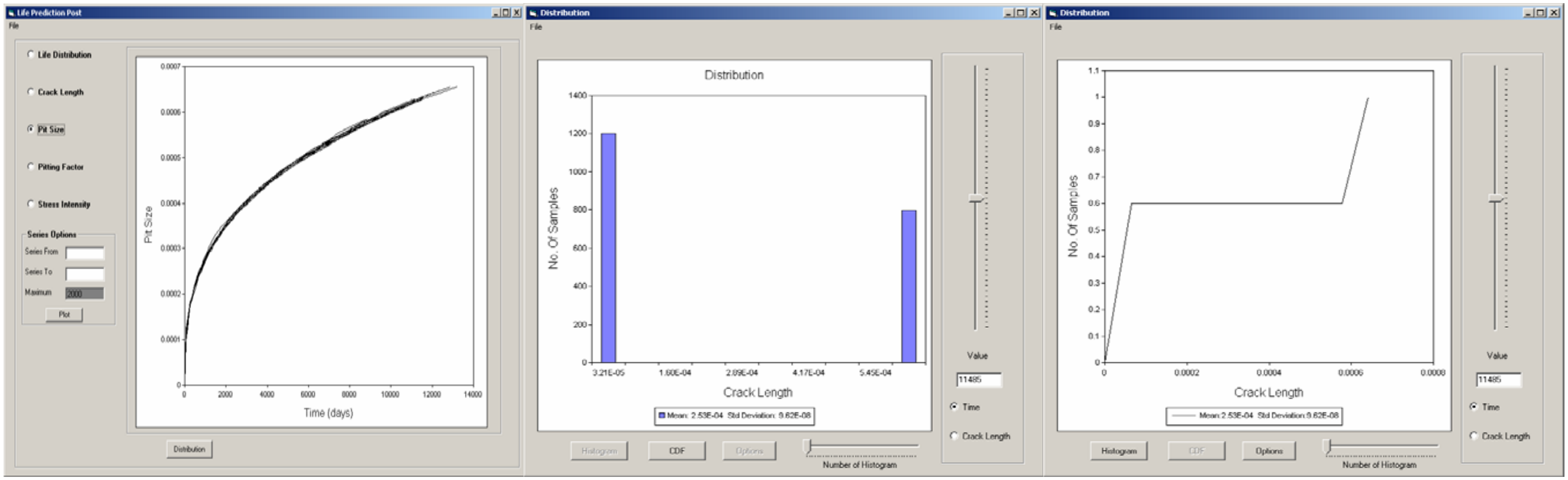
(a) Histogram **(b) Cumulative Distribution**

