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MATERIALS RESEARCH LABORATORY

ASSESSMENT of NDE RELIABILITY DATA

by

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16. Abstract

Twenty sets of relevant NDT reliability data have been identified, collected, compiled, and categorized. Three relevant on-going programs are being monitored for future usage. A criterion for the selection of data for statistical analysis considerations has been formulated. A model to grade the quality and validity of the data sets has been developed. Data input formats, which record the pertinent parameters of the defect/specimen and inspection procedures, have been formulated for each NDE method. A comprehensive computer program has been written and debugged to calculate the probability of flaw detection at several confidence limits by the binomial distribution. This program also selects the desired data sets for pooling and tests the statistical pooling criteria before calculating the composite detection reliability. An example of the calculated reliability of crack detection in bolt holes by an automatic eddy current method is presented in this report.

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Foreword

This interim (semi-annual) progress report covers work performed under Contract NAS-3-18907 from July to December 1974. This contract is being accomplished by General Dynamics Corporation, Fort Worth Division, Fort Worth, Texas and Vanderbilt University, Nashville, Tennessee. The program is managed by Dr. Bill G. W. Yee of General Dynamics with Dr. J. C. Couchman and Dr. F. H. Chang serving as principal investigators. Valuable contributions were made to the development of the statistical analysis by Dr. G. H. Lemon. Dr. P. F. Packman of Vanderbilt University is the associate program manager. This program is under the technical direction of Mr. S. J. Klima, NASA Lewis Research Center, Cleveland, Ohio.

This program is indebted to many people in the NDE community for either furnishing data to this program or consultation. Thank you.

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SUMMARY

The overall objective of this program is to assess available nondestructive testing data for the determination of the sensitivity and reliability of state-of-the-art production NDT methods for flaw detection on metallic materials. This program is separated into four different tasks. They are:

Task I Acquisition of Information

Task II Screening and Separation of Data by NDE Method and Material

Task III Statistical Determination of NDT Reliability

Task IV Reporting

During the first six months of this twelve month program, many sets of relevant NDT reliability data have been identified, collected, compiled, and categorized. Relevant on-going programs are being monitored for future usage. A criterion for the selection of data for statistical analysis considerations has been formulated. A model to grade the quality and validity of the data sets has been developed. Data input formats, which record the pertinent parameters of the defect/specimen and inspection procedures, have been formulated for each NDE method. A comprehensive computer program has been written and debugged to calculate the probability of flaw detection at several confidence limits by the binomial distribution. This program also selects the desired data sets for pooling and tests the statistical pooling criteria before calculating the composite detection reliability. An example of the calculated reliability of crack detection in bolt holes by an automatic eddy current method is presented in this report.

I. INTRODUCTION

In order to apply linear-elastic fracture mechanics to structural design, NDE has to guarantee to a high degree of confidence that no flaw larger than a specific size exists in the structure. To establish this minimum flaw size, many companies and organizations have conducted NDE demonstration programs. Most of these demonstration programs have been conducted in the production environment, some in the field-service environment, and even some in the laboratory environment.

The results obtained from demonstration programs are lacking in universal agreement. This lack of agreement is not surprising because each company or organization may use a different NDE procedure, different personnel, different procedures and parameters to generate the test flaws, different types of flaw and material type, and even different statistical analysis procedures. There appears to be a need to (1) collect much of the available NDE reliability data, (2) closely examine all the parameters that could affect the detection reliability, (3) compare the parameters used by each organization to obtain the data, and (4) attempt to identify the parameters that most likely cause the differences in the detection reliability. It appears worthwhile to obtain a composite detection reliability for each NDE method, material type, and flaw type by pooling data obtained from several sources. At the same time, the merits and shortcomings of several statistical analysis procedures should be carefully examined and the procedure most suitable for the analysis of NDE reliability data should be selected and any needs for improved methods should be identified.

The purpose of this program is to address the aforementioned needs.

II. ACQUISITION OF INFORMATION

This section describes the acquisition of NDE reliability related data, identification of on-going programs, and preparation of a bibliography on the acquired data.

2.1 Acquisition of NDE Reliability Related Data

During the first six months of this program, twenty-three sets of potentially useful data have been identified and twenty sets have been acquired. The three outstanding sets are on-going programs and the data are not yet available. As soon as they become available, all efforts will be made to acquire them for the purpose of this program. Of the twenty sets of data received, two sets cannot be used because they have not been released for publication by the rightful owners. Three sets cannot be used because the procedures or specifications used to obtain the data have not been received and/or documented. Of the twenty sets of data obtained, only fifteen sets are potentially usable at this time.

Efforts are continuing to identify and acquire further NDE reliability related data for input to this program for reliability analysis.

2.2 Bibliography

The twenty sets of NDE reliability related data that have been acquired are tabulated in this subsection. Some of the references are private data and only have company or committee report numbers. Several references are government funded programs, and they have not been published. For these references, only the sponsoring agencies and the name of an individual associated with the company where the actual work was conducted are identified. Copies of the data can be obtained from either contacting an individual within the sponsoring agency, such as the B-1 SPO/USAF, or an individual associated with the company.

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17. A10 USAF/Fairchild Hiller NDI Demonstration Program, Ted Renshaw of Fairchild Hiller, (Set of Reports), Sept. 1973.

18. F-111 USAF/General Dynamics NDI Human Factors Study Program. Bill Kloster of General Dynamics, Fort Worth Division, (Set of Reports) 1971.

19. AFML Round Robin Results on (1) Delta Scan and (2) Magnetic Particle, Lee Gulley, AFML, WPAFB, Dayton, Ohio, March 1971.

20. Raatz, C. F., Senske, R. A. Woodmansee, W. E., et al. "Detection of Cracks Under Installed Fasteners," AFML-TR-74-80, April 1974.

2.3 Monitoring of On-Going Programs

There are several on-going programs that are currently known. The data from these programs will be considered for reliability analysis as soon as they become available. Of these, only three are government funded but several privately funded on-going programs exist. The data from these privately funded programs may never be made available for input to this study, however, every effort will be made to continue to identify and acquire new data for this contract.

The three government funded on-going programs are:

1. Crack detection reliability on welded plates and structures, Martin Marietta, Ward Rummel, sponsored by NASA/Johnson Space Center.

2. Crack detection reliability on actual aircraft structures at the depot level, Lockheed, GA., W. Lewis, sponsored by Kelly Air Force Base.

3. Crack detection reliability on F-111 fatigue tested structures, General Dynamics, Fort Worth Division, B. G. W. Yee, sponsored by SMALC.

III. SCREENING AND SEPARATION OF DATA BY NDE METHOD AND MATERIAL

This section describes the development of data selection criteria, separation and categorization of data, development of a model to grade quality of the data, and the development of a data input format for each NDE method.

3.1 Criteria for Selection of Data for Statistical Analysis

All of the reliability related NDE data are not necessarily suitable for statistical analysis. Some are lacking in the documentation of certain key pertinent parameters, such as the defect dimension, defect type, NDE method, etc. Statistical analysis of data when the key pertinent parameters are not documented would be marginal in value. A data selection criteria is needed to screen the data and prejudge the suitability of the data for statistical analysis. Such a criteria is necessarily subjective because it involves human judgment of data value or usefulness. It is felt that such a subjective criteria will still be useful to screen out data having marginal statistical value and to eliminate lost time in processing the data.

To be eligible for statistical analysis, a set of data must satisfy the following conditions:

a) An NDE procedure or specification must accompany the data which clearly describes the equipment and the parameters used so that the data may be reproduced in other facilities (assuming the same equipment or its equivalent is used).

b) The defect dimensions and specimen geometry must be well documented so that data may be statistically analyzed and compared to defect detection in the proper defect size range. When artificial methods of defect fabrication are used, at least ten percent (10%) of all defects in a given set must be destructively tested to obtain the defect dimensions. For methods that are used to produce multiple defects in a specimen or methods that are questionable for producing controllable defect dimensions, at least fifty percent (50%) of all defects in a given set must be destructively tested to verify the defect dimensions.

3.2 Separation and Categorization of Data Set

The twenty sets of data listed in the Bibliography in Subsection 2.2 can be separated into three categories. Table 3-1 describes the data separated into the three categories and the status of these data sets. The first category is the data that appear to satisfy the criteria discussed in Subsection 3.1, and they will be considered for statistical analysis. There are fifteen (15) sets of data in this category. The second category is data that probably could be used if either additional inspection documentation is received or permission to use the data is granted by the rightful owner of the data. There are three sets of data in this category. The third category is the data that are very unlikely to be useful and will not be considered for statistical analysis. There are two sets of data in this category and the rationale for the rejection of these data are presented in Table 3-1.

A large majority of the data were obtained on thin flat plates which contain fatigue cracks or weld defects. There are few sets of data that were obtained with relatively complex shaped specimens such as a T, I, or H shape. In order to gain a better understanding of the availability of data on material type, defect type, and specimen complexity, a table (Table 3-2) is constructed to categorize the data sets according to test specimen complexity. Within each data set, a brief description of the material type, NDE methods, and defect type is presented.

3.3 A Model to Grade the Quality of the Data Sets

The thoroughness of the characterization of the defect-specimen and the documentation of the inspection procedures affects the quality and the usefulness of the data sets. Quality and usefulness are defined as the confidence which a designer has in applying the results of the data to his design. He must be certain that a crack of given size can be detected with the necessary reliability, such as 90% probability at 95% confidence level. He will not use the data unless it is sufficiently documented that it can be reproduced in future inspections.

The model described in this section will only address the quality of each set of data. It will not address the question of applicability. That is, a set of data obtained on flat

Table 3-1 STATUS AND CATEGORY OF DATA

Data that appears to satisfy the criteria discussed in Subsection 3.1 and will be considered for statistical analysis	Data that lack inspection documentation or permission to be used	Data that are very unlikely to become useful and will not be considered for structural analysis
References:	References:	References:
1	5 Pressure Vessel Research Committee approval needed before data can be used	12 Lack of defect dimension verification
2		
3		
4		
7		
8	6 Same as 5 above	19-(1) Lack of inspection documentation
9		
10		
11	17 Waiting for inspection documentation	
13		
14		20 Same as 12 above
15		
16		
18		
19-(2)		

Table 3-2 Data Grouping According to Specimen Thickness and Complexity

Flat Plates and Simple Shape	Cylindrical, I, H, T and other Moderately Complex Shapes	Actual Aircraft Structures
References: 1 2219-T87 Al up to 1 cm thick o Cracks in plates and welded plates o Ultrasonics, penetrant, eddy current, and X-ray o Laboratory environment 2 2219-T87 Al up to 1 cm thick o Fatigue cracks in flat plates o Ultrasonic, penetrant, eddy current, and X-ray o Laboratory environment (mostly) 4 2219-T87 Al up to 1 cm thick o Fatigue cracks in flat plates o Ultrasonic, penetrant, eddy current, and X-ray o Laboratory environment (mostly)	References: 3 7075-T6511 Al o Fatigue cracks in cylindrical tubes o Ultrasonic, penetrant, and X-ray 4300 V Steel o Fatigue cracks in cylindrical tubes o Ultrasonics, penetrant, X-ray, and magnetic particle o Laboratory environment 10 2024 Al o Forged defects o Ultrasonic, penetrant, eddy current, X-ray o Production environment 4340 M Steel o Forged defects o Ultrasonics, penetrant eddy current, X-ray, and magnetic particles o Production environment Some grinding cracks and hydrogen embrittlement cracks	References: 11 ? o Naturally occurring fatigue cracks in bolt holes o Eddy current o Laboratory and depot level 13 6Al-4V-Ti and 7075-T6Al o Fatigue cracks off C-5A Pylon (actual and simulated) o Ultrasonics and X-ray 14 7075-T6 Al o Fatigue cracks off C-130 wing boxes (actual and simulated) o Ultrasonics and eddy current 20 KC-135 lower wing skin panel and laboratory specimens with fatigue cracks under installed fastener o Ultrasonic o Laboratory and field environment

Table 3-2 (Continued)

