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**PROBABILITY OF DETECTION (POD) ANALYSIS
FOR THE ADVANCED RETIREMENT FOR
CAUSE (RFC)/ENGINE STRUCTURAL
INTEGRITY PROGRAM (ENSIP)
NONDESTRUCTIVE EVALUATION (NDE)
SYSTEM DEVELOPMENT
VOLUME 2 – USERS MANUAL**



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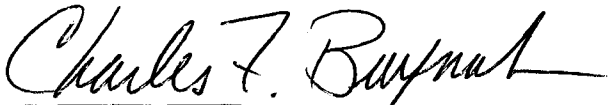
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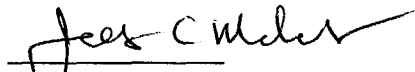
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Foreword

This is the second volume of a technical report prepared by the University of Dayton Research Institute for the Materials and Manufacturing Directorate (ML) of the Air Force Research Laboratory (AFRL), Wright-Patterson Air Force Base, Ohio. The work was performed under Contract Number F33615-95-C-5242 with Mr. Charles F. Buynak (AFRL/MLLP) as the Air Force project engineer. The technical effort was performed between 29 September 1995 and 31 December 1999, with Dr. Alan P. Berens of the University of Dayton Research Institute as the principal investigator.

The final report of this work comprises three volumes. Volume 1 presents a description of changes made to the probability of detection (POD) analysis program of Mil-HDBK-1823 and the statistical evaluation of modifications that were made to version 3 of the Eddy Current Inspection System (ECIS v3). Volume 2 contains the Users Manual for the version 3 update of the POD program. The results of a separate study for predicting POD from specimens of like geometry and materials are presented in Volume 3.

Section 1

Introduction

The probability of detection computer program POD Version 3 is a C⁺⁺ program that interacts with a Microsoft Excel 97 workbook to perform a POD analysis on the results of a nondestructive evaluation (NDE) capability demonstration. The interface between the user and POD is an Excel workbook. The POD program controls the analysis through a window that opens and closes workbooks, calls for recalculations using the analysis and data specified on the input sheets of the workbook, and executes Excel macros that produce the output of the analysis. POD names, uses, and controls a maximum of 11 sheets of the workbook. Two of these sheets contain the input information for an analysis and the other nine contain analysis output in the form of tables and graphs. Graphical output sheets are optional.

This Users Manual assumes familiarity with the objectives and analysis methods for fitting the cumulative lognormal and log odds models to \hat{a} versus a and pass/fail (find/no find) forms of NDE reliability data. See References 1 - 4 for details of such analyses. Reference 4 contains a discussion of the specific analyses performed by POD Version 3.

Section 2 presents a description of the use of the program and the worksheets of a POD workbook for both the \hat{a} versus a and pass/fail (find/no find) analyses. The descriptions emphasize the input sheets for a POD(a) analysis and the explanation of the output tables and graphs. The input and output sheets are standard worksheets of an Excel workbook. All Excel 97 commands can be used at the discretion of the user. Knowledge of Excel is assumed and no Excel commands are discussed. Section 3 presents the details of implementing the commands of the POD window. The list of references are in Section 4.

Section 2

Description of POD Version 3

The program POD Version 3 opens an Excel workbook and uses inspection results from a sheet named **Data** to perform analyses as specified on a sheet named **Info**. These two sheets comprise the input to the POD analysis. The output is produced in the form of tables and graphs on as many as nine new workbook sheets that are regenerated each time the POD maximum likelihood calculations are executed. If the data in a workbook have not been previously analyzed by POD, the program will assist users in setting up an **Info** sheet and will immediately perform the first set of calculations and create a **Results** sheet and a **Residuals** sheet. Pod will then create additional plots upon request. If a valid **Info** sheet is present when POD opens the workbook, the program will recalculate for the analysis as indicated on the existing **Data** and **Info** sheets and will renew all existing output sheets. This recalculation ensures that the output sheets will agree with the analysis as defined by the current **Info** and **Data** sheets. The following subsections describe the contents of the input and output sheets of POD for the \hat{a} versus a and pass/fail analysis methods. Material that is common to both analyses is repeated.

2.1 \hat{a} versus a (Ahat) Analysis

The input for a POD analysis is contained on the **Data** and **Info** sheets of the Excel workbook. The **Data** sheet contains the flaw sizes and inspection responses, \hat{a} , from an NDE capability evaluation. The **Info** sheet contains identification and modeling information that will be used by the POD program. The \hat{a} versus a analysis output comprises as many as nine worksheets that summarize the POD(a) analysis in tables and graphs. The specific graphs to be generated are selected by the analyst.

When POD opens a new Excel worksheet containing \hat{a} inspection results, the program first ensures that the sheet is named **Data**. An **Info** sheet is then initiated that contains the minimum information needed to perform a POD analysis. See section 3.3.1 for an example. Whenever POD opens a workbook, the POD(a) model parameters are recalculated to ensure that all results and plots were generated from the current setup on the **Info sheet**. After a workbook has been opened and recalculated, the **Data** sheet can be modified and the **Info** sheet can be changed to provide a more complete description of an analysis run and to change analysis parameters.

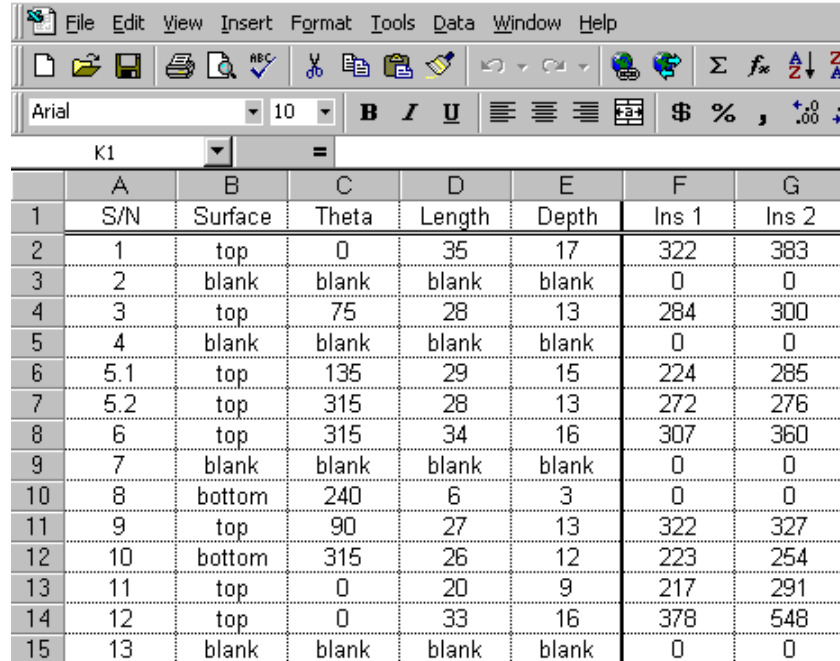
Columns not used by-POD on the **Data** and **Info** worksheets can be used at the discretion of the analyst, and the information will remain in the workbook. However, POD produces output on a set of named worksheets and these output sheets are recreated every time the analyses are recalculated. To preserve new or existing worksheets, they must be assigned names that are different from the standard POD output sheets.

The following subsections describe the contents of all of the worksheets of an \hat{a} versus a analysis.

2.1.1 Data Sheet for Ahat Analysis

The inspection result input to POD is contained on the **Data** sheet of the workbook. The columns of the **Data** sheet contain crack identification fields, crack size fields and the inspection results obtained for each of crack sites. The first row of the spreadsheet must be a header row containing, as a minimum, the names of the crack size column and inspection columns to be used in the analysis. Each succeeding row after the first contains the identifying information, sizes of the cracks, and all \hat{a} inspection results for each crack of the specimen set. The POD program uses only the column that contains the crack size and the columns that contain the \hat{a} values. The POD program will request the column letter that contains the results of the first inspection of each crack. Results from any additional inspections must be in columns that are contiguous to the first set. If other information is placed on the **Data** sheet, it must be separated by at least one column from the \hat{a} values.

As an example, Figure 1 presents part of a spreadsheet that contains the first 15 cracks from a **Data** sheet for an \hat{a} versus a analysis. The first three columns of this example **Data** sheet contain identifying information for the cracks and these columns will be ignored by POD. Both crack length and depth are listed for the cracks, and the analyst will specify which is to be used in the analysis on the **Info** sheet. Each crack shown in the example data sheet has been inspected twice and the inspection designations are Ins1 and Ins 2. Note that some of the inspection sites do not contain flaws and this absence of flaws is indicated by “blank” in the size columns. These inspection sites were the unflawed sites, and such sites will have no effect on the analysis.