Figure 4-4 Life Prediction Results – Life Distribution



(a) Crack Growth **(b) Distribution** **(c) CDF**

Figure 4-5 Life Prediction Results – Crack Growth



(a) Pit Size Growth **(b) Distribution** **(c) CDF**

Figure 4-6 Life Prediction Results – Pitting Growth

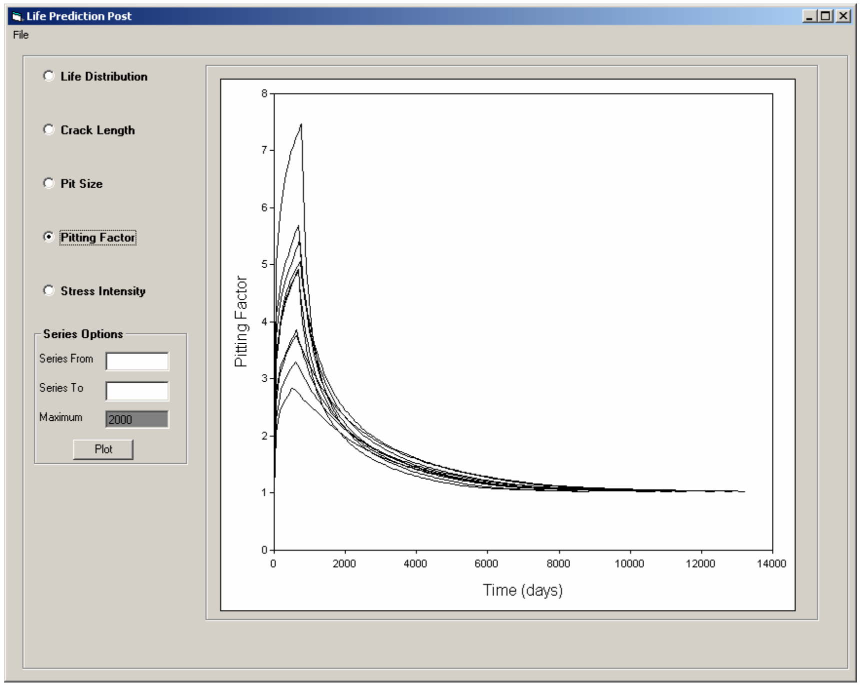
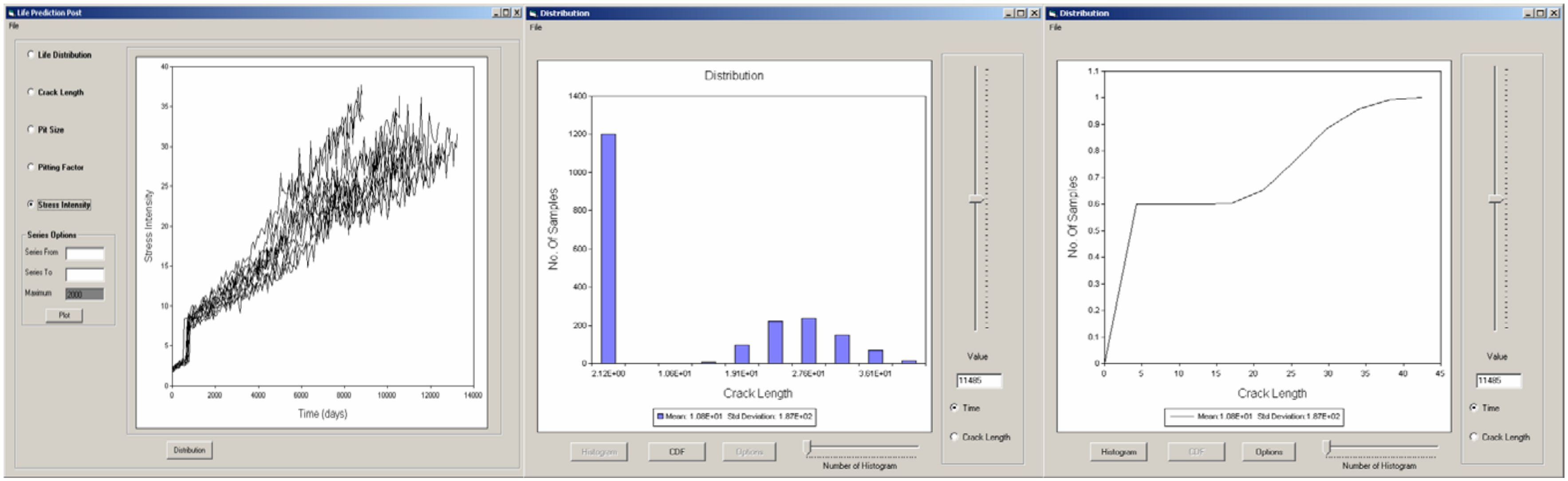


