PROCORFA

User Manual



Ghiocel Predictive Technologies Inc.

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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 stepby-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

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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=982b0359-0a86-4fb2a7ee-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/m², =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	4
Hole # 1 Location # 3 Hole # 1 Location # 4 Hole # 3 Location # 7	
$ \begin{bmatrix} Hore & H & J \\ Data & I \\ 64.79022 & 8.42472 & 67.94812 & 10.72 \\ 64.64272 & 7.9627 & 67.94812 & 10.72 \\ 64.64272 & 7.96272 & 67.94812 & 10.72 \\ 64.64272 & 7.96727 & 67.94812 & 10.72 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 67.94812 & 7.96727 & 7.96727 & 7.96727 \\ 7.96727 & 7.96727 & 7.96727 & 7.96727 $	932
67.88134 8.45344 70.35964 10.89 71.10082 3.39862 71.85642 4.28 67.90253 5.28493 68.05993 6.66	844 482 783
More Data	
Data 2 [case=1 ho]e=1 Loc=4] 65.43642 8.48642 10.88 65.69208 2.94248 67.35238 3.77 63.00107 8.24587 64.65757 10.48 65.69672 3.31652 66.83402 4.24 69.77723 5.32073 72.42423 6.76	172 148 187 152 263
Data 3 [case=1 hole=3 Loc=7] 32.38744 14.16984 37.14114 17.37 24.25000 7.69370 26.49400 9.48 7.89868 -18.04302 9.19278 -17.38 26.81931 7.03981 27.01980 8.23 18.58416 -1.76144 19.77846 0.01 More Data	274 400 582 991 626
Data 4 [case=1 ho]e=3 Loc=8] 23.20646 5.22236 7.45 16.95560 0.35560 20.16810 2.68 22.58292 -2.58697 25.00253 -1.55 18.96207 -0.53883 19.96627 1.18 20.41235 0.18265 21.45275 1.51 More Data	086 5550 547 455
	-

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

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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.

D airports.txt - Notepad						
File Edit Format View Help						
 Total number of airports 5, 2.2e-5, 1.1e-5, 0.333, 0.0333 Airport No., Visit times, Cmean, Cstd, qmean, qs: 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 	:d					
pit size pit=c*t**q t is the time in days	T					

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 stepby-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 <u>Header Tab</u> 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 <u>Material Tab</u> of the GUI as shown in Figure 3-2. From the <u>Material</u> <u>Dropdown Box</u> select the material <u>2024-T3 Aluminum (Metric)</u>. 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 <u>Mechanical Tab</u> of the GUI (Figure 3-2). Accept or modify the input shown in Table 3-1

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

Table 3-1	Mechanical	Properties
	moonamoa	110001100

3.4.2. Constitutive Properties

Click on the <u>Constitutive Tab</u> 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:

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

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 <u>Crack Initiation Tab</u> 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:

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma_{f}}{E} (2N_{f})^{b} + \varepsilon_{f} (2N_{f})^{c}$$
(3-2)

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:

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

3.4.4. Crack Growth Model

Click on the <u>Crack Growth Tab</u> 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:
$$\frac{da}{dN} = \frac{C(1-R)^m \Delta K^n (\Delta K - \Delta K_{th})^p}{\left[(1-R)K_C - \Delta K\right]^q}$$
(3-3)

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

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

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

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}
- △K 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 <u>Mechanical Tab</u> 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:
$$a_{pit} = \left\{ \left[\frac{3MI_{p0}}{2\pi nF\rho} \exp\left(-\frac{\Delta H}{RT}\right) \right] t + a_0^3 \right\}^{1/3}$$
 (3-7)