	A	B	C	D	E	F	G
1	S/N	Surface	Theta	Length	Depth	Ins 1	Ins 2
2	1	top	0	35	17	322	383
3	2	blank	blank	blank	blank	0	0
4	3	top	75	28	13	284	300
5	4	blank	blank	blank	blank	0	0
6	5.1	top	135	29	15	224	285
7	5.2	top	315	28	13	272	276
8	6	top	315	34	16	307	360
9	7	blank	blank	blank	blank	0	0
10	8	bottom	240	6	3	0	0
11	9	top	90	27	13	322	327
12	10	bottom	315	26	12	223	254
13	11	top	0	20	9	217	291
14	12	top	0	33	16	378	548
15	13	blank	blank	blank	blank	0	0

Figure 1. Example **Data** Worksheet for an Ahat Analysis Using POD

The data to be used in an analysis are selected on the **Data** worksheet. The POD program will use all cracks that have a clear (uncolored) background. To eliminate any cracks or range of cracks

from an analysis, select them and add a highlight background color. This selection process makes it very convenient to select particular inspections of all cracks, to exclude ranges of crack size, and to check the influence of apparent outliers. Note that an asterisk in the inspection result column indicates that the site was not inspected. A missing inspection is distinct from a missed flaw and the program will not interpret the asterisk as a miss.

Note that POD provides an easy sort by crack size of the data in the worksheet (see POD window, **Tasks – Sort by size**, section 3.4). But note also that the **Data** worksheet is an Excel spreadsheet, and any spreadsheet functions can be directly performed. It is necessary to maintain the inspection results in contiguous columns starting in the column as indicated on the **Info** worksheet.

2.1.2 Info Sheet for Ahat Analysis

The **Info** sheet of a POD workbook contains information that the program will use to generate the output tables and graphs. An example **Info** Sheet for an \hat{a} versus a analysis is shown in Figure 2. The information is grouped in 4 categories for ease of interpretation. Entries in column A define the type of information in the row but only the entries that end with a colon have meaning to POD. For example, the names of the 4 categories of information are ignored by POD as would be any other entry. Further, the order of the lines on the **Info** sheet is not important. However, exact spelling of the entries that end with a colon must be maintained.

Column B of the **Info** sheet contains the following information for the POD pertinent rows:

- *Title* – Identification entry that will appear on the **Results** output sheet and all graphs.
- *Subtitle* – Additional identification. The first four Subtitle entries will appear on all graphs. All subtitle entries will appear on the **Results** sheet in the order in which they are on the **Info** sheet. As many subtitle lines as desired can be inserted in the **Info** sheet by adding rows at the bottom with “Subtitle:” in column A. All Subtitle lines will be printed on the **Results** sheet.
- *Flaw Column* – Column letter of the **Data** sheet containing the flaw sizes to be used in the analysis.
- *Flaw Units* – Flaw size units that will appear in the output.
- *Flaw Transform* – Definition of flaw size transformation to be used in the analysis. The default transformation for flaw size is the natural logarithm. Different transformations can be used by entering the transformation name in the row labeled Flaw Transform. Column B should contain one of the following entries:

<u>Column B Entry:</u>	<u>Transform:</u>
none	$y = x$
log	$y = \ln(x)$
inverse	$y = 1/x$
custom	User defined

Either no entry or log in column B is the default natural logarithm transformation. In a custom transformation, Column D in the same row must contain a formula transforming the value in column C of the same row. Similarly, column F must contain the formula inverting the transform for the value in column E of the same row. Figure 3 shows an example of the formulas needed to define a log transformation using the custom option.


	A	B	C	D
1	ID INFO			
2	Title:	Titanium Small Bolt Holes		
3	Subtitle:	Example line 2		
4	Subtitle:	Example line 3		
5	Subtitle:	Example line 4		
6	Subtitle:	Example line 5		
7	Subtitle:	Example line 6		
8				
9	FLAW INFO			
10	Flaw Column:	E		
11	Flaw Units:	mil		
12	Flaw Transform:	log		
13				
14	SIGNAL INFO			
15	Insp Start:	F		
16	Insp Units:	counts		
17	Insp Transform:	log		
18	Signal Min:	50		
19	Signal Max:	1024		
20				
21				
22	ANALYSIS			
23	Analysis:	Ahat		
24	Version:	POD 3.0		
25	Thresholds:	50	500	
26	POD Threshold:	150		
27	POD level:	90		
28	Confidence:	95		
 Info / Data / Results / FitPlot / Residuals Plot				

Figure 2. Example **Info** Sheet for an Ahat Analysis Using POD

9	FLAW INFO					
10	Flaw Name:	Depth				
11	Flaw Units:	mil				
12	Flaw Transform:	custom	10	=LN(C12)	2.303	=EXP(E12)
13						
14	SIGNAL INFO					
15	Insp Start:	F				
16	Insp Units:	counts				
17	Insp Transform:	custom	10	=LN(C12)	2.303	=EXP(E12)
18	Signal Min:	50				
19	Signal Max:					

Figure 3. Example Showing Formulas for Custom Data Transformations

- *Insp Start* – **Data** sheet column that contain the first set of inspection results.
- *Insp Transform* – Definition of flaw size transformation to be used in the analysis. The default transformations for signal response, \hat{a} , is the natural logarithm. Different transformations can be used by entering the transformation name in the row labeled Insp Transform. Column B should contain one of the following entries:

<u>Column B Entry:</u>	<u>Transform:</u>
none	$y = x$
log	$y = \ln(x)$
inverse	$y = 1/x$
custom	User defined

Either no entry or log in column B is the default natural logarithm transformation. In a custom transformation, Column D in the same row must contain a formula transforming the value in column C of the same row. Similarly, column F must contain the formula inverting the transform for the value in column E of the same row. Figure 3 shows an example of the formulas needed to define a log transformation using the custom option.

- *Signal Min* – Minimum \hat{a} value that can be registered by the NDE system.
- *Signal Max* – Maximum \hat{a} value that can be registered by the NDE system.
- *Analysis* – Ahat directs POD to perform an \hat{a} versus a analysis.
- *Version* – Version of POD being used for the analysis.
- *Thresholds* – Columns B and C define the range of \hat{a} decision thresholds for the a_{90} versus \hat{a}_{dec} plot. Threshold entries in column D, E, etc. can be used to extend or refine the a_{90} versus \hat{a}_{dec} plot.
- *POD Threshold* – \hat{a} decision threshold for a plot of the $POD(a)$ function with confidence bound.
- *POD level* – POD percent value for which confidence bound will be calculated. Default value is 90 percent.
- *Confidence* – Percent confidence bound for POD value. Choices are 90, 95, and 99. Default value is 95.

2.1.3 Results Sheet from Ahat Analysis

The **Results** sheet contains a summary of the \hat{a} versus a analysis. An example is presented as Figure 4. The top lines repeat all of the identifying information from the Title and Subtitle lines of the **Info** sheet. The identification lines are followed by the range of crack sizes, the number of cracks, the number of censored recordings, and the inspection titles. In the example sheet, there are two inspections per crack identified as Ins 1 and Ins 2, the inspection names from the **Data** sheet. Four of the cracks had both responses less than the minimum (signal threshold), and one crack had one response above and one below the minimum. None of the cracks had \hat{a} values above the maximum (saturation).

The analysis type and model for the analysis are followed by the parameter estimates and standard errors of the \hat{a} versus a fit parameters. The standard errors (Std. Error) are the standard deviations of the estimates of the parameters and indicate the degree of precision of the estimates. The Residual Error is the standard deviation of the differences between the average \hat{a}

values and the linear fit. The Repeatability Error is the pooled standard deviation of the repeated \hat{a} values for each crack. The results of the hypothesis tests for model fit are presented in terms of the calculated test statistic and the significance level of the test. High values of P indicate that the data are compatible with the assumption.

	A	B	C	D	E	F	G
6	Example line 6						
7							
8	Flaw Depth Range:		3	to	17	mils	
9							
10	Cracks analyzed:		42				
11						some	all
12	Signal Minimum:		50	counts	below	1	4
13	Signal Maximum:		1024	counts	above	0	0
14					between		37
15							
16	Inspections: Ins 1		Ins 2				
17							
18	"a _{hat} vs. a" Analysis			Version:	POD 3.0		
19							
20	Model:	ln(a _{hat}) = B0 + B1*ln(a)					
21							
22	Parameter		Estimate		Std. Error		
23	Intercept (B0)		0.856657		0.371049		
24	Slope (B1)		1.829921		0.155633		
25	Residual Error		0.300438		0.034897		
26							
27	Repeatability Error		0.102684				
28							
29	Tests of Assumptions						
30						P, if true	
31	Normality: Anderson-Darling			A* =	0.414763	P > 0.1	
32	Equal Variance: Bartlett			χ² =	0.057012	P > 0.1	
33	Lack of fit: Pure Error (df=27)			F =	1.620293	P > 0.1	
34							
35	POD Model Parameters						
36							
37	Sigma	0.168907					
38							
39	Inspection						
40	Threshold	a50	a90	a90/95			
41	250	12.79665	15.89052	18.43548			
◀ ▶ ◀▶ ▶▶ Info Data Results FitPlot Residuals Plot Ahat vs							

Figure 4. Example POD **Results** Sheet from Ahat Analysis

The POD parameters are summarized only in terms of Sigma and a_{50} , a_{90} , and $a_{90/95}$ values for the POD Threshold on the **Info** sheet. The parameter μ depends on the decision threshold, $\mu = \ln(a_{50})$. The variance-covariance matrix for the estimates of μ and σ are contained in a different worksheet.