Figure 4-7 Life Prediction Results - Pitting Factor



(a) Stress Intensity **(b) Distribution** **(c) CDF**

Figure 4-8 Life Prediction Results – Stress Intensity

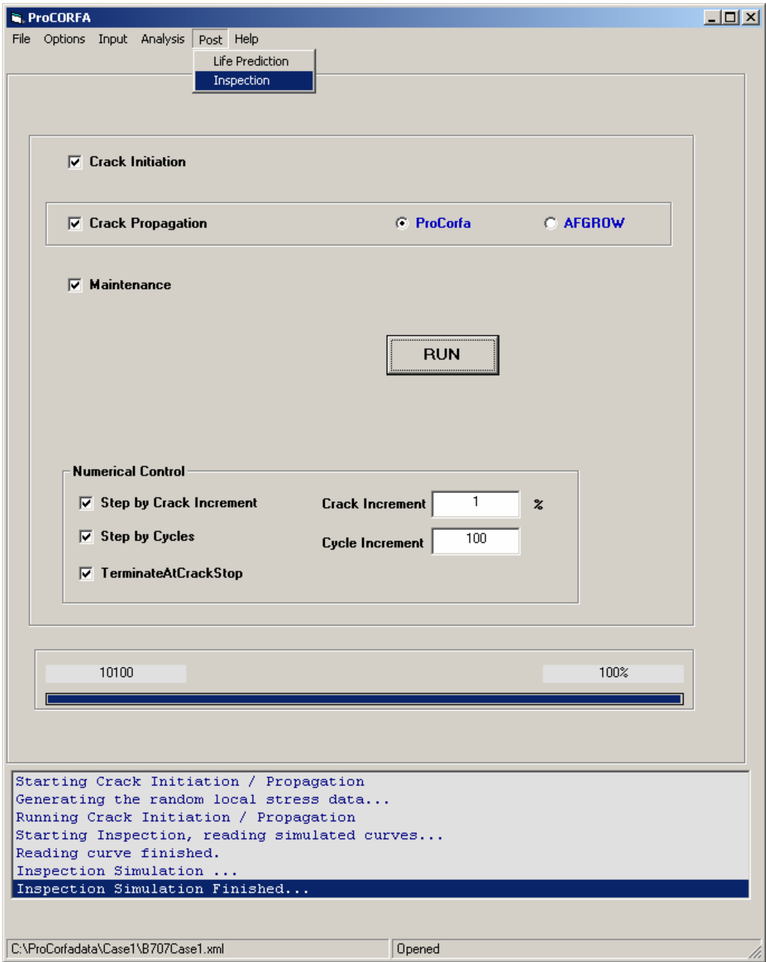


Figure 4-9 Post-Processor menu for Inspection

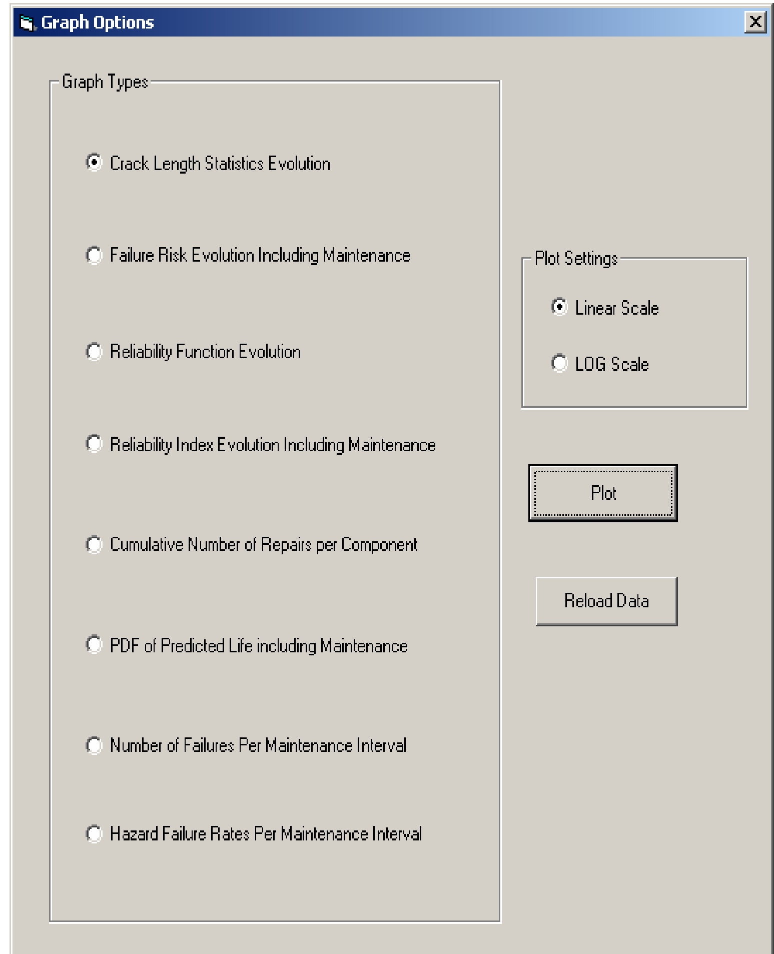