Flat Plates and Simple Shape	Cylindrical, I, H, T and other Moderately Complex Shapes	Actual Aircraft Structure
5 Steel forging up to 25 cm thick o Induced and naturally occurring defects o Ultrasonics o Laboratory environment	15 6Al-4V-Ti o Induced forging defects o Ultrasonics, penetrant X-ray o Most production environment	
6 Steel welded-plates up to 28 cm thick o Induced weld defects o Ultrasonics and X-ray o Laboratory environment	18 D6ac Steel o Induced forging defects o Ultrasonics, magnetic particle and rubber o Production environment	
7 2219-T87 welded plates of 0.62 and 1.25 cm thick o All types of weld defects o Ultrasonic and X-ray		
8 2219-T87 Al up to 1 cm thick o Fatigue cracks in flat plates o Ultrasonic, penetrant, eddy current, and X-ray o Production environment (mostly)		
9 2219-T87 and 2014-T6Al up to 2.5 cm thick 6Al-4V-Ti and 5Al-2.5 Sn Ti up to 1½ cm thick o Fatigue cracks in flat plates weld defects in plates		

Table 3-2 (Continued

Flat Plates and Simple Shape	Cylindrical, I, H, T and other Moderately Complex Shapes	Actual Aircraft Structure
o Ultrasonic, penetrant, X-ray, and eddy current o Laboratory environment		
12 2219-T87 Welded plates of 1.25 and 2.5 cm thick o All types of weld defects o Ultrasonic and X-ray		
16 6Al-4V-Ti up to 13 cm thick o Ultrasonic o Flat bottom holes and induced defects		
6Al-4V-Ti Diffusion Bonded thin plates o Induced defects o Penetrant		
Al Samples o Fatigue cracks in flat plates o Penetrant		
6Al-4V-Ti o Fatigue cracks in flat plates o Penetrant		
Steel o Induced weld defects o Ultrasonics		

Table 3-2 (Continued)

Flat Plates and Simple Shape	Cylindrical, I, H, T and other Moderately Complex Shapes	Actual Aircraft Structure
Al, Ti, and Steel Plates (multiple) o Cracks in fastener holes o Eddy current All in production environment		
17 Similar to those described in Reference 16		
19 o D6ac Steel Plate Delta Scan Ultrasonics		19 o D6ac, 4340, and other Steel Alloys Actual Aircraft Structure Magnetic Particle

plates will not be graded on the basis of its applicability to the design of complex structures. When the reliability curves are plotted for each set of data during the second half of this contract, a comparison of the reliability of detection as a function several inspection parameters will be made.

The model to be described is preliminary and the weighting factors assigned to the various known pertinent parameters are rather arbitrary. It will be refined during the second half of this contract. However, it does represent a first attempt to quantitatively evaluate the quality of a data set. Each of the pertinent parameters in this model is listed in the Input Data Format which will be discussed in the next subsection. The grade for a given set of data can be tallied in the computer by checking the entries to the columns containing these pertinent parameters. A score of one hundred (100) corresponds to a perfect set of data. A perfect set of data is one where all the pertinent parameters are documented.

The preliminary model to grade the data quality for the ultrasonic, eddy current, liquid penetrant, magnetic particle, and X-ray methods is given in Table 3-3. The model is divided into two major groups. Group A is the characterization of specimens and defects and it is common to all techniques. Group B is the documentation of the inspection. The first eight parameters in this group are common to all techniques. Each technique has eleven parameters that are considered pertinent to adequately document the inspection. Parameter A1 is the description of the specimen geometry and defect location. This is considered a key parameter and a value of 7 points is assigned to it. If no description about the specimen geometry and defect location is given, that data point or set of data will receive no points. The points by each parameter will not be awarded to a data point or set of data if it is not documented. Those parameters that are marked by an asterisk are considered key parameters. If any of them is not recorded, the data point or set will be flagged and consideration will be given for possible exclusion from statistical analysis.

Table 3-3 A MODEL TO GRADE DATA QUALITY

A.	Specimen - Defect Characterization		35
	1. Specimen geometry complexity/defect location	*	7
	2. Defect orientation, location, and presence expectation	*	9
	3. Crack dimension verification	*	10
	4. Defect type	*	3
	5. Surface condition	*	3
	6. Material characterization		3
	7. Material inside defect	*	3
B.	Inspection Documentation		65
	1. False indication recording		4
	2. Operator qualification		3
	3. Use of proof load	*	3
	4. Use of specimen without crack	*	3
	5. Modes of data recording		3
	6. Method of scanning for data taken		3
	7. Insp. environment	*	3
	8. Number of insp. prior to this insp.		3
	9. Parameters recorded by NDTS		
	a. Radiograph		38
	1) Radiographic source	*	3
	2) Ref. standard		3

9. (Continued)

3)	Detector type	*	4
4)	Voltage	*	4
5)	Current	*	4
6)	Exposure time	*	4
7)	Source/film distance	*	4
8)	Angle of entry		3
9)	Film development parameters		3
10)	Radiographic density	*	3
11)	Radiographic equipment type		3
b.	Ultrasonics		38
1)	Ultrasonic method	*	4
2)	Frequency	*	4
3)	Transducer type and size	*	4
4)	Reference standard type and size	*	4
5)	Angle of incidence (inside the material)	*	3
6)	Equipment type		3
7)	Gate alarm level (% of ref. signal)	*	4
8)	Gain setting (% of screen saturation)	*	4
9)	Type of coupling		3
10)	Index internal	*	3
11)	Contact or Immersion		3

9. (Continued)

c.	Eddy Current		38
1)	Types of measurement	*	3
2)	Coil size	*	4
3)	Coil arrangement and shape	*	3
4)	Frequency	*	4
5)	Reference type and size	*	4
6)	Equipment type		3
7)	Index interval	*	3
8)	% of meter response (R)	*	4
9)	% of meter response (X)	*	4
10)	Lift-off compensation		3
11)	Signal processing		3
d.	Penetrant		38
1)	Penetrant type	*	4
2)	Developer type	*	4
3)	Classification of penetrant (group no.)		2
4)	Emulsifier type	*	4
5)	Pre-insp. surface cleaning and penetrant removal	*	3
6)	Method of penetrant application		3
7)	Dwell time	*	4
8)	Development time	*	4

9. (Continued)

9)	Wash time		4
10)	Light intensity at specimen surface		3
11)	Reference standard type		3
e.	Magnetic Particle		38
1)	Types of current used	*	4
2)	Ampere	*	4
3)	Method of magnetization		4
4)	Direction of magnetization	*	4
5)	Magnetic flux density	*	4
6)	Magnetic particle type and size	*	3
7)	Magnetic particle density		3
8)	Types of liquid vehicle		3
9)	Method of particle application		3
10)	Equipment type		3
11)	Dwell time (seconds)	*	4

The models described in this subsection along with the criteria described in Subsection 3.1 can be used as a data acceptance or rejection criteria.

3.4 Data Input Format and Keys

The formats developed for data entry to the computer for the ultrasonic, eddy current, liquid penetrant, magnetic pargicle, and radiography method are given in Figures 3-1, 3-2, 3-3, 3-4, and 3-5. The key which explains the entries to the five formats is given in the Appendix. In each format the pertinent parameters necessary to characterize the defects and specimens are recorded and entered into the computer for grading the quality of the data. The pertinent parameters considered necessary to properly and adequately document each NDE method are recorded in the format for each method. (There are probably several more parameters for each NDE method that are not included, and perhaps should be). If in the future, any of these additional parameters are considered to be necessary for adequate documentation, they can be added to the existing formats. In order to keep the data input formats and the model for grading data quality as simple as possible, only the parameters that are thought to be necessary are recorded.

FIGURE 3-1
DATA INPUT FORMAT for Ultrasonics

1	Data Point
2	Specimen and Specific Defect Iden. No.
3	Data Source
4	Program Identification
5	Material
6	Defect Type
7	Operator Identification Number
8	Specimen Surface Finish
9	Def. Orien. Location, and Presence Exp.
	Insp. Environment
	Defect Detection/False Indication
	Operator Qualification
	Detection Enhancement
	Data Recording & Presentation
	Mode of Scan
10	$2c_{act.}$ (Actual Defect Length in 2.54×10^{-3} cm)
11	$2c_{NDI}$ (NDI - Defect Length in 2.54×10^{-3} cm)
12	a (Actual Defect Depth in 2.54×10^{-3} cm)
13	t (Plate Thickness in 2.54×10^{-2} cm)
14	Insp. Proc. /Multi-Defect Specimen
15	Ref. Standard Type and Size
16	Ultrasonic Method
	Frequency in MHz
17	Transmitting Trans. Type and Size
18	Receiving Trans. Type and Size
19	Equipment Type
20	Type of Coupling/Contact or Immers.
21	Angle of Incidence in Coupling
22	Gain Setting % of Screen Saturation (S.S)
23	Gate Alarm Level in % S.S.
24	Index Interval (2.54×10^{-2} cm)
25	
	Material in Defect
	Defect Location/Specimen Geometry
26	a (NDI Defect Depth in 2.54×10^{-3} cm)
	NDI Methods
	Grade
27	
28	

FIGURE 3-2

DATA INPUT FORMAT for Eddy Current

Data Point
Specimen and Specific Defect Iden. No.
Data Source
Program Identification
Material
Defect Type
Operator Identification Number
Specimen Surface Finish
Def. Orien. Location, and Presence Exp. Insp. Environment
Defect Detection/False Indication
Operator Qualification
Detection Enhancement
Data Recording & Presentation
Mode of Scan
$2c_{act.}$ (Actual Defect Length in 2.54×10^{-3} cm)
$2c_{NDI}$ (NDI - Defect Length in 2.54×10^{-3} cm)
a (Actual Defect Depth in 2.54×10^{-3} cm)
t (Plate Thickness in 2.54×10^{-2} cm)
Insp. Proc. /Multi-Defect Specimen
Ref. Standard Type and Size
Instrumentation Type
Diameter of Coil (2.54×10^{-3} cm)
Arrangement and Shape of Coils
Frequency (10^4 Hz)
Type of E.C. Response
Lift-Off-Compensation
Signal Processing
%-of-Meter Response (R)
~~%-of-Meter-Response (X)~~
Index Interval (2.54×10^{-2} cm)
Material in Defect
Defect Location/Specimen Geometry
a (NDI Defect Depth in 2.54×10^{-3} cm)
NDI Methods
Grade

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FIGURE 3-3

DATA INPUT FORMAT for Liquid Penetrant

Data Point
Specimen and Specific Defect Iden. No.
Data Source
Program Identification
Material
Defect Type
Operator Identification Number
Specimen Surface Finish
Def. Orien, Location, and Presence Exp.
Insp. Environment
Defect Detection/False Indication
Operator Qualification
Detection Enhancement
Data Recording & Presentation
Mode of Scan
$2c_{act.}$ (Actual Defect Length in 2.54×10^{-3}cm)
$2c_{NDI}$ (NDI Defect Length in 2.54×10^{-3}cm)
a (Actual Defect Depth in 2.54×10^{-3}cm)
t (Plate Thickness in 2.54×10^{-2}cm)
Insp.Proc./Multi-Defect Specimen
Ref. Standard Type and Size
Penetrant Type
Developer Type
Classification of Penetrant Grp.
Emulsifier Type
Method of Application
Dwell Time (Minutes)
Developing Time (Minutes)
Wash Time (Minutes)
Insp. Light Intensity (10^2 lumens/sq. meter)
Penetrant Removal Method
Pre-Insp. Cleaning Proc.
Pre-Insp. Cleaning Proc.
Material in Defect
Defect Location/Specimen Geometry
a' (NDI Defect Depth in 2.54×10^{-3}cm)
NDI Methods
Grade

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FIGURE 3-4

DATA INPUT FORMAT for Magnetic Particle

	Data Point
	Specimen and Specific Defect Iden. No.
	Data Source
	Program Identification
	Material
	Defect Type
	Operator Identification Number
	Specimen Surface Finish
	Def. Orien. Location, and Presence Exp.
	Insp. Environment
	Defect Detection/False Indication
	Operator Qualification
	Detection Enhancement
	Data Recording & Presentation
	Mode of Scan
	$2c_{act}$ (Actual Defect Length in 2.54×10^{-3} cm)
	$2c_{NDI}$ (NDI Defect Length in 2.54×10^{-3} cm)
	a (Actual Defect Depth in 2.54×10^{-3} cm)
	t (Plate Thickness in 2.54×10^{-2} cm)
	Insp. Proc./Multi-Defect Specimen
	Ref. Standard Type and Size
	Method of Magnetization
	Direction of Magnetization (Degrees)
	Current Type
	Current Amplitude (100 Amp.)
	Magnetic Flux Density (Kilo Gauss)
	Particle Material Type & Size
	Method of Particle Application
	Vehicle Material Type
	Dwell Time (Seconds)
	Equipment Type
	Particle Material Density
	Material in Defect
	Defect Location/Specimen Geometry
	a (NDI Defect Depth in 2.54×10^{-3} cm)
	NDI Methods
	Grade