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 (3-8)
```

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 <u>Crack Geometry Tab</u> 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 <u>Load Tab</u> 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.

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- 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 <u>General Tab</u> 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 <u>**POD Parameter Tab</u>** of the GUI (Figure 3-10). Accept or modify the input shown.</u>

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 <u>File \rightarrow Save</u> or <u>File \rightarrow Save As</u> menu of the GUI. For analysis proceed to Section 4.

🖷, ProCORFA				💐 ProCORFA				
File Options Input	Analysis Post Help			File Options Ir	nput Analysis Post Help			
Header	Material CrackGe	eometry Load	Maintenance	Header	Material	CrackGeometry	Load	Maintenance
	ProCOR	FA Input		Material Mechani	2024-T3 Alumin cal Constitutive	um (Metric) e Crack Initiation	CrackGrowth	Pitting
Title		h î			Distribution	Mean	Standard Deviation	Graphs
User	Letian Wang	liysis		E	Normal	70300	70	
Date	12/1/2005			ν	Deterministic •	0.33		
- Units				σ"	Normal	344.7	4	مىللىر
System	Metric			συ	Normal 💌	489.5	10	
Force	N	Numerical						
Stress	MPa	Parameters (Samples) 2000						
Length	m	Random Seed 327680						
Time	Days							
	,							
	07070 4				107070 1 /			
U: VProCorradata/Case1 \	NB7U7Case1.XMI	U Initialization Done	li.	L:/ProCorradata/U	laservb/U/Laser.xml	UInitia	alization Done	1

Figure 3-1 Header Input

Figure 3-2 Mechanical Properties

ProCORFA	N ProCORFA
File Options Input Analysis Post Help	File Options Input Analysis Post Help
Header Material CrackGeometry Load Maintenance	Header Material CrackGeometry Load Maintenance
Material 2024-T3 Aluminum (Metric)	Material 2024-T3 Aluminum (Metric)
Mechanical Constitutive Crack Initiation CrackGrowth Pitting	Mechanical Constitutive Crack Initiation CrackGrowth Pitting
	Strain Life Annyageh
	Mean Stress Correction Modified Morrow Correction -
Distribution Mean Standard Deviation Graphs	Distribution Mean Standard Deviation Graphs
K' Normal 🔻 590 25	σf Normal 🔽 1044 50
n' Deterministic 💌 0.04	ε _f Normal v 1.765 0.015
Kf Normal 💌 2.6 0.05	b Deterministic V -0.114
Plat Mana Course Seather Plat	C Deterministic -0.927
	Plot Mean Curve Scatter Plot
	Damage Accumulation Model
	Damage Model Linear Damage Model
C:\ProCorfadata\Case1\B707Case1.xml 0 Initialization Done	C:\ProCorfadata\Case1\B707Case1.xml 0 Initialization Done

Figure 3-3 Constitutive Properties

Figure 3-4 Crack Initiation Model

is, ProCORFA	S. ProCORFA
Header Material CrackGeometry Load Maintenance	Header Material CrackGeometry Load Maintenance
Material 2024-T3 Aluminum (Metric)	Material 2024-T3 Aluminum (Metric)
CrackGrowthModel	Airport Rotation Without Rotation
FORMAN Distribution Mean Standard Deviation Graphs	Model Vei Model 💌
m Deterministic 0.39 n Deterministic 1.66 P Deterministic 0.93 q Deterministic 1.54	Faraday's Model Data Distribution Mean Standard Deviation Graphs ipo Uniform Expone < -2.3
Kc Uniform 94.7 100.7 DKth0 Normal 3 0.5 \alpha Deterministic 0.8075	ρ Deterministic 2700000 m Deterministic 27 n Deterministic 3 T Deterministic 293
C:\ProCorfadata\Case1\8707Case1.xml 0 Initialization Done	C\ProCorfadata\Case1\B707Case1.xml 0 Initialization Done

Figure 3-5 Crack Growth Model

Figure 3-6 Pitting Model

😜 ProCORFA	ProCORFA
File Options Input Analysis Post Help	File Options Input Analysis Post Help
Header Material CrackGeometry Load Mainten	nance Header Material CrackGeometry Load Maintenance
ProCORFA Crack Type Two Symmetric Cracks in a Hole	LoadType Constant Amplitude Loading (Single cycle) with Stochastic FE Input Constant Load Data Mission Details Number of Missions / Day 1.5