Figure 4-10 Inspection Results

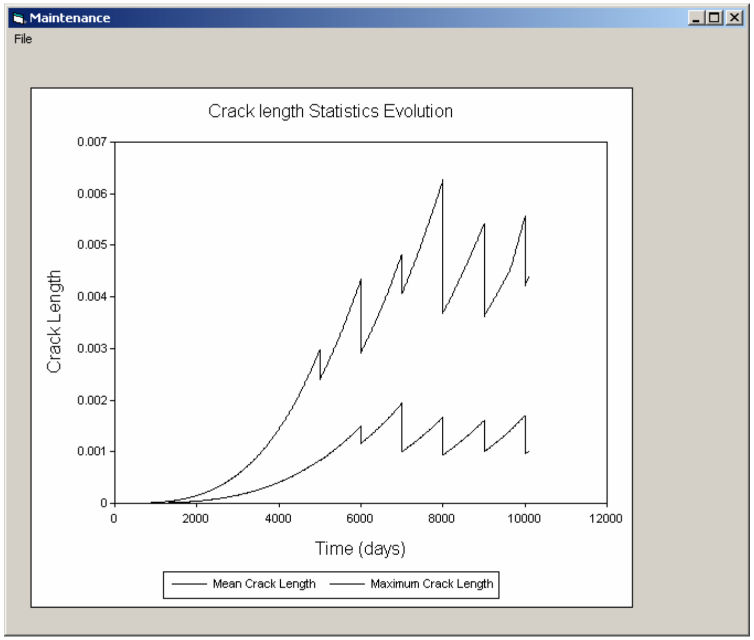


Figure 4-11 Crack Length Evolution

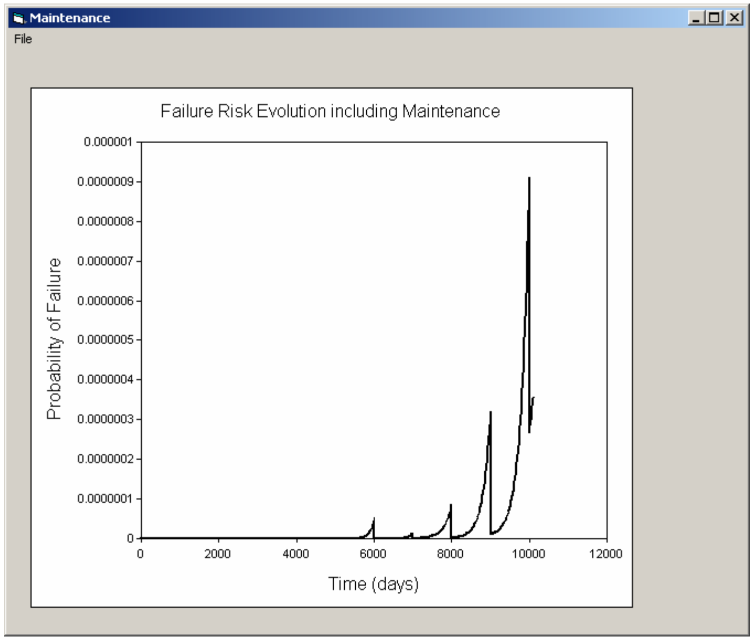


Figure 4-12 Failure Risk Evolution Including Maintenance

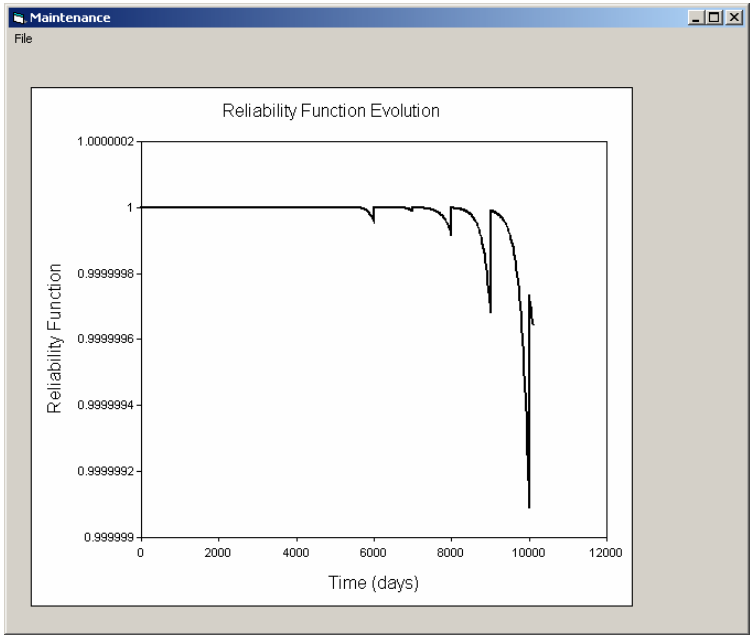


Figure 4-13 Reliability Function Evolution