FIGURE 3-5

DATA INPUT FORMAT for Radiography

- Data Point
- Specimen and Specific Defect Iden. No.
- Data Source
- Program Identification
- Material
- Defect Type
- Operator Identification Number
- Specimen Surface Finish
- Def. Orien, Location, and Presence Exp.
- Insp. Environment
- Defect Detection/False Indication
- Operator Qualification
- Detection Enhancement
- Data Recording & Presentation
- Mode of Scan
- $2c_{act}$ (Actual Defect Length in 2.54×10^{-3} cm)
- $2c_{NDI}$ (NDI Defect Length in 2.54×10^{-3} cm)
- a (Actual Defect Depth in 2.54×10^{-3} cm)
- t (Plate Thickness in 2.54×10^{-2} cm)
- Insp. Proc./Multi-Defect Specimen
- Ref. Standard Type and Size
- Radiographic Source
- Source Energy
- Source Strength
- Exposure Time (Minutes)
- Film Developing Process
- Detector Type
- Source to Film Distance (In.)
- Angle of Incidence
- Densitometer Reading
- Material in Defect
- Defect Location/Specimen Geometry
- a (NDI Defect Depth in 2.54×10^{-3} cm)
- NDI Methods
- Grade

IV STATISTICAL DETERMINATION OF NDE RELIABILITY

This section describes the binomial statistical method, cumulative schemes, statistical pooling procedure, and digital computer code for computing NDE reliability.

4.1 Introduction

There are four possible outcomes from any nondestructive inspection of an item: (1) detection of a defect that is present, (2) non-detection of a defect that is present, (3) detection of a defect that is not present (false indication), and (4) non-detection of a defect that is not present. Because of these four possible outcomes, any single inspection may be called a quadrinomial event. Although it is recognized that false indications of defects and true indications of non-defective items (cases 3 and 4) are of practical significance to both the manufacturer and the customer, it is beyond the scope of this investigation to develop a straightforward statistical method for handling the quadrinomial event.

Preliminary indications show that most NDE reliability investigations have neglected to report information concerning either false indications of defects, or true indications that specimens contained no intentionally induced flaws. However, the data input format discussed in the previous section provides for storage of information concerning false indications for future use when more of these data become available.

Cases (1) and (2) involve either a detection or non-detection of a defect that is known to exist. This event can best be described statistically by applying the binomial distribution. The Normal, Chi-square, and Poisson distributions are sometimes used as approximations to the binomial. Their applicability to the problem of NDE reliability is to be considered in this contract but will not be discussed in this report.

4.2 Application of Binomial Distribution

An event that has only two possible outcomes is referred to as a binomial event. Suppose, for example, an experiment in NDE is performed where N specimens, all containing identical

flaws, are routed through an ultrasonic inspection system. Suppose further, that the system capability does not change throughout the entire inspection process, i.e., each specimen is evaluated independently of the others. Let p equal the true,(but as yet unknown) probability of detecting each flaw and q=1-p be the probability of missing each flaw. Assuming p remains the same for all specimens, the random variable X can be defined as being the number of flaws that are detected. X, then, is referred to as a binomial random variable with parameters N and p. Its possible values are 0, 1, 2, ...,N. Equivalently, it can be said that X has a binomial distribution. The probability of obtaining any one of the N+1 possible values of X from such an experiment is described by the following equation:

$$P(X=n) = \binom{N}{n} p^n \; q^{N-n}, \qquad n=0,1,\ldots,N \tag{1}$$

where $\binom{N}{n} = \frac{N!}{n!(N-n)!}$.

The sum of all the possible values for equation (1) is equal to unity and can be written as follows:

$$(p+q)^N = \sum_{n=o}^{N} \binom{N}{n} p^n \; q^{N-n} = 1 \tag{2}$$

The probability of detecting n or more flaws can be found by summing equation (1) over all the values of X for which $X \geq n$. Thus,

$$P(X \geqq n) = \sum_{i=n}^{N} \binom{N}{i} p^i \; q^{N-i}. \tag{3}$$

4.2.1 Confidence Interval Estimates of the True Probability of Detection

If the objective is to estimate the true proportion of defects of a particular type and size that can be detected by a given NDE method. The best single estimate, $\bar{p}$, of the true

detectable proportion is the number of flaws detected divided by the total number of flaws present:

$$\bar{p} = \frac{n}{N+1} \tag{4}$$

Such an estimate of the true proportion p, however, is somewhat meaningless without some statement regarding the accuracy of the estimate.

If a binomial experiment (N, n) is performed which consists of N inspections of test specimens (containing flaws) and n successful flaw detections, equation 3 can be used to make a statistical statement about the confidence G, that the true probability-of-detection is equal to or greater than some lower limit p_1:

$$G = 1 - \alpha \tag{5}$$

where

$$\alpha = \sum_{i=n}^{N} \binom{N}{i} p_1^{i} (1-p_1)^{N-i} \tag{6}$$

If the binomial experiment is repeated,* G is the fraction of experiments for which n_k will be less than n and α is the fraction of experiments for which n_k will be greater than or equal to n. G is interpreted as the probability (confidence) that the single binomial experiment (N, n) has determined a lower limit p_1 to the true detection proportion p. α represents the probability that $p < p_1$. G is referred to as the "lower one-sided confidence estimate" that the true proportion, p, is equal to or larger than the lower "one-sided confidence limit", P_1.

---

* A subscript k on (N_k, n_k) refers to the k th binomial experiment.

It is the lower one-sided confidence limit, p_1, at a specified confidence level, G, that is of interest in calculating the reliability of an NDE method. The choice of G and α is arbitrary and depends upon the acceptable risk or proportion of times that one is willing to accept a wrong decision. A 95 percent confidence (G = .95) that the true probability of detection exceeds 90% (p_1 = .90) is the currently accepted criterion for demonstrating an NDE method.

4.2.3 Sample Size Required To Estimate The Lower One-Sided Confidence Limit and Confidence Level

The objective is to determine the sample size required to estimate the lower confidence limit and confidence level. This can be accomplished by utilizing equation (6). By specifying the confidence level, G, and the lower confidence limit p_1, a set of values (which must be integers) can be computed for N and n. Each combination of N and n in this set indicates the number of inspections and the number of detections required to achieve the specified probability of detection at the stated confidence level. For example, if G and p_1 are chosen to be 0.95 and 0.9 respectively, equation (6) becomes

$$0.95 = 1 - \sum_{i=n}^{N} \binom{N}{i} (0.9)^{i}(0.1)^{N-i}. \qquad (7)$$

One of the combinations of N and n is 29 and 29 respectively. This represents the smallest sample size that can be utilized to meet the minimum specified values for G and p_1. The next smallest sample size is N=46. In this case n must equal at least 45 to achieve 90% probability of detection at 95% confidence level. The higher the reliability requirements, of course, the larger the sample size required.

Equation (6) can also be used to calculate the number of added NDE tests required to upgrade an existing batch of data in the hope of achieving higher reliability estimates. Equation (6) takes on the form

$$1-G = \sum_{i=n+\delta-\epsilon}^{N+\delta} \binom{N+\delta}{i} p_1^{i} \cdot (1-p_1)^{N+\delta-i} \qquad (8)$$

where δ is the required number of additional tests and ϵ is the maximum number of additional misses (nondetections). For example, if an experiment consisting of 29 inspections and 28 detections was performed, the reliability (equation 6) is 90% probability of detection at 80% confidence level. If a 95% confidence level is desired, the additional data requirements are indicated by equation (8). Thus, $\delta = 17$ with $\epsilon = 0$ represents the minimum added sample required to upgrade the existing data.

4.3 Cumulative Schemes

The calculated value for the lower confidence limit (probability of detection POD at some selected confidence level CL) is influenced by the total number of measurements (sample size). In order to achieve a high POD at a high CL, such as 90% at 95% confidence level, a minimum of 29 measurements have to be made without a miss for a given flaw size. Because of the high costs involved, it is generally not economical to make 29 or more measurements for each flaw size for the entire range of flaw sizes of interest. At the same time, in the inspection of actual structural components, it is unlikely to have 29 or more measurements per flaw size to occur. As a result, some cumulative scheme has to be used in order to obtain a sufficient number of measurements to achieve a high POD at a high CL and to smooth over the flaw sizes that have no measurements. A cumulative scheme permits the accumulation of data over a range of flaw sizes for computing a POD which is representative of that range. For this method to be valid, it must be assumed that POD is monotonically increasing with crack size.

Several cumulative schemes were considered for estimating the POD. These schemes include the (1) cumulated-up, (2) cumulated-down, (3) range, (4) overlapping 60 points, and (5) the scheme developed under this contract which will be called the modified cumulated up (MCU) scheme. There are two variations within the MCU scheme: MCUI and MCUII. For the same set of data, the POD can be considerably different depending on which of these cumulative schemes is used.

Generally, NDE reliability is demonstrated by inspecting specimens containing flaws distributed uniformly over a wide flaw size range. The smallest flaws should be virtually nondetectable and the largest flaws should be 100% detectable.

First, the raw data set is arranged in order of increasing flaw size with the appropriate outcome indicated for each flaw, then:

(a) In the cumulated-up scheme, the number of measurements N and the associated number of detections n are summed beginning with the smallest flaw size and stopping at a point where N is large enough to produce a potentially high POD (e.g., N=29). The resultant POD at the selected CL is calculated with the binomial method and plotted at the largest flaw size in the interval. The next POD is calculated when the number of measurements and detections of the next larger flaw size is added. The procedure is repeated until the number of measurements and detections of the largest flaw size have been included in the POD calculation. Note that the inspection data obtained with the smallest cracks are included in every interval for which the POD is computed. This scheme tends to produce over conversative POD results because it is heavily biased by the large number of misses of small size flaws.

(b) The cumulated down scheme works just like the cumulated up scheme except the cumulation begins with the largest flaw size. The problem with this scheme is knowing where to plot the calculated POD; at the largest flaw size, at the median, or at some other flaw size within that particular interval. This scheme may tend to produce optimistic results because the POD can be biased by the large number of detections of large size flaws, especially if the POD is plotted below the median size in the interval.

(c) In the range scheme, the total number of measurements is lumped into several groups. Each group contains a large enough sample size to produce a potentially high POD at a high CL. As in the previous two schemes, each group contains a range of flaw sizes. The calculated POD for each separate group is then plotted somewhere within that flaw size range. This scheme is the most appropriate for treating NDE reliability data, provided a large number of measurements are made so that each flaw size range can be reasonably small.

(d) The overlapping sixty point scheme begins by cumulation of 60 data points starting with the largest flaw size. The POD is calculated for this group and reported at one of the flaw sizes

within the range. The next range is obtained by locating the median of the initial group and cumulating down 60 points from that point. The POD for this new group is plotted and the process is repeated until the data set is exhausted. Thus, each group so obtained overlaps each adjacent group by 50%.

(e) The modified cumulated up scheme (MCUI) was developed under this contract and it hopefully embraced the strength and avoided some of the shortcomings of the previously discussed schemes. In the MCU scheme, the POD curve at a selected CL is plotted using the cumulated up scheme. The curve is normalized so the maximum POD is unity. An example of this is illustrated in Figure 4-1. The normalized POD is then divided into 5% intervals. The flaw sizes within each of the 20 intervals form a range and thereby divides a set of data into 20 ranges in a systematic manner. The size interval is found that contains the first miss, counting from the size interval in which the largest flaw size is located. Then, starting with the next larger size interval, the POD is calculated by the cumulated up scheme and is reported at the size interval where the cumulation stops. The POD for the size interval containing the first miss and the other ranges toward the smallest flaw size is calculated with the range scheme.