Distribution Mean Standard Deviation Graphs	Hours / Mission 2.0
a0 Log Normal v 13.6055e-6 6.0224e-6 Julic Dat	la l
ai Deterministra el 254e-4	Stochastic Stresses from FEA
	Load Factor Normal V0.95 U.05
ac Deterministic • 10e-3	Input File C.\ProCortadata\Case1\B707CASE1.str Browse
r0 Log Normal V 2.68e-3 2.64e-5	Location Hole #1 Location #3
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Kt Normal 💌 2.6 0.05	
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Figure 3-7 Crack Geometry Model

Figure 3-8 Load Specification

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Header Material	CrackGeometry	Load Main	ntenance	Header	Material	CrackGe	ometry	Load		Maintenance
General	POD Parameters	Maintenance Calcu	lation	Gene	ral	POD Pa	rameters	Ma	aintenance (Calculation
Number of Cracks 10 Days in Service 10 Crack Growth Calculation Fit Initial Failure Probability 1.6 Time Step (days) 20 Inspection Strategy Re Rejectable Crack Size 2e Distribut Repair Efficiency Normal Crack Size for Failure Crack Size for Failure Determit	000 100 Crack Growth with Equation = 15 placement when crack reaches rej -3 ution Mean v 0.8 nistic v 10e-3	ect size Standard Deviation 0.1	Graph	Input Meth C Inpu POD Curve Paral INSPECTION TECHNIQUE Visual Liquid Penitration Magnetic particle Eddy current Radiography Ultrasonic User Defined 1 User Defined 3 User Defined 4	od It Shape and Scale It Mean and Standa meters POD CL Distribution Log Normal Log Normal Log Normal Log Normal Log Normal Log Normal Log Normal Log Normal POL POL	ard Deviation JRVE PARAMETE Shape 1.01 0.56 0.44 0.4724 0.65 0.28 0.28 0.28 0.28 0.28 0.28 0.28 0.28	RS Scale -6.243 -6.613 -7.103 -6.7962 -5.513 -6.693 -5.513 -6.693 -5.513 -6.693 -5.515 -5.513 -5.513 -5.513 -5.513 -5.513 -5.513 -5.513 -5	Update	SIZING E Mean 0 0 0 0 0 0 0 0	RROR STD 1e-6 1e-6 0.1e-3 1e-6 1e-6
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Figure 3-9 Maintenance General Parameters

Figure 3-10 POD Parameters

Header	Matarict	CrackCoometry	Laad		Header	Material	Uracklieometry	Load Maintenand
Header	Materiai	Стаскоеотекту	Load	Maintenance	Gene	eral	POD Parameters	Maintenance Calculation
G	eneral	POD Parameters	Maintenance C	alculation				
laintenance Ca	Iculation Parameters				- Maintenance (Calculation Para	neters	
Calculation Me	thod			-	Calculation I	Method	Given probability of failure	
ourould of the		Given inspection interval	-					
					Failure Probab	ility Method Data —		
Inspection Inter	val Method Data Time (Davs)	Inspection Meth	lod		Failure Pro	bability	1e-5	
1	1000	Eddy Current		-	Inspection ⁻	Technique	Eddy Current	
2	2000	Eddy Current						
3	3000	Eddy Current						
4	4000	Eddy Current	•					
5	5000	Eddy Current		-				
6	6000	Eddy Current	•	-				
7	7000	Eddy Current	-	• II				
8	8000	Eddy Current	-]				
9	9000	Eddy Current	-	-				
10	10000	Eddy Current	-]				
11		Eddy Current		-				
12		Eddy Current	•	·				

Figure 3-11 Maintenance Calculation Model

4. ANALYSIS

4.1. Probabilistic Corrosion Fatigue Analysis

4.1.1. Input

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

4.1.2. Output

LIFE PREDICTION OUTPUT

Select <u>**Post** \rightarrow Life Prediction</u> 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 <u>CDF</u> button to display the Cumulative Distribution shown in Figure 4-4 (b).

Crack Length Growth

Select <u>Crack length Option</u> 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 <u>CDF</u> button to display the Cumulative Distribution shown in Figure 4-5 (c).

Pitting Size

Select <u>*Pitting Size Option*</u> 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 <u>*CDF*</u> button to display the Cumulative Distribution shown in Figure 4-6 (c).

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Pitting Factor

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

Stress Intensity Variation