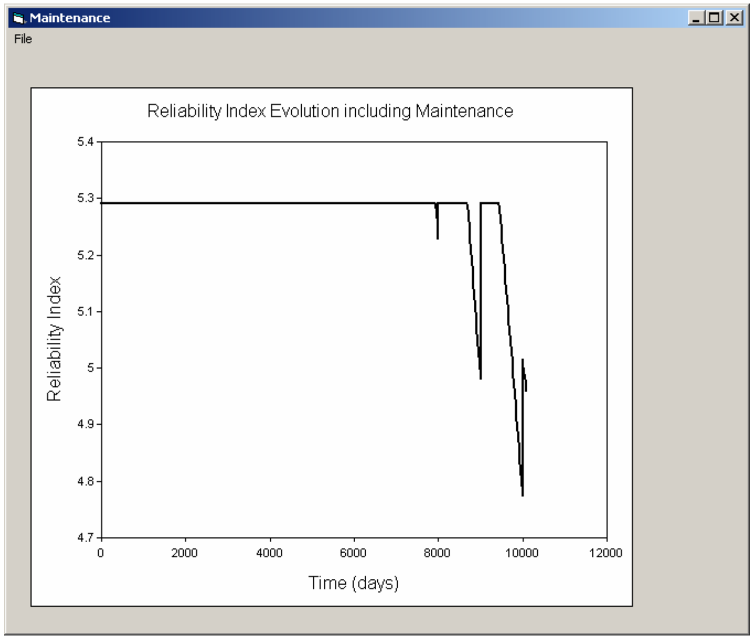


Figure 4-14 Reliability Index Evolution Including Maintenance

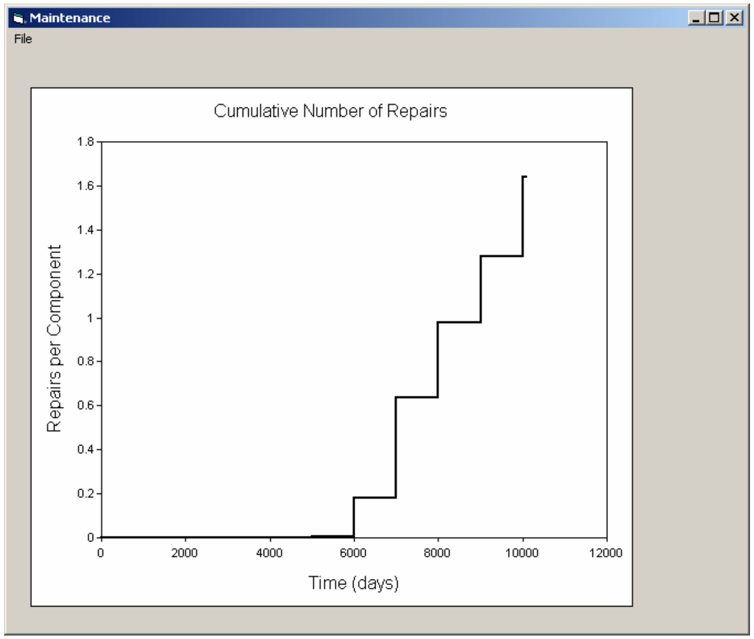


Figure 4-15 Cumulative Number of Repairs

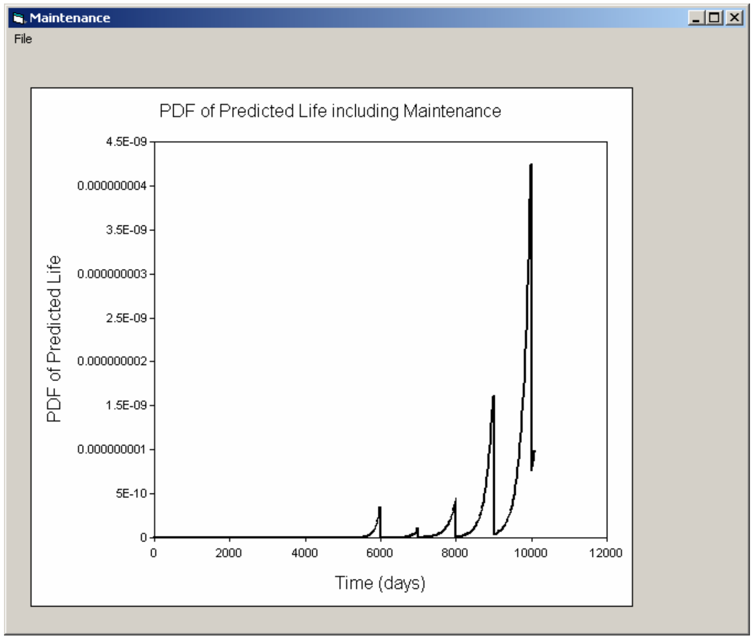
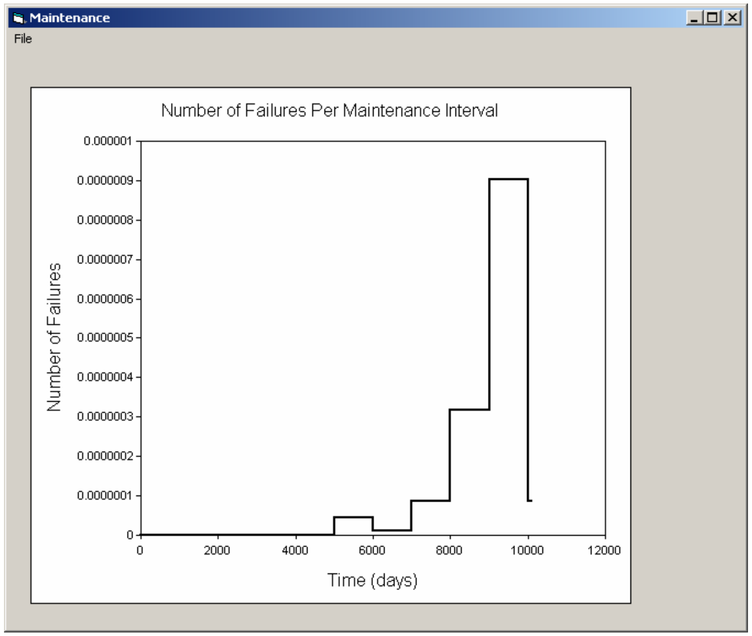