(f) The MCUII scheme was developed to avoid a potential shortcoming with the MCUI system. In the MCUI scheme it was assumed that the largest cracks are 100% detected. It was possible that a miss or failure of detection may occur at or near the largest flaw size range. In that event, the MCUI scheme reverts to the range scheme which contains 21 ranges. In order to avoid the potential drawback, the MCUII scheme was developed. The MCUII scheme works very similar to the MCUI scheme except that cumulation begins with the next larger size interval above second size range containing a miss.

Comparison of these six cumulative schemes with a common set of data will be given in a later section of this report.

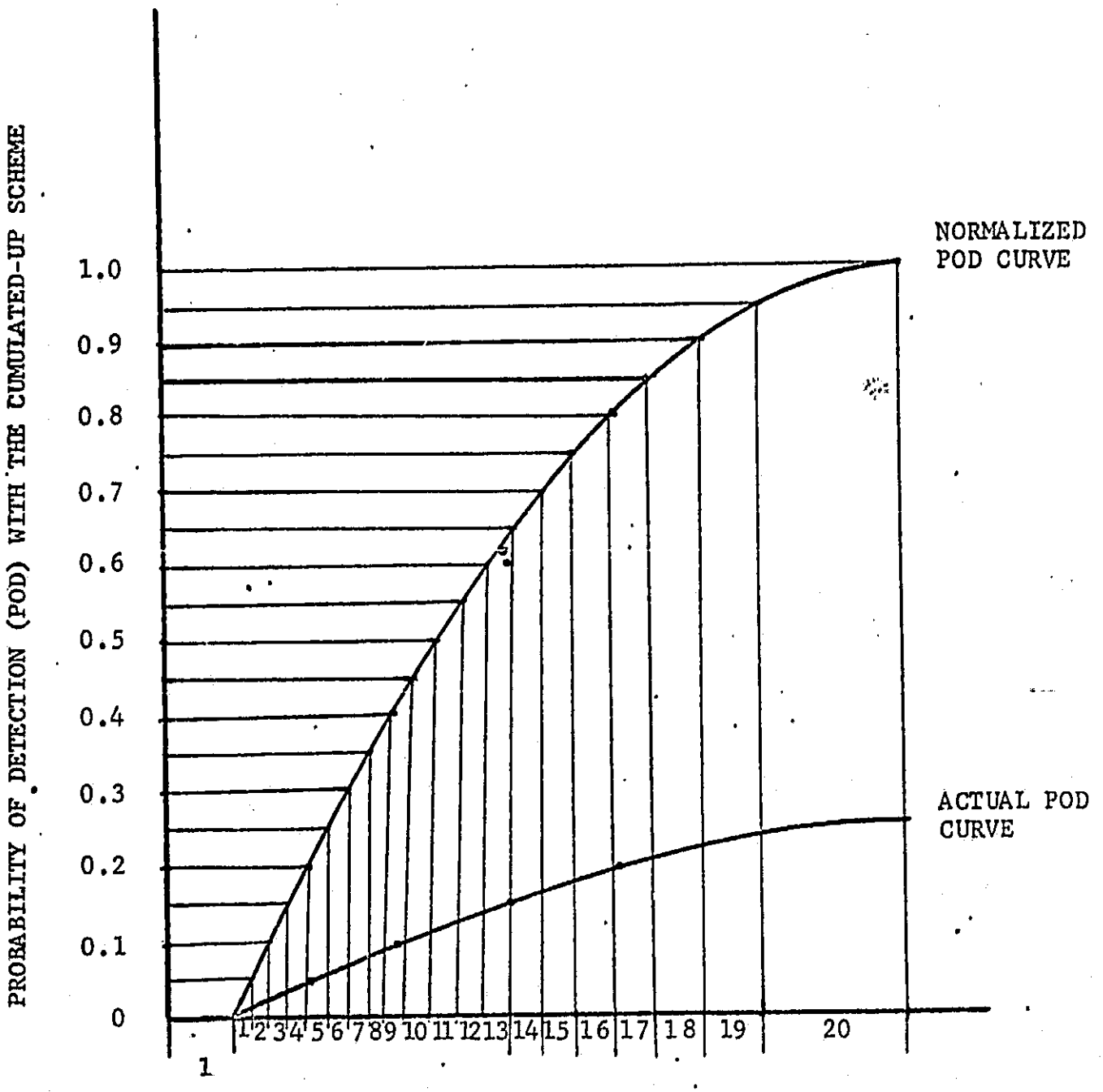

Figure 4-1 Flaw Size in Ranges

4.4 Data Pooling

4.4.1 Data Pooling by NDE Method and Parameters

Data that meets the preliminary criterion as described in subsection 3.1 will be input to the computer for statistical analysis. Then data from several sets will be pooled and analyzed if they have a common set of parameters. Data from different NDE methods will not be pooled. For a given NDE method such as ultrasonic shear wave at 5 MHz, reliability curves will be plotted for a material type, a defect type, an environment, a specimen geometry and defect location, and either before or after enhancement such as proof test. Composite reliability curves can be plotted by pooling data with different parameters, such as pooling 5 and 10 MHz shear wave data, laboratory and production data, flat plate and cylindrical shell data, etc. Table 4-1 is a matrix showing the possible combination of parameters for a given NDE method for reliability analysis.

4.4.2 Statistical Pooling Criteria

The NDE data that is compiled for this contract is being collected from different sources using different calibration factors, different equipment, different personnel, different environments, etc. Each set of data therefore contains unique source characteristics that preclude indiscriminate pooling for reliability calculations.

A statistical pooling criteria has been developed to safeguard against mistakes or inconsistencies in the data which could produce abnormal statistical results. The data pooling technique is based solely on the binomial distribution and is described below as a procedure which can be implemented on a computer. The procedure consists of the following four steps.

(1) All data sets having common parameters that are considered to be poolable are used to estimate the probability of detection from

$$\bar{p}_c = \frac{\sum_{k=1}^{M} n_k}{\sum_{k=1}^{M} N_k + 1} \quad . \tag{9}$$

TABLE 4-1 DATA POOLING MATRIX

Material	Defect Type 1	2	3	4	5	6	7	Environment 1	2	3	Before/ After Enhancement 1	2	Specimen Geometry and Defect Location 1	2	3	4	5	6	7	8
Al Alloy 1																				
2																				
3																				
4																				
5																				
6																				
7																				
Ti Alloy 1																				
2																				
3																				
4																				
5																				
Steel Type 1																				
2																				
3																				
4																				
5																				
6																				
7																				

(2) The average probability

$$\bar{p}_k = \frac{n_k}{N_k} \tag{10}$$

of each of the data sets is computed.

(3) Consider the binomial distribution function for each data set (N_k, n_k) having a true probability of detection given by $\bar{p}_c$. The two-sided probability, α_2, that (N_k, n_k) and all less likely outcomes are possible is computed from

$$\alpha_2 = 2 \sum_{i=0}^{n_k} \binom{N_k}{i} \bar{p}_c^{\,i} \; (1-\bar{p}_c)^{N_k-i} \tag{11}$$

$$\text{if} \quad \frac{n_k}{N_k} < \bar{p}_c$$

or by

$$\alpha_2 = \sum_{i=n_k}^{N_k} \binom{N_k}{i} \bar{p}_c^{\,i} \; (1-\bar{p}_c)^{N_k-i} \tag{12}$$

$$\text{if} \quad \frac{n_k}{N_k} > \bar{p}_c \; .$$

(4) All data sets having a value of α_2 less than a reference value α' (computer input value) are removed as candidates for pooling.

The choice of α' is somewhat arbitrary and depends upon the acceptable risk. The exact value of α' selected will have to be compatible with the data sets. A different value of α' might have to be selected for each NDE method. The data sets that will be rejected from pooling for a given α' value will be reviewed. If no abnormalties are found within each set of data (i.e., no mistakes in data recording, or other possible means of causing the probability of detection to be normally high or low),

a new value of α' will be tried and one that will permit the data sets to be pooled with the data base will be selected.

Table 4-2 is an example which contains six hypothetical binomial experiments (assuming all sets have the same measurement parameters). The α_2 values (confidence levels) for sets C, E, and F are very low. The α_2 values for sets C and E were calculated using equation (11) and for set F was calculated using equation (12). For set C one is only 2.22% confident that one out of eight measurements is successful. For set E one is only 0.86% confident that one out of ten measurements is successful. For set F one is only 0.11% confident that seven out of seven measurements are successful. The confidence is too low for measurements to be pooled with those of sets A, B, and D.

Upon rejecting sets C, E, and F, new α_2 values are calculated for sets A, B, and D using the new probability (P=16/40). These three sets have comparable confidence limits and they will be pooled.

Table 4-2

SIX SETS OF DATA FROM DIFFERENT SOURCES
(A-F) TESTED FOR POOLING

Source	N Number of Measurements	n Number of Successes	α (Alpha)
A	24	9	.4085 (accepted)
B	8	3	.3612 (accepted)
C	8	1	.0222 (rejected)
D	8	4	.3572 (accepted)
E	10	1	.0086 (rejected)
F	7	7	.0011 (rejected)
TOTAL	65	25	
A	24	9	.3641 (accepted)
B	8	3	.3361 (accepted)
D	8	4	.3834 (accepted)
TOTAL	40	16	

4.5 Computer Codes

This section presents the latest outline of the NASAR computer procedure which will be used to determine NDE reliability. The computer flow logic is given in Figure 4-2 with some of the block functions described in the included glossary. The current status of the code segments is shown in Table 4.3.

The code is modular in construction and consequently amenable to growth or improvement. It is entirely based on binomial statistics. It is written in Fortran IV and constructed in a format that will make it convertible for any digital computer with minor modification.

A main calling program guides the flow logic and calls on subroutines as required. At the first branch point (MODE) there is a choice to read in new data (REDAT), to edit the mass data (LIBEDI)*, or to proceed with calculations. The options that are to be exercised in calculations are read in and the desired data is then retrieved from mass storage through the use of a special subroutine (OPTEX). At this point there is a choice to list the extracted data according to a pre-determined format and to run or terminate. The choice to run calls GRPR which groups data into twenty one flaw size intervals for analysis by cumulating up, normalizing, then segmenting into 5% steps of increasing probability of detection. The data at this point may be from different sources and must therefore be pooled. A subroutine (POOLR) is used to test data for compatibility in pooling, list rejected data, and to form a compatible data set. Data pooling can however be bypassed and all data can be combined. Once an acceptable set of data for 21 flaw size intervals has been assembled, the binomial equation (BINOM) is solved to determine the lower limit probability of detection POD at confidence levels of 50, 70, 90, 95, and 99 percent. Data requirements that are expected to produce a 90% probability of detection at 95% confidence in each size range category will be computed (DEFIC) for the case where <u>no</u> misses result, or where <u>one</u> or <u>two</u> misses result. Data will be plotted or printed out, depending upon computer peripherals available.

---

* LIBEDI may be removed from this flow logic and made available as a separate computer code.