2.1.4 Residuals Sheet from Ahat Analysis

Figure 5 presents a portion of the **Residuals** sheet of the Ahat example. The **Residuals** sheet for an \hat{a} versus a analysis comprises four tables that are used to generate the **Ahat vs. a**, **Fit Plot**, and **Residuals Plot** graphs. The residual table lists only the cracks used in the analysis and includes the crack sizes, the average \hat{a} for each crack, the log of crack size, log of average \hat{a} , and the differences (residuals) between the average and predicted log \hat{a} values. The \hat{a} versus a table lists all of the cracks from the **Data** sheet and contains the crack sizes, the individual \hat{a} values from all inspections, and the predicted \hat{a} for the crack size. The fit table is a two cell by two cell table of the straight line fit to the data used in the analysis. The min/max table is used to plot the minimum and maximum \hat{a} value over the range of data.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	a	ln(a)	ahat	ln(ahat)	fit	diff	a	sig. min	sig. max		a	fit	Ins 1	Ins 2
2	5	1.6094	51.5	3.942	3.8	0.14	3	50	0		3		50	50
3	7	1.9459	77.8	4.3547	4.42	-0.06	17	50	0		5		50	58
4	7	1.9459	142	4.9538	4.42	0.536					5		50	50
5	7	1.9459	80.4	4.3873	4.42	-0.03	a	ahat			6	62.51676	50	50
6	8	2.0794	129	4.8604	4.66	0.199	5.3104	50			7	82.89031	73	83
7	8	2.0794	74.5	4.3108	4.66	-0.35	17	420.4026			7	82.89031	151	133
8	8	2.0794	85	4.4427	4.66	-0.22					7	82.89031	84	77
9	9	2.1972	110	4.7003	4.88	-0.18					7	82.89031	50	50
10	9	2.1972	126	4.8355	4.88	-0.04					8	105.8338	140	119
11	9	2.1972	251	5.5266	4.88	0.649					8	105.8338	50	50
12	9	2.1972	98	4.585	4.88	-0.29					8	105.8338	75	74
13	10	2.3026	175	5.1628	5.07	0.093					8	105.8338	85	85
14	10	2.3026	175	5.1665	5.07	0.096					9	131.2894	108	112
15	10	2.3026	147	4.9903	5.07	-0.08					9	131.2894	121	131
16	10	2.3026	260	5.5606	5.07	0.49					9	131.2894	217	291
17	11	2.3979	203	5.3132	5.24	0.069					9	131.2894	113	85
18	11	2.3979	213	5.3612	5.24	0.117					10	159.207	186	164
19	11	2.3979	292	5.6765	5.24	0.432					10	159.207	167	184
20	11	2.3979	281	5.6379	5.24	0.393					10	159.207	145	149
21	12	2.4849	238	5.4723	5.4	0.068					10	159.207	257	263
22	12	2.4849	266	5.5843	5.4	0.18					11	189.5429	202	204
23	12	2.4849	169	5.1298	5.4	-0.27					11	189.5429	210	216
24	12	2.4849	262	5.5697	5.4	0.166					11	189.5429	286	298
25	12	2.4849	153	5.0291	5.4	-0.37					11	189.5429	273	289
26	12	2.4849	181	5.1976	5.4	-0.21					12	222.2581	223	254
27	13	2.5649	274	5.6131	5.55	0.063					12	222.2581	279	254
28	13	2.5649	324	5.7823	5.55	0.232					12	222.2581	171	167
29	13	2.5649	292	5.6764	5.55	0.126					12	222.2581	271	254
30	13	2.5649	278	5.6275	5.55	0.077					12	222.2581	145	161
31	13	2.5649	373	5.9218	5.55	0.372					12	222.2581	197	166
32	13	2.5649	228	5.4289	5.55	-0.12					13	257.3176	272	276
33	15	2.7081	460	6.1318	5.81	0.32					13	257.3176	322	327
34	15	2.7081	253	5.5321	5.81	-0.28					13	257.3176	284	300
35	16	2.7726	455	6.1206	5.93	0.19					13	257.3176	283	273
36	16	2.7726	332	5.8065	5.93	-0.12					13	257.3176	348	400

Figure 5. Example **Residuals** Sheet from Ahat Analysis

2.1.5 Ahat vs. a Sheet from Ahat Analysis

The **Ahat vs. a** sheet contains a plot of \hat{a} versus a for all of the inspections of all of the cracks. An example of this plot for the data from Figure 5 is presented in Figure 6. This plot aids in the selection of the range of crack sizes or in the model formulation to be used in the POD(a) analysis. It also can identify individual inspection results that do not agree with other inspections of the same crack.

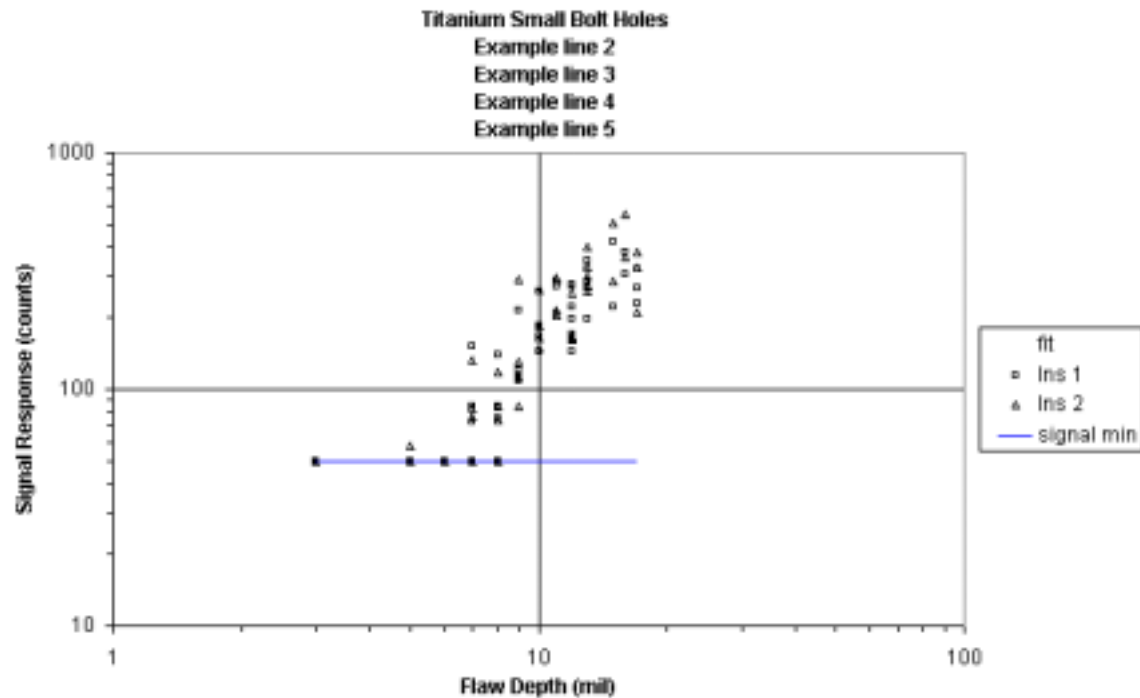


Figure 6. Example **Ahat vs. a** Sheet from Ahat Analysis

2.1.6 Fit Plot Sheet from Ahat Analysis

The **Fit Plot** sheet for an \hat{a} versus a analysis contains a plot of the average \hat{a} for each crack versus the crack size with a superimposed straight line fit obtained from the analysis. Figure 7 presents an example fit plot for the data of Figures 3, 4 and 5. The **Fit plot** provides for easy visual inspection of the goodness of fit and can be used to choose crack size regions for which the relation might be more linear.

2.1.7 Residuals Plot Sheet from Ahat Analysis

The **Residuals Plot** presents the difference between average and predicted $\log \hat{a}$ as a function of the size of the crack. An example **Residuals Plot** is presented in Figure 8 for the fit of Figure 7. The residuals plot for \hat{a} versus a data aids in identifying crack size regions for which the fit may not be linear or for which the scatter in residuals is changing. The **Residuals Plot** is also useful in identifying the outlying data points that may be affecting the tests of hypotheses.