Select <u>Stress Intensity Option</u> 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 <u>CDF</u> button to display the Cumulative Distribution shown in Figure 4-8 (c).

INSPECTION OUTPUT

Select <u>Post \rightarrow Inspection</u> 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 <u>Crack Length Statistics Evolution Option</u> 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 <u>*Reliability Function Evolution Option*</u> 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 <u>*Cumulative Nymber of Repairs Option*</u> in Figure 4-10to display the evolution of cumulative repairs shown in **Error! Reference source not found.**.

PDF of Predicted Life

Select <u>*PDF of Predicte Life including Maintenance Option*</u> 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 <u>Number of Failures Per Maintenance Interval Option</u> 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.

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Figure 4-1 Analysis menu

Figure 4-2 Probabilistic Corrosion Fatigue Analysis

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Inspect	ion Si	mulati	on Finished			

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

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starting Inspection, s	reading simulated cur	ves		
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inspection Simulation	Finished			
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Figure 4-9 Post-Processor menu for Inspection





Figure 4-11 Crack Length Evolution



Figure 4-12 Failure Risk Evolution Including Maintenance



Figure 4-13 Reliability Function Evolution







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 <u>Analysis → Net Section Analysis</u> <u>Menu</u> 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 <u>*Run*</u> 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
 - o 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

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Figure 4-19 Net Section Analysis Menu

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File				
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Yield stress	Normal	- 20000	3000	illu_
Bearing stress	Normal	4 0000	6000	
Plate thickness	Log Normal	• 0.25	0.001	_ بالله_
Hole diameter	Normal	• 0.25	.001	
Number of holes	10			
Plate width	8			
-Probability of Failur	e			
Net Section Yieldi	na Probability	0.05		Run
Fastoner Bearout F	Probability	0.12	4	
r usteller Deditut r	Tobability	0.12		Close





(b) Net Section Analysis Output



4.3. Life cycle cost analysis

Select <u>Analysis \rightarrow Life Cycle Cost Analysis</u> <u>Menu</u> 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
 - o Inspection cost
 - Unplanned
 - o Repair cost
 - Replacement cost
 - Unplanned
 - Planned
 - o Availability cost
 - o Discount rate
 - o Number of cost bins
- Crack Data
 - o Number of cracks
 - o Rejectable crack size
 - Crack size for failure
 - o Mean repair time

Accept or modify the input data. Click <u>Run</u> 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
 - o Planned cost
 - Unplanned costs
 - o Availability cost
 - o Total cost
- Plots
 - o Probability of failure
 - Cost distribution

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─Numerica I⊽ Step I⊽ Step I⊽ Terr	ul Control I by Crack Increment I by Cycles ninateAtCrackStop	Crack Increment 1 &	
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Starting Crac Jenerating th Running Crack Starting Insp Reading curve Inspection Si	k Initiation / Propa e random local stres : Initiation / Propag pection, reading simu e finished. imulation	ugation s data gation llated curves	
Inspection Si	mulation Finished		
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Figure 4-21 Life Cycle Cost Analysis menu



(a) Cost Data

(b) Cost Distribution

Figure 4-22 Life Cycle Cost Analysis