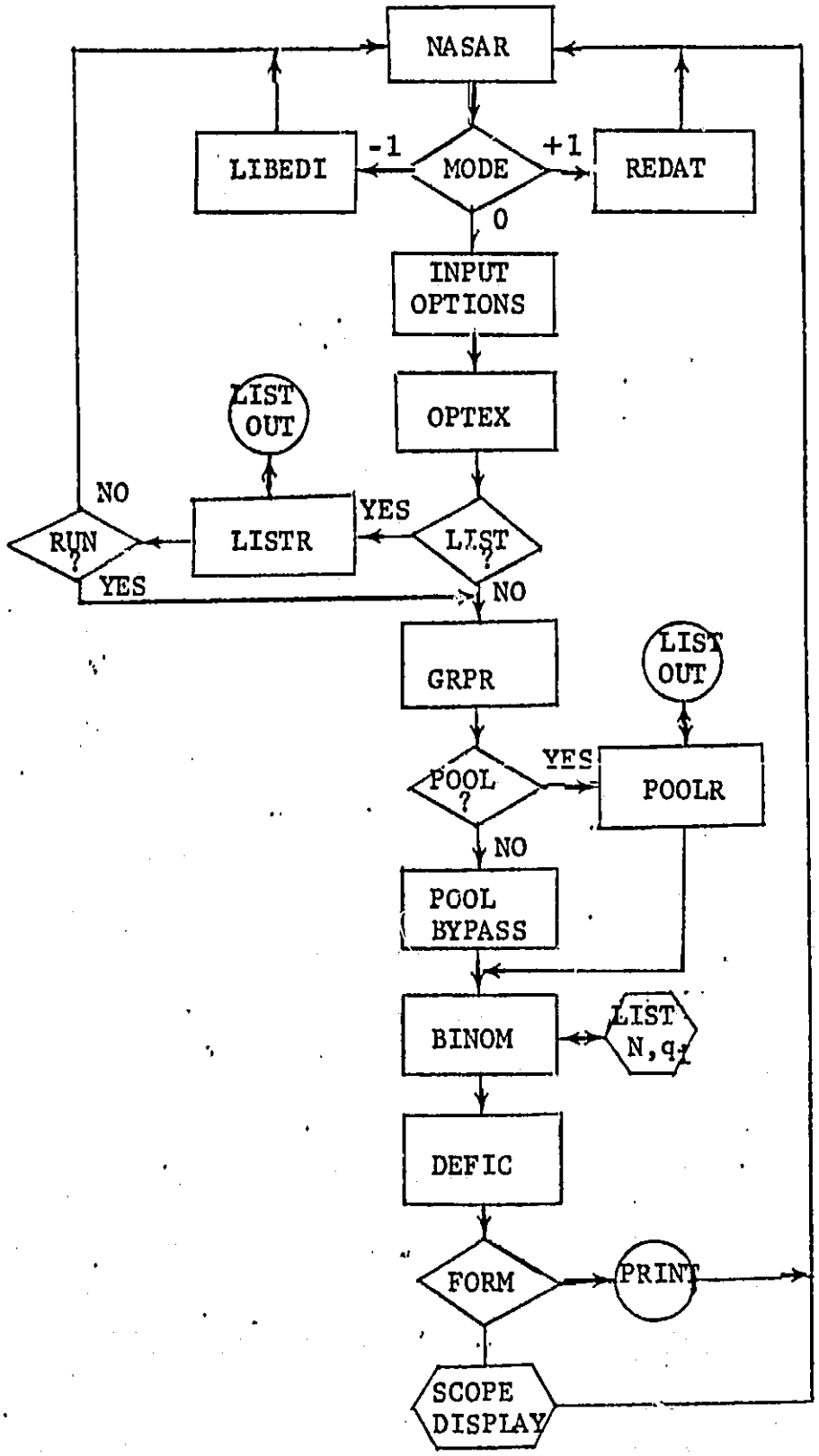

FIGURE 4-2 COMPUTER CODE FLOW LOGIC

TABLE 4-3

STATUS OF COMPUTER PROGRAMMING

SEGMENT NAME	FORMULATED	CODING	DEBUG*
MAIN	Complete	Complete	Complete
REDAT	Complete	Complete	Complete
LIBEDE	Complete	50%	
INPUT OPTIONS	Complete	Complete	Complete
OPTEX	Complete	Complete	Complete
LISTR	Complete	Complete	Complete
GRPR	Complete	Complete	Complete
POOLR	Complete	Complete	Complete
POOL BYPASS	Complete	Complete	Complete
BINOM	Complete	Complete	Complete
DEFIC	Complete	Complete	Complete
DISPLAY	Complete	Complete	Complete

GLOSSARY

MAIN: ---------- is a calling program which accomplishes the flow logic shown in Figure 4.2.

REDAT: ---------- is a computer procedure that transfers input data to mass storage as sequential blocks of 18-4 digit numbers JJ(N) (N=1,18).

LIBEDE: --------- makes it possible to locate a specific block of data from mass storage and replace it with an edited block.

INPUT OPTIONS: -- is a set of input blocks OPT(J,N) (J=1...5; N=1,18) which selects data sets for special listings or data analysis. This allows a sorting of data according to NDI technique, material type, source, etc.

OPTEX: ---------- scans mass memory data blocks and rewrites these satisfying selection options onto disk memory for data analysis or listing.

LISTR: ---------- allows a data set to be listed according to a pre-determined format.

GRPR: ---------- converts the data stored on disk into 5 percent intervals of increasing probability of detection by the "cumulating up" scheme.

GLOSSARY (Cont'd)

POOLR:---------- tests data from different data sources for pooling into a common data set. Lists out rejected data.

POOL BYPASS:---- pools data into a common data set without statistical tests for compatibility.

BINOM:---------- Iteratively solves the binomial equation

$$G = \sum_{i=0}^{n-1} \binom{N}{i} p_1^{i} (1 - p_1)^{N-i}$$

for p_1 when the confidence level G, the number of tests N, and the number of detections n are specified. p_1 values corresponding to G = .50, .70, .90, .95, and .99 are computed.

DEFIC:---------- the binomial equation with G = .95, $P_L = .90$, $N = N_o + \delta$, and $n = n_o + \delta - \epsilon$ where N_o is the number of tests, n_o is the number of successes, and δ is the number of new tests required if ϵ failures are encountered.

DISPLAY:------- will list NDT reliabilities, and data deficiencies in tables or on a scope display.

4.6 Lower One-Sided Confidence Limits Calculations

This section is a detailed presentation of the procedure used for computing one-sided-lower confidence limits for NDT reliability data and for determining data deficiencies.

Data input to this calculation will be in 21 flaw size intervals as shown in Table 4-4 (typical data from eddy current detection of cracks in fastener holes). Cumulation of detection and measurements assumes that larger cracks are more detectable than smaller cracks.

For each histogram interval, the number of measurements N is read from the column labeled, "Number of Measurements" and the number of detections n is obtained from the next column to the right.

The binomial Equation (6) is solved by setting G equal to the confidence level desired and determining the value of which satisfies the equation. A Fortran IV program which has been made operable in a PDP 11/45 computer to perform this function is given in Figure 4-3. p_1 is the probability of detection at the lower limit.

The procedure used to determine how many more measurements are required in each interval for the 95% confidence curve to reach the 90% probability of detection level is computed by solving for δ and ϵ in Equation (7). Figure 4-4 gives the listing of a Fortran IV program to perform this calculation. The main computer program of which the BINOM, the DEFIC, and all the other subroutines have been completed; and they will be included in the final report.

Using these computer programs the p_1 is calculated at the lower one-sided confidence limits at confidence levels of 50, 70, 90, 95, and 99 percent. The data used for these calculations was obtained with an automated eddy current method to inspect for cracks in bolt holes. This set of data is presented in Table 4-4(a). The first three columns give the lower, median, and upper length of the cracks in each of the 21 ranges. The fourth and fifth columns give the number of measurements and detections for each of the ranges, respectively. The sixth to tenth columns give the POD at 50, 70, 90, 95, and 99 percent confidence limits, respectively. The eleventh to thirteenth columns give the new measurements required to achieve a 90% POD at 95% confidence level with zero, one, and two misses respectively.

Table 4-4a Data Base Set and POD with the Range Scheme

CRACK LENGTH			DATA		LOWER ONE SIDED CONFIDENCE LEVELS					NEW DATA REQ.		
LOX	MED	HIX	N	DET	50PCT	70PCT	90PCT	95PCT	99PCT	MS0	MS1	MS2
2.	8	10.	44.*	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
10.	10.	10.	6.	1.	0.109	0.058	0.017	0.009	0.002	0.	0.	0.
12.	12.	12.	2.	1.	0.293	0.163	0.051	0.025	0.005	0.	0.	0.
12.	15.	20.	24.	2.	0.069	0.046	0.022	0.015	0.006	0.	0.	0.
20.	25.	30.	12.	2.	0.136	0.091	0.045	0.030	0.013	0.	0.	0.
30.	33.	35.	3.	2.	0.500	0.363	0.196	0.135	0.059	0.	0.	0.
40.	48.	60.	7.	2.	0.228	0.156	0.079	0.053	0.023	0.	0.	0
60.	60.	60.	1.	1.	0.500	0.300	0.100	0.050	0.010	0.	0.	0.
70.	70.	70.	2.	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59.
75.	75.	77.	3.	2.	0.500	0.363	0.196	0.135	0.059	0.	0	0.
85.	85.	100.	2.	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59.
110.	110.	130.	2.	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59.
130.	130.	140.	2.	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59.
140.	140.	150.	2.	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59.
150.	150.	150.	2.	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59.
160.	160.	160.	3.	3.	0.794	0.669	0.464	0.368	0.215	26.	43.	58.
160.	160.	165.	2	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59
170.	170.	180.	2.	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59.
220.	250.	260.	3.	3.	0.794	0.669	0.464	0.368	0.215	26.	43.	58.
260.	295.	380.	3.	3.	0.794	0.669	0.464	0.368	0.215	26.	43	58

Table 4-4b Data Set and POD with the Cumulated Up Scheme

CRACK LENGTH			DATA		LOWER ONE SIDED CONFIDENCE LEVELS					NEW DATA REQ.		
LOX	MED	HIX	N	DET	50PCT	70PCT	90PCT	95PCT	99PCT	MS0	MS1	MS2
2.	8.	10.	44.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	44.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
10.	10.	10.	50.	1.	0.014	0.007	0.002	0.001	0.000	0.	0.	0.
12	12	12.	52.	2.	0.032	0.021	0.010	0.007	0.003	0.	0.	0.
12.	15.	20.	76	4.	0.048	0.036	0.023	0.018	0.011	0.	0.	0.
20.	25.	30.	88.	6.	0.064	0.051	0.036	0.030	0.021	0.	0.	0
30.	33.	35.	91.	8.	0.084	0.070	0.052	0.044	0.033	0.	0.	0.
40.	48.	60.	98.	10.	0.098	0.083	0.064	0.056	0.043	0.	0.	0.
60.	60.	60.	99.	11.	0.107	0.092	0.072	0.064	0.050	0.	0.	0.
70.	70.	70.	101.	13.	0.125	0.109	0.087	0.078	0.062	0.	0.	0.
75.	75.	77.	104.	15.	0.141	0.123	0.101	0.091	0.074	0.	0.	0.
85.	85.	100.	106.	17.	0.157	0.139	0.115	0.105	0.087	0.	0.	0.
110.	110.	130.	108.	19.	0.172	0.154	0.129	0.118	0.099	0.	0.	0.
130.	130.	140.	110.	21.	0.187	0.168	0.143	0.132	0.112	0.	0.	0
140.	140.	150.	112.	23.	0.202	0.182	0.156	0.145	0.124	0.	0.	0.
150.	150.	150.	114.	25.	0.216	0.196	0.169	0.157	0.136	0.	0.	0.
160.	160.	160.	117.	28.	0.236	0.216	0.188	0.176	0.154	0.	0.	0.
160.	160.	165.	119	30.	0.249	0.228	0.200	0.188	0.165	0.	0.	0
170.	170.	180.	121.	32.	0.261	0.240	0.212	0.199	0.176	0.	0.	0.
220:	250.	260.	124.	35.	0.279	0.258	0.229	0.216	0.193	0.	0.	0.
260.	295.	380	127.	38.	0.296	0.275	0.246	0.233	0.208	0.	0.	0.

Table 4-4c Data Set and POD with the Cumulated Down Scheme

CRACK LENGTH* LOX	MED	HIX	DATA N	DET	LOWER ONE SIDED CONFIDENCE LEVELS 50PCT	70PCT	90PCT	95PCT	99PCT	NEW DATA REQ. MS0	MS1	MS2
2.	8.	10.	127.	38.	0.288**	0.267**	0.237**	0.224**	0.199**	0.	0.	0.
0.	0.	0.	83.	38.	0.452	0.424	0.383	0.364	0.329	0.	0.	0.
10.	10.	10.	83.	38.	0.452	0.424	0.383	0.364	0.329	0.	0.	0.
12.	12	12.	77.	37.	0.474	0.444	0.402	0.382	0.346	0.	0.	0.
12.	15.	20.	75.	36.	0.473	0.443	0.401	0.380	0.343	0.	0.	0.
20.	25.	30.	51.	34.	0.656	0.621	0.568	0.543	0.495	200.	212.	224.
30.	33.	35.	39.	32.	0.805	0.771	0.717	0.689	0.636	90.	103.	115.
40.	48.	60.	36.	30.	0.816	0.781	0.726	0.697	0.642	80.	93.	106.
60.	60	60.	29.	28.	0.943	0.918	0.872	0.847	0.792	17.	32.	47.
70.	70.	70.	28.	27.	0.941	0.915	0.868	0.842	0.785	18.	33.	48.
75.	75	77.	26.	25.	0.936	0.909	0.858	0.830	0.771	20.	35.	50.
85.	85.	100.	23.	23.	0.970	0.949	0.905	0.878	0.819	6.	23.	38.
110.	110.	130.	21.	21.	0.968	0.944	0.896	0.867	0.803	8.	25.	40.
130.	130.	140.	19.	19.	0.964	0.939	0.886	0.854	0.785	10.	27.	42.
140.	140.	150.	17	17.	0.960	0.932	0.873	0.838	0.763	12.	29.	44.
150.	150.	150.	15.	15.	0 955	0.923	0.858	0.819	0.736	14.	31.	46.
160.	160.	160.	13.	13.	0.948	0.912	0.838	0.794	0.702	16.	33.	48.
160.	160.	165.	10.	10.	0.933	0.897	0.794	0.741	0.631	19.	36.	51.
170.	170.	180.	8.	8.	0.917	0.860	0.750	0.688	0.562	21.	38.	53.
220.	250.	260.	6.	6.	0.891	0.818	0.681	0.607	0.464	23.	40.	55.
260.	295.	380.	3.	3.	0.794	0.669	0.464	0.368	0.215	26.	43	58.