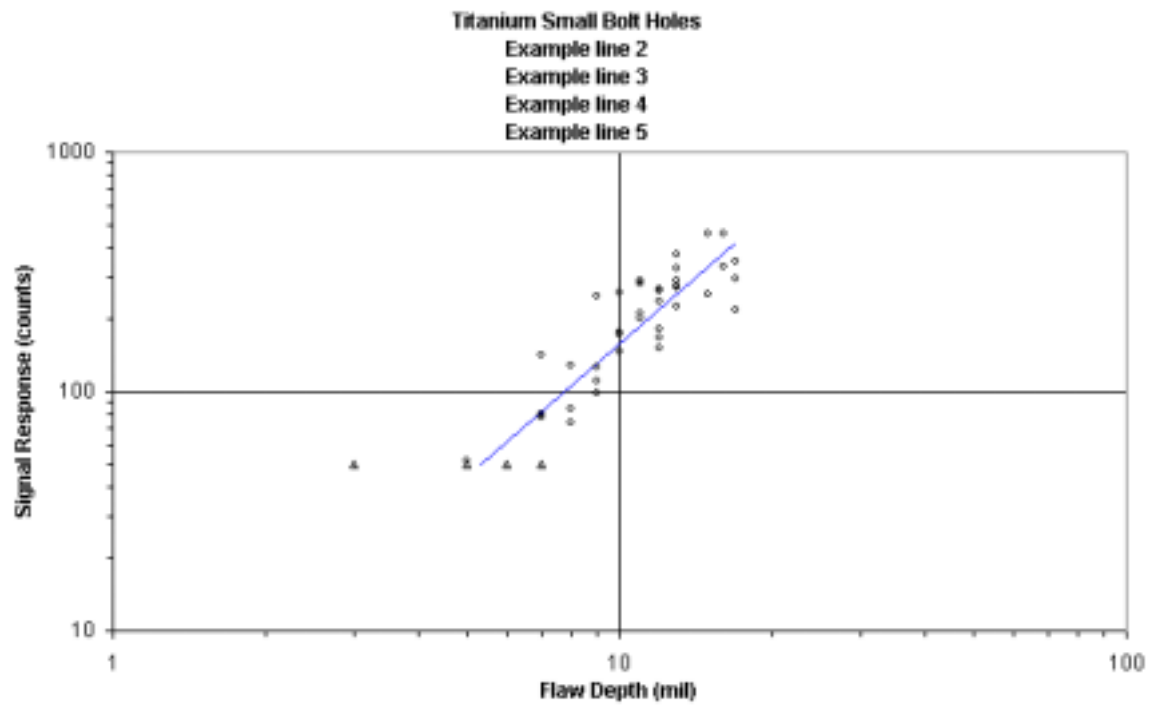


Figure 7. Example **Fit Plot** Sheet from Ahat Analysis

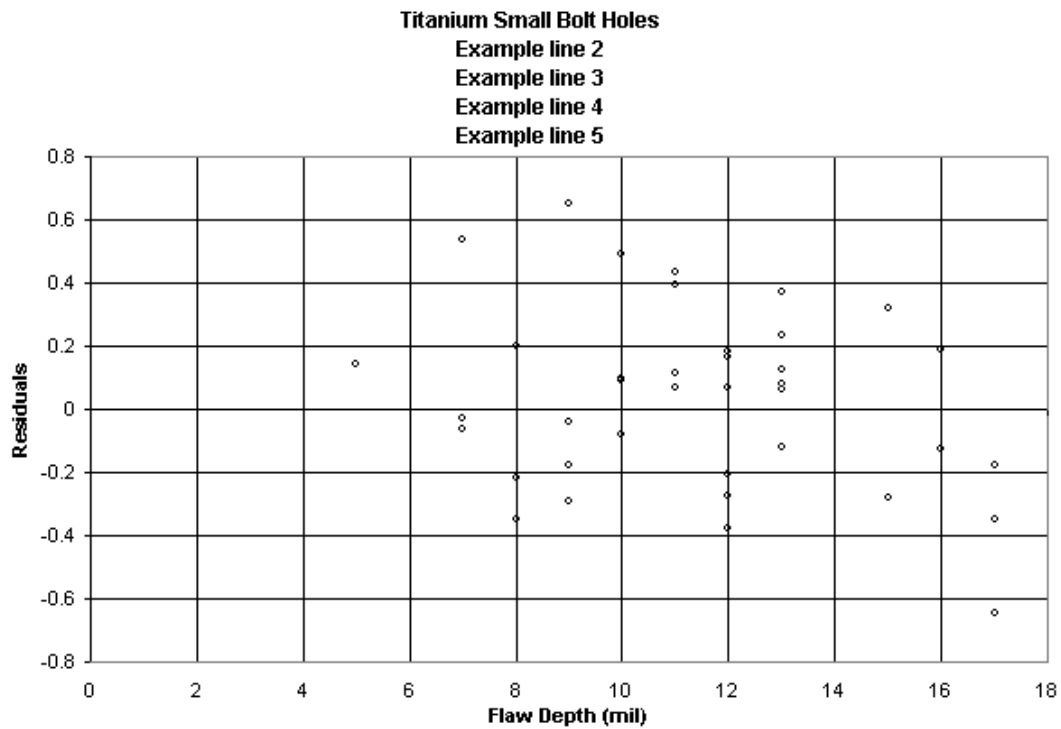


Figure 8. Example **Residuals Plot** Sheet from Ahat Analysis

2.1.8 Threshold Data Sheet from Ahat Analysis

The **Threshold Data** sheet is a table that contains a_{50} , a_{90} , $a_{90/95}$, V_{11} , V_{12} , and V_{22} for ranges of thresholds that are specified for the analysis on the **Info** page. The program will insert nine equally spaced threshold values between the listed thresholds. More than one threshold range can be included by entering larger threshold values in contiguous columns in the POD Threshold row of the **Info** sheet. Figure 9 presents the **Threshold Data** sheet for the analysis of the data in Figure 6.

	A	B	C	D	E	F	G	H	
1	Threshold	a50	a90	a90/95		V11	V12	V22	
2	50	5.310422	6.594332	7.508603		0.004165	-0.00074	0.000508	
3	95	7.541539	9.364871	10.36314		0.001529	-0.00036	0.000508	
4	140	9.321553	11.57524	12.87156		0.000798	-0.00013	0.000508	
5	185	10.85513	13.4796	15.23459		0.000675	4.12E-05	0.000508	
6	230	12.22665	15.18271	17.47546		0.000812	0.000172	0.000508	
7	275	13.48082	16.7401	19.60711		0.001077	0.000279	0.000508	
8	320	14.64481	18.18551	21.64399		0.00141	0.00037	0.000508	
9	365	15.73659	19.54125	23.59919		0.00178	0.000449	0.000508	
10	410	16.76882	20.82305	25.48361		0.002169	0.000519	0.000508	
11	455	17.7508	22.04245	27.30614		0.002567	0.000582	0.000508	
12	500	18.68963	23.20826	29.07404		0.002968	0.000638	0.000508	
13									

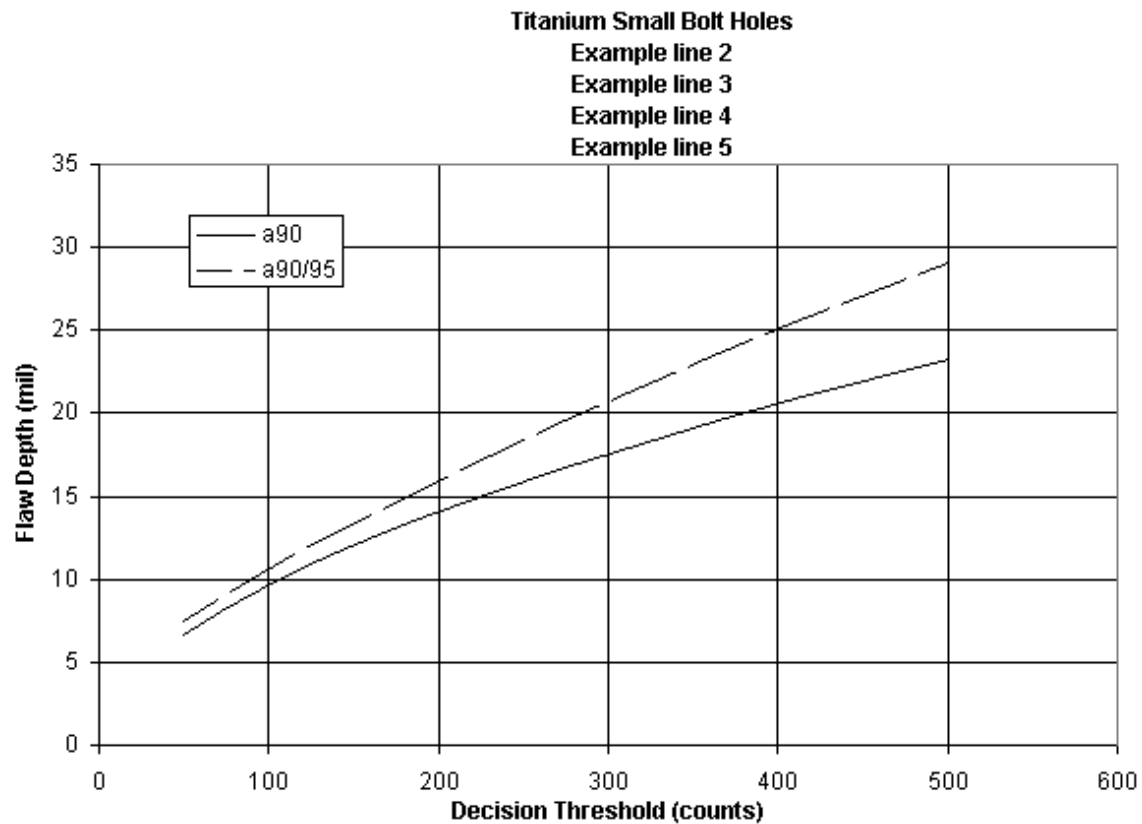
Figure 9. Example **Threshold Data** Sheet from Ahat Analysis

2.1.9 Threshold Plot Sheet from Ahat Analysis

The **Threshold Plot** presents the estimates of a_{90} and $a_{90/95}$ as functions of the decision threshold. The **Threshold Plot** for the data of the Figures 6 and 9 is presented in Figure 10. This plot has become the most useful characterization of NDE capability for \hat{a} versus a data because a single demonstration of capability is often used for different target a_{90} values. Further, thresholds in automated systems often need to be adjusted, and the threshold plots readily yield the a_{90} values that would result for different choices.