Figure 4-16 PDF of Predicted Life Including Maintenance



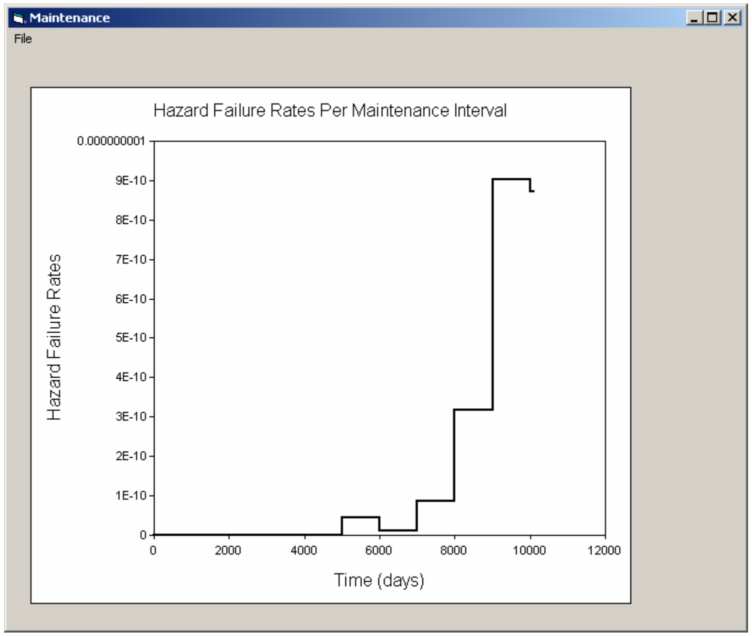


Figure 4-17 Number of failures Per Maintenance Interval

Figure 4-18 Hazard Failure Rates Per Maintenance Interval

4.2. Net section Analysis

Select *Analysis → Net Section Analysis Menu* from GUI as shown in Figure 4-19. The analysis options window

Figure **4-20** (a) is displayed.

4.2.1. Input

The input consist of the following:

- Far-field stress
- Yield stress
- Bearing stress
- Plate thickness
- Hole diameter
- Number of holes
- Plate width

Accept or modify the input data. Click ***Run*** to perform the nest section analysis.

4.2.2. Output

The results of net section analysis are presented in both graphical and numerical form. The graphical output is shown in

Figure 4-20 (b). The results consist of the following.

- Failure Probability
  - Net section yielding probability
  - Fastener bear out probability
- Plots
  - Monte Carlo sample distribution
  - PDF of applied direct stress
    - Probability that the stress is below yield strength
    - Probability that the stress is above yield strength
  - CDF of yield strength
  - PDF of applied bearing stress
    - Probability that the stress is below bearing strength
    - Probability that the stress is above above bearing strength
    - CDF of bearing strength