Table 4-4d Data Set and the POD with Overlapping 60 Points Scheme

CRACK LENGTH* LOX	MED	HIX	DATA N	DET	LOWER ONE SIDED CONFIDENCE LEVELS 50PCT	70PCT	90PCT	95PCT	99PCT	NEW DATA REQ. MS0	MS1	MS2
0.	0	0.	0.	0.	0.000	0.000	0.000	0 000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
10.	10.	10.	37.	0.	0 000	0.000	0.000	0.000	0.000	0.	0.	0.
20.	20.	20.	60.	4.	0.061	0.046	0.029	0.023	0.014	0.	0.	0.
50.	50.	50.	60.	10.	0.160	0.137	0.106	0.093	0.072	0.	0.	0.
380.	380.	380.	60.	35.	0.575	0.541	0.492	0.469	0.426	100.	100.	100.

*Multiply by .00254 to obtain flaw-size in cm

Table 4-4e Data Set and POD with the MCUI Scheme

CRACK LENGTH *			DATA		LOWER ONE SIDED CONFIDENCE LEVELS					NEW DATA REQ.		
LOX	MED	HIX	N	DET	50PCT	70PCT	90PCT	95PCT	99PCT	MS0	MS1	MS2
2.	8.	10.	44.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
10.	10.	10.	6.	1.	0.109	0.058	0.017	0.009	0.002	0.	0.	0.
12.	12.	12.	2.	1.	0.293	0.163	0.051	0.025	0.005	0.	0.	0.
12.	15.	20.	24.	2.	0.069	0.046	0.022	0.015	0.006	0.	0.	0.
20.	25.	30.	12.	2.	0.136	0.091	0.045	0.030	0.013	0.	0.	0.
30.	33.	35.	3.	2.	0.500	0.363	0.196	0.135	0.059	0.	0.	0.
40.	48.	60.	7.	2.	0.229	0.156	0.079	0.053	0.023	0.	0.	0.
60.	60.	60.	1.	1.	0.500	0.300	0.100	0.050	0.010	0.	0.	0.
70.	70.	70.	2.	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59.
75.	75.	77.	3.	2.	0.500	0.363	0.196	0.135	0.059	0.	0.	0.
85.	85.	100.	2.	2.	0.707	0.548	0.316	0.224	0.100	27.	44.	59.
110.	110.	130.	4.	4.	0.841	0.740	0.562	0.473	0.316	25.	42.	57.
130.	130.	140.	6.	6.	0.891	0.818	0.681	0.607	0.464	23.	40.	55.
140.	140.	150.	8.	8.	0.917	0.860	0.750	0.688	0.562	21.	38.	53.
150.	150.	150.	10.	10.	0.933	0.887	0.794	0.741	0.631	19.	36.	51.
160.	160.	160.	13.	13.	0.948	0.912	0.838	0.794	0.702	16.	33.	48.
160.	160.	165.	15.	15.	0.955	0.923	0.858	0.819	0.736	14.	31.	46.
170.	170.	180.	17.	17.	0.960	0.932	0.873	0.838	0.763	12.	29.	44.
220.	250.	260.	20.	20.	0.966	0.942	0.891	0.861	0.794	9.	26.	41.
260.	295.	380.	23.	23.	0.970	0.949	0.905	0.878	0.819	6.	23.	38

Table 4-4f Data Set and POD with the MCUII Scheme

CRACK LENGTH *			DATA		LOWER ONE SIDED CONFIDENCE LEVELS					NEW DATA REQ.		
LOX	MED	HIX	N	DET	50PCT	70PCT	90PCT	95PCT	99PCT	MS0	MS1	MS2
2.	8.	10.	44.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
0.	0.	0.	0.	0.	0.000	0.000	0.000	0.000	0.000	0.	0.	0.
10.	10.	10.	6.	1.	0.109	0.058	0.017	0.009	0.002	0.	0.	0.
12.	12.	12.	2.	1.	0.293	0.163	0.051	0.025	0.005	0.	0.	0.
12.	15.	20.	24.	2.	0.069	0.046	0.022	0.015	0.006	0.	0.	0.
20.	25.	30.	12.	2.	0.136	0.091	0.045	0.030	0.013	0.	0.	0.
30.	33.	35.	3.	2.	0.500	0.363	0.196	0.135	0.059	0.	0.	0.
40.	48.	60.	7.	2.	0.228	0.156	0.079	0.053	0.023	0.	0.	0.
60.	60.	60.	1.	1.	0.500	0.300	0.100	0.050	0.010	0.	0.	0.
70.	70.	70.	3.	3.	0.794	0.669	0.464	0.368	0.215	26.	43.	58.
75.	75.	77.	6.	5.	0.736	0.640	0.490	0.418	0.294	40.	55.	70.
85.	85.	100.	5.	5.	0.871	0.786	0.631	0.549	0.398	24.	41.	56.
110.	110.	130.	7.	7.	0.906	0.842	0.720	0.652	0.518	22.	39.	54.
130.	130.	140.	9.	9.	0.926	0.875	0.774	0.717	0.599	20.	37.	52.
140.	140.	150.	11.	11.	0.939	0.896	0.811	0.762	0.658	18.	35.	50.
150.	150.	150.	13.	13.	0.948	0.912	0.838	0.794	0.702	16.	33.	48.
160.	160.	160.	16.	16.	0.958	0.928	0.866	0.829	0.750	13.	30.	45.
160.	160.	165.	18.	18.	0.962	0.935	0.880	0.847	0.774	11.	28.	43.
170.	170.	180.	20.	20.	0.966	0.942	0.891	0.861	0.794	9.	26.	41.
220.	250.	260.	23.	23.	0.970	0.949	0.905	0.878	0.819	6.	23.	38.
260.	295.	380.	26.	26.	0.974	0.955	0.915	0.891	0.838	3.	20.	35.

*Multiply by .00254 to obtain flaw size in cm

```
      SUBROUTINE BIN(AR1,AR2,AR3,AR10)
    1 IF(AR2)2,2,4
    2 AR10=0.0
    3 RETURN
    4 IF(AR2-AR1)7,5,5
    5 AR10=(1.0-AR3)**(1.0/AR1)
    6 RETURN
    7 ATT=2.0*AR2
    8 IF(ATT-AR1)9,9,12
    9 AR4=AR2-1.0
   10 AR5=-1.0
   11 GO TO 15
   12 AR4=AR1-AR2
   13 AR3=1.0-AR3
   14 AR5=-1.0
   15 AR10=0.5
   16 AR6=1.0
   17 AR8=0.0
   18 AR9=1.0
   19 AR11=AR1
   20 AR7=(AR10**AR8)*((1.0-AR10)**(AR1-AR8))
   21 IF(AR8-AR4)22,27,22
   22 AR8=AR8+1.0
   23 AR9=AR9*AR11/AR8
   24 AR11=AR11-1.0
   25 AR7=AR7+AR9*(AR10**AR8)*((1.0-AR10)**(AR1-AR8))
   26 GO TO 21
   27 IF(AR3-AR7)28,28,30
   28 AR20=AR10-AR5/(2.0**(AR6+1.0))
   29 GO TO 31
   30 AR20=AR10+AR5/(2.0**(AR6+1.0))
   31 CCC=ABS(AR7-AR3)
   32 IF(CCC-0.0001)36,36,33
   33 AR6=AR6+1.0
   34 AR10=AR20
   35 GO TO 17
   36 IF(ATT-AR1)6,6,37
   37 AR10=1.0-AR10
   38 RETURN
   39 END
```

Figure 4-3 Computer Code to Calculate Lower One-Sided Confidence Limit

```
      SUBROUTINE DEFIC(AR1,AR2,FFF,AR4)
    1 A=AR1-AR2+FFF
    2 AR4=0.0
    3 IF(A)4,4,9
    4 AR4=29.0-AR1
    5 IF(AR4)6,6,7
    6 AR4=0.0
    7 RETURN
    9 X=1.0
   10 AR5=0.0
   11 C=1.0
   12 CCC=AR1+AR4
   13 AR5=0.9**CCC
   14 C=(C/X)*(AR1+AR4+1.0-X)
   15 DDD=AR1+AR4-X
   16 AR5=AR5+(0.1**X)*C*(0.9**DDD)
   17 IF(A-X)18,18,21
   18 IF(0.05-AR5)19,19,7
   19 AR4=AR4+1.0
      IF ( AR4 .EQ. 100. ) RETURN
   20 GO TO 9
   21 X=X+1.0
   22 GO TO 14
   23 END
```

Figure 4-4 Computer Code to Calculate Additional Measurements to Achieve 90% POD at 95% CL

Tables 4-4(b), 4-4(c), 4-4(d), 4-4(e), and 4-4(f) present the POD at the five confidence levels for the cumulated up scheme, the cumulated down scheme, the overlapping 60 points scheme, and the modified cumulated up (MCUI and MCUII) schemes respectively.

Figure 4-5(a) is the result obtained using the range scheme. Only the probability of detection at 95 and 50 percent confidence level is presented. The maximum POD at 95% CL is 0.368 for this scheme, which represents 3 detections with 3 measurements. This scheme is potentially the most appropriate to treat NDE reliability data, provided a large number of measurements are made. If the number of measurements is small for each range, such as 3 or 5, the results are not very useful. Figure 4-5(b) is the result obtained using the cumulated up scheme and reporting the binomial result at the defect range where the cumulation stops. The maximum POD at 95% CL is 0.233 for this scheme. The maximum POD is heavily biased by the large number of misses or failure of detection for small size defects. This scheme yields over-conservative results.

Figure 4-5(c) is the result obtained using the cumulated down (starting from the largest defect size) scheme and reporting the binomial results at the defect range where the cumulation stops. The maximum POD at 95% CL is 0.878 for this scheme which was obtained with 23 detections for 23 measurements. This scheme bias the POD with the large number of detections of large size defects. This scheme generally yields optimistic results. Further, this scheme does not produce larger POD for increasing defect sizes which has been shown to be the case when adequate measurements are made.

Figure 4-5(d) is the result obtained using the overlapping 60 point scheme. This scheme begins by cumulation of 60 points or measurements starting with the largest defect sizes. The POD is calculated for the total number of detections out of these measurements and reporting the calculated results at the largest defect size. The next POD is calculated by dropping 30 points, starting with the largest defect size and adding 30 new points of smaller defect sizes and reporting the calculated results at the largest defect size in these 60 points. Because this set of data has a total of 127 measurements, only three calculations can be made with this scheme. This scheme does not yield representative results when the total number of points or measurements is small (like 100 to 300).