2.1.10 POD Data Sheet from Ahat Analysis

The **POD Data** sheet comprises three columns that contain the array of crack sizes, the estimated $\text{POD}(a)$ function, and the confidence bound for $\text{POD}(a)$. Figure 11 presents a small portion of the **POD Data** Sheet for the example \hat{a} versus a analysis.



	A	B	C	D	E
1	a	POD(a)	95% confidence bound		
2	7.709564	0.00135	5.44E-05		
3	7.83511	0.00184	8.9E-05		
4	7.960657	0.002475	0.000142		
5	8.086203	0.003288	0.000223		
6	8.21175	0.004315	0.000342		
7	8.337296	0.005597	0.000514		
8	8.462842	0.007181	0.000758		
9	8.588389	0.009115	0.001099		
10	8.713935	0.011454	0.001565		
11	8.839482	0.014252	0.002194		
12	8.965028	0.017568	0.003026		
13	9.090575	0.021462	0.00411		
14	9.216121	0.025993	0.005501		
15	9.341668	0.031221	0.00726		

Figure 11. Example POD Data Sheet from Ahat Analysis

2.1.11 POD Sheet from Ahat Analysis

The **POD** sheet contains the $POD(a)$ function and its confidence bound. Figure 12 presents the plot of the **POD** sheet for the example \hat{a} versus a analysis. In an \hat{a} versus a data analysis, the decision threshold of the $POD(a)$ function is that identified as the POD Threshold on the **Info** sheet. In Figure 12, the $POD(a)$ function and the confidence bound stop at the maximum crack size ($a = 17$ mil) in the data of the analysis.

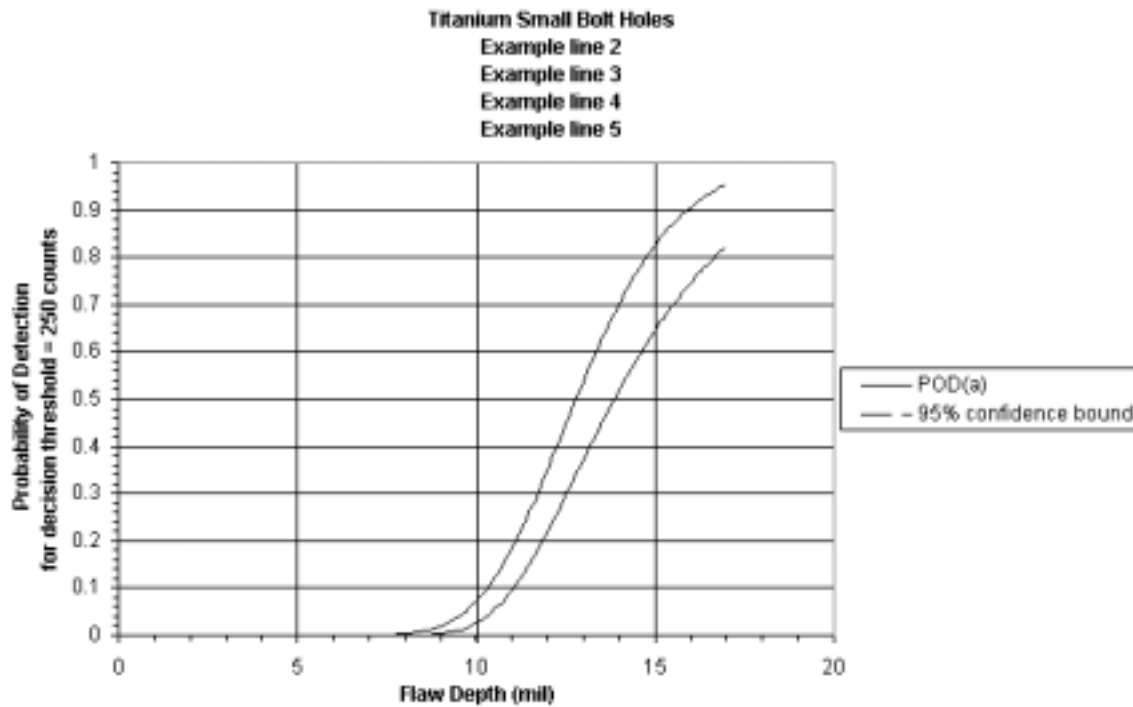


Figure 12. Example POD Plot with Confidence Bound from Ahat Analysis

2.2 Pass/Fail Analysis

The input for a POD analysis is contained on the **Data** and **Info** sheets of the Excel workbook. The **Data** sheet contains the flaw sizes and the quantified find/no find decisions (one for a find and zero for a no find) from an NDE capability evaluation. The **Info** sheet contains identification and modeling information that will be used by the POD program. The pass/fail analysis output comprises as many as six worksheets that summarize the POD(a) analysis in tables and graphs. The specific graphs to be generated are selected by the analyst.

When POD opens a new Excel worksheet containing the pass/fail inspection results, the program first ensures that the sheet is named **Data**. An **Info** sheet is then initiated that contains the minimum information needed to perform a POD analysis. See section 3.3.1 for an example. Whenever POD opens a workbook, the POD(a) model parameters are recalculated to ensure that all results and plots were generated from the current setup on the **Info sheet**. After a workbook has been opened and recalculated, the **Data** sheet can be modified and the **Info** sheet can be changed to provide a more complete description of an analysis run and to change analysis parameters.

Columns not used by POD on the **Data** and **Info** worksheets can be used at the discretion of the analyst, and the information will remain in the workbook. However, POD produces output on a set of named worksheets and these output sheets are recreated every time the analyses are recalculated. To preserve new or existing worksheets, they must be assigned names that are different from the standard POD output sheets.

The following subsections describe the contents of all of the worksheets of a pass/fail analysis.

2.2.1 Data Sheet for Pass/Fail Analysis

The inspection result input to POD is contained on the **Data** sheet of the workbook. The columns of the **Data** sheet contain crack identification fields, crack size fields and the inspection results (one for a find and zero for a miss) that were obtained from the inspections of the crack sites. The first row of the spreadsheet must be a header row containing, as a minimum, the names of the crack size column and inspection columns to be used in the analysis. Each succeeding row after the first contains identifying information (if any), sizes of the cracks, and the inspection results for each crack of the specimen set. The POD program uses only the columns that contain the crack size and the inspection results. The POD program will request the column letter that contains the results of the first inspection of each crack. Results from any additional inspections must be in columns that are contiguous to the first set. If other information is placed on the **Data** sheet, it must be separated by at least one column from the inspection results values.

As an example, Figure 13 presents part of a spreadsheet that contains the first 17 cracks from a **Data** sheet for a pass/fail analysis. The first column of this example **Data** sheet contains identifying information for the cracks and this column will be ignored by POD. The crack size information is in the column named *Depth*. The analyst will specify this column on the **Info** sheet as the *Flaw Column* to be used in the analysis. Each crack shown in the example data sheet was

inspected once and the inspection designation is Ins1. More inspections for each crack are possible. Note that inspection sites that do not contain flaws can be included on the **Data** sheet. This absence of a flaw at a site can be indicated by an initial alpha character such as “blank” in the size column. Such inspection sites will be ignored in the analysis. Note also that an asterisk in the inspection result column indicates that the site was not inspected. A missing inspection is distinct from a missed flaw and the program will not interpret the asterisk as a miss.

	A	B	C
	Seq.#	Depth	Ins 1
1			
2	28	2.5	0
3	29	2.5	0
4	54	2.5	1
5	57	2.5	0
6	65	2.5	1
7	74	2.5	1
8	91	2.5	0
9	92	2.5	0
10	93	2.5	0
11	94	2.5	1
12	30	4.28	0
13	45	4.28	0
14	47	4.28	0
15	56	4.28	0
16	31	5.17	0
17	32	5.17	0
18	37	5.17	0

Figure 13. Example **Data** Worksheet for a Pass/Fail Analysis Using POD

2.2.2 Info Sheet for Pass/Fail Analysis

The **Info** sheet of a POD workbook contains information that the program will use to generate the output tables and graphs. An example **Info** Sheet for a pass/fail analysis is shown in Figure 14. The information is grouped in 4 categories for ease of interpretation. Entries in column A define the type of information in the row but only the entries that end with a colon have meaning to POD. For example, the names of the 4 categories of information are ignored by POD as would be any other entry. Further, the order of the lines on the **Info** sheet is not important. However, exact spelling of the entries that end with a colon must be maintained.