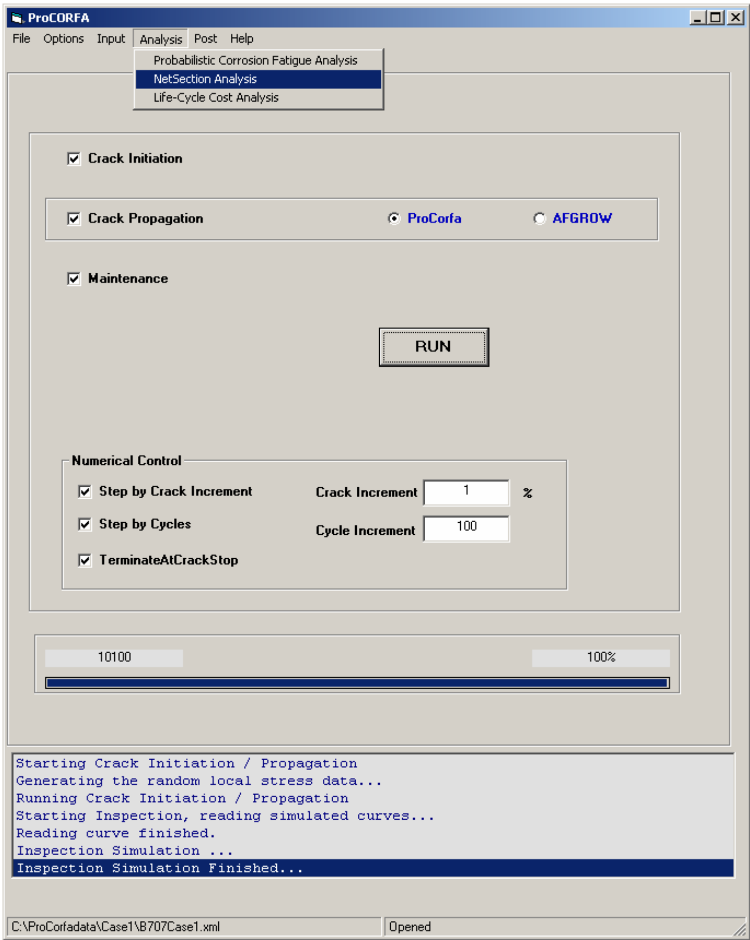
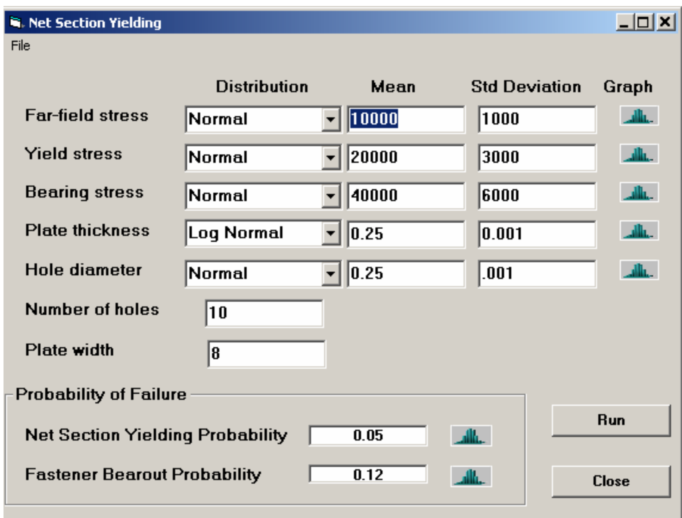
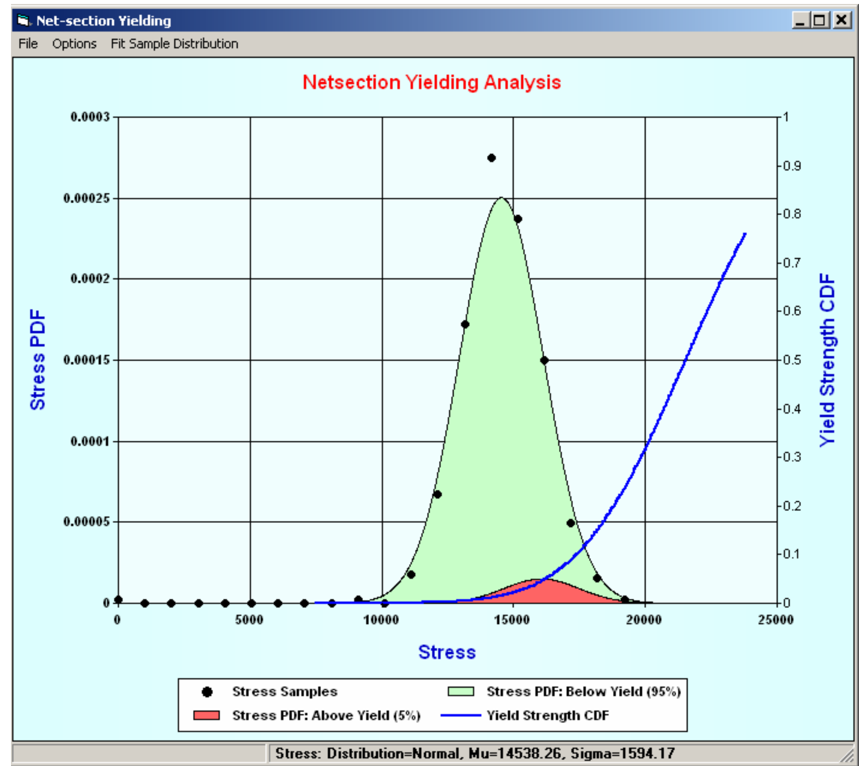


Figure 4-19 Net Section Analysis Menu



(a) Net Section Analysis Input



(b) Net Section Analysis Output

Figure 4-20 Net Section Analysis

4.3. Life cycle cost analysis

Select ***Analysis → Life Cycle Cost Analysis*** ***Menu*** from GUI as shown in Figure 4-21. The analysis options windowFigure 4-22 (a) is displayed.

4.3.1. Input

The Life Cycle Cost Analysis input consist shown in Figure 4-22 (a) of the following:

- Cost data
    - Inspection cost
        - Unplanned
    - Repair cost
    - Replacement cost
        - Unplanned
        - Planned
    - Availability cost
    - Discount rate
    - Number of cost bins
- Crack Data
    - Number of cracks
    - Rejectable crack size
    - Crack size for failure
    - Mean repair time

Accept or modify the input data. Click ***Run*** to perform the nest section analysis.

4.3.2. Output

The Life Cycle Cost Analysis output shown in Figure 4-22 (b) consists of the following:

- Failure probability
- Maintenance costs
    - Planned cost
    - Unplanned costs
    - Availability cost
    - Total cost
- Plots
    - Probability of failure
    - Cost distribution