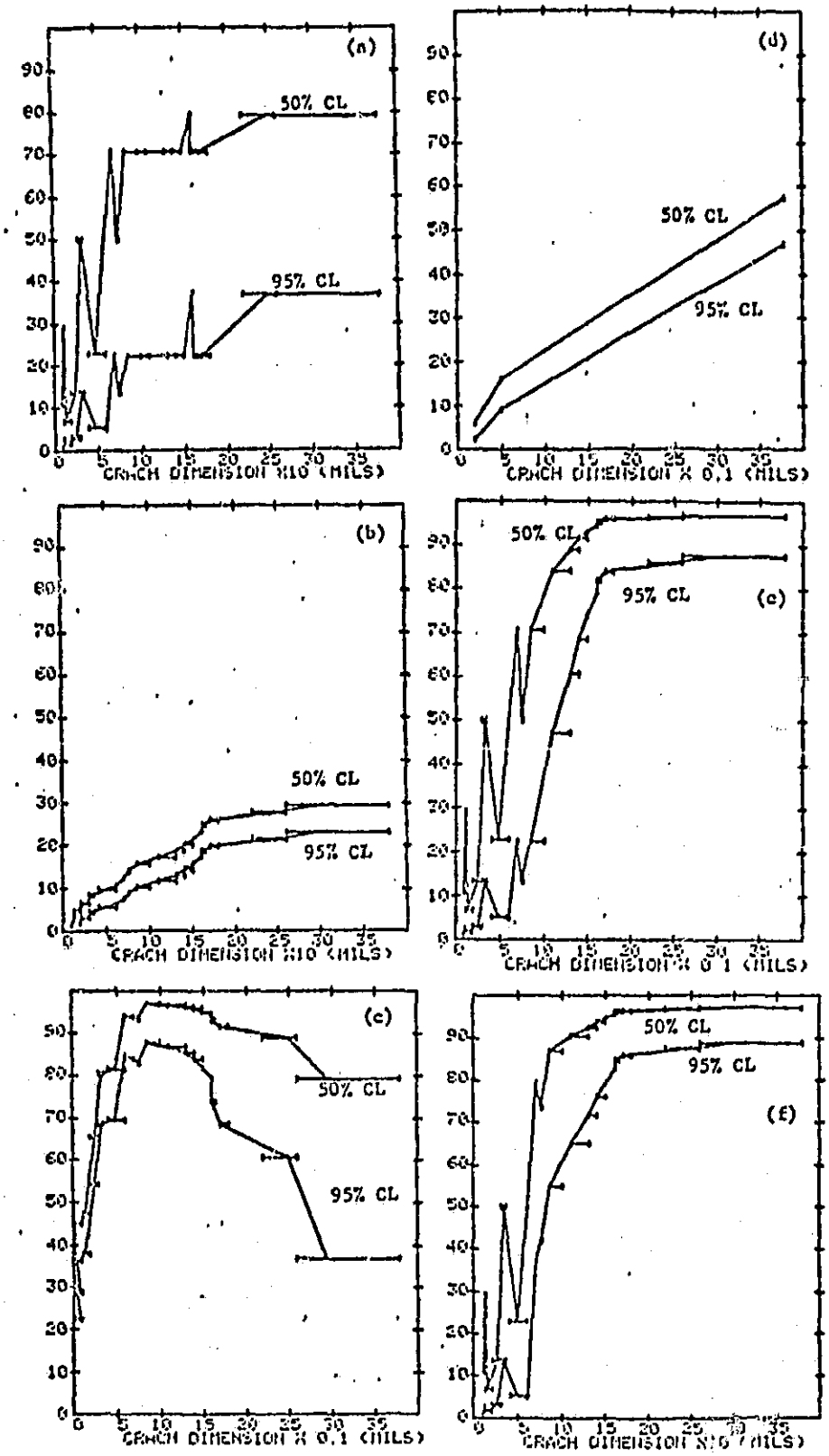

Figure 4-5 Probability of Defect Detection for the Range (a), Cumulated Up (b), Cumulated Down (c), Overlapping 60 Points (d), MCUI (e), and the MCUII (f) Scheme

Figure 4-5(e) is the result obtained using the MCUI scheme. This scheme begins by locating the first range from the end with the largest defect size that has a miss or failure of detection. Then, starting with the next range toward the largest defect size, the POD is calculated by the cumulated up scheme and reporting the calculation at the range where the cumulation stops. The POD for the range containing the first miss and the ranges toward the smallest defect size is calculated with the range scheme. The maximum POD at 95% CL for this scheme is 87.8% which represents 23 detections with 23 measurements.

Figure 4-5(f) is the result obtained using the MCUII scheme. The maximum POD at 95% CL for this scheme is 89.1% which represents 26 detections with 26 measurements. Both of the MCU schemes yield comparable results.

The last three columns of Tables 4-4(a) to 4(f) indicate the number of new measurements that must be made with zero, one, or two misses in order to achieve a 90% POD at 95% CL. For the MCUI scheme, six (6) more measurements without a miss must be made in order to achieve 90% POD at 95% CL. The zeroes indicate that the number of new measurements need to be made are too large for practical considerations.

V. CONCLUSION

During the first six months of this contract, twenty-five sets of relevant NDE reliability data have been identified and twenty-two sets have been collected. These data have been separated into three categories: (1) fifteen sets of data that satisfy a preliminary criterion will be considered for statistical analysis; (2) three sets of data that can be used if additional documentation is received or permission to use the data is granted; and (3) four sets of data that are very unlikely to become usable. These data have also been separated according to the complexity of specimen geometry.

A preliminary criterion to select data for consideration for statistical analysis has been developed. A preliminary model to grade the quality of the data sets has been developed. Data input formats and keys for the ultrasonics, eddy current, liquid penetrant, magnetic particle, and radiography have been formulated. A comprehensive computer program to calculate the probability of flaw detection at several confidence limits by the binomial distribution has been written and made operative. This program also selects data sets for pooling and tests the statistical pooling criteria before calculating the composite detection reliability. It also identifies data deficiency. An example of the calculated reliability of crack detection in bolt holes by an automated eddy current method is presented.

During the next six months of this program, the criteria to evaluate the data for statistical analysis will be refined. The model to grade the data quality and validity will be refined. The data input formats and key for each NDE method will be finalized. A large majority of this next six months will be used to calculate the reliability of flaw detection per NDE method per sets of parameters identified in Table 4-1 as well as to complete the necessary tasks identified in the program plan.

APPENDIX

DATA INPUT FORMAT KEYS (DIFK)

FOR

ASSESSMENT OF NDE RELIABILITY DATA

DATA ENTRY NUMBER SEQUENCE COL. 1-5

IDENTIFICATION NUMBER FOR DATA POINT ENTRY. STARTING WITH

00001

SPECIFIC CRACK NUMBER COL. 6-9

IDENTIFICATION NUMBER FOR A SPECIFIC CRACK OR FLAW IN TEST SPECIMENS. MULTIPLE CRACKS IN THE SAME SPECIMEN ARE IDENTIFIED IN COLUMN 42

0000 CONTROL SPECIMEN WITH NO FLAWS
0001 CRACKS NUMBERED BY STARTING WITH 0001

DATA SOURCE COL. 10-11

00 NO INFORMATION
01 GD/FW
02 CONVAIR/SAN DIEGO
03 BOEING COMMERCIAL AIRPLANE CO.
04 MARTIN MARIETTA
05 ROCKWELL INTERNATIONAL B-1 DIVISION
06 LOCKHEED GEORGIA CO.
07 MC DONNELL DOUGLAS
08 AFML
09 TRW
10 GENERAL ELECTRIC, EVENDALE, OHIO
11 FAIRCHILD HILLER
12 LOCKHEED CALIF.
13 ROCKWELL INTERNATIONAL SPACE CENTER
14 BOEING WICHITA

PROGRAM IDENTIFICATION COL. 12-13

00	
01	PRACTICAL SENSI. LIMITS OF PRODUCTION NDT METHODS IN A1 & STEEL
02	THE DETECTION OF FATIGUE CRACKS BY NDT METHODS
03	EVAL. OF THE RELI AND SENSI OF NDT METHODS FOR TI ALLOYS
04	USAF A10 SPO DEMO PROGRAM
05	USAF B-1 SPO DEMO PROGRAM
06	
07	
08	
09	
10	
11	
12	A-4 (F-111)
13	FW # 1-3 (F-111)
14	FW # 1-4 (F-111)
15	F-111 SPO-HUMAN FACTORS PROGRAM

MATERIAL COL. 14-15

00	NOT KNOWN
01	2219-T87 A1
02	2024 A1
03	4340M STEEL 270-300 ksi
04	Ti-6A1-4V
05	
06	
07	
08	
09	
10	D6AC STEEL 220-240 ksi
11	17-4 STAINLESS STEEL

DEFECT TYPE COL. 16 and 17

00 PERFECTLY CLEAR, FREE OF FLAWS
01 FATIGUE CRACK WITH NO ADDITIONAL FATIGUE CYCLES AFTER REMOVAL OF EDM STARTER NOTCH
02 ELOX SLOT
03 SAW CUT
04 WELD DEFECT (LACK OF FUSION)
05 WELD DEFECT (LACK OF PENETRATION)
06 WELD DEFECT (POROSITY)
07 FORGING FLAWS WITH OXIDE IN FLAW
08 HYDROGEN EMBRITTLEMENT
09
10 FATIGUE CRACK WITH ADDITIONAL FATIGUE CYCLES AFTER REMOVAL OF EDM STARTER NOTCH
11 FORGING FLAWS WITH
12 FORGING FLAWS WITH

OPERATOR IDENTIFICATION NUMBER COL. 18

This column is used to identify the inspection operator who participated in the inspection to obtain the data.

SPECIMEN SURFACE FINISH COL. 19-20

00 NO INFORMATION
01 0-32 RMS AS MACHINED
02 33-64 RMS AS MACHINED
03 65-125 RMS AS MACHINED
04 126-250 RMS AS MACHINED
05 0-32 RMS AS MACHINED THEN CHEMICALLY ETCHED
06 33-64 RMS AS MACHINED THEN CHEMICALLY ETCHED
07 65-125 RMS AS MACHINED THEN CHEMICALLY ETCHED
08 126-250 RMS AS MACHINED THEN CHEMICALLY ETCHED
09
10 NO COATING
11 E, Cd (EPOXY, CADMIUM PLATE COATING)
12 E, C/A (EPOXY, CONVERSION AND ANODIZED COATING)
13 P, Cd (POLYURETHANE, CADMIUM PLATE COATING)
14 P C/A (POLYURETHANE, CONVERSION AND ANODIZED COATING)
15 E, FSA/Cd EPOXY, FLAME SPRAYED ALIMINUM, CADMIUM PLATE COATING)
16 P, FSA/Cd (POLYURETHANE, FLAME SPRAYED ALIMINUM, CADMIUM PLATE COATING)
17 DRY FILM LUBRICANT

DEFECT ORIENTATION, LOCATION, AND PRESENCE EXPECTATION COL. 21

THIS COLUMN COMBINES INFORMATION ON PRIOR AND OR LACK OF KNOWLEDGE ON DEFECT ORIENTATION, LOCATION, AND PRESENCE IN THE SPECIMEN

0 Defect orientation, location, and presence not known
1 Defect orientation known, location and presence not known
2 Defect orientation and location known, presence not known
3 Defect orientation, location, and presence known
4 Defect orientation not known, location and presence known
5 Defect orientation and location not known, presence known
6 Defect orientation and presence known, location not known
7
8

INSPECTION ENVIRONMENT COL. 22

0 NO INFORMATION
1 PRODUCTION LINE ENVIRONMENT
2 LABORATORY
3 FIELD SERVICE

DEFECT DETECTION/FALSE INDICATION COL. 23

THIS COLUMN SIGNIFIES THE SUCCESS OR FAILURE OF THE INSPECTION.