	A	B	C	D	E
1	ID INFO				
2	Title:	Ultrasonic Surface Wave Inspection			
3	Subtitle:	Example line 2			
4	Subtitle:	Example line 3			
5	Subtitle:	Example line 4			
6	Subtitle:	Example line 5			
7	Subtitle:	Example line 6			
8					
9	FLAW INFO				
10	Flaw Column:	B			
11	Flaw Units:	mil			
12	Flaw Transform:	log			
13					
14	SIGNAL INFO				
15	Insp Start:	C			
16					
17	ANALYSIS				
18	Analysis:	Pass/Fail			
19	Version:	POD 3.0 (6/28/2000)			
20	Amax:				
21	Guess:				
22	POD level:				
23	Confidence:				
24					
 Info / Data / Results / Solve / Residuals / POD / POD Data / FitPlot /					

Figure 14. Example **Info** Sheet for a Pass/Fail Analysis using POD

Column B of the **Info** sheet contains the following information for the POD pertinent rows:

- *Title* – Identification entry that will appear on the **Results** output sheet and all graphs.
- *Subtitle* – Additional identification. The first four Subtitle entries will appear on all graphs. All subtitle entries will appear on the **Results** sheet in the order in which they are on the **Info** sheet. As many subtitle lines as desired can be inserted in the **Info** sheet by adding rows at the bottom with “Subtitle:” in column A. All Subtitle lines will be printed on the **Results** sheet.
- *Flaw Column* – Column letter of the **Data** sheet containing the flaw sizes to be used in the analysis.
- *Flaw Units* – Flaw size units that will appear in the output.
- *Flaw Transform* – Definition of flaw size transformation to be used in the analysis. The default transformation for flaw size is the natural logarithm. Different transformations can be used by entering the transformation name in the row labeled Flaw Transform. Column B should contain one of the following entries:

<u>Column B Entry:</u>	<u>Transform:</u>
none	$y = x$
log	$y = \ln(x)$
inverse	$y = 1/x$
custom	User defined

Either no entry or log in column B is the default natural logarithm transformation. In a custom transformation, Column D in the same row must contain a formula transforming the value in column C of the same row. Similarly, column F must contain the formula inverting the transform for the value in column E of the same row. Figure 15 shows an example of the formulas needed to define a log transformation using the custom option.

9	FLAW INFO					
10	Flaw Column:	B				
11	Flaw Units:	mil				
12	Flaw Transform:	custom	10	=LN(C12)	2.303	=EXP(E12)

Figure 15. Example Showing Formulas for Custom Data Transformation of Flaw Size

- *Insp Start* – **Data** sheet column that contain the first set of inspection results.
- *Analysis* – Pass/Fail directs POD to perform a pass/fail analysis.
- *Version* – Version of POD being used for the analysis.
- *Amax* – Upper limit of crack size on plots if POD defaults are not wanted.
- *Guess* – Columns B and C can contain initial estimates of μ and σ , respectively, that will override the POD default initial estimates in the iterative m estimation calculations. See section 2.2.5.
- *POD level* – POD percent value for which confidence bound will be calculated. Default value is 90 percent.
- *Confidence* – Percent confidence bound for POD value. Choices are 90, 95, and 99. Default value is 95.

2.2.3 Results Sheet from Pass/Fail Analysis

A **Results** sheet for the example pass/fail analysis is presented in Figure 16. The top lines repeat all of the identifying information from the Title and Subtitle lines of the **Info** sheet. Next are the range of crack sizes in the analyzed data, the number of unique crack sizes, and the total number of cracks in the analysis. This example has one inspection that is named Ins 1. The analysis and model are identified and followed by the estimates of the $POD(a)$ parameters. Estimates of a_{50} , a_{90} , and $a_{90/95}$ are listed along with the variance-covariance matrix of the parameter estimates.

2.2.4 Residuals Sheet from Pass/Fail Analysis

The **Residuals** sheet for a pass/fail analysis comprises the observed proportion of the cracks of each size that were detected, the $POD(a)$ estimate for each crack size, and the difference between the observed and estimated POD . Figure 17 presents the small crack portion of the **Residuals** sheet for the pass/fail example.

	A	B	C	D	E	F	G	H
1	Ultrasonic Surface Wave Inspection							
2	Example line 2							
3	Example line 3							
4	Example line 4							
5	Example line 5							
6	Example line 6							
7								
8	Flaw Depth Range:		2.5	to	27.8116	mil		
9								
10	# of unique cracks:		46	of	144	valid cracks		
11								
12								
13	Inspections: Ins 1							
14								
15	Pass/Fail Analysis							
16								
17	Model:		lognormal					
18								
19	POD Parameters							
20	Mu-hat		1.557202					
21	Sigma-hat		0.599553					
22								
23	Percentile Estimates					Estimated Covariance Matrix		
24		a50	a90/50	a90/95		V11	V12	V22
25		4.745527	10.23241	15.18824		0.010588	-0.0061	0.01147

Figure 16. Example POD **Results** Sheet from Pass/Fail Analysis

	A	B	C	D	E
1	a	log(a)	p	fit	diff
2	2.5	0.916291	0.4	0.142539	0.257461
3	4.28	1.453953	0	0.431636	-0.43164
4	5.17	1.642873	0.5	0.556812	-0.05681
5	5.615	1.725442	0.75	0.610494	0.139506
6	6.06	1.80171	0.625	0.658296	-0.0333
7	6.505	1.872571	0.3	0.700558	-0.40056
8	6.95	1.938742	0.8	0.737733	0.062267
9	7.395	2.000804	0.333333	0.770316	-0.43698
10	7.84	2.059239	0.666667	0.798802	-0.13214
11	8.285	2.114447	1	0.823668	0.176332
12	8.73	2.166765	0.833333	0.845351	-0.01202
13	9.62	2.263844	1	0.880724	0.119276
14	10.065	2.309064	1	0.895086	0.104914

Figure 17. Example **Residuals** Sheet from Example Pass/Fail

2.2.5 Solve Sheet from Pass/Fail Analysis

The pass/fail **Solve** sheet tracks the iterations of the parameters, usually to convergence for reasonably designed capability demonstrations. If convergence is not reached in 20 iterations, POD changes the initial estimates and tries again. If convergence is not reached at the end of POD's pattern of changes, the program returns a message that convergence could not be reached. If the analyst so chooses, initial guesses can be entered on the **Info** sheet in the row labeled *Guess* and the manually entered values will override POD's initial guesses. The **Solve** sheet on occasion has indicated the direction of changes that should be made to the initial estimates. Note that convergence to a maximum likelihood solution is not always possible. The **Solve** sheet for the pass/fail example is shown in Figure 15. Convergence was reached in 6 iterations in this example.

	A	B	C	D	E	F	
1							
2	Trial	1					
3							
4	iteration	mu	sigma	fnorm			
5	0	1.505276	0.789553	11.56465			
6	1	1.623194	0.473732	18.3812	damping:	1.404439	
7	2	1.58317	0.563332	3.113032			
8	3	1.561206	0.593345	0.502407			
9	4	1.557339	0.599313	0.020372			
10	5	1.557203	0.599552	8.54E-05			
11	6	1.557202	0.599553	1.25E-08			
12							
13							

Figure 18. Example **Solve** Sheet from Example Pass/Fail Analysis

2.2.6 Fit Plot Sheet from Pass/Fail Analysis

The **Fit Plot** sheet for a pass/fail analysis is a plot showing the $POD(a)$ fit on the observed detection probabilities. Observed detection probability for a crack size is the proportion of all inspections of cracks of that size that resulted in detections. Figure 19 is the **Fit Plot** for the example pass/fail analysis. A subjective judgement of goodness of fit can be made from this plot.

2.2.7 POD Data Sheet from Pass/Fail Analysis

The **POD Data** sheet comprises three columns that contain an array of crack sizes, the estimated $POD(a)$ function, and the confidence bound for $POD(a)$. Figure 20 presents a small portion of the **POD Data** sheet for the example pass/fail analysis.