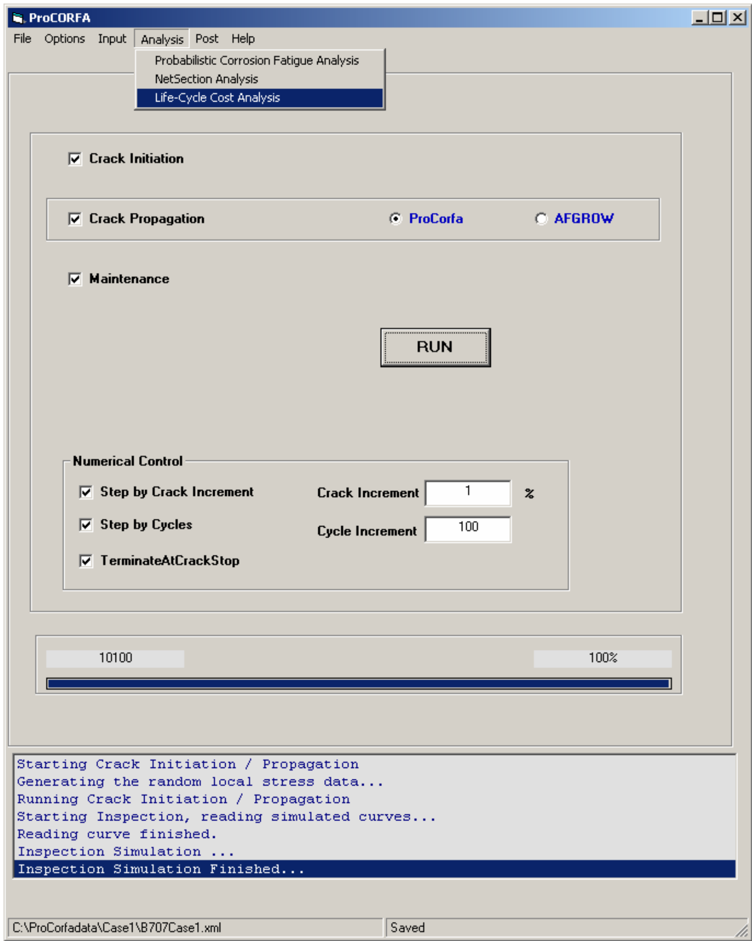
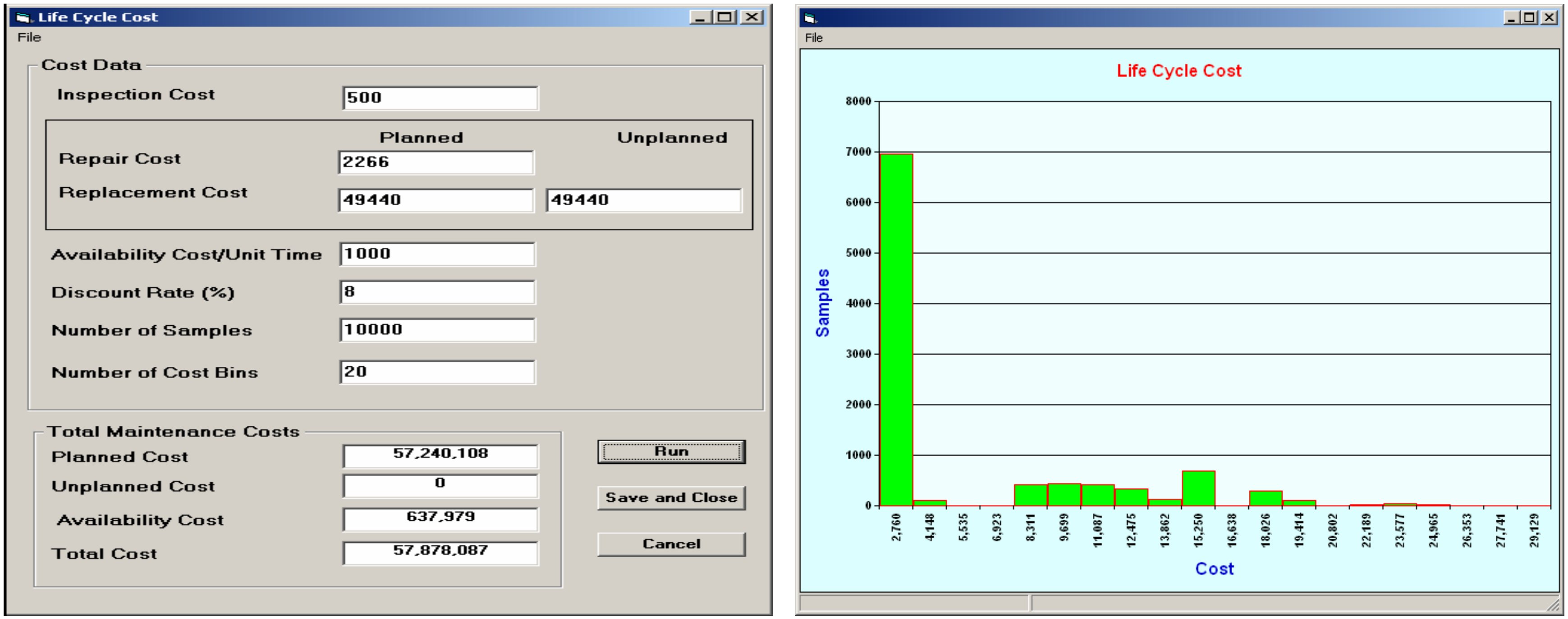


Figure 4-21 Life Cycle Cost Analysis menu



(a) Cost Data **(b) Cost Distribution**

Figure 4-22 Life Cycle Cost Analysis