0 No Defect Found, False Indication Not Recorded
1 No Defect Found, False Indication Recorded, Found None
2 No Defect Found, False Indication Recorded, Found One
3 No Defect Found, False Indication Recorded, Found Two
4 No Defect Found, False Indication Recorded, Found Three
5 Defect Found, False Indication Not Recorded
6 Defect Found, False Indication Recorded, Found None
7 Defect Found, False Indication Recorded, Found One
8 Defect Found, False Indication Recorded, Found Two
9 Defect Found, False Indication Recorded, Found Three

OPERATOR QUALIFICATION COL. 24

0 NO INFORMATION
1 LEVEL 1
2 LEVEL 2
3 LEVEL 3
4 FIELD SERVICE TECHNICIAN
5 LABORATORY TECHNICIAN
6 LABORATORY ENGINEER OR SCIENTIST
7
8
9 ENGINEER

DETECTION ENHANCEMENT COL. 25

THIS COLUMN IDENTIFIES ANY ENHANCEMENT SCHEME FOR CRACK DETECTION SUCH AS:

0 NO INFORMATION
1 PROOF LOAD
2 OPAQUE ADDITIVE
3 FLUORESCENT ADDITIVE
4 ELECTRONIC IMAGE ENHANCEMENT
5

DATA RECORDING AND PRESENTATION COL. 26

THIS COLUMN REFERS TO THE METHOD OF DATA RECORDING AND PRESENTATION BY THE CODES:

0 NO INFORMATION
1 MANUAL RECORDING OF VISUAL DISPLAY
2 MANUAL RECORDING OF METER OR SCOPE DISPLAY
3 MECHANIZED RECORDING OF VISUAL DISPLAY
4 RECORDING OF METER OR SCOPE DISPLAY
5 COMPUTER RECORDING OF METER OR SCOPE DISPLAY

MODE OF SCAN COL. 27

THIS COLUMN REFERS TO THE MODE OF SCANNING IN THE INSPECTION PROCESS

0 NO INFORMATION
1 MANUAL HAND SCAN
2 MECHANIZED SCAN, HAND INDEX
3 MECHANIZED SCAN AND INDEX
4 COMPUTER CONTROLLED SCAN AND INDEX

ACTUAL CRACK LENGTH (*) COL. 28-31

THE CRACK LENGTH AS DETERMINED BY NDI TECHNIQUES WHERE APPLICABLE (*) COL. 32-35

THE ACTUAL CRACK DEPTH (*) COL. 36-38

THE THICKNESS OF THE SPECIMEN AREA WHERE THE CRACK IS LOCATED (**) COL. 39-41

INSPECTION PROCEDURE/MULTI-FLAW SPECIMEN COL. 42

THIS COLUMN SIGNIFIES WHETHER THERE WAS A STANDARD PROCEDURE FOR THE INSPECTOR TO FOLLOW. MULTIPLE CRACK SPECIMENS ARE ALSO IDENTIFIED BY A CODE IN THIS COLUMN.

0 NO INFORMATION
1 STANDARD INSPECTION PROCEDURE USED, SINGLE FLAWED SPECIMEN
2 " " " " , MULTIPLE " "
3 " " , " NOT USED, SINGLE FLAWED SPECIMEN
4 STANDARD INSPECTION PROCEDURE NOT USED, MULTIPLE SPECIMEN
5
6
7
8
9
10

* Units (cm/.00254)
** Units (cm/2.54)

REFERENCE STANDARD TYPE AND SIZE COL. 43-44

THIS COLUMN IDENTIFIES THE TYPE AND SIZE OF REFERENCE STANDARD USED IN THE INSPECTION AS FOLLOWS:

0	REFERENCE STANDARD NOT USED
1	ELOX SLOT
2	FATIGUE CRACK
3	FLAT BOTTOM HOLE
4	FORGING FLAW
5	SAW CUT
6	SIDE DRILLED HOLE
7	VERTICAL DRILLED HOLE
8	.0396875 cm. (1/64 in.) Dia. FBH
9	.079375 cm. (2/64 in.) " "
10	.1190625 cm. (3/64 in.) " "
11	.15875 cm. (4/64 in.) " "
12	.1984375 cm. (5/64 in.) " "

MATERIAL IN DEFECT COL. 65

This col. identifies the type of material within the defect.

0	No information
1	Air
2	Water

SPECIMEN GEOMETRY AND DEFECT LOCATION COL. 66-67

These columns describe the location of the defect in the test specimen

0	No information
1	On flat parts and more than 2.54/2 cm. from the edge
2	On flat parts and less than or equal to 2.54/2 cm. from edge
3	On right cylindrical shell of 3 x 2.54 cm. in diameter and more than ½ inch from the edge
4	On right cylindrical shell of 3 x 2.54 cm. in diameter and less than or equal to (2.54/2 cm.) inch from the edge
5	On the top corner of a bolt hole
6	On the bottom corner of a bolt hole

NDI DEFECT DEPTH COL. 68-70

These columns contain the depth of the defect as indicated by the NDI method.**

0 NDI method cannot tell defect depth
1

NDI METHODS COL. 71

This Col. identifies the NDI method used in the inspection

0 Ultrasonic
1 Eddy Current
2 Liquid Penetrant
3 Magentic Particle
4 X-ray
5
6
7
8
9

GRADE COL. 72

This col. contains the grade which describes the non-statistical quality of the data according to the model developed in TASK II of this program. An ideal set will be given a score of 100. The overall quality of the data which includes the statistical quality will be obtained for each sub-set of data.

0	0 - 9
1	10 - 19
2	20 - 29
3	30 - 39
4	40 - 49
5	50 - 59
6	60 - 69
7	70 - 79
8	80 - 89
9	90 - 100

** Units cm./2.54

DATA INPUT FORMAT KEY FOR ULTRASONICS

ULTRASONIC METHODS COL. 45

This column identifies the ultrasonic method used in the inspection

0 No information
1 Shear Wave - Pulse Echo
2 " " - Pitch-Catch
3 Delta Scan
4 Compressional Wave - Pulse Echo
5 " " - Through Transmission
6 Surface Wave

FREQUENCY IN MHz COL. 46

This column identifies the frequency used for the ultrasonic method

0 No information
1 1
2 2.25
3 5
4 10
5 15
6
7
8
9

TRANSMITTING TRANSDUCER TYPE AND SIZE COL. 47-48

These columns describe the type and size of transmitting transducer used

0 No information
1 SIL, Flat faced, .9525 cm. in diameter
2
3

RECEIVING TRANSDUCER TYPE AND SIZE COL. 49-50

These columns describe the type and size of receiving transducer used

0 . Not used, operate in Pulse Echo
1

ULTRASONIC EQUIPMENT TYPE COL. 51-52

These columns identify the type of ultrasonic equipment used in this inspection

0 No information
1 UM 715 Automation with 10N Pulser/Receiver

TYPES OF COUPLING/CONTACT OR IMMERSION (I - WATER PATH) COL. 53

This column identifies the type of coupling used and whether the inspection was performed in the contact or immersion mode. If immersion mode was used, the water path length should be included.

0 Water/I (3.4925 cm.)
1 Oil/Contact

ANGLE OF INCIDENCE IN COUPLING COL. 54-55

These columns identify the angle of sound beam makes with the normal to the surface of the test specimen in the coupling

0 No information
1 27¼ degree

GAIN SETTING IN % OF SCREEN SATURATION COL. 56-57

These columns identify the gain or sensitivity setting for the signal amplitude to attain the preselected level in conjunction with the ref. standard type and size. The amplitude will be described in percent of screen saturation (S.S). This level usually indicates a rejectable defect.

0 No information
1 80
2
3

GATE ALARM LEVEL IN % OF S.S. COL. 58-59

These columns identify the gate alarm level in percent of S.S. in which a potential defect has been detected, but not necessarily a rejectable defect. This level is almost always smaller than the level for Col. 56-57.

0 No information
1 33

INDEX INTERVAL COL. 60-61

These columns identify the index interval used during scanning of the test specimen. The number for the index interval will be in .0254 cm.

0 No information
1 12.5
2

DATA INPUT FORMAT KEY FOR EDDY CURRENT

INSTRUMENTATION TYPE COL. 45-46

These columns describe the eddy current instrument type used in the inspection

0 NO INFORMATION
1 NORTER NDT-3

DIAMETER OF COIL COL. 47-49

These columns describe the diameter of the coil used in the inspection

0 NO INFORMATION
3/8 INCH IN DIAMETER = .9525 cm.

ARRANGEMENT AND SHAPE OF COILS COL. 50-51

These columns describe the arrangement and shape of coil(s) used.

0 NO INFORMATION
1 DUAL COIL, AIR CORE

FREQUENCY COL. 52-54

These columns identify the frequency used in the inspection

0 NO INFORMATION
100 KHz or 10×10^4 Hz

TYPE OF E.C. RESPONSE COL. 55

This column identifies if the amplitude or phase is used for defect indication

0 AMPLITUDE
1 PHASE

LIFT-OFF COMPENSATION COL. 56-57

These columns indicate the amount of lift-off compensation used in data taken

0 NO INFORMATION
1 NO LIFT-OFF COMPENSATION USED

SIGNAL PROCESSING COL. 58

This column describes the type of signal processing used between the eddy current instrument and the signal display device.

0 STRAIGHT AMPLIFICATION WITH NO OTHER TYPES OF SIGNAL CONDITIONING
1

PERCENT (%) OF METER RESPONSE (R) COL. 59-60

PERCENT (%) OF METER RESPONSE (X) COL. 61-62

INDEX INTERVAL COL. 63-64

These columns describe the index interval used in scanning the test specimen

0 NO INFORMATION
1/8" = .3048 cm.

DATA INPUT FORMAT KEY FOR LIQUID PENETRANT

REF. STANDARD TYPE AND SIZE COL. 43-44

These columns describe the type and size ref. standard used for liquid penetrant inspection

0 NO REF. STANDARD WAS USED
1

PENETRANT TYPE COL. 45-46

These columns describe the type of liquid penetrant used

0 NO INFORMATION
1 URESCO P-151

DEVELOPER TYPE COL. 47-48

These columns describe the type of developer used

0 NO INFORMATION
1 URESCO D499C

CLASSIFICATION OF PENETRANT GROUP COL. 49

This column describes the Group classification of the penetrant

0 NO INFORMATION
1 GROUP I
2 GROUP II
3 GROUP III
4 GROUP IV
5 GROUP V
6 GROUP VI
7 GROUP VII
8
9

REMOVER OR EMULSIFIER TYPE COL. 50-51

These columns identify the type of remover or emulsifier used

0 NO INFORMATION
1 URESCO K-410

METHOD OF APPLICATION COL. 52

This column describes the method of applying the penetrant to the test specimen

0 NO INFORMATION
1 HAND BRUSH

DWELL TIME COL. 53-54

These columns identify the dwell time used in the inspection

0 NO INFORMATION
30 MINUTES

DEVELOPING TIME COL. 55-56

These columns identify the developing time used in the inspection

0 NO INFORMATION
30 MINUTES

WASH TIME COL. 57-58

These columns identify the time used to wash the specimen prior to the application of developer

0 NO INFORMATION

INSP. LIGHT INTENSITY COL. 59-60

These columns identify the light intensity used in viewing for defect

0 NO INFORMATION
1 1350 LUMENS/SQ. METER

PENETRANT REMOVAL AND PRE-CLEANING PROC. COL. 61-62

These columns are used to identify the pre-inspection cleaning procedure and penetrant removal procedure after inspection.

0 NO INFORMATION
1 THE PROCEDURE USED BY MARTIN MARIETTA AS DESCRIBED IN REPORT NASA CR-2369

DATA INPUT FORMAT KEY FOR RADIOGRAPHY

REF. STANDARD TYPE AND SIZE COL. 43-44

These columns describe the type and size ref. standard used for radiographic inspection

0 NO INFORMATION
1

RADIOGRAPHIC SOURCE COL. 45

This column describes the type of radiography used in the inspection

0 X-RAY
1 NEUTRON

SOURCE ENERGY COL. 46-48

These columns identify the level of the energy source used in the inspection

30KV for .1524 cm. AL PANEL
40KV for .5207 cm. AL PANEL

SOURCE STRENGTH COL. 49-51

These columns identify the strength of the energy source used in the inspection

20 MILLI-AMPERE

EXPOSURE TIME COL. 52-53

These columns identify the time of exposure

7 MINUTES FOR .1524 cm. AL PANEL
15 MINUTES FOR .5207 cm. AL PANEL

FILM DEVELOPING PROCEDURE COL. 54

This column identifies the procedure used for film development.

0 KODAK MODE B AUTOMATIC PROCESSOR, DEVELOPMENT TEMPERATURE OF 78°F

DETECTOR TYPE COL. 55-56

These columns identify the type of detectors used to detect the radiation

0 NO INFORMATION
1 KODAK, TYPE M

SOURCE TO FILM DISTANCE COL. 57-59

These columns identify the distance of separation between the film and the source

117 cm.

ANGLE OF INCIDENCE COL. 60-61

These columns identify the angle made between the film and incident energy

0 DEGREE (PERPENDICULAR)

DENSITOMETER READING COL. 62-64

These columns give the radiographic density of the film

3