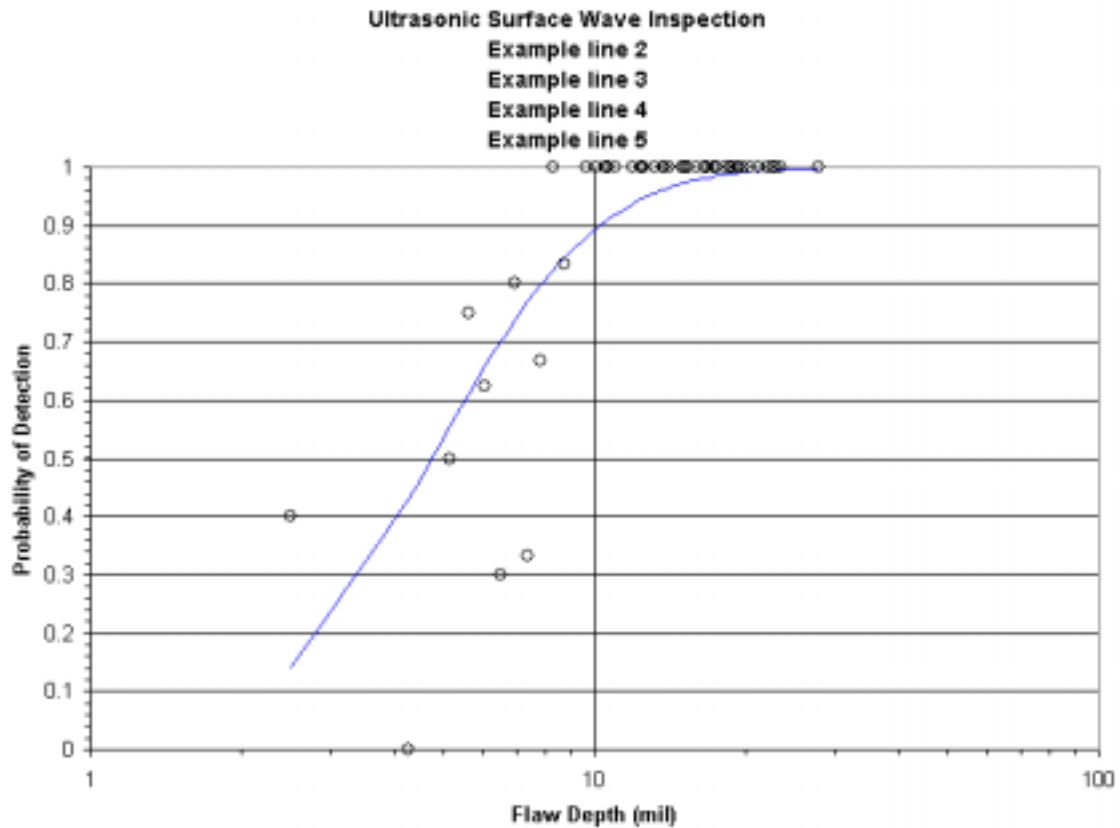


Figure 19. Example **Fit Plot** Sheet from Pass/Fail Analysis

	A	B	C	D
1	a	POD(a)	95% confidence bound	
2	0.785483	0.00135	3.86E-06	
3	1.150701	0.00906	0.000169	
4	1.515918	0.028495	0.00161	
5	1.881136	0.061372	0.007183	
6	2.246354	0.106122	0.02063	
7	2.611572	0.159586	0.044783	
8	2.97679	0.218331	0.080448	
9	3.342007	0.279334	0.126405	
10	3.707225	0.340229	0.180083	
11	4.072443	0.399314	0.238363	
12	4.437661	0.455461	0.298214	
13	4.802879	0.507993	0.357084	
14	5.168096	0.556569	0.413068	
15	5.533314	0.601088	0.464932	

Figure 20. Example **POD Data** Sheet from Pass/Fail Analysis

2.2.8 POD Sheet from Pass/Fail Analysis

The **POD** sheet contains plots of the $POD(a)$ function and the confidence bound. Figure 21 presents the **POD** sheet for the example pass/fail analysis.

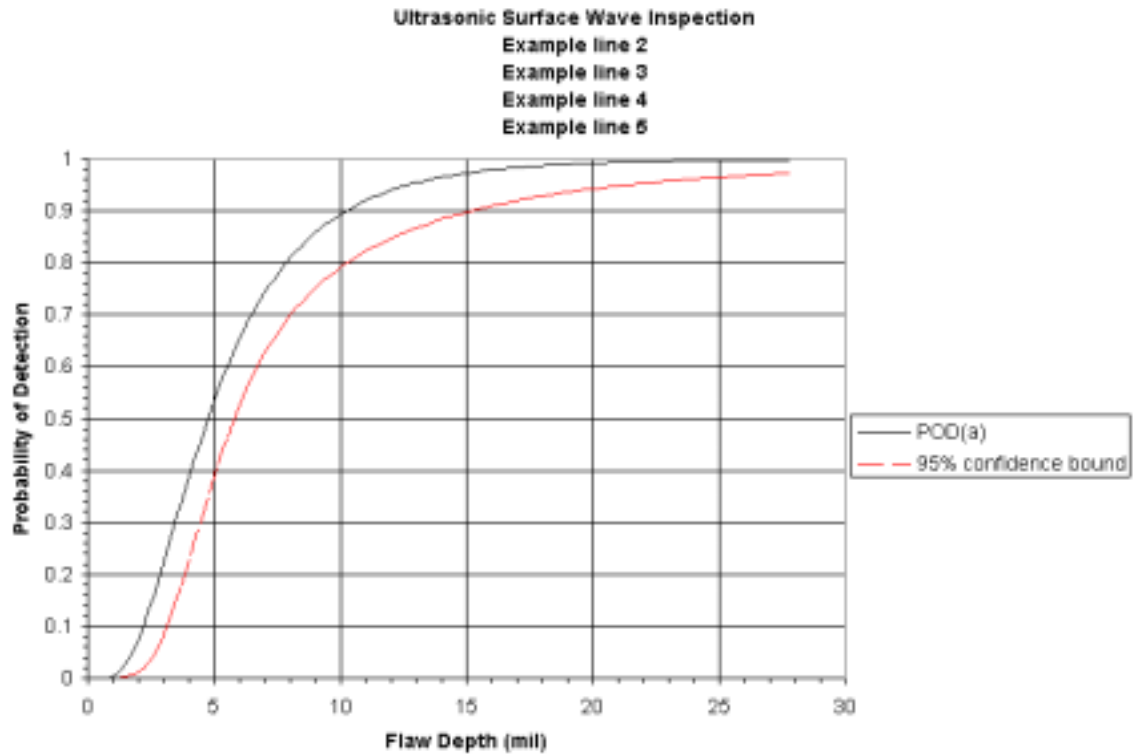


Figure 21. Example **POD** Plot with Confidence Bound from Example Pass/Fail Analysis

Section 3

Implementation of POD Version 3

This section describes how to use POD Version 3 to perform POD analyses of \hat{a} versus a and pass/fail data that are contained in an Excel workbook.

3.1 POD Version 3.0 Installation

To install, copy POD Version 3 to any directory in the search path. The POD Version 3 requires Microsoft Windows 95 (or later) and Excel 97 (or later). The POD program requires design link libraries MFC42.DLL, dated 04/27/1999 or later, and MSVCRT.DLL, dated 07/23/1996, or later.

3.2 Starting POD

Start POD by double clicking on the POD icon. A shortcut to the icon can be placed on the screen, if desired. When POD activates, it first brings up a copy of Excel and opens the POD window, Figure 22. Do not close this copy of Excel while POD is running.

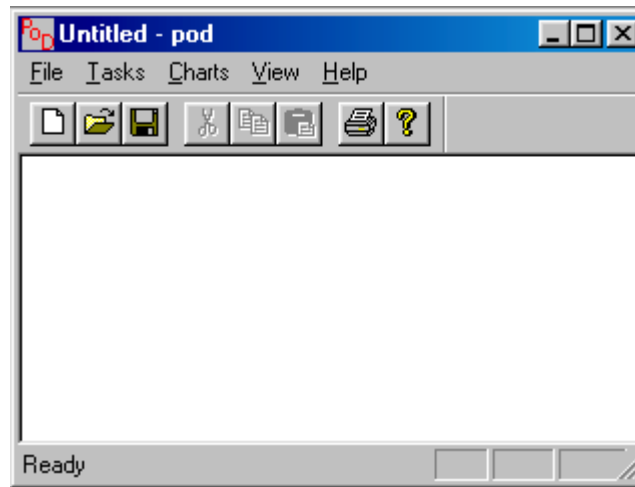


Figure 22. POD Window

3.3 POD File Operations

The **File** menu in the POD window contains items associated with opening and saving the Excel data and analysis files. It also contains a list of the most recently used files and a menu item for exiting the application. The POD **File** menu is shown in Figure 23.

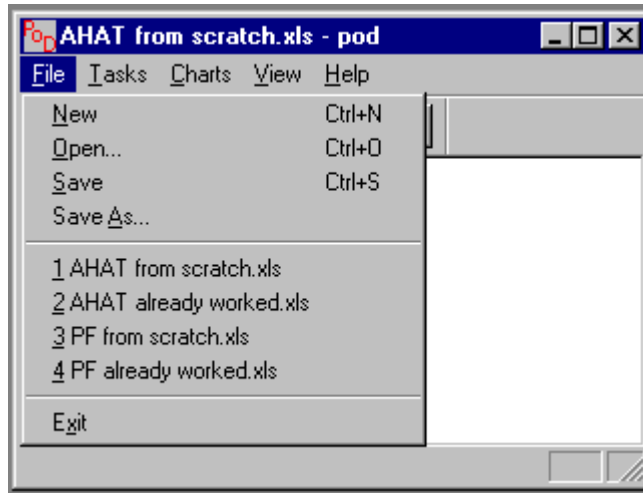
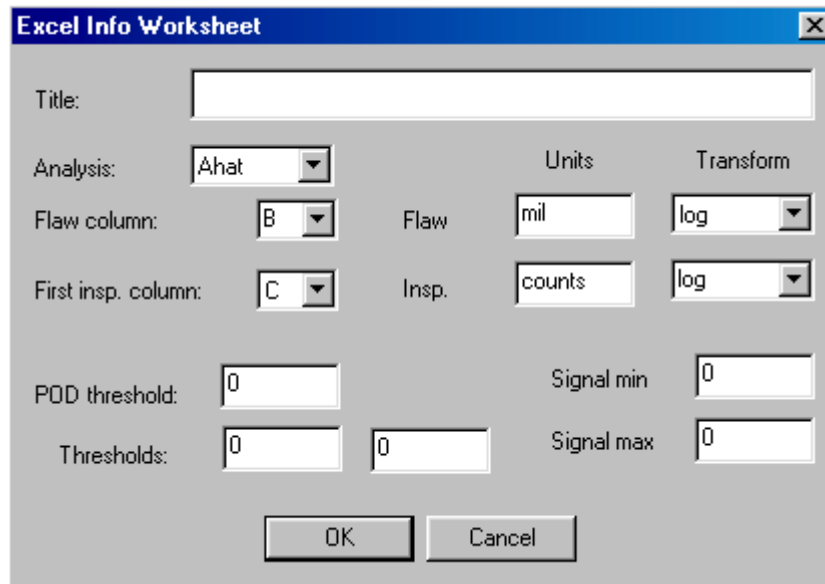


Figure 23. POD File Menu

3.3.1 Opening a File

Selecting the **File – New** menu item opens the Excel workbook to a blank **Data** sheet for direct entry of new data. A message appears that prompts the user to enter the data and **Recalculate**. Data in the correct format for a **Data** sheet can be entered by any convenient method. See subsection 3.4 for the **Recalculation** command. In this **File – New** sequence, the **Recalculation** command will first open an **Info Worksheet** window that requests the necessary information to start an analysis (as discussed below). POD will then generate a preliminary **Info** sheet and will perform the analysis as indicated on the **Info** and **Data** sheets. Note that is often more convenient to enter the data in a spreadsheet without opening POD. The file can then be saved and opened using the **File – Open** command.

Selecting the **File – Open** command opens an Excel workbook that contains a valid **Data** sheet. If the workbook also contains a valid **Info** sheet, POD will automatically recalculate the analysis as indicated on the **Info** sheet using the selected data on the **Data** sheet. This would be the case for files that had been previously opened by POD. If the workbook does not contain an **Info** sheet, POD opens an **Info Worksheet** window that prompts for an initial set of information and creates a preliminary **Info** sheet. Figure 24 presents the **Info Worksheet** window for creating the preliminary **Info** sheet. If the analysis, flaw column, or flaw inspection entries are not entered correctly on the **Info** sheet, POD may not be able to perform the analysis.



The dialog box is titled "Excel Info Worksheet". It contains the following fields and controls:

- Title:** A text input field.
- Analysis:** A dropdown menu with "Ahat" selected.
- Flaw column:** A dropdown menu with "B" selected.
- First insp. column:** A dropdown menu with "C" selected.
- Flaw:** A text input field with "mil".
- Insp.:** A text input field with "counts".
- Units:** A text input field (empty).
- Transform:** Two dropdown menus, both with "log" selected.
- POD threshold:** A text input field with "0".
- Thresholds:** Two text input fields, both with "0".
- Signal min:** A text input field with "0".
- Signal max:** A text input field with "0".
- Buttons:** "OK" and "Cancel" buttons at the bottom.

Figure 24. POD Info Worksheet

3.3.2 Save and Save As Menu Items

The **File – Save** and **File – Save As** menu items operate as in Excel.

3.3.3 Recently Used File List

Double clicking on a file in the list of recently used files will open the workbook.

3.3.4 Exit Menu Item

The POD **File – Exit** menu item will first ask if the workbook should be saved since it is automatically modified upon opening. The POD program will then close both the POD program and the Excel application. The workbook can also be closed using the Excel **File** commands. It is not desirable to close the Excel application opened by POD using the Excel close commands. Closing Excel early can cause POD to generate communication errors, since POD expects the workbook it created to be open. If closing Excel early produces one of a variety of warning and error messages, close and restart POD.

3.4 POD Tasks Menu

There are two menu items under the **Tasks** menu (Figure 25). **Recalculate** uses the information on the **Info** sheet and the selected data from the **Data** sheet to calculate the maximum likelihood estimates of the parameters of the model and to regenerate and replace all existing POD tables and graphs. Recalculating does not change the **Info** and **Data** sheets or any sheet with a name not used by POD.

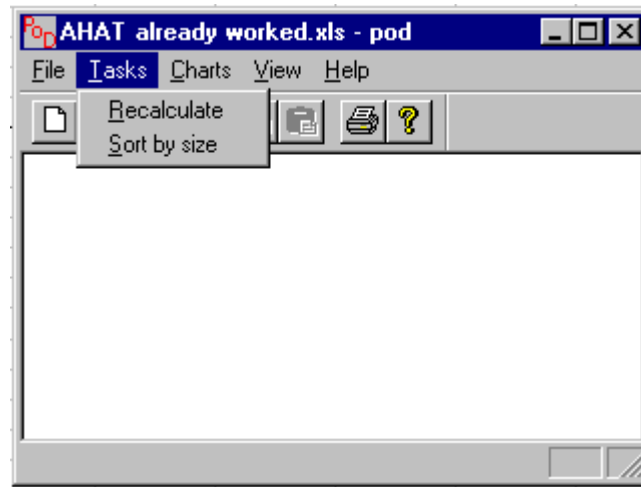


Figure 25. POD Recalculate Menu

It is often necessary or convenient to select ranges of crack sizes for analysis. The **Tasks – Sort by size** menu item rearranges the contiguous inspection result columns of the **Data** sheet in ascending order of the flaw size column.

3.5 POD Charts Menu

The Excel macros that generate the graphs are not activated the first time POD opens a workbook. The **Charts** menu allows the user to choose the particular graphs of interest. Computing time is saved when unwanted graphs are not generated. The **Charts** menu is shown in Figure 26. Clicking on a specific graph activates the macro that produces the graph as a sheet in the workbook. If a graph sheet exists in the workbook when a recalculation is performed, a new graph will overwrite the existing graph. Changing the name of a graph (or any other worksheet) generated by POD to a name not used by POD will prevent loss of the graph (or other worksheet).

All of the plots listed on the **Charts** menu are available in an \hat{a} versus a analysis. See Section 2.1 for examples. Only the **Fit plot**, **Residuals plot**, and **POD plot** are available from a pass/fail analysis. See Section 2.2 for examples.

3.6 POD Help Menu

The **Help** menu contains the **About POD** menu item. Figure 27 presents the **About POD** window which is a statement of proprietary rights and limits of liability.

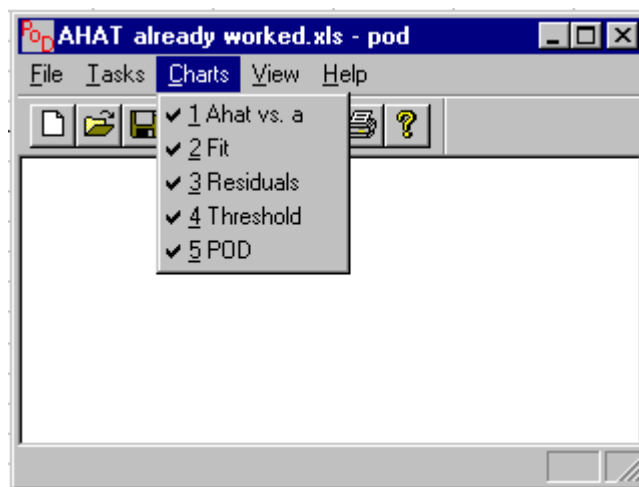


Figure 26. POD Charts Menu Showing All Graphs Selected from an \hat{a} versus a Analysis

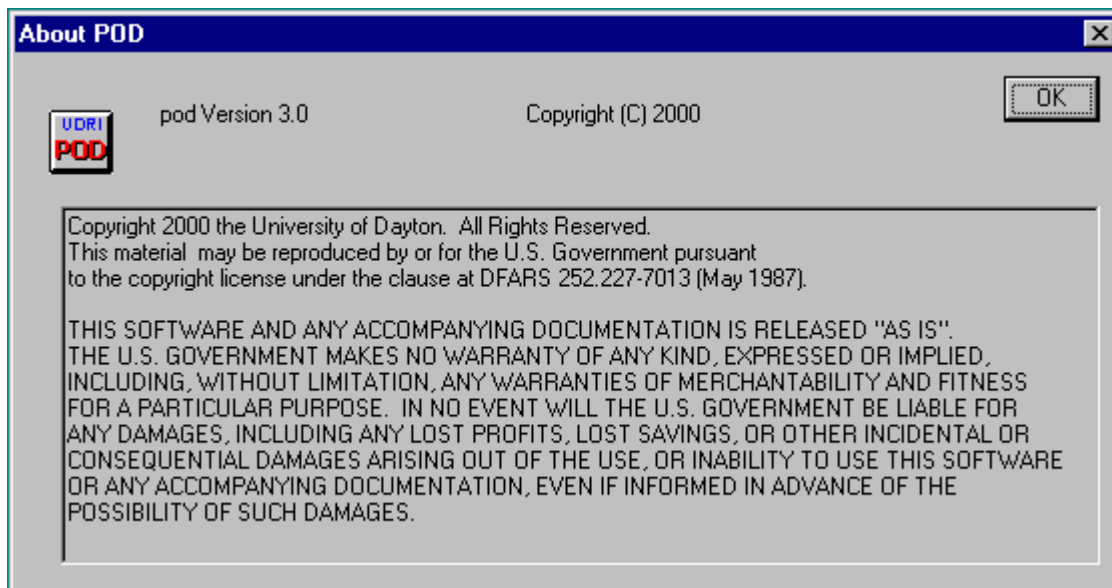


Figure 27. About POD Window

Section 4

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